

Morphological characteristics of on-farm water storages and their similarity to natural waterbodies in the Border Rivers Catchment, Australia

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ABSTRACT

1. Natural wetlands throughout the world are under threat from water resource development required to support an ever increasing population. In the Border Rivers Catchment in Queensland, Australia, a large irrigation industry and highly variable flow regime have necessitated the building of large on-farm water storages. With the decline in number and size of natural wetlands, the presence of these storages on the floodplain has raised the question of their suitability as alternative habitat for aquatic fauna. This paper explores the variety of water storage types in the Border Rivers Catchment and how their morphology compares to that of natural wetlands, in particular, factors likely to influence aquatic biodiversity.

2. Storages and natural wetlands formed two distinct groups based on morphology. Storages tended to be large, deep structures with a more regular shape while natural wetlands were irregular and shallow with large perimeters. Although there was a degree of variability amongst the storage sites, a large proportion fell into one group and were considered 'typical storages'. Typical storages contained tailwater and had the following characteristics: situated 3 km from the source river, 10 years old, embankment height of 5 m, area of 400,000 m², perimeter of 2.5 km and capacity of 1,700,000 m³.

3. Due to their uniform structure we believe that most on-farm storages are unlikely to support as diverse or abundant an aquatic population as natural wetlands. The presence of tailwater and associated chemicals is also likely to reduce the aquatic biodiversity of storages compared with natural wetlands. While they may be unsuitable as replacement wetlands, given their numbers they could provide significant aquatic habitat across the landscape, if managed effectively.

Keywords on-farm storages, classification, natural wetlands, biodiversity, aquatic habitat

INTRODUCTION

With an ever increasing world population the security of water for consumption, agriculture, electricity production, recreation and tourism is a major international issue (Fischer and Heilig, 1997; Vörösmarty *et al.*, 2000). Unfortunately, an increase in water security is reflected in an increase in water resource development and a consequent loss of natural wetlands (Ligon *et al.*, 1995; Kingsford, 2000; Lemly *et al.*, 2000). Across the globe, the regulation of large rivers for water supply has seen a decrease in the number and size of floodplain wetlands (Kingsford, 2000) such that since 1900, 50% of the world's wetlands have been lost (OECD, 1996).

The situation in Australia mirrors the global trend; dams, diversions and river management have all reduced the frequency, magnitude and duration of flooding in floodplain wetlands (Kingsford, 2000), while clearing, draining, filling and damming have led to large scale wetland loss (Lukacs and Pearson, 1996). Australia is also prone to frequent and severe droughts; on average every 18 years (BOM, 2008). These dry periods can be long lasting with the most recent drought beginning in 1996 and persisting in large parts of southern and eastern Australia for over a decade (MDBC, 2008). Maintaining irrigated agriculture in a semi-arid environment with variable rainfall is associated with problems in securing access to water (Deng *et al.*, 2006), so in many irrigation regions of Australia on-farm water storages have been built to overcome the problem of an unreliable natural water supply. These storages are large, raised earth structures, designed to hold water for irrigating crops such as cotton, sorghum and wheat. Storages allow water to be harvested from the floodplain or pumped from the river channel during high flow events, stored and used at a later time when flows and rainfall are low. The importance of artificial wetlands for biodiversity in agricultural areas has already been recognised in Europe (Céréghino *et al.*, 2008; Céréghino *et al.*, 2008) and the US (Knutson *et al.*, 2004). With the destruction and decline of natural wetlands, on-farm storages in irrigation areas of Australia have been suggested as alternative aquatic habitat for a range of fauna (Hazell *et al.*, 2004; Markwell and Fellows, 2008). However, their morphology and physical habitat characteristics may make them unsuitable as replacement floodplain wetlands.

35 Floodplain wetlands exist in many shapes and sizes and waterholes with different
physical characteristics vary in their biological productivity and in turn, the organisms
which they support (Davis *et al.*, 2002). Hydrological connection history has been
shown to influence invertebrate assemblage composition of natural waterholes
(Sheldon *et al.*, 2002; Marshall *et al.*, 2006) and wetlands (Timms, 2001; Jenkins and
40 Boulton, 2003), while the availability of physical habitat at a range of scales can also
influence assemblage composition in rivers (Sheldon and Walker, 1998). Due to this
variation, classification systems are well developed for natural wetlands using
features, such as hydrology and geomorphology, so as to allow generalisations about
each class in terms of management or conservation potential (Cowardin and Golet,
45 1995).

As with natural wetlands, storages can be morphologically and hydrologically diverse
and support diverse faunal and floral assemblages. An important step in
understanding how effective storages are as alternatives to natural wetlands, is to
50 understand the variety of storage types and how their hydrological and morphological
characteristics compare to those of natural wetlands (Figure 1). Many storages differ
intrinsically from natural wetlands by their constructed nature and lack many of the
attributes that native species have become adapted to, such as coarse woody debris,
riparian vegetation and macrophytes (Lutton, 2005). These factors combined with the
55 morphological differences between natural wetlands and the more uniform storages
could lead to differences in species composition, diversity and abundance.

In this paper we explore the degree of variation in both morphological and
hydrological characteristics of storages in the irrigation area of the Border Rivers
60 Catchment, Murray-Darling Basin, Australia. We use this classification to comment
on how effective storages may be as alternative habitat for aquatic fauna. This is a
vital step in identifying both pattern (assemblage composition) and process attributes
of storages and is critical for understanding the conservation value of storages and
recommending best management practices to landholders.

STUDY AREA

70 The Border Rivers Catchment (Figure 2), of the Murray-Darling Basin, spans the border between north-west New South Wales and southern Queensland, Australia, covering an area of approximately 49,470 km² (DLWC, 1999). The Great Dividing Range forms the eastern boundary of the catchment with elevations of up to 1350 m above sea level (ASL), dropping to approximately 150 m ASL at Mungindi, the
75 catchment's most western town (Boddy and Bales, 1996). The rivers of the Border Rivers region, such as the Macintyre and Barwon Rivers, contain many significant natural wetlands particularly downstream of Boggabilla. A number of effluent streams diverge from the Macintyre River near Boggabilla and Goondiwindi (DWR, 1995) to form some of the streams that fill these waterholes and floodplain lagoons
80 (Medeiros, 2004). The wetlands include lagoons or waterholes in flood channels, anabranch channels and associated intermittent and semi-permanent billabongs (DWR, 1995; Southwell, 2002).

Irrigation is concentrated in the west of the catchment along the floodplains of the
85 Macintyre-Barwon River between Goondiwindi and Mungindi. This area of the catchment receives an average annual rainfall of 500 mm (records from Boggabilla show a low of 174 mm in 1902 to a high of 1041 mm in 1950), with 55% of the annual rainfall occurring from November to March (DWR, 1995). Mean annual inflow is approximately 1,200,000 ML, with roughly half originating from the NSW
90 portion of the catchment. Under natural conditions, mean annual end of system flow, after channel losses and natural processes, would be 580,000 ML (derived from natural flows at Mungindi through the daily flow model IQQM: (BRFF, 2002). Flows within the system are also highly variable; the Macintyre River at Goondiwindi (1916 – 2006) has a mean annual flow of 82,156 ML (\pm s.e. 6214) with a coefficient of
95 variation of 2.06. On average, about 40% of the total Border Rivers inflows are currently extracted to storages for irrigation (GHD, 1992), with a catchment storage capacity in 2008 of 510,000 ML (T. Napier, pers. comm., 2008), or 42.5% of the average annual inflow.

METHODS

Data collection

A sample of water storages in the Border Rivers Catchment (see Figure 3 for examples), totalling 99 storages distributed across 41 properties, were identified as study sites in consultation with industry representatives, using aerial photographs and maps. Hydrological, morphological and management data were obtained via site visits, Geographical Information System (GIS) mapping and landholder interviews. At each storage GPS points were taken at the corners and subsequently incorporated into a GIS map which was used to calculate variables describing aspects of size and shape for each storage site (Table 1). Landholders were either interviewed in person or completed a questionnaire about each of the storages on their property. This provided management information, hydrological and morphological data that could not be obtained from site visits or the GIS map. The complete data set of 99 storages was used for the classification of storage sites.

A total of 70 natural floodplain wetlands (see Figure 3 for examples), were selected from aerial photographs of the Border Rivers Catchment and GIS layers for the Murray Darling Basin. Only wetlands covering an area of greater than 20,000 m² were included. These comprised floodplain lagoons, anabranch channels, waterholes within the channels of ephemeral streams and permanent floodplain wetlands or billabongs. Variables describing the position on the floodplain and the size, shape (the derivative measures circularity index (CI), Horton's form factor (HFF) and elongation ratio (ER) are described in Table 1), surface area, perimeter and length of each natural wetland were generated from the GIS map (Table 1) with five measured transects along each wetland used to calculate the average width. Landholders provided the average depth for 20 of these natural wetlands and the values were used to estimate the bankful volume. Landholders were unable to provide length and width measurements for two of the storage sites, therefore a subset of 97 storages with complete length and width measurements was used for comparison with the natural wetlands.

Classification of Storages

The complete data set of 99 storages were classified using morphological and hydrological variables as well as age of the storage and position on the floodplain. Morphological variables included data relating to size and shape and hydrological variables reflected the source of water used to fill each storage (Table 1). Five different sources of water for irrigation purposes were identified; (i) 'allocated' (supplemented) flows, those supplied by releases from dams and supplemented by tributary flows; (ii) 'unregulated' (supplementary) flows, those supplied by natural drainage and tributary flows; (iii) 'overland' flow (floodplain harvesting), that harvested predominantly from out of bank flows during floods; (iv) 'groundwater', supplied from both alluvial and artesian underground sources; and (v) 'tailwater', any excess water running off an irrigation field while being watered. It is now common practice for 'tailwater' to be recycled to one or more storages on a property. Depending on the type of application system and management, the average amount of tailwater produced during surface irrigations is 22% of the water that is applied but this can vary from 0 to 56% with a median figure of 14% (G. Harris, pers. comm., 2006). On average only 85% of this tailwater is recycled due to seepage and evaporation losses (R. Jackson, pers. comm., 2007). One storage may contain any combination of these five sources of water.

Statistical analysis

Variations in morphology between water body types were explored using frequency of occurrence histograms. Initial analyses included all 70 wetlands and 97 storage sites but had a reduced number of variables because depth and capacity were not available for all of the former and so were omitted from the analyses. A second set of analyses, comparing depth and capacity only, were conducted using the subset of 20 natural wetland sites for which these measurements were available.

As spatial variability (morphology) and temporal variability (hydrology) are related we wished to use both to classify the storage sites into meaningful groups. Dendrograms for both the morphological dataset and the hydrological dataset were generated using hierarchical agglomerative cluster analysis (UPGMA) in the Primer 5 Software package (PRIMER 5.2.9; Clarke and Gorley, 2001). Normalised Euclidean distance was used as the measure of similarity, with group averaging used to generate

the clusters. The hydrology and morphology dendrograms were then compared using a manual two-way cluster analysis which separated the storages into groups based on both hydrology and morphology.

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While classification provided us with a mechanism for grouping storages based on hydrology and morphology we wished to further explore the morphological and hydrological attributes driving the differences. Principal Component Analysis (PCA) was therefore used to isolate those variables contributing most to the difference
175 between storages. PCA was conducted using the default settings in Primer 5 (PRIMER 5.2.9; Clarke and Gorley, 2001).

RESULTS

180 **Comparison of storages with floodplain wetlands**

Floodplain wetlands in the Border Rivers Catchment were very different from storages with respect to their morphology. Storages tended to be bigger than natural wetlands with a greater area (Figure 4b) and larger capacity (Figure 4g). There were also differences in shape. Although natural wetlands tended to cover a smaller area
185 they had longer perimeters than storages (Figure 4c), implying that natural wetlands were more irregular in shape. Natural wetlands and waterholes tended to be long and meandering while storage sites were considerably shorter but generally deeper. The circularity index (CI) and Horton's form factor (HFF) suggested storages were more likely to resemble circles while floodplain wetlands were more likely to be linear in
190 shape. On the floodplain, storages occurred closer to the river with a mean distance of 6.2 km compared with natural wetlands, with a mean distance of 11.1 km (Table 2), reflecting the need for storages to be built as close to the river as possible to reduce the distance that water has to be pumped.

195 **Classification of storages**

Of the 99 on-farm water storages analysed 12 did not contain tailwater and only three had access to groundwater. Most were filled by a combination of allocated flows, unregulated flows and overland flows and contained recycled tailwater. All but two had access to river flows either in the form of allocated or unregulated flows or both.

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Morphologically, storages in the Border Rivers Catchment were quite diverse (Figure 4). The oldest storage surveyed in this study was built in 1977 and the youngest in 2004. Older storages were generally smaller compared to younger storages; the oldest covered an area of only 110,000 m² and had a capacity of 300,000 m³ while the
205 youngest had a surface area of 810,000 m² and could hold 4,000,000 m³ of water. Depth varied from 2 m to 8 m and capacity from 150,000 m³ to a vast 10,000,000 m³.

Hydrologically the storages clustered into 11 groups that reflected the source of water to the storage (Figure 5; Table 3). River flows, either in the form of unallocated or
210 allocated flows, were present in all but two of the groups (A and B), overland flow was predominant in groups A, B, C, E, G, I & J, groundwater was only evident in Groups A and C and only four groups did not contain tailwater (H-K). The majority of sites, 58 in total, were found in one group (G). With the exception of groundwater, this group contained all sources of water including tailwater.

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In relation to morphology, most storages were very similar, forming one large group in the cluster, six smaller groups and two extreme outliers site 77 and site 33 (Figure 5); however, four of the groups contained three or less sites. The majority of sites, 65
220 in total, were found in group 'g', which had a mean age of 10 years and was found close to the source river (mean of 3 km). Storages represented in group 'g' were relatively small when compared with the other groups (mean area of 378,809 m²) (Figure 5 and Table 4).

The manual two-way cluster combining output from the hydrological and
225 morphological clusters separated the storages into 27 distinct groups based on a combination of hydrology and morphology variables (Figure 5). Of these, 15 groups were comprised of only one storage. The large number of groups, and the fact that many of them contained only one site, reflects the variability of storage types. However, the analysis revealed that most storages, 39 in total, could be placed in one
230 group (Figure 5). This group comprised storages containing all sources of water apart from groundwater and had very similar characteristics to morphology group 'g' (Table 4); with an average age of 10 years, mean embankment height of almost 5 m and area of just over 400,000 m². They were located approximately 3 km from the source river, had a perimeter of 2.5 km and could hold almost 1,700,000 m³ of water.

235 Storages found in this group were considered to be a 'typical' on-farm storage in this region.

Descriptors of Storage Groups

When storage hydrology data were explored with PCA (Figure 6a), 57% of the total
240 variation was captured in the first two principal components. PC1 explained 32% of the variation with unregulated flows (-0.637) and groundwater (0.545) loading on this component. PC2 explained 25.4% of the variation with tailwater (0.725) and overland flow (0.534) loading on PC2. PCA placed hydrology group 'G' low on PC1 and high on PC2 (Figure 6a), suggesting sites in this group contained tailwater, overland flow
245 and unregulated flows but not groundwater.

The PCA of storages based on morphology data (Figure 6b) again suggested differences between storage groups with 84% of the total variation explained by the first three principal components. PC1 explained 49% of the variation and was related
250 to storage size, with capacity (-0.556), area (-0.546) and perimeter (-0.478) loading on this component. PC2 explained 18% of the variation and was positively correlated with age (0.653); PC3 explained 17% of the variation with distance from river (0.683) and height (0.583) loading on this component. PCA placed morphology group 'g' high on PC1 (Figure 6b), suggesting storages in this group were smaller in size
255 compared to storages in other groups. Group 'g' occurred low on PC2 which was correlated with age, suggesting storages in this group, while somewhat variable, were constructed relatively recently.

DISCUSSION

260 This study clearly showed that, within the Border Rivers Catchment, storages and natural wetlands differ markedly with respect to their morphology. In general, storages were large, deep structures while natural wetlands were shallower. Storages were also more regular in shape, resembling squares or circles while natural wetlands were irregular with high length to width ratios and large perimeters. These
265 morphological differences between natural wetlands and the storages are significant as they are likely to influence aquatic species composition, diversity and abundance as well as important ecosystem processes such as littoral production (Hansson *et al.*, 2005).

The amount, type and complexity of habitat has been found to positively correlate
270 with the abundance and diversity of fish and macroinvertebrate populations
(O'Connor, 1991; Bunn and Arthington, 2002). Natural wetland sites in the Border
Rivers Catchment have been described as generally having poor aquatic habitat
(Medeiros, 2004). The uniform nature of storage sites and the observed lack of
aquatic habitat (woody debris, snags) suggest that habitat diversity at storages will be
275 even lower, limiting the aquatic biodiversity of storages and also the abundance of
those organisms that can survive in storages.

It is well known that the biomass of both fish and invertebrates in lakes is
concentrated around the edge, or littoral zone (Keast and Harker, 1977), with the
280 complexity of the shoreline influencing diversity (Jackson and Harvey, 1993). In
wetlands and rivers, surface area, volume, perimeter, depth and channel complexity
are all thought to influence the overall health of aquatic ecosystems (Olden *et al.*,
2001; Bunn and Arthington, 2002). Surface area, volume and shoreline perimeter
have been positively correlated with habitat diversity which in turn affects species
285 diversity (Jackson *et al.*, 2001). In dryland rivers increased channel complexity not
only increases the amount of habitat available for lower order aquatic organisms but
also enlarges the surface area available for organic matter to provide a food source
(Thoms *et al.*, 2006).

290 The observed changes in storage design over the relatively short history of irrigated
agriculture, from smaller, shallower structures to larger, deeper structures, suggest a
progression towards ever larger storages over time. If this trend continues the number
of artificial aquatic sites per cubic metre of water stored will reduce. This combined
with the reduction in size and number of natural wetlands will continue to lessen the
295 amount of aquatic habitat in the Border Rivers Catchment and have a detrimental
effect on aquatic species across the region.

Seasonal changes in morphological characteristics of floodplain lagoons have been
well documented in several Australian river systems (Hart and McGregor, 1982;
300 Kennard, 1995). Over the course of a season natural wetlands will experience wetting
and drying periods and in turn fluctuations in water levels. When these occur the
morphology of the natural wetland will change; for instance, as it is flooded a wetland

will increase in overall size (area, volume and perimeter) and depth (Medeiros, 2004). In contrast, the steep sides and regular shape of storages means as they are filled the water does not spread over lower portions of the floodplain, thus changing the shape of the aquatic habitat but merely changes the water level in the storage. Therefore, the temporal variation in habitat characteristics observed in natural wetlands in association with filling and drying (Medeiros, 2004) may not be evident at storage sites. Flooding also allows a two way exchange of material between floodplain wetlands and the river channel. In comparison, storages only have a one-way exchange of material.

Floodplain wetlands are filled during overland flows or from water rising to the surface naturally from underground. Unlike natural wetlands, storages have access to tailwater. As tailwater is excess irrigation water, which has flowed along the crop rows, it is likely that it will contain chemical residues from recent spraying, either in solution or adsorbed onto soil particles. A number of pesticides and herbicides have been detected in tailwater (Crossan, 2002; Rose, 2006) and might therefore accumulate in those storages that hold recycled tailwater (Crossan, 2002). The presence of chemicals in these storages is likely to limit the diversity of aquatic assemblages found within (Ward *et al.*, 1995).

Age of wetlands has been found to influence the species richness of invertebrates and affect the abundance and richness of aquatic vegetation (Hansson *et al.*, 2005) with older wetlands likely to have more complex littoral zone habitats (Markwell and Fellows, 2008). This is particularly relevant as the storages were much younger structures than the established natural wetlands. The young age of many of the storages is also reflected in their reduced or absent riparian zone. Even if riparian vegetation was encouraged to grow on the banks of storages it would be very different to that found at natural wetlands because of the time required to establish trees and understorey vegetation. Natural wetlands have a multilayered band of riparian vegetation along their edge (Lovett *et al.*, 2003) which influences the abundance and richness of aquatic assemblages (Markwell and Fellows, 2008). The observed lack of riparian vegetation around many storages is therefore likely to have an adverse effect on the composition of aquatic communities.

Despite the marked differences between storages and natural wetlands, there was a degree of variability within the storages themselves. However, a large number of the storages (39 out of 99) sampled could be placed in one group which shared similar morphological and hydrological characteristics; the 'typical storage' group. The 'typical storage' in the Border Rivers region contained water sourced from a combination of allocated flows, unallocated flows, overland flows and recycled tailwater, was not particularly large and was constructed relatively recently. Within and between site variability of macroinvertebrate populations as a result of habitat diversity has been well documented in natural wetlands in Australia (Sheldon and Walker, 1998; Marshall *et al.*, 2006) and other parts of the world (Scarsbrook and Townsend, 1993; Sandin and Johnson, 2004). The fact that most storages are similar and that there is little within site or temporal variability suggests that this diversity will not be maintained if natural wetlands are replaced by farm storages.

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Irrigated agriculture in semi-arid environments such as the Border Rivers region of Australia means storages have become part of the floodplain landscape. As the abundance of natural wetlands decline, understanding how storages compare with natural wetlands is an important management and conservation issue. The findings outlined in this paper have been used to design further studies to compare the patterns and functions of aquatic assemblages and food web processes associated with different groups of storages with natural wetlands and test some of the predictions made in this paper (Lutton, In Review).

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Storages primarily function as water supplies and their associated management makes them mostly unsuitable as 'replacement' wetlands. However, given the large numbers of storages across the catchment, if managed effectively, they might provide an additional source of aquatic habitat and help maintain regional biodiversity. To maximise the biodiversity of storages it will be essential to reduce the morphological homogeneity of storages across the landscape and increase habitat diversity within storage sites. In the future, improved design of new storages and alterations to existing storages and their management could help overcome this problem of low diversity of habitat. New storages built with gently sloping sides, shallow areas and central islands would create habitat for wading birds, frogs and invertebrates (Broome and Jarman, 1983; Jarman and Montgomery, 2002). If existing storages were split

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into smaller cells this would not only decrease evaporation losses but increase the bottom surface area for pesticide breakdown and improve water quality (Kennedy and Jarman, 2006). Planting aquatic vegetation and adding coarse woody debris to the banks of storages will provide additional habitat, shelter and a food source for aquatic species. Tailwater could also be managed so that it is limited to only one storage on the property, improving the water quality in the remaining storages (Lutton, 2005; Kennedy and Jarman, 2006). A number of property holders are starting to implement some of these design changes to their on-farm storages which will not only improve aquatic biodiversity but also benefit the farmer (CCC CRC, 2008).

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As a group, storages in the Border Rivers Catchment are still fundamentally different to natural waterbodies and most of the storages fall into a fairly uniform group. If we are to sustain the aquatic biodiversity in the Border Rivers Catchment and other similar irrigation regions we need to preserve the diversity of available aquatic habitat.

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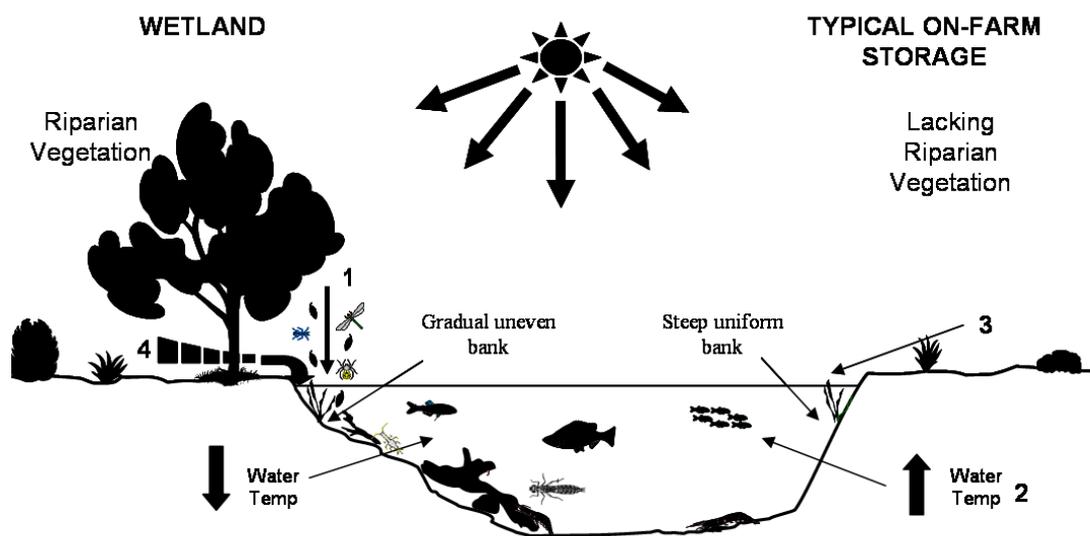


Figure 1. Conceptual model with example plates, comparing potential drivers affecting biodiversity between natural wetlands and storages; 1. inputs of leaf litter and terrestrial invertebrates, 2. rise in water temperature due to lack of shading, 3. no source of logs and branches, 4. filtration of sediments and nutrients. (Adapted from Bunn *et al.*, 1999; In Lutton, 2005)

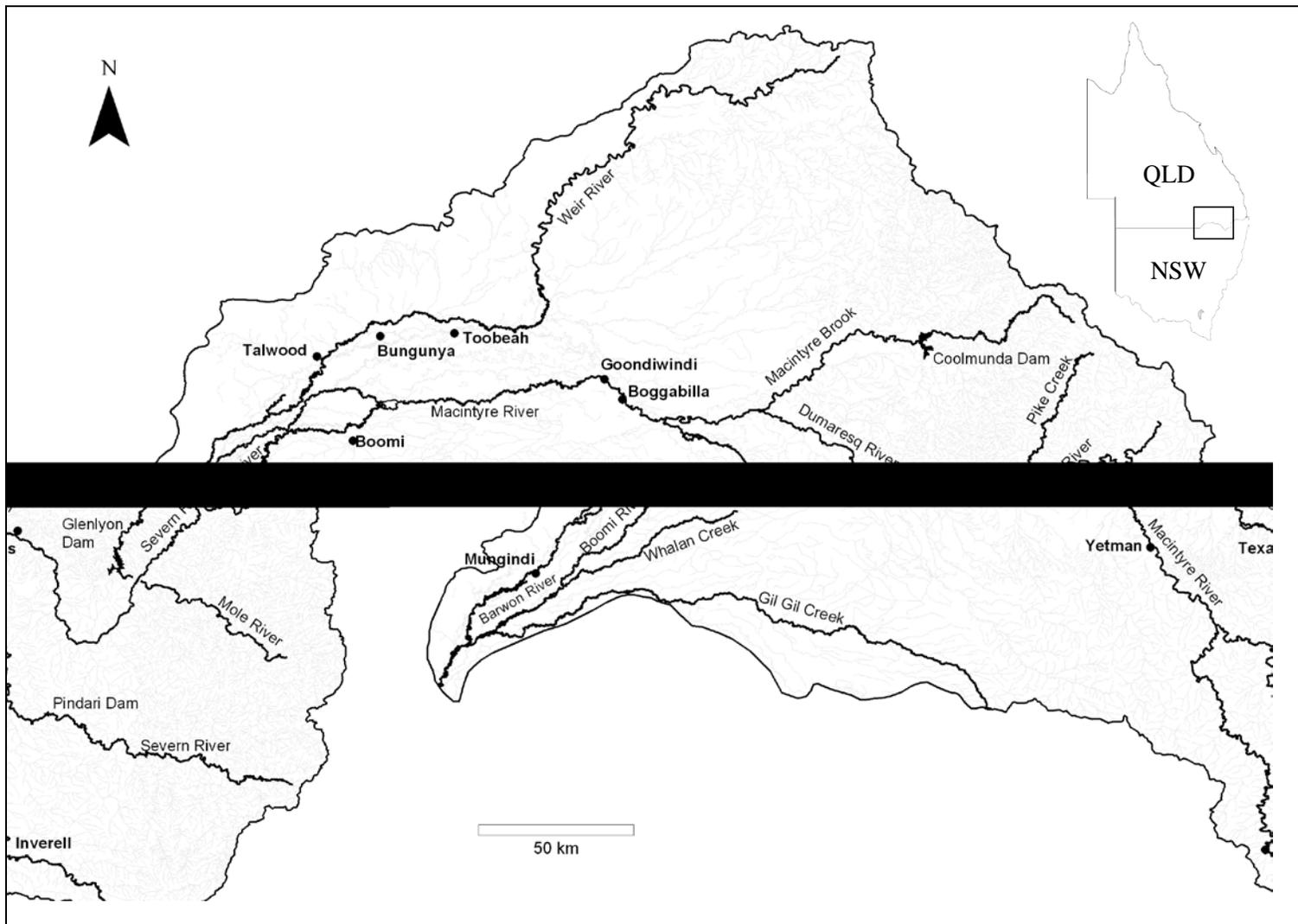


Figure 2. Map showing the location of the Border Rivers Catchment within Queensland and New South Wales (inset).



a) Boongargil Storage 1



b) South Callandoon Storage 2



c) Teriadi Storage 2



d) Yambocully Lagoon



e) Crawler Lagoon



f) Punbougall Lagoon

Figure 3. Example photos of storage (a-c) and natural wetland sites (d-f) in the Border Rivers Catchment. Photos: Susan Lutton.

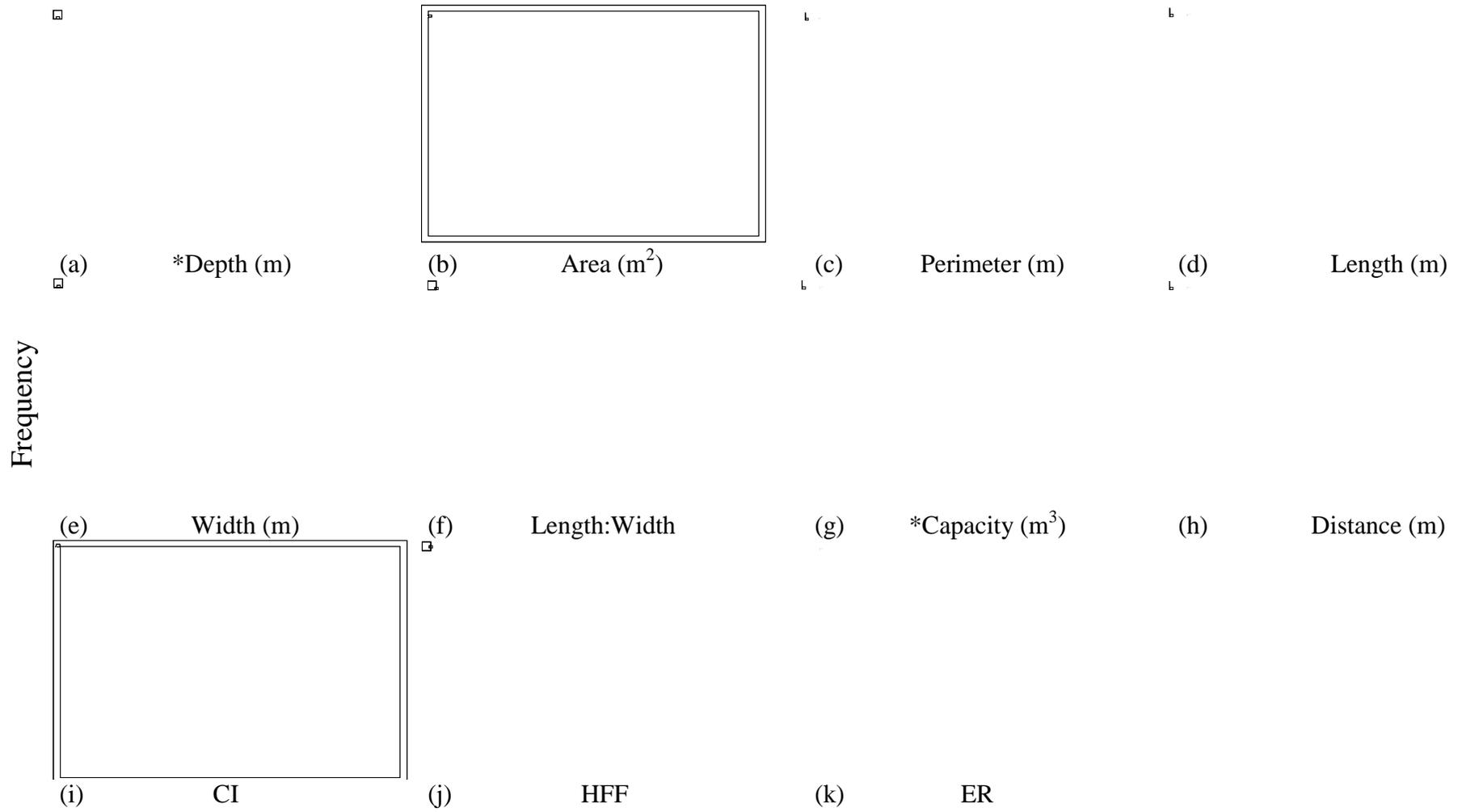


Figure 4. Frequency of occurrence histograms of storage and natural wetland sites. *Only includes 20 natural wetland sites. Black bars represent the storage sites and white bars represent the natural wetland sites.

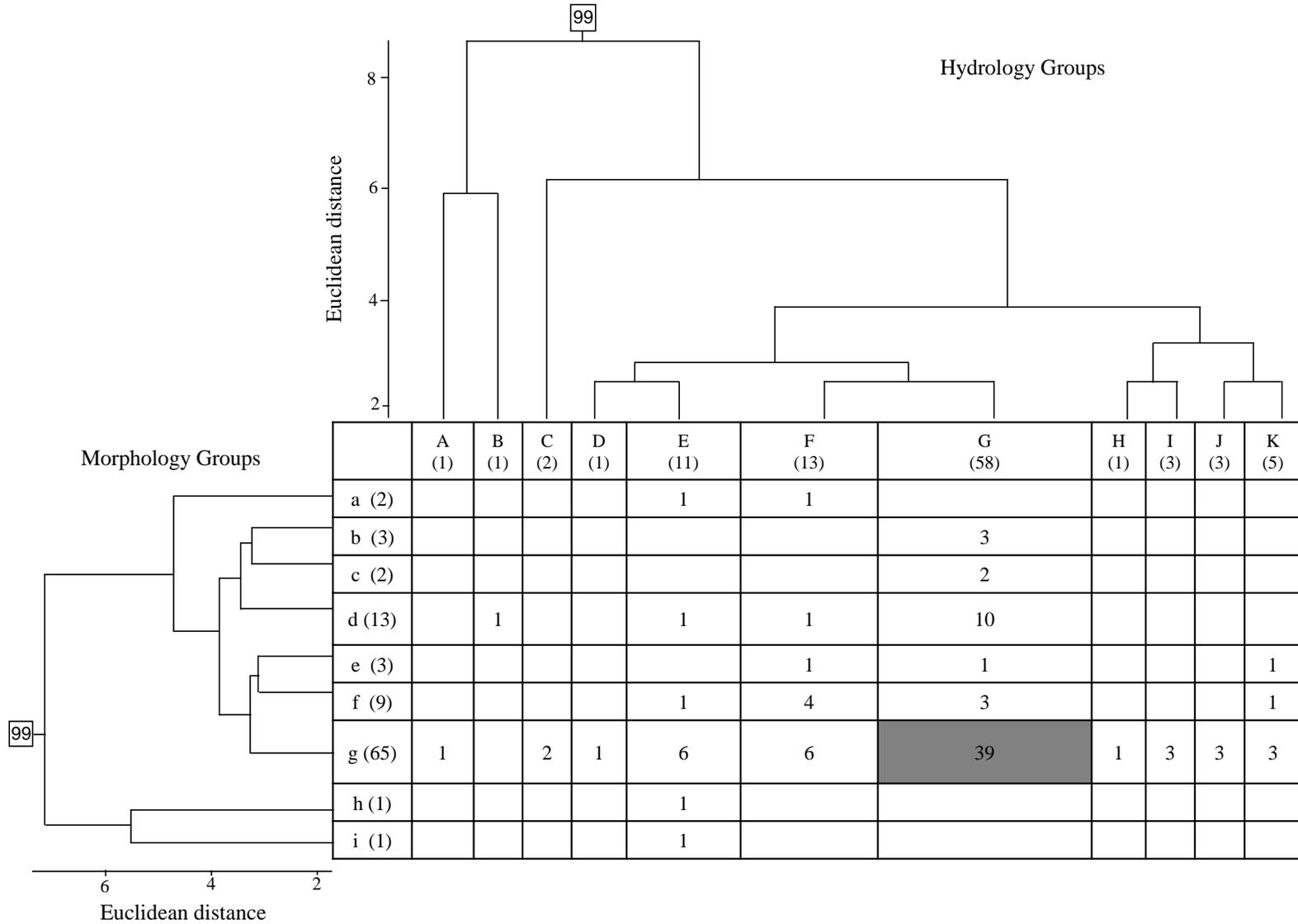


Figure 5. Two-way cluster output of the dendrogram based on hydrology data and dendrogram based on morphology data for 99 storages in the Border Rivers Catchment. Shaded box depicts 'typical' storages.

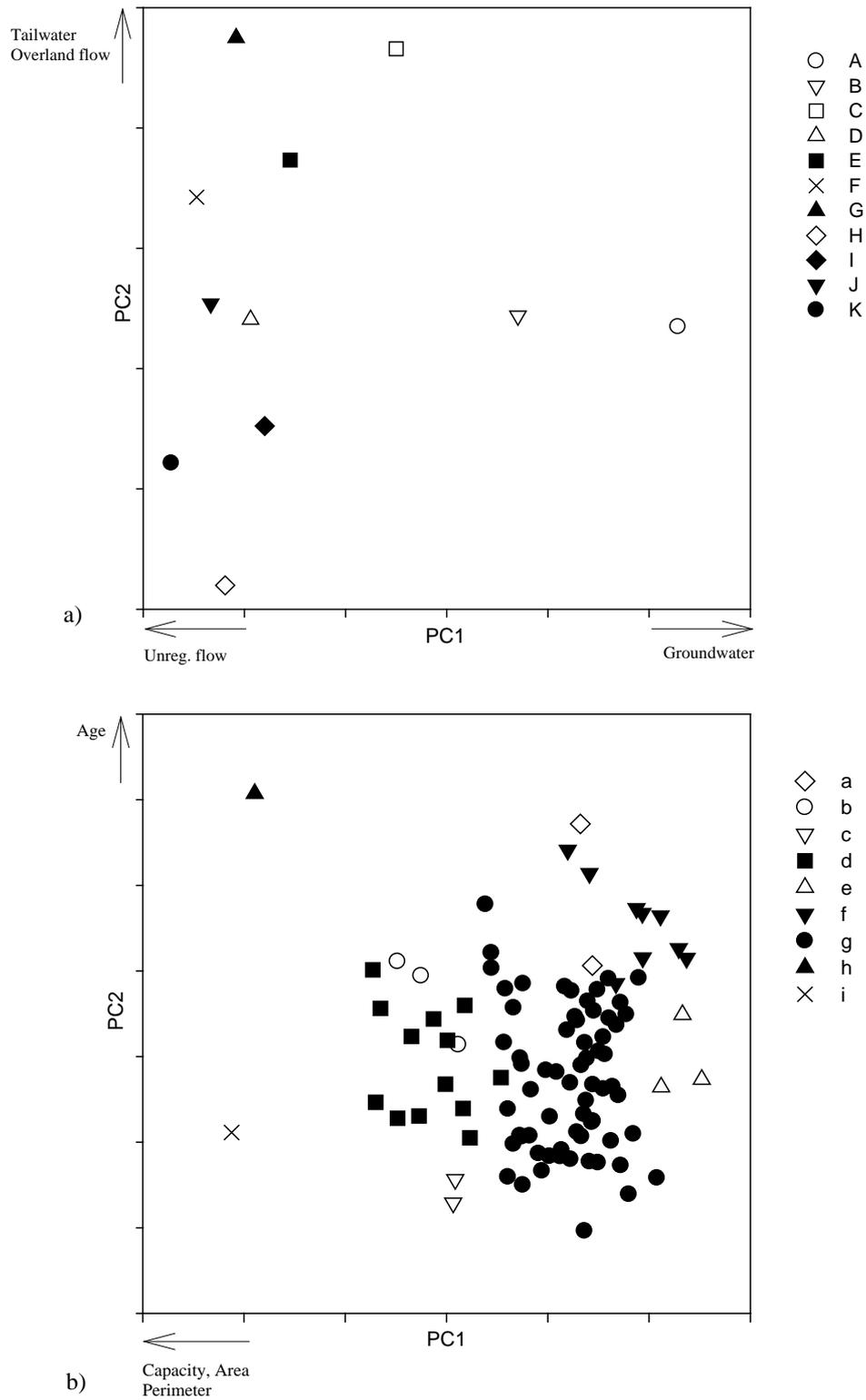


Figure 6. Position of each storage site within the ordination space defined by the first two factors identified by PCA of a) hydrology data and b) morphology data. Symbols show a) hydrology groups and b) morphology groups as identified by Cluster.

Table 1. A description of the variables used for the classification of storages and to compare storages with natural wetlands (NW).

Variable	Description	Data Source	Type	Used for comparison of storages and NW	Used for classification of storages
Depth (m) - D	Height of embankment around edge of storage Average depth of the NW when full	Landholder Landholder	M	✓ ✓	✓
Surface Area (m ²) – A	Generated from Arcview	GIS Map	M	✓	✓
Perimeter (m) – P	Generated from Arcview	GIS Map	M	✓	✓
Length (m)- L	Measured using Arcview	GIS Map	M	✓	
Width (m) – W	Average bankfull width measured using Arcview	GIS Map	M	✓	
Length:Width ratio – LW	Length of waterhole divided by width	GIS Map	M	✓	
Capacity (m ³) - C	The amount of water held by the storage when full Estimated volume of water held by the NW when full	Landholder GIS Map	M	✓ ✓	✓
Distance from River (km) – Dis	The shortest distance from the waterhole to the Barwon-Macintyre River	GIS Map	P	✓	
Circularity Index – CI	The circularity index was calculated using a formula to determine the shape of drainage basins (Miller, 1953) $F=4\pi A/P^2$ Where A is the surface area of the waterhole and P is the perimeter of the waterhole. As F approaches 1 the waterhole will be more circular in shape, as F approaches 0 the waterhole will become more linear in shape	GIS Map	M	✓	
Horton's Form Factor – HFF	Horton's form factor is another calculation normally used to obtain a measure of drainage basin shape (Horton, 1932) $F=A/L$ Where A is the surface area of the waterhole and L is the length of the waterhole	GIS Map	M	✓	
Elongation Ratio - ER	Elongation ratio was calculated for each of the wetlands (Schumm, 1956) ER=diameter of a circle with the same area as the waterhole/length	GIS Map	M	✓	
Age (Years)	Using the year the storage was built; age was calculated at time of analysis.	Landholder	A		✓
Distance from source river (km)*	The distance from the river that water is pumped from during allocated and unregulated flows*	Landholder	P		✓
Groundwater	Presence/absence of groundwater.	Landholder	H		✓
Allocated flows	Presence/absence of water from regulated flows.	Landholder	H		✓
Unregulated flows	Presence/absence of water from unregulated flows.	Landholder	H		✓
Overland flow	Presence/absence of water from overland flow.	Landholder	H		✓
Tailwater	Presence/absence of tailwater.	Landholder	H		✓

*Where access to more than one river was available, the river that was closest to the storage was used. M: morphology, H: hydrology, P: position on floodplain, A: age

Table 2. Mean values for each of the variables for both floodplain wetlands and storages. *Only 20 natural wetlands were included for these variables. Refer to Table 1 for explanations of abbreviations.

	Natural Wetlands				Storages			
	Max.	Min.	Mean	S.E.	Max.	Min.	Mean	S.E.
D (m)*	3.0	0.8	1.6	0.1	8	1.5	4.8	0.1
A (m ²)	1999802	10100	245398	37352.09	1780000	50000	469344	31266.82
P (m)	28710	750	6124	635.24	6270	1010	2733	95.06
L (m)	8959	185	1974	194.52	2030	320	893	33.74
W (m)	559	39	115	10.620	938	159	490	19.28
L:W	109.26	1.45	21.41	2.32	4.91	1.0	2.00	0.09
C (m ³)*	3999604	10100	705795	212904.0	10000000	150000	2028990	157223.47
Dis (km)	40.3	0.1	11.1	1.145	37.9	0	6.2	0.721
CI	0.416	0.012	0.119	0.01	1.187	0.4	0.738	0.02
HFF	525.58	17.69	119.61	10.22	1635.99	143.3	497.80	21.58
ER	1.01	0.11	0.33	0.02	2.06	0.5	0.86	0.02

565 Table 3. Storage site groups created by cluster of hydrology data where AF = Allocated Flow, UF = Unallocated Flow, OF = Overland Flow, GW = Groundwater, TW = Tailwater

Group	No. of Sites	Type of Water Present
A	1	OF, GW, TW
B	1	OF, TW
C	2	AF, UF, OF, GW, TW
D	1	UF, TW
E	11	UF, OF, TW
F	13	AF, UF, TW
G	58	AF, UF, OF, TW
H	1	UF
I	3	UF, OF
J	3	AF, UF, OF
K	5	AF, UF

Table 4. Mean values for characteristics of each cluster group based on morphology (\pm SE). Number in brackets is the number of sites in that group.

Groups	Mean Age (Yrs)	Mean Height (m)	Mean Area (m²)	Mean Perimeter (m)	Mean Capacity (m³)	Mean Distance (km)
a (2)	23.5 (\pm 1.50)	2.75 (\pm 0.750)	225000 (\pm 75000)	5500 (\pm 500.0)	450000 (\pm 150000)	1.55 (\pm 1.450)
b (3)	4.3 (\pm 0.33)	5.83 (\pm 0.601)	850333 (\pm 150267)	3677 (\pm 394.9)	4266666 (\pm 233333)	8.33 (\pm 0.333)
c (2)	6.5 (\pm 0.50)	7.50 (\pm 0.500)	560000 (\pm 40000)	2960 (\pm 60.0)	3556000 (\pm 44000)	0.25 (\pm 0.050)
d (13)	8.2 (\pm 1.52)	5.14 (\pm 0.235)	903007 (\pm 56786)	4129 (\pm 121.7)	3900000 (\pm 233424)	1.00 (\pm 0.265)
e (3)	17.0 (\pm 3.61)	2.50 (\pm 0.500)	150000 (\pm 28868)	1493 (\pm 139.6)	350000 (\pm 104083)	0.30 (\pm 0.252)
f (9)	22.3 (\pm 1.04)	4.78 (\pm 0.222)	228188 (\pm 46985)	1901 (\pm 225.3)	872222 (\pm 181833)	7.56 (\pm 0.835)
g (65)	10.1 (\pm 0.69)	4.73 (\pm 0.089)	378809 (\pm 20642)	2495 (\pm 67.9)	1546153 (\pm 87379)	2.96 (\pm 0.309)
h (1)	8.0	5.00	1780000	6270	6800000	10.00
i (1)	4.0	8.00	1210000	4400	10000000	0.20