Assessment of Water Use from Farm Dams in the Mount Lofty Ranges South Australia

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DWLBC photo-archive, Farm dams in the Mt Lofty Ranges

FOREWORD

South Australia's natural resources are fundamental to the economic and social wellbeing of the State. One of the State's most precious natural resources, water is a basic requirement of all living organisms and is one of the essential elements ensuring biological diversity of life at all levels. In pristine or undeveloped situations, the condition of water resources reflects the equilibrium between rainfall, vegetation and other physical parameters. Development of these resources changes the natural balance and may cause degradation. If degradation is small, and the resource retains its utility, the community may assess these changes as being acceptable. However, significant stress will impact on the ability of a resource to continue to meet the needs of users and the environment. Understanding the cause and effect relationship between the various stresses imposed on the natural resources is paramount to developing effective management strategies. Reports of investigations into the availability and quality of water supplies throughout the State aim to build upon the existing knowledge base enabling the community to make informed decisions concerning the future management of the natural resources thus ensuring conservation of biological diversity.

Bryan Harris
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EXECUTIVE SUMMARY

Surface water use is vital to the economics of the Mount Lofty Ranges region. 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 water extracted from farm dams is an important input for these hydrological studies.

This technical report describes the methodology and outcomes of a study to determine by direct means the quantity of water extracted and evaporated from farm dams within the Mount Lofty Ranges, South Australia. This was achieved by comparing the quantity of water in a large sample of farm dams from pre-summer and post-summer aerial photography.

For the study period (December 2001 to April 2002 inclusive), a total of 39% of farm dam storage was removed based on the average of all dams in the study over 1 ML. Around half (20%) of this was lost to evaporation and the other half (19%) was extracted (leakage was assumed to be negligible).

When the results for only dams over 5 ML are averaged, slightly lower figures of total water lost (34%) were obtained, with 17% lost to evaporation and 17% extracted. These lower figures were attributed to a trend of lower extraction rates for larger dams.

The study period was cooler than average (based on lower pan evaporation figures and subjective recollection). Thus, the figures for usage and loss to evaporation will be higher in a typical summer (say 25-30%) and even higher in a hotter than average summer.

The study included an assessment of potential errors than became quite large for smaller farm dams, and dams from which the usage was low. This required all dams less than 1 ML to be excluded from the study, and dams with a low estimated usage to be assumed to be zero usage. Dams subject to apparent (and indeterminable) inflow or water transfers were also excluded.

The main source of error was potential digitising errors in defining the water outline from the aerial photography. Uncertainties in evaporation data and pan factor also contributed to significant potential errors. When all sources of worst-case error are added, fairly wide error bands result. For example, the figure for average usage from dams over 1 ML could lie with in the range 8.5% to 27.5% (19+8.5/-10.5%).

Although the error bands are quite large, the figure derived for average total water usage (19% of storage total volume for a less than typical summer), adds support to the figure (30% for a typical summer) currently being used in hydrological studies in the Mount Lofty Ranges.

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INTRODUCTION

Aim

Many hydrological studies are being conducted on the water resources of catchments within the Mount Lofty Ranges. Due to the absence of data on the quantity of water extracted from farm dams, estimates are used in these studies. The aim of this project was to quantify the volume of water used from farm dams within the Mount Lofty Ranges using a method that directly assessed the usage rather than by employing assumptions on usage rates.

The method utilised aerial photography flown before and after summer to estimate the volume of water in farm dams when full and at their lowest capacity. A model was then used to determine evaporation and water extracted from each dam.

Prior to commencing this study, it was predicted that the methodology may contain errors that had the potential to render the results unreliable. An important component of this study was, therefore, to quantify potential errors.

Study Areas

As there are a large number of farm dams across the Mount Lofty Ranges (around 22 000), a set of five study areas were selected from the whole region. The study areas were selected after consideration of the following aspects:

- They were distributed right across the main area of farm dam development;
- They included the area with the highest density of storage volume;
- They incorporated areas with a variety of landuses and or land types, and
- They either are currently under study for water resource issues or are under consideration for future study.

The locations of the study areas are shown in Figure 1. Their main characteristics are described below.

Area 1 – Flaxman Valley, Upper Marne.

- Mostly within the upper North Para catchment (principally the upper Flaxman Valley) with part of the upper Marne catchment.
- Region with highest density of farm dam development.
- Major viticulture region.
- Most northerly part of the study region.

Area 2 – Mount Pleasant.

- Within the upper Torrens catchment.
- Generally flat terrain, sandy soils.
- Lower rainfall.
- Mainly cattle grazing with some large areas of viticulture development.

Area 3 – Cox Creek, Lenswood.

- Within the Onkaparinga catchment.
- High farm dam development.
- Large concentration of bores with good yield.
- Large areas of horticulture.
- Many steep slopes.
- Fairly high rainfall.

Area 4 - Echunga - Mount Barker.

- Within the Onkaparinga catchment and the upper Bremer catchment (Mount Barker Creek).
- High density of farm dam development.
- Mainly grazing.

Area 5 – Finnis.

- Within the Finnis catchment.
- Mainly grazing.
- Southern part of the high farm dam development region.

METHOD

Farm Dam Data

Aerial photography was flown during November 2001 and again at the end of April 2002. The photography captured in November was timed to show the farm dams at their highest storage level at the end of the seasonal rains and before the start of summer irrigation. The photography captured at the end of April the following year was timed to show the farm dams at their lowest storage level at the end of the irrigation period and before the onset of the winter rains.

The water outlines for the farm dams were manually digitised on-screen (heads-up digitising) to produce two GIS datasets for each study area. One set of GIS datasets contained the water outlines for November (dams full) and the second set contained water outlines with the farm dams at their capacity at the end of April.

The perimeters of many dams were partly obscured by over-hanging trees or bushes or by reed or algae growth near the edge of dams. In most cases, the obscured portion of the water outline could be determined by subjective judgement. However, if there was any serious doubt as the perimeter location that could have a major impact on accuracy, on either the November of the April imagery, that dam was not included in the study.

The number of farm dams from each study area that were used in the analysis are listed in Table M1. The lower number of dams included in the estimation of water used was due many dams being subject to apparent inflow (from springs or water transfers) that could not be quantified.

Table M1. Number of farm dams from each study area used in the analysis.

Study	Number of Farm Dams used for estimation of:	
Area	Water Evaporated	Water Used
1	206	173
2	220	190
3	87	78
4	237	206
5	99	84
Total	849	731

The volume of water in all farm dams for both their November and April capacities were estimated using the following volume-surface area relationship (McMurray 2002).

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

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

Where $\quad$ A = Surface Area in m^2

V = Estimated Volume in ML.

Evaporation Data

There were only five operational evaporation monitoring sites within the study region with evaporation data for the study period. The data from one of these sites, McLaren Vale (Pirramimma), was not used it was considered not representative of any of the study areas. A site existed at Lenswood but was closed in 1999 prior to the study period.

Correlation studies between various sites showed that data from two of the sites required adjustment (B. Murdoch *pers comms*). The data from the Nuriootpa site (number 023373) was reduced 3.9% due to an assumed exposure change. This was used for study area 1. The data from the South Para Reservoir site (number 023820) was reduced by 12.5% due a shift in site location. This was used for study area 2.

A plot of the annual data from all stations showed that the Lenswood data (up to when the station closed in 1999) followed a similar pattern to that from South Para Reservoir with the average being 15.7% lower. The data from South Para Reservoir was reduced by 15.7% and used to represent the Lenswood data for area 3 of this study.

The data from the Mount Bold Reservoir site (number 023734) was used for study area 4.

The mean of the data from the Mount Bold Reservoir site and the Myponga Reservoir site (number 023783) was used for study area 5.

The data, together with the monthly averages for each site, are given in Appendix A.

The total evaporation figures for the study period are 79% to 89% lower than the average for the period. This is in keeping with personal recollections that the 2001/02 summer was cooler with more cloud and rain periods than considered normal.

A pan factor of 0.75 was used to allow for differences between Class A pan recordings and evaporation from farm dams (B. Murdoch *pers comms*).

Rainfall & Stream Flow

The stream flow and rainfall records for several sites within or close to each of the study areas were obtained. The monthly rainfall data were incorporated into the model to allow for direct input into the surface of the dams. The streamflow data was examined to determine whether there had been any runoff inflow into the farm dams during the study period.

The rainfall records showed that a total of around 60-110 mm of rain fell across the region for the period December 2001 to April 2002 inclusive. The largest event was around 20 mm in the third week of January 2002 with another slightly small event towards the end of March 2002.

For study area 1, errors were discovered in the stream flow records, for the study period, for the station near Mount McKenzie (AW505533). It was not possible to determine whether there was any flow during this period. No flow was recorded at the station downstream at Penrice (AW505517). However, it was possible that some inflow into farm dams in the upper parts of the catchments did occur, although this was not considered in the assessment.

For study area 2, the flow record for Mount Pleasant (AW504512) indicated a very small flow in the third week of January. This was considered insignificant and it was assumed that there was no inflow into dams during the study period

Small stream flows were recorded at Lenswood (AW503507), Echunga Creek (AW503506) and Finniss River (AW426504) during the December and January. These flows were small compared to the annual means but indicate that there may have been some inflow into farm dams during the study period for the study areas 3, 4 and 5. The model (described below) assessed scenarios both with and without inflow into farm dams during the December 2001 (the first month of the study period) for these three study areas.

Models

The quantity of water evaporated and the quantity of water used were both determined by two separate models. One model was simple a GIS-based one-step model and the second used a spreadsheet-based monthly-step model.

The GIS-based one-step model produced similar results to the monthly-step model and would be ideal for rapid assessments of water use from farm dams. This model is described in the Appendices. All results presented in this report were based on use of the spreadsheet-based monthly-step model.

Leakage from farm dams was not assessed in this study. For simplicity, the term “water usage” has been used in this report to refer to the sum of extraction and leakage.

Although the aerial photography was captured at various times during November, the data for November 2001 was assumed to represent the storage capacity at the end of that month. The data for April 2002 was used to determine the storage capacities at the end of April as all the aerial photography was captured in the last week of that month.

The monthly step model was developed in a Microsoft Excel spreadsheet. The model calculated (a) water lost through evaporation with allowance for rainfall input (i.e. the combined climatic effects) and (b) the quantity of water used. These were calculated month by month for each of the months December 2001 to April 2002 inclusive. A monthly distribution of water usage was assumed, this being 15%, 25%, 25%, 20% and 15% of the total for the whole period, for the months December to April respectively. The model was calibrated by adjusting the value of an overall usage factor for each dam, such that the calculated volume of water in each dam at the end of April was the same as that determined from the aerial photography. Full details of the model are described in the Appendices.

In the final stage of the model, the total volume of water lost due to evaporation and the total volume used for each dam were determined by summing the values calculated for each month, for each study area individually and all study areas combined. These were then calculated as percentages of the November storage volumes.

A separate model was used for each of the five study areas so that any differences in usage pattern could be determined.

Assessment of Errors

An assessment of errors was undertaken to determine the effects of possible digitising errors and the sensitivity to errors in evaporation data and the assumed monthly distribution of water usage.

The data from a sample of around 140 farm dams within study area 2 (Mt Pleasant, upper Torrens) were incorporated into the monthly-step model. The values of evaporation data and monthly usage distribution were varied and the effects noted. The effects of digitising errors were determined by simulating errors in the surface areas of the dams for both their November and April capacities. Further details are given in Appendix C.

The use of a volume-surface area relationship has the potential to introduce errors. In particular, in regard to determining the storage capacity as surface area reduces with water loss through each step of the model. The volume-surface area relationship was devised to estimate the volume of farm dams at full capacity and has not been tested on dams not at their full capacity. Given the absence of any study in this regard, the effect of errors from this source was not investigated in this study.

RESULTS

Average of all Farm Dams

For the study period (December 2001 to April 2002 inclusive), the total volume of water lost and extracted from all the studied farm dams (excluding farm dams under 1 ML) was estimated to be around 39% of the water stored at the beginning of the period.

Around half (20%) of the water in farm dams was lost to evaporation with the other half (19%) being the sum of water extracted for use and water lost through leakage.

When only farm dams over 5 ML are included, slightly lower figures were obtained for the combined total water lost (34%), total water evaporated (17%) and total water used (17%). A lower figure for water evaporated is due to the surface area-volume relationship (linear for large dams, power-law for smaller dams) used in the model. A lower figure for usage is consistent to the general trend shown in Figure R1 (a to e) where the percentage usage (not absolute volume) tends to be lower for larger dams.

Note that the evaporation data together with subjective assessment indicated that the summer of the study period was cooler with more cloud and rain periods that normal. In a more typical hotter summer, both the evaporation rates and usage rates are likely to be higher than the figures derived in this study.

The results for each study area are given in Table R1.

For the no-flow scenario, the estimated water usage across the five study areas is similar although the usage within study area 4 (Echunga-Mt Barker), at 13%, is notably lower than the other study areas that range from 18% to 23%. However, this difference may be due to potential errors in the methodology.

The lost of water through evaporation is higher (24%) for study area 1 (Flaxman Valley, upper Marne) than the other areas (16-19%). This was due to much higher climatic effect (difference between evaporation and rainfall) for this northerly area when compared to the other study areas (data is given in Appendix A).

The simulation of inflow (for study areas 3, 4 and 5) in part or all of December (last two columns of Table R1) had only a small effect on the estimation of water usage.

Table R1. Results of average water lost from farm dams - total lost: lost due to climatic effects (evaporation less rainfall); and usage (extracted plus leakage). Expressed as percentages of the total volume at end of November. Only dams >1 ML included.

Study Area	Total (%)	Climatic[1] (%)	Usage (%)[4]		
	(Evap. plus Usage)	(Evap. Less rain input)	No inflow	Inflow part Dec.[2]	Inflow Dec.[3]
1 - Flaxman Valley, upper Marne	42	24	19		
2 - Mt Pleasant upper Torrens	42	18	23		
3 - Cox Creek, Lenswood	40	16	23	24	25
4 – Echunga, Mt Barker	32	19	13	14	15
5 - Finniss	35	18	18	20	20
Dams from all areas combined	**39**	**20**	**19**		

Notes:

1 “Climatic” refers to water lost through evaporation less direct input from rainfall.
2 “Inflow part Dec.” refers to simulated stream flow into dams during the first half of December.
3 “Inflow Dec.” refers to simulated stream flow into dams throughout December such that all dams were full at the end of December.
4 The figures given for usage were based only on dams greater than 1 ML (storage volume at end November) and excluding those that indicated water gain (due for example to water transfers) over the study period.
5 All figures were calculated excluding dams less than 1 ML (storage volume at end November).

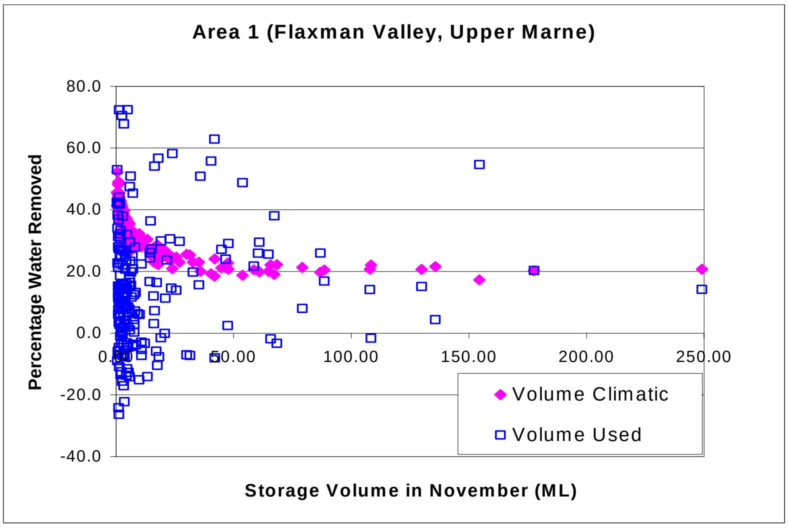
Individual Farm Dams

The estimated values of percentages of water evaporated and of water used for individual farm dams are shown in Figure R1 (a to e). Only the data for dams over 1 ML are plotted because high potential digitising errors render results meaningless for these smaller dams.

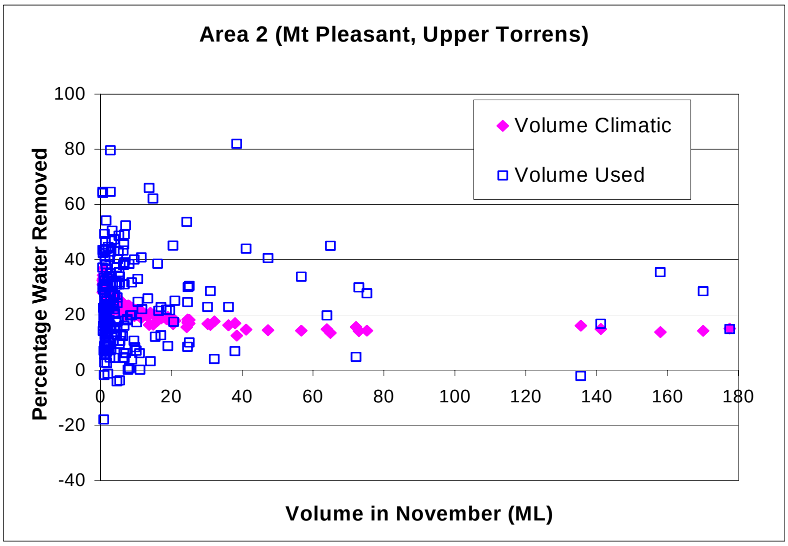
There was considerable spread in the values of estimated usage, and to a lesser extent in estimated evaporation. Although a larger number of smaller dams show higher values for water usage, there is only a very low correlation between dam size and usage.

Many dams show high negative estimated usage. It was assumed that these dams were subject to water transfers or, possibly, inflows from upstream springs or leaking dams. It was not possible to quantify these water transfers or inflows. Therefore, these dams were excluded from the calculations of average estimates of water usage given in Table R1 above. Also, many dams show low usage figures of between –10% and +10%. These were assumed to be zero usage in the average estimates because potential digitising errors rendered results with low usage unreliable.

The variation in estimated evaporation with dam size is due to the surface area-volume relationship used in the estimation of surface area for each monthly step of the model. This relationship was linear for volumes over around 56 ML and a power-law relationship for volumes less than this. The scatter in the data was attributed to the inter-relationship between evaporation losses and usage.

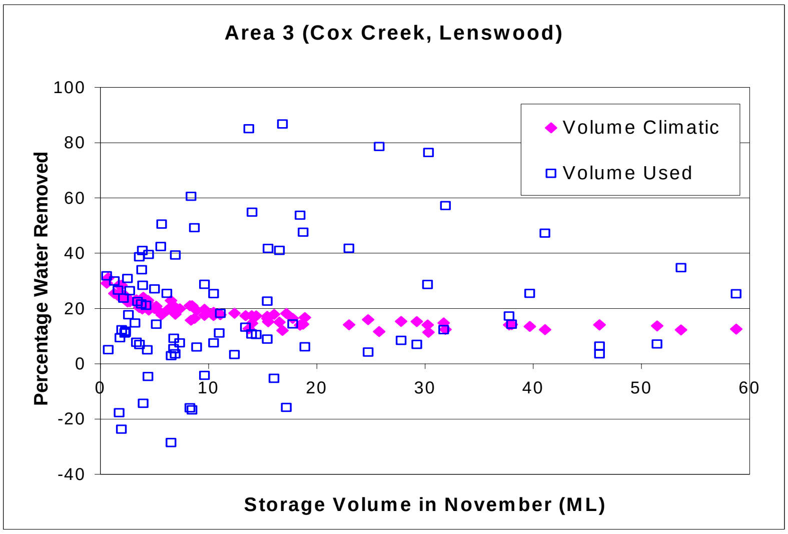


(a)

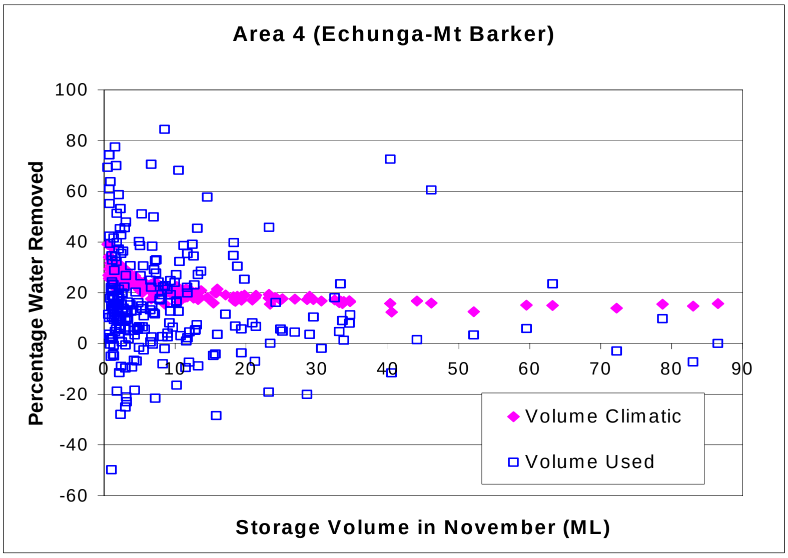


(b)

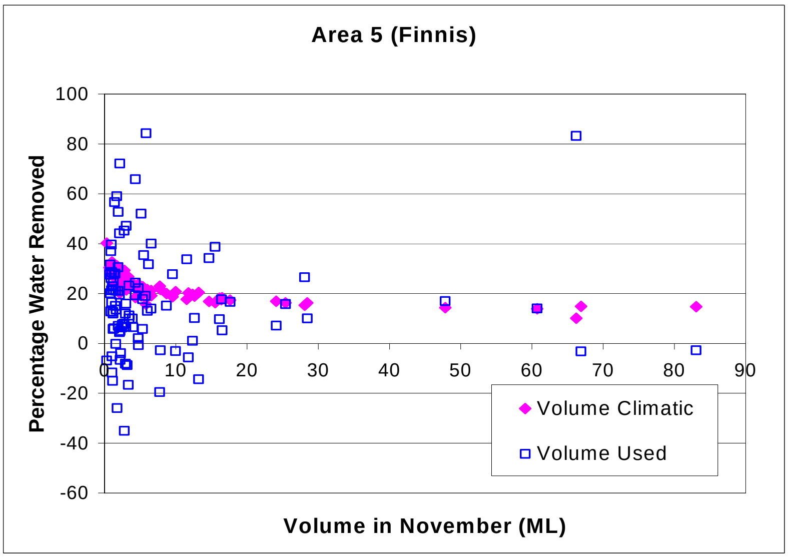
Figure R1 (continued over). Plots of percentage water lost through climatic effects (evaporation less rainfall) and percentage water used (extracted plus leakage). Shown for individual farm dams in each study area.



(c)



(d)



(e)

Figure R1 (continued from above). Plots of percentage water lost through climatic effects (evaporation less rainfall) and percentage water used (extracted plus leakage). Shown for individual farm dams in each study area.

Potential Errors

The analysis of potential errors from the sources investigated revealed the figures shown in Table R2. As each of the error sources investigated were independent of each other, the total error range in the value of estimated total water used is the sum of the individual errors as shown in Table R2.

The error band for estimated total water evaporated was 20+5/-4% (16-25%) for all dams >1 ML combined and 17+4.2/-3.5% (13.5-21.2%) for dams >5 ML.

The error band for estimated total water usage was 19+8.5/-10.5% (8.5-27.5%) for all dams >1 ML combined and 17+6/-7% (10-23%) for dams >5 ML.

Table R2. Effect of potential errors on estimates of average total water evaporated and total water usage.

Source of Error	**Potential Error in Estimated Total Water Evaporated**		**Potential Error in Estimated Total Water Usage**	
	Dams >1ML	Dams >5ML	Dams >1ML	Dams >5ML
Digitising errors	+1.5/-0.4	+0.8/-0	+6/-8	+3.6/-4.6
Monthly usage distribution	±0.5	±0.5	±0.5	±0.5
Climatic data	±3	±3	±2	±2
Totals	+5/-4	+4.2/-3.5	+8.5/-10.5	+6/-7

The above figures do not consider the effect of errors introduced by use of a volume-surface area relationship to estimate storage capacity from surface area, nor to estimate surface area from the volume remaining at the end of each month in the monthly-step model. These were not investigated in this study.

The effects of errors were determined from a sample of dams in one study area and are assumed to be applicable to all the dams in the study.

DISCUSSION

Quantities of Water Used and Lost

This study indicated that the average water usage from farm dams was around 19% of capacity and a similar figure for water lost through evaporation. This was during the cooler than typical summer of the study period (summer 2001/02). More typical average figures of usage and evaporation could be around 25-30% each, possibly higher.

If all dams are assumed to fill to capacity, and if usage and evaporation rates are each 25% of capacity, there is approximately half of the water in farm dams carried over to the next season. This suggests that the current level of farm dam development could be reduced, although many irrigators would require a larger storage capacity to allow for drier periods.

However, if the typical values of usage and evaporation are higher than 25%, say 30% or more, then the quantity of water removed from catchments by farm dams becomes a higher percentage of the total capacity of all farm dams. More importantly, more of the early flows will be removed from streams until the dams begin to over flow. Removal of early flows is likely to have a considerable impact on the riparian environment.

The quantity of water lost to evaporation was shown to be around 20% in this study, but could exceed 30% during a more typical and hotter summer. This is not good storage efficiency especially with an important and increasingly stressed resource. Dams with a higher volume to surface area ratio (i.e. deeper) would increase the storage efficiency. Effective covers would reduce evaporation losses to very low figures.

The above considerations have implications for catchment management. These are being addressed by detailed hydrological (and hydrogeological) studies and resource management controls on farm dam development. The latter by Prescription processes in the several areas including the eastern Mount Lofty Catchments, and by development controls (i.e. the “50% Rule”) in the Mount Lofty Ranges Watershed.

Assessment of Errors

The main cause of the large uncertainty in accuracy of the results is the possibility of digitising errors. Another cause of concern is the suitability of the volume-surface area relationship, particularly in regard to estimation storage volume at less than full capacity. The latter was not addressed in this study. Uncertainty in the accuracy of climatic data (evaporation, pan factor and rainfall) was a factor, but of lower significance than the foregoing. Monthly distribution of usage was shown to produce relatively low levels of uncertainty.

Digitising Accuracy

It could be debated whether the size of the digitising errors simulated (0.5m) was realistic, and whether it was justified in incorporating the digitising errors to act in opposite directions in the November and the April data. In regard to the latter, it was considered reasonable to simulate a worst-case scenario, particularly as the two sets of aerial photography were of different spectral types (colour for November, infrared for April). Interpretation of colour imagery has different problems and issues than the interpretation of infrared imagery. This was the reason for using the worst-case scenario. The magnitude of the simulated digitising error (0.5m) was considered reasonable, as this was only one pixel in the ortho-imagery. However, the same error was applied equally round the perimeter of all dams, which may have caused an over estimate of the effect of errors. Potential sources of digitising errors are covered in more detail in Appendix C.

For a study of this type, accuracy of digitising the water outline is of paramount importance. However, the usual application for digitising farm dams is to determine full capacity. Accuracy is less important in these applications as a large uncertainty already exists in the estimation of volume from either a volume-surface area relationship, or from a volume-depth-surface area relationship following field determinations of maximum depth. Therefore, it is necessary to consider the importance of this water-use application when accessing potential funding for further work in improving the accuracy of digitising farm dam water outlines.

Volume-Surface Area Relationships

The volume-surface area relationship used in this study was derived from farm dams in the vicinity of, and with similar landuses as study area 1. It should, therefore, be suitable for estimating volume in this area. However, there is uncertainty in the suitability for its application in the other four study areas. More work is required to establish volume-surface area relationships in regions without intensive agriculture and/or agriculture with a high economic value (e.g. viticulture). A study is currently in progress in the Torrens catchment.

As mentioned previously, the volume-surface area relationship was used to determine surface area of dams for the storage volume at the end of each month in the monthly step model. The relationship was derived for estimation volume only at full capacity. More work is required to establish the relationship between volume and surface area for a range of capacities less than full capacity.

One aspect that was apparent is that there remained a large quantity of water in farm dams at the end of summer 2002/01. Estimates of this quantity of water could be made if volume-surface area relationships were developed for estimating volume of dams at less than full capacity.

Climatic Data

The accuracy of climatic data (evaporation, pan factor and rainfall) has a direct effect on estimation of the quantity of water evaporated and a flow-on effect on the estimation of water usage.

Rainfall data was used in this study mainly to determine the quantity of water added to dams by direct rainfall. This was only a relatively small component of the quantities of water involved. Therefore, although there is a general shortage of rain stations at the higher altitudes, the rainfall data available was considered adequate for the purpose.

The pan factor is required to convert data from class A pan evaporation rate to the evaporation rate in a larger body of water. The value used in this study was considered a reasonable average based on an assessment of other studies (Murdoch *pers comm*), however, some uncertainty remains.

There are very few evaporation stations with the Mount Lofty Ranges. There were only six stations suitable for use in this study. Only one of these (Lenswood) was within a study area, but was closed prior to the study period and required the data to be extrapolated. However, this extrapolated data was considered to be of reasonable accuracy. The other five evaporation stations were all well outside the study areas and may not be representative of the evaporation rates within the study areas. Lack of adequate evaporation data and valid pan factors affect all hydrological studies. It is strongly recommended that these deficiencies are addressed.

Streamflow

Streamflow data was used to access whether there was any inflow into the dams during the study period. There was some uncertainty as to whether streamflow actually occurred in some study areas. However, assuming that streamflow only occurred during December, the differences in estimated total usage were relatively small (±1 or 2 percentage points, see Table R1). This was not seen to be of major concern.

CONCLUSIONS & RECOMMENDATIONS

The aim of this study was to utilise a method of directly measuring the quantity of water extracted from farm dams in the Mount Lofty Ranges. A sample of around 800 farm dams in five study areas across the regions were used. The results, as an average of all dams over 1 ML, showed that around 19% of storage capacity is used (the sum of extracted for irrigation plus leakage), and around 20% is lost due to evaporation. Slightly lower figures were obtained when the results of dams over 5 ML are averaged. These were around 17% for both usage and evaporation indicating slightly higher usage and evaporation from smaller dams.

The study period (summer 2001/02) was cooler than a typical summer. Thus, the figures of usage and evaporation will be higher in a typical summer (say 25-30%) and much higher in a hotter than average summer.

The assessment of errors indicated quite wide error bands under the worse case scenarios. However, a statistical advantage could be assumed. In either case, the results provide an indication of the usage and evaporation rates from dams. When considering the cooler than average summer of the study period, the results adds support to the figure of 30% currently being used in hydrological studies in the Mount Lofty Ranges.

The effect of potential digitising errors reduces to a few percent as the size of the dams increase (charts are given in the Appendices). These smaller potential errors, even when considering potential errors from other sources, indicate that the methodology used in this study is suitable for determining the quantities of water evaporated and water used in larger dams greater than around 20-40 ML.

It is recommended that consideration is given to addressing the following short-comings in available data:

- Evaporation data and pan factor. Additional evaporation stations are required at suitable locations across with the Mount Lofty Ranges to ensure that any variation in evaporation across the region can be determined. Additional studies are also required to determine the most suitable pan factor to convert from class A pan readings to true evaporation from farm dams, particularly the variation (if any) in evaporation rate with dam size.

- Volume-surface area relationships. The relationship used in this study was derived from farm dams in areas with intensive farm dam and irrigation development, and only for dams at full capacity. A relationship or relationships is/are required for areas with less intensive development and to estimate volume at storages less than full capacity. A study is in progress study farm dams in the Torrens catchment, but results were not available for this study.

- Accuracy of digitising. It is essential that uncertainties in digitising the water outline from ortho-photography are reduced to much lower proportions. However, it is first necessary to develop a cost-effective methodology for assessing the accuracy of digitising water outlines.

GLOSSARY

Climatic (effect)

This term is used in this report to describe the net effect of evaporation, pan factor and rainfall on water lost or gained from farm dams.

Inflow

Water that flows into farm dams from runoff, springs or upstream leaking dams.

GIS

Geographic Information Systems. Computer programs for the analysis of spatial data and preparation of maps.

Monthly-step (model)

A method that performs a series of calculations on data representing a month of time, and that are repeated for a series of consecutive months each using data applicable to the particular month being calculated.

Ortho-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 use in the correct location relative to other spatial (GIS) data.

Pan factor

A correction factor(s) used to adjust for differences in evaporation rates between the standard Class A pan used for measuring and bodies of water such as farm dams and reservoirs.

Volume-surface area relationship

A formula or equation used to estimated the full storage capacity of farm dams where only surface area is known. Based on analysis of a large number of surveyed farm dams. Intended to estimate the combined storage volume of groups of farm dams (in catchments or sub-catchments) where the varying geometric shapes of farm dams are effectively averaged. Large errors can be expected for individual farm dams.

Water used

In this report, the sum of water extracted for use and water lost through leakage.

Water transfers

Water added to farm dams from other sources such as pumped from a bore or other farm dams or added from a reticulated mains supply.

SI Units Commonly Used Within Text

Name of unit	Symbol	Definition in terms of other metric units	
Millimetre	mm	10^{-3} m	length
Metre	m		length
Kilometre	km	10^{3} m	length
Hectare	ha	10^{4} m^2	area
Microlitre	µL	10^{-9} m^3	volume
Millilitre	mL	10^{-6} m^3	volume
Litre	L	10^{-3} m^3	volume
Kilolitre	kL	1 m^3	volume
Megalitre	ML	10^{3} m^3	volume
Gigalitres	GL	10^{6} m^3	volume
Microgram	µg	10^{-6} g	mass
Milligram	mg	10^{-3} g	mass
Gram	g		mass
Kilogram	kg	10^{3} g	Mass

Abbreviations Commonly Used Within Text

Abbreviation		Name	Units of measure
TDS	=	Total Dissolved Solids *(milligrams per litre)*	mg/L
EC	=	Electrical Conductivity *(micro Siemens per centimetre)*	µS/cm
pH	=	Acidity	
δD	=	Hydrogen isotope composition	**°/oo**
CFC	=	Chlorofluorocarbon *(parts per trillion volume)*	pptv
$\delta^{18}O$	=	Oxygen isotope composition	**°/oo**
^{14}C	=	Carbon-14 isotope *(percent modern Carbon)*	pmC
ppm	=	Parts per million	
ppb	=	Parts per billion	

REFERENCES

McMurray, D. (2002). Technical Report: Volume-Surface Area Relationships for Farm Dams in the Mount Lofty Ranges South Australia. Internal technical report, draft v0.1. South Australia. Department of Water, Land and Biodiversity Conservation.

Personal Communications

B. Murdoch. Hydrological Assessment Officer. Department of Water, Land and Biodiversity Conservation.

APPENDIX A – Climatic Data

The evaporation data used in this study are shown in Figure A1. Also shown are the study areas for which the data was used.

Correlation studies between various sites showed that data from two of the sites required adjustment (B. Murdoch pers comms). The data from Nuriootpa (site number 023373) was reduced 3.9% (due to an assumed exposure change) and the data from South Para Reservoir (site number 023820) was reduced by 12.5% (due a shift in site location).

The Lenswood site was closed in 1999 prior to the period of this study. A plot of the annual data from all stations showed that the Lenswood data followed a similar pattern to that from South Para Reservoir with the average being 15.7% lower. The data from South Para Reservoir was reduced by 15.7% and used to represent the Lenswood data for area 3 of this study.

The mean of the data from Mount Bold and Myponga sites was used for study area 5.

The figures in the column headed "% of Mean" indicate that the season for this study was below normal in terms of total evaporation over the study period.

Table A1. Evaporation Figures (mm).

Station	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	Total	% of Mean	Study Area
Nuriootpa (stn 023373)								
Site Data	220.1	251.1	221.2	204.6	138.0	1035.0		
Data Reduced by 3.9%	211.5	241.3	212.6	196.6	132.6	994.6	89.0	**1**
Monthly Means	245.9	299.7	254.2	193.8	123.8	1117.4		
South Para/Williamstown (stn 023820)								
Site Data	169.2	207.7	168.0	158.1	108.0	811.0		
Data Reduced by 12.5%	148.1	181.7	147.0	138.3	94.5	709.6	78.6	**2**
Monthly Means	209.5	233.3	201.5	160.4	98.3	903.0		
Lenswood Extrapolated								
S. Para data reduced by 15.7%	124.8	180.2	145.8	137.2	93.7	681.6		**3**
Mt Bold Reservoir (stn 023734)								
Site Data	151.9	176.7	159.6	142.6	96.0	726.8	79.5	**4**
Monthly Means	208.4	232.4	205.7	165.4	102.4	914.3		
Myponga Reservoir (stn 023783)								
Site Data	148.8	176.6	157.6	142.6	93.0	718.6	89.3	
Monthly Means	181.9	202.8	181.0	145.3	93.9	804.9		
Mean of Mt Bold & Myponga								
Site Data	150.4	176.7	158.6	142.6	94.5	722.7	84.1	**5**
Monthly Means	195.2	217.6	193.4	155.4	98.2	859.6		

Rainfall data used in the model are shown in Table A2. The combined effect of evaporation, pan factor and direct rainfall on farm dams is shown for each study area in Table A3.

Table A2. Rainfall data used in the model.

Station	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	Total	Study Area
Average of 3 stns (note 1)	15	34	1	16	4	70	1
Torrens River @ Mt Pleasant AW504512	12.2	32.2	2.6	5.8	11.6	64.4	2
Lenswood Creek @ Lenswood AW503507	33.4	34.2	5.2	14.6	17.6	105.0	3
Echunga Golf Course M023713	35.5	24.1	0	13.8	14.8	88.2	4
Average of 2 stns (note 2)	51	27	3	15.5	11	107.5	5

Notes

1 Average of three stations North Para River @ Mt McKenzie AW505533, Tanunda Creek @ Trig Point Hill AW505538, and North Para Catchment @ Mt Adam AW505537.

2 Average of two stations Mount Compass M023735 and Finniss River Catchment @ Kyeema AW426639.

Table A3. Climatic effect (combined effect of evaporation, pan factor and direct rainfall on farm dams).

Study Area	Climatic Effect (mm)
1 – Flaxman Valley, upper Marne	676.3
2 – Torrens River Mt Pleasant	468.1
3 – Cox Creek, Lenswood	406.5
4 – Echunga – Mt Barker	457.1
5 – Finniss River	434.8

Notes

1 Climatic Effect = Evaporation x Pan Factor - Rainfall.

APPENDIX B – Model Descriptions

ONE-STEP MODEL

This was a very simple model that performed calculations on the attributes of the spatially joined GIS data.

The quantity of water lost through evaporation (Vol_{evap}) was determined for each dam by the product of (a) the difference between the evaporation and the rainfall each summed over the five months (Σ_{Dec}^{Apr}(Evap) - Σ_{Dec}^{Apr}(Rain)); (b) the pan factor (F_{pan}) and (c) the average of the November surface area (A_{nov}) and the April surface area (A_{apr}).

$$Vol_{evap} = (\Sigma_{Dec}^{Apr}(Evap) - \Sigma_{Dec}^{Apr}(Rain)) \times F_{pan} \times (A_{nov} – A_{apr})/2)/1000000$$

The water used (Vol_{used}, the sum of extraction and leakage) was determined for each dam by subtracting the quantity of water evaporated from the total water lost. The latter was the difference between the November (Vol_{nov}) and April (Vol_{apr}) storage capacities. The water used figures were converted to percentages of the November storage capacities.

$$Vol_{used} = Vol_{nov} – Vol_{apr} - Vol_{evap}$$

$$Percent_{used} = (Vol_{used} \times 100)/Vol_{nov}$$

MONTHLY STEP MODEL

The monthly step model was developed in a spreadsheet (using Microsoft Excel) and calculated water lost through evaporation and water used on a monthly basis over the period December 2001 to April 2002 inclusive.

For each month, the model performed the following four calculations:

1. The water lost through evaporation (Vol_{evap}) was calculated for each farm dam by multiplying the surface area from the previous month (A_{m-1}) with the difference between the product of evaporation (Evap) and pan factor (F_{pan}) and rainfall for that month (Rain).

   $$Vol_{evap} = (A_{m-1} \times (Evap \times F_{pan} – Rain))/1000000$$

2. The water used (Vol_{used}) was calculated by first determining the volume of water removed or lost from each dam from that month onwards. This was calculated from the difference between the volume carried over from the previous month (Vol_{m-1}) and the volume at the end of April (Vol_{apr}). This was then multiplied by the usage factor for that month (U_m) and an overall usage factor (U_F) for each dam. The monthly usage factor was based on an assumed usage distribution over the study period, such that the sum of all monthly usage factors equalled unity. The overall usage factor was adjusted individually for each dam to calibrate the model (i.e so the model produced the same volume at the end of April as was determined from the aerial photography). The overall usage factor is effectively the fraction of water used compared to the total water removed from each dam over summer. For example, an overall usage factor of 0.4 indicates that 40% of the water removed over summer was extracted (or lost through leakage) and 60% was lost through evaporation.

   $$Vol_{used} = (Vol_{m-1} – Vol_{apr}) \times U_m \times U_F$$

3. The volume remaining in each dam at the end of each month (Vol_m) was calculated by subtracting the volume evaporated (Vol_{evap}) and the volume used (Vol_{used}) from the volume carried over from the previous month (Vol_{m-1}).

   $$Vol_m = Vol_{m-1} - Vol_{evap} - Vol_{used}$$

4. The surface area of each dam at the end of each month (A_m) was calculated from the volume remaining at the end of that month (Vol_m) using a surface area-volume relationship. The surface area-volume relationship was the inverse of the volume-surface area relationship (McMurray 2002) used to estimate the volumes for the GIS datasets.

   $$A_m = (Vol_m/K)^{1/Exp}$$

   Where K and Exp differ for large and small dams, and are given previously.

In the final stage of the model, the total volume of water lost due to evaporation and the total volume used for each dam were determined by summing the values calculated for each month. These were also calculated as percentages of the November storage volumes.

The averages of the percentage water evaporated and water used were calculated from the sums of water evaporated and used (in ML) and expressed as percentages of the sum of the total storage volumes for November.

The model was run for several combinations of monthly usage distribution. Various values of pan factor were also trialled. Each time a parameter was changed, the model was re-calibrated by adjusting the value of the overall usage factor (U_F) so that the final volume was the same as the volume determined from the aerial photography. This was achieved with a macro that ran the MS-Excel “goalseek” tool for each dam in a loop.

The monthly evaporation figures used are shown elsewhere, and the pan factor used was 0.75. The monthly usage distribution used was 15%, 25%, 25%, 20% and 15% for the months December to April respectively.

APPENDIX C – Assessment of Errors & Parameter Sensitivity

Digitising Errors

INTRODUCTION

There is always a degree of uncertainty in determining the exact location of the water outline of farm dams in imagery. Apart from cases where the outline is obscured, the pixelisation of the imagery tends to blur the outline. This blurring is more pronounced in the compressed ECW format. This uncertainty could potentially lead to errors in the placement of the water outline.

The digitising process involved judging the correct pixel in the image that represented the water outline. Each image pixel represents a constant size on the ground, and as all dams were digitised at similar scales, the linear distance of digitising errors would be independent of dam size. Therefore, the errors would have a greater affect on the surface area of smaller dams (with a smaller surface area) than with larger dams.

Further, the water evaporated and water used from dams was determined from the difference between the two surface areas determined from the November and the April imagery. Thus, any digitising errors would be more significant where the two surface areas were of similar size, i.e. the total of water evaporated and water used was low.

Rather than attempt to predict the errors mathematically, a practical test was undertaken for both the monthly model and the GIS one-step model.

METHOD

Digitising errors were simulated in the following manner. The GIS data of a sample of around 140 farm dams from region 2 were buffered (increased in size right around the perimeter) using linear distances of 0.3m, 0.5m and 1.0m. It was noted that the differences between the surface areas of the buffered dams and the surface areas of the unbuffered dams closely followed a trend. This is shown plotted in Figure C1 together with lines of regressions. It was decided to use the regression equations to modify the surface areas of the sample dams in the spreadsheet-based monthly step model and so simulate digitising errors.

Modelling with simulated errors was undertaken only for the 0.5m buffer. This size corresponds to the size of one pixel in the imagery. This was considered to represent a typical error. Although this would not represent the largest possible error on any individual dam, a statistical advantage can be assumed when a large number of dams are considered.

The simulated errors were incorporated to represent the worse case situation where the errors for the November dams were acting in the opposite direction to the simulated errors on the April dams.

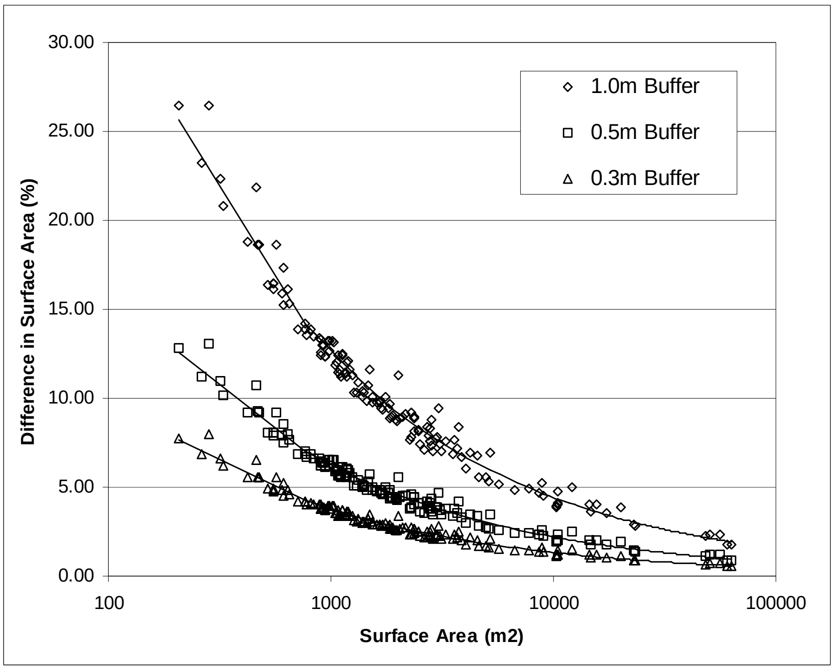


Figure C1. Percentage differences in volume with different buffer distances.

RESULTS

Errors for individual dams

The results from the modelling with the simulated digitising errors were compared to the results of the modelling without simulated errors with all other parameters identical.

The results of this exercise showed that some very large percentage errors (>>100%) were possible in the estimation of water usage. Several causes for these large errors were discovered as follows:

- Small dams, especially those that dried out completely over the summer, produced large errors. This was considered to be due to the actual evaporation rate of these smaller dams being higher than that assumed from the evaporation data;
- Some dams appeared to have a relatively low but negative water usage resulting in unrealistically large percentage errors when, in practice, the actual water usage was most likely zero or close to zero; and
- Many dams with a low estimated water usage produced large errors. If the water used from dams is low, the difference between the surface area in November and that in April would be smaller. Thus, any errors in the surface areas would have a greater impact.

For the above, it was apparent that the methodology of this study was not suitable for estimating water usage from the smaller farm dams. In the following assessment of the effect of digitising errors, consideration is only given to farm dams of size greater than 1 ML.

The errors produced for individual dams >1 ML are shown in Figure C2 plotted against dam volume and in Figure C3 plotted against estimated water usage. The data shown was with positive errors on the November surface areas and negative errors on the April surface areas. Predictably, the effect of potential digitising errors increases as the size of dams reduces, and as estimated water used reduces.

An analysis also was conducted with simulated digitising errors acting in the opposite direction (negative errors on the November surface areas, positive errors on the April surface areas, producing lower estimated of water usage). These errors were similar, although slightly larger, than those shown in the above figures.

The data indicates that the margin in potential errors exceeds the value of percentage water used at around 4-5%, i.e. an estimated value of water usage of 5% for a farm dam could lie in the range 1% to 8% (for a digitising error of 0.5m). A larger size dam, say 60 ML, with an estimated water usage of 20%, the error margin would be 20+2/-3%.

In general, these large potential errors for smaller farm dams and dams with low water usage are not likely to present serious problems as the absolute quantity of water involved with the potential errors is not large. The potential errors for large dams and dams with higher than say 10% usage rates, are within reasonable bounds.

The potential errors in the estimation of water evaporated are much lower than the potential errors for estimated water usage. These are shown for individual dams plotted in Figures C4 and C5.

The reasons for lower errors in estimation of water evaporated compared to the estimation of water usage are as follow. Water evaporated was calculated from evaporation data and surface area for each month. However, water usage was calculated (a) on the difference between the surface area at the beginning of each month and the final surface area in April, and (b) on the difference between the total water used and water evaporated. Thus, the digitising errors have a compounding effect on estimated water usage.

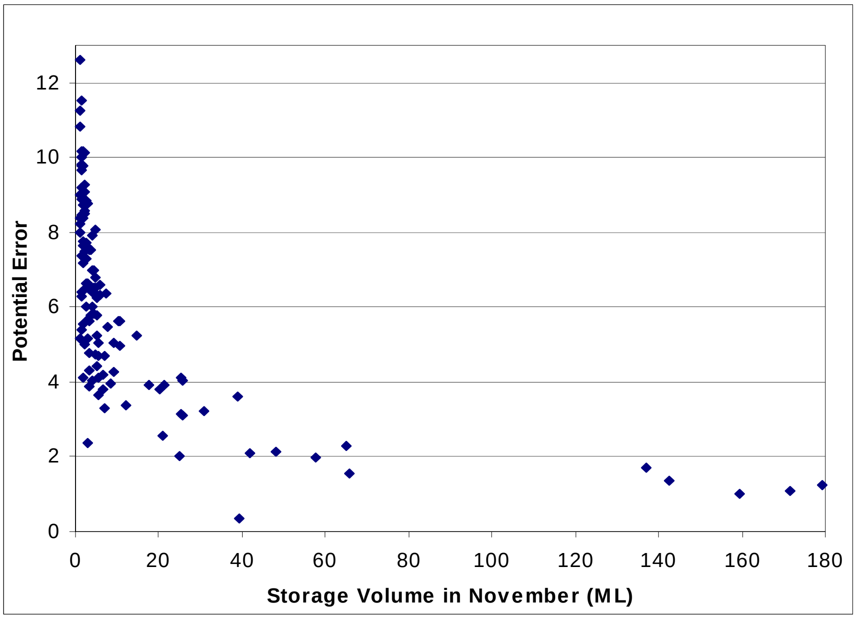


Figure C2. Potential errors in estimated water used plotted against dam volume (dams > 1ML only). Simulated digitising errors of 0.5m.

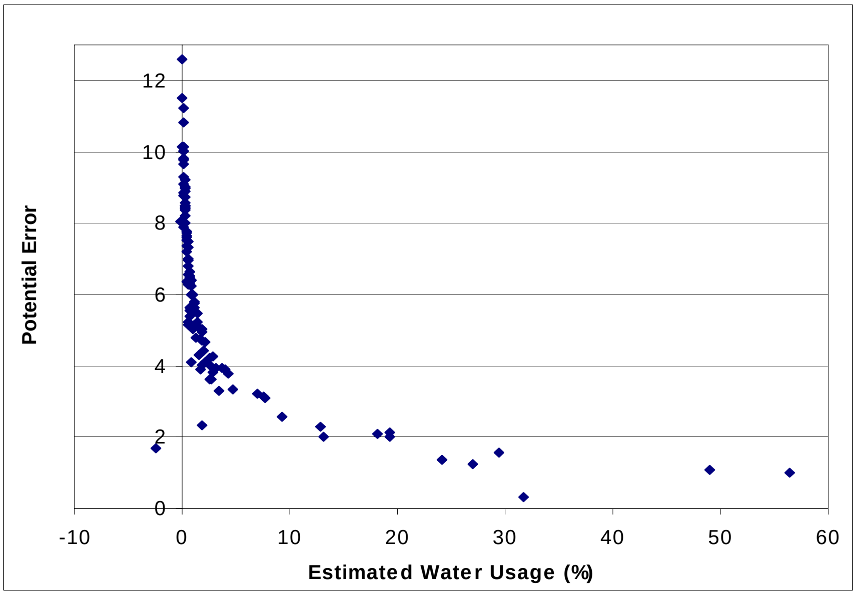


Figure C3. Potential errors in estimated water used plotted against estimated water used (dams > 1ML only). Simulated digitising errors of 0.5m.

Notes re the potential errors plotted above:

1 The simulated errors are for positive errors in the November surface area and negative errors in the April surface area. This combination produced larger estimates of water usage.

2 The potential errors are the absolute differences in percentage estimated water usage for dams with simulated digitising errors and the estimated usage without the simulated errors. For example, from Figure C3, the potential error for an estimated water usage of 10% would be around 2.5% expressed alternatively as 10±2.5% (assuming the negative errors are similar to the positive errors).

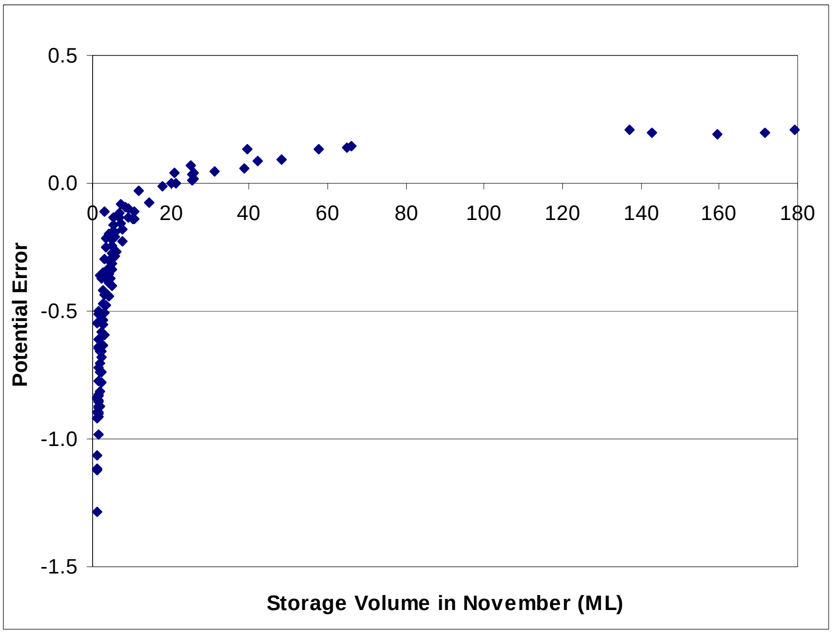


Figure C4. Potential errors in estimated water evaporated plotted against dam volume (dams > 1ML only). Simulated digitising errors of 0.5m.

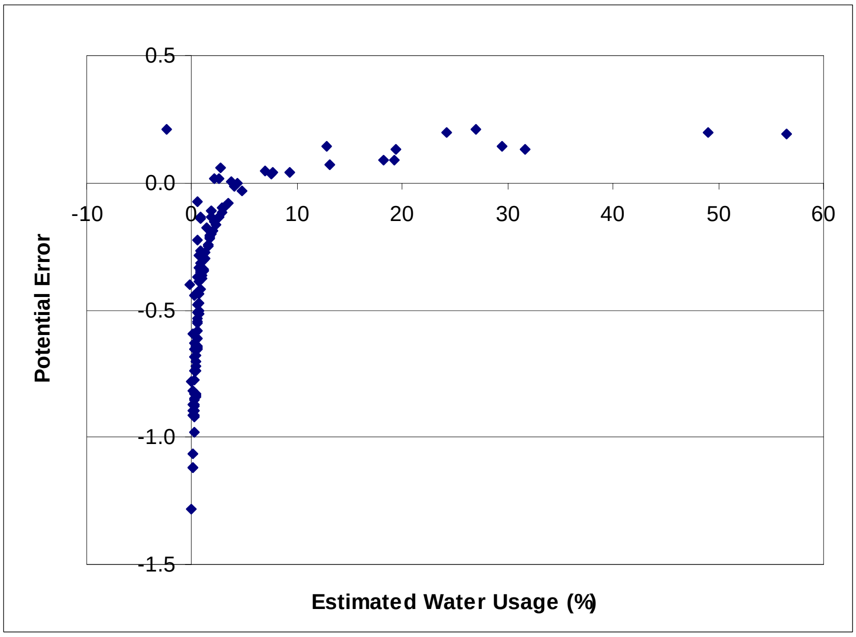


Figure C5. Potential errors in estimated water evaporated plotted against estimated water used (dams > 1ML only). Simulated digitising errors of 0.5m.

Notes re the potential errors plotted above:

1 The simulated errors are for positive errors in the November surface area and negative errors in the April surface area. This combination produced larger estimates of water usage but with a varying effect on estimation of water evaporated.
2 The potential errors are the absolute differences in percentage estimated water evaporated for dams with simulated digitising errors and the estimated usage without the simulated errors.

Errors for groupings of dams

The forgoing has considered the effect of potential digitising errors on estimation of water usage and estimation of water evaporated for individual dams. Table C1 summarises statistics for the average errors for groupings of all dams in the sample and for dams of various size ranges.

Table C1 Statistics on potential errors in estimated water usage and in estimated water evaporated. Simulated digitising errors of 0.5m.

	Water Evaporated		Water Usage	
	Negative errors	Positive Errors	Negative errors	Positive Errors
Mean, dams >20ML	0.1	0.5	-3.1	2.3
Mean, dams 10-20ML	-0.1	0.9	-5.7	4.5
Mean, dams 5-10ML	-0.2	1.1	-6.6	4.8
Mean, dams 2.5-5ML	-0.3	1.4	-7.8	6.0
Mean, dams 1-2.5ML	-0.8	2.1	-10.8	8.4
Mean, all dams >1ML	-0.4	1.5	-7.9	6.1
Median, all dams >1ML	-0.4	1.4	-7.9	6.1
Std Dev, all dams >1ML	0.4	0.7	3.4	2.6
Min, all dams >1ML	-1.3	0.3	-16.6	0.3
Max, all dams >1ML	0.2	3.1	-0.8	12.6

Notes:

1 The data in the columns headed “Positive Errors” were produced by positive errors in the November surface area and negative errors in the April surface area producing larger estimates of water usage. The data in the columns headed “Negative Errors” are the converse.

2 The data are statistics based on the errors each individual dams. The errors for each individual dam were determined as the absolute difference between the percentage estimated water usage/evaporated for dams with simulated digitising errors and the percentage estimated water usage/evaporated without the simulated errors.

GIS One Step Model

The calibration process for the spreadsheet-based monthly-step model adjusts the value of the overall usage factor (U_F) which directly changes the values of estimated water usage. This, together with any digitising errors, may have an unrealistic effect on estimated water usage. The effect of simulated digitising errors was tested on the GIS one-step model that did not use a calibration process.

The results of this exercise showed that the simulated errors in estimated water used are similar for both models. Similarly, the simulated errors for water evaporated are similar for both models. This indicated that there is unlikely to be any major fundamental error in method or excessive sensitivity to digitising errors.

SOURCES OF DIGITISING ERRORS

The following aspects can affect the accuracy of digitising water outlines of farm dams:

- In colour ortho-imagery captured in winter, the water often has a green tinge that is difficult to distinguish from grass on the banks.
- In infrared ortho-imagery the water body usually appears black, and any shallow water appears dark grey. However, any shadow from the banks also appears black, and wet soil around the perimeter appears dark grey. These two aspects make it difficult to distinguish the exact location of the water outline.
- Frequently, there are two or more “tide marks” around or close to the perimeter. It is often difficult to tell which of these is the actual water perimeter. They may have been a mark left by an earlier higher water level, or they may be the boundary between shallow water and deeper water.
- Processing of the raw off-scanner imagery, in particular file compression algorithms, tend to blur object outlines (a soft focus effect). The water outline tends to become spread over several pixels requiring subjective judgement as to where to locate the water outline.
- Overhanging trees obscure the water outline. In some case obscuring trees make it impossible to determine the water outline with any certainty. Dams with this problem were not included in this study.
- Shadow from nearby trees also obscure the water outline. This is worse in infrared ortho-imagery as the shadow is black the same colour as water appears. In colour ortho-imagery it is often possible to detect short sections of water outline due to scattered light within the shadow, enabling the water outline to be interpolated with a reasonable degree of certainty.
- Vegetation growth near the perimeter can obscure the water outline. Algae grow on the water surface and should be included in the water outline. Reeds may be growing on the bank or within the water. It is usually impossible to tell which. In colour ortho-imagery such growth appears green and often can not be distinguished from grass on the banks. In infrared ortho-imagery, this type of growth appears pink, which is easy to see, but it is not possible to tell whether the growth is on the surface or outside of the water body.
- The two sets of imagery were captured in different seasons (as was the requirement) and at different times of day. This resulted in shadow from nearby trees being in a different location in the two sets of imagery. However, the shadow obscured the water outline of several dams in the November imagery, but not the April imagery, and other dams were obscured in the April imagery but not the November imagery. This resulted in a larger number of dams necessitating exclusion from the study than had been the case if the shadow had been in the same location in both sets of imagery.

Monthly Distribution of Usage

The monthly step model was run for the sample of approximately 140 farm dams in area 2 using a range of different monthly usage distributions. The figures obtained for averaged percentage estimated evaporated and estimated usage for dams >1 ML are shown in Table C2.

Table C2. Average estimated water evaporated and water usage for a range of monthly usage distributions.

Assumed Monthly Usage Distribution (%)					Estimated	Estimated
Dec	Jan	Feb	Mar	Apr	Evaporated (%)	Usage (%)
100	0	0	0	0	14.6	27.2
0	100	0	0	0	15.7	26.1
0	0	100	0	0	16.8	25.0
0	0	0	100	0	17.8	23.9
0	0	0	0	100	18.4	23.3
0	50	50	0	0	16.3	25.5
0	0	50	50	0	17.3	24.5
27	32	26	15	0	16.1	25.7
15	25	25	20	15	16.7	25.1

The estimated usage is affected by the timing of use due to the effect this has on evaporation. The 100% usage in December and the 100% usage in April represent extreme scenarios. The 100% usage in December leaves the minimum quantity of water for evaporation, and produced estimated total usage of 27.2%. At the other end of the scale, the 100% usage in April leaves the maximum quantity of water for evaporation, and produced estimated total usage of 23.3%. This is a range of 25.2±2% of total storage capacity.

The range of possible error from this source in the estimation of total water evaporated was similar to that for water used (16.5±1.9% of total capacity).

The range of estimated evaporation and usage resulting from these extreme scenarios is not excessive. When considered in isolation from other potential sources of error, the model was considered not unduly sensitive to the assumed monthly distribution pattern. The variability in estimated evaporation and usage will be quite low provided the assumed monthly usage distribution is reasonably representative of the actual situation as illustrated by the last two scenarios in Table C2 (16.4±0.3% of total storage capacity for evaporation and 25.4±0.3% for usage).

Climatic Data

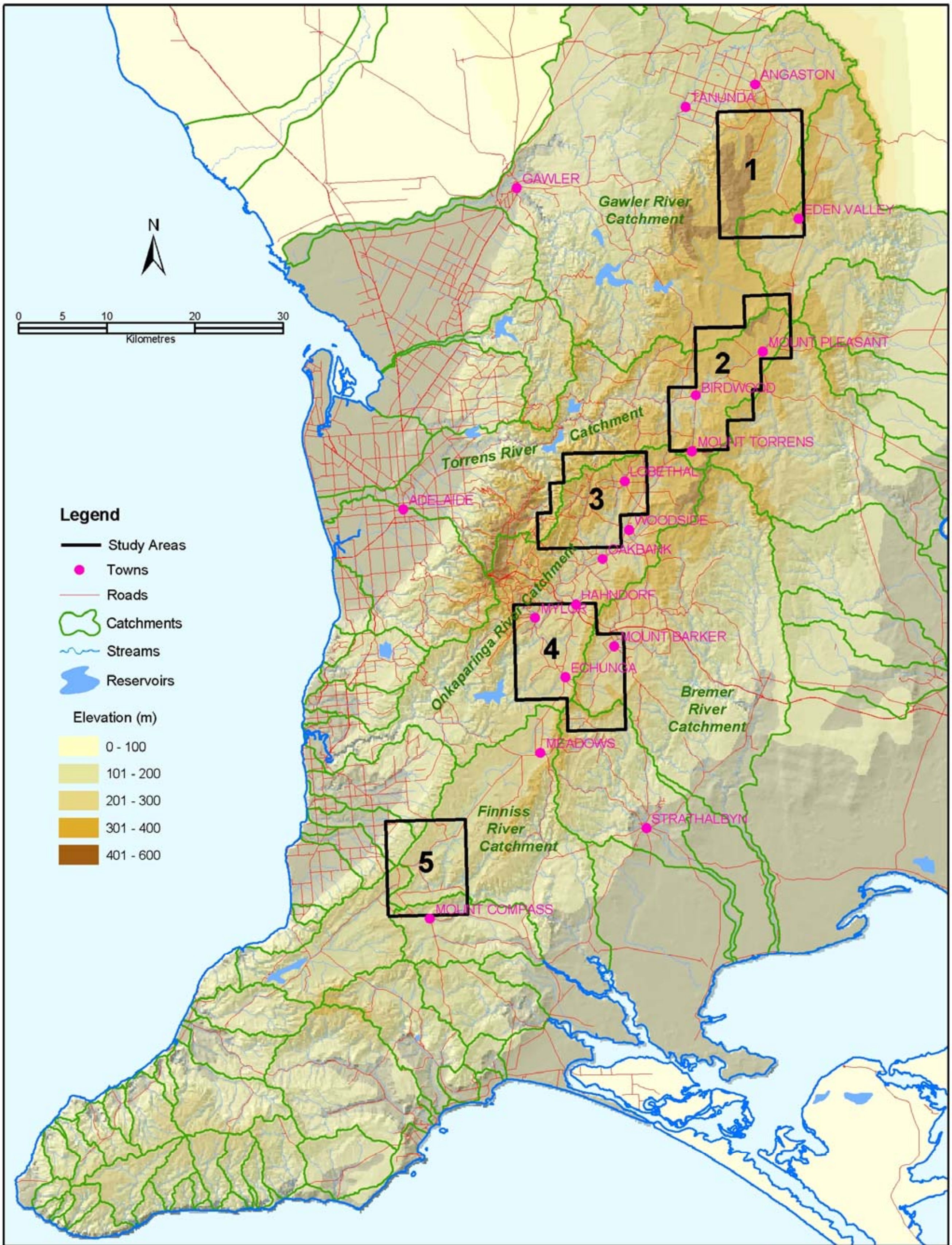
Using the data from around 140 farm dams in study area 2, the monthly-step model was run for different values of pan factor, the results of which are shown in Table C3.

Table C3. Total estimated water evaporated and water usage with various values for pan factor.

Pan Factor	Estimated Total Evaporated (%)	Estimated Total Usage (%)
0.7	15.5	26.4
0.75	16.7	25.1
0.8	18.0	23.9
0.85	19.2	22.7

A pan factor change of ±6.7% (0.75±0.05) produced a change in estimated total water evaporated of ±7.2% (16.7±1.2/3) and 4.8% (25.1±1.2/3%) for estimated usage. Thus, when considered in isolation from other potential sources of error, these results show that the model is not unduly sensitive to pan factor.

Similar affects resulted from variations in evaporation and/or rainfall data. Given the lack of comprehensive evaporation data for the study areas (the nearest evaporation station was in most cases well outside the study areas), it was difficult to simulate a worst-case or a typical error range. It was assumed that an error range of ±10% was reasonable for pan evaporation. This, combined with possible errors in pan factor would result in an error band of around ±3% for estimated evaporation and ±2% for usage.



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Date: January 2004

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Figure 1. Location of the Five Study Areas

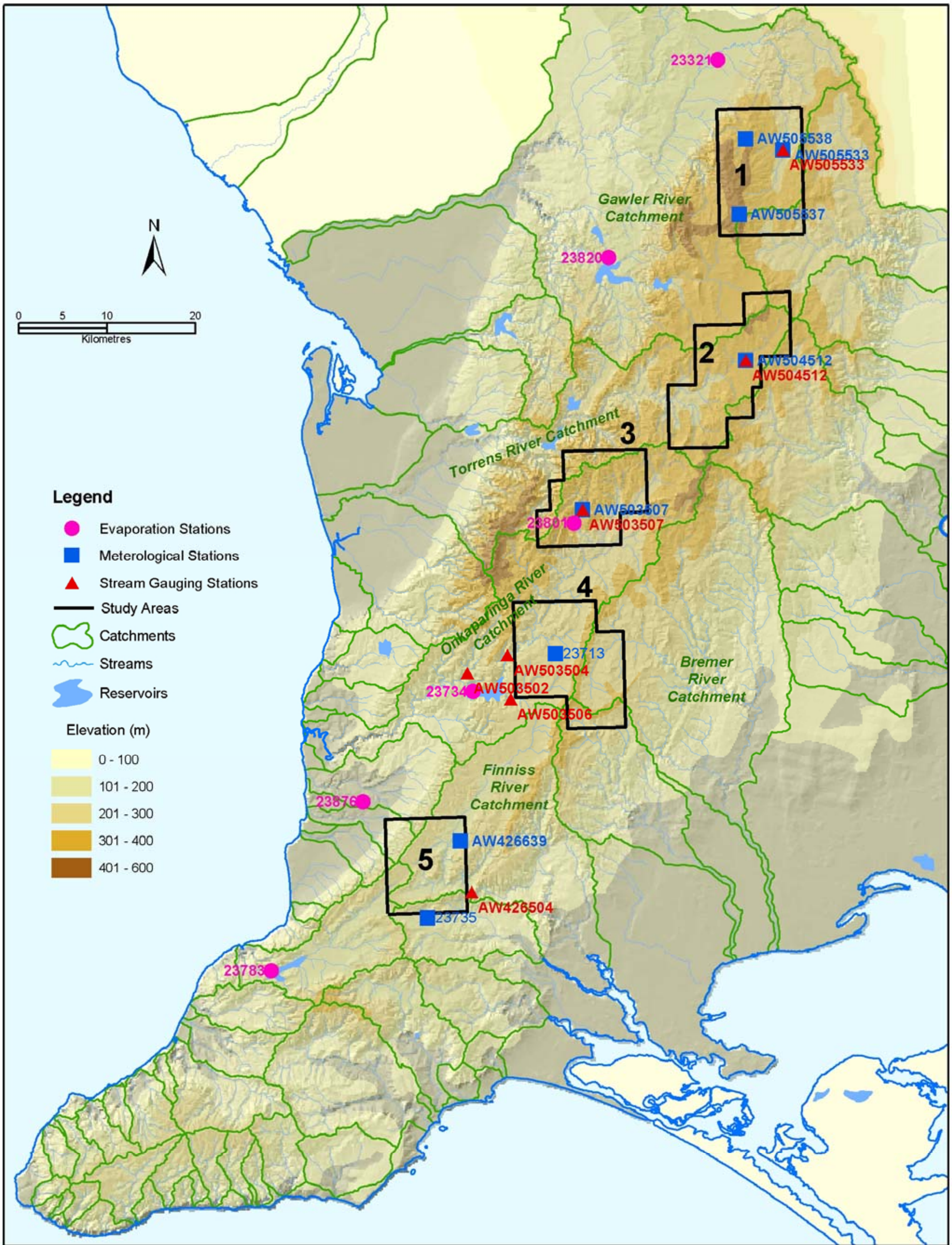

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Figure 2. Hydrological Monitoring Stations