Risk of Pest Plant Recruitment as a Result of the Operation of Chowilla Environmental Regulator

Jason Nicol

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Executive Summary

The Chowilla Floodplain is one of the largest areas of undeveloped floodplain in the lower Murray-Darling Basin (O'Malley and Sheldon 1990). The condition of the overstorey vegetation on the floodplain has been declining in recent years due to the accumulation of salt in the soil and lack of overbank flooding (Overton and Jolly 2004). To address this problem an environmental regulator is proposed for lower Chowilla Creek, which will inundate 29% of the floodplain when operated under low flow conditions (10,000 Ml day^{-1} flow to South Australia) (Department of Water, Land and Biodiversity Conservation 2006). The operation of the regulator is expected to improve the condition of much of the overstorey vegetation and recruitment of native floodplain herbs and grasses is also expected. Nevertheless, pest plant species (exotic and native) are also expected to recruit or expand their distribution and abundance as a result of the operation of the regulator.

The main factors that influence plant recruitment in wetland and floodplain habitats are presence or absence of standing water (van der Valk 1981), depth, duration, frequency and timing of flooding (Casanova and Brock 2000), soil salinity (Nielsen *et al.* 2003; Brock *et al.* 2005) and soil moisture (Nicol 2004). Under the current situation, much of the Chowilla floodplain is subjected to dry conditions with low soil moisture. Consequently the floodplain is dominated by terrestrial species (Weedon and Nicol 2006), which will remain dominant in the absence of flooding. Whilst most of these species are native to the region (Weedon and Nicol 2006), it is doubtful that they were present in such high numbers historically (James Robertson pers. com.).

Whether water is delivered to the floodplain by a natural or engineered flood is of little consequence to plants unless the natural flood has sufficient flow velocity to physically damage or uproot plants. Plants (whether they are native or exotic species) that are adapted to the proposed hydraulic regime will recruit; therefore, the risk of invasion of pest plants as a result of the operation of regulator is probably no greater than that of a natural flood with the same hydrograph.

The aim of this review and risk assessment is to collate information on pest plant species in the Chowilla system, to determine which species pose a significant invasion risk and determine which areas of the floodplain are at greatest risk of invasion. Finally monitoring and mitigation strategies and knowledge gaps identified.

Eighty-six exotic plant species from 23 families have been recorded in the Chowilla system since 1988 including 11 species, which are declared noxious in South Australia. Three native taxa

(Typha spp*., Phragmites australis* and *Paspalum distichum*) were also identified as potential pest plants. Information on the biology, ecology and current and historical distribution and abundance of pest plants in the Chowilla system were used to formulate a matrix that determined the risk of invasion or expansion for each species. From this information eight species (*Heliotropium europaeaum, Xanthium occidentale, X. californicum, H. curassivicum, Phyla canescens, Cuscuta campestris, Lycium ferocissimum* and *Nicotiana glauca*) were identified as an extreme invasion/expansion risk and a further 15 as a high risk.

The area of the floodplain determined to be most at risk of invasion by exotic species is the area that is inundated under low flows and is characterised by low soil salinity. The majority of exotic species are annuals with low salinity tolerance, which are able to complete their life cycles between flood events. Higher elevations are likely to be colonised by desiccation tolerant perennial species.

Scientifically defensible and statistically robust monitoring will be required to inform managers of weed expansions and new infestations in order to control pest plants. Existing monitoring sites will be able to be used for future monitoring and provide baseline data; however, extra sites may be required to gain adequate spatial coverage of the area influenced by the regulator under a range of operating scenarios.

The most effective control measures for most invasive plant species are spraying with herbicides; nevertheless, spraying is only practical for small monospecific infestations, or areas with only grass or broadleaf weeds where a selective herbicide can be used. Other control strategies include flooding of seedlings, solarisation (covering infestations with black plastic sheets), physical removal, cultivation and controlled grazing by domestic stock.

Key knowledge gaps relating to weeds in the Chowilla system include the distribution and abundance of weeds in the seed bank and the effectiveness of different control strategies. In addition, the spatial coverage of existing monitoring sites needs to be assessed to determine whether it is sufficient to monitor the impacts of the regulator and evaluate Living Murray targets 5, 6, 7 and 8. Finally water regime preferences for many native and exotic species and competitive interactions between native and exotics are not well understood.

Introduction

The Chowilla Floodplain is one of the largest areas (17,700 ha) of undeveloped floodplain in the Lower River Murray (O'Malley and Sheldon 1990). The system has been designated as a wetland of international importance under the Ramsar Convention (O'Malley and Sheldon 1990) and is one of the Living Murray Initiative's Icon Sites (Scientific Reference Panel for the Murray-Darling Basin Commission, Living Murray Initiative 2003). Despite being a Ramsar listed wetland and a Living Murray Icon Site, over half of the overstorey vegetation in 2005 was considered to be in poor condition (Overton *et al.* 2005).

Studies by CSIRO identified the main cause of the poor condition of the overstorey vegetation was salt accumulation in floodplain soils and a lack of over-bank flooding (Overton and Jolly 2004). To improve the condition of overstorey vegetation on the Chowilla floodplain, in the absence of high natural flows, a regulator on lower Chowilla Creek is currently being investigated that will allow 29% of the floodplain (~5,180 ha) to be inundated under low flow conditions (10,000 Ml day^{-1} flow into South Australia) and up to 55% of the floodplain (~9,690 ha) to be inundated during flows of 60,000 Ml day^{-1}) (Department of Water, Land and Biodiversity Conservation 2006). Generally the structure will be operated on average once every three years for three months (in spring and early summer) to simulate the hydrograph of a "natural" flood (Overton *et al.* 2005). In addition to the regulator on lower Chowilla Creek, the inlet structures on Pipeclay and Slaney Creeks will be upgraded and operated to maximise the area flooded and maintain water movement through the anabranch (Department of Water, Land and Biodiversity Conservation 2006).

The potential benefits of the resultant water regime to the overstorey vegetation (*Eucalyptus camaldulensis* (river red gum), *Eucalyptus largiflorens* (black box), *Acacia stenophylla* (coobah) and *Muehlenbeckia cunninghamii* (lignum)) have been demonstrated by the numerous watering trials undertaken at Chowilla and throughout the lower Murray River floodplain. In addition to the improvement of the condition of overstorey vegetation, the watering trials have (in most cases) resulted in significant increases in the abundance of native flood dependent herbs and grasses (Nicol and Weedon 2007). Nevertheless, in many sites, there has also been a significant increase in the abundance of exotic plant species after watering. For example, *Hypochaeris radicata* was present in significantly higher numbers in Twin Creeks and *Polypogon monspeliensis* in the northern basin of Werta Wert Wetland after the aforementioned wetlands were watered for a second time (Nicol and Weedon 2007).

Eighty-six exotic species from 23 families have been recorded in the Chowilla system since 1988 (Table 1). Asteraceae (daisies) was the most represented family with 22 species followed by the Poaceae (grasses) with 14 species (Table 1). Thirty-nine of the species recorded originated in Europe and 27 from the Mediterranean (Table 1).

The aim of this review is to determine:

- which plant species pose a significant invasion risk as a result of the operation of the proposed Chowilla Creek environmental regulator,
- whether the risk is greater than that posed by a natural flood,
- which areas of the Chowilla floodplain are at the greatest risk of weed infestation,
- monitoring and mitigation strategies,
- identify key knowledge gaps.

Using this information, a matrix that determines the invasion risk of each species has been developed (Table 2).

For the purpose of this review only species that have been observed in recent surveys, those that are listed as noxious (these species may legally require control) and species with a high or extreme invasion risk (Table 2) will be discussed in detail because they pose the greatest risk (many species observed by O'Malley (1990) and Roberts and Ludwig (1990) were recorded in very low numbers and have not been subsequently observed). Nevertheless, all species observed in the Chowilla system since 1988 have been included in the risk assessment matrix (Table 2).

The impact of the operation of the Slaney Creek and Pipeclay Creek structures will only be discussed minimally because the operation of these structures will not result in the inundation of large areas of floodplain (Department of Water, Land and Biodiversity Conservation 2006).

Table 1: List of exotic species documented on the Chowilla floodplain since 1988, their origin, life history strategy, germination requirements, water regime requirements, when last observed and legislative status.

Species	Common Name	Family	Origin	Reproduction	Life History Strategy	Germination Requirements	Water Regime Requirements	Most Recent Observation in Chowilla	Status	References
Galenia pubescens	Galenia	Aizoaceae	Southern Africa	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		O'Malley 1990, Dashorst and Jessop 1998
Galenia secunda	Galenia	Aizoaceae	Southern Africa	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial/Floodplain	2007		O'Malley 1990, Nicol 2004, Dashorst and Jessop 1998
Mesembryanthemum crystallinum	Iceplant	Aizoaceae	Southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	2006		O'Malley 1990, Dashorst and Jessop 1998, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Mesembryanthemum nodiflorum	Small Iceplant	Aizoaceae	Southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		Jessop and Tolken 1986, O'Malley 1990
Arctotheca calendula	Capeweed	Asteraceae	Southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Aster subulatus	Bushy Starwort	Asteraceae	North America	Seed	Perennial	Exposed sediment with high soil moisture	Will tolerate shallow flooding but not top flooding	2007		O'Malley 1990, Dashorst and Jessop 1998, Nicol *et al.* 2003, Zampatti *et al.* 2006b
Carduus tenuiflorus	Winged Slender Thistle	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988	Declared noxious in South Australia	Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Carthumus lanatus	Saffron Thistle	Asteraceae	Europe/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Centaurea calcitrapa	Star Thistle	Asteraceae	Europe	Seed	Annual/Biennial	Exposed sediment with high soil moisture	Terrestrial	1988	Declared noxious in South Australia	Cunningham *et al.* 1981, Dashorst and Jessop 1998, Weedon and Nicol 2006
Conyza bonariensis	Flax Leaf Fleabane	Asteraceae	South America	Seed	Annual/Biennial	Exposed sediment with high soil moisture	Terrestrial	2007		Dashorst and Jessop 1998, Zampatti *et al.* 2006b, Nicol and Weedon 2007, Nicol pers obs.
Dittrichia graveolens	Stinkwort	Asteraceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		Cunningham *et al.* 1981, O'Malley 1990
Hypochoeris glabra	Smooth Catsear	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Hypochoeris radicata	Flatweed	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Lactuca saligna	Wild Lettuce	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Dashorst and Jessop 1998, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Lactuca serroilia	Prickly Lettuce	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981,Dashorst and Jessop 1998, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Onopordum acaulon	Stemless Thistle	Asteraceae	Spain/southern France	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Nicol 2004
Picris hieracioides	Hawkweed, Ox Tongue	Asteraceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham et al. 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Riechardia tingitana	False Sowthistle	Asteraceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		O'Malley 1990, Dashorst and Jessop 1998, Nicol *et al.* 2003, Nicol and Weedon 2007
Soliva anthemifolia	Dwarf Jo Jo	Asteraceae	South America	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Sonchus asper	Prickly Sowthistle	Asteraceae	Northern Hemisphere	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		O'Malley 1990, Dashorst and Jessop 1998
Sonchus oleraceus	Common Sowthistle	Asteraceae	Europe/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Dashorst and Jessop 1998, Nicol *et al.* 2003, Nicol and Weedon 2007
Sonchus tenemimus	Sowthistle	Asteraceae	Mediterranean/south-western Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Jessop and Tolken 1986, O'Malley 1990
Taraxacum officinale	Dandelion	Asteraceae	Europe	Seed	Biennial	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Urospermum picroides	False Hawkbit	Asteraceae	Mediterranean/south-western Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Xanthium californicum	California Burr	Asteraceae	North America	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	2007	Declared noxious in South Australia	O'Malley 1990, Dashorst and Jessop 1998
Xanthium occidentale	Noogoora Burr	Asteraceae	North America/Caribbean	Seed	Annual	Exposed sediment with high soil moisture, temperatures above 30° C	Will tolerate shallow flooding but not top flooding	2007	Declared noxious in South Australia	Cunningham *et al.* 1981, Jessop and Tolken 1986, Victorsen 2001, Nicol 2004, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Echium plantagineum	Salvation Jane, Patterson's Curse	Boraginaceae	Northern Africa/Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2005	Declared noxious in South Australia	Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol 2004, Nicol and Weedon 2007
Heliotropium amplexicaule	Blue Heliotrope	Boraginaceae	South America	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Dashorst and Jessop 1998, Nicol 2004, Nicol and Weedon 2007
Heliotropium curassivicum	Smooth Heliotrope	Boraginaceae	South America	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	2007		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Nicol 2004, Nicol and Weedon 2007

Species	Common Name	Family	Origin	Reproduction	Life History Strategy	Germination Requirements	Water Regime Requirements	Most Recent Observation in Chowilla	Status	References
Heliotropium europaeum	Common Heliotrope	Boraginaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Dashorst and Jessop 1998, Nicol 2004, Weedon and Nicol 2006, Nicol and Weedon 2007
Heliotropium supinum	Common Fiddleback	Boraginaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Jessop and Tolken 1986, O'Malley 1990, Blanch *et al.* 2000
Neatostema apulum	Hairy Sheepweed	Boraginaceae	Canary Islands to Iraq	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Jessop and Tolken 1986, O'Malley 1990
Brassica tournefortii	Wild Turnip	Brassicaceae	Mediterranean/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		O'Malley 1990, Dashorst and Jessop 1998, Nicol and Bald 2006
Carrichtera annua	Ward's Weed	Brassicaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Sisymbrium erysimoides	Smooth Mustard	Brassicaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Sisymbrium irio	London Rocket	Brassicaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Herniaria hirsuta	Dense Mat-plant	Carophyllaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Polycarpon tetraphyllum	Allseed	Carophyllaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Seline apetala	Catchfly	Carophyllaceae	Southern Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Seline gallica var. *gallica*	French Catchfly	Carophyllaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Spergularia diandra	Small Sandspurrey	Carophyllaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Spergularia marina	Salt Sandspurrey	Carophyllaceae	Europe/temperate Northern Hemisphere	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Chenopodium murale	Nettle-leaved Goosefoot	Chenopodiaceae	Cosmopolitan	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Cuscuta campestris	Golden Dodder	Convolvulaceae	North America	Seed, stem fragments	Annual	Exposed sediment with high soil moisture	Terrestrial	2007	Declared noxious in South Australia	Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Zampatti *et al.* 2006b, Nicol *et al.* 2007
Citrullus lanatus	Paddy Melon	Cucurbitaceae	Tropical and southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Nicol 2004
Medicago minima	Small Woolly Burr Medic	Fabaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Medicago polymorpha	Burr medic	Fabaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007
Melilotus indica	Hexham Scent	Fabaceae	Mediterranean and Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Trifolium spp.	Clover	Fabaceae	Cosmopolitan	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		Nicol *et al.* 2003, Nicol and Weedon 2007
Erodium botrys	Long Storksbill	Geraniaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Erodium cicutarium	Common Crowfoot	Geraniaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2006		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol unpublished data
Elodea canadensis	Elodea	Hydrocharitaceae	North America	Stem fragments	Perennial	NA (clonal)	Submergent	2007	Declared noxious in South Australia	Jessop and Tolken 1986, Sainty and Jacobs 1994, Zampatti *et al.* 2006a
Marrubium vulgare	Horehound	Lamiaceae	Europe	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial	2007	Declared noxious in South Australia	Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol *et al.* 2006
Salvia verbenaca	Wild Sage	Lamiaceae	Europe/northern Africa	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Limonium lobatatum	Sea Lavender	Limoniaceae	Northern Africa to south-western Asia	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial	1988		Jessop and Tolken 1986, O'Malley 1990
Abutilon theophrasti	Swamp Chinese Lantern	Malvaceae	Tropical Asia	Seed	Annual	Exposed sediment with high soil moisture	Floodplain	2007		Cunningham *et al.* 1981, Jessop and Tolken 1986, Nicol and Weedon 2007
Malva parviflora	Small Flowered Mallow	Malvaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Jessop and Tolken 1986, Nicol and Weedon 2007
Papaver hybridum	Rough Poppy	Papaveraceae	Europe/Africa/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Avena fatua	Wild Oat	Poaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Nicol pers. obs.
Bromus rubens	Red Brome	Poaceae	Southern Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol and Weedon 2007

Species	Common Name	Family	Origin	Reproduction	Life History Strategy	Germination Requirements	Water Regime Requirements	Most Recent Observation in Chowilla	Status	References
Cynodon dactylon	Couch Grass	Poaceae	Cosmopolitan	Seed, stolons	Perennial	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham et al. 1981, Roberts and Ludwig 1990, Dashorst and Jessop 1998, Nicol 2004, Nicol pers. obs.
Hordeum lepronium	Barley Grass	Poaceae	Europe/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Dashorst and Jessop 1998, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Lamarckia aurea	Golden Top	Poaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Lolium rigidum	Wimmera Ryegrass	Poaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Lophochloa cristata	Annual Catstail	Poaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Lophochloa pumilia	Tiny Bristle Grass	Poaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Parapholis incruva	Curley Ryegrass	Poaceae	Europe/northern Africa/Asia	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Pentaschistis airoides	False Hairgrass	Poaceae	Southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Polypogon monspeliensis	Annual Beardgrass	Poaceae	Europe/northern Africa/Asia	Seed	Annual	Exposed sediment with high soil moisture	Will tolerate shallow flooding but not top flooding	2007		Dashorst and Jessop 1998, Nicol *et al.* 2003, Zampatti *et al.* 2006a, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Schisimus barbartus	Arabian Grass	Poaceae	Mediterranean/Africa /India	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Vulpia muralis	Fescue	Poaceae	Mediterranean	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Jessop and Tolken 1986, O'Malley 1990
Vulpia myuros	Rat's Tail Fescue	Poaceae	Central Europe to Britain	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Emex australis	Three Cornered Jack	Polygonaceae	Southern Africa	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988	Declared noxious in South Australia	Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Polygonum aviculare	Wireweed	Polygonaceae	Europe	Seed	Annual/Biennial	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, Dashorst and Jessop 1998, Nicol 2004, Weedon and Nicol 2006
Rumex crispus	Curled Dock	Polygonaceae	Europe/northern Africa	Seed	Perennial	Exposed sediment with high soil moisture, shallow water	Amphibious	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol unpublished data
Anagallis arvensis	Pimpernel	Primulaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture, shallow water	Amphibious	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998
Myosurus minimus var. *australis*	Mouse Tail	Ranunculaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial/Floodplain	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990, Nicol 2004
Ranunculus sceleratus	Poison Buttercup	Ranunculaceae	Europe	Seed	Perennial	Exposed sediment with high soil moisture	Emergent aquatic, will tolerate flooding but not top flooding	2007	Declared noxious in South Australia	Sainty and Jacobs 1994, Zampatti *et al.* 2006b
Salix babylonica	Weeping Willow	Salicaceae	Europe	Stem fragments	Perennial	NA (clonal)	Will tolerate flooding but not top flooding	2007		O'Malley 1990, Sainty and Jacobs 1994, Cremer 1995, Zampatti *et al.* 2006b
Veronica peragrina ssp. *xalapensis*	Wandering Speedwell	Scrophulariaceae	North and South America	Seed	Annual	Exposed sediment with high soil moisture	Floodplain	1988		Cunningham *et al.* 1981, Jessop and Tolken 1986, O'Malley 1990
Lycium ferocissimum	African Boxthorn	Solanceae	Southern Africa	Seed, root suckers, stem fragments	Perennial	Exposed sediment with high soil moisture	Terrestrial	2007	Declared noxious in South Australia	Cunningham *et al.* 1981, Dashorst and Jessop 1998, Blood 2003, Nicol *et al.* 2006, Weedon and Nicol 2006
Nicotiana glauca	Tobacco Bush	Solanceae	South America	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol 2004, Nicol pers. obs.
Solanum nigrum	Black Nightshade	Solanceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	2007		Cunningham et al. 1981, Dashorst and Jessop 1998, Weedon and Nicol 2006, Nicol and Weedon 2007
Urtica urens	Small Nettle, Stinging Nettle	Urticaceae	Europe	Seed	Annual	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Nicol *et al.* 2003
Phyla canescens	Lippia	Verbeneaceae	Tropical Africa, Asia and the Americas	Seed, stem fragments	Perennial	Exposed sediment with high soil moisture	Terrestrial/floodplain but will tolerate top flooding for at least 99 days	2007		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998, Taylor and Ganf 2005, Zampatti *et al.* 2006b, Nicol and Weedon 2007
Verbena officinalis	Common Verbena	Verbeneaceae	Mediterranean	Seed	Perennial	Exposed sediment with high soil moisture	Terrestrial	1988		Cunningham *et al.* 1981, O'Malley 1990, Dashorst and Jessop 1998

Risk Assessment Matrix

The proposed risk assessment matrix assesses the likelihood of invasion or further establishment for each exotic species (and three native species) that have been observed in the Chowilla system since 1988. The matrix takes into consideration several factors that include; aspects of the biology and ecology of each species, recent presence in the Chowilla system and whether it was observed in an area recently subjected to temporary flooding. Each factor is given a score and the total score (out of 30) relates to the invasion potential of that species (Table 2).

Water regime preference was determined to be the most important factor in assessing the invasion risk of a particular species because water regime is arguably the most important factor in determining wetland and riparian plant community structure (e.g. Yamasaki and Tange 1981; Walker *et al.* 1992; van der Sman *et al.* 1993; Rea and Ganf 1994a; Rea and Ganf 1994b; van Diggelen *et al.* 1996; Siebentritt 1998; Blanch *et al.* 1999; Blanch *et al.* 2000; Casanova and Brock 2000; Roberts and Marston 2000; Nicol *et al.* 2003; Siebentritt 2003; Brock *et al.* 2005; van Geest *et al.* 2005). Therefore, for a species to invade as a result of the operation of the proposed regulator it must be adapted to the resultant water regime. Hence, water regime preference was given a score out of 12. The scoring rationale for water regime preference follows:

- 0-Submergent aquatic.
- 1-Emergent aquatic.
- 4-Terrestrial/floodplain species that requires high soil moisture.
- 8-Terrestrial/floodplain species with intermediate desiccation tolerance.
- 12- Terrestrial/floodplain species with high desiccation tolerance or flexible life history.

Therefore, a submergent species poses no risk and a species that has a high desiccation tolerance or flexible life history poses the greatest risk because it is more likely to survive to a point where seed will be produced and the seed bank replenished.

Germination requirement was considered to be of less importance and was given a score out of three:

- 0-Requires complete submergence to germinate.
- 1-Only reproduces asexually.

- 3-Requires exposed sediment with high soil moisture to germinate.

Species that germinate on exposed sediment with high soil moisture were considered to pose the greatest risk because the operation of the proposed regulator will result in large areas of exposed sediment with high soil moisture as water levels fall. Asexual propagules are generally not desiccation tolerant to the same degree as seeds (Thompson 1992); hence, a species that relies solely on asexual reproduction (e.g. *Salix babylonica*) is only given a score of one

Growing season was considered to be of greater importance than germination requirement but of less importance than water regime preference and was given a score out of four:

- 0-Requires submergence
- 1-Requires continuous high soil moisture.
- 2-Late autumn/winter/early spring growing season.
- 4-Late spring/summer/early autumn or year round growing season.

Species that grow over the warmer months or year round were considered to be the greatest risk because the operation of the regulator would result in large areas of exposed sediment with high soil moisture in late spring and early summer, which is the growing season for the aforementioned species.

Seed bank characteristics were considered to be of the same importance as germination requirements and were given a score out of three:

- 0-Relies entirely on asexual reproduction.
- 1-Produces a transient seed bank (sensu Thompson and Grime 1979).
- 2-Seed bank characteristics unknown.
- 3-Produces a long-lived or persistent seed bank (sensu Thompson and Grime 1979).

Species that produce a long-lived or persistent seed bank were considered to be the greatest risk because the resident seed bank will probably be the origin of most weeds that recruit and species with a long-lived or persistent seed bank will have a greater chance of recruiting when suitable conditions arise.

Propagule dispersal characteristics were considered to be of the same importance as germination requirements and seed bank characteristics and given a score out of three:

- 0-Wind dispersed.
- 1-Unknown.
- 2-Animals.
- 3-Water.

Species that are adapted for hydrochory (dispersal by water) were considered to be the greatest risk because propagules will be dispersed into the area under the influence of the regulator. Seeds dispersed by animals were considered to be a slightly lesser risk because of the tendency of animals to congregate around water and wind dispersed seeds were considered no risk because they will disperse into an area whether water present or not.

Whether a species was observed in the Chowilla system since 2004 was considered the least important factor because it is impossible for a vegetation survey to cover 100% of the area and a species may be present in the seed bank. This factor was given a score out of one:

- 0-Not observed in the Chowilla system since 2004.
- 1- Observed in the Chowilla system since 2004.

The final factor is whether a species has been observed in area that has been recently subjected to flooding (natural of artificial). This was considered to be of the same importance as growing season and given a score out of four:

- 0-Not observed in an area recently subjected to flooding.
- 1-Observed at one location in low numbers.
- 2-Observed at one location in intermediate numbers or more than one location in low numbers.
- 3-Observed at one location in large numbers or at more than one location in intermediate numbers.
- 4-Observed at more than one location in high numbers.

A species that was either more abundant or widespread was considered to be a greater risk than a species present in low numbers or that had a restricted distribution because it will have a greater ability of dispersing into unaffected areas.

The matrix identified eight species that are an extreme invasion risk and 15 that are a high risk (Table 2). These species are well adapted to the conditions that are likely to be created by the operation of the regulator and there is a high chance their distribution and abundance will increase. The matrix could also be used to determine which native species will be favoured by the operation of the regulator (or natural flood with a similar hydrograph) and, in conjunction with seed bank and survey data, be used to predict the distribution and abundance of species on the area of the floodplain influenced by the regulator.

Table 2: Risk assessment matrix for the invasion of exotic and potential pest native species as a result of the operation of the Chowilla Creek environmental regulator and associated structures (* denotes native species; total score 0-10=negligible risk, 11-15 low risk, 16-20 intermediate risk, 21-25 high risk, 26-30 extreme risk).

Species	Water Regime Preference	Germination Requirements	Growing Season	Seed Bank	Propagule dispersal	Observed in Chowilla System since 2004	Observed in Area Recently Subjected to Temporary Flooding	Total
Heliotropium europaeum	12	3	4	3	3	1	3	**29**
Xanthium californicum	12	3	4	3	3	1	3	**29**
Xanthium occidentale	12	3	4	3	3	1	3	**29**
Heliotropium curassivicum	12	3	4	3	3	1	2	**28**
Phyla canescens	12	3	4	2	3	1	2	**27**
Cuscuta campestris	12	3	4	3	2	1	1	**26**
Lycium ferocissimum	12	3	4	3	3	1	0	**26**
Nicotiana glauca	12	3	4	3	3	1	0	**26**
Cynodon dactylon	12	3	4	2	3	1	0	**25**
Polygonum aviculare	12	3	4	2	1	1	1	**25**
Abutilon theophrasti	8	3	4	2	3	1	3	**24**
Emex australis	12	3	4	3	2	0	0	**24**
Medicago minima	8	3	4	3	3	1	2	**24**
Medicago polymorpha	8	3	4	3	3	1	2	**24**
Trifolium spp.	8	3	4	3	3	1	2	**24**
Galenia secunda	12	3	4	3	1	0	0	**23**
Galenia pubescens	12	3	4	2	1	0	0	**22**
Heliotropium amplexicaule	8	3	4	2	3	1	1	**22**
Malva parviflora	8	3	4	2	3	1	1	**22**
*Paspalum distichum**	8	3	4	3	3	1	0	**22**
Hypochoeris glabra	8	3	4	2	2	1	1	**21**
Hypochoeris radicata	8	3	4	2	2	1	1	**21**
Solanum nigrum	8	3	4	2	2	1	1	**21**
Arctotheca calendula	8	3	2	2	3	1	1	**20**
Bromus rubens	8	3	2	2	2	1	2	**20**
Carrichtera annua	8	3	2	3	2	1	1	**20**
Dittrichia graveolens	8	3	4	2	3	0	0	**20**
Heliotropium supinum	8	3	4	2	3	0	0	**20**
Polypogon monspeliensis	8	3	4	2	1	1	1	**20**
Avena fatua	8	3	2	3	2	1	0	**19**
Citrullus lanatus	8	3	4	2	2	0	0	**19**
Echium plantagineum	8	3	2	2	2	1	1	**19**
Erodium cicutarium	8	3	2	2	2	1	1	**19**
Hordeum lepronium	8	3	2	2	2	1	1	**19**
Marrubium vulgare	8	3	2	3	3	0	0	**19**
Brassica tournefortii	8	3	2	2	3	0	0	**18**
Lolium rigidum	8	3	2	3	2	0	0	**18**
Polycarpon tetraphyllum	8	3	4	2	1	0	0	**18**

Species	Water Regime Preference	Germination Requirements	Growing Season	Seed Bank	Propagule dispersal	Observed in Chowilla System since 2004	Observed in Area Recently Subjected to Temporary Flooding	Total
Spergularia diandra	8	3	4	2	1	0	0	**18**
Spergularia marina	8	3	4	2	1	0	0	**18**
Chenopodium murale	8	3	2	2	2	0	0	**17**
Conyza bonariensis	8	3	4	2	0	0	0	**17**
Erodium botrys	8	3	2	2	2	0	0	**17**
Lophochloa cristata	8	3	2	2	2	0	0	**17**
Lophochloa pumilia	8	3	2	2	2	0	0	**17**
Melilotus indica	8	3	2	2	2	0	0	**17**
Mesembryanthemum crystallinum	8	3	2	2	1	1	0	**17**
Picris hieracioides	8	3	2	2	0	1	1	**17**
Soliva anthemifolia	8	3	4	2	0	0	0	**17**
Aster subulatus	4	3	4	2	0	1	2	**16**
Carthumus lanatus	8	3	2	3	0	0	0	**16**
Herniaria hirsuta	8	3	2	2	1	0	0	**16**
Mesembryanthemum nodiflorum	8	3	2	2	1	0	0	**16**
Neatostema apulum	8	3	2	2	1	0	0	**16**
Papaver hybridum	8	3	2	2	1	0	0	**16**
Parapholis incruva	8	3	2	2	1	0	0	**16**
Riechardia tingitana	8	3	2	2	0	1	0	**16**
Salvia verbenaca	8	3	2	2	1	0	0	**16**
Seline apetala	8	3	2	2	1	0	0	**16**
Seline gallica var. *gallica*	8	3	2	2	1	0	0	**16**
Sisymbrium erysimoides	8	3	2	2	1	0	0	**16**
Sisymbrium irio	8	3	2	2	1	0	0	**16**
Sonchus oleraceus	8	3	2	2	0	1	0	**16**
Urospermum picroides	8	3	2	2	1	0	0	**16**
Urtica urens	4	3	4	2	3	0	0	**16**
Vulpia muralis	8	3	2	2	1	0	0	**16**
Vulpia myuros	8	3	2	2	1	0	0	**16**
Lactuca saligna	4	3	4	2	0	1	1	**15**
Lactuca serriola	4	3	4	2	0	1	1	**15**
Limonium lobatatum	8	3	2	2	0	0	0	**15**
Onopordum acaulon	8	3	2	2	0	0	0	**15**
Sonchus asper	8	3	2	2	0	0	0	**15**
Sonchus tenemimus	8	3	2	2	0	0	0	**15**
Taraxacum officinale	8	3	2	2	0	0	0	**15**
Ranunculus sceleratus	1	3	4	2	3	1	0	**14**
Rumex crispus	4	3	1	2	3	0	0	**13**
Myosurus minimus var. *australis*	4	3	2	2	1	0	0	**12**
Pentaschistis airoides	4	3	2	2	1	0	0	**12**
Schisimus barbartus	4	3	2	2	1	0	0	**12**
Verbena officinalis	4	3	2	2	1	0	0	**12**
Veronica peragrina ssp. *xalapensis*	4	3	2	2	1	0	0	**12**
Anagallis arvensis	4	3	2	2	0	0	0	**11**
Carduus tenuiflorus	4	3	2	2	0	0	0	**11**

Species	Water Regime Preference	Germination Requirements	Growing Season	Seed Bank	Propagule dispersal	Observed in Chowilla System since 2004	Observed in Area Recently Subjected to Temporary Flooding	Total
Centaurea calcitrapa	4	3	2	2	0	0	0	**11**
Lamarckia aurea	4	3	2	2	0	0	0	**11**
Typha spp.*	1	3	1	3	0	1	1	**10**
Salix babylonica	1	1	1	0	3	1	0	**7**
Elodea canadensis	0	0	0	0	3	1	0	**4**
*Phragmites australis**	1	0	1	0	1	1	0	**4**

Exotic Species

Species Declared Noxious in South Australia

Eleven species that are declared noxious in South Australia have been recorded in the Chowilla system since 1988 (Table 1). Of the 11 declared species *Xanthium occidentale, Echium plantagineum, Cuscuta campestris, Elodea canadensis, Marrubium vulgare, Ranunculus scleratus* and *Lycium ferocissimum* have been observed since 2004 (Weedon and Nicol 2006; Zampatti *et al.* 2006a; Zampatti *et al.* 2006b; Nicol and Weedon 2007).

Carduus tenuiflorus (Winged Slender Thistle)

This species is generally a problem weed in the wetter regions of South Australia. Most infestations in drier regions are usually localised and small and do not persist for long periods (Cunningham *et al.* 1981). Germination occurs in the cooler months (May-September), the plant initially forms a large rosette from which flowering stems ascend (Cunningham *et al.* 1981). The plant dies after flowering and the seed is dispersed by wind (Cunningham *et al.* 1981). The most effective control methods are hand pulling (small infestations) or spraying with herbicides. Cultivation, slashing or grazing are not effective (Cunningham *et al.* 1981).

This species has not been observed in the Chowilla system in recent years and probably does not pose a significant risk; in fact, operation of the regulator in spring may prevent plants in inundated areas from completing their life cycle.

Centaurea calcitrapa (Star Thistle)

Similar to *Carduus tenuiflorus, Centaurea calcitrapa* rarely appears in large infestations; usually occurring as scattered plants or in small clumps in agricultural situations (Cunningham *et al.* 1981). Germination usually takes place in autumn, flowering occurs in spring after which the plant may die or persist until the next growing season (Cunningham *et al.* 1981). Seed is dispersed mainly by water or as a contaminant of grain (Cunningham *et al.* 1981). It can be controlled by cutting and burning, repeated cultivation of infested areas before plants have flowered or by spraying with herbicides (Cunningham *et al.* 1981). Plants are not grazed by domestic stock due to its spininess (Cunningham *et al.* 1981).

Centaurea calcitrapa has not been observed in the Chowilla system in recent years and probably does not pose a significant risk. Operation of the regulator may prevent plants that have germinated in areas inundated due to the regulator from completing their life cycle.

Xanthium californicum and Xanthium occidentale (California Burr and Noogoora Burr)

There appears to be some confusion surrounding the taxonomy of these two species (Cunningham *et al.* 1981; Jessop and Tolken 1986; Jessop 1993) and for the purpose of this review they will be treated as one because they occupy identical niches. These two species are major weeds of riparian areas and can form extensive infestations along the banks of creeks and rivers after spring and summer flooding with masses of seedlings crowding out all other species (Cunningham *et al.* 1981). Germination occurs on exposed sediment after water levels recede (Nicol 2004) and flowering occurs in late summer/autumn after which the plants die (Cunningham *et al.* 1981). Seeds are dispersed by animals or water (Cunningham *et al.* 1981). Infestations can be controlled by hand pulling, cultivation or spraying with herbicides before seeding; however, eradication is a long-term project because each seed capsule contains two seeds, one germinates immediately and one may remain dormant for several years after the first seed has germinated (Cunningham *et al.* 1981). Plants are toxic to domestic stock (especially when young) and are not grazed (Cunningham *et al.* 1981); however, the large seeds of these species may be susceptible to damage by trampling from the hard hooves of domestic stock (Nicol *et al.* 2007).

Xanthium californicum and *Xanthium occidentale* are probably the major pest plant threat (along with *Heliotropium europaeum*) in the Chowilla system and their distribution and abundance will undoubtedly increase due to the operation of the regulator. *Xanthium occidentale* has been observed in Kulkurna, Twin Creeks, Werta Wert and Coppermine after these wetlands were artificially flooded. In addition, *Xanthium occidentale* significantly increased in abundance along the banks of the River Murray downstream of Lock 6, Punkah Creek and Monoman Creek after the in channel water level rise of spring 2005 (Zampatti *et al.* 2006b).

The predicted increase in abundance of these species due to the operation of the proposed Chowilla Creek regulator and associated structures would probably be no different to natural floods with similar hydrographs; however, they are declared noxious in South Australia and pose a significant threat to the attainment of Living Murray targets 5, 6, 7 and 8.

Echium plantagineum (Salvation Jane, Patterson's Curse)

Echium plantagineum is a major weed of agricultural and disturbed land (such as roadsides) (Cunningham *et al.* 1981). Seed germinates in autumn and large rosettes form (which can smother other species) and in late winter flowering stems ascend from the rosettes (Cunningham *et al.* 1981). Flowering occurs throughout spring and early summer and plants usually die off with the onset of hot weather (Cunningham *et al.* 1981). Seeds germinate readily, although a proportion of the seed remains dormant for up to five years in the soil. There is evidence to suggest that cultivation may stimulate germination of dormant seeds (Cunningham *et al.* 1981). Control is achieved by cultivation or spraying with herbicides (Cunningham *et al.* 1981).

One individual of this species was recorded during sampling conducted between 2005 and 2007 at one site in Coppermine Waterhole (Nicol and Weedon 2007) and no aggressive infestations have been observed; therefore, it probably poses little risk. In addition, plants present in the areas inundated by operation of the regulator may not complete their life cycle in years when the regulator is used.

Cuscuta campestris (Golden Dodder)

Cuscuta campestris is a leafless parasitic plant, wholly dependent on its host for its water and nutritional requirements (Cunningham *et al.* 1981). This species is not host specific; however, it shows preferences for *Xanthium* spp., *Medicago* spp. and many agricultural and horticultural crops (Cunningham *et al.* 1981). Seeds germinate in the warmer months and seedlings must make contact with a host plant within a few days in order to survive (Cunningham *et al.* 1981). Growth is usually rapid with the stems twining around the host plant (Cunningham *et al.* 1981). Flowering begins shortly after attachment to the host and occurs throughout the life of the plant (Cunningham *et al.* 1981). This species is a prolific seeder and seed is spread as a contaminant of agricultural seed, by attachment to stock or passing unaffected through the digestive system of animals (Cunningham *et al.* 1981). Seed can remain dormant in the soil for several years and new plants can form from stem fragments (Cunningham *et al.* 1981). *Cuscuta campestris* can be controlled by spraying with herbicides or heaping and burning infested material (Cunningham *et al.* 1981). Nicol *et al.* (2007) reported that *Cuscuta campestris* was present in large numbers in the seed bank of ungrazed areas in Thegoa Lagoon (western NSW) but absent in grazed areas, which suggest that grazing by domestic stock may also help control this species.

This species was observed along the banks of the River Murray downstream of Lock 6 (Zampatti *et al.* 2006a) on a variety of host plants, particularly *Xanthium* spp. The operation of the regulator will probably result in outbreaks of this species because of the increase in abundance of suitable host plants; nevertheless, if *Xanthium* spp., *Medicago* spp. and *Trifolium* spp. are controlled *Cuscuta campestris* is generally controlled.

Elodea canadensis (Elodea)

Elodea canadensis is a submergent species that reproduces by stem fragments because only male plants are present in Australia (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Plants may temporarily colonise areas inundated by the regulator; however, it is unable to survive exposure to the atmosphere and does not form a seed bank (Cunningham *et al.* 1981) and therefore poses no significant risk.

Marrubium vulgare (Horehound)

This species is a common weed of disturbed areas such as roadsides, stock watering points, farm buildings and rabbit warrens (Cunningham *et al.* 1981). Seed germinates in autumn and rapid growth occurs in winter and spring. Once established, *Marrubium vulgare* is extremely hardy and can prevent other species from establishing (Cunningham *et al.* 1981). One plant can produce over 20,000 seeds, which are spread by animals and water and can remain dormant in the soil for up to seven years (Blood 2003). Control is achieved by spraying with herbicides and burning will kill mature plants and reduce the soil seed bank by up to 80% (Blood 2003)

Marrubium vulgare has been observed in the Chowilla system in recent years (A. Herbert pers. com.). However, the growing season is in winter/spring and the operation of the regulator may prevent individuals that germinated over winter in the area inundated by the regulator from completing their life cycle. Therefore, this species probably does not pose a high risk.

Emex australis (Three-Cornered Jack)

Similar to *Marrubium vulgare*, this species is a weed of disturbed areas (Cunningham *et al.* 1981). Seeds generally germinate in winter/spring but plants can appear at any time of the year (Cunningham *et al.* 1981). Growth occurs in the warmer months with plants persisting until late summer or early autumn if conditions are favourable; persistence is aided by a well-developed taproot (Cunningham *et al.* 1981). Seeds are spread by animals and especially rubber tyred vehicles (Cunningham *et al.* 1981) and can remain dormant in the soil for at least four years (Cheam 1996). Control is achieved by spraying with herbicides (Addenbrooke 1996; Gilbey 1996; Ralph 1996); however, eradication is a long-term project because of the persistent seed bank (Cheam 1996).

Despite not being recorded in Chowilla since 1988 (O'Malley 1990) *Emex australis* does pose a significant invasion risk because of its persistent seed bank (Cheam 1996), desiccation tolerance and year round growing season (Cunningham *et al.* 1981).

Ranunculus sceleratus (Poison Buttercup)

Ranunculus sceleratus is an emergent aquatic generally found in eutrophic situations (Sainty and Jacobs 1994). Seeds germinate in autumn and growth occurs throughout winter and spring with flowering in late spring/early summer (Sainty and Jacobs 1994). This species is not grazed by stock (Sainty and Jacobs 1994) and information on its control is not available.

This species has been recorded in relatively high numbers along the edge of Pilby Creek (Zampatti *et al.* 2006b); however it does not pose a significant risk because it is restricted to areas that have continuously high soil moisture (Cunningham *et al.* 1981; Sainty and Jacobs 1994).

Lycium ferocissimum (African Boxthorn)

This species is generally a weed of regions with high rainfall, where it can form impenetrable thickets many metres across, smothering other plants (Cunningham *et al.* 1981). In drier regions it is found as scattered plants less than 2 m tall and rarely develops into thickets (Cunningham *et al.* 1981); nevertheless, it is extremely hardy and will become virtually dormant during extended dry periods (Muyt 2001). Germination, growth and flowering occur throughout the year with plants reaching sexual maturity two years after germination (Muyt 2001). Large plants produce thousands of fruits that contain at least 20 seeds (Muyt 2001), which are spread by animals, machinery and water (Muyt 2001; Blood 2003). In addition, plants may reproduce by root suckering and stem fragments (Muyt 2001; Blood 2003). This species can be controlled by hand pulling or spraying with herbicides when plants are small and injecting or cutting and painting with herbicides for larger plants (Muyt 2001). Nevertheless, control of *Lycium ferocissimum* is a long-term project because mass germination often occurs after large-scale clearing and plants often re-shoot after spraying (Muyt 2001).

Lycium ferocissimum has not been observed in large numbers in Chowilla in recent years (J. Nicol pers. obs.); nevertheless, it does pose an extreme risk because of its life history, persistent seed bank, dispersal mechanisms and drought tolerance (Muyt 2001).

Other Exotic Species Observed in the Chowilla System Since 2004

Galenia pubescens and *Galenia secunda* (Galenia)

These two species have very similar characteristics and are weeds of disturbed areas, such as roadsides and areas of human habitation, with very similar characteristics (Cunningham *et al.* 1981). They generally occur as scattered plants; however, they are desiccation tolerant and can persist for long periods even during times of low rainfall (Nicol 2004). Germination occurs after rainfall or after floodwaters recede and growth occurs year round (Nicol 2004) with flowering in summer (Cunningham *et al.* 1981). Seed is spread by water or animals and *Galenia secunda* is known to form a persistent soil seed bank (Nicol 2004). *Galenia* spp. are highly palatable to domestic stock and generally do not persist for long periods in grazed situations (Cunningham *et al.* 1981); therefore, controlled grazing may be an effective control strategy.

Galenia spp. whilst not being observed in high numbers in recent surveys in the Chowilla system, do pose a significant threat because of their life history characteristics, dispersal mechanisms, drought tolerance, germination requirements and persistent seed bank. These two species may increase significantly in abundance due to the operation of the regulator but may be relatively easy to control by grazing.

Mesembryanthemum crystallinum (Ice Plant)

This species is only common on floodplains after years of high winter rainfall, usually occurring in scattered patches (Cunningham *et al.* 1981). Seeds germinate in the cooler months and plants grow until mid summer when they dry out; nevertheless, under favourable conditions they may persist until the next growing season (Cunningham *et al.* 1981). *Mesembryanthemum crystallinum* does not appear to be grazed by stock (Cunningham *et al.* 1981) and information on its control is not available.

Mesembryanthemum crystallinum was observed in Hancock Creek in large numbers in spring 2005 after above average winter rainfall that year (Zampatti *et al.* 2006b). It has also been observed in low numbers in Kulkurna, Punkah Island Horseshoes, Chowilla Horseshoe, Lake Littra, Monoman Depression, Punkah Depression, Punkah Flood Runner and Woolshed Creek (Nicol and Weedon 2007). This species is relatively salt tolerant (Cunningham *et al.* 1981) and flooding may facilitate its spread into areas that are too saline for other species. Nevertheless, this species may be controlled in some areas through operation regulator in spring, which may prevent individuals in areas inundated from completing their life cycle.

Arctotheca calendula (Capeweed)

Arctotheca calendula is a major weed of disturbed areas and overgrazed paddocks in wetter regions of southern Australia (Cunningham *et al.* 1981). Seeds germinate in the cooler months, large rosettes develop (that may exclude other species) and plants die off in early summer (Cunningham *et al.* 1981). Flowering occurs in spring (Cunningham *et al.* 1981; Blood 2003) and large amounts seeds with woolly fruits are produced that are spread by wind, animals and water

(Cunningham *et al.* 1981). Plants are sparingly grazed and control can be achieved by spraying with herbicides (Cunningham *et al.* 1981).

This species was observed in low numbers in Coppermine Waterhole, Kulkurna and Twin Creeks after these wetlands were flooded (Nicol and Weedon 2007). The seed dispersal strategies and drought tolerance make it a significant risk; nevertheless, its growing and flowering season is when the regulator is likely to be operated; therefore, some control of plants that germinated in winter may be achieved.

Aster subulatus (Bushy Starwort)

This species is a weed of poorly drained areas; growth commences in spring and continues through the warmer months as long as moisture is available or until the onset of cold conditions after which leaf growth ceases (Cunningham *et al.* 1981). Seed is dispersed by wind or water (Cunningham *et al.* 1981). *Aster subulatus* is not grazed by stock but can be controlled by cultivation or spraying with herbicides (Cunningham *et al.* 1981).

This species does not pose a serious widespread risk because it requires high soil moisture to persist (Cunningham *et al.* 1981). Nevertheless, it may be locally abundant in areas with high soil moisture over the summer.

Hypochoeris glabra and *Hypochoeris radicata* (Smooth Catsear and Flat weed)

These two species occupy similar niches and generally occur as scattered plants particularly in neglected lawns, fallow paddocks or disturbed areas (Cunningham *et al.* 1981; Blood 2003). Blood (2003) reported that *Hypochoeris radicata* is the most widespread weed in southeastern Australia. Germination, growth and flowering occur during the cooler months with the plant dying after flowering (Cunningham *et al.* 1981). *Hypochoeris* spp. seeds are spread by wind and animals (Blood 2003). Plants are readily grazed by domestic stock but grazing or slashing are not effective control strategies because plants readily resprout (plants have been observed flowering two weeks after slashing) (Blood 2003). The most effective control strategy is the application of herbicides (Cunningham *et al.* 1981).

Despite growing in the cooler months, *Hypochoeris* spp. pose a significant risk because they are relatively desiccation tolerant and dispersed by animals. In addition, *Hypochoeris radicata* was present in significantly higher numbers in the post watering survey of Twin Creeks and was also present in Werta Wert Wetland, Coppermine Waterhole and Chowilla Horseshoe (Nicol and Weedon 2007).

Lactuca saligna and *Lactuca serriola* (Wild Lettuce and Prickly Lettuce)

These two species occupy similar niches and are weeds of moist and disturbed areas such as river and creek banks, areas subjected to flooding, roadsides and places of human habitation (Cunningham *et al.* 1981). Growth commences from seed or the rootstock of previous year's growth in the spring or early summer and continues through to late autumn, providing there is sufficient soil moisture (Cunningham *et al.* 1981). Seed is spread by the wind (Cunningham *et al.* 1981). Young plants are grazed by domestic stock until prickles develop on the leaves and stems, after which it is ignored unless there is no other green feed available (Cunningham *et al.* 1981). Control is achieved by spraying with herbicides (Cunningham *et al.* 1981).

These species do not pose a high invasion risk, despite growing over the summer, because they are not desiccation tolerant (Cunningham *et al.* 1981). In the Chowilla system they have been observed in low numbers downstream of the Boat Creek Bridge and along the banks of the River Murray (Zampatti *et al.* 2006b).

Picris hieracioides (Hawkweed, Ox-tongue)

Picric hieracioides usually occurs as scattered plants on floodplains and along roadsides (Cunningham *et al.* 1981). Germination takes place in the cooler months and plants continue to grow and flower into the summer providing there is sufficient soil moisture (Cunningham *et al.* 1981). Seed is dispersed by wind (Cunningham *et al.* 1981). This species is not grazed by stock because of its covering of prickly hairs but effective control can be achieved by spraying with herbicides (Cunningham *et al.* 1981).

Picric hieracioides does not pose a high invasion risk because it germinates in winter and may be controlled to a limited extent by the operation of the regulator. Cunningham *et al.* (1981) stated that *Picric hieracioides* rarely occurs in sufficient numbers to be regarded as a pest, which is supported by the data from Chowilla where it has been observed in low numbers (Weedon and Nicol 2006) but not in areas that were recently flooded (Zampatti *et al.* 2006a; Nicol and Weedon 2007).

Riechardia tingitana (False Sowthistle)

The abundance of *Riechardia tingitana* may vary greatly from year to year depending on rainfall; in wet years it is fairly common on most soil types and vegetation communities but in dry years it may be reduced to a few scattered individuals (Cunningham *et al.* 1981). Germination and growth are restricted to the cooler months but in shaded or moist sites it may persist into summer or autumn (Cunningham *et al.* 1981). Seed is dispersed by wind (Cunningham *et al.* 1981). This species is readily grazed by domestic stock at most stages of growth (Cunningham *et al.* 1981), which may be an effective control strategy for localised infestations.

Reichardia tingitana does not pose a high invasion threat because it germinates and grows in winter and may be controlled to a limited extent by the operation of the regulator. Cunningham *et al.* (1981) reported that the abundance of this species was on the increase but it has only been observed recently on the Chowilla Floodplain in low numbers (Weedon and Nicol 2007). Nevertheless, some of the areas where it was found were artificially flooded (Weedon and Nicol 2007).

Sonchus oleraceus (Common Sowthistle)

Sonchus oleraceus is a common weed of pastures and places of human habitation (Cunningham *et al.* 1981). Germination and growth occur in the cooler months and plants die if favourable conditions do not persist; nevertheless, in favourable situations such as gardens, plants may grow and flower throughout the year (Cunningham *et al.* 1981). Seed is dispersed by wind (Cunningham *et al.* 1981). *Sonchus oleraceus* is readily eaten by domestic stock (Cunningham *et al.* 1981), which may be an effective control strategy for localised infestations.

This species does not pose a high invasion threat because it germinates and grows in winter and may be controlled to a limited extent by the operation of the regulator. Nevertheless, it has been observed in low numbers at several sites that were recently subjected to artificial flooding (Nicol and Weedon 2007)

Heliotropium amplexicaule (Blue Heliotrope)

This species is a weed of disturbed areas (such as roadsides) and areas subjected to flooding (Cunningham *et al.* 1981). Growth occurs in spring and autumn but growth and flowering will occur at any time providing there is sufficient soil moisture (Cunningham *et al.* 1981). Seeds are dispersed by animals and water (Cunningham *et al.* 1981). *Heliotropium amplexicaule* is not grazed by stock, with the most effective control strategy being spraying with herbicide (Cunningham *et al.* 1981).

Heliotropium amplexicaule poses a high invasion risk (although not as high as *Heliotropium curassivicum* or *Heliotropium europaeum* because it is not as desiccation tolerant as the aforementioned species) because it grows during the summer, is relatively desiccation tolerant and seed is dispersed by water (Cunningham *et al.* 1981). It has been observed in low numbers along the banks of the River Murray downstream of Lock 6 after the 2005 in channel flow event (Zampatti *et al.* 2006a).

Heliotropium curassivicum (Smooth Heliotrope)

Heliotropium curassivicum is a weed of floodplains and dry wetlands and is usually only present in very wet years or after flooding, when it can become locally abundant (Cunningham *et al.* 1981; Nicol 2004; Zampatti *et al.* 2006b). In addition, it is moderately tolerant of saline conditions and will grow in areas that are not suitable to many other species (Cunningham *et al.* 1981; Zampatti *et al.* 2006b). Growth and flowering occurs year round and seeds are dispersed by water and animals (Cunningham *et al.* 1981). It is not grazed by stock (Cunningham *et al.* 1981) and control methods have not been documented.

This species poses an extreme invasion risk because it grows year round, seed is dispersed by water (Cunningham *et al.* 1981), it forms a persistent seed bank, germinates on exposed sediment and is highly desiccation tolerant (Nicol 2004). In addition, it has been observed in moderate numbers in areas of the Chowilla system recently subjected to flooding (Zampatti *et al.* 2006a; Nicol and Weedon 2007). *Heliotropium curassivicum* is also the most salt tolerant exotic species present in the Chowilla system (Cunningham *et al.* 1981) and whilst it has not been observed in areas with very high soil salinity (e.g. Lake Limbra) (Zampatti *et al.* 2006b), it may become abundant in these areas if the operation of the regulator reduces soil salinity.

Heliotropium europaeum (Common Heliotrope)

This species is a widespread weed of many soil types and vegetation communities and is prevalent in disturbed areas such as roadsides (Cunningham *et al.* 1981) and areas of floodplains with heavy clay soils (Nicol 2004). Germination is initiated by summer rainfall (Cunningham *et al.* 1981) or receding floodwaters (Nicol 2004) and growth and flowering can be quite rapid (Cunningham *et al.* 1981). Seed is dispersed by water (Cunningham *et al.* 1981) and forms a persistent soil seed bank (Nicol 2004). Sheep only graze plants if there is an absence of other green feed and there is some evidence of causing copper poisoning in cattle, sheep and horses (Cunningham *et al.* 1981). Information on the control of this species is not available.

Heliotropium europaeum poses an extreme invasion risk. Consequently this species will increase in abundance as a result of the operation of the regulator. This species has a flexible life history strategy, is desiccation tolerant, forms a persistent seed bank, germinates in response to receding floodwaters (Nicol 2004), grows over the summer and seed is dispersed by water (Cunningham *et al.* 1981). In addition, this species was present in high numbers at Werta Wert Wetland after it was flooded and present in moderate numbers in Chowilla Horseshoe, Kulkurna, Punkah Island Horseshoes, Punkah Depression (Nicol and Weedon 2007) and Hancock Creek (Zampatti *et al.* 2006b)

The predicted increase in abundance of this species due to the operation of the proposed Chowilla Creek regulator would probably be no different to natural floods with similar hydrographs; nevertheless, it does pose a significant threat to the attainment of Living Murray targets 5, 6, 7 and 8 because it is a potential increaser species and has the ability to out compete and smother natives.

Carrichtera annua (Ward's Weed)

Carrichtera annua is a weed of disturbed areas and is prevalent in years of high winter and spring rainfall (Cunningham *et al.* 1981). Germination, growth and flowering occur during the cooler months and two distinct seed banks are formed; a persistent soil seed bank and aerial seed bank where seeds are retained in lignified (hardened) pods on dead adult plants (Cooke *et al.* 2004). Plants are not grazed by domestic stock (Cunningham *et al.* 1981; Cooke *et al.* 2004) but the aerial and soil seed banks can be reduced significantly by burning (Cooke *et al.* 2004).

This species poses an intermediate threat, the growing season is over the winter and spring and operation of the regulator may control *Carrichtera annua* to some degree; nevertheless, it does have a persistent seed bank (Cooke *et al.* 2004) and was observed in Coppermine Waterhole after it was artificially flooded (Nicol and Weedon 2007).

Medicago minima and *Medicago polymorpha* (Small Woolly Burr Medic and Burr Medic)

These two species are common in improved pastures and are deliberately planted because they provide high protein feed for domestic stock (Cunningham *et al.* 1981). Cunningham *et al.* (1981) stated that germination and growth occurs in the cooler months; nevertheless, germination, growth and seed set have also been observed for these species in late spring and summer as inundated sediment is exposed to the atmosphere (Nicol 2004; Nicol and Weedon 2007). These *Medicago* species have flexible life history strategies and flower and set large quantities of seed once soil moisture levels fall (Nicol 2004). Seeds are dispersed by animals and water (Cunningham *et al.* 1981) and form long-lived persistent seed banks (Nicol 2004). Germination occurred in seed bank samples from Lake Malta in the Menindee Lakes system that had been subjected to five wetting and drying cycles over two years with no seed input (Nicol 2004). *Medicago minima* and *Medicago polymorpha* are readily grazed by stock (Cunningham *et al.* 1981) but plants still flower and set seed when subjected to intense grazing pressure (J. Nicol pers. obs.).

In addition, sheep will consume dry seeds and burrs (Cunningham *et al.* 1981), which may reduce the seed bank. Control can be achieved by spraying with herbicides (Cunningham *et al.* 1981); however, this may be difficult because plants are often found growing amongst native species (J. Nicol pers. obs.)

Medicago spp. pose a high risk of invasion because they are relatively drought tolerant, form a persistent seed bank, germinate on exposed sediment, grow throughout the year (Nicol 2004) and seeds are dispersed by water and animals (Cunningham *et al.* 1981). *Medicago* spp. were present in low numbers at several of the river red gum watering sites (Nicol and Weedon 2007). In addition, these species may have been planted in the past in the Chowilla system in areas such as Lake Littra and Werta Wert Wetland to provide high protein feed for domestic stock.

Trifolium spp. (Clover)

Similar to *Medicago* spp., *Trifolium* spp. are common components of improved pastures and are often planted to provide high protein stock feed (Cunningham *et al.* 1981). Cunningham *et al.* (1981) reported that germination and growth for *Trifolium* spp. occurs in the cooler months; nevertheless, germination, growth and seed set have been observed for these species in late spring and summer as inundated sediment is exposed to the atmosphere (Nicol and Weedon 2007). Seeds are dispersed by animals and water (Cunningham *et al.* 1981) and many *Trifolium* species have long-lived persistent seed banks and flexible life history strategies although not to the same degree as *Medicago* spp. and native floodplain species such as *Epaltes australis* or *Glinus lotoides* (Cunningham *et al.* 1981; Nicol 2004). *Trifolium* spp. are readily grazed by stock (Cunningham *et al.* 1981); however, plants still flower and set seed when subjected to intense grazing pressure (J. Nicol pers. obs.). In addition, sheep will consume dry seeds (Cunningham *et al.* 1981), which may reduce the seed bank. Control can be achieved by spraying with herbicides (Cunningham *et al.* 1981); however, this may be difficult because plants are often found growing amongst native species (J. Nicol pers. obs.)

These species pose a high risk of invasion because they are relatively drought tolerant, form a persistent seed bank, seeds are dispersed by water and animals (Cunningham *et al.* 1981), grow throughout the year and germinate on exposed sediment (Nicol and Weedon 2007). In addition, these species may have been planted in the past in the Chowilla system in areas such as Lake Littra and Werta Wert Wetland to provide high protein feed for domestic stock. *Trifolium* spp. has; however, only been recorded in Werta Wert Wetland albeit in moderate numbers (Nicol and Weedon 2007).

Erodium cicutarium (Common Crowfoot)

Erodium cicutarium is a common winter/spring annual found in most soil types and vegetation communities, including floodplains (Cunningham *et al.* 1981). Growth commences in the autumn and flowering often occurs when the plant is quite small after which seeds with sharp awns are produced (Cunningham *et al.* 1981). Seed is spread by animals (Cunningham *et al.* 1981). Plants are grazed by domestic stock (Cunningham *et al.* 1981), which may be an effective control strategy. Information on other control strategies is not available.

This species poses an intermediate risk because the timing of its growing season (cooler months) and operation of the regulator may control *Erodium cicutarium* to some degree by flooding plants that have germinated. *Erodium cicutarium* was observed in several red gum watering trial vegetation surveys undertaken by Todd Goodman in 2005; however, it is unlikely that it was present in an area that was flooded because the inundated areas were minimally surveyed.

Abutilon theophrasti (Swamp Chinese Lantern)

This species is a weed found along the margins of creeks, shallow depressions and areas subjected to temporary flooding (Cunningham *et al.* 1981). Germination occurs after water levels recede and growth and flowering occurs year round (Cunningham *et al.* 1981). Seeds are dispersed by animals and water (Cunningham *et al.* 1981). Plants are not grazed by domestic stock (Cunningham *et al.* 1981) and information on control strategies is not available.

Abutilon theophrasti poses a high invasion risk because it is well adapted to the water regimes such as those that may result from the operation of the regulator, it grows year round and seeds are dispersed by water (Cunningham *et al.* 1981). This species was observed in large numbers throughout Werta Wert Wetland and Punkah Depression after they was watered (Nicol and Weedon 2007).

Malva parviflora (Small Flowered Mallow)

Malva parviflora is a common weed of gardens and places of human habitation (Cunningham *et al.* 1981). This species is fast growing and is often abundant in years of high winter rainfall and (Cunningham *et al.* 1981). Germination and growth occur in the cooler months and flowering commences at an early stage and continues throughout the life of the plant (Cunningham *et al.* 1981). Seed is spread by animals and water (Cunningham *et al.* 1981). This species is grazed by domestic stock, which may provide the most effective means of control because it is relatively resistant to herbicides (Cunningham *et al.* 1981). Other control strategies are cultivation and establishment of more competitive species (Cunningham *et al.* 1981).

This species poses a high invasion risk because it germinates on exposed sediment, is relatively desiccation tolerant, seeds are spread by water and, in contrast to information reported in Cunningham *et al.* (1981), it has been observed growing in summer in areas subjected to artificial flooding (Nicol and Weedon 2007). *Malva parviflora* was recorded in low numbers in Coppermine Waterhole and Werta Wert Wetland after they were watered in spring/summer 2005-06 (Nicol and Weedon 2007).

Avena fatua (Wild Oat)

This species is a common weed of cereal crops, roadsides, cultivated land and places of human habitation (Cunningham *et al.* 1981). Germination occurs in autumn and plants grow until late spring/early summer (depending on soil moisture) after which it flowers, sets seed and dies (Cunningham *et al.* 1981). Seeds are dispersed by wind and animals and form a long-term persistent seed bank (Cunningham *et al.* 1981). Young plants are grazed by stock (Cunningham *et al.* 1981), which may provide effective control. Other control measures include spraying with herbicides and cultivation but eradication is a long-term project because of the longevity of the seed bank (Cunningham *et al.* 1981).

Despite its well-documented invasion of every continent except Antarctica (Cunningham *et al.* 1981), *Avena fatua* poses an intermediate invasion risk due to the operation of the proposed regulator. The growing season is over the winter and spring (Cunningham *et al.* 1981) and may be partially controlled by the operation of the regulator. In addition, *A. fatua* has not been observed in the Chowilla system in areas recently subjected to artificial flooding (Nicol and Weedon 2007) but in low numbers around areas of human habitation (J. Nicol pers. obs.).

Bromus rubens (Red Brome)

Bromus rubens is a common weed present on most soil types and in most vegetation communities, including floodplains (Cunningham *et al.* 1981). Germination and growth occur in the cooler months and flowering in spring (Cunningham *et al.* 1981). Seeds are dispersed by wind and animals (Cunningham *et al.* 1981). Young plants are grazed by stock (Cunningham *et al.* 1981), which may provide effective control. Other control measures include spraying with herbicides and cultivation (Cunningham *et al.* 1981).

This species poses an intermediate invasion risk. Operation of the regulator may provide some control of plants that have germinated through the winter. Nevertheless, *B. rubens* is relatively desiccation tolerant, germinates on exposed sediment (Cunningham *et al.* 1981) and has been observed in low numbers in several watering sites across the Chowilla Floodplain (Nicol and Weedon 2007).

Cynodon dactylon (Couch Grass)

Cynodon dactylon is a widely planted grass, which has invaded most vegetation communities throughout southern Australia (Muyt 2001). This species germinates and grows throughout the year providing moisture is available, except in the coldest months, and is very drought tolerant when established (Cunningham *et al.* 1981; Muyt 2001). Mats of *Cynodon dactylon* can eliminate smaller native species but larger native herbs commonly persist, although their growth can be significantly reduced (Muyt 2001). Seed is spread by wind, animals and water (Cunningham *et al.* 1981). Plants are readily grazed by domestic stock but resprout rapidly and are resistant to trampling (Cunningham *et al.* 1981). Small infestations can be dug out but care needs to be taken to remove all rhizomes and stolons (Muyt 2001). Solarisation is also an effective treatment in sunny locations over the warmer months (Muyt 2001). Plastic sheeting should be laid over the infestation for 4-12 weeks regrowth should be sprayed with herbicide once it reaches 5-10 cm (Muyt 2001). Control can also be achieved by spraying with grass selective herbicides (Muyt 2001).

This species poses a high invasion risk because it is well adapted to the proposed water regime; it grows during the summer if water is available, is desiccation tolerant and seed is dispersed by water. However, it has not been recorded in any of the areas recently subjected to natural or artificial flooding in the Chowilla system (Nicol and Weedon 2007) and is only present around areas of human habitation in the remainder of the system (J. Nicol pers. obs.).

Polypogon monspeliensis (Annual Beardgrass)

This species is generally found in moist situations such as stream banks, pool edges, seepage areas near channels and in drains (Cunningham *et al.* 1981). Germination occurs during the winter (Cunningham *et al.* 1981) or when water levels recede in temporary wetlands (Nicol *et al.* 2003) and growth occurs throughout the year until flowering (Cunningham *et al.* 1981). Cunningham *et al.* (1981) reported that this species is restricted to areas with high soil moisture; nevertheless, it has been observed in relatively dry situations such as the northern basin of Werta Wert Wetland after it had been dry for several months (Weedon and Nicol 2007). *Polypogon* *monspeliensis* is not readily grazed by domestic stock (Cunningham *et al.* 1981) and no information is available on its control.

Polypogon monspeliensis poses an intermediate risk because it is relatively desiccation tolerant (Nicol *et al.* 2003; Nicol and Weedon 2007), germinates on exposed sediment and grows throughout the year (Nicol *et al.* 2003). It has been observed in the Chowilla system in Werta Wert Wetland (Nicol and Weedon 2007) and along the edges of Pilby, Boat, Punkah and Pipeclay creeks (Zampatti *et al.* 2006b)

Polygonum aviculare (Wireweed)

Polygonum aviculare is a common weed of disturbed areas, such as roadsides, pastures and places of human habitation (Cunningham *et al.* 1981). Germination occurs from spring to early summer; and rapid growth is exhibited during summer and in some cases plants may resprout the next spring (Cunningham *et al.* 1981). Seeding is prolific and is spread by humans and animals (Cunningham *et al.* 1981). Young plants are grazed by domestic stock but only the leaves are eaten on older plants (Cunningham *et al.* 1981). Control can be achieved by spraying with herbicides but may be difficult because it is a prolific seeder (Cunningham *et al.* 1981).

This species poses a high invasion risk because it grows over the summer months, is desiccation tolerant (Cunningham *et al.* 1981) and germinates on exposed sediment (Nicol 2004). It was observed in Werta Wert Wetland in low numbers (Nicol and Weedon 2007) and is present in areas of human habitation, such as around Lock 6 (J. Nicol pers. obs.)

Salix babylonica (Weeping Willow)

This species is a common woody weed of watercourses throughout southern Australia (Sainty and Jacobs 1994; Cremer 1995; Cremer 2000; Muyt 2001; Blood 2003). Trees are deciduous with growth generally commencing in early to mid spring, which continues until mid to late autumn (depending on climate) (Sainty and Jacobs 1994; Cremer 1995; Cremer 2000; Muyt 2001; Blood 2003). Most *Salix babylonica* plants in Australia are female and spread by stem fragments (Sainty and Jacobs 1994; Cremer 1995; Cremer 2000). Control of small or isolated plants can be achieved by physical removal but care must be taken to remove all roots and all material should be disposed of well away from areas subjected to flooding (Sainty and Jacobs 1994; Cremer 1995; Cremer 2000). Larger plants and infestations can be controlled by spraying, injecting or cutting and painting with herbicides (Sainty and Jacobs 1994; Cremer 1995; Cremer 2000).

Salix babylonica poses a negligible invasion risk because it requires high soil moisture, prefers stable water levels, does not produce seed (Sainty and Jacobs 1994) and is not salt tolerant (Kennedy *et al.* 2003). This species is common along the banks of the River Murray in the Chowilla system, especially upstream of Lock 6 (Zampatti *et al.* 2006b).

Nicotiana glauca (Tobacco Bush)

Nicotiana glauca is a widespread weed of disturbed areas (e.g. roadsides and rabbit warrens), places of habitation and ephemeral streams (Cunningham *et al.* 1981; Florentine and Westbrooke 2005; Westbrooke *et al.* 2005; Florentine *et al.* 2006). Germination and growth occurs year round, it is desiccation tolerant (Cunningham *et al.* 1981) and produces large numbers of seeds, which are spread by animals and flooding (Florentine and Westbrooke 2005; Westbrooke *et al.* 2005), and forms a long-term persistent seed bank (Florentine *et al.* 2006). Plants are not grazed by domestic stock, except in times of extreme feed shortage (Cunningham *et al.* 1981) and information on control is not available.

This species poses an extreme invasion risk because it is well adapted to the proposed water regime; growth occurs year round, it is desiccation tolerant (Cunningham *et al.* 1981), germination occurs on exposed sediment after flooding, seed is spread by water (Florentine and Westbrooke 2005; Westbrooke *et al.* 2005; Florentine *et al.* 2006) and it forms a persistent seed bank (Florentine *et al.* 2006). Scattered individuals have been observed on the Chowilla Floodplain (J. Nicol pers. obs.) but not in areas, which have recently been subjected to natural or artificial flooding (Nicol and Weedon 2007)

Solanum nigrum (Black Nightshade)

This species is a common weed on a wide range of soil types and vegetation communities especially cultivated land, places of human habitation and waste areas, (Cunningham *et al.* 1981). Growth and flowering occur year round providing there is sufficient soil moisture (Cunningham *et al.* 1981). Plants are not readily grazed by stock (Cunningham *et al.* 1981) small infestations; however, can be controlled by physical removal and larger infestations by spraying with herbicides (Bunn 2004).

Solanum nigrum poses a high invasion risk because it is relatively desiccation tolerant, germinates on exposed sediment (Nicol 2004) and grows year round (Cunningham *et al.* 1981). In the Chowilla system it was recorded in Werta Wert Wetland after it was flooded and Chowilla Horseshoe before it was flooded (Nicol and Weedon 2007).

Phyla canescens (Lippia)

Phyla canescens is a common weed of floodplains (especially in the northern Murray-Darling Basin), which can quickly cover large areas under favourable conditions (Cunningham *et al.* 1981; Earl 2003; Leigh and Walton 2004). It is grows year round, is desiccation tolerant (Cunningham *et al.* 1981) and will tolerate flooding of at least 80 cm for at least 99 days (Taylor and Ganf 2005). Reproduction is by seed and stem fragments, which are spread by water (Cunningham *et al.* 1981; Earl 2003; Leigh and Walton 2004). Plants are not grazed by stock (Cunningham *et al.* 1981; Earl 2003; Leigh and Walton 2004) and control can be achieved by cultivation or spraying with herbicides (Earl 2003; Leigh and Walton 2004).

This species poses an extreme invasion risk because it is well adapted to the proposed water regime; propagules are spread by water, it is desiccation tolerant and grows year round (Earl 2003; Leigh and Walton 2004). In contrast to other species that pose high or extreme invasion risks) *P. canescens* is able to persist through flooding as an adult plant whilst most other species persist as seed in the seed bank. *Phyla canescens* has been recorded in low numbers in Twin Creeks, Punkah Island Horseshoes (Nicol and Weedon 2007) and is abundant on the floodplain adjacent to the Boat Creek Bridge (Zampatti *et al* 2006b) and around Lock 6 (J. Nicol pers. obs.).

Potential control methods for each species are outlined in Table 3.

Native Species

Three native taxa (*Paspalum distichum, Phragmites australis* and *Typha* spp.) have been identified as potential pest plants that may expand their distribution due to the operation of the proposed regulator. These species, whilst native, can rapidly colonise large areas under favourable conditions forming monospecific stands that prevent the establishment of other species (Sainty and Jacobs 1994).

Paspalum distichum (Water Couch)

Paspalum distichum is a native grass that forms dense mats in shallow still or running water and on the margins of streams and wetlands (Cunningham *et al.* 1981). Plants are sensitive to frost and germination and growth does not commence until temperatures reach 20°C; it is relatively desiccation tolerant (Cunningham *et al.* 1981; Sainty and Jacobs 1994) and tolerates deep flooding as rhizomes rapidly sprout once the sediment is exposed (Siebentritt 2003). Seed is spread by animals and water and new plants can establish from stem and rhizome fragments, which are also spread by water (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Plants are readily grazed by domestic stock but, unless stocking rates are very high, this is not an effective control strategy (Cunningham *et al.* 1981). Mechanical disturbance of the soil has been shown to increase growth but control has been gained by the use of herbicides (Cunningham *et al.* 1981).

This species poses a high risk because it is well adapted to the proposed water regime; it is relatively desiccation tolerant, grows during the warmer months, propagules are dispersed by water (Cunningham *et al.* 1981; Sainty and Jacobs 1994) and it germinates on exposed sediment (Nicol 2004). In addition, *Paspalum distichum* is able to persist as rhizomes (once established) whilst inundated (Siebentritt 2003) thus enabling rapid colonisation when water levels recede (sensu Grace 1993). *Paspalum distichum* is common along the banks of the River Murray in the Chowilla system (Zampatti *et al.* 2006b) but has not been recorded in any of the watering sites (Nicol and Weedon 2007).

Phragmites australis (Common Reed)

This species is a cosmopolitan grass that grows up 4 m tall, it can form dense (almost impenetrable) beds along the edges of streams, in shallow stationary water bodies and boggy areas (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Growth commences in spring, when rhizomes sprout, and continues until late autumn (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Flowering occurs in summer but in most situations spread is by rhizomes (asexual)

(Cunningham *et al.* 1981; Sainty and Jacobs 1994). New shoots are grazed by domestic stock (especially cattle), which can at times be an effective control measure (Cunningham *et al.* 1981). Other control measures include cutting below the water in autumn and spraying with herbicides (Sainty and Jacobs 1994).

Phragmites australis poses a very low invasion risk because it requires high soil moisture year round (Roberts and Marston 2000) and generally spreads by rhizomes (Cunningham *et al.* 1981; Sainty and Jacobs 1994). In the Chowilla system it is very common along the edges of creeks and backwaters and banks of the River Murray (Zampatti *et al.* 2006b) but it has not been recorded in any of the watering sites (Nicol and Weedon 2007).

Typha domingensis and T. orientalis (Bulrush, Cumbungi)

Typha spp. are native species that grow along the edges of streams and wetlands, in boggy areas and in shallow stationary water bodies up to 2 m deep (Sainty and Jacobs 1994). Growth commences in spring, when shoots sprout from rhizomes, and continues until late autumn (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Flowering occurs in late summer and one inflorescence can produce more than 200,000 seeds, which are dispersed by the wind (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Seeds germinate on exposed or inundated sediment (Nicol and Ganf 2000) under high light conditions (Froend and McComb 1994). Seedlings and newly sprouted plants are grazed by domestic stock, particularly cattle, which can be an effective control measure (Cunningham *et al.* 1981; Sainty and Jacobs 1994). Other control strategies include cutting below the water level in autumn and spraying with herbicides (Sainty and Jacobs 1994).

This species poses a very low invasion risk because it requires high soil moisture year round (Roberts and Marston 2000). In the Chowilla system it is very common along the banks of the River Murray and the edges and shallow margins of creeks and backwaters (Zampatti *et al.* 2006b). In the watered sites one *Typha* spp. plant was observed in Monoman Horseshoe in November 2005 (Nicol and Weedon 2007).

Potential control methods for each species are outlined in Table 3.

Table 3: Summary of potential control methods for each native and exotic pest plant species recorded in the Chowilla system since 1988.

Species	Herbicides	Controlled Grazing	Flooding	Solarisation	Physical Removal	Cultivation	Burning	Slashing
Abutilon theophrasti								
Anagallis arvensis	*		*		*			
Arctotheca calendula	*		*		*			
Aster subulatus	*				*	*		
Avena fatua	*		*		*	*		
Brassica tournefortii	*		*		*			
Bromus rubens	*		*		*	*		
Carduus tenuiflorus	*		*		*			
Carrichtera annua	*		*		*		*	
Carthumus lanatus	*		*		*			
Centaurea calcitrapa	*		*		*	*	*	*
Chenopodium murale	*		*		*			
Citrullus lanatus	*		*		*			
Conyza bonariensis	*		*		*			
Cuscuta campestris	*	*					*	
Cynodon dactylon	*		*	*	*			
Dittrichia graveolens	*		*		*			
Echium plantagineum	*		*		*	*		
Elodea canadensis	*				*			
Emex australis	*		*		*			
Erodium botrys	*	*	*		*			
Erodium cicutarium		*	*					
Galenia pubescens	*	*	*		*			
Galenia secunda	*	*	*		*			
Heliotropium amplexicaule	*							
Heliotropium curassivicum								
Heliotropium europaeaum								
Heliotropium supinum								
Herniaria hirsuta	*		*		*			
Hordeum lepronium	*		*		*			
Hypochoeris glabra	*		*		*			
Hypochoeris radicata	*		*		*			
Lactuca saligna	*		*		*			
Lactuca serriola	*	*			*			
Lamarckia aurea	*	*			*			
Limonium lobatatum	*		*		*			
Lolium rigidum	*	*	*		*			
Lophochloa cristata	*		*		*			
Lophochloa pumilia	*		*		*			
Lycium ferocissimum	*		*		*			
Malva parviflora		*	*		*	*		
Marrubium vulgare	*		*		*		*	
Medicago minima	*	*	*		*			
Medicago polymorpha	*	*	*		*			
Melilotus indica	*	*	*		*			
Mesembryanthemum crystallinum								

Species	Herbicides	Controlled Grazing	Flooding	Solarisation	Physical Removal	Cultivation	Burning	Slashing
Mesembryanthemum nodiflorum								
Myosurus minimus var. *australis*	*		*		*			
Neatostema apulum	*		*		*			
Nicotiana glauca								
Onopordum acaulon	*		*		*			
Papaver hybridum	*		*		*			
Parapholis incruva	*		*		*			
Pentaschistis airoides	*		*		*			
Phyla canescens	*				*			
Picris hieracioides	*		*		*			
Polycarpon tetraphyllum	*		*		*			
Polygonum aviculare	*		*		*			
Polypogon monspeliensis								
Ranunculus scleratus								
Riechardia tingitana		*	*		*			
Rorippa palustris	*		*		*			
Rumex crispus	*		*		*			
Salix babylonica	*				*			
Salvia verbenaca	*		*		*			
Schisimus barbartus	*		*		*			
Seline apetala	*		*		*			
Seline gallica var. *gallica*	*		*		*			
Sisymbrium erysimoides	*		*		*			
Sisymbrium irio	*		*		*			
Solanum nigrum	*		*		*			
Soliva anthemifolia	*		*		*			
Sonchus asper		*	*		*			
Sonchus oleraceus		*	*		*			
Sonchus tenemimus		*	*		*			
Spergularia diandra	*		*		*			
Spergularia marina	*		*		*			
Taraxacum officinale	*		*		*			
Trifolium spp.	*	*	*		*			
Urospermum picroides	*		*		*			
Urtica urens	*		*		*			
Verbena officinalis	*		*		*			
Veronica peragrina ssp. *xalapensis*	*		*		*			
Vulpia muralis	*		*		*			
Vulpia myuros	*		*		*			
Xanthium californicum	*	*	*		*	*		
Xanthium occidentale	*	*	*		*	*		
Paspalum distichum	*	*		*	*			
Phragmites australis	*	*			*			
Typha spp.	*	*			*			

Areas of the Chowilla System at the Greatest Risk of Invasion by Pest Plants

Numerous factors (biotic and abiotic) effect the distribution and abundance of plants at the landscape scale. Factors that need to be considered in the Chowilla system are:

- Presence of viable propagules or propagules that are able to disperse into the system.
- Water regime requirements for germination, growth and reproduction.
- Desiccation tolerance.
- Life history characteristics.
- Soil moisture.
- Soil salinity.
- Grazing.

The spatial distribution of pest plant propagules across the Chowilla system is a significant knowledge gap, which needs to be addressed. This knowledge will assist in predicting where outbreaks may occur and where to concentrate control efforts. Nevertheless, the distribution and abundance of plant propagules changes through time and regular repeat surveys will be necessary.

The majority of pest plant species and all of the species that pose a high or extreme invasion risk (Table 2) require exposed sediment with high soil moisture for seeds to germinate and are desiccation tolerant to varying degrees (Table 1 and Table 2). All species (except *Phyla canescens* and *Paspalum distichum*) will not tolerate flooding but, with the exception of *Lycium ferocissimum*, are able to complete their life cycle and replenish the seed bank between inundation events (Cunningham *et al.* 1981). *Phyla canescens* and *Paspalum distichum* are able to tolerate flooding for several months (Siebentritt 2003; Taylor and Ganf 2005) and will persist whilst the proposed regulator is in use.

Therefore, the area most at risk of invasion by the largest number of species is probably the area inundated by the operation of the regulator under low flows (10,000 Ml day^{-1}). Areas that are inundated under higher flows are probably more at risk from perennial, desiccation tolerant and flood intolerant species such as *Lycium ferocissimum* (Cunningham *et al.* 1981) because in the areas that are more frequently flooded such species will not be able to complete their life cycle.

Within the area inundated by the operation of the regulator at low flows, soil characteristics and land use will determine plant distribution. Areas that are highly saline, such as Lake Limbra and Coombool Swamp, are not at risk of invasion from the majority of species (unless the operation of the regulator significantly reduces the soil salinity in these areas) because most weed species recorded at Chowilla are not salt tolerant (except *Heliotropium curassivicum* and *Bromus rubens*) (Cunningham *et al.* 1981).

Grazing may also impact the distribution and abundance of pest plants in the area of floodplain inundated by the regulator under low flows. It is unlikely that grazing sensitive species such as *Galenia* spp., *Medicago* spp. and *Trifolium* spp. (Cunningham *et al.* 1981) are going to be abundant on the grazed section of the floodplain; however, they may be a problem in the ungrazed areas.

Monitoring and Mitigation Strategies

Existing monitoring sites from the River Red Gum Watering Trial Vegetation Monitoring Project (Nicol and Weedon 2007), Chowilla Icon Site Floodplain Vegetation Monitoring Project (Weedon and Nicol 2006) and Chowilla Fish and Macrophytes Project (Zampatti *et al.* 2006a; Zampatti *et al.* 2006b) will be able to be utilised to monitor and provide baseline data on weed distribution and abundance (and assess Living Murray targets 5, 6 and 8 (Department of Water, Land and Biodiversity Conservation 2006). As part of the aforementioned projects approximately 1,300 quadrats have been established across the floodplain, on the banks of creeks and backwaters and banks of the River Murray (Weedon and Nicol 2006; Zampatti *et al.* 2006a; Zampatti *et al.* 2006b; Nicol and Weedon 2007). Additional sites at key locations especially in areas that are inundated by the operation of the Chowilla Creek regulator and Pipeclay Creek and Slaney Creek structures under low flows may need to be established.

Monitoring programs will need to be scientifically and statistically robust and comparable with past monitoring activities, especially if past monitoring results are going to be used as baseline data. The vegetation surveying protocol developed for the Chowilla Fish and Macrophytes Project (Zampatti *et al.* 2006b) was adopted by the River Red Gum Watering Trial Vegetation Monitoring Project (Nicol and Weedon 2007) and Chowilla Icon Site Floodplain Vegetation Monitoring Project (Weedon and Nicol 2006). This technique has proven to be robust (able to detect differences in floristic composition through time and between locations) and is designed so data collected by different individuals will be identical (i.e. percent covers or Braun-Blanquet (1932) cover/abundance scores are not used). Nevertheless, individual monitoring strategies may need to be developed for individual wetlands and the use of remote sensing techniques such as high-resolution aerial photography or videography need to be investigated.

Monitoring vegetation may provide an indication of the extent of pest plant invasion as a result of the operation of the regulator; however, the seed bank is the most likely the source of recruits. Information on the distribution and abundance of species in the seed bank can be gained by taking soil samples from the field and subjecting the samples to conditions that will promote germination or manually separating seeds from the soil (Gross 1990; Brock *et al.* 1994). Both techniques may provide an indication of plant recruitment patterns and in turn be useful in developing control strategies.

The most effective control strategy for the majority species is spraying with herbicides (Cunningham *et al.* 1981). Spraying is probably an effective control strategy for localised monospecific infestations, where a non-selective herbicide such as glyphosate can be used, or small areas that require only grass or broadleaf weed control and a selective herbicide can be used. Nevertheless, spraying is impractical for large infestations near watercourses or where pest species coexist with desirable native species (Muyt 2001; Blood 2003).

Another strategy for eradicating small monospecific infestations (especially clonal monocots) is solarisation (Muyt 2001). Solarisation is the technique of placing plastic sheets over weeds for a period of time during their main growth phase to inhibit photosynthesis and increase temperatures beyond the plants tolerance levels (Muyt 2001). It is most effective in open sunny locations, with the material left in place for several weeks over the summer (Muyt 2001).

Flooding areas where weeds have germinated is an effective control for species such as *Xanthium* spp. (Victorsen 2001; Nicol 2004); however, flooding may also kill native species (Nicol 2004; Nicol *et al.* 2007) that have germinated and potentially deplete their seed banks. The operation of the proposed regulator may partially control weed species that have germinated in response to winter rainfall. However, it is unclear whether these species germinate in response to sediment with high soil moisture and require cool temperatures for germination and growth or whether they germinate in response to high soil moisture and continue to grow providing there is sufficient soil moisture regardless of temperature. For species that require cool temperatures the operation of the regulator may break the lifecycle by flooding plants before they have the opportunity to flower and set seed but if germination and growth are independent of temperature the regulator may promote these species.

Controlled grazing by domestic stock is a strategy that may be able to be employed to control grazing sensitive exotic species such as *Galenia* spp., *Trifolium* spp. and *Medicago* spp. (Cunningham *et al.* 1981). In addition, *Xanthium* spp. and *Cuscuta campestris* had significantly smaller seed banks in areas that were grazed by sheep or cattle compared to adjacent ungrazed areas in the Menindee Lakes (Nicol 2004) and Thegoa Lagoon (Nicol *et al.* 2007). Controlled grazing needs to be carefully monitored because of the potential negative impacts of grazing by domestic stock such as decreased bank stability, lower coarse woody debris accumulation (Jansen and Robertson 2001) and elimination or reduction of desirable native species from the extant vegetation (Lodge 1991; Robertson and Rowling 2000; Marty 2005) and seed bank (Nicol 2004; Nicol *et al.* 2007).

Effective weed control in the Chowilla system will rely the timely consideration of monitoring results so that control measures can be put in place before plants set seed. In addition, trials need to be established to determine the most efficient long-term control strategies.

Discussion, Conclusions and Knowledge Gaps

A comparison of the floodplain vegetation before and after a natural flood event (with the exception of Zampatti *et al.* 2006a) has not been undertaken in the Chowilla system; therefore, much of the information in the preceding sections has been derived from other systems (e.g. the Menindee Lakes). The vegetation monitoring of the watering trials (Nicol and Weedon 2007) and the flood response monitoring (Zampatti *et al.* 2006a) may provide an indication of what may occur as a result of the operation of the proposed regulator; however, the hydrological regime of the watering trials was very different from that of the proposed regulator (Department of Water, Land and Biodiversity Conservation 2006) and the flood response monitoring investigated the effect of a small in channel water level rise (Zampatti *et al.* 2006a). The operation of the regulator will result in a staged water level rise over several weeks, the water level will then be held at a constant level for approximately 3 months after which water levels will be drawn down over several weeks (Department of Water, Land and Biodiversity Conservation 2006). The wetlands that were watered to improve overstorey vegetation condition were filled rapidly by pumping, which continued for several days to maintain a constant water level then water levels fell in response to evaporation and infiltration. The rate of drawdown in these instances was much slower than the proposed operation of the regulator (Department of Water, Land and Biodiversity Conservation 2006) or a natural flood and the period of inundation was variable depending on the geomorphology of the wetland. The small in channel rise monitored by Zampatti *et al.* (2006a) did not inundate large areas of floodplain and was of much shorter duration than an engineered flood resulting from the operation of the proposed regulator (Department of Water, Land and Biodiversity Conservation 2007).

Evidence from similar systems and experimental studies suggests that the proposed operation of the environmental regulator and associated structures probably poses no greater risk of pest plant recruitment than for a natural flood with a similar hydrograph. The most important components of water regime for recruitment and survival of aquatic and riparian plants are; the presence or absence of standing water (sensu van der Valk 1981), depth, duration and frequency of flooding (sensu Casanova and Brock 2000) and rate of drawdown (sensu Nicol *et al.* 2003; Nicol 2004). Whether the water regime is the result of a natural or engineered flood is of little consequence for plants. Flow velocity generally does not impact on plants unless velocities are sufficient to uproot plants and cause scouring, which should not happen in the Chowilla system.

The species that will most likely recruit as a result of the operation of the environmental regulator are those with seeds that do not germinate, but remain viable whilst submerged and germinate as water levels fall and the sediment surface is exposed to the atmosphere with high moisture content. Therefore, it is the annual terrestrial and floodplain species and desiccation tolerant amphibious species (both native and exotic) that will be favoured by the operation of the structure. Many of the exotic species that have successfully colonised the floodplains of dryland river systems have similar water regime preferences to native floodplain species (Nicol 2004) and further investigation is required to determine what subtle differences in water regime may give native species an advantage (e.g. rate of drawdown, short-term inundation tolerance, small-scale water level fluctuations).

The species that pose the greatest invasion or expansion risk and threat to the system are those that germinate and grow rapidly to a size where they can shade or crowd out other species (e.g. *Xanthium* spp. and *Heliotropium europaeaum* (Cunningham *et al.* 1981)). Species that take longer to germinate may not be able to take advantage of the "window of opportunity" for germination (exposed sediment with high surface soil moisture) (sensu Nicol 2004) and may be lost from the system if the more rapidly growing pest species are not controlled.

Submergent species (e.g. *Elodea canadensis*) may be present whilst water is present but die shortly after the sediment is exposed to the atmosphere and pose little or no risk. Similarly, emergent species such as *Typha* spp., *Phragmites australis, Salix babylonica* or *Ranunculus scleratus* pose little or no risk because when the regulator is not in operation there will be insufficient soil moisture for plants to survive most of the time (Roberts 1987; Sainty and Jacobs 1994; Roberts and Marston 2000; Nicol *et al.* 2003).

This review has identified several knowledge gaps that need to be addressed to gain a better understanding of pest plants in the Chowilla system and determine the most efficient control strategies. The distribution and abundance of pest plants in the seed bank needs to be investigated to provide an indication of the distribution and abundance of weeds across the floodplain following the operation of the regulator. This information will assist in planning control strategies, particularly where to concentrate control efforts.

The effectiveness of different pest plant control strategies (spraying, flooding, controlled grazing, cultivation, solarisation and physical removal) are not well understood in floodplain systems and the construction and operation of the regulator provides an opportunity to compare these strategies under controlled conditions in the field. This information will useful to managers of floodplain systems in similar areas of the Murray Darling Basin when designing and implementing weed control programs.

The spatial coverage of the existing monitoring sites needs to be compared with the area influenced by the regulator to determine whether the existing sites can be used to assess the impacts of the proposed regulator and Living Murray targets 5, 6, 7 and 8 or whether additional sites are needed. In addition, other monitoring techniques such as remote sensing (e.g. high resolution aerial photography or videography) or mapping infestations using GIS software could be trialled to determine whether such techniques are more effective in providing information on where to concentrate control efforts.

Using a regulator to artificially flood a floodplain under low flow conditions has not been used as a restoration technique anywhere in the world on this scale. Therefore, if the regulator is constructed, data collected from this large-scale experiment has the potential to inform scientists and managers both locally and globally. Thus it is essential that there is a significant investment in evaluating the impacts of the regulator at the landscape scale.

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