Murray-Darling Basin Sustainable Yields Project

PROJECTIONS OF EFFECT OF FUTURE FARM DAM DEVELOPMENT TO THE YEAR 2030 ON RUNOFF

- Rainfall Runoff Modelling Scenario D
- Final
- 20 December 2007

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Contents

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Draft	15/11/2007	Peter Hill	Rowan Barling	15/11/2007	Draft Issued to CSIRO
Draft A	20/12/2007	Peter Hill	Rowan Barling	20/12/2007	Draft Issued to CSIRO
Final	23/9/2010	Brad Neal	Rowan Barling	23/9/2010	Re-issued without change as final version

Distribution of copies

Revision	Copy no	Quantity	Issued to
Draft	Electronic PDF	1	Francis Chiew, CSIRO
Draft A	Electronic PDF	1	Francis Chiew, CSIRO
Final	Electronic PDF	1	Mary Mulcahy, CSIRO

Printed:	23 September 2010
Last saved:	23 September 2010 02:23 PM
File name:	**I:\VWES\Projects\VW04949\Communications\In\VW03910 MDBSY\Deliverables\SKMReport_FarmDamModelllingOnly\R03pwj_FarmDamsProj**
Author:	**Phillip Jordan and Chloe Wiesenfeld**
Project manager:	Peter Hill
Name of organisation:	CSIRO
Name of project:	Murray-Darling Basin Sustainable Yield
Name of document:	Projections of Effect of Future Farm Dam Development to the Year 2030 on Runoff
Document version:	Final
Project number:	VW03910.300

1 Introduction

Australia is the driest inhabited continent on Earth, and in many parts of the country – including the Murray-Darling Basin – water resources for rural and urban use is comparatively scarce. Into the future, climate change and other risks (including catchment development) are likely to exacerbate this situation and hence improved water resource data, understanding and planning and management are of high priority for Australian communities, industries and governments.

On 7 November, 2006, the Prime Minister of Australia met with the First Ministers of Victoria, New South Wales, South Australia and Queensland at a water summit focussed primarily on the future of the Murray-Darling Basin (MDB). A key outcome from the Summit on the Southern Murray-Darling Basin, was the commissioning of CSIRO to "report progressively by the end of 2007 on sustainable yields of surface and groundwater systems within the MDB, including an examination of assumptions about sustainable yield in light of changes in climate and other issues".

The Murray-Darling Basin Sustainable Yields (MDBSY) Project specifically calls in its terms of reference for:

- An estimate current and likely future water availability in each catchment and aquifer in the MDB considering:
  - climate change and other risks,
  - surface-groundwater interactions, and
- To compare the estimated current and future water availability to that required to meet the current levels of extractive use.

The MDBSY Project will be the most comprehensive Basin-wide assessment of water availability undertaken to-date. Sinclair Knight Merz were engaged by CSIRO to provide significant input to the project, across many of the different technical aspects, including providing projections of the future impact of farm dam development on streamflows to the year 2030.

The assessment of current and future water availability in the MDBSY Project is organised around separate assessments for four main scenarios of historical and future climate and current and future development, all of which are defined by daily time series of climate variables based on different scalings of the 1895–2006 climate:

- Scenario A: Historical climate and current development
- Scenario B: Recent climate (1997-2006) and current development
- Scenario C: Future climate and current development
- Scenario D: Future climate and future development

The fourth scenario (Scenario D) uses the same climate series as Scenario C (incorporating projected climate change to 2030), but supply system inflows will be modified to reflect land use change and groundwater development. Land use change will be limited to a consideration of ~2030 projections of forestry plantations and farm dams. The considerations of land use change are thus limited to aspects that affect inflows and for which reasonably robust projections are possible.

To assess the impact of increased development of storage in the MDB, only farm dams or small catchment dams were considered in this project. While there are a number of common definitions of a farm dam, for this study they were defined as dams that are filled from their own catchment area, are not located on a watercourse and do not divert water from a watercourse (Department of Sustainability and Environment, 2006).

This report provides detailed methods and results associated with incorporation of farm dam impacts on yield assessments for the modelling in Scenario D. A summary of the most important results from the farm dam modelling is included in the *Rainfall Runoff Modelling Technical Report* (CSIRO, 2007).

2 Overall approach for estimation of farm dam impacts

The Murray-Darling Basin Sustainable Yields Project involves setting up and running models of the surface water resources of each of the major basins in the MDB. These surface water models include the Integrated Quantity and Quality Model (IQQM) (for reporting regions in New South Wales and Queensland), the Resource Allocation Model (REALM) (for reporting regions in Victoria), WaterCRES (for the Eastern Mount Lofty Ranges in South Australia) and the Murray Simulation Model-Bigmod (MSM-Bigmod) (for the main stem of the Murray River). Although there are differences in how these models account for and route water through the systems that they represent, they have many similarities. A significant similarity is that each model subdivides the area that it represents into “modelling subcatchments”. The boundaries of these modelling subcatchments were defined by the river system modelling team of the MDBSY Project. Inflows from subcatchments were represented as inputs in the form of timeseries of flows, with time steps, depending on the model, of daily, weekly or monthly.

Subcatchment inflows for Scenario D were produced by taking the Scenario C inflow time series and modifying them so that they represent the additional effects of both farm dams and changes in plantation forestry.

There are two main steps in deriving the farm dam impacts for Scenario D, for each subcatchment, in each surface water resource model:

1) For the year 2030, predict the change in the number, total volume and size distribution (i.e. the change in the number of dams that will be within a given range of volumes);
2) Apply a conceptual model to modify the timeseries of flow to represent the effect of the predicted changes in farm dams.

Step 1: Predicting the change in number and volume distribution of farm dams in each subcatchment

It is widely acknowledged that there has been significant growth in the number and total volume of farm dams in the MDB over the last few decades. Each of the four State Governments in the MDB has legislation in place that will control future growth in farm dams in some way. Chapter 3 of this report contains a review of the relevant legislation, explaining the implications of these for growth in farm dam numbers and volumes between now and 2030.

Chapter 4 analyses the available data on the existing spatial distribution of farm dams across the MDB. This information was foundational for the projections of future farm dam development because, in some areas of the MDB, legislative caps in conjunction with existing farm dam development will limit future development. The existing density of farm dam development (compared with either area or rural population served) was also used as a guide in projecting future increases in farm dam storage volume.

Projected future construction of farm dams will be influenced by a combination of social and economic drivers for increased development and legislative controls. Chapter 5 discusses three independent projections of future farm dam development for the MDB:

1) A limitation to volume determined by policy constraints.
2) Change in stock and domestic farm dam volume determined by the change in population.
3) Extrapolation and application of historical trend to existing storage volume.

One projection of the increase in farm dam storage volume was derived for each modelling subcatchment in the MDB, as discussed in Chapter 6. The adopted projection for each modelling subcatchment was derived from a combination of the three methods discussed in Chapter 5, with the most appropriate method for a given modelling catchment selected according to the policy constraints applicable in the jurisdiction containing the modelling subcatchment and the drivers for farm dam development that are applicable in that area.

Step 2: Applying a conceptual model to represent the effect of predicted changes in farm dams on the streamflow timeseries for each catchment

The CHEAT model (Nathan *et al.*, 2005) was used to represent farm dam impacts for the MDB. CHEAT is a conceptual model for estimating time series of runoff from catchments with existing farm dams or a projected increase in farm dams from their existing level. Chapter 7 provides background on the structure of the CHEAT model.

For each modelling subcatchment in this project, the CHEAT model was provided with the projected increase in total farm dam volume and the distribution of farm dam sizes, specified as the proportion of the projected farm dam increase comprised of dams from one of twelve volume classes (from Step 1, above). CHEAT was also provided with several other inputs, including time series of rainfall and point potential evaporation, a relationship between dam storage volume and surface area, a relationship between dam storage volume and assumed catchment area, assumed ratios of annual consumptive demand to storage volume and monthly patterns of demand. These other inputs to the CHEAT model are outlined in Section 7.2.

The CHEAT model was then run for each of the modelling subcatchments, in each reporting region, for each of the nine combinations of GCM and global warming scenarios that were considered in Scenario D. The results of the modelling of future farm dam impacts are shown and discussed in Chapter 8.

3 Overview of current state government policies controlling future farm dam development

This chapter provides an overview of current farm dam policy in each State and Territory in the MDB and the potential for unlicensed future farm dam development under those policies.

3.1 Australian Capital Territory

The management of water resources in the ACT is currently in a transitional period as the *Water Resources Act 1998* (Australian Capital Territory Government, 1998) is replaced by the *Water Resources Act 2007* (Australian Capital Territory Government, 2007). The new Act comes into force in September 2007. Under the new Act all extractions from surface or ground water will require a water access entitlement (WAE) (s19) unless it is for domestic and stock purposes. The WAE gives the holder the right to extract the minimum of a percentage of the total volume available for taking and a stated maximum volume. This means that it is possible for the entitlement to change as water resource availability changes due to climate change or other environmental factors. Under s20, the minister can reject a claim for a water access entitlement based on the volume being requested being more than a reasonable amount for its intended purpose or if the water is to be used for urban residential purposes or the licence holder has a poor environmental record.

The WAE gives a person the right to take a particular volume of water, but it does not allow for the water to be taken from any location. A licence to take water is needed to extract water from a particular location. Both of these are available from the Environmental Protection Authority (the Authority). In addition, a permit to build a dam is required under the *Land (Planning and Environment) Act 1991* (Australian Capital Territory Government, 2007) unless the storage is less than 2 ML and not on a waterway.

A policy document *Think Water Act Water* (Environment ACT, 2004) was first released in 1999. It was again released in 2004 to set policy objectives for up to 2050. The ACT has been divided into 32 separate management units (or sub-catchments) and for most of these, 10% of flows above the 80th percentile has been selected as a suitable portion of flow that can be abstracted. Currently only a small proportion of the amount that can be abstracted has been allocated, but this document outlines future allocation provisions for the period from 2004 to 2014. Over this period the Murrumbidgee and Gudgenby Rivers and tributaries have been allocated water mostly for agricultural purposes, in particular the growing of pasture or permanent crops such as grapes and olives. The allocation of water to farm dams is not explicitly dealt with in any legislation or policy document currently existing.

A Murray-Darling Basin Cap still has not been set by the ACT, although efforts are being made to establish one. This indicates that development is not limited and diversions are able to increase up to the limits set by environmental flows.

3.2 New South Wales

Under the s53 of the *Water Management Act 2000* (New South Wales Government, 2000) an owner or occupier of a landholding within a harvestable rights area is entitled to construct a dam for the purpose of capturing, storing and using rainwater run-off in accordance with the harvestable rights order. On the 31 March 2006 two harvestable rights orders were gazetted under s54 of the *Water Management Act.* These cover (1) the Western Division (Department of Natural Resources, 2006b) and (2) the Eastern and Central Division (Department of Natural Resources, 2006a) of NSW as set out in s4 *Crown Lands Act 1989* (New South Wales Government, 1989) which provides that NSW is divided into these two divisions. This effectively means that all of NSW is covered by a harvestable rights order which governs the right of owner or occupiers to construct new dams.

Under the *Harvestable Rights- Eastern and Central Division Order* (Department of Natural Resources, 2006a) a landholder in the Eastern and Central Division has the right to build a farm dam under two circumstances:

1) A land holder may capture 10% of the average regional rainwater run-off on the land if that land is located on a minor stream. This is known as landholder's harvestable right and is calculated as the maximum harvestable right dam capacity (MHRDC). The MHRDC is calculated by taking into account:
   - Stream order – A minor stream includes 1st and 2nd order streams (minor streams) based on the Strahler stream ordering system applied to the most detailed map available at 1 January 1999 can have unlicensed dams. Any dams on 3rd order streams (or higher) require a licence. The most detailed map is a 1:25,000 scale map for the tablelands and part of the slopes of NSW and further inland it is 1:50,000 or 1:100,000 (a full list of the relevant maps was gazetted on 24 March 2006 under s5(1) of the *Water Act 1912* (New South Wales Government, 1912).
   - Maximum harvestable right dam capacity (MHRDC) – This is determined by applying the MHRDC multiplier previously calculated by the NSW Department of Natural Resources to the property of interest. This multiplier is a spatially variable runoff coefficient that converts a property area into the harvestable right, which is equivalent to 10% of the property's estimated runoff. A MHRDC calculator is available online at http://www.farmdamscalculator.dnr.nsw.gov.au for landholders to calculate their property's MHRDC.

2) Where the MHRDC is less than 1 ML and the property was approved for subdivision before 1 January 1999, a farm dam of up to 1 ML can be constructed. This is a transition policy to avoid disaffecting property developers with approved subdivisions prior to the new harvestable rights legislation coming into force in 1999 and is not expected to result in any significant increase in future farm dams from 2007 onwards.

In each case the potential for future dams must be assessed at a property scale. A property is defined as a parcel of land valued as one unit by the Valuer General's Department under the *Valuation of Land Act 1916* (New South Wales Government, 1916). The Department of Natural Resources has the discretion to treat multiple parcels of land as one property for the purposes of calculating the MHRDC, but generally only where landholdings are made up of land in adjoining parcels.

If a property is subdivided or one of the adjoining land parcels in that property is sold after 1 January 1999, then the MHRDC is separated accordingly. If the dams on one of the subdivided properties exceeded the MHRDC, the dams would need to be modified or a new licence would need to be applied for. This means that there is no potential for any new subdivisions after 1 January 1999 to increase total farm dam capacity for the subdivided land.

A number of dams are exempt from harvestable rights calculations. These include dams for erosion control, flood mitigation and drainage water reuse. Farm dams in the Western Division of New South Wales do not require a licence because there is negligible potential to capture runoff in this area (see *Harvestable Rights – Western Division Order (DNR, 2006b)*).

3.3 Queensland

The central piece of legislation governing water management in Queensland is the *Water Act 2000 (Qld)* (Queensland Government, 2000). This Act sets out the framework for water allocation in Queensland, this includes the management of overland flow. Overland flow is water that runs across the land after rainfall, either before it enters a watercourse or after it overflows from river banks as flood water.

The Act sets out two provisions which govern the interception of overland flow. In the first instance, an owner of land on which there is overland flow is authorised to collect water in a dam for stock and domestic purposes (s4). This right to take water exists irrespective of whether a moratorium notice (see below) is in place.

In the second instance, s20(6) provides that a person is authorised to take overland flow water unless there is a moratorium notice, a water resource plan or a wild river declaration in place. A moratorium notice is a notice published by the Minister if the Minister is satisfied that action should be taken to protect natural ecosystems or to protect existing water entitlements and other authorities under the *Water Act 2000* to take or interfere with water (s26(1)). A moratorium notice may provide that (s26(4)):

- No new works impacting on water (including overland flow) may be physically started; and
- Complete works impacting on water (including overland flow) may not be raised, enlarged, deepened or changed.

The penalty of contravening the provisions in a moratorium notice is 1664 penalty units (s26(6)).

Moratorium notices have been established for the Condamine Balonne Basin and Border Rivers Catchment (20 September 2000) and for the Moonie River Catchment and the Warrego/ Paroo/ Buloo/ Nebine Catchments (9 June 2001). This means that landowners in these catchments are not able to expand the existing network of farm dams in these unless the dam is for stock and domestic purposes (s4).

3.4 South Australia

In South Australia, the water allocation framework is set out in the *Natural Resources Management Act 2004* (South Australia Government, 2004). Under s124(2) the occupier of land is entitled to take surface water from the land for any purpose. The exception to this is where the resource is prescribed. Prescription is a means of protecting water resources in the region and will ensure they are not over used, and that there is enough water for all water users, including the environment. Once a water resource is prescribed, all people who take water need a licence to do so s124(3) unless the water is being used for stock and domestic use.

In the South Australian component of the Murray-Darling Basin, catchment farm dams only occur to any significant extent in the Eastern Mount Lofty Ranges. This area was prescribed on 8 September 2005. A legally enforceable water allocation plan is currently being prepared. This will set out the conditions under which new licences in the Eastern Mount Lofty Ranges can be granted. Licences will only be issued once this water allocation plan has been adopted. In the meantime there is a ban on the issue of new licences in the area. Following the adoption of the water allocation plan new licences will only be issued if the plan identifies that there is water available. It is unknown whether this will be the case at this time.

The previous policy contained within the River Murray Catchment Water Management Plan prior to the resource being prescribed allowed for farm dam volume development up to 30% of the mean winter flow at both a property scale and a catchment scale, whichever was the most limiting.

At the time of commencing the MDBSY Project the Water Allocation Plan was under development by the South Australian Department of Water, Land and Biodiversity Conservation (DWLBC). In the absence of a clear policy position from DWLBC at the commencement of the MDBSY Project, it was assumed that future farm dam development in the Eastern Mount Lofty Ranges Region

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would continue in line with the previous policy. However, there clearly is significant uncertainty on the projected increases in farm dam volumes for the Eastern Mount Lofty Ranges because any future policy could be different to both the previous policy and the current ban. See Section 5.2.4 for a discussion of the adopted projections for the Eastern Mount Lofty Ranges.

3.5 Victoria

Rights to water in Victoria are primarily set out in the *Water Act 1989* (Victorian State Government, 1989). Under this Act there are three legal forms of rights to water in farm dams. The first of these is set out in s8(1)(c), which provides that a person has the right to take water for domestic and stock use because that person occupies land on which the water flows or occurs. Importantly, this right only extends to domestic and stock use and is tied to the occupation of land.

At present, where water is being collected in a farm dam for irrigation or commercial uses a licence must be held (s51(1)(c)). In order to licence a new dam a person must apply to the relevant water Authority. Under s55 the water Authority *must* refuse an application if:

- It would conflict with an approved management plan for a water supply protection area;
- It would result in the permissible consumptive volume for the area to be exceeded; or
- It is likely to have an adverse effect on maintaining the environmental water reserve.

Importantly, the *Murray-Darling Basin Act 1993 (Vic*) (Commonwealth of Australia, 2005) forms part of the environmental water reserve (s4B). The *Murray-Darling Basin Act 1993* is the piece of legislation which gives legal effect to the Murray-Darling Basin Agreement and the cap of water usage within the basin as set out in Schedule F. This means that any application for a s51(1)(c) is subject to the MDB cap.

The *Water Act 1989* has recently been amended to facilitate the unbundling of rights to water from land rights in declared systems. This will be rolled out in regulated systems in Northern Victoria after July 1. In declared systems, licences will be converted to water shares. In a declared system a person must not take water from a dam for irrigation or commercial reasons unless that person is authorised to do so under a water share (s33E(d)). As above, an application for new water shares is subject to the MDB cap.

Future subdivisions of rural properties may result in additional requirements for stock and domestic water, which would include the development of new farm dams that are not included in the MDB cap.

4 Existing storage volumes of farm dams

4.1 Relationships between farm dam storage volume and surface area

The farm dam surface area to volume relationship has been used to estimate the surface area of farm dams in the Murray-Darling Basin for two main purposes:

1) To estimate the volume of each of the existing farm dams that are in the Murray-Darling Basin. Projections of future potential farm dams are, in some cases, based upon observed growth rates from existing densities of farm dams and in other cases, restricted to the difference between a limit set by state government policy and the existing number of farm dams.
2) To estimate the surface area of the projected new farm dams from their volume. This was used by the CHEAT model to determine evaporative losses from the surface of the projected new farm dams.

Since 2004, four independent studies from Victoria, South Australia, Western Australia and a sample of the whole MDB have been completed. These studies were used to develop equations that relate a farm dam’s storage volume to its visible surface area. The equations produced by each study were reviewed and compared and the most appropriate method selected for relating farm dam storage volume to surface area. The equations are presented in chronological order of publication, below.

4.1.1 Victoria: Sinclair Knight Merz (2004b)

Sinclair Knight Merz (2004b) derived a relationship between farm dam storage volume and surface area by obtaining data from two different sources:

- Engineering plans were sourced from Victorian licensing authorities for 42 dams that were used on-farm; none of these dams were used purely for aesthetic purposes. The volumes from this data source ranged from 1.6 ML to 420 ML, although the volume of most dams was greater than 10 ML.
- Light Detection and Ranging (LIDAR) survey of 110 farm dams in the Corangamite region of Southern Victoria. The dam volumes produced from the LIDAR data ranged from 0.4 to 69.2 ML, where 97 of the farm dams had a total volume less than 5 ML.

A power law relationship was fitted to the combined data for all 152 dams, using least squares regression. The fitted relationship was:

$$V = 0.000145 \times S^{1.314}$$

where V is the storage volume of the farm dam in ML and S is the surface area of the farm dam in m². The regression relationship had an r^2 value in log-log space of 0.95.

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About two thirds of the dams used to derive the Sinclair Knight Merz (2004b) equation had a storage volume of less than 5 ML (or a surface area of less than about 2800 m²). This relationship was therefore likely to be most appropriate for estimating the volume of smaller dams, which are most likely to be for stock and domestic purposes.

4.1.2 South Australia: Department of Land Water and Biodiversity Conservation (2004)

The Department of Land Water and Biodiversity Conservation (McMurray, 2004) obtained data from dams across several regions of South Australia, including the Eastern Mount Lofty Ranges. Storage volume and surface area estimates were obtained for a total of 487 dams. Ground based survey methods were used to obtain the data for 131 of the dams, with data for the remaining 356 dams coming from a rapid field assessment method. The rapid field assessment method involves estimating the surface area of the dam using a tape measure in the field, estimating its approximate depth from the height of the dam wall and then estimating the volume from:

$$V = \frac{0.4DS}{1000}$$

where D is the estimated height of the dam wall in metres.

Of the total number of 487 dams used in this study, 220 had a total volume less than 5 ML.

This study found that to obtain the most accurate results two separate relationships were required, one for small dams and a separate one for larger dams. The relationship between smaller farm dams volumes and surface areas was best represented by a power law relationship, while for larger dams a linear relationship was more appropriate. The apparent demand for surface water from dams within that catchment was also found to impact the farm dams' surface area to volume relationship. McMurray (2004) included the Upper Marne River catchment in the high demand group but it included the Bremer River catchment and Eastern Mount Lofty Ranges data sets in the low demand group.

The equations derived by McMurray (2004) were as follows.

High demand group (inc. Upper Marne):

$$V = \begin{cases} 0.000215 \times S^{1.26} & ,S \le 20000m^2 \\ 0.0028S & ,S > 20000m^2 \end{cases}$$

Low demand group (inc. Bremer River catchment and Eastern Mount Lofty Ranges data set):

$$V = \begin{cases} 0.0002 \times S^{1.25} & ,S \le 15000m^2 \\ 0.0022S & ,S > 15000m^2 \end{cases}$$

The overall r^2 value in log-log space for the relationship for the high demand group was 0.94.

4.1.3 Sample of whole MDB: Agrecon (2005)

Agrecon (2005) derived a relationship between farm dam volume and surface area as part of a larger project on estimation of the existing volume of farm dams across the MDB. Agrecon (2005) digitised the surface area of a large number of farm dams from satellite imagery distributed across the MDB. They derived a digital terrain model (DTM) of the underlying terrain around each of the dams in their sample from contours on available topographic mapping, usually with 5 m contour intervals. The dams in their sample were grouped into classes according to their surface area, and an average surface area and an average dam volume was computed for each class. A regression equation was fitted to the average volumes and surface areas from the classes:

$$V = 0.0008552 \times S^{1.1147}$$

No statistics were provided on the goodness of fit of this equation for either the class averages or the raw data from the individual dams. The main purpose of this equation was not as a direct conversion between surface area and volume but as an indicator of the typical minimum depth of hillside farm dams. This was used to provide a cross check on the volumes estimated from their DTM.

Since the DTM was derived by interpolating from a relatively low resolution contour mapping (compared with alternative methods such as engineering plans or LIDAR), the input data on storage volumes used by this study would be relatively inaccurate. The method of using class averages (in preference to the raw data) and the lack of statistics on goodness of fit compromises the accuracy of this equation for direct estimation of farm dam storage volumes from surface areas.

4.1.4 Western Australia: Department of Water (2006)

Department of Water (2006) obtained survey information from 557 farm dams located in South-West Western Australia. The information relating to dam volume was obtained from the Department of Water’s Water Resources Licensing System (WRLS), and the corresponding dam surface area was digitised from aerial photographs. The source of the WRLS farm dam volume data came from surveys of existing dams where the land owners were required to report the total volume of their dams, potentially enabling an underestimate of the storage capacity of dams. The majority of the dams surveyed were between 10 and 50 ML in capacity. A power law equation was fitted by regression to the data as follows:

$$V = 0.0007 \times S^{1.0709}$$

The regression relationship had an r^2 value in log-log space of 0.82. Department of Water (2006) comments that although this relationship provides a generally good fit overall, it tends to underestimate the volumes of large dams and overestimate the volumes of small dams.

4.1.5 Comparison of methods

The relationships between volume and surface area were compared from each of the four studies. The most important comparison was for dams with estimated volumes less than about 10 ML because current legislation in the states of the MDB (see Chapter 3) limits future development either to dams that are for stock and domestic purposes only or it limits development of new farm dams to a percentage of the estimated runoff from the property. In either case, it is projected that the vast majority of new dams, under the current state policies, will have storage volumes less than 5 ML.

Figure 4-1 compares the relationships from the literature, concentrating on small dams with volumes less than about 10 ML. For dams less than 5 ML in volume, the Sinclair Knight Merz (2004b) and DWLBC (McMurray, 2004) High Demand relationships are almost identical. In this range, the DWLBC (McMurray, 2004) Low Demand equation would give a storage volume approximately 20% lower than either of the other two equations across this range of surface areas. The Agrecon (2005) and Department of Water (2006) relationships sit at the high and low extremes respectively across this range. However, these equations would provide less reliable predictors of farm dam storage volume from surface area because:

- in the case of Agrecon (2005), all of the farm dam volumes were estimated from a relatively low resolution DTM, derived from topographic mapping with contour intervals of around 5 m; and
- in the case of Department of Water (2006), the data comes from farm dams that are in the southwest of Western Australia (well outside of the MDB) and the farm dam volume data came from volumes reported by farmers into the WRLS, which is potentially biased toward underestimation of storage volume for a given surface area.

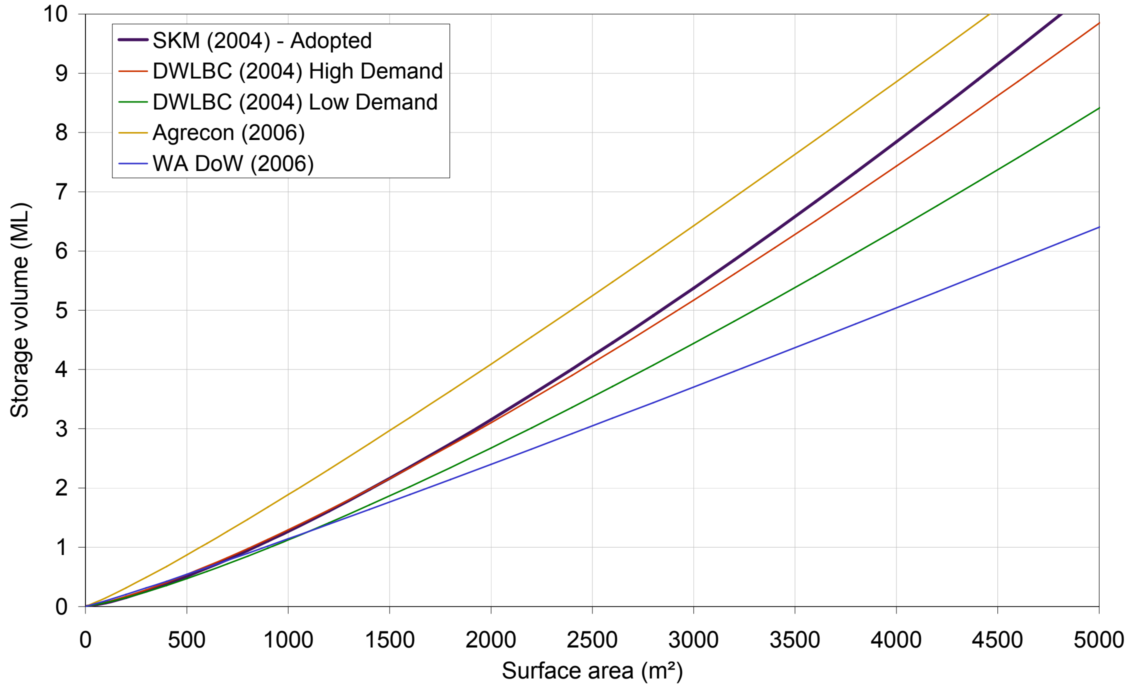
The equation from Sinclair Knight Merz (2004b) was adopted for estimation of farm dam volumes from surface areas for most tasks in this study because:

- it was derived from a relatively large sample of dams;
- for which their surface areas and volumes were estimated from reliable engineering plans or LIDAR data; and
- across the range of primary interest in this study (given that most of the projected new farm dams will be less than 5 ML in capacity) the Sinclair Knight Merz (2004b) relationship is very similar to the two relationships derived by DWLBC (McMurray, 2004).

The adopted equation was:

$$V = 0.000145 \times S^{1.314}$$

This equation was used for estimating the volumes of existing farm dams from spatial data representing their surface areas in New South Wales, Queensland and Victoria. It was also used in all of the CHEAT modelling to estimate the dam surface areas from their storage volumes.



- **Figure 4-1 Surface area versus storage volume relationships from studies in literature, showing only surface areas up to 5000 m² and volumes up to 10 ML**

4.2 Available data on existing farm dam development

The available spatial data on existing farm dam development varies between the states and territories. This section explains the existing farm dam data that was available for this study.

Prior to the commencement of this study in 2007, there had been several projects (ICAMM/SKM, 1999; SKM, 2001) undertaken that had identified farm dam development in several small parts of the New South Wales MDB. However, there was limited metadata available on these studies and considerable inconsistencies in the approaches that had been undertaken to collect the spatial data on farm dams. Geoscience Australia were in the process of collecting data on existing farm dam development across much of eastern Australia in 2007, with progressive delivery of the spatial data through the life of this project. This data set was derived from analysis of satellite imagery and provides a consistent spatial layer of farm dam development across the part of the New South Wales MDB for which it was available. The Geoscience Australia (2007) farm dam layer was used to estimate existing farm dam development for those parts of the New South Wales MDB shown in

Figure 4-2. As there is no harvestable right in the western district of NSW, the existing volume of stock and domestic dams was not estimated.

The best available data on existing farm dam development in the Queensland MDB was from Geoscience Australia (2007). The Queensland MDB data from Geoscience Australia (2007) was collected in two zones, with different specification in each zone on the minimum surface area of farm dam that was to be identified from the satellite imagery. In the eastern Queensland MDB zone (mapped in Figure 4-2), all farm dams were identified that had a surface area greater than 600 m², which would relate to a farm dam storage volume greater than about 0.65 ML. This data set was useful for estimating existing farm dam coverage in this area because it covered virtually all farm dams, from small to large. However, in the western Queensland MDB zone (mapped in Figure 4-2) the minimum dam size identified was 6400 m², or approximately 15 ML. In this zone, only large irrigation dams would be detected and the contributions of smaller irrigation dams and all stock and domestic dams would be ignored. The Geoscience Australia (2007) data for Queensland was therefore used in the eastern Queensland zone to estimate existing farm dam development but the data from the western Queensland zone was not used.

The DWLBC in South Australia have used aerial photography to derive a spatial layer of all farm dams in the Eastern Mount Lofty Ranges. The storage volumes for each dam were estimated from their surface area using the relationship from DWLBC (2004):

$$V = \begin{cases} 0.002S^{1.25}, S < 15000m^2 \\ 0.0022S, S \geq 15000m^2 \end{cases}$$

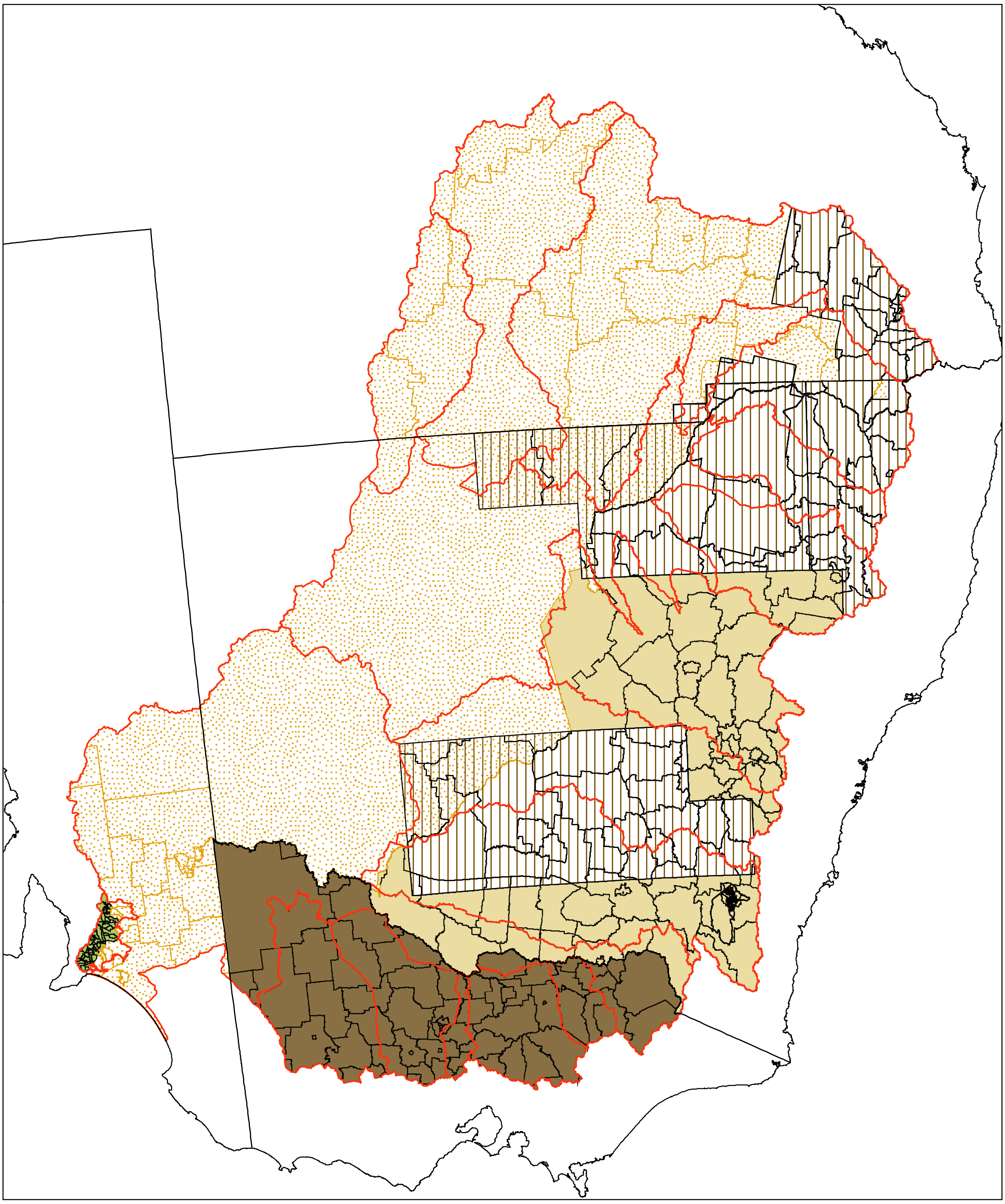
where *V* is the storage volume in ML and *SA* is the surface area of the dam in m².

DWLBC did not supply the spatial layer of farm dams, but instead provided the total volume of existing farm dams for each of the management subcatchments in the Eastern Mount Lofty Ranges. The area covered by the DWLBC supplied information is mapped in Figure 4-2. It was assessed that there was no potential for farm dam development in the rest of the South Australian MDB, so existing volumes of farm dams were not required for any parts of South Australia outside of the Eastern Mount Lofty Ranges.

Existing farm dam development in the Victorian MDB was determined from the 1:25 000 scale topographic mapping layer. In the Vicmap topographic map layer, some dams (including most of the larger dams) are represented as polygons of their perimeter while other dams (including many of the smaller dams) are represented as points in the layer. For the dams represented by polygons, the existing storage volume was estimated for each of the dams using the equation from Sinclair Knight Merz (2004b):

$$V = 0.000145S^{1.314}$$

Storage volumes for those dams represented in the Vicmap data as points were estimated using the method in Sinclair Knight Merz (2004b), which was based on analysis of the Vicmap point dam data for areas with aerial photo or satellite capture of farm dams.



Legend

Source of Farm Dam information

- No estimate required
- Capture of farm dams from satellite imagery by Geoscience Australia (2007)
- Estimated from Current Land Use
- Total volumes supplied for each management subcatchment by DWLBC (2007)
- Capture of farm dams from Vicmap topographic maps

Kilometers

0 50 100 200

Figure 4-2 Sources of data on existing farm dam storage volume.

4.3 Existing spatial distribution of total storage volume of farm dams

Spatial layers that identified the individual existing farm dams were available to the project team with an acceptable resolution and coverage for the Victorian MDB, the eastern part of the Queensland MDB and for parts of the New South Wales MDB for which Geoscience Australia (2007) data was available as at 1 August 2007 (as shown in Figure 4-2). Aggregated totals of existing farm dam storage volume were available by management subcatchment for the Eastern Mount Lofty Ranges. For those parts of the MDB with adequate spatial data on existing farm dam development, the total storage volume of farm dams was aggregated for each SLA.

Apart from Geoscience Australia (2007) data (made available on 1 August 2007), at the time of the study, there was no adequate spatial data on existing farm dam development the western Queensland MDB, and the parts of the New South Wales MDB that were not already covered by the Geoscience data.

Estimates of existing farm dam volumes were required for all of the New South Wales MDB. For NSW, existing farm dam development by SLA was estimated using spatial data on existing landuse in the MDB and the existing farm dam coverage in those parts of the New South Wales MDB with coverage by the Geoscience Australia (2007) data. In SLAs where data was not available on existing farm dams from Geoscience Australia (2007), the volume of farm dams as at 2006 was estimated on the assumption that the density of farm dam development (ML/ha) is related to existing landuse. Appendix A lists the density of existing farm dam development by landuse for properties in NSW that were covered by Geoscience Australia (2007). For SLAs without coverage by the Geoscience Australia data, the total area covered by each landuse was extracted for each SLA and then these were multiplied by the estimated density of existing farm dams to derive a preliminary estimate of the existing total volume of farm dams in the SLA.

A similar method was used in Queensland based on landuse and dams in the Geoscience Australia data (2007) that were less than 140 ML. As the data was not required for further calculations in the Project, the existing volume of dams in Queensland was calculated for reporting regions rather than on an SLA basis.

The total observed or estimated storage volume of farm dams was derived for each SLA in Victoria, New South Wales and the eastern part of Queensland MDB. These total volumes were divided by the area of each SLA and mapped in Figure 4-3 to show the spatial density of existing total farm dam storage volume.

As can be seen in Figure 4-3 the highest density of farm dams follows along the eastern part of the Basin, from central Victoria to SE Queensland. There was no data available for the western part of the Basin; this was adequate as there was no projected change in farm dam volume in the western part of the Basin. The range of farm dam density is from 0 ML/km², to almost 30 ML/km².

SKM

- **Table 4-1 Existing volume of farm dams (GL), listed by data source, reporting region and state.**

Reporting Region	NSW, QLD and ACT			VIC	SA	Total for all states
	Captured from GA 2007 data	Estimated based on landuse	Total for NSW, QLD and ACT	Captured from VicMap topographic image	Supplied by DWLBC	
Paroo	0	0	0	-	-	0
Warrego	0	75	75	-	-	75
Condamine-Balonne	75	188	263	-	-	263
Moonie	7	39	46	-	-	46
Border Rivers	121	35	156	-	-	156
Gwydir	113	0	113	-	-	113
Namoi	98	46	145	-	-	145
Macquarie-Castlereagh	22	219	242	-	-	242
Barwon-Darling	70	28	98	-	-	98
Lachlan	197	63	261	-	-	261
Murrumbidgee	217	134	351	-	-	351
Murray	6	67	73	21	Not estimated	94
Ovens	-	-	-	30	-	30
Goulburn-Broken	-	-	-	105	-	105
Campaspe	-	-	-	35	-	35
Loddon-Avoca	-	-	-	98	-	98
Wimmera	-	-	-	34	-	34
Eastern Mount Lofty Ranges	-	-	-		22	22
Whole of MDB	927	894	1822	324	22	2168

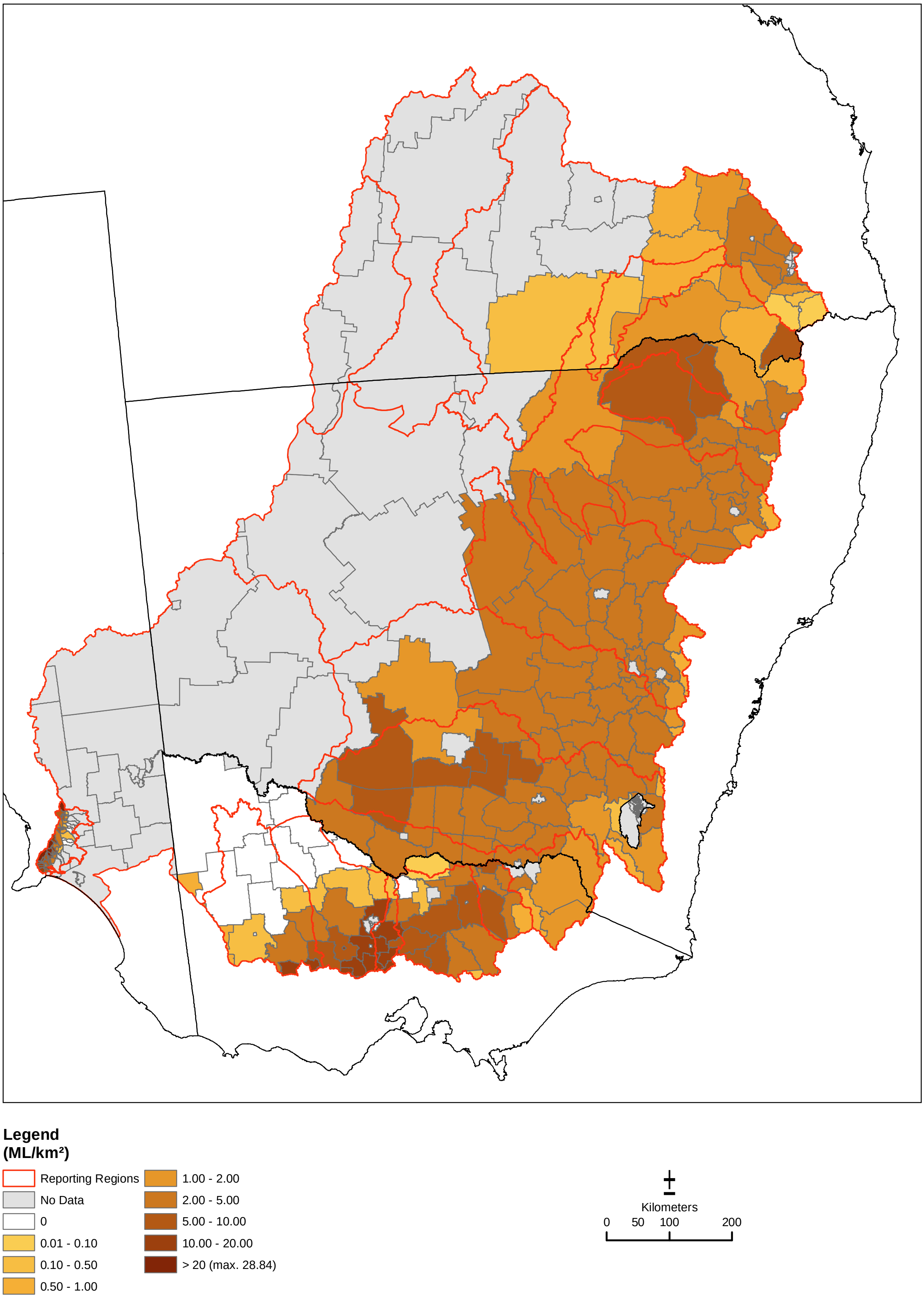


Figure 4-3 Spatial density of existing total farm dam storage volume (in ML/km²) by SLA in Victoria, New South Wales and Queensland and management subcatchment for the Eastern Mount Lofty Ranges.

4.4 Existing spatial distribution of total volume of stock and domestic farm dams

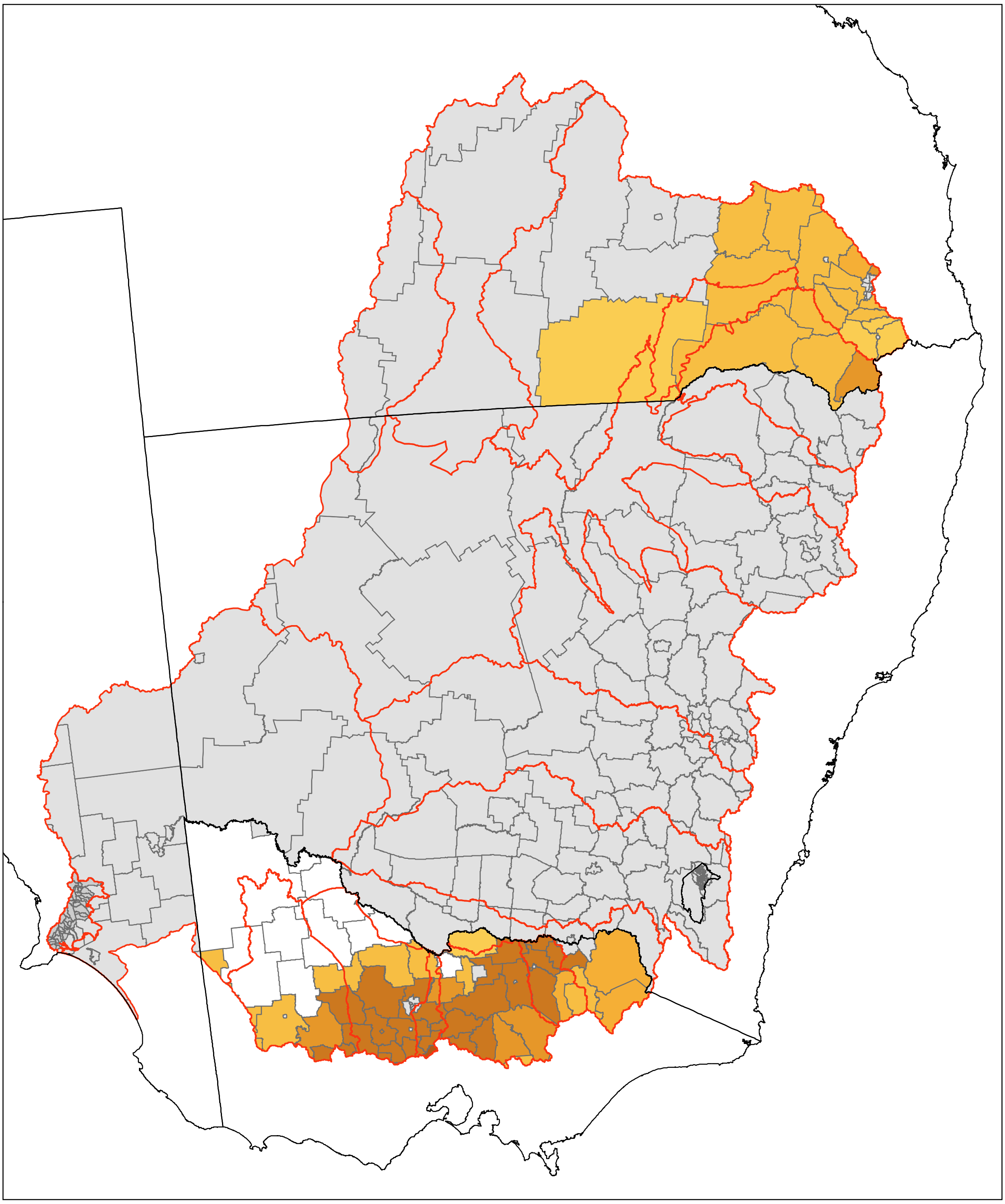
Current legislation in Queensland and Victoria (see Sections 3.3 and 3.5) dictates that the only future farm dam development is for stock and domestic purposes. It was assumed that current requirements for stock and domestic water for existing landholders are met by current surface and groundwater infrastructure, including existing farm dams. Future subdivisions of rural properties may however, result in additional requirements for stock and domestic water, which would include the development of new farm dams.

In order to derive projections of future stock and domestic farm dams, it is necessary to understand the spatial distribution of existing stock and domestic farm dams only. In Victorian studies (Sinclair Knight Merz, 2004a) it has been assumed that all dams less than 5 ML in estimated storage volume are for stock and domestic purposes and all dams greater than 5 ML are for irrigation purposes. A fact sheet on "Planning your farm dam" (Fitzimon, 2006), provides guidance on typical water requirements from farm dams per person and per head of cattle. Based upon the rates provided in Fitzimon (2006) and assuming that a typical stock and domestic farm dam would store two years worth of usage, a 5 ML farm dam would supply a family of four people and approximately 110 head of cattle. On the basis of these studies, all dams less than 5 ML in storage capacity were assumed to be for stock and domestic purposes and all dams larger than 5 ML were assumed to be for irrigation purposes.

Total storage volume of stock and domestic farm dams was derived for each SLA in Victoria and the eastern part of Queensland MDB by adding the volume of only those farm dams that were less than 5 ML in storage volume. These total volumes were divided by the area of each SLA and mapped in Figure 4-4 to show the spatial density of existing stock and domestic farm dam storage volume.

There was no data available on the existing volume of stock and domestic farm dams in New South Wales or South Australia. As with the total farm dam density, the highest densities of stock and domestic farm dams were in central Victoria and SE Queensland.

SKM



Legend
(ML/km²)

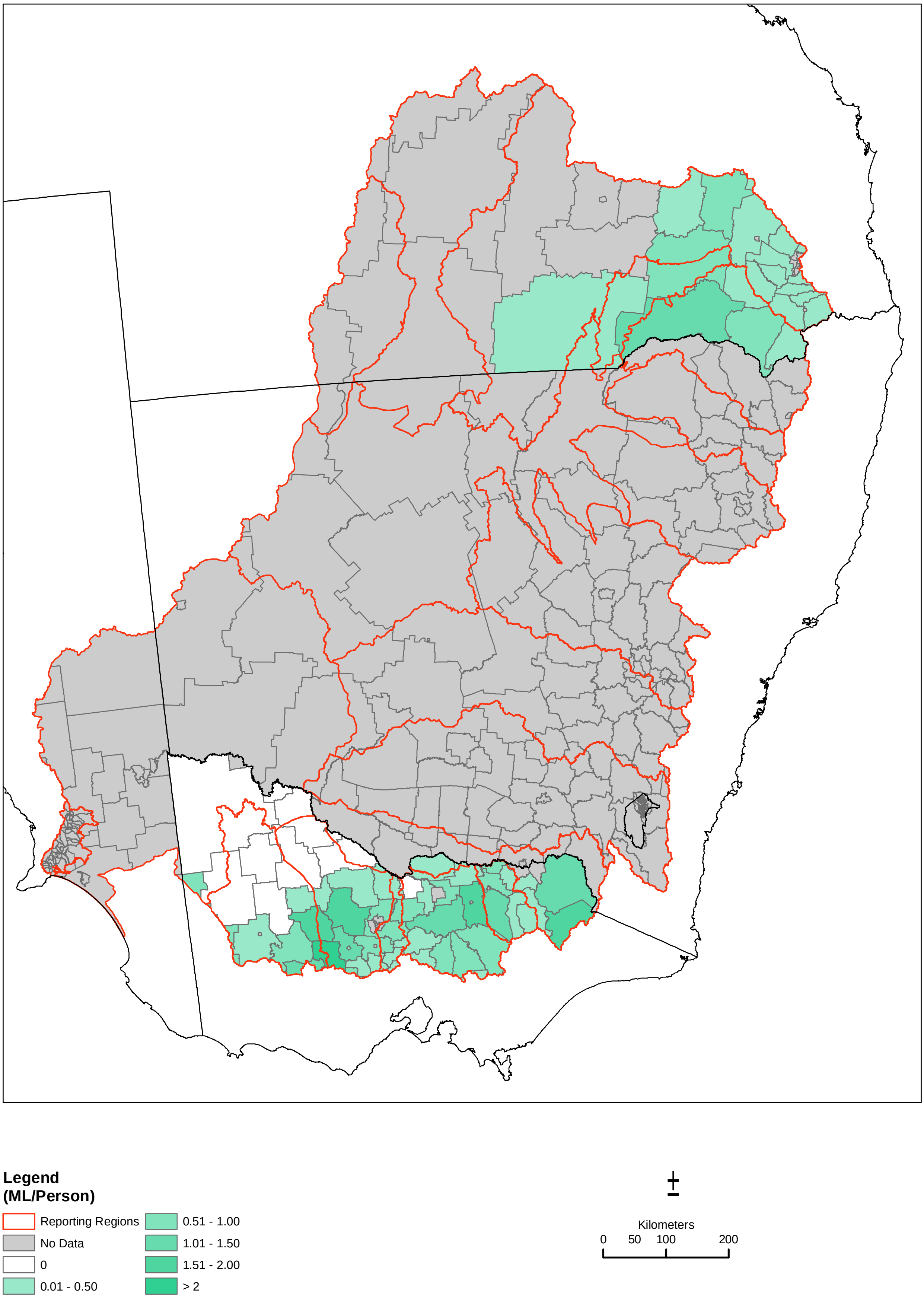
- Reporting Regions
- No Data
- 0
- 0.01 - 0.10
- 0.10 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- > 5.00 (max. 5.98)

Kilometers
0 50 100 200

n **Figure 4-4 Spatial density of existing stock and domestic farm dam storage volume (in ML/km²) by SLA for Victoria and the Eastern part of the Queensland MDB.**

Stock and domestic farm dam density was also related to the density of population. For each rural SLA in Victoria and the eastern part of the Queensland MDB, the volume of stock and domestic farm dams was divided by the population in that SLA, as at the year 2006. Figure 4-5 shows the density of farm dam storage volume per person for these areas.

The average density of stock and domestic farm dam storage per person was 0.48 ML/person across the Murray-Darling Basin, with an average of 0.24 ML/person in Queensland and 0.58 ML/person in Victoria. The maximum volume of stock and domestic storage per person was 2.22 ML/person in the Pyrenees (S) – North SLA. There was no data on the volume of stock and domestic dams in western Queensland, the ACT, or in NSW.



n **Figure 4-5 Density of existing stock and domestic farm dam storage volume per person (in ML/person) by SLA.**

5 Possible methods for projecting future farm dam storage volumes

5.1 Overview of approaches

5.1.1 Three possible approaches

Three projection methods were used to calculate the possible storage volume of future farm dams in the Murray-Darling Basin. These were based on:

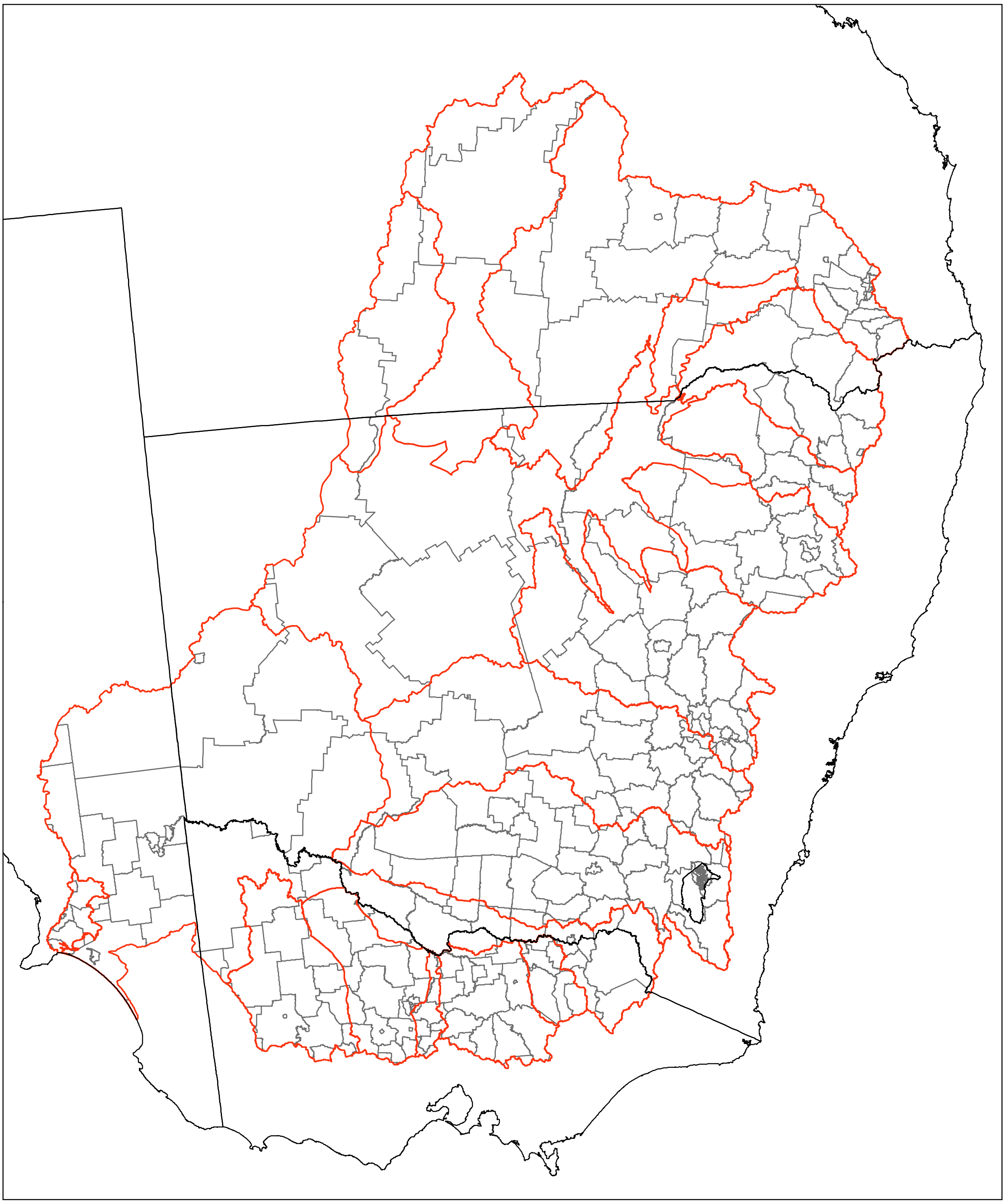
1) A limitation to volume determined by policy restraints.
2) Change in stock and domestic farm dam volume determined by the change in population.
3) Extrapolation and application of historical trend to existing storage volume.

These approaches are detailed in Sections 5.2, 5.3 and 5.4. For each method, a projection was made based on Statistical Local Area (SLA) boundaries as described in Section 5.1.2. The actual method used to project the volume of farm dams for each SLA, reporting region and subcatchment is detailed in Section 6.

5.1.2 Use of Statistical Local Areas as the spatial unit for farm dam projections

The primary spatial units for making projections of future farm dam development were SLAs, as defined by the Australian Bureau of Statistics in ASGC2001. Figure 5-1 shows a map of the SLAs that overlap the reporting regions used in the Murray-Darling Basin Sustainable Yields Project.

SKM



Legend

Reporting Regions

SLA Boundaries (ASGC 2001)

State Boundaries

Kilometers

0 50 100 200

Figure 5-1 Statistical Local Areas (SLA) in the Murray-Darling Basin and reporting regions adopted for this project.

Farm dams, as suggested by their name, are a potential source of water in rural areas. Urban areas are serviced by reticulated water systems that are operated by local government or state government constituted water authorities. It is therefore relatively rare for farm dams to occur in urban areas. For this study, it was assumed that there would be no growth in farm dam volume within urban areas. The distinction between rural and urban areas was made by classifying all of the SLAs that intersected the MDB as either rural or urban. Table 5-1 lists the number of SLAs by state and territory and urban or rural classification. There are a total of 372 SLAs that overlap the MDB, with 225 of these SLAs classified as rural. A list of the SLAs classified into rural and urban is provided in Appendix B.

- **Table 5-1 Number of Statistical Local Areas (SLAs) overlapping with the MDB by state or territory and classification into urban or rural (on the basis of availability of town water supply)**

State or Territory	Number of Statistical Local Areas		
	Urban	Rural	Total
Victoria	18	60	78
Queensland	13	36	49
New South Wales	11	96	107
South Australia	1	30	31
Australian Capital Territory	106	1	107
Total	149	223	372

There were several reasons why SLAs were chosen as the primary spatial unit for projections of future farm dam development:

- Although projections were ultimately required for each of the modelling subcatchments in the MDB, the boundaries of modelling subcatchments were defined progressively over the course of the project by the river system modelling teams as they were applied to their tasks. It was important that there was consistency in application of farm dam development across similar catchments of the MDB and using subcatchment boundaries, which were progressively changing during the project, would have significantly hampered the development of consistent projections.
- Legislation in Queensland and Victoria restricting future development of farm dams to stock and domestic purposes, created an assumed link to future population growth. Population growth projections were most readily available on an SLA basis. It was therefore logical to perform projections of future farm dam development using the same spatial arrangement as the population growth projections were available for.
- In its application for this project, the CHEAT model does not make any particular assumption about the location of individual farm dams within a river system modelling subcatchment. Any

heterogeneity, within a modelling subcatchment, in factors that may affect farm dam density such as variability in population density, landuse, topography or climate would be ignored in application of the CHEAT model. The SLA are similar in scale and shape to modelling subcatchments, with a similar level of heterogeneity in population density, landuse, topography and climate represented within them.

SLA boundaries from 2001 were used for the projection of future farm dam growth because population growth projections from the Australian Bureau of Statistics were made using these boundaries. Population projections produced by the Victorian Department of Sustainability and Environment (2004) were also made on the 2001 ASGC boundaries. The New South Wales Department of Infrastructure, Planning and Natural Resources (2004) used SLA boundaries from ASGC 2003, which differed only marginally from the 2001 boundaries due to changes in local government boundaries. Differences in the boundaries are detailed in Appendix C.

5.2 Policy limitations on future development of farm dams

5.2.1 Australian Capital Territory

As discussed in Section 3.1, the *Water Act 2007* does not explicitly limit farm dams for stock and domestic purposes. There are however limitations on the amount of water that can be extracted for other purposes.

5.2.2 New South Wales

5.2.2.1 Calculation of Harvestable Right

The Harvestable Rights policy in NSW dictates the maximum volume of farm dams that may be constructed on each individual property without the purchase of a water right for that property. The intent of the policy is that the Harvestable Right (HR) represents 10% of the estimated runoff from the property.

The NSW Department of Natural Resources (now Department of Water and Energy) produced a contour map of the HR in ML/ha of land for the central and eastern divisions of NSW. To estimate the HR for each parcel of land, SKM took this contour map and converted it into a grid of HR in ML/ha with a spatial resolution of 1000 metres.

The HR was calculated for each parcel of land in the central and eastern divisions of the NSW MDB by multiplying the area of the parcel by the average of the HR entitlement for those cells that intersected the parcel of land. It is recognized that, under the NSW legislation, a HR farm dam cannot be placed upon a stream that is identified as being of 3rd or higher order (as defined on the relevant scale of topographic mapping). However, one or more farm dams could still be constructed on this parcel of land, up to the HR, on other streams, gullies or depressions. Every parcel of land therefore has a HR entitlement, although it is recognized that in practice it may be difficult to build a HR farm dam on some parcels of land.

Cadastral boundaries for properties in NSW were analysed, and for many properties it is unlikely that farm dams would ever be constructed on that particular parcel of land. The best guide to the likelihood that farm dams would be constructed on a particular parcel of land is its current landuse. For those properties with landuse categories listed in Appendix D, it was assumed that no further farm dams would be constructed. The effective HR for these properties was therefore assumed to be zero. Furthermore, some land parcels are sufficiently small and their resulting HR sufficiently small that it would be uneconomic to construct a farm dam on those parcels of land. The effective HR was therefore assumed to be zero for all parcels of land for which the calculated HR was less than 0.10 ML.

There were 797,000 properties in the central and eastern divisions of the NSW MDB for which the HR was calculated. Of those, approximately 210,000 properties were assumed to have no future development of HR. This left approximately 597,000 properties with a HR of appropriate size that farm dams could be developed and for which the current landuse makes development of future farm dams possible.

Projections of future farm dam development were made in this study for each SLA that intersects with the MDB. The effective HR was therefore calculated for each SLA of the NSW MDB by summing the effective HR for all of those properties that intersected with each SLA. An individual land parcel was deemed to lie within a particular SLA on the basis of the location of the centroid of the land parcel.

The fifth column of Appendix E lists the total effective HR that was computed for each SLA in the NSW MDB.

5.2.2.2 Calculation of Available Harvestable Right

Prior to the implementation of the HR policy in 1999, landholders could develop farm dams on their properties without significant legislative restrictions, from a water resources management perspective, on the volume of farm dams that could be developed (there were dam safety considerations that landholders would have considered, but these would generally only have applied to much larger farm dams).

There are three possible situations that can apply to any individual property:

- The property has existing farm dams, with a total volume that is equal to or exceeds the HR of that property. In this case, there is no further potential for farm dam development (under the HR policy) without the purchase of a water entitlement by the land holder;

- The property has no existing farm dams. In this case, there is potential for the landholder to construct farm dams with a total volume up to the HR, without the purchase of a water entitlement.
- The property has existing farm dams, but their total volume is less than the HR for that property. In this case, the landholder may either enlarge the existing farm dam or dams or construct new dams to bring the total volume of dams up to the HR, without the purchase of a water entitlement.

Geoscience Australia (2007) used satellite imagery to identify and delineate the boundaries of individual farm dams across some parts of NSW, as shown in Figure 5-2. For properties that lie within those boundaries, it is possible to directly compare the existing volume of farm dams with the effective HR. The available HR was computed for those properties as:

- Zero, for those properties with the total volume of existing farm dams equal to or exceeding the effective HR; or
- The difference between the HR and the total volume of existing farm dams for those properties with either no existing dams or with a total volume of dams less than the HR.

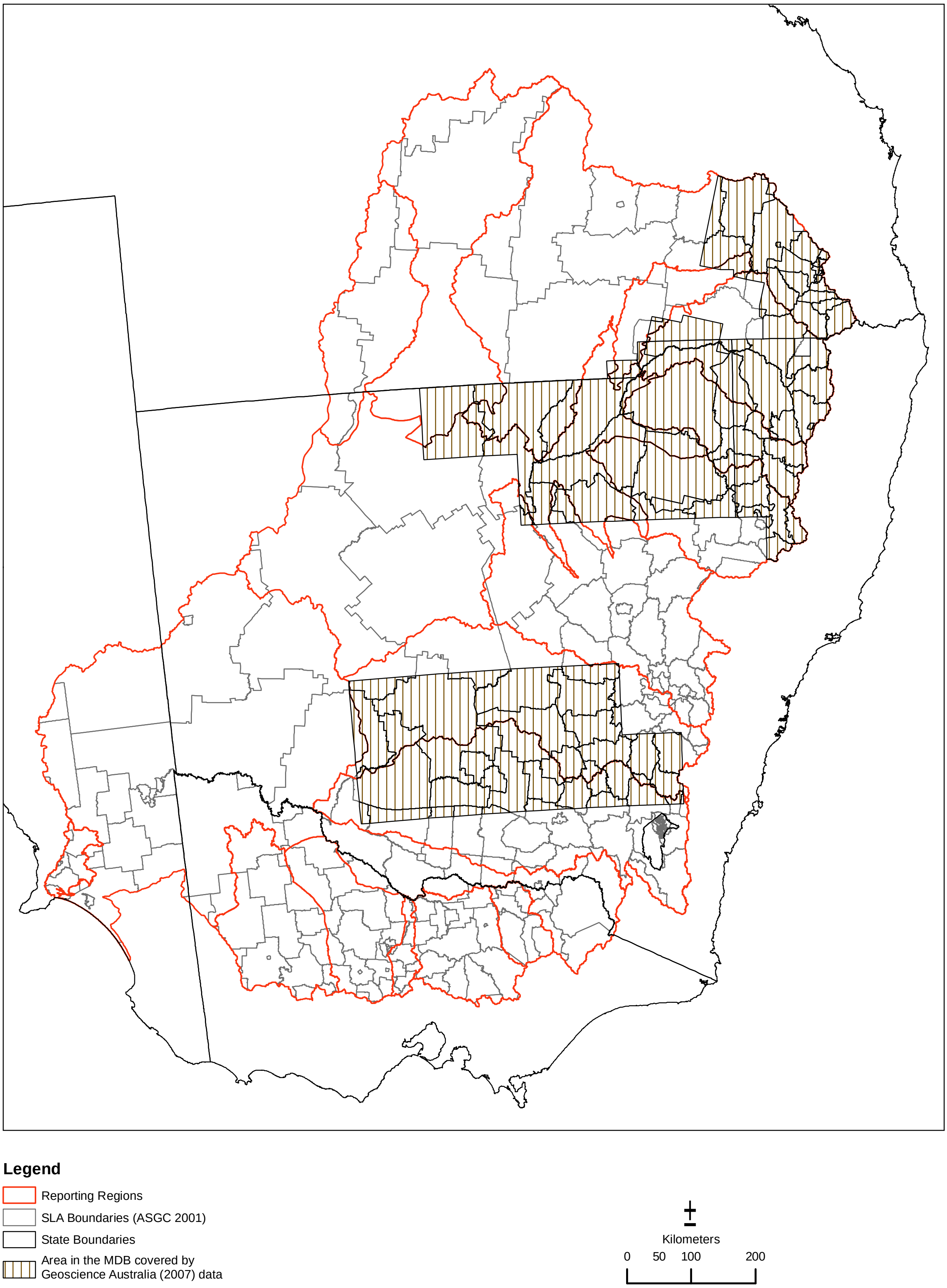


Figure 5-2 Extent of Geoscience Australia (2007) data on existing farm dam development and SLA boundaries for NSW and Qld.

Volumes of existing dams were estimated by taking the surface area of each dam (as detected in the Geoscience Australia, 2007 interim data set) and converting it using the relationship discussed in Section 4.1.

There is a large area of the NSW MDB where it was not possible to directly calculate the available HR for individual properties (see Figure 5-2). It was assumed that landuse would be a reliable indicator of the likelihood that a particular property would either have no existing farm dams, have existing farm dams but with a total volume less than HR, or would have a total volume of existing farm dams equal to or exceeding HR. For properties in NSW that were outside the area of the Geoscience Australia (2007) dataset, the likelihood that a particular property would be within each of the three categories (no farm dams; existing farm dams but with a total volume less than HR; or existing farm dams with a total volume equal to or exceeding HR) was estimated by assuming that it would be the same as other properties with the same landuse that were covered by the GA dataset.

The volume of available HR for each SLA was estimated using the following equation:

$$\Delta V_{SLAi} = \sum_{Properties\ with\ GA\ data} HR_{avail(Calculated)} + \sum_{Properties\ without\ GA\ data} HR_{avail(Estimated)}$$

Expanding out the second term gives:

$$\Delta V_{SLAi} = \sum_{Properties\ with\ GA\ data} HR_{avail(Calculated),\ propertyj} + \sum_{Landuse\ k} \left[p_{Landuse\ k} \left(\sum_{\substack{Properties\ without\ GA\ data \\ of\ Landuse\ k}} HR_{property\ j} \right) \right]$$

where $HR_{avail(Calculated)}$ is the calculated harvestable right for property j. The available harvestable right can only be calculated for those properties with data on existing farm dams from the Geoscience Australia (2007) data. $HR_{avail(Estimated)}$ is the estimated available harvestable right for those properties that do not have data on existing farm dams (i.e. the area of NSW that is not covered by the Geoscience Australia (2007) data set). $p_{Landuse\ k}$ is the proportion of harvestable right that is available for landuse type k. $HR_{property\ j}$ is the full harvestable right for property j.

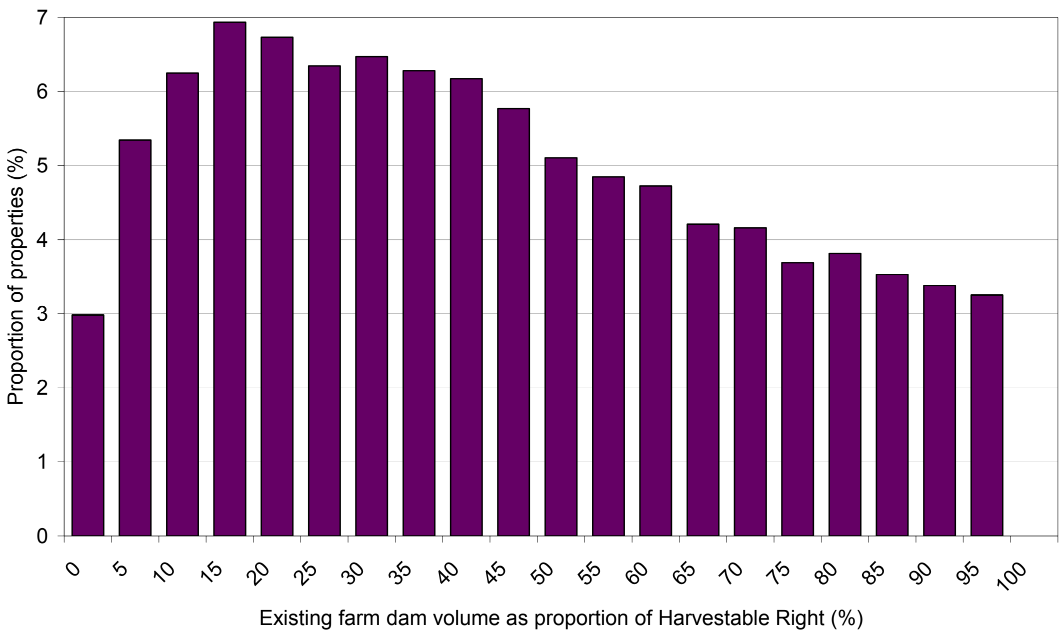
Estimates of proportion of harvestable right available by landuse were made from those properties for which Geoscience Australia (2007) farm dam data was available. Appendix F shows the breakdown by landuse type, of the number of properties in each of the three categories.

Figure 5-3 shows the proportion of properties where the existing farm dam volume is less than the HR. There is a bias toward properties within this category having used between 5% and 55% of their harvestable right. On average, properties within this category will have utilised 40% of their harvestable right and will have 60% of their harvestable right still available.

The estimated volume available as a proportion of HR was given by:

Estimated Proportion of HR available = Proportion of land parcels with no existing farm dams + 0.6 × (Proportion of land parcels with existing farm dams but with total volume less than HR)

The estimated proportion of HR available for each landuse is listed in the last column of Appendix F. The available HR represents the upper limit on potential farm dam development within each SLA and is detailed in Appendix E.



- **Figure 5-3 Histogram of existing farm dam volume as a proportion of harvestable right, for those properties in New South Wales with existing farm dam(s) but where the total volume of farm dams is less than the harvestable right, calculated for those properties with coverage by the Geoscience Australia manmade hydrology data layer**

5.2.3 Queensland and Victoria

Legislation in Queensland and Victoria limits future farm dam development to only those for stock and domestic purposes. It was assumed that current requirements for stock and domestic water for existing landholders are met by current surface and groundwater infrastructure, including existing farm dams. Future subdivisions of rural properties may however, result in additional requirements for stock and domestic water, which would include the development of new farm dams. For projection of future farm dam development in Queensland and Victoria, it was assumed that the increase in the storage volume of farm dams is proportional to the projected increase in rural population. Projected increase in farm dams based upon population increase is discussed in Section 5.3.

5.2.4 South Australia

As discussed in Section 3.4, there is currently a moratorium on future development of farm dams in the Eastern Mount Lofty Ranges whilst a water management plan is in preparation. Once the water management plan for the Eastern Mount Lofty Ranges is released, development of farm dams may once again be permitted (subject to limitations). It is also expected that the water management plan will place limitations on the area of plantation forestry development in the Eastern Mount Lofty Ranges.

In the absence of a publicly released water management plan, some assumptions were made in this project on the nature of future policy for the purposes of projecting future farm dam development to the year 2030. The assumed policy in regard to farm dams and plantation forestry was based upon the policy that was in place in the Eastern Mount Lofty Ranges prior to the commencement of the current ban and informal discussions with the Department of Water Land and Biodiversity Conservation (DWLBC).

It was assumed that DWLBC will implement their policy such that the combined farm dam and plantation development will be limited for each of the management subcatchments. The boundaries for the management subcatchments were supplied in a spatial layer by DWLBC. The DWLBC management subcatchments are smaller (in most cases) than the modelling subcatchments that have been adopted for the MDB project, with one or more management subcatchments combining to form one of the subcatchments adopted for modelling in this project.

DWLBC provided, for each management subcatchment:

- The estimated volume of runoff (in ML) for the winter season (May through November); and
- The estimated total volume of existing farm dams.

For this project, the following assumptions were made about the future South Australian Government policy in regard to farm dam development and development of future plantation forestry in the Eastern Mount Lofty Ranges:

- The total volume of water available for extraction on an annual basis for each individual property, would be the volume of water such that if all of the water was taken by farm dams, the total storage volume of farm dams would be equal in volume to 30% of the estimated volume of runoff from that property for the May through November season; and

- The total volume of water available for extraction on an annual basis for each individual property, by farm dams, plantations or a combination of both, is 30% of the estimated volume of runoff from that property for the May through November season; and
- For farm dams, the volume of water available for extraction in each year is deemed to be equal to the total storage volume of dams on that property;
- Except that, where the total storage volume of farm dams within a management subcatchment plus the cumulative annual volume of water extracted by new plantations within the same management subcatchment exceeds 30% of the estimated volume of runoff from the subcatchment for May through November, no further farm dams or plantations may be developed on any properties within that management subcatchment.

The process of determining the policy limit for projected storage volume of future farm dams and the projected future area of plantations for each modelling subcatchment was as follows:

1) DWLBC (Alcorn, 2007 pers. comm.) provided a list of runoff volume for the May through November period for each of the management subcatchments in the Eastern Mount Lofty Ranges.
2) The allowable storage volume of farm dams was computed for each management subcatchment as 30% of the May through November runoff volume.
3) The existing storage volume of farm dams (supplied by Alcorn, 2007 pers. comm.) was compared with the allowable storage volume of farm dams in each management subcatchment. The upper limit of additional farm dam development, in the absence of plantations, was the difference between these two volumes.
4) Existing areas of plantations were defined from spatial data on woody vegetation provided by the Australian Greenhouse Office (2006) and Bureau of Rural Sciences (2005). The expected reduction in mean annual runoff resulting from existing plantations was estimated for each management subcatchment by using the difference between the Zhang *et al*. (1999) curves for forested and non-forested catchments. The Zhang curves were computed by using the mean annual rainfall for each of the management subcatchments.
5) The upper limit of additional farm dam development, considering existing plantations but not new plantations, was computed by deducting the reduction in mean annual runoff from existing plantations (step 4) from the upper limit of additional farm dam development in the absence of plantations (step 3).
6) The upper limit of additional plantation development area, considering existing farm dams and plantations but not new farm dams, was computed by dividing the volume limit of additional farm dams (from step 5) by the difference between the Zhang *et al*. (1999) curves for forested and non-forested catchments.

7) This upper limit on additional farm dam development area for each management subcatchment (from step 6) was supplied as a spatial layer to the team projecting and estimating future plantation impacts as a constraint on the location and area of future plantations in the Eastern Mount Lofty Ranges.
8) Bureau of Rural Sciences projected that there would be an increase of 2000 ha of plantations in the Eastern Mount Lofty Ranges by 2030. The team projecting future areas of plantation impacts provided a projection of which management subcatchments this additional 2000 ha would occur within (subject to the constraints provided in step 7).
9) The projected impact on mean annual flow of the new plantation area was computed by multiplying the areas of plantations (supplied in step 8) by the difference between the Zhang *et al*. (1999) curves for forested and non-forested catchments.
10) The upper limit of additional farm dam development, considering existing farm dams, and existing and new plantations, was computed by deducting the projected impact of additional plantations on mean annual flow (from step 9).

Appendix G details the calculation of the upper limits on future farm dam development and future plantation forestry area for each of the management subcatchments in South Australia. Upper limits on future farm dam development were calculated for each modelling subcatchment by adding the upper limits for the management subcatchments that comprised each of them. Figure 5-4 maps the upper limit on future farm dam development by modelling subcatchment.

SKM

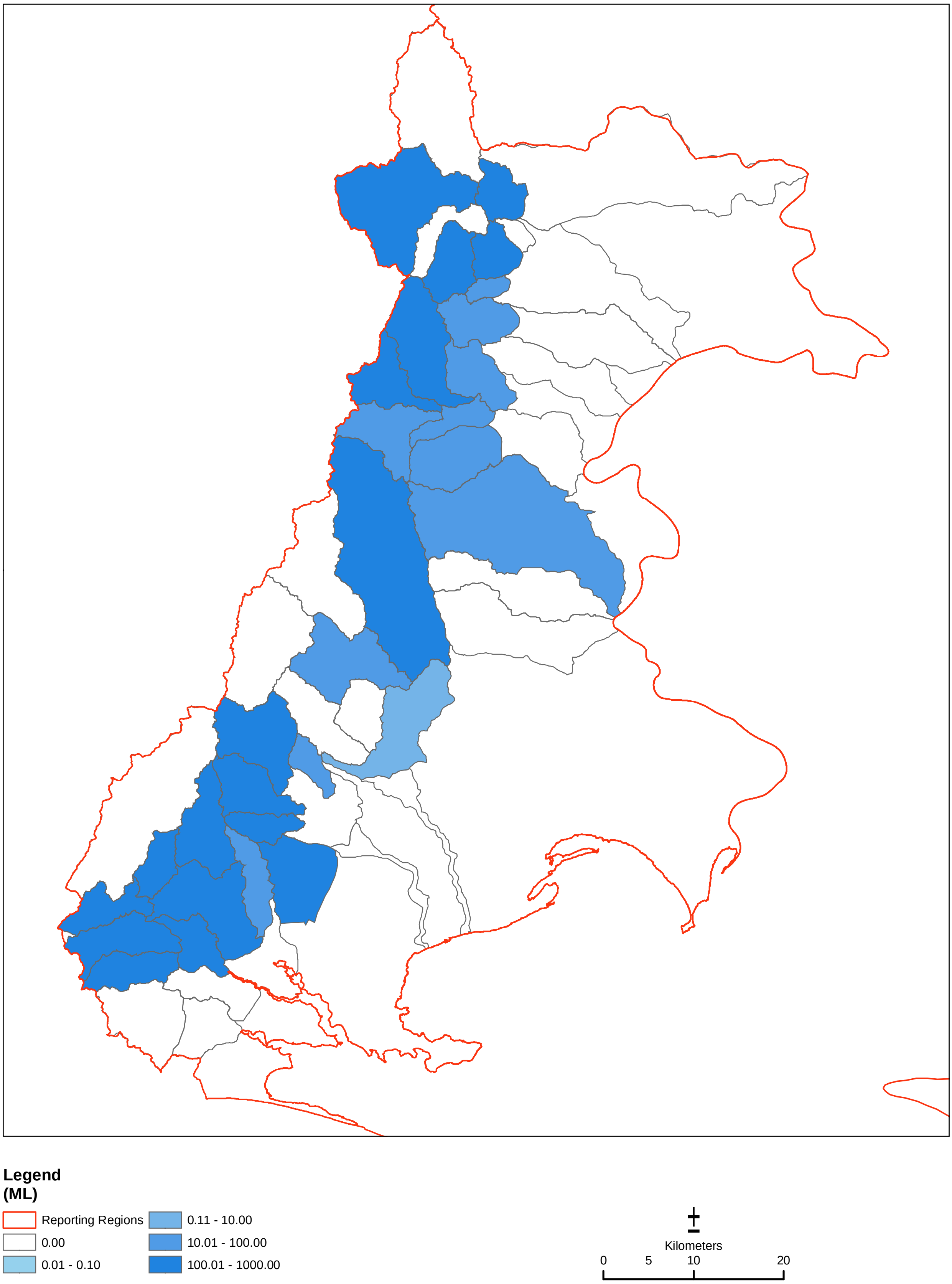


Figure 5-4 Upper limit on future growth in farm dam volume for modelling subcatchments in the EMLR, based on assumed farm dam development policy, existing farm dam volumes and existing and projected areas of plantation forestry.

It was assumed that the limitation on storage volume of farm dams would be applied to all properties within a management subcatchment or for individual properties, which ever of these two limits was lower. This policy would place an upper limit on the total volume of farm dams that could be placed on each property within the Eastern Mount Lofty Ranges, according to the product of the property area and 30% of the expected May to November runoff.

It was assumed landholders with no existing farm dams or plantations would develop the majority of farm dams. They would take up their full entitlement to farm dams in random order within each management subcatchment. The resulting histogram of farm dam sizes for each management subcatchment would have the same shape as the histogram of upper limits of available farm dam volume by property but it would be scaled so that the overall projection would be limited for each modelling subcatchment (as discussed in Section 5.2.4). Separate histograms were derived for each management subcatchment.

5.2.5 Limitations and uncertainties in applying policy limitations on future farm dam development

As discussed above, there is different legislation and policy that applies to future farm dam development in each of the states and the Australian Capital Territory.

The upper limits on projections of farm dams have been based upon a continuation of the current legislation and policy in each jurisdiction until 2030. Legislation and policy are at the behest of governments and it is possible that they may change over the course of the next two decades. In particular, the Australian Government's National Plan for Water Security (Howard, 2007), may result in the Commonwealth Government passing legislation that would regulate future development of farm dams, which would supersede the existing state and territory legislation. It is very difficult to project the changes that may occur to policies in regard to farm dams over the forthcoming decades and the effects that these changes may have on projected increases in farm dam development.

5.3 Projection of future development based upon growth in rural population

5.3.1 Approach

As discussed in Section 5.2.3, projected future farm dams in Queensland and Victoria are restricted to stock and domestic dams and it was assumed for this study that the rate of growth in farm dam volumes in these states would be proportional to the rate of population growth. Although legislation and government policies for farm dams in New South Wales and South Australia allow farm dams for irrigation purposes, due to rural subdivisions there may still be a relationship between future population growth and future growth in the volume of farm dams, particularly in areas within commuting distance of urban areas.

The approach taken to derive a population based projection of future farm dam development was as follows:

1) Projections of future population growth, for the period 2006 – 2030, were obtained for each rural SLA intersecting the MDB from the Australian Bureau of Statistics (ABS) and from the planning departments in each state and territory.
2) The maximum projected population for the period between 2006 and 2030 from the population projection series for each rural SLA was calculated. If the projected population in an SLA increases monotonically, then this will be the projected population for 2030 but if there is a period of projected population decline the maximum projected population may occur in a year prior to 2030. The maximum was adopted because it was assumed that subdivision and hence farm dam development would occur to meet the maximum population but that farm dams would not be removed once the population in an area started to decline.
3) The maximum population from the period between 2001 and 2006 was adopted as the recent maximum population for each SLA.
4) The projected population increase was computed for each SLA as the difference between the projected maximum for 2006 to 2030 and the observed maximum for 2001 to 2006. The population projections (steps 1 to 4) above are discussed in Section 5.3.2.
5) A projected rate of stock and domestic farm dam development per person was adopted for each SLA, based upon current densities of stock and domestic farm dams per person in different parts of the MDB.
6) The projected increase in population was multiplied by the projected rate of stock and domestic farm dam development per person to produce a projection of future stock and domestic farm dam development in each SLA.

Projection of future stock and domestic farm dam development in each SLA steps 5) and 6) above are discussed in Section 5.3.3. Potential uncertainties in the projections of farm dam development based on population change are discussed in Section 5.3.4.

5.3.2 Projections of future population change

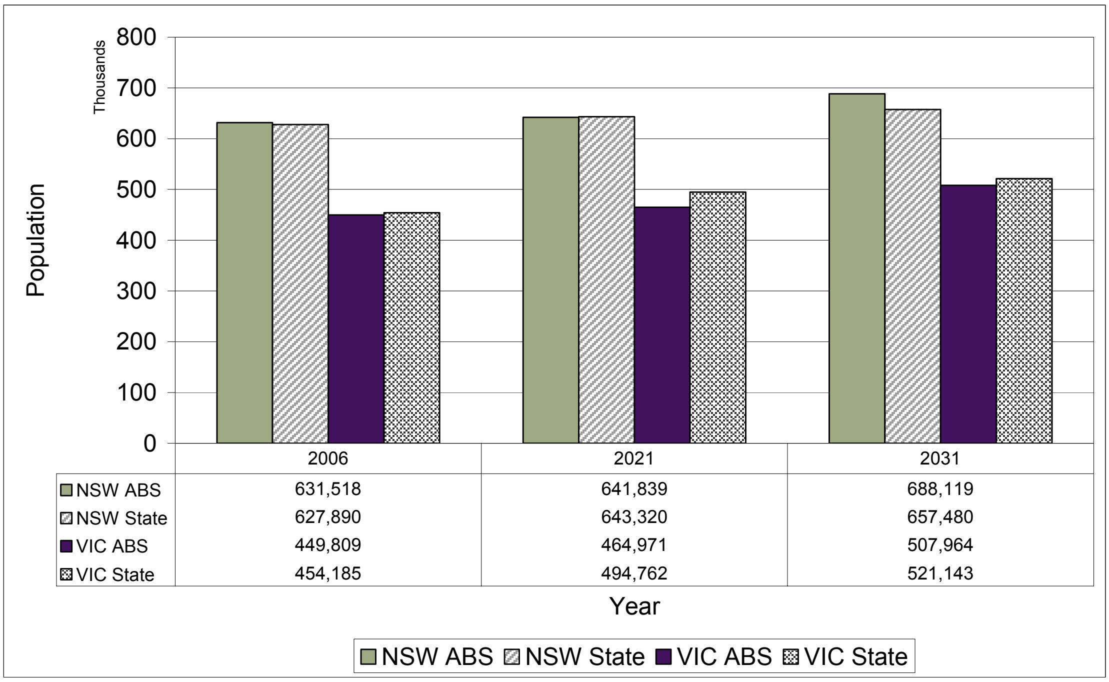
Data was available from the ABS and from each state or territory. The Australian Bureau of Statistics (ABS) developed a set of population projections for each statistical local area (SLA) in Australia based on the 2001 census, according to assumptions agreed to by the Department of Health and Ageing (Australian Bureau of Statistics, 2004). The projections were based on the 2001 ASGC boundaries, and were available annually from 2002 – 2022. The ABS data was extended to 2030 by calculating a growth rate over the period 2018 – 2022 and extrapolating that forward for the period from 2022 to 2030.

For both Queensland and the ACT, the available projections were not for SLAs and they were not available for the entire period of interest. In the ACT, population projections were available for each suburb and district from 2004 – 2014 (Stakelum, 2004). In Queensland, the projections were available from the Department of Local Government and Planning (2003) for Local Government Areas from 2001 – 2026. In SA, the projections were available from Planning SA (2007) for the period 1996 – 2016 for SLAs. For each of these areas, the ABS projections were used as a consistent alternative that was available for a reasonable period.

For NSW, projections were available from the Department of Infrastructure, Planning and Natural Resources for the period 2001 – 2031 based on SLA boundaries (Department of Infrastructure, 2004). In Victoria, the Department of Sustainability and Environment have published the *Victoria in Future 2004 – population projections* (Department of Sustainability and Environment, 2004). This publication includes population projections for SLAs annually from 1991 – 2031.

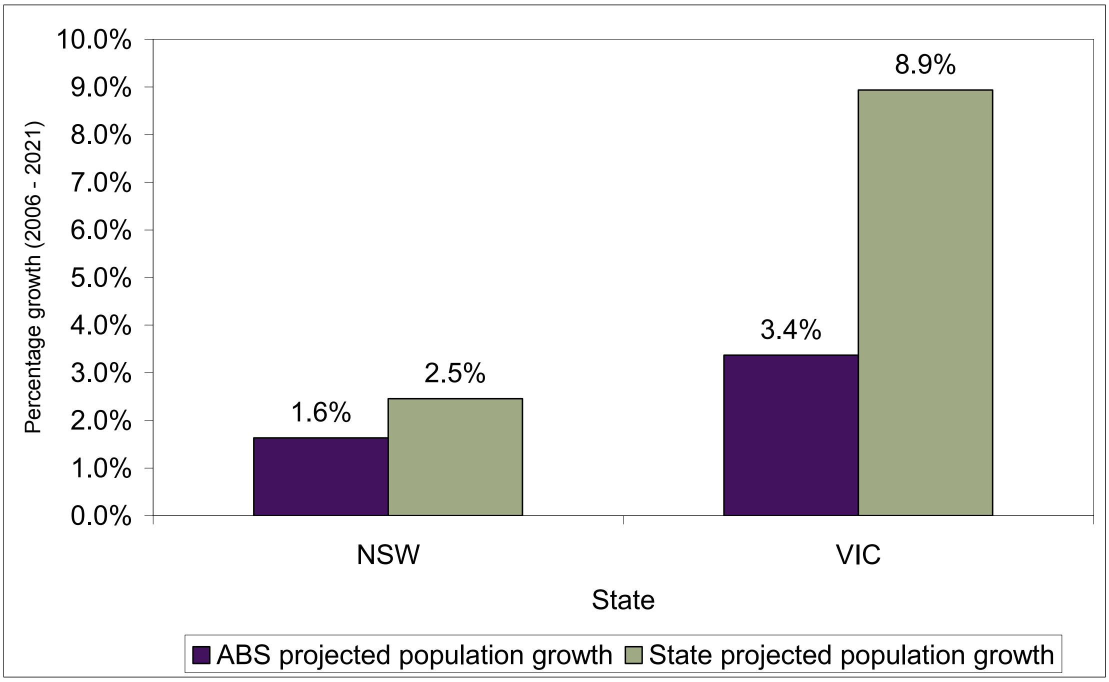
For NSW and Victoria, a comparison of the ABS and state data was required as either could potentially provide appropriate population projections. Figure 5-5 illustrates how similar the population projections were for 2006 and 2021. The figures for 2031 are the actual state projections and the extended ABS data. As the ABS data was only available up until 2022, more detailed analysis was carried out based on the years 2006 and 2021 (Figure 5-6). On a state-wide basis, the growth in the population in NSW was very similar for both the ABS (1.6%) and State (2.5%) projections. For Victoria, the State projection was higher (8.9%) than the ABS projection (3.4%).

The population growth characteristics in each SLA are slightly different. As Figure 5-7 illustrates for NSW, there was a slight bias in the SLA populations, with the State projections slightly higher than the ABS projections on an SLA by SLA basis. This trend is more pronounced in the Victoria projections (Figure 5-8).

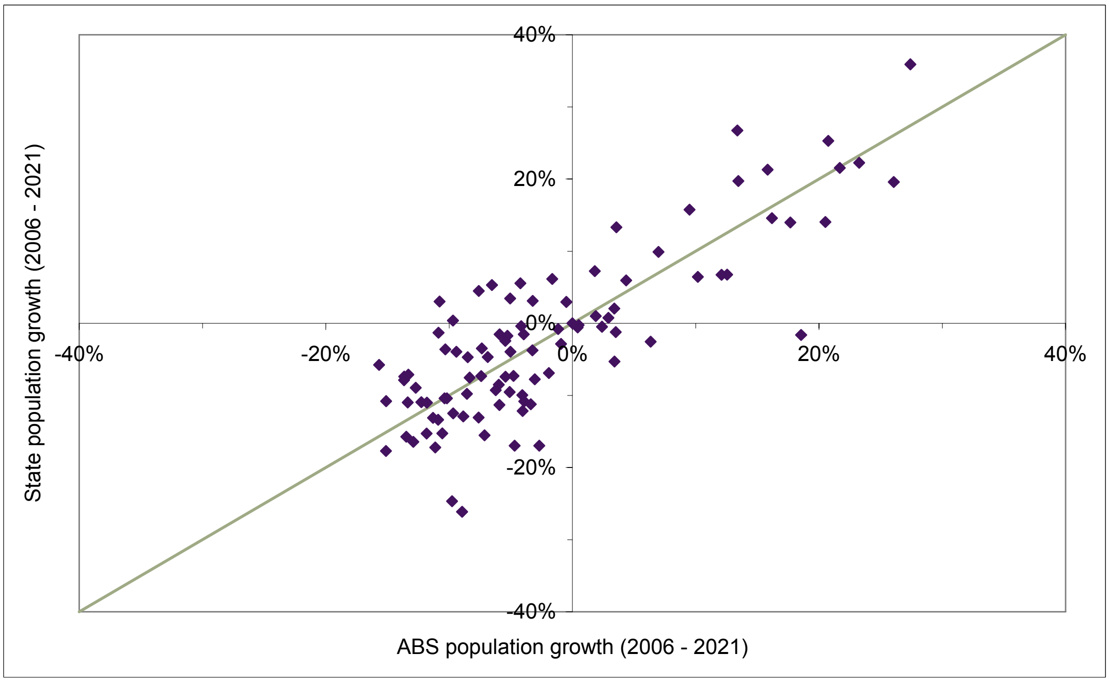


	2006	2021	2031
NSW ABS	631,518	641,839	688,119
NSW State	627,890	643,320	657,480
VIC ABS	449,809	464,971	507,964
VIC State	454,185	494,762	521,143

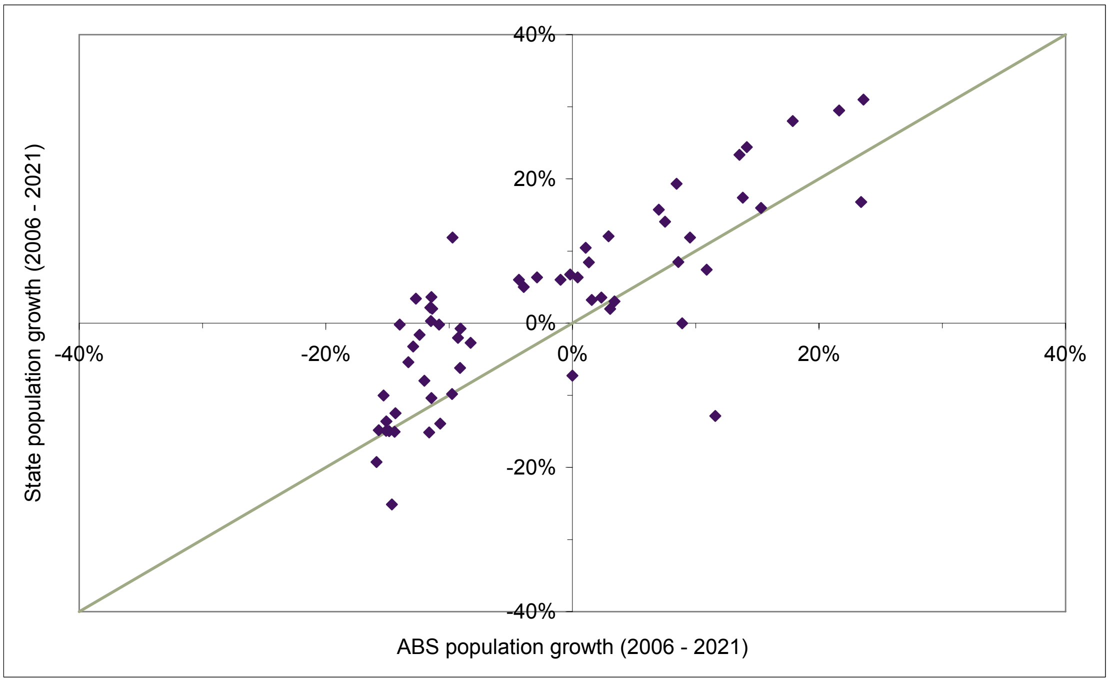
- **Figure 5-5 Summary of ABS and State rural population projections for New South Wales and Victoria.**



- **Figure 5-6 Comparison of ABS projected rural population and NSW and Vic State projected rural population over the years 2006 – 2021**



- **Figure 5-7 Comparison of ABS and State projected population growth for each rural SLA in New South Wales over the years 2006 – 2021**



- **Figure 5-8 Comparison of ABS and State projected population growth for each rural SLA in Victoria over the years 2006 – 2021**

5.3.2.1 Summary of adopted SLA population projections

The ABS projections of population were adopted for rural SLAs in the Australian Capital Territory, Queensland and South Australia, for slightly different reasons in each case:

- In the Australian Capital Territory, the projections of Stakelum (2004) were only for the suburbs of Canberra and there was no population projection provided for the rural “Remainder of ACT” SLA;
- In Queensland, the projections from the Queensland Department of Local Government and Planning (2003) were only provided for each local government area and could not be easily separated into the individual SLAs;
- In South Australia, the projections from Planning SA (2007) only extended to 2016, which would have required a long period of extrapolation to provide projected population to 2030.

For New South Wales and Victoria, the respective states’ projections and ABS projections were very similar, although in both states, the states’ projections anticipated higher population growth. In the analysis of farm dam demands, a higher population growth results in a more conservative estimate; this, in combination with the longer available record of state projections, meant that the state projections were more appropriate for use for New South Wales and Victoria.

The maximum projected population for the period between 2006 and 2030 was extracted from the population projection series that was adopted for each rural SLA. If the projected population in an SLA increases monotonically, then this will be the projected population for 2030 but if there is a period of projected population decline the maximum projected population may occur in a year prior to 2030. The maximum was adopted because it was assumed that subdivision and hence farm dam development would occur to meet the maximum population but that farm dams would not be removed once the population in an area started to decline.

5.3.3 Projection of future development in farm dams based upon population projection

In estimating the future volumes of farm dams, based on population growth, it was assumed that the current volume of stock and domestic farm dams per head of population for a particular part of the MDB will be replicated in the future. Existing densities of stock and domestic farm dams per head of population for each SLA in the MDB are discussed in Section 4.4.

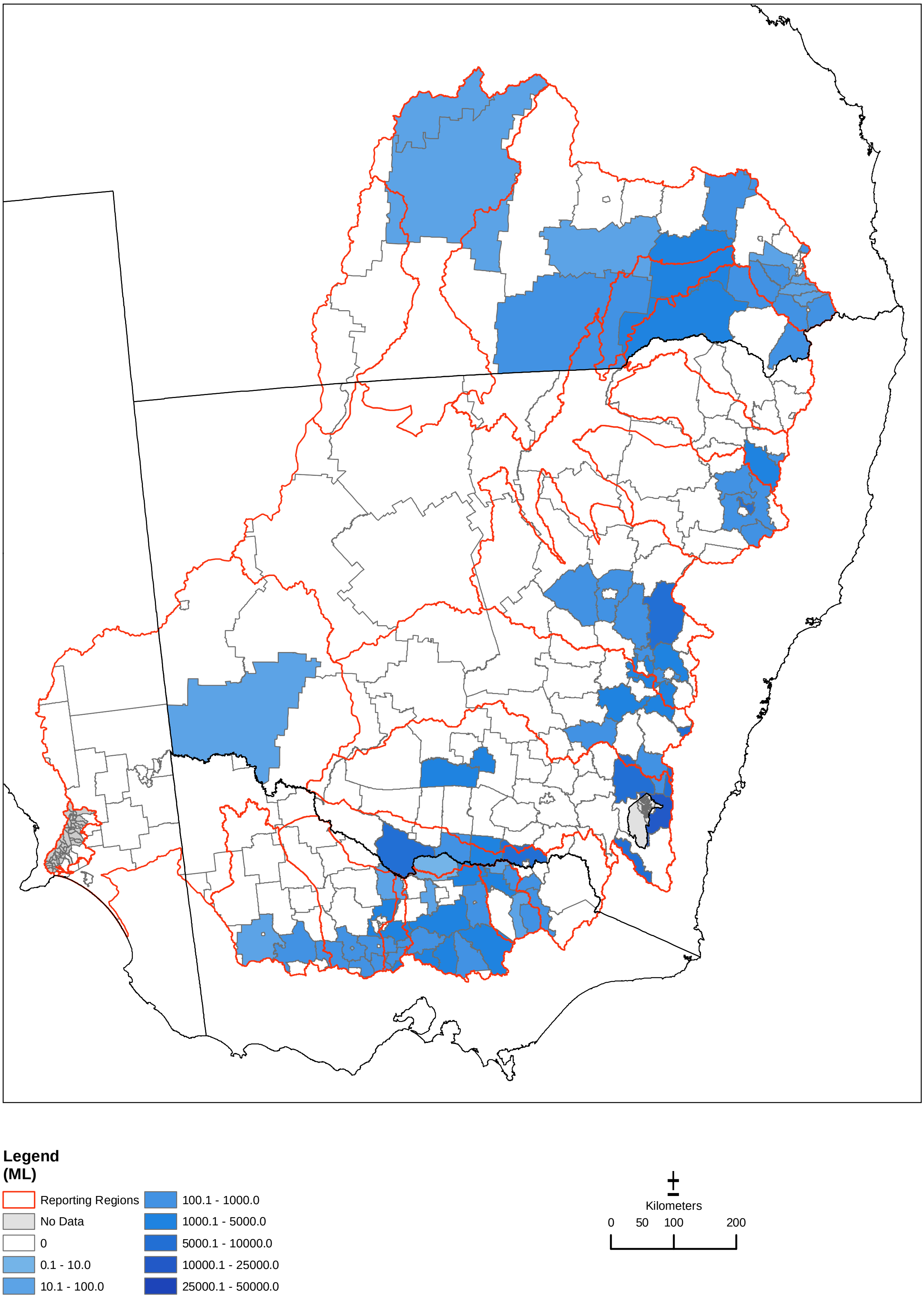
In New South Wales and Victoria, there was good quality spatial data across much of the MDB . It was therefore possible to derive a reliable estimate of the existing storage volume of stock and domestic farm dams per head of population for each SLA in both New South Wales and Victoria. For these two states, the projected increase in farm dam volumes (due to population change) was produced by multiplying the maximum projected increase in population to 2030 for the SLA by the existing rate of stock and domestic farm dam volume per person for that SLA.

In Queensland, good quality spatial data on stock and domestic dams was only available from the Geoscience Australia (2007) data set in the eastern part of the Queensland MDB. It was not possible therefore to use a “local” estimate of existing stock and domestic farm dam volume per person that was derived separately for each SLA. The average rate for all SLA in Queensland was 0.32 ML of stock and domestic farm dams per person. The Queensland average rate was adopted for projection of future farm dam volumes for all SLA in Queensland.

No spatial data on individual existing farm dams was made available to the project team for South Australia, but only total volumes for each management subcatchment in the Eastern Mount Lofty Ranges. The projected increase in population for the Eastern Mount Lofty Ranges for the period 2006 to 2030 is approximately 30%. The population based increase that was therefore applied in the Eastern Mount Lofty Ranges was 30% of the existing total storage volume of farm dams in each management subcatchment.

Figure 5-9 shows a map of the projected additional storage volume to 2030 for the SLA or management subcatchments (as discussed above) based upon projected increases in rural population. Figure 5-10 shows the density of additional dams (in ML/km^2) that would result in the SLA or management subcatchments from this same projection method.

These projections were based upon an assumption that future farm dam development is tied only to increases in population and that increases in farm dam storage volume are reflected by current rates of stock and domestic dam volumes per head of population. There are policy limitations (as discussed in Section 5.2 above) in some parts of the MDB that would cap the projected growth to a lower level. Legislation in Queensland and Victoria that restricts future farm dam development to stock and domestic use only makes this population based projection the most appropriate. It is less applicable in New South Wales and South Australia where current policies do not explicitly link future development to stock and domestic purposes only.



n **Figure 5-9 Projected additional farm dam storage volume to 2030 (ML) for a projection based only upon increases in rural population.**

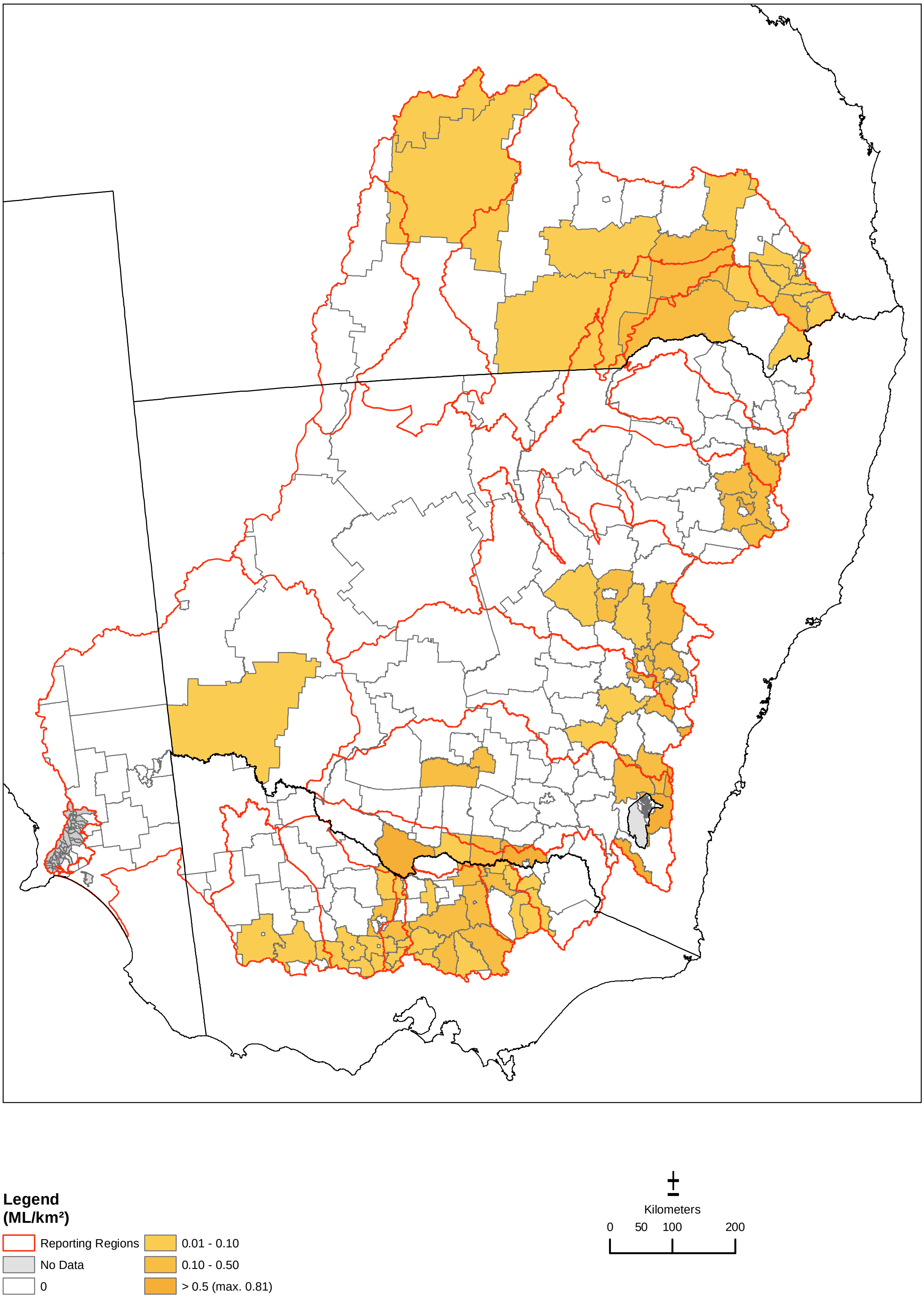


Figure 5-10 Projected density of additional farm dam storage volume to 2030 (ML/km²) for a projection based only upon increases in rural population.

SKM

5.3.4 Limitations and uncertainty in projections based upon population

All population projections are developed based on a number of assumptions that are integral to the magnitude of the final numbers. Generally, each state has a number of projection series that reflects the uncertainty inherent in the assumptions that are made about future births, deaths and migration rates.

The Australian Bureau of Statistics (ABS) (2007) has compiled three main series, A, B and C. The three series provide an indication of the overall uncertainty in the projections, and the B series is generally a moderate series with series A generally higher and series C generally lower. The projections were available over the period 2004 – 2051 and the state/territory series were separated into two areas, the capital city area and the balance of the state. The balance of the state was used to illustrate rural population growth as related to farm dams; however the balance of state population also includes growth in regional centres. A summary of the population growth in the balance of each state is presented in Table 5-2. It indicates that population growth could be twice that projected by Series B or could be less than half.

Despite this uncertainty, the B series projections were most suitable for use in this assessment. The annual SLA population projections as provided by the ABS were developed using the B Series assumptions. And the State projections used for NSW and Victoria were based on a series that is also designated as "B", which had underlying assumptions that were similar to but not exactly the same as the B Series projections from the ABS.

- **Table 5-2 Percentage growth in projected population from 2006 – 2031 in each series for the balance for each state. Note that the Australian Capital Territory projection includes the Canberra population.**

Area	Series A	Series B	Series C
Balance of New South Wales	29%	19%	10%
Balance of Queensland	56%	41%	28%
Balance of South Australia	3%	2%	5%
Balance of Victoria	9%	11%	16%

5.4 Projection of future development based upon extrapolation of historical observed trends in farm dam development

Several studies have been conducted on the historical trend in volumes of catchment farm dams in Australia. There have been several studies for individual catchments and the more recent Agrecon (2005) study, which used small sample squares spread across the MDB, as listed in Table 5-1.

The individual studies are analysed in Section 5.4.1, to identify a possible linkage between trends in farm dam development and population change. It is possible that studies into historical trends in farm dam development have been biased toward those catchments that have had particularly high rates of farm dam development and this may limit the applicability of any findings from those catchments more broadly across the MDB. All of these studies considered farm dam data from prior to 2001 and the rates of growth identified are likely to have slowed under the farm dam policies that have been implemented by the states in more recent years.

The data from the Agrecon (2005) is reanalysed in Section 5.4.2 to identify trends in farm dam development that are from more recent years (post-1999) and with broader geographic distribution, which may then be applicable for projection of the future trend to 2030.

5.4.1 Previous studies into historical trends in farm dam development

As listed in Table 5-3, there have been four studies into historical farm dam development in individual catchments, located either in or near the MDB. Data on the total number and volume of farm dams (as available) was obtained from each of these studies. Where possible, historical population data was obtained across the same time span for the SLA that each catchment lies within. The intention was to determine whether there was a correlation between the rate of growth in total farm dam storage volume in each catchment and the rate of change in population for the SLA that the catchment lies within.

SKM

Table 5-3 Previous studies into historical trends in farm dam development

Study Author and Date	Catchment	Comments on study
Agrecon (2005)	All of MDB	Eighty-four by 7x7km samples spread across MDB with mean annual rainfall > 500 mm. Generally four dates for each sample from late 1980's to 2004.
Sinclair Knight Merz (2003) and GHD (1987)	Moorabool River	Located just outside of MDB, immediately to south of Loddon Reporting Region. Six dates from 1970-2001.
Integrated Catchment Assessment and Management Centre of the Australian National University and Sinclair Knight Merz (1999)	Swamp Oak Creek @ Limbri	Located in Border Rivers Reporting Region (NSW). Three dates from 1971-1990.
ICAMC (ANU) and SKM (1999)	Warrah Creek @ Old Warrah	Located in Namoi Reporting Region. Three dates from 1943-1990.
ICAMC (ANU) and SKM (1999)	Yass River @ Gundaroo	Located in Murrumbidgee Reporting Region. Three dates from 1976-1998.

5.4.1.1 Historical population estimates for comparison

Historical population estimates were only available for SLAs, rather than for these specific catchments and indicative rates of population growth were derived by analysing the change in population for the whole SLA that the catchment lies within. The farm dam volumes should ***not*** be divided by the historical population estimates in this section to derive a representative ML/person figure because the population figures relate to the whole SLA while the farm dam estimates relate to a catchment that generally forms only a portion of that SLA. In addition, the historical population estimates were derived from sources of varying reliability and there have been changes in SLA and local government area boundaries over this period, creating some uncertainty in the historical population estimates.

From 1996, there were population estimates available from the ABS publication *Regional Population Growth, Australia* (Publication No. 3218.0, (2007)) on SLA boundaries and these were considered to be the most reliable; as such they were used after 1996.

5.4.1.2 New South Wales catchments

For the three catchments in New South Wales, historic populations from the period prior to 1996 were sourced from the ABS *Year Book* publications for New South Wales. Over time the populations were available for different spatial extents; including shires, states, local government areas, statistical subdivisions and statistical local areas. There was some disparity created in the population estimates by using the populations from the ABS and the *Year Books*, this was unavoidable and the estimates are based on the best available data. Given the different spatial extents, there were only three catchments that were able to be analysed with confidence in the estimates of population. These were Yass River @ Gundaroo, Warrah Creek @ Old Warrah and Swamp Oak Creek @ Limbri.

Figure 5-11 shows that for the Swamp Oak Creek catchment, there was an eight-fold increase in the estimated total volume of farm dams between 1971 and 1990 but the population in the corresponding SLA (Tamworth Regional Council, Part B) had only increased by approximately 50% over this same period of time. The rapid growth in farm dam volumes over this period of time was much more rapid than population growth.

Similarly, Figure 5-12 shows that for the Yass River catchment, there was almost a four-fold increase in the estimated total volume of farm dams between 1976 and 1998 but the population in the corresponding SLA (Yass Valley, formerly Yass Shire) had only increased by 56% over this same period of time. As for the Swamp Oak Creek catchment, the increase in the storage volume of farm dams was significantly faster than the population growth rate.

Figure 5-13 shows that in the Warrah Creek catchment, there was also a steep increase in volume of farm dams recorded between the 1940's and 1990, with a 60% increase in farm dam volume over the period from 1984 to 1990. The population in the corresponding SLA (now called Liverpool Plains – Part A, previously Quirindi and part of Parry – Part B) had been close to static over the period from 1972 through 2006. Once again, the rapid rate of growth in farm dam volumes is not represented by the change in population.

In summary, for these three catchments in New South Wales, the historical rate of growth in farm dam volumes was much larger than the rate of population growth in the corresponding locations. On this evidence, it would be unreasonable to assume, for catchments in New South Wales at least, that there is a direct connection between the rate of growth of volumes of farm dams and population.

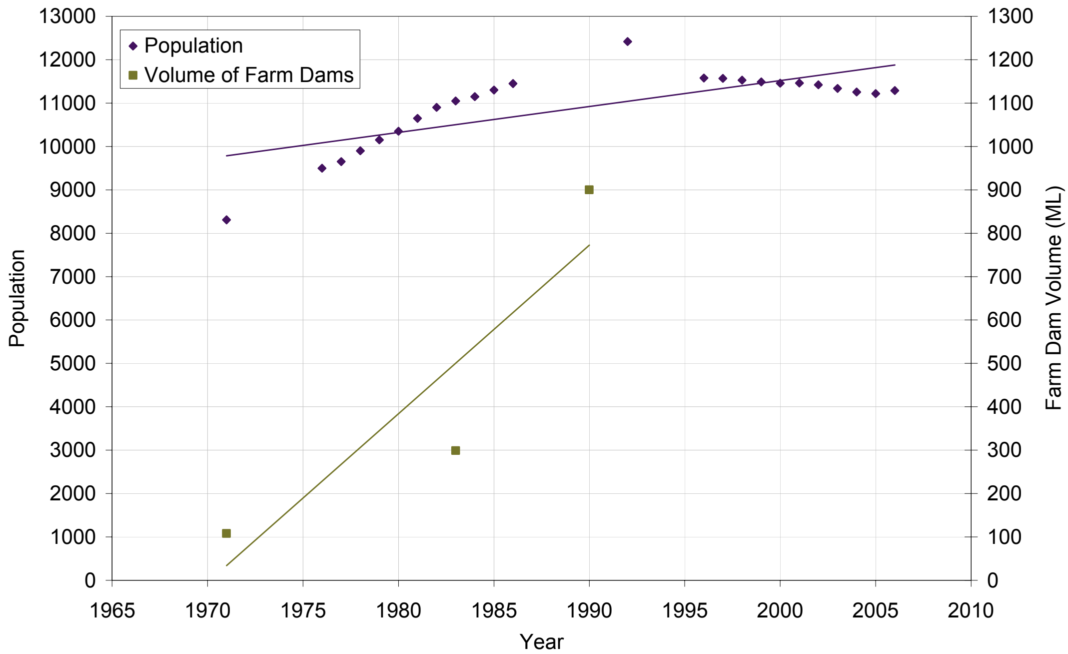


Figure 5-11 Population and estimated farm dam volume in the Swamp Oak Creek @ Limbri Catchment in NSW

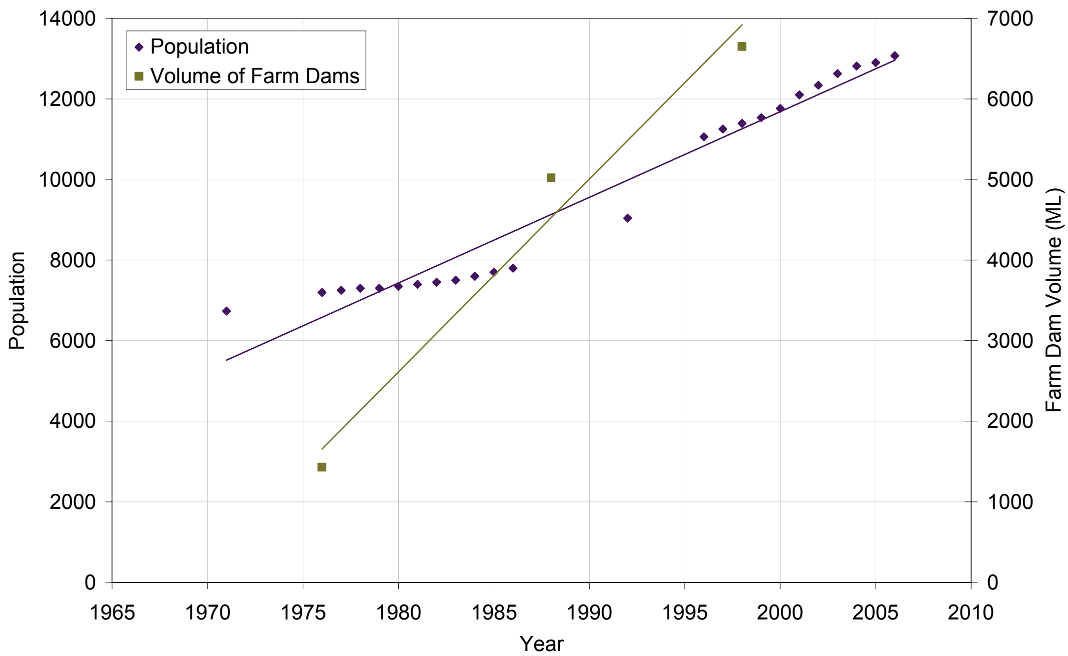
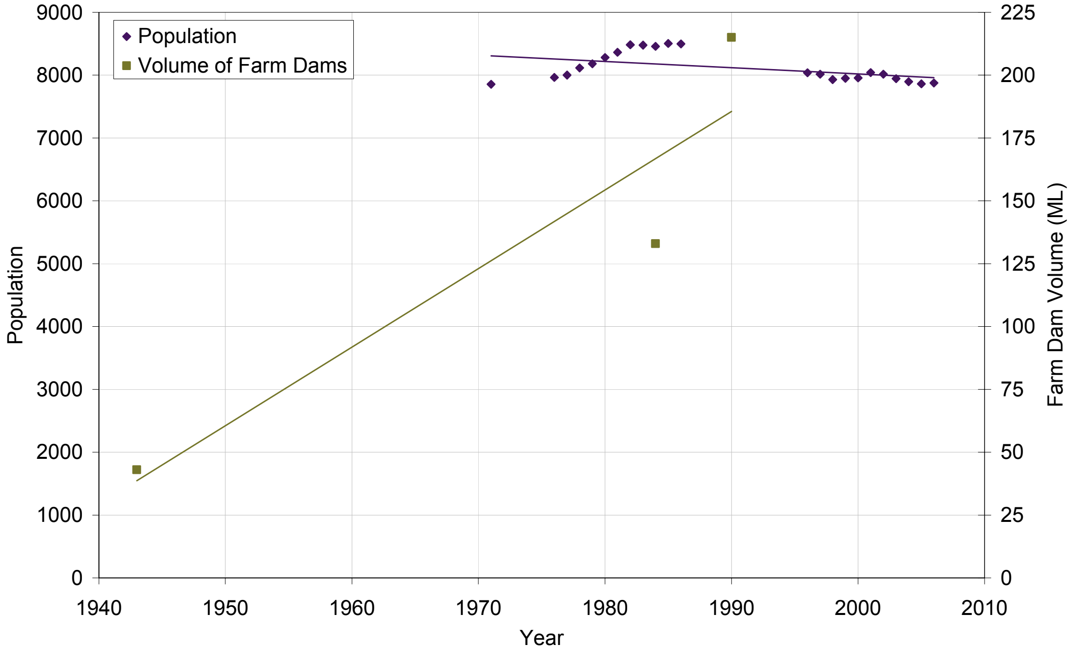


Figure 5-12 Population and estimated farm dam volume in the Yass River @ Gundaroo Catchment in NSW



- **Figure 5-13 Population and estimated farm dam volume in the Warrah Creek @ Old Warrah Catchment in NSW**

5.4.1.3 Moorabool River catchment, Southern Victoria

Historical data was available on farm dam development in the Moorabool River Catchment, which is located immediately to the south of the Great Dividing Range in Victoria. Although the catchment is just outside the Murray-Darling Basin, it is located approximately 60 km to the west of Melbourne and would have experienced similar social and economic changes and would have similar climate and topography to many catchments, on the other side of the Great Dividing Range, in the Victorian section of the MDB.

The total population in the Moorabool River Catchment was estimated for the period, from 1970 through 2002 as follows:

- For 1991 and 1996 through 2002, the population was the sum of the populations for Moorabool (S) – Ballan and Moorabool (S) – West Statistical Local Areas from the Australian Bureau of Statistics.
- For 1981 and 1996, the population was estimated from the Ballan Balance figure given in *Towns in Time* (Department of Sustainability and Environment, 2001), after making a slight correction between the *Towns in Time* figure based on the overlapping estimates with the Australian Bureau of Statistics population estimates for 1991 and 1996.
- For 1968, 1971, 1974, 1976, 1978 and 1980 populations for Ballan were extracted from the *Victorian Yearbooks* of 1970, 1972, 1976, 1980 and 1982 and these were then adjusted by the

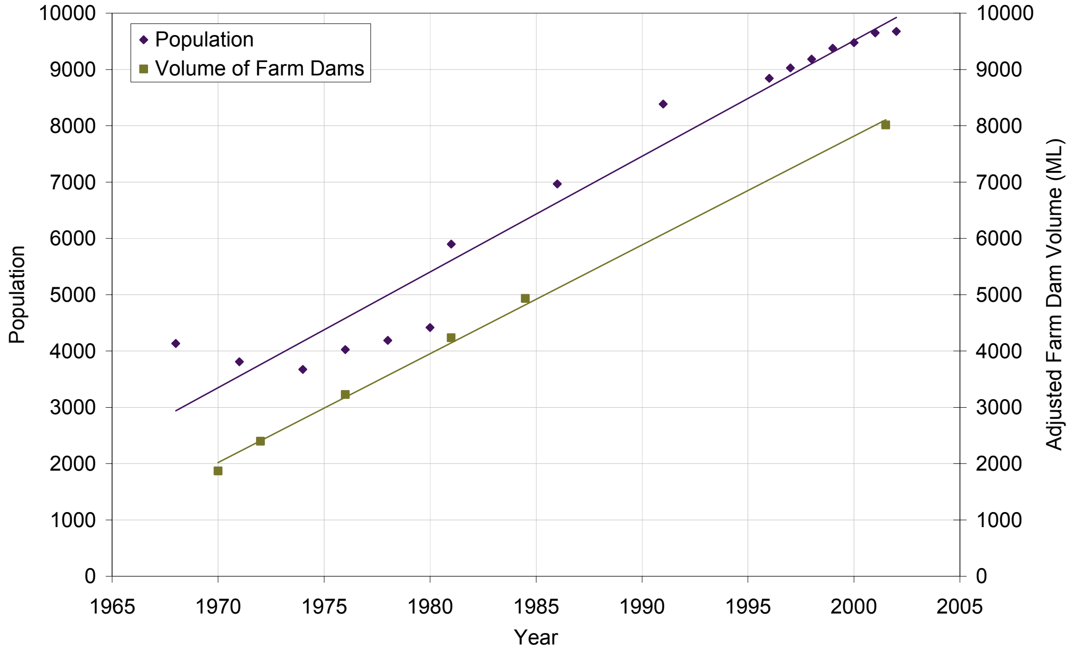
ratio between the Australian Bureau of Statistics population and the *Towns in Time* estimate for Ballan for the years of 1991 and 1996.

GHD (1987) used aerial photography to identify farm dams in the Moorabool River Catchment at five dates between 1970 and 1984. GHD (1987) provided a count of the number of farm dams present at each date (see Table 5-4) and also estimated the total storage volume held in those dams. An examination of the GHD (1987) data by SKM (2003) found that it was likely that GHD (1987) had only captured dams that were larger than 0.7 ML in its spatial data. SKM (2003) used Vicmap topographic data to identify farm dams that were present in 2001 (see Table 5-4). The volume of each of these dams was estimated from its surface area, using a power-law relationship. Based on the SKM (2003) analysis, there were 1033 farm dams that had a volume exceeding 0.7 ML (the smallest size likely to have been captured by GHD (1987), and that the total volume of these dams was approximately 8000 ML. From the SKM (2003) data, the mean volume of each farm dam was 7.8 ML. The total volume of farm dams for each of GHD's (1987) time slices was estimated by multiplying the number of farm dams counted by 7.8 ML (see Table 5-4). The storage volumes estimated by GHD (1987) in their report were overestimated because they used a much older (and less reliable) means of estimating the dam storage volumes from surface areas.

The time series of the population estimate and the estimated total volume of farm dams for the Moorabool River Catchment are plotted in Figure 5-14 and linear regression was used to fit a trend line to each series. The trend lines for population and total farm dam volume have the same slope, indicating that there is a direct correlation between increasing population and increasing farm dam development in this catchment. The total volume of farm dams in the Moorabool River Catchment represents 0.79 ML per person.

- **Table 5-4 Number and estimated storage volume of farm dams in Moorabool River Catchment, 1970-2001**

Year	Number of farm dams	Source for number of dams	Estimated storage volume (ML)
1970	241	GHD (1987)	1869
1972	309	GHD (1987)	2397
1976	416	GHD (1987)	3227
1981	546	GHD (1987)	4235
1984	636	GHD (1987)	4933
2001	1033	SKM (2003)	8012



- **Figure 5-14 Time series of population and total estimated storage volume of farm dams in the Moorabool River Catchment for 1968 through 2002.**

5.4.1.4 Summary of findings in previous catchment specific studies

There were somewhat contradictory findings in the four catchment specific studies listed above. For the Moorabool River Catchment there was a direct correlation between increasing population and increasing farm dam development. This would be consistent with growth in stock and domestic farm dams, resulting from increasing population causing subdivision of rural properties within commuting distance to an urban centre. However, for the three catchments in New South Wales, the rate of growth of farm dam development was many times faster than the change in the corresponding population. For these catchments, there were clearly drivers of the farm dam growth other than population growth leading to rural subdivisions. It should be noted that there was probably a bias in selecting these four catchments for analysis because historical data was more likely to have been collected for analysis in those catchments where farm dam development is perceived to be high and areas with lower rates of farm dam development are more likely to have been ignored.

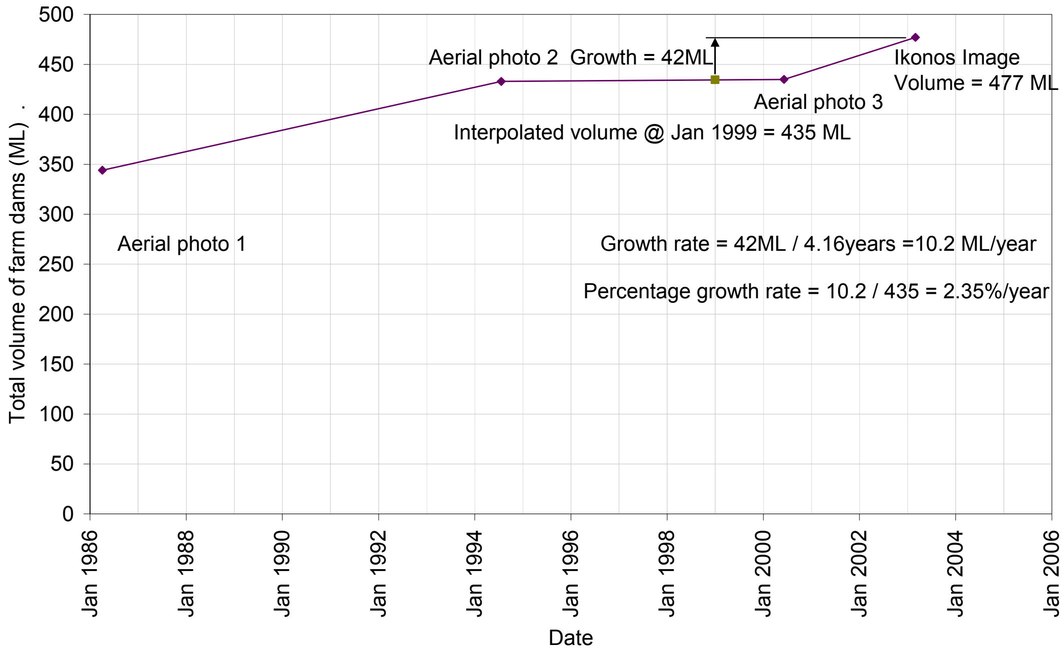
5.4.2 Historical trends observed in Agrecon (2005) study

The only previous study that has attempted to study historical trends in farm dam development widely across the MDB was that undertaken by Agrecon (2005). The Agrecon (2005) study digitized farm dams from satellite imagery for 84 square tiles, distributed across the zone of the Murray-Darling Basin with mean annual rainfall exceeding 500 mm. Agrecon (2005) obtained Ikonos satellite imagery and digitized all of the farm dams that were located within a 7 km by 7 km tile from each satellite image. Agrecon (2005) also collected data on the change in the number of farm dams within each of the square tiles that they analysed. They did this by analysing aerial photography of the same areas covered by the Ikonos imagery and determining the presence or absence of the individual dams within the imagery. Agrecon (2005) then estimated the volume of each farm dam in the tile and summed the volumes of those farm dams that were visually present in each of the aerial photos and in the satellite imagery.

For all of the Agrecon (2005) square tiles located in New South Wales, there was an estimate of total farm dam volume based on the satellite imagery (dated between 24 March 2002 and 18 November 2003, depending upon the individual tile) and also for three previous points in time, which stretch back as far as August 1982, depending upon the individual tile. The tiles analysed by Agrecon (2005) in the other states also have farm dam volume analysed for between 1 and 3 time slices prior to the satellite imagery, depending upon the availability of aerial photos for the locations of each tile. Detailed information on the presence or absence of individual farm dams was not made available from the Agrecon (2005) data set. Re-analysis of the Agrecon (2005) data was therefore limited to the summary tables on total farm dam volumes located in the Appendix to their report.

For the current project, the data presented by Agrecon (2005) in the Appendices to their report were reanalysed to estimate the historical trend in farm dam growth over recent years. New South Wales introduced their Harvestable Rights policy in 1999. In Queensland, there has been a moratorium on development of new farm dams that are not for stock and domestic purposes since either 2000 or 2001, depending upon the basin under consideration. Legislation in Victoria since 1993 has prevented development of new farm dams that are not for stock and domestic purposes. Policies on farm dam development in New South Wales, Queensland and Victoria that have been in place since about 1999 or 2000 are similar to the current policies and the policies that are expected to be in place for the projection period to 2030. The historical growth trend in storage volume of farm dams since about 1999 therefore provides a guide to the future trend in farm dam storage volume.

The data from Agrecon (2005) was reanalysed to estimate the growth rate in farm dam volume for each tile. The appendices of the Agrecon (2005) report provide, for each tile, the total volume of farm dams counted for four time-based phases of development and the dates of the aerial photograph that relates to each of those four phases. The volume of farm dams that was present at 1 January 1999 was estimated by interpolating the cumulative volume of farm dams at the conclusion of each phase (Agrecon, 2005) according to the dates of capture of the aerial photography and satellite imagery for each tile. The rate of farm dam growth (in ML/year) was estimated by dividing the difference between the volume estimated for the Ikonos image and the interpolated volume at 1 January 1999 by the number of years between 1 January 1999 and the Ikonos image. The rate of farm dam growth was then divided by the interpolated volume at 1 January 1999 to estimate the rate of growth as a percentage per year. Figure 5-15 shows an example of the estimation of the growth rate for the Agrecon tile from the Clive topographic map sheet. Details of the calculation of growth rates for every Agrecon tile are given in Appendix H.



- **Figure 5-15 Example of method of estimation of growth rate in farm dam volumes since 1999 for Agrecon tile from the Clive topographic map sheet**

Historical population counts were obtained for each SLA at 1999 and 2004 (see section 5.3.2 above for the sources of population data). The SLA that contains each Agrecon tile was determined and it was assumed that the rate of population growth for the SLA as a whole would be representative of the rate of population growth for the Agrecon tile or tiles that are located within it. The change in population, both as a number of people and as an annual rate of change, were computed for each SLA that was mapped to an Agrecon square, as detailed in Appendix I.

The Agrecon (2005) data set used satellite imagery that covered a range of different landuse types and farming systems. Some of the square tiles collected by Agrecon were from areas where virtually all of the farm dams would be operated as off-stream storages, collecting water diverted from nearby streams or irrigation channel systems. The Agrecon (2005) data set did not distinguish between off-stream storages and catchment farm dams, which are located on first or second order streams and capture their own local runoff without relying on diversions from another watercourse.

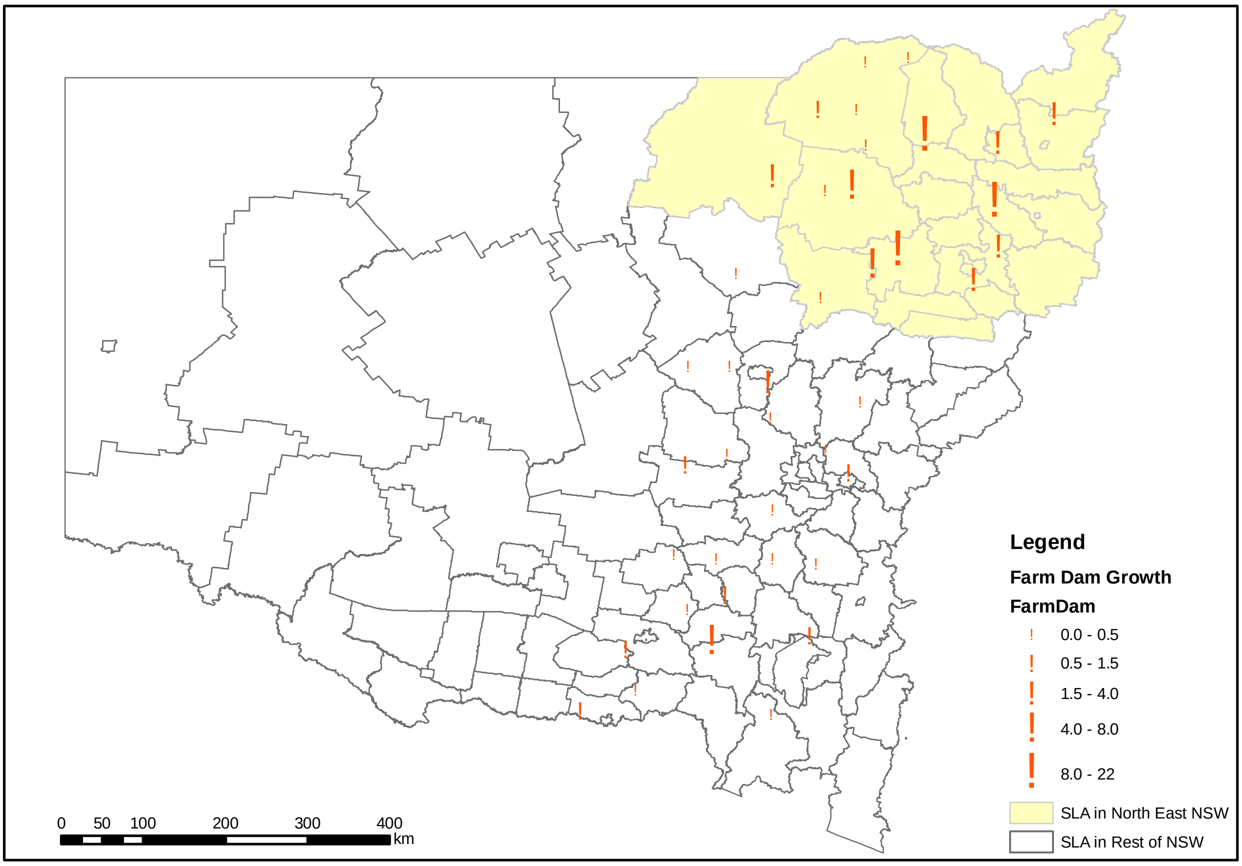
Satellite imagery was examined to decide on the Agrecon tiles that included a majority of off-stream storages and then to exclude these tiles from the analysis of historical growth rates. Since the focus of the current study is on projected growth in catchment farm dams, tiles from the Agrecon (2005) data set that included mainly off-stream storages would not be representative of the historical growth rate in catchment farm dams. Appendix J lists the tiles from the Agrecon (2005) data set that were excluded from the analysis on this basis.

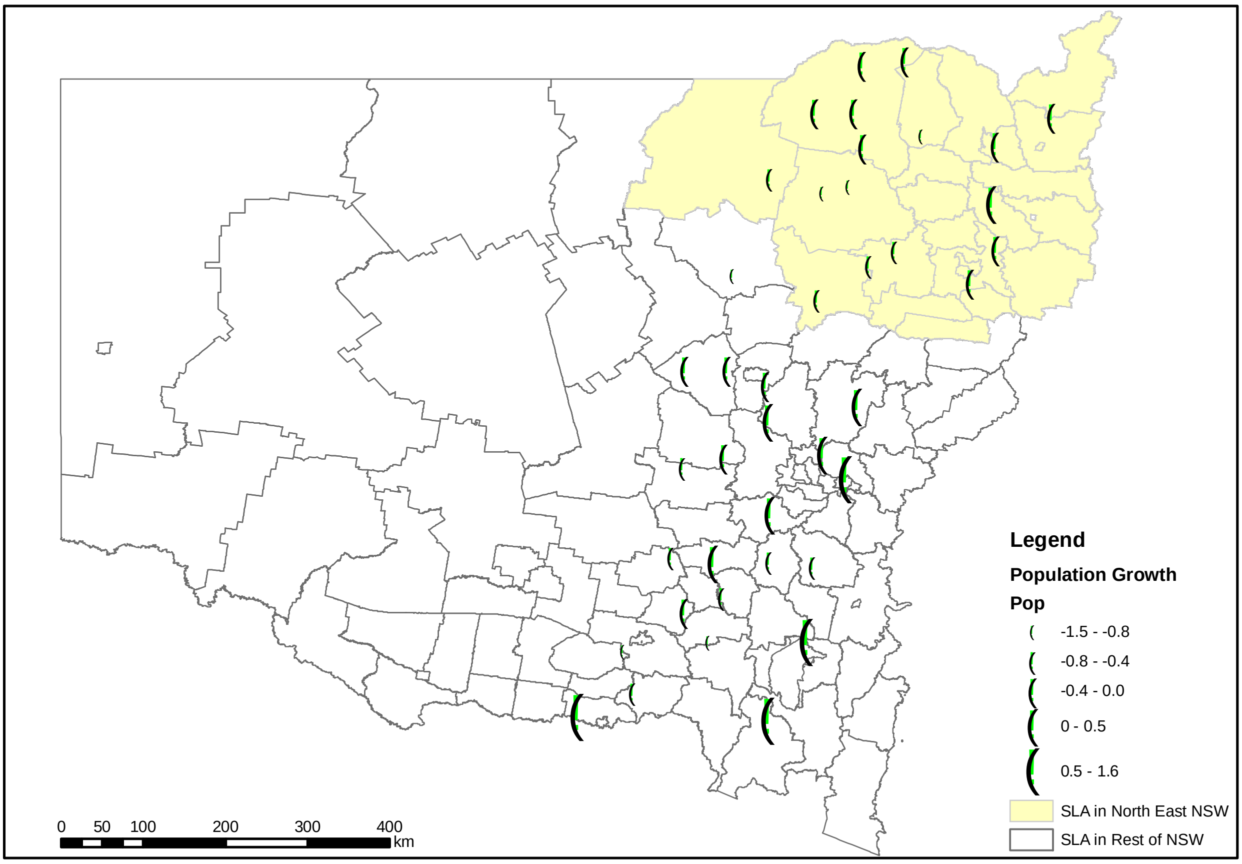
Appendix K provides a summary of the annual growth rate in total farm dam volume and the annual rate of change in estimated population for each Agrecon tile. Mean growth rates for the period from 1999-c.2004 were calculated for Queensland, South Australia and Victoria and separately for North East New South Wales and the rest of New South Wales regions. These mean historical growth rates are shown in Appendix K.

The mean historical growth rate of 4.0%/year in North East NSW was much larger than the growth rates observed in the rest of NSW or in any of the other states. Figure 5-16(a) shows a map of the historical growth in the volume of dams from each of the Agrecon squares in NSW, for the period post-1999. Figure 5-16(b) shows the corresponding estimates of rate of population change for the 1999-2004 period at each of the Agrecon squares. The figure reveals a stark contrast in the historical growth rates for this period between the Agrecon squares in the North East of NSW and those in the rest of the NSW MDB. Growth rates in North East NSW were large, even for those Agrecon squares where population was declining or only experienced slow rates of growth. In the rest of NSW, growth rates in farm dam volumes were more moderate and appear to be more closely aligned with the historical change in population over this period.

Several statistical tests were performed to demonstrate that the observed annual growth rate in farm dam volumes in North East NSW was greater than the growth rate that was observed in the rest of NSW. Details of the statistical tests that demonstrate this difference in growth rates are provided in Appendix L.

The historical growth rate in the storage volume of farm dams in the one Agrecon (2005) tile in South Australia for the period 1999-2002 was 1.9% per year, which was virtually identical to the average growth rate from the 14 Agrecon (2005) tiles in Victoria. If this growth rate of 1.9% per year was to continue for the 24 years from 2006 to 2030, the overall growth rate in farm dam volumes in the Eastern Mount Lofty Ranges would be 46%. This growth rate is broadly similar to the projected growth in population in the Eastern Mount Lofty Ranges for 2006 to 2030.





n **Figure 5-16 Map of historical trend in percentage annual growth rate in farm dam volume for each Agrecon square in NSW.**

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5.4.3 Extrapolation of observed trends for projection of future farm dam development

Projections of percentage increases in total farm dam volumes were made on the assumption that the observed historical trend for 1999-c.2004 would continue for the forthcoming years of 2006-2030. Table 5-5 shows that the historical annual growth rates (in percent per year) were multiplied by 24 years to provide a projected overall percentage increase in farm dam storage volume from current (c.2006) to 2030. There are different policies in place in each state and different drivers on potential farm dam development. Different percentage growth projections were therefore applied in each of the states and different percentage growth projections were also applied in North East NSW to those in the rest of NSW.

- **Table 5-5 Projected percentage increase in total farm dam volume for 2006 – 2030 if continued at historical rate, based on reanalysis of Agrecon (2005) data**

Region	Number of samples analysed by Agrecon (2005)	Linear growth rate in total volume of farm dams 1999 – c. 2004 (%/year)	Projected increase in total farm dam volume for 2006 – 2030 if continued at historical rate (%)
North East NSW	16	4.0	96
Rest of NSW	24	0.6	14
South Australia	1	1.9	46
Queensland	20	1.2	29
Victoria	14	1.9	46

The projected increases in farm dam volume to 2030, based on the observed historical trend, were calculated by multiplying the total storage volume of existing farm dams (see Section 4.3) by the percentage growth projections for their respective region in the last column of Table 5-5. Projected increases were estimated using this method for:

- each SLA in Victoria;
- each SLA in New South Wales;
- each SLA in the eastern part of Queensland, which was covered by the Geoscience Australia (2007) dataset; and
- each management subcatchment in the Eastern Mount Lofty Ranges Reporting Area of South Australia.

No projections were made using this method for the western part of Queensland (for which adequate coverage of existing farm dam development was not available), for which projections of farm dam growth were ultimately adopted based upon population growth.

Figure 5-17 shows a map of the projected additional storage volume to 2030 for the SLA or management subcatchments (as discussed above) based upon an extrapolation of the historical observed growth rate for the period 1999-c.2004. Figure 5-18 shows the density of additional dams (in ML/km^2) that would result in the SLA or management subcatchments from this same projection method.

These projections are based upon a crude extrapolation of the estimated trend for the period 1999-c.2004. There are policy limitations (as discussed in Section 5.2 above) in some parts of the MDB that would cap the projected growth to a lower level. In some parts of the MDB (for example Queensland and Victoria) policy changes in recent years to restrict farm dam development to stock and domestic use only would make the extrapolation of the historical trend inappropriate.

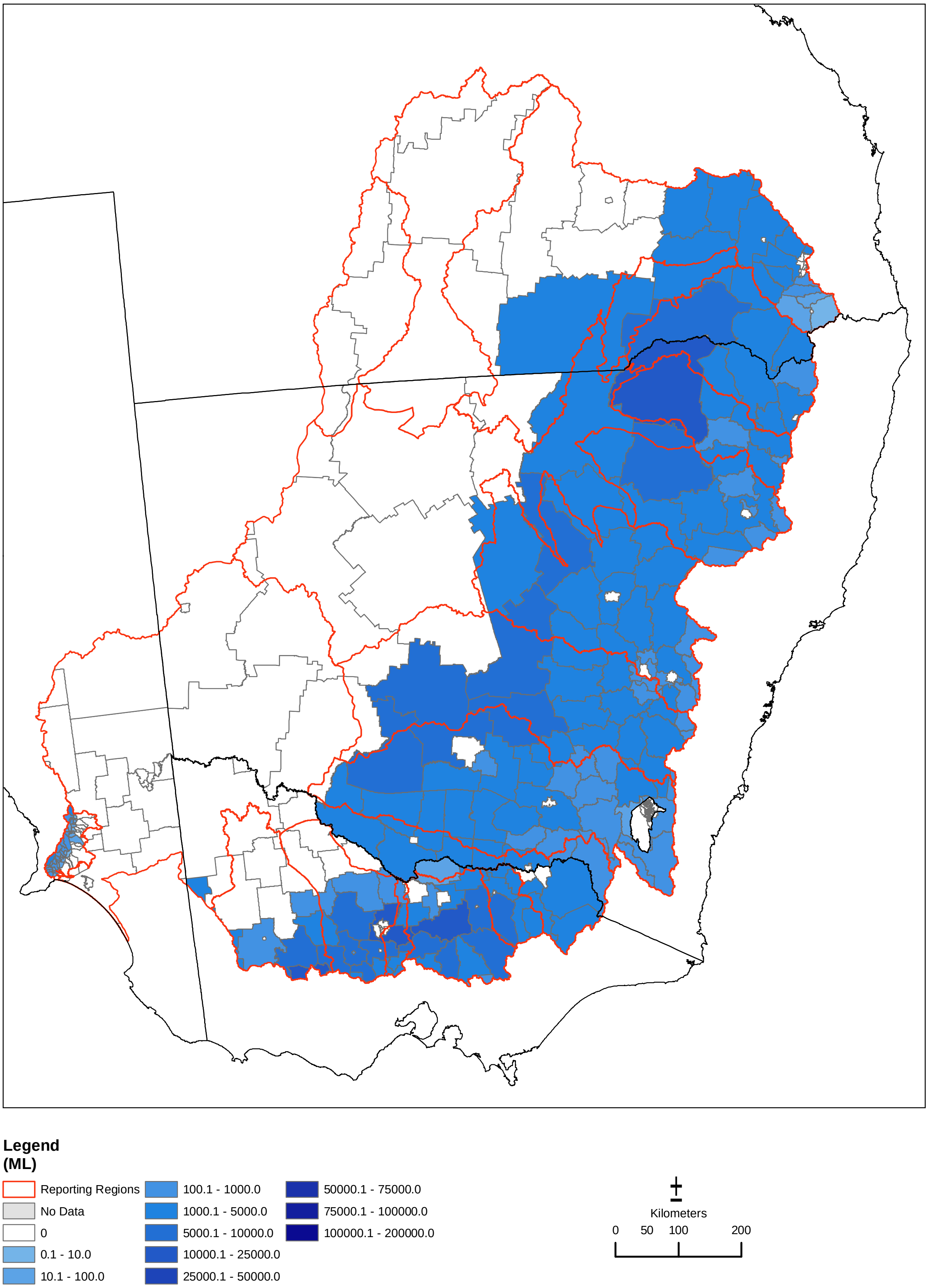
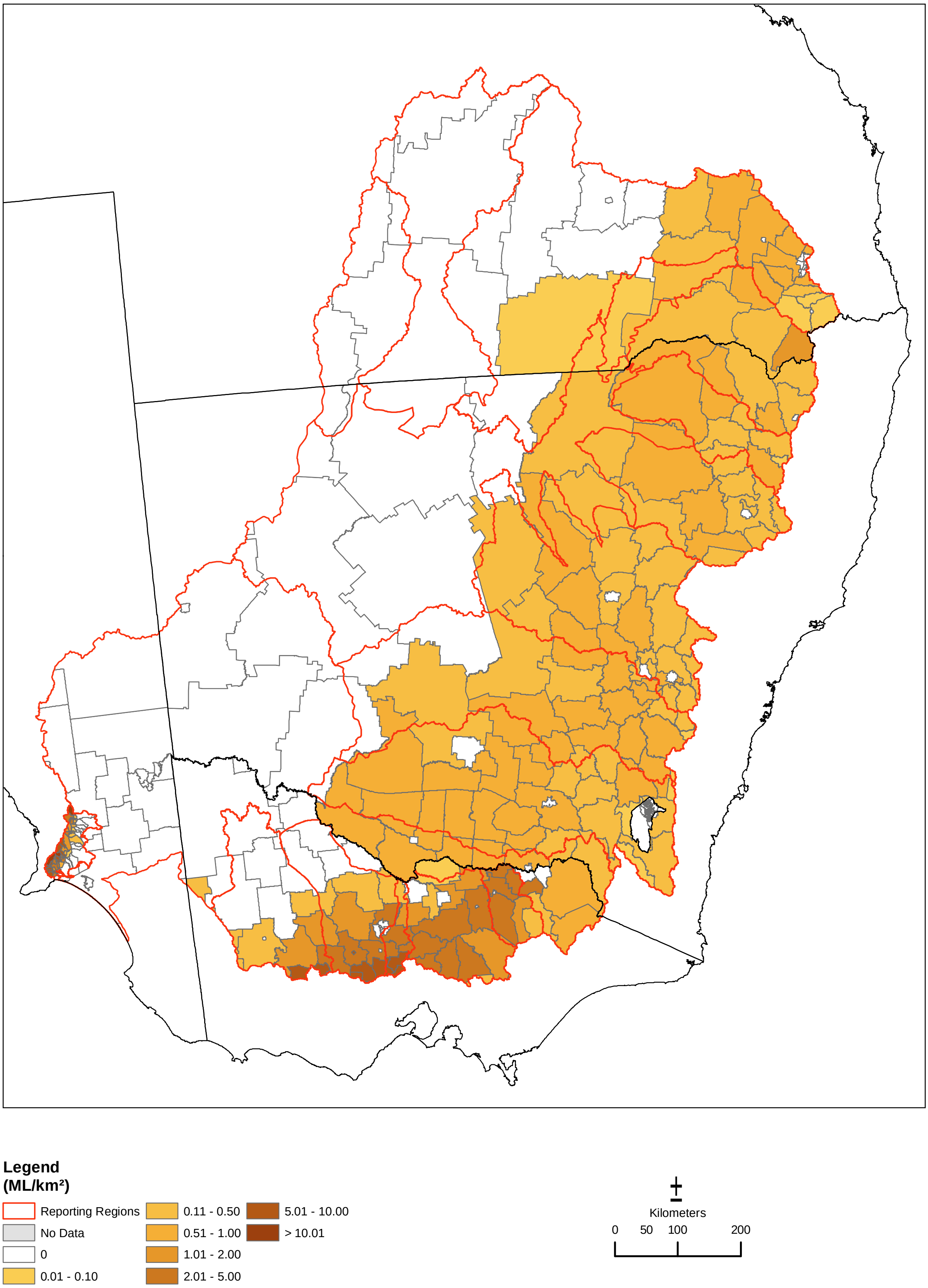


Figure 5-17 Projected additional farm dam storage volume 2030 (ML) for a projection based only upon an extrapolation of the historical observed growth rate in farm dam development for the period 1999-c.2004



n **Figure 5-18 Projected density of additional farm dam storage volume to 2030 (ML/km²) for a projection based only upon an extrapolation of the historical observed growth rate in farm dam development for the period 1999-c.2004**

6 Adopted projections for future farm dam storage volumes

6.1 Introduction

Projections were required of the additional volume of farm dam storages for each of the modelling subcatchments in the MDB to the year 2030. Three possible projection approaches were trialled, as explained in Chapter 5 of this report:

1) A limitation to volume determined by policy restraints.
2) Change in stock and domestic farm dam volume determined by the change in population.
3) Extrapolation and application of historical trend to existing storage volume.

A different combination of approaches is applicable in different parts of the MDB, depending upon the policies that area applicable in each of the states and territories.

This chapter has the adopted projections for each of the modelling subcatchments and discusses the approaches that were taken in deriving those adopted projections for each of the jurisdictions.

As discussed in Section 5, the primary spatial unit for projection of future farm dam volumes across New South Wales, Queensland, Victoria and the ACT was the SLA, defined using boundaries as at 2001. Future farm dam projections were derived for modelling subcatchments by intersecting the projections made by SLA with the boundaries for the model subcatchments, as discussed in Section 5.1.2.

This chapter sets out the projections that were adopted for the SLA by state and ultimately for each of the modelling subcatchments and reporting regions.

6.2 Adopted projections of future farm dam storage volumes by SLA or management subcatchment

6.2.1 Australian Capital Territory

There were three SLAs in the ACT that were considered to be Rural (Remainder of ACT, Stromlo and Tuggeranong – SSD Bal). For each of these SLAs, there was no growth in population in the ABS projections; and very little or no growth in the surrounding SLAs in NSW. The ACT SLAs were also considered to be in water supply catchments; therefore very little development of farm dams would occur. For these reasons, it was projected that there would be no growth in the volume of farm dams in the ACT.

6.2.2 New South Wales

The Harvestable Rights policy in NSW dictates the maximum volume of farm dams that may be constructed on each individual property without the purchase of a water right for that property. The intent of the policy is that the Harvestable Right (HR) represents 10% of the estimated runoff from the property.

In some parts of the NSW MDB, the combination of existing farm dam development and the projected growth in farm dam development is sufficiently large that the HR will act as a cap on the additional farm dam development. However in other parts of the NSW MDB, projected growth rates in farm dam development, from extrapolation of historical growth rates, are sufficiently low that they will form a more appropriate projection of additional storage volumes and the HR will not be reached.

For each rural SLA in New South Wales, the adopted projection of additional storage volume of farm dams for 2030 was adopted as the lower of:

- the available harvestable right volume (from Section 5.2); and
- the projected additional storage volume of farm dams based upon extrapolation of the historical growth rate in farm dam volumes (from Section 5.4).

As discussed in Section 5.1.2, no increase in farm dam volumes was projected for SLA that were designated as urban. Projected increases in population were not used in deriving the adopted projections of additional farm dam volumes for New South Wales because:

- unlike Queensland and Victoria, future development of farm dams are not linked to a stock and domestic purpose test and this makes any link between increase in farm dam development and population growth tenuous; and
- over the historical period 1999-c.2004, there was no correlation between the observed rate of growth in farm dam volumes and rates of change in population for the Agrecon tiles in New South Wales (see Figure 5-16).

Appendix M shows the derivation of the overall adopted projected increase in farm dam volumes for each SLA in New South Wales. This same information is presented as a map in Figure 6-5 and Figure 6-6.

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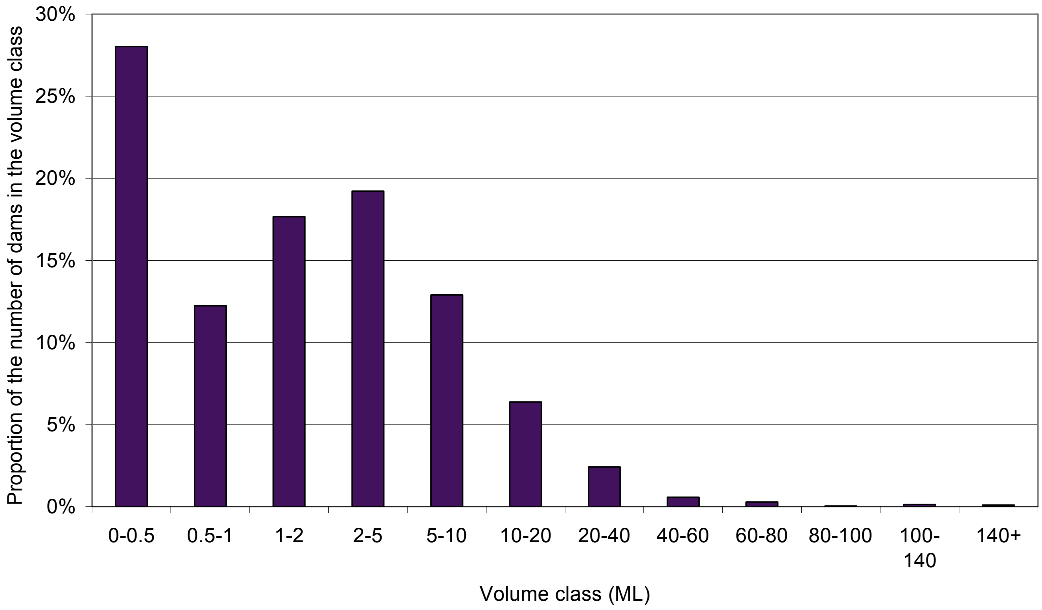
- **Table 6-1 Projected increase in farm dam storage volume, existing volume of farm dams, harvestable right and available harvestable right for each reporting region in New South Wales (All volumes include those parts of the reporting regions outside of NSW as well)**

Reporting Region	Estimated existing farm dam volume (GL)	Harvestable right (GL)	Harvestable right taken by existing farm dams (GL)	Available harvestable right (GL)	Projected additional dams to 2030 (GL)	Projections as a percentage of existing dam volume
Border Rivers*	77	103	30	72	11	13.9%
Gwydir	113	141	39	102	16	14.0%
Namoi	145	200	57	142	20	13.9%
Macquarie-Castlereagh	242	324	103	222	38	15.8%
Barwon-Darling*	94	131	31	100	13	14.0%
Lachlan	261	322	127	194	36	14.0%
Murrumbidgee	351	373	134	239	47	13.5%
Murray*	73	80	24	56	10	13.9%
Total for NSW part of MDB	1,356	1,674	546	1,128	192	14.2%

* NSW volume only (79 GL in Border Rivers (QLD), 4 GL in Barwon-Darling (QLD), 21 GL in Murray (VIC), SA volume in Murray is unknown)

A histogram of the projected increase in the number of farm dams, according to the size of the farm dams, was produced for each SLA in New South Wales. The histogram was derived by assuming that the probability distribution of the projected increase in farm dams would have the same shape as the probability distribution of the available harvestable right for properties within the SLA. In other words, if 20% of the properties in an SLA have an available harvestable right of between 2 and 5 ML, then it was assumed that 20% of the projected increase in dams for the SLA would also have a storage volume of between 2 and 5 ML. Individual histograms of projected additional volume of farm dams to the year 2030, by farm dam volume, are provided in Appendix N. A summary histogram, combining the individual histograms for all SLA in New South Wales, is shown in Figure 6-1.



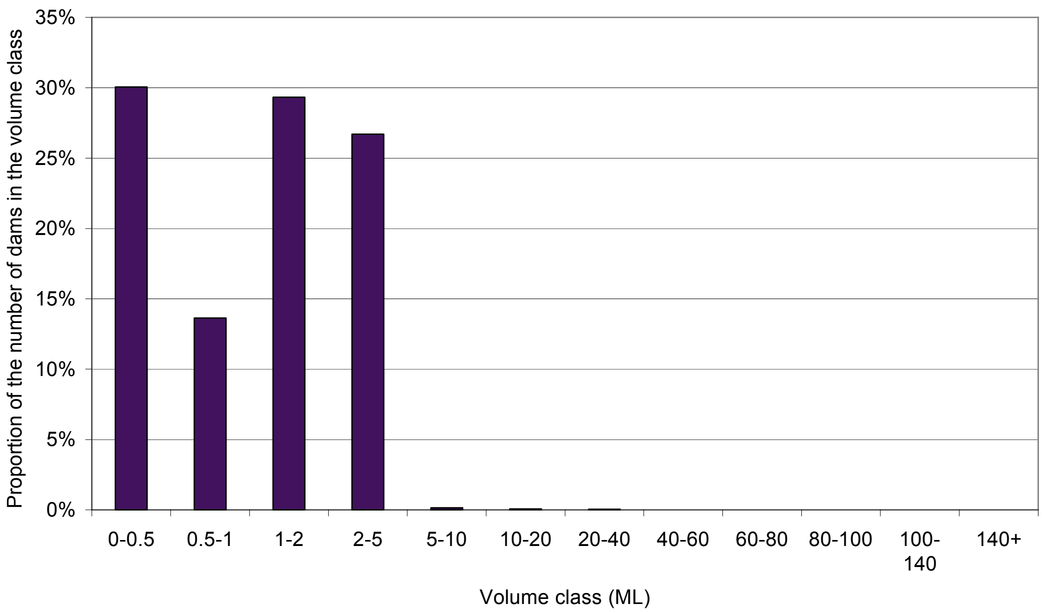
- **Figure 6-1 Summary histogram of projected additional numbers of farm dams to the year 2030, by farm dam volume, for New South Wales.**

6.2.3 Queensland

As discussed in section 5.2.3, projected future farm dams in Queensland are restricted to stock and domestic purposes and it was assumed for this study that the rate of growth in farm dam volumes in these states would be proportional to the rate of population growth. Projections of additional farm dam storage volumes to 2030 were therefore adopted from the projections based on projected population growth, as produced in Section 5.3.

Adopted projections of additional farm dam storage for each SLA in Queensland are shown in Figure 6-5 and as an area density map in Figure 6-6.

Figure 6-2 shows a probability distribution of the existing storage volume of stock and domestic farm dams only (less than 5 ML capacity) for the part of the eastern Queensland MDB covered by Geoscience Australia (2007) farm dam data. Under legislation, all new farm dams in Queensland are to be stock and domestic farm dams, so this probability distribution was used to break up the adopted projection of new farm dams, for each SLA in Queensland, into a projected histogram of additional farm dams by volume class.



- **Figure 6-2 Probability distribution of existing storage volume of stock and domestic farm dams (less than 5 ML capacity), by farm dam volume, for Queensland**

6.2.4 Victoria

As discussed in section 5.2.3, projected future farm dams in Victoria are restricted to stock and domestic purposes and it was assumed for this study that the rate of growth in farm dam volumes in these states would be proportional to the rate of population growth. Projections of additional farm dam storage volumes to 2030 were therefore adopted from the projections based on projected population growth, as produced in Section 5.3.

Adopted projections of additional farm dam storage for each SLA in Victoria are shown in Figure 6-5 and as an area density map in Figure 6-6.

Figure 6-3 shows a probability distribution of the existing storage volume of stock and domestic farm dams only (less than 5 ML capacity) for Victoria. Under legislation, all new farm dams in Victoria are to be stock and domestic farm dams, so this probability distribution was used with to break up the adopted projection of new farm dams, for each SLA in Victoria, into a projected histogram of additional farm dams by volume class.

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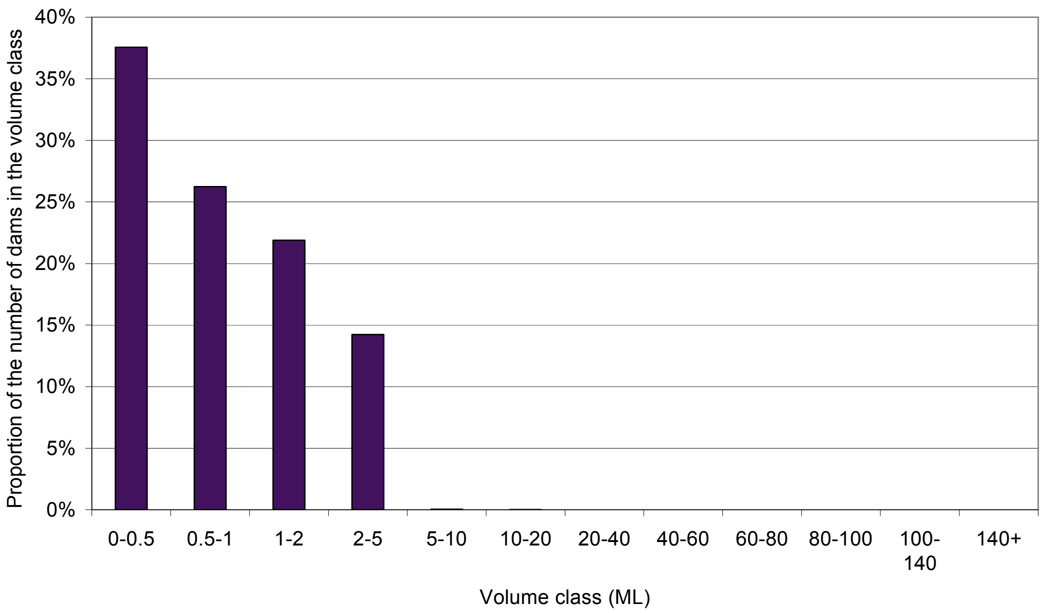


- **Figure 6-3 Probability distribution of existing storage volume of stock and domestic farm dams (less than 5 ML capacity), by farm dam volume, for Victoria**

6.2.5 South Australia

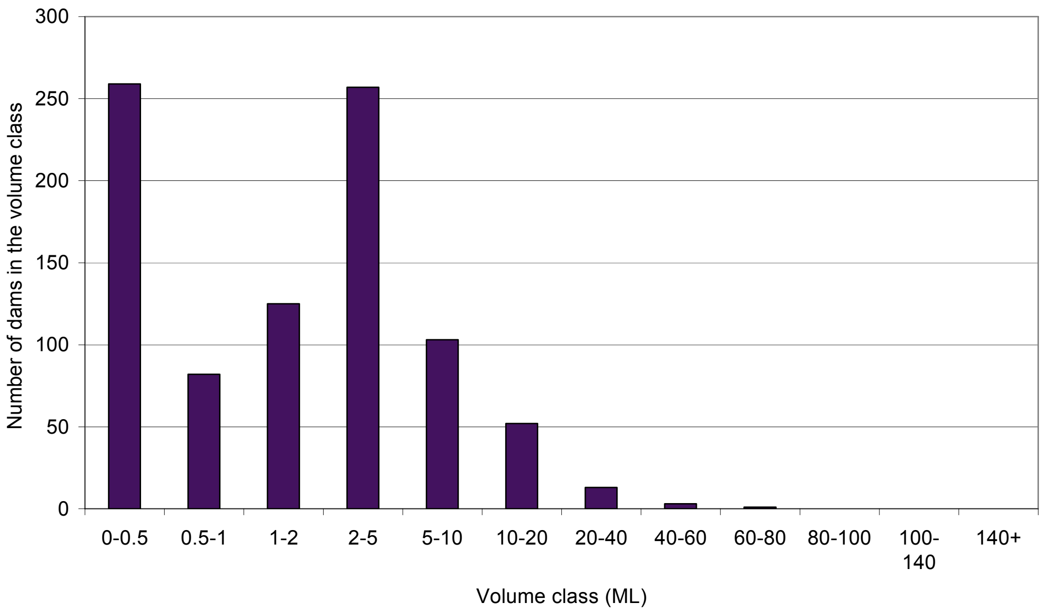
Projections of additional farm dam development for South Australia were produced using management subcatchments instead of SLA, as provided by DWLBC. The projected growth in farm dam development in each management subcatchment was adopted as the lower of:

- the policy limitation for the Eastern Mount Lofty Ranges to 30% of estimated May to November runoff, after removing existing farm dams and existing and projected plantation development to 2030 (from Section 5.2); and
- the projected additional storage volume of farm dams based upon extrapolation of the historical growth rate in farm dam volumes (an additional 46% of existing storage volume, from Section 5.3).

If the historical rate of farm dam growth in the Eastern Mount Lofty Ranges was extrapolated to 2030, the projected increase in farm dam storage volume would be 46%. This is slightly higher than the projected population growth for the Eastern Mount Lofty Ranges for the corresponding period of 30%. Unlike Queensland and Victoria, future development of farm dams is not linked to a stock and domestic purpose test. The extrapolation of the historical growth rate (46%) was therefore adopted in preference to the slightly lower projection based upon population growth (which would be approximately 30%).

Adopted projections of additional farm dam storage for each management subcatchment in South Australia are shown in Figure 6-5 and as an area density map in Figure 6-6.

A histogram of the projected increase in the number of farm dams, according to the size of the farm dams, was produced for each management subcatchment in the Eastern Mount Lofty Ranges. The histogram was derived by assuming that the probability distribution of the projected increase in farm dams would have the same shape as the probability distribution of 30% of the estimated May through November runoff for each property in the management subcatchment. In other words, if 20% of the properties in a management subcatchment have an estimated May through November runoff of between 2 and 5 ML, then it was assumed that 20% of the projected increase in dams for the management subcatchment would also have a storage volume of between 2 and 5 ML. A summary histogram, combining the individual histograms for all management subcatchments in the Eastern Mount Lofty Ranges, is shown in Figure 6-4.



- **Figure 6-4 Summary histogram of projected additional numbers of farm dams to the year 2030, by farm dam volume, for the Eastern Mount Lofty Ranges.**

6.2.6 Summary of adopted projections by SLA

The projections were calculated on the basis of SLAs for all states except for the Eastern Mount Lofty Ranges. The data for the EMLR in both Figure 6-5 and Figure 6-6 are based on the management subcatchments that were provided by the DWLBC. Of those SLAs with a projected increase in the volume of farm dams, the increase was between 100 and 5000 ML in the great majority of areas (Figure 6-5). The maximum projected increase of approximately 13,700 ML was in the Gwydir SLA in the north east of NSW. In contrast, the maximum projected increase in farm dam density was in the south west in the EMLR (Figure 6-6).

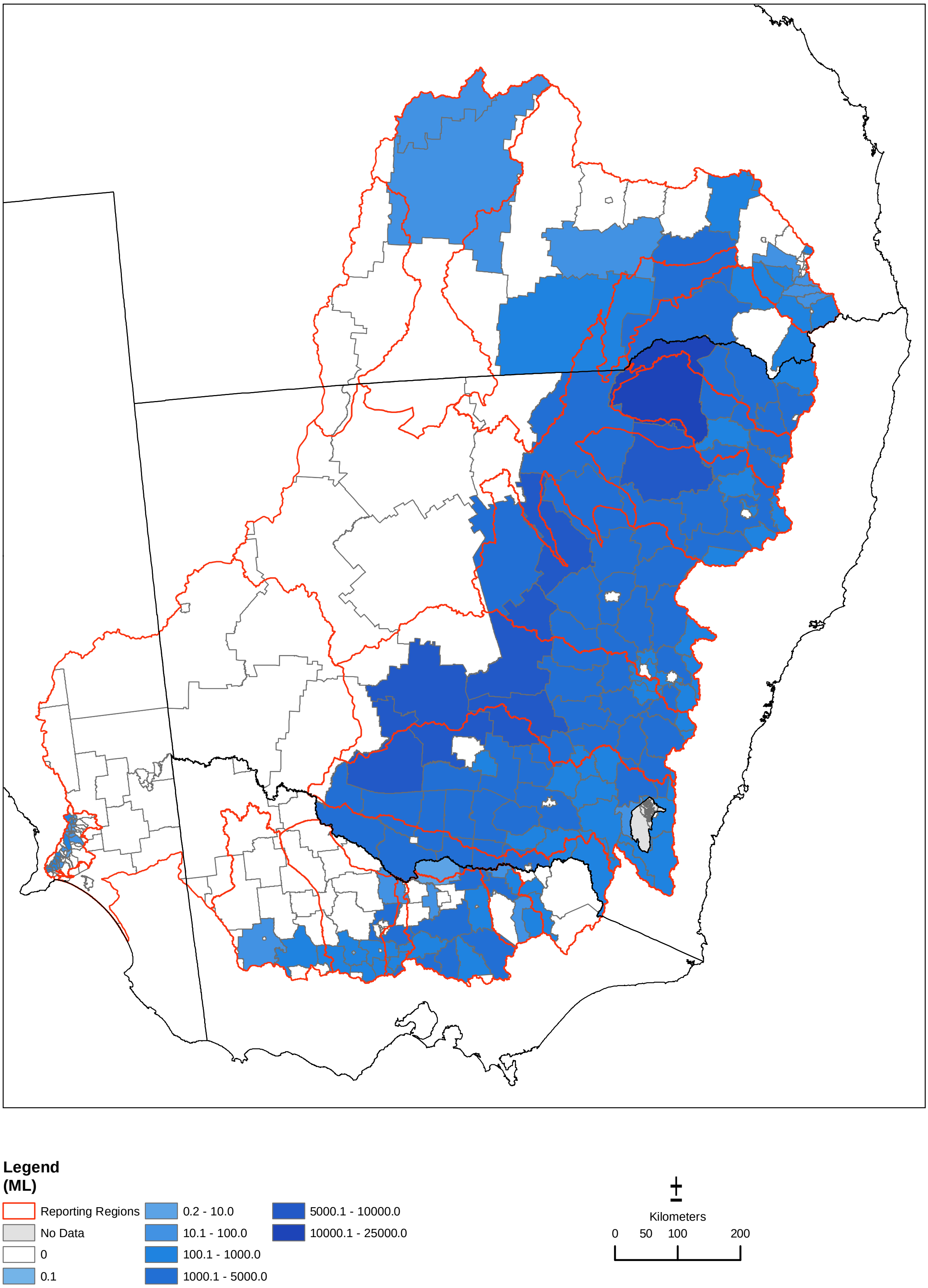


Figure 6-5 Adopted projection of additional farm dam storage volume to 2030 (ML) by SLA for New South Wales, Queensland and Victoria and management subcatchments for South Australia.

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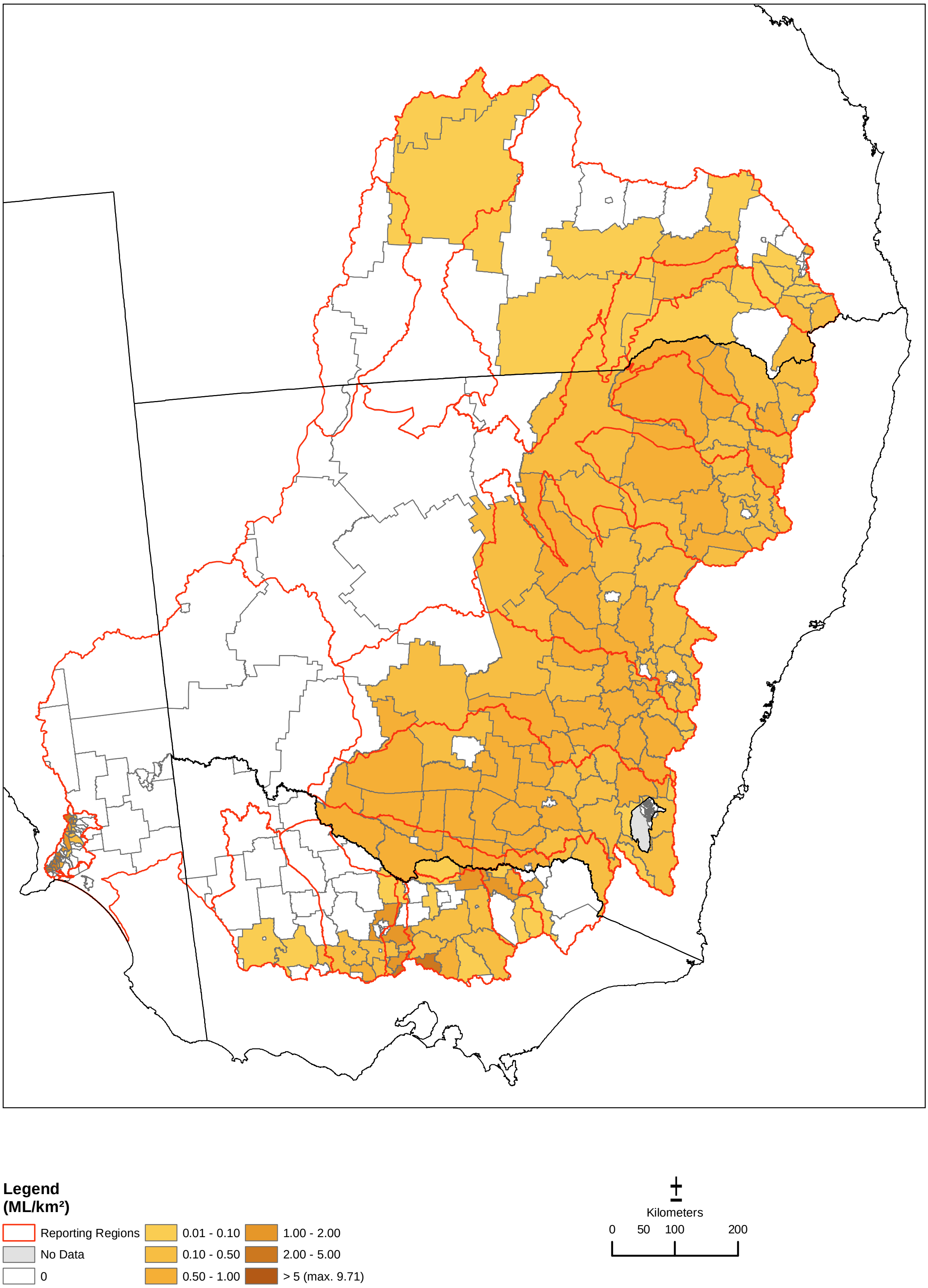

Figure 6-6 Adopted projection of additional density in farm dam storage volume to 2030 (ML/km²) by SLA for New South Wales, Queensland and Victoria and management subcatchments for South Australia.

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6.3 Adopted projections of future farm dam storage volumes by modelling subcatchment and reporting region

6.3.1 Approach for all reporting regions other than the Eastern Mount Lofty Ranges

For the areas in the Murray-Darling Basin outside of South Australia, the final projections, based on SLA boundaries, were intersected with the modelling subcatchment boundaries and the projected additional storage volume of farm dams was calculated.

The projected increase in farm dam volume for the period from current to 2030 for subcatchment *i*, $\Delta V_{SC,i}$, was estimated by assuming that the density per unit area of the projected increase in farm dams will be uniform across each SLA. Mathematically, this calculation is represented by:

$$\Delta V_{SCi} = \sum_{SLAj} \left(\frac{\Delta V_{SLAj}}{A_{SLAj}} A_{SCi \cup SLAj} \right)$$

where ΔV_{SLAj} is the projected increase in farm dam volume for the period from current to 2030 for SLA *j*, A_{SLAj} is the total area of SLA j and $A_{SCi \cup SLAj}$ is the area of overlap of subcatchment *i* and SLA *j*.

6.3.2 Approach for the Eastern Mount Lofty Ranges

DWLBC provided a spatial layer defining the boundaries of their management subcatchments in the Eastern Mount Lofty Ranges. The DWLBC management subcatchments are smaller (in most cases) than the modelling subcatchments that have been adopted for the MDB project, with one or more management subcatchments combining to form one of the subcatchments adopted for modelling in this project. The projected volumes were derived for each modelling subcatchment by simple addition of the adopted projections for each of the management subcatchments that lie within it.

6.3.3 Adopted projections of future farm dam volumes by modelling subcatchment

The adopted projections for the growth in farm dam volume for the subcatchments were calculated based on the approaches outlined in Section 6. They are outlined on a reporting region scale in Table 6-2, Figure 6-9 and Figure 6-10. The projections are also illustrated on a subcatchment basis in Figure 6-7 and Figure 6-8. The volumetric change in farm dams is shown in Figure 6-7. The highest volumetric increase in farm dams was in the Murrumbidgee Reporting Region, followed by the Lachlan and Condamine-Balonne Reporting Regions. This big increase in the Murrumbidgee and the Lachlan are also reflected in Figure 6-9, as well as a large increase in the Macquarie-Castlereagh. The change in storage volume is driven by the rate of growth and the existing volume of farm dams, for the bigger subcatchments with higher volumes of existing dams, the volumetric change will generally be high. To compare each subcatchment regardless of size, Figure 6-8

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illustrates the change in density of farm dam volumes across the MDB. The highest change in density is in the Eastern Mount Lofty Ranges, followed by subcatchments in the Campaspe and Macquarie-Castlereagh Reporting Regions. Across the Reporting Regions, the Eastern Mount Lofty Ranges also had the highest increase in density of farm dam volume with an extra 0.73 ML/km², followed by the Campaspe (0.69 ML/km²) and Gwydir (0.64 ML/km²) Reporting Regions (Figure 6-10).

- **Table 6-2 Existing and projected volume and density of farm dams, by reporting region, excluding Queensland.**

Reporting Region	Area (km²)	Estimated Existing Volume (GL)	Estimated Existing Density (ML/km^2)	Projected Volume increase by 2030 (GL)	Projected increase as % of existing dams	Projected density increase by 2030 (ML/km^2)
Paroo	35,587	0	0.00	0	0%	0.00
Warrego	76,615	75	0.98	0.05	0%	0.00
Condamine-Balonne	136,642	263	1.92	10	4%	0.08
Moonie	14,662	46	3.16	2	4%	0.13
Border Rivers	43,633	156	3.57	13	8%	0.29
Gwydir	24,947	113	4.54	16	14%	0.64
Namoi	39,780	145	3.63	20	14%	0.51
Macquarie-Castlereagh	73,453	242	3.29	38	16%	0.52
Barwon-Darling	142,173	98	0.69	13	13%	0.09
Lachlan	85,532	261	3.05	36	14%	0.43
Murrumbidgee	87,331	351	4.02	47	14%	0.54
Murray	207,723	94	0.45	11	12%	0.05
Ovens	7,813	30	3.88	2	8%	0.30
Goulburn-Broken	22,337	105	4.72	9	8%	0.39
Campaspe	3,961	35	8.91	3	8%	0.69
Loddon-Avoca	24,918	98	3.92	3	3%	0.12
Wimmera	30,640	34	1.12	0.3	1%	0.01
Eastern Mt Lofty Ranges	4,693	22	4.63	3	16%	0.73
Whole of MDB	1,062,438	2,168	2.04	228	11%	0.21

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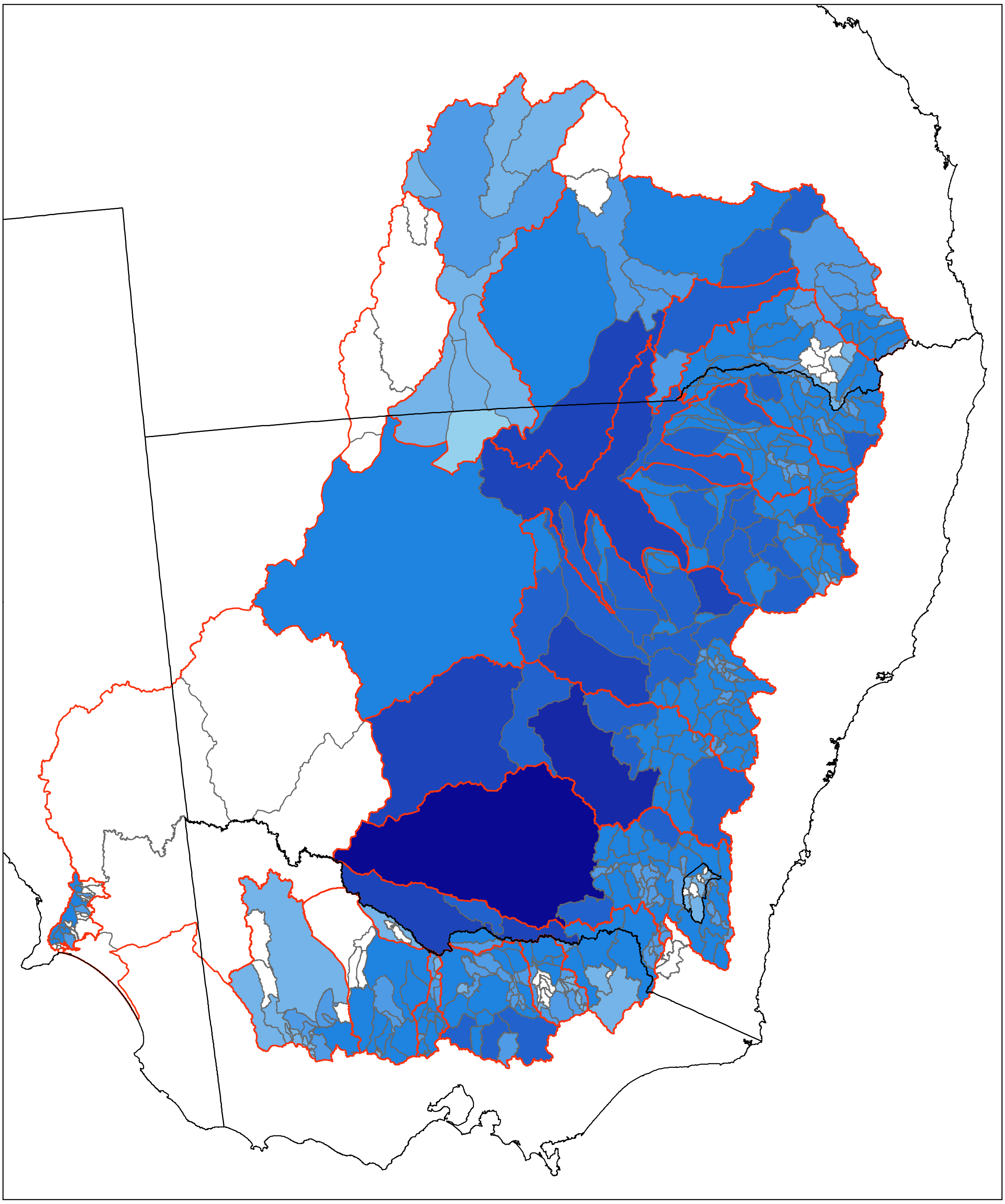

n **Figure 6-7 Adopted projection of additional farm dam storage volume to 2030 (ML) by modelling subcatchment.**

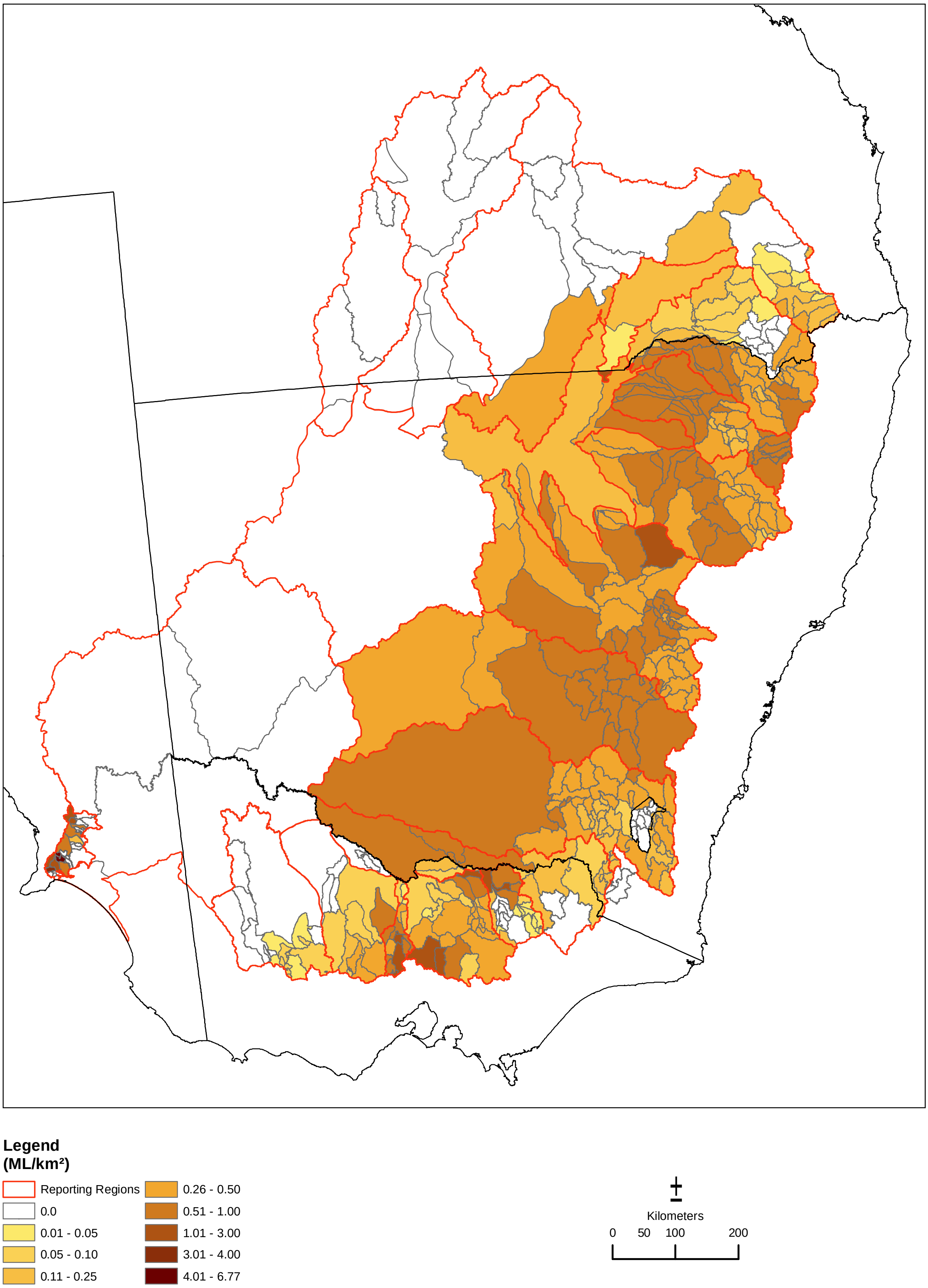

Figure 6-8 Adopted projection of additional density in farm dam storage volume to 2030 (ML/km²) by modelling subcatchment.

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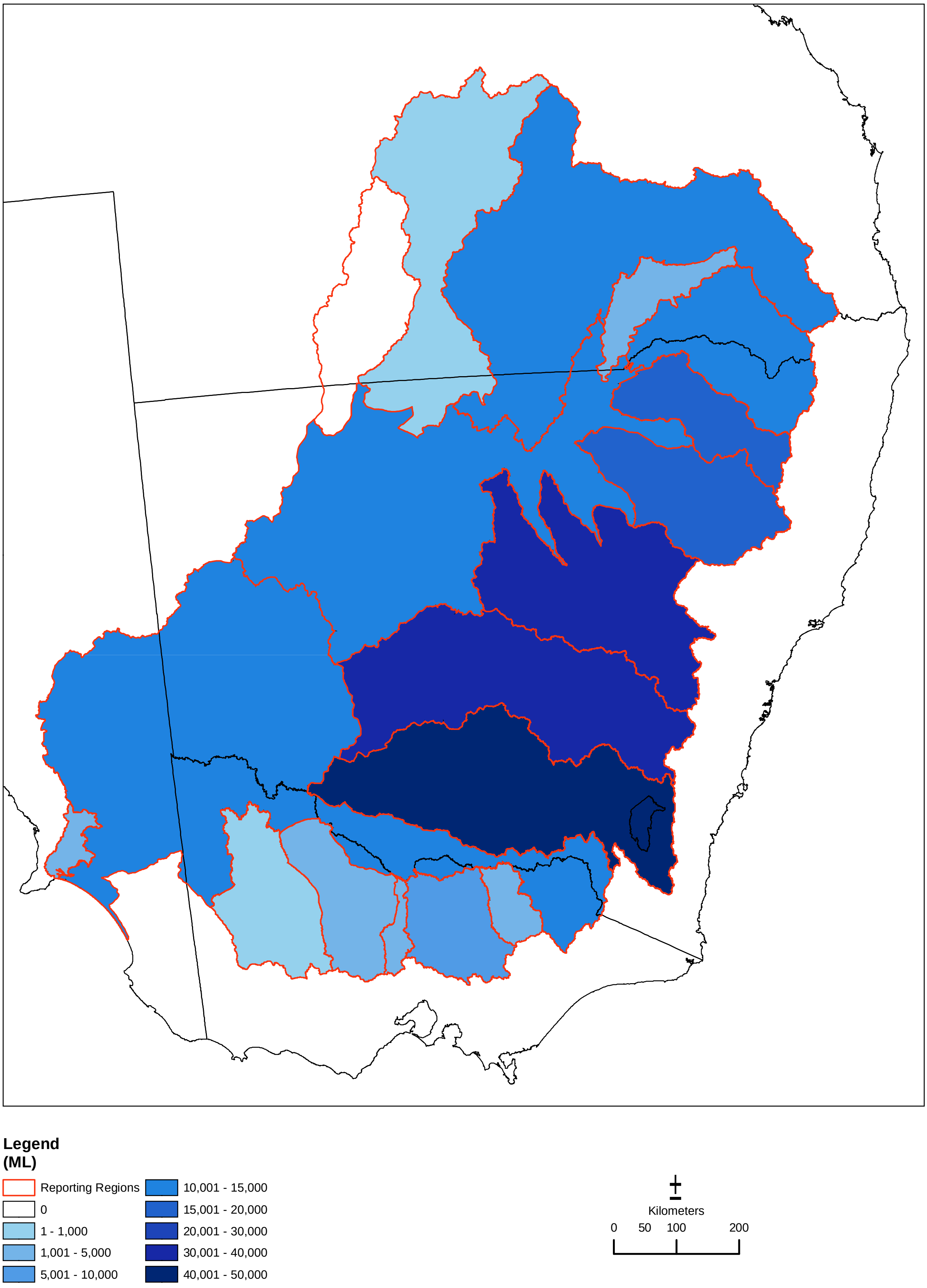

n **Figure 6-9 Adopted projection of additional farm dam storage volume to 2030 (ML) by reporting region.**

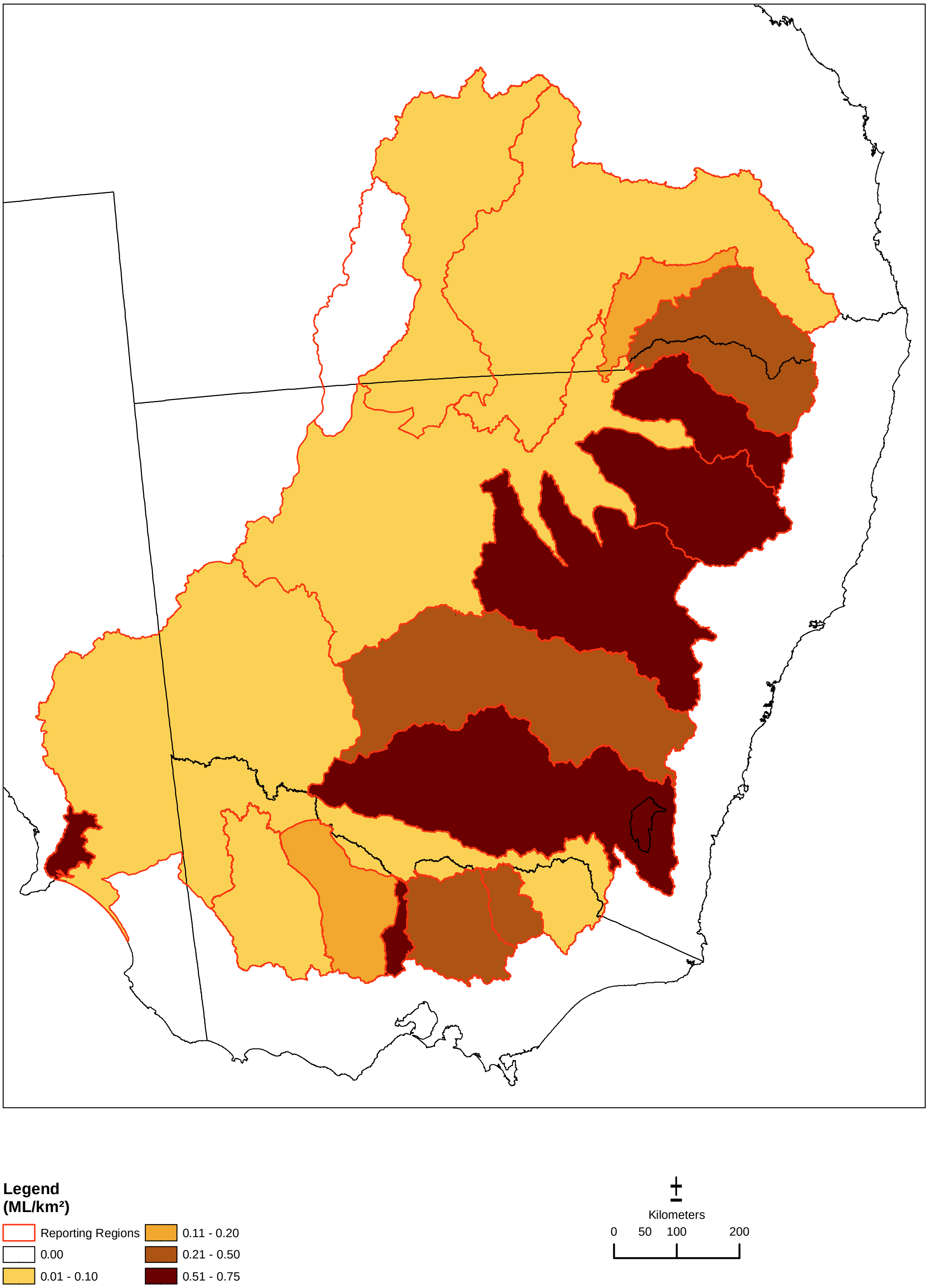

Figure 6-10 Adopted projection of additional density in farm dam storage volume to 2030 (ML/km²) by reporting region.

7 CHEAT

7.1 Background

CHEAT is a conceptual model for estimating time series of runoff from catchments with existing farm dams or a projected increase in farm dams from their existing level (Nathan *et al.*, 2005). In this project, CHEAT was only used to estimate the timeseries of flows impacted by the projected increase in farm dams, using the timeseries of runoff estimated from rainfall runoff modelling of the catchments with adjustment for future plantation forestry. The model can be used, in the reverse direction, to estimate the timeseries of unimpacted flows from the timeseries of flows impacted by farm dams, but it was not used this way in the Project.

The CHEAT model simulates the water balance components of individual farm dams in a catchment. Although CHEAT can be run using a detailed, spatially-explicit representation of farm dams in a catchment using a network topology from a Geographic Information System (GIS), this method was not used because:

- in some modelling subcatchments, the projected increase in the number of farm dams would be in the hundreds or thousands, requiring a considerable volume of input data; and
- because it is a projection of future farm dam development that is being modelled, it is impossible to precisely forecast the specific locations of future farm dams within a modelling subcatchment.

For each modelling subcatchment in this project, the CHEAT model was provided with the projected increase in total farm dam volume and the distribution of farm dam sizes, specified as the proportion of the projected farm dam increase comprised of dams from one of twelve volume classes. CHEAT then generates a sample of individual dams from this distribution.

CHEAT performs a daily water balance for each dam in the generated sample. The water balance for each dam considers inflows from the local catchment area, rainfall falling directly on the dam surface, evaporation losses from the dam, and consumption from the dam to meet irrigation and stock and domestic demands. Demands are extracted from the dams uniformly throughout the year for small, mostly stock and domestic dams, whilst a seasonal pattern of demands for irrigation purposes is specified for dams over a nominated size. The water balance computes the storage in each dam at the end of the day and the volume of any spills from each dam. The dams are assumed to be full at the start of the simulation period but thereafter storage contents are tracked on a daily basis, thus allowing unused water from one year to be carried over to the next. Seepage losses from the dams were assumed to be negligible and were ignored.

For typical catchments with several hundred farm dams, the size distribution in a generated sample will closely approximate the actual distribution and the random effect of this process on natural streamflow calculations is very small. The model does not represent the dams in a spatially explicit manner, and outflows from each dam are directed to the catchment outlet, regardless of whether a proportion of the dams are arranged in a cascade. Nathan *et al*. (2005) demonstrated that the approach of sampling dam sizes from a probability distribution and directing all outflows to the catchment outlet has a negligible impact on the generated streamflow timeseries.

The catchment area corresponding to each farm dam is assumed to be related to farm dam size, and a simple two-stage relationship was adopted in which it is assumed that catchment area is directly proportional to dam size up to a volume of 5 ML, and another linear function relating catchment area to dam volume is adopted for larger dams. This is a gross simplification as it does not consider the large degree of variability associated with local topographic differences; however it does obviate the need for the collection and analysis of high resolution digital elevation data.

An additional simplification is introduced whereby it is assumed that inflows to each individual dam are directly proportional to catchment area, regardless of position in the landscape. Accordingly, it is assumed that a dam with twice the upstream area of another receives twice the inflows. Nathan *et al*. (2005) demonstrated for three catchments that this simplification also has a negligible impact on the generated streamflow timeseries.

The CHEAT model is conceptually very simple, but its complexity is commensurate with the nature of available data. The collation of information on farm dam numbers and size is straightforward, and it is generally possible to obtain information on water demand characteristics and use. The least defensible aspects of the model are the assumptions that the catchment area corresponding to each farm dam is linearly related to farm dam size, and that there is a linear relationship between surface runoff and catchment area for all areas up to the size of the catchment. Clearly these assumptions are unlikely to be valid, but to improve upon them it would be necessary to explicitly consider the spatial arrangement of dams within the catchment, and to have knowledge of the non-linear relationship between upslope area and yield for different geomorphic units within the catchment.

The CHEAT model has the capacity to simulate low flow bypass structures for some or all of the farm dams within a catchment. A low flow bypass structure allows a relatively small flow to pass, in a pipe or open channel, under or around a farm dam with flows in excess of the bypass flow rate capacity available for capture within the dam. Low flow bypasses have been installed on farm dams in a few small Australian catchments to reduce the impact of farm dams on streamflow but there use is not currently widespread. It was assumed for this study that none of the projected new farm dams to 2030 would have low flow bypasses installed.

7.2 Inputs

The input data requirements for CHEAT modelling of each subcatchment are provided in Table 7-1. The following sections provide information on each of the input data sources for the CHEAT modelling in this project. The modelling period for the CHEAT models was 01 January 1895 – 31 December 2006.

- **Table 7-1 Summary of input data requirements for CHEAT modelling in each subcatchment**

CHEAT input required	Source
Daily time series of runoff, adjusted for a climate change scenario and projected future plantation forestry to 2030	Supplied by CSIRO from SimHyd modelling for relevant Scenario C runs (3GCMs x 3 global warming scenarios), after adjustment for projected future plantation forestry. See Section 7.2.1 below
Daily time series of subcatchment average rainfall, adjusted for projected climate change to 2030	Supplied by CSIRO for relevant Scenario C runs. See Section 7.2.2 below
Daily time series of subcatchment average point potential evaporation, adjusted for projected climate change to 2030	Subcatchment average areal actual evaporation supplied by CSIRO for relevant Scenario C runs and then scaled by average ratio of point potential to areal actual evaporation (also supplied by CSIRO). See Section 7.2.2 below
Projected increase in total volume of farm dams to the year 2030	See Chapters 3 to 6 of this report
Distribution of farm dam sizes for projected new farm dams to the year 2030	See Chapters 3 to 6 of this report
Functional relationship between farm dam storage volume and surface area	Adopted from Sinclair Knight Merz (2004b) see Section 4.1 of this report
Ratio of annual demand on each dam to its storage volume	See Section 7.2.3 below
Monthly pattern of diversions from each farm dam	See Section 7.2.3 below
Functional relationship between farm dam storage volume and catchment area	See Section 7.2.4 below

7.2.1 Daily time series of runoff

A daily series of Scenario C runoff was provided by CSIRO from rainfall runoff modelling. The series were provided for each subcatchment for each of the 9 global climate models chosen for the reporting region. If there was projected future plantation forestry in the reporting region, this was already accounted for in the runoff time series.

7.2.2 Daily time series of rainfall and point potential evapotranspiration

Subcatchment averages of daily rainfall and daily areal potential evapotranspiration were provided by CSIRO for each climate change scenario. Point potential evapotranspiration is required for use in CHEAT, so a factor was used to convert the areal potential evaporation to point potential evaporation (see Table 7-2) according to the reporting region.

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- **Table 7-2 Conversion factor to convert areal potential evapotranspiration to point potential evapotranspiration provided to CSIRO**

Reporting region number	Reporting region name	APET to PPET Conversion factor
1	Paroo	1.71
2	Warrego	1.62
3	Condamine-Balonne	1.50
4	Moonie	1.48
5	Border Rivers	1.37
6	Gwydir	1.40
7	Namoi	1.39
8	Macquarie-Castlereagh	1.43
9	Barwon-Darling	1.61
10	Lachlan	1.46
11	Murrumbidgee	1.42
12	Murray	1.51
13	Ovens	1.32
14	Goulburn-Broken	1.33
15	Campaspe	1.35
16	Loddon-Avoca	1.43
17	Wimmera	1.43
18	Eastern Mt Lofty Ranges	1.37

7.2.3 Rate and monthly pattern of diversions from farm dams to consumptive use

A demand factor is used to calculate the annual demand for each dam. The demand pattern is then used to disaggregate the annual demand into monthly demands for use in CHEAT modelling. These demand factors are different for stock and domestic dams and irrigation demands as are the demand patterns. The assumptions and methods are detailed in 7.2.3.1 and 7.2.3.2.

7.2.3.1 Stock and domestic farm dams

Each year, it is estimated that approximately half the volume of each stock and domestic dam is consumed. The demand factor for each dam is therefore 0.5. As stock and domestic dams are used to water stock each day and for domestic purposes, it is assumed that the demand pattern for stock and domestic dams is constant throughout the year. The difference in the demand from month to month as seen in Figure 7-1 is caused by the different number of days in each month.

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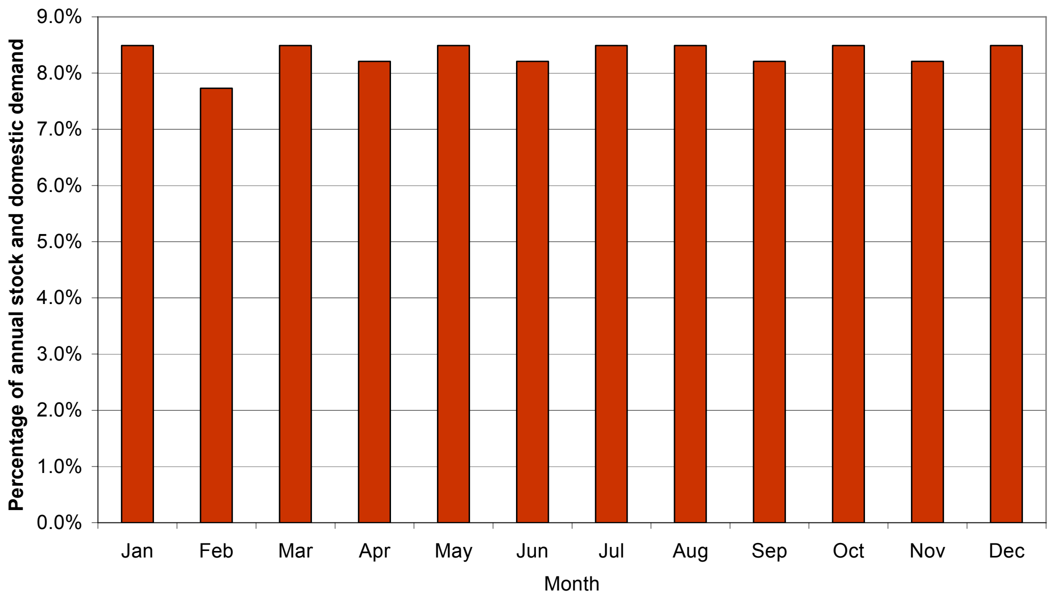


- **Figure 7-1 Annual pattern of demand for stock and domestic farm dams. The demand is governed by the number of days in each month.**

7.2.3.2 Farm dams used for irrigation

In Victoria, it has been calculated that the annual irrigation demand is 84% of the dam volume. This demand factor has been applied across the MDB (Sinclair Knight Merz, 2004a).

It is assumed that the demand pattern from irrigation dams is equivalent to the average monthly net evapotranspiration for the area. Therefore the monthly irrigation demand patterns were calculated using the rainfall and areal potential evapotranspiration for each global warming scenario. These data were used on a daily basis to calculate the monthly net evaporation for the entire period January 1895 to December 2006. The average monthly net evaporation for the scenario was then computed. This monthly net evaporation was used as a monthly pattern of diversions from irrigation dams. These patterns are detailed in Appendix O for the median climate change scenario in each reporting area in New South Wales, Queensland and South Australia.

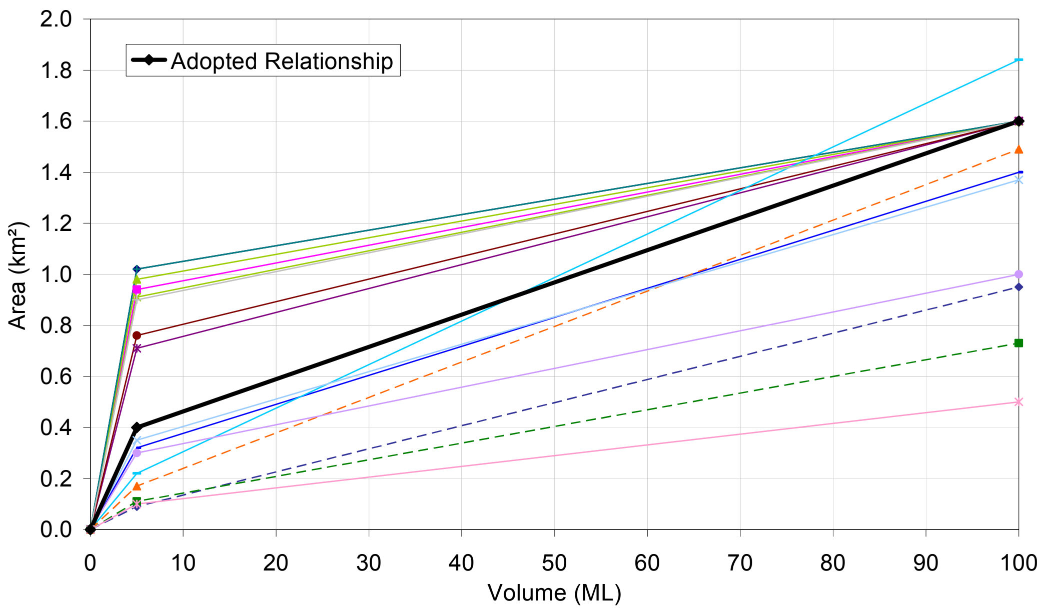
While the monthly net evapotranspiration is a reasonable estimate of the demand from irrigation demands, it does not incorporate the irrigation requirements of different crops.

7.2.4 Relationship between volume and catchment area of individual farm dams

In order to determine how much water flows into each farm dam and therefore how much of the total catchment flow is affected by each farm dam, the subcatchment area upstream of each dam must be estimated. This is difficult to estimate with any certainty as the subcatchment area for each dam is very different, depending on the specific location and topography. However, as a general trend, it has been observed that larger dams tend to have larger catchment areas, usually in order to ensure a viable long term yield for the dam. For this reason, there is some correlation between the volume of a dam and its subcatchment area.

The relationship between the catchment area and the volume of the farm dam is dependent on the topography of the catchment. If the terrain is steep, the catchment size for a dam of a particular volume is likely to be smaller, and conversely if the terrain is flat, the catchment area for the same size dam is likely to be bigger. In general, this relationship can be calculated from either a digital elevation model, or from the stream density of an area. This has been undertaken for a wide range of catchments in Victoria covering many different types of topography, and the resulting relationships between volume and catchment area are illustrated in Figure 7-2.

For this project, estimation of specific relationships between dam volume and subcatchment area on a regional basis was not possible because this would have involved detailed spatial analysis of farm dam subcatchment areas across the entire Murray-Darling basin. Instead, a single relationship was adopted across the entire basin which was considered to be typical for catchments in Victoria and South Australia, and was therefore assumed to provide a reasonable representation of most areas within the basin. The adopted relationship is shown in Figure 7-2 as the black bold line. The detail of this relationship is provided in Table 7-3.



- **Figure 7-2 Comparison between the volume-catchment area relationship adopted for this study (black bold line) and relationships derived from several other similar studies from catchments in Victoria and South Australia.**

- **Table 7-3 Adopted relationship between volume and catchment area of individual farm dams**

Dam volume (ML)	Catchment area (km^2)
0	0.0
5	0.4
100	1.6

8 Results and discussion

The growth in farm dams will impact on the hydrology of the Murray-Darling Basin in a number of different ways. The following chapter provides and discusses the results from the CHEAT modelling in terms of the different impacts that could be expected. These are principally the mean annual impact on runoff, impact on daily flows and the seasonality and timing of flows. Also included is a discussion of the uncertainties in the projection and modelling assumptions made; and the variability in the climate change scenarios.

8.1 Projected reductions in mean annual runoff

The magnitude of the reduction in runoff was variable across the basin and was dependent on a combination of factors, although the projected increase in farm dam storage volume to 2030 was the main driver. Farm dam growth was projected to centre on areas with a high volume of existing dams, or in areas of higher population growth. High volume of existing farm dams is an indicator that the area is climatically and hydrologically suitable for the development of future farm dams. Likewise, high projection of population growth is an indicator that the number of dams built for stock and domestic purposes will increase to support new subdivisions and increased domestic usage.

The overall projected increase in farm dam development to 2030 for the whole MDB is 228 GL. This would result in a reduction in mean annual runoff of 180 GL. This represents a reduction in mean annual runoff for this scenario of 0.17 mm or 0.64% of mean annual runoff.

The increase in farm dams in the Eastern Mount Lofty Ranges reporting region had the highest percentage impact on runoff, with a 3% decrease in mean annual runoff over the reporting region. This was because the projected growth in the reporting region was high, at 16% over the 24 year period.

Campaspe had the next highest percentage impact, driven by the relatively large 25% projected increase in population in the reporting region. The impact of farm dams in the NSW reporting regions of Lachlan, Namoi, Gwydir and Macquarie-Castlereagh resulted in a reduction of runoff of between 1% and 1.45% in those reporting regions. The large volume of existing dams in these areas and therefore the high projected volume of farm dams, and the reasonably low runoff combined to make the impact of farm dams in these areas considerable.

As can be seen in Table 8-1, the highest volumetric reduction in runoff, caused by the increase in farm dams in the MDB, was in the Murrumbidgee. Although this produced the largest volumetric reduction in runoff, the 0.95% reduction in runoff was similar to the other reporting regions in NSW.

In the western part of NSW, Queensland and Victoria, there was very little change in the volume of farm dams as the runoff in the area was not generally high enough to support many more farm dams, the low projections reflected current policy in those areas and the low runoff. Reductions in runoff in the Paroo, Warrego, Wimmera, Barwon-Darling and Murray reporting regions were small.

The Goulburn-Broken and the Ovens reporting regions are the wettest reporting regions in the MDB. While the Goulburn-Broken has a high volume of existing farm dams, the projection was small due to relatively low projected population growth. In the Ovens there was a small volume of existing dams and the projection was also small. Due to the low projection of farm dams, small reduction in runoff and high total runoff in these reporting regions, the percentage impact on runoff was low when compared to the other wet reporting regions.

This information is also represented spatially in Figure 8-1 for the D_{mid} scenarios for each subcatchment. The reduction is concentrated in the eastern part of NSW, the central Victorian part and the Eastern Mount Lofty Ranges. These are modelling subcatchments where projected increases in farm dam volumes are relatively high and runoff is also relatively high and therefore water is available for capture by farm dams.

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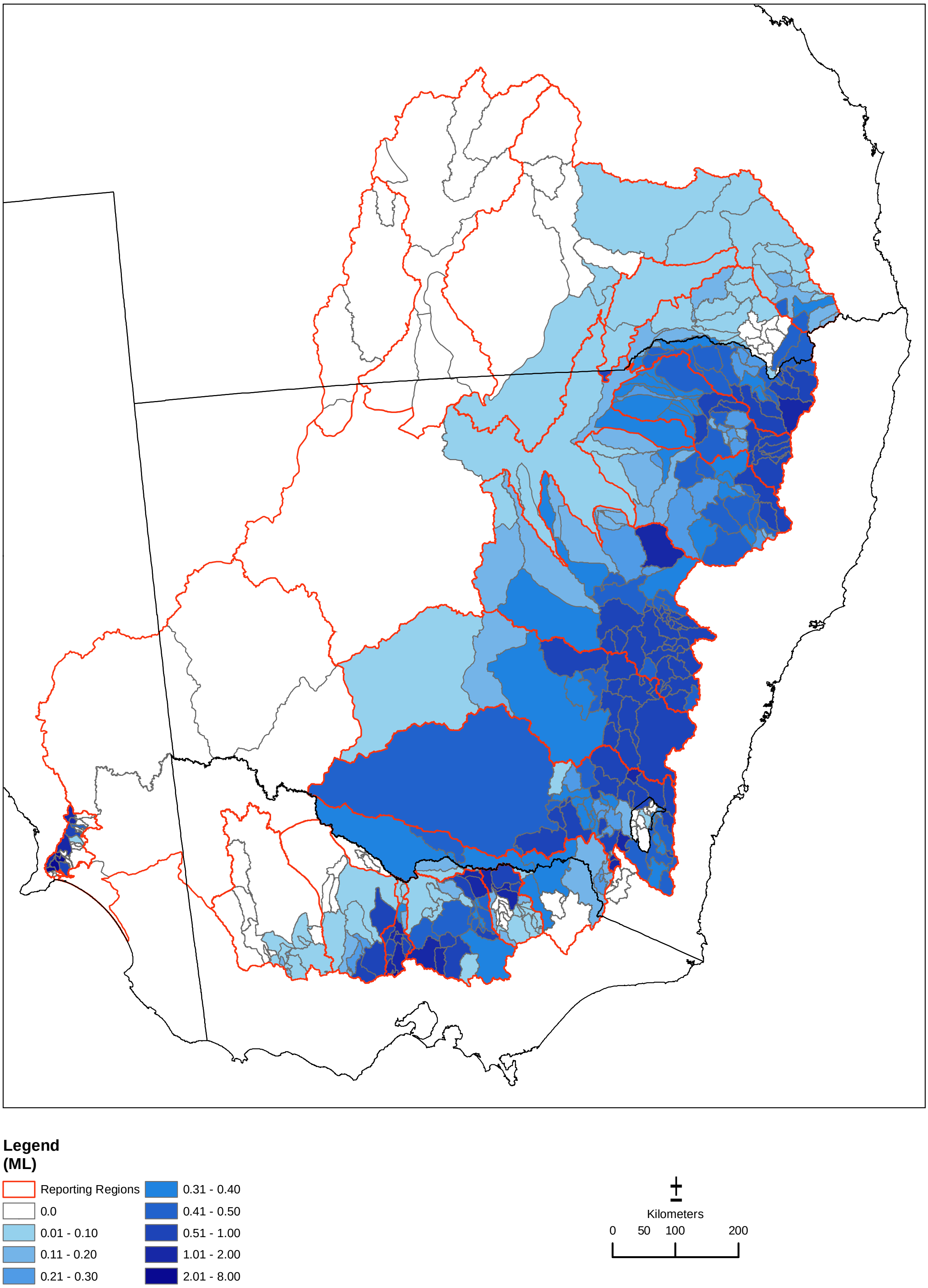
■ **Table 8-1 Summary of CHEAT modelling and results for the D_{mid} scenario**

Reporting region	Reporting region area (km²)	Existing volume of dams (GL)	Projected additional dams (GL)	Runoff for the $C_{+Plantations}$ scenario (mm)	Reduction in runoff over the reporting region (mm)	Reduction in runoff over the reporting region (GL)	Percentage of impact from $C_{+plantations}$ to Dmid
Paroo	35,587	0	0	14.56	0.00	0	0.00%
Warrego	76,615	75	0.05	29.20	0.00	0.1	0.00%
Condamine-Balonne	136,642	263	10	17.31	0.03	5	0.20%
Moonie*	14,662	46	2	15.61	0.11	2	0.68%
Border Rivers*	43,633	156	13	29.37	0.32	14	1.09%
Gwydir	24,947	113	16	36.87	0.48	12	1.31%
Namoi	39,780	145	20	22.95	0.32	13	1.38%
Macquarie-Castlereagh	73,453	242	38	32.32	0.40	30	1.25%
Barwon-Darling	142,173	98	13	5.92	0.02	3	0.35%
Lachlan	85,532	261	36	20.81	0.30	26	1.44%
Murrumbidgee	87,331	351	47	48.80	0.46	40	0.95%
Murray	207,723	94	11	20.84	0.04	9	0.20%
Ovens	7,813	30	2	203.65	0.46	4	0.23%
Goulburn-Broken	22,337	105	9	129.16	0.56	13	0.44%
Campaspe	3,961	35	3	57.17	0.95	4	1.66%
Loddon-Avoca	24,918	98	3	17.37	0.14	3	0.80%
Wimmera	30,640	34	0.3	13.80	0.01	0.4	0.09%
Eastern Mt Lofty Ranges	4,693	22	3	27.13	0.87	4	3.22%
Whole of MDB	1,062,438	2,168	228	26.11	0.17	180	0.65%



- **Figure 8-1 The areal reduction in runoff (mm) across the Murray-Darling Basin caused by the projected increase in farm dams from 2006-2030 for the Dmid scenario.**

8.2 Temporal variations in impact on runoff

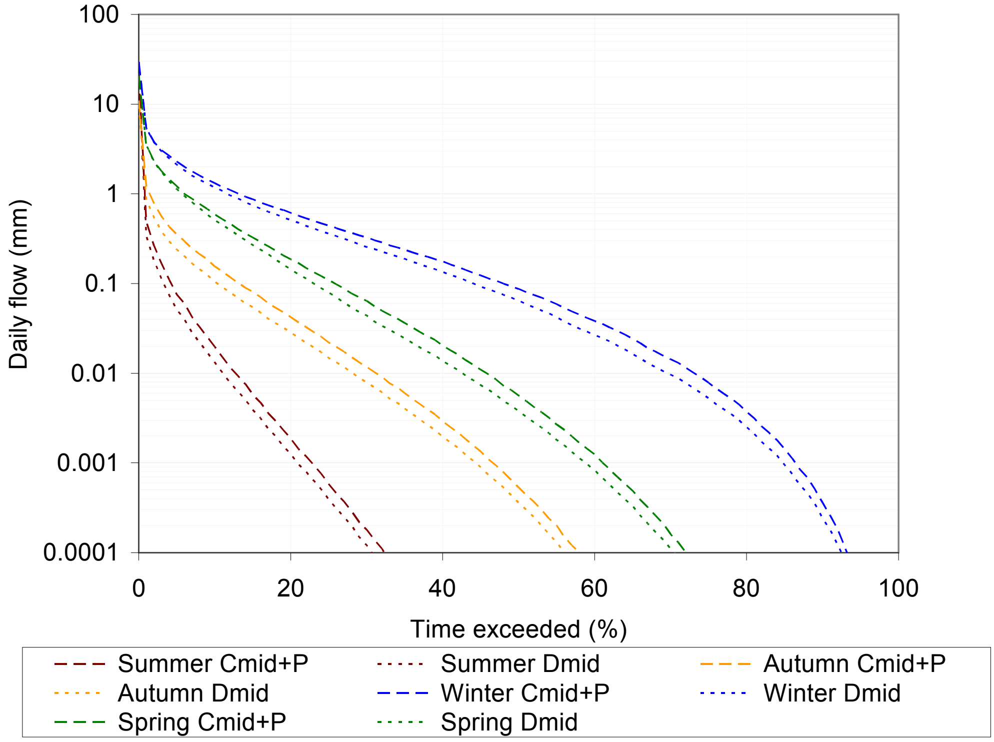
The impact of farm dams is not spread uniformly within years. Farm dams capture inflows over the wet season and the water stored in the dams are then lost by evaporation and used for consumptive use, with losses and demands often concentrated in the dry season.

In the southern part of the MDB, the wet season usually commences in May or June and runs through until October or November. Unless low flow bypasses are installed, the farm dams built in these areas capture most of their runoff over May through July and these are the months when farm dams cause the largest reductions in overall catchment runoff. In the southern MDB, the farm dams would fill and typically spill during late winter and spring (typically August through November), so relative reductions on runoff in these months are lower. Unless low flow bypasses are installed, farm dams will capture any runoff occurring over summer and autumn that does occur, although runoff events during these months are infrequent.

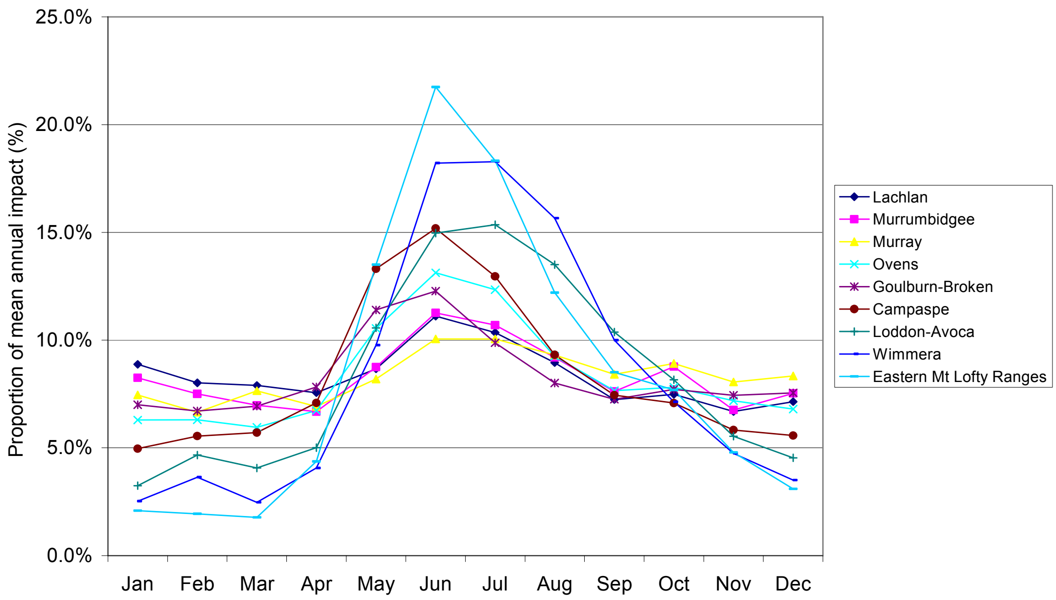
Figure 8-2 shows flow duration curves by season, for an example catchment in the southern MDB, the Angus River at Angus Weir in the Eastern Mount Lofty Ranges Reporting Region. Runoff in summer and autumn is lower than runoff in winter and spring, for both the $C_{mid+Plantations}$ and D_{mid} scenarios. For moderate to low flows (up to the 20th percentile), the gap between the two curves is about the same on the logarithmic scale regardless of the season, indicating that in this catchment farm dams have a consistent percentage impact upon low and moderate flows. In the very high flow range (fifth percentile and above) the flow duration curves for the $C_{mid+Plantations}$ and D_{mid} scenarios converge because during periods of very high runoff the farm dams would fill and spill and overall catchment runoff would be unaffected. However, in the high flow range (between the fifth and 20th percentile), there is a significantly larger percentage difference between the $C_{mid+Plantations}$ and D_{mid} scenarios for autumn than for winter, spring or summer. This is evidence of farm dams in the southern MDB capturing high flows at the end of autumn. This seasonal pattern is also demonstrated for the southern reporting regions (Ovens, Goulburn-Broken, Campaspe, Loddon-Avoca, Wimmera and EMLR) in Figure 8-3.

The seasonal pattern of runoff is reversed in the northern MDB, with the wet season occurring over summer and autumn and the dry season over winter and spring. Figure 8-4 shows that for the northern reporting regions the seasonality of the impact is also reversed from the southern ones, with the highest impacts occurring over December through February.

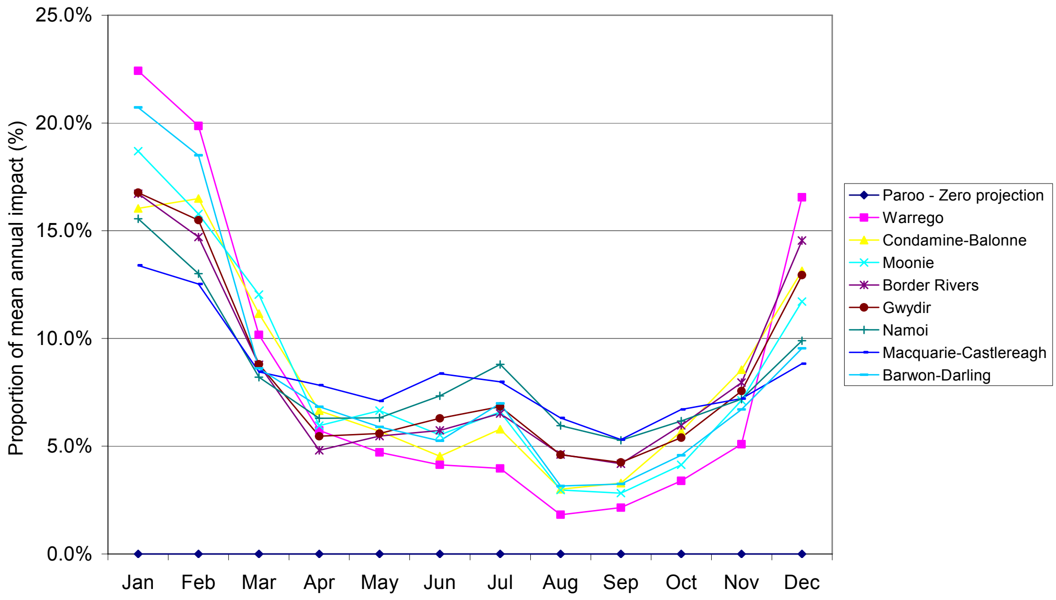
The Murrumbidgee, Murray and Lachlan reporting regions can produce runoff in both the northern and southern wet seasons. The seasonal pattern of impacts in these three reporting regions (see Figure 8-3) is distributed more uniformly across the year.



- **Figure 8-2 Flow duration curves by calendar season for $C_{mid+plantaions}$ and D_{mid} scenarios for the subcatchment 426050030 (Angus at Angus Weir in the Eastern Mount Lofty Ranges Reporting Region)**



- **Figure 8-3 Proportion of mean annual impact that occurs in each month of the calendar year for reporting regions that are generally in the south of the MDB**



- **Figure 8-4 Proportion of mean annual impact that occurs in each month of the calendar year for reporting regions that are generally in the north of the MDB. Note that there was no projected change in the volume of farm dams in Paroo**

8.3 Confidence in farm dam projections and modelling of impacts

The estimates of rainfall runoff for 2030 between different GCM and global warming scenarios carried the lowest level of confidence and the highest level of uncertainty for both Scenario C and Scenario D modelling, but this source of uncertainty is not considered further in this section of the report. There is a variable level of confidence in the data used to model the impact of farm dams on runoff in the MDB. There is a high level of confidence in a number of the inputs to the CHEAT modelling, and in the modelling techniques used in the CHEAT program. There is lower confidence in the assumptions required to project the change in the volume farm dams.

Table 8-2 lists the major types of data that were used to project the future impact of farm dam storage, and the coloured dots in the table represent a qualitative indication of the relative level of confidence held in the data compared to the overall confidence in projecting future impacts of farm dams.

The first seven types of data from the left of Table 8-2 are data that were used to project the future increase in storage capacity of farm dams. These data are likely to have the highest impact on the results of modelling and they have a moderate level of confidence associated.

For catchments in New South Wales, the lowest confidence is in the extrapolation of the historical growth rate to produce the projection of the increase in storage capacity of farm dams. There are several reasons for this:

- The historical trend is based upon a sample of farm dams in the MDB captured by Agrecon (2005), which represents only about 1% of the total area and there is sampling uncertainty associated with the estimate of the historical growth rate;
- The future trend in farm dam development rate assumes that the historical rate of farm dam growth is maintained for the forthcoming 24 years, yet the historical growth rate was based upon observations taken only over a period of approximately 5 years (1999-c.2004);
- For the area of NSW that is not covered by Geoscience Australia (2007) farm dam data, the volume of existing farm dams have been estimated based upon landuse and these estimated values will then be reflected in the projection based upon the historical growth rate;
- Historical growth rates have been derived from total volumes of farm dams in the Appendices to the Agrecon (2005) report. There were some differences in the transformation function from surface area to volume for farm dams used in the rest of this study to the method used by Agrecon (2005). A reanalysis of the raw Agrecon data (which was not available to the project team) may have resulted in slight adjustments to the estimated historical growth rates.

The projections for the New South Wales reporting regions assumed a growth rate of 0.6% per year for the period to 2030 in rural SLA, based upon an extrapolation of the historical growth rates. At this projected rate of growth, in most reporting regions only around 20% of the available

Harvestable Right as of 2006 would be consumed by 2030. There is some potential for growth rates in farm dam volumes, at least in some parts of the New South Wales MDB, to be considerably higher than the projected growth rate used in this study without even approaching the limit set by the Harvestable Right Policy.

The low confidence in estimating the available Harvestable Right only apply to NSW and even there, the potential impact upon the projected runoff is low because the Harvestable Right can be accurately estimated for each individual property, the proportion of the Harvestable Right available is relatively consistent across different landuse classes and in virtually all SLAs the adopted projection is much lower than the available Harvestable Right.

The assumption across the MDB that current legislation and policy in each jurisdiction will continue until 2030 has a moderate level of confidence. Legislation and policy are at the behest of governments and it is possible that they may change over the course of the next two decades. In particular, the Australian Government's National Plan for Water Security (Howard, 2007) may result in the Commonwealth Government passing legislation that would regulate future development of farm dams, which could supersede the existing state and territory legislation. It is difficult to project the changes that may occur to policies in regard to farm dams over the forthcoming decades and the effects that these changes may have on projected increases in farm dam development. Changes in policy are particularly relevant for the Eastern Mount Lofty Ranges, where a water management plan is still under development and the projections in this study have been based upon a continuation of the policies that were in place prior to prescription in September 2005.

Projections in Queensland and Victoria are primarily based upon an assumption that growth in stock and domestic farm dam volumes are proportional population growth. There is a moderate level of confidence in the impact on runoff resulting from the variation between rates of growth of farm dams and population growth. There is also a moderate level of confidence about the population projections themselves from demographic modelling over the projection period to 2030. If these projections are not accurate, the impact will be lower for the reporting regions that are wholly within New South Wales or the EMLR because the population based growth projections were used only as a secondary guide there.

There are reliable estimates of existing farm dam development from high quality spatial data in all of the Victorian reporting regions, the Border Rivers and Gwydir. Less accurate estimates of existing farm dam development are available in the Namoi, Macquarie, Lachlan, Barwon-Darling, Murrumbidgee and Murray reporting regions. These uncertainties in estimation of existing farm dam development leads to uncertainties in both the projections made using an extrapolation of historical growth rates and in projections made based upon population growth.

The last five data types, those on the right side of Table 8-2, are related to modelling the impact on runoff of the projected increases in farm dam volumes. The most significant of these is the assumed ratio of consumptive demand from the farm dam storages to their storage volume because there is virtually no metering of consumption from farm dams and any change demand will cause a direct change in the volume of runoff from the catchment. There is also some potential that climate change may increase the consumptive demand from both existing and new farm dams relative to their volumes; however this effect has not been explicitly modelled because of a lack of data on how this may change. Simulation studies with the CHEAT model by Nathan et al. (2005) have demonstrated that the assumed relationship between dam storage volume and catchment area and representation of cascading of farm dams in the catchment normally have an insignificant influence on runoff. The confidence in the ratio of point to areal evaporation only affects the net evaporation losses, which are normally a smaller component of the water balance than the consumptive demands, thereby having a lower effect on the level of confidence in runoff. For this present study, the relationship between farm dam volume and surface area has a low influence on confidence because this relationship is only used to estimate the surface area from the projected new dams, affecting only the smaller net evaporation term of the water balance.

- **Table 8-2 Summary of uncertainties in the future farm dam volume projections and the CHEAT modelling**

Reporting Region	Policy Change	Relationship between population and farm dam growth	Uncertainty in population projections	Continuation of growth rate in NSW (Agrecon trend)	Existing density of farm dams	Harvestable right method estimate based on method and data	Size distribution of farm dams	Relationship between surface area and volume	Relationship betwen volume of dams and catchment area	Demand factors – irrigation and stock and domestic	Cascading of farm dams	Conversion of APET to PPET
Paroo	Moderate	Moderate	Moderate				Low	Low	Low	Moderate	Low	Low
Warrego	Moderate	Moderate	Moderate				Low	Low	Low	Moderate	Low	Low
Condamine-Balonne	Moderate	Moderate	Moderate				Low	Low	Low	Moderate	Low	Low
Moonie	Moderate	Moderate	Moderate				Low	Low	Low	Moderate	Low	Low
Border Rivers	Moderate	Moderate	Moderate	High	Low	Low	Low	Low	Low	Moderate	Low	Low
Gwydir	Moderate	Low	Low	High	Low	Low	Low	Low	Low	Moderate	Low	Low
Namoi	Moderate	Low	Low	High	Moderate	Low	Low	Low	Low	Moderate	Low	Low
Macquarie-Castlereagh	Moderate	Low	Low	High	High	Low	Low	Low	Low	Moderate	Low	Low
Barwon-Darling	Moderate	Low	Low	High	Moderate	Low	Low	Low	Low	Moderate	Low	Low
Lachlan	Moderate	Low	Low	High	Moderate	Low	Low	Low	Low	Moderate	Low	Low
Murrumbidgee	Moderate	Low	Low	High	Moderate	Low	Low	Low	Low	Moderate	Low	Low
Murray	Moderate	Moderate	Moderate	High	High	Low	Low	Low	Low	Moderate	Low	Low
Ovens	Moderate	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low
Goulburn-Broken	Moderate	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low
Campaspe	Moderate	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low
Loddon-Avoca	Moderate	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low
Wimmera	Moderate	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low
Eastern Mt Lofty Ranges	High	Moderate	Moderate		Low		Low	Low	Low	Moderate	Low	Low

Potential impact on modelling results:

Blank = not relevant to reporting region   Low   Moderate   High

9 Conclusion

To produce the D scenario runoff series for the Murray-Darling Basin Sustainable Yields Project, the nine C scenario runoff time series (with the impacts of plantations included) were altered by the modelled impact on runoff caused by the development of farm dams in the Murray-Darling Basin (MDB) to the year 2030. To do this, the current volume of storage in farm dams was estimated and the 2030 volume of storage in farm dams was projected for each subcatchment. To model the impact of the change in storage on the runoff in each subcatchment, the CHEAT model was applied. CHEAT was used to estimate the timeseries of flows impacted by the projected increase in farm dams, using the timeseries of runoff estimated from rainfall runoff modelling of the catchments with adjustment for future plantation forestry.

The change in runoff for each subcatchment was modelled for each climate change scenario and the resultant D scenario timeseries was developed. A comparison between the D_{mid} scenario runoff and the $C_{mid+Plantations}$ scenario runoff was done on an annual basis, looking at the reduction in dam density and reduction in runoff. Analysis was also done on the seasonality of runoff for the Dmid scenario in each subcatchment and reporting region.

It was projected that there would be an increase in farm dam development across the MDB of 228 GL. This increase would result in a reduction in runoff of 180 GL which is a reduction in mean annual runoff across the MDB of 0.17 mm. This is a reduction of 0.64% of the $C_{mid+Plantations}$ runoff. The reduction in runoff was greatest in areas where the projected volume change was greatest, these areas were the Eastern Mount Lofty Ranges, the eastern part of NSW and the central part of Victoria.

Between seasons, there was a differential in the flow duration curve with the main difference being in the high flows for the example catchment in the Eastern Mount Lofty Ranges. Across the year, there was a distinct north-south difference in the monthly percentage of impact. In the southern part of the basin, runoff was mainly impacted in the winter when the total runoff is highest. Conversely, in the summer dominated systems in the north, the greatest impact on runoff was in summer.

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Appendix A Density of existing farm dam volume by landuse for New South Wales

- **Density of existing total farm dam development by landuse for properties in NSW that have farm dam data coverage from Geoscience Australia (2007)**

  *** "Adopted values" are implemented in cases where there is a lack of data for that land use type.**

Landuse		Number of parcels	Total area (km²)	Existing volume of farm dams (ML)	Existing density of farm dams (ML/ha)	Existing density of farm dams – adopted* (ML/ha)
Code No.	Description					
210	Relatively natural environments : Livestock grazing	68611	83530	373231	0.045	0.045
330	Dryland agriculture and plantations : Grazing modified pastures	23530	18789	93882	0.050	0.050
340	Dryland agriculture and plantations : Cropping	15	33	45	0.013	0.038 Adopted value from #341
341	Dryland agriculture and plantations : Cropping : Cereals	18912	28563	107725	0.038	0.038
343	Dryland agriculture and plantations : Cropping : Hay and silage	6	4	4	0.011	0.038 Adopted value from #341
344	Dryland agriculture and plantations : Cropping : Oilseeds and oleaginous fruit	2986	2780	13408	0.048	0.048
346	Dryland agriculture and plantations : Cropping : Cotton	215	501	934	0.019	0.019
348	Dryland agriculture and plantations : Cropping : Legumes	1268	2200	8905	0.040	0.040
351	Dryland agriculture and plantations : Perennial horticulture : Tree fruits	32	31	69	0.022	0.022
353	Dryland agriculture and plantations : Perennial horticulture : Tree nuts	0	0	0	N/A	0.022 Adopted value from #351
354	Dryland agriculture and plantations : Perennial horticulture : Vine fruits	10	22	16	0.008	0.022 Adopted value from #351

Landuse		Number of parcels	Total area (km²)	Existing volume of farm dams (ML)	Existing density of farm dams (ML/ha)	Existing density of farm dams – adopted* (ML/ha)
Code No.	Description					
364	Dryland agriculture and plantations : Seasonal horticulture : Vegetables and herbs	5	4	5	0.010	0.038 Adopted value from #341
430	Irrigated agriculture and plantations : Irrigated modified pastures	861	1062	6324	0.060	0.060
440	Irrigated agriculture and plantations : Irrigated cropping	49	79	894	0.113	0.113
441	Irrigated agriculture and plantations : Irrigated cropping : Irrigated cereals	1771	2389	19338	0.081	0.081
443	Irrigated agriculture and plantations : Irrigated cropping : Irrigated hay and silage	1	1	0	0	0.081 Adopted value from #441
444	Irrigated agriculture and plantations : Irrigated cropping : Irrigated oilseeds and oleaginous fruit	38	43	80	0.018	0.018
446	Irrigated agriculture and plantations : Irrigated cropping : Irrigated cotton	1456	2387	43604	0.183	0.183
448	Irrigated agriculture and plantations : Irrigated cropping : Irrigated legumes	46	55	160	0.029	0.029
451	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated tree fruits	87	98	347	0.035	0.035
453	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated tree nuts	0	0	0	0.000	0.035 Adopted value from #451
454	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated vine fruits	119	122	567	0.047	0.047
464	Irrigated agriculture and plantations : Irrigated seasonal horticulture : Irrigated vegetables and herbs	95	105	398	0.038	0.038

Appendix B Classification of SLA into urban and rural for projection of future farm dam volumes

Farm dams, as suggested by their name, are a potential source of water in rural areas. Urban areas are serviced by reticulated water systems that are operated by local government or state government constituted water authorities. It is therefore relatively rare for farm dams to occur in urban areas.

For this study, it was projected that there would be no growth in farm dam volume within urban areas. The distinction between rural and urban areas was made by classifying all of the SLA that intersected the MDB as either rural or urban. The table below shows the classification of SLA into urban, where the projected growth in farm dams was assumed to be zero, and rural, where projected growth in farm dam volumes was possible.

- **Statistical Local Area (SLA) classification into Urban (assumed no projected growth in farm dams) and Rural (projected growth in farm dams possible)**

State or Territory	SLA considered as "Urban" Assumed no growth in farm dams	SLA considered as "Rural" Growth in farm dam volumes possible
Vic	Campaspe (S) - Echuca Delatite (S) - Benalla Greater Bendigo (C) - Central Greater Bendigo (C) - Eaglehawk Greater Bendigo (C) - Inner East Greater Bendigo (C) - Inner North Greater Bendigo (C) - Inner West Greater Bendigo (C) - S'saye Greater Shepparton (C) - Pt A Horsham (RC) - Central Mildura (RC) - Pt A Moorabool (S) - Bacchus Marsh Mount Alexander (S) - C'maine Swan Hill (RC) - Central Towong (S) - Pt A Wangaratta (RC) - Central Whittlesea (C) - North Wodonga (RC)	All other SLA in Vic
Qld	Cambooya (S) - Pt A Crow's Nest (S) - Pt A Dalby (T) Goondiwindi (T) Jondaryan (S) - Pt A	All other SLA in Qld

State or Territory	SLA considered as "Urban" Assumed no growth in farm dams	SLA considered as "Rural" Growth in farm dam volumes possible
	Roma (T) Rosalie (S) - Pt A Toowoomba (C) - Central Toowoomba (C) - North-East Toowoomba (C) - North-West Toowoomba (C) - South-East Toowoomba (C) - West Warwick (S) - Central	
SA	Mount Barker (DC) - Central	All other SLA in SA
NSW	Albury (C) Bathurst (C) Broken Hill (C) Deniliquin (A) Dubbo (C) - Pt A Glen Innes (A) Griffith (C) Orange (C) Queanbeyan (C) Tamworth (C) Wagga Wagga (C) - Pt A	All other SLA in NSW
ACT	All other SLA in the ACT (All suburbs of Canberra)	Remainder of ACT Stromlo Tuggeranong – SSD Bal.

Appendix C Changes to SLA boundaries between 2001 and 2004

The changes to relevant SLA boundaries that occurred between 2001 and 2004 were as follows:

- Windouran (A), in NSW, was abolished and included in Conargo (A);
- Greater Lithgow (A), in NSW, changed its name to Lithgow (A);
- Delatite (S), in Victoria, was abolished and split into Benalla (RC) and Mansfield (S);
- There were minor boundary changes, resulting a total reduction in population of 366 residents from Delatite (S), Alpine (S) and Baw Baw (S) (all in Victoria) and a corresponding increase to the populations of the Alpine resort areas of Mount Buller, Mount Stirling, Falls Creek, Mount Hotham and Mount Baw Baw.

These boundary changes were taken into account when comparing the population growth projections produced by the Australian Bureau of Statistics and the projections produced by the state agencies.

The population projections from NSW were based on the ASGC 2001 SLA boundaries (Australian Bureau of Statistics, 2001) with the exceptions of two areas (Table below). The area called Greater Lithgow (C) in 2001 was called Lithgow (C) by DIPNR (2004). The area called Conargo (A) by NSW is a combination of the two areas Conargo (A) and Windouran (A) in the ASGC 2001 boundaries. To use the NSW data for Conargo (A) the population was distributed between the two original SLAs based on the percentage of the total area. In the ASGC 2001 boundaries, the total area of the two SLAs was 8,762km^2; Windouran (A) was 5,068km^2 (57.8%) and Conargo (A) was 3,694km^2 (42.2%).

- **Changes to Statistical Local Areas in New South Wales between 2001 census and those used by DIPNR (2004)**

Original SLA name in ASGC 2001 Layer	New SLA name and proportion used in DIPNR (2004) projections
Greater Lithgow (C)	Lithgow (C)
Conargo (A)	42.2% of area of Conargo (A)
Windouran (A)	57.8% of area of Conargo (A)

There were three changes to SLA names in between the publication of the ASGC 2001 boundaries and the *Victoria in Future 2004 – population projections* report (Department of Sustainability and Environment, 2004). The boundaries remained the same. These changes are illustrated in the table below; the projections based on the new names were mapped to the areas in the 2001 layer.

- **Changes to Statistical Local Areas in Victoria between the 2001 census and those used by DSE (2004)**

SLA name in ASGC 2001 Layer	SLA name used in Victoria in Future (2004) report
Delatite (S) - Benalla	Benalla (RC) - Benalla
Delatite (S) - North	Benalla (RC) Bal
Delatite (S) - South	Mansfield (S)

Appendix D Landuse categories in New South Wales for which there was expected to be no future farm dam development

Code No.	Description
0	No data
111	Conservation and natural environments : Nature conservation : Strict nature reserve
112	Conservation and natural environments : Nature conservation : Wilderness area
113	Conservation and natural environments : Nature conservation : National park
114	Conservation and natural environments : Nature conservation : Natural feature protection
115	Conservation and natural environments : Nature conservation : Habitat/species management area
117	Conservation and natural environments : Nature conservation : Other conserved area
120	Conservation and natural environments : Managed resource protection
130	Conservation and natural environments : Other minimal use
131	Conservation and natural environments : Other minimal use : Defence
133	Conservation and natural environments : Other minimal use : Remnant native cover
220	Relatively natural environments : Production forestry
310	Dryland agriculture and plantations : Plantation forestry
320	Dryland agriculture and plantations : Farm forestry
500	Intensive uses
541	Intensive uses : Residential : Urban residential
571	Intensive uses : Transport and communication : Airports/aerodromes
610	Water : Lake
611	Water : Lake : Lake - conservation
620	Water : Reservoir
630	Water : River
631	Water : River : River - conservation
650	Water : Marsh/wetland
651	Water : Marsh/wetland : Marsh/wetland - conservation

Appendix E Available Harvestable Right in New South Wales

- **Calculation of Available Harvestable Right volume by rural SLA for NSW. Note that urban areas and areas with less than 1% of their area in the Eastern/Central MDB have been removed from this table.**

SLA Name	Area (km²)	% of SLA in MDB & East./Cent. Division	Harvestable Right (ML)	Available HR (ML)		
				Calc. GA (2007) data	Est. from Landuse	Total
Armidale Dumaresq (A) Bal	4186	7.4	2219	1615	0	1615
Barraba (A)	3058	100	19489	14148	0	14148
Berrigan (A)	2072	100	9790	0	6909	6909
Bingara (A)	2845	100	12522	8847	0	8847
Bland (A)	8549	100	40718	13751	0	13751
Blayney (A) - Pt A	516	100	3584	0	2380	2380
Blayney (A) - Pt B	1006	100	6047	0	4048	4048
Bogan (A)	14560	81.5	38391	427	26656	27083
Boorowa (A)	2577	100	15207	8632	343	8975
Cabonne (A) - Pt A	875	100	5218	0	3549	3549
Cabonne (A) - Pt B	518	100	2708	0	1828	1828
Cabonne (A) - Pt C	4619	100	26161	932	16356	17288
Carrathool (A)	18907	53.0	40910	28878	0	28878
Conargo (A)	3694	100	16843	2088	10190	12279
Coolah (A)	4787	100	23559	0	16189	16189
Coolamon (A)	2433	100	13248	4229	0	4229
Cooma-Monaro (A)	4945	84.1	9519	0	6518	6518
Coonabarabran (A)	7549	100	25900	2295	15189	17484
Coonamble (A)	9891	100	43914	19144	11677	30822
Cootamundra (A)	1524	100	9478	6491	0	6491
Corowa (A)	2178	100	10724	0	7389	7389
Cowra (A)	2806	100	15596	1708	8622	10330
Crookwell (A)	3611	93.7	22033	9814	4805	14618
Culcairn (A)	1602	100	9998	0	6867	6867
Dubbo (C) - Pt B	3088	100	12618	0	8689	8689
Evans (A) - Pt A	474	100	2919	0	1970	1970
Evans (A) - Pt B	3828	100	17546	38	11800	11838
Forbes (A)	4710	100	24325	13750	0	13750
Gilgandra (A)	4819	100	22781	0	15748	15748
Greater Lithgow (C)	3510	26.9	4427	0	2946	2946
Gundagai (A)	2460	100	14204	5024	5321	10345
Gunnedah (A)	5003	100	30010	9581	12430	22012
Gunning (A)	2211	97.2	11522	6621	557	7178

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SLA Name	Area (km²)	% of SLA in MDB & East./Cent. Division	Harvestable Right (ML)	Available HR (ML)		
				Calc. GA (2007) data	Est. from Landuse	Total
Guyra (A)	4393	48.3	14872	10418	0	10418
Harden (A)	1869	100	12322	9044	0	9044
Hay (A)	11323	84.4	38665	22293	1008	23301
Holbrook (A)	2609	100	11942	0	8123	8123
Hume (A)	1931	100	11884	0	8136	8136
Inverell (A) - Pt A	6861	100	29710	23387	0	23387
Inverell (A) - Pt B	1710	100	9668	6348	0	6348
Jerilderie (A)	3380	100	15493	2130	9020	11150
Junee (A)	2032	100	12247	6930	756	7686
Lachlan (A)	14934	100	62555	19119	21613	40732
Leeton (A)	1167	100	4655	3324	0	3324
Lockhart (A)	2900	100	15977	0	10921	10921
Manilla (A)	2186	100	14991	11005	0	11005
Merriwa (A)	3489	2.7	961	0	667	667
Moree Plains (A)	17884	100	96485	74514	0	74514
Mudgee (A)	5524	83.6	25784	0	17728	17728
Mulwaree (A)	5209	14.9	4704	117	2935	3052
Murray (A)	4357	100	16087	0	11308	11308
Murrumbidgee (A)	3506	100	15470	11673	0	11673
Murrurundi (A)	2472	61.9	9564	0	6632	6632
Narrabri (A)	12987	100	47983	32334	0	32334
Narrandera (A)	4117	100	18217	8080	508	8588
Narromine (A)	5247	100	27263	0	19024	19024
Nundle (A)	1595	78.5	5909	2556	1601	4157
Oberon (A)	2904	65.5	8594	0	5825	5825
Parkes (A)	5942	100	31005	3605	14466	18071
Parry (A) - Pt A	300	100	234	123	62	185
Parry (A) - Pt B	4088	100	26032	12324	6314	18638
Quirindi (A)	3024	100	17985	0	12629	12629
Rylstone (A)	3816	46.3	9108	0	6284	6284
Severn (A)	5559	47.5	16384	9123	0	9123
Snowy River (A)	6058	20.1	4748	0	3238	3238
Temora (A)	2801	100	15551	6697	0	6697
Tenterfield (A)	7162	38.3	12875	9172	0	9172
Tumbarumba (A)	4390	100	10500	0	6982	6982
Tumut (A)	3775	100	9508	0	6523	6523
Uralla (A)	3219	77.8	18598	11236	0	11236
Urana (A)	3363	100	14912	908	9453	10361
Wagga (C) - Pt B	4611	100	26675	1742	15664	17406
Wakool (A)	7528	100	26242	808	17732	18539
Walcha (A)	6245	17.4	8796	5454	0	5454

SLA Name	Area (km²)	% of SLA in MDB & East./Cent. Division	Harvestable Right (ML)	Available HR (ML)		
				Calc. GA (2007) data	Est. from Landuse	Total
Walgett (A)	22270	50.6	49575	40977	0	40977
Warren (A)	10723	100	44307	6344	25021	31364
Weddin (A)	3405	100	17416	8213	0	8213
Wellington (A)	4101	100	23275	0	15889	15889
Windouran (A)	5069	100	21036	5095	9805	14900
Yallaroi (A)	5327	100	29845	19738	0	19738
Yarrowlumla(A) - Pt A	1934	100	7640	0	5208	5208
Yarrowlumla(A) - Pt B	1044	100	278	0	192	192
Yass (A)	3301	100	17629	7066	3555	10621
Young (A)	2692	100	15992	9302	0	9302

Appendix F Estimated proportion of available harvestable right by landuse for New South Wales

- **Percentage of properties with no existing farm dams, existing farm dam volumes less than Harvestable Right (HR) and farm dam volumes at or above HR by landuse. The adopted estimate of the percentage available is also provided.**

Landuse		Percentage of land parcels with			Estimated proportion of HR available
Code No.	Description	No existing farm dams	Existing dam volume <HR	Existing dam volume ≥HR	
210	Relatively natural environments : Livestock grazing	50.9%	33.7%	15.4%	71.1%
330	Dryland agriculture and plantations : Grazing modified pastures	43.1%	35.7%	21.2%	64.5%
340	Dryland agriculture and plantations : Cropping	48.0%	36.1%	15.9%	69.6%
341	Dryland agriculture and plantations : Cropping : Cereals	48.0%	36.1%	15.9%	69.6%
343	Dryland agriculture and plantations : Cropping : Hay and silage	48.0%	36.1%	15.9%	69.6%
344	Dryland agriculture and plantations : Cropping : Oilseeds and oleaginous fruit	40.6%	38.3%	21.1%	63.6%
346	Dryland agriculture and plantations : Cropping : Cotton	71.2%	24.2%	4.7%	85.7%
348	Dryland agriculture and plantations : Cropping : Legumes	56.6%	30.4%	13.0%	74.8%
351	Dryland agriculture and plantations : Perennial horticulture : Tree fruits	53.1%	34.4%	12.5%	73.8%
353	Dryland agriculture and plantations : Perennial horticulture : Tree nuts	53.1%	34.4%	12.5%	73.8%
354	Dryland agriculture and plantations : Perennial horticulture : Vine fruits	70.0%	30.0%	0.0%	88.0%
364	Dryland agriculture and plantations : Seasonal horticulture : Vegetables and herbs	54.7%	25.3%	20.0%	69.9%
430	Irrigated agriculture and plantations : Irrigated modified pastures	51.5%	33.1%	15.4%	71.3%
440	Irrigated agriculture and plantations : Irrigated cropping	63.3%	22.4%	14.3%	76.7%
441	Irrigated agriculture and plantations : Irrigated cropping : Irrigated cereals	57.9%	27.6%	14.6%	74.4%
443	Irrigated agriculture and plantations : Irrigated cropping : Irrigated hay and silage	57.9%	27.6%	14.6%	74.4%
444	Irrigated agriculture and plantations : Irrigated cropping : Irrigated oilseeds and oleaginous fruit	44.7%	42.1%	13.2%	70.0%
446	Irrigated agriculture and plantations : Irrigated cropping : Irrigated cotton	67.9%	9.7%	22.4%	73.7%
448	Irrigated agriculture and plantations : Irrigated cropping : Irrigated legumes	58.7%	32.6%	8.7%	78.3%
451	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated tree fruits	52.9%	31.0%	16.1%	71.5%

Landuse		Percentage of land parcels with			Estimated proportion of HR available
Code No.	Description	No existing farm dams	Existing dam volume <HR	Existing dam volume ≥HR	
453	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated tree nuts	52.9%	31.0%	16.1%	71.5%
454	Irrigated agriculture and plantations : Irrigated perennial horticulture : Irrigated vine fruits	55.5%	28.6%	16.0%	72.6%
464	Irrigated agriculture and plantations : Irrigated seasonal horticulture : Irrigated vegetables and herbs	54.7%	25.3%	20.0%	69.9%

Appendix G Projected increases in farm dam storage volumes by management subcatchment for the Eastern Mount Lofty Ranges

Code	Catchment Name	Mean annual rainfall (mm/y)	May to Nov runoff volume (ML/y)	Existing storage volume of farm dams (ML)	Estimated Impact on runoff of plant'ns (mm/y)	Area of existing plant'ns (ha)	Impact on runoff of existing plant'ns (ML/y)	Max. volume of new farm dams, cons. existing farm dams and plant'ns (ML)	Max. area of new plant'ns, cons. existing farm dams and plant'ns (ha)	Projected area of new plant'ns (ha)	Max. volume of new farm dams, cons. existing dams and projected plant'ns (ML)	Projected additional storage volume of farm dams (ML)
A1	Angas River	725	6800	1630	129	0	0	410	319	0	410	410
A2	Angas River	773	4100	825	143	0	0	405	282	0	405	380
A3	Angas River	672	1700	230	113	0	0	280	249	0	280	106
A4	Angas River	578	750	150	85	0	0	75	88	0	75	69
A5	Angas River	485	300	210	60	0	0	0	0	0	0	0
B1	Bremer River	534	4200	735	73	0	0	525	722	0	525	338
B2	Bremer River	733	3600	1090	131	0	0	0	0	0	0	0
B3	Bremer River	798	6000	1810	151	0	0	0	0	0	0	0
B4	Bremer River	639	1000	545	103	0	0	0	0	0	0	0
B5	Bremer River	565	1200	275	81	0	0	85	105	0	85	85
B6	Bremer River	539	140	45	74	0	0	0	0	0	0	0
B7	Bremer River	421	50	9	44	0	0	6	14	0	6	4
C1	Currency Creek	860	6000	1100	170	6	11	700	404	404	0	0
C2	Currency Creek	627	1100	190	99	0	0	140	141	141	0	0
D1	Deep Creek	544	1200	380	75	0	0	0	0	0	0	0
E1	Sandergrove Plains	827	1500	120	160	0	0	330	206	0	330	55
F1	Finnis River	851	4200	400	168	0	0	860	513	0	860	184

Code	Catchment Name	Mean annual rainfall (mm/y)	May to Nov runoff volume (ML/y)	Existing storage volume of farm dams (ML)	Estimated Impact on runoff of plant'ns (mm/y)	Area of existing plant'ns (ha)	Impact on runoff of existing plant'ns (ML/y)	Max. volume of new farm dams, cons. existing farm dams and plant'ns (ML)	Max. area of new plant'ns, cons. existing farm dams and plant'ns (ha)	Projected area of new plant'ns (ha)	Max. volume of new farm dams, cons. existing dams and projected plant'ns (ML)	Projected additional storage volume of farm dams (ML)
F2	Finnis River	883	18600	3500	178	1397	2482	2080	0	0	0	0
F3	Finnis River	678	3000	255	114	178	204	645	385	0	441	117
F4	Finnis River	772	2800	445	143	3	4	395	273	0	391	205
F5	Finnis River	607	3300	335	93	2	2	655	701	0	653	154
F6	Finnis River	529	700	190	71	0	0	20	28	0	20	20
F7	Finnis River	405	250	135	41	0	0	0	0	0	0	0
G1	Rocky Gully Creek	483	0	0	59	0	0	0	0	0	0	0
L1	Milendilla Creek	322	500	68	24	0	0	82	340	0	82	31
M1	Marne River	608	5424	1033	94	44	41	594	591	0	553	475
M2	Marne River	540	4251	3218	74	0	0	0	0	0	0	0
M3	Marne River	481	812	6	59	0	0	238	405	0	238	3
N1	Salt Creek	376	350	47	34	0	0	58	169	0	58	22
P1	Preamimma Creek	374	0	0	34	0	0	0	0	0	0	0
R1	Reedy Creek	694	1400	390	119	0	0	30	25	0	30	30
R2	Reedy Creek	650	1200	160	106	0	0	200	188	0	200	74
R3	Reedy Creek	577	1700	215	85	55	46	295	293	0	249	99
R4	Reedy Creek	462	500	56	54	0	0	94	174	0	94	26
R5	Reedy Creek	442	200	46	49	0	0	14	28	0	14	14
R6	Reedy Creek	427	200	7	45	0	0	53	116	0	53	3
R7	Reedy Creek	301	0	0	21	0	0	0	0	0	0	0
S1	Saunders Creek	558	950	460	79	0	0	0	0	0	0	0

Code	Catchment Name	Mean annual rainfall (mm/y)	May to Nov runoff volume (ML/y)	Existing storage volume of farm dams (ML)	Estimated Impact on runoff of plant'ns (mm/y)	Area of existing plant'ns (ha)	Impact on runoff of existing plant'ns (ML/y)	Max. volume of new farm dams, cons. existing farm dams and plant'ns (ML)	Max. area of new plant'ns, cons. existing farm dams and plant'ns (ha)	Projected area of new plant'ns (ha)	Max. volume of new farm dams, cons. existing dams and projected plant'ns (ML)	Projected additional storage volume of farm dams (ML)
S2	Saunders Creek	574	1221	225	84	0	0	141	169	0	141	104
S3	Saunders Creek	454	780	34	52	0	0	200	384	0	200	16
S4	Saunders Creek	481	240	16	59	0	0	56	95	0	56	7
S5	Saunders Creek	475	0	0	57	0	0	0	0	0	0	0
T1	Tookayerta Creek	833	7200	490	162	33	54	1670	998	631	594	225
T2	Tookayerta Creek	873	5100	525	174	0	0	1005	576	504	125	125
T3	Tookayerta Creek	698	3000	105	120	147	177	795	513	319	234	48
Y1	Long Gully	340	0	0	27	0	0	0	0	0	0	0
	Totals		107518	21706		1865	3020	13135	9496	2000	7401	3429

Appendix H Calculation of historical trend in total volume of farm dams from Agrecon (2005) data

1:100,000 scale map sheet containing sample square		Dates of valid aerial photos			Date of Ikonos satellite image	"Phase" in Agrecon analysis related to each air photo or Ikonos image				Agrecon estimate of total volume of farm dams constructed to end of corresponding phase (ML)				Interpolated total volume of farm dams at 1Jan1999 (ML)	Number of years between 1Jan1999 and Ikonos date	Rate of increase of total volume post-99 (ML/y)	Linear growth rate in total volume post-99 (%/year)	Interpolated total volume of farm dams at 1Jan2003 (ML)
Number	Name	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th					
8840	Boomi	15/10/89	20/05/94	07/09/99	12/07/02	1	2	3	4	34	40	40	40	40	3.53	0.0	0.0	40
8940	Goondiwindi	09/09/89	20/05/94	25/08/99	31/01/03	1	2	3	4	54	64	64	64	64	4.08	0.0	0.0	64
9138	Inverell	28/02/85	21/07/94	16/06/01	09/06/03	1	2	3	4	147	172	206	210	194	4.44	3.6	1.9	208
9239	Clive	05/04/86	22/07/94	07/06/00	02/03/03	1	2	3	4	344	433	435	477	435	4.16	10.2	2.3	475
8739	Bunarba	07/06/85	23/09/96	05/06/01	05/09/03	1	2	3	4	86	118	125	128	121	4.68	1.4	1.2	127
8838	Bellata	20/06/85	22/09/96	14/08/01	12/07/02	1	2	3	4	132	181	181	184	181	3.53	0.9	0.5	184
8839	Moree	27/06/91	23/09/96	15/06/01	01/07/02	1	2	3	4	19	32	33	33	32	3.50	0.1	0.5	33
8938	Gravesend	27/06/91	08/06/97	09/06/02	09/06/02	1	2	4	-	154	154	397	-	230	3.44	48.6	21.1	424
9137	Bundarra	21/10/91	08/03/97	31/10/01	12/05/02	1	2	3	4	178	178	252	265	207	3.36	17.3	8.4	276
8637	Pilliga	23/09/86	20/07/94	01/02/98	04/04/03	1	2	3	4	22	27	27	32	28	4.25	1.0	3.5	32
8737	Wee Waa	14/06/89	20/07/94	01/12/98	27/09/03	1	2	3	4	1015	1015	1452	1452	1452	4.74	0.0	0.0	1452
8835	Tambar Springs	17/12/89	28/05/94	10/05/98	06/06/03	1	2	3	4	15	15	184	243	192	4.43	11.6	6.1	238
8837	Narrabri	13/03/87	20/07/94	11/12/98	04/11/03	1	2	3	4	721	935	935	1276	939	4.84	69.6	7.4	1217
8936	Boggabri	24/03/86	27/03/97	15/08/01	29/12/02	1	2	3	4	33	33	116	116	66	3.99	12.4	18.7	116
9035	Tamworth	15/07/89	27/11/93	02/08/98	17/06/03	1	2	3	4	225	255	261	290	263	4.46	6.0	2.3	287
9136	Bendemeer	28/02/86	24/02/93	12/05/02	12/05/02	1	2	4	-	233	302	382	-	353	3.36	8.7	2.5	388
North East NSW - Summary Statistics														4797		191.4	4.0	5563

SINCLAIR KNIGHT MERZ

1:100,000 scale map sheet containing sample square		Dates of valid aerial photos			Date of Ikonos satellite image	"Phase" in Agrecon analysis related to each air photo or Ikonos image				Agrecon estimate of total volume of farm dams constructed to end of corresponding phase (ML)				Interpolated total volume of farm dams at 1Jan1999 (ML)	Number of years between 1Jan1999 and Ikonos date	Rate of increase of total volume post-99 (ML/y)	Linear growth rate in total volume post-99 (%/year)	Interpolated total volume of farm dams at 1Jan2003 (ML)
Number	Name	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th					
8429	Temora	10/08/86	24/09/91	12/01/03	12/01/03	1	2	4	-	94	95	100	-	98	4.03	0.4	0.5	100
8431	Bogan Gate	20/08/93	20/07/97	10/01/02	16/03/03	1	2	3	4	0	106	109	110	107	4.20	0.7	0.7	110
8529	Young	28/11/89	29/01/94	20/12/97	07/11/02	1	2	3	4	397	413	413	413	413	3.85	0.0	0.0	413
8531	Parkes	29/09/89	28/09/93	31/12/01	12/06/03	1	2	3	4	340	353	367	367	362	4.44	1.1	0.3	366
8629	Boorowa	13/09/82	29/01/94	20/12/97	23/04/02	1	2	3	4	192	234	234	237	235	3.31	0.7	0.3	237
8630	Cowra	02/11/82	11/11/92	29/03/98	23/04/02	1	2	3	4	204	519	530	531	530	3.31	0.2	0.0	531
8729	Crookwell	13/09/82	29/01/94	09/01/00	07/05/02	1	2	3	4	323	341	376	376	370	3.35	1.8	0.5	377
8433	Dandaloo	28/05/92	22/10/96	16/03/03	16/03/03	1	2	4	-	109	114	114	-	114	4.20	0.0	0.0	114
8533	Narromine	28/02/83	02/05/91	22/10/96	12/06/03	1	2	3	4	223	562	562	579	568	4.44	2.6	0.5	578
8535	Gulargambone	30/05/92	11/11/96	21/07/01	05/09/03	1	2	3	4	234	235	235	235	235	4.68	0.0	0.0	235
8632	Wellington	14/01/88	31/05/91	30/11/95	23/04/02	1	2	3	4	125	145	145	148	146	3.31	0.5	0.3	148
8633	Dubbo	21/01/88	13/12/95	23/04/02	23/04/02	1	2	4	-	157	165	192	-	178	3.31	4.2	2.4	195
8731	Orange	30/10/89	27/09/93	29/08/96	16/05/02	1	2	3	4	35	37	37	38	37	3.37	0.2	0.5	38
8735	Coonabarabran	11/08/82	23/05/94	06/04/98	01/07/02	1	2	3	4	115	140	145	145	145	3.50	0.0	0.0	145
8831	Bathurst	05/10/89	27/09/93	02/07/98	04/11/03	1	2	3	4	421	498	570	598	573	4.84	5.2	0.9	594
8832	Mudgee	13/01/88	01/09/94	27/10/03	27/10/03	1	2	4	-	292	299	311	-	305	4.82	1.3	0.4	310
8226	Walbundrie	24/02/90	14/02/96	04/05/03	18/11/03	1	2	3	4	180	194	194	200	194	4.88	1.2	0.6	199
8326	Holbrook	21/04/87	13/01/91	16/01/98	15/11/02	1	2	3	4	489	495	503	505	503	3.87	0.4	0.1	505
8327	Wagga Wagga	26/10/90	04/02/95	31/01/98	16/10/03	1	2	3	4	287	289	289	301	291	4.79	2.1	0.7	299
8428	Junee	26/09/86	09/07/94	21/02/98	16/03/03	1	2	3	4	196	213	218	218	218	4.20	0.0	0.0	218
8527	Tumut	23/12/86	14/10/91	17/02/98	07/11/02	1	2	3	4	76	89	101	121	105	3.85	4.2	4.0	122

1:100,000 scale map sheet containing sample square		Dates of valid aerial photos			Date of Ikonos satellite image	"Phase" in Agrecon analysis related to each air photo or Ikonos image				Agrecon estimate of total volume of farm dams constructed to end of corresponding phase (ML)				Interpolated total volume of farm dams at 1Jan1999 (ML)	Number of years between 1Jan1999 and Ikonos date	Rate of increase of total volume post-99 (ML/y)	Linear growth rate in total volume post-99 (%/year)	Interpolated total volume of farm dams at 1Jan2003 (ML)
Number	Name	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th					
8528	Cootamundra	26/09/86	22/01/94	13/01/98	04/05/02	1	2	3	4	617	639	641	663	646	3.34	5.1	0.8	666
8626	Tantangara	12/11/90	31/01/95	17/01/98	23/04/02	1	2	3	4	131	193	202	202	202	3.31	0.0	0.0	202
8727	Canberra	06/02/85	13/10/92	12/02/01	24/03/02	1	2	3	4	395	725	835	841	807	3.23	10.5	1.3	849
Rest of NSW - Summary Statistics														7382		42.7	0.6	7552
8047	Glanworth	10/10/94	11/03/02	-	11/03/02	2	4	-	-	72	85	-	-	79	3.19	1.8	2.2	86
8245	Angellala	01/11/93	15/01/03	-	15/01/03	1	4	-	-	0	67	-	-	38	4.04	7.3	19.4	67
8247	Caldervale	10/10/94	19/03/03	-	19/03/03	2	4	-	-	13	13	-	-	13	4.21	0.0	0.0	13
8347	Chesterton	29/06/88	30/06/95	29/11/02	29/11/02	1	2	4	-	62	62	63	-	62	3.91	0.1	0.2	63
8344	Ularunda	24/06/92	05/04/02	19/10/03	19/10/03	2	3	4	-	8	8	8	-	8	4.80	0.0	0.0	8
8443	Abbieglassie	22/06/92	29/06/02	08/10/02	08/10/02	2	3	4	-	29	29	29	-	29	3.77	0.0	0.0	29
8446	Forest Vale	20/05/87	29/06/95	08/10/02	08/10/02	1	2	4	-	49	49	49	-	49	3.77	0.0	0.0	49
8542	Boolba	22/05/88	05/09/02	-	05/09/02	1	4	-	-	10	10	-	-	10	3.68	0.0	0.0	10
8545	Waroonga	05/07/87	19/07/97	13/12/02	13/12/02	1	3	4	-	21	29	29	-	29	3.95	0.0	0.0	29
8643	Cogoon	10/07/92	07/04/02	07/04/03	07/04/03	2	3	4	-	17	17	24	-	17	4.26	1.6	9.7	24
8644	Roma	04/10/90	10/08/96	07/04/03	07/04/03	1	3	4	-	86	174	176	-	175	4.26	0.3	0.2	176
8743	Surat	22/08/94	03/08/02	-	03/08/02	1	4	-	-	0	83	-	-	46	3.59	10.4	22.9	87
8744	Yuleba	12/07/92	15/03/02	03/08/02	03/08/02	2	3	4	-	79	79	85	-	79	3.59	1.7	2.1	86
8943	Tara	26/06/89	13/03/02	-	13/03/02	1	4	-	-	109	152	-	-	141	3.20	3.4	2.4	155
9044	Chinchilla	06/09/90	09/01/02	-	09/01/02	1	4	-	-	25	27	-	-	26	3.02	0.2	0.7	27
9143	Dalby	10/08/91	16/08/01	23/04/03	23/04/03	2	3	4	-	759	1094	1094	-	1006	4.31	20.4	2.0	1088
9242	Toowoomba	18/07/88	04/02/93	03/09/01	12/06/03	1	2	3	4	19	23	23	23	23	4.44	0.0	0.0	23

1:100,000 scale map sheet containing sample square		Dates of valid aerial photos			Date of Ikonos satellite image	"Phase" in Agrecon analysis related to each air photo or Ikonos image				Agrecon estimate of total volume of farm dams constructed to end of corresponding phase (ML)				Interpolated total volume of farm dams at 1Jan1999 (ML)	Number of years between 1Jan1999 and Ikonos date	Rate of increase of total volume post-99 (ML/y)	Linear growth rate in total volume post-99 (%/year)	Interpolated total volume of farm dams at 1Jan2003 (ML)
Number	Name	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th					
9341	Warwick	07/08/89	24/10/95	28/01/02	28/01/02	1	2	4	-	104	646	708	-	678	3.07	9.9	1.5	717
8741	Talwood	20/07/89	18/10/98	05/09/03	05/09/03	1	2	4	-	125	125	125	-	125	4.68	0.0	0.0	125
8842	Flinton	11/07/90	25/09/99	03/02/03	03/02/03	1	3	4	-	1306	1339	1339	-	1336	4.09	0.6	0.0	1339
8425	Corryong	04/02/91	04/03/94	05/03/03	05/03/03	1	2	4	-	1057	1086	1114	-	1101	4.17	3.1	0.3	1113
Queensland – Summary Statistics														668		12.8	1.9	719
6627	Milang	30/01/87	09/04/94	15/12/99	12/07/02	1	2	3	4	534	622	677	713	668	3.53	12.8	1.9	719
South Australia – Summary Statistics														668		12.8	1.9	719
8225	Albury	06/01/90	27/12/95	26/09/04	26/09/04	1	2	4	-	1305	1639	1730	-	1670	5.74	10.4	0.6	1712
8125	Wangaratta	07/03/90	14/03/00	27/08/04	27/08/04	1	3	4	-	437	493	493	-	486	5.65	1.2	0.2	491
7923	Yea	28/11/89	02/09/02	-	02/09/02	1	4	-	-	727	1473	-	-	1259	3.67	58.5	4.6	1492
7924	Nagambie	26/11/89	14/03/00	13/09/02	13/09/02	1	3	4	-	98	124	131	-	121	3.70	2.7	2.2	132
8023	Alexandra	26/03/90	14/02/03	-	14/02/03	1	4	-	-	745	1185	-	-	1044	4.12	34.1	3.3	1181
8024	Euroa	07/03/90	11/01/93	17/03/00	01/06/02	1	2	3	4	1232	1363	1399	1420	1393	3.41	7.9	0.6	1425
8025	Dookie	06/01/90	14/03/00	01/06/02	01/06/02	1	3	4	-	128	181	189	-	175	3.41	4.2	2.4	191
7723	Castlemaine	28/11/89	12/12/96	24/10/98	30/10/02	1	2	3	4	223	285	286	288	286	3.83	0.5	0.2	288
7623	Creswick	05/12/89	04/06/03	-	04/06/03	1	4	-	-	65	75	-	-	72	4.42	0.7	1.0	75
7724	Bendigo	28/11/89	21/03/00	17/02/03	17/02/03	1	3	4	-	347	397	439	-	391	4.13	11.6	3.0	438
7523	Beaufort	05/12/89	31/01/93	05/05/03	20/08/03	1	2	3	4	123	178	178	214	178	4.63	7.8	4.4	209
7324	Horsham	13/01/89	07/02/93	14/10/03	14/10/03	1	2	4	-	524	549	568	-	559	4.78	1.8	0.3	567
7423	Ararat	05/12/89	04/01/97	05/05/03	05/05/03	1	2	4	-	134	134	174	-	147	4.34	6.3	4.3	172
Victoria – Summary Statistics														7781		147.7	1.9	8372

Appendix I Calculation of rate of change in historical population for SLA corresponding to Agrecon (2005) sample tiles

1:100,000 scale map sheet containing sample square		Name of SLA containing sample square	Population in SLA		Change in population 1999 - 2004	Annual linear rate of change in population (%/year)
Number	Name		1999	2004		
8840	Boomi	Moree Plains (A)	15726	16002	276	0.35
8940	Goondiwindi	Moree Plains (A)	15726	16002	276	0.35
9138	Inverell	Inverell (A) - Pt B	10942	11149	207	0.38
9239	Clive	Tenterfield (A)	6828	6799	-29	-0.08
8739	Bunarba	Moree Plains (A)	15726	16002	276	0.35
8838	Bellata	Moree Plains (A)	15726	16002	276	0.35
8839	Moree	Moree Plains (A)	15726	16002	276	0.35
8938	Gravesend	Yallaroi (A)	5772	5563	-209	-0.72
9137	Bundarra	Uralla (A)	6015	6031	16	0.05
8637	Pilliga	Walgett (A)	8449	8083	-366	-0.87
8737	Wee Waa	Narrabri (A)	14392	14217	-175	-0.24
8835	Tambar Springs	Gunnedah (A)	12532	12108	-424	-0.68
8837	Narrabri	Narrabri (A)	14392	14217	-175	-0.24
8936	Boggabri	Gunnedah (A)	12532	12108	-424	-0.68
9035	Tamworth	Parry (A) - Pt B	11488	11255	-233	-0.41
9136	Bendemeer	Parry (A) - Pt B	11488	11255	-233	-0.41
North East NSW - Mean of rates at sample squares						-0.13
8429	Temora	Temora (A)	6162	6285	123	0.40
8431	Bogan Gate	Forbes (A)	10181	9958	-223	-0.44
8529	Young	Young (A)	11706	11938	232	0.40

1:100,000 scale map sheet containing sample square		Name of SLA containing sample square	Population in SLA		Change in population 1999 - 2004	Annual linear rate of change in population (%/year)
Number	Name		1999	2004		
8531	Parkes	Parkes (A)	15126	15011	-115	-0.15
8629	Boorowa	Boorowa (A)	2497	2472	-25	-0.20
8630	Cowra	Cowra (A)	12832	13126	294	0.46
8729	Crookwell	Crookwell (A)	7257	7321	64	0.18
8433	Dandaloo	Narromine (A)	6934	7009	75	0.22
8533	Narromine	Narromine (A)	6934	7009	75	0.22
8535	Gulargambone	Coonamble (A)	4927	4721	-206	-0.84
8632	Wellington	Wellington (A)	8856	8654	-202	-0.46
8633	Dubbo	Dubbo (C) - Pt B	3606	3512	-94	-0.52
8731	Orange	Evans (A) - Pt B	5030	5042	12	0.05
8735	Coonabarabran	Coonabarabran (A)	10860	10534	-326	-0.60
8831	Bathurst	Bathurst (C)	29877	31515	1638	1.10
8832	Mudgee	Mudgee (A)	3606	3538	-68	-0.38
8226	Walbundrie	Hume (A)	4009	4010	1	0.00
8326	Holbrook	Holbrook (A)	6681	6469	-212	-0.63
8327	Wagga Wagga	Lockhart (A)	3582	3522	-60	-0.34
8428	Junee	Junee (A)	5907	5883	-24	-0.08
8527	Tumut	Gundagai (A)	3770	3757	-13	-0.07
8528	Cootamundra	Harden (A)	3856	3765	-91	-0.47
8626	Tantangara	Snowy River (A)	6801	7311	510	1.50
8727	Canberra	Yass (A)	11537	12818	1281	2.22
Rest of NSW - Mean of rates at sample squares						0.06

Appendix J Agrecon tiles excluded from analysis

- **Tiles from Agrecon (2005) data set that were excluded from the analysis of historical growth rates on examination of satellite imagery that revealed most dams in these tiles would be off-stream storages, collecting water diverted from nearby streams or irrigation channel systems.**

1:100,000 scale map sheet containing sample square		
Number	**Name**	**State**
8940	Goondiwindi	NSW
8839	Moree	NSW
8938	Gravesend	NSW
8737	Wee Waa	NSW
8835	Tambar Springs	NSW
8837	Narrabri	NSW
8936	Boggabri	NSW
8431	Bogan Gate	NSW
8226	Walbundrie	NSW
8327	Wagga Wagga	NSW
9143	Dalby	Qld

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Appendix K Historical trend in farm dams

- **Historical trend in total volume of farm dams for the period 1999 to circa-2004, based on reanalysis of data from Agrecon (2005) and rates of population change at corresponding SLA**

1:100,000 scale map sheet containing sample square Number	Name	Interpolated total volume of farm dams at 1 Jan 1999 (ML)	Linear growth rate in total volume post-1999 (%/year)	Interpolated total volume of farm dams at 1 Jan 2003 (ML)	Annual linear rate of change in population (%/year)
8840	Boomi	40	0.0	40	0.35
9138	Inverell	194	1.9	208	0.38
9239	Clive	435	2.3	475	-0.08
8739	Bunarba	121	1.2	127	0.35
8838	Bellata	181	0.5	184	0.35
9137	Bundarra	207	8.4	276	0.05
8637	Pilliga	28	3.5	32	-0.87
9035	Tamworth	263	2.3	287	-0.41
9136	Bendemeer	353	2.5	388	-0.41
North East NSW Summary		1822	2.7	2018	
8429	Temora	98	0.5	100	0.40
8529	Young	413	0.0	413	0.40
8531	Parkes	362	0.3	366	-0.15
8629	Boorowa	235	0.3	237	-0.20
8630	Cowra	530	0.0	531	0.46
8729	Crookwell	370	0.5	377	0.18
8433	Dandaloo	114	0.0	114	0.22
8533	Narromine	568	0.5	578	0.22
8535	Gulargambone	235	0.0	235	-0.84
8632	Wellington	146	0.3	148	-0.46
8633	Dubbo	178	2.4	195	-0.52
8731	Orange	37	0.5	38	0.05
8735	Coonabarabran	145	0.0	145	-0.60
8831	Bathurst	573	0.9	594	1.10
8832	Mudgee	305	0.4	310	-0.38
8326	Holbrook	503	0.1	505	-0.63
8428	Junee	218	0.0	218	-0.08
8527	Tumut	105	4.0	122	-0.07
8528	Cootamundra	646	0.8	666	-0.47
8626	Tantangara	202	0.0	202	1.50
8727	Canberra	807	1.3	849	2.22
Rest of NSW Summary		6790	0.6	6944	
6627	Milang	668	1.9	719	2.51
South Australia Summary		668	1.9	719	2.51
8047	Glanworth	79	2.2	86	1.13
8245	Angellala	38	19.4	67	0.47

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1:100,000 scale map sheet containing sample square: Number	Name	Interpolated total volume of farm dams at 1 Jan 1999 (ML)	Linear growth rate in total volume post-1999 (%/year)	Interpolated total volume of farm dams at 1 Jan 2003 (ML)	Annual linear rate of change in population (%/year)
8247	Caldervale	13	0.0	13	0.47
8347	Chesterton	62	0.2	63	0.47
8344	Ularunda	8	0.0	8	0.47
8443	Abbieglassie	29	0.0	29	-0.39
8446	Forest Vale	49	0.0	49	-0.39
8542	Boolba	10	0.0	10	1.33
8545	Waroonga	29	0.0	29	-0.39
8643	Cogoon	17	9.7	24	0.90
8644	Roma	175	0.2	176	-0.03
8743	Surat	46	22.9	87	0.90
8744	Yuleba	79	2.1	86	0.90
8943	Tara	141	2.4	155	1.01
9044	Chinchilla	26	0.7	27	0.03
9242	Toowoomba	23	0.0	23	1.25
9341	Warwick	678	1.5	717	0.62
8741	Talwood	125	0.0	125	1.52
8842	Flinton	1336	0.0	1339	1.01
8425	Corryong	1101	0.3	1113	-1.04
Queensland Summary		4064	1.0	4226	0.53
8225	Albury	1670	0.6	1712	2.22
8125	Wangaratta	486	0.2	491	-0.46
7923	Yea	1259	4.6	1492	1.69
7924	Nagambie	121	2.2	132	0.24
8023	Alexandra	1044	3.3	1181	0.19
8024	Euroa	1393	0.6	1425	-0.18
8025	Dookie	175	2.4	191	2.31
7723	Castlemaine	286	0.2	288	1.18
7623	Creswick	72	1.0	75	0.04
7724	Bendigo	391	3.0	438	0.14
7523	Beaufort	178	4.4	209	-0.72
7324	Horsham	559	0.3	567	1.05
7423	Ararat	147	4.3	172	-0.48
Victoria Summary		7781	1.9	8372	0.56

Appendix L Statistical tests performed on observed rate of farm dam growth in New South Wales

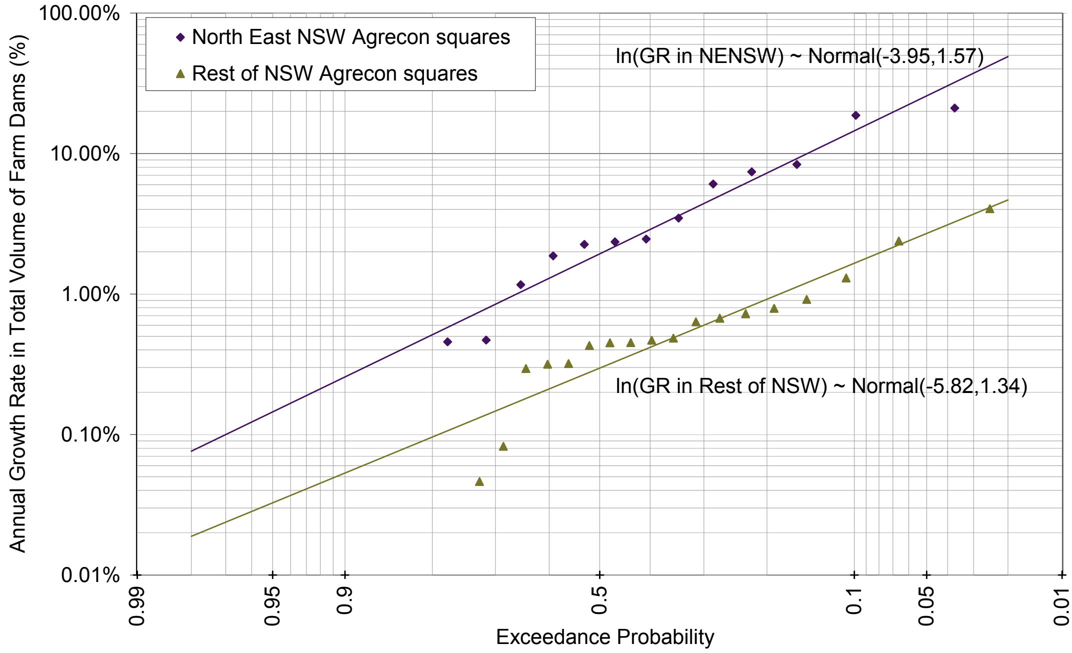
Several statistical tests were performed to demonstrate that the observed annual growth rate in farm dam volumes in North East NSW was greater than the growth rate that was observed in the rest of NSW.

Firstly, it was established that the historical farm dam growth rates for each of the two regions of NSW were not normally distributed. The samples of growth rate from the Agrecon tiles were plotted on a normal probability scale (not shown) and the correlation coefficient was computed. Filliben's test (Filliben, 1975) was used to determine that the assumption that either data set had come from a normal distribution can be rejected at the 1% level of significance. For further statistical comparisons on the data set, a distribution other than normal should therefore be used.

Secondly, the log-normal distribution was proposed as an alternative for comparing the statistical parameters of the two distributions. The historical rates of farm dam growth for each of the two regions of NSW were plotted on a log-normal probability plot, as shown in the figure below. Tiles that had no observed historical growth in farm dams (3 tiles in North East NSW and 6 tiles in the rest of NSW) were used in the calculation of the plotting position for the other samples but they were not plotted on the log-normal probability plot because the logarithm of 0% is not defined. Log-normal distributions were then fitted to the observed values for each region by linear regression. For North East NSW, the fitted distribution to the natural logarithm of the annual growth rates had a mean value of –3.95 and a standard deviation of 1.57. For the rest of NSW, the fitted distribution to the natural logarithm of the annual growth rates had a mean value of –5.82 and a standard deviation of 1.34. Filliben's test (Filliben, 1975) was applied to demonstrate that the log-normal distribution was an appropriate one for these data. It showed that the assumption of log-normality could not be rejected at the 5% level of significance for the North East NSW data and the 1% level of significance for the Rest of NSW data. It was therefore most appropriate to perform statistical tests using the logarithms of the growth rates (since the distributions are log-normal rather than normal) instead of the growth rates themselves.

Thirdly, it was established that the variances of the logarithms of the annual growth rates from the North East NSW and Rest of NSW data sets were equal. The ratio of the variances of the two data sets was 1.37. The critical value of the F-distribution for a 5% level of significance would be a ratio of 2.38 and since the observed ratio is lower than this, the ratio of the variances of the two samples are not significantly different at the 5% level of significance.

Finally, it was established that the mean of the logarithms of the annual growth rates for North East NSW was greater than the mean of the logarithms of the annual growth rates for the Rest of NSW. The value of the t-statistic, based on equal variances for the two data sets, was 3.56. The critical value of the t-distribution for a one-sided test and a 1% level of significance was 2.46. Since the observed t-statistic is higher than the critical value, it was established that the mean of the logarithms of the annual growth rates was higher in North East NSW than in the rest of NSW.



- **Log-normal distribution probability plot for historically observed growth rates in total farm dam volumes, based upon re-analysis of Agrecon (2005) tile data for period post-1999**

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Appendix M Projected increase in farm dams in New South Wales

- **Projected increase in farm dam storage volumes for SLA in New South Wales**

SLA Name	Area (km²)	Proport'n in MDB (%)	Harvest. Right (ML)	Available Harvest. Right (ML)	Estimated volume of existing farm dams (ML)	Projected increase to 2030 based upon historic trend (ML)	Adopted projected increase in farm dams to 2030 (ML)
Armidale Dumaresq (A) Bal	4186	7%	2219	1615	932	131	131
Barraba (A)	3058	100%	19489	14148	8474	1186	1186
Bingara (A)	2845	100%	12522	8847	5878	823	823
Coonabarabran (A)	7549	100%	25900	17484	17869	2502	2502
Glen Innes (A)	67	100%	501	272	494	0	0
Gunnedah (A)	5003	100%	30010	22012	21210	2969	2969
Guyra (A)	4393	48%	14872	10418	8806	1233	1233
Inverell (A) - Pt A	6861	100%	29710	23387	13064	1829	1829
Inverell (A) - Pt B	1710	100%	9668	6348	7277	1019	1019
Manilla (A)	2186	100%	14991	11005	5479	767	767
Moree Plains (A)	17884	100%	96485	74514	97781	13689	13689
Murrurundi (A)	2472	62%	9564	6632	5667	793	793
Narrabri (A)	12987	100%	47983	32334	64412	9018	9018
Nundle (A)	1595	79%	5909	4157	2767	387	387
Parry (A) - Pt A	300	100%	234	185	847	119	119
Parry (A) - Pt B	4088	100%	26032	18638	13291	1861	1861
Quirindi (A)	3024	100%	17985	12629	11164	1563	1563
Severn (A)	5559	48%	16384	9123	15269	2138	2138
Tamworth (C)	185	100%	1044	735	717	0	0
Tenterfield (A)	7162	38%	12875	9172	6379	893	893
Uralla (A)	3219	78%	18598	11236	12462	1745	1745
Walcha (A)	6245	17%	8796	5454	4965	695	695
Walgett (A)	22270	100%	49575	40977	28518	3993	3993
Yallaroi (A)	5327	100%	29845	19738	26846	3758	3758
Albury (C)	106	100%	423	298	269	0	0
Balranald (A)	21674	100%	0	0	0	0	0
Bathurst (C)	239	100%	1433	979	976	0	0
Bega Valley (A)	6320	0%	0	0	0	0	0
Berrigan (A)	2072	100%	9790	6909	9332	1306	1306
Bland (A)	8549	100%	40718	13751	41218	5771	5771
Blayney (A) - Pt A	516	100%	3584	2380	2114	296	296
Blayney (A) - Pt B	1006	100%	6047	4048	3653	511	511
Bogan (A)	14560	100%	38391	27083	33337	4667	4667
Boorowa (A)	2577	100%	15207	8975	9944	1392	1392
Bourke (A)	41553	100%	0	0	0	0	0

SLA Name	Area (km²)	Proport'n in MDB (%)	Harvest. Right (ML)	Available Harvest. Right (ML)	Estimated volume of existing farm dams (ML)	Projected increase to 2030 based upon historic trend (ML)	Adopted projected increase in farm dams to 2030 (ML)
Brewarrina (A)	19132	100%	0	0	0	0	0
Broken Hill (C)	170	100%	0	0	0	0	0
Cabonne (A) - Pt A	875	100%	5218	3549	2947	413	413
Cabonne (A) - Pt B	518	100%	2708	1828	1681	235	235
Cabonne (A) - Pt C	4619	100%	26161	17288	19163	2683	2683
Carrathool (A)	18907	100%	40910	28878	37778	5289	5289
Central Darling (A)	53338	96%	0	0	0	0	0
Cobar (A)	45455	100%	0	0	0	0	0
Conargo (A)	3694	100%	16843	12279	16299	2282	2282
Coolah (A)	4787	100%	23559	16189	16017	2242	2242
Coolamon (A)	2433	100%	13248	4229	15934	2231	2231
Cooma-Monaro (A)	4945	84%	9519	6518	6683	936	936
Coonamble (A)	9891	100%	43914	30822	26156	3662	3662
Cootamundra (A)	1524	100%	9478	6491	4379	613	613
Corowa (A)	2178	100%	10724	7389	8665	1213	1213
Cowra (A)	2806	100%	15596	10330	10462	1465	1465
Crookwell (A)	3611	94%	22033	14618	14441	2022	2022
Culcairn (A)	1602	100%	9998	6867	6714	940	940
Deniliquin (A)	130	100%	442	316	472	0	0
Dubbo (C) - Pt A	329	100%	1492	1026	1145	0	0
Dubbo (C) - Pt B	3088	100%	12618	8689	9407	1317	1317
Eurobodalla (A)	3434	0%	0	0	0	0	0
Evans (A) - Pt A	474	100%	2919	1970	1953	273	273
Evans (A) - Pt B	3828	100%	17546	11838	11209	1569	1569
Forbes (A)	4710	100%	24325	13750	16620	2327	2327
Gilgandra (A)	4819	100%	22781	15748	16857	2360	2360
Greater Lithgow (C)	3510	27%	4427	2946	2617	366	366
Griffith (C)	1639	100%	7147	5198	11223	0	0
Gundagai (A)	2460	100%	14204	10345	7105	995	995
Gunning (A)	2211	97%	11522	7178	8139	1139	1139
Harden (A)	1869	100%	12322	9044	6178	865	865
Hay (A)	11323	100%	38665	23301	62415	8738	8738
Holbrook (A)	2609	100%	11942	8123	6939	972	972
Hume (A)	1931	100%	11884	8136	7624	1067	1067
Jerilderie (A)	3380	100%	15493	11150	13166	1843	1843
Junee (A)	2032	100%	12247	7686	6563	919	919
Lachlan (A)	14934	100%	62555	40732	45994	6439	6439
Leeton (A)	1167	100%	4655	3324	6751	945	945
Lockhart (A)	2900	100%	15977	10921	12082	1692	1692
Merriwa (A)	3489	3%	961	667	629	88	88

SLA Name	Area (km²)	Proport'n in MDB (%)	Harvest. Right (ML)	Available Harvest. Right (ML)	Estimated volume of existing farm dams (ML)	Projected increase to 2030 based upon historic trend (ML)	Adopted projected increase in farm dams to 2030 (ML)
Mudgee (A)	5524	84%	25784	17728	16903	2366	2366
Mulwaree (A)	5209	15%	4704	3052	3270	458	458
Murray (A)	4357	100%	16087	11308	15675	2195	2195
Murrumbidgee (A)	3506	100%	15470	11673	18502	2590	2590
Narrandera (A)	4117	100%	18217	8588	23164	3243	3243
Narromine (A)	5247	100%	27263	19024	24142	3380	3380
Oberon (A)	2904	65%	8594	5825	4834	677	677
Orange (C)	284	100%	2156	1466	1132	0	0
Parkes (A)	5942	100%	31005	18071	28121	3937	3937
Queanbeyan (C)	52	100%	0	0	0	0	0
Rylstone (A)	3816	46%	9108	6284	5698	798	798
Scone (A)	4027	0%	0	0	0	0	0
Singleton (A)	4882	0%	0	0	0	0	0
Snowy River (A)	6058	20%	4748	3238	3369	472	472
Tallaganda (A)	3329	0%	0	0	0	0	0
Temora (A)	2801	100%	15551	6697	13799	1932	1932
Tumbarumba (A)	4390	100%	10500	6982	5176	725	725
Tumut (A)	3775	100%	9508	6523	4912	688	688
Unincorp. Far West	92996	34%	0	0	0	0	0
Urana (A)	3363	100%	14912	10361	12400	1736	1736
Wagga Wagga (C) - Pt A	220	100%	905	626	690	0	0
Wagga Wagga (C) - Pt B	4611	100%	26675	17406	19921	2789	2789
Wakool (A)	7528	100%	26242	18539	31873	4462	4462
Warren (A)	10723	100%	44307	31364	38494	5389	5389
Weddin (A)	3405	100%	17416	8213	14902	2086	2086
Wellington (A)	4101	100%	23275	15889	15913	2228	2228
Wentworth (A)	26226	100%	0	0	0	0	0
Windouran (A)	5069	100%	21036	14900	27669	3874	3874
Yarrowlumla (A) - Pt A	1934	100%	7640	5208	5123	717	717
Yarrowlumla (A) - Pt B	1044	100%	278	192	158	22	22
Yass (A)	3301	100%	17629	10621	12500	1750	1750
Young (A)	2692	100%	15992	9302	11717	1640	1640

Appendix N Distribution of projected additional storage volume of farm dams, by farm dam volume, for each rural SLA in New South Wales, Queensland and Victoria

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Armidale Dumaresq (A) Bal	NSW	1	2	8	21	25	35	24	11	5	0	0	0	131
Balranald (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Barraba (A)	NSW	15	19	57	152	204	252	270	102	59	18	17	21	1,186
Bega Valley (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Berrigan (A)	NSW	19	23	56	253	564	338	47	7	0	0	0	0	1,306
Bingara (A)	NSW	13	14	39	102	120	130	177	82	45	26	34	41	823
Bland (A)	NSW	89	70	148	674	1,074	2,021	1,418	186	20	0	70	0	5,771
Blayney (A) - Pt A	NSW	14	17	92	69	57	30	18	0	0	0	0	0	296
Blayney (A) - Pt B	NSW	15	22	102	110	92	80	51	15	24	0	0	0	511
Bogan (A)	NSW	7	22	42	241	412	512	949	556	368	460	699	397	4,667
Boorowa (A)	NSW	47	70	261	318	294	211	156	32	2	0	0	0	1,392
Bourke (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Brewarrina (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Cabonne (A) - Pt A	NSW	15	20	74	109	79	64	31	12	0	8	0	0	413
Cabonne (A) - Pt B	NSW	5	6	27	44	36	48	40	18	12	0	0	0	235
Cabonne (A) - Pt C	NSW	74	91	302	614	646	548	278	46	34	10	25	16	2,683
Carrathool (A)	NSW	29	41	80	460	1,267	1,871	1,153	226	87	43	14	19	5,289
Central Darling (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Cobar (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Conargo (A)	NSW	13	28	93	503	1,069	464	80	14	18	0	0	0	2,282
Coolah (A)	NSW	32	42	138	308	373	497	533	194	53	61	10	0	2,242
Coolamon (A)	NSW	54	47	115	454	653	732	149	26	0	0	0	0	2,231
Cooma-Monaro (A)	NSW	34	62	135	318	198	93	57	14	0	0	0	23	936
Coonabarabran (A)	NSW	28	44	114	338	400	533	613	272	67	54	37	0	2,502
Coonamble (A)	NSW	25	53	102	441	807	857	789	372	107	50	59	0	3,662
Cootamundra (A)	NSW	22	29	131	160	146	102	19	0	0	4	0	0	613
Corowa (A)	NSW	20	30	89	311	451	286	26	0	0	0	0	0	1,213
Cowra (A)	NSW	45	46	168	361	384	290	141	13	6	0	11	0	1,465
Crookwell (A)	NSW	50	77	390	466	379	290	227	89	41	0	14	0	2,022
Culcairn (A)	NSW	16	16	60	247	384	187	29	0	0	0	0	0	940
Dubbo (C) - Pt B	NSW	17	50	73	212	226	320	271	76	28	18	26	0	1,317
Eurobodalla (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Evans (A) - Pt A	NSW	7	14	48	56	65	49	34	0	0	0	0	0	273
Evans (A) - Pt B	NSW	29	50	179	236	295	292	230	112	67	68	11	0	1,569
Forbes (A)	NSW	58	79	149	490	586	513	317	116	3	16	0	0	2,327
Gilgandra (A)	NSW	17	24	56	216	399	668	670	257	20	18	0	16	2,360
Greater Lithgow (C)	NSW	11	11	52	89	47	61	56	7	12	8	11	0	366
Gundagai (A)	NSW	32	42	176	235	231	149	94	13	10	11	0	0	995
Gunnedah (A)	NSW	39	40	177	504	653	699	648	120	69	0	20	0	2,969
Gunning (A)	NSW	43	69	247	274	232	180	73	14	8	0	0	0	1,139
Guyra (A)	NSW	20	26	99	217	263	302	211	49	27	7	12	0	1,233
Harden (A)	NSW	35	34	144	209	199	133	99	8	5	0	0	0	865

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Hay (A)	NSW	54	94	205	917	2,250	1,901	1,285	405	472	360	303	492	8,738
Holbrook (A)	NSW	16	20	78	207	220	222	155	37	17	0	0	0	972
Hume (A)	NSW	27	42	167	338	324	113	49	8	0	0	0	0	1,067
Inverell (A) - Pt A	NSW	28	33	115	299	353	318	318	164	56	54	64	28	1,829
Inverell (A) - Pt B	NSW	37	32	132	229	192	162	118	96	21	0	0	0	1,019
Jerilderie (A)	NSW	15	19	57	356	838	461	81	17	0	0	0	0	1,843
Junee (A)	NSW	21	31	108	267	237	169	81	0	5	0	0	0	919
Lachlan (A)	NSW	40	59	114	447	778	1,590	1,829	810	222	143	289	118	6,439
Leeton (A)	NSW	65	42	135	302	228	130	42	0	0	0	0	0	945
Lockhart (A)	NSW	19	20	57	325	618	513	117	23	0	0	0	0	1,692
Manilla (A)	NSW	15	18	56	138	150	160	168	38	14	11	0	0	767
Merriwa (A)	NSW	1	0	2	4	11	10	30	4	0	0	0	27	88
Moree Plains (A)	NSW	83	122	301	1,194	1,956	2,891	3,611	1,990	940	411	191	0	13,689
Mudgee (A)	NSW	56	153	327	438	498	470	293	63	13	16	22	17	2,366
Mulwaree (A)	NSW	7	15	65	74	94	98	96	9	0	0	0	0	458
Murray (A)	NSW	29	71	135	461	755	464	220	31	17	11	0	0	2,195
Murrumbidgee (A)	NSW	14	29	68	453	1,050	492	259	136	79	11	0	0	2,590
Murrurundi (A)	NSW	6	8	32	52	89	163	140	98	39	51	11	104	793
Narrabri (A)	NSW	114	129	305	1,025	1,649	2,140	2,164	897	303	197	61	35	9,018
Narrandera (A)	NSW	60	83	161	638	1,074	790	378	32	26	0	0	0	3,243
Narromine (A)	NSW	25	36	67	266	450	1,022	990	463	51	11	0	0	3,380
Nundle (A)	NSW	12	12	22	36	39	52	93	75	22	12	8	5	387
Oberon (A)	NSW	18	27	126	148	122	139	70	23	6	0	0	0	677
Parkes (A)	NSW	68	57	117	359	624	1,211	1,111	277	25	0	35	53	3,937

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Parry (A) - Pt A	NSW	10	4	19	51	6	28	0	0	0	0	0	0	119
Parry (A) - Pt B	NSW	38	34	135	362	412	477	300	78	19	0	6	0	1,861
Quirindi (A)	NSW	32	47	154	279	346	258	264	109	34	30	9	0	1,563
Rylstone (A)	NSW	17	33	106	181	138	147	100	29	18	9	0	20	798
Scone (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Severn (A)	NSW	55	68	246	416	436	376	284	75	90	38	55	0	2,138
Singleton (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Snowy River (A)	NSW	14	28	83	143	114	59	26	4	0	0	0	0	472
Tallaganda (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Temora (A)	NSW	55	53	133	399	571	511	168	42	0	0	0	0	1,932
Tenterfield (A)	NSW	23	23	83	157	144	155	126	57	62	44	19	0	893
Tumbarumba (A)	NSW	17	19	47	147	181	175	99	30	4	6	0	0	725
Tumut (A)	NSW	35	32	110	166	139	112	84	10	0	0	0	0	688
Unincorp. Far West	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0
Uralla (A)	NSW	49	45	156	387	336	384	262	93	15	0	18	0	1,745
Urana (A)	NSW	19	32	79	327	551	440	118	37	25	30	52	25	1,736
Wagga Wagga (C) - Pt B	NSW	43	65	188	619	740	706	270	124	23	0	13	0	2,789
Wakool (A)	NSW	50	53	141	621	1,167	1,025	842	256	110	80	64	53	4,462
Walcha (A)	NSW	12	11	56	195	148	145	117	11	0	0	0	0	695
Walgett (A)	NSW	13	24	56	262	511	865	1,037	764	247	158	48	9	3,993
Warren (A)	NSW	23	47	119	645	1,320	1,228	1,228	516	94	98	37	35	5,389
Weddin (A)	NSW	48	64	145	396	648	518	215	44	8	0	0	0	2,086
Wellington (A)	NSW	54	71	224	463	576	497	310	12	22	0	0	0	2,228
Wentworth (A)	NSW	0	0	0	0	0	0	0	0	0	0	0	0	0

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Windouran (A)	NSW	22	52	148	989	1,849	538	221	54	0	0	0	0	3,874
Yallaroi (A)	NSW	34	39	131	409	577	637	970	573	151	98	140	0	3,758
Yarrowlumla (A) - Pt A	NSW	40	61	172	113	135	86	73	18	19	0	0	0	717
Yarrowlumla (A) - Pt B	NSW	1	1	2	3	6	2	3	4	0	0	0	0	22
Yass (A)	NSW	69	76	345	441	401	255	130	20	0	0	14	0	1,750
Young (A)	NSW	86	67	227	407	445	284	101	23	0	0	0	0	1,640
Balonne (S)	QLD	26	35	154	325	0	0	0	0	0	0	0	0	540
Bauhinia (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Bendemere (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Blackall (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Boonah (S)	QLD	10	14	60	127	0	0	0	0	0	0	0	0	211
Booringa (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Bulloo (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Bungil (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Cambooya (S) - Pt B	QLD	2	2	11	23	0	0	0	0	0	0	0	0	38
Chinchilla (S)	QLD	23	31	134	282	0	0	0	0	0	0	0	0	469
Clifton (S)	QLD	1	2	9	18	0	0	0	0	0	0	0	0	30
Crow's Nest (S) - Pt B	QLD	11	15	67	141	0	0	0	0	0	0	0	0	235
Gatton (S)	QLD	1	2	7	14	0	0	0	0	0	0	0	0	24
Inglewood (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Jondaryan (S) - Pt B	QLD	1	2	7	15	0	0	0	0	0	0	0	0	25
Kingaroy (S)	QLD	33	45	197	414	0	0	0	0	0	0	0	0	688
Laidley (S)	QLD	1	1	4	8	0	0	0	0	0	0	0	0	14
Millmerran (S)	QLD	11	15	68	142	0	0	0	0	0	0	0	0	237

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Murilla (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Nanango (S)	QLD	11	15	65	136	0	0	0	0	0	0	0	0	226
Paroo (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Pittsworth (S)	QLD	5	7	30	62	0	0	0	0	0	0	0	0	103
Quilpie (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Rosalie (S) - Pt B	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Stanthorpe (S)	QLD	35	47	208	438	0	0	0	0	0	0	0	0	729
Tambo (S)	QLD	1	1	5	11	0	0	0	0	0	0	0	0	18
Tara (S)	QLD	111	150	660	1387	0	0	0	0	0	0	0	0	2308
Taroom (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Waggamba (S)	QLD	52	70	308	648	0	0	0	0	0	0	0	0	1079
Wambo (S)	QLD	0	0	0	0	0	0	0	0	0	0	0	0	0
Warroo (S)	QLD	2	3	12	26	0	0	0	0	0	0	0	0	43
Warwick (S) - East	QLD	9	12	51	107	0	0	0	0	0	0	0	0	178
Warwick (S) - North	QLD	1	1	3	6	0	0	0	0	0	0	0	0	11
Warwick (S) - West	QLD	30	41	178	375	0	0	0	0	0	0	0	0	623
Wondai (S)	QLD	13	17	75	159	0	0	0	0	0	0	0	0	264
Alpine (S) - East	VIC	14	29	48	65	0	0	0	0	0	0	0	0	156
Alpine (S) - West	VIC	2	4	7	9	0	0	0	0	0	0	0	0	23
Ararat (RC)	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Ballarat (C) - Inner North	VIC	59	128	238	373	0	0	0	0	0	0	0	0	799
Ballarat (C) - North	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Baw Baw (S) - Pt B East	VIC	14	30	48	55	0	0	0	0	0	0	0	0	147
Buloke (S) - North	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Buloke (S) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
C. Goldfields (S) - M'borough	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
C. Goldfields (S) Bal	VIC	26	56	94	135	0	0	0	0	0	0	0	0	310
Campaspe (S) - Kyabram	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Campaspe (S) - Rochester	VIC	7	14	22	18	0	0	0	0	0	0	0	0	61
Campaspe (S) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Delatite (S) - North	VIC	63	133	211	230	0	0	0	0	0	0	0	0	637
Delatite (S) - South	VIC	120	254	411	736	0	0	0	0	0	0	0	0	1522
E. Gippsland (S) - Orbost	VIC	31	67	110	144	0	0	0	0	0	0	0	0	352
E. Gippsland (S) - South-West	VIC	76	162	287	419	0	0	0	0	0	0	0	0	945
E. Gippsland (S) Bal	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Gannawarra (S)	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Gr. Bendigo (C) - Pt B	VIC	195	414	721	1651	0	0	0	0	0	0	0	0	2980
Gr. Shepparton (C) - Pt B East	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Gr. Shepparton (C) - Pt B West	VIC	5	10	16	23	0	0	0	0	0	0	0	0	54
Hepburn (S) - East	VIC	29	62	104	140	0	0	0	0	0	0	0	0	336
Hepburn (S) - West	VIC	28	60	112	202	0	0	0	0	0	0	0	0	402
Hindmarsh (S)	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Horsham (RC) Bal	VIC	1	2	4	3	0	0	0	0	0	0	0	0	10
Indigo (S) - Pt A	VIC	71	151	262	422	0	0	0	0	0	0	0	0	907
Indigo (S) - Pt B	VIC	4	8	13	16	0	0	0	0	0	0	0	0	41
Loddon (S) - North	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Loddon (S) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Macedon Ranges (S) - Kyneton	VIC	55	117	194	272	0	0	0	0	0	0	0	0	637

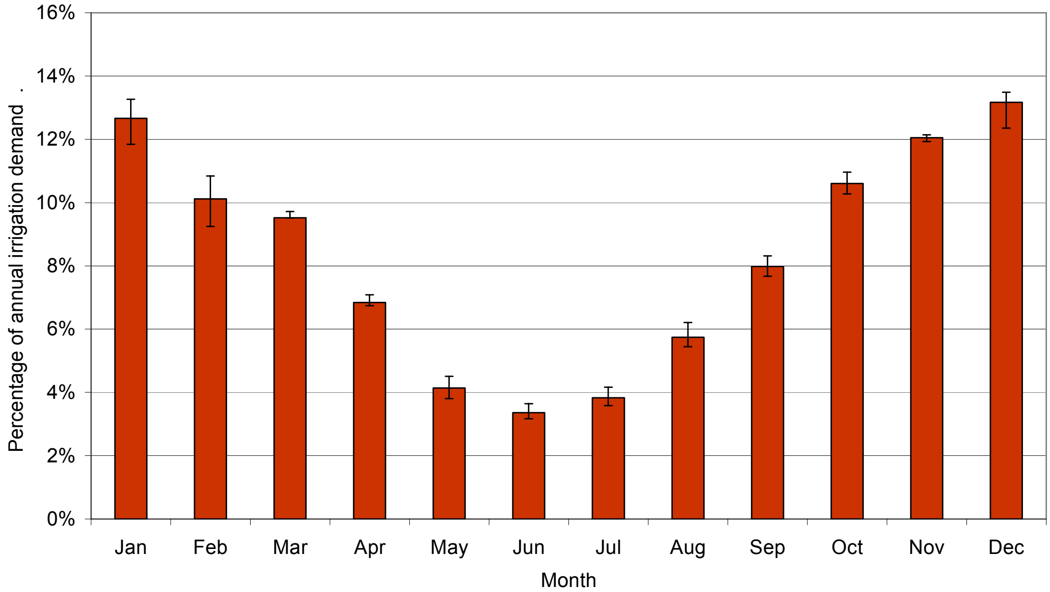
SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
Macedon Ranges (S) - Romsey	VIC	116	245	394	513	0	0	0	0	0	0	0	0	1268
Macedon Ranges (S) Bal	VIC	150	317	509	632	0	0	0	0	0	0	0	0	1607
Mildura (RC) - Pt B	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Mitchell (S) - North	VIC	15	33	53	132	0	0	0	0	0	0	0	0	234
Mitchell (S) - South	VIC	238	503	839	1257	0	0	0	0	0	0	0	0	2836
Moira (S) - East	VIC	154	326	526	642	0	0	0	0	0	0	0	0	1649
Moira (S) - West	VIC	1	2	3	2	0	0	0	0	0	0	0	0	8
Moorabool (S) - Ballan	VIC	51	109	191	369	0	0	0	0	0	0	0	0	720
Moorabool (S) - West	VIC	35	76	153	314	0	0	0	0	0	0	0	0	578
Mount Alexander (S) Bal	VIC	43	93	165	301	0	0	0	0	0	0	0	0	602
Murrindindi (S) - East	VIC	13	28	49	86	0	0	0	0	0	0	0	0	176
Murrindindi (S) - West	VIC	126	268	451	627	0	0	0	0	0	0	0	0	1472
N. Grampians (S) - St Arnaud	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
N. Grampians (S) - Stawell	VIC	22	47	81	121	0	0	0	0	0	0	0	0	271
Pyrenees (S) - North	VIC	19	42	69	95	0	0	0	0	0	0	0	0	225
Pyrenees (S) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Strathbogie (S)	VIC	104	221	362	491	0	0	0	0	0	0	0	0	1178
Swan Hill (RC) - Robinvale	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Swan Hill (RC) Bal	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Towong (S) - Pt B	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Wangaratta (RC) - North	VIC	151	318	514	573	0	0	0	0	0	0	0	0	1556
Wangaratta (RC) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Wellington (S) - Avon	VIC	1	1	2	3	0	0	0	0	0	0	0	0	7
Wellington (S) - Maffra	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0

SLA Name	State	<0.5 ML	0.5-1 ML	1-2 ML	2-5 ML	5-10 ML	10-20 ML	20-40 ML	40-60 ML	60-80 ML	80-100 ML	100-140 ML	>140 ML	Total for all classes (ML)
West Wimmera (S)	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Yarra Ranges (S) - North	VIC	41	86	144	176	0	0	0	0	0	0	0	0	446
Yarra Ranges (S) - Pt B	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Yarriambiack (S) - North	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0
Yarriambiack (S) - South	VIC	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix O Monthly pattern of demands from farm dams use for irrigation

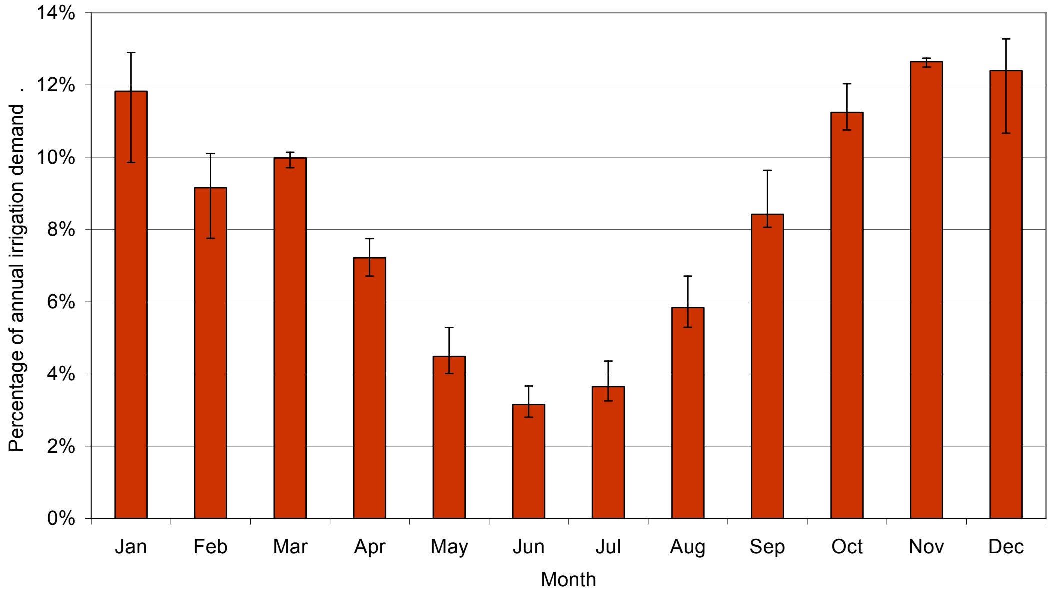
The following graphs illustrate the irrigation demand factors for each of the reporting regions. Each graph represents the median climate change scenario for that reporting region. Note that error bars are the difference between the maximum of the factors for each subcatchment and the median, and the difference between the median and the minimum.

O.1 Paroo reporting region



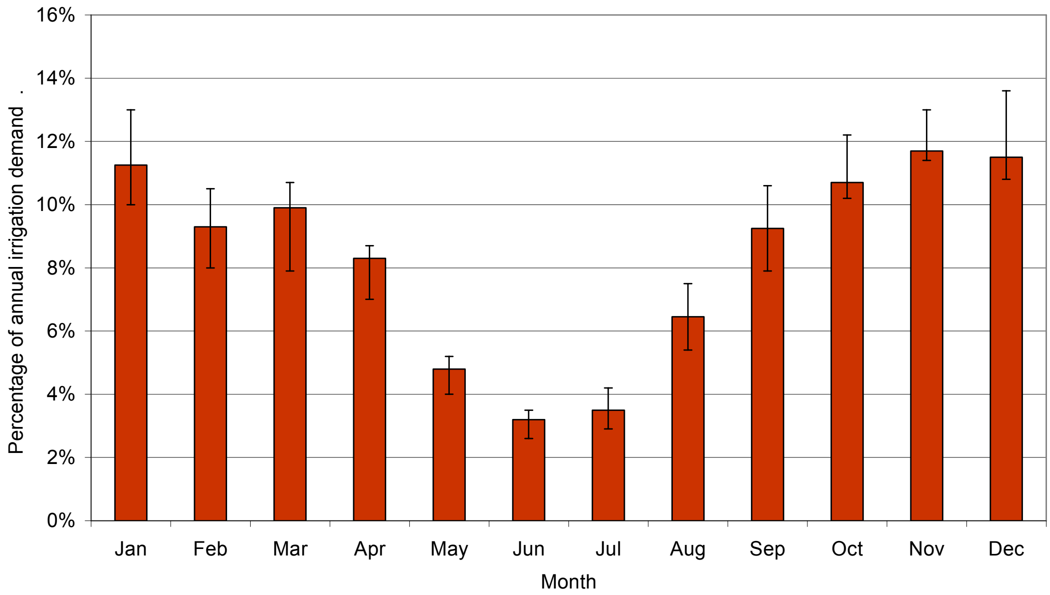
- **Irrigation demand factors for the CNRM H global warming scenario in the Paroo reporting region**

O.2 Warrego reporting region



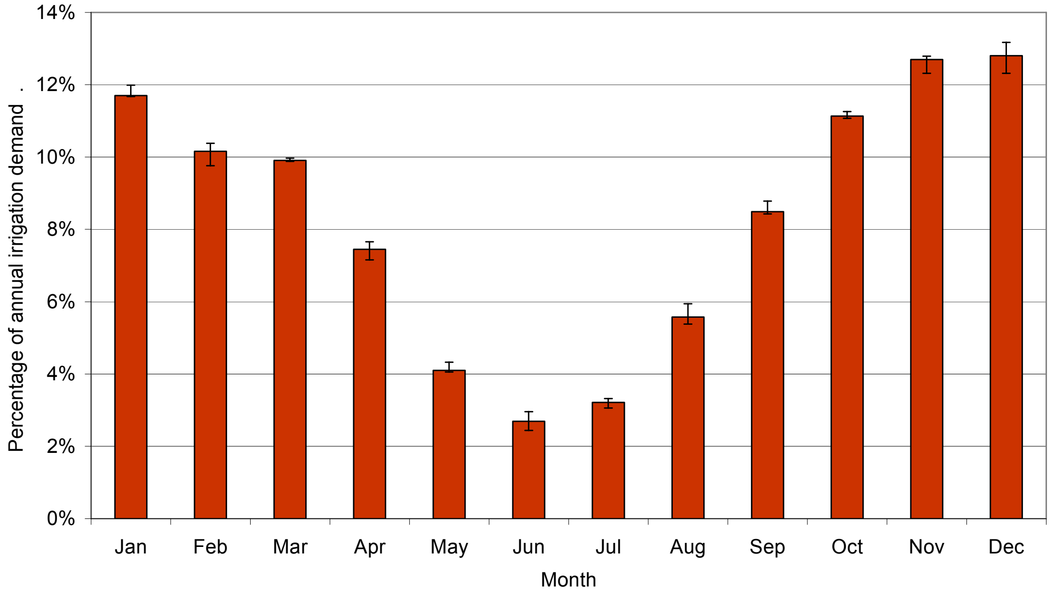
- **Irrigation demand factors for the GFDL H global warming scenario in the Warrego reporting region**

O.3 Condamine-Balonne reporting region



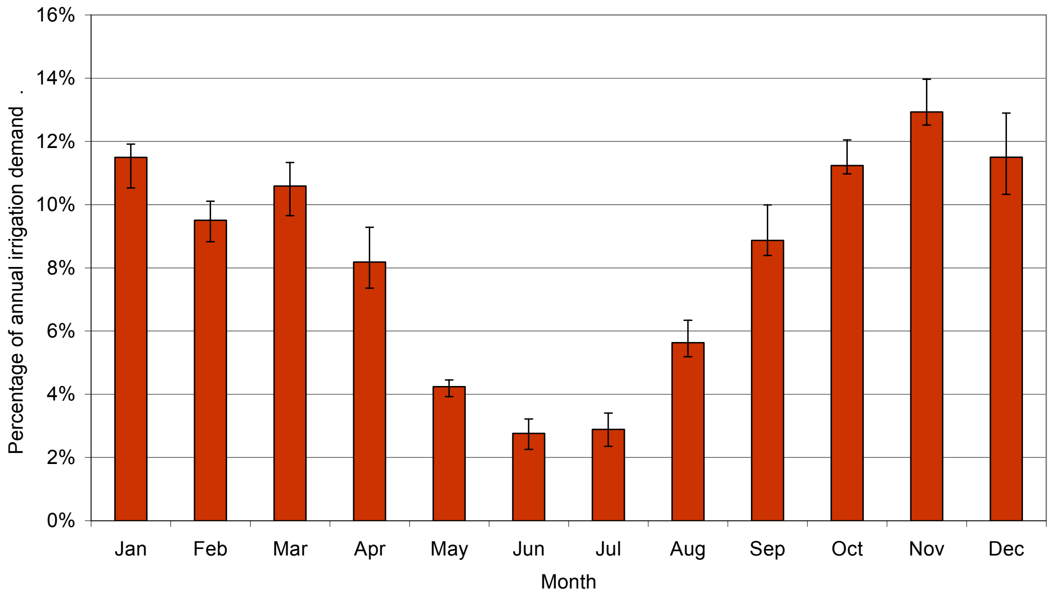
- **Irrigation demand factors for the IAP M global warming scenario in the Condamine-Balonne reporting region**

O.4 Moonie reporting region



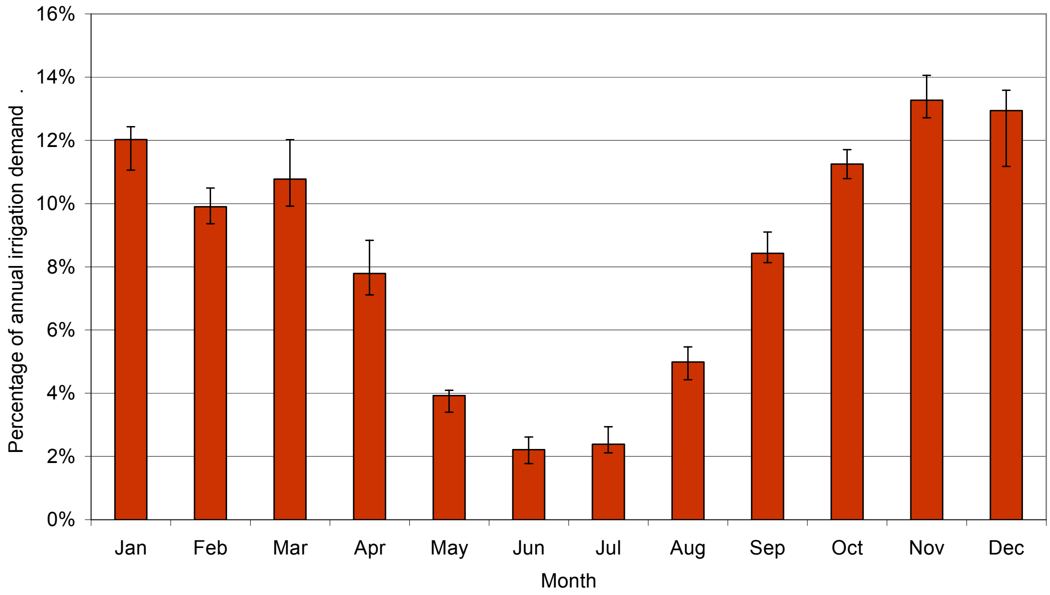
- **Irrigation demand factors for the GFDL M global warming scenario in the Moonie reporting region**

O.5 Border Rivers reporting region



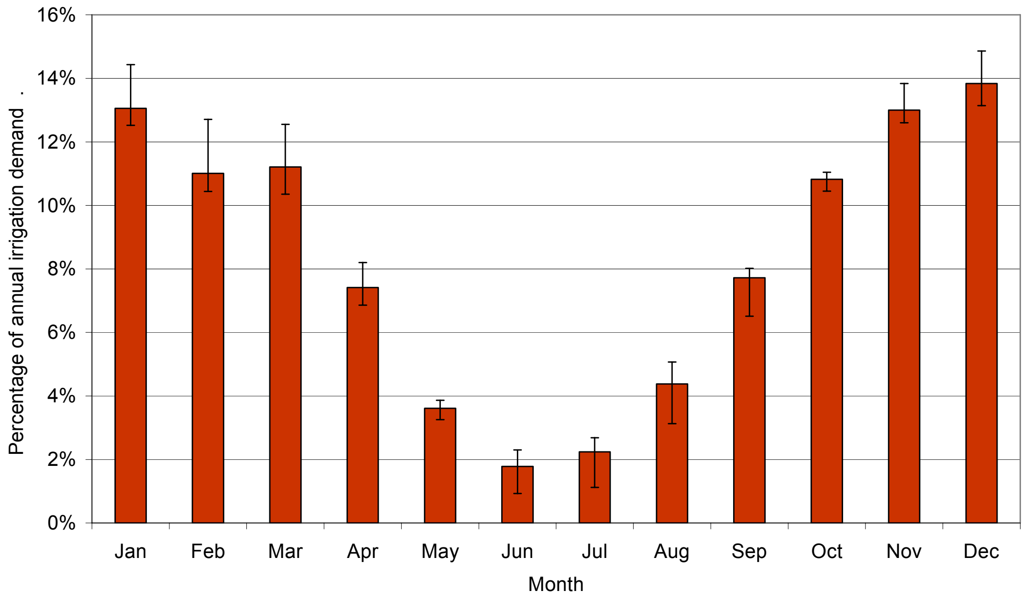
- **Irrigation demand factors for the IPSL M global warming scenario in the Border Rivers reporting region**

O.6 Gwydir reporting region



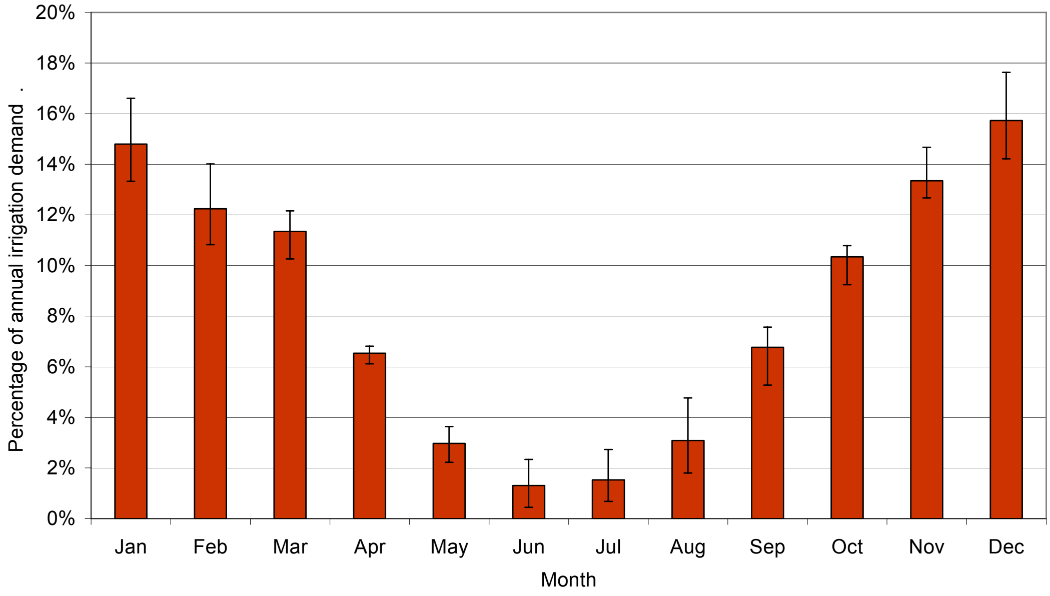
- **Irrigation demand factors for the IPSL M global warming scenario in the Gwydir reporting region**

O.7 Namoi reporting region



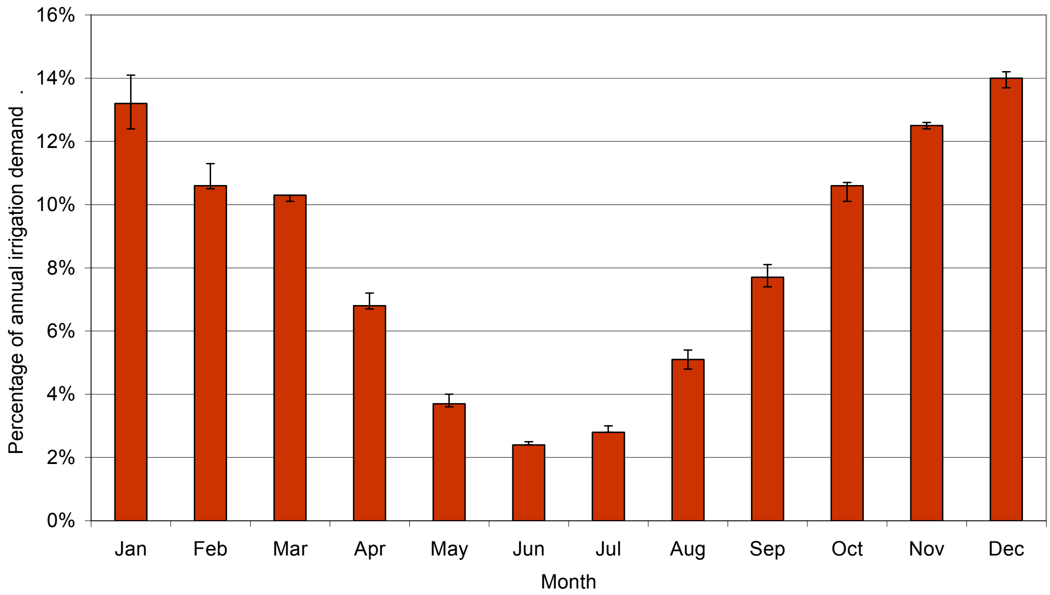
- **Irrigation demand factors for the CSIRO M global warming scenario in the Namoi reporting region**

O.8 Macquarie-Castlereagh reporting region



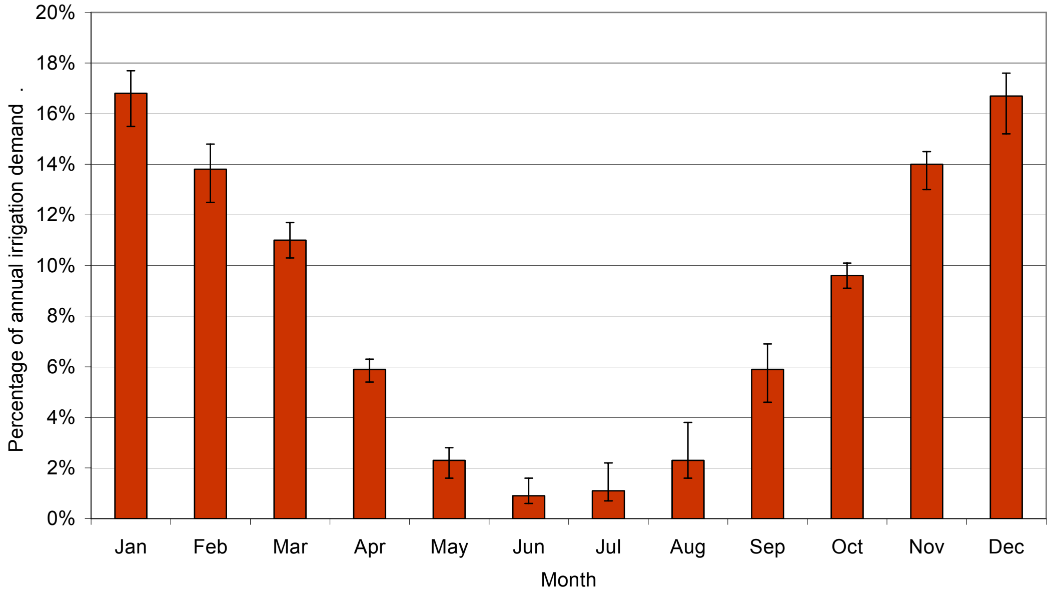
- **Irrigation demand factors for the MRI M global warming scenario in the Macquarie-Castlereagh reporting region**

O.9 Barwon-Darling reporting region



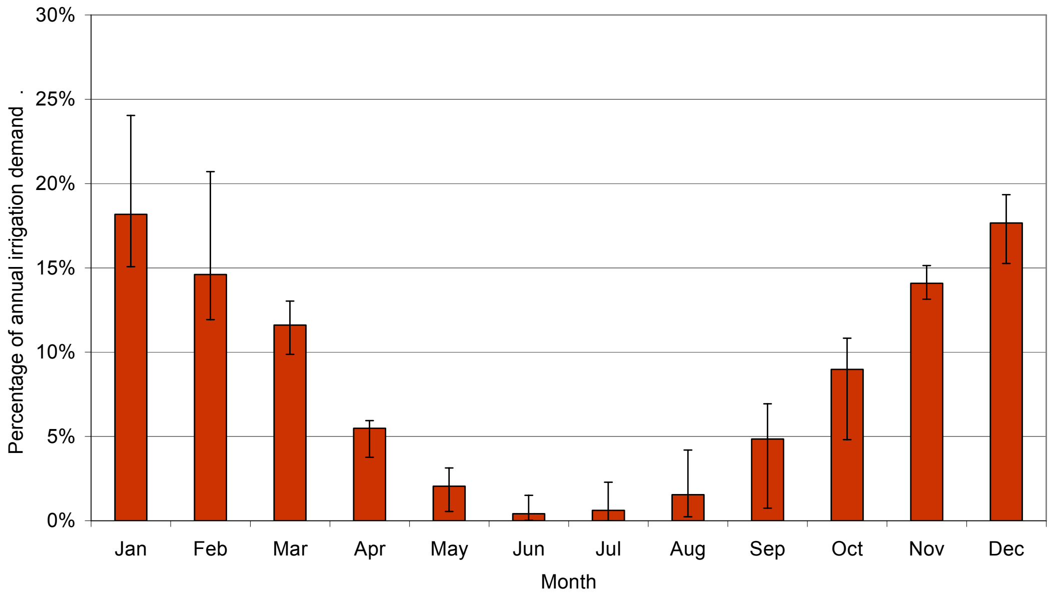
- **Irrigation demand factors for the MRI M global warming scenario in the Barwon-Darling reporting region**

O.10 Lachlan reporting region



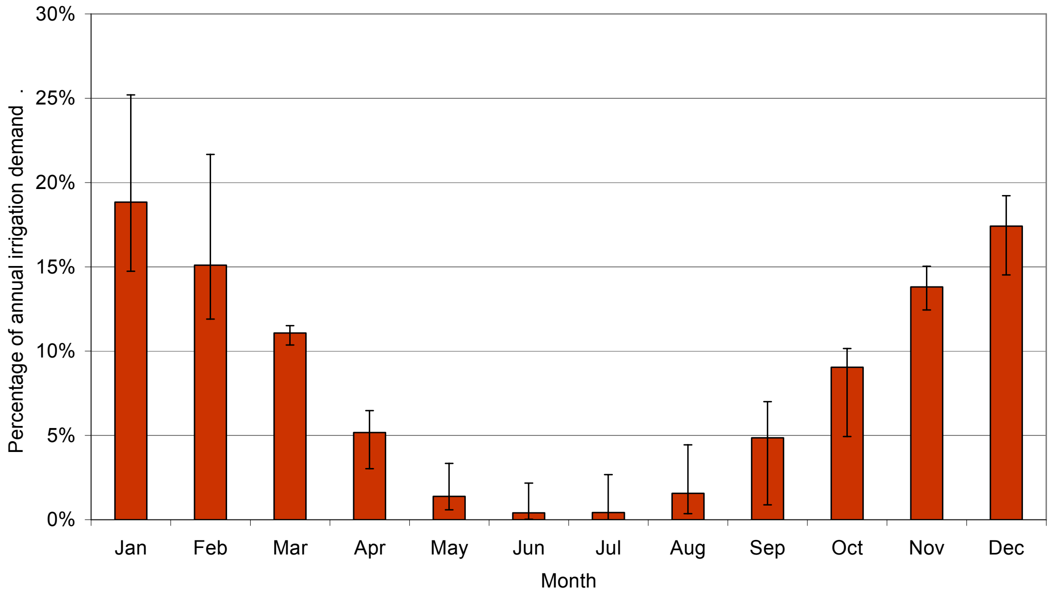
- **Irrigation demand factors for the MPI M global warming scenario in the Lachlan reporting region**

O.11 Murrumbidgee reporting region



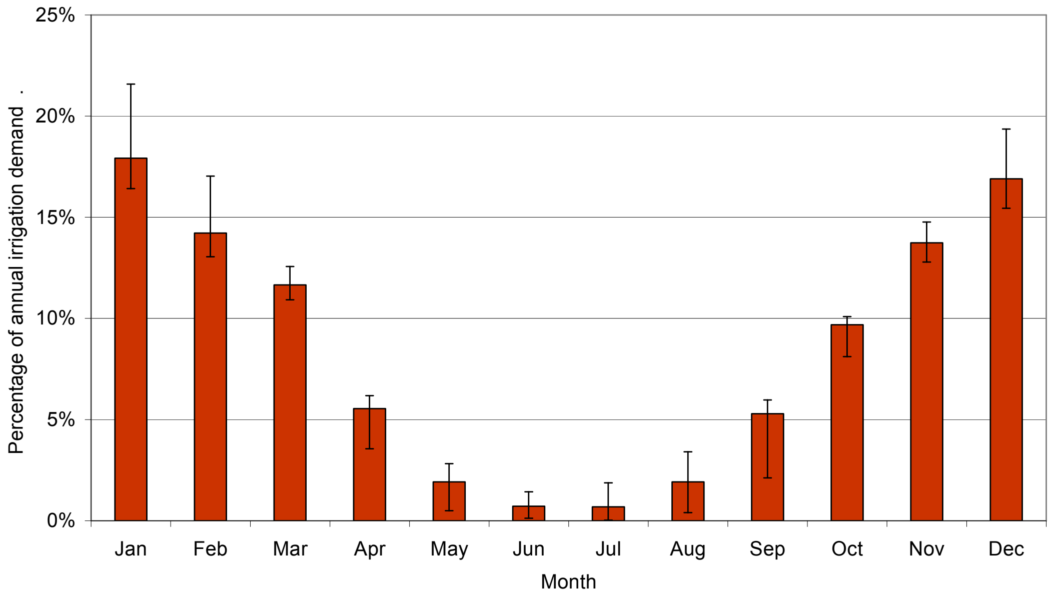
- **Irrigation demand factors for the MRI M global warming scenario in the Murrumbidgee reporting region**

O.12 Murray reporting region



- **Irrigation demand factors for the MPI M global warming scenario in the Murray reporting region**

O.13 Eastern Mount Lofty Ranges reporting region



- **Irrigation demand factors for the MIUB M global warming scenario in the Eastern Mount Lofty Ranges reporting region**