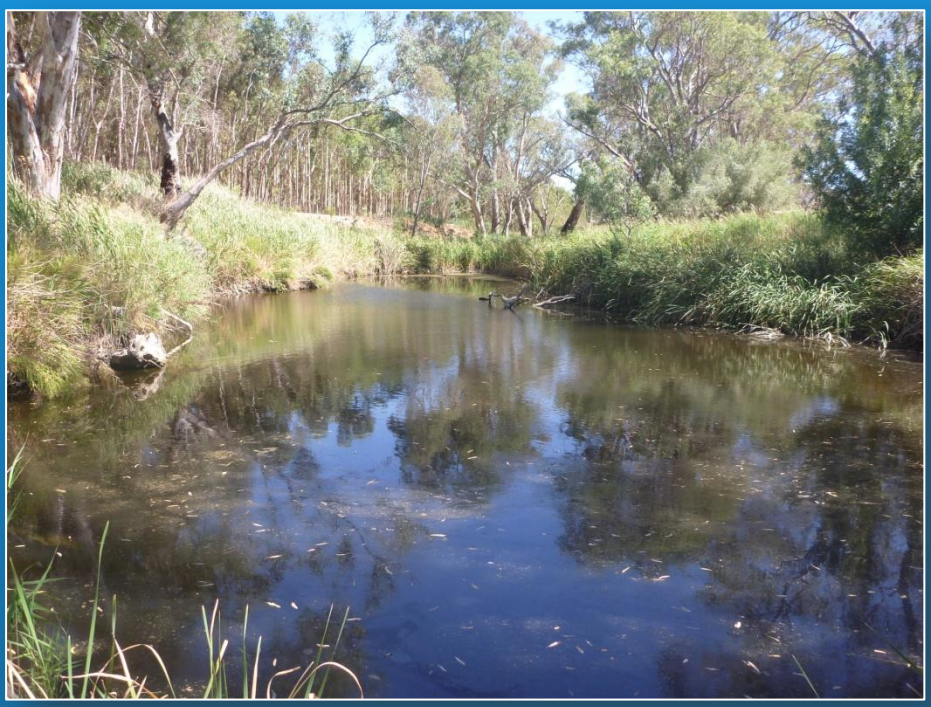
Inland Waters & Catchment Ecology

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

Characterisation of the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area

Data and methods report



Jason Nicol

SARDI Publication No. F2013/000413-1
SARDI Research Report Series No. 745

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

November 2013

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Characterisation of the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area
Data and methods report

Jason Nicol

SARDI Publication No. F2013/000413-1
SARDI Research Report Series No. 745

November 2013

This Publication may be cited as:
Nicol, J.M. (2013). Characterisation of the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area. Data and methods report. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2013/000413-1. SARDI Research Report Series No. 745. 25pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 2400
Facsimile: (08) 8207 5406
http://www.sardi.sa.gov.au

DISCLAIMER

The authors warrant that they have taken all reasonable care in producing this report. The report has been through the SARDI internal review process, and has been formally approved for release by the Research Chief, Aquatic Sciences. Although all reasonable efforts have been made to ensure quality, SARDI does not warrant that the information in this report is free from errors or omissions. SARDI does not accept any liability for the contents of this report or for any consequences arising from its use or any reliance placed upon it. The SARDI Report Series is an Administrative Report Series which has not been reviewed outside the department and is not considered peer-reviewed literature. Material presented in these Administrative Reports may later be published in formal peer-reviewed scientific literature.

Printed in Adelaide: November 2013

SARDI Publication No. F2013/000413-1
SARDI Research Report Series No. 745

Author(s):	Jason Nicol
Reviewer(s):	Susan Gehrig, Kate Frahn and Doug Green
Approved by:	Dr Qifeng Ye Science Leader – Inland Waters & Catchment Ecology
Signed:	
Date:	20 November 2013
Distribution:	DEWNR, AMLRNRM Board and SARDI Aquatic Sciences Library
Circulation:	Public Domain

Table of Contents

List of Figures

List of Appendices

Acknowledgements

The author thanks Doug Green, Sally Maxwell and Michael Stephens for field assistance, Kate Frahn and Arron Strawbridge for data entry and collation and Susan Gehrig, Kate Frahn, Sally Maxwell, Jason Vanlaarhoven and Doug Green for constructive comments on early drafts of this report. This study was funded by the Department of Environment, Water and Natural Resources through the Adelaide and Mount Lofty Ranges Natural Resources Management Board.

Executive Summary

The Barossa Prescribed Water Resources Area is located 40 km north of Adelaide and (with the exception of upper Stockwell Creek, which is part of the Light River Catchment) is a sub-catchment of the Gawler River (the area includes all of the North Para River catchment and parts of the South Para River, Greenock Creek and Stockwell Creek catchments). The catchment is highly modified with very little remnant native vegetation and extensive surface and groundwater resource development, primarily for viticulture. There is no information regarding the in stream and riparian plant communities and the aim of this project was to gain information regarding the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area.

Vegetation surveys of streams in the area were undertaken in February 2013 and used the same techniques used in the Mount Lofty Ranges environmental flows project, where the whole pool and adjacent upstream riffle was surveyed and the percentage cover of each species present recorded. The surveys were undertaken after one of the driest recorded springs on record, resulting in all of the pools being hydrologically disconnected and no flow through riffles, runs and cascades, with the exception of three areas where there was groundwater fed base flow. A total of 264 sites were surveyed, including 159 permanent pools, three cascades, 33 riffles, 51 runs and 18 temporary pools. Data were analysed using PERMANOVA, cluster and indicator species analyses.

A total of 99 taxa (55 exotics, nine species declared noxious in South Australia, including five weeds of national significance) were recorded at the survey sites. The most abundant species (in decreasing order of abundance) were *Phragmites australis, Typha domingensis, Eucalyptus camaldulensis, Bolboschoenus caldwellii* and *Schoenoplectus pungens* and are all native. *Cynodon dactylon* was the sixth most abundant species and the most abundant exotic species. Despite the large number of exotic species recorded, percentage cover scores were generally low. Plant communities were significantly different in all habitat types, except riffles and runs with permanent pools dominated by open water; temporary pools by bare substrate, *Eragrostis australasica* and *Juncus pallidus* and cascades by bed rock, *Asparagus asparagoides, Aster subulatus, Fraxinus angustifolia* and *Polypogon monspeliensis*. The most abundant species were highly abundant across all different habitat types and widespread throughout the study area.

Cluster analyses comparing the understorey and overstorey plant communities identified definite communities; however, they showed no relationship to location within the prescribed water resources area except the understorey plant community in temporary pools which formed two

related groups from sites generally in tributaries of the North Para River. The absence of a relationship between location and plant community was due to the most abundant species being widespread throughout the study area.

1. Introduction and context

The Barossa Prescribed Water Resources Area is located 40 km north of Adelaide and (with the exception of upper Stockwell Creek, which is part of the Light River Catchment) is a sub-catchment of the Gawler River (the area includes all of the North Para River catchment and parts of the South Para River, Greenock Creek and Stockwell Creek catchments). The catchment is highly modified with very little remnant native vegetation and extensive surface and groundwater resource development, primarily for viticulture. Nevertheless, all of the water resource development is farm dams and bores with no large reservoirs such as those on the South Para, Torrens, Onkaparinga or Myponga rivers.

There is little information regarding the in stream and riparian plant communities, which are needed to aid in the determination of environmental water requirements, in the Barossa Prescribed Water Resources Area. Water allocation planning requires that the environmental water requirements of water dependent ecosystems are identified; therefore, the aim of this project is to gain information regarding the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area. This information will be used, in the longer-term, to aid in the development of environmental water requirement of streams in the Barossa Prescribed Water Resources Area.

2. Methods

2.1. Vegetation surveying protocol

The in stream and riparian vegetation were characterised using two methods; the first method will use the same technique used for the western Mount Lofty environmental flows monitoring project. Sites (where possible) consisted of a reach comprising a pool and the adjacent upstream riffle (run or cascade). The understorey of entire pools and riffles/runs/cascades was surveyed separately in February 2013. The percentage cover of each species (including bare soil, bedrock and open water, which were recorded as taxa and included in the multivariate analyses) were visually estimated by two observers in the pool and riffle/run/cascade below the spring high water mark (Figure 1). In addition, the percentage cover of overhanging overstorey was recorded separately, where present. A total of 264 sites were surveyed (Figure 2; Appendix 1) including 159 permanent pools, three cascades, 33 riffles, 51 runs and 18 temporary pools. GPS coordinates of the survey sites are presented in Appendix 1.

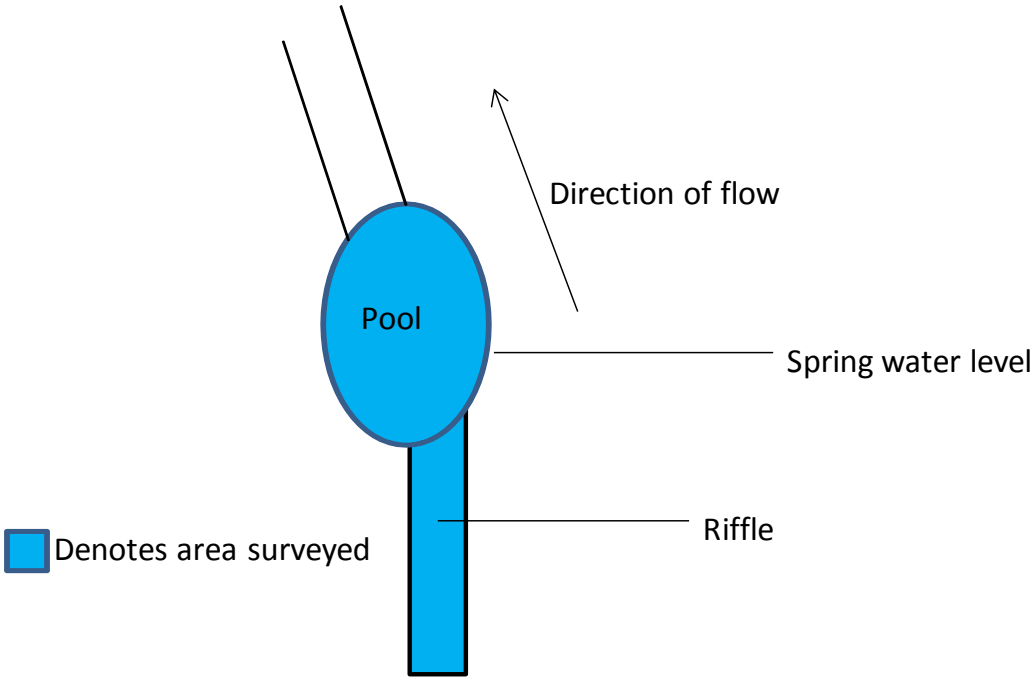


Figure 1: Plan view of an idealised survey site.

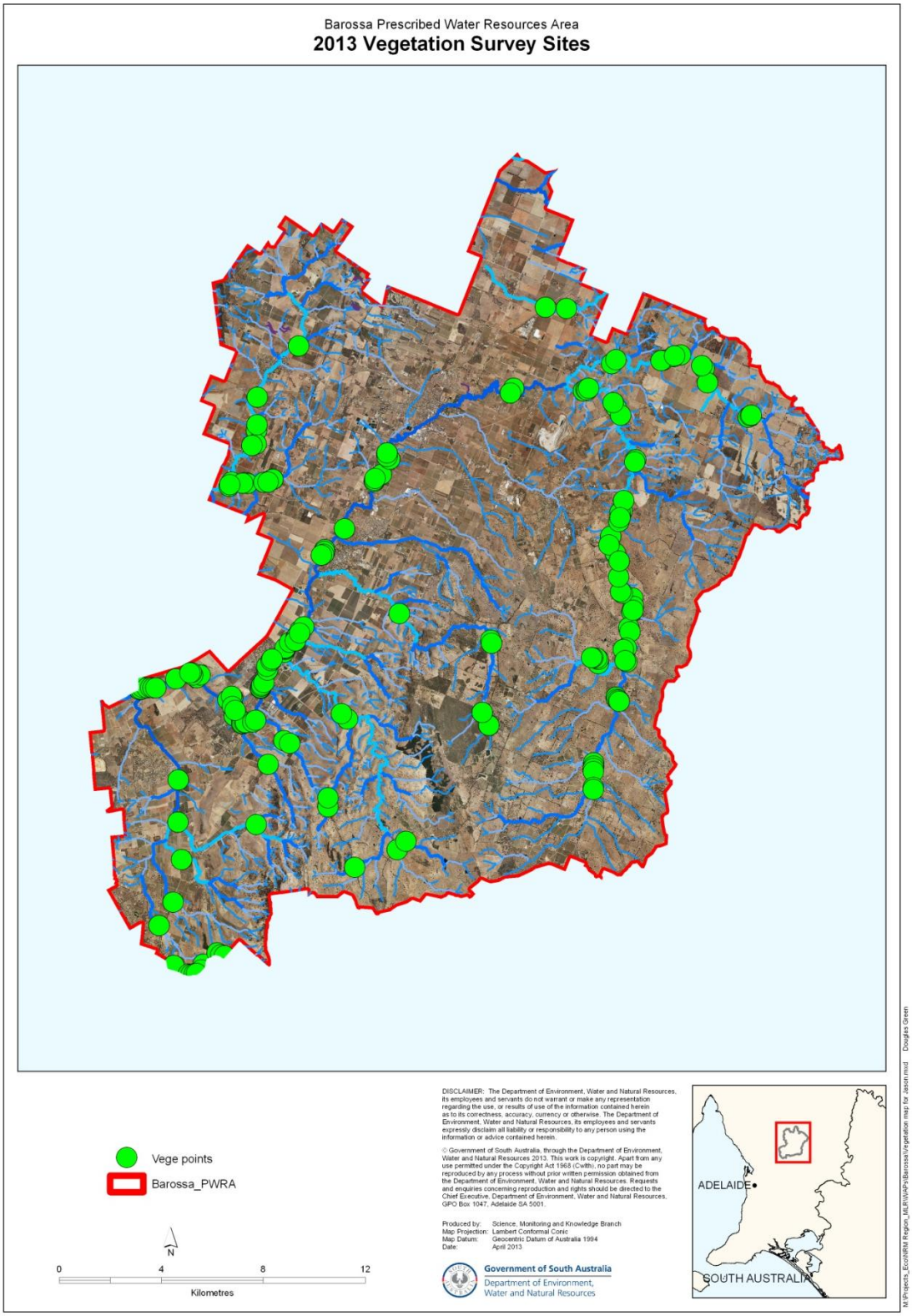


Figure 2: Aerial photo of the Barossa Prescribed Water Resources Area showing the location of survey sites.

The second technique recorded the species distributions at individual sections of stream where cross section measurements were taken, by recording the distribution of species across the cross

section was measured at each site, using a point intercept method. A measuring tape was extended horizontally across the stream at the site of the cross section measurement and the horizontal extent of species present recorded. The data collected in this manner will not be presented in this report due to difficulties in displaying the data; however, uses of these data and improvements in the methods used to collect vegetation data at cross sections will be discussed.

2.2. Data analysis

Data were analysed using indicator species analysis (Dufrene and Legendre 1997), PERMANOVA (Anderson 2001; Anderson and Ter Braak 2003) and group average cluster analysis (McCune *et al.* 2002). Single factor PERMANOVA and indicator species analysis were used to compare the entire plant community between habitat types (permanent pools, temporary pools, riffles, runs and cascades). In addition to comparing the plant communities, indicator species analysis was also used to compare the abundances of different plant functional groups (*sensu* Casanova 2011) between habitats (permanent pools, temporary pools, riffles, runs and cascades).

Individual group average cluster analyses were undertaken on the understorey and overstorey plant community in pools (temporary and permanent) and riffles, runs and cascades to identify the dominant plant communities in the different habitats (McCune *et al.* 2002) throughout the Barossa Prescribed Water Resources Area. Species that characterised the major groups detected by cluster analysis were identified by indicator species analysis. Bray-Curtis (1957) similarities were used to construct the similarity matrices for the PERMANOVA and cluster analyses and $\alpha=0.05$ for all statistical analyses.

2.3. Plant identification and nomenclature

Plants present were identified to species where possible using keys in Sainty and Jacobs (1981), Jessop and Tolken (1986), Prescott (1988), Dashorst and Jessop (1998), Romanowski (1998), Sainty and Jacobs (2003) and Jessop *et al.* (2006). In some cases due to immature individuals or lack of floral structures, plants were identified to genus only. Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2013).

3. Results

A total of 99 taxa (55 exotics, nine species declared noxious in South Australia, including five weeds of national significance) were recorded at the survey sites (Appendix 2). The most

abundant species was *Phragmites australis,* followed by *Typha domingensis, Eucalyptus camaldulensis, Bolboschoenus caldwellii* and *Schoenoplectus pungens*. These five most abundant species were native emergent and amphibious species. *Cynodon dactylon* was the sixth most abundant species and the most abundant exotic species. Despite the large number of exotic species recorded (Appendix 2), the percentage cover scores were generally low for exotics, which was probably due to the surveys being undertaken in February 2013, when winter annuals were absent. When cross sections were surveyed in May 2013 there was extensive cover of exotic grasses (probably immature *Avena* spp., *Bromus* spp., *Lolium* spp. *Holcus lanatus, Ehrharta longiflora, Briza* spp. and *Hordeum* spp.) and exotic forbs (primarily *Oxalis pes-capre* and *Fumaria* spp.) in the riparian zone.

PERMANOVA analysis comparing the plant community between different habitats (permanent pools, temporary pool, riffles, runs and cascades) throughout the study area showed there was a significant difference (PERMANOVA: *Pseudo* $F_{4,263}$=21.15; P<0.001) between habitats. Bonferroni corrected multiple comparisons showed that the plant community was significantly different between each habitat type, except for runs and riffles. Indicator species analysis showed that permanent pools were characteristed by open water; temporary pools were characterised by bare substrate, *Eragrostis australasica* and *Juncus pallidus*; and cascades by bed rock *Asparagus asparagoides, Aster subulatus, Fraxinus angustifolia* and *Polypogon monspeliensis*. There were no significant indicators for riffles or runs. The most abundant species (*Phragmites australis, Typha domingensis, Eucalyptus camaldulensis, Bolboschoenus caldwellii* and *Schoenoplectus pungens*) were widespread throughout the study area and highly abundant across all different habitat types. Indicator species analysis comparing the abundance of plant functional groups across the different habitat types detected no significant indicators and examination of the data showed that all functional groups present were widespread across the different habitat types, except the submergent r-selected group, which were only present in permanent pools with very low cover.

Cluster analysis comparing the understorey plant community of the permanent and temporary pools detected five groups at a similarity of 25% (Figure 3). Sites classified into Group 1 were all permanent pools, predominately from the North Para River dominated by open water and the native emergent species *Typha domingensis*. Sites in Groups 2 and 3 were also all permanent pools, predominately from the North Para River with Group 2 dominated by the native emergent species, *Phragmites australis* and Group 3 dominated by exposed bed rock. Groups 4 and 5 were predominantly temporary pools located on tributaries of the North Para River (generally Lyndoch, Tanunda and Angaston creeks). Group 4 sites were dominated by *Eucalyptus camaldulensis* and *Rumex bidens* and terrestrial weeds (*Chenopodium album, Chenopodium glaucum, Cynodon dactylon, Foeniculum vulgare, Lactuca serriola, Polygonum aviculare* and *Prunus* sp.) and Group 5 sites by bare soil and *Eragrostis australasica.*

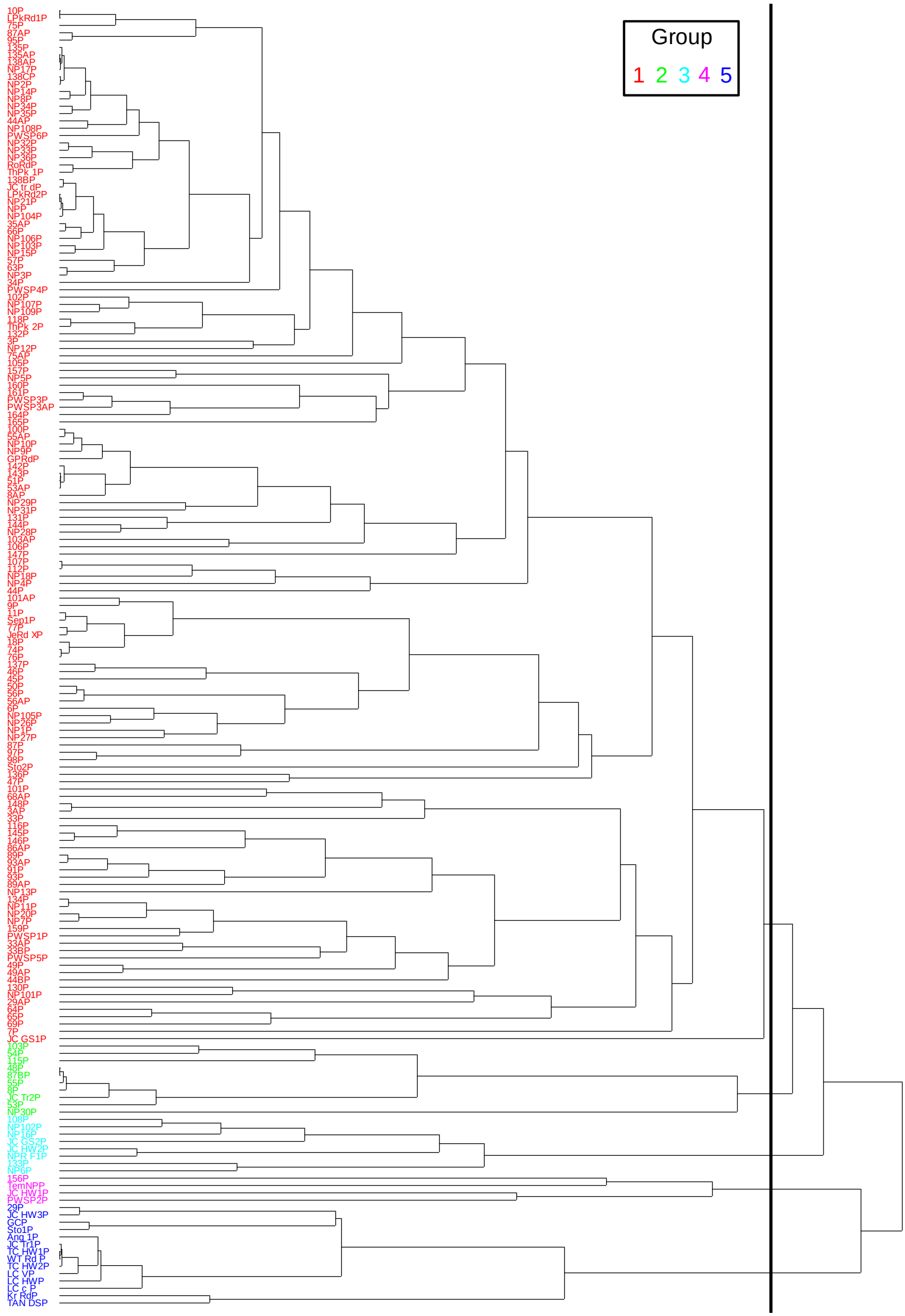


Figure 3: Group average cluster analysis comparing the understorey plant community of permanent and temporary pools.

Cluster analysis comparing the overstorey plant community of the permanent and temporary pools detected four groups at a similarity of 25% (Figure 4). In contrast to the understorey plant community, where the main division on the dendrogram was between permanent and temporary pools (with one exception), the overstorey plant community showed little relationship with respect to pool permanency. Sites in Group 1 were dominated by the native riparian tree *Eucalyptus camaldulensis* and sites in Group 3 by the exotic terrestrial tree *Fraxinus angustifolia*. There were no significant indicators for Groups 2 and 4.

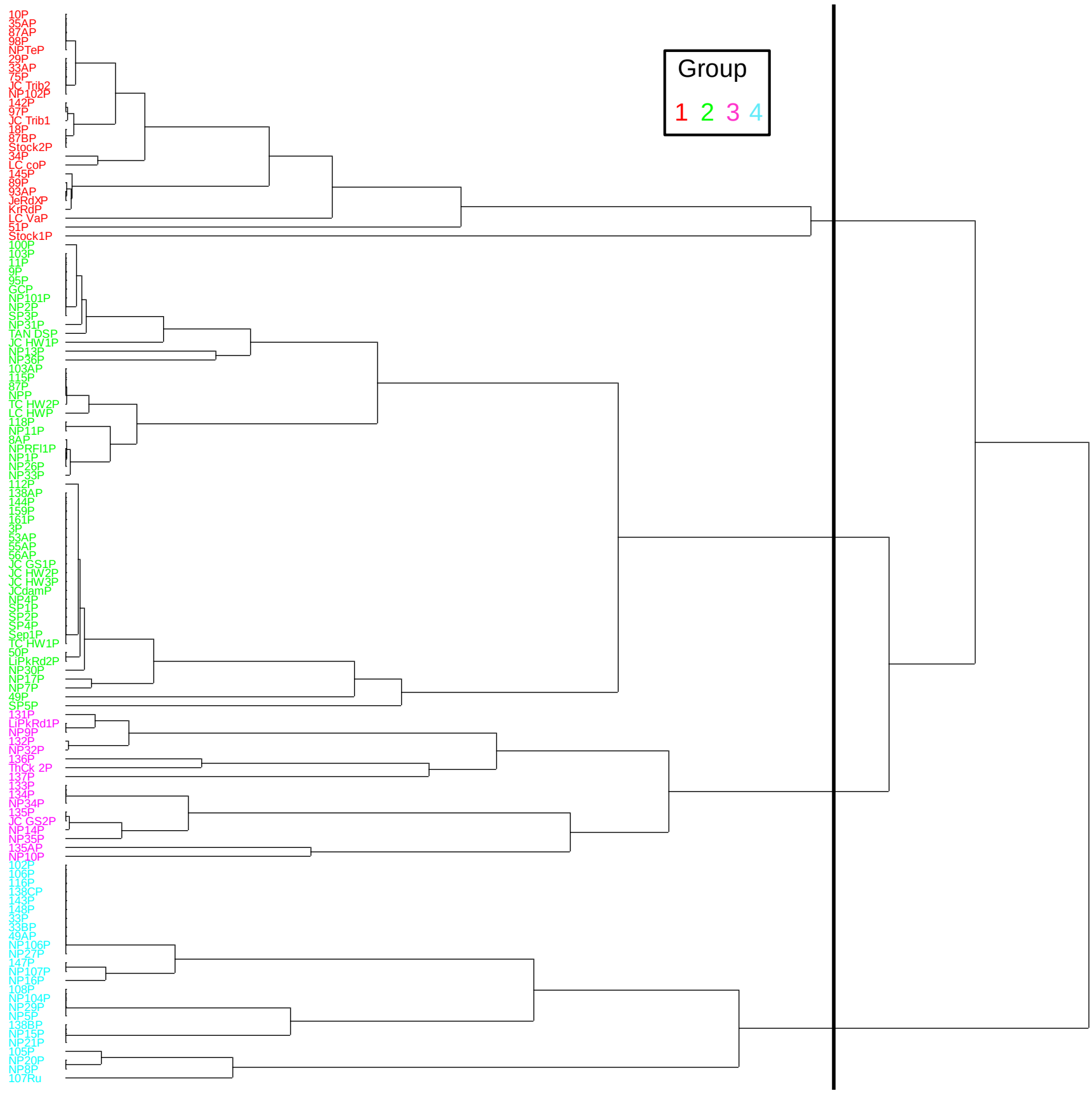


Figure 4: Group average cluster analysis comparing the overstorey plant community of permanent and temporary pools.

Cluster analysis comparing the understorey plant community of the riffles, runs and cascades detected three groups at a similarity of 25% (Figure 5). Group 1 was dominated by the native emergent species *Typha domingensis* and *Phragmites australis*; Group 2 by the native emergent *Bolboschoenus caldwellii,* exotic terrestrial *Cynodon dactylon* and concrete; and Group 3 by the amphibious exotic species *Paspalum distichum* and *Juncus acutus*.

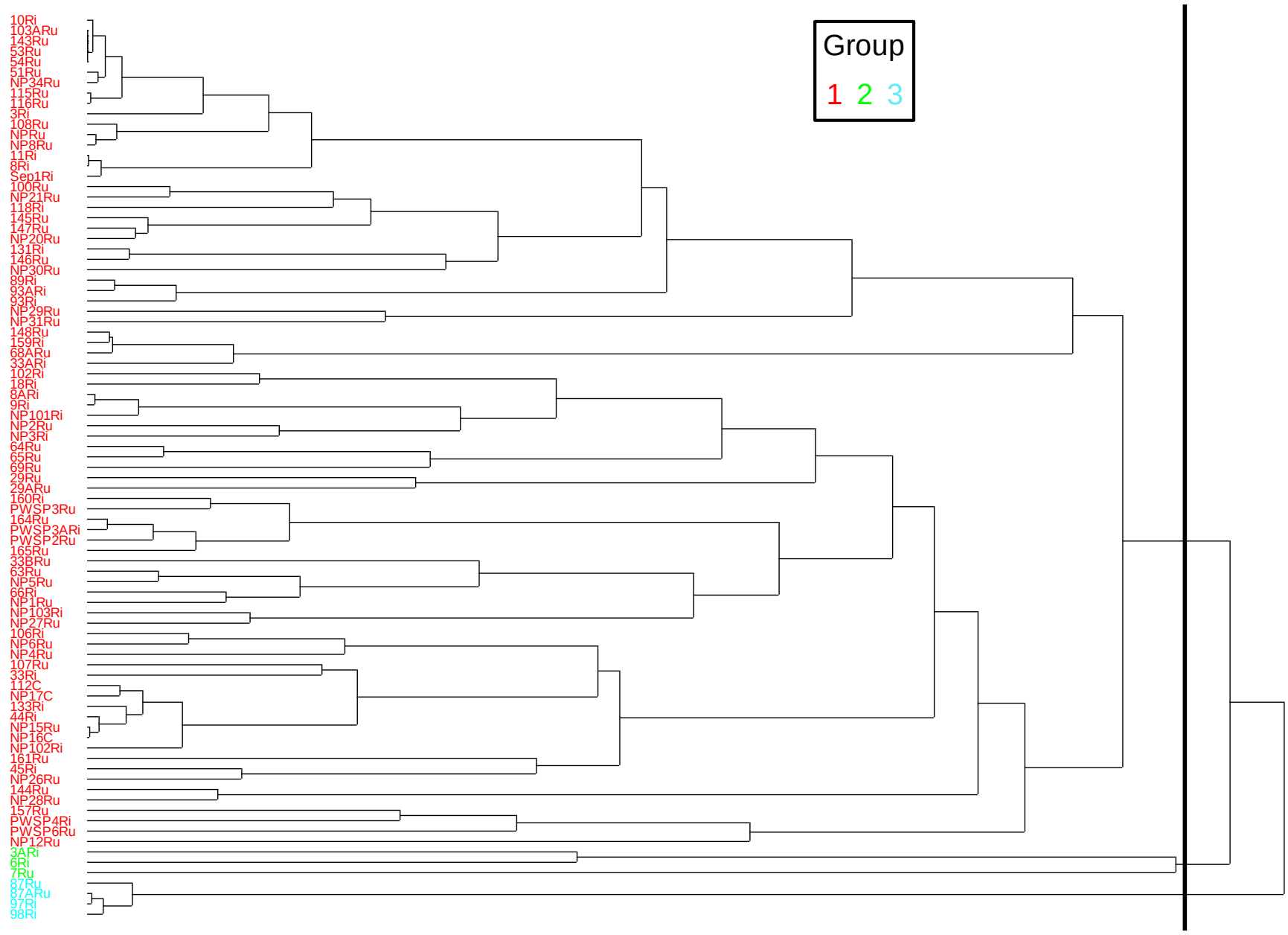


Figure 5: Group average cluster analysis comparing the understorey plant community of riffles, runs and cascades.

Cluster analysis comparing the overstorey plant community of the riffles, runs and cascades also detected three groups at a similarity of 25% (Figure 6). Sites in Group 1 were dominated by the native riparian tree *Eucalyptus camaldulensis* and sites in Group 3 by the exotic terrestrial tree *Fraxinus angustifolia*. There were no significant indicators for Group 2.

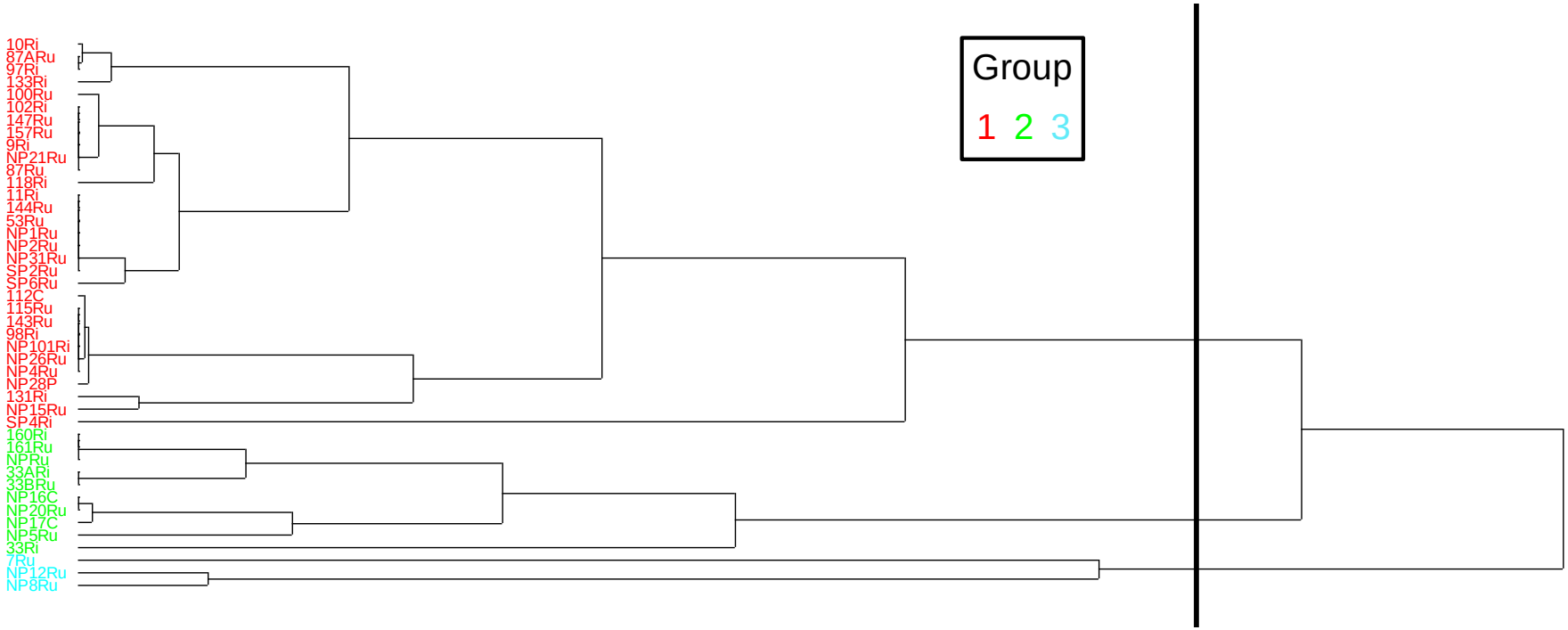


Figure 6: Group average cluster analysis comparing the overstorey plant community of riffles, runs and cascades.

4. Discussion

The vegetation surveys undertaken as part of this project provided good spatial coverage of streams in the prescribed water resources area, except for Jacobs Creek, which was largely inaccessible due to access issues. The survey method employed, which did not use fixed area quadrats but estimated cover of all of the species present in a pool or riffle, run or cascade resulted in a more representative species list because all of the species in a survey area were recorded. This technique worked well for small pools and riffles (or runs); however, in some large, deep pools where there was difficulty in accessing some parts of the pool that may have resulted in species being missed. Furthermore, small or inconspicuous species may have been missed; however, due to their low cover, these species would have had little effect on the outcomes of the statistical analyses but may be of conservation significance. This method also allows for relationships between plants and other biota (e.g. fish, macroinvertebrates) to be investigated because that data are collected at the same spatial scale and a similar approach was used to determine fish habitat associations in the River Murray (Bice *et al.* 2013)

Almost all of the pools surveyed were hydrologically disconnected; hence the riffles, runs or cascades were not flowing. However, there were two reaches in the North Para River (one reach between Tanunda and Lyndoch and another north of Angaston) and one in Jacobs Creek (at the gauging station) where there was groundwater fed base flow. Spring and early summer 2012 in the Barossa region was one of the driest on record (Bureau of Meteorology 2013) and several landholders indicated that some pools on their properties had dried for the first time in living memory. Therefore, all of the pools designated as permanent for this project are perennial waterbodies, but this survey probably represents an extremely dry state for the streams in the prescribed water resources area. Despite the dry conditions just prior to the vegetation surveys, there were species present such as *Typha domingensis, Phragmites australis, Schoenoplectus validus* and *Bolboschoenus caldwellii* that have high water requirements (i.e. permanent shallow water or waterlogged soils) (Roberts and Marston 2000; Casanova 2011; Roberts and Marston 2011). The aforementioned species were widespread throughout the prescribed water resources area in pool, riffle and run habitats. However, submergent taxa were rare with the charophyte *Nitella* sp. and filamentous green alga *Cladophora aegagropila* (Appendix 2) the only submergent species recorded. It is unclear why submergent species were rare because there were numerous permanent pools and the extended period of very low flow has provided the clear, still water conditions required for recruitment and persistence of many submergent species (e.g. Chambers and Kalff 1987; Hudon *et al.* 2000)

There was widespread evidence of ongoing recruitment of *Eucalyptus camaldulensis* on stream edges and in riparian zones, especially in areas that were protected from grazing (pers. obs.). The presence of trees of varying sizes, ranging from large individuals (probably several hundreds of years old) to trees decades old through to saplings (<10 cm; diameter) and seedlings suggests a balanced proportion of growth stages, indicating that there are a sufficient number of medium sized to large floods to facilitate recruitment in the channels and on stream edges. Hence, it is likely that recruitment of *Eucalyptus camaldulensis* in channels and close proximity to stream edges is more restricted by land management practices, primarily grazing, than by hydrological factors.

Eucalyptus camaldulensis seedlings and saplings were generally not observed away from stream channels despite the presence of large trees considerable distances from stream edges. The absence of recent recruitment in these areas may be due to grazing; however, many of the streams in the Barossa Prescribed Water Resources Area are deeply incised due to erosion. Stream incision would result in less frequent inundation of the historical floodplains due to the larger volumes required for overbank flows and less opportunities for recruitment of *Eucalyptus camaldulensis*.

The exotic terrestrial tree *Fraxinus angustifolia* was widespread on stream edges and riparian zones of streams in the prescribed water resources area. Similar to *Eucalyptus camaldulensis*, there is evidence of ongoing recruitment with large adult trees, seedlings and saplings present. *Fraxinus angustifolia* trees were planted extensively throughout the Barossa for ornamental purposes due to their vivid displays of colour during autumn. Mature trees produce large numbers of seeds with winged fruits that facilitate wind dispersal short distances (100s of metres to several kilometres) (Muyt 2001). Other exotic trees include *Populus deltoides, Olea europaea* (which were locally abundant in places along the edges of the North Para River), *Prunus* sp., *Pyrus communis, Pinus halepensis, Pinus radiata, Salix babylonica* and *Salix nigrum* (all of which were with low cover) (pers. obs.). The impact of exotic trees on the ecology of the streams in the Barossa region is unclear. They probably displace native riparian species but there is no information regarding the historical vegetation of Barossa watercourses or the possible interactions between native and exotic species. Furthermore, *Fraxinus angustifolia*, *Populus deltoides, Salix babylonica* and *Salix nigrum* are deciduous species and the seasonal leaf fall and subsequent pulse of organic matter probably has implications for stream trophodynamics (*sensu* Janssen and Walker 1999; Cremer 2000).

Exotic understorey taxa were less abundant and widespread than native species. The most abundant native species (*Typha domingensis* and *Phragmites australis*) were rhizomatous perennials that can rapidly colonise large areas of stream bank or shallow reaches such as rifles and runs often forming dense monospecific stands that can prevent other species from colonising (Sainty

and Jacobs 1981; Romanowski 1998; Sainty and Jacobs 2003). Nevertheless, *Cynodon dactylon* was widespread around the edges of riffles and runs where some exotic species were locally abundant. For example, *Paspalum distichum* and *Juncus acutus* were common in Duck Pond Creek and *Rorippa nasturtium-aquaticum* was only present in areas with base flow (pers. obs.).

Cluster analysis detected clear groups of pools, riffles, runs and cascades based on the understorey and overstorey plant community; however, (with the exception of the division that separated the permanent and temporary pools) the groups showed very little relationship with respect to stream order or location in the catchment. There were permanent pools dominated by open water and *Typha domingensis* throughout the catchment. Similarly, pools dominated by *Phragmites australis* and bedrock were also widespread throughout the catchment. Riffles and runs dominated by *Typha domingensis, Eucalyptus camaldulensis* and *Phragmites australis* were also widespread throughout the catchment.

Stream channelisation and bank erosion were also widespread throughout the prescribed water resources area particularly in Greenock, Duck Pond, Angaston and Lyndoch creeks (pers. obs.). The channelisation is probably due to clearing of native riparian vegetation most of which would have occurred in the 1800s shortly after the area was settled by Europeans. However, there were many stream reaches throughout the prescribed water resources area where domestic stock were able to access stream banks further exacerbating the risk of erosion and channelisation.

The cross section data provided information regarding the distribution of species across a stream cross section; however, there were problems in displaying the data and at some sites the vegetation cross section was unable to be undertaken at the same points as the hydrological cross section (e.g. when a cross section was undertaken at gauging weir and devoid of vegetation). However, the data provided information regarding the distribution of plant species and communities at the site scale and (due to the surveys being undertaken in May after the opening rains) an indication of the abundance of winter annuals. In the future these types of data would be best collected using a differential GP system (e.g. Trimble RTK™) that can accurately plot positions in three dimensions (Trimble 2013). Using such a system, it would be possible to obtain the positions of plant species and communities in three dimensions, which would include elevation. When elevation information is obtained where there is stream gauging information available, it can then be used to determine the flow magnitude that will inundate a community and the frequency of inundation. This information can then be used to develop or refine eco-hydrological models.

5. References

Anderson, M.J. (2001). A new method for non-parametric analysis of variance. *Austral Ecology* **26**: 32-46.

Anderson, M.J. and Ter Braak, C.J.F. (2003). Permutation tests for multi-factorial analysis of variance. *Journal of Statistical Computation and Simulation* **73**: 85-113.

Bice, C.M., Gehrig, S.L., Zampatti, B.P., Nicol, J.M., Wilson, P., Leigh, S.L. and Marsland, K. (2013). Flow-induced alterations to fish assemblages, habitat and fish–habitat associations in a regulated lowland river. *Hydrobiologia*, in press.

Bray, J.R. and Curtis, J.T. (1957). An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs* **27**: 325-349.

Bureau of Meteorology (2013). Climate averages for Nuriootpa. http://www.bom.gov.au/climate/averages/tables/cw_023321.shtml

Casanova, M.T. (2011). Using water plant functional groups to investigate environmental water requirements. *Freshwater Biology* **56**: 2637-2652.

Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2013). Australian Plant Census, IBIS database. http://www.chah.gov.au/apc/index.html

Chambers, P.A. and Kalff, J. (1987). Light and nutirients in the control of aquatic plant community structure II. *In situ* observations. *Journal of Ecology* **75:** 621-628.

Cremer, K. (2000). Willow management for Australian rivers. *Natural Resource Management, The Journal of the Australian Association of Natural Resource Management* **Special Issue**: 1-22.

Dashorst, G.R.M. and Jessop, J.P. (1998). 'Plants of the Adelaide Plains and Hills.' (The Botanic Gardens of Adelaide and State Herbarium: Adelaide).

Dufrene, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**: 345-366.

Hudon, C., Lalonde, S. and Gagnon, P. (2000). Ranking the effects of site exposure, plant growth form, water depth, and transparency on aquatic plant biomass. Canadian *Journal of Fisheries and Aquatic Sciences* **57:** 31-42.

Janssen, M.A. and Walker, K.F. (1999). Processing of riparian and wetland plant litter in the River Murray, South Australia. *Hydrobiologia* **411**: 53-64.

Jessop, J., Dashorst, G.R.M. and James, F.R. (2006). 'Grasses of South Australia. An illustrated guide to the native and naturalised species.' (Wakefield Press: Adelaide).

Jessop, J.P. and Tolken, H.R. (1986). 'The Flora of South Australia.' (Government of South Australia Printer: Adelaide).

McCune, B., Grace, J.B. and Urban, D.L. (2002). 'Analysis of Ecological Communities.' (MjM Software Design: Gleneden Beach, Oregon).

Muyt, A. (2001). 'Bush invaders of south-east Australia. A guide to the identification and control of environmental weeds found in south-east Australia.' (R.G. and F.J. Richardson: Meredith, Victoria).

Prescott, A. (1988). 'It's Blue with Five Petals. Wild Flowers of the Adelaide Region.' (Ann Prescott: Prospect, South Australia).

Roberts, J. and Marston, F. (2000). Water Rregime of wetland and floodplain plants in the Murray-Darling Basin. CSIRO Land and Water, 30-00, Canberra.

Roberts, J. and Marston, F. (2011). Water regime for wetland and floodplain plants: a source book for the Murray-Darling Basin. National Water Commission, Canberra.

Romanowski, N. (1998). 'Aquatic and Wetland Plants. A Field Guide for Non-tropical Australia.' (University of New South Wales Press: Sydney).

Sainty, G.R. and Jacobs, S.W.L. (1981). 'Water Plants of New South Wales.' (Water Resources Commission New South Wales: Sydney).

Sainty, G.R. and Jacobs, S.W.L. (2003). 'Waterplants in Australia.' (Sainty and Associates: Darlinghurst, N.S.W., Australia).

Trimble (2013). GNSS Surveying Systems. http://www.trimble.com/survey/GNSS-Surveying-Systems.aspx

6. Appendices

Appendix 1: GPS coordinates (UTM format; map datum WGS 84) for survey sites and the habitat types present at each site.

Site	Habitat Type	Easting	Northing
Dry season pool 003	Permanent pool and riffle	309444	6180519
Dry season pool 003A	Permanent pool and riffle	309609	6180543
Dry season pool 006	Permanent pool and riffle	309791	6180656
Dry season pool 007	Permanent pool and run	306743	6168672
Dry season pool 008	Permanent pool and riffle	308091	6180290
Dry season pool 008A	Permanent pool and riffle	308113	6180353
Dry season pool 009	Permanent pool and riffle	308170	6180456
Dry season pool 010	Permanent pool and riffle	309034	6182538
Dry season pool 011	Permanent pool and riffle	309045	6182011
Dry season pool 018	Permanent pool and riffle	318685	6174835
Dry season pool 029	Permanent pool and run	310808	6170441
Dry season pool 030	Permanent pool and riffle	311030	6170345
Dry season pool 033	Permanent pool and riffle	321863	6184877
Dry season pool 033A	Permanent pool and riffle	321912	6184861
Dry season pool 033B	Permanent pool and run	321963	6184927
Dry season pool 034	Permanent pool	323077	6184249
Dry season pool 035	Permanent pool	323279	6183948
Dry season pool 035A	Permanent pool	322962	6184424
Dry season pool 044	Permanent pool and riffle	323962	6182226
Dry season pool 044A	Permanent pool and riffle	323933	6182148
Dry season pool 046	Permanent pool	323554	6180197
Dry season pool 047	Permanent pool	323496	6180006
Dry season pool 048	Permanent pool	323476	6180126
Dry season pool 049	Permanent pool	323376	6178532
Dry season pool 050	Permanent pool	324158	6176804
Dry season pool 051	Permanent pool and run	324212	6176478
Dry season pool 053	Permanent pool and run	324153	6176270
Dry season pool 053A	Permanent pool	324200	6176326
Dry season pool 054	Permanent pool and run	324069	6175640
Dry season pool 055	Permanent pool	324124	6175471
Dry season pool 056	Permanent pool	324020	6174831
Dry season pool 057	Permanent pool	323902	6174773
Dry season pool 063	Permanent pool and run	322997	6170268
Dry season pool 064	Permanent pool and run	323005	6170138
Dry season pool 065	Permanent pool and run	323001	6170038
Dry season pool 066	Permanent pool and riffle	323005	6169928
Dry season pool 068	Permanent pool and run	323041	6169303
Dry season pool 069	Permanent pool and run	323043	6169218
Dry season pool 074	Permanent pool	322940	6174322
Dry season pool 075	Permanent pool	322875	6174371
Dry season pool 076	Permanent pool	322725	6174386
Dry season pool 077	Permanent pool	322684	6174378
Dry season pool 086	Permanent pool	322807	6185949
Dry season pool 086A	Permanent pool	322968	6186109
Dry season pool 087	Permanent pool and run	326448	6185969
Dry season pool 087A	Permanent pool and run	326347	6186065
Dry season pool 089	Permanent pool and riffle	324808	6186194
Dry season pool 089A	Permanent pool	324742	6186174
Dry season pool 091	Permanent pool	325497	6186443
Dry season pool 093	Permanent pool	325212	6186351
Dry season pool 093A	Permanent pool and riffle	325258	6186389
Dry season pool 095	Permanent pool	326618	6185405
Dry season pool 097	Permanent pool and riffle	328370	6184213
Dry season pool 098	Permanent pool and riffle	328396	6184232
Dry season pool 100	Permanent pool and run	305008	6172122

Site	Habitat Type	Easting	Northing
Dry season pool 101	Permanent pool	305029	6172115
Dry season pool 101A	Permanent pool	305078	6172140
Dry season pool 102	Permanent pool and riffle	305092	6172125
Dry season pool 103	Permanent pool	305130	6172183
Dry season pool 103A	Permanent pool and run	305127	6172213
Dry season pool 105	Permanent pool	307246	6172712
Dry season pool 106	Permanent pool and riffle	306431	6172616
Dry season pool 107	Permanent pool and run	307366	6172824
Dry season pool 108	Permanent pool and run	308601	6171912
Dry season pool 112	Permanent pool and cascade	308515	6171916
Dry season pool 115	Permanent pool and run	308686	6172008
Dry season pool 116	Permanent pool and run	308804	6171346
Dry season pool 118	Permanent pool and riffle	309767	6172428
Dry season pool 130	Permanent pool	310607	6173891
Dry season pool 131	Permanent pool and riffle	310652	6174014
Dry season pool 132	Permanent pool	310650	6174055
Dry season pool 133	Permanent pool	310648	6174079
Dry season pool 134	Permanent pool	310811	6174306
Dry season pool 135	Permanent pool	311043	6174494
Dry season pool 135A	Permanent pool	311022	6174382
Dry season pool 136	Permanent pool	311062	6174538
Dry season pool 137	Permanent pool	311086	6174567
Dry season pool 138	Permanent pool	311184	6174791
Dry season pool 138A	Permanent pool	311326	6174943
Dry season pool 138B	Permanent pool	311312	14174964
Dry season pool 138C	Permanent pool	311178	6174691
Dry season pool 142	Permanent pool	313756	6180801
Dry season pool 143	Permanent pool and run	313772	6180846
Dry season pool 144	Permanent pool and run	314031	6181082
Dry season pool 145	Permanent pool and run	314315	6181720
Dry season pool 146	Permanent pool and run	314289	6181740
Dry season pool 147	Permanent pool and run	314262	6181762
Dry season pool 148	Permanent pool and run	314198	6181921
Dry season pool 156	Permanent pool	319028	6184770
Dry season pool 157	Permanent pool and run	306984	6161386
Dry season pool 159	Permanent pool and riffle	307583	6161077
Dry season pool 160	Permanent pool and riffle	308132	6161298
Dry season pool 161	Permanent pool and run	308169	6161330
Dry season pool 162	Permanent pool and run	308147	6161498
Dry season pool 164	Permanent pool and run	308664	6161976
Dry season pool 165	Permanent pool and run	308804	6161902
Gawler Park Rd Ford Pool	Permanent pool	323592	6180603
Greenock Creek @ Roenfeldt Rd	Permanent pool	308992	6183846
Greenock Creek 01	Permanent pool	310503	6185943
Jacobs Creek gauging station 01	Permanent pool	313248	6171428
Jacobs Creek gauging station 02	Permanent pool	312998	6171623
Jacobs Creek headwater 01	Temporary pool	313859	6165628
Jacobs Creek headwater 02	Temporary pool	315487	6166422
Jacobs Creek headwater 03	Temporary pool	315808	6166773
Jacobs Creek Tributary 01	Temporary pool	310235	6169480
Jacobs Creek Tributary 02	Temporary pool	312654	6168294
Jacobs Creek Tributary Dam	Permanent pool	312681	6167945
LC Lyndoch Creek @ Kreig Rd	Temporary pool	306831	6167009
Lindsay Park 02	Permanent pool	323166	6179177
Lyndoch Creek headwater	Temporary pool	309902	6167088
Lyndoch Creek @ Lyndoch Valley Rd	Temporary pool	307048	6165553
Lyndoch Creek @ Williamstown Rd	Temporary pool	306317	6162920
Lyndoch Creek confluence	Temporary pool	306817	6163869
North Para River @ Flaxman Rd	Temporary pool	323725	6172885
North Para River @ Jenke Rd	Permanent pool	308615	6180441
North Para River @ Lindsay Park Rd	Permanent pool	323111	6178830

Site	Habitat Type	Easting	Northing
North Para River @ Seppeltsfield	Permanent pool and riffle	308890	6181936
North Para River @ Thorne Clark Vineyard 01	Permanent pool	323446	6179772
North Para River @ Thorne Clark Vineyard 02	Permanent pool	323487	6179933
Permanent Pool North Para River 001	Permanent pool and run	305323	6172200
Permanent Pool North Para River 002	Permanent pool and run	305463	6172227
Permanent Pool North Para River 003	Permanent pool and riffle	305550	6172222
Permanent Pool North Para River 004	Permanent pool and run	305665	6172228
Permanent Pool North Para River 005	Permanent pool and run	307023	6172900
Permanent Pool North Para River 006	Permanent pool and run	306964	6172880
Permanent Pool North Para River 007	Permanent pool	307078	6172814
Permanent Pool North Para River 008	Permanent pool and run	309099	6171121
Permanent Pool North Para River 009	Permanent pool	309109	6171011
Permanent Pool North Para River 010	Permanent pool	309150	6171015
Permanent Pool North Para River 011	Permanent pool	309221	6171042
Permanent Pool North Para River 012	Permanent pool and run	309259	6171064
Permanent Pool North Para River 013	Permanent pool	309537	6171101
Permanent Pool North Para River 014	Permanent pool	309638	6171175
Permanent Pool North Para River 015	Permanent pool and run	309999	6173163
Permanent Pool North Para River 016	Permanent pool and cascade	309972	6173320
Permanent Pool North Para River 017	Permanent pool and cascade	310125	6173547
Permanent Pool North Para River 018	Permanent pool	310148	6173604
Permanent Pool North Para River 019	Permanent pool	308648	6172068
Permanent Pool North Para River 020	Permanent pool and run	308708	6171668
Permanent Pool North Para River 021	Permanent pool and run	308826	6171513
Permanent Pool North Para River 026	Permanent pool and run	324070	6174292
Permanent Pool North Para River 027	Permanent pool and run	324006	6174335
Permanent Pool North Para River 028	Permanent pool and run	313786	6180926
Permanent Pool North Para River 029	Permanent pool and run	314324	6181706
Permanent Pool North Para River 030	Permanent pool and run	314206	6181811
Permanent Pool North Para River 031	Permanent pool and run	314197	6181949
Permanent Pool North Para River 032	Permanent pool	312703	6178881
Permanent Pool North Para River 033	Permanent pool	311971	6178010
Permanent Pool North Para River 034	Permanent pool and run	311966	6177937
Permanent Pool North Para River 035	Permanent pool	311941	6177837
Permanent Pool North Para River 036	Permanent pool	311856	6177795
Permanent Pool North Para River 101	Permanent pool and riffle	323760	6172801
Permanent Pool North Para River 102	Permanent pool and riffle	323814	6172772
Permanent Pool North Para River 103	Permanent pool and riffle	323860	6172725
Permanent Pool North Para River 104	Permanent pool	323750	6176980
Permanent Pool North Para River 105	Permanent pool	323671	6177030
Permanent Pool North Para River 106	Permanent pool	323559	6177597
Permanent Pool North Para River 108	Permanent pool	323542	6178222
Permanent Pool North Para River 109	Permanent pool	323542	6178218
Permanent Pool South Para River 001	Permanent pool	308988	6161831
Permanent Pool South Para River 002	Permanent pool and run	308948	6161873
Permanent Pool South Para River 003	Permanent pool and run	308083	6161271
Permanent Pool South Para River 004	Permanent pool and riffle	307692	6161070
Permanent Pool South Para River 005	Permanent pool	307819	6161101
Permanent Pool South Para River 006	Permanent pool and run	307894	6161119
Stockwell Creek 01	Temporary pool	320916	6188004
Stockwell Creek 02	Permanent pool	320088	6188010
Tanunda Creek @ Betheny Reserve	Temporary pool	315037	6175684
Tanunda Creek headwater 01	Temporary pool	318805	6171501
Tanunda Creek headwater 02	Temporary pool	318510	6171989
Temporary Pool North Para River 01	Temporary pool	318908	6184574

Appendix 2: Species list and functional group classification (*sensu* Casanova 2011) for steams in the Barossa Prescribed Water Resources Area (*denotes exotic species, **denotes proclaimed pest plant in South Australia, ***denotes weed of national significance; Tdr=Terrestrial dry, Tda=Terrestrial damp, ATe=Amphibious Fluctuation Tolerator emergent, AFTw=Amphibious Fluctuation Tolerator woody, AFTl=Amphibious Fluctuation Tolerator low growing, AFRp=Amphibious Fluctuation Responder plastic, AFRf= Amphibious Fluctuation Responder floating, E=Emergent, Sr=Submergent r-selected).

Species	Functional Group	Species	Functional Group
Acacia paradoxa	Tdr	*Lycopus australis*	ATe
Allocasuarina verticillata	Tdr	*Medicago* spp.*	Tdr
Alternanthera denticulata	Tda	*Melilotus albus**	Tdr
*Apium graveolens**	Tda	*Mentha piperita**	ATe
*Arundo donax**	ATe	*Mimulus repens*	AFTl
*Asparagus asparagoides****	Tdr	*Myriophyllum verrucosum*	AFRp
*Aster subulatus**	Tda	*Nicotiana glauca**	Tdr
*Atriplex prostrata**	Tdr	*Nitella* sp.	Sr
Baumea juncea	ATe	*Olea europaea***	Tdr
Berula erecta	ATe	*Paspalum distichum*	ATe
Bolboschoenus caldwelli	E	*Pennisetum clandestinum**	Tdr
*Bouteloua dactyloides**	Tdr	*Persicaria lapathifolia*	AFRp
*Brassica rapa**	Tdr	*Phalaris arundinacea**	Tda
Callistemon sp.	Tdr	*Phragmites australis*	E
Callitriche sp.	AFRp	*Phyla canescens*	Tdr
Calystegia sepium	ATe	*Picris squarrosa*	Tda
Carex appressa	ATe	*Pinus halepensis***	Tdr
*Centaurea calcitrapa**	Tda	*Pinus radiata**	Tdr
*Chenopodium album**	Tda	*Plantago coronopus**	Tdr
*Chenopodium glaucum**	Tda	*Plantago lancoelata**	Tdr
Cladophora aegagropila	Sr	*Plantago major**	Tdr
*Convolvulus erubescens**	Tdr	*Polygonum aviculare**	Tdr
*Conyza bonariensis**	Tda	*Polypogon monspeliensis**	ATe
*Cotula coronopifolia**	AFRp	*Populus deltoides**	Tdr
Crassula helmsii	AFTl	*Prunus* sp.*	Tdr
*Cynara cardunculus***	Tda	*Pyrus communis**	Tdr
*Cynodon dactylon**	Tdr	*Quercus robur**	Tdr
Cyperus gymnocaulos	ATe	*Ranunculus tribolus**	AFRp
Cyperus vaginatus	ATe	*Rorippa nasturtium-aquaticum**	AFRp
Distichlis distichophylla	Tda	*Rosa canina***	Tdr
Eleocharis acuta	ATe	*Rubus fruticosus* agg.****	ATe
Eragrostis australasica	Tda	*Rumex bidens*	ATe
Eucalyptus camaldulensis	AFTw	*Salix babylonica**	E
Ficinia nodosa	ATe	*Salix nigrum****	E
*Foeniculum vulgare**	Tda	*Samolus repens*	Tda
*Fraxinus angustifolia**	Tdr	*Scaevola* sp.	Tdr
*Genista monspessulana****	Tdr	*Scabiosa atropurpurea**	Tdr
*Holcus lanatus**	Tda	*Schoenoplectus pungens*	ATe
Hydrocotyle verticillata	AFRp	*Schoenoplectus validus*	E
*Hypochaeris radicata**	Tdr	*Schinus molle**	Tdr
Isolepis platycarpa	AFTl	*Solanum nigrum**	Tda
*Juncus acutus**	ATe	*Sonchus asper**	Tda
Juncus pallidus	ATe	*Sonchus oleraceus**	Tdr
Juncus usitatus	ATe	*Sporobolus virginicus*	Tda
Lachnagrostis filiformis	Tda	*Trifolium* spp.*	Tdr
*Lactuca saligna**	Tdr	*Triglochin striatum*	ATe
*Lactuca serriola**	Tdr	*Typha domingensis*	E
Lemna disperma	AFRf	*Typha orientalis*	E
Leptospermum sp.	Tdr	*Ulex europaeus****	Tdr
Ludwigia peploides	AFRp		