DWLBC REPORT

Impact of Farm Dams on Streamflow in the Tod River Catchment, Eyre Peninsula, South Australia

2006/22

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

Impact of Farm Dams on Streamflow in the Tod River Catchment, Eyre Peninsula South Australia

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March 2006

Report DWLBC 2006/22

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

Government of South Australia
Eyre Peninsula Natural Resources Management Board

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ISBN 1 921218 21 5

The Eyre Peninsula Natural Resources Management Board supports this document.

Preferred way to cite this publication

McMurray, D 2006, *Impact of farm dams on streamflow in the Tod River catchment, Eyre Peninsula South Australia,* DWLBC Report 2006/22, Department of Water, Land and Biodiversity Conservation, Adelaide.

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.

Rob Freeman
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Tod River catchment is located to the north of the City of Port Lincoln in south-eastern Eyre Peninsula, South Australia. Since European settlement, clearing of land, agricultural development including harvesting of surface water for stock use and use of water for potable water supply has considerably changed water resource management from this landscape. This includes a wide spread of stock and domestic farm dams of different sizes in addition to the Tod River Reservoir and two diversion weirs. Further, several areas are affected by dryland salinity and waterlogging which threaten agricultural productivity and water quality. The Tod River is one of the unique perennial river systems on Eyre Peninsula. The in-stream zones provide important habitat and refuge areas for many wetland organisms.

The draft Eyre Peninsula Catchment Water Management Plan sets management principles (water-affecting activities) for existing farm dam capacity in sub-catchments, threshold volumes and future volumes for farm dams. The draft Eyre Peninsula Catchment Water Management Plan currently forms part of the Eyre Peninsula Initial Natural Resources Management Plan. One of the priority projects identified by the former Eyre Peninsula Catchment Water Management Board (EPCWMB) is the investigation of the impact of farm dams on streamflow in the Tod River catchment. As the spatial distribution of hydrological and catchment conditions (for example rainfall, topography and concentration of farm dams) may not be uniform across the catchment, the Eyre Peninsula Natural Resources Management Board (EPNRMB) considered it imperative to assess the impact of farm dams with the actual spatial representation of farm dams and hydrological conditions.

This technical report contains the results of an assessment of farm dam data and hydrological monitoring data; modelling of the impacts of farm dams on streamflow; and recommendations for on-going monitoring and resource management. This study did not investigate the impact of the operation of the Tod River Reservoir and associated diversion weirs, and did not investigate a water balance for the catchment.

The modelling of the impacts of farm dams on streamflow showed that under the median and wet-year scenarios, the amount of water removed by farm dams was unlikely to cause major or significant environmental harm over the majority of the catchment. Several small areas high in stream branches were likely to suffer significant or major environmental harm that may require more detailed site-specific investigation. However, under a dry-year scenario the modelling results showed that the majority of the streams within the Tod River catchment are placed under high environmental stress conditions. The long-term effect of a dry period on the environment was not determined in this study. It is recommended that further studies are undertaken to investigate the impacts of farm dams in dry years. These studies should assess whether the modelling results are realistic under a dry-year scenario, and the level of environmental impacts caused by the variability and length of dry periods.

Assessment of available data showed that the quantity and quality of the topographic, farm dam, rainfall and evaporation data were generally acceptable for the purposes of this study. Streamflow gauging data were used to calibrate the model to a reasonable degree. However, there were several technical issues with the available streamflow gauging data that renders most of the data of dubious quality for more detailed hydrological studies.

Given the importance of the Tod River catchment from environmental and water resources perspectives, together with the fact that there are no other streamflow gauging stations on Eyre Peninsula, it is strongly recommended that a thorough investigation into these technical issues be made and then implement effective corrective measures.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE OF THE STUDY

This study was undertaken by the Department of Water, Land and Biodiversity Conservation (DWLBC) on behalf of the Eyre Peninsula Natural Resources Management Board (EPNRMB).

The study area was the Tod River catchment, with the following aims:

- review and assess the available hydrological data for the catchment
- assess the impacts of farm dams by use of a GIS-based annual rainfall-runoff model
- make recommendations on future monitoring requirements.

1.2 BACKGROUND

The Tod River catchment is one of the unique perennial river systems on Eyre Peninsula. Since European settlement, clearing of land, agricultural development including harvesting of surface water for stock use, and the use of water for potable water supply has considerably changed the water resource flow patterns from this landscape. These management changes include a wide spread of stock and domestic farm dams of different sizes. The major surface water storage is the Tod River Reservoir. Capturing surface runoff in a semi-arid climate is considered critical to the environmental needs of the water dependent ecosystem.

To address these issues, the draft Eyre Peninsula Catchment Water Management Plan sets management principles (water-affecting activities) for existing farm dam capacity in sub-catchments, threshold volumes and future volumes for farm dams. The draft Eyre Peninsula Catchment Water Management Plan currently forms part of the Eyre Peninsula Initial Natural Resources Management Plan. One of the priority projects identified by the former Eyre Peninsula Catchment Water Management Board (EPCWMB) is the investigation of the impact of farm dams on streamflow in the Tod River catchment. As the spatial distribution of hydrological and catchment conditions (e.g. rainfall, topography and concentration of farm dams) may not be uniform across the catchment, the EPNRMB considered it imperative to assess the impact of farm dams with the actual spatial representation of farm dams and hydrological conditions.

1.3 STUDY APPROACH

The approach used in this study was to apply a GIS-based annual rainfall-runoff model that incorporated simulated streamflow capture by farm dams. This spatial model has been developed by DWLBC, and is relatively easy to apply once the input data has been assembled and processed.

This approach was adopted, as it is more rapid than building a full daily time-step hydrological model. Although the model used was not subject to detailed calibration, nor does it assess the impact of farm dams on the flow regime, the outputs are considered to provide a good indication of the levels of environmental stress in watercourses, where environmental stress is based on the percentage of water removed from streamflow due the capture of water by farm dams.

The steps employed with data preparation were as follows:

- process topographic data
- assemble annual rainfall data across the catchment
- review and analyse streamflow gauging data
- develop a rainfall-runoff relationship from rainfall and streamflow gaugings
- estimate water usage and evaporation from farm dam data.

The model was then run for a 30-year climatic period (1971–2000) with outputs (in the form of GIS datasets and printed maps) available for each year of the study period. The results for the median of all years and extreme rainfall years were selected for presentation in this report.

The Tod River catchment contains the Tod River Reservoir and associated diversion weirs that have been used for reticulated water supply to the lower Eyre Peninsula region. This study does not address the impact of these water harvesting activities, and hence does not investigate the water balance for the catchment. Only the potential impact of farm dams is addressed.

2. CATCHMENT DESCRIPTION

2.1 OVERVIEW

The Tod River catchment is located to the north of the City of Port Lincoln on south-eastern Eyre Peninsula, South Australia (Fig. 2.1). The catchment area is ~388 km^2, and the Tod River flows north to south for ~35 km before turning east to the coastal plain and discharging into Louth Bay and Spencer Gulf. There are several tributaries — Pillaworta and Rock Valley Creeks in the northeast of the catchment, and Toolillie Gully, Charlton Gully and Meadows Creek in the west and south (Fig. 2.2).

The two northern branches, Upper Tod River and Pillaworta Creek, have diversion weirs near the junction of the two creeks. These weirs are equipped with gates that can divert streamflow from the two creeks along open channels and into the Tod River Reservoir. The reservoir is located in Toolillie Gully, just up stream of the confluence with the Tod River. The Tod River Reservoir captures all runoff from Toolillie Gully, and from the Upper Tod River and Pillaworta sub-catchments if the diversion gates are open.

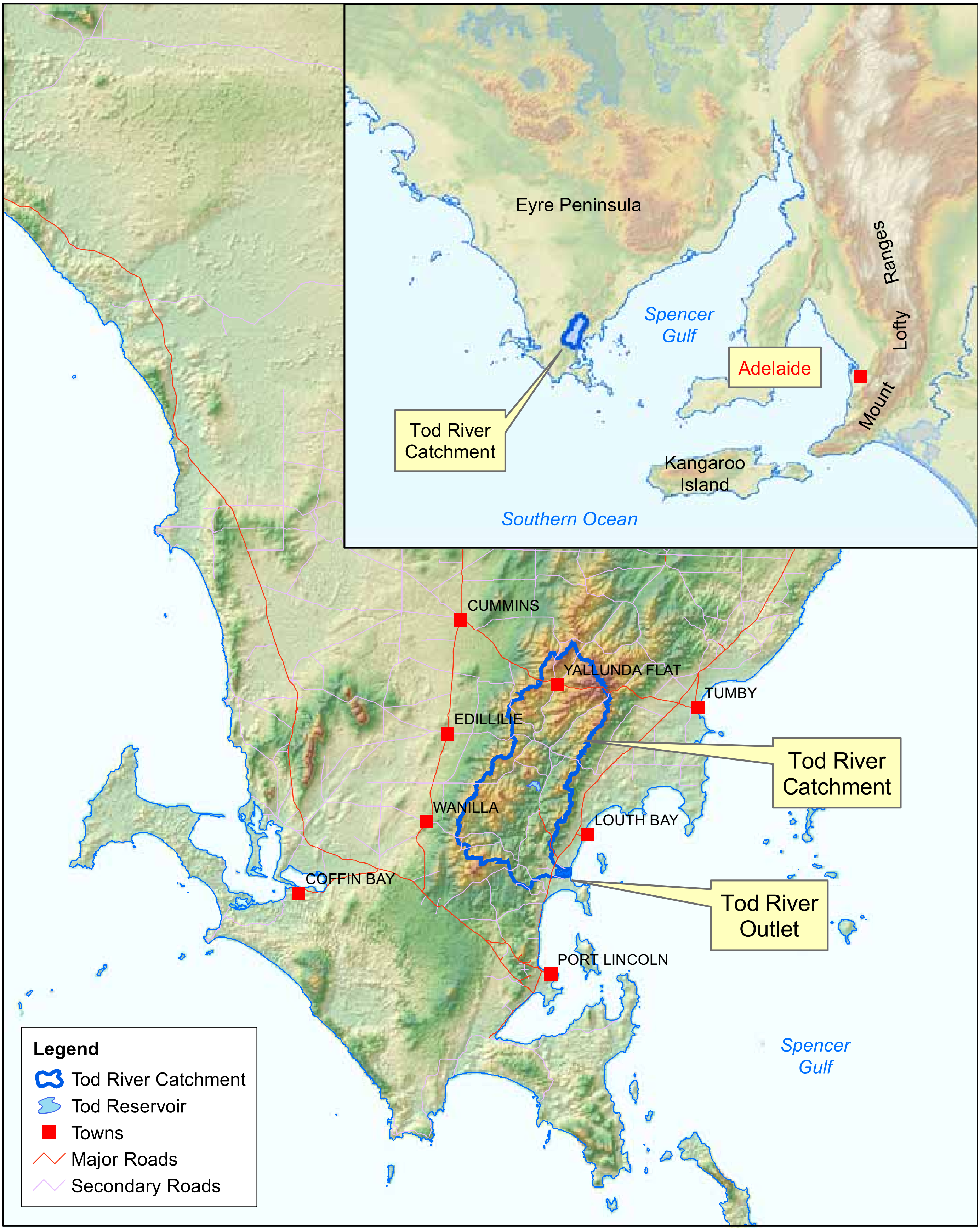
The Tod River Reservoir, with a maximum capacity of 11 300 ML, has been used since ~1925 as a water supply for lower Eyre Peninsula. The reservoir rarely fills and the annual yield has been in the order of 2200 ML (EWS 1984; State Water Plan 2000). In recent years, inflow to the reservoir has been low, reflecting low rainfall in the region. Also, less water has been diverted from the weirs due to increasing salinity of the runoff water. This has meant that progressively less water has been taken from the reservoir and more from the Eyre Peninsula groundwater basins to supply the region's water needs.

An informal assessment of farm dams across all catchments in the south-eastern side of Eyre Peninsula showed that the Tod River catchment had the highest concentration of farm dams. The catchment has 676 farm dams (from 2001 data) with a total combined capacity estimated at 884 ML. Although most of these dams are small in comparison to those in the Mount Lofty Ranges, the runoff coefficients in the Tod River catchment are much lower than those in catchments in the Mount Lofty Ranges (results are given in this report). There is therefore the potential for farm dams to capture a large percentage of runoff that could jeopardise the riparian environment and lead to conflict with down-stream users and reduce yield for the reticulated water supply.

An inventory of the status and condition of the riparian environment is reported in Rixon, Kotz and Thomas (2002).

2.2 TOPOGRAPHY

The topographic features of the catchment range from <10 m over most of the coastal plain, to ~320 m at the highest point, with the elevation exceeding 200 m in many parts of the catchment (Fig. 2.2). The topography was represented in an electronic format as a digital elevation model (DEM) sometimes referred to as a digital terrain model (DTM). The DEM was created from 10 m interval contour data and drainage data obtained from the Department for Environment and Heritage. The DEM creation procedure included steps to ensure that the final DEM correctly represented water flow paths, i.e. the DEM was hydrologically correct.



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Map_Study Area.mxd

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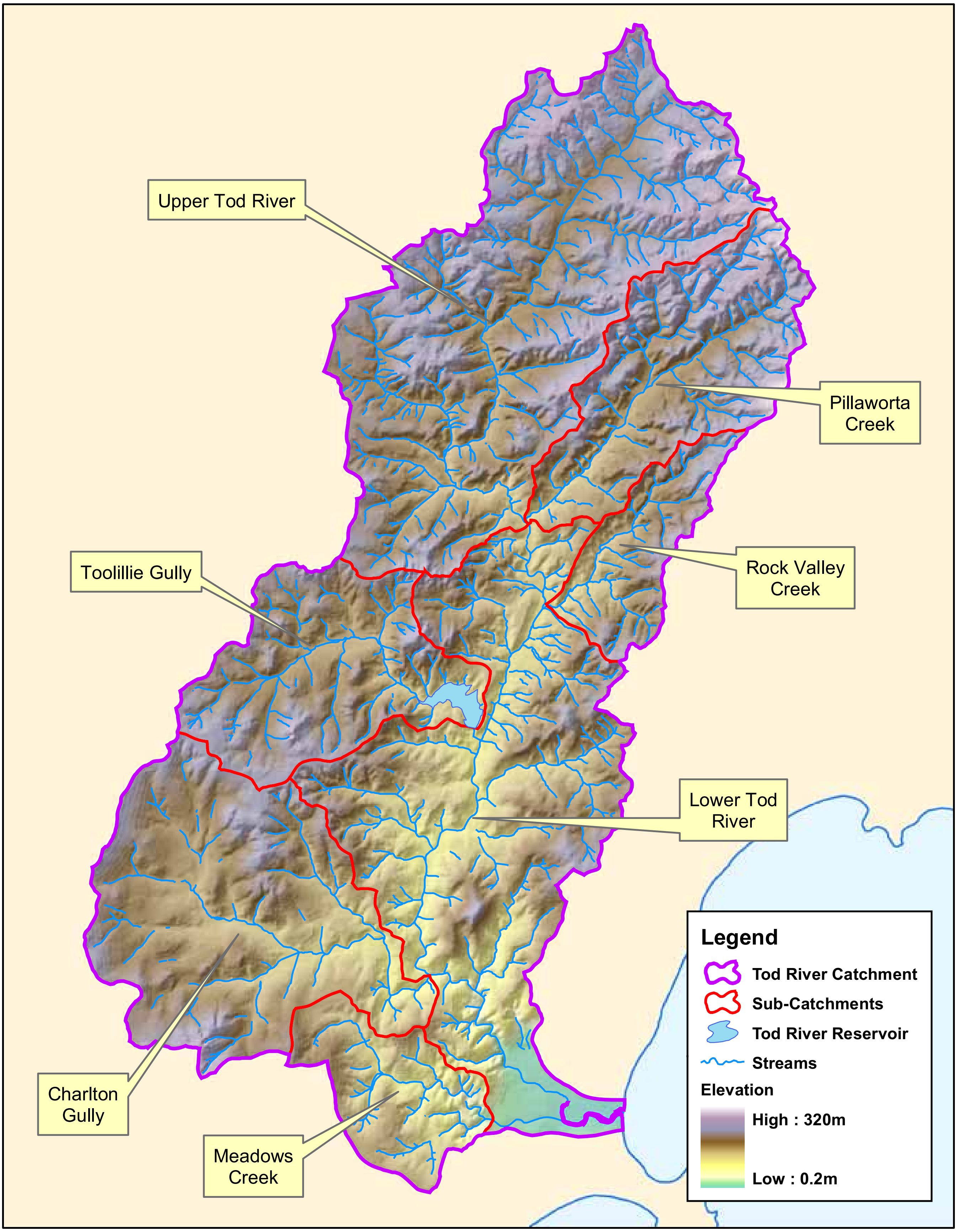
Figure 2.1
Location of the Tod River Catchment



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N W E S

0 2.5 5 10
Kilometres

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Figure 2.2
Topography and Sub-Catchments of the Tod River Catchment

Map_Topography.mxd

A flow direction grid was created from the hydrologically corrected DEM in GIS. A flow direction grid is an electronic dataset comprising a mesh of cells whose value represents the flow direction of runoff water. This dataset is used in the model (described later) when modelling runoff and streamflow.

2.3 FARM DAMS

2.3.1 THE IMPORTANCE OF FARM DAMS

Farm dams are water storage structures generally constructed in rural areas for capturing surface water runoff generated from the catchment area above them. The water stored in farm dams provides an additional source of water for domestic, stock and irrigation purposes during the summer months. Farm dams, as well as providing an important source of water, also provide a barrier to streamflow downstream until the dam fills and overflows. This delays the commencement of flow at the beginning of the wet season and reduces the total quantity of water available to users and the environment downstream. This impact is greater when a large dam is constructed across a stream and/or to the accumulative effect of many small farm dams.

A particularly undesirable impact of farm dams is the effect on the flow regime, including the delay on commencement of streamflow. This has a negative impact on the riverine and water-dependent ecosystems. Each habitat within aquatic ecosystems is associated with a community of plants and animals ranging in size from micro-organisms and invertebrates through to the largest species. The life history of plants and animals that inhabit the aquatic, riparian and floodplain environments of river systems are dependent on the flow regimes that maintain these habitats (G. Scholz, DWLBC, pers. comm., 2005).

The impact of farm dams on the flow regime is not directly addressed in this study, however this study investigated the impact of farm dams on annual flows from which the effect on water-dependent ecosystems can be estimated. The current thinking is that where up to 10% of the annual streamflow is removed, this will have minimal impact; 10–20% streamflow removed will cause impacts on sensitive species; 20–40% of streamflow removed will cause a significant impact; and >50% of streamflow removed will cause a major environmental change within 25 years (G. Scholz, DWLBC, pers. comm., 2005).

2.3.2 FARM DAM DATA

The farm dam data used for this study were based on aerial photography captured in November 2001 by the Department for Environment and Heritage, from which, the farm dam outlines were digitised. The photography was captured at a scale of 1:80 000, and scanned and ortho-corrected with an image pixel size of 2 m. This was a coarser resolution than the 1:20 000 scale aerial photography and 0.5 m pixel ortho-imagery normally recommended for capturing farm dam data. However, it was considered that the loss of potential accuracy was a reasonable compromise between cost and accuracy, especially when considered in terms of other potential sources of error such as estimating volumes with a volume–area relationship (described below) and the use of an annual-step model in lieu of a daily-step model.

The distribution of farm dams across the catchment is shown in Figure 2.3. The volumes of the digitised farm dams were estimated with the volume–area relationship taken from McMurray (2004) and shown below.

For area <15 000 m^2 $\quad$ $V = 0.0002\ A^{1.25}$

For area ≥15 000 m^2 $\quad$ $V = 0.0022\ A$

where V = volume (ML), and A = surface area (m^2).

This relationship was based on surveys of farm dams in the Clare Prescribed Water Resources Area and some of the catchments in the Mount Lofty Ranges considered as having low demand for irrigation water (McMurray 2004). This relationship was used in the current study, as there have not been any studies of the geometries of farm dams in the Tod River catchment.

If further, more detailed studies of hydrology of the Tod River catchment are to be undertaken, it is recommended that a sample of farm dams be surveyed. The surveyed volumes should be used in the hydrological assessments and the appropriateness of the above volume–area relationship should be assessed. Advice on suitable survey techniques and volume–area relationship assessment methods are given in McMurray (2004).

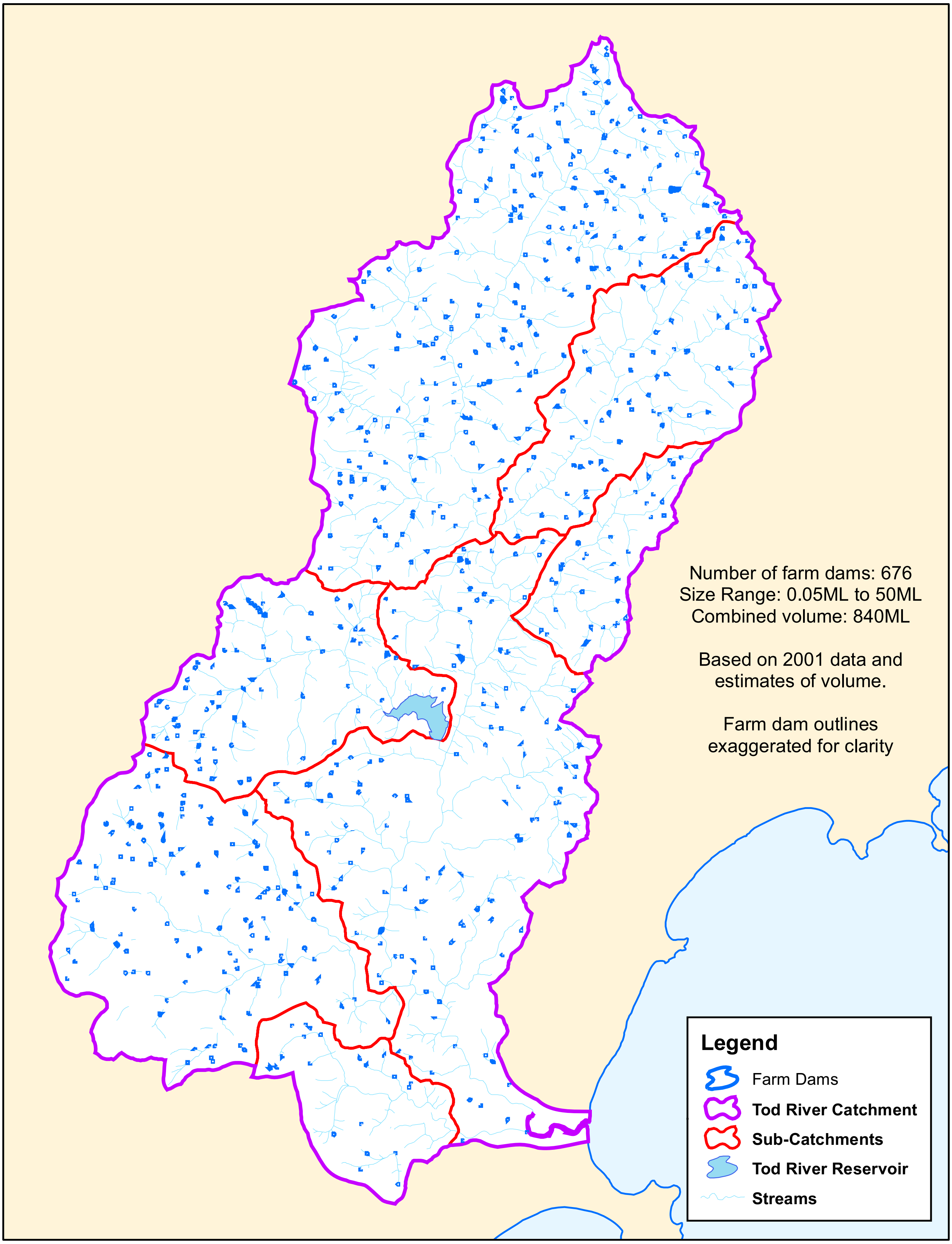
Using the farm dam data and estimated volumes, the number of farm dams and combined estimated volumes were determined for the whole Tod River catchment in size classes as shown in Table 2.1 and Figure 2.4. The majority of farm dams by number (86% of the total in the catchment) are in the smallest two size classes. The majority of the storage capacity (71% of the total in the catchment) is in the farm dams in the size range 0.5–5 ML (size classes 0.5-2 ML and 2–5 ML). There are only 16 farm dams (2% of the total) >5 ML in storage capacity, accounting for 22% of the total storage capacity.

Table 2.1 Number and total combined storage volume and percentages of the total in the whole catchment by size class for farm dams.

Farm dam size class	Number of farm dams* (% of total number)	Total storage capacity (ML)* (% of total storage)
<0.5 ML	227 (34%)	61 ML (7%)
0.5–2 ML	353 (52%)	366 ML (44%)
2–5 ML	80 (12%)	229 ML (27%)
5–10 ML	9 (1%)	60 ML (7%)
10–20 ML	6 (1%)	74 ML (9%)
20–50 ML	1 (0.1%)	49 ML (6%)
Total	676 (100%)	840 ML (100%)

*Does not include Tod River Reservoir

In terms of resource management in the Tod River catchment, the main impacts are likely to be with the accumulative effects of a large number of smaller dams, although 22% of storage in farm dams over 5 ML should not be ignored. This is in contrast to farm dam impacts in catchments of the Mount Lofty Ranges where a small number of large farm dams contain the majority of storage capacity.



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N W E S

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Figure 2.3
Farm Dams in the Tod River Catchment

Map_FarmDams.mxd

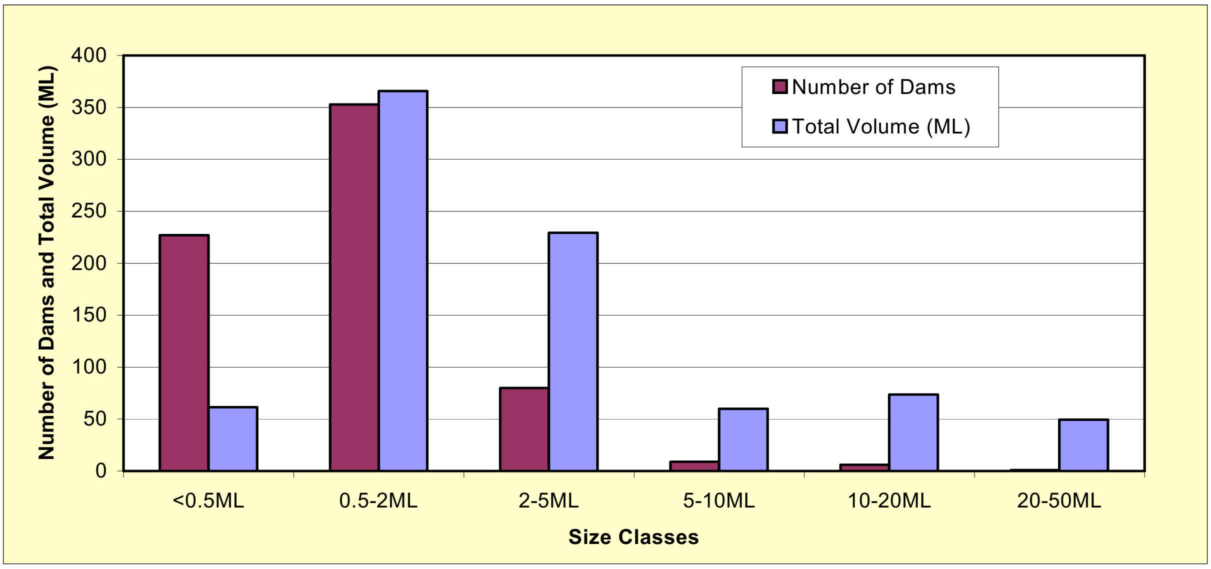


Figure 2.4 Number and total combined storage capacity of farm dams by size class.

The number and combined storage capacity of farm dams in each of the sub-catchments is shown in Figure 2.5. There is a large variation between the sub-catchments. The Upper Tod River sub-catchment contains the largest number (234) of farm dams and greatest storage capacity (316 ML); Meadows Creek sub-catchment has the lowest number (22) of farm dams and lowest storage capacity (14 ML).

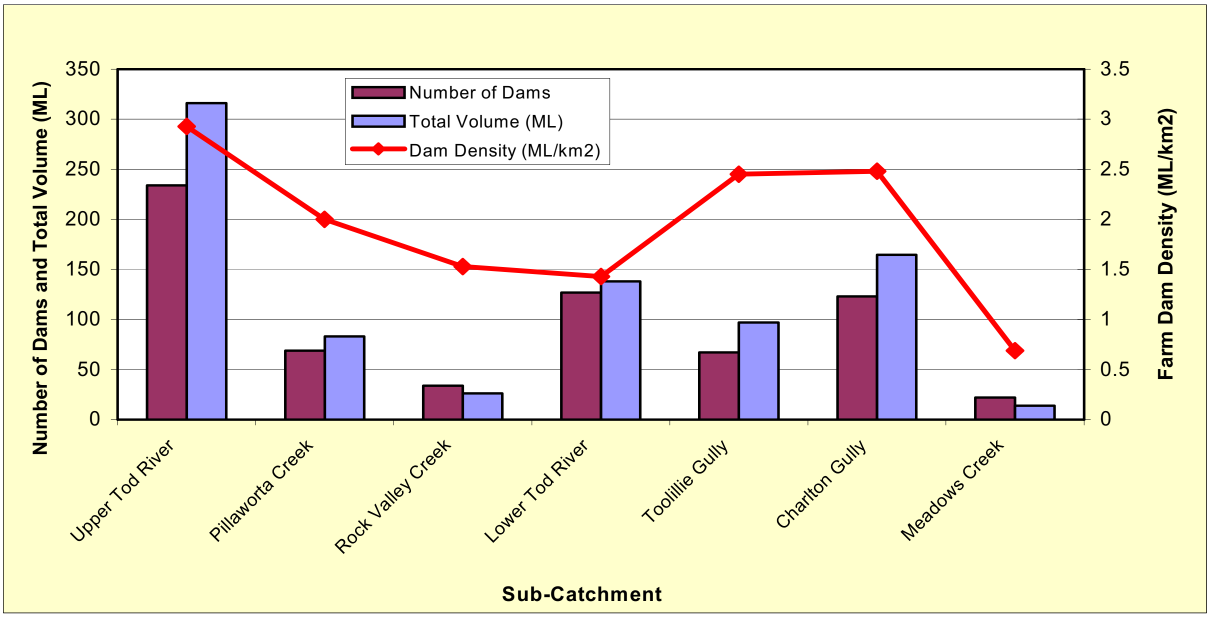


Figure 2.5 Comparison of the number, total combined storage capacity, and farm dam density (storage capacity per unit area) between sub-catchments.

However, considering just the number and storage capacity of farm dams within sub-catchments may result in misleading conclusions as to the level of development. Farm dam density should be evaluated as this expresses the total storage capacity per unit area of each sub-catchment (ML/km^2) and provides a better measure of possible relative farm dam impacts in each sub-catchment. Farm dam density is shown (by the red line) for each sub-catchment in Figure 2.5. This shows, for example, that Toolillie Gully sub-catchment (which contains the Tod River Reservoir), with a relatively low number and storage capacity in farm dams, has a farm dam density approaching that for the Upper Tod River sub-catchment, which also contains one of the diversion weirs for the Tod River Reservoir. The farm dam impacts in Toolillie Gully sub-catchment may therefore be as significant as those in the Upper Tod River sub-catchment, an issue not apparent from the figures of farm dam numbers and total storage capacity.

2.3.3 ESTIMATION OF WATER USAGE

The model outputs (as described later) provide an indication of the environmental stress placed on streams by determining the percentage of streamflow removed by farm dams. The quantity of water removed by each farm dam was estimated as the sum of a winter component and a summer component.

For the winter component (taken as May to November inclusive), it was assumed that (a) there was no extraction for irrigation and (b) the dams were full, and the quantity of water removed was assumed to be due to evaporation only, based on a constant surface area.

The summer component (taken as December to April inclusive) was calculated from the dam volumes and a single usage factor. The usage factor included an allowance for extractions for irrigation or stock, domestic use and for evaporation. The usage factor was based on another study in the Mount Lofty Ranges (McMurray 2003) into water usage from farm dams. That study showed that water extraction averaged ~19% and losses due to evaporation averaged ~20% of dam capacity. These results were based on modelling for the summer period December 2001 – April 2002. As this summer was considered cooler and wetter than normal, it was suggested that the figures of both extraction and evaporation would be higher in a more typical summer. In the current study, a factor for summer losses of 0.5 of capacity was used.

The calculation of water removed from streamflow by farm dams that incorporates both the winter and summer components can be represented by the following equation:

$$Q\ (\text{ML}) = (\text{Surface Area (ha)} \times \text{Winter\_Evaporation (mm)} \times \text{Pan\_Factor} / 100) + (\text{Dam Volume (ML)} \times \text{Use\_Factor})$$

where Q = mean annual quantity of water removed from streams by farm dams

Pan_Factor = 0.75 was assumed

Use_Factor = 0.5 for all dams.

A correction factor (/100) to rationalise units to ML.

In the GIS-based model, the farm dam polygons were converted to points based on the centroid of each polygon. The points were then converted to raster data (raster data are explained in a later section) where the cell value corresponding to each point was allocated the estimated usage for each dam.

3. HYDROLOGICAL DATA

3.1 RAINFALL

Rainfall is one of the primary drivers of the hydrological cycle, with the amount of rainfall directly affecting the volume of water available within a catchment and hence its productivity. Rainfall is generally not uniform across a catchment and can vary spatially due, for example, to catchment topography where areas with higher elevation generally receive more rainfall than areas with lower elevation. A good understanding of both volume and spatial variability of rainfall is important if realistic modelling of runoff is to be achieved.

The sources of that data and methods employed in data processing are described in this section.

3.1.1 RAINFALL STATIONS

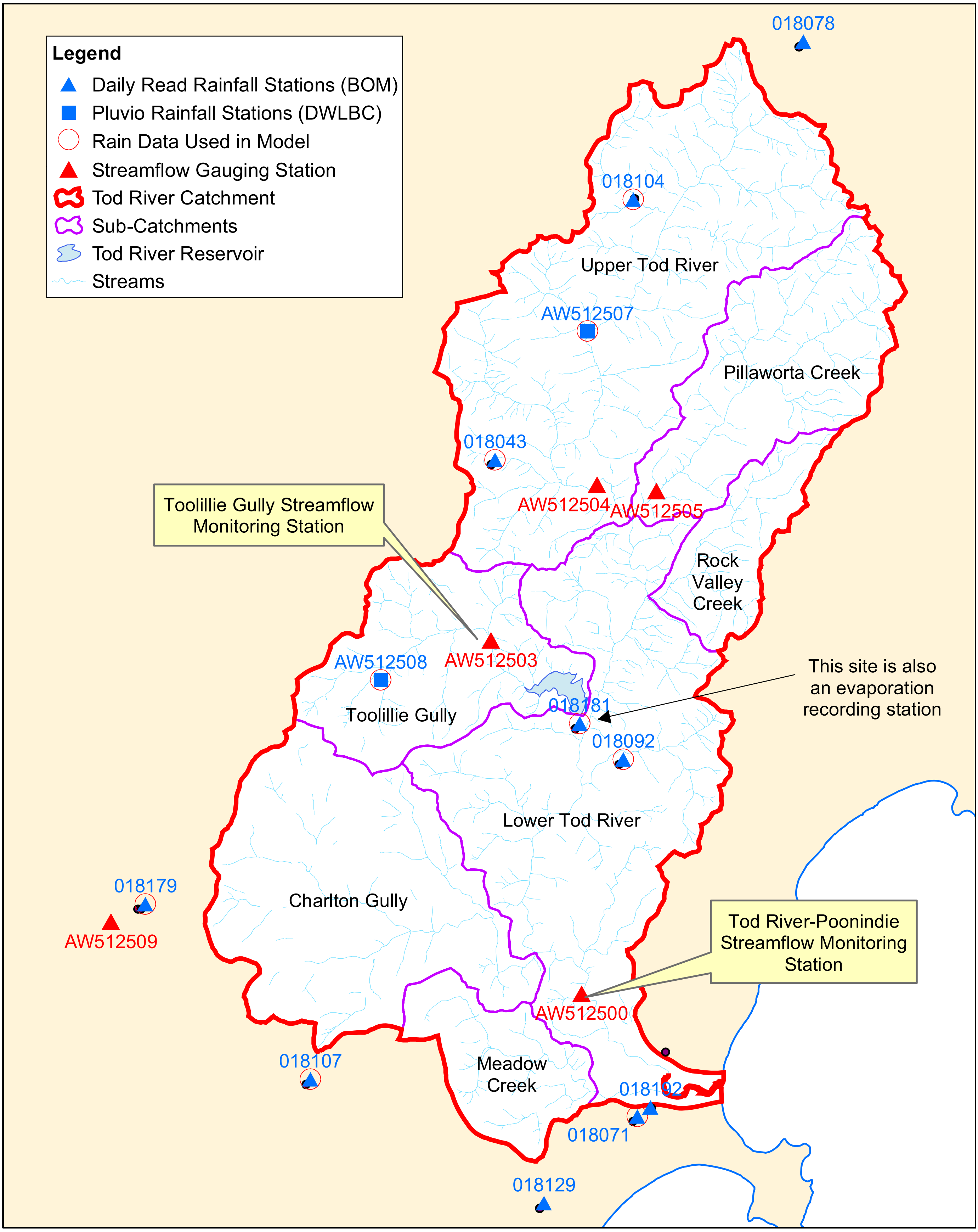
A total of 12 sites were identified within or close to the Tod River catchment where rainfall data was or had been collected (Fig. 3.1). Ten of these sites were or had been operated by the Bureau of Meteorology (BoM) as shown by sites number commencing with '018', and two sites were equipped with pluvio recorders and operated by DWLBC as shown by site numbers commencing with 'AW512'.

Three of the BoM rainfall stations had been closed prior to the study period (1971–2000). Although the data from these stations could have been extended, it was considered that the data from the nine remaining stations would be sufficient. These stations are shown in Figure 3.1 with a red circle. Some of the data from these stations had gaps in the records, and in some cases the period of record did not cover the whole study period. Some of the missing data were obtained from the Sinclair Mertz Knight (SKM) in-filled dataset; some were obtained from the SILO database (point-patched dataset, see SILO reference); and some were in-filled and/or extended in-house.

3.1.2 RAINFALL STATISTICS

The annual rainfall averaged across the catchments of the Toolillie Gully and Tod River (Poonindie) streamflow gauging stations (station numbers AW512503 and AW512500, respectively) are shown in Figure 3.2. These figures were determined from the rainfall surfaces described later.

The median rainfall for the two catchments is ~505 mm (504 mm for Toolillie Gully; 506 mm for Tod River (Poonindie)). The mean rainfall (not shown) is 510 mm for both Toolillie Gully and Tod River (Poonindie). The year 1992 was notably wet with ~860 mm of rainfall over the catchments. There were several dry years with rainfall averaged over the catchments at ~350–400 mm. There are slight differences between the two catchments for some years indicating differences in the spatial distribution of rainfall across the Tod River catchment.



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ReportMap_Monitoring_Stations.mxd

Figure 3.1
Rainfall, Streamflow and Evaporation Monitoring Stations

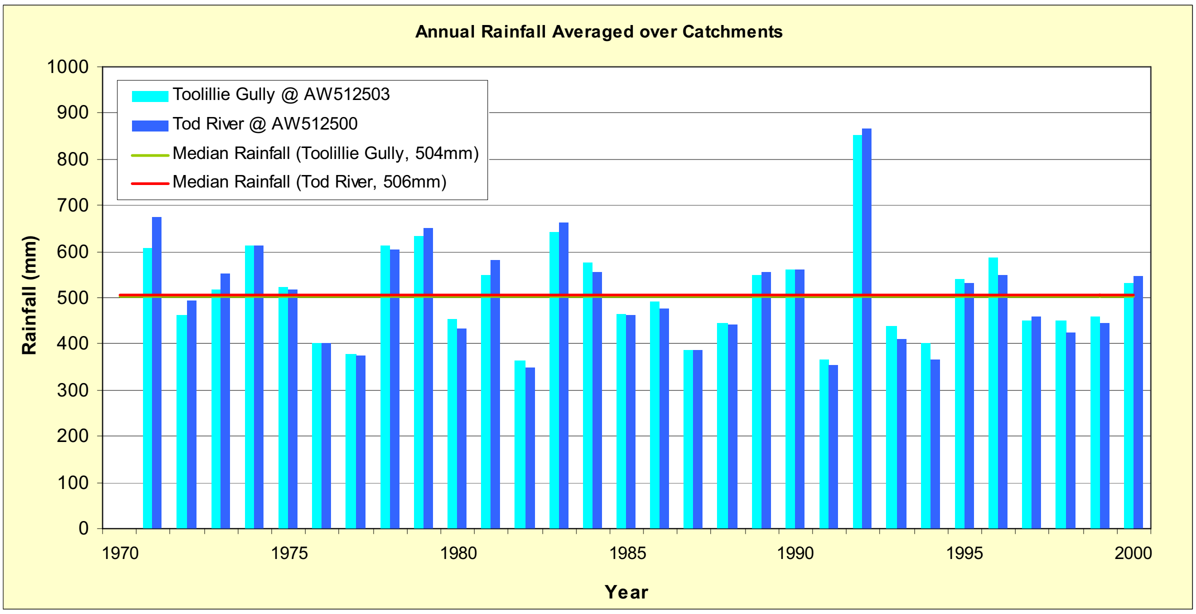


Figure 3.2 Annual and median rainfall averaged over the Toolillie Gully and Tod River (Poonindie) gauging station catchments for the study period (1971–2000).

3.1.3 LONG-TERM RAINFALL RECORD

A long-term record of rainfall was available for the BoM station at Yallunda (station number 018104) in the northern part of the Tod River catchment (Fig. 3.1). The data are shown plotted in Figure 3.3 together with the residual mass curve and linear trend line. The mean and median annual rainfalls at this station over the 91 year period (1910–2000) are 526 mm and 522 mm, respectively.

Long-term rainfall trends can be observed using residual mass curves. A residual mass curve is a plot of the cumulative deviation of a set of data from the mean value of the data. In a residual mass curve plotted for annual rainfall data, a distinctive upward slope above the mean indicates a wetter than average period for that section of the curve and visa versa. A residual mass curve plotted for the Yallunda rainfall station (Fig. 3.3) indicates wetter than average periods during 1930–55 and 1968–75. The data indicate drier than average periods during 1917–30, 1956–67, and 1983–2000 with the exception of a very wet year in 1992.

Analysis of rainfall data on a decadal time scale is shown in Figure 3.4. This indicates that the last two decades (1980s and 1990s) had rainfall that was ~30 mm lower than the long-term mean annual rainfall. The 10-year moving average shows the average of the 10 years immediately preceding all points on the curve.

3.1.4 MEAN ANNUAL RAINFALL SURFACE AND ISOHYETS

Knowledge of the spatial variability of rainfall across the catchment was required to ensure that the annual rainfall surfaces (explained in Section 3.1.5) used in the modelling would represent the correct spatial distribution of rainfall for each year of the study period. The spatial variability can be obtained from either isohyets (lines of mean annual rainfall) or gridded data of mean annual rainfall.

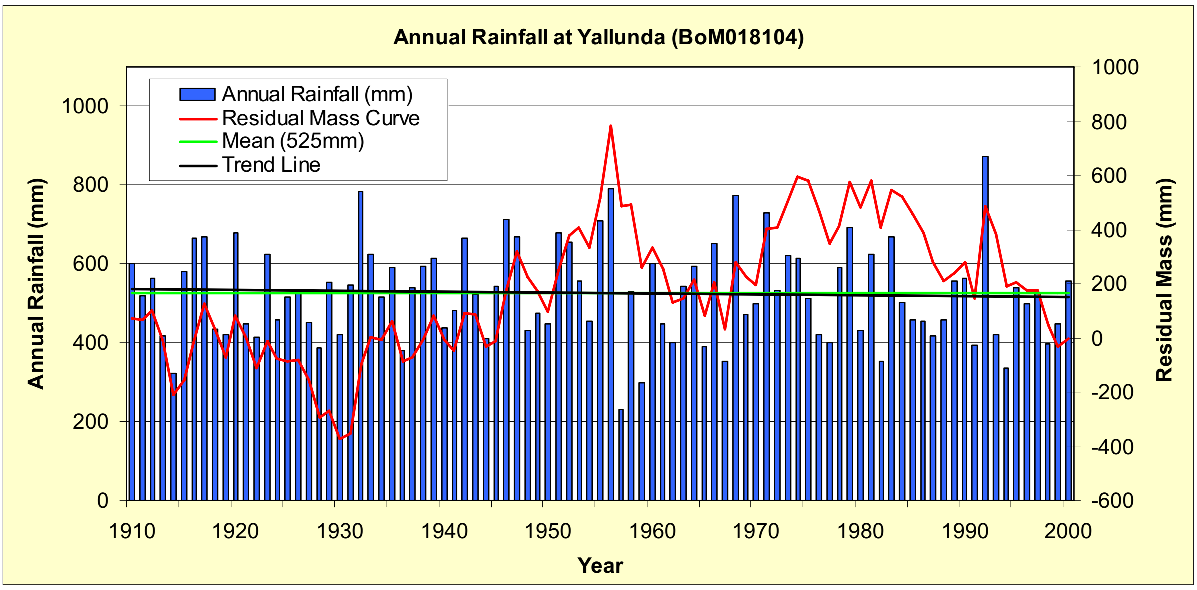


Figure 3.3 Annual rainfall totals and variability for the Upper Tod River catchment (rainfall station BoM018104).

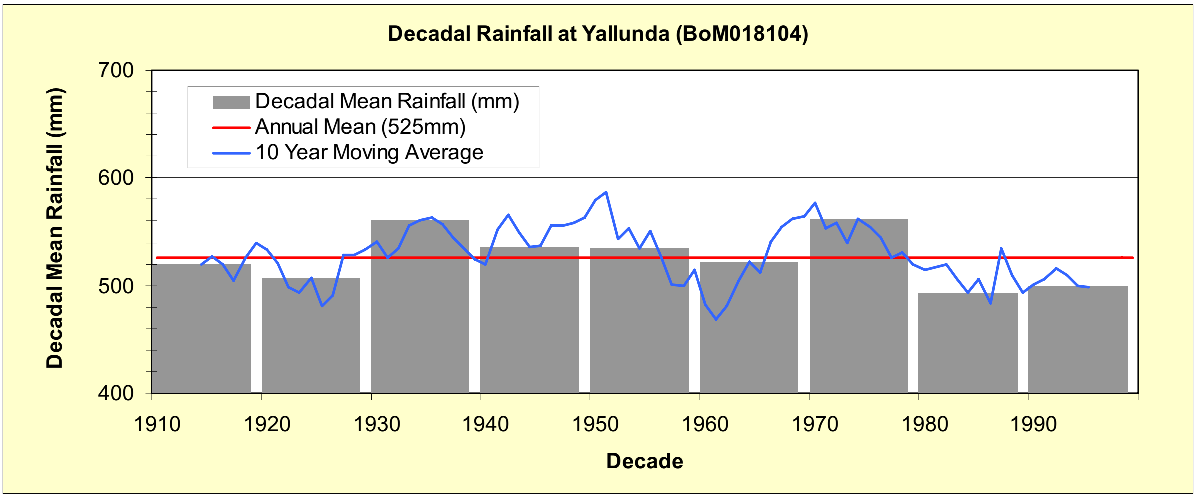


Figure 3.4 Decadal rainfall pattern for the Upper Tod River catchment (rainfall station BoM018104).

Two sources of data were available for this study. These were isohyets from the DWLBC database, and gridded data from BoM. To facilitate a comparison between the two datasets and with the mean annual rainfall at each rainfall station, isohyets were created from the BoM gridded data. It was noted that the isohyets from the DWLBC GIS database deviated considerably from the figures of mean annual rainfall derived from the rainfall stations. Deviations were also evident in the isohyets derived from the nation-wide gridded data but to a lesser extent.

The DWLBC GIS isohyets were produced state wide by averaging a total of 106 surfaces of annual rainfall for the years 1890–1995 inclusive. These were created from annual rainfall from all rainfall stations with a complete record for each particular year. Patched or in-filled data were not used, resulting in a low number of rain stations in some areas in some years, and no allowance was made for elevation or other climatic effect. Thus, when these data were studied at catchment scales, some discrepancies were noted between the isohyets and the mean annual rainfall from local rainfall stations.

The BoM nation-wide gridded rainfall data were created using a complex spatial interpolation algorithm (Hutchinson 1995) that considered many aspects including elevation, latitude and longitude. The process utilised only selected rainfall stations for which a high confidence could be placed on the overall data quality. The data were created for the whole Australian continent with a cell size of 5 km. As this was national-scale data, it was not surprising to note some anomalies when examined at local scales and compared against rainfall stations with a reasonably long record, but that may not have been included in the analysis.

It was decided that the best approach for this project was to manually modify the isohyets derived from the BoM gridded data. This was performed on-screen subjectively such that the modified isohyets corresponded as closely as possible to the figures of mean annual at the rainfall stations, followed the general topography of the terrain (as determined from the DEM), and without deviating excessively from the original isohyets.

The final adopted modified isohyets are shown in Figure 3.5 (thicker light blue lines). Also shown are the original isohyets derived from the BoM gridded data (thin black lines); the DWLBC isohyets (thin dark blue lines); the terrain elevation (background); and the rain stations with the mean annual rainfall in millimetres (blue triangles).

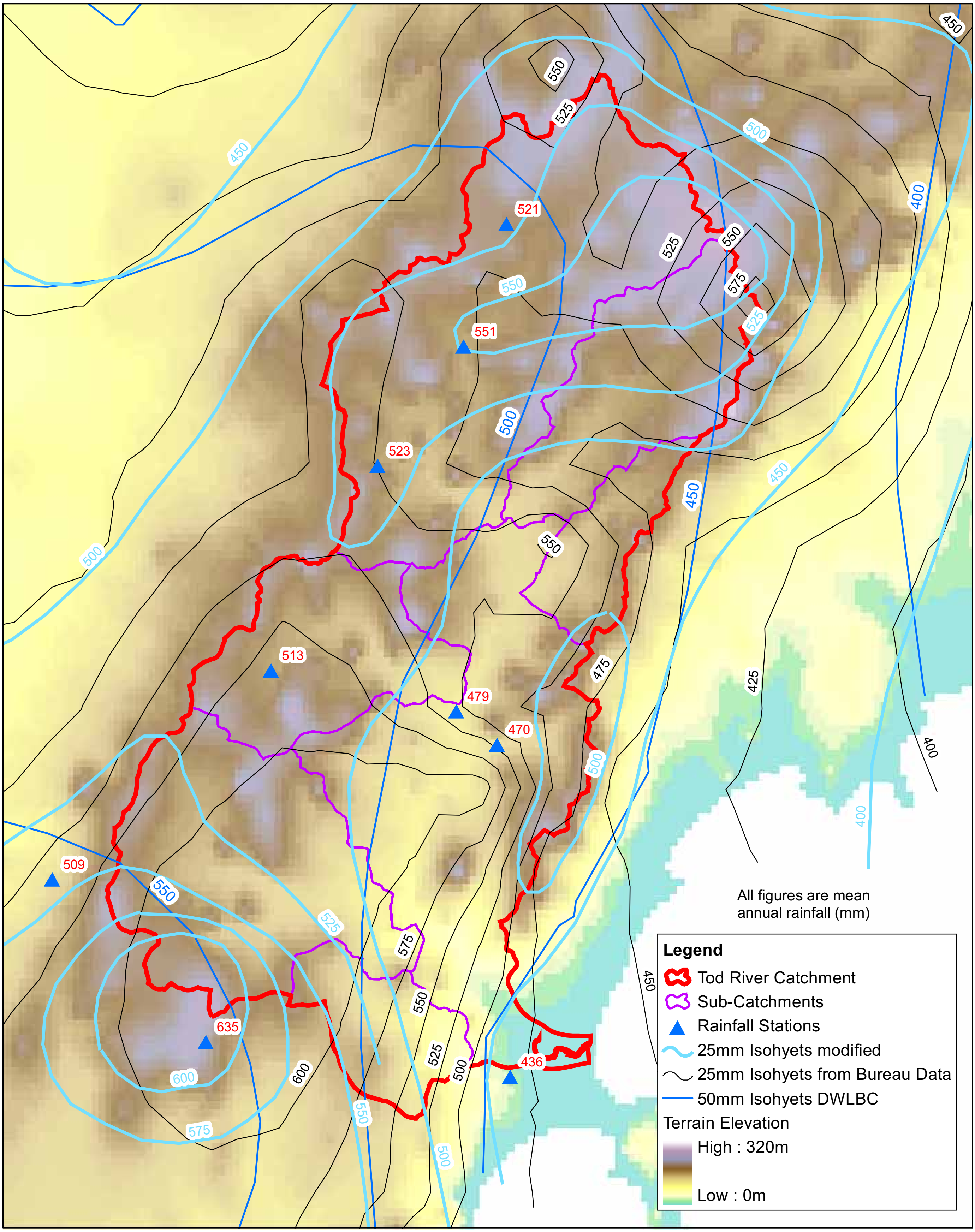
Revised gridded data (mean annual rainfall surface) were created from the modified isohyets, which were used to determine the mean annual rainfall averaged across the catchments of the Toolillie Gully and Tod River (Poonindie) gauging stations (described in Section 3.2).

3.1.5 ANNUAL RAINFALL SURFACES

The modelling and analysis conducted for this study required information on the annual rainfall and spatial variability of that rainfall data over the Tod River catchment for each year of the study period, chosen as the 30-year climatic period 1971–2000 inclusive. The information was built into a series of GIS datasets, one for each of the years 1971–2000. The GIS datasets were grids or a mesh of cells where each cell has a value representing the rainfall at that location for one particular year. These types of GIS datasets are referred to as surfaces, which were created as described below.

A GIS point-dataset was first created from the coordinates of each of the rainfall stations selected for this study. The values of annual rainfall for each of the years of the study period were added to the attribute table of the GIS rainfall point-dataset. The rainfall surfaces were then created from this by spatial interpolation. There are many methods of spatial interpolation that use a mathematical or statistical method to estimate the value of the variable (rainfall in this case) at all points across the study area. The method used in this study was a two-step process that first used the TIN (triangulated irregular network) spatial interpolator and then converted the resulting TIN to a grid using a quintic algorithm.

In order for the spatial interpolation method to correctly define the spatial distribution of rainfall across the whole catchment, it was necessary to have data from rainfall stations at points close to and outside of the catchment boundary. As a sufficient number and spatial distribution of actual rainfall stations were not available, a total of 13 virtual rainfall stations were added. The locations of these virtual stations were selected by iterative means to



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Datum: Geocentric Datum of Australia 1994
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Figure 3.5
Topography, Derived and Modified Isohyets; and Actual and Virtual Rainfall Stations

ReportMap_RainAnnSurface.mxd

ensure that the rainfall surfaces conformed to the general shape of the mean annual rainfall surface (the method of creating the mean annual rainfall surface was described in Section 3.1.4).

Figure 3.6 shows the location of the real and virtual rainfall stations. Also shown are the modified isohyets (described in Section 3.1.4) and an example of a rainfall grid (actually the mean annual rainfall). A total of 30 rainfall surfaces were produced, one for each of the years 1971–2000.

The rainfall surfaces were used in the modelling (described later) and also to determine the annual rainfall averaged across the catchments of the Toolillie Gully and Tod River (Poonindie) streamflow gauging stations (described in Section 3.2) for each year of the study period.

3.2 STREAMFLOW

3.2.1 STREAMFLOW GAUGING STATIONS

Streamflow gauging data were required to adjust the parameters in the GIS-based model and to confirm that the model was operating correctly. Streamflow gauging is carried out by DWLBC in catchments in South Australia. A total of eight streamflow gauging stations were present in the DWLBC Hydstra database for the lower Eyre Peninsula. However, due to the reasons explained below, data from only two of these could be used in this study.

Two of these (DWLBC station numbers AW512501 and AW512502) had no history files and no data files. A third station (number AW512510) located at the Tod River Reservoir measures reservoir water level and not streamflow. The remaining five streamflow stations are shown in Figure 3.1. One of these (station number AW512509, Popes Creek at Wanilla) is located just outside the south-western boundary of the Tod River catchment. This station has only ~2½ years of data and has no rating, rendering the data of no value for this study.

Two gauging stations are integral to two diversion weirs located just above the junction of the upper Tod River and Pillaworta Creek. An overview of the site history files determined that these two stations have had a chequered history due to a combination of technical problems for which a long-term cure has been difficult to find. The technical problems have resulted in significant data gaps and low confidence in the accuracy of much of the data. Also, the design of the weirs means that reasonable determinations of low flows are not possible. It was considered that the issues were too complex to investigate fully as part of this study, especially as a monitoring review of the region is currently under way, so the data from these two sites were not used.

The two remaining stream gauging stations with data suitable for this study were Toolillie Gully upstream of the Tod River Reservoir (station number AW512503) and Tod River 5 km northwest of Poonindie (station number AW512500). The Toolillie Gully station had continuous data available for the period 1992–2001 (10 years), and Tod River (Poonindie) station had data for the period 1972–89 (18 years). Both these periods are within the study period (1971–2000) although they do not overlap. In the case of the data from Tod River

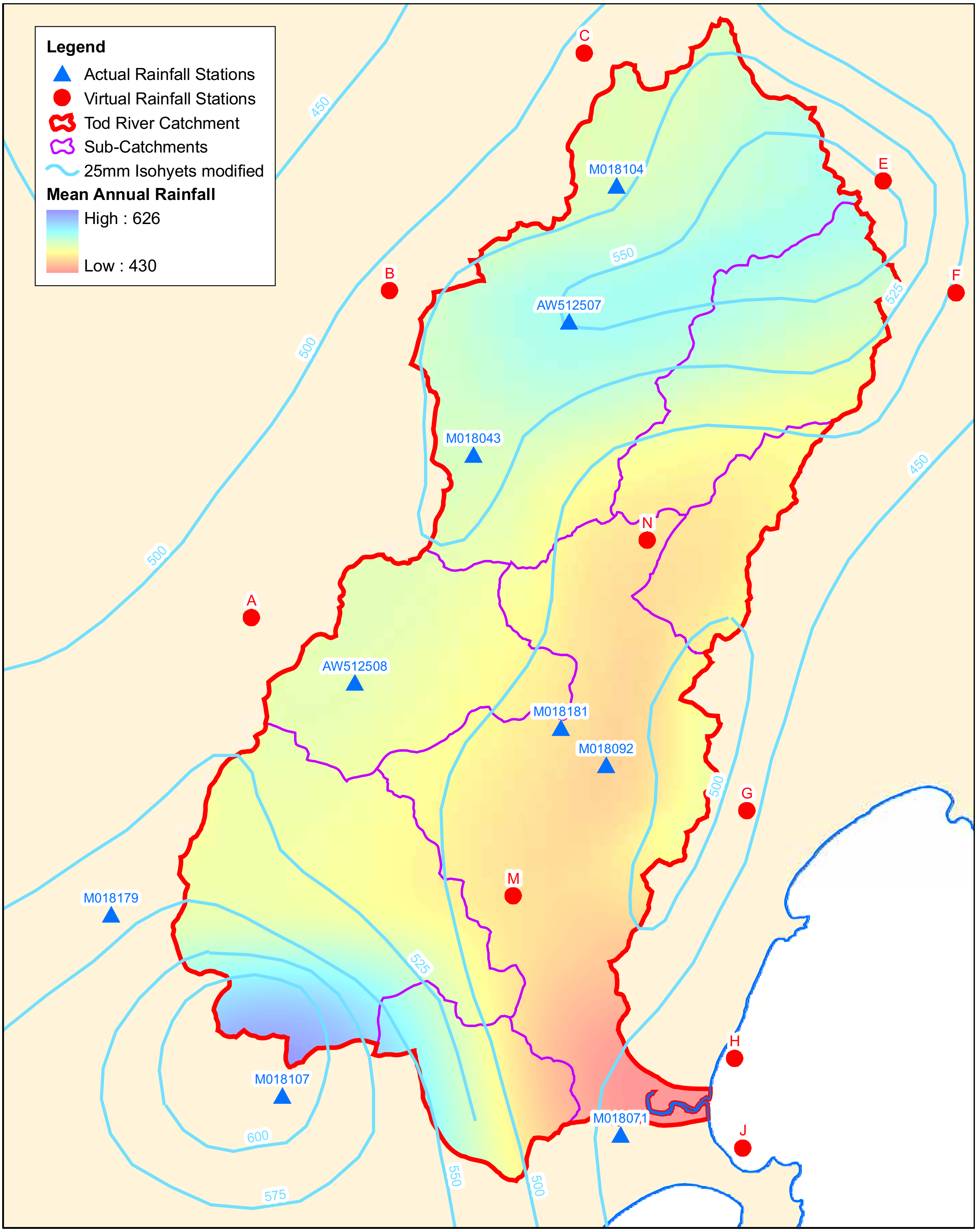

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Figure 3.6
Actual and Virtual Rainfall Stations, Modified Isohyets, and Gridded Mean Annual Rainfall Surface

(Poonindie) station, it was necessary to add the quantities of water diverted by the Tod River Reservoir and associated diversion weirs in order to provide true figures of runoff from the catchment (catchment yield) above the gauging station. The figures for diverted water were obtained from Tomlinson (1996), who calculated total diversions using a water balance model. There will be some uncertainties in the values of calculated diverted water due to assumptions in the water balance model and also due to leakages from Tod River Reservoir.

3.2.2 STREAMFLOW (CATCHMENT YIELD) STATISTICS

The mean and median flows are shown in Table 3.1. The gauged and modelled annual streamflows are shown in Figures 3.7 (for Toolillie Gully) and 3.8 (Tod River (Poonindie)).

Table 3.1 The mean and median of gauged and modelled streamflows from the Toolillie Gully and Tod River (Poonindie) gauging station catchments.

Gauging station catchment	Gauged streamflow ML (mm)		Modelled streamflow ML (mm)	
	Mean	**Median**	**Mean**	**Median**
Toolillie Gully	724 (24)	352 (12)	996 (33)	772 (22)
Tod River (Poonindie)	11 794 (33)	10 132 (29)	12 614 (36)	9649 (27)

The mean and median of the modelled flows are for the period 1971–2000.

The mean and median of the gauged flows for Toolillie Gully are for the period 1991–2000.

The mean and median of the gauged flows for Tod River (Poonindie) are for the period 1972–98.

The gauged runoff for Toolillie Gully catchment varies from 81 ML (2.7 mm) in 1991 to 2590 ML (87 mm) in 1996. There is a large difference between the mean (724 ML) and the median (352 ML). This was due to the single larger runoff in 1996 compared to the other eight years in the record (Fig. 3.8). This suggests that the 10-year record is too short to provide a good indication of the mean and the variation of runoff.

The gauged runoff for the Tod–Poonindie catchment varies from 2350 ML (6.6 mm) in 1977 to 31 400 ML (89 mm) in 1978. The mean and median are 11 794 ML and 10 132 ML, respectively.

3.3 RAINFALL-RUNOFF RELATIONSHIP

The modelling undertaken in this study used an annual rainfall-runoff relationship. Although an annual rainfall-runoff relationship is simple in comparison to the more complex algorithms usually employed in hydrological modelling, it provides a straightforward means of estimating the quantity of runoff (catchment yield) that can be expected from a catchment for a range of rainfall levels. The relationship can be used for comparing the characteristics of different catchments or sub-catchments; for estimating the quantity of runoff generated in different years; and, as in this study, for providing an estimate of the impact of farm dams on runoff. Two commonly used rainfall-runoff relationships are runoff coefficient and an equation based on the tanh function.

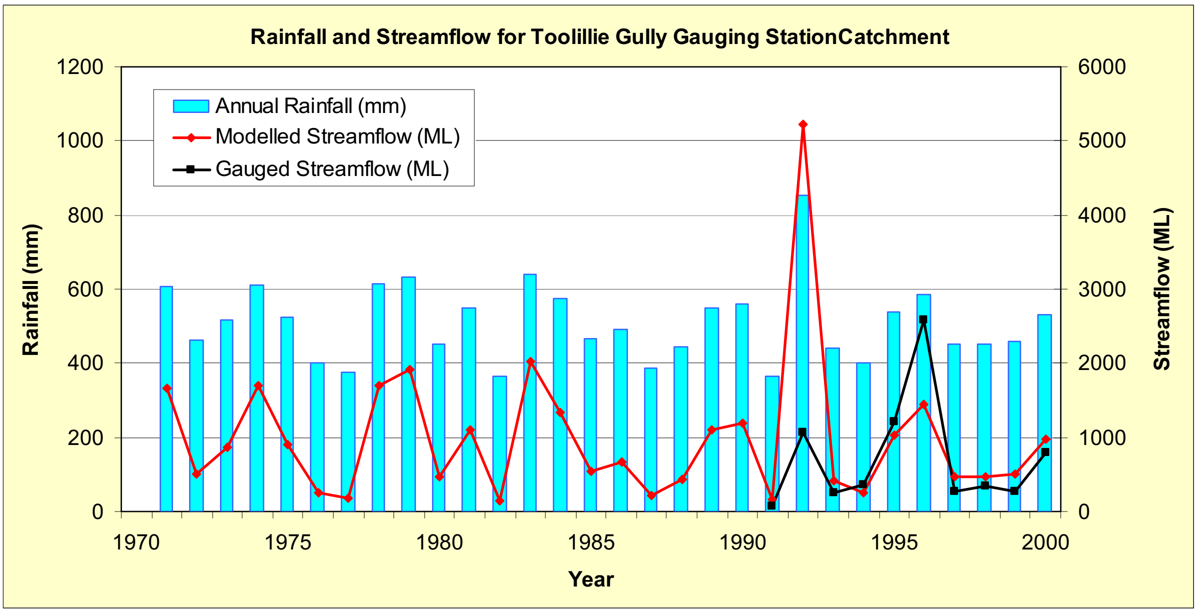

Figure 3.7 Annual rainfall, modelled streamflow and gauged streamflow for the Toolillie Gully gauging station (AW512503) catchment.

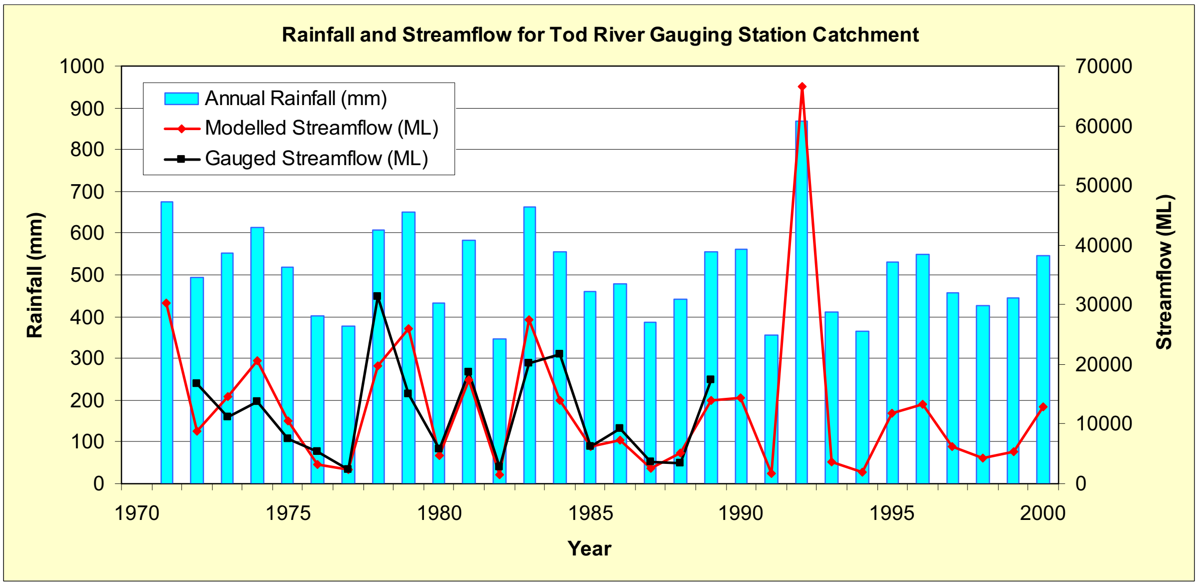

Figure 3.8 Annual rainfall, modelled streamflow and gauged streamflow for the Tod River (Poonindie) gauging station (AW512500) catchment.

Values for runoff coefficient are provided in Table 3.2. These were calculated by dividing the average of the gauged streamflow data for the period of available record (not the modelled data) with the mean annual rainfall average over the catchments for the period 1971–2000. The runoff coefficients may be compared to the runoff coefficients derived for catchments elsewhere as part of other hydrological studies (for example Teoh 2002, p.67; Heneker 2003, p.55; Savadamuthu 2004, p.29). From the foregoing studies, the runoff coefficients for the sub-catchments of several westerly-flowing catchments of the Mount Lofty Ranges range from 0.11–0.28. For the dryer easterly-flowing catchments the runoff coefficients are lower,

Table 3.2 Runoff coefficients for gauged catchments.

Gauged catchment	Average annual runoff coefficient
Toolillie Gully (AW512503)	0.047
Tod River (Poonindie) (AW512500)	0.066

0.06 for the Marne River catchment and 0.09 for the Bremer River catchment. This comparison indicated that the runoff coefficients of the Tod River (Poonindie) catchment are much lower than those of catchments in the Mount Lofty ranges.

The rainfall-runoff relationship used in the modelling for this study was based on the tanh function given below. Due to limited availability of gauged streamflow data, a single rainfall-runoff relationship was used for the whole of the Tod River catchment. This was based on the gauged data from the Toolillie Gully and Tod River (Poonindie) gauging stations (described previously).

The rainfall-runoff relationship was based on the tanh hyperbolic function as below;

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

where Q = mean annual runoff (mm)
P = mean annual rainfall (mm) averaged across the catchment
L = notional initial loss parameter
F = notional ongoing loss parameter.

The values of L and F were derived iteratively by setting one of them subjectively and using a curve fitting routine (based on minimum root-mean-square error) to determine the other value. A curve fitting technique could be used to determine both L and F, however, this method tends to bias the fit to the higher values and produces very large errors for smaller values and it is the smaller values (very low runoff in low rainfall years) that are the most critical. The final values (L = 180; F = 630) were chosen following several trials and based on examination of plots of the tanh relationship (Fig. 3.9), and by running the GIS-based model and comparing the model runoffs at both stations with the actual gauging data (Fig. 3.10).

There were two possible outliers in the data for Toolillie Gully gauging station catchment. These are for the years 1992 and 1996 (Fig. 3.7). The outlier for 1992 can be explained by very high rainfall (859 mm cf mean of 510 mm) late in the season when extensive grass cover and climatic conditions were conducive to high evapotranspiration and evaporation rates leading to lower runoff than would be expected for the rainfall (B. Murdoch, DWLBC, pers. comm., 2005). The outlier for 1996 was not investigated but could have been due to a high-intensity rainfall event(s). It was not possible to allow for these extreme cases in a simple annual rainfall-runoff relationship. However, apart from these two data points, it was considered that the final relationship would be a reasonable representation of the annual rainfall-runoff characteristics of the whole Tod River catchment.

The mean annual rainfall averaged over the Tod–Poonindie gauging station catchment is ~510 mm (Section 3.1.2). From the tanh rainfall-runoff relationship (Fig. 3.9), this produces a runoff of 25 mm. In a wet year (e.g. 1971 with an annual rainfall of 675 mm), the runoff indicated from the tanh rainfall-runoff relationship would be ~85 mm. This is a 240% increase in runoff for a 32% increase in rainfall. More importantly, in a dry year (e.g. the years 1982, 1991 and 1994 with ~350–365 mm of rainfall), the runoff would be only ~5 mm. This is a five-

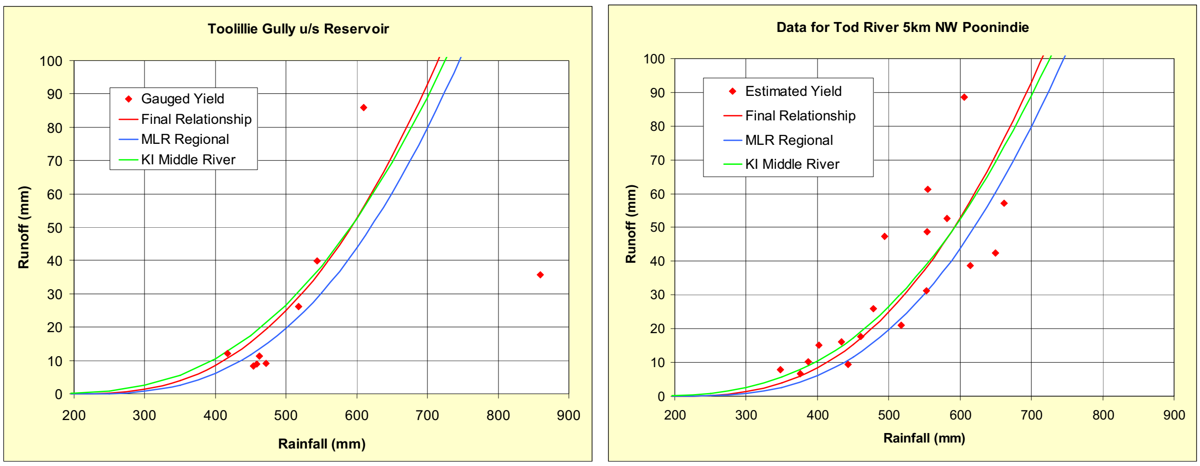

Figure 3.9 Gauged catchment yield plotted against rainfall averaged over each catchment for the Toolillie Gully and Tod River gauged catchments. Also shown are plots of the final tanh rainfall-runoff relationships and those for the Mount Lofty Ranges region and Middle River, Kangaroo Island, for comparison.

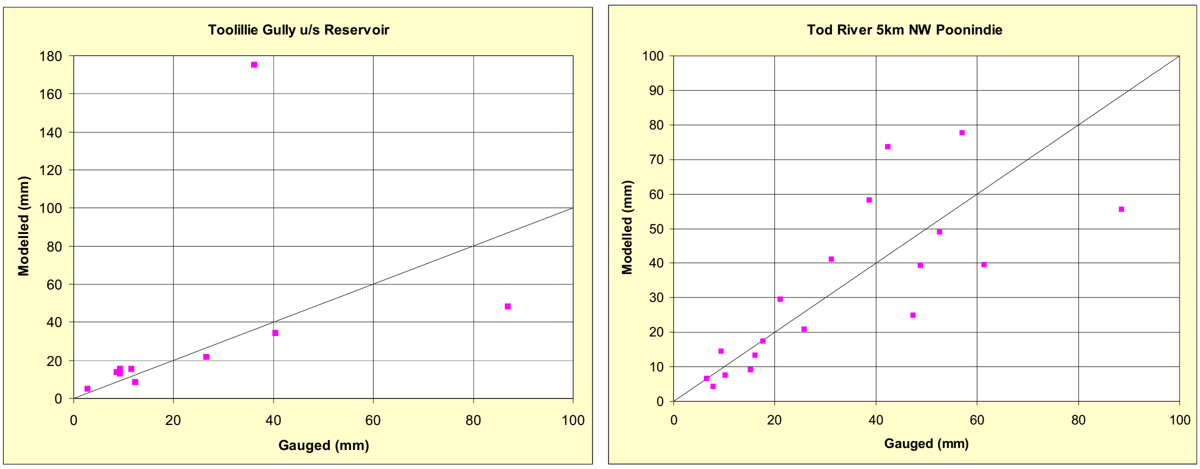

Figure 3.10 Runoff modelled with the final tanh rainfall-runoff relationship plotted against gauged runoff for the Toolillie Gully and Tod River gauged catchments.

fold reduction in runoff for a 31% reduction in rainfall, which has major climate change implications. The foregoing figures are supported by the rainfall and streamflow monitoring data as shown in Figure 3.9.

This dramatic change in runoff for relatively small changes in rainfall is typical of other catchments in South Australia as indicated by the tanh rainfall-runoff relationships for the Mount Lofty Ranges catchments and for Kangaroo Island, shown in Figure 3.9. Of greatest concern is the large reduction in runoff in dry years as the impacts of farm dams (and other water-harvesting activities) are likely to be a lot more severe. The modelled farm dam impacts investigated in this study included the impacts in dry years, with results presented later.

3.4 EVAPORATION

Evaporation is the transfer of moisture into the atmosphere from a exposed water surface such as a farm dam or reservoir and by the process of evapotranspiration from plants. The latter is not specifically addressed in this study due to the use of a simple rainfall-runoff relationship. However, evaporation from farm dams has been shown to account for a significant loss of water of the order of 20–25% of farm dam capacity over the summer months in the Mount Lofty Ranges (McMurray 2003). It is therefore important to have accurate evaporation data available for use in the modelling to estimate the evaporation losses from farm dams.

3.4.1 STATION HISTORY

The only monitoring station recording evaporation on lower Eyre Peninsula is the station ‘Port Lincoln (Tod River)’ BoM station number 18181, which is located within the Tod River catchment near the Tod River Reservoir. Operations at the station commenced in 1933 and continue to the present day, albeit with a varied history. The equipment comprised a standard sunken tank during 1933–57 (a bird guard being fitted around 1935), a square sunken tank during 1960–69, and a class–A pan with standard bird guard from 1968 to the present day (B. Murdoch, DWLBC, pers. comm., 2005).

Evaporation data in electronic format was available from the BoM database from 1 January 1968 to 18 March 1994 (all based on the class–A pan). These data were recorded daily, with few missing records. From 1994 data were collected by SA Water and entered into the DWLBC Hydstra database under station number A5120506 (previously AW512506). DWLBC also holds data from prior to 1968 in electronic format although these data are not all daily records.

3.4.2 MONTHLY DATA FOR MODELLING

For the modelling component of this study, monthly evaporation data were used for the period 1968–84 as this period overlapped available data from evaporation stations in the Mount Lofty Ranges that were used for comparison purposes. A plot of the monthly means for the Tod River Reservoir stations and for the comparison stations is given in Figure 3.11.

For the period 1968–85, the annual mean for the Tod evaporation station was 1515 mm. The winter period was taken as May to November inclusive, with a winter mean evaporation of 476 mm, a figure used to estimate evaporation losses during winter (as explained in Section 2.3.3). The summer mean (December to April inclusive) was 1039 mm, although this figure was not used in the model.

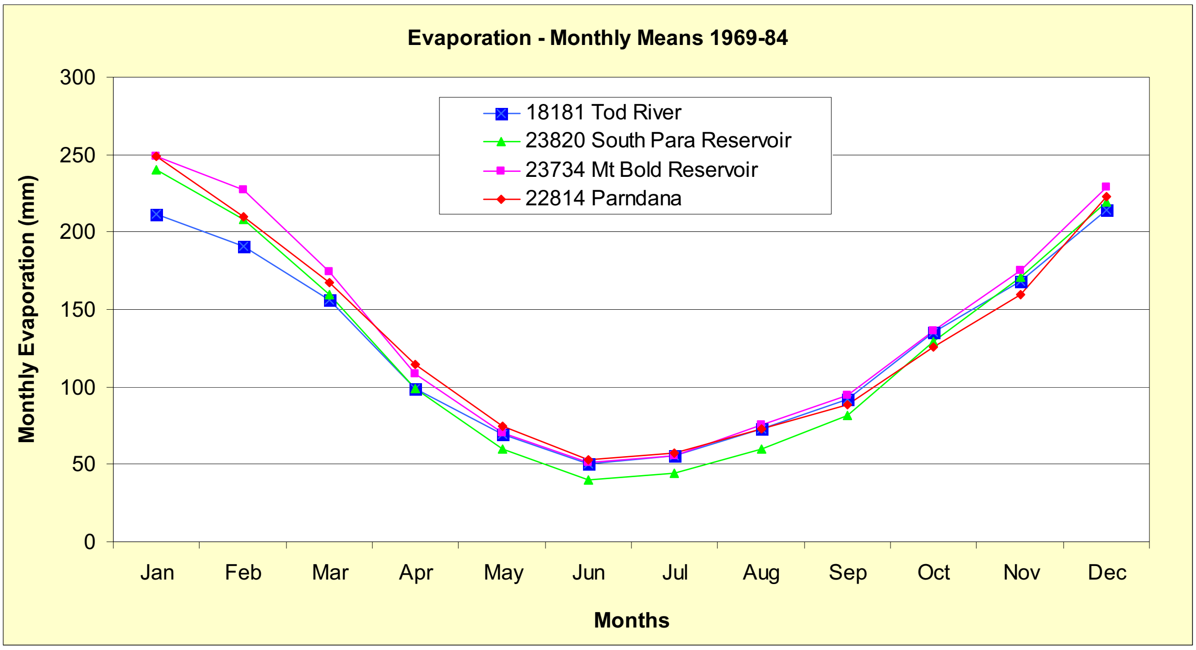

Figure 3.11 Monthly mean evaporation for the Tod River Reservoir evaporation station (number 18181) and other near-region stations for comparison.

3.4.3 LONG-TERM EVAPORATION RECORD

As data are available from 1933 to the present day, it should be possible to investigate long-terms trends in evaporation for the study area. However, the equipment was changed from a sunken tank to a class–A pan in 1968. These two different types of equipment exhibit different evaporation characteristics that lead to a step change in the data of the order of 13%, the class–A pan producing the higher readings. Attempts were made to change to earlier sunken tank data to align with the later class–A pan data using homogeneity tests and correlations with other stations. However, due to a combination of reasons, the confidence in the validity of this work was low (B. Murdoch, DWLBC, pers. comm., 2005). Therefore, the data was analysed in two separate batches, one for each of the periods using the sunken tank and the class–A pan.

The annual evaporation data together with the period means and trend lines are shown in Figure 3.12 for the period 1933–68 inclusive (data from the sunken tank), and in Figure 3.13 for the period 1968–99 inclusive (data from the class–A pan). Both the figures are drawn using the same vertical scale that enables the different evaporation rates recorded by the two types of equipment to be seen. The mean for the period 1933–68 was 1269 mm, and 1467 mm for the period 1968–99. Note again that this difference is due to the different equipment types and not due to climatic change.

Of greatest interest is the trend over the longer term. There is a slight downward trend in evaporation in the period 1933–68 (Fig. 3.12) and a larger downward trend in evaporation in the period 1968–99 (Fig. 3.13). By looking at the evaporation data, it can be seen that the downward trend started in the early 1970s. This has implications for climate change investigations.

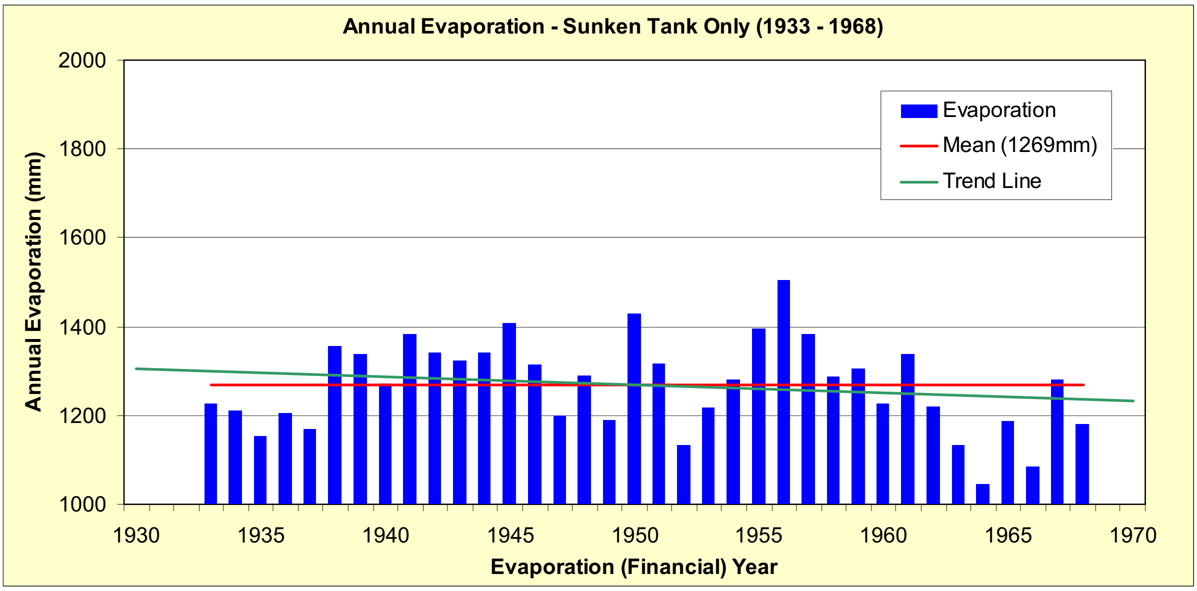

Figure 3.12 Annual evaporation data from the sunken tank in use from 1933 to 1968, and the mean and trend line. Tod River Reservoir BoM station number 018181.

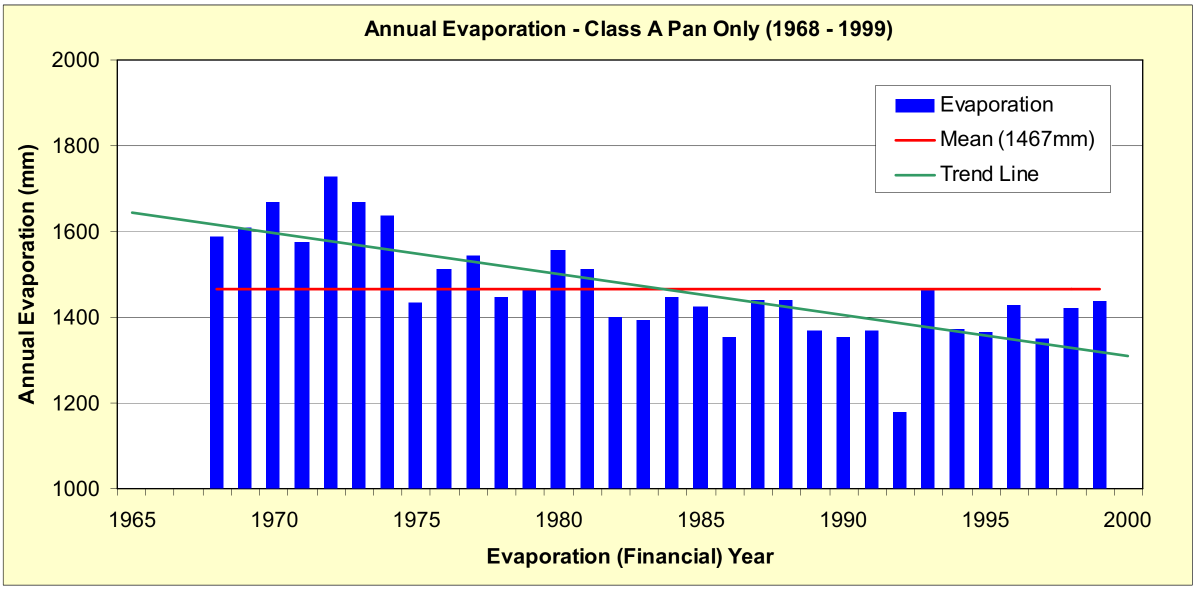

Figure 3.13 Annual evaporation data from the class-A pan in use from 1968 to1999, and the mean and trend line. Tod River Reservoir BoM station number 018181.

4. FARM DAM IMPACT MODELLING

4.1 OVERVIEW

The modelling of farm dam impacts involved estimating runoff using a rainfall-runoff relationship and determining the percentage of water removed due to farm dams (the sum of evaporation losses and extractions). The percentages were divided into environmental stress categories for each stream reach. The final step determined the contributing area or catchment for each stream reach.

The model was run for the 30-year climatic period 1971–2000. A series of maps was produced showing the spatial distribution of the level of environmental stress (due to farm dam impacts) across the Tod River catchment for the median and also a wet-year and a dry-year to show possible extreme-case scenarios. The types of model outputs are described in Section 5.2, and maps are provided and described in Sections 5.3–5.5.

4.2 RASTER DATA

The model was based on a type of GIS data known as raster data, usually simply referred to as grids. Raster data (or grids) are a rectangular mesh or net of cells where each cell has a numeric value.

The rectangular grid can represent any area of the earth's surface, hence each cell has coordinates representing its position on the earth's surface. The study area can be of any shape (such as a catchment boundary), and the size of the rectangle is set to ensure that the study area is covered.

Cells outside of the study area, but still within the rectangle, have a null value. Other cells in the mesh have numeric values that represent any natural or imaginary phenomenon. Examples include elevation (as in a DEM), land use, soil type, rainfall and runoff. The cells are usually exactly rectangular and can be of any size. The size of the cells is chosen so as to adequately capture the changing phenomenon they represent. Typical cell sizes range from a few metres or less for a very high definition DEM (intended to capture subtle changes in elevation) to 5 km or more for a continent-wide rainfall grid (intended to show only the major variations in rainfall).

A cell size of 25 m was chosen for this study as experience has shown that this adequately represents data conforming to standard 1:50 000 scale mapping standards. However, cell sizes up to 100 m are considered adequate for the type of modelling work used in this study.

4.3 MODEL DESCRIPTION

The model was a GIS-based annual step model (using raster data or grids) run with rainfall data for the 30-year period 1971–2000 inclusive. The main steps of the model are described below and illustrated in the block diagram in Figure 4.1.

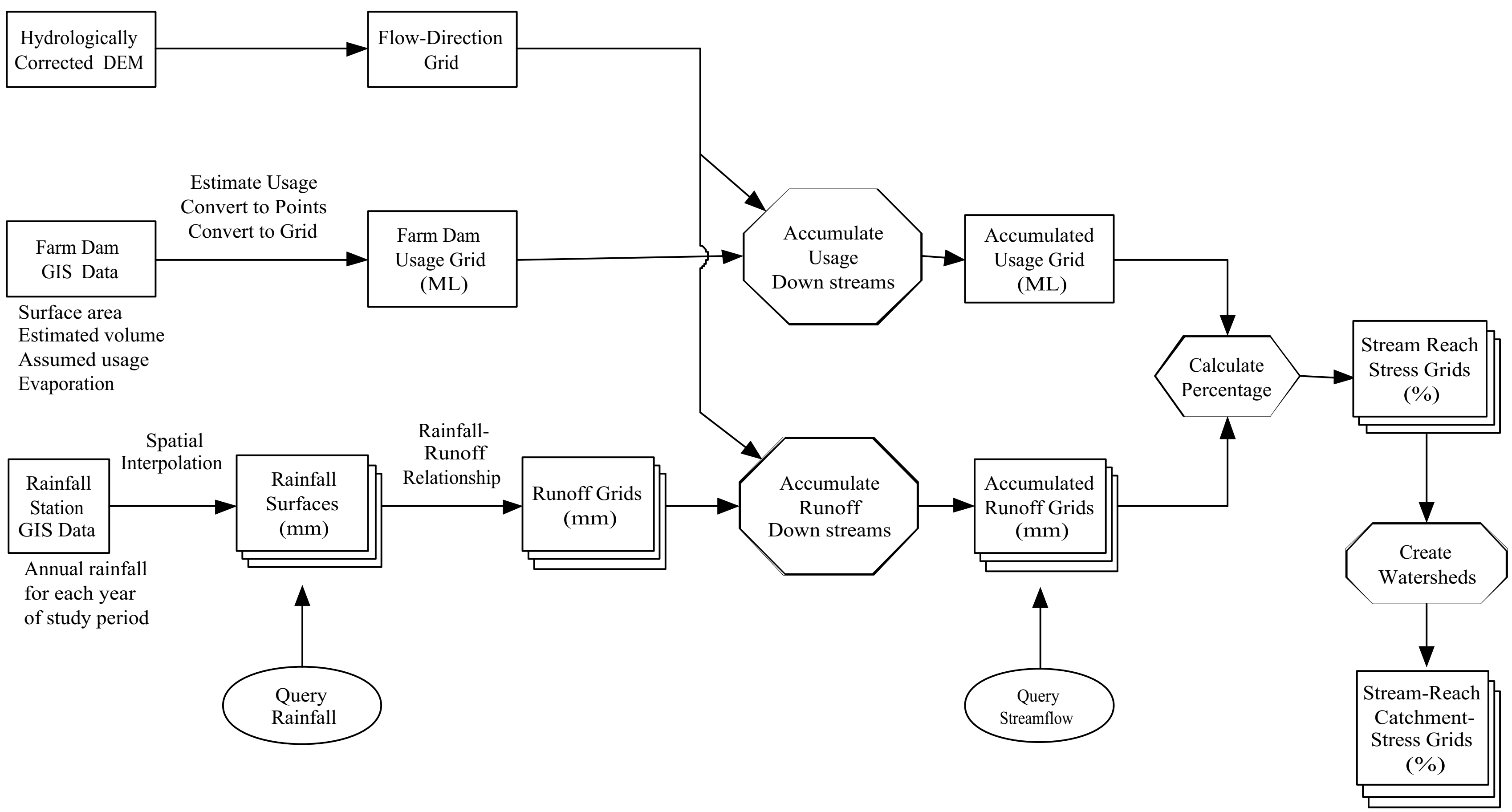

Figure 4.1 Block Diagram of the GIS-Based Annual-Step Farm Dam Impact Model.

1. Create a hydrologically corrected DEM and a flow-direction grid.
2. Obtain GIS data of farm dam outlines; calculate surface areas; estimate storage capacities; and determine evaporation and extraction volumes (as described in Section 2.3). Convert to a GIS-point dataset and convert this to a grid with single cells representing each farm dam, with the cell values equal to the volume of water removed (the sum of evaporation and extraction).
3. Use the flow-direction grid to direct the flow accumulation process to accumulate the volumes of water removed by farm dams down all flow paths. The result is a grid of the total volume of water removed (sum of evaporated and extraction) due to farm dams at all points on all flow paths (in streams and on hillsides).
4. Obtain GIS data of rainfall stations (both actual and virtual rainfall stations as described in Sections 3.1.1 and 3.1.5) with annual rainfall for each year of the study period as attributes of the GIS dataset.
5. From the GIS rainfall station dataset, create annual rainfall surfaces (using the TIN spatial interpolator and convert to grids as described in Section 3.1.5) for each year of the study period (30 GIS grids for each of the years 1971–2000 inclusive).
6. Create surfaces of runoff (one for each year of the study period) from each of the annual rainfall surfaces using the rainfall-runoff relationship (described in Section 3.3).
7. Use the flow-direction grid to direct the accumulation process to accumulate runoff down all flow paths for each of the runoff grids. The result is a set of GIS grids (one for each year of the study period) of the volume of runoff at all points on all flow paths (in streams and on hillsides).
8. Determine the percentage of water removed by farm dams from the grid of accumulated volume of water removed by farm dams as a percentage of the accumulated runoff grids (one for each year of the study period). Divide the range of percentages into a set of environmental stress categories for each stream reach. These are mapped to show the level of stress placed on watercourses.
9. Determine the contributing catchment areas for each level of environmental stress for each year of the study period and produce maps. These maps show the relative level of farm dam development across all areas based on the impact of water removed due to the combined effect of all farm dams in each area.

5. RESULTS AND DISCUSSION

5.1 OVERVIEW

The results of analyses of farm dam and hydrological data are presented in earlier sections, and are summarised in Section 6. Statistics on farm dams were given in Section 2.3, statistics on rainfall in Section 3.1, streamflow in Section 3.2, and evaporation in Section 3.4.

The results presented and discussed in this section are the outputs of the farm dam impact modelling. Note that as mentioned previously, this study considered only the impact of farm dams and did not consider any effects due to harvesting of water for water supply purposes.

5.2 FORMAT OF THE RESULTS

There are two main types of output from the modelling for each of the 30 years of the study period (1971–2000) plus medians. The two types are as below:

- Stream Stress Levels. These are GIS stream-based line datasets showing the level of environmental stress on each reach of the stream network. Levels of environmental stress are based on modelled percentages of water assumed to be removed due to usage and evaporation from farm dams. These provide a guide as to the level of stress placed on the riparian environment for each stream reach.
- Catchment Stress Levels. These are GIS area-based polygon datasets showing the level of environmental stress within stream-reach catchments. The levels of environmental stress are those at the lowest downstream point within each stream-reach catchment. These provide a guide as to where additional farm dams may or may not be allowed, and also provide a more graphic assessment of the overall level of stress across the whole catchment and the spatial distribution of that stress.

The levels of environmental stress used in the above datasets have been divided into categories (or classes) that are based on the levels of environmental impact caused by removal of streamflow as given in Section 2.3.1. These categories are listed in Table 5.1 together with the colours used to represent these stress levels in Figures 5.1–5.3.

Three sets of results are presented — the median of the results from each year of the study period (Fig. 5.1); results from 1982, the driest year of the study period (Fig. 5.2); and results from 1971, the second wettest year (Fig. 5.3). The second wettest year was selected for presentation as it was considered likely to be more typical of a wet year as the wettest year (1992) had much higher rainfall than other wetter-than-average years (Fig. 3.2).

In each of Figures 5.1–5.3, the left frame (a) shows the spatial distribution of rainfall for each scenario; the centre frame (b) shows the levels of environmental stress within each stream reach; and the right frame (c) shows the levels of environmental stress in each stream-reach catchment.

Table 5.1 Levels of environment impacts considered to be caused by various levels of removal of streamflow from streams.

Percentage streamflow removed	Displayed colours (Figs 5.1–5.3)		Likely environmental impact
0–10%	Green		Minimal impact
10–20%	Light green		Impacts to sensitive species
20–30%	Yellow	}	Significant impact
30–40%	Orange		
40–50%	Red		
50–100%	Purple	}	Major environmental change within 25 years (>50%)
>100%	Dark blue		

5.3 MEDIAN ENVIRONMENTAL STRESS LEVELS

Figures 5.1(b) and (c) show that around two-thirds of the stream reaches and stream-reach catchments are not subject to serious environmental stress due to the impact of farm dams (shown in green). The modelling indicates that farm dams remove <10% of the median streamflow, which is considered to have minimal environmental harm. Further, the majority of remaining reaches and stream-reach catchment areas have 10–20% of median streamflow removed, which is likely to impact only on sensitive species (shown in light green). It is recommended that further studies investigate whether any sensitive species are present in the study area.

Relatively small lengths of stream reaches and stream-reach catchment areas are subject to significant environmental impact (shown yellow and orange) or major environmental impact (shown red, purple and blue). These high-stress areas are due to farm dams situated high in the catchment where the accumulated runoff is low or, as in the far north of the catchment, a relatively large farm dam (estimated volume 49 ML) situated low in a stream branch. All further farm dam development should be precluded from these areas (Fig. 5.1(c)) until on-site studies are undertaken to confirm the results of this study.

5.4 DRY-YEAR SCENARIO

The driest year of the 1971–2000 study period (based on the annual rainfall averaged across the Tod–Poonindie gauging station catchment) was 1982 (Fig. 3.2). The modelled results for this year are presented in Figure 5.2.

Figure 5.2(b) shows that the majority of stream reaches have >20% of streamflow removed due the impact of farm dams (show in yellow, orange, red, purple and blue). This suggests that at first glance these stream reaches may be subjected to high environmental impacts. Similarly, Figure 5.2(c) shows that all the stream-reach catchments (based on the stress level in the stream reach at the lowest downstream point of each stream-reach catchment), except for Meadows Creek sub-catchment in the south, may also be subject to high environmental impacts. However, rainfall variability is normal, resulting in frequent occurrences of lower than average rainfall as shown by the analysis of long-term rainfall in Section 3.1.3. Therefore, before any management actions on farm dam development are made, it is advised that further investigations are undertaken to address the relationships between dry-year scenarios and environmental impacts.

5.5 WET-YEAR SCENARIO

The wettest year of the study period (based on the annual rainfall averaged across the Tod–Poonindie gauging station catchment) was 1992. However, as shown in Figure 3.2, the total rainfall for this year is much higher than other wetter years. It was considered therefore, that a more typical wet year would be 1971, and the modelling results for this year are given in Figure 5.3.

As shown in Figures 5.3(b) and (c), the levels of environmental stress in stream reaches and stream-reach catchments are generally much lower than those for the median of all years. The instances of significant and major environmental impact are much lower but are still present in several locations. It may be considered acceptable for this to be allowed to remain provided there are no significant environmental assets endangered.

5.6 POSSIBLE INACCURACIES

No model can be assumed to give highly accurate results. In particular, with the modelling used in this study, there are weaknesses due to the use of an annual-step model rather than the usual daily-step model as acknowledge earlier (Sections 1.3 and 2.3.1). However, there are three main areas of potential inaccuracies in the model results and in the manner in which those results are interpreted:

- The degrees of environmental impacts for the given range of percentage removal of streamflow are believed to be indicative guidelines at this stage. It is not certain how much science is behind the figures used in this study. Further research on the topic was beyond the scope of this project.
- The long-term environmental impacts due to dry period. The relationship between dry period duration and environmental impacts is likely to be a complex issue and was not addressed in this study.
- The assumed usage of water from farm dams used in the model was the same for each year within the study period. In practice, it is highly likely that in a dry year with much lower runoff than average, landowners may have used less water than in the median scenario. The model may therefore exaggerate the amount of water removed in dry years.

Median Rainfall

(median of the stress for years 1971-200)

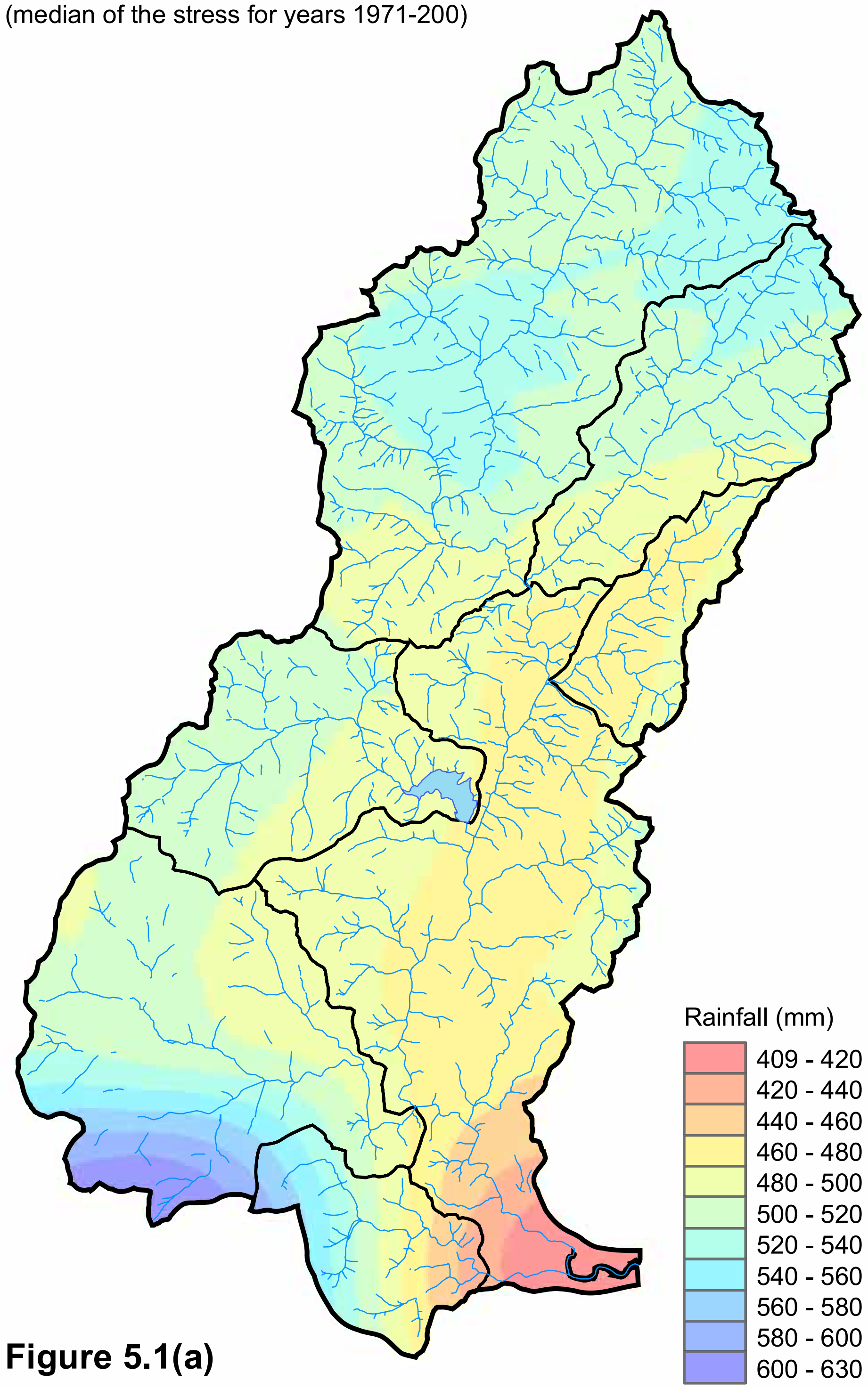

Figure 5.1(a)

Median Stream Stress

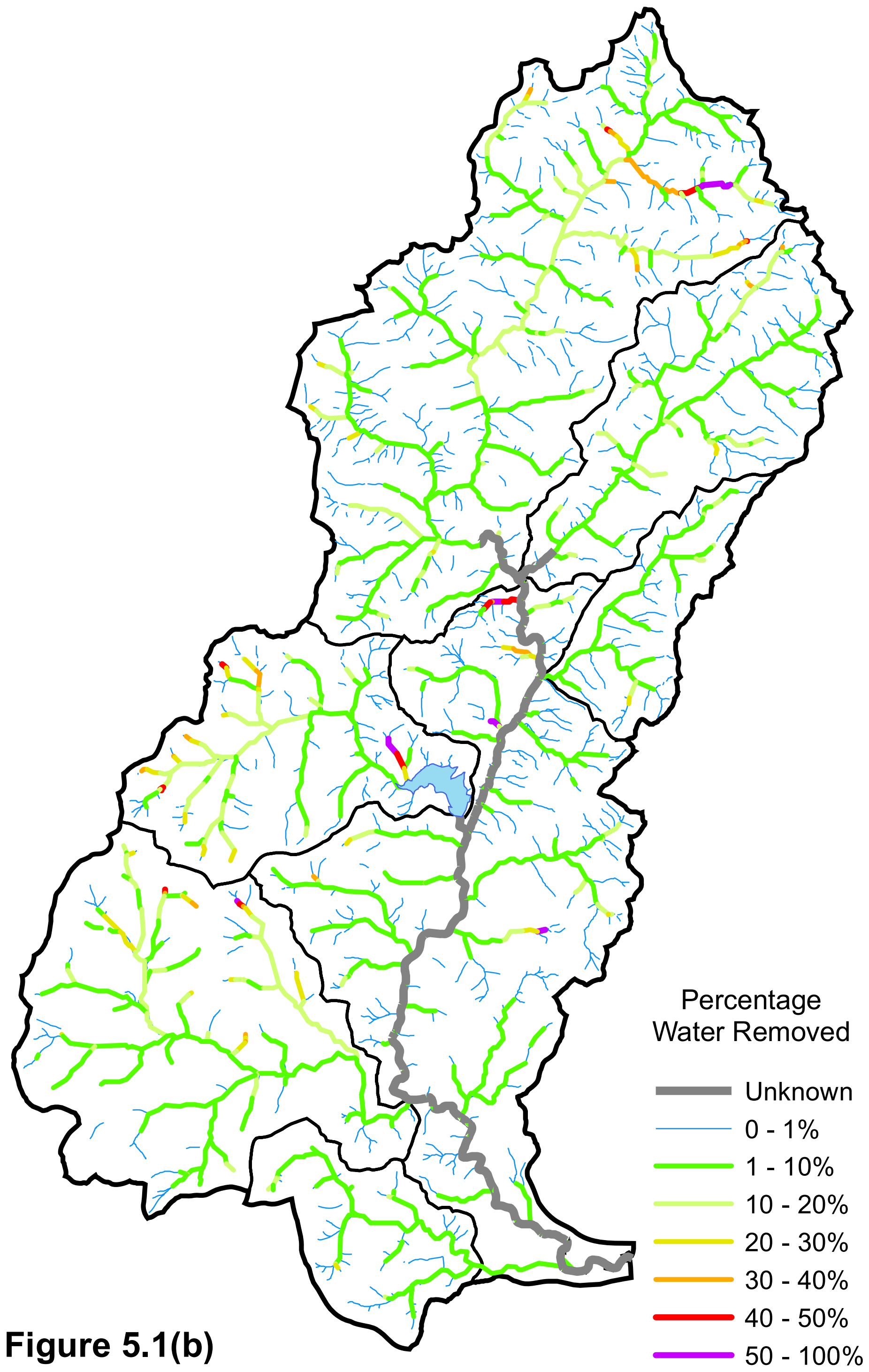

Figure 5.1(b)

Median Catchment Stress

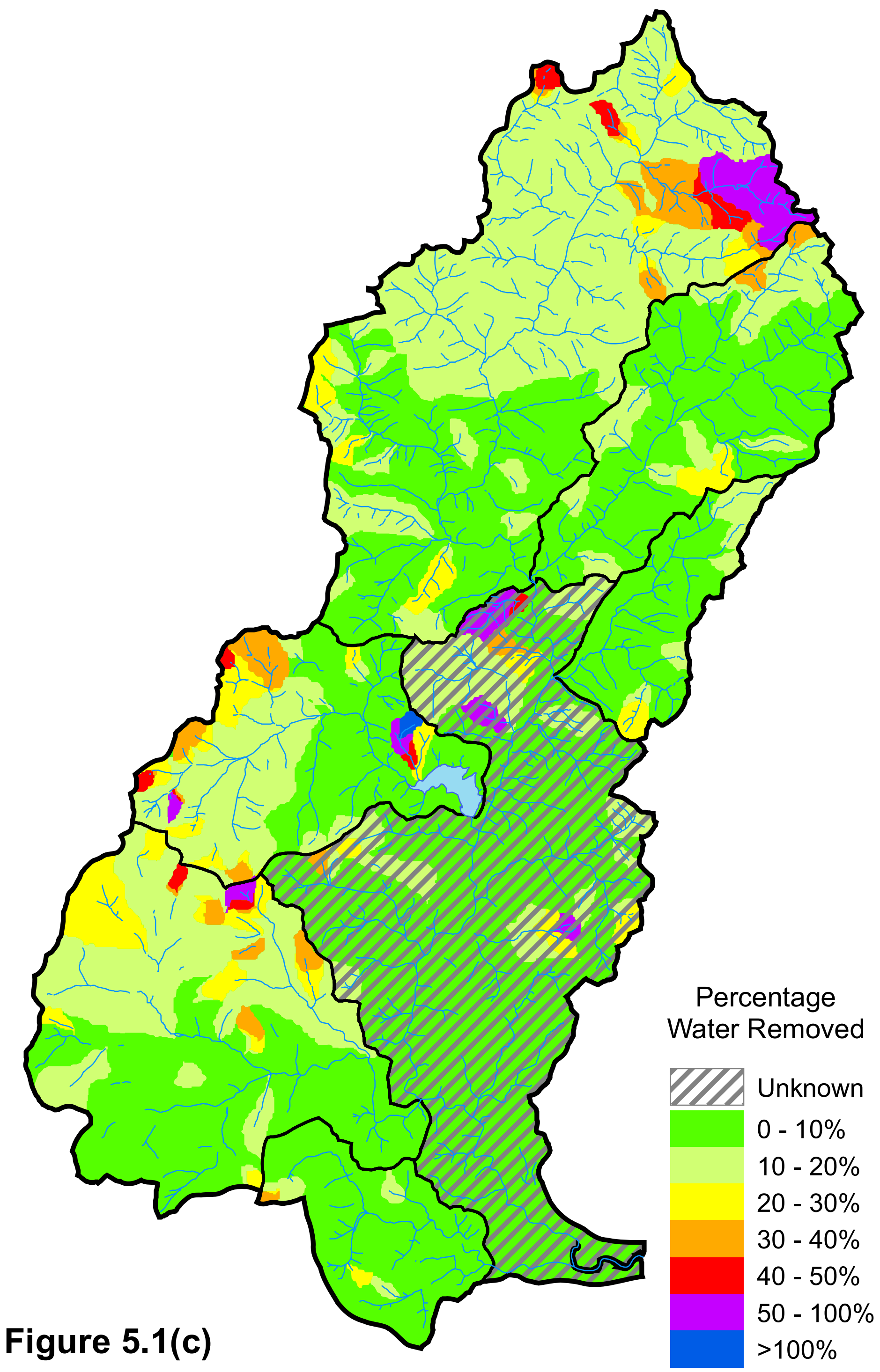

Figure 5.1(c)

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Produced By: Surface Water Group
Knowledge and Information Division
Department of Water, Land and Biodiversity Conservation

Projection: Lambert Conformal Conic
Datum: Geocentric Datum of Australia 1994
Date: February 2006

The streams and areas shown as unknown are affected by extractions for water supply that were not included in the modelling.

Stress levels are based on modelled runoff and water removed by farm dams (due to evaporation and assumed usage).
Runoff modelled with standard tanh equation where L = 180, F = 630.
Usage assumed as 0.25 of estimated volume over summer period.
Annual rainfall and evaporation data from Bureau of Meterology.

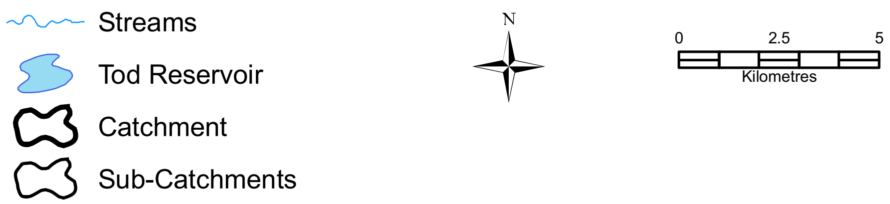

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Figure 5.1
Median Rainfall, Median Modelled Stream Stress Levels and Median Catchment Stress Levels

Rainfall 1982

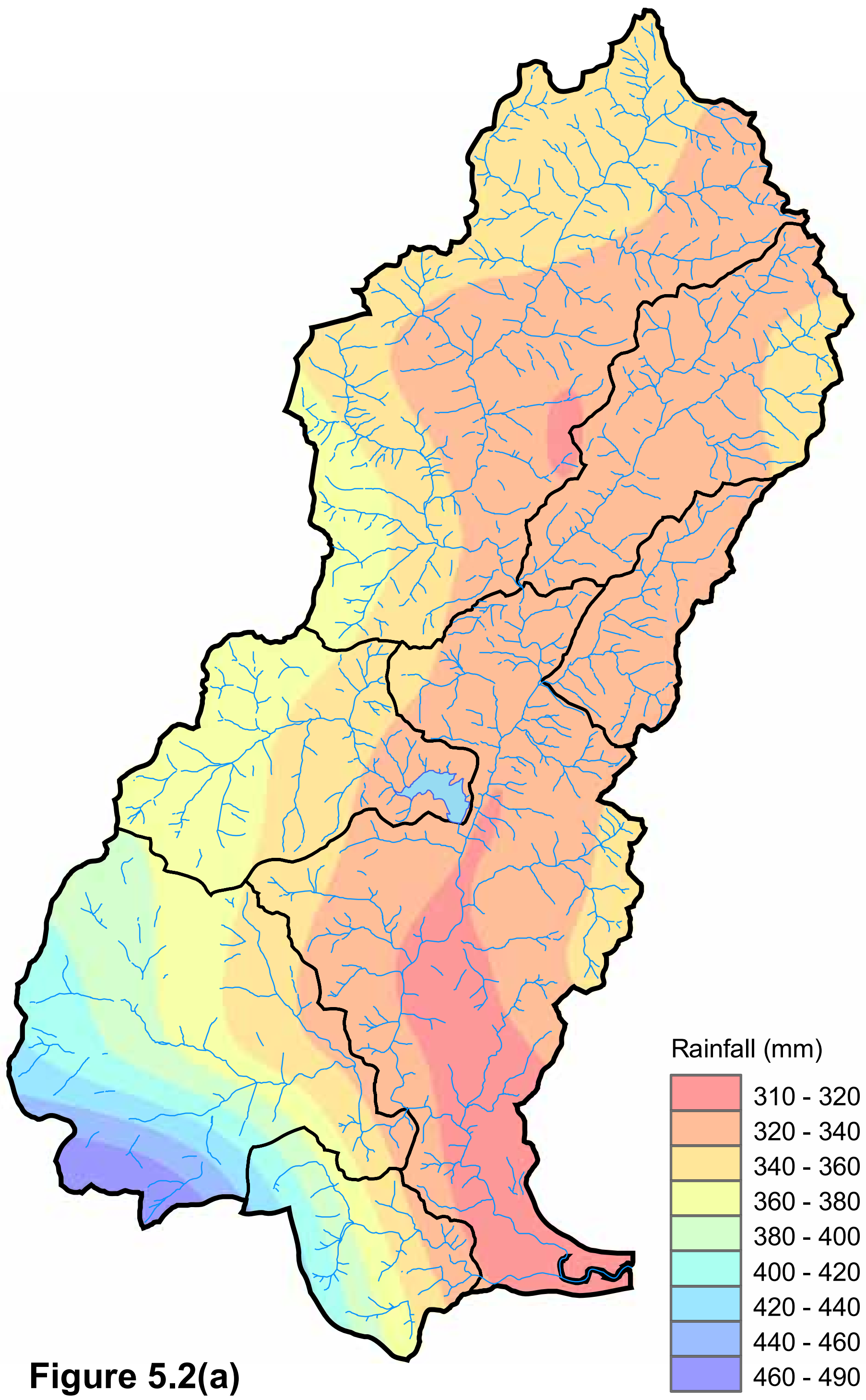

Figure 5.2(a)

Stream Stress 1982

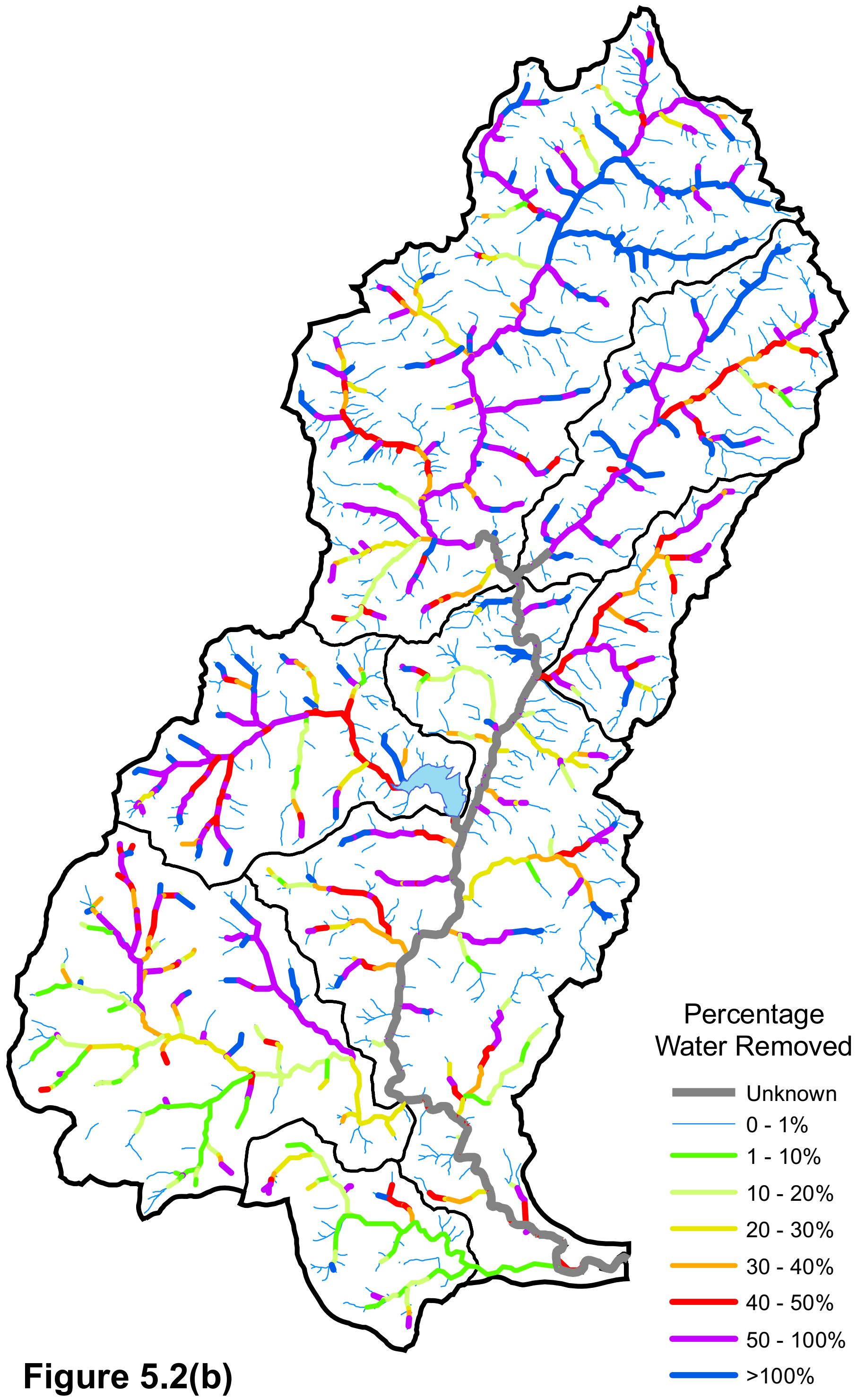

Figure 5.2(b)

Catchment Stress 1982

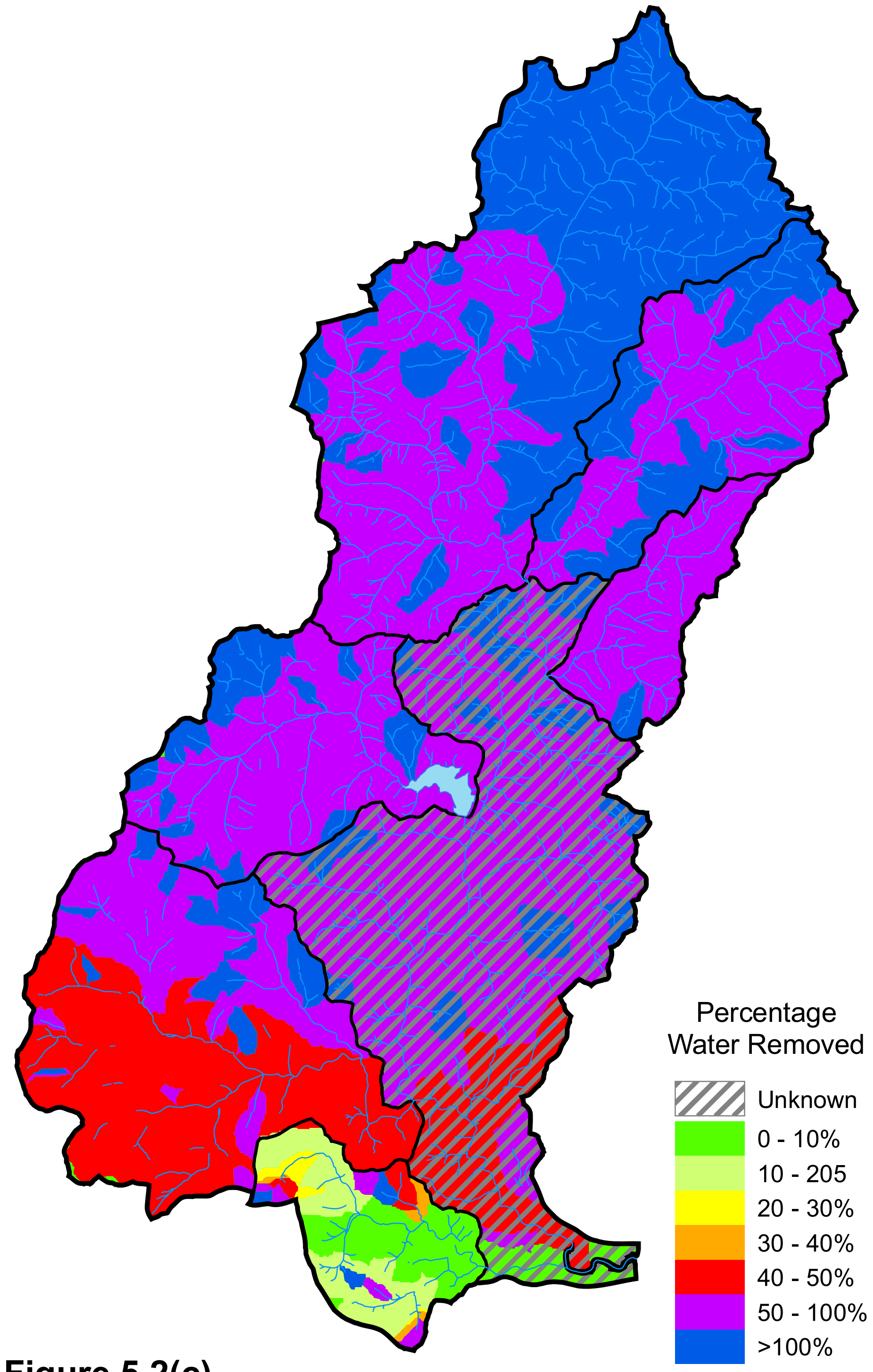

Figure 5.2(c)

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Department of Water, Land and Biodiversity Conservation

The streams and areas shown as unknown are affected by extractions for water supply that were not included in the modelling.

Stress levels are based on modelled runoff and water removed by farm dams (due to evaporation and assumed usage).
Runoff modelled with standard tanh equation where L = 180, F = 630.
Usage assumed as 0.25 of estimated volume over summer period.
Annual rainfall and evaporation data from Bureau of Meterology.

The year 1982 had the lowest rainfall averaged over the Tod-Poonindie gauging station catchment for the study period 1971-2000.

Streams
Tod Reservoir
Catchment
Sub-Catchments

N

0 2.5 5
Kilometres

Figure 5.2
Rainfall, Modelled Stream Stress Levels and Catchment Stress Levels for the Dryest Year (1982)

Rainfall 1971

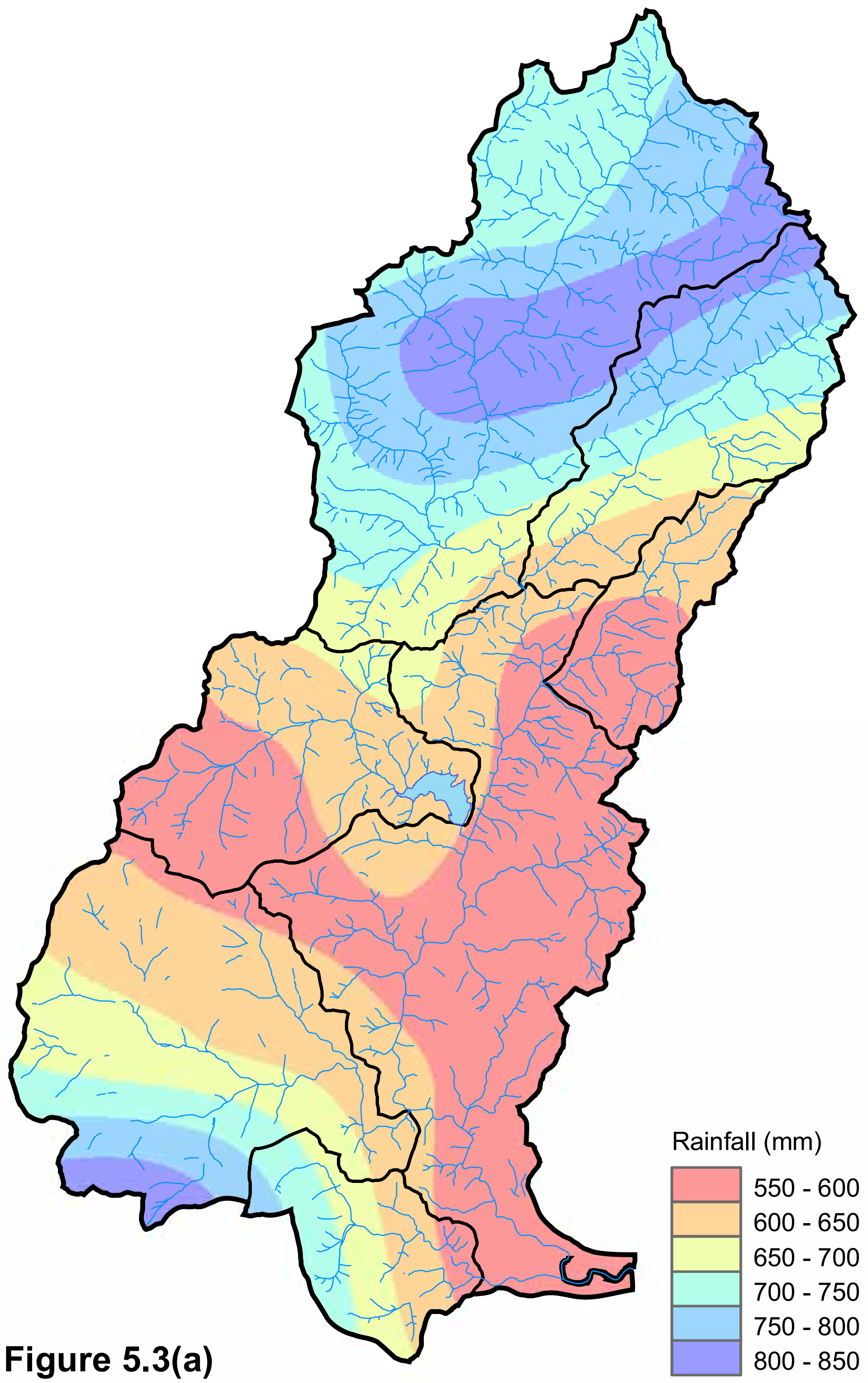

Figure 5.3(a)

Stream Stress 1971

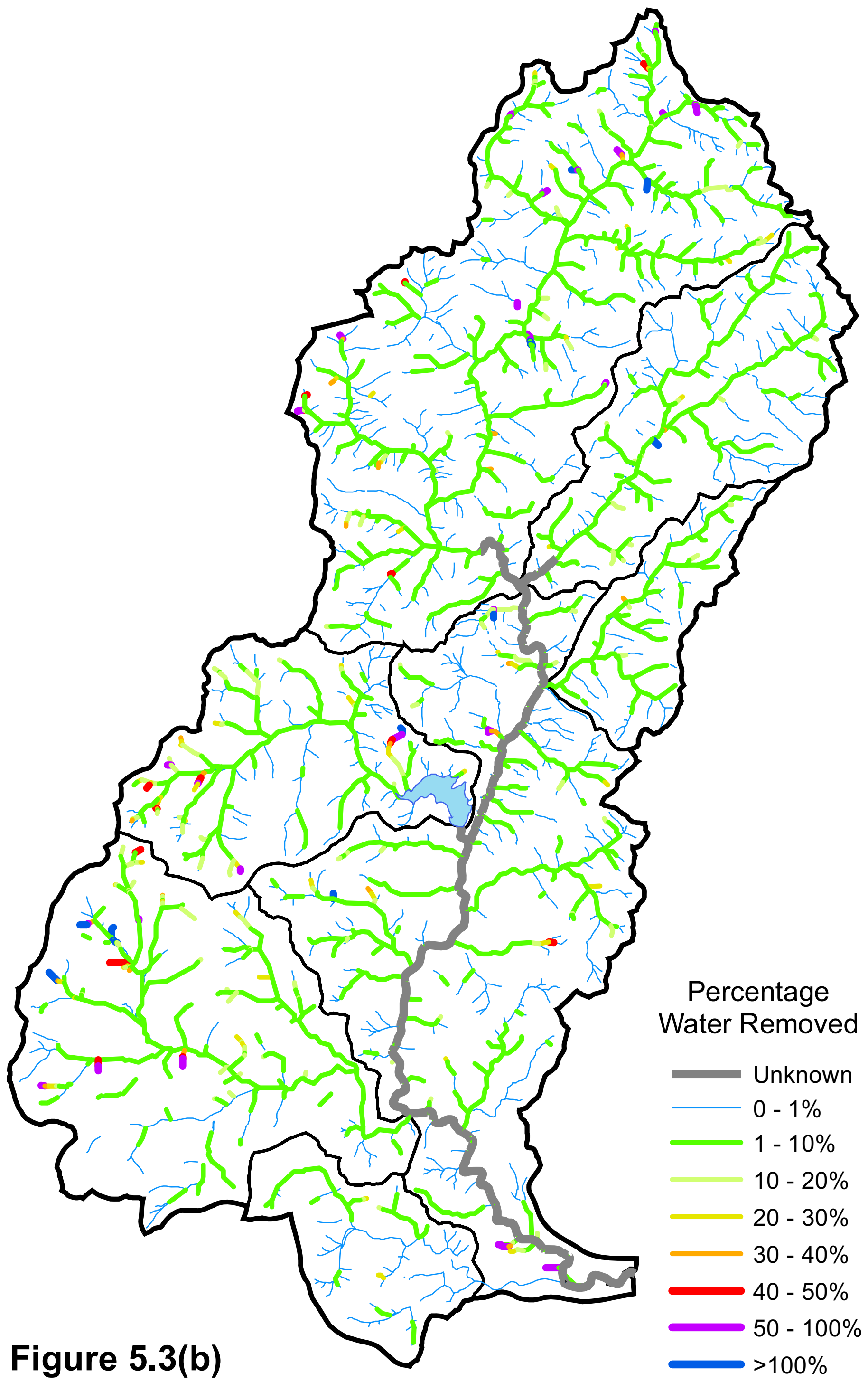

Figure 5.3(b)

Catchment Stress 1971

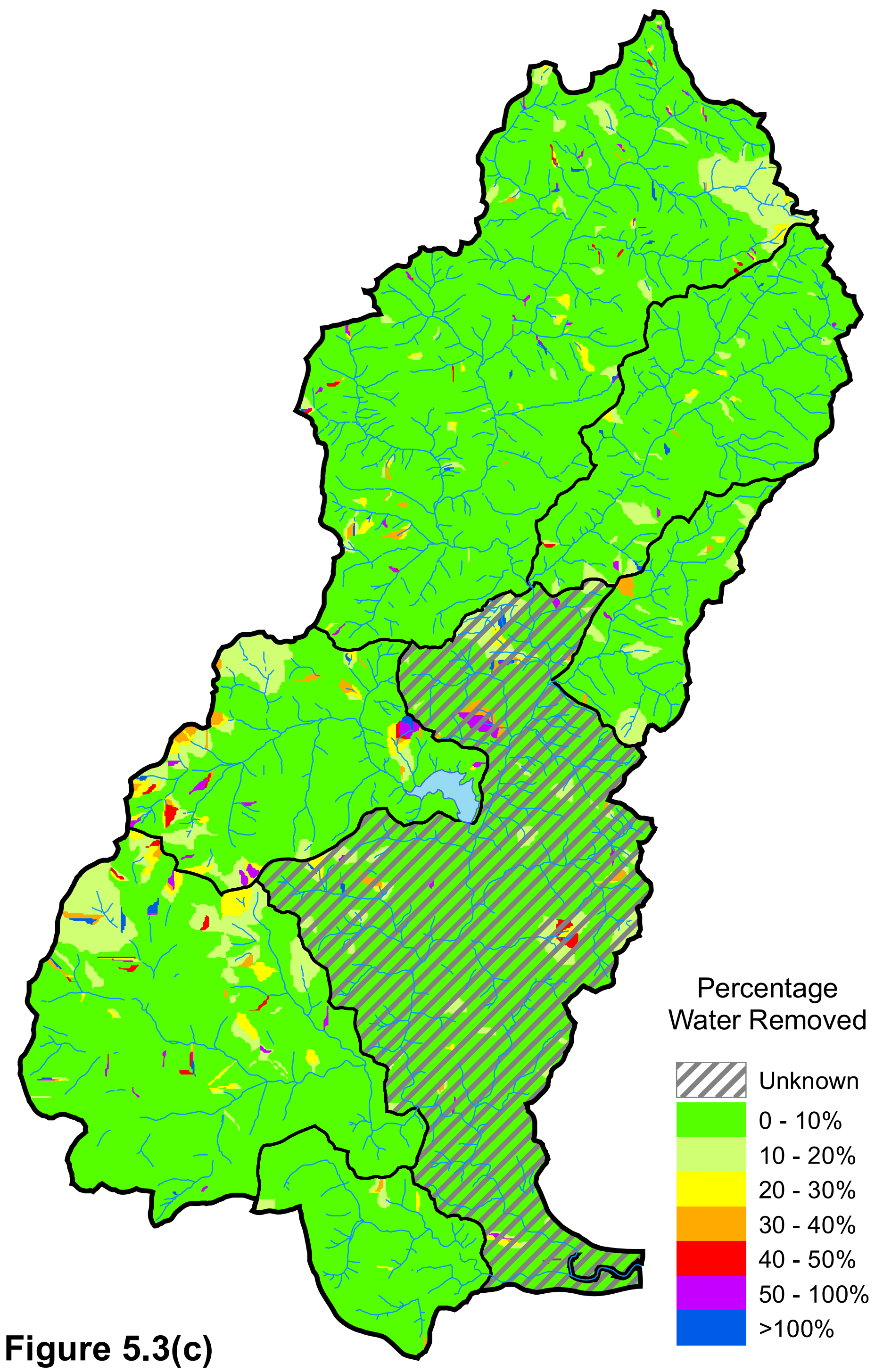

Figure 5.3(c)

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Projection: Lambert Conformal Conic
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The streams and areas shown as unknown are affected by extractions for water supply that were not included in the modelling.

Stress levels are based on modelled runoff and water removed by farm dams (due to evaporation and assumed usage).
Runoff modelled with standard tanh equation where L = 180, F = 630.
Usage assumed as 0.25 of estimated volume over summer period.
Annual rainfall and evaporation data from Bureau of Meterology.

The year 1992 had the highest rainfall averaged over the Tod-Poonindie gauging station catchment for the study period 1971-2000. However, this was much higher than other high years and the results from 1971 (the second highest rainfall year) were selected as being more representative of a wetter than average scenario.

Streams
Tod Reservoir
Catchment
Sub-Catchments

N

0 2.5 5
Kilometres

Figure 5.3
Rainfall, Modelled Stream Stress Levels and Catchment Stress Levels for a Wet Year (1971)

6. SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 HYDROLOGICAL DATA

The hydrological data used in this study, their spatial and temporal representativeness for analysis purposes and future data requirements are summarised in this section.

6.1.1 RAINFALL DATA

The data from eight BoM and DWLBC rainfall stations were used in this study. Some in-filling of data was required to provide complete annual records for the study period (1971–2000). Some of the stations used are now closed. Only one of the stations had a long-term record for long-term climate analysis (Figs 3.3–3.4). Spatially, the rainfall stations were reasonably spread across the catchment, although there was a distinct gap in the north-east of the catchment (upper part of the Pillaworta Creek sub-catchment, Fig. 3.1).

Although several virtual rainfall stations were created as part of the modelling, it is considered unreasonable to expect the large number of rainfall stations required for this type of spatial modelling. Thus, apart from the spatial gap in the north-east of the catchment, it was considered that the availability of rainfall data was adequate for the purposes of this study. However, it is important for future studies (for example more detailed studies, updates to this study, and climate-change monitoring) that adequate rainfall data continue to be collected. The availability of the wider region should be considered in association with the Tod River catchment in a review of suitable rainfall monitoring sites.

6.1.2 STREAMFLOW DATA

Although there were five streamflow monitoring stations within or close to the study area (Fig. 3.1), data from only two of these was suitable for use without further manipulation. These data were considered reasonable to permit a basic calibration of the relatively simple annual-step model.

In terms of on-going streamflow monitoring, there are some points of concern:

- There are on-going issues with equipment reliability and accuracy, particularly at the two sites at the diversion weirs. This would place serious doubt on the accuracy of more detailed hydrological studies if these were to be undertaken.
- It is believed that the main reason to install the four streamflow monitoring sites within the Tod River catchment was for water supply purposes. Now, streamflow monitoring is also vital for water allocation and environmental monitoring purposes.
- There are no other streamflow monitoring sites on Eyre Peninsula.

Due to the above, it is recommended an investigation into the reliability and accuracy issues with the streamflow monitoring sites be undertaken. As part of this investigations make recommendations and implement measures to overcome these problems. If water, land and environmental management are to be implemented based on as much science as is reasonably possible, continuous appropriately accurate streamflow monitoring data are required for a considerable period of time (a decade or more).

6.1.3 EVAPORATION DATA

Evaporation data were available from only one station within the catchment. However, BoM no longer recognises this station and the data has been collected since 1994 onwards by SA Water and stored in the DWLBC database. This is the only evaporation-monitoring site on lower Eyre Peninsula. Knowledge of evaporation is vital for hydrological studies (evaporation of water from farm dams is a major component of farm dam impacts) and for climate change monitoring. It is recommended that BoM be encouraged to take responsibility for this important site.

6.2 FARM DAM DATA

There are three components associated with farm dam data. These are (a) capture of the outline of farm dams, (b) estimates of storage volume, and (c) monitoring the temporal trend in farm dam development.

In relation to the capture of farm dam outlines, the data used in this study were from 2001 aerial photography. There may have been additional farm dams constructed since that time. Aerial photography is now available from 2004. It would be possible, as part of further studies, to update farm dam outlines from this photography and assess the degree of farm dam construction over the intervening period. It is recommended that farm dam development be monitored on a periodic basis to track the changing extent of surface water interception by farm dams. It should be noted that the routine aerial photography programs are no longer conducted for this area.

Estimates of storage volumes were made in this study using a volume–area relationship developed from farm dam surveys in the Mount Lofty Ranges and Clare districts. If further and more detailed hydrological studies are to be undertaken, it is recommended that a reasonable number of farm dams be surveyed within the Tod River catchment and the volume–area relationships investigated as recommended in McMurray (2004).

6.3 FARM DAM IMPACT MODELLING

A GIS-based, annual-step model was used to model runoff from rainfall using a rainfall-runoff relationship and simulate the removal of water due to usage and evaporation from farm dams. Results are presented as the percentage of water removed due to farm dams spatially over the whole study area and temporally for each year of the study period (chosen as 1971–2000). Although some effort is required in data preparation, the model is fairly simple to apply and can be readily re-run with updated farm dam data when this becomes available.

The results presented in Section 5 show that the median level of impact of farm dams is low over the majority of the catchment. Some stream reaches are subject to high levels of impact (significant or major environmental impacts) but these are generally fairly short reaches high in each stream branch. These high-impact stream reaches become even shorter in a wet year. There is potential for further farm dam development over the majority of the catchment subject to closer scrutiny of existing environmental conditions.

The situation becomes a lot more severe in a dry year. Nearly all stream reaches are highly impacted, potentially leading to significant or major environmental changes. It would appear from these results that there is no potential for further farm dam development, but that the combined volume of existing farm dams should be reduced.

To assess the implications of the impacts of the existing farm dams in dry years, it is recommended that the EPNRMB:

- assess the existing environmental assets (there may be sufficient information in Rixon et al. 2002) to determine the location and number of already stressed or particularly sensitive environmental assets
- investigate the long-term effect of dry years, as the occasional dry year may not cause as much impact as the results tend to indicate
- investigate the actual water usage from farm dams in dry years as the model may have incorporated over-estimated usage quantities.

GLOSSARY

Act (the). In this document, refers to the *Natural Resources Management Act 2004* (SA).

Annual adjusted catchment yield. Annual catchment yield with the impact of dams removed.

Aquifer. An underground layer of rock or sediment, which holds water and allows water to percolate through.

Biological diversity (biodiversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the ecosystems (see below) they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

BoM. Bureau of Meteorology.

Biota. All of the organisms at a particular locality.

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff at a particular point.

Catchment water management board (CWMB). A statutory body established under Part 6, Division 3, s. 53 of the *Water Resources Act 1997,* whose prime function under Division 2, s. 61 is to implement a catchment water management plan for its area.

Catchment water management plan. The plan prepared by a CWMB and adopted by the Minister in accordance with Part 7, Division 2 of the *Water Resources Act 1997*.

CWMB. Catchment Water Management Board.

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. Off-stream dams 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.

Dams, turkey nest dam. An off-stream dam that does not capture any surface water from the catchment above the dam.

DEM (Digital Elevation Model). A surface in which points of elevation are spaced at regular intervals so as to create a grid or lattice. These surfaces are usually derived from other elevation information such as contours or irregularly spaced spot elevations.

Domestic purpose. The taking of water for ordinary household purposes and includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares.

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

Ecological processes. All biological, physical or chemical processes that maintain an ecosystem.

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

Ecologically sustainable development (ESD). Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

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

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

Environmental values. The uses of the environment that are recognised as of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions. Those parts of environmental water requirements that can be met, at any given time. This is what can be provided at that time with consideration of existing users' rights, and social and economic impacts.

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.

EP. Eyre Peninsula.

EPNRMB. Eyre Peninsula Natural Resources Management (NRM) Board.

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

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

GIS (geographic information system). Computer software allows for the linking of geographic data (e.g. 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.

Grid, raster data. A method of storing and displaying spatial data. Areas are divided into rows and columns to form a rectangular grid structure. Each cell within this grid has its spatial location and attribute value stored implicitly within the ordering of the matrix. It is an abstract method of displaying real world data in a spatial context, often used to display rainfall and DEM's.

Groundwater. *See underground water.*

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

Hydrology. The study of the characteristics, occurrence, movement and utilisation of water on and below the earth's surface and within its atmosphere. *(See hydrogeology.)*

Hydstra. A suite of software for the water resources industries that allows environmental data management and analysis.

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

Megalitre (ML). One million litres (1 000 000 L).

ML. *See megalitre.*

MLR. Mount Lofty Ranges.

Model. A conceptual or mathematical means of understanding elements of the real world, which 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.

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.

Natural Resources Management Board. A body established under Chapter 3 Part 3 and includes a body appointed under that Part to be a regional NRM Board under the Act.

Prescribed area, surface water. Part of the state declared to be a surface water prescribed area under Section 125 of the Act.

Prescribed water resource. A water resource declared by the Governor to be prescribed under Section 125 of the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Reticulated water. Water supplied through a piped distribution system.

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.

Spatial interpolation. The procedure of estimating the value of features at unobserved sites within an area covered by observations. Contours are an example whereby they have been derived from a DEM through interpolation.

State water plan. The plan prepared by the Minister under Part 7, Division 1, s.90 of the *Water Resources Act 1997*.

Stream-reach. A specific portion of the length of a stream.

Stream-reach catchment. The area in which rainfall runoff would contribute, or flow into, a stream-reach.

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

Stormwater. Runoff in an urban area.

Surface. A representation of continuous surfaces interpolated from non-continuous sources through interpolation techniques.

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.

TIN (Triangular Irregular Network). A vector-based representation of the physical land surface, constructed of irregular nodes and lines with three-dimensional coordinates arranged in a mesh of non-overlapping triangles. TIN's are usually derived from DEM's.

To take water. From a water resource includes (a) to take water by pumping or syphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water in a watercourse from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir.

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

Water-affecting activities. Activities referred to in Chapter 7 Section 127 of the Act.

Water allocation. (a) in respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence; (b) in respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation.

Water plans. The State Water Plan, catchment water management plans, water allocation plans and local water management plans prepared under Part 7 of the *Water Resources Act 1997*.

Waterbody. Waterbodies include 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, which 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.

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 or 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 6 m.

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SILO. See Queensland Department of Natural Resources and Mines' web site for the SILO Patched Point Dataset (PPD). http://www.nrme.qld.gov.au/silo/ppd/PPD.html.

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