DWLBC Technical Report

Impact of farm dams on streamflow in the Big Swamp and Little Swamp Catchments, Eyre Peninsula, South Australia

Government of South Australia
Department of Water, Land and Biodiversity Conservation

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Impact of farm dams on streamflow in the Big Swamp and Little Swamp catchments, Eyre Peninsula, South Australia

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FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the state. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources, it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

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The author would also like to acknowledge the local landholders of the Big Swamp and Little Swamp catchments. Their observations and local knowledge were a valuable source of information in guiding this report.

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SUMMARY

This report describes the assessment of impact of farm dams on streamflow in the Big Swamp and Little Swamp catchments on South Australia's Eyre Peninsula. It was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) on behalf of the Eyre Peninsula Natural Resources Management Board (EPNRMB).

The Big and Little Swamp catchments lie on the Lower Eastern Eyre Peninsula to the west of Port Lincoln. Both catchments contain important wetland habitats with Big Swamp being listed on the register of nationally important wetlands. The predominant land use in the catchments is dryland cropping of cereals with some grazing and a small amount of irrigated agriculture. Over the recent past, an increase in the number of farm dams being constructed in the catchments has led to community concern on the possible effect on streams and water dependent ecosystems.

Farm dams capture runoff from their upstream catchment area and are critical water supply sources in regional areas. They are generally constructed to provide water for stock use, domestic supply, irrigation for development where other water sources are not available and, in instances, as a supply for fire fighting. The extent of farm dam development and their possible impacts on streamflow and, ultimately, water dependent ecosystems, has been well documented in studies undertaken in other regions across the state. This study was commissioned to provide an assessment of that extent for the Big Swamp and Little Swamp catchments.

Aerial photography, undertaken in 2008, was used to capture and digitise the farm dams across the study area. Dam capacities were calculated using regional surface area to volume relationships. There are ~253 dams within the two catchments with an estimated total dam capacity of 320 ML. The development levels expressed as dam densities of 2 ML/km^2 and 2.7 ML/km^2 for Big Swamp and Little Swamp catchments respectively are relatively low in comparison to other areas in the state, like the Mount Lofty Ranges.

The methodology for this project was based on an annual time step rainfall–runoff model using rainfall data from the catchments and streamflow data from the gauged Toolillie Gully sub-catchment upstream of the Tod River Reservoir. This relationship was used as that gauged sub-catchment was considered the most appropriate to use in terms of data availability, and analyses of several catchment characteristics indicate that it was suitable in terms of catchment similarity.

The mean annual rainfall is 580 mm for the Big Swamp catchment and 560mm for the Little Swamp catchment. The estimated mean annual estimated/modelled runoffs are 54 mm for the Big Swamp catchment and 46 mm for the Little Swamp catchment. The set of rainfall surfaces developed for this study and the modelled runoff represented spatially over the catchment were overlayed with estimates of farm dam water use.

Results of the analysis indicate that in the range of median–to–wet years, farm dams are not considered to cause significant reductions in annual streamflow, except in a few localised cases. The median reduction in streamflow at both the Big Swamp and Little Swamp was estimated to be around 5%. This results in 5% of the stream network (by stream length) showing impact of greater than 10%.

The impact during drier years was considerably higher with ~12% of water estimated to be extracted from the catchments upstream of both swamps. This results in 13% of stream reaches (by length) with more than 20% of streamflow extracted. A further 35% of the stream network was estimated to have between 10–20% of streamflow extracted. This raises concern, particularly during a succession of dry years. The cumulative effect of farm dams, added to a climatic drought sequence has the potential to have significant impacts on water dependant ecosystems.

This study was conducted at an annual time scale. More detailed hydrological modelling was not considered possible due to a lack of hydrological data in the study area. The results and interpretation of this modelling was constrained by the scarcity of streamflow data in the Lower Eyre Peninsula.

Recommendations for improved monitoring in the region include establishing water level and ambient water quality monitoring in the Big and Little Swamps proper, streamflow measurements in the reaches above both swamps, and the establishment of a baseline ecological survey. Given the ecological significance of the Big and Little Swamps, these recommendations should be considered as part of any natural resources management planning for the region.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF STUDY

This report describes the assessment of impact of farm dams on streamflow in the Big Swamp and Little Swamp catchments on South Australia's Eyre Peninsula. It was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) on behalf of the EPNRMB. The report describes the methodology and outcomes of the study with the following aims:

- Review and assess the available hydrological data.
- Assess the impact of farm dams on streamflow using an annual time step Geographic Information System (GIS) based model.
- Make recommendations on future monitoring and/or management options

The objective of this report was to provide a broad scale assessment of the risks to water resources posed by farm dams.

1.2 BACKGROUND

Community concern in recent years over an apparent reduction in quality and quantity of streamflows led the EPNRMB to commission DWLBC to investigate the possibility that farm dams may be having a negative impact on water resources in the catchment. Anecdotal reports suggest that the streamflow regime at various locations in the catchment has changed significantly.

The assessment of the impact of farm dams on streamflow detailed in this report provides a catchment scale evaluation. In other areas of the state, farm dams have been found to significantly reduce streamflow and alter the flow regime in highly developed areas.

Farm dams are important in providing water for stock use, domestic supply and irrigation for development where other water sources are not available. A similar study looking at farm dam impacts in the Tod River catchment was completed in 2006 (McMurray 2006). That study reported that in the range of median to wet years, very little of the Tod River catchment was likely to be under any significant level of stress due to the presence of farm dams alone. It reported however that the impact during dry years was much more likely to be significant in all areas influenced by farm dam activity.

1.3 STUDY APPROACH

This study uses the approach described by McMurray (2004a, 2004b) to develop an annual time step spatially based approach to modelling streamflow in the study area. This approach is a useful first-pass appraisal to the relative impact of farm dams, as a precursor to any detailed hydrological modelling.

As streamflow data was not available for the study area, this study relies upon the relationship between rainfall and streamflow as developed for Toolillie Gully of the Tod River catchment. Toolillie Gully is located 20 km to the north east of Big and Little Swamp catchments, refer Figure 2.1.

Rainfall and runoff relationships from the Toolillie Gully catchment were used because this catchment was the closest representative catchment with reliable rainfall and streamflow data. An assessment of the Toolillie Gully catchment characteristics was undertaken and it was found to exhibit similar climatic conditions as well as having similar soils, land use and farm dam characteristics to the Big and Little Swamp catchments.

The model employs the use of GIS to:

- perform terrain analysis on topographic data
- predict the spatial variation of annual rainfall across the catchments
- define flow direction paths
- capture and analyse farm dam outlines and surface areas and estimate water extraction
- calculate and accumulate annual streamflow down defined flow paths.

Using the rainfall–runoff relationship and maps of annual rainfall, the model employs a grid-based approach to calculate both the runoff generated and water extracted from farm dams, for each year of the analysis.

The period of analysis for this study is from 1970 to 2007 inclusive. Thus, there are outputs for each of the 38 years of the study.

The impact due to farm dams is analysed at a stream reach and sub-watershed level, and describes the percentage of water removed cumulatively for each stream/sub-watershed.

2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

Big Swamp catchment

Big Swamp lies to the north and west of Little Swamp catchment (Figure 2.1) and drains around 48 km^2 of catchment into a sequence of terminal wetland basins (Big Swamp). Rising in the north at an elevation of ~250 m, the catchment falls away to the swamp at around 90 m elevation (Figure 2.1).

Being a terminal wetland, the main hydrological processes for Big Swamp are evaporation and recharge through seepage. This seepage is thought to recharge the Uley–East Lens in wetter years when the third basin overflows, roughly two years in five (Evans 2002).

This wetland is described as a seasonal/intermittent freshwater lake (B6—based on the Directory of Important Wetlands definitions) and is currently included as a nationally important wetland It is thought to provide important habitat for animal taxa at a vulnerable stage in their life cycles, as well as providing refuge when adverse conditions such as drought prevail (Australia New Zealand Environmental Consultative Council—ANZECC—criteria 1,3) (Environment Australia 2001).Average rainfall over the catchment is around 580 mm ranging from 530 mm to the west and south to 630 mm in the northern higher elevations.

Little Swamp catchment

The Little Swamp catchment rises in the north-east where numerous springs flow high in the steeper slopes of the sub-catchments of Green and Coomunga Swamps. The two creeks flowing from Green and Coomunga Swamps meet around 4 km upstream of the Little Swamp and drain in a southerly direction eventually draining around 90 km^2 (Figure 2.1).

Seaman (2002) categorised Little Swamp as a permanent freshwater lake (B5—based on the *Directory of Important Wetlands in Australia* definitions).

Downstream of the Little Swamp, the creek drains into the Duck Ponds Creek, so named after a small wetland complex in the south of the catchment, before draining into Proper Bay at Tulka. Anecdotal advice suggests that there have been relatively few instances in the past 30 years where the Little Swamp has overflowed into Duck Ponds Creek. This is most likely due to a combination of factors including the manipulation of the Little Swamp Outlet to a higher than natural level, and possible reductions in flows into Little Swamp over recent times due to periods of below average rainfall. Anecdotal advice also suggests that there has been a reduction in runoff as a result of the widespread adoption of minimum or zero-till land management practices over recent years.

Average rainfall over the catchment is around 560 mm ranging from 510 mm to the west and south to 630 mm in the northern higher elevations.

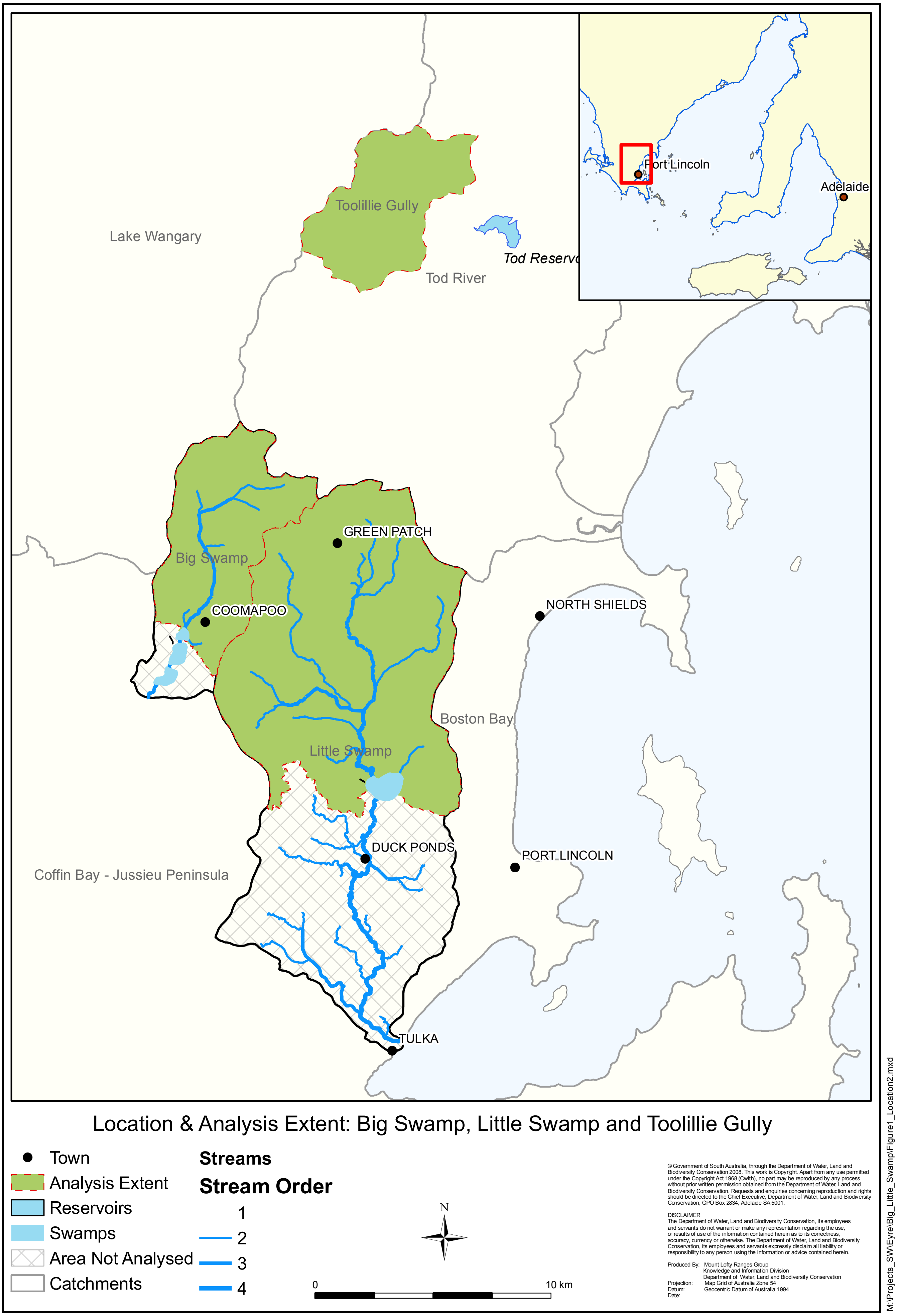


Figure 2.1 Big and Little Swamp catchments location map

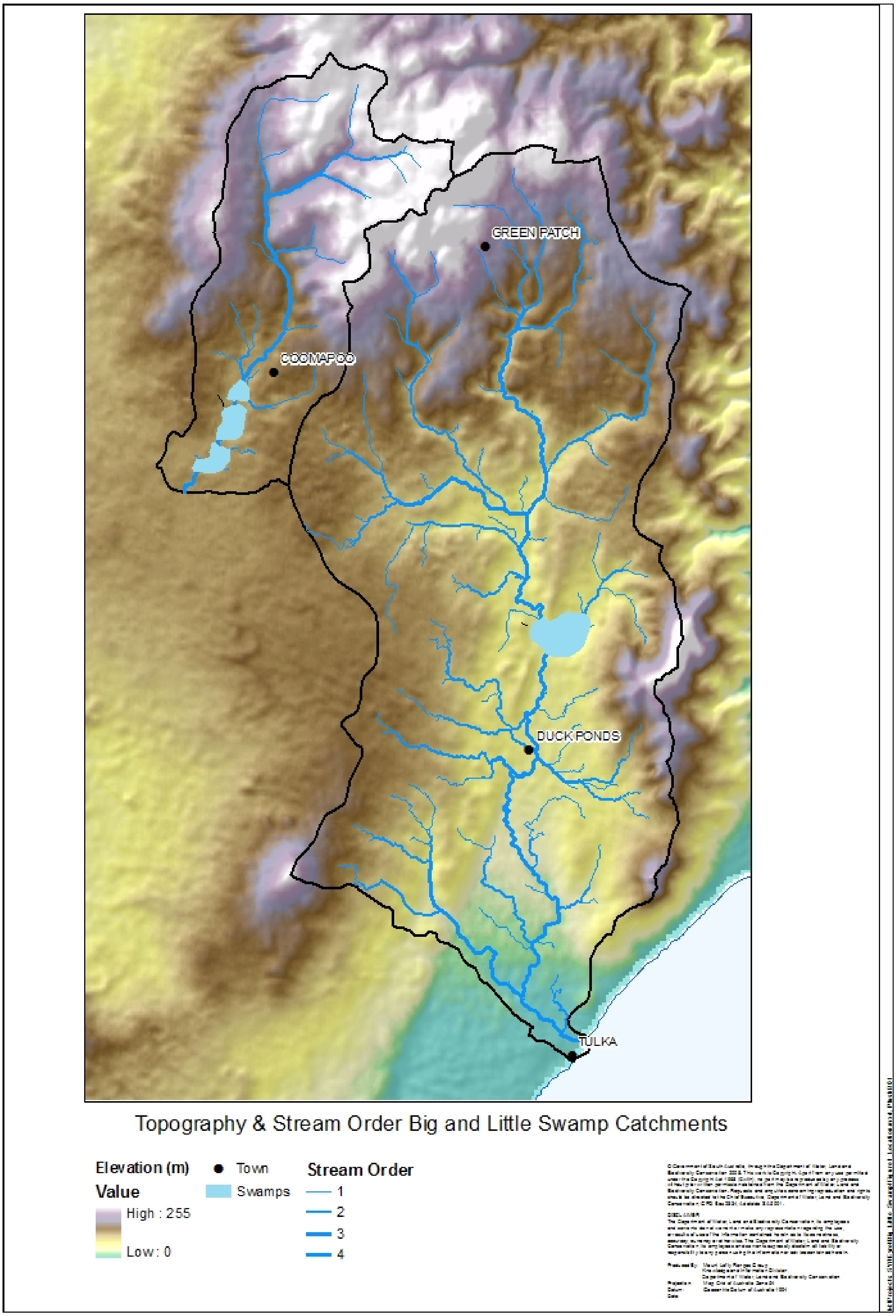


Figure 2.2 Topography and stream order in Big and Little Swamp catchments

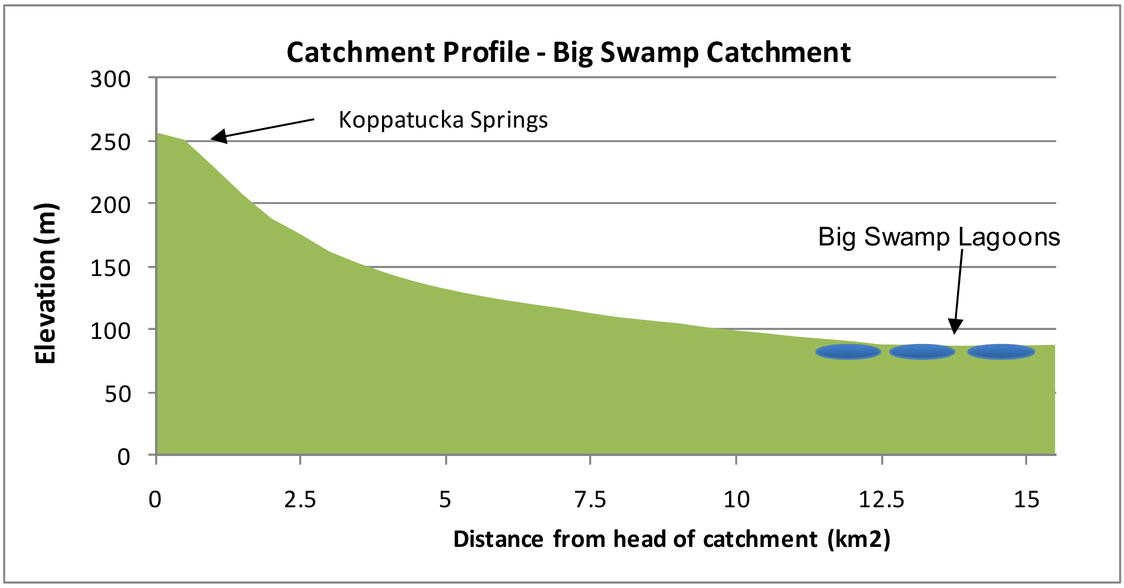


Figure 2.3 Longitudinal catchment profile of Little Swamp (Green Patch to Tulka)

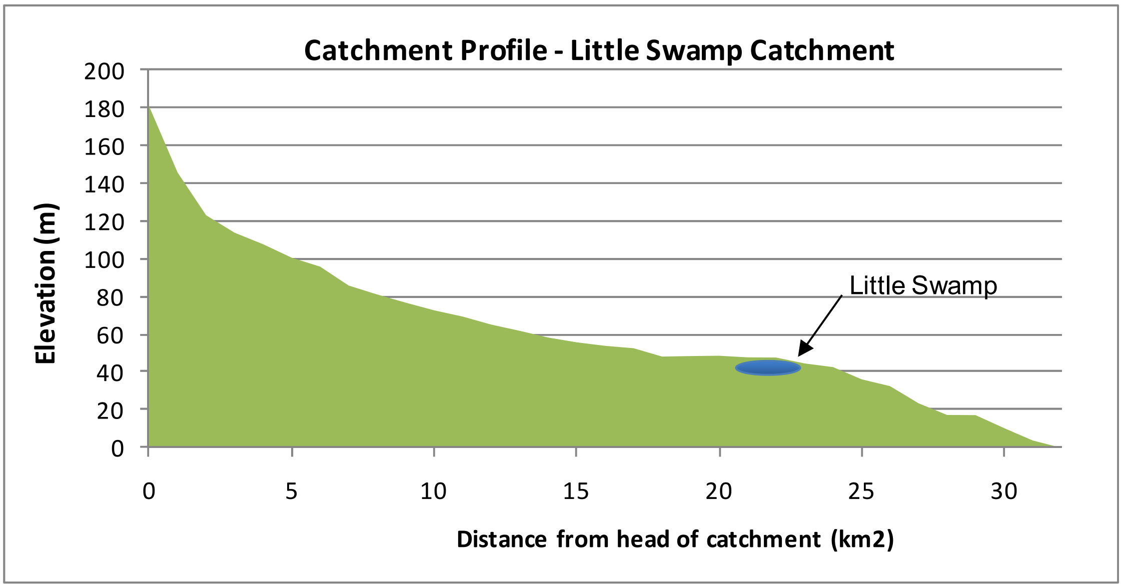


Figure 2.4 Longitudinal catchment profile of Little Swamp (Green Patch to Tulka)

2.2 ECOLOGY

Since European settlement, 55% of the original vegetation on the Eyre Peninsula has been cleared, 43% is still intact, with the remaining 2% largely representing areas of revegetation (Wen 2005). The clearance of native vegetation has been even more pronounced in the riparian zones of both the Big and Little Swamp catchments. Within the Big Swamp catchment less than 15% of riparian vegetation now exists due primarily to the impact of clearing, grazing and altered water regimes. Within the Little Swamp catchment only the upper reaches continue to support relatively intact sedgelands with a decrease in diversity and extent observed below the intersection of Greenpatch and Hyde Road. The lower sections are largely devoid of sedges and riparian vegetation except for some regions immediately above the swamp proper (Bebbington 2000). Across much of this catchment there is a concerning lack of overstorey riparian vegetation significantly reducing structural diversity within the riparian zone.

Besides the information available regarding Big and Little Swamp specifically, there is very little information available concerning the condition or extent of water-dependent ecosystems throughout these catchments. Bebbington (2000) does note however that within the Big Swamp catchment 90% of creek lines and floodplains/swamps are affected by salinity to some degree, and acid sulphate soil conditions are common in the upper catchment.

Both Big Swamp and Little Swamp were sampled as part of *The Wetland Inventory for Eyre Peninsula, South Australia* (Seaman 2002). Big Swamp had the equal highest invertebrate diversity of the wetlands sampled, and marginal salinity (1.0–2.7 mS/cm), noticeably less than most wetlands sampled on the Eyre Peninsula. The sequence of terminal wetland basins comprising Big Swamp provides important diversity in habitats and conditions. This wetland was considered to have moderate wetlands value and was deemed a priority site to monitor. Little Swamp recorded invertebrate diversity similar to most wetlands sampled and was deemed to have brackish salinity levels (3.0–9.1 mS/cm) which is also noticeably less than the majority of wetlands. This was also considered to have moderate wetlands value.

2.3 LAND USE

For the purposes of comparison between the study catchments and the sub-catchment from which hydrological properties were inferred, an examination of land use is appropriate. Land use data from 2008 (DEH, 2008), was sourced from the Department for Environment and Heritage (DEH).

Using the primary land use classification, land use for all upstream sub-catchments is dominated by dryland agriculture, particularly cropping. There exists very little irrigated agriculture or plantations. There does exist some difference between the two study catchments in terms of the classification: Conservation and Natural Environments. Toolillie Gully sub-catchment shows 40% in this category compared with less than 20% for the two study sub-catchments. Despite this discrepancy, the distribution of land use types for both the primary and secondary classification are similar enough not to indicate significant differences in runoff or evapotranspiration processes.

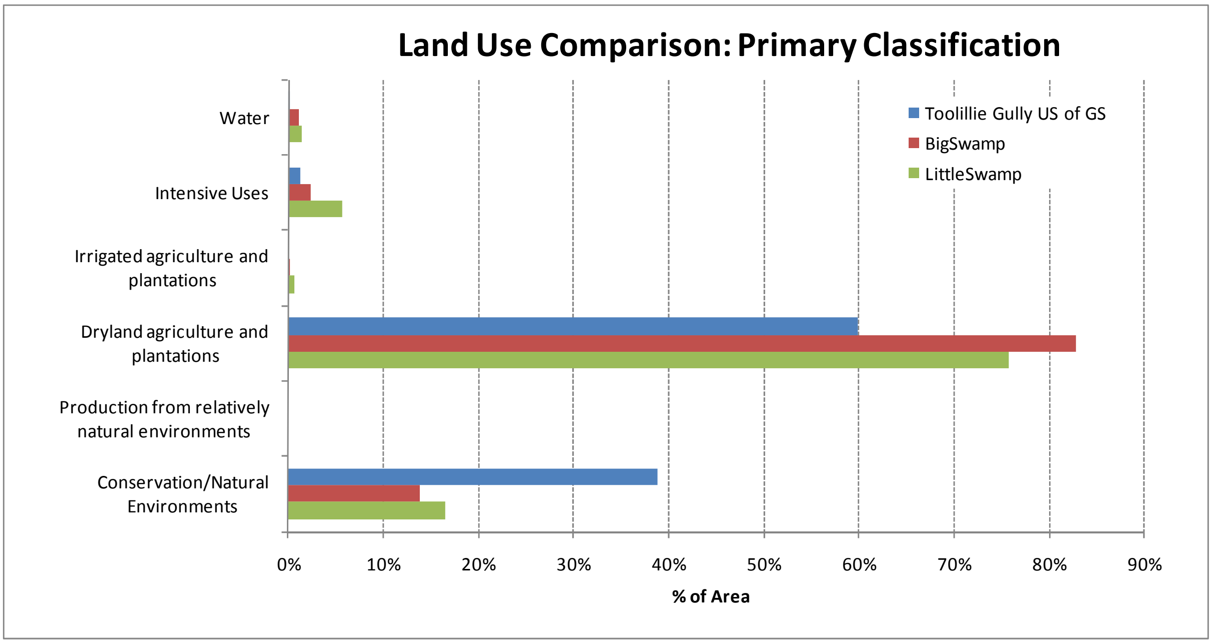


Figure 2.5 Comparison of land uses in the upper catchments of Toolillie Gully, Big Swamp and Little Swamp, Primary Classification

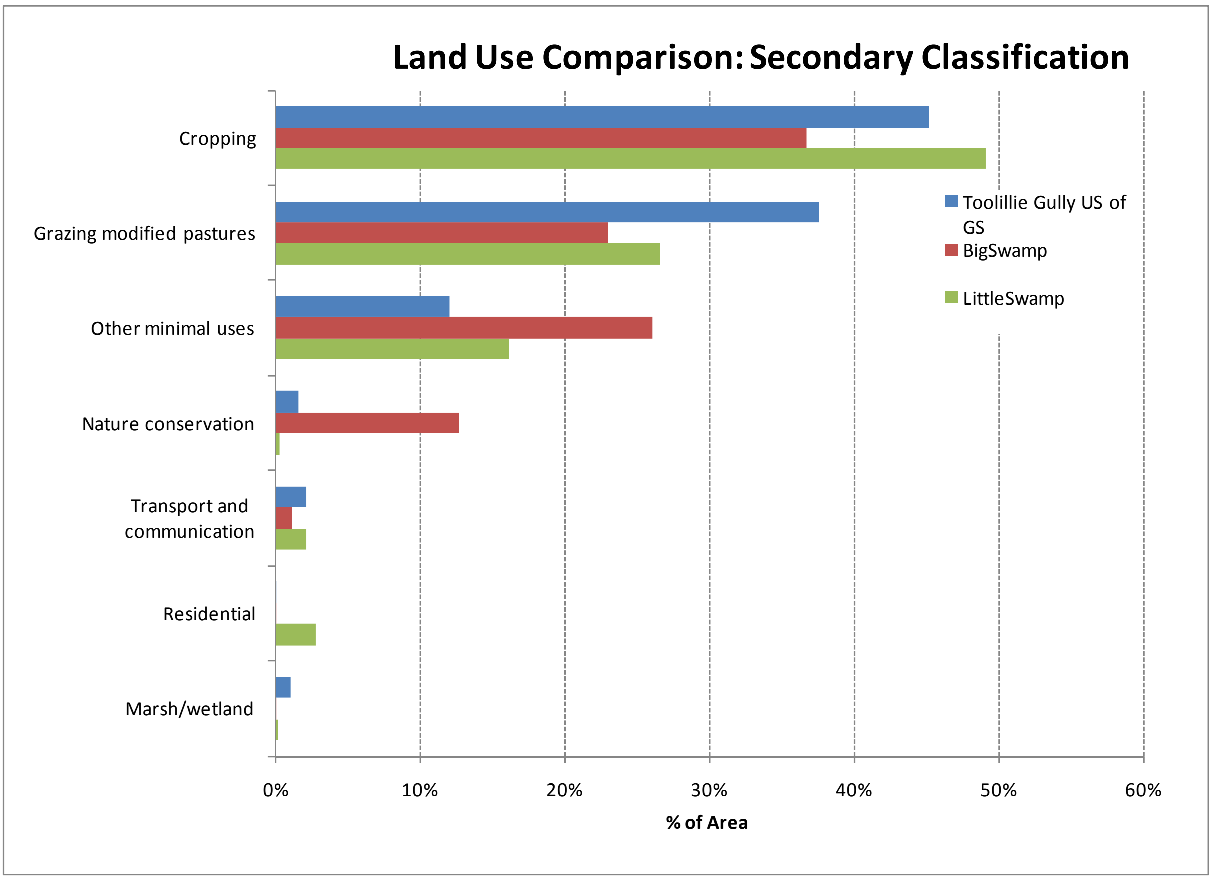


Figure 2.6 Comparison of land uses in the upper catchments of Toolillie Gully, Big Swamp and Little Swamp, Secondary Classification

2.4 FARM DAMS

Farm dams and water bodies were digitised on screen from ortho-rectified aerial photography flown in January of 2008. The ortho-rectified photography had a resolution of 40 cm pixel size. Digitisation was carried out at a scale of around 1:1000. Where possible, interpretation was made as to the full supply level of the dam given the location of a high water mark or spillway so the maximum capacity of the dam could be determined. Interpretation of the full supply level was made difficult by the fact that the imagery was flown in January when most dams were around half full or less. Farm dam locations are shown in Figure 2.9. Although farm dams are digitised as polygons, they are shown here as graduated points to enable clearer visualisation.

2.5 DAM TYPES

Following digitisation, each dam was classified and counted according to the following types:

1. On-stream dam
2. Off-stream dam
3. On-stream dam located on spring
4. Groundwater access trench
5. Unknown.

A description of each dam type follows.

2.5.1 TYPE 1 ON-STREAM DAM

Dams of this type were considered either located on a well-defined channel or having an obvious flow path draining into the dam. This is taken to include dams that may be on a drainage line, as evidenced by the topography upstream of the dam. Dams were also classified this way if the contours above the dam suggested a probable flow path (even if there was no clearly defined channel). It is possible that the number of dams in this category may be over estimated

The shape of most dams in this category is triangular, with the dam wall perpendicular to the direction of flow, and narrowing to the upstream gradient.

2.5.2 TYPE 2 OFF-STREAM DAM

This broad classification was used to describe dams that are on neither a defined watercourse nor obvious drainage path. Some off-stream dams, whilst located in close proximity to watercourses, show some kind of diversion from the main stream, whilst others store water of an unknown source. Many in this class may employ the use of contour banking to direct water from surrounding watersheds. In these cases, the true catchment area was often indistinct and hard to interpret from the aerial imagery.

Included in this type were many dams that appeared to have only road runoff feeding them.

2.5.3 TYPE 3 ON-STREAM DAM LOCATED ON A SPRING

Usually within an identifiable location of spring activity, these dams may consist of either a built up wall to catch and store flows, or be scooped out of the spring or watercourse. Dams of this type will usually not dry out over summer, and always appear to have a supply of water. The dynamics of these type of dams are complicated by depth to the groundwater or spring level (seasonally changing), height of dam wall, and upstream area. Springs were not classified explicitly in this study and classification for this type relied upon the author's interpretation from the aerial imagery.

2.5.4 TYPE 4 GROUNDWATER ACCESS TRENCH

Groundwater access trenches (GATs) are a type of open well, where the ground is simply excavated until groundwater is found. These are generally used for stock watering.

Determination of this kind of water feature is difficult to interpret using aerial imagery. Depending on the size of the GAT, the shape may be indistinguishable from a small rocky outcrop due to the presence of spoil on the land surface and a relatively small water surface area to identify. Some attempt was made to classify water bodies in this class, however; lower confidence is placed in the classification of this type.

2.5.5 TYPE 5 UNKOWN

Dams, water bodies, or GATs that could not be easily classified were placed in this category. In general, the reason for this category is that the scale of the imagery was insufficient for clear classification. The 29 bodies classified as unknown averaged just over 200 kL. They are left in this analysis to allow them to be ground proofed later. The small number and volume means they will have little effect on the outcomes of the analysis.

2.6 FARM DAM NUMBERS AND CAPACITY ESTIMATES

A total of 253 farm dams were digitised from the aerial photography. The total estimated capacity of farm dams for the two catchments is approximately 320 ML.

The volume estimate was calculated using the relationship to convert surface area to dam volume previously developed by DWLBC (McMurray 2004a). This relationship is presented in Equation 2.1 below:

Equation 2.1

For $A < 15\ 000$; $V = 0.0002\ A^{1.25}$

For $A \geq 15\ 000$; $V = 0.0022\ A$

Where: A = surface area (m_2)

V = estimated volume (ML)

The relationship was based on dams in the Mount Lofty Ranges. There has been no ground truthing or testing of this relationship for its applicability to the Eyre Peninsula and hence it is unknown what errors may be associated with using it (but there currently is no better alternative).

The largest proportions of farm dams are estimated to be below 0.5 ML in volume, with 47% of the total number, but only 8% of the total volume. The greatest contribution by volume is the class 2–5 ML (28%). Of interest is that dams larger than 20 ML make up only 1% of the number but 20% of the volume in the catchments. Classification by volume is shown in Figure 2.7 below.

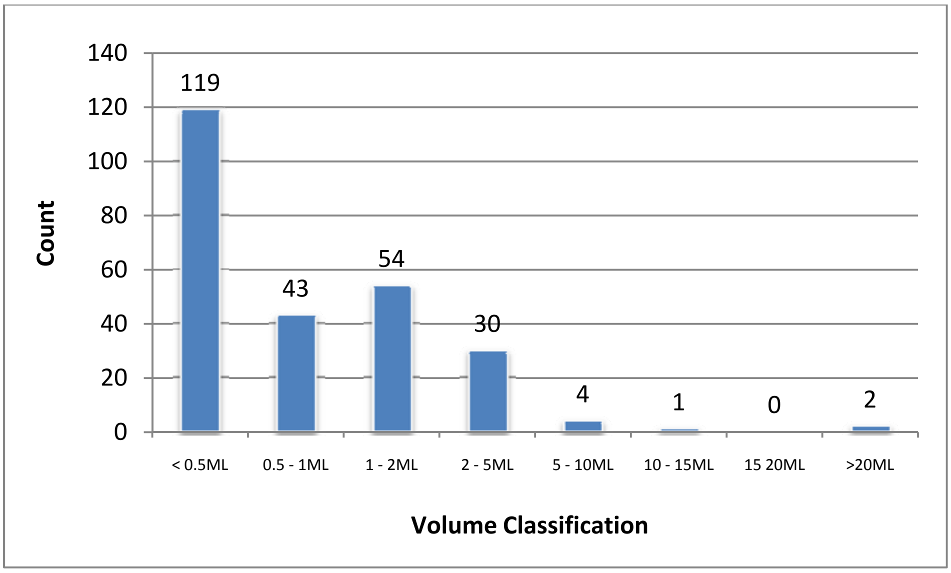


Figure 2.7 Farm dam size classification counts

The results for each catchment are:

- Big Swamp: 117 dams, approximate capacity 105 ML
- Little Swamp: 136 dams, approximate capacity 214 ML.

Comparing the capacity of farm dams within a catchment can give an indication of the level of farm dam development within a catchment. This measure, called farm dam density, is defined as the volume of storage per unit of catchment area. It is usually represented in units of ML/km^2. A higher value of farm dam density may indicate an area of higher stress.

It would be typical to use the total area of the catchments in this calculation, however, since there are very clearly two distinct zones in each of the catchments, only the area above the swamps was used to calculate farm dam density. Almost all dams are in these zones, and the majority of runoff is generated here. The adjusted catchment areas are in Table 2.1 along with the farm dam density estimate.

Table 2.1 Farm dam capacity for Big and Little Swamp

Catchment	Total area (km^2)	Adjusted area (km^2	Total dam capacity (ML)	Dam density (ML/km^2)
Big Swamp	46.1	38.9	105	2.7
Little Swamp	178.8	108.2	212	2.0

The estimates of farm dam density for Big and Little Swamp catchments are very low when compared to catchments in the Mount Lofty Ranges: Upper Angas River 23 ML/km^2 (Savadamuthu 2006) and Upper Mount Barker Creek 23 ML/km^2 (Alcorn 2008). However, they are similar to the dam density for the Toolillie Gully sub-catchment upstream of the gauging station, which is 2.1 ML/km^2.

This could indicate that the dam volumes are underestimated, or that the catchments exhibit very poor runoff characteristics, or simply that the catchments are much less developed than in other areas.

Table 2.2 Size distribution of farm dams, Big and Little Swamp catchments combined

Size distribution	Count	% of total count	Volume (ML)	% of total volume
< 0.5 ML	119	47%	24.9	8%
0.5–1 ML	43	17%	30.0	9%
1–2 ML	54	21%	75.1	24%
2–5 ML	30	12%	89.4	28%
5–10 ML	4	2%	23.8	7%
10–15 ML	1	0%	10.3	3%
15–20 ML	0	0%	0	0%
>20 ML	2	1%	65.2	20%
Total	253	100%	318.7	100%

Table 2.3 Count and volume by dam type, Big and Little Swamp catchments combined

Dam type	Count	% of total count	Volume (ML)	% of total volume
1	69	27%	123.5	39%
2	114	45%	161.1	51%
3	25	10%	25.1	8%
4	16	6%	2.5	1%
5	29	11%	6.6	2%
Total	253	100%	318.7	100%

2.7 FARM DAM FLOW DYNAMICS

This study reports on the percentage of water removed from streamflow by farm dams at an annual time step, however it is worth discussing some of the dynamics of farm dams and the seasonal impacts they may have on streamflow.

The overall impact of a farm dam, or a series of farm dams, will be determined by various factors including the size of the structure, the amount of water diverted (if off-stream), the rate of extraction for irrigation, stock water use, or domestic use, and the timing of those extractions.

In general, the greatest impact on streamflow due to farm dams is early in the flow season when creeks are beginning to flow, which can happen as early as January in parts of the catchment but is usually around late autumn to early winter. During this time, farm dams located on-stream will capture all water up until the time the dam is full, at which time any additional flows will continue to flow through the dam and over the spillway as illustrated in Figure 2.8 below. During the early season, all flow events, shown here in blue, are captured.

This flow dynamic can have negative consequences for downstream ecosystems and water users by delaying the start of the flow season. Break of season events may be small in magnitude and may not cause streams to flow consistently, however, removing this component of the flow regime can:

- reduce the wetting up of the stream bank
- prolong the disconnection between refuge pools
- prolong the storage of salt within the riparian zone

- prevent the flushing of salt through the system
- potentially dry out previously permanently wet systems in the case of swamps.

The amount extracted from the dam over the summer period will further define the level of stress placed on the downstream reaches with higher extraction resulting in emptier dams, which will in turn take longer to refill.

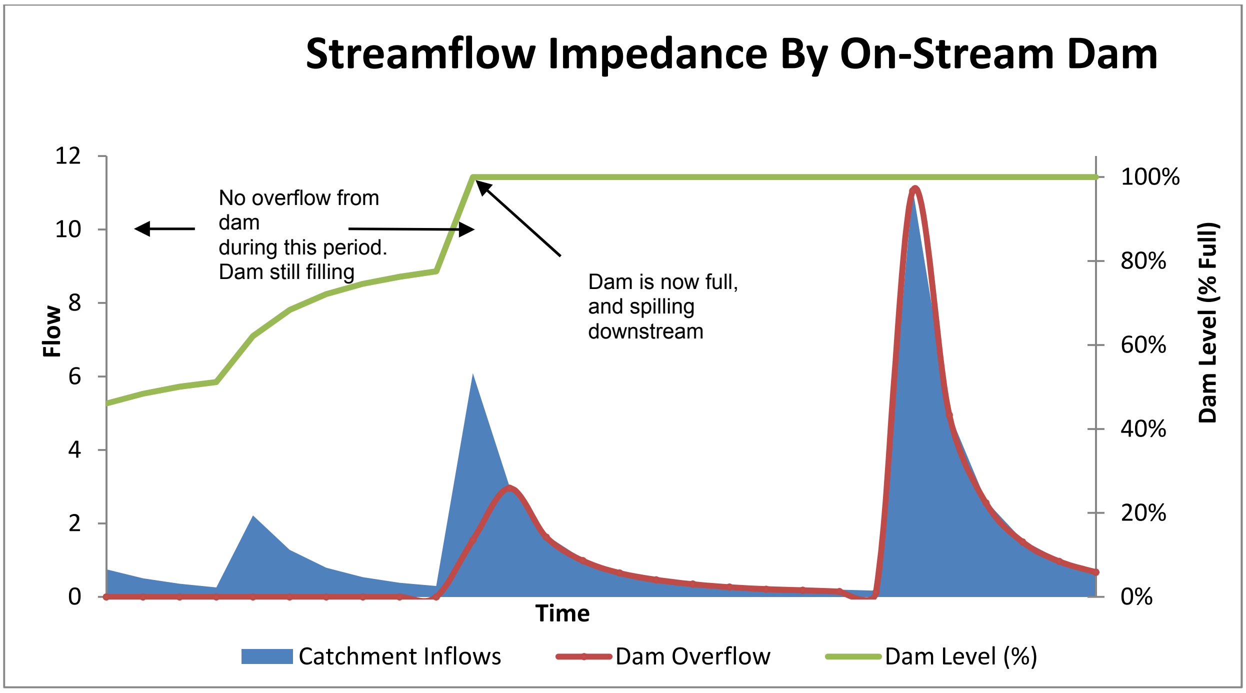


Figure 2.8 Stream hydrograph showing the impact on streamflow due to an on-stream dam

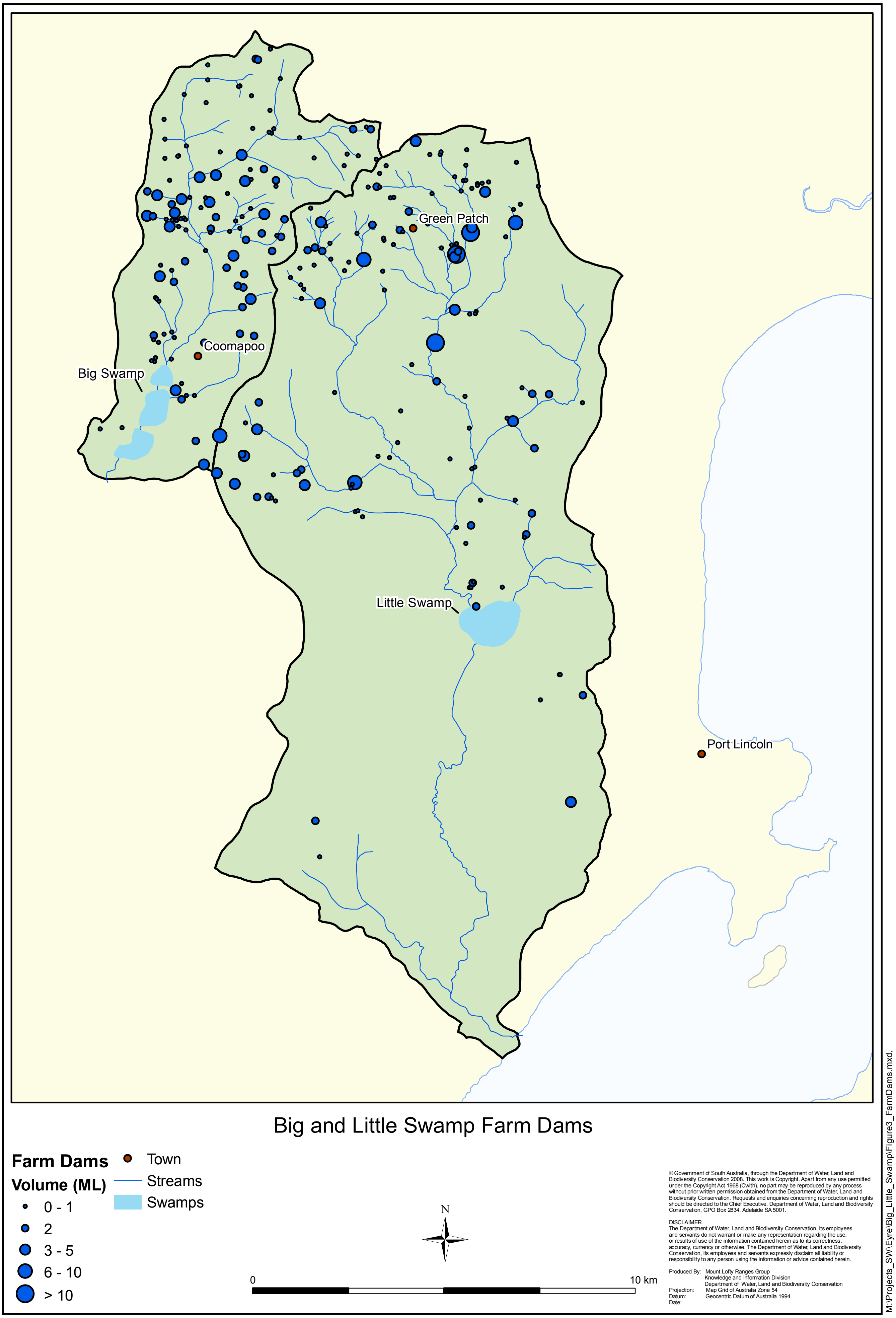


Figure 2.9 Farm dams in Big and Little Swamp catchments

2.8 ESTIMATION OF WATER USE FROM FARM DAMS

The method for estimating water usage from farm dams used by McMurray (2006) was adopted for this study. Although the impacts estimated here are at an annual time step, the water extracted is calculated for both a summer and winter component, and summed to give a total water use.

For the winter component (May to November inclusive), it was assumed that no extractions take place from the dam and that the only water lost from the dam will be due to evaporation from the water surface.

For the summer component (December to April inclusive), water use is made up of a usage component and an evaporation component. Based on the results of a study conducted in the Mount Lofty Ranges (McMurray 2004b), results showed that over the summer months of December 2001 to April 2002 water use across several catchments averaged ~19% and evaporation ~20% of dam capacity. As this was considered a cooler and wetter than average period, it was suggested that average net loss from the dam—usage plus evaporation—would equate to around 50%. For this study, this 50% summer use factor was applied. The total extractions, and hence impacts, are calculated as shows in Equation 2.2 below.

Equation 2.2:

$$Q = ((A \times E) \times PF/100) + (V \times UF)$$

Where: *Q* = Total water removed from the system (ML)
A = Surface area of dam (Ha)
PF = Pan factor for open water surface (0.75 used here)
V = Maximum capacity of dam (ML)
UF = Summer usage factor (0.5 used here)
(/100) correction factor to rationalise units to ML
E = Pan evaporation (May to November) (mm)

2.9 SOIL ATTRIBUTES

For the purposes of comparison between the study catchments and the sub-catchment from which hydrological properties were inferred, an examination of soil characteristics was undertaken using the South Australian land and soil spatial database (DWLBC 2002). Soil characteristics were assessed for the Big and Little Swamp catchments because soil properties are known to significantly influence rainfall–runoff relationships. Furthermore, the soil characteristics of Big and Little Swamp have been compared with Toolillie Gully to ascertain whether the rainfall–runoff relationships from Toolillie Gully can be considered suitably representative of the Big and Little Swamp catchments.

Rainfall and streamflow data is available for Toolillie Gully catchment, which has enabled a rainfall–runoff relationship to be established for that catchment. Unfortunately, there is no streamflow data available for Big or Little Swamp catchments but there is rainfall data. Hence, in the absence of streamflow data from the study area, provided the comparison of key soil properties and land use was favourable, the rainfall data from Big and Little Swamp could be used to estimate runoff from the rainfall–runoff relationship developed from the Toolillie Gully data sets

It should be noted that the analysis included here is qualitative, and was not intended to be used for modification of the rainfall–runoff relationship. This would require significant streamflow data from other catchments in the region, which did not exist at the time of writing. Rather it was used to determine the validity of using the relationship in these ungauged catchments.

The following three soil characteristics (from the South Australian land and soil spatial database—DWLBC 2002) were analysed for the watersheds upstream of Big Swamp (39.4 km^2), Little Swamp (107.9 km^2), and for the Toolillie Gully sub-catchment (38.8 km^2):

- recharge potential
- available water holding capacity (AWHC)
- soil groups.

Each analysis describes the proportional area of soil landscape unit falling under each category.

The soil analysis was limited to those areas above the Big and Little Swamps as most surface runoff and stream baseflow is thought to be generated upstream of these features and the area upstream of the swamps was the primary area of interest for this study. See Figure 2.1 for definition of the soil analysis area.

Soil attribute maps for each parameter can be found in *Appendix A*.

2.9.1 RECHARGE POTENTIAL

Recharge potential is used to describe the potential for water to recharge the groundwater table via percolation through the soil profile. It is calculated from a number of other soil attributes including:

- soil profile water holding capacity
- substrate porosity
- rainfall.

Recharge potential (Figure 2.10) shows that the dominant recharge category is 'low' in all three sub-catchments. Recharge to the Port Lincoln aquifer is thought to occur more substantially in the area below the Little Swamp where the recharge potential and soil type changes. Similarly, recharge potential over the floodplains below, and including the area of Big Swamp, is thought to be higher, recharging to the Uley–East Basin. However, as this study is focused on streamflow through the catchment and entering the two swamps and not on estimating recharge to these basins, those areas are not discussed further in this report.

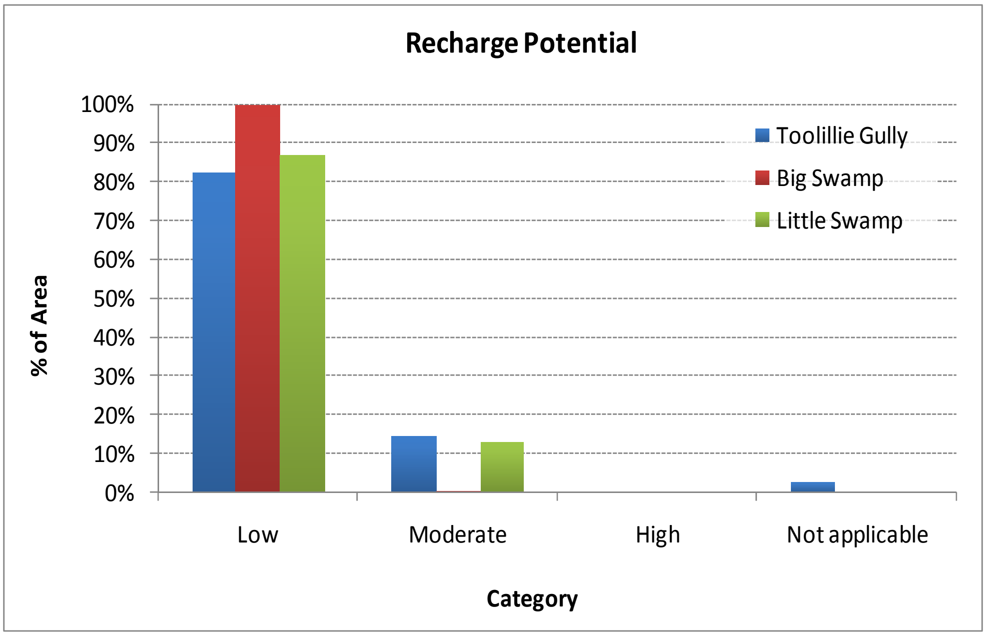


Figure 2.10 Recharge potential of soils in Big Swamp, Little Swamp and Toolillie Gully

2.9.2 AVAILABLE WATER HOLDING CAPACITY

The AWHC of soils is determined by physical and chemical barriers and the approximate clay content of the soil. Here it was calculated from the properties: soil structure and stone content within the available root zone of a wheat crop.

AWHC is shown for the six depth categories in Figure 2.11 below. All three catchments appear to exhibit similar properties here. The dominant category showing most of the areas under analysis have an AWHC of between 70–100 mm. Big Swamp displays a more even distribution with all area falling within two categories, showing all soils to have AWHC between 40–100 mm. Toolillie Gully and Little Swamp appear to display a broader distribution though both still showing most area in the range 40–100 mm.

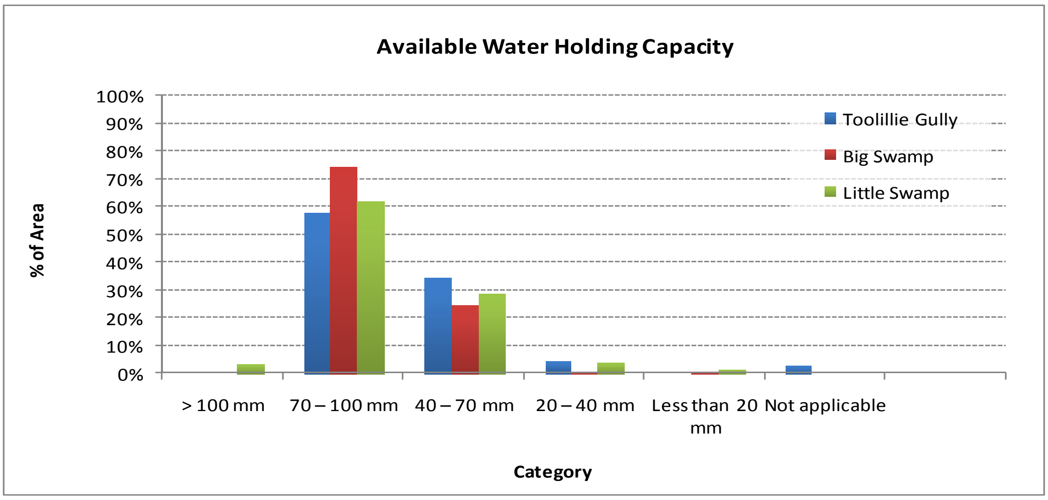


Figure 2.11 Available water holding capacity of soils in Big Swamp, Little Swamp and Toolillie Gully

2.9.3 SOIL GROUPS

Soils are grouped into 18 broad classifications as shown in Table 2.4 and Figure 2.12 below. For all three catchments, the dominant soil type is J, Ironstone Soils. Big Swamp Little Swamp and Toolillie Gully being comprised of 44%, 41% and 40% ironstone type soils respectively.

Under this classification, Big Swamp and Toolillie Gully appear to be the most similar. The second most dominant category for Little Swamp is F, 'Deep loamy texture contrast soils with brown or dark subsoil' comprising some 35% of the area upstream of the swamp.

Table 2.4 Soil group categories

Category	Description	Category	Description
A	Calcareous soils	J	Ironstone soils
B	Shallow soils on calcrete or limestone	K	Shallow to moderately deep acidic soils on rock
C	Gradational soils with highly calcareous lower subsoil	L	Shallow soils on rock
D	Hard red–brown texture contrast soils with alkaline subsoil	M	Deep uniform to gradational soils
E	Cracking clay soils	N	Wet soils
F	Deep loamy texture contrast soils with brown or dark subsoil	O	Volcanic ash soils
G	Sand over clay soils	R	Rock
H	Deep sands	W	Water
I	Highly leached sands	N	Wet soils

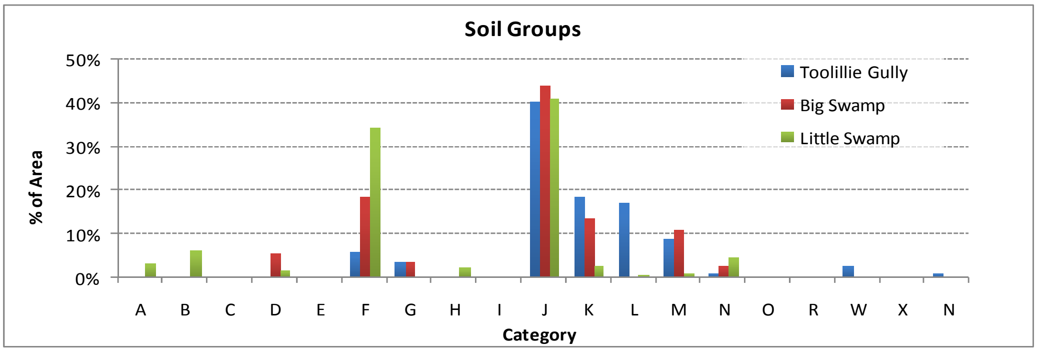


Figure 2.12 Soil Groups in Big Swamp, Little Swamp and Toolillie Gully

The above comparison of soil characteristics indicates (in qualitative terms at least) that the soil characteristics and distributions across the Big and Little Swamps catchments are of sufficient similarity to the Toolillie Gully catchment for rainfall–runoff relationships from that catchment to be applied to the Big and Little Swamp catchments (in the absence of actual recorded data).

Of the two catchments, Big Swamp appears to exhibit greater similarity than Little Swamp to Toolillie Gully. These similarities and anticipated differences were observed during a recent visit to the study area. During that trip, it was noted both visually and commented on by local landholders that spring creek flows from both Green Patch and the Coomunga Swamp sub-catchments form a large part of the streamflow, although this flow may not always reach Little Swamp. Toolillie Gully does not appear to exhibit as much spring flow activity. It is unclear, without adequate streamflow data from Little Swamp, what affect this will have on the estimates of annual catchment runoff.

3. HYDROLOGICAL DATA

3.1 RAINFALL DATA

Long-term rainfall data was available from two stations within the study area:

- M018107 (Port Lincoln–Big Swamp)
- M018107 (Port Lincoln–Woolga).

Both stations are located in the upper reaches of Little Swamp and Big Swamp respectively. The next nearest station is at Port Lincoln just outside the catchment area.

Data from the Woolga station has been collected since 1891 and at Big Swamp station since 1897.

Table 3.1 below shows the stations and their period of records, data quality, mean and median for the extended period.

Table 3.1 Rainfall station details

Station	Mean annual rainfall (mm)	Median annual rainfall (mm)	Opened	Data quality		
				Good quality	Disaggregated	Missing
M018017—Big Swamp	555	545	1897	97.3%	0.1%	2.6%
M018107—Woolga	603	583	1891	97.3%	0.1%	2.6%

Rainfall at both stations is winter dominant with the maximum rainfall occurring in the month of July.

Figures 3.1 and Figure 3.2 show the distribution of mean and median monthly rainfalls for the two stations. Median monthly figures are in general lower than the mean.

Toolillie Gully rainfall data from site A5120508 (located inside the sub-catchment) was used to create the rainfall–runoff relationship used in McMurray's (2006) study. It is worth noting that the mean annual rainfall in this sub-catchment is around 510mm, which is lower than the rainfall in this study's catchments. For analysis of the effect this has on annual streamflow, please refer to Section 3.3.

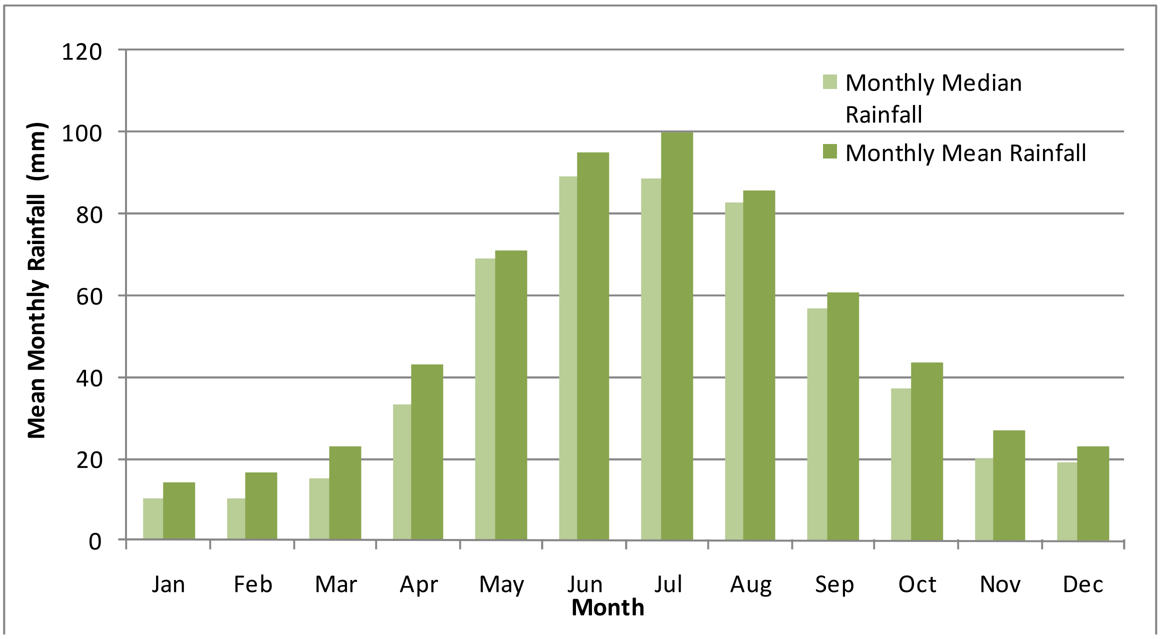


Figure 3.1 Mean monthly rainfall for station M018017 (Woolga) for the period 1898–2007

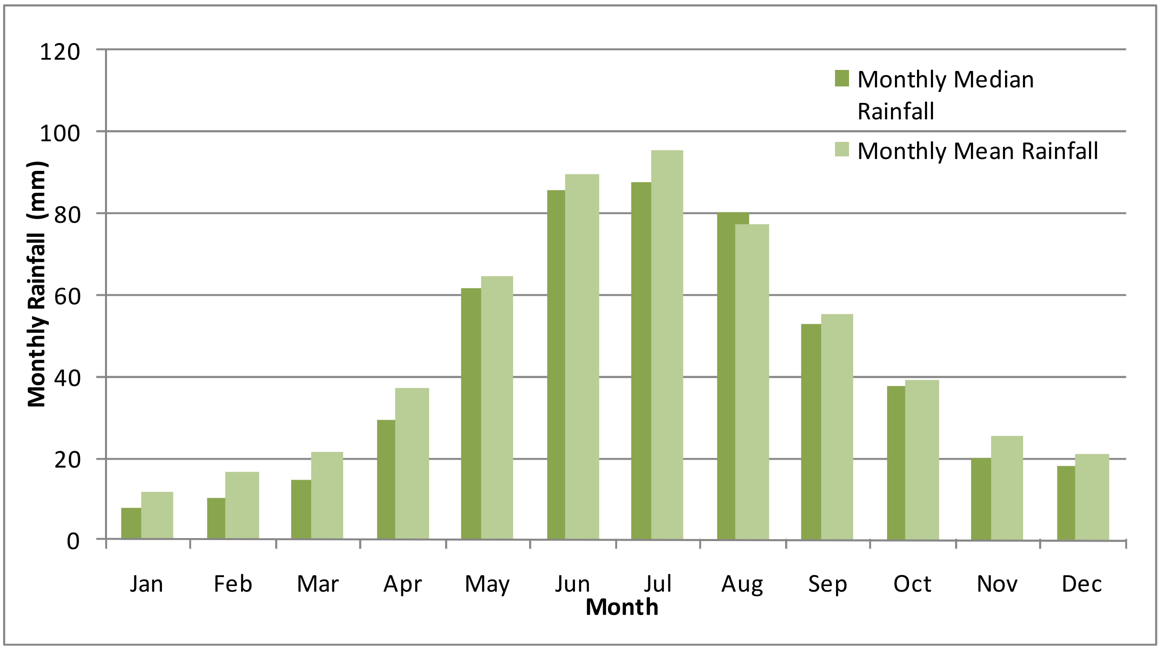


Figure 3.2 Mean monthly rainfall for station M018107 (Big Swamp) for the period 1892–2007

Annual rainfall data is presented in Figure 3.3 and below. Rainfall variability over the period is described by the residual mass curve (red line) on the annual series. The residual mass describes the cumulative deviation from the long-term mean. It is useful in showing rainfall trends during different periods. For example, the curve for Big Swamp shows a significantly drier period spanning the 1940s through to early 1960s. Thereafter the curve shows a modestly increasing period of rainfall towards 1992 (illustrated by the generally positive slope on the residual mass curve between 1967 and 1992). The minimum and maximum rainfall years were 1957 (350 mm) and 1968 (917 mm) respectively. The standard deviation for the annual series is 108 mm.

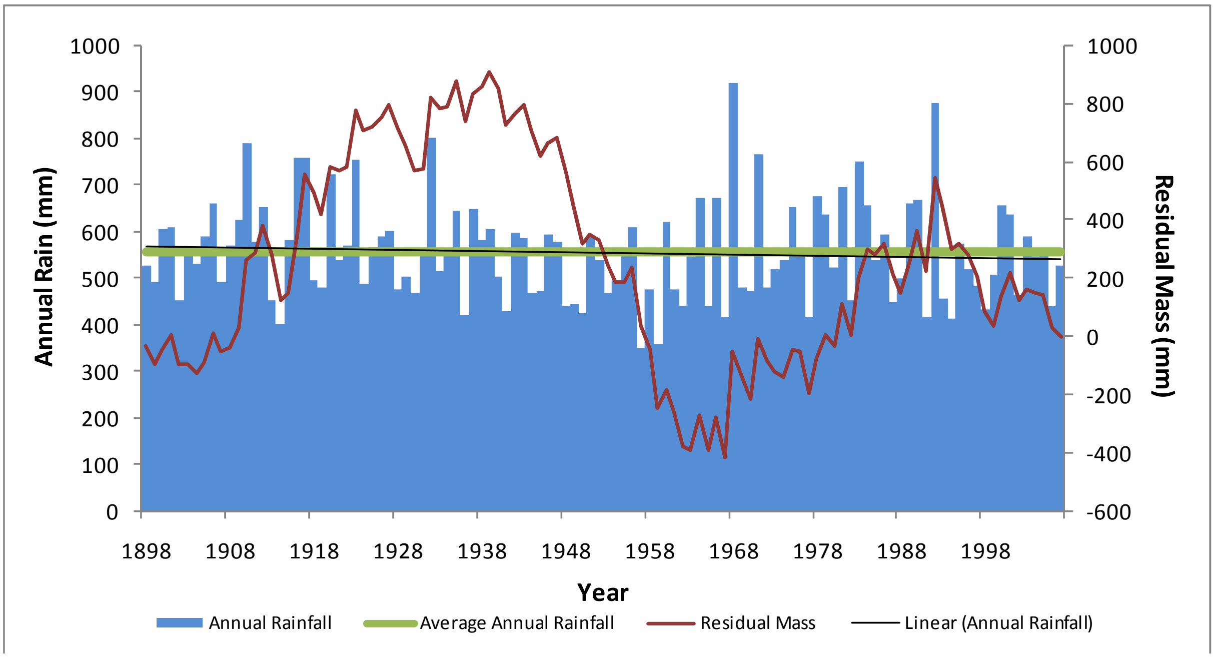


Figure 3.3 Annual rainfall for Big Swamp showing residual mass curve in red

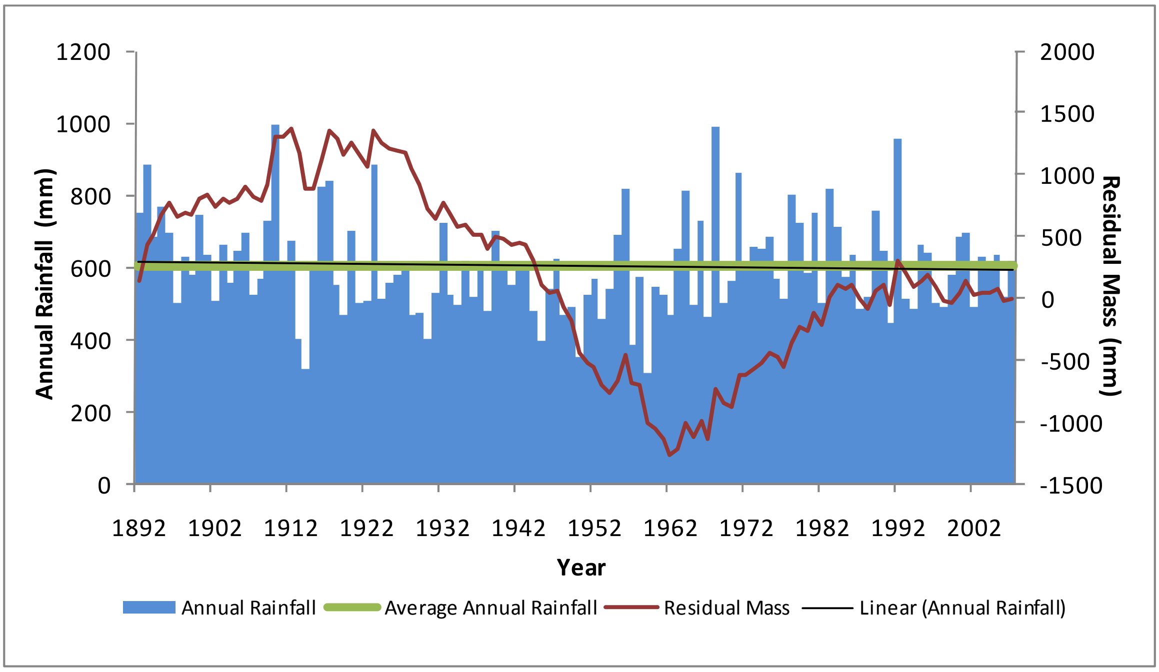


Figure 3.4 Annual rainfall for Woolga showing residual mass curve in red

3.2 ANNUAL RAINFALL SURFACES

Modelling the variation of runoff over the catchment required the use of rainfall grids that show the spatial variability of rainfall. The process requires the interpolation of annual rainfalls between existing stations to create a set of rainfall 'surfaces'—one for each year of the study. Since the network of rainfall stations only included two stations within the actual study area, it was necessary to introduce the use of 'virtual' rainfall stations.

Virtual rainfall stations were added in key areas in and around the catchment to 'force' the interpolation of rainfall point locations to continuous rainfall surfaces.

To determine the rainfall sequence for the virtual stations, a GIS spatial analysis method was used to relate easting (latitude), northing (longitude) and station elevation to annual rainfall. The method chosen was the ordinary least squares method. This method fits a linear regression of the form:

Equation 3.1

$$P_p = X.a + Y.b + Z.c + d$$

Where: P_p = Predicted rainfall at station
X = Easting of the station
Y = Northing of the station
Z = Elevation

The *a, b, c* and *d* are parameters fitted by the least squares error model.

This analysis was conducted for each year of the study (38 years) for 21 rainfall stations across the Eyre Peninsula, producing a table of coefficients to be applied to the virtual rainfall stations—given the known easting, northing and elevation of the virtual station.

The eastings and northings were calculated using ArcMap. Elevation was derived from the a regional digital elevation model (NASA SRTM DEM) which was resampled from ~10,000 m^2 grids to 1 km^2 to smooth out elevation effects).

Results from the objective least squares analysis (OLS) showed that the regressions were generally able to predict the rainfall for most years and most stations quite well—Multiple R^2 >0.7. Although there were three years where the model performed poorly (1973, 1974 and 1992), it is not expected that this will affect the overall performance of the modelling, as the largest residuals for those years do not lie in the spatial range of the study area. *Appendix B* shows the coefficients for each year and the Multiple R^2 statistic, describing the fit of the regression model.

After determining the rainfall sequences for these virtual stations, rainfall surfaces were interpolated between these points. The interpolation method chosen was a regularised spline. Visual inspection of the surfaces confirmed that the inclusion of the virtual stations to 'force' the interpolation produced satisfactory results. The strongest relationship of the three parameters used for the rainfall model was the elevation parameter, with higher rainfalls predicted for higher elevations.

The use of these virtual rainfall stations, whilst satisfactory for this type of coarse scale analysis, is not a substitute for quality long-term daily read or pluviometric rainfall data.

Figure 3.5 shows the location of actual and virtual stations that were used to create the rainfall surfaces used in the modelling.

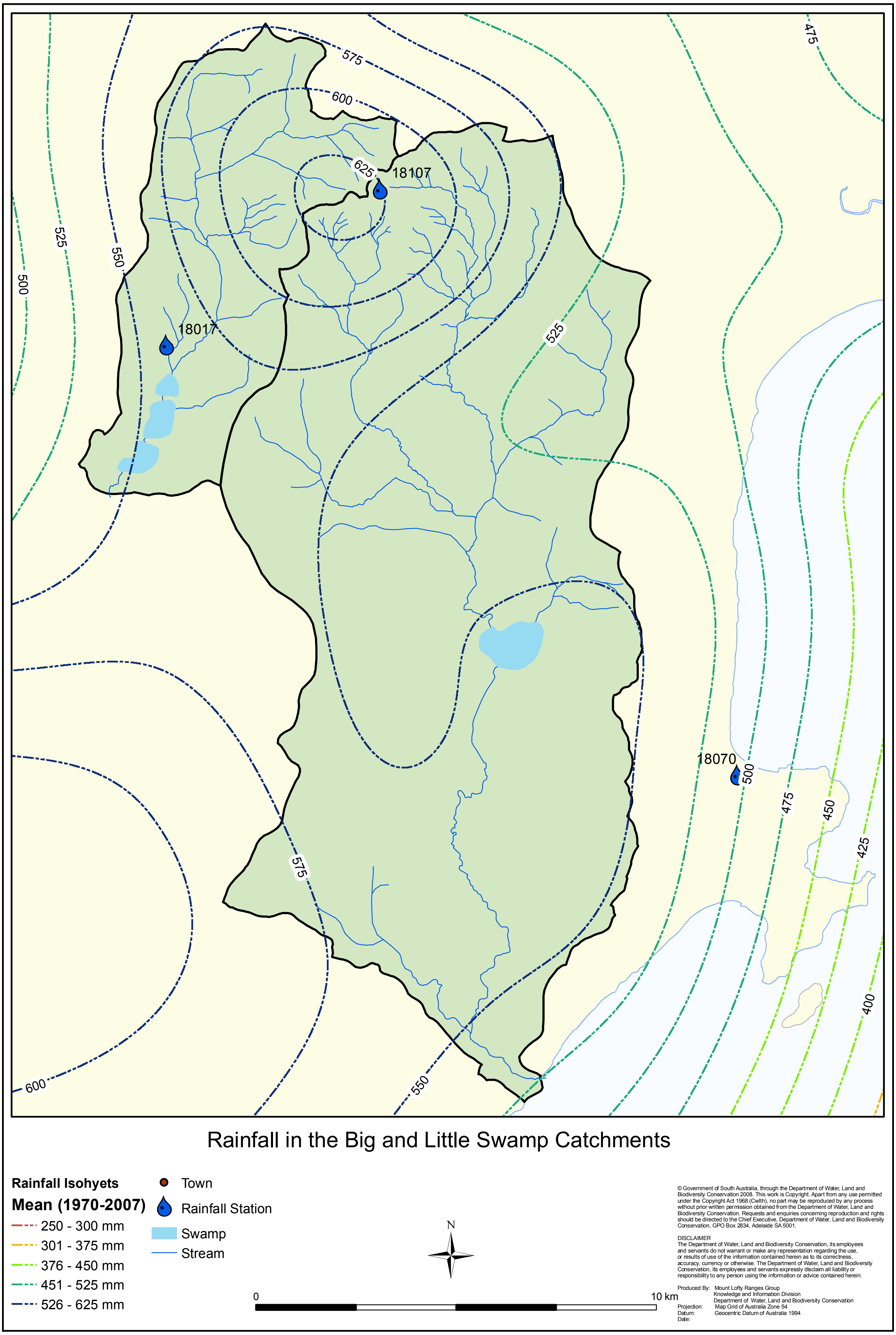


Figure 3.5 Rainfall isohyets, Bureau of Meteorology (BoM) stations and virtual stations in Big and Little Swamp catchments

3.3 STREAMFLOW DATA

There is currently no streamflow record available for the Big Swamp or Little Swamp catchments.

As discussed previously, the rainfall–runoff model used in this study used a relationship derived for the Toolillie Gully sub-catchment upstream of the Tod Reservoir (at measurement station A5120503).

McMurray (2006) examined the flow record for the gauging station A5120503 up to the year 2000, and found that the record for the 10 years (1991–2000), whilst having some missing data, was of a reasonable quality. Since McMurray's (2006) analysis of the flow data, there has only been one continuous year of data collected (2002), with data gaps ranging from 58 days in 2004 to 287 days in 2006, the latter being mostly due to equipment malfunction following the bushfires earlier in that year. This means that little extra data is available to further validate rainfall–runoff relationships.

Table 3.2 Streamflow record details for Toolillie Gully (Site A5120503)

Year	Annual total (mm)	Days missing
1991	2.7	185
1992	35.9	24
1993	8.4	23
1994	12.1	0
1995	40.2	0
1996	86.6	0
1997	9.1	18
1998	11.4	0
1999	9.1	0
2000	26.4	0
2001	6.9	98
2002	4.9	0
2003	7.1	122
2004	23.3	58
2005	19.1	202
2006	1.1	287

3.3.1 RAINFALL–RUNOFF RELATIONSHIP

The rainfall–runoff relationship used in this study was based on the hyperbolic tanh function given in Equation 3.2 below.

This method, described by Grayson (1996), can be used to define runoff based on different rainfall. The non-linear nature of this relationship means that for higher rainfall events the runoff is more likely to be much higher than if a standard runoff coefficient was used. Depending on the catchment, this can be 3 to 4 times higher.

Equation 3.2

$$Q = (P - L) - F \times \tanh[(P - L)/F]$$

Where:		
	Q	is runoff (mm)
	P	is rainfall (mm)
	L	is notional loss (mm)
	F	is notional infiltration (mm)

The tanh relationship is normally used for annual runoff relationships, however it can be used for months or seasons. Insufficient data was available to be able to use this approach.

Figure 3.6 below shows the rainfall–runoff tanh relationship for the Toolillie Gully upstream of Tod Reservoir gauging station. This is the same relationship that was used to model runoff for the Big and Little Swamp catchments.

The relationship is generally of a good fit, excepting the years 1996 and 1992. The record showed a maximum runoff year in 1996, which was not predicted well by the tanh relationship that underestimated flow for that year. In addition, the highest rainfall year during the period (1992) showed only average runoff at the gauge when the model predicts a much larger event. Several factors could explain the poor performance of the model.

The higher than expected runoff for 1996 is most likely due to a wetter than average period in the months of June to September when the soil profile is likely to have been almost completely saturated, compared with a combined deficit for the drier months of around 70 mm. This illustrates one of the limitations of the annual time step model, which fails to take into account rainfall intensity or antecedent conditions. Greyson et. al. (1996) recommended the use of this kind of model for the purpose of infilling monthly or annual data, but work throughout the Mount Lofty Ranges has shown it is generally suitable to predict runoff better than is evident here.

The low runoff figure is likely due to missing data during several high rainfall events. During these periods, whilst heavy rainfalls on the catchment would have produced significant runoff events, data was not recorded on those days, hence the low total runoff in that year.

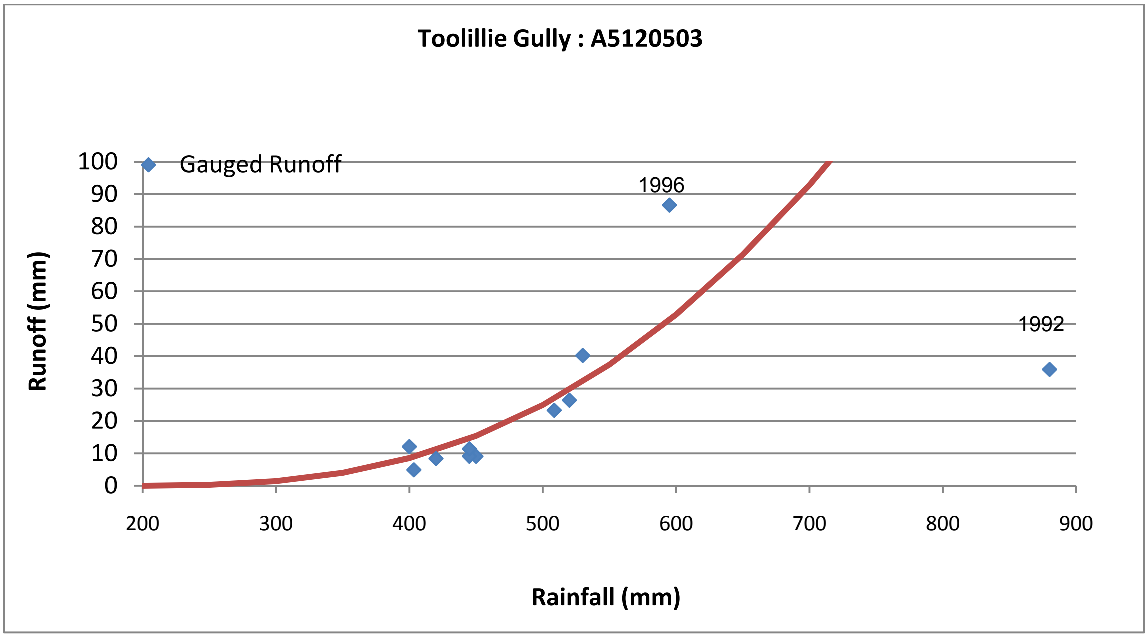


Figure 3.6 Toolillie Gully tanh rainfall–runoff relationship

For the rainfall averages of Toolillie Gully this curve produces a runoff coefficient of around 5%, however for the wetter catchments of Big and Little Swamp (upstream of the respective swamps), with average rainfalls around 590 and 555 mm respectively, this relationship will produce runoff coefficients of around 8% and 7% respectively. (This can be seen in Figure 3.7 below.) Thus, any difference produced in the annual models for Big and Little Swamp will be due to their higher rainfall in the upper slopes of the catchment.

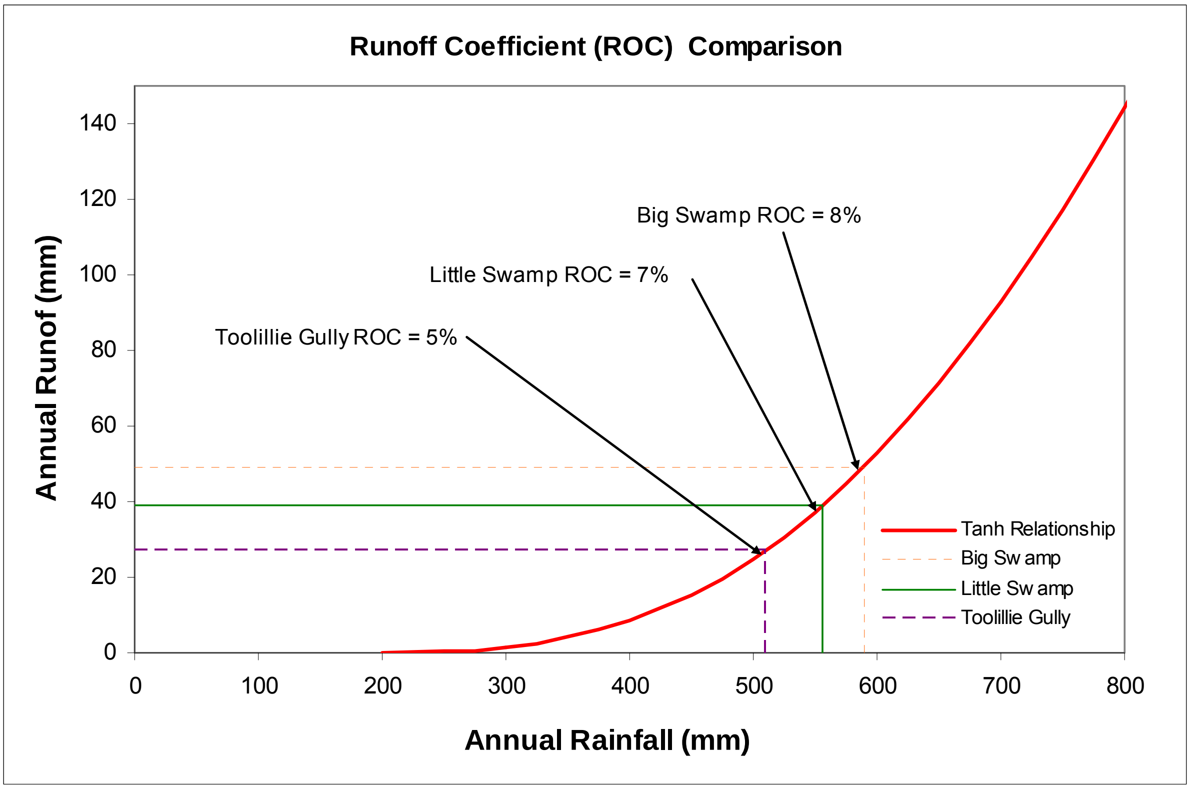


Figure 3.7 Comparison of runoff coefficients for the upstream sections of Toolillie Gully, Big Swamp and Little Swamps

4. METHODOLOGY

4.1 FARM DAM IMPACT MODELLING

4.1.1 OVERVIEW

The analysis carried out to estimate the impact of farm dams on streamflow employed the use of a grid based GIS model run at an annual time step. Using a digital elevation model (DEM) supplied by the DEH, with a resolution of 10 m x 10 m, the model works on the following method:

1. Each cell is assigned a rainfall for each year.
2. Runoff is calculated from that rainfall using the tanh relationship.
3. That runoff is accumulated downstream according to the down-slope direction of the DEM.
4. At each grid cell with a farm dam co-located, an assumed value of usage is subtracted from the runoff flowing through the cell..
5. The original accumulated runoff grid is compared with the grid with farm dam usage removed to characterise the level of extraction from each stream reach.

4.1.2 DIGITAL ELEVATION MODEL AND TERRAIN PROCESSING

The terrain data—or DEM—used here was supplied by DEH and derived from ortho-rectified aerial photography acquired in March of 2008. The metadata reports that 90% of features should be within +/- 2 m in horizontal and vertical position.

The aerial imagery was also used to digitise streamlines in a GIS format. This process was made difficult in some areas due to a lack of a well-defined watercourse. In areas of low physical relief, it is especially necessary to have some understanding of where streamlines will run in order for later stages of the GIS terrain processing to function correctly.

The following steps, and Figure 4.1, describe the terrain processing that was carried out on the DEM to determine flow paths, define flow accumulation and generate automated sub-catchments. All processing was carried out with the ArcHydro extension of the ArcGIS software suit. ArcHydro allows for complete pre-processing of terrain data in order to facilitate the type of model carried out here.

1. Levelling the DEM: This step required setting the approximate level of the swamps at their most upstream level, essentially placing a flat area where the swamps are located.
2. DEM reconditioning: ArcHydro employs the use of the AGREE method (Hellweger 1997), which 'burns' the streams into the terrain to create a DEM that has a network that all cells within the catchment can drain into and eventually drain out of the system—a dendritic network.
3. Fill sinks: Working on the reconditioned DEM, this step ensures that there are no 'sinks'. Sinks can exist in some situations, however often many are introduced into the DEM through the result of DEM interpolation or manipulation.

4. Determine flow direction grid: Models of this type assume that all cells flow in one of eight directions (also known as the 'D8' method). Based on the elevation of surrounding cells, the direction of flow for each cell is determined as the steepest path.
5. Determine the flow accumulation grid: Using the flow direction from the previous step, the area occupied by each cell (100 m^2) is accumulated downstream. The effect is a streamline with ever-increasing value according to the total area upstream of each cell. The resulting flow accumulation grid will also exhibit jumps in value at the confluence of streams. The highest values in the grid will appear at the outlet of the catchment.
6. Stream definition: Using the flow accumulation grid, a synthetic stream network can be generated based on the input of a stream area threshold (SAT) value. This network will naturally lie along the same lines that were burnt into the DEM in step 2 above, however may include more stream reaches than are able to be determined using aerial photography and contours alone. The SAT used in the this model was 5000 cells (0.5 km^2), which produced a similar density of stream network as was digitised.
7. Catchment definition: Sub-catchments are then automatically defined based on the confluence of streams as generated in the previous step. These sub-catchments will be used later in the analysis to visualise the levels of extraction for the various stream reaches and their associated catchment areas.

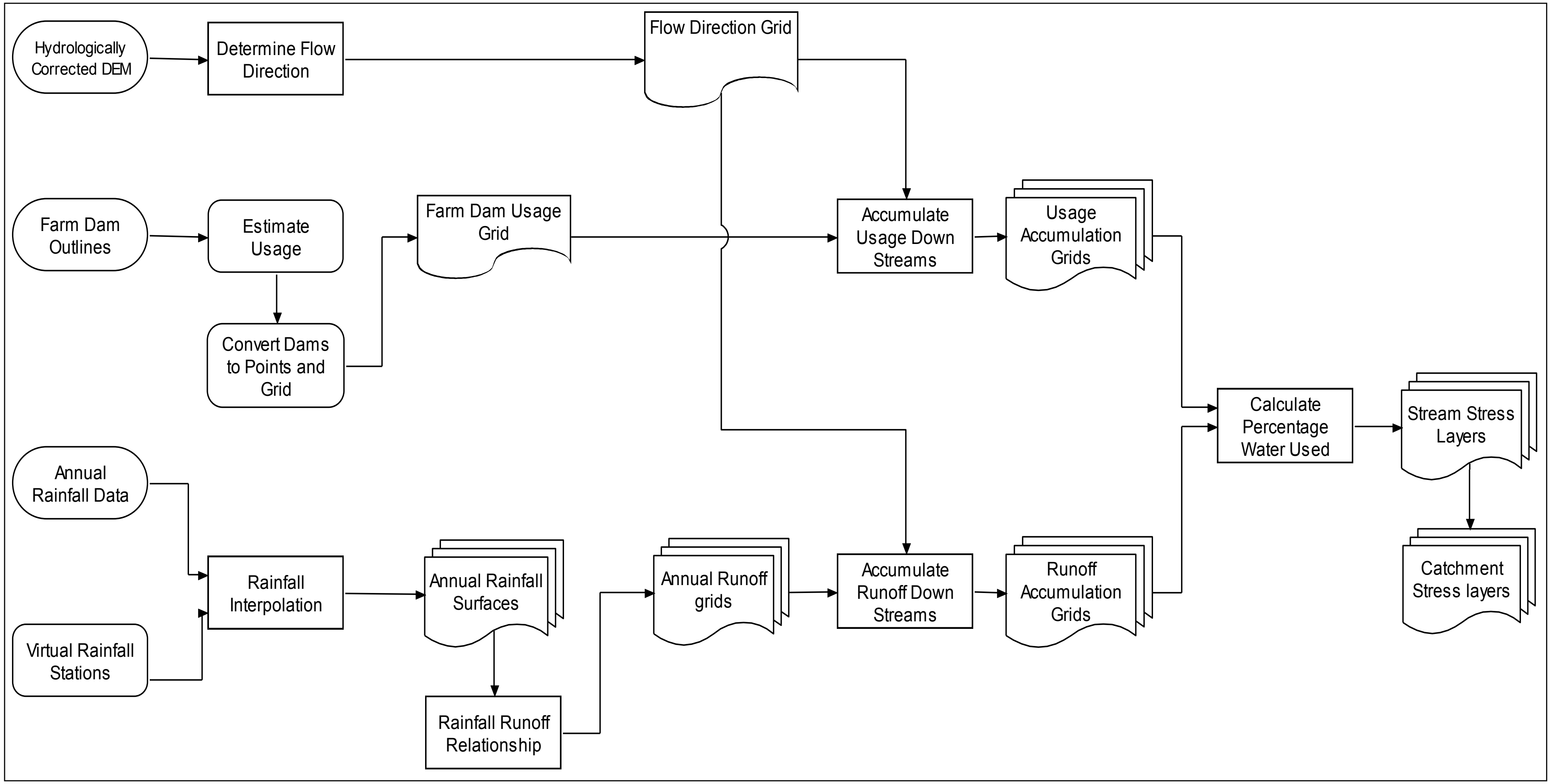


Figure 4.1 Flowchart showing process of GIS annual time step model

5. RESULTS AND DISCUSSION

5.1 INTRODUCTION

The results presented here describe the outputs from the GIS farm dam impact model. Details of the farm dam location and volume assessments are provided in *Section 2* and rainfall and streamflow analysis in *Section 3*.

The results are presented as follows:

1. stream stress results
2. catchment stress results.

Both result formats describe the relative impact due to farm dams on the stream reach or sub-catchment. The stream stress results show the locations of changes to the stress levels in the stream. In the case of an increase in stress, this would indicate the location of a dam along the stream. Conversely, a decrease in the stress level would indicate the dilution of the stress via the confluence of a stream. As the stream passes further down the catchment without the influence of dams, the stress on the stream is negated due to the cumulative flows.

Catchment stress is displayed as the cumulative stress at the most downstream point in the sub-catchmet. Sub-catchments were derived from a stream area threshold of 0.5 km^2.

The model was run for all 38 years of the study period (1970–2007) however, only three sets of results are presented here. These are the impacts during:

1. A wet year corresponding to the 80th percentile of years.
2. A dry year, corresponding to the 20th percentile of years.
3. The median stream stress, taken from the median year.

This approach differs from that used in McMurray (2006), which used the driest year and wettest year on record.

The results are described in terms of the percentage of water removed from the catchment. The results then summarised by categorising stress levels into six bands of stress that are intended represent the long-term implications for water dependent ecosystems The stress ranking system developed for the Tod River study (McMurray 2006) was employed here. This ranking is described in Table 5.1 below.

Table 5.1 Environmental stress levels associated with removal of water from catchment (McMurray 2006)

Stress rating	% of streamflow removed	Displayed colours	Likely environmental impact
1	0–10%	**Green**	Minimal impact
2	10–20%	**Yellow**	Impact to sensitive species
3	20–40%	**Dark orange**	Significant impacts
5	40–50%	**Bright orange**	
6	50–100%	**Red**	Major environmental change within 25 years (>50%)

5.2 WET YEAR SCENARIO

The year representing the wet year scenario—1984—was the eighth wettest year of the study period with recorded rainfalls of 650 mm and 711 mm of rainfall recorded at the Big Swamp and Woolga stations respectively. The modelled results for this year are presented in Figure 5.1 (Stream Stress) and Figure 5.2 (Catchment Stress).

As expected, this scenario exhibits the least amount of stress of all years with 99% of stream reaches (by length) showing less than 10% of water removed. This is due to the catchment producing runoff around four times the average for the study period.

5.3 DRY YEAR SCENARIO

The year representing the dry year scenario—1996— was the eighth driest year of the study period with 440 mm and 516 mm of rainfall recorded at the Big Swamp and Woolga stations respectively. In any catchment of a similar nature to these, including many in the Mount Lofty Ranges, lower than 350 mm rainfall will produce negligible runoff. Any runoff produced would be related to higher intensity rainfall events, or as may be in the case of Little Swamp, the early wet season baseflow if soil moisture or groundwater levels are sufficient to be carried over from the previous year.

With this in mind, the dry scenario year modelled here showed the highest levels of stress with 13% of stream reaches (by length) having greater than a 20% reduction in annual flow. A further 35% of the stream network was estimated to have between 10% and 20% reduction in annual streamflow. The proportional reduction in streamflow is higher in dry years and this may be significant by causing cumulative impacts on a system that is already under stress due to the lower than average flows caused from natural climatic variations.

5.4 ESTIMATED REDUCTION IN STREAMFLOW

The median stress level represents the calculated median stress level of all 38 years recorded, as opposed to a single year. The median scenario is probably the most representative of the scenarios in that it suggests the most likely set of events that will take place in the catchment, and represents the long-term hydrologic behaviour of the catchment.

The results from the median scenario show that relatively little stress is apparent throughout the catchment due to the impact of farm dams. At the entrance to Big and Little Swamps, only 5% of streamflow is estimated to be removed from the system due to farm dams. Only 5% of stream reaches (by length) exhibit streamflow removal of 10% or greater, all of these being higher in the catchments immediately downstream of significantly sized farm dams.

5.5 DISCUSSION OF RESULTS

In the most extreme of cases—the dry year scenario—significant proportions of stream reaches appear to be impacted by the removal of water from farm dams. The magnified impact of farm dams on streamflow is significant particularly given the variability of rainfall in this region. This impact is also compounded when the impacts due to farm dams in drier than average years occur in a sequence of dry years such as those experienced during 1997–1999. A succession of increased reductions in flows will inevitably have consequences for ecosystems such as some of those experienced in the Big and Little Swamp catchments.

The results presented in this report give an indication of the annual impact of farm dams on streamflow, but as streamflow has not been gauged for either catchment, the modelling of runoff is a best estimate. The best way to investigate the impact of farm dams is by producing hydrological models at a monthly or daily time step so that seasonal flow dynamics can be taken into account. The data available at the time of the study was insufficient for this to be carried out so the annual time step tanh model was thought to be the most appropriate method to use.

Refer to *Appendix C* for rainfall and estimated runoff.

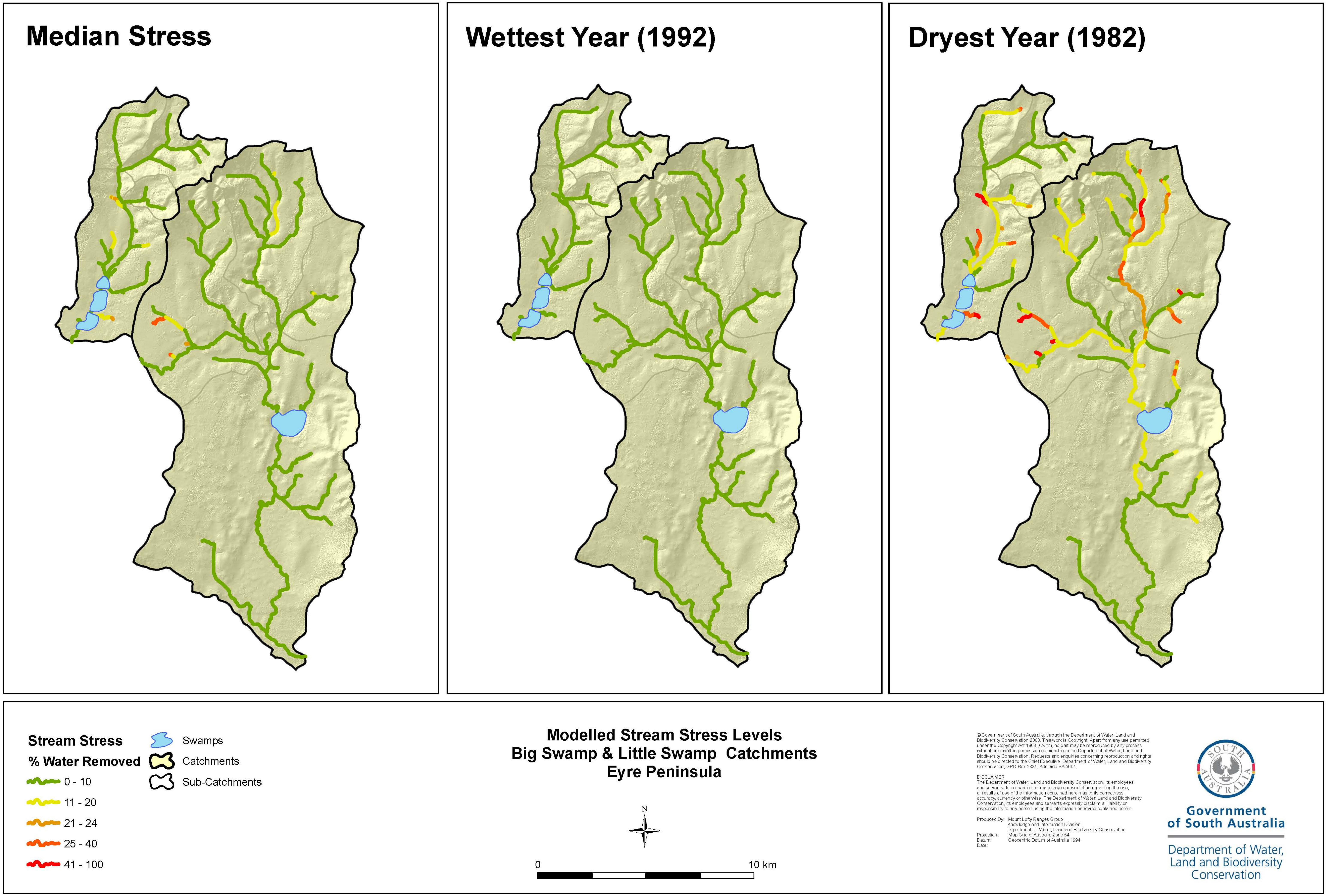


Figure 5.1 Modelled stream stress levels for Big and Little Swamp catchments showing percentage of water removed from streams

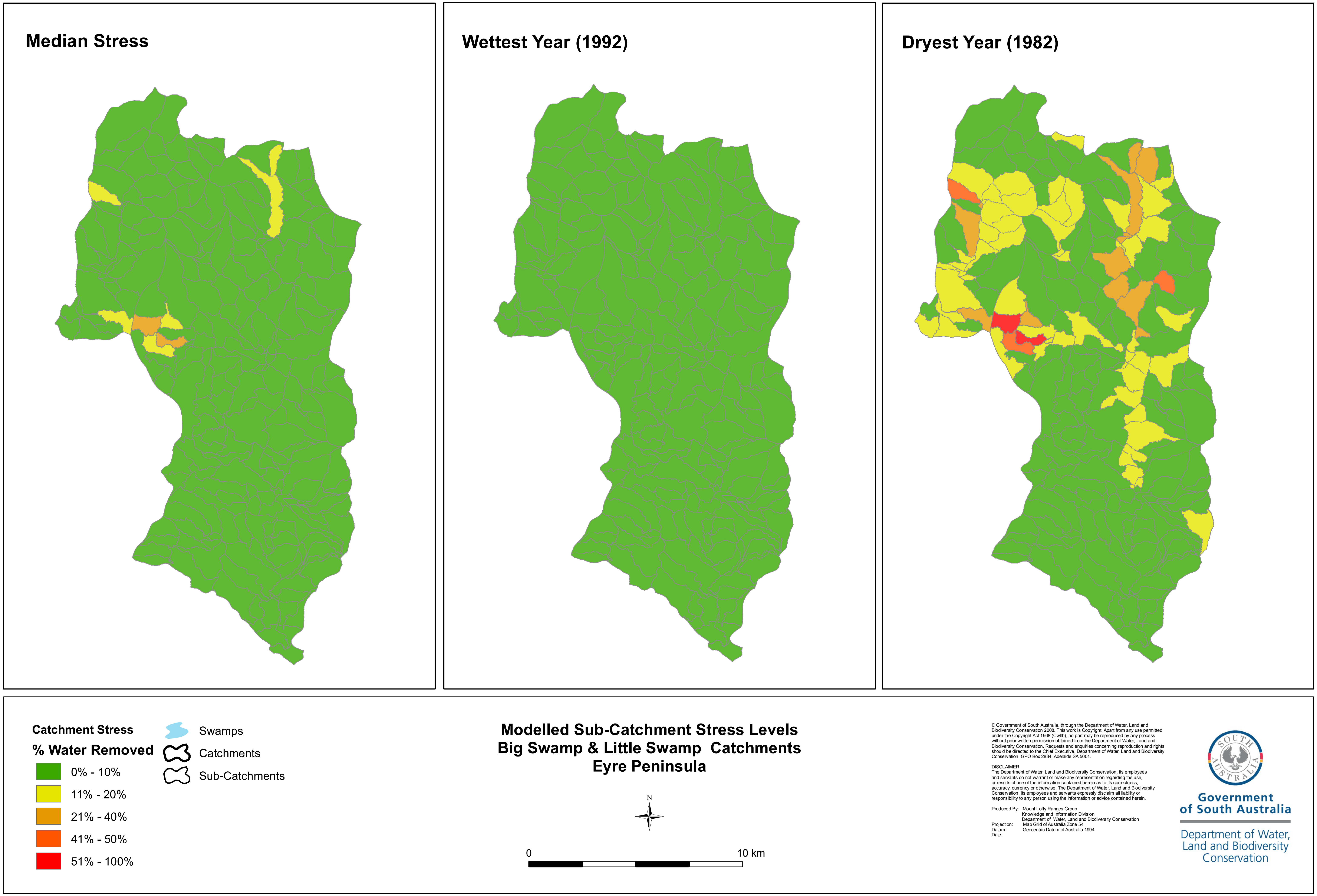


Figure 5.2 Modelled sub-catchment stress levels for Big and Little Swamp catchments showing percentage of water removed from streams

6. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 HYDROLOGICAL DATA

6.1.1 RAINFALL DATA

The coverage of rainfall stations in both the catchments and surroundings was considered fair for this type of annual analysis, given that there were two rainfall records and the study area is quite small. The use of interpolated rainfall surfaces to model the catchment is thought to give a reasonable explanation of the variation over the catchment.

6.1.2 STREAMFLOW DATA

A rainfall–runoff relationship derived from the Toolillie Gully upstream of Tod Reservoir gauging station, was used to model runoff at an annual time step for the 38 years from 1970 to 2007 because no streamflow data were available for the Big and little Swamp catchments.

Through the analysis of various catchment characteristics, it was found that there was enough similarity between the catchments to warrant the use of this relationship. It should be noted however that through a field visit to the region and from anecdotal advice, the flow regime is thought to be of a different nature. Both Big and Little swamp catchments appear to show more significant baseflow generated through natural springs in the headwaters of the catchments. This appears to produce significant amounts of local baseflow higher in the stream network, however it is unclear what exact proportion that baseflow contributes to total streamflow. Analysis of the Toolillie Gully streamflow record reveals very little in the way of baseflow, and stream conditions displaying incised channels that are not evident in much of the study catchments. This suggests that the runoff regime in Toolillie Gully is likely to be more event based with a higher proportion of surface runoff than the two study catchments. What effect this has on total catchment yield is unclear at this stage.

6.2 FARM DAM DATA

The capture and use of farm dam information was carried out as a desktop exercise with farm dam outlines being digitised from ortho-rectified aerial imagery acquired in early 2008. Initial data capture errors associated with this process can involve:

- Projection errors during the ortho-rectification process (+/-2 m).
- Digitising error, such as the incorrect interpretation of the dams' full supply level. This error is exacerbated when digitising small farm dams.
- Attribute error. Incorrectly classified farm dams i.e. on- or off-stream.
- Estimated use from farm dams error. As farm dam usage was assumed to be the same for all farm dams, this is a considerable source of error given that most dams in the region are not used for irrigation purposes. Estimation of water use may be considered an over-estimate—a conservative assumption.

6.3 FARM DAM IMPACT MODELLING

This project modelled the impact on streamflow due to farm dams. An annual time step GIS based model was used to estimate runoff and water use from stream reaches and sub-catchments. Results were presented for three scenarios:

1. a dry year (1982)
2. a wet year (1992)
3. the median stress level.

Due to a dearth of hydrological and water use data, several key assumptions underpin the modelling which emphasises the point that the results given in this study may be used only as a first cut estimate of the impact of farm dams. The key assumptions were:

- Farm dam volume estimates. A volume–to–surface area relationship was used to estimate farm dam volumes. As detailed surveying of farm dams has not been carried out on the Eyre Peninsula, the veracity of this relationship could not be confirmed.
- Water use estimates. Water use was not modelled dynamically for this study. That is, the same annual water use was extracted in each year of analysis. Water use during dry years, when dams may not reach their full potential water use, may be overestimated.
- Rainfall–to–runoff relationship. The relationship used for this study was extended from the nearby Toolillie Gully gauged sub-catchment upstream of the Tod River Reservoir as this was the only available and relevant streamflow information from the Eyre Peninsula. The relationship compares well with regional curves developed from various catchments in the Mount Lofty Ranges (McMurray 2006), and is thought to provide a reasonable estimate of streamflow variability over a range of annual rainfall totals.

Furthermore, analysis of the complex interactions between groundwater and surface water evident in some parts of the catchments was beyond the scope and data limitations of this study. The seasonal responses to the rising and falling of local and regional groundwater tables may have a more considerable impact on streamflow dynamics than can be incorporated by a study of this kind. Given that the results of this study conclude that farm dams are having only a low–to–moderate impact on streamflow at the catchment scale, and that there has been anecdotal concern noted over the declining condition of some stream habitats, there may yet be other factors to consider. These factors would include land use change over time, changes in water use from local and regional groundwater resources, and general climate variability, particularly successions of dry years.

6.4 MONITORING RECOMMENDATIONS

Hydrological understanding of the Big and Little Swamp catchments is limited due to a lack of data about streamflow, surface-water and groundwater interactions, and environmental water requirements. This study reports a low–to–moderate level of stress due to the impact of farm dams. However, community concern over the decline in conditions of the swamps and water dependent ecosystems in the recent past still warrants concern. In order to properly assess any changes to these systems and understand the processes involved, a monitoring program should be established covering the areas below. The monitoring recommendations below are consistent with those in the *Water Monitoring Review in the Eyre Peninsula Natural Resources Management Region* (Wen 2005), and should be considered in the context of broader regional and statewide monitoring programs.

6.4.1 ECOLOGICAL SURVEY

Given that concerns regarding the water resources within catchments such as the Big and Little Swamp catchments are often raised due to anecdotal observations of change in both condition and extent of the water dependent ecosystems, it is important to develop an understanding of how the ecology of these catchments is being impacted by changes in the hydrologic regime. This then enables better, more informed decision making on how these catchments could best be managed.

While there have been limited investigations undertaken to describe components of these water dependent ecosystems they currently provide little understanding of what is present and what changes are occurring. Implementing a number of the aquatic ecosystem monitoring recommendations from the *Water Monitoring Review in the Eyre Peninsula Natural Resources Management Region* (Wen 2005) within the catchment would be valuable. These include mapping and registering all surface and groundwater dependent ecosystems and undertaking an integrated wetland monitoring program.

In order to understand the likely trajectory of change, an understanding of the ecological functions operating within these systems is essential. Currently, DWLBC is undertaking a project, the *Strategic Assessment of South Australia's Aquatic Ecosystems*, to elucidate ecological functions for various aquatic ecosystem types. It is advised that links should be made with this project to improve the ecological understanding of these catchment and associated wetlands.

6.4.2 HYDROLOGICAL MONITORING

Rainfall

As stated previously, whilst the current network was considered adequate for coarse annual analysis, in order to correctly describe variation of the rainfall over the catchment (Little Swamp in particular), a rainfall station should be established near the Little Swamp. A simple daily read rain gauge would suffice, however, a pluviometer would be preferable as information on rainfall intensity would prove invaluable to understanding the dynamics of recharge and runoff processes.

Evaporation

For catchment scale annual water balance the evaporation station at the Tod Reservoir, currently managed by SA Water, was considered sufficient for this study. However, accurate assessment at finer temporal resolution may need the inclusion of a soil moisture monitoring program in conjunction with the pan measurements currently undertaken.

Streamflow

At a minimum, monitoring of streamflow should be carried out in the mid to upper reaches of each of the two catchments to enable the correct estimate of catchment yield to the swamps and the nature of the seasonal flow regime. The site should be chosen so that a flow to elevation relationship can be established. Parameters to measure should include at a minimum:

- water level—from which a level to flow relationship can be derived
- conductivity

- temperature
- pH.

Water quality

Water quality, particularly salinity, is of critical value in these catchments due to the highly variable quality of springs and seeps in the upper reaches of the catchments. In addition to logging of salinity, pH and temperature at future stream gauging sites, salinity should be monitored in key swamps and streams to determine the salt balance of the catchments. This can be achieved through either a periodical and managed community-based ambient monitoring program or using logging devices as mentioned above.

Water level

Water level in both swamps should be collected continuously by logging devices at a suitable location to enable the measurement of storage flux (as also recommended by Wen 2005).

Survey and development hypsographic curves

Volume, area and depth data should be gathered for Big and Little Swamps so that storage fluctuations can be calculated, and water requirements estimated through water and salt balance calculations.

6.4.3 GROUNDWATER MONITORING

Examination of the Obswell Database reveals that there is a high density piezometer network to the south of Big and Little Swamp catchments. This is likely because the prescribed wells area lies to the south of the Flinders Highway covering only a small section of the study area. To gain a better understanding of surface water–groundwater interactions, particularly in the higher elevations of Big and Little Swamp catchments, it would be necessary to install more piezometers in these areas. Whilst it was beyond the scope of this study to advise on groundwater monitoring strategies, assessment of the dependence of riparian ecosystems on the groundwater regime should not be overlooked.

6.4.4 FARM DAMS

As part of a broader regional strategy into investigation of the effects of farm dams on streamflow and water dependent ecosystems, investigations into regional volume estimates and water use estimates should be carried out. Studies similar to those carried out by McMurray (2004a, 2004b) should be investigated.

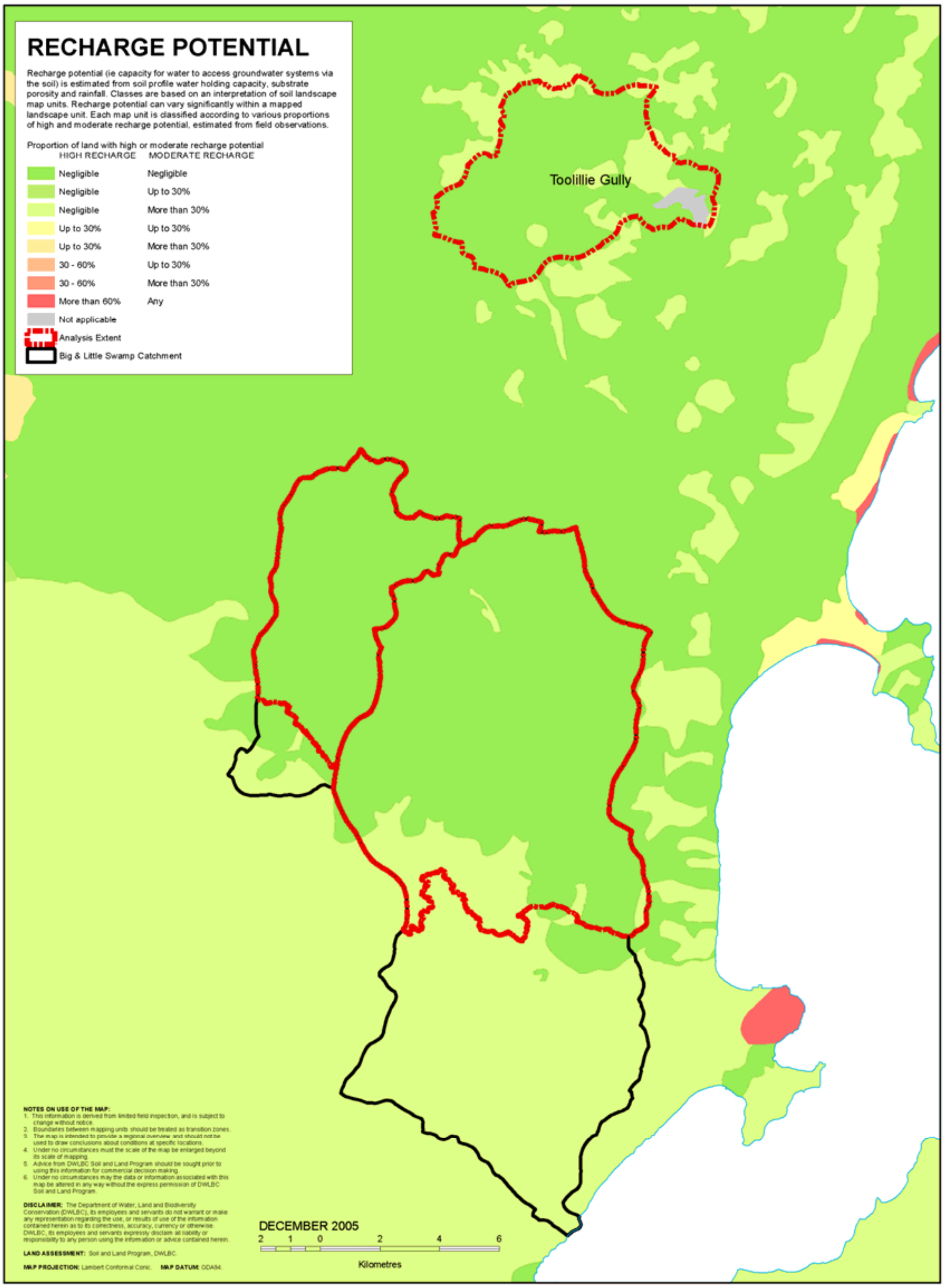
6.5 MANAGEMENT ACTIONS

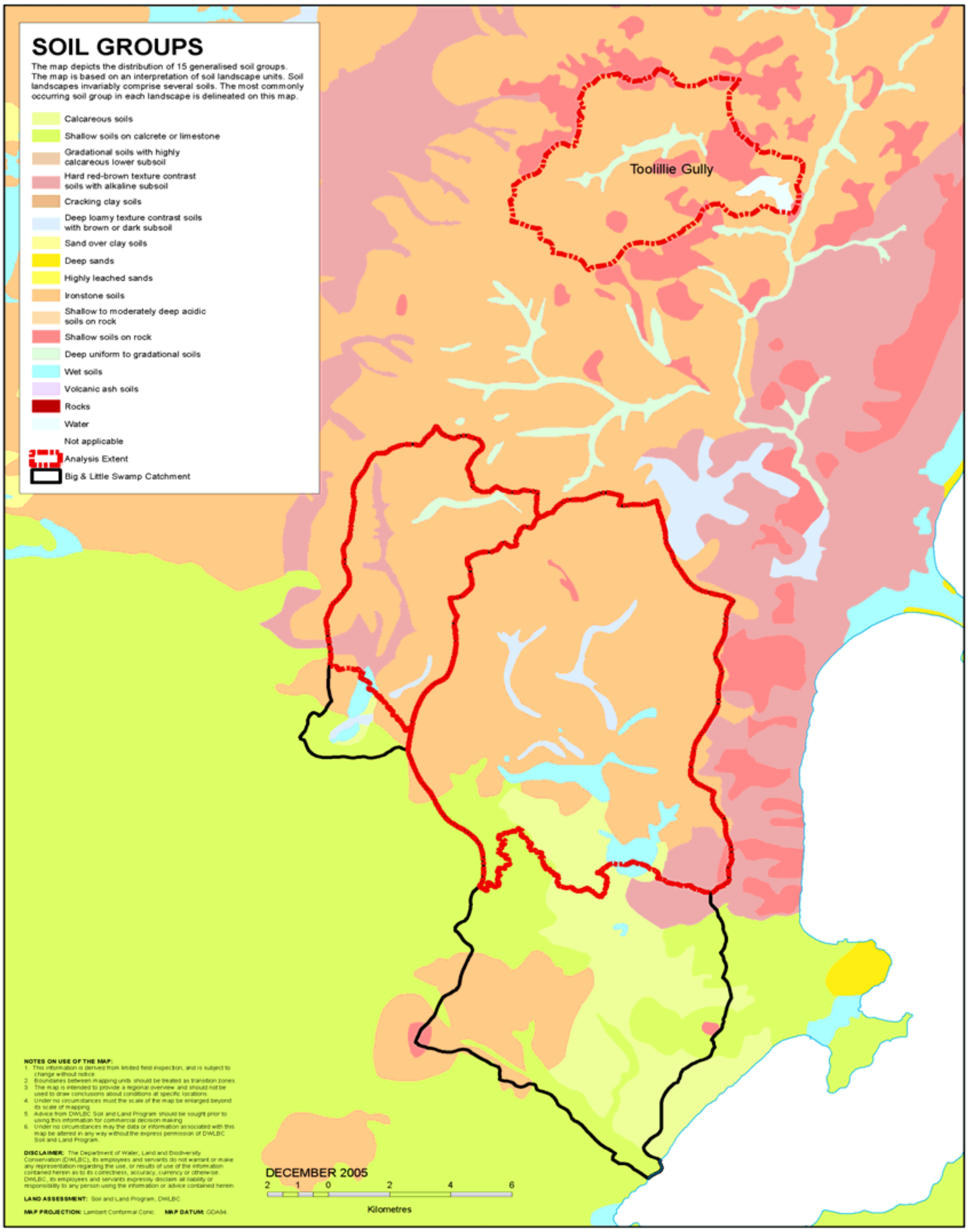
The continued management of water affecting activities (WAA) is essential as the impact of WAA—such as farm dams, water crossings and watercourse rehabilitation—can all have impacts on streamflow. Future options for managing the impact of farm dams could include:

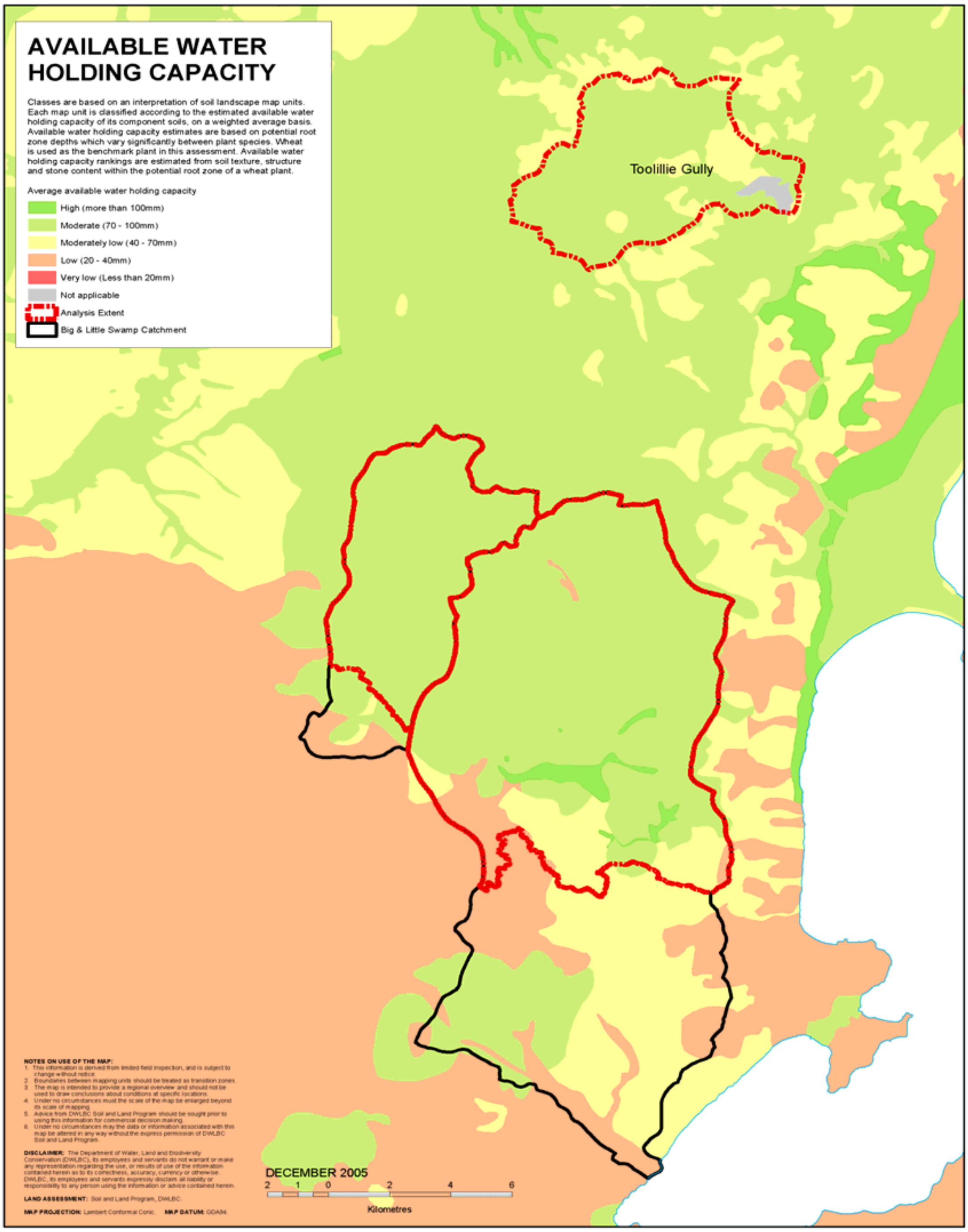
- Installation of low-flow bypass devices on any future farm dams.
- Retrofitting of low-flow bypass devices on existing dams could be considered where they may be impacting negatively on biodiversity. This issue should be considered in the EPNRMB’s plans as well as being raised with any relevant local catchment groups.

7. APPENDICES

A. SOIL ATTRIBUTE MAPS




SOIL GROUPS
The map depicts the distribution of 15 generalised soil groups. The map is based on an interpretation of soil landscape units. Soil landscapes invariably comprise several soils. The most commonly occurring soil group in each landscape is delineated on this map.
Calcareous soils
Shallow soils on calcrete or limestone
Gradational soils with highly calcareous lower subsoil
Hard red-brown texture contrast soils with alkaline subsoil
Cracking clay soils
Deep loamy texture contrast soils with brown or dark subsoil
Sand over clay soils
Deep sands
Highly leached sands
Ironstone soils
Shallow to moderately deep acidic soils on rock
Shallow soils on rock
Deep uniform to gradational soils
Wet soils
Volcanic ash soils
Rocks
Water
Not applicable
Analysis Extent
Big & Little Swamp Catchment
Toolillie Gully
DECEMBER 2005
2 1 0 2 4 6
Kilometres


AVAILABLE WATER HOLDING CAPACITY
Classes are based on an interpretation of soil landscape map units. Each map unit is classified according to the estimated available water holding capacity of its component soils, on a weighted average basis. Available water holding capacity estimates are based on potential root zone depths which vary significantly between plant species. Wheat is used as the benchmark plant in this assessment. Available water holding capacity rankings are estimated from soil texture, structure and stone content within the potential root zone of a wheat plant.
Average available water holding capacity
High (more than 100mm)
Moderate (70 - 100mm)
Moderately low (40 - 70mm)
Low (20 - 40mm)
Very low (Less than 20mm)
Not applicable
Analysis Extent
Big & Little Swamp Catchment
Toolillie Gully
NOTES ON USE OF THE MAP:
1. This information is derived from limited field inspection, and is subject to change without notice.
2. Boundaries between mapping units should be treated as transition zones.
3. The map is intended to provide a regional overview and should not be used to draw conclusions about conditions at specific locations.
4. Under no circumstances must the scale of the map be enlarged beyond its scale of mapping.
5. Advice from DWLBC Soil and Land Program should be sought prior to using this information for commercial decision making.
6. Under no circumstances may the data or information associated with this map be altered in any way without the express permission of DWLBC Soil and Land Program.
DISCLAIMER: The Department of Water, Land and Biodiversity Conservation (DWLBC), its employees and servants do not warrant or make any representation regarding the use, or results of use of the information contained herein as to its correctness, accuracy, currency or otherwise. DWLBC, its employees and servants expressly disclaim all liability or responsibility to any person using the information or advice contained herein.
LAND ASSESSMENT: Soil and Land Program, DWLBC.
MAP PROJECTION: Lambert Conformal Conic. MAP DATUM: GDA94.
DECEMBER 2005
2 1 0 2 4 6
Kilometres

B. RAINFALL ANALYSIS

Table B1 Yearly coefficients for OLS analysis

Year	Ca	Cb	Cc	Cd	Multiple R2
1970	-0.00265	-0.00166	0.415694	12175	0.75
1971	-0.00518	-0.00157	0.552503	13306	0.81
1972	-0.00256	-0.00179	0.543751	12936	0.73
1973	-0.00145	-0.0014	0.45286	9968	0.47
1974	-0.00043	-0.00104	0.399926	7223	0.35
1975	-0.00247	-0.00278	0.451679	19122	0.85
1976	-0.00228	-0.00227	0.429889	15745	0.81
1977	-0.00195	-0.00139	0.505433	10002	0.74
1978	-0.00158	-0.00324	0.559242	21505	0.70
1979	-0.0026	-0.00106	0.534205	8629	0.59
1980	-0.00171	-0.00264	0.313212	17742	0.80
1981	-0.00324	-0.00313	0.556026	21751	0.80
1982	-0.00265	-0.00256	0.239526	17660	0.83
1983	-0.0014	-0.00343	0.571393	22622	0.71
1984	-0.00215	-0.00384	0.580252	25473	0.86
1985	-0.00137	-0.00302	0.313351	19867	0.79
1986	-0.00279	-0.00314	0.473373	21409	0.90
1987	-0.00189	-0.00158	0.290207	11196	0.79
1988	-0.00218	-0.003	0.29254	20204	0.82
1989	-0.0017	-0.00335	0.412411	22220	0.74
1990	-0.00137	-0.00299	0.264944	19793	0.78
1991	-0.00145	-0.00148	0.306034	10304	0.72
1992	-0.00161	-0.00208	0.474694	14573	0.46
1993	-0.00115	-0.00105	0.263635	7561	0.62
1994	-0.00114	-0.00301	0.351206	19585	0.76
1995	-0.0013	-0.00195	0.395906	13318	0.73
1996	-0.00203	-0.00226	0.211753	15672	0.71
1997	-0.00152	-0.00052	0.338592	4495	0.57
1998	-0.00111	-0.00178	0.159112	12028	0.69
1999	-0.00146	-0.00255	0.386373	17016	0.77
2000	-0.00321	-0.00185	0.43596	13810	0.86
2001	-0.00245	-0.00228	0.536235	15974	0.81
2002	-0.00223	-0.00206	0.318443	14360	0.81
2003	-0.00208	-0.00262	0.384066	17895	0.85
2004	-0.00357	-0.00144	0.652468	11327	0.90
2005	-0.00332	-0.0013	0.386067	10445	0.81
2006	-0.00131	-0.0017	0.280384	11652	0.71
2007	-0.00173	-0.00225	0.605828	15314	0.74

C. RAINFALL AND RUNOFF TO BIG AND LITTLE SWAMPS

	Big Swamp		Little Swamp	
Year	Rain (mm)	Flow (mm)	Rain (mm)	Flow (mm)
1970	527	32	505	26
1971	812	152	745	116
1972	559	41	527	32
1973	594	52	577	46
1974	607	56	600	53
1975	661	76	617	59
1976	540	35	483	22
1977	465	19	425	12
1978	729	107	691	90
1979	690	89	660	76
1980	544	36	516	29
1981	717	101	666	79
1982	460	17	420	12
1983	775	131	735	110
1984	672	81	623	62
1985	549	37	528	32
1986	601	53	551	38
1987	464	18	437	14
1988	516	29	511	27
1989	687	87	638	68
1990	647	70	623	61
1991	429	12	403	9
1992	917	218	886	198
1993	475	20	443	15
1994	438	14	411	10
1995	614	58	588	49
1996	586	49	585	48
1997	495	24	467	18
1998	459	17	450	15
1999	537	34	502	26
2000	663	77	612	57
2001	656	74	602	55
2002	471	19	436	13
2003	616	59	601	53
2004	571	44	504	27
2005	600	53	570	43
2006	473	20	451	16
2007	570	44	525	32

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

Shortened forms

~	approximately equal to
pH	acidity

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supercedes the *Water Resources (SA) Act 1997*

AGREE — A digital elevation model surface recondition system, used in spatial analysis to enforce a drainage network

Ambient — The background level of an environmental parameter (eg. a measure of water quality such as salinity)

Ambient water quality — The overall quality of water when all the effects that may impact upon the water quality are taken into consideration

ANZECC — Australia New Zealand Environmental Consultative Council

Aquatic ecosystem — The stream channel, lake or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

Aquifer — An underground layer of rock or sediment that holds water and allows water to percolate through

AWHC — Available water holding capacity

Baseflow — The water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

Basin — The area drained by a major river and its tributaries

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biological diversity — See 'biodiversity'

BoM — Bureau of Meteorology, Australia

Catchment — That area of land determined by topographic features within which rainfall will contribute to runoff at a particular point

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source; may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

DEH — Department for Environment and Heritage (Government of South Australia)

DES — Drillhole Enquiry System; a database of groundwater wells in South Australia, compiled by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC)

Digital elevation model (DEM) — A grid based map representing the elevation of the land surface

Diversity — The distribution and abundance of different kinds of plant and animal species and communities in a specified area

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

EPNRMB — Eyre Peninsula Natural Resources Management Board

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

Floodplain — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Flow regime — The character of the timing and amount of flow in a stream

Geological features — Include geological monuments, landscape amenity and the substrate of land systems and ecosystems

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Groundwater access trench (GAT) — A shallow excavation in the land surface. Usually dug out to exposed the underlying water table, for the purpose of stock watering

Habitat — The natural place or type of site in which an animal or plant, or communities of plants and animals, live

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

Intensive farming — A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or mechanical means

Irrigation — Watering land by any means for the purpose of growing plants

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Local water management plan — A plan prepared by a council and adopted by the Minister in accordance with the Act

Metadata — Information that describes the content, quality, condition, and other characteristics of data, maintained by the Federal Geographic Data Committee

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm runoff, assessing the impacts of dams or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

Natural resources management (NRM) — all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Obswell — Observation Well Network

Objective least squares (OLS) — A method used to relate multiple variables to a process by minimizing the difference between the observed and predicted data.

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Piezometer — A narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc

Pluviometer — An automated rain gauge consisting of an instrument to measure the quantity of precipitation over a set period of time

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the Act

Prescribed well — A well declared to be a prescribed well under the Act

Ramsar Convention — This is an international treaty on wetlands titled *The Convention on Wetlands of International Importance Especially as Waterfowl Habitat*. It is administered by the International Union for Conservation of Nature and Natural Resources. It was signed in the town of Ramsar, Iran in 1971, hence its common name. The convention includes a list of wetlands of international importance and protocols regarding the management of these wetlands. Australia became a signatory in 1974.

Recharge — The flux of water from (generally) the land surface to the underground. The proportion of water falling as precipitation on the land that passes though the soil-atmosphere interface.

Rehabilitation (of water bodies) — Actions that improve the ecological health of a water body by reinstating important elements of the environment that existed prior to European settlement

Riparian — Of, pertaining to, or situated or dwelling on the bank of a river or other water body

Riparian ecosystems — A transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; these are identified by soil characteristics or distinctive vegetation communities that require free or unbound water

Riparian zone — That part of the landscape adjacent to a water body that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses

Stream area threshold (**SAT)** — An objective measure used to describe the uppermost extent of a stream system. In mapping and spatial analysis this is most often described by a specified area, below which no stream is considered to exist

SA Water — South Australian Water Corporation (Government of South Australia)

Sensitive species — Those plant and animal species for which population viability is a concern

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to runoff at a particular point

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Taxa — General term for a group identified by taxonomy, which is the science of describing, naming and classifying organisms

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Water affecting activities (WAA) — Activities referred to in Part 4, Division 1, s. 9 of the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water-dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Watershed — The land area that drains into a stream, river, lake, estuary, or coastal zone

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

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