Farm Dam Volume Estimations from Simple Geometric Relationships

DWLBC Report 2004/48

Government of South Australia

Department of Water, Land and Biodiversity Conservation

Farm Dam Volume Estimations from Simple Geometric Relationships

Mount Lofty Ranges and Clare Regions
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 continues 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

Surface water use is vital to the economics of the Mount Lofty Ranges and Clare regions of South Australia. However, the rapid development of farm dams over the last decade or two has raised considerable concerns over the sustainability of water resources and the impacts on the ecosystems dependant on them. Detailed hydrological studies are being conducted on the major catchments of the region in order to quantify the impact of farm dam development and to recommend water resource management actions. Knowledge of the storage capacity of farm dams is an important input for these hydrological studies. This study reports on investigations into cost-effective techniques for estimating volumes of farm dams and other farm dam relationships.

This technical report contains:

a. A description of the methodology of the study of farm dam geometries;
b. The results and recommendations on volume estimations using both desktop techniques and cost-effective rapid field assessments;
c. The development of a relationship to estimate surface area from volume at capacities below full supply level for use in hydrological models; and
d. A review of historical volume-area relationships.

Volume-Area Relationships

The major focus of this study is the investigation of volume-area relationships that are used to estimate farm dam capacities from dam outlines digitised from remotely-sensed data (aerial photography or satellite imagery). An extensive review was undertaken of previous volume-area relationships and all available farm dam survey data from the Mount Lofty Ranges and Clare regions.

The results show that there is a large variation in farm dam geometries resulting in a wide range of possible volumes (up to 5:1) for any given surface area. There is also evidence in the sample data to indicate that farm dam geometries tend to vary between areas and/or catchments. A volume-area relationship is not, therefore, a good instrument for estimating the storage volumes of individual farm dams. However, a statistical advantage can be assumed when a volume-area relationship is used to estimate the combined volume of a reasonable number of farm dams, say within sub-catchments, as is the case with hydrological modelling.

It is recommended that as part of any detailed hydrological study in areas where farm dams are considered an issue, the most significant farm dams are surveyed, at least with the rapid field assessment method. This will provide a reasonable estimate of the storage capacity of these farm dams, and permit the suitability of a volume-area relationship to be determined and used to estimate the volume of the remaining farm dams. It is important that the costs of these surveys are incorporated into the project budgets at the planning stage.

The final recommended volume-area relationship for use in the majority of catchments or regions with a low demand for irrigation from surface water is as follows:

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); and

V = estimated volume (ML).

In catchments or regions with a high demand for irrigation from surface water, it is permissible to either increase volumes estimated with the above relationship by around 15-20% or use the following relationship:

For $A < 20\,000$ $V = 0.000215\,A^{1.26}$

For $A \geq 20\,000$ $V = 0.0028\,A$

where A = surface area (m^2); and

V = estimated volume (ML).

A study of data from a full topographic survey of farm dams shows that there is no benefit to be gained from estimating volume from geometric relationships that incorporates any of the following:

a. knowledge of the average slope immediately adjacent to the farm dams;
b. knowledge of the depth of the original gully in which the farm dams were constructed (as determined with desktop techniques); and
c. streambed slope measured across the outside length of the farm dam and farm dam wall.

Volume-area relationships should be used for estimating only the full capacity of farm dams, as estimates of volume have increasing errors as the capacity reduces.

Historical Volume-Area Relationships

The relationship from Billington and Kotz (1999) produced good average volume estimates form the surveyed farm dams from the Marne catchment, but generally over-estimated volumes from most other catchments that had a lower demand for irrigation from surface water.

The relationships from Pikusa (1999) and Sinclair Knight Merz (2001) produced good average volume estimates for farm dams under around 50 ML in catchments with a low demand for irrigation from surface water.

It was concluded that there was no advantage in the continued use of any of the existing volume-area relationships that were reviewed.

Volume-Area-Depth Relationship

The traditional volume-area-depth relationship used in rapid field assessment of farm dams is as follows:

$V = 0.4\,D_{max}\,A$

where V = volume (kL);

D_{max} = maximum depth (external wall height used as a surrogate)(m); and

A = surface area (m^2).

This study has shown that this relationship has produced good volume estimates on average when actual maximum depth is used. However, higher errors result particularly for larger farm dams, when the external wall height is used as a surrogate for maximum depth. Knowledge of the depth of the original gully (prior to farm dam construction) or the streambed slope is shown not to increase accuracy of maximum depth estimation. Operator discretion is therefore required in the determination of maximum depth particularly where the streambed slope is high.

It is recommended that the surface area is determined from digitised farm dam outlines rather than using simple in-field measurements, and the correctness of digitisation is checked during the field inspection.

Area-Volume Relationship

The following area-volume relationship was developed for determining surface area from volume at capacities less than full supply level:

$$A = A_{max} (V/V_{max})^{0.6}$$

where A = surface area (m^2) to be determined at volume V;

A_{max} = surface area (m^2) at maximum capacity;

V = volume (kL or ML) for which A is to be determined; and

V_{max} = volume (kL or ML) at maximum capacity.

This relationship is suitable for use in time-step hydrological models that simulate the impact of farm dams on runoff and the flow regime.

1. INTRODUCTION

1.1 BACKGROUND

In several regions of South Australia farm dams are seen as a critical issue. Several hydrological studies (e.g. Teoh 2003; Savadamuthu 2003; Heneker 2003) have investigated the impact of farm dams. These studies have shown that:

a. farm dams are capable of capturing a significant proportion of stream flow (i.e catchment yield), particularly in drier regions and in drier years;
b. farm dams have a major impact on the flow regime, especially the capture of low and early season flows. These low flows and early flows are important for water-dependant ecosystems; also
c. an important issue addressed by these and other studies involves water users' access rights to a finite resource.

In order to undertake these hydrological studies, it is important to know the number, location and volume of all farm dams. Accurate volumes for these farm dams can be determined from topographic surveys. However, this type of survey is time-consuming and very expensive when a large number of farm dams are involved, for example, there are over 22 000 farm dams within the Mount Lofty Ranges (Fig. 1.1), and it is therefore considered totally impractical to conduct full topographic surveys of all these farm dams.

An alternative method of determining the volume of farm dams is to use a rapid field assessment technique, which although less accurate, is considerably more cost-effective. In this technique the external wall height of each farm dam is measured, and the surface area determined from either digitised farm dam outlines or simple field measurements. The volume is then estimated from a volume-area-depth relationship ($V = 0.0004\ A\ D$). This method still requires all farm dams to be visited, and can still be expensive for reviews of a large number of farm dams.

A very cost-effective method, although at even further-reduced accuracy, is to use a desktop technique. The current practice is to produce geographic information system (GIS) data showing the size and shape of farm dams from ortho-corrected aerial photography (high definition satellite imagery may also be used). Farm dam volumes are then estimated using a volume-area relationship (e.g $V = 0.000215\ A^{1.26}$).

Since 1996 there have been several investigations in South Australia and elsewhere (e.g. McMurray 1996; Billington & Kotz 1999; Pikusa 1999; Sinclair Knight Merz 2001; and Maaren and Moolman 1985) that have produced different volume-area relationships, mostly from a small sample of farm dams and all in a single catchment. The availability of several volume-area relationships has produced a dilemma for hydrologists as to the choice of an appropriate relationship for a given catchment.

The purpose of this study is to analyse all available data; assess previous volume-area relationships; and make recommendations on the use of simple geometric relationships in hydrological modelling and assessments of farm dams.

1.2 AIMS

The aims of this study cover many aspects relating to geometric relationships of farm dams as listed below.

- To collate and analyse all available data from surveys of farm dams within the focus regions;
- Assess the accuracy of each of the existing relationships;
- Recommend the most appropriate volume-area relationship(s);
- Evaluate the accuracy of the volume-area-depth relationship currently used in rapid field assessments. This is a particularly important aspect of this study as the rapid field assessment technique is used in the majority of farm dam surveys presented in this study;
- Investigate methods of improving the accuracy of rapid field assessment techniques by incorporating additional simple in-field measurements or desktop-derived parameters; and
- Derive an area-volume relationship for use in time-step hydrological models (that are required to estimate surface area from reducing volume).

1.3 STUDY AREA

The study area was determined by the availability of farm dam survey data. Data was available for several areas within the Central Mount Lofty Ranges and in the Clare Prescribed Water Resources Area (PWRA) as shown in Figure 1.2, which also shows the number and size range of farm dams surveyed in each catchment and region.

The Mount Lofty Ranges commence south of Adelaide, South Australia, extending east of the city and continue to the north. The Clare PWRA is located approximately 80km north of Adelaide within the Northern Mount Lofty Ranges.

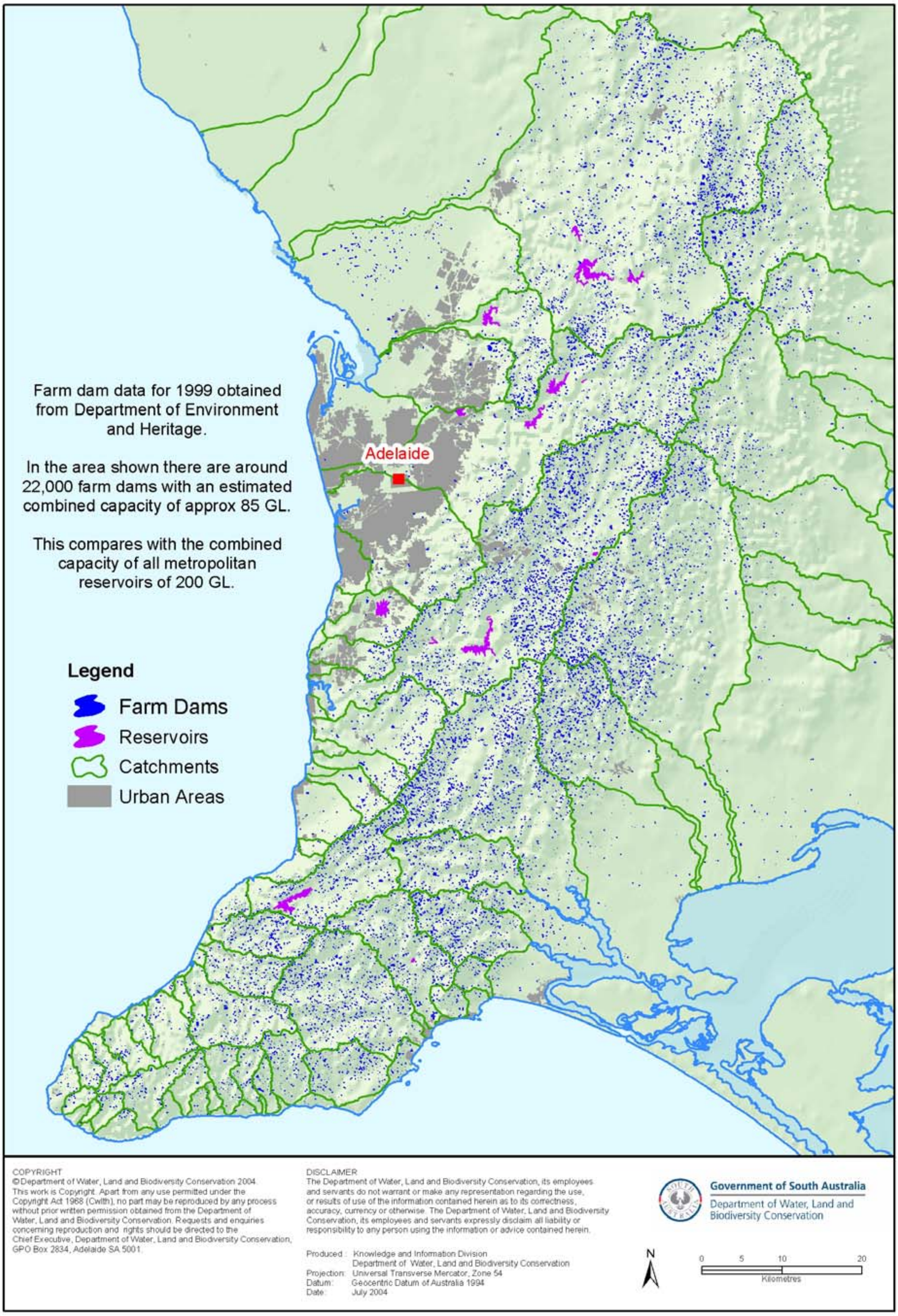


Figure 1.1 Farm Dams in the Mount Lofty Ranges.

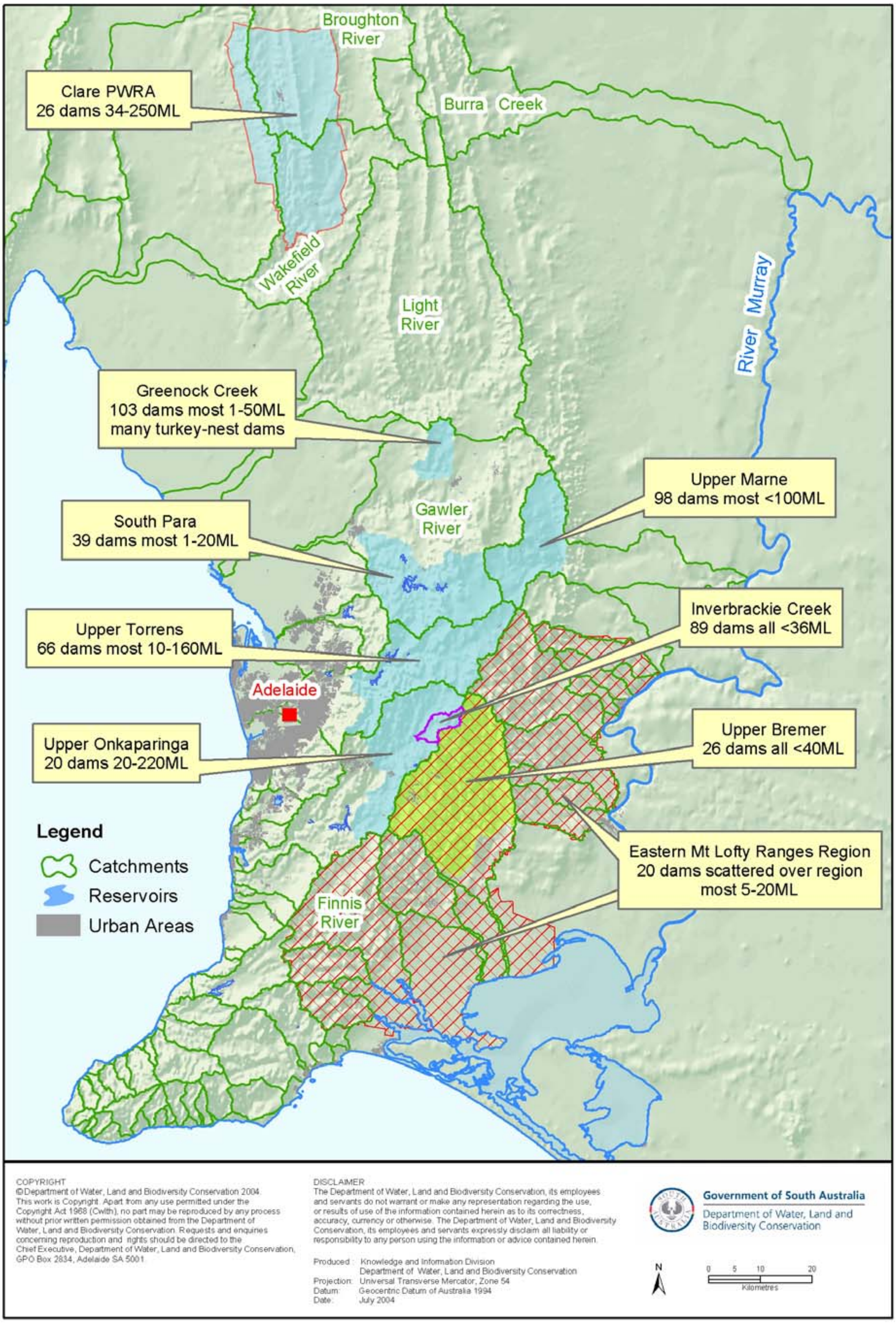


Figure 1.2 Surveyed Farm Dam Locations.

2. SURVEY DATA

2.1 DATA OVERVIEW

Over a period of time farm dams were surveyed within several catchments and regions as listed below (see also Fig. 1.2):

- Marne River catchment;
- Greenock Creek catchment (part of the North Para River catchment);
- South Para River catchment;
- Onkaparinga River catchment;
- Inverbrackie Creek (part of the Onkaparinga River catchment) catchment;
- Bremer River catchment;
- River Torrens catchment;
- Eastern Mount Lofty Ranges (EMLR); and
- Clare Prescribed Water Resources Area (PWRA).

The data from the Bremer River and River Torrens catchments were based on full topographic surveys by qualified surveyors. All other data was from rapid field assessments (this method is described in the Appendix).

Collectively, the data comprised a total of 487 farm dams. Table 2.1 lists the number of farm dams surveyed in each catchment or region and the numbers in each size class.

Table 2.1 Number of surveyed farm dams in each catchment or region and in each size class and total numbers.

Size Class	Surface Area (m^2)	<800	800–1500	1500-3000	3k–5k	5k–9k	9k–20k	20k–40k	>40k	Totals All Classes	Total Number In Catchment
	Approx Vol (ML)	<1	1–2	2–5	5–10	10–20	20–50	50–100	>100		
Catchment	**Date**										
Bremer River	1984	4	6	6	3	4	3	_	_	26	2040
Inverbrackie Ck	1998	37	12	14	10	12	4	_	_	89	150
Marne River	1998	20	16	15	16	13	11	5	2	98	680
Greenock Crk	2000	5	18	35	28	9	7	1	_	103	150
South Para R.	2001	4	12	11	7	3	1	1	_	39	980
Onkaparinga R.	2002	–	_	_	_	_	4	14	2	20	2700
Clare PWRA	2002	_	_	_	_	_	3	14	9	26	1570
River Torrens	2003	_	_	_	3	24	25	9	5	66	1350
EMLR	2004	_	3	2	6	5	3	1	_	20	6080
Totals		**70**	**67**	**83**	**73**	**70**	**61**	**45**	**18**	**487**	

Size classes are based on surface area, and the volumes size classes given are approximate only.

PWRA = Prescribed Water Resources Area.

EMLR = Eastern Mount Lofty Ranges.

The size classes shown in Table 2.1 (and elsewhere in this report) are based on surface area which is the independent (or known) variable in volume-area relationships. The equivalent volumes are approximate only because the volume (the dependant or unknown variable) depends on which volume-area relationship is used. The size class break points were chosen subjectively.

There were some deficiencies in the data from a purely statistical or scientific viewpoint, for example, the farm dams selected for survey were chosen mostly on logistical considerations rather than random selection. Further, within some catchments or regions some size classes were not well represented, or the sample size was low compared to the total number of farm dams in that region. However, that was the data to hand, and it was considered that a sample size of 487 farm dams was a reasonable number on which to base this study. Due allowance was made for low numbers of farm dams in some catchments and size classes in various aspects of this study.

2.2 SURVEYED CATCHMENTS

This section briefly describes each catchment or region where farm dams were surveyed and provides some details of the respective surveys.

2.2.1 BREMER RIVER CATCHMENT

The Bremer River catchment covers a large area on the eastern (and drier) side of the Mount Lofty Ranges. The predominant land use in this area is grazing.

The Engineering and Water Supply (E&WS) Department (now SA Water) conducted a full bathometric (or topographic) survey on a sample of farm dams in 1984. The surveyed farm dams were scattered over the upper reaches of the Bremer River catchment and included some farm dams within the upper Angas and upper Finniss catchments. Data for 26 of these was available from an earlier study (McMurray 1996). Sizes ranged from 0.2 to 39 ML. The sample size was very small (26 farm dams) for such a large catchment containing over 2000 farm dams. Also, the number of farm dams in each size class was very low (three to six). Therefore, caution was used when this data was considered in isolation from the other data.

Further, most of the surveyed farm dams had a lower volume for a given surface area when compared to the majority of surveyed farm dams in the other catchments. The reasons for this were not established. It was postulated that this could be due to changed construction techniques following increased agricultural development since 1984 (South Central Region Network 2000). It is also possible that the lower volume-area ratios of these farm dams are typical of the drier eastern regions. This uncertainty resulted in this data being regarded as potentially atypical, and was therefore given a lower importance during the analyses.

2.2.2 INVERBRACKIE CREEK CATCHMENT

Inverbrackie Creek catchment forms a sub-catchment of the upper Onkaparinga River catchment on the western side of the Mount Lofty Ranges. The main land use in the Inverbrackie Creek catchment is cattle grazing with some viticulture and cropping.

A rapid field assessment was conducted on 89 farm dams during January 1998. The surveyed sizes ranged from 0.1 to 36 ML. The sample set was a large percentage of the 150 farm dams in this catchment, with reasonable numbers in all the represented size classes (Table 2.1). Therefore, this data was considered to be representative for farm dams in this catchment (with a predominantly grazing land use).

2.2.3 MARNE RIVER CATCHMENT

The Marne River catchment is on the eastern side of the Mount Lofty Ranges and drains to the River Murray. Within the upper Marne River catchment there are large areas of grazing as well as areas of intensive viticulture with large farm dams used for irrigation. The rainfall is significantly lower than most westerly catchments in the Mount Lofty Ranges. The relatively high demand for water for high value crops (e.g. grape vines) has led to intensive farm dam development, particularly in the south-western part of the catchment.

A sample of 98 farm dams was surveyed using the rapid field assessment method during February 1998. Sizes ranged from 0.1 to 228 ML. The survey was part of a project to update information on water resources within the catchment. A Notice of Restriction was later declared, and subsequently Prescription.

The sample set contained a statistically reasonable percentage (13%) of the total number of the farm dams in this catchment, with good representation in most size classes (Table 2.1). This data, therefore, was considered to be representative for farm dams in this catchment (a catchment with a high demand for a limited resource).

2.2.4 GREENOCK CREEK CATCHMENT

The Greenock Creek catchment is part of the North Para River catchment, which forms a major portion of the Gawler River catchment. The Greenock Creek catchment is intensively developed with viticulture and also contains cropping and some grazing. Relatively low runoff and the high value viticulture activities, has lead to an intensive demand for surface water resources.

A rapid field assessment survey was conducted on 103 farm dams during October and November 2000. Sizes ranged from 0.4 to 70 ML. The survey was part of the assessment process after a Notice of Restriction was declared.

Many of the surveyed farm dams were recorded as “turkey nest dams” or “excavated tanks”. These are off-stream farm dams usually without their own catchment area. Water stored in these farm dams is usually obtained from sources other than stream flow, such as groundwater or mains water. The presence of a large number of turkey nest dams could be attributed to limited available surface water and the high value viticultural crops.

The initial assessment of this data showed the turkey nest dams to have a larger volume for a given surface area than the majority of farm dams surveyed in the other catchments. These farm dams were considered atypical when compared to the most likely farm dam types found across the whole Mount Lofty Ranges.

The spread of surveyed farm dams across the size classes was uneven, with only a small number of farm dams in several of the size classes (Table 2.1). Therefore, caution was used when this data was considered in isolation from the other data.

2.2.5 SOUTH PARA RIVER CATCHMENT

The South Para River catchment is part of the Gawler River catchment, a large catchment that drains westward to the Gulf of St Vincent. This catchment contains three major water supply reservoirs (Warren Reservoir, the South Para Reservoir and the Barossa Reservoir). The major land uses include large areas of forestry plantation and conservation parks, together with grazing and some viticulture.

There were approximately 980 farm dams in this catchment. A sample of 39 of these was surveyed during February and March 2001 as part of a water resource assessment project. Sizes ranged from 0.3 to 73 ML.

The surveyed farm dams were not well spread across the overall geographic distribution of farm dams, and were not distributed evenly across the size classes, with some size classes containing a low number of farm dams (Table 2.1). For these reasons, this sample set may not have been representative of farm dams within this catchment. Any analysis of volume-area relationships for this catchment cannot be considered valid for farm dams greater than around 10 ML.

2.2.6 ONKAPARINGA RIVER CATCHMENT

The Onkaparinga River catchment is a major catchment on the western side of the Mount Lofty Ranges. There are a variety of land uses in this catchment including urban development, forestry, grazing, horticulture and viticulture. The Mount Bold Reservoir is also located within this catchment.

There were around 2700 farm dams located upstream of Mount Bold Reservoir. Twenty of the larger farm dams (20 to 222 ML) were surveyed using the rapid field assessment method during July and August 2002. These farm dams were surveyed as part of this study in order to provide more data on larger farm dams, as these were not well represented in the available data. The data was intended to be considered in association with data from other surveys and not to be representative of farm dams within this catchment.

From observations during the survey, one of the surveyed farm dams was used for golf-course irrigation, and many others appeared to be for pasture or crop irrigation. However, there was no obvious requirement for the large capacity of many of the surveyed farm dams given their apparent use.

2.2.7 CLARE PRESCRIBED WATER RESOURCES AREA (PWRA)

The Clare Prescribed Water Resources Area (PWRA) is located approximately 80 km north of Adelaide in a northern section of the Mount Lofty Ranges. The region covers the upper reaches of both the Wakefield River (flowing south) and the Broughton River (flowing north). Although the area contains grazing and cropping, it is noted primarily for viticulture.

As part of a review of water allocation strategies within the area, the outlines of all farm dams were digitised from aerial photography captured in November 2001. Twenty-five of the larger farm dams (34 to 250 ML) were surveyed using the rapid field assessment technique (the surface area was taken from the digitised data). The purpose of this survey was to determine the storage capacity of these larger farm dams and to derive a volume-area relationship for the region.

Although the farm dams surveyed can be regarded as representative of larger farm dams in the region, this data cannot be considered representative of all farm dams in the region as none of the smaller farm dams were surveyed.

A volume-area relationship was derived specifically for this region (McMurray 2003), which was produced as an aid to a water resources review of the region.

2.2.8 TORRENS RIVER CATCHMENT

The Torrens River catchment is a major catchment on the western side of the Mount Lofty Ranges. It contains large areas of grazing, more so towards the flatter (and drier) upper eastern reaches. The steeper westerly parts of the upper catchment contain significant areas of forestry and native vegetation. Some horticulture and viticulture is also located within the catchment. This catchment contains two major water supply reservoirs (Kangaroo Reservoir and Millbrook Reservoir).

As part of a hydrological assessment in the catchment (Heneker 2003), a full topographic survey was conducted on a large percentage of the larger farm dams. There were 66 farm dams ranging in size from 10 to 160 ML.

The survey data included only a small number of the total of around 1350 farm dams in the upper Torrens River catchment, and some of the size classes only contained a low number of farm dams. Therefore, this data cannot be considered representative of all farm dams within this catchment. However, the survey was conducted to aid the hydrological study (Heneker 2003) and to provide data for several aspects of this study.

The survey data was used in investigations of volume-area-depth and area-volume relationships and in an investigation of potential improvements to volume estimations.

2.2.9 EASTERN MOUNT LOFTY RANGES (EMLR)

Most of the Eastern Mount Lofty Ranges had recently been placed under a Notice of Restriction and may become a Prescribed Water Resources Area (PWRA). This large area encompasses most of the land east of the Mount Lofty Ranges divide with catchments draining into the River Murray or the lower lakes (Figs 1.1 and 1.2). The major land use is broad scale grazing with other major land uses being intensive grazing, dairying, forestry, conservation, horticulture and viticulture.

Part of the prescription process includes a review of the water resources, which in turn includes an assessment of all farm dams. At the time of the later part of this study (mid 2004) survey data was available from only 20 farm dams scattered across the region. These were surveyed using the rapid field assessment method with the surface area derived from farm dams digitised from ortho-corrected aerial photography. The farm dams ranged in size from 0.7 to 83 ML with most between 5 and 20 ML.

The number of farm dams in each size class was low (Table 2.1) and the number of farm dams in each catchment within the region was also low. This data was, therefore, not representative of any particular catchment or region. The data was considered only in association with other data.

3. METHODOLOGY

The first part of this section (Section 3.1) describes the size class assessment method that was used to assess the accuracy of geometric relationships (volume-area; volume-area-depth; and area-volume relationships).

The second part of this section (Section 3.2) briefly describes the desktop techniques used to derive some topographic parameters of the surveyed farm dams. The purpose of determining topographic parameters is to investigate whether these could be used to improve the accuracy of desktop volume estimations.

3.1 SIZE CLASS ASSESSMENT METHOD

The method of assessing the accuracy of geometric relationships involved summing the estimated volumes of all farm dams separately in each size class, and then comparing these with the surveyed volumes also summed separately in each size class. The result for each size class was expressed as a percentage error, and the percentage errors plotted against size class for each tested volume-area relationship.

Figure 3.1 presents an example of the percentage error charts for three different relationships under test. The horizontal axis contains the size classes and the vertical axis contains the percentage errors between the summed estimated volumes and the summed surveyed volumes in each size class. The lines between the points have no meaning and are included for visual clarity only. The results of an application of three volume-area relationships to a group of surveyed farm dams are plotted in this figure.

The size classes shown in Figure 3.1 are based on surface area, although it is usual to base size classes on volume. This was done in this study because surface area was the dependent variable (i.e. the known quantity) and volume was the independent variable (i.e. the unknown quantity). The volume equivalents shown in Figure 3.1 and elsewhere in this report are approximate only, as these depend on which volume-area relationship they are based. The size classes were initially based on earlier volume-area relationships and some results are given using those size classes. Later, the size class break points were changed to more closely match the final recommended relationship.

The initial method used to analyse the data and assess the effectiveness of volume-area relationships was to examine scatter plots of volume against surface area with regression (trend) lines added. This method was abandoned and replaced with the size class assessment method for the reasons listed below.

- Regression lines tended in some cases to deviate from the plotted data over one or more parts of the size range. It was frequently considered that a better trend line could be drawn by hand.
- The data could generally be represented by a power-law relationship for smaller farm dams and a linear-law relationship for larger farm dams. This, together with the observed deviations of the regression lines from the observed data, lead to the decision to adopt a dual-equation volume-area relationship.

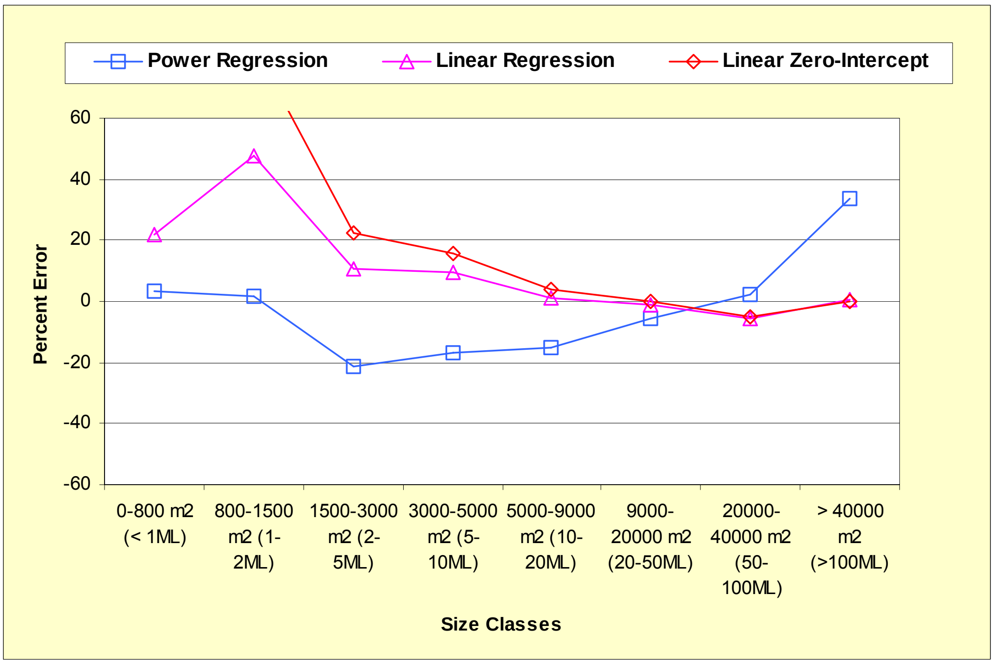


Figure 3.1 An example of results obtained using the size-class assessment method. Shown are the errors produced in each size class when regression equations were applied to farm dams from all survey data combined.

- There were differences in the general trend of the data between several of the catchments, leading to several trials attempting to group the data from the different catchments into two or more categories.

The use of scatter plots to judge the accuracy of volume-area relationships by visual means was considered too informal. Although statistical fitting methods could be used, it was decided to test the accuracy of geometric relationships against the survey data separately in each of a series of size classes. This provided several advantages which are outlined below.

The use of the size class assessment method:

- provided a ready means of assessing and comparing various volume-area relationships;
- provided a means to assess the average accuracy of relationships across all size ranges;
- tested the accuracy of relationships in estimating the summed volume of groups of farm dams, as was the objective, rather than the root-mean-square value used with regression equations;
- did not rely on the subjectivity of visually assessing the fit of regression equations across all sizes;
- permitted iteratively-derived (non-regression) relationships to be tested;
- permitted compound relationships (e.g. power-law for smaller farm dams, linear for larger farm dams) to be tested; and
- a relationship derived for a specific catchment or region could be confidently considered to provide reasonable estimates of volume, where the distribution of farm dams across the size range was different to that of the sample used to derive the relationship.

Note that the errors, referred to in this report as “the overall errors in each size class”, were calculated from the total combined volume in each size class. This is not equivalent to the average error in each size class, and these two figures differed in magnitude depending on the distribution of the data. This method was chosen for this study as the main application of volume-area relationships was to estimate the combined volume of groups of farm dams.

3.2 TOPOGRAPHIC ANALYSIS

The term “topographic analysis” refers to the derivation of some parameters based on the terrain in which each farm dam is situated, and employing these parameters in geometric relationships.

The aim was to determine whether a desktop-determined topographic parameter could be incorporated into a relationship to improve the accuracy of volume estimates; and whether different volume-area relationships could be applied to farm dams in different terrain types to further improve the accuracy of volume estimates.

The parameters investigated were:

a. the average slope of the land surrounding the farm dams;
b. the assumed depth determined from contours (also known as GIS-determined depth); and
c. the streambed slope.

Due to a combination of logistical and time constraints the topographic analyses were conducted on sub-sets of the survey data. The topographic analyses based on (a) and (b) above were conducted on the data from the Inverbrackie, Marne, South Para and Onkaparinga catchments. The analyses involving streambed slope were based on the topographically surveyed farm dams in the River Torrens catchment. The Torrens data were also used in the investigations into volume-area-depth and area-volume relationships.

The results of the topographic analyses are given in Sections 4.5.3 and 4.5.5.

3.2.1 AVERAGE TERRAIN SLOPE

The average slope of the terrain in which the farm dams were situated was determined using automated geographical information system (GIS) techniques as follows.

Firstly, a GIS dataset of slope was created from a 10m cell size digital elevation model (DEM) of each catchment.

Secondly, an external buffer of 25 m was combined with and internal buffer of one-third of this (8.3 m) to form an annulus of each farm dam outline. The figure of 25 m was chosen subjectively by examining several farm dams of different sizes in relation to the slope of the terrain. The internal buffer was included so as to exclude the usually flatter terrain in gullies where most of the farm dams were situated. The result was intended to represent the average slope of the land surrounding each farm dam.

Thirdly, the dataset containing the annulus of each farm dam was overlaid on the slope dataset, and the average of the slope contained within each was calculated. The figures for average slope were divided into slope classes (in one-degree intervals from zero to ten degrees). These calculated slope classes were then added as an attribute to the attribute table of the farm dam dataset.

Using the average terrain slope thus determined, the relationships between slope and various geometric attributes of the studied farm dams were then investigated. Those investigations are explained in later sections of this report.

3.2.2 GIS-DETERMINED DEPTH

The assumed depth of each farm dam was determined using automated GIS techniques (described below), which were equivalent to determining the depth of farm dams by manually interpolating between contours on a map. The GIS method was automated and quicker than the manual method, and was thus considered likely to be more accurate and consistent. However, neither method produced totally accurate results, as it was not possible to determine the degree of excavation from the topographic data.

The GIS technique used to estimate each farm dam's depth was as follows. Firstly, a 5 m buffer was applied to each farm dam. The main purpose of the buffer was to ensure that the smaller farm dams were adequately represented once the buffered farm dam outlines were converted to a raster dataset at the cell size adopted. Cell sizes of both 25 m and 10 m were trialled with very little change in results.

The dataset of buffered farm dam outlines was then overlaid over a DEM. The assumed depth was calculated from the difference between the maximum elevation and the minimum elevation of each farm dam. The results were added as an attribute to the attribute table of the farm dams dataset.

3.2.3 STREAMBED SLOPE

Streambed slope was determined from the full topographical survey of farm dams in the River Torrens catchment. The survey data included survey points at the extreme tail of each farm dam as well as the external base of the farm dam wall. From these two survey points it was possible to calculate the average streambed slope over the farm dam as the ratio of drop over run (Fig. 3.2).

Streambed Slope = Drop/Run

where Drop and Run were determined from the survey data.

Also, from knowledge of streambed slope it was possible to infer a value for the maximum depth of farm dams as follows (also shown in Fig. 3.2).

Streambed Slope = Depth/Length

where Depth was unknown and Length was determined from the survey data.

Therefore, Depth can be determined from the above two equations as follows:

Depth = Length x Drop/Run

It was assumed that the true depth of the farm dam (shown as a dotted line in Fig. 3.2) was the same as the internal height of the idealised farm dam wall (shown as a solid line in Fig. 3.2). The farm dam length was taken as the length of the centre line through the full supply level of each farm dam, following the estimated position of the original stream in the cases where farm dams had a curved shape.

The results obtained from investigations utilising streambed slope are given in Section 4.5.5.

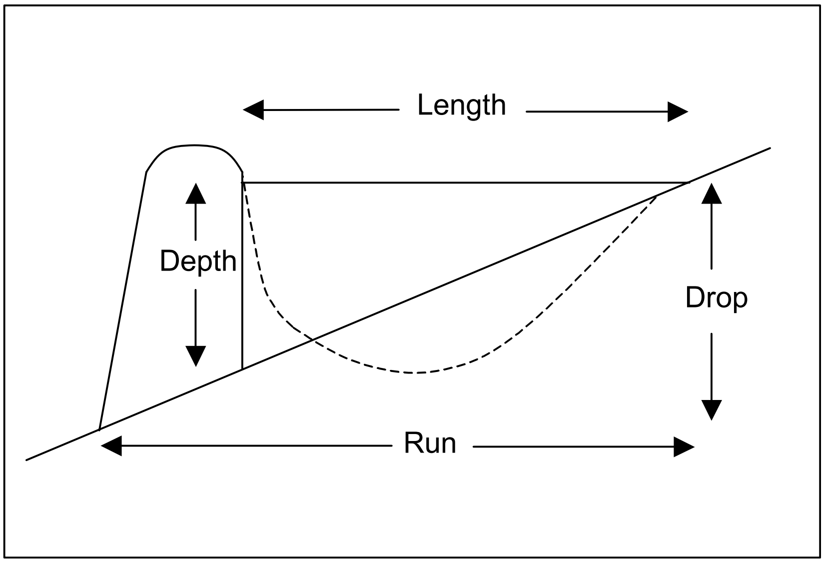


Figure 3.2 Simplified cross-section of a farm dam (solid lines) and a more likely profile (dotted line)

4. PROPOSED VOLUME-AREA RELATIONSHIPS

4.1 OVERVIEW

The focus of this section is to report on the investigations into the relationships between volume and surface area of the surveyed farm dams, and to describe the evolution of the final recommended volume-area relationships. A volume-area relationship is required for desktop methods of estimating the storage volume of farm dams that have been digitised from remotely-sensed data. Other aspects investigated and reported here include topographic analyses involving average slope around farm dams, GIS-determined depth and streambed slope.

Several issues were noted during assessment of the survey data. These included a large spread in farm dam volume-area ratios; differences between data from different catchments and regions; and varying trends in volume-area relationship over the size range. These issues presented difficulties in producing one or more volume-area relationship that had some scientific validity, which resulted in the development of the final relationship to follow a disjointed path. A concerted effort has been made, however, to present the reasoning behind the final recommendation in a logical sequence.

4.2 INITIAL ASSESSMENT OF THE DATA

4.2.1 SCATTER IN THE DATA

The survey data is shown plotted in scatter plots (x-y plots) of volume against surface area in Figure 4.1(a) for all farm dams, and in Figure 4.1(b) for smaller farm dams only.

Figures 4.1(a) and (b) clearly show that there is wide scatter in the data, that is, for any given surface area there is a wide range of possible volumes. This shows (as expected) that a volume-area relationship is not a suitable instrument for estimating the volume of individual farm dams, although there is frequently no practical alternative.

The aim of this study, and also of developing volume-area relationships, is to provide reasonable average estimates of volume, so that total combined estimates of volume can be made for regions, catchments and if possible, sub-catchments.

4.2.2 TREND DIFFERENCES BETWEEN CATCHMENTS

It is possible to see some differences in the general trend between data from different catchments from Figures 4.1(a) and (b). The differences can be seen more clearly in Figure 4.2, which shows the regression equations for the data from each catchment. The data for Greenock Creek shows higher volumes for given surface areas than most of the other data. There are also significant differences between the regression equations for smaller farm dams around 5 to 10 ML (Fig. 4.2(b)). As described later in this section, these observed differences between catchments lead to the investigation of volume-area relationships based on various combinations of catchment data, and the recommendation of different relationships depending on apparent surface water demand within catchments.

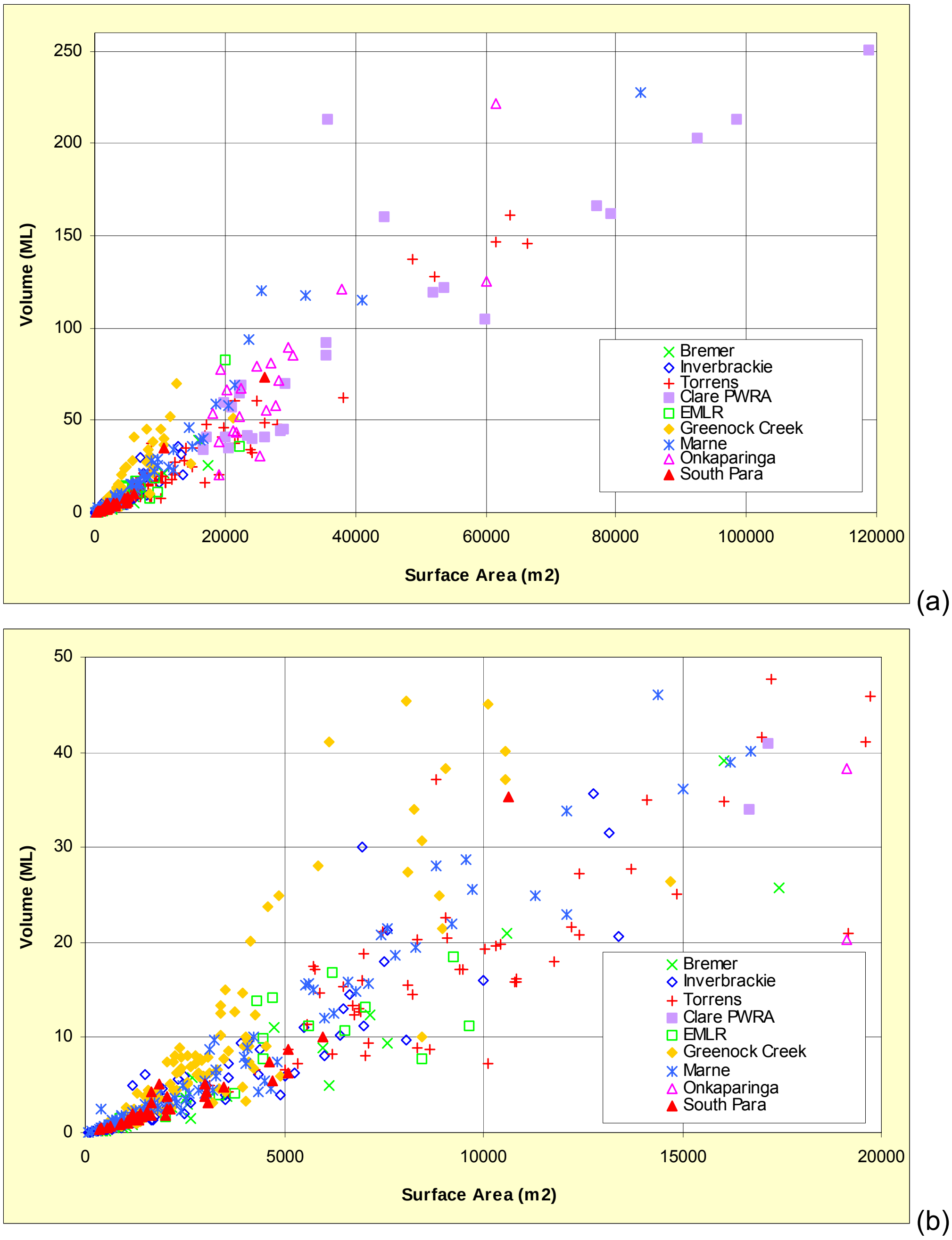
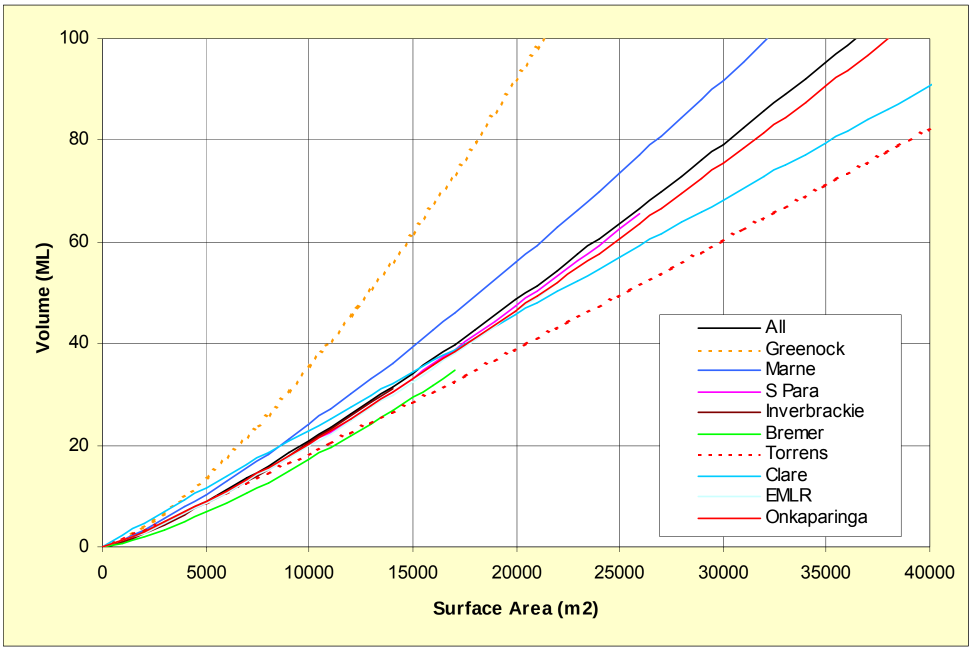
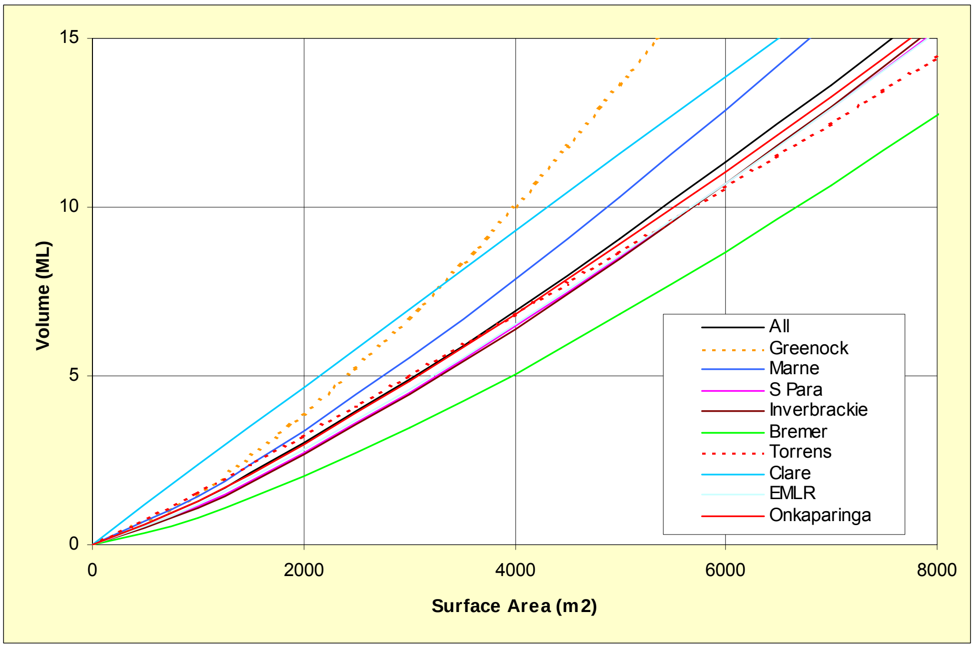


Figure 4.1 **Scatter plots of volume against surface area for (a) all surveyed farm dams and (b) smaller farm dams only, showing the wide scatter in the available data.**



(a)



(b)

Figure 4.2 Power-law regression equations for each catchment, showing different trends between catchments, for (a) larger farm dams and (b) smaller farm dams.

4.2.3 REGRESSION EQUATIONS

Power-law regression equations (of the form $V = kA^{exp}$) were derived separately for each catchment. The parameters are shown in Table 4.1.

Table 4.1 Parameters for the power-law regression equations from each catchment and region.

Catchment/Region	Parameters for Power-Law Regression Equations		
	Coefficient	*Exponent*	R^2
All Data Combined	0.000305	1.2094	0.94
Bremer River	0.000083	1.3285	0.95
Clare PWRA	0.002525	0.9899	0.79
Eastern MLR	0.000273	1.2157	0.88
Greenock Creek	0.000111	1.3757	0.86
Inverbrackie Ck	0.000174	1.2673	0.95
Marne River	0.000318	1.2196	0.97
Onkaparinga R.	0.000345	1.1926	0.60
South Para River	0.000225	1.2377	0.94
River Torrens	0.000868	1.0814	0.86

The catchment-derived regression equations for the Marne River, Inverbrackie Creek, Greenock Creek and South Para River catchments were applied as volume-area relationships to the farm dams in each respective catchment. Results obtained are presented in Figure 4.3.

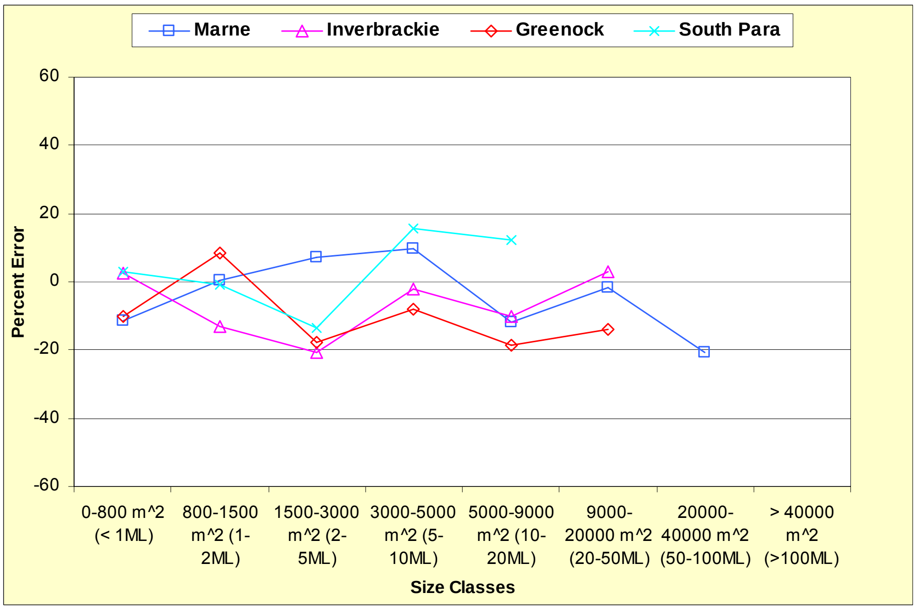


Figure 4.3 Errors produced in each size class when the catchment-based power-law regression equations were applied separately to each catchment's farm dams.

No errors are shown for the larger size classes as there were no surveyed farm dams in those size classes for those catchments. The errors for the other catchment data are not shown as the data was considered to be unrepresentative of all farm dams in those catchments (as described in Section 2).

This exercise indicated that a catchment-derived power-law regression equation might be suitable as a volume-area relationship for some individual catchments, if average errors of up to ±20% are considered acceptable. However, none of the catchment-derived regression equations were considered suitable as a “universal” volume-area relationship. As an example, Figure 4.4 shows the errors produced when four of the catchment-derived regression equations were applied to all the survey data combined. Errors were quite large in some size classes.

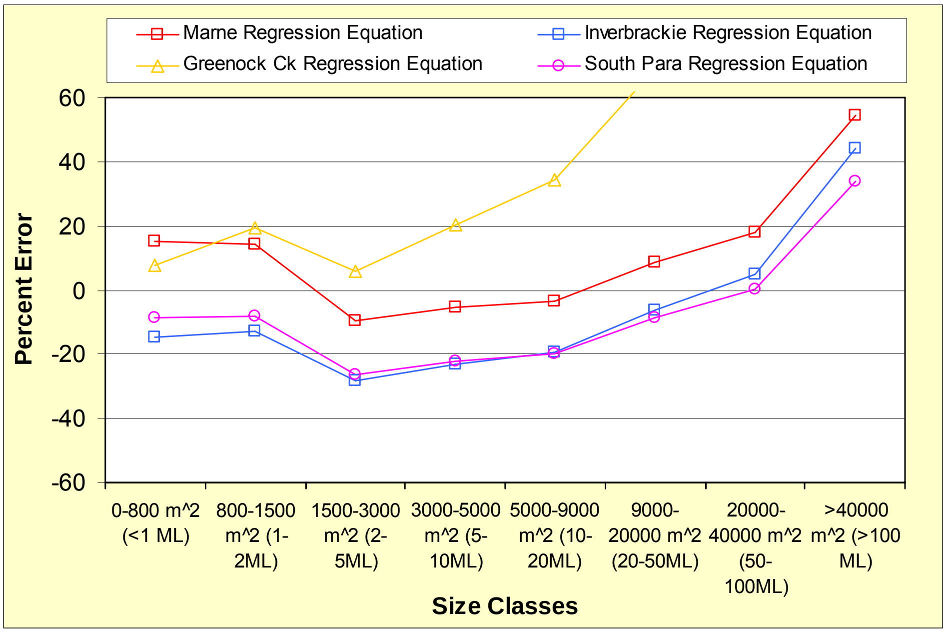


Figure 4.4 Average errors produced in each size class when catchment-based power-law regression equations are applied to all the surveyed farm dams combined.

The errors produced when the power-law regression equation derived from all the survey data combined (the first entry in Table 4.1) was applied to all the data combined, is shown in Figure 4.5. Also shown in Figure 4.5 are the errors produced when the linear regression equation (V = c + kA) and the linear zero-intercept regression equation (V = kA), both derived from all the data combined, were applied to all the data combined.

The power-law regression equation produced errors of around -10% in the middle size classes and around 35% in the largest size class. Both of the linear regression equations produced low errors in the larger size classes and large errors in the smaller size classes (10 to 50% for the linear regression equation and 22 to 116% for the linear zero-intercept regression). These large errors indicate that a regression equation applied across all size ranges is not the most suitable volume-area relationship.

Figure 4.5 Errors produced in each size class when regression equations were applied to farm dams from all catchments combined.

The three regression equations produced low errors (0 to 5%) when the sum of the estimated volumes from all size classes was compared to the combined sum of the surveyed volume from all farm dams. This was not surprising given that regression equations are based on the minimum overall root-mean-square error.

4.2.4 OTHER FORMS OF RELATIONSHIPS

Several other forms of single-equation relationship were trialled. These included regression-derived equations, as well as iteratively-derived relationships of various forms (power-law, second-order polynomial, linear and linear with zero-offset).

Power-law relationships (of the form $V = kA^{exp}$) tended to overestimate volume in the larger size classes, if the parameters were adjusted to fit small to medium size classes. The parameters could be adjusted to fit the larger size classes as well as either the small or medium size classes, but not both.

The general form of the polynomial relationships trialled was as follows:

$$V = C + k_1A^{exp1} + k_2A^{exp2}$$

where V = volume (ML);

A = surface area (m^2);

C = Y-axis intercept (C = 0 for zero-intercept);

k(n) = coefficients; and

exp(n) = exponents.

Second-order polynomial relationships based on regression equations (where "exp1" = 1 and "exp2" = 2) produced varying results with very large errors in one or more size classes. Polynomial relationships derived by iterative means (where "exp1 and "exp2" were generally between 1 and 2) could be made to reduce the range of errors across the various size classes. It was argued that the higher-order term would tend to dominate at the higher volumes of surface area, and the lower-order term could be made to dominate at the lower values of surface area. It was hoped that by manipulation of the magnitude of the coefficients and the exponents that the equation could be made to fit small, medium and large farm dams. However, those polynomial relationships trialled did not produce lower errors than could be produced with other forms of relationship.

Single linear relationships (of the form V = kA + C) applied to the whole range of size classes would, as noted earlier, always produce very large errors over several size classes. Compound linear relationships (such as the dual relationship proposed by Billington and Kotz 1999) could be made to produce reasonable results over most size classes. However, with a negative value for C, farm dams with a small surface area would always result in a negative volume. Further, there seemed to be a need for two (or three) linear equations for farm dams with surface area less than 3000 m^2 (Fig. 4.6), resulting in a relationship that would be complicated to apply in practice. Single linear relationships, however, could be made to produce low errors for larger size classes as shown in Figure 4.5, albeit with very large errors for the smaller size classes.

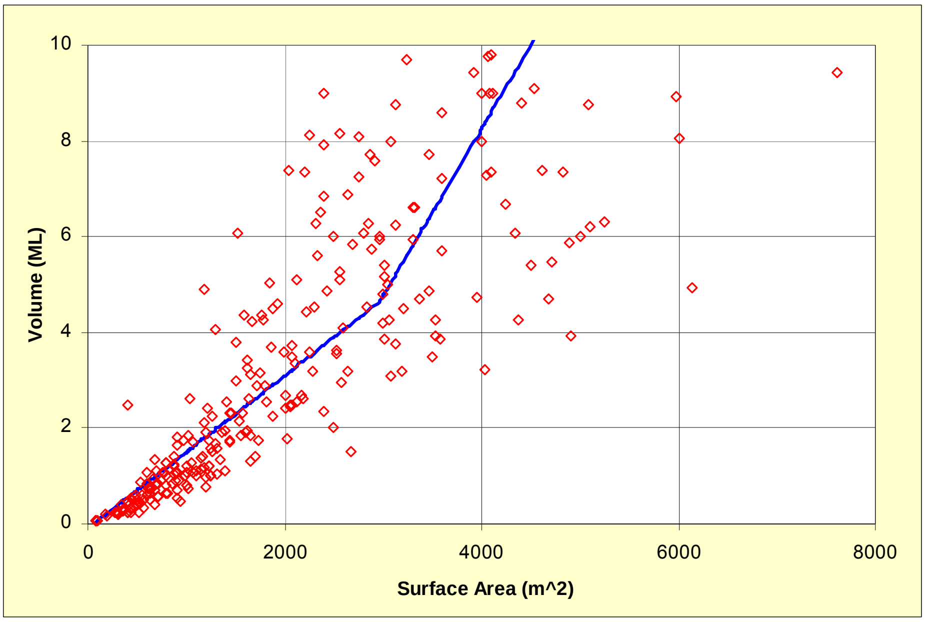
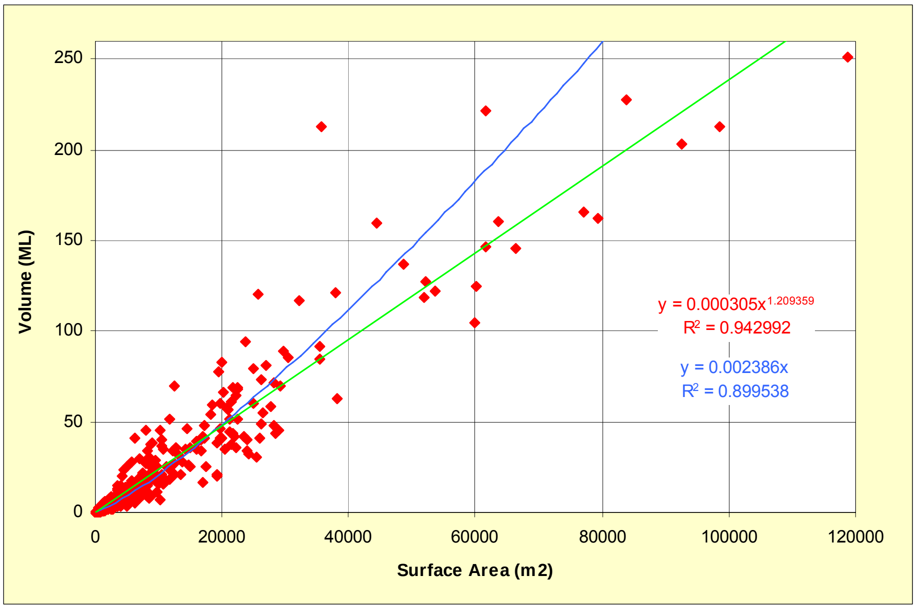


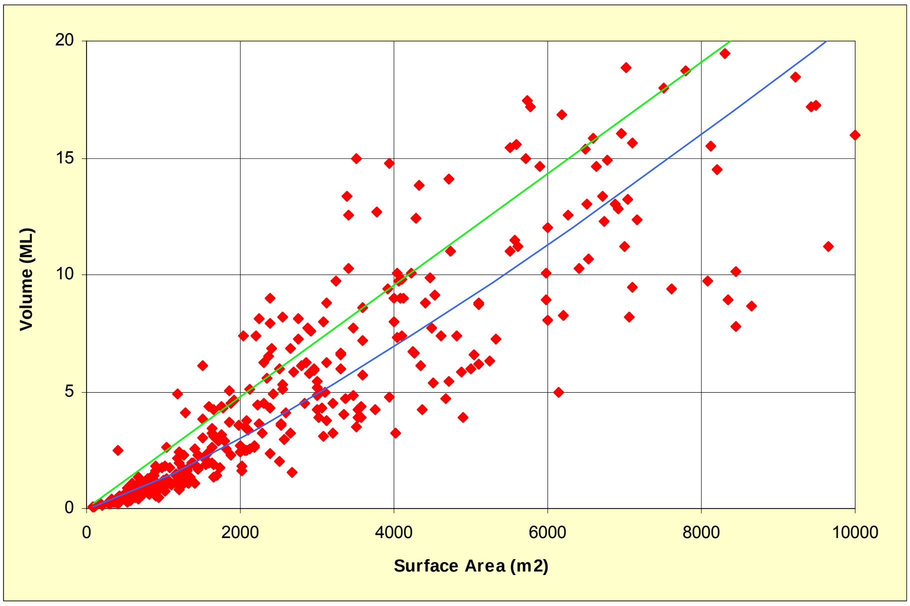
Figure 4.6 Smaller farm dams and a double-linear relationship (Billington & Kotz 1999)

4.2.5 DUAL-EQUATION RELATIONSHIP

Figure 4.7 shows power-law and linear zero-intercept regression equations derived from the data from all catchments combined, on a scatter plot of all the data. As deduced in part by some of the findings reported above, it was noted that (a) a power-law volume-area relationship would be appropriate for the smaller farm dams but would overestimate volumes



(a)



(b)

Figure 4.7 The power-law and linear regression equations for all data combined on scatter plots of the data for (a) all farm dams and (b) smaller farm dams only.

of larger farm dams; and (b) it appeared possible that a linear relationship may prove more appropriate for the larger farm dams (apart from some significant outliers) but would overestimate the volume of smaller farm dams.

Given the difficulties encountered in using regression equations and other forms of equations as described above, it was decided to investigate a compound relationship based on a power-law equation for smaller farm dams and a linear relationship for larger farm dams.

A compound volume-area relationship that employed a power-law equation for smaller farm dams and a linear equation for larger farm dams had a total of four parameters requiring determination. In order to streamline this process, the parameters were determined one at a time in a logical sequence as presented below.

a. The exponent for the power-law equation (based on the smaller farm dams);
b. the coefficient for the power-law relationship (based on the smaller farm dams);
c. the coefficient for the linear equation (based on the larger farm dams); and
d. the break point between the power-law and the linear equation.

The exponent of the power-law equation was selected to give a "slope" of the error curve close to horizontal (Fig. 4.8). The coefficient of the power-law equation was then selected so that the errors across the smaller size classes were as close to zero as possible. The coefficient of the linear equation was selected to produce the smallest errors in the larger size classes (Fig. 4.9).

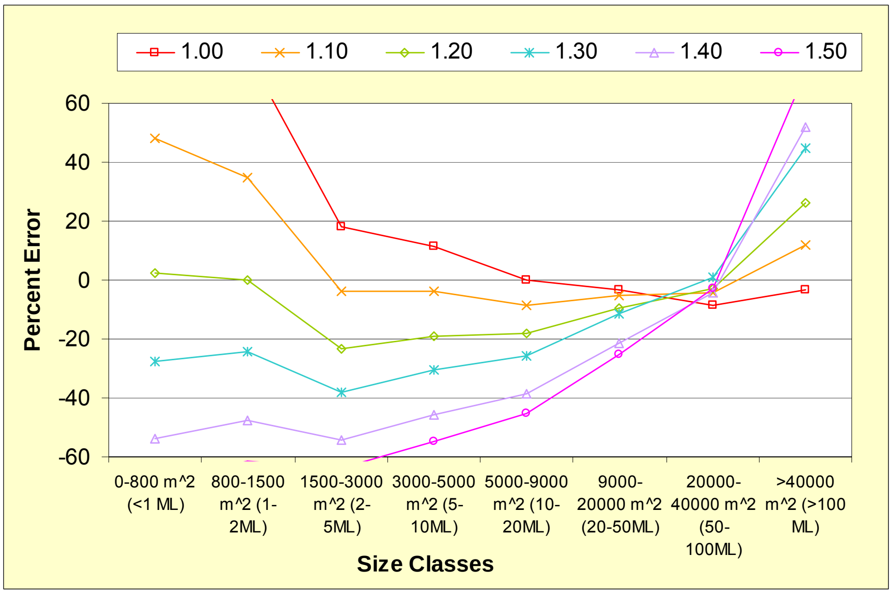


Figure 4.8 Percentage errors across the size classes with different exponents in a power-law relationship.

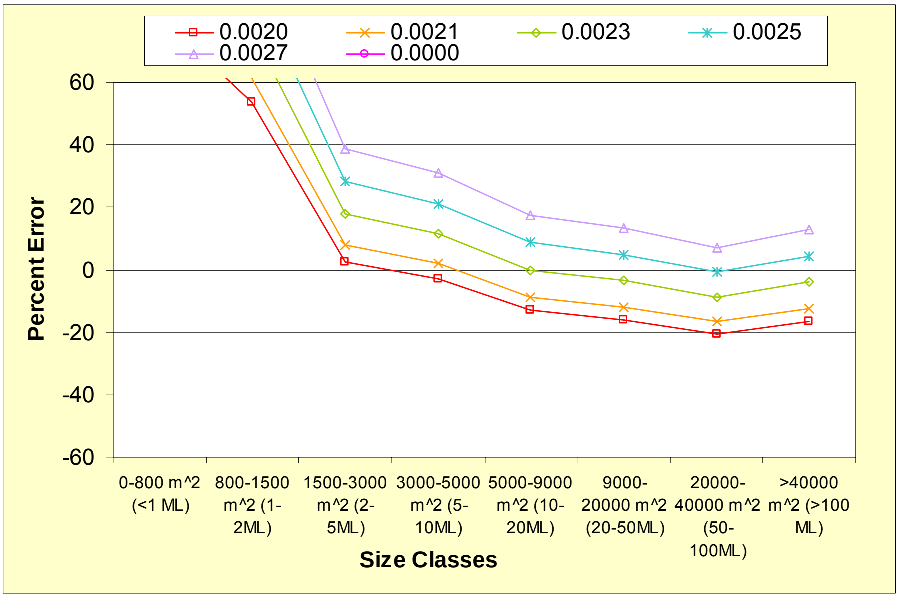


Figure 4.9 Percentage errors across the size classes with different coefficients in a linear equation.

The break point between the two equations was selected as the point where the two equations intersected. This was considered important so there would then be no ambiguity in volume estimates for surface areas near the break point, i.e. there would not be two, possibly widely varying, values of volume estimates depending on which equation was used.

As anticipated, there were issues where either the two equations did not intersect, and/or errors in intermediate size classes were less than ideal. In these situations, the parameters of the two equations were "fine-tuned" by iterative means to give the best possible overall performance, that is, good accuracy across all the size classes.

Trials were also conducted using a second power-law equation for the larger farm dams. Exponents around 0.85 to 1.1 provided reasonable results for some groupings of data, however the results were judged no better overall than could be achieved with a linear equation for larger farm dams, hence this avenue was not pursued further.

4.2.6 INTERIM DUAL-EQUATION RELATIONSHIPS

An interim volume-area relationship was developed using the techniques discussed above in the initial phase of this study (before survey data became available from the Clare PWRA, River Torrens catchment and EMLR) as reported in McMurray (2002), as follows:

For $A < 20\,000$ $\quad V = 0.000215\,A^{1.26}$ $\quad$ } Relationship 4.1

For $A \geq 20\,000$ $\quad V = 0.0028\,A$ $\quad$ }

where A = surface area (m^2); and

V = estimated volume (ML).

This gave reasonably low errors overall except for the data in catchments at the extremes (Greenock Creek and Bremer River catchments), with slightly low volume estimates for the Marne River catchment data. This relationship was utilised in other work at that time.

When the data from the Clare PWRA became available another volume-area relationship was developed specifically for that region (McMurray 2003) as presented below.

For $A < 15\,000$ $\quad V = 0.0002\,A^{1.25}$ $\quad$ } Relationship 4.2

For $A \geq 15\,000$ $\quad V = 0.0022\,A$ $\quad$ }

where A = surface area (m^2); and

V = estimated volume (ML).

This relationship was used to assist in the surface water assessment of that region. Only larger farm dams were surveyed, on which the linear part of the relationship was based. The power-law part of the relationship was based on the assumption that the smaller farm dams would be around 20% lower in volume for any given surface area (as was the case with the larger surveyed farm dams) than farm dams in the Mount Lofty Ranges (McMurray 2003).

In the later phases of this study, the data from the Clare PWRA and the River Torrens catchment and the EMLR were incorporated into further analyses to revise the previous recommendations. Due to difficulties in finding one relationship that was applicable to the majority of the catchment-based data, it was decided to investigate the possibility of developing two or more relationships for different regions, based on the observed differences in the data from different catchments.

4.3 ASSESSMENT IN GROUPINGS OF CATCHMENT DATA

Considerable difficulty was experienced in deciding on the most suitable groupings of catchments. The final decision was based on a combination of (a) observed differences in the data; (b) knowledge of the types and value of crops grown in the region; and (c) knowledge of irrigation demand relative to the availability of surface water.

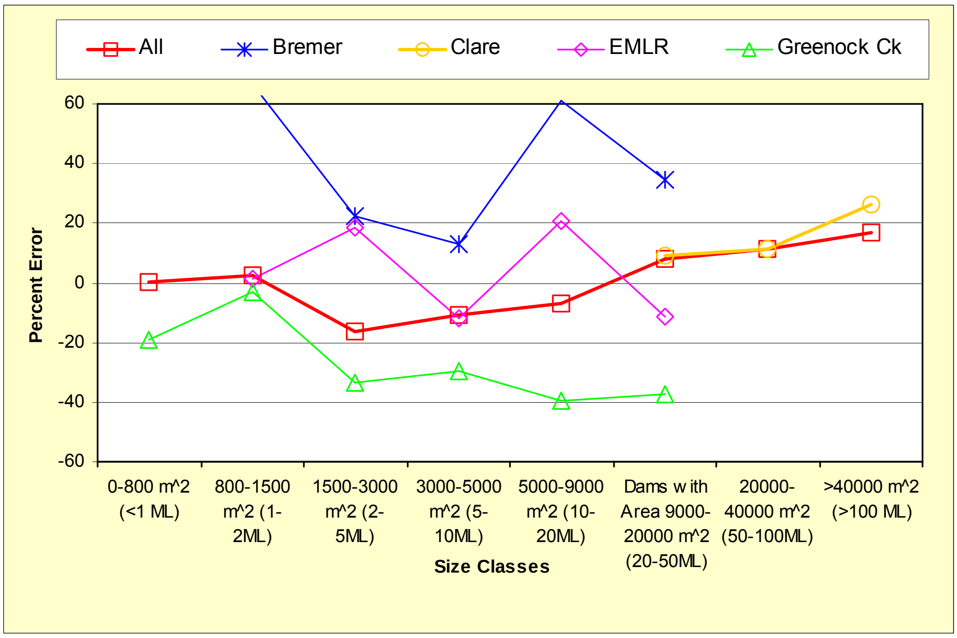
The differences in the data can be seen in Figures 4.1 and 4.2 (shown earlier), and also Figures 4.10(a) and (b) which show the errors obtained when relationship 4.1 was applied to each catchment separately, as well as to all the data combined. The farm dams in Greenock Creek catchment are generally underestimated, and the sampled farm dams in the Bremer river catchment are overestimated. The errors for the remaining catchments were generally between these two extremes and varied with size class, which made it difficult to decide upon suitable groupings based only on differences in the data.

In areas where there is a high demand for irrigation and/or a high value crop where water (surface water and groundwater) availability is low or highly variable, it is likely that farm dam construction techniques involve more intensive excavations of the base of the farm dam in order to give a higher storage capacity. Although the scientific validity of this assumption is questionable, the data supports the theory at least in part. For example, both Greenock Creek and the Marne River catchments have large areas of viticulture, lower runoff (compared to other areas in the Mount Lofty Ranges) and little groundwater, but the volume-area ratios of the farm dams in these areas are high. Conversely, the Inverbrackie Creek and Bremer River catchments, although located towards the drier easterly side of the Mount Lofty Ranges, have mainly grazing activities with few areas of high value crops, and the farm dams therefore have lower volume-area ratios.

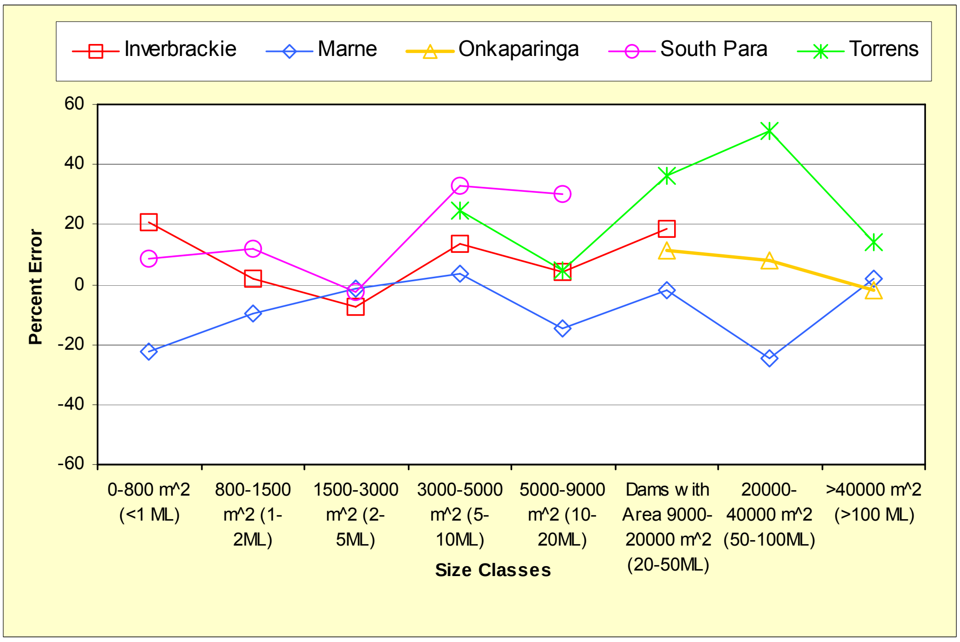
The situation is complicated by the likelihood that intensity of irrigation demand (or the value placed on surface water) is based on regions defined by factors other than the boundaries of surface water catchments. Such factors could include climate, soil types, and economic or logistic considerations. The specific areas in the Mount Lofty Ranges where water for agricultural practices is particularly important include the viticultural areas of Greenock Creek catchment, the Barossa Valley and the upper Marne River catchment, and the horticultural areas in the western parts of the upper Onkaparinga River catchment.

Farm dams in Greenock Creek and the upper Marne River catchments are well represented in the available survey data, however farm dams in the Barossa Valley are not represented. The upper Onkaparinga River catchment is represented only by: (a) a few large farm dams, many of which are outside of the main horticultural region although, as noted during fieldwork, some farm dams were associated with horticulture or viticulture; and (b) farm dams in the Inverbrackie Creek catchment, which is also outside of the main horticultural region.

A further consideration in selecting an appropriate method by which to group catchments is the way that any final volume-area relationships are likely to be used in practice. For simplicity of application, the most practical approach, if more than one volume-area relationship is to be used, is that segregation be based on surface water catchments. On this basis, the whole Gawler River catchment (that encompasses Greenock Creek and the South Para River catchment), the Marne River catchment and Onkaparinga River catchment (which also encompasses the Inverbrackie Creek catchment) would be regarded as having relatively



(a)



(b)

Figure 4.10 Errors in size classes obtained when Relationship 4.1 was applied to data from each catchment individually and to all data combined.

high demand or value placed on surface water. One volume-area relationship would be used in these catchments, and another relationship used in all other catchments that would be regarded as having relatively low demand or value placed on surface water. This concept is employed for the next part of the assessment.

Several groupings were trialled, and one of these was based on the reasoning given above. This grouping is presented in Table 4.2 with possible problems given in parentheses.

Table 4.2 Groupings of catchment farm dam data based on perceived irrigation demand (surface water demand and/or crop value).

Irrigation Demand	Groupings of Catchment Data
High	Greenock Creek (a possible outlier)*
	Marne River
	Onkaparinga River (larger farm dams only)
	South Para River (data not representative)*
Low	Bremer River (a possible outlier)*
	Clare PWRA (larger farm dams only)
	East Mt Lofty Ranges (few farm dams scattered)*
	Inverbrackie Creek (part of the Onkaparinga)
	River Torrens (larger farm dams only)

* Refer to the description of surveyed catchments in Section 2.

The following sections describe the accuracy of the two interim volume-area relationships (relationships 4.1 and 4.2 in Section 4.2.6), when applied to groupings of the survey data (as described in Table 4.2) and to variations of the groupings.

4.3.1 AREAS WITH HIGH IRRIGATION DEMAND

All figures given in this section are the errors obtained when relationship 4.1 (given in Section 4.2.6) was applied, firstly to groupings of catchment data and then to data from the individual catchments. Each of the catchments were regarded as having high irrigation demand with the exception of the Inverbrackie Creek catchment that was included as it is part of the Onkaparinga River catchment.

The errors for three groupings of catchment data are shown in Figure 4.11.

The errors for Group 1 (the grouping of data from Greenock Creek, Marne River, Onkaparinga River and South Para River catchments) were around 10 to 20% low in the middle and lowest size classes. However, when the data from Greenock Creek was removed from the grouping (Group 2, Fig. 4.11), the errors in the middle size classes improved to acceptable levels. Removal of the Greenock Creek catchment data was justified as this data was regarded as an outlier.

As stated above, Inverbrackie Creek catchment data was regarded as an area with low irrigation demand but is within the Onkaparinga River catchment. When the data from the Inverbrackie Creek catchment was included into this grouping (Group 3, Fig. 4.11), it had little influence on the errors in the middle size classes, but improved the error in the smallest size class. With this grouping of data there were only four farm dams in the largest size class. In order to include more farm dams in this size class, the break points of larger size classes were changed slightly, resulting in seven farm dams in the largest size class. Again however, this made only small changes to the errors across all size classes (not shown).

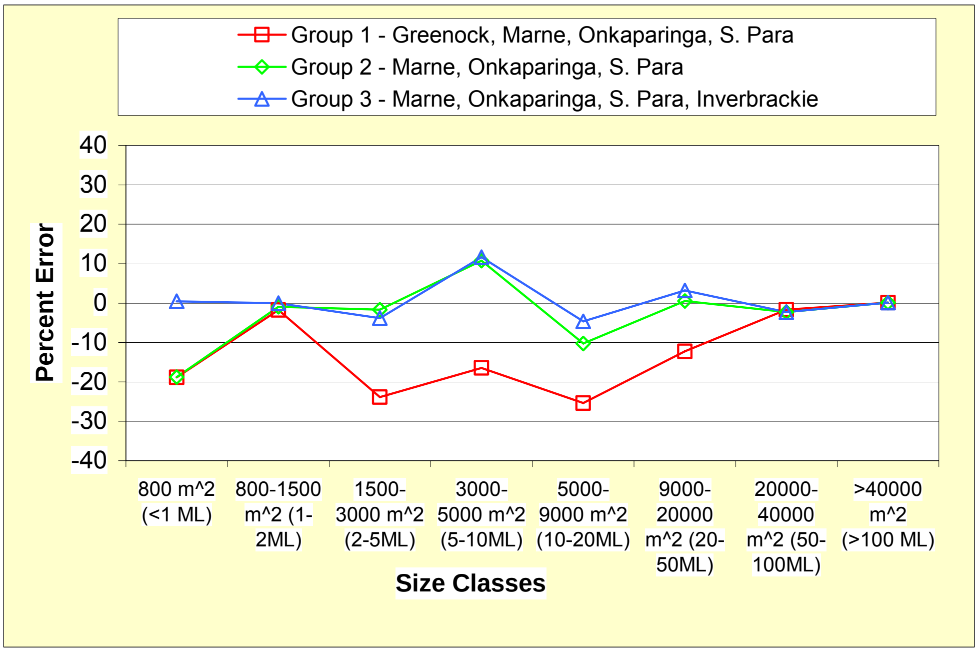


Figure 4.11 Errors produced in each size class when relationship 4.1 was applied to the given groupings of data from catchments with high irrigation demand.

The errors produced when relationship 4.1 was applied separately to each of the catchments with high irrigation demand are shown in Figure 4.12 (the same data is shown in Figures 4.10(a) and (b) but is presented differently, and is repeated here for reader convenience).

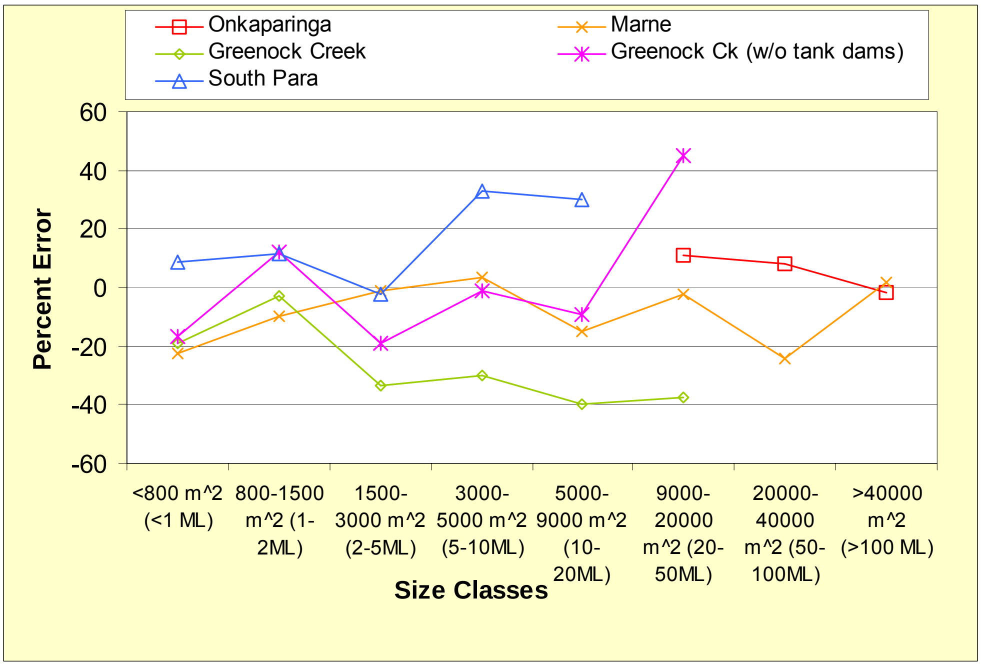


Figure 4.12 Errors produced in each size class when relationship 4.1 was applied separately to the data in each catchment with high irrigation demand (data repeated from Fig. 10).

Onkaparinga River Catchment

Reasonable errors (-2% to 11%) were produced when relationship 4.1 was applied only to the Onkaparinga River catchment data (that had survey data only for the larger farm dams).

Marne River Catchment

The errors produced when relationship 4.1 was applied only to the Marne River catchment data are negative in several size classes, indicating that many farm dams in this catchment have a relatively high volume for given surface area. The errors overall however, are not excessive (maximum -24%). The sample sizes were low in the larger size classes (five farm dams in the 20 000 to 40 000m^2 class and only two farm dams in the largest class), causing some doubt on the validity of these results.

Greenock Creek Catchment

The errors produced when relationship 4.1 was applied only to the Greenock Creek catchment data were considered unacceptably large (up to -40%) in the middle size classes. This was not surprising given the nature of farm dams in this area (large percentage of turkey-nest farm dams). The only solution to this would be to create a specific volume-area relationship for this type of farm dam which was not done in this study.

In this study when the turkey-nest farm dams were removed from the sample set, there was only one farm dam in the sample set for the larger size classes, however the errors were acceptable for the other size classes as shown in Figure 4.12. This indicates that the non-turkey nest farm dams in this catchment are typical for the region.

South Para River Catchment

The errors produced with the South Para data are reasonable in the smaller size classes but become large (around 30%) in the larger of the represented size classes. There were no large farm dams in this sample set.

4.3.2 AREAS WITH LOW IRRIGATION DEMAND

All figures given in this section show the errors obtained when relationship 4.2 was applied firstly to groupings of catchment data, and then to data from individual catchments, all of which were regarded as areas with low irrigation demand. The errors for two groupings of catchment data are shown in Figure 4.13.

The errors for Group 4 (the grouping of data from the Bremer River, Clare PWRA, EMLR, Inverbrackie Creek and River Torrens) (shown in Fig. 4.13) are mostly under 10% across all size classes. To test whether the atypical Bremer River catchment data was placing bias on the results, a fifth grouping was tested without the Bremer River data (Group 5, Fig. 4.13). The errors were slightly worse in the middle size classes but remained within 20%, which was considered reasonable given the variable nature of farm dams.

The errors produced when relationship 4.2 was applied separately to each of the catchments with low irrigation demand are shown in Figure 4.14.

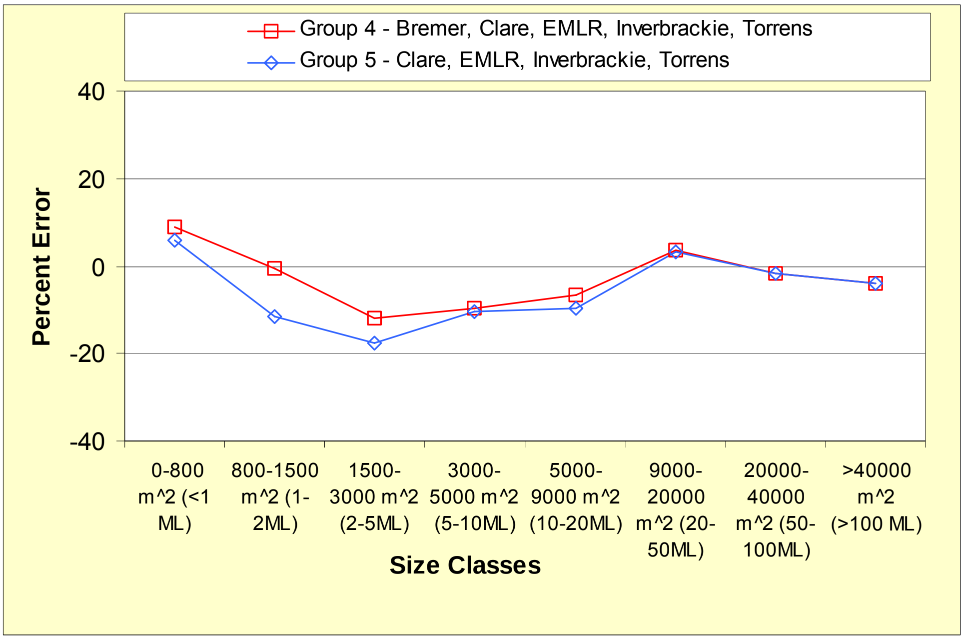


Figure 4.13 Errors produced in each size class when relationship 4.2 was applied to the given groupings of data for catchments with low irrigation demand.

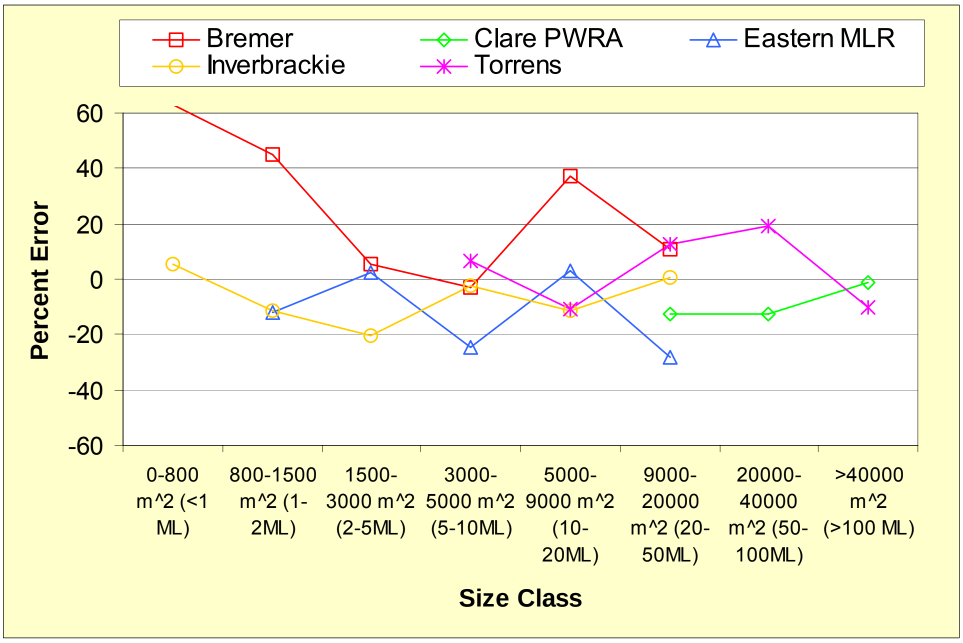


Figure 4.14 Errors produced in each size class when relationship 4.2 was applied separately to the data in each catchment with low irrigation demand.

Bremer River Catchment

The errors produced with the Bremer River catchment data were reasonable only in three of the size classes. The errors were very high (37% to 63%) in the remaining size classes. This was to be expected given the earlier observations that showed the Bremer River data was atypical.

Clare Prescribed Water Resources Area

The worst error produced with the Clare PWRA data was around 12%, which was considered reasonable.

Note that the errors reported here for the Clare PWRA farm dams are marginally different to those reported earlier in McMurray (2003), due to the use of different size class break points.

Eastern Mount Lofty Ranges

The errors produced with the Eastern Mount Lofty Ranges (EMLR) data were reasonable in three size classes, rising to over 20% in two size classes. As described earlier, the EMLR data was obtained from a small sample of farm dams spread over a large geographic area and could not be considered representative of any particular catchment or economic region.

Inverbrackie Creek and River Torrens Catchments

The errors produced using the Inverbrackie Creek and the River Torrens data were generally reasonable, although the errors approached 20% in some size classes.

4.4 SUMMARY – PROPOSED VOLUME-AREA RELATIONSHIPS

The following section (section 4.5) describes results from some other aspects of investigations into volume-area relationships, however none of these contributed any additional assistance to this study and therefore have not influenced the recommendations presented in this report.

Given the highly variable geometry of farm dams, as shown by the data from this study, it was considered that average errors of up to ±20% in some size classes could be considered reasonable, provided that the errors across the majority of size classes were better than approximately 10%. On this basis it was considered that the relationship 4.1 and relationship 4.2 (as given in Section 4.2.6) assessed above, and applied on the basis of perceived irrigation demand from surface water and/or crop value, produced errors of overall volume estimations across the size classes that were reasonable.

Several other relationships of the same form (power-law/linear for smaller and larger farm dams respectively) were trialled, but with different values of coefficient and exponent. In some cases improved results were obtained, however as with the results presented above, the errors obtained across size classes, catchments and data groupings, varied considerably. This made it difficult to judge whether any of the results were an actual overall improvement.

The two relationships referred to above (relationships 4.1 and 4.2) were already in use in hydrological studies and farm dam assessments. It was considered that any potential improvements to volume estimations provided by alternative relationships would be marginal, and therefore did not warrant causing further confusion by introducing yet more relationships. It is therefore recommended that relationships 4.1 and 4.2 discussed in this report continue to be used, but are applied based on perceived irrigation demand from surface water and/or crop value generally within the catchments.

The recommendation is based on a fairly large dataset (487 surveyed farm dams) and is supported by the results presented in the charts. Even if purely statistical techniques could be utilised, it is doubtful whether a firm recommendation could be made given the highly variable nature of farm dam geometry. If additional survey data becomes available a review of this work could be undertaken.

As will be documented in the following sections of this report, the recommended volume-area relationships are only valid for estimating the full supply level capacity of farm dams, as increasing errors result in estimating volume at less than full capacity. Also, due to the wide error band in volume estimations for individual farm dams (as documented in Section 4.5.1 following), a volume-area relationship is only suitable for estimating the volume of groups of farm dams (for example in sub-catchments) where a statistical advantage can be assumed with errors averaging.

4.5 FURTHER ANALYSES

4.5.1 MINIMUM AND MAXIMUM ERRORS

As explained previously, the errors discussed above (Sections 4.2 to 4.4) in relation to the size class assessment method are the differences between the summed estimated volumes of all farm dams in each size class, and the summed surveyed volumes of all farm dams in each size class expressed as percentages.

This is the most important consideration as the prime purpose of volume-area relationships is to provide reasonably accurate estimates of the combined volume of groups of farm dams across regions or within catchments or sub-catchments. Frequently however, volume-area relationships are used as initial estimates of volume of individual farm dams. Therefore, the range of errors for individual farm dams is also of interest.

Table 4.3 and Table 4.4 show the worst-case (minimum and maximum) errors as well as the mean, median and standard deviation, obtained when relationship 4.1 and relationship 4.2 were applied to groupings of catchment data and individual catchments for catchments regarded as having high surface water demand, and low surface water demand respectively.

The data presented in Table 4.3 and 4.4 shows that the worst-case errors are fairly large. The extremes are -84% and 177%. This corresponds to error ratios of 0.54 and 2.77 respectively, i.e. the estimated volume for an individual farm dam could be between 0.54 and 2.77 times the true volume. The figures for standard deviation indicate that the majority (68%) of volume estimates would be within around ±40% of true volume. The estimated volume of all farm dams combined for each grouping or catchment are within -9.3% and 6.3%, if the results for Greenock Creek and the Bremer River catchments are disregarded.

Table 4.3 Percentage errors when Relationship 4.1 is applied to grouped and individual catchments with high surface water demand.

	Greenock, Marne, Onkaparinga, South Para	Marne, Onkaparinga, South Para *	Greenock Creek	Marne	Onkaparinga	South Para
Total Error (all farm dams combined)	-9.2	-1.4	-32	-9.3	6.3	4.7
Mean Error	-3.1	4.1	-14	-4.1	21	16
Median Error	10	0	-24	-7.4	4.9	21
Minimum Error	-84	-84	-69	-84	-30	-44
Maximum Error	163	163	133	95	163	77
Standard Deviation of error	37	32	40	26	48	27

* Excludes Greenock Creek catchment data

Table 4.4 Percentage errors when Relationship 4.2 is applied to grouped and individual catchments with low surface water demand.

	Bremer, Clare, EMLR, Torrens, Inverbrackie	Clare, EMLR, Torrens Inverbrackie *	Bremer	Clare	EMLR	Torrens	Inverbrackie
Total Error (all farm dams combined)	-2.4	-3.0	16	-5.8	-11	2.4	-7.4
Mean Error	11	8	38	0.6	5.1	12	7.6
Median Error	6.8	4	24	1.0	-3.7	3.9	10
Minimum Error	-72	-72	-34	-63	-49	-54	-72
Maximum Error	177	177	152	-42	108	177	109
Standard Deviation of error	39	36	47	25	43	40	34

* Excludes Bremer River catchment data

4.5.2 RANKING OF RELATIONSHIPS

During the initial phase of this study (before data from the Clare PWRA, River Torrens catchment and the EMLR became available) a ranking system was devised to determine the relative performance of the historical relationships and relationship 4.1. A score was generated for each relationship based on the sum of products of errors and an associated error weighting.

Errors considered included the average errors in each size class, the overall error of the sum of all farm dams, and the minimum and maximum errors. Each of these was taken for each catchment individually and for groupings of catchments. Weightings were applied to all aspects including the catchments and number of farm dams in each size class.

The intention was to devise an objective means of comparing relationships, however subjectivity was inherent in deciding on the weightings. Also, the use of a single overall score (that included a large number of error-weighted products, each with their own weighting) for each relationship meant that important aspects tended to be masked by the "noise" from all the other aspects even when weightings were biased towards the important aspect(s).

This ranking system did show that the new relationship 4.1 was marginally better overall than the historical relationships, based on the sample set at that time. However, as the application of the ranking system was time-consuming and offered little confidence in its relevance, it was decided not to repeat the exercise when the additional data (from the Clare PWRA, River Torrens catchment and the EMLR) became available.

4.5.3 TOPOGRAPHIC ANALYSIS

As explained in Section 3, the average slope of the terrain in which the farm dams were situated was determined, and possible depths were determined from topographic data using GIS methods. The aim was to investigate whether these desktop-determined parameters could be used to improve the accuracy of desktop volume estimates. The analyses were conducted on a smaller sub-set of farm dams that could be identified in GIS farm dam data.

Each of the surveyed characteristics of farm dams (depth, area, volume and also area/depth ratio) were plotted against both slope class and against GIS-determined depth. These are shown in Figures 4.15(a) through 4.15(h). Regression lines are also shown for GIS-determined depth.

There was very little correlation between any of the plotted characteristics of farm dams and slope class. Therefore, slope class (as determined) is not a suitable parameter to fulfil either of the aims of this analysis.

There were some general trends between some of the plotted farm dam characteristics and GIS-determined depth. However, the correlations (r^2) are very weak and there is wide scatter in the data. The wide scatter indicates that GIS-determined depth is also unlikely to be a suitable parameter for the aims of this analysis.

It was also noted that the correlation between the surveyed depth of farm dams and the GIS-determined depth is very weak (Fig. 4.15(b)). This indicates that the GIS method of determining depth is not an effective tool and cannot be used in place of field-surveyed wall height in volume-area-depth relationships.

In order to further explore the possibility of using desktop-determined parameters in a volume-estimating relationship, a principle component analysis and multiple regression analysis were conducted on the surveyed characteristics of the farm dams. However, early results indicated that these methods were unlikely to add any useful information to assist with desktop techniques, and given time constraints, these analyses were not pursued further.

4.5.4 VOLUME ESTIMATES AT LESS THAN FULL SUPPLY LEVEL

Various volume-area relationships were applied to the farm dams in the River Torrens catchment at different levels of capacity less than full supply level. The River Torrens catchment farm dams were used as the surface area and volume could be determined at any capacity from the topographic survey data. All the historical relationships, the two relationships produced in this study and the volume-area-depth relationship (described later in Section 6) were tested. In each case the errors increased dramatically as the capacities were reduced. As an example, the errors obtained with relationship 4.1 are shown in Figure 4.16.

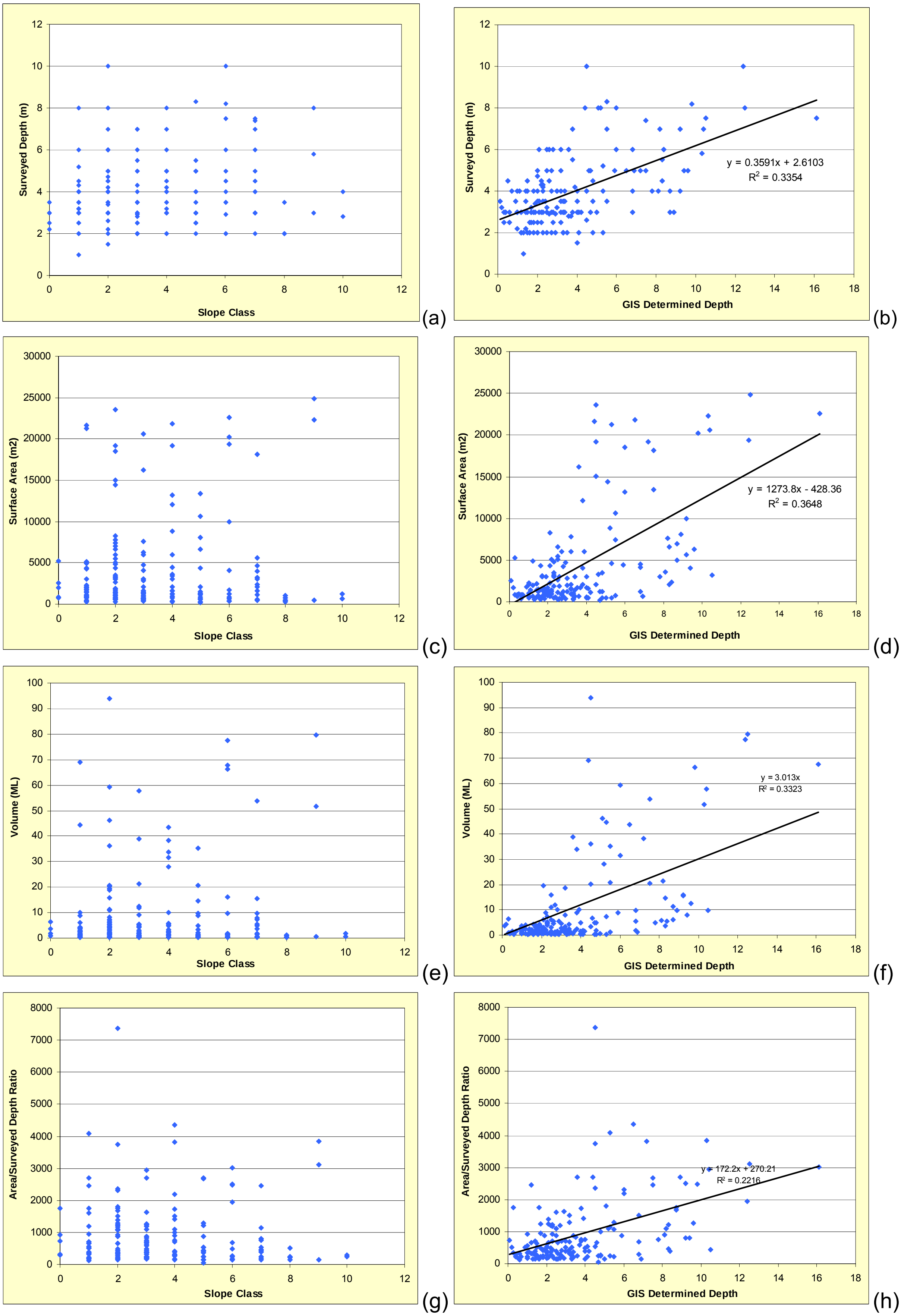


Figure 4.15 Scatter plots of farm dam characteristics (depth, area, volume and area/depth ratio) against slope class and against GIS-determined depth.

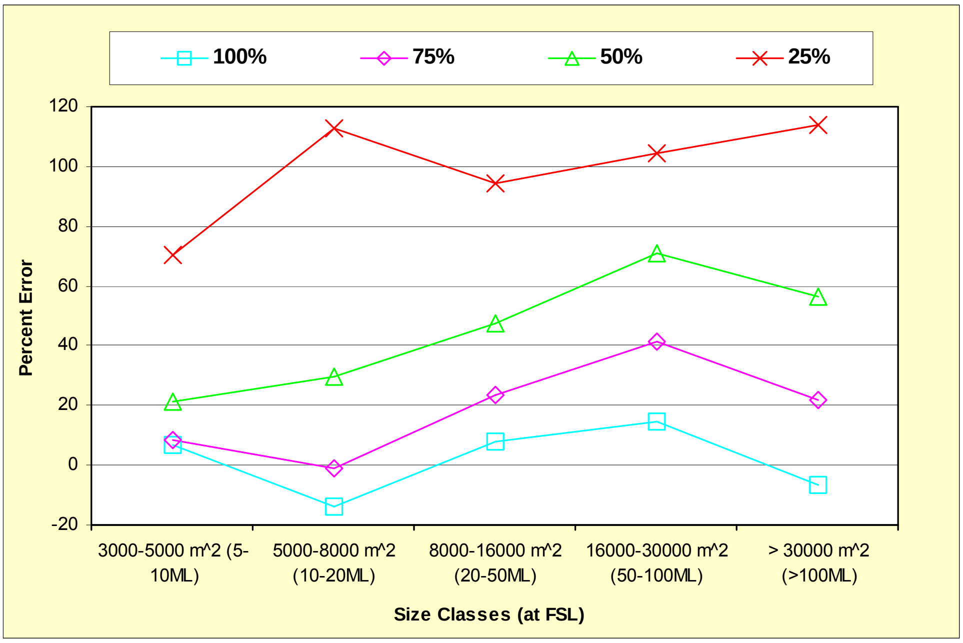


Figure 4.16 Overall errors in each size class when relationship 4.1 was used to estimate the volume of the River Torrens catchment farm dams at varying capacities.

The tested volume-area and volume-area-depth relationships are therefore suitable only for estimating the volume of farm dams at full, or near-full, capacity.

4.5.5 STREAMBED SLOPE

As explained in Section 3, streambed slope can be determined either from in-field surveys or by using desktop techniques. Streambed slope can then be used to estimate the maximum depth of farm dams, and hence the volume estimated with a volume-area-depth relationship (volume-area-depth relationships are described in Section 6).

In this study, streambed slope was determined for each farm dam from the topographic survey of farm dams in the River Torrens catchment. From streambed slope and length of the farm dams, farm dam depths were estimated and volumes calculated using a volume-area-depth relationship. The equations for this were as follows:

Streambed Slope = Drop/Run

Estimated Depth = Length x Drop/Run

Estimated Volume = 0.4 x Estimated Depth x Surface Area / 1000

The estimated volumes were then compared to the surveyed volumes using the size class assessment method, with the errors obtained shown in Figure 4.17. The overall errors range from -20% in the middle size classes (the smallest size class in the sample data) to zero error in the largest size class.

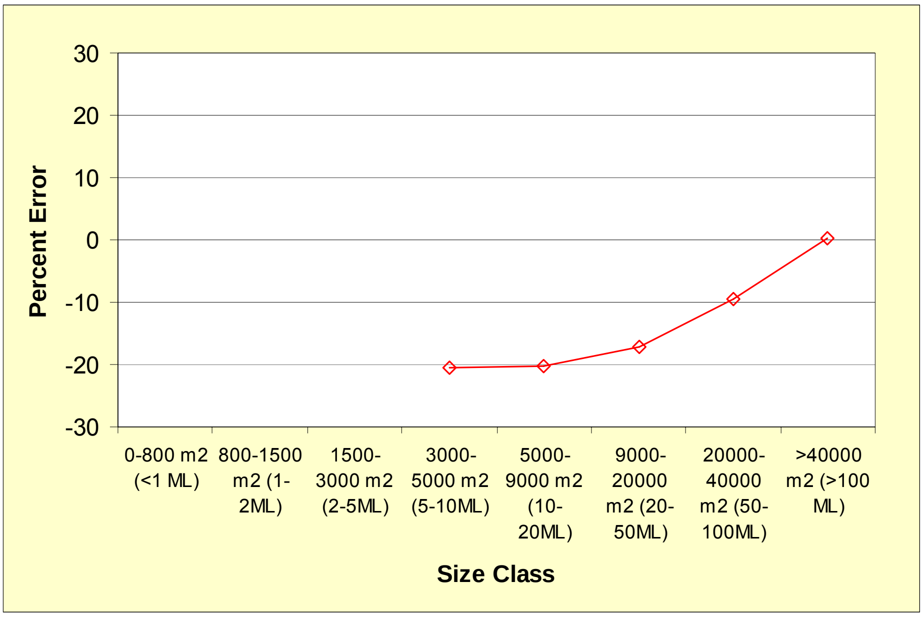


Figure 4.17 Overall errors in each size class when the volumes for the River Torrens catchment farm dams were estimated with a relationship that included farm dam length and streambed slope.

The worst-case errors for individual farm dams were –68% and 20% (Table 4.5). These errors are not unreasonable when compared to the errors produced by other types of relationships. However, there were too few farm dams in the smaller and largest size classes for this to be a valid assessment in those size classes.

Table 4.5 Table of overall and worst-case errors for individual farm dams for volumes estimated with a relationship that included farm dam length and streambed slope.

Size Class	3000-5000m² (50-10ML)	5000-9000m² (10-20ML)	9000-20000m² (20-50ML)	20000-40000m² (50-100ML)	>40000m² (>100ML)
Number of Farm dams	2	22	25	9	5
Overall	-20.5	-20.4	-17.3	-9.6	0.2
Minimum	-25	-46	-68	-34	-7
Maximum	-15	6	19	20	7

In order to judge the accuracy of the length-streambed slope method of estimating depth, the estimated depth is shown plotted against surveyed depth in Figure 4.18, and the percentage differences in Figure 4.19. Figure 4.18 shows the general trend is for depth to be increasingly underestimated as actual depth increases. This is probably due to smaller farm dams being excavated more (relative to their size) than larger farm dams. Figure 4.19 shows that the percentage errors are quite large for many farm dams, with errors up to -64%.

The range of errors in estimating depth with this method is similar to the errors in estimating depth by using external wall height (described in Section 6). The difference is that the latter tends to increasingly overestimate depth as depth increases (Fig. 6.2), and the length-streambed slope method increasingly underestimates depth with increasing depth (Fig. 4.18).

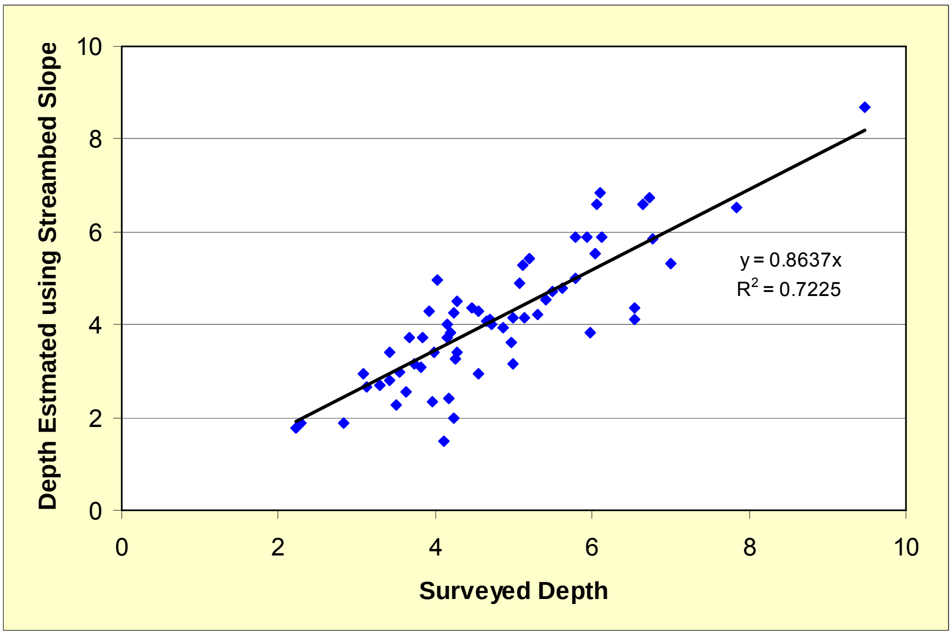


Figure 4.18 Scatter plot and regression line for depth estimated using farm dam length and streambed slope against surveyed depth.

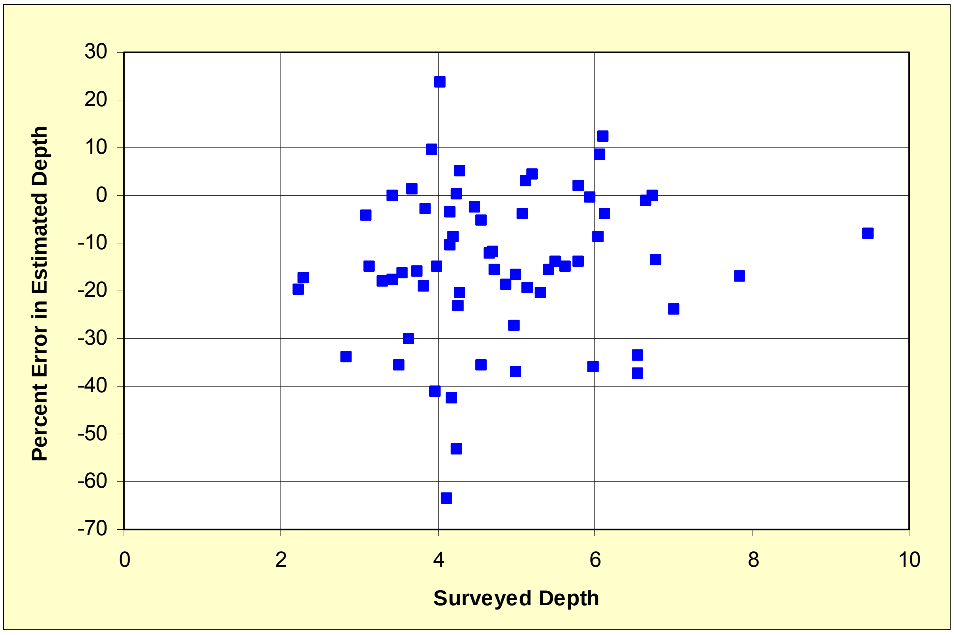


Figure 4.19 Percentage errors in estimating depth using farm dam length and streambed slope plotted against surveyed depth.

These large errors in estimated depth indicate that the length-streambed slope method of estimating depth, although resulting in reasonable overall estimates of volume in each size class (if ±20% is considered reasonable), does not provide increased accuracy on individual farm dams. Therefore, this method is unlikely to improve the accuracy of volume estimates.

5. HISTORICAL VOLUME-AREA RELATIONSHIPS

5.1 INTRODUCTION

Several volume-area relationships have been developed as part of other studies involving farm dams. As part of the current study, several of these existing relationships were reviewed and assessed. The assessment used the size class assessment method (described in Section 3.1) and the large sample of surveyed farm dams collated for this study. All charts are given at the end of this section.

In the following text, references are made to groupings of catchment data and to catchments or areas with either high irrigation demand or low irrigation demand. These terms were described fully in Section 4.3 and summarised in Table 4.2. In brief, some of the sample data was identified as having generally high volume to area ratios and were located in catchments that were perceived to have a high demand for irrigation. Other sets of sample data showed generally lower volume to area ratios and were located in catchments with perceived low irrigation demand. In order to fully assess the historical relationships, they were tested against both sets of data, as well as all data combined and on individual catchment data.

5.2 MAAREN AND MOOLMAN (1985)

Description

In a study by Maaren and Moolman (1985) two relationships were established for farm dams in two catchments in South Africa. In the reference document the formulae were presented as surface area expressed as a function of volume. When rearranged the formulae became:

$$V = 0.0016\ A^{1.56}$$

$$V = 0.077\ A^{1.3}$$

where V = volume (kL); and
A = surface area (m^2).

No assessment of errors was given. The differences between the relationships for the two catchments were attributed to differences in geographical relief (Maaren and Moolman 1985).

Assessment in Size Classes

These two relationships give much lower estimates of volume than any of the other relationships, as shown by the high negative errors across the majority of size classes (Fig. 5.1). This indicates that the farms dams in that study's catchments tended to be of a shallower construction than the surveyed farm dams in the Mount Lofty Ranges. These relationships were therefore considered unsuitable for application to farm dams in the Mount Lofty Ranges and Clare regions.

5.3 MCMURRAY (1996)

Description

The following relationship was developed in a study of a sample of farm dams in the Bremer River catchment as part of an assessment of all farm dams in the Mount Lofty Ranges (McMurray 1996):

$$V = (0.044 \ A^{1.4}) / 1000$$

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

The data were sourced from the results of a topographic survey of a sample of farm dams in the upper reaches of the Bremer River catchment. These were surveyed in 1984 by the then Engineering and Water Supply (EWS) Department. Data from 26 of these farm dams were utilised. One of these farm dams was around 39 ML, four farm dams were between 10 to 5 ML, ten farm dams were between 2 to 10 ML and the remaining eleven were under 2 ML.

The results from that study showed that this relationship gave the total volume estimate to within a few percent when the volumes of all the 26 sample farm dams were totalled, as was the intention of the formula. The standard deviation of the error was 34% and the worst-case errors on individual farm dams were -52%/+81%. It was also noted that the formula gave reasonable volumes estimates for farm dams down to around half capacity.

This relationship was used for the 1996 study of farm dams in the Mount Lofty Ranges as there was no other relationship derived for the Mount Lofty Ranges at that time. However, the sample size was very small (only 26 farm dams); most of the sample farm dams were under 20 ML; all sample farm dams were in one catchment in the drier part of the Mount Lofty Ranges; and all farm dams were constructed before 1984. Construction techniques, and hence farm dam geometry, might have changed with the increase in demand for irrigation water since that time.

Assessment in Size Classes

This relationship produced reasonable errors across all represented size classes when applied to the Bremer River catchment farm dams from which the relationship was derived (Fig. 5.1). However, when applied to other groupings of farm dams, large negative errors were obtained across the smaller and middle range size classes (Figs 5.2 and 5.3). This was attributed to the Bremer River catchment farm dams being generally of a shallower construction than the other farm dams. Conversely, large positive errors were produced in the larger size classes. This was attributed to the high value of the exponent (1.4). The use of this relationship in these larger size classes is an extrapolation as there was no data for these larger size classes in the original study.

Due to these large errors produced across most size ranges, and the small sample size on which the relationship was derived, the continued use of this relationship is not advisable.

5.4 BILLINGTON & KOTZ 1999

Description

A volume-area relationship was derived during an inventory of farm dams in the Marne River catchment (Billington and Kotz 1999; South Central Region Network 2000) as follows:

For $A < 3000$ $V = 0.0016\,A - 0.1086$

For $A \geq 3000$ $V = 0.0035\,A - 5.7425$

where V = volume (ML); and

A = surface area (m^2).

The source data was a field survey using rapid field assessment techniques of around 100 farm dams in the upper Marne River catchment in 1998. The volume-area relationship was derived using regression analysis (South Central Region Network 2000). Many relationships were trialled (linear, exponential, power) with the final relationship chosen on the ability of the equation to represent the data and ease of application (South Central Region Network 2000).

This relationship was based on a reasonable size dataset (100 of the 680 farm dams in the catchment). However, the larger farm dams were not well represented with only eight sample farm dams over 50 ML and only one over 100 ML. Also, all sample farm dams were in one catchment in the drier part of the Mount Lofty Ranges. This catchment had a large number of large irrigation farm dams when compared with many other catchments with different land uses.

Assessment in Size Classes

This relationship produced reasonable low average errors (worst-case -10/+22%) across all size ranges for the Marne River farm dams (Fig. 5.4) from which the relationship was derived, and also for the high irrigation demand grouping of catchments (Fig. 5.2).

With the grouping of low irrigation demand catchments, the errors are generally quite large and positive (Fig. 5.3) due to this relationship overestimating farm dams in these areas.

The foregoing shows that this relationship is suitable for catchments with high irrigation demand, but is likely to overestimate volumes in catchments with low irrigation demand.

5.5 PIKUSA (1999)

Description

As part of a study of water resources in the Barossa Valley (in the Gawler River catchment) the following volume-area relationship was proposed (Pikusa 1999):

$V = 0.0002\,A^{1.2604}$

where V = volume (ML); and

A = surface area (m^2).

Details of the methodology were not documented but the relationship was assumed to be a regression equation. The source data was initially assumed to be the farm dam data from the Marne River (as in Billington & Kotz 1999 above), however it later came to be suspected that this relationship was a regression of survey data from the Inverbrackie Creek catchment.

Assessment in Size Classes

The errors produced when applied to the Marne River catchment farm dams tend to vary from around -14% to -5%, except for +30% in the largest size class (Fig. 5.4). The high positive error in the largest size class is a common issue with most single-equation power-law relationships. The consistent negative errors across the other size ranges suggest that this relationship was not based on the Marne River catchment farm dams.

When this relationship was applied to the Inverbrackie Creek catchment farm dams the errors are reasonable across all represented size classes (there were not any farm dams in the larger size classes in the Inverbrackie Creek catchment sample set) as shown in Figure 5.4. A regression on the Inverbrackie Creek catchment farm dams was very similar to this relationship. These aspects suggest that this relationship was derived from the Inverbrackie Creek catchment farm dams.

In the small to medium size classes, this relationship produced the lowest average errors with the low irrigation demand catchment grouping (Fig. 5.3) when compared to the high irrigation demand catchment grouping (Fig. 5.2), and produced reasonable errors for grouping of all data (Fig. 5.1). The relationship produced very large positive errors in the larger size classes for all three groupings.

The foregoing shows that this relationship is suitable for farm dams in the smaller size classes within low irrigation demand catchments or regions. Note also that this relationship produced very similar errors to the relationship produced by Sinclair Knight Merz (2001), as described in Section 5.7.

5.6 MCMURRAY (2001)

Description

The study by McMurray (2001) used the following volume-area relationship:

$$V = 0.000131\, A^{1.32}$$

where V = volume (ML); and

A = surface area (m^2).

This relationship was based on an initial collation of farm dam survey data in the early stages of the current study. This was prior to the availability of some survey data, in particular, the larger farm dams from the Onkaparinga catchment. This relationship was used in the 2001 study as it was the most promising relationship emerging at that time (McMurray 2001).

Assessment in Size Classes

This relationship produced errors generally in the range ±20% for the small to medium size classes for the three catchment groupings (Figs 5.2 to 5.3). However, large positive errors were produced in the larger size classes (as with other power-law relationships).

This was an interim relationship, it is believed it was used in only one study, and it does not produce lower errors than some other relationships. It is not recommended for further use.

5.7 SINCLAIR KNIGHT MERZ (2001)

Description

A regression of the survey data from 42 surveyed farm dams in the South Para River catchment produced the following volume-area relationship (Sinclair Knight Merz 2001):

$$V = 0.0001757\ A^{1.2731}$$

where V = volume (ML); and

A = surface area (m^2).

Assessment in Size Classes

This relationship produced almost identical results to the relationship described in Pikusa (1999); refer to Section 5.5 and Figures 5.1 to 5.3.

5.8 PITMAN AND PULLEN (DATE UNKNOWN)

Description

A regression analysis on a number of farm dams in South Africa (Pitman and Pullen date unknown) produced a volume-area-depth relationship and two volume-area relationships for different farm dam sizes and regions as follows:

For A >5ha $V = 0.01\ (A\ D)^{0.25}$

For A <5ha $V = 16\ A$ low relief areas

$V = 20\ A$ hilly areas

where V = volume (ML);

A = surface area (ha); and

D = depth (m).

Assessment in Size Classes

This relationship uses a linear equation for smaller farm dams that does not follow the general power-law trend of the farm dams in the current study and produced very large average errors in several size classes (not shown). These errors ranged from -45% through to 45% over the size ranges for the equation with the smaller coefficient, and -20% to 81% for the equation with the larger of the two coefficients.

The equation for the larger farm dams (>5ha) incorporating depth and surface area, produced very low estimates of volume. This may have been due to the use of an incorrect exponent value, due to the poor quality copy of the source document in which this study was reported.

These relationships are not recommended for use in the Mount Lofty Ranges and Clare PWRA regions.

5.9 SUMMARY – HISTORICAL VOLUME-AREA RELATIONSHIPS

All the single-equation power-law volume-area relationships tested produced increasingly large errors for larger size classes. This type of relationship should be used only for small to medium size farm dams, with capacities of 50 ML or less.

The relationships produced in the South African studies (Maaren and Moolman 1985; Pitman and Pullen date unknown) were shown to be unsuitable for application in the Mount Lofty Ranges and Clare PWRA regions.

The relationship reported in McMurray (1996) underestimated the volume of farm dams in most size classes, and overestimated volumes in the largest size class. It is recommended that this relationship is no longer used.

The relationship reported in McMurray (2001) was an interim relationship and it is not known to have been used in any other study. Although it produced reasonable volume estimates in many of the combinations of catchment groupings in the small to medium size classes, it produced very large errors in the larger size classes. It is recommended that this relationship is no longer used.

The relationships reported in Pikusa (1999) and Sinclair Knight Merz (2001) are very similar equations and hence produced very similar results. The volume estimates are generally between those of the two relationships recommended from the current study, except in the largest size class where the relationships overestimated volume by varying amounts depending on the groups of data. Some of these errors reached 60% (Fig. 5.3). It is considered that these relationships may produce generally reasonable estimates for groups of farm dams with volumes of up to around 50 ML, but may underestimate volumes in catchments or regions with high irrigation demand.

The relationship reported in Billington and Kotz (1999) produced good results for the Marne farm dams, but produced overestimates for most of the other regions. It is recommended that this relationship is not used for catchments or regions with low irrigation demand.

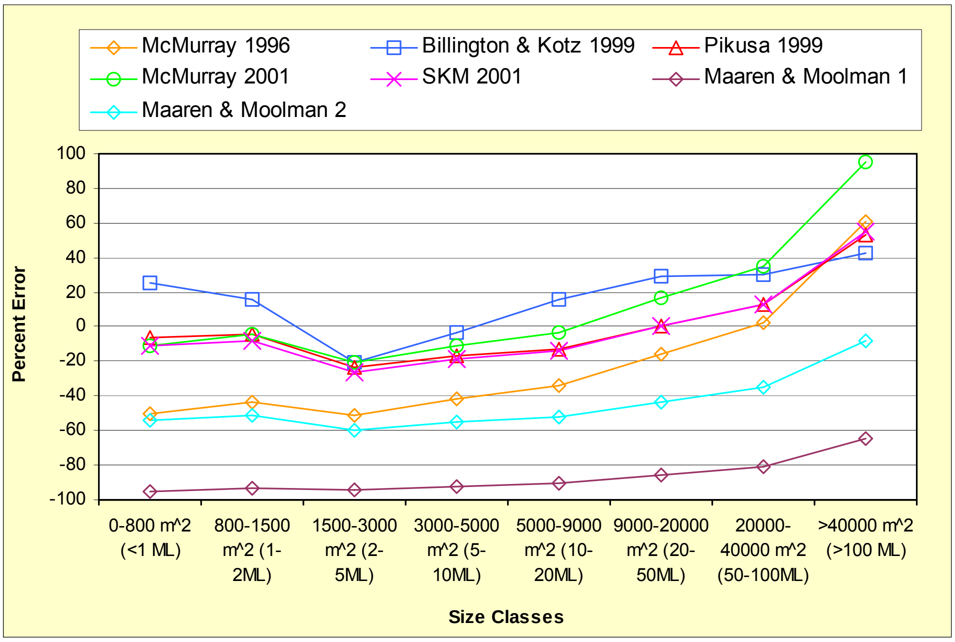


Figure 5.1 Errors produced in each size class by the historical volume-area relationships when applied to the grouping of data from all catchments.

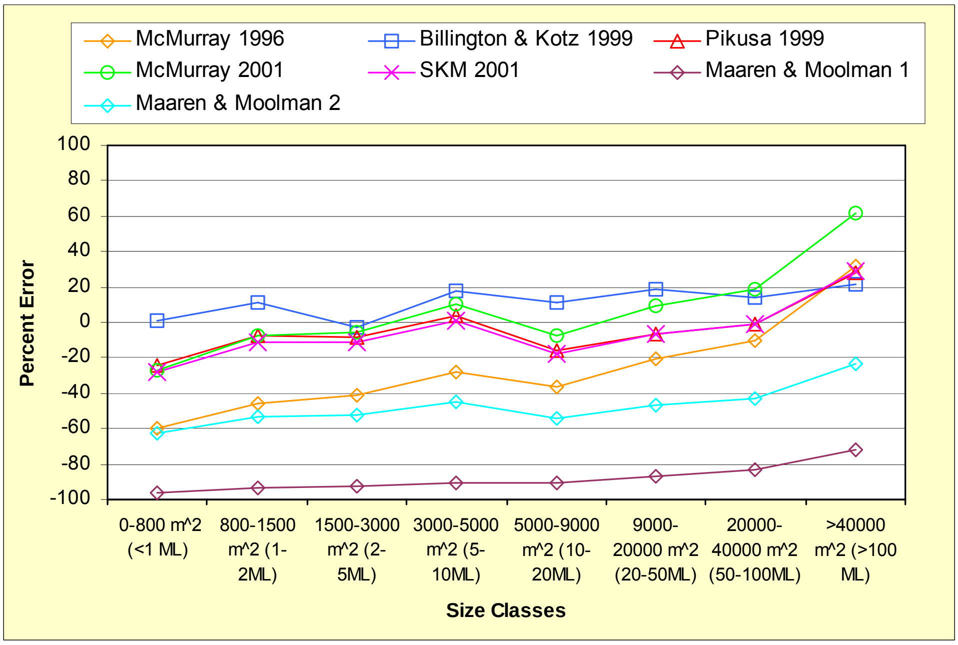


Figure 5.2 Errors produced in each size class by the historical relationships when applied to the grouping of data from catchments with high irrigation demand.

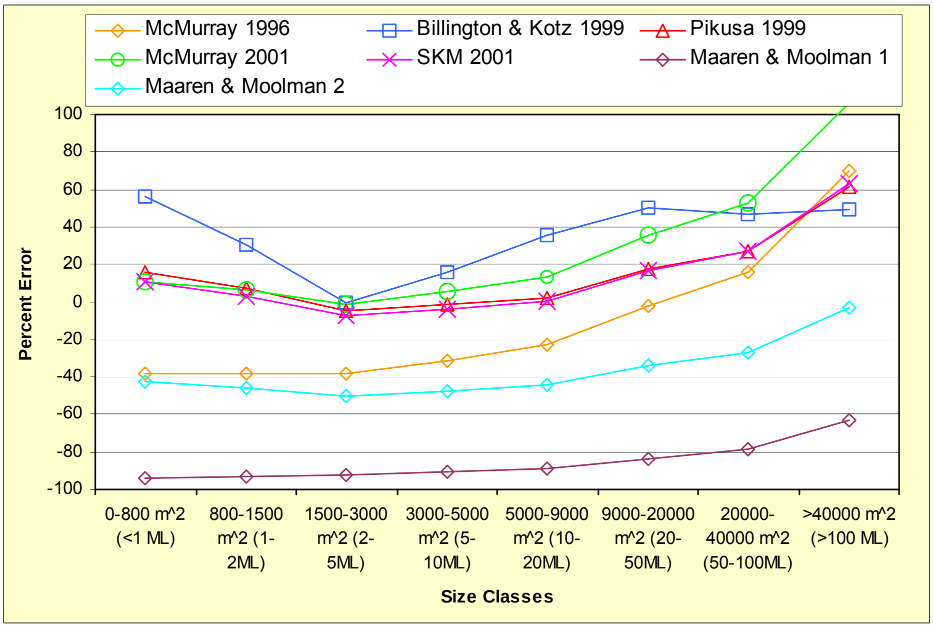


Figure 5.3 **Errors produced in each size class by the historical relationships when applied to the grouping of data from catchments with low irrigation demand.**

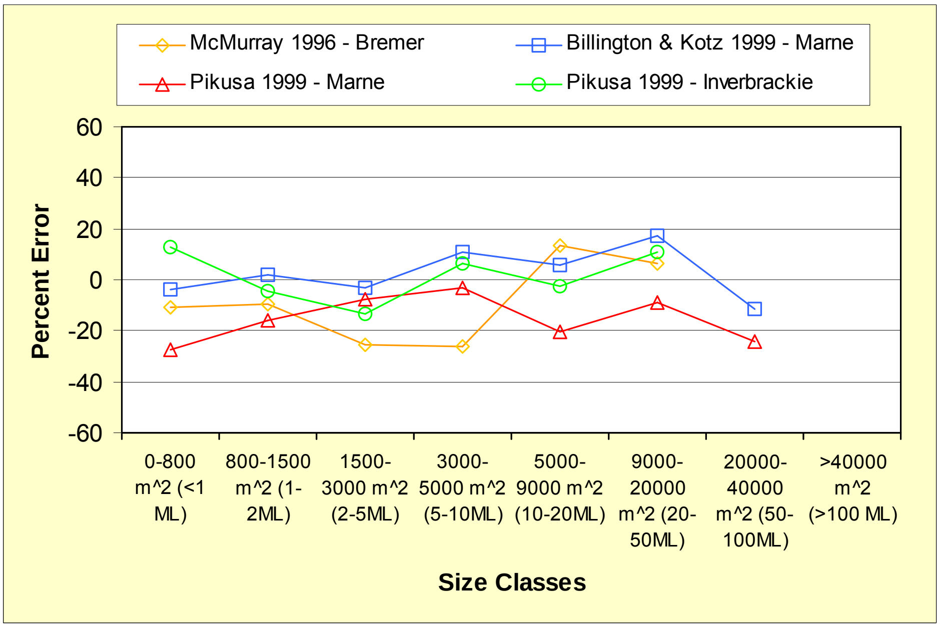


Figure 5.4 **Errors produced by selected historical volume-area relationships when applied to the catchment data from which they were derived.**

6. VOLUME-AREA-DEPTH RELATIONSHIPS

6.1 INTRODUCTION

During farm dam assessments in the 1980s to early 1990s (that utilised rapid field assessments), the following volume-area-depth relationship was proposed (Cresswell pers. comm.):

$V = 0.45\ D\ A$ Relationship 6.1

where V = volume (kL);

D = maximum depth (m); and

A = surface area (m^2).

A similar volume-area-depth relationship was derived by Lenz and others (Lenz pers. comm.) during rapid field assessments of farm dams (date unknown). Also and independently, McMurray and Healey (1996) derived the same relationship during the assessment of the Bremer River catchment farm dams (Section 5.3):

$V = 0.4\ D\ A$ Relationship 6.2

where V = volume (kL);

D = maximum depth (m); and

A = surface area (m^2).

The study by McMurray and Healey (1996) showed that this relationship gave the overall estimated volume to within 2% of the surveyed volume when applied to the 26 surveyed Bremer River catchment farm dams. The standard deviation of error was 17% and the worst-case errors on individual farm dams were -32% and 44%. This spread of error on individual farm dams was lower than that obtained with the surface-area-only relationship reported in McMurray (1996) which were -52% and 81%. This smaller spread in error is due to the inclusion of another geometric variable (i.e. depth) into the relationship.

The volume-area-depth relationship shown above (relationship 6.2) is used in rapid field assessments of farm dams. The rapid field assessment technique involves: (a) determining the surface area of farm dams, either from simple geometry and length and width measurements, or from digitised outlines; (b) measuring the external wall height as a surrogate for maximum depth; and (c) calculating the volume from relationship 6.2. The rapid field assessment technique is described further in the Appendix.

The rapid field assessment technique was used for the majority of the surveyed farm dams used in this study. It was important therefore, to verify the accuracy of the relationship.

6.2 METHOD

The volume-area-depth relationship used in rapid field assessments of farm dams (relationship 6.2) was assessed by comparing the calculated volumes with the volumes determined from the topographic survey of the Torrens River catchment farm dams. Also tested was the validity of using external wall height as a surrogate for maximum depth.

Another aspect tested was the use of streambed slope to determine maximum depth. This is described under Streambed Slope in Section 4.5.5.

6.3 RESULTS

The volume-area-depth relationship 6.2 was applied in size classes to the topographically surveyed farm dams in the Torrens River catchment. The relationship was tested using both the maximum depth and external wall height and the results are shown in Figure 6.1. Other statistics, including minimum and maximum errors for individual farm dams, are shown in Table 6.1.

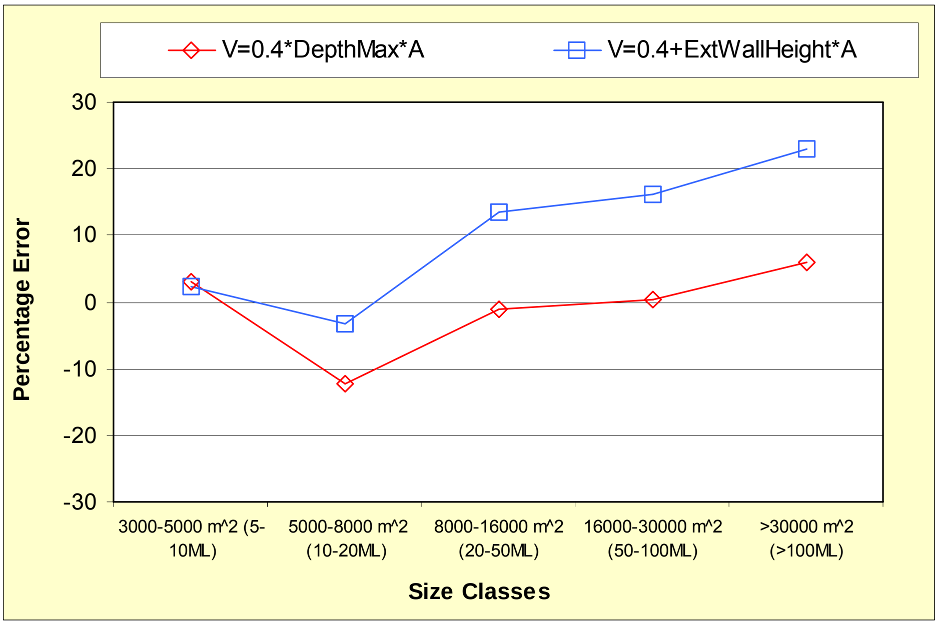


Figure 6.1 Average percentage errors across the size ranges obtained with the volume-depth surface area relationship (6.2) using both external wall height and maximum depth.

Table 6.1 Statistics of overall percentage errors when the volume-area-depth relationship 6.2 was applied to the Torrens River catchment farm dams.

	V = 0.4 D A	V = 0.4 W A
Total Error (all farm dams combined)	0.8	16
Mean Error	-0.9	13
Median Error	-1.2	14
Standard Deviation of error	17	25
Minimum Error	-31	-39
Maximum Error	75	91

V = volume (ML)

A = surface area (m^2)

D = maximum depth (m)

W = external wall height (m)

When the surveyed value of maximum depth was used in the relationship, the average errors were less than +6/-12% in each of the represented size classes (farm dams greater than 5 ML). The worst-case errors with individual farm dams were -31% and +75%, and the standard deviation of the errors was 17%.

When the surveyed value of external wall height was used in the relationship, the average errors ranged from ±3% in the two smaller size classes up to +23% in the largest size class (farm dams over 100 ML). The worst-case errors with individual farm dams were -39% and +91% and the standard deviation of the errors was 25%. These potential errors are larger than when maximum depth is used, however the results can still be regarded as reasonable.

As with volume-area relationships, the volume-area-depth relationship 6.2 is valid only for estimating the maximum capacity of farm dams. Increasing errors were obtained when the relationship was tested at lower capacities, rising to over 100% (average error) at 25% of maximum surface area.

This relationship was not tested at less than full capacities using actual depth (rather than maximum depth or external wall height).

6.4 DEPTH ESTIMATION

A plot of external wall height against maximum depth is shown in Figure 6.2, and the percentage difference between external wall height (the error) and surveyed depth is shown in Figure 6.3. As shown in Figure 6.2, the regression line has a slope near 1:1.1 rising as maximum depth increases. This indicates that in general, larger farm dams have a higher external wall height in proportion to their maximum depths. This is possibly due to a steeper streambed slope in locations where larger farm dams are usually situated. Field operators could compensate for this by using discretion when applying external wall height as a substitute for maximum depth.

The errors produced when estimating maximum depth by the use of external wall height (Fig. 6.3) are not insignificant for many farm dams, with the worst-case errors being -41% and 72%. This indicates that the volume-area-wall height relationship 6.2 is not necessarily accurate for individual farm dams.

6.5 SUMMARY – VOLUME-AREA-DEPTH RELATIONSHIPS

When the volume-area-depth relationship using maximum depth (relationship 6.2) was tested on the surveyed farm dams from the Torrens River catchment, reasonably accurate results were obtained across all represented size classes. However, when external wall height was substituted as a surrogate for maximum depth, both the average and worst-case errors were larger. There was therefore, an issue with determining maximum depth by the simple means applied in this case. This was not improved by measuring streambed slope over the length of the farm dam (as described in Section 4.5.5).

Given the cost-effectiveness of the rapid field assessment method together with the fact that the errors resulting from the use of the volume-area-wall height relationship 6.2 are not grossly large, it is recommended that the volume-area-depth relationship is continued to be used, with the proviso that discretion is used in determining the maximum depth of farm dams by measuring the external wall height, particularly where the streambed slope is high.

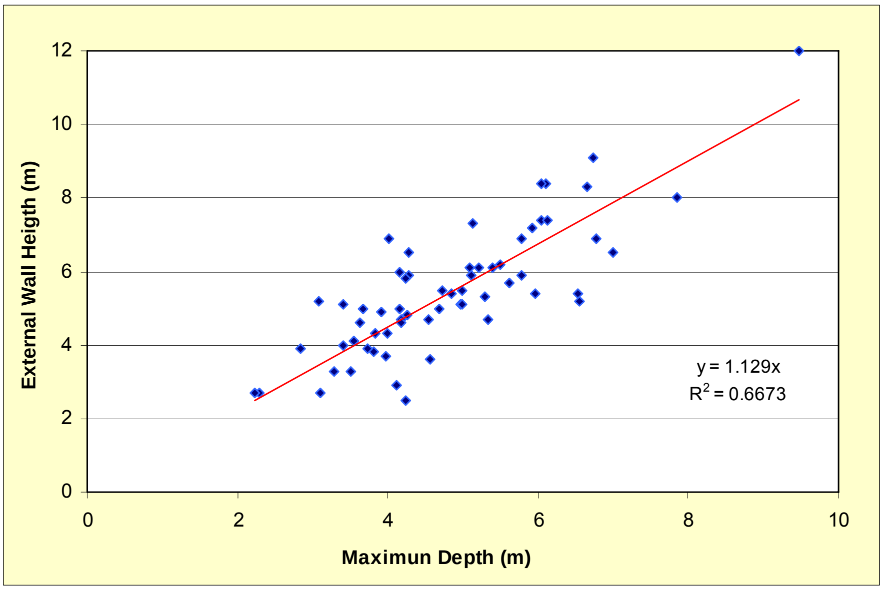


Figure 6.2 Scatter plot of external wall height against maximum depth and trend line.

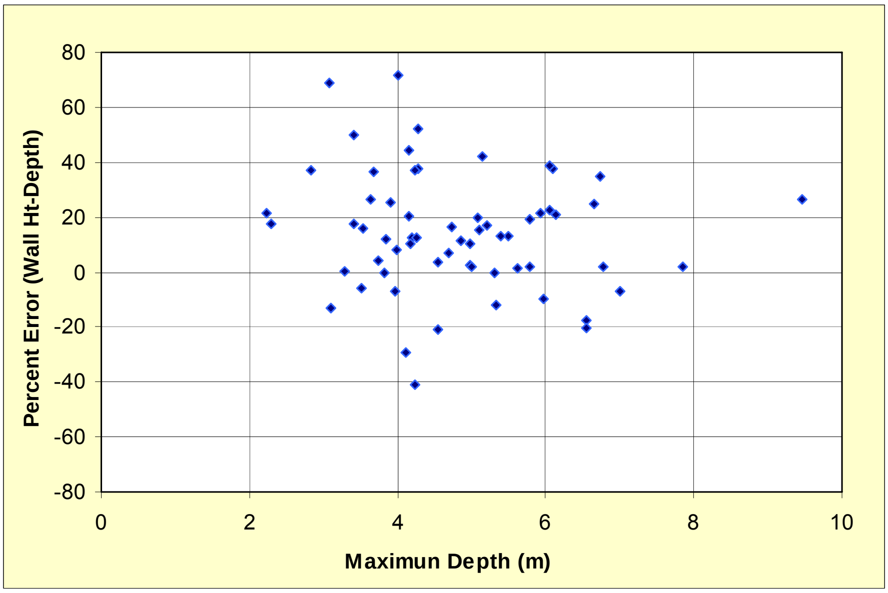


Figure 6.3 Percentage error between external wall height and surveyed maximum depth.

It should be noted that the use of the volume-area-depth relationship 6.2 does not necessarily produce accurate estimates on individual farm dams. A statistical advantage can be assumed when the volumes of groups of farm dams are combined. This has implications for the majority of sample data used in this study to derive volume-area relationships and to test historical volume-area relationships.

7. AREA-VOLUME RELATIONSHIPS

7.1 INTRODUCTION

Area-volume relationships estimate surface area from known volume and are used in time-step hydrological models. These models calculate parameters for every time-step, which is usually daily, but can be any interval such as hourly, monthly or annual. The model parameters calculated at each step include runoff from rainfall, water extractions, and the capacity of water in storages including farm dams. At each step of the model, the stored volume within farm dams changes due to stream flow, extractions and evaporation. At the end of each step the volume of water held in farm dams is known, but it is necessary to determine the surface area in order to calculate the volume of water that will evaporate in the next step of the model. This is the application of area-volume relationships.

Area-volume relationships were investigated using the data from the topographically surveyed farm dams in the Torrens catchments and also tested on the surveyed farm dams from the Bremer catchment.

7.2 METHOD

GIS-based techniques were used to calculate the storage volume and surface area at depths in 0.5 m intervals for each of the 66 farm dams surveyed. Plots of this data were then used to determine one parameter from any other parameters at any required interval.

The area-volume relationship was developed using an iterative approach with the results assessed by examining the average errors produced in each of the represented size classes. The smaller size classes were not represented because the survey data contained only farm dams over around 10 ML.

Various types of relationships were trialled including inverted forms of volume-area relationships and various order polynomials as single, dual and triple-equation relationships. The suitability of results varied considerably. The final relationship produced the lowest overall errors across the size classes. It was simple to apply and when $V = V_{max}$, $A = A_{max}$ (i.e. when V is at the starting volume V_{max}, the area A is also at the starting area A_{max}). The latter ensures that there is no error at the first step of a time-series-based hydrological model.

7.3 RESULTS

The recommended surface area-volume relationship is as follows:

$$A = A_{max} (V/V_{max})^{0.6}$$ Relationship 7.1

where A = surface area (m^2) to be determined at volume V;

A_{max} = surface area (m^2) at maximum capacity;

V = volume (kL or ML) for which A is to be determined; and

V_{max} = volume (kL or ML) at maximum capacity.

The overall errors in each size class are shown in Figure 7.1(a) and (b) for the Torrens River and Bremer River catchment farm dams respectively. Note that the size classes are different for the two Figures as the available data contained only larger farm dams in the River Torrens catchment data and mainly smaller farm dams in the Bremer River catchment data.

For the River Torrens catchment farm dams (on which the relationship was developed) the average errors in each size class were less than ±5% for volumes of 100%, 75% and 50% of maximum volume across all represented size classes (farm dams >5 ML), rising to around 10% at 25% of maximum volume in the smaller of the represented size classes (farm dams 5 to 20 ML).

For the Bremer River catchment farm dams the overall errors in size classes were higher (Fig. 7.1(b)). The majority were within 10% rising to 31% in the larger of the size classes at 25% of full capacity. There were only three farm dams in the larger size class with one farm dam showing a large error (49%) and thus biasing the overall error. These errors were considered reasonable, and provided support for the area-volume relationship for farm dams smaller than those surveyed in the Torrens catchment.

The overall errors for all farm dams combined and the worst-case errors on individual farm dams are shown in Table 7.1 for both the River Torrens and Bremer River catchment farm dams. These were considered reasonable given the highly variable nature of farm dams.

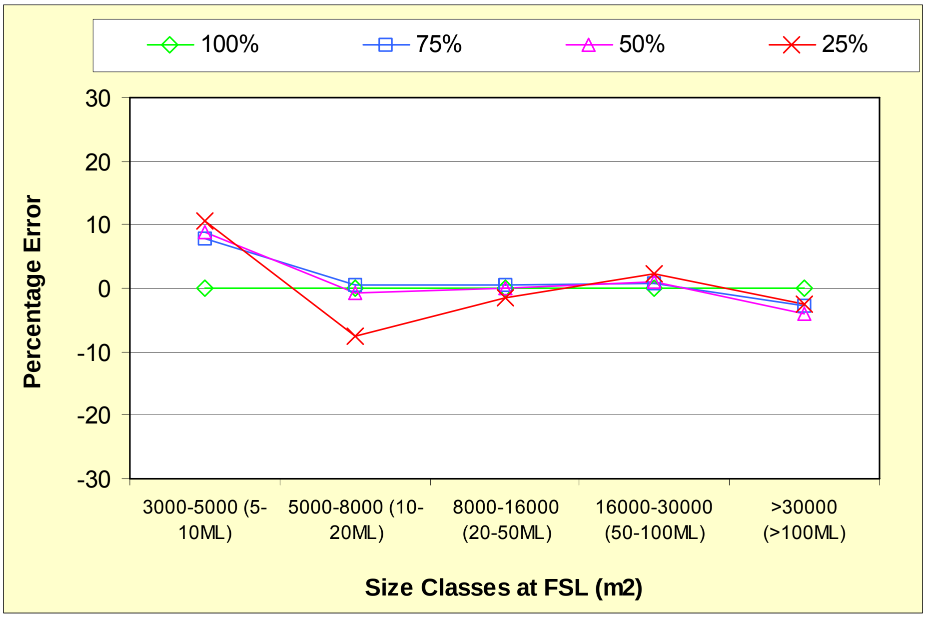
Table 7.1 Minimum and maximum errors for individual farm dams and total errors for all farm dams when relationship 7.1 was used to estimate surface area from volume at different capacities.

Percent of Capacity	100%	75%	50%	25%
Torrens farm dams:				
Total Error	0	0	-1	-1
Minium Error	0	-8%	-19%	-34%
Maximum Error	0	17%	50%	84%
Bremer Farm dams:				
Total Error	0	10	17	18
Minium Error	0	-10	-29	-42
Maximum Error	0	18	45	88

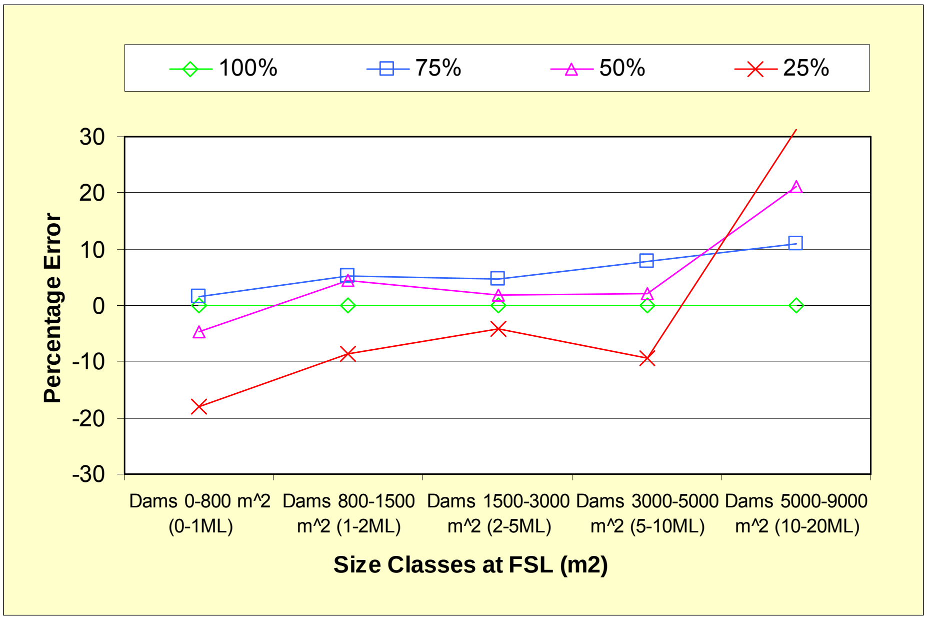
An example of relationship 7.1 plotted for one farm dam is shown in Figure 7.2. The relationship gave $A = A_{max}$ at full volume (when $V = V_{max}$). This is important as time-step hydrological models would otherwise produce an error at the first time-step.

The value of the exponent, although derived imperially by examining results within each size class, was supported by regressions of surface area against the ratio V/V_{max} for a sample of the surveyed farm dams. The value of the exponent of the regressions varied from 0.5 to 0.65 for different farm dams. An example is given in Figure 7.3.

This relationship was also tested on the combined parameters of five groupings of four to six of the River Torrens catchment farm dams. The worse-case errors for the five groups were +7/-18%. These results indicate that the relationship is valid also for combined parameters of groups of farm dams, which are often utilised in hydrological models.



(a)



(b)

Figure 7.1 Errors in size classes produced when area-volume relationship 7.1 was applied to (a) the Torrens River catchment farm dams and (b) the Bremer River catchment farm dams at different percentages of full supply level (FSL).

Note that the size classes are different for the two sets of farm dams.

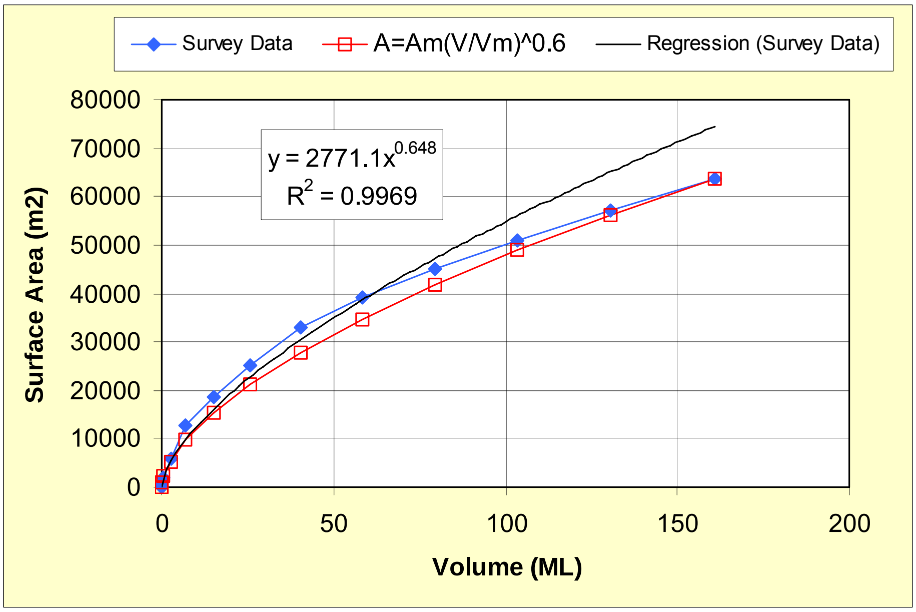


Figure 7.2 Plots of surface area and power-law regression equation, and relationship 7.1 against volume for one of the surveyed farm dams.

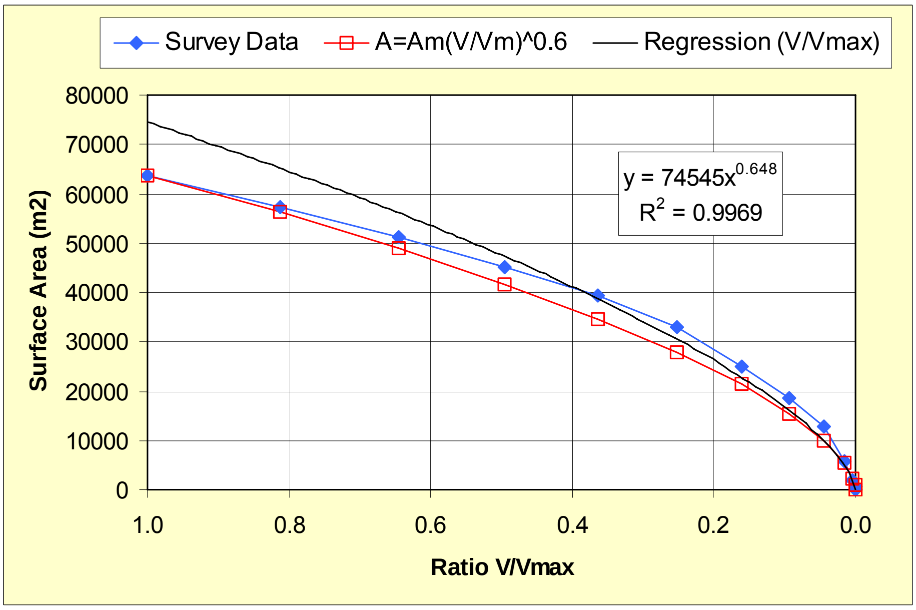


Figure 7.3 Plots of the surface area and power-law regression equation and relationship 7.1 against the ratio V/Vmax for one of the surveyed farm dams.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 ESTIMATION OF FARM DAM VOLUME

There was a large variation in farm dam geometries resulting in a wide range of possible volumes (up to 5:1) for any given surface area. There was evidence in the sample data to indicate that farm dam geometries tend to vary between areas and/or catchments.

Due to the wide variation of farm dam geometries, a volume-area relationship has proven to be unsuitable for estimating the storage volumes of individual farm dams. However, a statistical advantage can be assumed when a volume-area relationship is used to estimate the combined volume of a reasonable number of farm dams, for example within sub-catchments, as is the case with hydrological modelling (e.g. Teoh 2003; Savadamuthu 2003; Heneker 2003).

It is recommended that as part of any detailed hydrological study in areas where farm dams are considered an important issue, the largest farm dams are surveyed, at least with the rapid field assessment method. This will provide a reasonable estimate of the storage capacity of these farm dams, and permit the suitability of a volume-area relationship to be determined and used to estimate the volume of the remaining farm dams. It is important that the costs of these surveys are incorporated into the project budgets at the planning stage.

It is also recommended that the size class assessment method (as described in Section 3.1) is used to assess all newly-derived volume-area relationships. This will ensure that reasonable estimates of volume are obtained, on average, across the whole size range. Single-equation power-law relationships should not be extrapolated beyond the sample data as they are likely to overestimate the volume of larger farm dams.

8.2 RECOMMENDED VOLUME-AREA RELATIONSHIP

The final recommendation on the use of volume-area relationships is based on the arguments given in Section 4.4. The recommended volume-area relationship to be used in the majority of areas and catchments is as follows:

For $A < 15\,000$ $V = 0.0002\,A^{1.25}$ } Relationship 4.2

For $A \geq 15\,000$ $V = 0.0022\,A$ }

where A = surface area (m^2); and

V = estimated volume (ML).

In some areas where there is a high demand for irrigation water (e.g. Marne River and Greenock Creek catchments) the above relationship may underestimate the volumes by around 20% on average. In these areas it is recommended that either (a) the volumes estimated with the above relationship are increased by 20%, or (b) estimated with the following relationship:

For $A < 20\,000$ $V = 0.000215\,A^{1.26}$ } Relationship 4.1

For $A \geq 20\,000$ $V = 0.0028\,A$ }

where A = surface area (m^2); and

V = estimated volume (ML).

No support was found for the hypotheses that improvement in estimating the volume from surface area-based relationships could be obtained from either of the following:

a. knowledge of the average slope immediately adjacent to the farm dams;
b. knowledge of the depth of the original gully in which the farm dams were constructed (as determined with desktop techniques); and
c. streambed slope measured across the outside length of the farm dam and farm dam wall.

Volume-area relationships should be used for estimating only the full capacity of farm dams, as estimates of volume have increasing errors as the capacity reduces.

8.3 HISTORICAL VOLUME-AREA RELATIONSHIPS

It is considered that in general there is no requirement to use any of the historical volume-area relationships for new work unless specific studies within those areas indicate otherwise. Single-equation power-law relationships should not be used for larger farm dams (of over 20 to 50 ML) unless confirmed for the study area.

A summary of the suitability of the historical relationships that were tested in this study is as follows:

McMurray (1996)

Recommended that this relationship is discontinued from use due to large errors in many size classes.

McMurray (2001)

An interim relationship that may be suitable for farm dams under around 50 ML, but there is no perceived advantage it its further use.

Billington and Kotz (1999)

Produced low average errors across all size classes for the Marne River catchment farm dams on which it was based. Recommended for use only in regions with high irrigation surface water demand relative to availability and/or with high value crops.

Pikusa (1999) and Sinclair Knight Merz (2001)

Suitable for use for farm dams only up to around 50 ML and in regions with lower demand on surface water and without significant areas of high value crops.

Maaren and Moolman (1985) and Pitman and Pullen (date unknown)

Not recommended for use within the Mount Lofty Ranges.

8.4 VOLUME-AREA-DEPTH RELATIONSHIP

The volume-area-depth relationship 6.2 (provided below) produced reasonable errors in volume estimations when the actual surveyed depth was used. Larger errors were obtained when external wall height was used as a surrogate for maximum depth. Due to the cost-effectiveness of the rapid field assessment method, and the reasonable errors produced by this relationship, it is recommended that the volume-area-depth relationship 6.2 is continued to be used in rapid field assessments of farm dams, with the proviso that discretion is used in determining the maximum depth of farm dams by measuring the external wall height, particularly where the streambed slope is high.

$V = 0.4\ D\ A$ Relationship 6.2

where V = volume (kL);

D = wall height as a surrogate for maximum depth (m); and

A = surface area (m^2).

Volume-area-depth relationships (where the maximum depth is used) should only be used for estimating maximum capacity of farm dams. Errors increase considerably when applied to farm dams as the volume is reduced below maximum capacity.

8.5 AREA-VOLUME RELATIONSHIP

The recommended area-volume relationship, as required in time-step hydrological models, is as follows:

$A = A_{max}\ (V/V_{max})^{0.6}$ Relationship 7.1

where A = surface area (m^2) to be determined at volume V;

A_{max} = surface area (m^2) at maximum capacity;

V = volume (kL or ML) for which A is to be determined; and

V_{max} = volume (kL or ML) at maximum capacity.

It is recommended that existing model platforms are modified to incorporate the above relationships as soon as possible.

APPENDICES

A. RAPID FIELD ASSESSMENT SURVEYS

The Method

The “rapid field assessment” technique is a cost-effective method of rapidly determining the volume of farm dams. The method, in brief, is to determine the surface area from simple measurements; measure the external height of the farm dam wall (as a surrogate for maximum depth); and calculate the volume from the following volume-area-depth relationship:

$$V = 0.4\ D\ A\ /\ 1000$$

where V = volume (ML);
D = external wall height (m); and
A = surface area (m^2).

The surface area is calculated using a geometric-area formula from simple measurements such as length and breadth. For example, if the shape of the farm dam approximates to a triangle, the surface area is calculated from 0.5 x width x length. If the shape approximates to an ellipse the surface area is calculated from (πAB)/4 where A and B are the minor and major diameters. The measurements are made generally with a surveyor’s wheel. Pacing can be used if the field operator is experienced.

The exterior wall height is generally measured by counting the number of ground-to-eye heights of the field operator while walking up the farm dam wall. A staff may also be used if it is possible to site from the top of the wall to the staff.

A total-station surveying instrument can also be used to measure both surface area and wall height. This will reduce the magnitude of errors but will increase the time, and hence cost, of surveying farm dams.

During fieldwork as part of this study, it was noted that the total time for rapid field surveys can be considerably reduced, and the accuracy possibly increased, if the full supply level outline is digitised into GIS data from ortho-photography and the area determined by the GIS program. The fieldwork is then reduced to only measuring the wall height and confirming that the full supply level outline was correctly digitised. This is the recommended method for future rapid field assessments where the GIS data is required for other purposes.

Discussion

The method has the potential to introduce errors arising from the following:

- the simple methods used to make measurements;
- considering the outline of farm dams to be simple geometric shapes when calculating surface area; and
- use of the simple volume-area-depth relationship (as above) to calculate volume.

The first two potential sources of error are reduced to negligible proportions if a total station surveying instrument is used for the measurements.

Surface Area Measurements

The use of a surveyor's wheel to measure linear distances can introduce errors due to rough ground surfaces arising from, for example, cattle-hoof potholes and vegetation.

Further errors can be introduced when straight-line measurements are made of farm dam width and length, when the farm dam edges are not usually straight. Measurements are made in straight lines on dry ground adjacent to, and as close as possible to, the farm dam edge. However, farm dam edges are not usually straight, requiring the ends of the farm dam to be visually estimated from the measurement line. This is a potential source of error with both the surveyor's wheel and pacing methods of linear measurements.

If the full supply outline is digitised from ortho-photography the above sources of error are removed. However, there exists a further potential source of error due to operator-subjectivity in interpretation of the full supply level. The large errors in the digitising can be detected during the field surveys by checking that the farm dam outline is correctly represented. These errors can then be corrected on-screen in the office. However, even relatively small errors in determining the location of the full supply level can had a large effect on the surface area.

Wall Height Measurements

Errors in measuring wall height will be mainly confined to ensuring the sighting from the observer's eye to a point on the farm dam wall is horizontal.

As mentioned previously, the measurement of exterior wall height is a surrogate to maximum depth of the farm dam at full supply level. The theory behind this is the assumption that the free-board distance is approximately the same as the depth of the borrow pit (Lenz pers. comm.). However, as shown in this study, there can be significant differences between external wall height and maximum depth.

Volume Calculation

The use of a simple volume-area-depth relationship does not consider variations likely in profiles of farm dams, therefore errors are likely to occur. The results of this study show that when actual maximum depth is used in the relationships, the errors on average are very low, albeit with a range of worst-case errors. However, the errors increase when external wall height is used as a surrogate for maximum depth. Further details are given in the main body of this report.

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	356 or 366 days	time interval

δD	hydrogen isotope composition
$\delta^{18}O$	oxygen isotope composition
^{14}C	carbon-14 isotope (percent modern carbon)
CFC	chlorofluorocarbon (parts per trillion volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million
ppb	parts per billion
TDS	total dissolved solids (mg/L)

GLOSSARY

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

Area-volume relationship. An equation for estimating the surface area of farm dams where the volume is known. This situation occurs in time-step hydrological models that simulate reducing volume (due to evaporation and extractions) at each time-step. The re-calculated surface area is used to estimate evaporation at the next step.

Borrow pit. The section within the farm dam that is excavated to obtain material for the farm dam wall.

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. A statutory body established under Part 6, Division 3, s. 53 of the Act whose prime function under Division 2, s. 61 is to implement a catchment water management

CWMB. Catchment Water Management Board.

DEM. Digital Elevation Model. Also know as Digital Terrain Model (DTM). Raster data where the cell values represent ground elevation above sea level. Used in computer modelling, catchment definition and relief shading as back-drops on maps.

EMLR. Eastern Mount Lofty Ranges. A region where runoff flows into the River Murray.

Free-board distance. The vertical distance between the full supply level (spillway level) and the top of the farm dam wall.

Full supply level. The maximum level that water can attain in a farm dam before overflow occurs (also known as the cease-to-flow point). The level of the spillway. This is not the maximum water level.

Gigalitre (GL). One thousand million litres (1 000 000 000).

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

GL. *See gigalitre.*

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.)*

Maximum water level. The highest water level when the spillway is flowing at the highest rate. With narrow spillways or large flow volumes, this level can be considerably higher than the full supply level.

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

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.

Notice of Restriction. Part of the State declared a moratorium area under the Water Resources Act 1997 to temporarily restrict further water usage while the water resources are assessed and a management plan is prepared. The area normally becomes a Prescribed Area after two years.

Ortho-corrected imagery. Imagery, in an electronic format, that was derived by scanning aerial photography, correcting the scale distortions caused by the camera and terrain, and providing spatial references so that the ortho-imagery can be used in the correct location relative to other spatial (GIS) data.

Prescribed area, surface water. Part of the State declared to be a surface water prescribed area under the Water Resources Act 1997.

Prescribed Water Resources Area (PWRA). Part of the State declared under the Water Resources Act 1997 for the purpose of managing water resources, including underground water and regulating water usage via a licensing system.

Raster Data. Electronic data arranged in a regular mesh of cells where each cell has a value representing some spatially varying phenomena.

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.

Turkey nest dam. A dam not constructed across a watercourse and is designed to hold water diverted or pumped from a watercourse, an aquifer or other source and does not capture any surface water from the catchment above the dam. Also known as an off-stream dam.

Volume-area relationship. An equation used to estimate the volumes of groups of farm dams (e.g. within sub-catchments) when only the surface area is known. In these situations, surface area is usually determined from digitised farm dam outlines.

Volume-area-depth relationship. An equation used to estimate the volumes of farm dams when only surface area and maximum depth are known. Used in rapid field assessments of farm dams. Surface area is usually determined from digitised farm dam outlines or from simple in-field measurements. External wall height is usually used as a surrogate for maximum depth.

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; and a lake through which water flows; and 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.

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