Ecological benefits of ‘Environmental Flows’ in the Eastern Mt. Lofty Ranges

by

Brian Martin Deegan

School of Earth and Environmental Sciences,
The University of Adelaide

A thesis submitted to The University of Adelaide
for the degree of Doctor of Philosophy

April 2007
Contents

1 General Introduction ................................................................. 1
  1.1 Deterioration of aquatic ecosystems ........................................... 1
  1.2 Regulation of flows ................................................................. 2
  1.3 Restoration approach ............................................................. 4
  1.4 Instalment of Environmental flows .......................................... 5
  1.5 The Project ............................................................................. 6
    1.5.1 Implications for flow restoration ......................................... 6
      1.5.1.1 Current ecological health/condition (Chapter 2) ............... 6
      1.5.1.2 Persistent aquatic and riparian seed bank (Chapter 3) ........ 7
      1.5.1.3 Species productivity in relation to water regime (Chapter 4) 7
      1.5.1.4 Influence of water regime over nutrient loading (Chapter 5) 8
      1.5.1.5 Consequence of catchment degradation (Chapter 6) .......... 8
  1.6 Eastern Mount Lofty Ranges – area of focus .............................. 9

2 Assessing the ecological condition of riverine reaches and their restoration potential: Implications for Environmental Flows .......... 14
  2.1 Introduction ............................................................................ 14
  2.2 Materials and Methods .......................................................... 16
    2.2.1 Study area ........................................................................ 16
    2.2.2 Index of Riverine Ecological Condition ............................... 17
    2.2.3 Reach selection and Rapid Appraisal Survey ....................... 17
    2.2.4 Data Analysis .................................................................... 20
  2.3 Results .................................................................................... 21
    2.3.1 Ecological condition scores .............................................. 21
2.3.2 Comparison of important indices between rivers .........................................23
  2.3.2.1 The Finniss ...............................................................................................23
  2.3.2.2 The Angas ...............................................................................................25
  2.3.2.3 Currency creek .......................................................................................27
  2.3.2.4 Tookayerta creek ....................................................................................29
  2.3.2.5 Combined analysis ................................................................................31

2.4 Discussion .............................................................................................................32
  2.4.1 Index of riverine ecological condition ..........................................................32
  2.4.2 Ecological condition, causative factors and restoration potential .................33
  2.4.3 Implications for Environmental Flows .........................................................34

3 Aquatic and riparian seed banks in the EMLR: the effects of anthropogenic changes in land use and flow regulations, and their restoration potential .................................................................36
  3.1 Introduction .......................................................................................................36
  3.2 Materials and Methods ....................................................................................38
    3.2.1 Study area ................................................................................................38
    3.2.2 Catchment division ..................................................................................38
    3.2.3 Material collection and preparation .........................................................39
    3.2.4 Seedling emergence technique .................................................................41
    3.2.5 Functional Classification .........................................................................41
    3.2.6 Data analysis ............................................................................................41
  3.3 Results ..................................................................................................................43
    3.3.1 Species Composition ............................................................................44
      3.3.1.1 River Angas ......................................................................................44
      3.3.1.2 River Finniss ....................................................................................48
      3.3.1.3 Currency creek ...............................................................................52
      3.3.1.4 Tookayerta creek ............................................................................54
    3.3.2 Seed Bank Density .....................................................................................57
  3.4 Discussion .............................................................................................................60
    3.4.1 Aquatic and riparian seed banks .................................................................60
    3.4.2 The impact and extent of catchment degradation on the aquatic and riparian seed banks ........................................................................................................61
4 The influence of water level fluctuations on the growth of emergent macrophytes: Implications for management as control measures........66

4.1 Introduction.................................................................66
4.2 Materials and Methods.........................................................68
  4.2.1 Study species..........................................................68
  4.2.2 Plant material............................................................69
  4.2.3 Experimental water regimes........................................70
  4.2.4 Pond Experiment.......................................................71
  4.2.5 Data Collection and Analysis .......................................71
  4.2.6 Estimation of Relative Growth Rate and Emergent Surface Area......72
4.3 Results...............................................................................72
  4.3.1 Species performance ..................................................72
    4.3.1.1 Biomass..............................................................72
    4.3.1.2 Relative Growth Rate............................................74
    4.3.1.3 Vegetative Reproduction .......................................75
    4.3.1.4 Leaf or Stem Length ............................................76
    4.3.1.5 Emergent Surface Area ........................................77
  4.3.2 Biomass Allocation.....................................................80
4.4 Discussion..........................................................................83
  4.4.1 Impact of Elevation and Amplitude of water level fluctuations on Leaf Length.................................................................83
  4.4.2 Impact of Elevation and Amplitude of fluctuation on Biomass and Growth84
  4.4.3 How does a fluctuating water level constrain plant performance? ..........85
  4.4.4 Imposition of environmental flows as control measures in the EMLR ......86
## 5 The effects of nutrient loading on emergent macrophytes and the influence of water regime: Implications for flow restoration

5.1 Introduction

5.2 Materials and Methods

5.2.1 Study species

5.2.2 Plant material

5.2.3 Experimental water regimes

5.2.4 Nutrient loading rates

5.2.5 Pond Experiment

5.2.6 Data Collection and Analysis

5.3 Results

5.3.1 Species performance

5.3.2 Biomass allocation

5.3.3 Tagging Study

5.4 Discussion

5.4.1 Species performance

5.4.2 Morphological response - Biomass allocation

5.4.3 Tagging study

5.4.4 Implications for flow restoration

## 6 Stream degradation results in a mismatch between consumers and their resources: the promotion of aquatic / riparian plant communities

6.1 Introduction

6.2 Materials and Methods

6.2.1 Selection of Study sites

6.2.2 Sampling protocol and collection of primary sources and consumers

6.2.3 Sample preparation and analysis

6.2.4 Modelling feasible source mixtures to explain shredder nutrition

6.3 Results

6.3.1 Pilot study

6.3.2 Modelled feasible source mixtures to explain shredder nutrition

6.3.3 C:N ratios found in primary sources and their primary consumers

6.4 Discussion
6.4.1 Conceptual model of the flow of nutrients through riverine ecosystems ... 128
6.4.2 Nutritional constraints as a result of anthropogenic alterations ............ 128

7 General Discussion ................................................................................. 130

7.1 Restoration potential ......................................................................... 130
7.2 Installation of environmental flows and their implications .................. 132
7.3 Ecological benefits of restoring and promoting aquatic plant communities .. 134
7.4 Conclusions ...................................................................................... 135
7.5 Future considerations ......................................................................... 135

8 Bibliography ......................................................................................... 137

9 Appendices .......................................................................................... 156

9.1 Appendix 1 ..................................................................................... 156
9.2 Appendix 2 ..................................................................................... 160
List of tables

Table 2.1: Subindices (and their weighting in the final score) and indicators of the index of riverine ecological condition, the range within which each indicator was scored, and the method of scoring for each indicator. ................................................................. 19

Table 2.2: Summary of Total Ecological Condition Scores (TECS) for surveyed reaches in each of the four catchments. ................................................................. 21

Table 3.1: The number of species recorded in each of the seed banks of the Angas, Finniss, Tookayerta creek and Currency creek in each of the categories: Aquatic and Riparian Natives, Aquatic and Riparian Exotics, Terrestrial Natives, Terrestrial Exotics, Unidentified Sedges, Unidentified Grass and Unknown Species. ......................... 44

Table 3.2: NPMANOVA statistics obtained from comparisons of seed bank species composition of each river section for the River Angas using Pair-Wise posteriori comparisons based on Bray-Curtis dissimilarities....................................................... 45

Table 3.3: Indicator species analysis comparing the seed bank species composition between reach sections of the Angas to provide an indication of which species characterise a particular reach section (Type A, B or C denotes why the species was not a significant indicator) and functional classification of the species present (* denotes naturalised). Sections in bold indicate the species is a significant indicator of that section, *** denotes species recorded in the seed bank but not recorded in the vegetation community during the ecological condition survey (Chapter 2). ........................................ 46

Table 3.4: NPMANOVA statistics obtained from comparisons of seed bank species composition of each river section for the River Finniss using Pair-Wise posteriori comparisons based on Bray-Curtis dissimilarities....................................................... 49

Table 3.5: Indicator species analysis comparing the seed bank species composition between reach sections of the Finniss to provide an indication of which species characterise a particular reach section (Type A, B or C denotes why the species was not a significant indicator) and functional classification of the species present (* denotes naturalised). Sections in bold indicate the species is a significant indicator of that section, *** denotes species recorded in the seed bank but not recorded in the vegetation community during the ecological condition survey (Chapter 2). ........................................ 50

Table 3.6: NPMANOVA statistics obtained from comparisons of seed bank species composition of each river section for Currency creek using Pair-Wise posteriori comparisons based on Bray-Curtis dissimilarities....................................................... 52
Table 3.7: Indicator species analysis comparing the seed bank species composition between reach sections of Currency creek to provide an indication of which species characterise a particular reach section (Type A, B or C denotes why the species was not a significant indicator) and functional classification of the species present (* denotes naturalised). Sections in bold indicate the species is a significant indicator of that section, *** denotes species recorded in the seed bank but not recorded in the vegetation community during the ecological condition survey (Chapter 2). ..........................53

Table 3.8: NPMANOVA statistics obtained from comparisons of seed bank species composition of each river section for Tookayerta creek using Pair-Wise posteriori comparisons based on Bray-Curtis dissimilarities.................................................. 55

Table 3.9: Indicator species analysis comparing the seed bank species composition between reach sections of Tookayerta creek to provide an indication of which species characterise a particular reach section (Type A, B or C denotes why the species was not a significant indicator) and functional classification of the species present (* denotes naturalised). Sections in bold indicate the species is a significant indicator of that section, *** denotes species recorded in the seed bank but not recorded in the vegetation community during the ecological condition survey (Chapter 2). ..........................56

Table 3.10: The number of aquatic and riparian species recorded both during the ecological condition survey (Chapter 2) and this seed bank study. ................................................................. 65

Table 4.1: Elevation distribution of the four study species in the EMLR. ........................... 69

Table 4.2: Comparison of total final biomass (dwt)(g) in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), n=3-5. ........................................................................................................................................ 73

Table 4.3: Results of a Three-way ANOVA performed on various indicators of performance for four species of emergent macrophytes subjected to four water level amplitudes at three elevations. .............................................................................................................. 74

Table 4.4: Comparison of RGR (mg g⁻¹ day⁻¹) in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), n=3-5. ........................................................................................................................................ 75

Table 4.5: Comparison of the final number of shoots per pot in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), n=3-5. ........................................................................................................................................ 76
Table 4.6: Comparison of final average leaf/stem length (cm) in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 40-339 \) ..................................................................................................................... 77

Table 4.7: Comparison of the final emergent surface area per pot (cm\(^2\)) in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 3-5 \) .............................................................................................. 78

Table 4.8: Comparison of biomass allocation (%) in *C. vaginatus* subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 3 \)........................................................................................................ 80

Table 4.9: Comparison of biomass allocation (%) in *P. australis* subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 4-5 \) ........................................................................................................ 81

Table 4.10: Comparison of biomass allocation (%) in *T. domingensis* subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 5 \) ........................................................................................................... 81

Table 4.11: Comparison of biomass allocation (%) in *T. procerum* subjected to four water level amplitudes at three elevations. Mean (Std. Dev.), \( n = 4-5 \) ........................................................................................................... 82

Table 4.12: Results of a Three-way ANOVA performed on biomass allocation (%) for four species of emergent macrophytes subjected to four water level amplitudes at three elevations. ..................................................................................................................... 83

Table 5.1: Elevation distribution of the four study species in Eastern Mt. Lofty Ranges. .. 92

Table 5.2: Comparison of indicators of performance for *C. gymnocaulos* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), \( n = 10 \) ........................................................................................................................... 96

Table 5.3: Comparison of indicators of performance for *P. australis* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), \( n = 10 \) ........................................................................................................................... 96

Table 5.4: Comparison of indicators of performance for *T. domingensis* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), \( n = 6-10 \)......................................................................................................................... 97

Table 5.5: Comparison of indicators of performance for *T. procerum* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), \( n = 10 \) ........................................................................................................................... 98

Table 5.6: Comparison of biomass allocation (%) in *C. gymnocaulos* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), \( n = 10 \) ........................................................................................................................... 98
Table 5.7: Comparison of biomass allocation (%) in *P. australis* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), *n* = 10. ................................................................................................................................. 99

Table 5.8: Comparison of biomass allocation (%) in *T. domingensis* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), *n* = 6-10. ............................................................................................................................... 100

Table 5.9: Comparison of biomass allocation (%) in *T. procerum* subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), *n* = 10. ........................................................................................................................................ 100

Table 5.10: Comparison of net recruitment (recruitment – loss) for each species subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), *n* = 6-10 ........................................................................................................................................ 101

Table 5.11: Comparison of gross recruitment for each species subjected to two water regimes at three nutrient loadings using a Two-way ANOVA. Mean (Std. Dev.), *n* = 6-10. ........................................................................................................................................ 102

Table 6.1: Primary sources (three dominant macrophyte species) and consumers collected from three sites during the pilot study (27th and 28th of March, 2005). ...................... 111

Table 6.2: All primary sources (terrestrial and aquatic) and consumers collected from nine sites during the second round of sampling (October 31st and November 2nd, 2005). CPOM: course particulate organic matter. ............................................................................................................ 112

Table 6.3: Plant species are grouped based on similar life forms. CPOM: course particulate organic matter. ......................................................................................................................... 114

Table 6.4: Corrected mean $\delta^{13}C$ and $\delta^{15}N$ values of dominant macrophytes (primary sources) and mean $\delta^{13}C$ and $\delta^{15}N$ values of primary consumers collected from three sites during first sampling period. Standard deviations in brackets. .................... 118

Table 6.5: Distribution of feasible contributions to Amphipoda nutrition presented for each vegetation grouping across each level of ecological condition (Excellent to Very Poor). Ranges: 1 and 99 percentiles. Median in brackets...................................................... 119

Table 6.6: Distribution of feasible contributions to Trichoptera nutrition presented for each vegetation grouping across each level of ecological condition (Excellent to Very Poor). Ranges: 1 and 99 percentiles. Median in brackets...................................................... 119

Table 6.7: Distribution of feasible contributions to shredder nutrition from primary sources collected from sites of very poor ecological condition based on $\delta^{13}C$ and $\delta^{15}N$ values.

Table 6.8: Distribution of feasible contributions to shredder nutrition from primary sources collected from sites of average ecological condition based on $\delta^{13}$C and $\delta^{15}$N values. Ranges: 1 and 99 percentiles. Median in brackets. CPOM: course particulate organic matter.

Table 6.9: Distribution of feasible contributions to shredder nutrition from primary sources collected from sites of excellent ecological condition based on $\delta^{13}$C and $\delta^{15}$N values. Ranges: 1 and 99 percentiles. Median in brackets. CPOM: course particulate organic matter.

Table 6.10: Mean C:N ratios of consumers and primary sources collected from sites of very poor ecological condition. CPOM: course particulate organic matter.

Table 6.11: Mean C:N ratios of consumers and primary sources collected from sites of average ecological condition. CPOM: course particulate organic matter.

Table 6.12: Mean C:N ratios of consumers and primary sources collected from sites of excellent ecological condition. CPOM: course particulate organic matter.
List of figures

Figure 1.1: Location of the four study catchments in the Eastern Mt. Lofty Ranges in South Australia........................................................................................................................ 11

Figure 1.2: Comparison of discharge through the Finniss River at a location 4 km East of Yundi, (35°19′ S, 138°40′ E) for the years 1970 and 2002. Total discharge in 1970 was 24.2GL and in 2002 was 5.8GL .......................................................................................... 12

Figure 1.3: Comparison of variations in water level on the Finniss River at a location 4 km East of Yundi, (35°19′ S, 138°40′ E) for the years 1970 and 2002........................................ 12

Figure 2.1: Mean scores for each subindex (Habitat, Banks, Riparian Cover, Soil & Water Chemistry and Vegetation Structure) for all sites in each category (1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = excellent) based on the TECS (n = 115). Error bars show standard deviations................................................................. 22

Figure 2.2: Non-metric multidimensional scaling (NMS) ordination of data for the Finniss catchment in each category (1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = excellent) based on the subindices indicator scores for each site (n = 51). Final Stress = 14%, $R^2 = 0.650$. ........................................................................... 24

Figure 2.3: Non-metric multidimensional scaling (NMS) of data for the Angas catchment in each category (1 = very poor, 2 = poor, 3 = average), based on the subindices indicator scores for each site (n = 29). Final Stress = 13%, $R^2 = 0.50$. .............................................. 26

Figure 2.4: Non-metric multidimensional scaling (NMS) ordination of data for Currency creek catchment in each category (1 = very poor, 2 = poor, 3 = average, 4 = good) based on the subindices indicator scores for each reach, (n = 22). Final Stress = 9.6%, $R^2 = 0.55$. ...................................................................................................................... 28

Figure 2.5: Non-metric multidimensional scaling (NMS) ordination of data for Tookayerta creek catchment in each category (1 = very poor, 2 = poor, 3 = average, 4 = good) based on the total index of site condition (n = 13). Final Stress = 6%, $R^2 = 0.70$. .............................. 30

Figure 2.6: Non-metric multidimensional scaling (NMS) of data for all four catchments in each category (1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = excellent) based on the subindices indicator scores for each site, (n = 115). Final Stress = 16.4%, $R^2 = 0.50$. ...................................................................................................................... 32

Figure 3.1: Catchment maps indicating the different stream sections for each catchment depending on their geomorphology and natural history for the longitudinal seed bank study.............................................................................................................. 40
Figure 3.2: Cluster analysis depicting the similarity between the seed bank species composition and each of the reach sections of the River Angas. 

Figure 3.3: Cluster analysis depicting the similarity between the seed bank species composition and each of the reach sections of the River Finniss. 

Figure 3.4: Cluster analysis depicting the similarity between the seed bank species composition and each of the reach sections of Currency creek. 

Figure 3.5: Cluster analysis depicting the similarity between the seed bank species composition and each of the reach sections of Tookayerta creek. 

Figure 3.6: Total number of seeds m$^{-2}$ along the River Angas. Means that are not significantly different ($p \leq 0.05$) using one-way ANOVA and Tukey HSD post hoc test are followed by the same letter. Error bars show standard deviations. 

Figure 3.7: Total number of seeds m$^{-2}$ along the River Finniss. Means that are not significantly different ($p \leq 0.05$) using one-way ANOVA and Tukey HSD post hoc test are followed by the same letter. Error bars show standard deviations. 

Figure 3.8: Total number of seeds m$^{-2}$ along Currency creek. Means that are not significantly different ($p \leq 0.05$) using one-way ANOVA and Tukey HSD post hoc test are followed by the same letter. Error bars show standard deviations. 

Figure 3.9: Total number of seeds m$^{-2}$ along Tookayerta creek. Means that are not significantly different ($p \leq 0.05$) using one-way ANOVA and Tukey HSD post hoc test are followed by the same letter. Error bars show standard deviations. 

Figure 4.1: Experimental water regimes. In each pond, potted plants were placed at three elevations: sediment surface 20, 40 and 60 cm above the pond base. 

Figure 4.2: Relationship between RGR (mg g$^{-1}$ day$^{-1}$) and average emergent surface area (cm$^2$) (averaged over the 100 days of the experiment) in four species of emergent macrophytes subjected to four water level amplitudes at three elevations. 

$C.\ vaginatus$: solid circle and solid line ($p<0.0001$; $r^2=0.7196$; $F=87.276$; $n=36$; RGR (mg g$^{-1}$ day$^{-1}$) = $-5.096 + 4.313 \times \ln$ (Average emergent surface area (cm$^2$)), $P.\ australis$: open circle, $T.\ procerum$, solid square, $T.\ domingensis$, open square. 

Figure 4.3: Comparison of variations in water levels on the Finniss River during spring/early summer at a location 4 km East of Yundi, (35°19′ S, 138°40′ E) for the years 1970 and 2002. 

Figure 5.1: Experimental water regimes. In each pond, potted plants were placed at optimal species elevation; sediment surface for $T.\ procerum$ was at 20 cm, for $T.\ domingensis$ and $P.\ australis$ was at 40 cm, and $C.\ gymnocaulos$ at 60 cm above the pond base.
Figure 5.2: Comparison of variations in water levels on the Finniss River during spring/early summer at a location 4 km East of Yundi, (35°19' S, 138°40' E) for the years 1970 and 2002 (pre and post regulation) .............................................................. 106

Figure 6.1: Map of the Finniss catchment indicating each of the study sites and their ecological condition ............................................................................................................. 110

Figure 6.2: Mean C:N ratios for each of the vegetation groupings across each level of ecological condition (Excellent to Very Poor). ........................................................................ 120

Figure 7.1: Comparison of variations in water levels on the Finniss River between the years 1970 and 2002, and the proposed water level for the future through the imposition of environmental flows. .......................................................... 133
Declaration

This thesis contains no material which has been accepted for the ward of any other degree or diploma in any university or other tertiary institution and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I consent to the thesis being made available for photocopying and loan if accepted for the award of the degree.

..............................

Brian Martin Deegan

April 2007
Acknowledgements

Thank you to the following institutions for financial support, which made this project possible; The River Murray Catchment Water Management Board and the School of Earth and Environmental Sciences, The University of Adelaide. Thanks also to the Department of Water, Land and Biodiversity Conservation for access to historical hydrological data and aerial videography of the Eastern Mt. Lofty Ranges.

I wish to take this opportunity to thank my supervisors, George G. Ganf and Jose M. Facelli. Your knowledge, guidance, enthusiasm and endless tolerance have been inspirational throughout the entire course of this project. George ‘Boss’, you have always put your students first and watched out for their best interests, not just in academic terms, and for this I owe you an enormous dept of gratitude.

Thank you to the ‘limnos’ for making this one of the greatest experiences of my life. Kane (Brucey) and Anna, you have provided me with a family away from home, welcoming me into your family on the very first day that I arrived in Australia. Thanks to my office mates Todd and Stephen for their assistance and for always knowing when to make me laugh, to Nadine (Princess) and Scotty for always putting a smile on my face. Thanks also to Kane, Sean and Stephen for assistance in the field and the ponds. A special thanks to Sean for the endless weeks spent in the ponds, you are an inspirational scientist.

Thank you so much to the technical staff, David, Helen, Julie and Helen for your assistance, and to my Biology 1 students for providing me with an outlet from the office.

Most of all I would like to thank my parents, family and friends back in Ireland for their continued support, not just during this project, but throughout my academic life. To say that I could not have come so far without your assistance would be an understatement.
Summary

This thesis examined the impact of anthropogenic alterations in four riverine catchments of the Eastern Mt. Lofty Ranges, South Australia, to identify if creek restoration via environmental flows is a viable management option and if so, to determine;

1) Whether an aquatic / riparian viable seed bank was present and if so what was its composition
2) The ecological condition of selected riverine reaches. This in combination with the seed bank study would identify those creeks that would most benefit from the imposition of environmental flows
3) The response of key species to the water regimes likely to result from the imposition of environmental flows
4) The influence of nutrient enrichment under a fluctuating water level and to use this information to formulate best practice policy for environmental flows
5) Whether aquatic plants promoted by environmental flows were a significant fraction of the diet for higher trophic levels represented by Trichopterans and Amphipods.

The seed banks were of comparable density (ranging from 4,000 to 110,000 seeds m$^{-2}$) and species richness (ranging from 13 to 20 aquatic / riparian species) to the seed banks of other Australian rivers and wetlands, but this varied significantly among riverine sections and across catchments. Out of a total of 81 species recorded, 51 were classified as terrestrial (63% of all species recorded). What is of greater concern was the number of exotic (both aquatic and terrestrial) species recorded: 43% of the species recorded in the Angas, 47% of the species in the Finniss, 39% of the species in Tookayerta creek and 43% of the species recorded in Currency creek were exotic, which are significantly higher in comparison to other Australian studies. There were 24 to 28 aquatic / riparian species recorded in the extant vegetation of each catchment that were not recorded in their seed banks. Likewise, a number of species (3 to 7) were recorded in each catchments seed bank that were not recorded in the extant vegetation of those catchments. A species of particular interest is *Crassula sieberana*, which is on the State endangered plant species list.

Indices for assessing the ecological condition, health or integrity of a river or riparian habitat were employed to investigate the relationship between the river/riparian habitat and
the land and water management practices associated with those habitats. Of the four catchments surveyed, each catchment identified a unique set of site parameters (subindex indicators) that were strongly correlated with its ecological condition. Indicator species analyses revealed pasture grasses to be a significant indicator of reaches in very poor condition \((p = 0.0010)\) along the Finniss and *Baumea juncea* of those reaches in good condition \((p = 0.0230)\). Along the Angas, *Cotula coronopifolia* was an indicator of those reaches in average condition \((p = 0.0240)\) and along Currency creek, *Cladium procerum* was an indicator of those reaches in good condition \((p = 0.0190)\). However, when all 115 surveyed reaches were analysed together, those reaches of average to excellent ecological condition were all strongly correlated \((R^2 = 0.50)\) with the subindex indicators: bank stability, % riparian cover, grazing, fenced, aquatic wood, and width of the riparian vegetation. This would indicate that these subindex indicators are the main site parameters determining the ecological condition of a riverine reach and hence its restoration potential. Those catchments or sub-catchments containing a high proportion of reaches classified to be in poor to very poor condition had significantly reduced seed banks.

The influence of water level fluctuations (±15 cm, ±30 cm and ±45 cm) on the growth of four species of emergent macrophytes (*Cyperus vaginatus*, *Phragmites australis*, *Typha domingensis* and *Triglochin procerum*) were species dependent. These species naturally inhabits different zones across the elevation gradient. *C. vaginatus*, which has a high elevation preference, was strongly inhibited by increasing water depth and fluctuations in water levels. In contrast, species with an intermediate elevation preference, such as *Phragmites australis* and *Typha domingensis*, were more tolerant to both depth and water level fluctuations. However, the biomass and relative growth rate (RGR) of *T. domingensis* and *P. australis* were depressed when grown under the combination of deep elevation and a highly fluctuating water level (±45 cm). Between the static and ±45 cm amplitude treatments, growth of *T. domingensis* was inhibited by 52%. The growth of *P. australis* appeared to be enhanced by fluctuating water levels and only showed a severe drop-off in growth in the deep elevation, ±45 cm amplitude treatment. In *C. vaginatus* the RGR was dependent of the average emergent surface area (and the implied rate of carbon acquisition) \((p<0.0001; r^2=0.7196; F=87.276; n=36; \text{RGR (mg g}^{-1} \text{ day}^{-1}) = -5.096 + 4.313 \times \ln \text{(Average emergent surface area (cm}^2\text{))})\), but this was not the case in *P. australis* and *T. domingensis* \((p>0.05)\) even when the photosynthetic canopy was partially inundated by rising water levels. Yet these two species demonstrated different growth rates when grown under
different water regime amplitudes and at different elevations. Growth of *T. procerum* did not respond to either amplitude or elevation, but its RGR remained negative. This suggests that another factor(s) was limiting the growth of *P. australis*, *T. domingensis* and possibly *T. procerum*, a factor that varies with water level.

*Cyperus gymnocaules* had significantly increased plant performance (*p* <.0001) with increased nutrient loading rates but this effect was significantly reduced under a fluctuating water regime (*p* =0.0007). Remarkably, under a fluctuating regime, *P. australis* had a significant reduction in performance with increased nutrient loading rates (*p* =0.0013), whereas *T. domingensis* performance was significantly limited (*p* =0.034) even with increased nutrient loading rates. *T. procerum* too had increased plant performance with increased nutrient loading rates but this effect was reduced under a fluctuating regime. The morphological response by *T. procerum* demonstrates that it is mainly limited by the nutrient loading rates and not the water regime. However, it was significantly limited/reduced by its increased turnover rates caused by a stochastic fluctuating water regime. Illustrating that in fact the effects of nutrient enrichment on *T. procerum* were independent of water regime but bearing in mind that water regime is the primary factor determining the productivity of this species. For those species with higher elevation preferences, e.g. *C. gymnocaules*, or low elevation preference, e.g. *T. procerum*, the effects of nutrient loading are independent of water regime, whereas those species with an intermediate elevation preference, e.g. *P. australis* and *T. domingensis* the effects of nutrient loading are largely dependent on the water regime.

Amphipoda and Trichoptera selectively fed on succulent semi-emergent macrophytes across sites of average to excellent ecological condition (31-64% to 65-97% of diet), depending on availability. These semi-emergent macrophytes contained the lowest C:N ratio (≈10:1), closest to that of their consumers (≈5:1) and therefore the highest nutritional content. In degraded riverine reaches, there were limited food resources available, hence course particulate organic matter (CPOM) formed the main dietary components of Amphipoda (20-53% of diet) even though it had the highest C:N ratio (≈40:1). At site VP. 1, filamentous algae was the main dietary component of Trichoptera (48-64% of diet) due to its availability and its low C:N ratio (≈14:1) in comparison to the other primary sources available. The imbalanced consumer-resource nutrient ratios in these degraded riverine
reaches are likely to impose constraints on the growth and reproduction of their aquatic shredder communities with probable knock-on effects at higher trophic levels.

The installation of environmental flows to restore and promote aquatic / riparian plant communities, which in turn would benefit higher trophic organisms, is a viable and realistic management option along selected reaches. Those selected reaches contain a significant aquatic / riparian seed bank and with sufficient physical habitat remaining to promote their germination and establishment. However, the imposition of environmental flows as a control measure to prevent the colonisation and dominance of particular species (*T. domingensis* and *P. australis*) was deemed to be redundant as a management technique given the limited water resources available.
Foreword

This thesis has been prepared as a series of chapters in a format that will be suitable for future publication in scientific journals. To maintain the sense of individual chapters, this has inevitably led to some repetition between chapters.