Australian Government
National Water Commission

Surface and/or groundwater interception activities
Initial estimates

Sinclair Knight Merz, CSIRO
Bureau of Rural Sciences

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Waterlines

A SERIES OF WORKS COMMISSIONED BY THE NATIONAL WATER COMMISSION ON KEY WATER ISSUES

Waterlines

This paper is part of a series of works commissioned by the National Water Commission on key water issues. This work has been undertaken by Sinclair Knight Merz, CSIRO and the Bureau of Rural Sciences on behalf of the National Water Commission.

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SKM

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Abbreviations and acronyms

ACT	Australian Capital Territory
AWR2005	Australian Water Resources 2005
GABSI	Great Artesian Basin Sustainability Initiative
GL	gigalitre
LTAEL	Long-term average extraction limit
ML	megalitre
ML/ML	megalitre of impact per megalitre of storage
mm	millimetres
NSW	New South Wales
NT	Northern Territory
NWI	National Water Initiative
Qld	Queensland
TAS	Tasmania
SA	South Australia
SWMA	Surface water management area
VIC	Victoria

Australian Government

National Water Commission

National Water Commission Interception position statement

Commitments on interception under the National Water Initiative

The National Water Initiative (NWI) explicitly recognises that water interception activities such as farm dams, plantation forestry, capture of overland flows and groundwater extraction, can reduce water availability.

In the NWI, governments committed that by 2011, significant interception activities will be identified for all water systems so that:

- in water systems that are fully allocated, over-allocated, or approaching full allocation, significant interception activities should be recorded (e.g. via a licensing system) – with any proposals for additional interception activities requiring a water access entitlement
- in water systems that are neither fully allocated or approaching full allocation, estimates are made of the amount of water likely to be intercepted over the life of the relevant water plan, and a threshold level of interception calculated, above which a water access entitlement would be required for additional significant interception activities.

All parties to the NWI recognised that activities which use unaccounted water present a risk to the security of water access entitlements and the achievement of environmental objectives for water systems. These activities therefore urgently need to be accounted for in planning and regulation regimes. This includes jurisdictions having an agreed view on concepts fundamental to managing interception (e.g. 'sustainable levels of extraction' and 'over-allocation').

Progress on interception

The *Australian Water Reform 2009* report (2009 Biennial) – the Commission's major assessment on how all Australian governments are tracking on their reform commitments – found that progress by governments to meet their NWI interception commitments has been limited. Aside from South Australia's process for dealing with forestry water use, there has been no evidence that states and territories have formally identified significant interception activities, or have established NWI-compliant policy responses.

The Commission acknowledges that major deficiencies in data make it difficult to quantify the impact of interception activities on water systems. These information gaps therefore need to be redressed urgently. However, imperfect data and information should not be an excuse for failing to act on the available knowledge or for developing policy and administration measures to account for significant water use by interception activities.

National Water Commission activities on interception

The National Water Commission has produced a Waterlines report titled *Surface and/or groundwater interception activities :initial estimates* This is the first national baseline assessment of unaccounted water use across the nation to assist governments to:

- understand the extent of water use that is unaccounted to provide a basis for further work to measure water use by these activities
- identify the key interception activities in their respective jurisdictions

The first-cut national estimate of total unaccounted water use on average per year as a result of interception activities is in the order of 5600 GL/yr comprised of: forestry plantations using approximately 2000 gigalitres a year (GL/yr), farm dams 1600 GL/yr, stock and domestic activities 1100 GL/yr, and overland flows (floodplain harvesting) on average 900 GL/yr. In a wet year, interception volumes are estimated to be even greater, for example overland flows (floodplain harvesting) may potentially use up to 2600 GL. The total volume of unaccounted water is equivalent to roughly one quarter of all entitled water on issue (~25 000 GL/yr: *Australia Water Markets Report 2008-09*).

Future reform priorities

The report findings provide further evidence of the urgency to the recommendations in the *Australian Water Reform 2009* report. The Commission considers that the NWI interception commitments can only be addressed by paying greater attention to the following priority activities:

Quantifying unaccounted water use

- Develop a nationally-aligned science agenda of research to remedy deficiencies in knowledge and data on interception activities and to improve the quality of information available for decision making.
- Invest in the development of nationally consistent models, tools and collection of data in association with catchment planners and managers and promote adoption across all jurisdictions.
- Identify and quantify immediately all interception activities that have a potentially significant effect on the security of water access entitlements and achievement of environmental objectives, with activities prioritised according to catchments at, or approaching, full allocation and peri-urban areas.
- Identify possible future interception impacts, including increases in interception water use from expanding forestry plantings as a result of future climate change responses policies and programs.

Accounting for unaccounted water use

- Prepare an overarching work program to address interception activities, including:
  - Establish planning and regulatory frameworks for dealing with unaccounted water use within the next six months, including processes to trigger management response before a water access entitlement is required. This is an urgent requirement for addressing forestry water use, given the possible significant expansion of forestry as a response to future climate change response policies and programs.
  - Harmonise principles and approaches for dealing with interception activities across all jurisdictions to allow more effective implementation.
  - Ensure any current, or possible future, interception actions are explicitly identified in all water plans.
  - Strengthen monitoring, compliance and enforcement efforts in relation to interception activities identified in water plans.
  - Ensure frameworks are in place to allow time for all interception activities to be accounted for by 2011 (committed timeline under the NWI).

The National Water Commission continues to support targeted investments to improve both the quantification of water use by interception activities, and to encourage the proactive development of planning and regulatory frameworks to address all unaccounted water use.

National Water Commission
May 2010

Executive summary

The National Water Commission engaged Sinclair Knight Merz (SKM) in partnership with Bureau of Rural Sciences and CSIRO to develop a national baseline paper that documents:

- the location of significant intercepting activities that fall outside the current entitlement framework
- the potential rate of expansion of each activity over various time periods
- and estimates of water usage of each activity in water management areas used in the *Australian Water Resources 2005* report (NWC 2007a,b).

This report includes a definition and description of activities that intercept surface water and groundwater and identified the following activities for further analysis:

- overland flows
- farm dams
- stock and domestic bores
- plantations
- peri-urban development

This project has analysed the available data throughout Australia in order to quantify the level of development of each of these activities according to the definition of intercepting activities. The impact of the baseline assessment was then estimated, as were projections of impacts for the years 2015 and 2030.

The method for each analysis involved sourcing and collating existing data relating to the interception activity and associated indicators of development. The data collation and analysis phase was conducted between September 2008 and March 2009. As such, the analysis was limited to the data that were available during this period. Due to the extent of current data for each activity, the baseline year varies from 2005 to 2008. An estimate of the current impact was also required. The baseline condition also takes into account the current rate of change or growth of the activity.

The project also required a projection of future levels of development and impacts. This involved projecting current trends: other approaches were used depending on the activity, our understanding of the trends, and indicators and relationships. The projections are long term and do not take into account the current climatic conditions at a particular point in time, and they are not forecasts. In developing the projections, no attempt to model and apply the impacts of current and future policy has been made (e.g. expanding forestry plantings as a result of introducing a carbon market). Therefore, the projections are based on the current level of development and trends estimated from the currently available data.

Different methods were developed and applied for each intercepting activity. For example, the derived relationships between land use and farm dam densities were used to estimate farm dam data. Therefore, the farm dam estimates align with changes in land use modelled by this project. However, current rates of development of stock and domestic bores were derived from available databases, and these rates were applied to the current levels of stock and domestic bores to estimate the numbers for each surface water management area for 2015 and 2030.

A key challenge of this project was to source relevant, quantifiable data relating to the intercepting activities. By definition, these activities fall outside of regulation, and so there is a lack of data relating to their development and hence their impact on water resources. Therefore, broad assumptions were required to extrapolate the existing data across all regions of Australia and into the future. As such, the limitations and assumptions relating to the method developed for each activity needs to be carefully understood before reviewing the results because this information sets the context within which the data should be viewed.

The key findings relating to each activity are summarised below.

Overland flows

Almost all current floodplain harvesting in Australia occurs in the northern Murray–Darling Basin. The estimated total volume of floodplain harvesting storages nationwide is approximately 2600 gigalitres; this volume is split between New South Wales (950 gigalitres) and Queensland (1625 gigalitres). Floodplain harvesting is not likely to expand; there are moratoriums in place in the relevant river basins to restrict construction of new storages.

Farm dams

Based on available farm dam datasets, the total impact of farm dams nationally is 1600 gigalitres per year (in 2008). The impact is projected to increase to 1840 gigalitres per year in 2015 and to more than 1900 gigalitres per year in 2030. Baseline dam volume/impact densities are greatest at a river-basin scale in central Victoria and the Mount Lofty Ranges, South Australia. Victoria is projected to experience increases in farm dam volume/impact across most of the state from 2008 to 2030.

Stock and domestic bores

Nationally, stock and domestic bore use is estimated at 1,100 GL/yr, which is equivalent to an additional 23% of the current allocated volumes of 4,700 GL/yr. The highest density of extraction for stock and domestic purposes is in regions where there is no other available source of water (e.g. Lower Limestone Coast SWMA); in areas where surface waters have been capped and so users look to alternate water supplies (e.g. Lachlan River SWMA); and in urban centres where water restrictions have caused domestic users to source alternate water sources for garden watering (e.g. Swan Coast SWMA, Yarra SWMA). These three factors are probably the key indicators of where future growth in stock and domestic bores may occur. The Great Artesian Basin is a significant source for stock and domestic bore users with an estimated 638 GL usage, compared to the estimated 289 GL of usage from other stock and domestic users in NSW, NT, SA and QLD. In these states the Great Artesian Basin accounts for 69% of the total stock and domestic use. There is no expected increase in stock and domestic bores in the GAB due to current policy and management.

Plantations

Plantations have currently been mapped in 156 surface water management areas (SWMAs) with the total plantation area in Australia estimated to be more than two million hectares in 2008 with a median of 4000 hectares per SWMA. The most highly impacted SWMAs include Moore-Hill Rivers (Western Australia), Millicent Coast, Glenelg and Latrobe River (Victoria), Lower Limestone Coast (South Australia), and Mary (Queensland). The plantation area was predicted to increase to 2,300,000 hectares, with a median of 5200 hectares per SWMA by 2015. A further increase of 79,700 hectares was predicted by 2030 with a median of 5800 hectares. It is estimated that the evapotranspiration from existing plantations is 2000 gigalitres per year greater than if this land was used for dryland agriculture or other non-forest. In addition, some plantations use groundwater in regions with shallow watertables, which may equate to several hundred gigalitres per year of additional water use across existing plantation estates.

Peri-urban development

The term ‘peri-urban’ generally refers to the transition zone between urban and rural areas. It can be characterised common characteristics such as their low population density, high rates of change, and the heterogeneous nature of land uses. This study considered the environmental impacts in peri-urban areas associated with extraction of groundwater by stock and domestic bores and interception of rainfall runoff by farm dams. The data produced by this project relating to these interception activities were used.

South Australia was found to have a high baseline peri-urban impact density. It was found that approximately 2 per cent of the baseline (2008) farm dam impacts and groundwater bore usage occur within peri-urban areas in South Australia. Victoria and New South Wales were also assessed to have relatively high peri-urban impact densities, with 1.4 per cent of baseline (2008) farm dam impacts and groundwater bore usage occurring in peri-urban areas. The Onkaparinga SWMA in South Australia was found to have a peri-urban impact density of 22 megalitres per square kilometre. Other highly impacted SWMAs include Yarra and Bunyip SWMAs in Victoria, Hawkesbury River SWMA in NSW, and Mary SWMA in Queensland.

Integration

The baseline assessment and projected impacts of intercepting activities provides a national and regional context for assessing intercepting activities, and it highlights regions where particular risks may be posed by these activities. In assessing hydrological impacts, a number of factors need to be taken into account in addition to volume of impact. These include temporal impacts (in particular impacts during low flows), groundwater–surface water interactions and cumulative effects, which is most clearly indicated in the peri-urban regions. It should also be noted that there is difficult to quantify the baseline due to the limited availability of data relating to these activities and the required assumptions to provide a national dataset. This lack of data are, to a large extent, related to the definition and subject of this project, which is concerned with activities that are outside of the current regulation and licensing regime. Because the activities are outside of the regulatory framework, there is no comprehensive monitoring of these activities and, therefore, a lack of data.

Integration of results from the analysis of plantations, farm dams, floodplain harvesting and stock and domestic bores highlight the following SWMAs as being potentially highly impacted: Condamine-Balonne (Queensland), Swan River (Western Australia), Onkaparinga and Limestone Coast (South Australia), Glenelg River and South Gippsland (Victoria), and Hawkesbury River (New South Wales). Integration of the 2030 results highlight the following SWMAs as being potentially highly impacted: Swan River (Western Australia), Limestone Coast (South Australia), Glenelg River and Yarra (Victoria), Murray River (New South Wales), and Tweed River (Queensland).

Further studies, including local hydrological assessments, are required at catchment scales to quantify and assess the significance of the temporal and spatial hydrological impacts of intercepting activities. This might be through a river model, a rainfall–runoff model, or a groundwater model.

1. Introduction

1.1 Project Overview

1.1.1 Background

The National Water Initiative (NWI) explicitly recognises reductions in water availability as a result of water interception activities. These activities include interception from farm dams, re-afforestation, overland flow harvesting, and groundwater extraction (Clauses 55–57).

Under the NWI, governments have committed to identifying by 2011 significant interception activities for all water systems. In water systems that are:

- over-allocated, fully allocated, or approaching full allocation, significant interception activities should be recorded (for example, via a licensing system), and any proposals for additional interception activities require a water access entitlement
- not yet fully allocated or approaching full allocation, estimates are made of the amount of water likely to be intercepted over the life of the relevant water plan, and a threshold level of interception calculated, above which a water access entitlement would be required for additional significant interception activities.

The National Water Commission considers that achieving these important NWI outcomes will be difficult without rigorous quantification (measurement and modelling) of the major forms of water interception and the impact that they have on allocation of water, including environmental water—as part of the water planning process (Duggan et al. 2008).

Duggan et al. (2008) outline significant challenges facing governments in understanding and managing interception of water by land use activities. The Duggan report observes that little progress has been made in dealing with interception management.

Duggan et al. (2008) highlight the variation in government responses to interception activities as well as the variation in understanding of the scale, location and magnitude of interception activities. The recent undertaking of the Murray–Darling Basin Sustainable Yields Project (CSIRO 2008a) has provided, for the first time, a comprehensive quantitative, spatially explicit knowledge base on the role of interception activities in water availability across more than one jurisdiction. It is with information such as this that NWI partners can make balanced decisions and apply consistent management approaches with broad understanding of the various types of interception activities, their location, and estimated water usage.

1.1.2 This project

The National Water Commission commissioned Sinclair Knight Merz in partnership with the Bureau of Rural Sciences and CSIRO to develop a national baseline paper that documents the location of intercepting activities that fall outside the current entitlement framework; the potential rate of expansion of each activity over various time periods; and estimates of water usage of each activity in water management areas used in the *Australian Water Resources 2005* (AWR2005) report (NWC 2007a,b). The project provides information to assist in the development of a common approach to bring interception activities into the water access entitlement and planning policy framework. This project had three stages.

Stage 1: Define and describe activities that intercept surface water and groundwater

The NWI explicitly recognises the reductions in water availability as a result of water interception activities that are not currently (or uniformly) included in the entitlement framework, such as farm dams, large-scale plantation forests (afforestation), capture of overland flow and groundwater extraction (Clauses 55–-57).

Stage 2: Quantify and map the baseline for significant activities that intercept surface water and groundwater

The current level of impact on hydrology *per se* simply defines the reference point (or baseline condition) from which the hydrologic effect of future interception activities can be measured. Establishing a quantitative and spatially explicit database of baseline impacts for selected activities that intercept surface water and groundwater will be an important output of the project and serve as a basis for future monitoring.

Stage 3: Quantify and map the trends in activities that intercept surface water and groundwater

A key concern of the NWI is **risk assignment**, that is, in the impact of changes in activities that intercept surface water and groundwater. Water sharing plans, industry strategies and other legislation all have a role to play. While forecasts may be inherently uncertain, providing some guide on the scale, magnitude and location of future impacts will help direct investment and focus management effort.

1.2 Definitions

In order to undertake the analysis stages of this project, an understanding is required of the definition of interception and an intercepting activity. Furthermore, a conceptual understanding of the water balance and interactions between groundwater and surface water is required to apply the definitions and to inform policy. This section considers these topics and provides the definitions for these concepts that have been applied in this project.

1.2.1 What is an intercepting activity?

The hydrological definition of interception relates to the direct capture or reduction of precipitation (rainfall, sleet, hail, snow). However, the proposed definition provided by the National Water Commission is:[1]

> Interception occurs when flows of surface water or groundwater are stopped, reduced or redirected.

This definition excludes precipitation. It focuses on changes to runoff and recharge, rather than changes to precipitation directly. Duggan et al. (2008) expand this definition to imply that interception activities are human-induced activities that intercept significant volumes of water and thus decrease the amount of water reaching surface waterbodies and groundwater.

[1] *http://www.nwc.gov.au/www/html/240-interception.asp?intSiteID=1*

The objective of this project is to provide greater understanding of intercepting activities relevant to the NWI Clauses 25 (xi) and 55–57, which are directed at the management of 'unregulated growth in interception'. Therefore this project will seek to identify and focus on intercepting activities that are unregulated or not currently accounted for in water policy and management plans. It is recognised that, as policies and planning frameworks vary regionally and from state to state, there will be spatial variation in considering whether a particular intercepting activity is within the entitlement system.

For the purposes of interpreting and applying the NWI, the definition of 'intercepting activities' used for this project includes land use change activities that:

- are human induced
- could significantly impact the availability of water to existing entitlement holders (including the environment)
- are expected to have an increased impact on water
- are currently outside of the entitlement or licensing framework.

It is important to note that this definition is clearly directed towards the management of terrestrial water resources (surface and groundwater resources) and the legal water entitlement system.

Intercepting activities that have been identified by the NWI and Duggan et al. (2008) include:

- farm dams and bores
- interception, storage of overland flows, floodplain flow harvesting
- large-scale plantation forestry.

A broad consideration of intercepting activities is presented in Section 1.3 and this is followed by an analysis that prioritises the activities in relation to the scope of this project.

1.2.2 Water balance approach

The interception of water from rivers through groundwater extractions has commonly been interpreted as an intercepting activity, and it is listed as such in the NWI under Clauses 55-57. This may, in part, be because water management plans commonly included only surface water resources. Within this framework groundwater – surface water interactions *affect* available surface water resources as they reduce the availability of surface water entitlements or surface water flows—hence the perception of groundwater as an intercepting activity. The NWI also recognises the **c**onnectivity between surface and groundwater resources and that connected systems should be managed as a single resource (Clause 23, Objective (x)). This creates ambiguity in the definitions as groundwater is listed as an intercepting activity as well as a resource that is inseparable from the resource being intercepted.

The physical reality is that groundwater and surface water are inter-connected resources that need to be managed jointly, and as such, groundwater – surface water interactions are not defined as an intercepting activity for this project. Furthermore, the separate management, accounting and entitlement for surface water and groundwater may lead to allocating the same water twice (double counting) (BRS 2006) or licensing and accounting for only part of the resource (e.g. the Murray–Darling Basin Cap on Surface Diversions, which has no comparable cap for groundwater). The risk and impacts of this management approach may not be fully realised until some point into the future due to the time lag between the extraction event and a measurable change in surface water flows or groundwater levels (CSIRO 2008a).

Therefore the approach adopted by this project will assess impacts of intercepting activities on a complete water balance that takes into account both surface water and groundwater.

1.3 Intercepting activities

1.3.1 Overview

Using the definition of interception provided in Section 1.2.1, intercepting activities can be observed to occur across the Australian landscape through a variety of processes. These activities occur within a range of sectors, including:

- *water resource development*—covers the expansion of water use that can be captured and supplied via a variety of methods (including farm dams and flood plain harvesting)
- *change in water management*—includes modifications to existing water management practices that may influence the water balance
- *change in land management*—adjustments to the land management practices in sectors such as forestry, agriculture and native vegetation management, which may impact on the water balance
- *change in land use*—conversion of land cover to high water use vegetation, through sectors such as forestry, agriculture and native vegetation management
- *other resource development, such as oil and mining activities*—includes specific activities that intercept water resources that have not been considered in any of the above activities
- *non-consumptive uses such as power and energy generation*—includes activities that generate power from the water itself, including geothermal power and hydro-electric schemes.

Urban development, which includes the expansion into new urban areas as well as the retrofit of existing urban areas, covers a number of these sector-based activities—specifically changes in land and water management.

Currently, intercepting activities are regulated to a limited extent, and differences exist in their treatment by various state and territory policies. In some instances, activities are captured within the existing water management regime with controls such as permits and licences. In these cases, the activities may be considered to be a controlled extraction rather than interception because administrative arrangements are already in place. In some jurisdictions, this includes intercepting activities such as farm dams for purposes other than stock and domestic consumption. In other cases, the ability to include the intercepting activity within the water resource management framework presents a challenge. For example, where the activity is not human induced, management for the minimisation of interception impacts may provide the best method of control rather than administrative arrangements.

Further discussion relating to the types of interception activities and assessment against the recommended definition criteria is provided in Appendix A (Table 20). The appendix lists a number of intercepting activities identified within the above broad sectors of the water industry. This list attempts to cover the full suite of intercepting activities within each of the above sectors that currently occur within and outside of the entitlement system.

In the application of the NWI definition of interception activities, those activities that are currently managed within the existing entitlement framework are excluded from assessment in this study. This includes water interception through licensed diversions, licensed groundwater bores, licensed farm dams, and large public dams. Furthermore, the redirection of water between connected resources within the existing entitlement framework is also excluded from the definition of interception for this study.

1.3.2 Evaluation of activities

Several selection criteria have been applied to the activities listed in Appendix A (Table 20) to discern which are the most significant for further analysis and reporting as part of this project. Factors used to determine whether the activity is likely to be significant nationally and is not currently included in the water regulatory system are:

- impact on average annual water balance
- capacity for change or likelihood of change
- both the capacity for change within current land management and policy environment and the potential drivers for change. These may vary between different states and regions
- ability to determine baseline
- available data to determine current impact, volumes of water use that can be attributed to this land use or activity
- ability to model and predict change scenarios
- considers current modelling techniques and data in order to develop change scenarios and predictions
- ability to bring the activity under an entitlement framework
- considerations include ability to manage, enforce, monitor and regulate the water use or the activity.

A summary of this analysis is presented in Table 1 for activities listed in Appendix A (Table 20) that meet the criteria in the definition.

Table 1: Evaluation of Intercepting Activities that meet initial project definition criteria

Type	*Activity*	*Potential impact on Water balance*	*Capacity or likelihood for change*	*Ability to determine baseline*	*Ability to model and predict change*	*Ability to manage and regulate*	*Priority*	*Currently licensed?*
Water resource development	Floodplain harvesting, overland flows	High	Medium	Yes	Yes	Yes	High	No
	New farm dams (including capture of groundwater springs)	High	Medium	Yes	Yes	Yes	High	Partially
	Groundwater extractions from unlicensed bores (stock and domestic bores)	High	High	Yes	Yes	Yes	High	Varies between states
Change in land management practices	Change in agricultural land management practice	Low	Medium	No	No	Variable	Medium	No
Change in rural land use	Afforestation—commercial plantations (both native and exotic)	High	High	Yes	Yes	Yes	High	No
	Native revegetation (e.g. corridors for ecological benefit, riparian revegetation)	Medium	Medium	No	No	Needs consideration of competing policies	Low	No
	Farming land use change to high water use vegetation	High	High	Yes	Yes	Partial	Medium	Partial
	Peri-urban expansion	High	High	Yes	Yes	Partial—planning policy	High	No
Urban	Urban expansion	Low	High	Yes	Yes	Partial	Low	No
Mining and resource extraction	Oil and gas extraction, coal seam methane gas extraction	High	Medium	No	No	Yes	High	No
	Open-cut mining	High	Medium	Yes	Yes	Yes	High	No
	Pit lakes and mines wastewaters	Medium	Medium	Yes	Yes	Yes	Medium	No
	Dewatering, mine voids	High	Medium	Yes	Yes	Yes	High	No

Table 1 highlights a number of high- and medium-priority interception activities that were considered for inclusion in the analysis and mapping phase of this project. These activities were presented and discussed with the National Water Commission Integration Coordination Committee, and a set of high priority interception activities were identified and recommended for further study and analysis as part of this project. The activities that were selected are:

- floodplain harvesting and capture of overland flows
- farm dams
- stock and domestic bores
- plantations and afforestation
- peri-urban expansion.

The following comments apply to the remaining activities: land use change, change in agricultural management practices, and mining and resource extraction activities.

Land use change

Land use change was modelled for key land uses—including plantations, cropping, sugar, cotton and horticulture—based on a national land use dataset (one-kilometre grid). Scenarios for land use for 2015 and 2030 were based on historical trends and industry or government projections. Impacts of land use change for each surface water management area were quantified using a static version of the Water 2010 modelling approach (Welsh et al. 2006). The results of the analysis include grids of annual evapotranspiration, runoff, deep drainage, irrigation and return flows. The methods and summary of the results are provided in Appendix B. This work provides context to the changes in interception activities relating to land use, for example plantations and peri-urban expansion. However, there are some uncertainties in the land use scenarios. It should be noted that the land use change projections based on the current baseline estimates and available information do not predict scenarios that could occur as a result of climate change, water access issues and future policy and legislation.

Change in agricultural management practices

Change in on-farm land management practices includes the adoption of practices such as minimum tillage, clay spreading and constructing contour banks. Whilst these practices are likely to increase in the future and result in a change to existing local water balances, it is difficult to predict the location and extent of these changes. The practices can be related to land use in localised regions (based on a knowledge of agricultural practices), and landholder surveys can be carried out to understand the uptake on individual properties. However, this would be extremely difficult to quantify consistently on a national scale. In addition, detailed modelling needs to be available for the different management practices in a range of environments to quantify impact—this is not available to an extent that is applicable for this current project. Consequently, it is not considered feasible to be able to determine a baseline and model the impacts of potential on-farm land management changes as part of this project.

Appendix C contains a literature review of the intercepting processes and potential impacts associated with selected management practices that are currently being promoted to improve on-farm water use efficiencies (minimum tillage, clay spreading and constructing contour banks).

Mining and resource extraction activities

It is recognised that mining, and gas and oil extraction activities may currently have a significant impact on water balances in many regions in Australia. Although a baseline map of current mining and resource extraction activities could be compiled, modelling of future activities is information that is tightly held by the industry, as are data relating to impacts to groundwater and surface water. Therefore, on this basis no further analysis and mapping of mining and resource extraction activities will be undertaken as part of this project.

1.4 Assessments

The baseline assessments for each intercepting activity include an approach to estimate current levels and to map them within each surface water management area (SWMA) from AWR2005. Due to the extent of current data for each activity, the baseline year varies from 2005 to 2008. An estimate of the current impact was also required. The baseline condition also takes into account the current rate of change or growth of the activity.

The project also required a projection of future levels of development and impacts. This involved projecting current trends; other approaches were used depending on the activity, our understanding of the trends, and indicators and relationships.

1.5 This document

This is the final report for the intercepting activities project. It incorporates earlier milestone reporting that was part of this project. This document includes a description of the methods and overview of the results together with the key findings for each of the intercepting activities (sections 2 to 6). More detailed descriptions of the methodology and results are provided in Appendix D. Integration of the results is provided in Section 7, which is followed by a summary of key findings (Section 8).

Digital data, including tables of results for each AWR2005 SWMA, will be provided to the National Water Commission as part of the final delivery of the project.

2 Overland flows (floodplain harvesting)

2.1 Introduction

2.1.1 Definition

Floodplain Harvesting refers to the capture and storage on a floodplain of water from two sources: (a) floodwaters; and (b) rainfall runoff. It involves building off-stream storages on a floodplain, often by constructing embankments in a ring.

At times when the floodplain is inundated, floodwater can enter storages by gravity, or it can be pumped in. Floodwaters may be diverted towards storages through the use of embankments and channels (Steinfeld and Kingsford 2008). These embankments and channels also facilitate diversion and capture rainfall–runoff when it occurs. It is noted that floodplain storages are also commonly used to store licensed diversions pumped from a watercourse when the watercourse is not in flood.

Storages used for floodplain harvesting are generally very large (greater than 100 megalitres in volume, including some storages exceeding 100 gigalitres in volume). By comparison, most hillside farm dams are smaller than 100 megalitres. Also, floodplain harvesting storages are built on flat parts of the landscape (see Figure 1), whereas hillside farm dams are commonly found in undulating landscapes (see Figure 2).

The term *floodplain harvesting* refers to the same practice as the NWI term *overland flows*. However, to avoid confusion, the term *floodplain harvesting* will be used in the following section, because the term *overland flows* is used by the Queensland Government to denote both floodplain harvesting and hillside farm dams.

The phrase *floodplain storages* will be used to refer to storages that have been identified to be on a floodplain and may be used to capture or store diverted floodwater and rainfall–runoff water.

In the application of the definition of intercepting activities to floodplain harvesting, the following points are noted:

- *Flood diversions*—diversion of floodwaters is an intercepting activity. It is understood that some diversions of floodwaters may be licensed, but the majority are not.
- *Rainfall–runoff diversion*—diversion of rainfall–runoff is an intercepting activity. In the case of floodplain storages, rainfall–runoff diversion is generally not licensed.
- *Pumped diversions from a watercourse*—these diversions are generally licensed, and as such are not an intercepting activity under the current definition.

Given these points, this study will investigate the impact of flood diversions and rainfall–runoff diversions into private floodplain storages, but this study will not address pumped diversions from watercourses that are not in flood.

Figure 1: Floodplain harvesting storage in the Condamine River catchment, Queensland

Figure 2: Hillside farm dam in the Yarra Valley, Victoria

It was noted that some flood diversions may be covered under existing entitlements, particularly for some of the larger private storages. However, no data were readily available to characterise such entitlements for this study. Therefore, the aim is to estimate the overall impact of flood diversions without distinction between licensed and unlicensed diversions. If more data become available at a later date, the overall estimates could be split to quantify the unlicensed portion. Based on the review of available literature for this study, the majority of flood diversions are unlicensed.

2.1.2 Government policy

Historically, there has been less regulation of floodplain harvesting than of other forms of diversion. In the past decade or so, governments have recognised the need to quantify the effects of floodplain harvesting, with a view to potentially regulating it to reconcile it with existing policies, such as the 'cap' on diversions in the Murray–Darling Basin. The following issues may have contributed to the low level of regulation of floodplain harvesting prior to the 1990s.

- *Difficulty in measurement of flood flows*—generally, once streamflows have overtopped riverbanks, measurement of flow rates becomes more difficult and less accurate. Also, although comparison between gauges on a river may yield estimates of the volumes lost in between, apportioning losses between natural causes (e.g. seepage into the floodplain) and floodplain harvesting is difficult.
- *Difficulty in measuring diversions on-site*—pumps within a river channel are generally metered to monitor usage under the existing entitlement framework. However, when harvesting floodwaters, diversions often occur by gravity or by using a different set of pumps, making measurement of these diversions more difficult.
- *Attitudes towards ownership of floodwater*—floodwaters are largely out of human control and can cause damage to infrastructure and property. As such, floodwaters have not been regarded with the same sense of ownership as water delivered under the entitlement framework has been. Floodwater diversions have historically been made opportunistically and with less accountability than metered diversions under licensed water entitlements. In 1995, the Murray–Darling Basin Ministerial Council agreed to place a Cap on diversions. Although in principle this Cap includes floodplain harvesting, it was not a focus in the initial policy reforms. Landholders sought to quickly install floodplain storages before moratoriums were put in place. Governments have moved in response to this trend, but the response time between on-ground issues and respective government policy has allowed considerable development to proceed in the meantime.

A summary of the current government policy setting is provided below. As discussed later in this section, the vast majority of floodplain harvesting occurs in the states of New South Wales and Queensland (see sections 2.1.4 and 2.3). Therefore, the following summary focuses on these two states.

New South Wales (NSW)

New South Wales (NSW) is currently (as of March 2009) finalising a policy with regards to floodplain harvesting. The text below is based on the *DRAFT Floodplain Harvesting Policy Framework* (DWE 2008) for NSW.

The draft policy states that:

- All extractions must be licensed and no licences will be issued that allow growth in floodplain harvesting.

- **In regulated systems**, issue of licences will be based on works that are (a) approved (or pending approval); or (b) in place before a specified cut-off date announced by the minister, which is to be confirmed. In regulated systems, floodplain harvesting will be given a fixed volumetric component of the Cap or Long-term average extraction limit (LTAEL), for each basin. This component will be calculated taking into account the works that were in place at the cut-off date.
- **In unregulated systems**, there will be no further licences provided for floodplain harvesting. This is because current licences (in unregulated systems) were allocated based on farmers identifying the **total** amount of water they extracted for on-farm activities. Therefore, floodplain harvesting water is included in the current licences in unregulated systems.
- The NSW Government reserves the right to revise LTAELs from time to time, but only in response to new modelling estimates. Licences will not be issued in perpetuity.
- Licences associated with floodplain harvesting will have 'appropriate carry over and account limit provisions to allow for the inherent annual variability'. This means that farmers will be able to harvest more than their licence in wet years if they have accumulated account credits in dry years.
- Permanent trading of floodplain harvesting licences will be permitted (within basin), but opportunistic temporary trading of allocations from season to season will not be allowed.

Queensland

In Queensland, the main documents of relevance are the water resource plans and resource operation plans for basins where floodplain harvesting occurs, rather than a state-wide policy framework. The *Water Act 2000* is also relevant. Features of Queensland policy include:

- The water resource plans each contain the following clause: 'The chief executive must not make a decision that would increase the average volume of water available to be taken in the plan area'.
- Floodplain harvesting dams and smaller farm dams are referred to collectively as 'overland flow take', with little distinction made between them.
- Under the *Water Act 2000,* the relevant minister can issue moratoriums on new works for overland flow take, other than for stock and domestic purposes. Retrospective notices (to 2000 or 2001) have been issued for all Queensland basins within the Murray–Darling Basin.
- Landholders were required to notify the government of existing works for diversion of 'land surface waters' by February 2006. In the Lower Balonne, the works needed to be certified by a registered professional engineer. Licences are not automatically required as they are in NSW, except in the Lower Balonne Basin.
- The resource operation plans allow for licences subject to limits on pumping rates, storage volumes, volumetric limits, or event management rules.
- Trading of water harvesting rights is not permitted.

2.1.3 Previous studies

As noted above, floodplain harvesting has increased dramatically over the past two decades. For example, Porter and Delforce (2000) estimated that the total storage volume in the Upper Condamine River increased by 60 per cent between 1997 and 1999. As such, all results from previous studies are strongly influenced by the *age of the source data* (which is often considerably older than the study itself).

The following is a brief description of relevant past studies, and Table 2 collates the results from these projects.

- Bewsher (2006)—*Land Surface Diversions Status Report*. This document collated estimates of floodplain harvesting storage and diversion from the NSW and Queensland governments, based on their respective IQQM models. The estimates for both states were based on a simulation period of at least 80 years.
- Webb, McKeown and Associates (2007)—*State of the Darling Report*. This document tabulated volumes of large on-farm storages, termed 'ring tanks', for each river basin that is a tributary to the Darling River. The report stated that 'the total volume of on farm storages in the upper Darling Basin is now equivalent to 60 per cent of the total volume of major dams'. The report also provides estimates of diversions by floodplain harvesting. However, the actual source of the data used was not stated. It is likely that a common source was shared with Bewsher (2006) for the Queensland basins, given the figures are practically identical.
- Steinfeld and Kingsford (2008)—*Floodplain development and vegetation health on the Macquarie River Floodplain*. This report, conducted by the University of NSW, gives the results of a detailed survey of levees, channels, storages and tanks on the Macquarie River floodplain. Fifty-four storages were identified, with a total surface area of 19 square kilometres. Using the formula developed later in this chapter, this has been converted to an estimated volume of 67 gigalitres. It is noted that the most upstream portion of the floodplain was not included in this survey.

Table 2: Summary of different estimates for floodplain harvesting storage or diversions

Basin	*Total volume of floodplain harvesting storages*	*Average annual diversions by floodplain harvesting storages*
Condamine-Balonne	1582 GL (Webb, McKeown and Associates 2007)	144 GL (Webb, McKeown and Associates 2007) 144 GL (Bewsher 2006)*
Moonie	–	4 GL (Webb, McKeown and Associates 2007) 4 GL (Bewsher 2006)*
Nebine	–	0.8 GL (Webb, McKeown and Associates 2007) 1 GL (Bewsher 2006)*
Border Rivers	459 GL (Webb, McKeown and Associates 2007)	13 GL (Webb, McKeown and Associates 2007) QLD – 26 GL (Bewsher 2006)* NSW – >3 GL (Bewsher 2006)**
Gwydir	351 GL (Webb, McKeown and Associates 2007)	97 GL (Webb, McKeown and Associates 2007) >114 GL (Bewsher 2006)
Namoi	190 GL (Webb, McKeown and Associates 2007)	88 GL (Webb, McKeown and Associates 2007) >94 GL (Bewsher 2006)
Macquarie	110 GL (Webb, McKeown and Associates 2007) 67 GL (Steinfeld and Kingsford 2008)	–
Barwon Darling	298 GL (Webb, McKeown and Associates 2007)	42 GL (Webb, McKeown and Associates 2007) >43 GL (Bewsher 2006)

GL = gigalitre (1000-million litres)
*Includes farm dam diversions **Including rainfall-runoff harvesting

2.2 Method

This study uses the following methods to identify floodplain harvesting storages and quantify their impacts:

- identify storages from topographic data (waterbodies layer)
- calculate the surface area of each storage
- convert surface areas into volume using a derived relationship
- estimate the hydrologic impact of floodplain harvesting storages.

Identify storages in topographic data

For each of the basins of interest, the best available GIS topographic dataset containing waterbodies was sourced. Floodplain harvesting storages were then identified using an automated filtering process followed by manual checking. For NSW, the dataset was extracted from the 2008 1:100,000 waterbodies dataset (Department of Lands, NSW). The data include Geoscience Australia's most recent mapping of water bodies and manmade structures for the Murray–Darling Basin. For Queensland, the data were extracted from 1:250,000 Geodata V3 (Geoscience Australia 2006).

Floodplain harvesting storages were identified from among the set of waterbodies in the topographic GIS data, using an analysis that selects water bodies with a surface area greater than 50,000 square metres and a ratio of surface area to perimeter of greater than 80. After the application of this filter, the selection was manually checked. Where necessary, the classification of a waterbody was verified using satellite imagery. Waterbodies were both added to and deleted from the list of selected storages in this process. In many cases, storages smaller than 50,000 square metres were added if they showed other attributes such as a regular plan-form and location on a floodplain. Note that in the case of the Lower Balonne, the surface areas and volumes were sourced directly from external data, rather than by the process described above.

Calculate surface areas

Once the set of floodplain harvesting storages was finalised, the surface areas of these storages were calculated using standard algorithms within GIS software.

Convert surface area to volume

A volume:surface area relationship was developed using data supplied by the Queensland Department of Natural Resources and Water, as shown in Appendix D. Linear regression analysis was undertaken using the obtained information to relate the storage volume and surface area. The derived equation indicates that the volume can be estimated by assuming a constant depth of around 3.5 metres over the entire surface area of the dam. Further details of this analysis are provided in Appendix D. The results are broadly consistent with estimates used in previous studies (e.g. Ramchurn 2002).

It is noted that the form of this equation is different from equations previously derived for hillside dams (e.g. Lowe et al. 2005), which use a power relationship. This is consistent with the difference in shape between the two types of dam. Hillside dams tend to inundate valleys, resulting in tapered or triangular vertical cross-sections. In contrast, floodplain-harvesting dams tend to be formed by a set of embankments in a ring on a flat landscape, resulting in square (vertical) cross-sections. This is why a simple linear relationship between volume and surface area is suitable.

Estimate hydrologic impact

The estimation of hydrologic impact for this project was split into two parts:

1) estimating diversions of flood waters
2) estimating diversions of rainfall–runoff and tailwater.

A detailed description of the approach is provided in Appendix D. It is noted that all methods used in this project to approximate the hydrologic impact of floodplain storages should be regarded as estimates with levels of confidence that are commensurate with the quality of the available data.

Estimating diversions of floodwaters

The capacity of a landholder to divert floodwaters into a storage at any point in time depends on many factors, including:

- position of the dam on the floodplain
- local level of the river relative to the dam elevation
- capacity and position of pumps, if pumps are present
- the volume of the dam and the amount of water already in the dam (airspace)
- presence or extent of embankments or channels to guide water towards the dam.

Given this interplay of factors, the quantification of floodwater diversions is a very difficult task (FSA/Aquatech 2007). As such, the estimates presented in this report should be regarded as approximations only.

The approach taken to quantify impacts was to obtain results within a limited study area, then assume that the estimated impacts are broadly representative of all floodplain harvesting dams. The selected study area is the Upper Condamine Floodplain near the town of Dalby. The Upper Condamine floodplain was covered by an earlier study in SKM (2003), which gathered detailed topographic data. With the permission of the client (Department of Natural Resources and Water, Queensland) this topographic dataset, in the form of a digital elevation model, was used in this study. Refer to Appendix D for more details.

Estimating diversions of rainfall–runoff

The capacity of a landholder to divert rainfall–runoff into a floodplain storage at any point in time depends on many factors, including:

- magnitude of surface runoff due to rainfall
- ‘catchment area’ of the dam—note that on a flat floodplain, this is more likely to be related to embankments and channels than to underlying topography. Embankments and channels are often purpose-built for diverting runoff (Steinfeld and Kingsford 2008)
- capacity and position of pumps, if pumps are present
- the volume of the dam and the amount of water already in the dam
- existence of upstream storages intercepting runoff (Porter and Delforce 2000).

The ability to predict the above five factors for any given dam is low without physically visiting the site. Delineation of catchment areas by using GIS is very difficult, as shallow embankments and channels are beyond the resolution of all but the most detailed digital elevation models. Because of these limitations, a regional approach was adopted for this task; and three sample areas were selected to undertake detailed analysis using rainfall–runoff modelling. The details of this approach are provided in Appendix D.

2.3 Results

Floodplain harvesting has been identified as a common intercepting activity in several catchments in the northern Murray–Darling Basin (Webb, McKeown and Associates 2007; Bewsher 2006) including in the river basins listed below (see also Figure 3):

- Condamine-Balonne
- Moonie
- Border Rivers
- Gwydir
- Namoi
- Macquarie
- Barwon-Darling.

Additionally, preliminary surveys have also indicated the possible presence of floodplain harvesting storages in other catchments, but in lower density than the basins mentioned above. These catchments are:

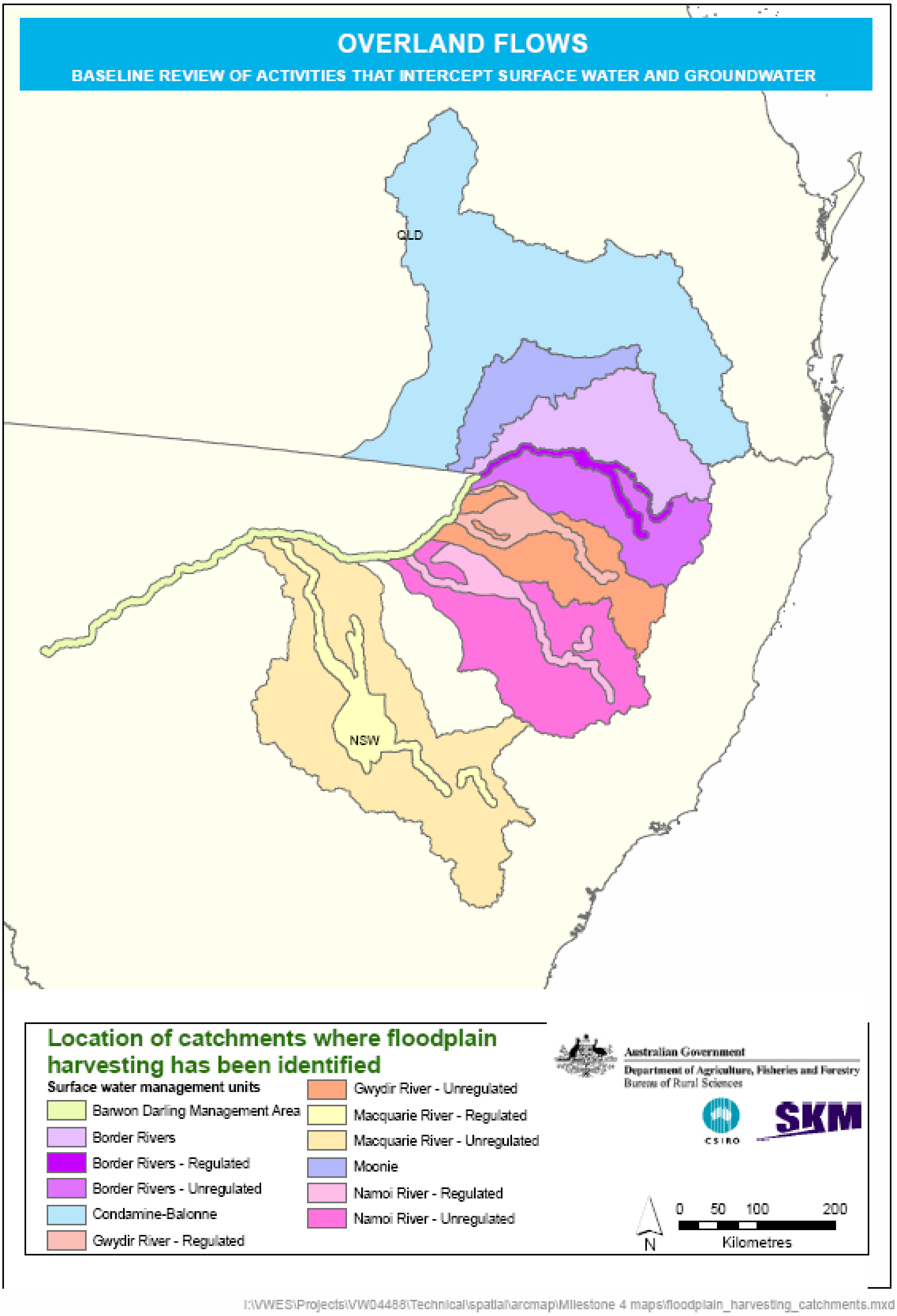
- Nebine
- Fitzroy (Queensland)
- Burdekin.

It is believed that there are no floodplain-harvesting dams in northern Western Australia, a view confirmed by Western Australia's Department of Water (R. Donohue, pers. comm., February 2009).

It is believed that there are no floodplain-harvesting dams in the Northern Territory, a view confirmed by the Northern Territory's Department of Natural Resources, Environment, The Arts and Sport (I. Lancaster, pers. comm., March 2009).

It is likely that there are some storages outside of the basins listed above, which are built for uses other than floodplain harvesting, but which may inadvertently collect floodflows. It is considered that the volumetric impact of such storages is small compared to the impact of the purpose-built floodplain-harvesting dams that are discussed in this report.

Figure 3: Location of catchments where floodplain harvesting has been identified



Storage volume estimates for each river basin

Table 3 below shows the estimates of the volumes of floodplain storages in each catchment.

Table 3: Estimates of volumes of floodplain storages, by catchment

River basin	*Number of floodplain storages*	*Total volume of floodplain storages (GL)*	*Average size of storages (GL)*	*Comments*
Murray–Darling Basin				
Condamine - Balonne	242	1340	5.5	~1100 GL of storages are downstream of Beardmore Dam
Moonie	13	31	2.4	
Nebine	1	1.4	1.4	
Border Rivers	229	426	1.9	169GL in NSW and 257GL in QLD
Gwydir	262	429	1.6	
Namoi	224	171	0.8	
Macquarie	22	24	1.0	
Barwon Darling	47	151	3.2	
Total Murray–Darling basin	*1040*	*2570*	*1.8*	*Totals by state (MDB only): NSW: 944GL; QLD: 1625GL*
Non Murray–Darling Basin				
Fitzroy (Queensland)	24	34	1.4	In two main groups: – Dawson River near Theodore – Comet River east of Springsure
Burdekin	3	7	2.3	– Around 100km upstream of Burdekin Dam

GL = gigalitre; Qld = Queensland

Diversion of floodwaters

The estimates of flood diversions within the Upper Condamine study area during the water years 1969–2007 are shown in Figure 4 below. The results indicate that the *diversions vary greatly from year to year*. As might be expected, the years of greatest diversions correspond to the years with the largest flow. In years of heavy flooding, the results indicated that the set of 27 storages would collectively divert up to 110 per cent of their total volume (as described above, this assumes that sufficient airspace can be created mid-season by irrigation usage or transfers to other storages).

The average diversions per year, reported as megalitre of impact per megalitre of storage (ML/ML), were:

- 0.25 ML/ML in the case of the upper estimate (assumed continuous pumping)
- 0.14 ML/ML in the case of the lower estimate (gravity fill only).

Possibly a more useful representation of year-to-year impact is the cumulative exceedance plot, shown in Figure 5. This shows that for a third of all years, the impact of flood diversions is practically zero (generally corresponding to dry years). At the wet end of the scale, the plot indicates that the wettest 10 per cent of years could see flood diversions of greater than

0.45 megalitres (lower estimate) or 0.9 megalitres (upper estimate) for every megalitre of storage.

Figure 4: Estimated impact of flood diversions, for a sample of 27 Condamine floodplain storages (bottom); flows in the Condamine River @ 422333 (top)

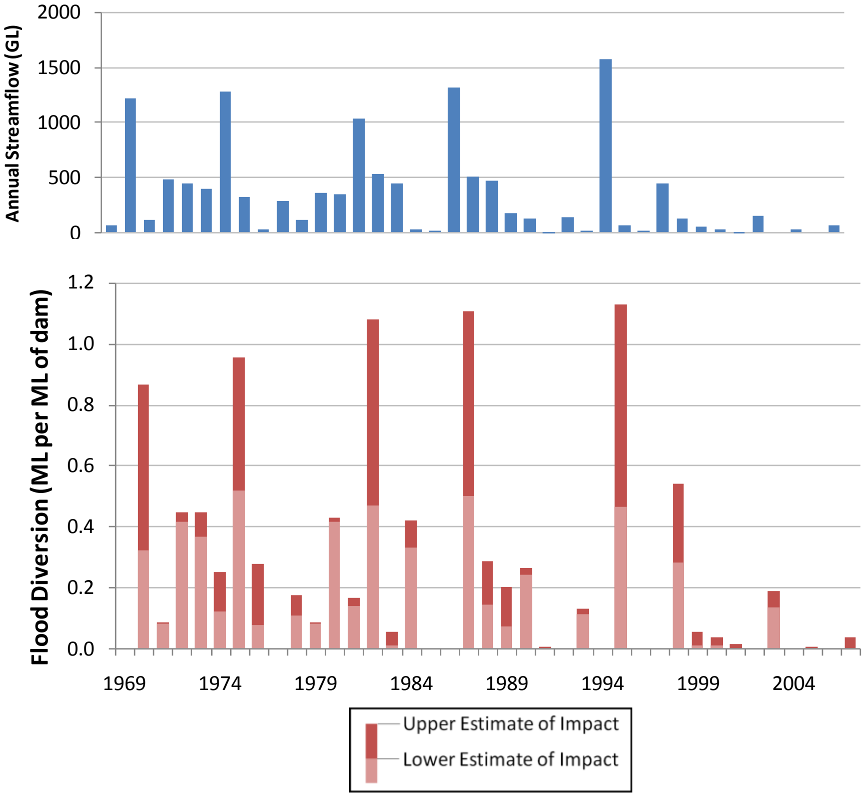
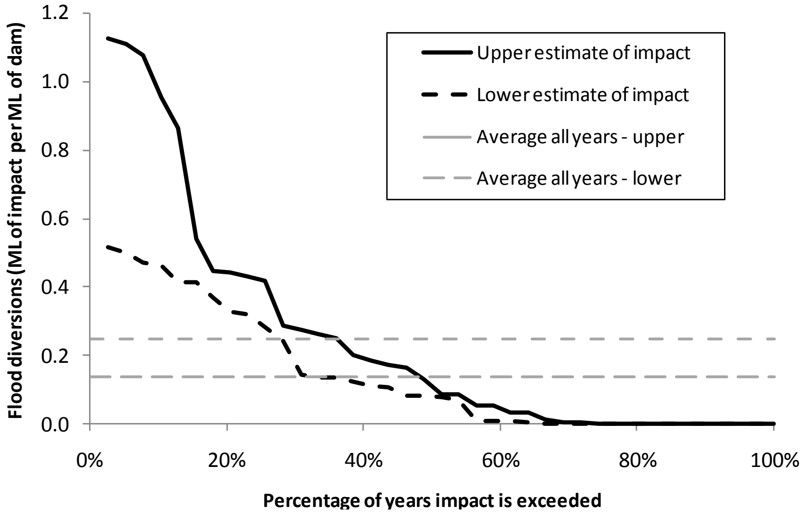


Figure 5: Cumulative exceedance plot for estimated flood diversions

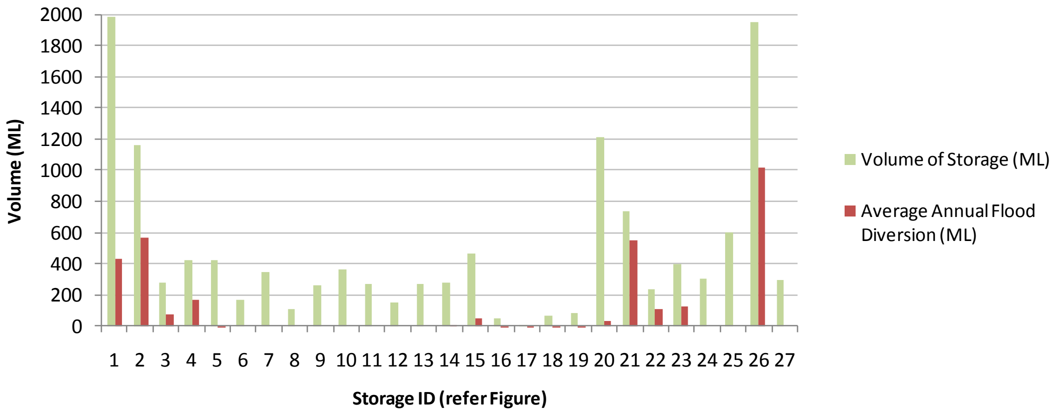


These results are averages over all 27 storages. Diversions varied greatly from one storage to another. In fact, the results indicated that many of the storages were never inundated during the 30-year modelling period. Nearly 13 of the 27 storages, accounting for 25 per cent of total volume, fitted this description. These 13 storages had zero flood diversions. A further five storages had close to zero diversions. Therefore, the impact is largely due to only nine out of 27 storages in the sample, as shown in Figure 6. It can be seen that, in general, larger storages had a greater impact per megalitre of storage. This is because, within the study area, larger storages tend to be built closer to the river, as illustrated in Figure 28 (Appendix D).

The assumption of active diversion through pumping (upper estimate) made a large difference to the results, particularly in wet years, during which the upper estimate of diversions was commonly about twice the lower estimate of diversions.

It will be assumed that the results obtained in this study catchment are broadly representative of floodplain harvesting storages in general. However, it is noted that many of the characteristics of the study site are not necessarily representative of all catchments. As such, considerable variation in impacts may occur between catchments.

Figure 6: Estimated average annual flood diversion for 27 Condamine floodplain storages (upper estimate used), along with storage volume



Note: Refer to Figure 28 for locations of storages

Diversion of rainfall runoff

Table 4 below shows the results of the process for estimating diversions of rainfall runoff by floodplain storages. The main assumptions in this process were:

1) average runoff is 50 millimetres (mm) per year from irrigated land and 18 mm/year from non-irrigated land
2) floodplain storages divert 50 per cent of runoff from non-irrigated land within the sample area and 100 per cent of runoff from irrigated land within the sample area.

Table 4: Estimation of rainfall runoff diversions in selected portions of floodplains

Location of sample area	*Volume storages in GL (number)*	*Area (km²) (% irrigated)*	*Estimated runoff (GL/year)*			*Diverted runoff (GL/year)*			*ML diversion per ML storage (per year)*
			Irrigated	*Dryland*	*Total*	*Irrigated*	*Dryland*	*Total*	
Border Rivers	101 GL (n=148)	720 km² (25%)	9.0	9.7	18.7	9.0	4.9	13.9	0.14
Gwydir	32 GL (n=138)	360 km² (30%)	5.4	4.5	9.9	5.4	2.3	7.7	0.24
Lower Condamine	650 GL (n=18)	1402 km² (20%)	14.0	20.2	34.2	14.0	10.1	24.1	0.04

GL = gigalitre; ML = megalitres

The results indicated that there is considerable variation between catchments. For example, storages in the Gwydir sample were estimated to divert six times as much rainfall runoff as those in the Lower Condamine, per megalitre of storage. However, as shown in Table 4, storage volume in the Condamine sample is much greater than the Gwydir, so the available runoff is split between a larger volume than in the Gwydir sample.

This analysis used sample areas that were contained wholly within a floodplain. As such, rainfall–runoff entering the sample areas from outside the floodplain was minimised. It is possible that storages on the edge of the floodplain might have larger catchment areas and, thus, a greater impact on rainfall and runoff. However, to intercept large quantities of runoff from outside the floodplain, storages would have to intersect drainage lines in a similar fashion to upland farm dams, and the shape of the dams would be different. This has not been observed in the survey that was part of this study.

It is to be expected that there is considerable variation from year to year in diversions of rainfall–runoff; however, this variation was not explicitly represented in these estimates. In general, the actual values for runoff in each of the catchments could be considerably different from the assumed values. It is estimated that in some catchments, the runoff could be as low as half of the assumed value, or alternatively as high as double the assumed value. The uncertainty in the magnitude of runoff is considered to be a key source of uncertainty in the analysis.

Combining diversions of flood water and rainfall runoff

As described in the results, estimates were obtained in two parts for the annual hydrologic impact of floodplain storages, as follows:

- flood diversion: highly variable from storage to storage and year to year, but the average of all years was 0.14 ML/ML or 0.25 ML/ML (lower-bound and upper-bound estimates).
- rainfall–runoff diversion: results for sample areas were: 0.04, 0.14 and 0.24 ML/ML for sample areas in the Condamine, Border Rivers and Gwydir basins, respectively.

It is possible that, in some years, these two types of diversion may interact, leading to a lesser overall impact. In a particularly wet summer, it may rain heavily at first, leading to some storages approaching capacity due to rainfall–runoff. This would lead to less airspace available for incoming floodflows, and less diversion of floodwaters. Alternatively, the reverse could occur, with floods filling up some storages so that rainfall–runoff is not fully diverted. These interactions are complex, and no attempt has been made to model them for this study.

The following section provides some comparisons between floodplain harvesting and other types of diversion and storage. For the purposes of comparison, the hydrologic impact quoted below has been applied. These figures are long-term averages and should be regarded as estimates.

- flood diversions: 0.2 ML/ML (this is the average of the upper and lower estimates)
- rainfall-runoff diversions: 0.14 ML/ML (this is the average of the three estimates)
- total: 0.34 ML/ML average annual impact.

These figures suggest that, on average, around 60 per cent of diversions due to floodplain storages are due to diversions of floodwaters, and 40 per cent are due to diversions of rainfall–runoff. It is noted that these proportions may vary from place to place. For example, in locations with relatively low rainfall but proximity to rivers that are prone to inundating the floodplain, the proportion of interception derived from flood diversions might be greater than 60 per cent. Conversely, in other areas this proportion might be less than 60 per cent. The figures above are adopted only for the purposes of broad indicators of impacts on a national scale.

Further discussion of the accuracy and limitations of the methods applied to assess hydrologic impact is provided below.

Projections of future growth

Generally, floodplain harvesting is not expected to increase in the future. As described previously, the state governments of NSW and Queensland have moratoriums in place that prohibit an increase in the amount of water intercepted by floodplain harvesting. Furthermore, the landuse projections developed for this baseline review do not project high growth in irrigation in the majority of the relevant basins, with some catchments experiencing a decline, as shown in Table 5. Due to these two factors, increases in the total aggregate volume of floodplain harvesting storages in the northern Murray–Darling Basin are considered unlikely.

The Northern Territory and northern Western Australia are also included in Table 5. In northern Western Australia, the Ord River Irrigation scheme is the only example of irrigation. Considerable expansion of this scheme is currently proposed. This is not reflected in the numbers in Table 5 because the projections in this study use current land use and tenure as a starting point for projected growth, whereas the proposed scheme expansion would represent a ‘step change’ relative to current land use and tenure in the region. It is suggested that expansion, if it occurs, would not lead to the construction of floodplain harvesting storages, due to the presence of a very large underutilised bulk storage (Lake Argyle), which has potential to supply the water requirements of the expansion, without landholders resorting to floodplain harvesting. In the case of the Northern Territory, slight growth is forecasted for irrigation. Although no floodplain storages currently exist in the Northern Territory, the Northern Territory Government has fielded some general enquiries as to their feasibility (I Lancaster, pers. comm., March 2009).

It is likely that the hydrologic impact of existing storages will be influenced by climate change. However, given the uncertainty in estimating current hydrologic impact, in addition to uncertainty regarding climate change, the quantification of changes due to climate change is considered infeasible at this time. In the Murray–Darling Basin in general, climate change is considered likely to reduce mean annual flows (CSIRO 2008a). However, in the northern section of the basin, it is possible that climate change may result in an increase in monsoonal rains and increased risk of large floods. As such, the volumetric impact of floodplain harvesting may increase due to climate change.

Table 5: Existing moratoriums on new works, and predicted irrigation expansion in relevant basins or regions

Basin or region	*Moratorium in place on new works?*	*Current volume of floodplain storages (GL)*	*Area under irrigation (km²)*		
			2008	*2015 (projected)*	*2030 (projected)*
Condamine	Yes	1340	2430	2140	2170
Moonie	Yes	31	39	37	37
Nebine	Yes	1.4	0	0	0
Fitzroy	No	34	887	404	404
Burdekin	No	7	1060	943	946
Border Rivers	Yes	426	1600	1480	1500
Gwydir	Yes	429	1430	1450	1460
Namoi	Yes	171	1550	1590	1690
Macquarie	Yes	24	1110	1250	1260
Barwon Darling	Yes	151	215	209	208
Northern Territory	No	0	181	215	214
Northern WA	No	0	26	26	26

Table 6 compares the estimated volume of floodplain storages identified within this study, with the volume of major dams and farm dams, for selected catchments.

Table 6: Storage volume in various storage types for selected catchments

Catchment	*Estimated floodplain harvesting storage (GL)*	*Farm dam storage* (GL)*	*Major dams or weirs** (GL)*
Condamine Balonne	1340	55	268
Border Rivers	426	28	656
Gwydir	429	19	1380
Namoi	171	19	911

* From Farm Dams, Section 3
** From Webb, McKeown & Associates (2007) and includes major dams, town water supply and weirs.

Table 7 compares the average hydrologic impact (estimated by applying the factor derived in Section 2.3) with the total diversions and 'surface water availability' (estimated for each catchment by the Murray–Darling Basin Sustainable Yields study (CSIRO 2008a,b)). As described in Section 2.3, the *hydrologic impact* in this case refers to the sum of estimated floodwater diversions and rainfall–runoff diversions. It is noted that hydrologic impact varies greatly from year to year.

Table 7: Comparison of estimated hydrologic impact of floodplain harvesting with surface water availability and diversions reported in CSIRO (2007)

Catchment	*Long term average hydrologic impact* of floodplain storages (GL/year)*	*Average total diversions (GL/year) (CSIRO 2008A)*	*Surface water availability (GL/year) (CSIRO 2008A)*
Condamine-Balonne	450	706	1300
Border Rivers	150	412	1210
Gwydir	150	317	782
Namoi	60	260	965

*assuming a long-term average annual impact of 0.34 ML/ML of storage, as per the above discussion. Interception is event-based and requires local flooding or significant local rainfall to be realised.

Table 8 below compares the estimates obtained in this report with previous estimates as described in Section 2.1.4, for both volume and hydrologic impact.

Table 8: Comparisons of estimates derived in the study with previous estimates

Basin	*Total volume of floodplain harvesting storages (GL)*		*Long-term average annual diversions* by floodplain harvesting storages (GL)*	
	Previous	*This report*	*Previous*	*This report*
Condamine-Balonne	1582	1340	144	450
Moonie	–	31	4	10
Nebine	–	1.4	0.8–1	0.5
Border Rivers	459	426	13–29	150
Gwydir	351	429	97–114	150
Namoi	190	171	88–94	60
Macquarie	67-110	24	–	8
Barwon Darling	298	151	42	50
Total		2600		880

Refer to Table 2 for sources of previous estimates
*Assuming a long-term average annual impact of 0.34 ML/ML of storage, as per the above discussion. Interception is event-based and requires local flooding or significant local rainfall to be realized

2.4 Discussion

Comparison with other types of storage and diversion

Table 6 compares the estimated volume of floodplain storages identified within this study, with the volume of major dams and farm dams, for selected catchments. In the Condamine Basin, which has relatively little storage in major dams, the floodplain storages account for around 75 per cent of total storage. However, in the other catchments, the floodplain storages account for 30 per cent or less of total storage. For the four catchments combined, which together account for 23 per cent of the inflows to the Murray–Darling Basin (CSIRO 2008a,b), floodplain storages are estimated to account for 35 per cent of all storage volume. This impact is the estimated average over the historic period, although river flows and diversions vary considerably within and between years.

In terms of diversions, the Condamine-Balonne is the most heavily impacted basin: floodplain storages are estimated to account for more than half of all diversions and a third of available surface water (based on annual averages, Table 7).

Uncertainty due to floodplain storage identification by remote sensing

It is likely that the estimates of aggregate volumes of floodplain storages in this study are underestimates; this is due to the difficulties of identifying floodplain storages by remote sensing. These difficulties are discussed below.

As explained above, two different sets of topographic data were used to identify storages and quantify surface areas. It is noted that there are some inconsistencies between the two datasets. Most storages appear in both datasets, but there are many storages that appear in one set but not the other.

This discrepancy between different datasets may be partially due to the age of the source data. As noted in Section 2.1, there has been rapid growth in floodplain harvesting in the past decade. Therefore, if a more recent dataset could containing storages that did not exist at the time of survey for an older dataset.

However, when comparing the two datasets, it appears that a different reason accounts for most of the variation. It is suggested that surveys are more likely to miss floodplain storages if they are empty at the time of survey. When empty, floodplain storages resemble bare earth. Depending on the resolution of the remote sensing, it may be difficult to resolve the encircling embankments. Therefore, whether the method used is manual or automatic (e.g. digital filter), empty floodplain storages are less likely to be detected. It is very unlikely that all storages are full or partly full at any point in time, so it is possible that a considerable proportion of storages could go undetected in any given study. This depends on image resolution and the method of identification used.

Steinfeld and Kingsford (2008) sought to identify embankments, channels and floodplain storages in the Macquarie basin by visual inspection of SPOT satellite imagery collected in 2005. On the Macquarie Floodplain this study identified two to three times more dams than either of the alternative datasets (see Appendix D, Figure 29). This difference could be due to:

- finer resolution of remote sensing used (it is likely that both alternative datasets were based on broader scale remote sensing than the SPOT imagery with 2.5-metre pixels)
- emphasis placed on identifying earthworks and embankments rather than bodies of water, which meant that empty storages were readily identified, along with full ones.

It is noted that underestimation of storages in other catchments may not be as severe as in the Macquarie (refer to the comparison with previous studies as discussed below).

Experience gained in this study has suggested that landuse data, such as that provided by the Bureau of Rural Sciences for this study, can be a useful indicator as to the presence of floodplain storages. Many of the storages are individually identifiable as the ‘bare earth’ category (400). Generally, storages are associated with irrigation, which is readily identified among land use categories.

As was shown in Table 7, the vast majority of floodplain storages lie in six or seven catchments in the northern Murray–Darling Basin. Within these catchments, they are confined to relatively small regions of the floodplain where irrigation occurs. Therefore, in future studies to identify floodplain storages, it may be feasible to adopt a method similar to that conducted in the Macquarie Basin (Steinfeld and Kingsford 2008), using medium-to-high resolution remote sensing coupled with manual identification. This method is recommended, if it is judged to be feasible in the area of interest. Alternatively, remote sensing capture of three-dimensional data would assist in identifying embankments and, if the storages are dry, models of surface levels and hence volumes could then be derived. Options for the capture of these data include photogrammetry using stereo aerial photography or capture of Airborne Laser Survey (LiDAR) data.

Accuracy of hydrologic impact assessment

The quoted values for hydrologic impact are based on various simplifications and assumptions, as listed below. For the estimates of flood diversions, the main assumptions include:

- Results obtained in the Condamine study area are applicable in other catchments.
- The inundation of the storages in the sample area can be predicted by reference to the level in a nearby gauge (422333) without using a more detailed hydraulic model.

- For the lower estimate, diversions are directly related to the maximum flood level.
- For the upper estimate:
  (a) diversions are directly related to the amount of time the storage is inundated at its base, and are derived by assuming a filling period of 10 days; and
  (b) the annual impact can exceed 100 per cent of the volume, with an upper annual limit of 200 per cent, due to the ability to transfer water onto crops or to other storages.

For the estimates of rainfall runoff diversions, the main assumptions include:

- Annual runoff is 50 mm (irrigated) or 18 mm (non irrigated) (Porter and Delforce 2000). Note that this runoff, which was estimated for the Upper Condamine catchment, may have limited applicability in other catchments.
- Within the sample areas, 100 per cent of runoff from irrigated areas is diverted; 50 per cent of runoff from non-irrigated areas is captured.
- There is no net import or export of runoff from the sample areas.

Given these broad sets of assumptions, the values quoted should be regarded as estimates only. These estimates are intended to indicate the possible range of values for diversion, rather than accurately defining the impact for a particular location or scenario. It is recommended that further work be conducted to validate the results obtained in this study.

Comparison with previous estimates

For volumes, the estimates obtained in this report are broadly in agreement with previous estimates, for most catchments (Table 8). The storage volumes in this report are within 20 per cent of previous estimates for Condamine, Border Rivers, Gwydir and Namoi. Notable exceptions occur for the Macquarie Basin, discussed above, and the Barwon–Darling SWMA. For both of these areas, the previous estimates were considerably larger. In the case of Barwon–Darling, some large storages may exist that opportunistically utilise pre-existing natural depressions. Because of the shape of natural depressions, these cases may not have met the filter requirements used in this study to identify floodplain storages. If information derived from on-ground surveys or landholder surveys were available (as may have been the case in previous studies), then it is possible that such storages would be identifiable using these data.

For estimates of diversions, there is considerably more variation between previous and current estimates. Estimates in this study are generally much larger than previous estimates. For example, in the Condamine Basin, the estimates of hydrological impact are three times larger, in Border Rivers five times larger and Gwydir 1.5 times larger. In some cases, previous estimates of diversions are considered to be very low. To take the Border Rivers as an example, the volume of storages is reported to be approximately 450 gigalitres in both Webb, McKeown and Associates (2007) and the current report. However, Webb, McKeown and Associates (2007) reported the annual diversion by floodplain harvesting to be 13 gigalitres. Using this ratio, a landholder with a 1 gigalitre of storage could expect to harvest only 3 megalitres (0.3% of capacity) per year on average. It is likely that this modest benefit to the landholder would not justify the economic cost of building of such a storage. The diversions reported in this study, while not highly accurate, are considered to give a more realistic estimate of likely diversions.

2.5 Findings

The estimated total volume of floodplain harvesting storages nationwide is approximately 2600 gigalitres; this volume is split between NSW (950 gigalitres) and Queensland

(1670 gigalitres). Almost all current floodplain harvesting in Australia occurs in the northern Murray–Darling Basin.

The hydrologic impact of floodplain harvesting fluctuates greatly from year to year and from dam to dam, but the estimated long-term average is around 0.34 megalitres per year (per megalitre of storage). It is noted that interception is event-based and requires local flooding or significant local rainfall to be realised. The above figure would indicate that the long-term average annual diversions due to floodplain harvesting are approximately 320 gigalitres per year in New South Wales and 570 gigalitres per year in Queensland. These figures should be regarded as estimates only.

The hydrologic impact is due to interception of both floodflows and rainfall–runoff. Results in this study indicate that an approximate split (by long-term averages) might be:

- 60 per cent of impacts due to flood diversion
- 40 per cent of impacts due to rainfall–runoff interception.

However, it is noted that these proportions are likely to vary from place to place in accordance with flooding regimes and local rainfall. Floodplain harvesting is not likely to expand, due to moratoriums being in place to restrict construction of new storages in the relevant river basins.

3 Farm dams

3.1 Introduction

3.1.1 Definition

Definitions of farm dams vary for each state and territory: general descriptions include on-stream, off-stream, and catchment dams. An on-stream dam is constructed on or across a waterway; an off-stream dam contains water that is diverted or pumped from a nearby stream. Catchment dams, on the other hand, are filled only by runoff from their own catchment. In some states the term ‘off-stream’ may encompass both off-stream and catchment dams as defined above. Farm dams are generally used for onsite irrigation, commercial, stock and domestic purposes (Figure 7). Stock and domestic dams are small (generally less than 5 megalitres) and tend not to require a licence, whereas large dams used for irrigation and commercial purposes generally have licensing requirements (see Section 3.1.2 for further details).

Figure 7: Example of a farm dam

Source: (SKM)

There is difficulty however in differentiating between dams that are licensed and unlicensed and on-stream, off-stream and catchment dams—farm dam datasets tend to not include this level of detail. A general assumption that can be applied is that farm dams used for irrigation are large and require a licence, whereas smaller dams with a capacity of around 5 megalitres or less are used generally for stock and domestic purposes, and do not require a licence. This 5-megalitre threshold has been assumed in Teoh (2007), SKM (2007a) and CSIRO (2008) and has been confirmed through a review of farm dam licence databases in Victoria. Using this approach, all farm dams of 5 megalitres or less have been identified in the available datasets as existing unlicensed dams (and therefore interception activities). This is a broad assumption, which is considered appropriate given the large scale of this project. General stock and domestic farm dams do not require a licence in most states or territories.

3.1.2 Government policy

A brief summary of the relevant policies for each state is provided below.

Tasmania

The *Water Management Act 1999* sets out the water allocation framework for Tasmania. Under the Act, a licence is required to take water from a river or stream or to store water in a farm dam for farming or other commercial purposes. A licence is not required to take water for stock and domestic purposes.

Victoria

Under the *Water Act 1989,* a person has the right to take water for domestic and stock use without requiring a licence because that person occupies the land in which the water flows or occurs. However a licence is required for farm dams used for irrigation or commercial purposes.

Australian Capital Territory

Under the *Land (Planning and Environment) Act 1991,* a permit is required to construct all on-stream dams and any dam greater than 2 megalitres. In addition, under the *Water Resources Act 2007,* all surface water extractions require a water access entitlement unless it is for stock and domestic purposes. The water access entitlement 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.

Queensland

Under the *Water Act 2000,* an owner of land on which there is overland flow is authorised to collect water in a dam for stock and domestic purposes. This right to take water exists irrespective of whether a moratorium notice is in place. A moratorium notice will be published if the Minister is satisfied that action is required to protect natural ecosystems or existing water entitlements. Moratorium notices have been established for the Condamine-Balonne Basin and Border Rivers Catchment (September 2000), the Moonie River Catchment (June 2001), and the Warrego, Paroo, Bulloo and Nebine catchments (June 2001), which means that landowners in these areas are not able to expand the existing network of farm dams unless the dam is for stock and domestic purposes.

New South Wales

Under the *Water Management Act 2000,* two harvestable rights orders were gazetted, which cover the Western Division and Eastern and Central Division of NSW. This effectively means that all of NSW is covered by a harvestable rights order that gives the right to an owner or occupier of a landholding to construct new dams. Under the Harvestable Rights – Eastern and Central Division Order a landholder may capture up to 10 per cent of the average regional rainfall runoff from their property in a dam built on a hillside or minor stream without a licence. Licences are also not required for farm dams built before 1999 (when the harvestable right was introduced) if these dams are only used for stock and domestic watering purposes. Farm dams in the Western Division of NSW do not require a licence because there is negligible potential to capture runoff in this area.

Western Australia

Water resources in Western Australia are managed under the *Rights in Water and Irrigation Act 1914*. Twenty-two (of 43) SWMAs have been proclaimed in Western Australia, and therefore a licence is required to take water within these areas unless it is for stock and domestic purposes. No licence is required outside of proclaimed areas.

South Australia

Under the *Natural Resources Management Act 2004,* the occupier of land is entitled to take surface water from the land for any purpose except where the resource is prescribed. The majority of significant water resources in South Australia are managed under prescription. Once a water resource is prescribed, a license is required for all users who take water unless the water is being used for stock and domestic purposes. Future dam development is dependent however on the availability of water—no new licences will be issued if there is no water available.

Northern Territory

The *Northern Territory Water Act 1992* allows for landholders to take surface water on their land and from minor waterways for stock and domestic purposes without a licence. Water extracted from waterways for other purposes requires a water extraction licence.

3.1.3 Previous studies

There have been several previous assessments of farm dam volumes and impacts around Australia, but they have generally focused on specific regions or catchments rather than the whole of Australia as is the case with this study. The discussion below presents some key findings from past farm dam studies that are of particular relevance to this study.

A key study was the Murray–Darling Basin Sustainable Yields project (CSIRO 2008a,b), which assessed the anticipated impacts of climate change, catchment development (including farm dams) and groundwater extraction on water resources in the Murray–Darling Basin. The growth of farm dams to 2030 in the basin and their impact on runoff in relation to climate change was estimated. Key points to take from the project include:

- The current capacity of small farm dams in the Murray–Darling Basin is estimated to be 2164 gigalitres; projections indicate a possible 10 per cent increase in this capacity by 2030.
- The projected impact of future dam development is a 0.7 per cent decrease in mean annual flow across the basin.
- The impact of farm dams is not uniform across the year but varies according to the season.

A further study of farm dam development in the Murray–Darling Basin was commissioned by the Murray–Darling Basin Commission and aimed to improve the mapping of the growth, location, and surface area of farm dams in the basin between 1994 and 2005 (MDBC 2008). The results of the study indicate the level of farm dam development (for eastern Murray–Darling Basin subcatchments) from 1994 to 2005, but do not quantify the volume of water retained by farm dams or their impacts on streamflow.

Key points to take from this study include:

- The highest farm dam densities within the Murray–Darling Basin are located within peri-urban areas.
- There was an estimated 6 per cent increase in farm dams in the study area from 1994 to 2005 (though it is suggested that this is an underestimate of the actual increase).

Outside of the Murray–Darling Basin, there have been studies of farm dam development in Victoria, South Australia and Western Australia. The Department of Water, Land and Biodiversity Conservation has conducted several studies into farm dams for catchments in the Mount Lofty Ranges, South Australia. One such study was an assessment of the impact of farm dam development in the Onkaparinga River Catchment (Teoh 2007). The assessment was undertaken on smaller subcatchments and at key infrastructure points (weirs) within the Onkaparinga River Catchment, and therefore the results are not easily translatable for comparison in this study. A key point to take out of the study, however, is the variation in the impact of farm dams on streamflows for wet, dry and median runoff periods. The results suggest that the impact of farm dams is greater during dry years than in median years, and it is significantly greater than in wet years. Similar results were also found for studies of farm dam impact for the Tod River Catchment on the Eyre Peninsula and South Para River Catchment. The latter study also suggested that farm dam impact was higher when water usage was greater (Teoh 2007).

Sinclair Knight Merz has undertaken assessments of farm dam impacts in catchments in the south-west of Western Australia. SKM (2009) assessed farm dam impact in the Wilyabrup and Lefroy catchments and, like other studies, found summer flows to be most heavily impacted (more than 70 per cent diversion of summer flows for each catchment).

3.2 Method

Two main tasks were undertaken to estimate the impact of farm dams around Australia:

1) develop a relationship between farm dam volume and runoff that could be utilised to determine the reduction in runoff resulting from farm dams
2) determine the volume of farm dams in Australia and apply the relationship developed to determine the impact of farm dams on runoff around Australia.

Development of dam volume and runoff relationship

Results from modelling undertaken for the Murray Darling Basin Sustainable Yields project (SKM 2007a) were used to develop a relationship to determine the impact of farm dams on runoff that could be applied to all of Australia. The relationship developed was:

Impact of dams (ML/year) = 1.1 x Volume of dams (ML)

Further details of how this relationship was derived are provided in Appendix D.

Calculation of current and projected farm dam volumes and impacts

In order to calculate the volume and impacts of farm dams around Australia the following steps were undertaken:

1) Available farm dam data for each state were collected.
2) For the SWMAs not covered by the available farm dam data, the presence of farm dams was assessed in the first instance using Google Earth. Areas without any farm dams were removed from further analysis.
3) All other SWMAs with unknown farm dam volumes were aligned with those SWMAs with farm dam data based on proximity to each other and similar land use types and distribution.
4) The dam density for each land use type for the SWMAs with farm dam data (i.e. the reference SWMAs) was applied to the same land use type for the aligned SWMAs in order to determine a total baseline dam volume for each of these SWMAs.
5) The baseline dam impact for each SWMA was determined using the derived dam volume to runoff relationship (refer to Appendix D)
6) Dam volume and impacts for 2015 and 2030 were determined using land use area projections developed by the Bureau of Rural Sciences for all states and territories except Victoria (where population projection data were used) and NSW (where projections were based on the projected available harvestable right). This is discussed in greater detail below.

Summary of approach taken to assess baseline farm dam volumes

Farm dams of 5 megalitres capacity or less were selected from the available farm dam data to determine the volume of baseline unlicensed farm dams around Australia (see Section 3.1.2 for further explanation). Details of the source data are provided in Appendix D. Based on the extent of the coverage of dam data, for some SWMAs it was assumed that the available data did not fully account for all farm dams present in that SWMA. In these cases an assumption about the percentage of area covered by the data was made, and dam volumes were adjusted accordingly. No farm dam data was available for the Northern Territory. The region was reviewed using Google Earth, and it was concluded that, based on the agricultural practices, land use types, high water availability and low population that there were no or negligible farm dams in the Northern Territory.

Dam volume data for Victoria were available from SKM (2004) for all SWMAs and hence no further analysis was required to determine baseline farm dam volumes. The Mallee and Millicent Coast SWMAs were assumed to have no farm dams due to low surface water flows.

No suitable farm dam data were available for Queensland. Median dam volume densities for each land use for northern NSW SWMAs were used as a guide to determine farm dam volumes in Queensland. Results gained from this method were comparable to results of farm dam development in other states.

Assessment of future dam volumes and impacts

After calculating the baseline dam volumes, the dam densities (megalitres of dams per square kilometre—ML/km^2) for each land use within each SWMA were calculated. These dam densities were assumed to remain constant up to 2030. In order to determine the 2015 and 2030 dam volumes (and hence dam impacts), the 2008 dam densities were multiplied by the projected land use areas for 2015 and 2030 provided by the Bureau of Rural Sciences. Where the total SWMA dam volume was projected to decrease (as a result of decreases in certain land use types) the dam volume for that SWMA was assumed to remain constant. This method was applied in Queensland, South Australia, Tasmania, and Western Australia, where farm dam policy indicates that stock and domestic dams (assumed to be 5 megalitres or less) can be built without a licence. A similar method was applied to the ACT, but only for dam sizes up to 2 megalitres as governed by farm dam policy.

The baseline dam volume data provided for Victorian SWMAs were not split into land use types but rather dam volume sizes. The above method for determining 2015 and 2030 dam volumes was therefore not applicable to Victoria, and instead, population projections were used. Population data were available for 2007, 2015 and 2030 for Victoria from the Department of Sustainability and Environment. The data were given in statistical divisions as opposed to SWMAs, therefore it was necessary to categorise the SWMAs into statistical divisions. A ratio of current (2007) people per square kilometre was determined for each statistical division, and this ratio was then applied to each SWMA using current and projected land use areas to estimate the current and projected populations for each SWMA. Using the current population estimation, the ratio of dam volume per person was determined for each SWMA (i.e. megalitres of dams per person). This ratio was assumed to be consistent in the future, and therefore using the estimated population projections for 2015 and 2030 for each SWMA, the future dam volume could be estimated. This method was applied to all farm dams less than 5 megalitres, which is consistent with Victorian legislation whereby new farm dams are to be stock and domestic farm dams only. If populations for particular SWMAs were projected to decrease, the volume of farm dams was assumed to remain the same.

In NSW, the maximum harvestable rights policy governs the size of farm dams that can be built without a licence (refer to Section 3.1.3). The harvestable right for each SWMA (within the Eastern Division of NSW) was calculated as 10 per cent of the projected 2015 and 2030 mean annual runoff values calculated by the Bureau of Rural Sciences as part of this project. The projected dam volume to 2015 and 2030 was taken as the lesser of the harvestable right and the increase in farm dam volume assuming a growth rate of 0.6 per cent per year (CSIRO 2008a,b). For SWMAs in the Western Division, a growth rate of 0.6 per cent per year was assumed. Therefore a uniform growth rate was applied to all of NSW.

Data analysis

The 2008, 2015 and 2030 dam volumes were estimated for each SWMA in each state, and the impacts of these dams were also able to be determined by applying the following formula:

Impact of Dams = 1.1 x Volume of Dams

Following estimation of 2008, 2015 and 2030 farm dam volumes and impacts, the percentage change in dam volume (and impact) from 2008 to 2015 and 2015 to 2030 was calculated. This analysis identified those SWMAs that are predicted to experience significant increases in dam volumes (and impacts) in the future. Given that dam impact is calculated as the dam volume multiplied by 1.1, the percentage changes in dam volume and percentage changes in dam impact over the relevant time periods have a linear relationship.

3.3 Results

The baseline density of unlicensed farm dams in each SWMA in Australia derived using the methodology described in Section 3.2 are shown in Figure 8.

Projections of future growth have been derived for all SWMAs and the results of these are represented in change maps presented in Figure 9 and Figure 10.

Table 9 summarises the dam volume estimates for 2008, 2015 and 2030 for all states in Australia along with the corresponding projected percentage changes from 2008 to 2015 and 2015 to 2030.

Table 9: Projections of future dam development for all states in Australia

State	*2008 Dam Volume (GL)*	*2015 Dam Volume (GL)*	*2030 Dam Volume (GL)*	*% Change from 2008 to 2015*	*% Change from 2015 to 2030*
ACT	0.4	0.4	0.4	0.0	0.0
NSW	272	283	308	4.0	8.0
Northern Territory	-	-	-	-	-
Queensland	351	530	530	33.8	0.0
South Australia	96	97	97	0.8	0.1
Tasmania	23	23	23	0.1	0.0
Victoria	340	361	398	5.7	9.3
Western Australia	374	380	380	1.6	0.0
Total	1460	1670	1740		

Figure 8: Baseline volume density of unlicensed farm dams

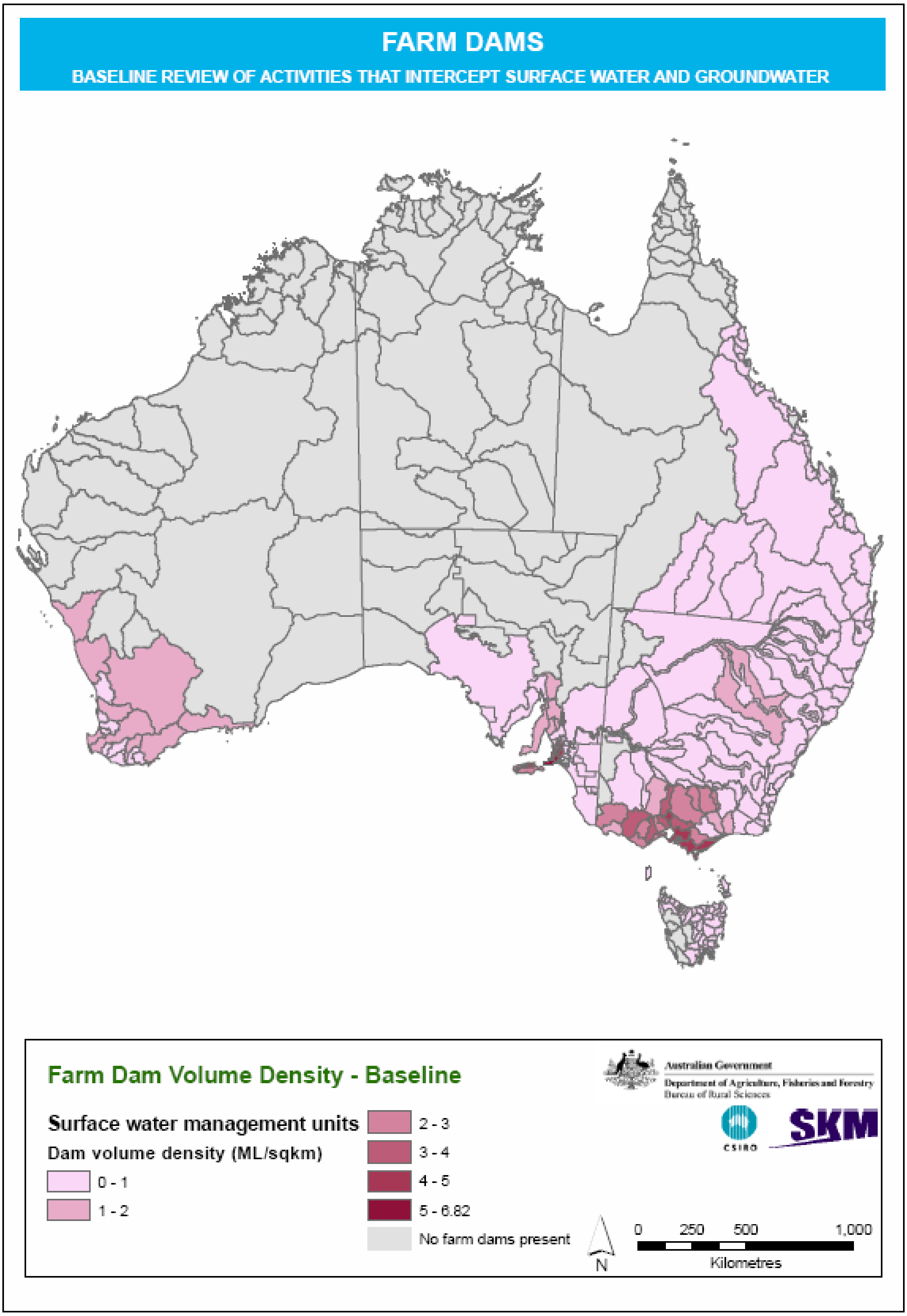


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Figure 9: Projected change in dam volume/impact from 2008 to 2015

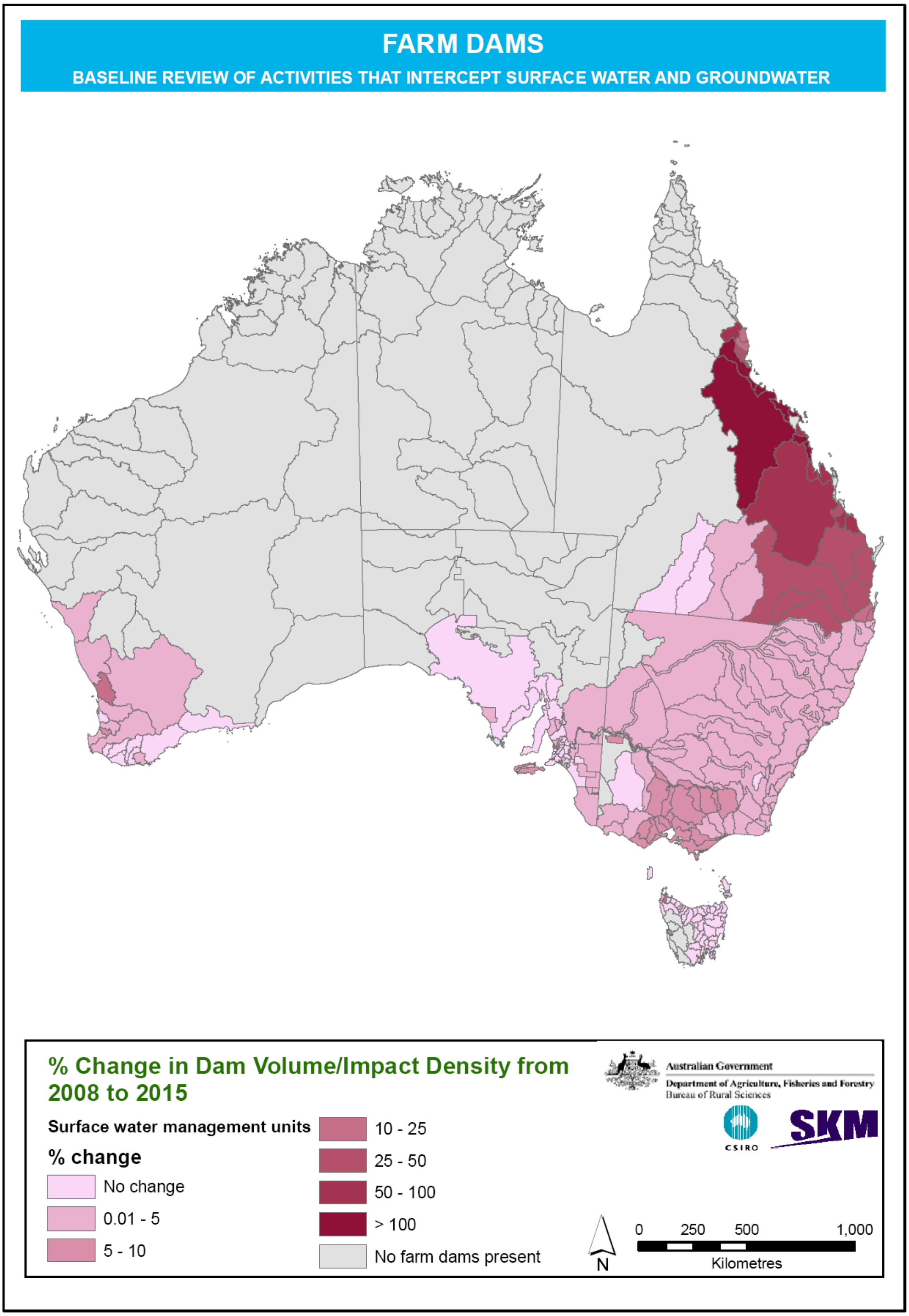

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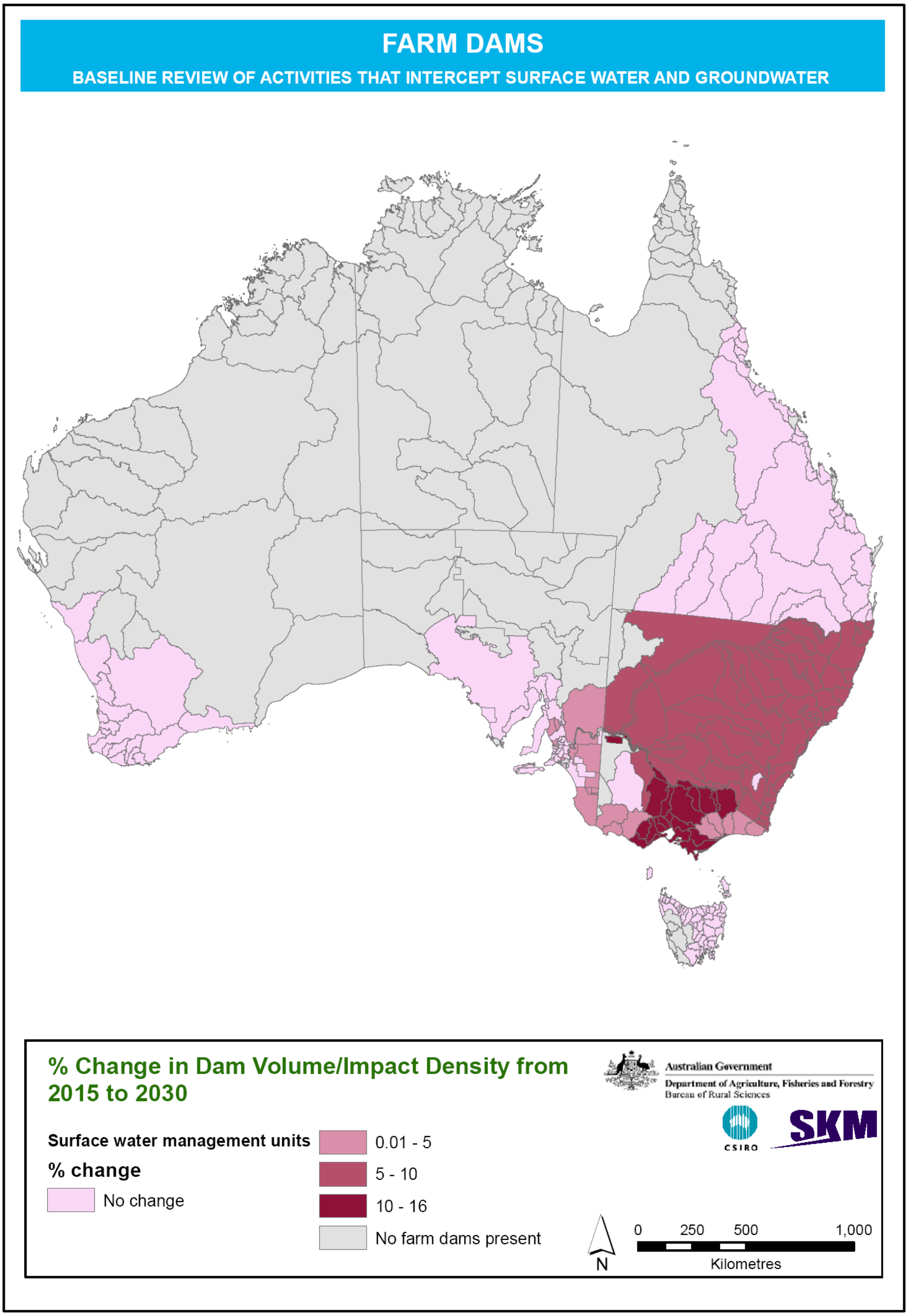
Figure 10: Projected change in dam volume/impact from 2015 to 2030



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Comparison with previous studies

Table 10 presents a selection of results from the Murray–Darling Basin Sustainable Yields project (CSIRO 2008a,b) and this project.

Table 10: Comparison of results for a selection of reporting regions from MDBSY project (no dam volume threshold) and this project (dams < 5 megalitres)

Reporting region	*Dam capacity (MDBSY project, no dam volume threshold) (GL)*	*Dam capacity (This project, only dams < 5ML assessed) (GL)*
Loddon-Avoca	98	33
Campaspe	35	14
Wimmera	34	11
Goulbourn Broken	105	45
Ovens	30	15
Macquarie-Castlereagh	242	86

MDBSY project = Murray–Darling Basin Sustainable Yields project

It is evident that there are significant differences between the results achieved for both projects: this is due to the use of different methods, even though they apply the same source data. A key difference in the methods used is that no maximum dam volume threshold was adopted in the Murray–Darling Basin Sustainable Yields project; whereas in this project, only dams with storage volumes of less than 5 megalitres were included in the analysis (see Section 3.2). Furthermore, different land use data were used for infilling missing dam volume data (i.e. updated land use data developed by the Bureau of Rural Sciences were used in this project). In addition, there were also differences in the aggregation and reporting of the result. Firstly, in the Murray–Darling Basin Sustainable Yields project, the farm dam assessment was generally undertaken on statistical local areas as opposed to SWMAs. Secondly, the reporting regions used in the Murray–Darling Basin Sustainable Yields project do not exactly coincide with the SWMAs assessed in this project.

3.4 Discussion

Baseline farm dam development estimates

Baseline unlicensed farm dam development around Australia was estimated based on the assumption that dams of 5 megalitres or less did not require a licence to build. Limitations of this assumption are discussed below. Figure 8 shows the highest baseline farm dam development (greater than 4 ML/km^2) to be in southern Victoria and the Mount Lofty Ranges in South Australia. Queensland, Tasmania and most of NSW had farm dam volume densities less than 1 ML/km^2. The farm dam impact densities presented in Figure 9 align with the farm dam volume densities as expected.

Accuracy of hydrologic impact assessment

As discussed earlier, based on modelling results from the Murray–Darling Basin Sustainable Yields project, it was found that 1 megalitre of farm dam volume will have an impact of 1.1 megalitres per year reduction in runoff volume for each SWMA in Australia. This is a broad assumption, and whilst it may be appropriate for a large-scale assessment such as this, individual catchment characteristics, seasonal impacts and usage patterns should be considered for a more robust hydrologic impact assessment.

Projections of future dam development

Figure 9 indicates the percentage change in dam volume/impact from 2008 to 2015. It is evident that SWMAs on the coast of Queensland are projected to experience significant growth in farm dams during this time period. In some SWMAs in Queensland, farm dam volume is projected to more than double from 2008 to 2015. A review of land use changes in Queensland suggests that there will be significant increases in high farm dam density land uses from 2008 to 2015, which accounts for the high percentage of dam volume/impact increase in some SWMAs. This result highlights that the outcomes of this assessment must be considered in light of the limitations of the land use projections developed for this project (Appendix B).

The majority of the SWMAs in Victoria are projected to increase in dam volume by between 5 and 25 per cent from 2008 to 2015, with the greatest increases occurring in central Victoria. It should be noted that all SWMAs in NSW are projected to have the same level of dam volume increase based on the previously discussed assumption that increases would occur at a rate of 0.6 per cent per year, and that for all SWMAs, the estimated harvestable right was greater than the volume determined from this growth rate.

Figure 10 indicates the percentage change in dam volume/impact from 2015 to 2030. All SWMAs in Western Australia, Tasmania and Queensland and some in South Australia are projected to have no change in farm dam volume over this time period. In reality, this is not likely to be the case, but this outcome occurs due to projected decrease in land uses with high farm dam densities or no change in land use areas. The greatest increases are projected for central Victoria. As discussed earlier, all SWMAs in NSW have the same farm dam volume growth rate applied.

From Table 9 it is evident that Queensland is projected to have a substantial increase (33.8 per cent) from 2008 to 2015. This is a result of significant increases in high farm dam density land uses in Queensland as mentioned earlier, which is not projected to continue from 2015 to 2030. Therefore the results are affected by the methods and assumptions applied in the development of the land use maps for 2015 and 2030 (Appendix B). Victoria and NSW are predicted to experience between approximately 4 per cent and 9.3 per cent increases in farm dam volume from 2008 to 2015 and 2015 to 2030. The Northern Territory was assumed to have no farm dams.

Limitations

This study was limited by the availability of farm dam volume data. Lack of farm dam volume data meant that Australia had to be ‘regionalised’ according to proximity and similar land use types, with each ‘region’ including a reference SWMA with farm dam data that could be applied to the remaining SWMAs. This method assumes that the dam volume densities for the land uses in the reference SWMA match those in the aligned SWMAs. Checks of farm dam volumes determined were undertaken using Google Earth, and it was found that this method was adequate to estimate the farm dam volumes in the SWMAs with no available farm dam data; however, more extensive and complete farm dam volume data would obviously improve the accuracy of the results.

In order to determine baseline dam volumes a broad assumption about the maximum **unlicensed** catchment dam volume was made (5 megalitres or less). Whilst this fits with general assumptions about volumes of stock and domestic farm dams (which do not require licences) it is likely that there are farm dams that are greater than 5 megalitres that are unlicensed, and there could also be farm dams less than 5 megalitres that are licensed. Furthermore, individual state and territory policy varies, and as such, dams greater than 5 megalitres may be able to be constructed without a licence—this is the case for NSW. Given the scale of this study, broad assumptions have been applied to maintain a consistent approach, and the accuracy of the results could be improved with more detailed assessment at a finer scale.

Another broad assumption made was that farm dam impact per year across Australia is equal to 1.1 times farm volume. As discussed earlier, this assumption does not consider usage patterns nor climatic or temporal impacts.

Projections of farm dam development were based on current state and territory policy, but it is possible that these policies will be reassessed in light of projected reductions in runoff due to climate change. For example, future dam development in South Australia is dependent on the availability of water.

As this study utilises current land use area assessments and projected land use area changes, the results are subject to the caveats in the methods documented in Section 3.2.

3.5 Findings

- Based on available farm dam datasets, the total impact of farm dams nationally is 1600 gigalitres per year (2008) and projected to increase to 1840 gigalitres per year in 2015 and to greater than 1900 gigalitres per year in 2030.
- Baseline dam volume/impact densities are greatest at a river basin scale in central Victoria and the Mount Lofty Ranges in South Australia.
- Large increases in farm dam volume/impact are projected for the Queensland coast as a result of significant changes in some land use types; these results should be viewed with caution.
- Victoria is projected to experience increases in farm dam volume/impact across most of the state from 2008 to 2030.
- South-west Western Australia is also projected to have increased impacts from farm dams, particularly between 2008 and 2015.

4 Stock and domestic bores

4.1 Introduction

4.1.1 Definition

Stock and domestic bores have been identified as an 'intercepting activity' for the purposes of this project. This means that bores currently extracting groundwater for stock and domestic purposes have the potential to 'intercept' water that would otherwise be extracted by other 'entitled' groundwater and surface water users. It should be noted that groundwater bores are normally licensed for construction (or permits are provided); however, extractions from stock and domestic bores are generally not licensed. Different state policies are listed in Section 4.1.2. Stock and domestic bores are generally unlicensed for extractions, but water management plans account for them to varying degrees. Generally, most plans do not consider the impacts of stock and domestic bores at all. The cumulative impact of stock and domestic bores on groundwater resources (with respect to other entitlements and users, including the environment) can be significant.

Extraction from groundwater for stock and domestic purposes can intercept water by either stopping, reducing or redirecting groundwater away from streams, lakes, and other groundwater users (extractors or other aquifers that may source or supply groundwater to that aquifer).

The definition of stock and domestic bores according to relevant state legislature, for each state, can be found in Appendix D (Table 26). This shows that stock and domestic use is generally defined as groundwater that is extracted for:

- domestic use by family or personal use by employees on the land
- irrigation of a small garden, where resulting goods are not for sale or barter
- watering of stock not associated with intensive farming
- watering of travelling stock

In this study, only 'stand-alone' domestic and stock bores were of interest. These are bores used only for the purpose of extracting groundwater for stock watering and domestic use. They are not dual purpose bores, where water is also extracted for dairying, irrigation, commercial or industrial uses, as these bores, with a combined purpose, would be covered through a different licensing or permitting environment. Wherever possible, only stand-alone domestic and stock bores were used. This includes both rural and urban domestic and stock bores and generally includes six different types of bore: dam (i.e. bores used to fill dams), domestic, garden (which includes most urban backyard bores), garden/domestic, garden/stock, and stock.

Of the uses listed above, all are expected to increase as discussed below; however it should be noted that groundwater extraction for stock is driven by stocking rates, and there is an inherent upper limit of sustainable stocking rate capacity of land. As such increases for purely stock use are not expected on land currently supporting grazing; however, increases may occur where land use changes to grazing, or where water demands transfer to groundwater sources. This stocking rate capacity limitation also applies to the Great Artesian Basin stock and domestic bores, however, the extraction volumes from the Great Artesian Basin may change for other reasons discussed below.

4.1.2 Government policy

Currently only the Northern Territory and NSW include stock and domestic bores within their groundwater management plans. Even within these plans, groundwater extractions are dealt with differently depending on their location. The potential to over-allocate resources within groundwater management units due to stock and domestic use is high in areas of highly developed resources. In Western Australia, Queensland, South Australia and to a lesser extent in Victoria, there are areas with groundwater extraction caps, but these do not take into account extractions by stock and domestic bores or cap them (refer to Figure 34).

Extraction from stock and domestic bores is generally unregulated except in the ACT, and some groundwater management areas in Victoria, NSW and the Northern Territory (Table 11).

Table 11: Current status of stock and domestic regulations in Australia

State or territory	*Ground-water plans include stock and domestic (Y/N)*	*Authority under which bore construction licenses and entitlements are given*	*Applicable Act(s)**	*Are stock and domestic bores licensed for extraction ? (Y/N)*	*General allowance per bore (if not licensed ?*	*Comments*
ACT	Yes	Department of the Environment Climate Change, Energy and Water	*Water Resources Act 2007*	Yes	4.9 ML/Year (DECCEW 2009)	
NSW	Yes (all macro plans)	Department of Water and Energy	*The Water Management Act 2000*	Partial (14 GMAs) GAB Bores all require entitlements	NA	
NT	Yes (some)	Department of Natural Resources, Environment, the Acts and Sport	*Water Act 1994*	Partial – for two GMAs	3.5 ML/Year for domestic/ garden use (NRETAS, 2009	
QLD	No	Department of Natural Resources and Water	*The Water Act 2000*	No	NA	Recently removed requirements to license stock and domestic bores
SA**	No	Department of Water, Land and Biodiversity Conservation (DWLBC)	*Natural Resources Management Act*	No	NA	

State or territory	*Ground-water plans include stock and domestic (Y/N)*	*Authority under which bore construction licenses and entitlements are given*	*Applicable Act(s)**	*Are stock and domestic bores licensed for extraction ? (Y/N)*	*General allowance per bore (if not licensed ?*	*Comments*
TAS	No	Department of Primary Industries and Water (DPIW)	*Water Management Act 1999*	No	NA	Tasmania are currently reviewing all bore licensing requirements and may require licenses for stock and domestic bores in the future. (*pers comm. L Schmidt, April 2009)*
VIC	No (1 or 2 exceptions)	SRW, GWMW, G-MW	*Water Act 1989*	No	2ML-5ML	State water report (GMUs only)
WA	Yes (some)	Department of Water (DoW)	*Rights in Water and Irrigation Act 1914*	For 12 GMAs entitlements	~1.5ML	Agriculture WA 'water supply for small holdings'' brochure

Source: AWR2005, websites and discussions from jurisdictions
* Extracts from relevant Acts are included in Appendix B
** The only area currently requiring licenses for stock and domestic bores in South Australia is in the Northern Adelaide Plains. The remaining regions do not license stock and domestic bores. They do in some areas account for extractions by making an allowance for the expected use by stock and domestic bores within their framework.
GAB = Great Artesian Basin; GMA = Groundwater management area; GMU = Groundwater management unit

4.1.3 Previous studies

Bores have been constructed in Australia for stock and domestic purposes for more than 100 years. Areas of significant development and use of stock and domestic bores include the Great Artesian Basin (primarily developed for use for stock watering purposes); the central and western regions of Australia encapsulating South Australia, Northern Territory and Western Australia, where surface water resources are scarce; and Queensland, where surface water resources are either scarce or not reliable. In south-eastern Australia, water availability has traditionally depended on surface water resources that historically were reliable and accessible. In south-eastern Australia, the development of stock and domestic bores has generally followed periods of drought when surface water becomes less reliable or available.

Given the distribution and history of development of stock and domestic bores, it would be assumed that there would be considerable knowledge and data available on them. A review of previous studies regarding stock and domestic bores was undertaken in order to establish existing knowledge and data sources. This review found that little information has been compiled on stock and domestic bores outside of the Great Artesian Basin. This is most likely due to the fact that, without regulation of the development of extractions by stock and domestic bores, there has been little need for authorities to intensively monitor or report on the number and volumes of groundwater extracted by stock and domestic bores.

The studies that provided the bulk of the data for this assessment are listed below. National studies comprise the bulk of the reports, which provided quantitative information on stock and domestic bores and total licensed groundwater extraction volumes. This list also includes any reports that have reviewed rates of development and potential areas for development of stock and domestic bores. The report or study has been listed below with a brief summary of the main conclusions.

Relevant results can be found in a tabulated form in Appendix D.

- The Murray Darling Basin Commission published a report *Projection of Groundwater Extraction Rates and Implications for Future Demand and Competition for Surface Water in 2003* (MDBC 2003). This report suggests that in 1999–2000, stock and domestic bores accountws for about 30 per cent of all groundwater use (Appendix D, Table 28). In the NSW Murray-Darling Basin, this figure has been estimated to be lower, representing 8–10 per cent of all groundwater use (DNR 2009). Significantly, use from the GAB is shown to represent 74% of all rural use in the Murray–Darling Basin (DNR 2009, Table 4-7, p. 24).
- The 2000 Australian Water Resources Assessment (AWRA 2000) suggests that, across Australia in 1996–97, rural domestic and stock bores accounted for 19 per cent of all groundwater used and 3 per cent of all water used. (Appendix D, Table 29)
- AWRA 2000 compiled estimates of stock and domestic bore numbers, together with estimated total groundwater extraction volumes. Using an assumed 2 megalitres per bore per year across Victoria, stock and domestic bore use accounts for approximately 18 per cent of all groundwater extraction. (Appendix D, Table 30)
- AWR2005 (NWC 2007a,b) updated the national water account to determine the volume of groundwater licensed for extraction and estimated usage by groundwater management area and jurisdiction. This information has been used to compare stock and domestic bore extraction volumes to determine its significance relative to other licensed groundwater uses.
- Victorian State Water Account reports (2003–05) indicate that across Victorian groundwater management units, stock and domestic bores account for about 10 per cent of all groundwater used. (Appendix D, Table 27)
- *Perth Groundwater Atlas*, 2nd edition, 2004 is published by the Department of Environment and details the aquifers from which urban domestic users can extract groundwater. This is a purely technical manual reviewing the issues that potential domestic bore owners will have to address prior to constructing a bore. It does not detail the number of existing bores in Perth.
- The National Water Commission funded a metering program for bores in the Darwin region. The results were documented by NRETAS in November 2008, and updated recently with data to June 2009. Both reports provide a summary of the typical bore yields and annual extraction volumes from domestic garden bores. An extract is given below detailing the main results with regards to stock and domestic bore users:

  > “Estimated Annual Water Usage on Residential-only blocks with varying size gardens in the Darwin Rural Area. The sample size is 33 blocks. A Negligible Garden is 0–0.1 ha (similar to that found in Darwin City); a Small Garden 0.11–0.25 ha; a Medium garden is 0.26–0.5 ha (the maximum allowed under the Water Act without a licence); and a Large Garden is over 0.5 ha in size.”

  The mean metered volume from these four garden types was 2.2, 2.3, 4.1 and 5.5. megalitres per year respectively. This has since been updated to 1.8, 1.7, 3.6 and 4.4 ML/yr for each of these garden types. It should also be noted that the 4.4 ML/yr is for large gardens which require a license. As such, the maximum unlicensed garden use is noted at 3.6 ML/yr.

Other studies were also reviewed to determine potential methods to assess the impacts of stock and domestic bores on other users. Two earlier studies undertaken for the Victorian Department of Sustainability and Environment assessed stock and domestic bore use by examining aerial images (SKM 2007c, 2007). SKM (2008) plotted bore locations on high-resolution images; a small representative section was then selected and visually examined to determine an ‘area of assumed use’ for each bore. Image analysis was undertaken to calculate the areas of assumed use, which then allowed for the calculation of groundwater extraction volumes. SKM (2008) also used visual inspection to determine bore locations on aerial photographs. The correlation between bore location and nearby features (bore-related buildings such as windmills, tanks and vegetation patterns) was also examined; it was found that a large number of bores were more than 200 metres from any such related features. However, it is thought that this could be due to inaccuracies in the recorded bore locations; these results are therefore inconclusive.

A recent internal study by NRETAS found that bore age and depth played a significant part in determining whether it was in “active” use (pers comm.. Chris Wicks, 2/3/2010). This correlates with a study by DSE into “active” bores in northern Victoria which used age and depth to quantify the number of “active” stock and domestic bores. The life cycle of bores is generally assumed to be around 25 years depending on the aquifer conditions (water quality) and maintenance and use over the life of the bore. The bore depth generally implies whether it can meet adequate yield requirements given shallow bores intersect aquifers at shorter intervals than those drilled deeper, and hence are more likely to be unreliable over the longer term.

4.2 Methodology

The approach used to determine the current and projected numbers and impact of stock and domestic bores in Australia is summarised below and further details are provided in Appendix D.

Stock and domestic bore data

The availability of stock and domestic bore data is summarised in Table 12. It is important to note that the ‘standalone’ nature of these bores was established by examining the registered ‘use.’ In some instances, a significant number of bores were excluded due to a lack of either location or use data. Detailed bore data was not available for Tasmania and therefore an estimate provided DPIW was used instead.

Table 12: Standalone stock and domestic (D&S) bore data across Australia

State	*No. D&S bores with location data**	*Source*	*Covers whole state?*	*Year*	*Comments*
ACT	150	Department of the Environment, Climate Change, Energy and Water	Yes	2003 to current	The dataset includes only bores licensed since 2003 with domestic bores licensed up to 30 ML assumed to represent 'standalone' stock and domestic bores (pers comm. H Chester (DECCEW)).
NSW	57,897	Department of Environment, Climate Change and Water**	Yes	2007	Only standalone domestic and stock bores
NT	18,525	Natural Resources, Environment, The Arts and Sports	Yes	2009	Difficult to determine only standalone. Through discussion with NRETA use types that were most likely to be domestic and stock were used. Bores older than 50 years have also been excluded.
Qld	51,958	Department of Water and Environment**	Yes	2007	Only stand alone domestic and stock bores.
SA	43,914	Drill hole Enquiry System (DWLBC)	Yes	2008	Only standalone domestic and stock bores.
Tas	4,500	Department of Primary Industry and Water (DPIW)	Yes	NA	Detailed data with bore location information were not available. An estimate of total bores was provided by DPIW
Vic	41,989	Groundwater Management System (DSE)	Yes	2007	Only standalone domestic and stock bores
WA Perth	n.a. 38,757	n.a. PRAMS Model Area	No	2007	Only standalone domestic and stock bores

**Bore data were obtained for the CSIRO MDBSY Project, but covers the whole state not just the portion within the Murray Darling Basin

Great Artesian Basin

One of the most significant uses of groundwater for stock watering is from the Great Artesian Basin. Current policy and initiatives within the Great Artesian Basin have put caps on extraction for each management zone; however, these caps do not include stock and domestic bores. Investigations into management approaches across the Great Artesian Basin have indicated that it is unlikely that there will '...be any major development in stock and domestic use into the future, as the areas suitable for grazing have already been developed', (SKM 2004b). For this reason, this review of impacts of stock and domestic bores has included current impacts of stock and domestic bores in the Great Artesian Basin, but it has not allowed for any further growth in the number of bores. The only change that may occur is a reduction in the volume extracted for stock and domestic purposes due to water savings from the current Great Artesian Basin Sustainability Initiative (GABSI) program.

The GABSI is an ongoing program that supports the capping and replacement of Great Artesian Basin bores and drainsthat are free flowing or corroded. The water savings were initially estimated at 170 gigalitres per year (GAB Resource study 1998); however, they have been reported as 41.5 gigalitres per year in the first three years of the GABSI program (2003

Review of the GABSI). The reduced savings have been attributed to pressure increases in bores that had ceased to flow, which are now flowing (or leaking into other aquifers) and are not on the GABSI program. Overall the program is delivering water savings and has increased pressures throughout the Great Artesian Basin. Work is still continuing on the GABSI. The water savings from the GABSI will be re-allocated for other purposes (e.g. town water supplies) and are unlikely to be utilised for stock and domestic use.

The method used to estimate future standalone stock and domestic bore growth

In order to produce growth estimates in the number of standalone stock and domestic bores in 2015 and 2030, relationships were examined between the number of these bores and groundwater salinity, land use, population, and temporal growth. Further details are provided of these analyses in Appendix D. Based on a review of these potential methods, the following conclusions can be made:

- Groundwater salinity—it was found that most standalone stock and domestic bores are found in areas with better quality groundwater (less than 3500 milligrams per litre of total dissolved solids). This relationship, however, is too broad and data are not available for states other than Victoria. Groundwater quality data could be used to indicate areas of future demand by excluding those areas where the resource is not of suitable quality (generally potable or stock watering standards). For this assessment, a national dataset was not available forsuch an analysis; however, consideration of water quality was made when reviewing the results of the projected demand areas.
- Land use—it was found that irrigated pastures and crops, horticulture, urban, rural residential, and sown pasture land uses generally have the highest concentration of bores. This approach was considered to be unreliable due to uncertainties within the land use dataset, specifically the irrigated land uses, and was not pursued. If land use data were available at a higher level of certainty this approach could predict future growth areas and demand for stock and domestic bores.
- Population analysis—it was found that there is a very approximate correlation between increasing population and an increase in the number of bores on a statewide basis. This is too broad a relationship and will therefore not be pursued. There was no relationship found at the higher scale when urban and rural centres were investigated individually because the census data included multiple land uses. Generally, though, there was some indication that urban cities had a high proportion of garden bores (mostly in cities where water restrictions had caused people to look for alternate water sources), and that rural regions of low population had little correlation with the demand for stock and domestic bores.
- Temporal increase—it was found that by examining the temporal growth of bores, on a SWMA basis, an average rate of bore growth (bores per year) could be calculated. This approach delivered results that appear to be relatively consistent and realistic. It is this method that was adopted to predict the future impacts of stock and domestic bores in 2015 and 2030. The temporal analysis outlined in Appendix D was undertaken only for NSW, NT, South Australia and Western Australia's Prams Model Areas where bore data were available on a SWMA basis. In Queensland, Tasmania and the ACT, there were no data regarding the dates that bores were drilled (Queensland) or because data were not available on a SWMA basis (ACT and Tasmania). The future impacts of stock and domestic bores for these states were estimated by applying relationships derived from neighbouring areas (the NSW relationship was applied to Queensland and the ACT and the Victorian relationship was applied to Tasmania).

It was found that there were several factors that indicated the likelihood of the development of stock and domestic bores. This included the following indicators:

- Groundwater resource indicators:
  - groundwater quality limits use for potable and stock watering where the water is high in salinity or other heavy metals and minerals
  - aquifer yield limits the ability to extract the requisite volumes of water, which is why fractured rock aquifers are sometimes used for filling of dams on a long-term basis but can't be used for daily supply (by windpump)
  - increasing depth to suitable quality groundwater will reduce the likelihood of use for stock and domestic users due to the cost of construction of the bores.
- Other available water sources:
  - groundwater is normally used in regions where either surface water is not available or reliable (e.g. northern Australia), or where they are capped (e.g. in the Murray–Darling Basin there has been significant increases in groundwater extraction since capping of surface water resources; MDBC (2003))
  - reticulated water supplies have historically meant that urban garden users have not required other water sources. Recent restrictions on reticulated water (in the past 10 years) has led to increased use of domestic bores, garden tanks, grey water re-use and other cost effective alternative water supplies. This demand has purely arisen out of need due to policy changes on water availability for urban users.

The most significant growth in demand for stock and domestic bores appears to have arisen out of management and policy impacts where caps or restrictions have been placed on other sources.

To determine the potential impact of stock and domestic bore use on other users, it was assumed that each stock and domestic bore used 2 megalitres per year (excluding bores in the Great Artesian Basin). This assumption is based on the following information:

- A recent study in the Northern Territory found that domestic bores used 2–5 megalitres per year (NRETAS 2008).
- The Victorian State Water Account has assumed that use is approximately 2 megalitres per year (DSE 2007).
- Stock water use and land carrying capacity for sheep has indicated lower water requirements (0.27 megalitres per year) in non-irrigated pastures in South Australia.
- Licensed entitlement for stock and domestic bores in the ACT ranges from 2 megalitres per year to 5 megalitres per year depending on the size of the block (these are what we also refer to as peri-urban developments; discussed further in Chapter 7).
- In Queensland a use of 1 megalitre per year was estimated using allocations volumes.

Limitations associated with this assumption include:

- The volume extracted normally also includes other losses from channels, dams, and other water features where water is pumped out to a holding area.
- Stock and domestic bores are not regulated or audited, so those registered with bore construction licenses are assumed to represent only a small proportion of those actually constructed, with many others also in existence (in some states only those within declared management areas are required to be registered).
- The definition of stock and domestic bores varies by state. As different bore depths require registration, there will be many bores outside the 'definition' that are also in existence and not on the register.

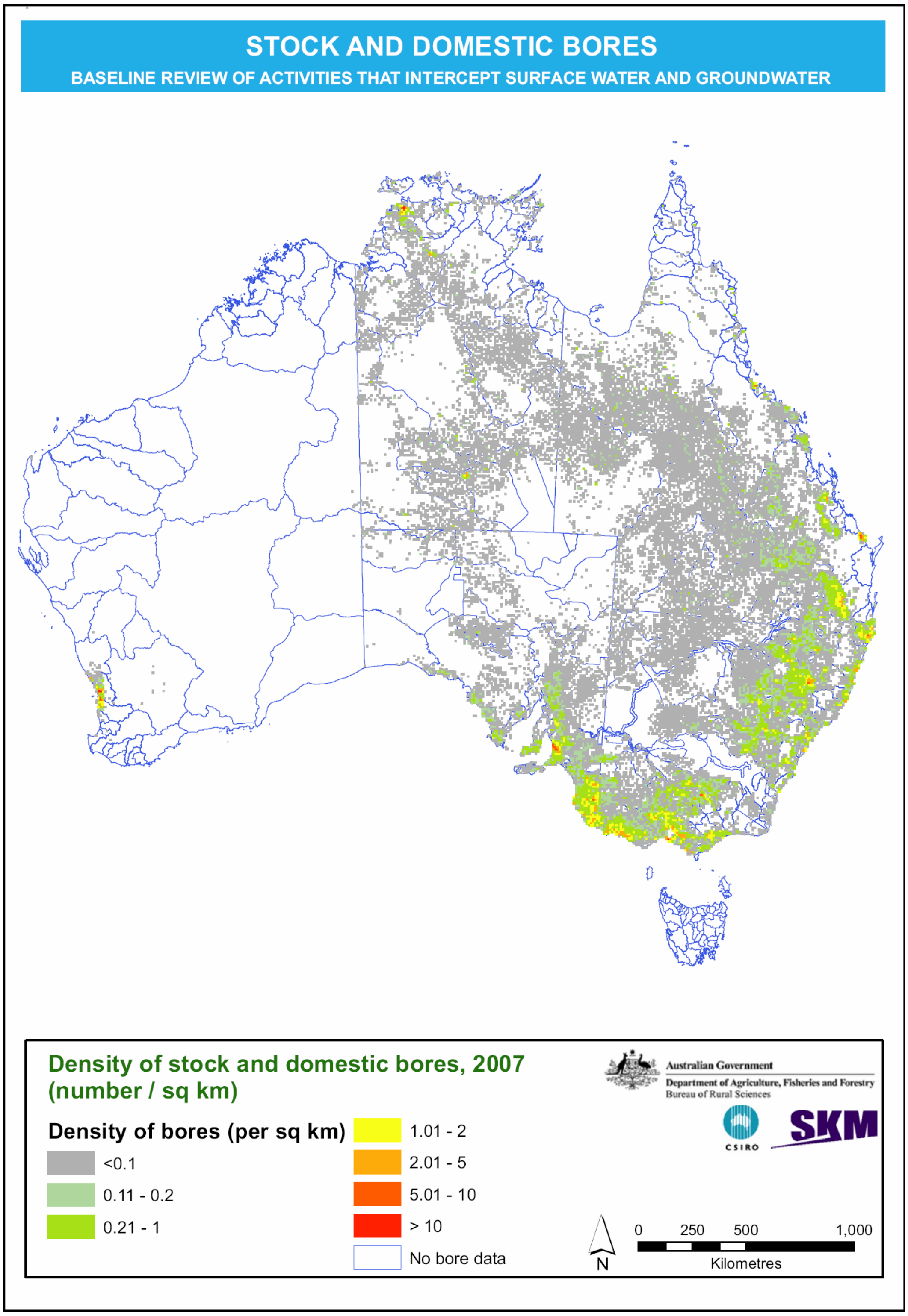
- Data were not available for some jurisdictions. There are significant regions of Queensland, Western Australia, Northern Territory and Tasmania without available data.

Bore abstraction volumes within the Great Artesian Basin are considerably higher than 2 megalitres per year (i.e. 20–80 megalitres per year) based on data available for Queensland, NSW and South Australia.

4.3 Results

The current distribution of stock and domestic bores as derived from the data made available for this project is shown in Table 11 and summarised in the Table 12 on a statewide basis.

Figure 11: Density of stock and domestic bores based on data obtained in this study



I:\VWES\Projects\VW04488\Technical\spatial\arcmap\final_report\Stock and domestic bore density 2007.mxd

The impact of stock and domestic bores are summarised in Table 12 using the assumed volume of 2 megalitres per year for bores outside the Great Artesian Basin.

Table 13: Groundwater use by standalone bores, assuming each bore uses 2 ML/year[a]

State	*Number of Great Artesian Basin (GAB) bores*[b]	*Volume extracted in the GAB (ML/yr)*	*No. of standalone D&S bores with location and use data*	*Volume of standalone D&S bores used (ML/Year)*	*Total volume used by D&S bores (ML/yr)*	*GW Extraction volume (ML)*	*% of licensed volume consumed by standalone S&D bores & GAB bores*
ACT	–	–	150	739	739	1,144[c]	65%
NSW	6,459	193,770	51,440	102,880	297,000	1,265,393	23%
NT	84	1,680	18,441	64,544[g]	66,200	188,364[g]	35%
Qld	15,679	313,580	36279	36,279	349,900	363,440	10%[f]
SA	1,293	129,300	42621	85,242	214,500	413,996	52%
Tas	–	–	4,500	9,000	9,000	45,000	20%
Vic	–	–	41,989	83,978	84,000	879,900	10%
WA	–	–	–	–	–	1,607,934 [e]	–
Perth	–	–	38,756	77,511	77,500	338,958[d]	23%

a. Volume used is calculated assuming each bores uses 2 megalitres per year (ML/year), with the exception of the ACT, Queensland (Qld) and Northern Territory (NT). In the ACT an estimate of total use of 739 ML was provided (DECCEW 2009) and in the NT, total use by rural groundwater users was estimated to be 33,000 ML by AWRA (2000). In Qld, 1 megalitre per year is estimated using allocations volumes

b. Number of Great Artesian Basin (GAB) bores for NSW and South Australia (SA) based on spatial intersections with groundwater management units that fall within the GAB. In Queensland, raw data were available stating which bores felling within a GAB Management Area.

c. Groundwater extraction calculated by adding total allocations from groundwater licensing information provided by DECCEW (2009)

d. Groundwater extraction for Perth as calculated by AWR (2005) water balance modelling.

e. Groundwater extraction volumes were taken from AWR (2005) except for Western Australia (DoW 2009) and Victoria (DSE 2006)

f. The percentage for Qld represents bores outside of the GAB only as the groundwater extraction volume total from AWR2005 for Qld is not complete and does not include GAB usage.

g. In the NT use per bore is assumed to be 3.5ML per bore (pers comm. NRETA 2010). In the GAB NT, bore use was assumed to be similar to the QLD GAB and a value of 20ML per bore was used. The total GW extraction volume of 188,364 ML was obtained by totalling the entitlements from NRETAs groundwater register and also includes the domestic and stock estimate calculated in this report of 66,224 ML.

After examining temporal increases of bores in NSW, South Australia, Victoria and Western Australia, due to data availability, the period 1993–2002 was chosen from which to determine current and future bore growth trends. The growth rates from this period were applied to SWMAs for which bore data were available. The results are summarised in Table 14 and the changes are mapped for each SWMA in Figure 12 and 13. More detail on how these results were obtained can be found in the ‘Temporal increases in stock and domestic bore data’ section of Appendix D.

Table 14: Summary of stock and domestic bore impacts 2007, 2015 and 2030 based on temporal increase modelling (including the GAB).

State	Number of bores 2007	Number of bores 2015	Number of bores 2030	2007 Use ML/year	2015 Use ML/year	2030 Use ML/year	GW Use Volumes (AWR 2005) (ML)	2007 % Consumed by standalone S&D Bores	2015 % Consumed by standalone S&D Bores	2030% Consumed by standalone S&D Bores
ACT[a]	150	160	180	739	800	900	1,144	65	70	78
NSW	57,900	62,200	70,300	297,000	305,000	321,000	1,265,393	23	24	25
NT[b]	18,500	21,000	25,800	66,200	75,300	91,800	188,400	35	40	49
QLD[c]	52,000	54,700	59,800	350,000	353,000	358,000	363,400	10*	11	12
SA	43,900	48,500	57,000	215,000	224,000	241,000	413,996	52	54	58
TAS[d]	4,500	4,700	5,100	9,000	9,400	10,200	45,000	20	21	23
VIC	42,000	44,000	47,700	84,000	87,900	95,300	879,900	10	10	11
WA	38,800	41,100	45,500	77,500	82,200	90,900	338,958	23	24	27
Total	257,800	276,400	311,400	1,099,000	1,138,000	1,209,000	3,496,000[e]	31	33	35

Note: Increases have not been projected for bores that are within the Great Artesian Basin

a. Bore growth in the ACT was assumed to follow a similar pattern to NSW. The volume consumed by each bore was assumed to be 4.9 megalitres per year (DECEW 2009)

b. Bore growth in the Northern territory (NT) was assumed to follow a similar pattern to South Australia (SA).

c. Bore growth rates were assigned on a SWMA basis for Queensland (Qld) following a similar pattern to NSW

d. Bore growth in Tasmania (TAS) was assumed to follow a similar pattern to Victoria (VIC)

e. The actual total groundwater allocation volume for all of Australia is 4,700GL. The value presented in this table is less because in WA the groundwater use value of 338,958 is for the Perth region only. The actual percentage consumed by S&D bores in relation to the 4,700GL for 2007, 2015 and 2030 are therefore 23, 24 and 26%, respectively.

Figure 12: Projected increase in use by stock and domestic bores from 2007 to 2015

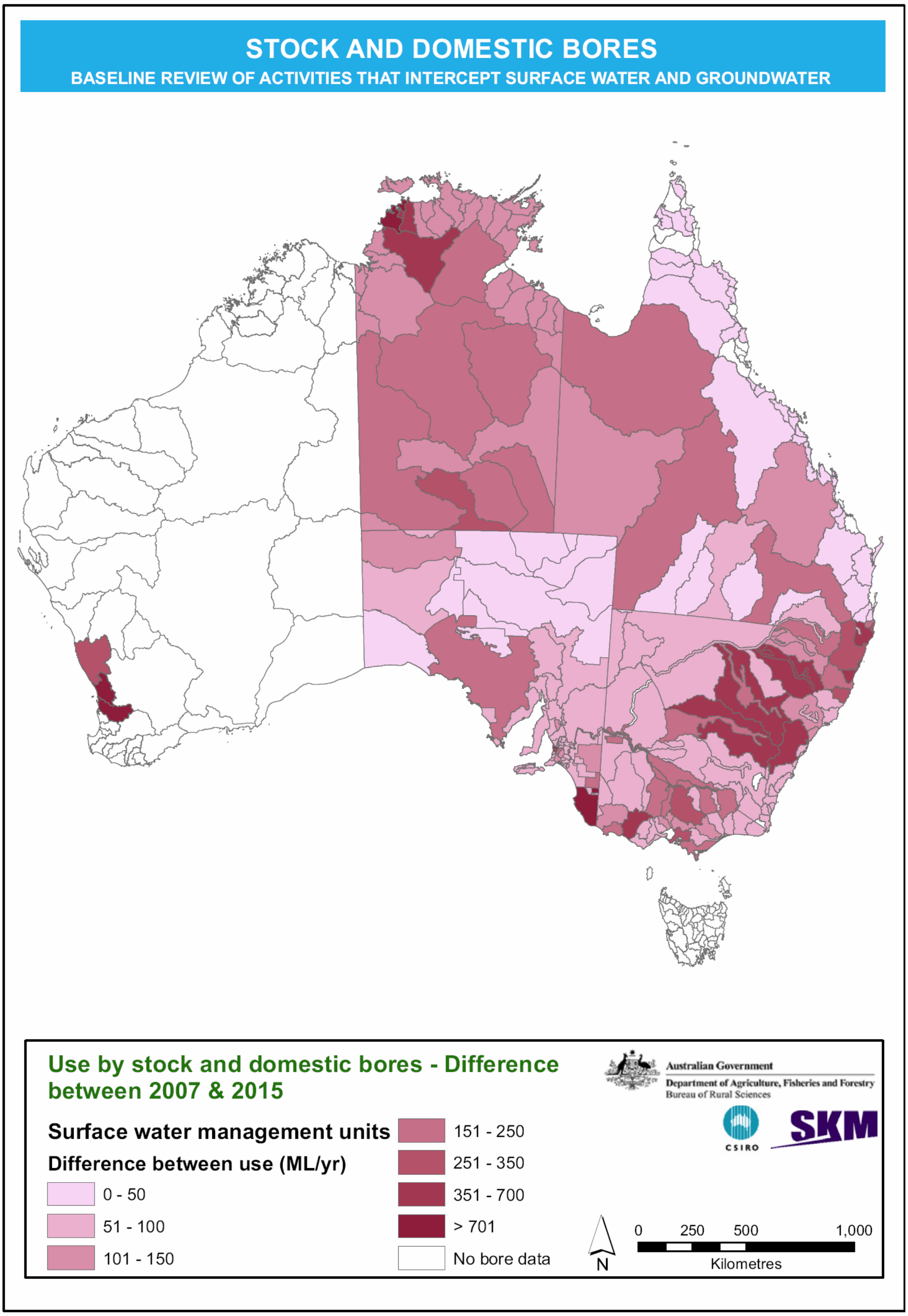


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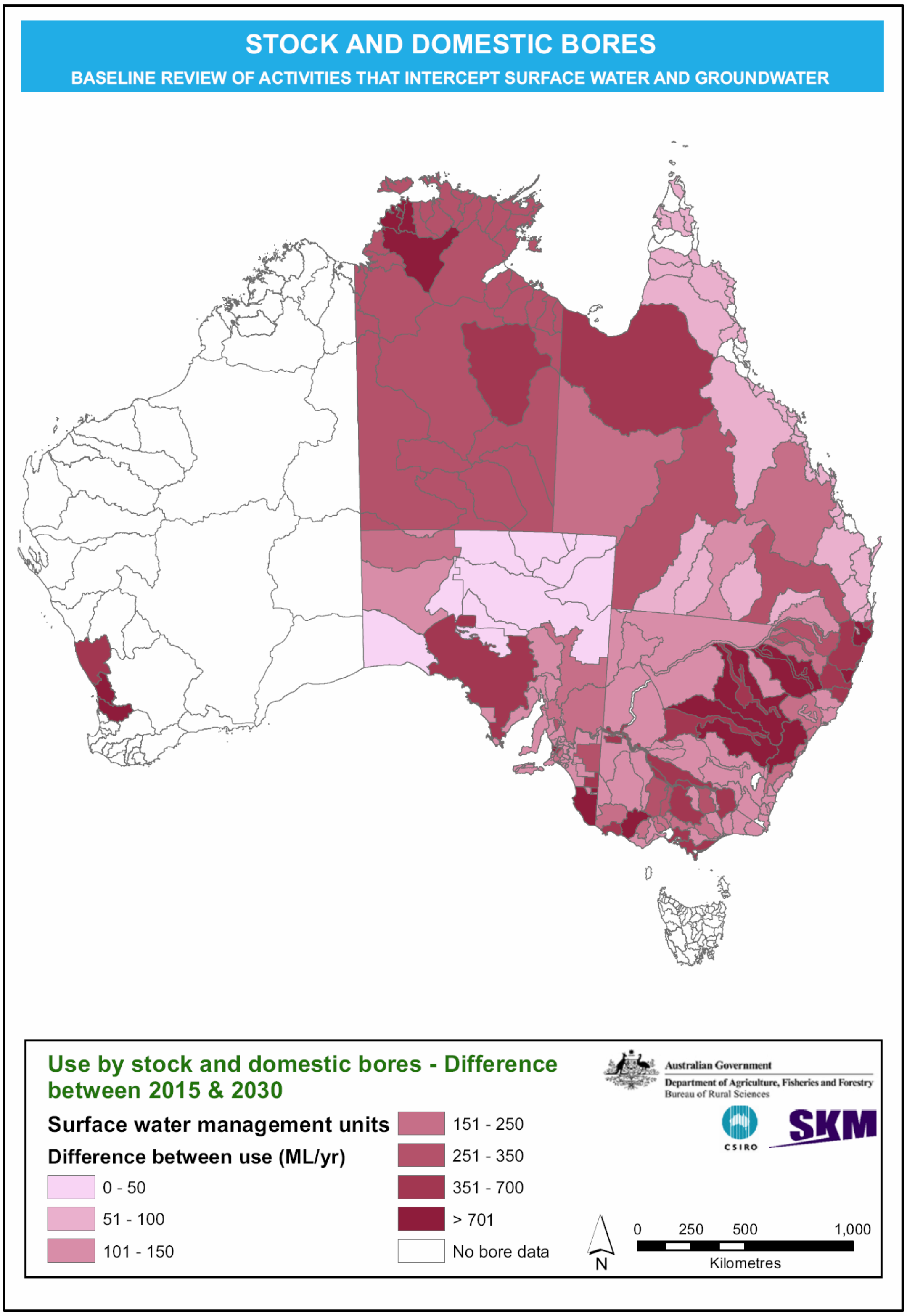
Figure 13: Projected increase in use by stock and domestic bores from 2015 to 2030



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The current impact of standalone stock and domestic bores has been estimated using existing information. This is summarised on a state-by-state basis below. 'Impact' has been defined as the estimated volume of standalone stock and domestic extractions compared to overall groundwater extraction for each SWMA, state and territory. On average, this study estimates that stock and domestic bores currently consume a volume equivalent to an additional 39 per cent of groundwater extractions per state (using AWR2005 estimates for groundwater extraction).

There are some limitations that should be applied to the forecasted growth with respect to the Murray–Darling Basin and the Great Artesian Basin, both of which we have assumed will have groundwater use capped, including stock and domestic bores, thereby limiting future growth in this extraction type. Also, updates using 2007–08 data would be significantly different to these rates of growth given the recent 10 years of drought in south eastern Australia.

Australian Capital Territory (ACT)

Data available for the ACT includes only bores that have been licensed since 2003: domestic bores licensed up to 30 megalitres per year are assumed to represent 'standalone' stock and domestic bores (DECEW 2009). This includes 150 bores with a total entitlement of 739 megalitres per year. This accounts for an extra 65 per cent of groundwater extraction within the ACT.

New South Wales (NSW)

There are 51,440 standalone stock and domestic bores in NSW, and available data indicate that there are a further 6459 stock and domestic bores within the NSW portion of the Great Artesian Basin (Appendix D, Table 32). Assuming 2 megalitres per year of use for non-Great Artesian Basin bores and 30 megalitres per year for Great Artesian Basin bores, stock and domestic bores use 296,650 megalitres per year, which accounts for an extra 23 per cent of groundwater extraction in NSW. This figure can be assumed to be an underestimate, given a large amount of data with missing location or use information, including the Murrumbidgee area.

SKM (2004a) has previously estimated that there were 3132 stock and domestic bores in the NSW portion of the Great Artesian Basin in 1999, and MDBC (2003) estimated use to be 127,039 megalitres per year. The current estimate is 194,000 megalitres per year.

Northern Territory

There are 18,441 standalone stock and domestic bores in NT and available data indicates that there are a further 84 stock and domestic bores, within the NT portion of the GAB. GAB use per bore was assumed to be similar to Queensland and taken to be 20 megalitres per year. A National Water Commission funded voluntary bore metering program indicated that extraction volumes for rural bores vary between 1.7 to 4.4 megalitres per year (NRETAS, 2009). Use for stock and domestic outside the GAB has been taken to be 3.5 megalitres per year upon advice from NRETA (NRETA 2010). Assuming these use values, standalone stock and domestic bores use approximately 66,200 megalitres per year. This accounts for 35% of the overall groundwater extraction in the NT.

Queensland

There are 36,279 standalone stock and domestic bores in Queensland and available data indicate that there are a further 15,679 stock and domestic bores within the Queensland portion of the Great Artesian Basin (Appendix D, Table 32). License allocation volumes suggest that the Great Artesian Basin bores use, on average, 20 megalitres per year and non-Great Artesian Basin bores use 1 megalitre per year. Standalone stock and domestic bores use 349,859 megalitres per year, which accounts for an additional 96 per cent of groundwater extraction in Queensland. The results from this analysis suggest that the reported total of 363,440 megalitres per year is a gross under-estimate of groundwater use in Queensland. For this reason the percentage estimate given in Table 14 (10%) is for stock and domestic bores outside the GAB only.

A previous estimate of 11,978 stock and domestic bores in the Queensland portion of the Great Artesian Basin has been reported (Great Artesian Basin Consultative Council 1998), with an estimated groundwater usage of 222,548 megalitres per year (SKM 2004b) and 273,739 megalitres per year (MDBC 2003). The current estimate is 314,000 megalitres per year.

South Australia

There are 42,621 standalone stock and domestic bores in South Australia and available data indicate that there are a further 1293 stock and domestic bores within the South Australian portion of the Great Artesian Basin (Appendix D, Table 32). Assuming 2 megalitres per year of use for non-Great Artesian Basin bores and 100 megalitres per year for Great Artesian Basin bores, stock and domestic bores use is 214,542 megalitres per year, which accounts for an additional 52 per cent of groundwater extraction in South Australia.

SKM (2004b) estimated that the South Australian portion of the Great Artesian Basin had 392 stock and domestic bores in 1999. The groundwater usage of these bores was estimated to be 33,253 megalitres per year (MDBC 2003). The current estimate is 129,000 megalitres per year.

Tasmania

Currently, there is no database of information regarding stock and domestic bores in Tasmania. An estimate of 4500 stock and domestic bores was provided by DPIW (2009). Assuming each bore uses 2 megalitres per year, standalone bores use 9000 megalitres per year of groundwater. This accounts for an extra 20 per cent of groundwater extraction each year, when compared to a total groundwater use volume of 45,000 megalitres per year (DPIW staff, pers. comm.,2009).

Victoria

There are 41,989 standalone stock and domestic bores in Victoria. This number is likely to be an underestimate as there were approximately 15,000 bores with no ‘use’ data and an even greater number that had no location data. Assuming each bore uses 2 megalitres per year (Victorian state water reports), standalone stock and domestic bores use approximately 84,000 megalitres per year of groundwater. This represents an extra 10 per cent of groundwater extraction in Victoria.

Western Australia

At the time of this report, data were available only for the number of standalone stock and domestic bores in the Perth (PRAMS Model) region of Western Australia. There are currently 9519 standalone stock and domestic bores recorded in this area; this value however is considered to be an underestimate. AWR2005 estimates groundwater extraction for domestic garden watering purposes as being 77,511 megalitres per year, and this value was assumed to give a more accurate estimate for groundwater use by stock and domestic bores in the Perth region. Assuming 2 megalitres per year of use per bore, this suggests that there are approximately 39,000 stock and domestic bores in the Perth region. This volume of use (for Perth area) represents an additional 23 per cent of groundwater extraction in Perth.

4.4 Discussion

Bore data from the different jurisdictions have been variable in consistency. This is further exacerbated when trying to source stock and domestic bore data, given the lower priority given to recording details on bores that in most instances are outside the licensing system of the jurisdictions.

Some estimates of current bore impacts have been made using available data. In order to produce estimates of the growth in the number of standalone stock and domestic bore in 2015 and 2030, relationships were examined between the number of these bores and groundwater salinity, land use, population, and temporal growth.

It was found that there were several factors that are correlated with the number of stock and domestic bores. These include the following:

- groundwater quality and aquifer yield—depth to groundwater is also a significant factor in limiting development of the resource due to economic considerations
- other available water sources:
  - groundwater is normally used in regions where either surface water is not available or has low reliability (e.g. northern Australia), or where surface water use has been capped. For example, there has been significant increases in groundwater extraction in the Murray–Darling Basin since capping of surface water resources (MDBC 2003)
  - reticulated water supplies have historically meant that urban garden users have not required other water sources. In southern Australia, water restrictions during the past 10 years has led to increased use of domestic bores, garden tanks, grey water re-use and other cost-effective alternative water supplies. This demand has arisen out of need—it is due to policy changes on water availability for urban users.

The most significant growth in demand for stock and domestic bores appears to have arisen out of management and policy impacts where caps or restrictions have been placed on other sources. Groundwater extraction for stock is driven by stocking rates, and there is an inherent upper limit to the sustainable stocking rate of the land. As a result, increases for purely stock use are not expected on land currently supporting grazing; however, increases may occur where land use changes to grazing, or where water demands transfer to groundwater sources. There is no expected increase in stock and domestic bores in the Great Artesian Basin due to current policy and management initiatives.

There is limited information on water extraction volumes for stock and domestic bores due to the varying nature of the use of the water—such as urban gardens, domestic, stock—and due to the lack of information on the use of groundwater for this purpose because it sits outside the regulatory regime in most states. To better understand the potential impacts of stock and domestic use, basic information has to be available to determine the extent of use. Furthermore, there are ‘other’ bores used for stock and domestic purposes, and these are not currently included in the definition of ‘stock and domestic’ bores. These ‘other’ bores should be included to ensure all users are captured in any management or regulatory regime.

4.5 Findings

- Current impacts of unlicensed extractions from stock and domestic bores are estimated to be an average of 39 per cent of total groundwater extraction volumes per state. This includes estimates from previous studies of between 10 and 30 per cent of total groundwater use and is considered to be an underestimate given the lack of completeness of the available data.
- Nationally, stock and domestic bore use is estimated at 1,100 gigalitres per year, which is equivalent to an additional 23 per cent of the current allocated volumes of 4,700 gigalitres per year.
- Using historical bore development data (based on the dates that bores were drilled), the current estimates of stock and domestic impacts are expected to increase to 24% per cent of current groundwater extraction in 2015. By 2030 this is expected to increase to 26% per cent of current total groundwater extraction.
- The highest density of extraction for stock and domestic purposes is in regions where there is no other available source of water (e.g. Lower Limestone Coast SWMA); in areas where surface waters have been capped and so users look to alternate water supplies (e.g. Lachlan River SWMA); and in urban centres where water restrictions have caused domestic users to source alternate water sources for garden watering (e.g. Swan Coast SWMA, Yarra SWMA). These three factors are probably the key indicators of where future growth in stock and domestic bores may occur.
- The Great Artesian Basin is a significant source for stock and domestic bore users. An estimated 638 gigalitres per year is used from this source, which is three times the estimated 289 gigalitres per year of usage from other stock and domestic users in NSW, South Australia and Queensland. In these states, the Great Artesian Basin accounts for 69 per cent of the total stock and domestic use. There is no expected increase in stock and domestic bores in the Great Artesian Basin due to current policy and management initiatives.

5 Plantations

5.1 Introduction

5.1.1 Definition

Afforestation is defined as the large scale planting of trees for timber production, carbon offsetting, land conservation or other environmental purposes. For this assessment, only commercial plantations have been considered as there are no reliable regional and national data available on other types of tree planting. In addition, it is assumed that afforestation by plantations is occurring on land that was not forested at that time. The study has not considered impacts on catchment water yields where plantations have directly replaced native forest (L. Zhang pers comm.).

The planting of trees for timber production fall into 2 broad categories:

1) Softwood forestry plantations—stands of softwood trees for commercial production using various species of pine, including Radiata Pine (*Pinus radiata*), *P. pinaster*, *P. elliotii* and P*. carribea*. Rotation lengths are typically 25–35 years.
2) Hardwood forestry plantations—stands of hardwood trees for commercial production, typically on a short rotation (10–15 years). The main species for this purpose in southern Australia is Blue Gum (*Eucalyptus globulus*) and *E. nitens*. Other eucalypt species are used in Queensland and NSW and in the Northern Territory—plantations are mainly acacias and exotic hardwoods. In addition, alternative species exist for other purposes (such as firewood). These species, such as the Sugar Gum (*E. cladocalyx*), typically require less rainfall than Blue Gum.

5.1.2 Government policy

A summary of the state issues relating to plantations across Australia is provided below, with information being current at the time of this report (June 2009).

- ACT—No policy. At the moment interception by plantations is not considered to be a major issue.
- NSW—No policy. Groundwater management plans in NSW have acknowledged that plantations are an activity requiring inclusion within the water management framework, but licenses for water extraction are not required at this time. Each water sharing plan will assess the likelihood of plantations being a significant intercepting activity (e.g. Hunter and Coffs Harbour background document to the draft water sharing plans). If there are significant plantation developments, they will be managed under the *Plantations And Reafforestation Act 1999* and '*assessed to determine if water access licenses are required for new plantations*'.
- Northern Territory—No policy, but some concern over effects of proposed plantation developments on the dry season flows in the Daly River catchment.
- Queensland—No policy. At the moment, interception by plantations is not considered to be a major issue.

- South Australia—Recent policy. Under a revision of the groundwater allocation plan, new plantations will need to acquire a water license[2] for groundwater extraction. For example, in the Lower Limestone Coast Prescribed Wells Area (LLCPWA) all new plantations in areas where median depth to groundwater is less than 6 metres have required an allocation since 2007. A draft proposal for the revised water allocation plan for the LLCPWA includes licensing of all plantations for interception of groundwater recharge (equivalent to about 80 per cent of recharge from agricultural land) and, where depth to groundwater is <6 metres, licensing of all plantations for groundwater extraction. A water allocation plan is also being drafted for the Mount Lofty Ranges to account for forestry.
- Tasmania—No policy. Currently undertaking modelling to determine the significance of interception by new plantations in various Tasmanian catchments and subcatchments.
- Victoria—No policy, but a policy is being developed during the next 12 months. The Victorian Government White Paper *Securing Our Water Future Together* (Department of Sustainability and Environment 2004) considered the impact of plantations on water resources under the title 'Addressing impacts of catchment land use'. The government will assess the hydrological impact of such developments on salinity, greenhouse and other environmental benefits and costs. This is also stated again in the Northern Sustainable Water Strategy, which states that interception activities, such as plantations, are a possible threat to water resources.
- Western Australian—No policy. A draft policy has been drafted, but it has not been further developed.

5.1.3 Previous studies

Plantation forestry is an increasingly important land use in Australia. According to the latest National Plantation Inventory, the plantation area, nationwide, has increased by more than 70 per cent since 1994 and reached a total area in excess of 1.9 million hectares in 2007. While bringing many commercial and environmental benefits, land use change to plantations has been recognised by the NWI as a water interception activity. It is important to consider the effects of plantations on water yield in water resources planning and allocation.

The water balance underpins our understanding of catchment hydrology. In the long-term, water yield from a catchment, including streamflow and groundwater recharge, is the difference between rainfall and evapotranspiration, assuming no net change in soil water storage in the catchment. Consequently, any change in evapotranspiration will translate directly to a change in catchment yield.

Recognising this balance helps us predict the hydrologic implications of planting trees in catchments and provides a basis for making informed management decisions. For example, if a large number of trees are removed from a catchment, total evapotranspiration will be reduced and this may cause the watertable to rise, leading to increased water yield. On the other hand, large plantations will increase evapotranspiration and hence reduce water yield.

Plantations impact on groundwater through two mechanisms:

1) reduction in recharge to the watertable through interception and use by the plants within the unsaturated soil zone
2) extraction of groundwater from the saturated zone (beneath the watertable).

[2] More details are provided in http://www.dwlbc.sa.gov.au/assets/files/ForestryfactsheetFINAL10-05.pdf

5.1.4 Studies of impacts on runoff and catchment yield

Many studies have found that trees use more water than rainfed pastures or crops under similar climatic conditions (Bosch and Hewlett 1982; Zhang et al. 2001). This means less water is available from forested catchments. Additionally, the presence of vegetation can affect the different components of catchment water balance and therefore modify streamflow characteristics (Zhang et al. 2001).

In a study by Zhang et al. (2001), runoff data from over 250 catchments from 28 countries around the world were analysed. The catchments varied in size from less than 1 square kilometre to over 100,000 square kilometre, spanned a variety of climates—including tropical, dry, and warm temperate—and included vegetation ranging from plantations to native woodlands, open forest, rainforest, eucalypts, pines through to native and managed grassland and agricultural cropping. These data revealed that, at least on a mean annual basis, the most important factors controlling evapotranspiration were rainfall and vegetation cover. Evapotranspiration from forested catchments is generally greater than that from grassed catchments with the same mean annual rainfall. The difference decreases in high rainfall catchments to low rainfall catchments. When annual rainfall is less than 500 mm, the difference in evapotranspiration due to different vegetation is comparatively small.

5.1.5 Studies of impacts on groundwater

As previously discussed, there has been considerable work investigating the impacts of plantations on runoff and recharge to groundwater. The most recent of these studies investigating the impacts on groundwater is by Benyon and Doody (2005) and Benyon (2007), which used field evidence from the south-east region in South Australia to determine rates of extraction of groundwater in shallow watertables. These studies follow on from a three-year study into the impacts of Blue Gum and Radiata Pine plantations on groundwater in south-east South Australia (Benyon and Doody 2004). This study showed that where median depth to groundwater was less than 6 metres, the plantations extracted groundwater directly from the root zone; this use was in addition to use of available rainfall. Where the groundwater was deeper, the only impact on groundwater was a reduction in recharge. From eight Blue Gum plantations with shallow watertables, the mean annual groundwater uptake was 435 mm per year, ranging from 107 to 671 mm per year (Benyon and Doody 2004). This was for plantations with full canopy closure.

A study by SKM for Southern Rural Water was recently undertaken on the Hawkesdale Groundwater Management Area in Victoria. Based on recent unpublished data from within that area, the Benyon and Doody (2004) prior plantation estimates were reduced to 1.29 megalitres per hectare per year (ML/ha/year) for the plantation areas for long-term climatic conditions, and 2.12 ML/ha/year in the recent climatic conditions of the past decade. Groundwater extraction by native forests was reduced to 1.07 ML/ha/year under long-term average annual rainfall, and 1.53 ML/ha/year under the climatic conditions of the past decade. Finally, groundwater uptake by open woodlands was stated as 0.53 ML/ha/year for long-term average annual rainfall, and 0.77 ML/ha/year under the climatic conditions of the past decade.

The review of the rates of extraction in the Hawkesdale region has shown that the rates will differ by location due to:

- Climatic conditions—reductions in rainfall resulted in an increased requirement for groundwater by the plantations. Similarly, in areas of higher potential evaporation the plantations would have higher water use requirements which could also increase groundwater extraction volumes.

- Site conditions (geology and soils)—any impeding clay or rock layers will stop or impede the trees accessing groundwater, so in some areas there could be no impact, whilst in other areas there will be significant impacts.

Studies of plantation water use from groundwater have shown significant variation in rates of extraction from 0.53 ML/ha/year for open woodlands, to 4.35 ML/ha/year in plantations with shallow watertables. Over large regions, this can have a significant impact on the availability of groundwater for other users.

5.2 Methodology

5.2.1 Methods to determine impacts on catchment yield

The model used in the analysis was developed by Zhang et al. (2001) and implemented into a GIS framework by Bradford et al. (2001) and modified by Dowling et al. (2004). Details of the model are provided in Appendix D.

To model the impact of plantation on mean annual water yield, the following input datasets were collated:

- mean annual rainfall
- mean annual potential evapotranspiration
- SWMA boundaries
- current land use data
- plantation coverage

The projected mean annual rainfall and potential evapotranspiration data were sourced from the Centre for Australian Weather and Climate Research. The surface water management area boundaries were sourced from the AWR2005, and the current and projected plantation coverage data have been sourced from Bureau of Rural Science.

This study modelled three scenarios based on plantation data provided by the Bureau of Rural Science as part of this current project:

- current plantation impact on water yield, based on 2008 land use data
- plantation impact on water yield by 2015, based on Bureau of Rural Science projections
- plantation impact on water yield by 2030, based on Bureau of Rural Science projections.

5.2.2 Method to determine impacts on groundwater

Making some broad assumptions about the locality and site conditions of plantation areas, it is possible to determine what the impact on groundwater could be due to land use change and increases in plantations.

Assuming that the existing plantations and growth areas of plantation are within regions of similar climatic conditions to those studied in south-east South Australia, the following assumptions are made:

- that impacts of plantation forestry only is accounted for (not open woodland or native forests)
- that rates of extraction are based on recent climatic conditions (not historical)

- that 10 per cent of the existing and new growth areas are regions with shallow watertables (< 5m depth to watertable) or have access to the watertable.

Using the based on the Hawkesdale example above, a rate of 2 ML/ha/year was applied as being representative of average conditions—it is known that other regions have shown higher rates. Northern Australia also has higher rates of rainfall and hence will have a different level of dependency on groundwater during the wet and dry seasons. As such, they may actually use more groundwater than in the southern regions of Australia. The assumption of 2 ML/ha/year will be used in the absence of any other available data.

An additional volume intercepted due to loss of recharge to groundwater has also been estimated, although this may be a duplication of the volume intercepted that is estimated using the Zhang et al. (2001) approach. In this study, it has been estimated to give an indication of the likely volume of groundwater intercepted independent of other losses such as reductions in catchment yield. The intercepted volume is independent of the depth to the watertable, but it is heavily dependent on local recharge conditions. Variability in recharge occurs due to various factors, including rainfall, soils, landform, vegetation and land use (SKM 2002). The rate used here is the recharge rate for the previous land use, which could have been dryland pasture or native vegetation. Groundwater recharge rates range from 0-100 mm per year for native vegetation in south-east Australia to 0–260 mm per year under post-clearing conditions (SKM 2002). Considering the variability in recharge across Australia, a conservative assumption of 2 mm per year has been applied nationally.

The limitation for this study is that there is no national depth to watertable map available to determine which areas are most at risk**.** There are also other methods which could be used if depth to watertable maps were available. Richard Benyon (pers. comm. 2008) has determined a relationship between evapotranspiration and groundwater extracted by plantations in south-eastern Australia. This relationship is based on net groundwater use equalling the difference between predicted annual evapotranspiration and annual rainfall. On average, net groundwater use was found to be equal to 0.86 times the potential evapotranspiration. An estimate of regions of shallow watertable was also required to determine which areas might use groundwater in those regions where the predicted annual evapotranspiration exceeded annual rainfall (and hence required additional water sources). This then would be more accurate than assuming 10 per cent of the plantation area is located in regions of shallow watertables.

Future assessments should also consider other sources of information including studies into groundwater dependent ecosystems (which includes native forests and other vegetation types), which would give a good indication of the groundwater regions most likely to be affected by plantations. There are several site-specific cases available, but there is nothing on a national scale that can currently be used for this assessment.

5.3 Results

5.3.1 Impacts on catchment yield

The current distribution of plantations in Australia is shown in Figure 14.

For each SWMA, mean annual water yield reduction was estimated using the method described above and is shown in Figure 15. Some key results are outlined below.

- The Lower Limestone Coast Prescribed Well Area in South Australia was predicted to have the largest water yield reduction of 131,000 megalitres per year by 2008; the Mary SWMA in Queensland ranked the second highest.

- The total water yield reduction from plantations was predicted to be just under 2 million megalitres per year in 2008 with a median of 3700 megalitres per year.

Estimates of present plantation area by 2008 and future plantation area by 2015 and 2030 for have been calculated and the projected changes are shown in Figures 16 and 17. Plantations were present in 156 SWMAs by 2008, with the Lower Limestone Coast Prescribed Well Area having the largest plantation area of 161,400 hectares. The total plantation area in Australia was estimated to be more than two million hectares in 2008, with a median of 4000 hectares per SWMA. The plantation area was predicted to increase to 2,303,900 hectares with a median of 5200 hectares by 2015. A further increase of 79,700 hectares was predicted by 2030 with a median of 5800 hectares:

- By 2015, Mary in Queensland was predicted to have the largest water yield reduction.
- The total water yield reduction for 2015 is projected to be 2,060,000 megalitres per year with a median of 4600 megalitres per year.
- By 2030, the total water yield reduction is project to be 2,062,000 megalitres per year with median of 4800 megalitres per year.

The smaller water yield reduction projected for 2015 and 2030 in some states (South Australia, Victoria and Western Australia) is due to projected decreases in mean annual rainfall. It should be noted that some of the SWMAs are groundwater dominated systems and generate little surface runoff (e.g. Millicent Coast in Victoria), and the method described in this report is not appropriate for estimating plantation impact in these areas.

A summary of current and projected plantation areas and estimated impacts is provided in Table 15.

Table 15: Summary of plantation areas and runoff reduction for each state and territory

	Plantation area (ha)			*Runoff reduction (ML/year)*		
State/ Territory	*2008*	*2015*	*2030*	*2008*	*2015*	*2030*
ACT	12,800	12,800	12,800	10,600	10,100	9,800
NSW	370,600	423,000	423,000	355,000	398,000	385,000
Northern Territory	18,100	38,900	67,100	5,000	14,100	21,800
Queensland	263,000	306,000	335,000	217,000	238,000	259,000
South Australia	196,800	203,000	203,000	148,000	133,000	127,000
Tasmania	302,000	344,000	363,000	438,000	467,000	493,000
Victoria	456,200	494,000	497,000	454,000	444,000	432,000
Western Australia	452,200	482,000	482,000	360,000	355,000	334,000

5.3.2 Impacts on groundwater

As previously discussed (see Appendix A), the total plantation area in Australia was estimated to be more than two million hectares in 2008 with a median of 4000 hectares per SWMA. The plantation area was predicted to increase to 2,303,900 hectares with a median of 5200 hectares by 2015. A further increase of 79,700 hectares was predicted by 2030, with a median of 5800 hectares. Applying an extraction rate of 2 ML/ha/year to 10 per cent of the plantation area results in the following impacts (Table 16).

Table 16: Indicative national impact of plantations on groundwater

Year	*Plantation area (ha)*	*Rate of extraction (ML/ha/yr)*	*Region assumed with shallow watertables*	*Lost recharge at rate of 2 mm/yr (ML/yr)*	*Total impact (ML/yr)*
2008	2,000,000	2	10%	40,000	440,000
2015	2,304,000	2	10%	46,100	507,000
2030	2,384,000	2	10%	47,700	524,000

Based on the broad indicative results above, plantation impacts on groundwater on a national scale may be in the same order as the impacts on catchment runoff. Obviously it is the catchment specific conditions that will determine the level of significance, as some catchments will be more susceptible to reductions in groundwater than others, and some catchments will have higher dependencies on groundwater. However, the magnitude of the impacts across Australia indicates that this is an important issue.

Figure 14: Areas including commercial plantations (2008)

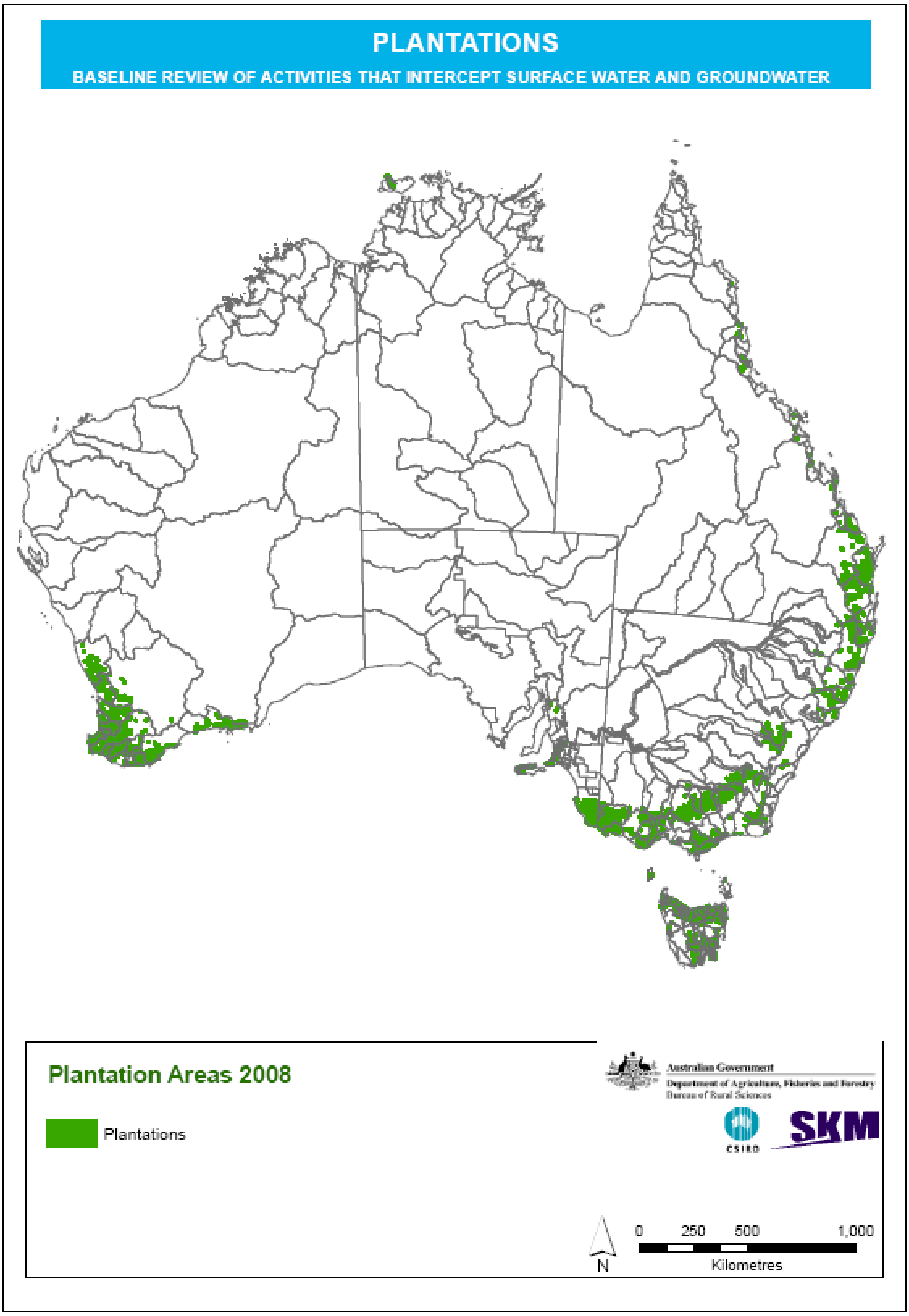

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Figure 15: Distribution of SWMAs where plantations potentially impact on hydrology—percentage runoff reduction against mean annual flow

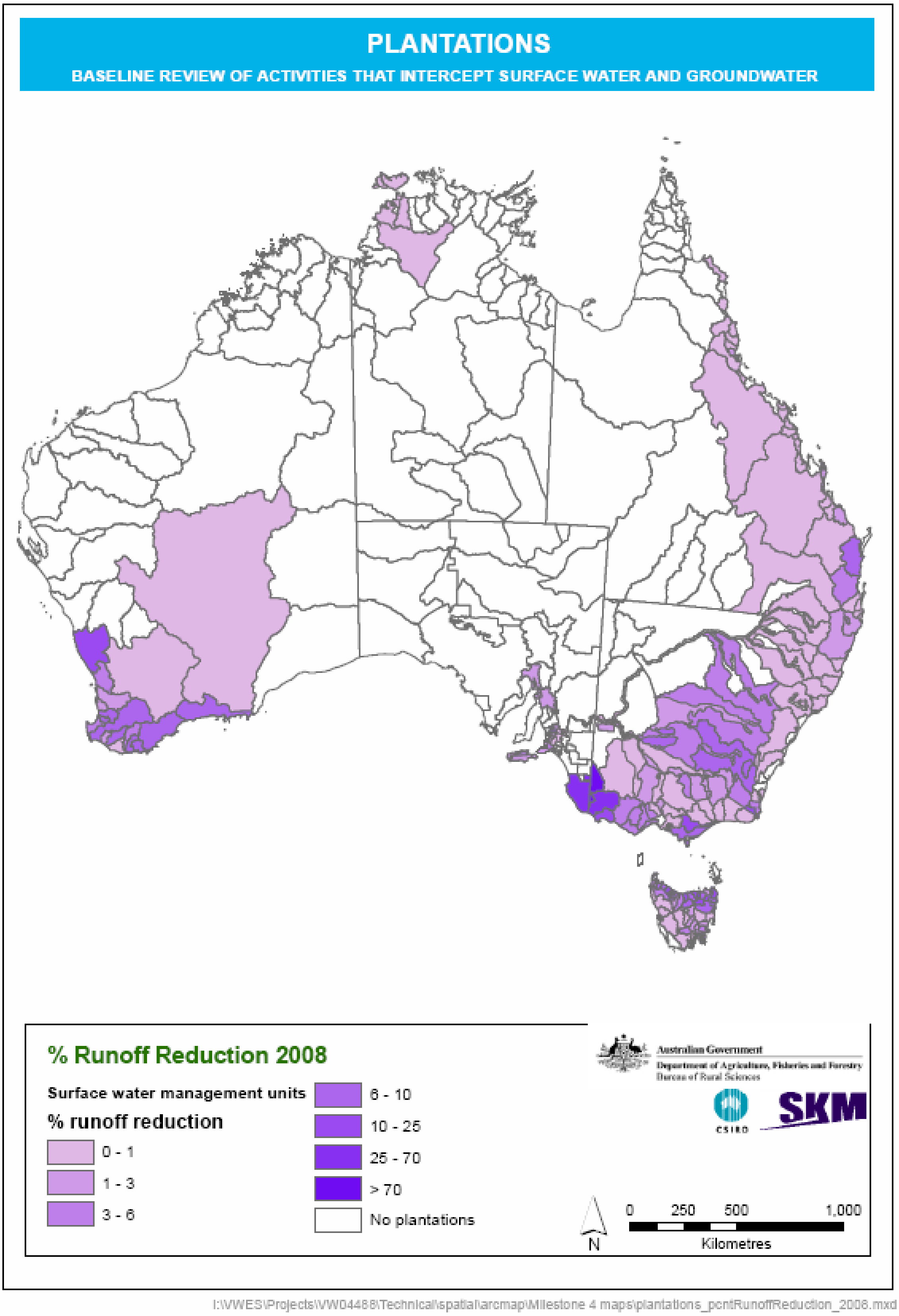


Figure 16: Distribution of SWMAs where plantations potentially impact on hydrology—projected increase in the impact of plantations, 2008–2015

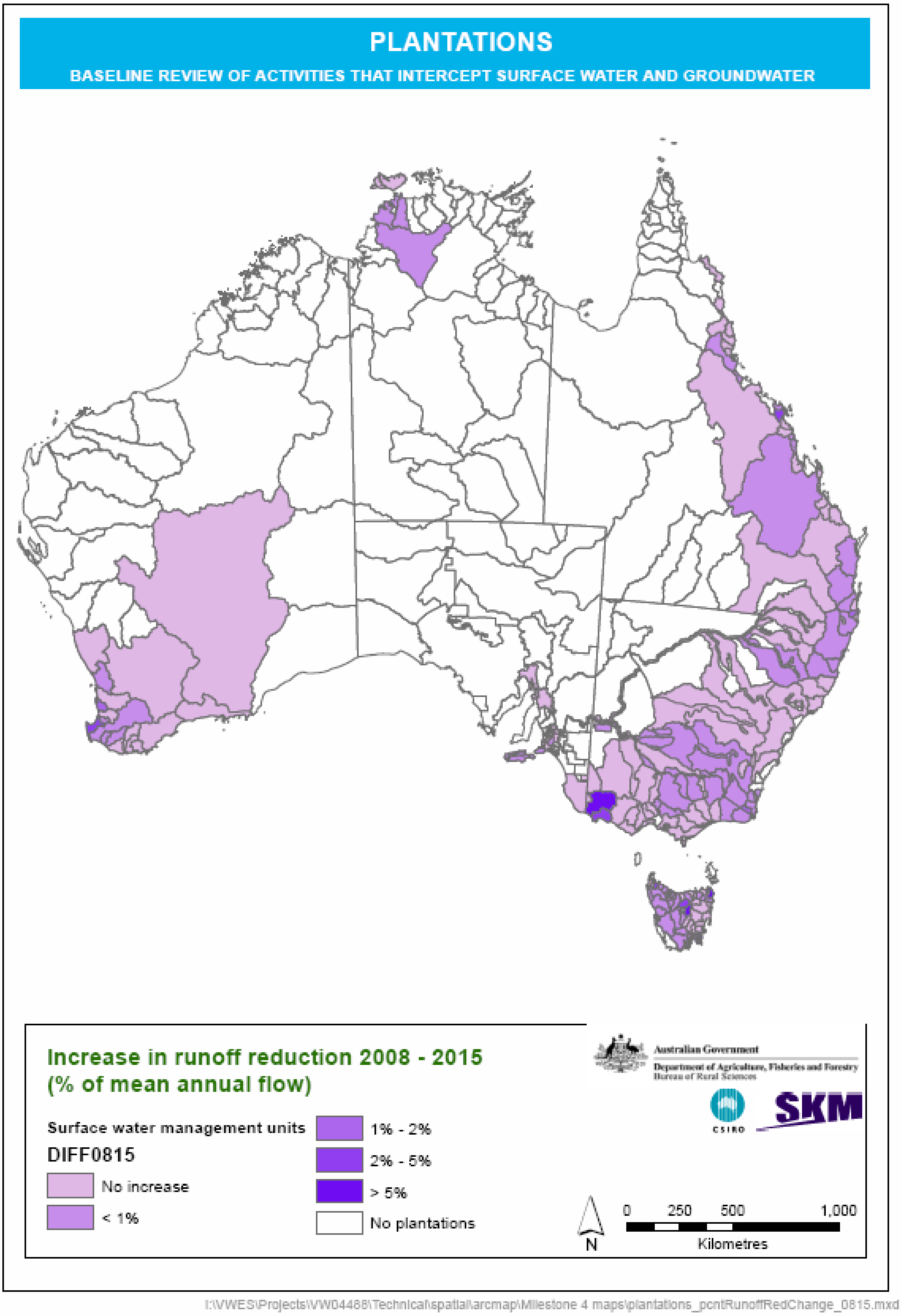
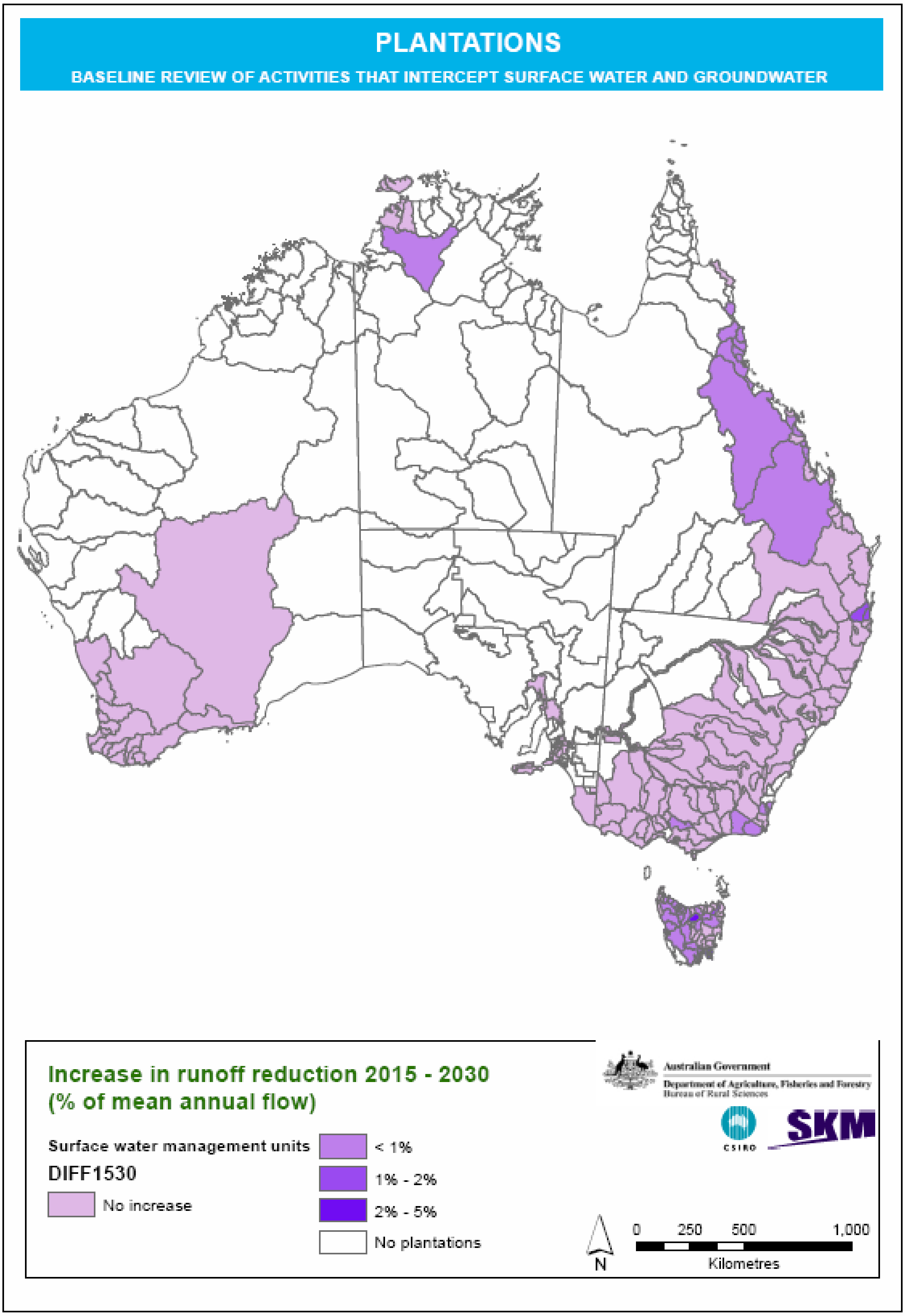


Figure 17: Distribution of SWMAs where plantations potentially impact on hydrology—projected increase in the impact of plantations 2015–2030



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5.4 Discussion

All jurisdictions include regions of plantations. The statistical distribution of the water yield reduction ratio for the majority of SWMAs, defined as the water yield reduction divided by runoff estimates (Appendix D), varies from 1 per cent to 27 per cent and increases linearly with the percentage of plantation cover.

The effect of plantations on water yield appears to be overestimated for Millicent Coast (Victoria), Glenelg River (South Australia and Victoria) and Lower Limestone Coast Prescribed Well Area (South Australia) due to low rainfall and minimal predicted surface runoff. Plantations in these areas have the potential to significantly affect groundwater as discussed in Section 5.1.4. The Cam and Little Forester SWMA in Tasmania also have relatively high impacts (41 per cent and 24 per cent respectively).

The method used in this project for estimating the impact of afforestation on water yield was developed by Zhang et al. (2001) and the same method was used in the Murray–Darling Basin Sustainable Yields project (Chiew et al. 2008). However, this project differs from the Murray–Darling Basin Sustainable Yields project in two aspects: (1) it estimated the impact of both existing plantation (i.e. 2008 plantation coverage) and future plantation expansion (e.g. 2015 plantation scenario) on water yield, while the Murray–Darling Basin Sustainable Yields project considered only the impact of future plantation expansions; (2) it uses updated plantation expansion projections as more information became available since the completion of the Murray–Darling Basin Sustainable Yields project. For catchments in the Murray-Darling Basin, this means that the estimated water yield reduction from the two projects could be different, and the results need to be interpreted in the context of plantation scenarios and climate data used.

5.5 Findings

- Plantations have currently been mapped in 156 SWMAs; the Lower Limestone Coast Prescribed Well Area has the largest plantation area of 161,400 hectares.
- The total plantation area in Australia was estimated to be more than two million hectares in 2008, with a median area of 4000 hectares per SWMA.
- The plantation area was predicted to increase to 2,300,000 hectares, with a median of 5200 hectares, by 2015. A further increase of 79,700 hectares was predicted by 2030, with a median of 5800 hectares.
- The estimated evapotranspiration from existing plantations across all the SWMAs is 2000 gigalitres per year greater than if there were no plantations. Thus it can be considered that in one sense these plantations are intercepting 2000 gigalitres per year. There is also considerable variation in evapotranspiration from plantations across the SWMAs. The most highly impacted SWMAs include Moore-Hill Rivers (Western Australia), Millicent Coast, Glenelg and Latrobe River (Victoria), Lower Limestone Coast (South Australia) and Mary (Queensland).
- The total water yield reduction for 2015 is projected to be 2060 gigalitres per year, with a median of 4600 megalitres per year. By 2015, Mary SWMA in Queensland was predicted to have the largest water yield reduction and the highest increase is estimated to occur in Glenelg SWMA (Victoria).
- By 2030, the total water yield reduction is project to be 2062 gigalitres per year, with median of 4800 megalitres per year. The highest increases in impacts are estimated to occur in Mary SWMA (Queensland) and Meander SWMA (Tasmania).

- Initial estimates indicate that some plantations use groundwater in regions with shallow watertables and they could affect groundwater potentially in the same order as their impacts on surface runoff (approximately 1000 gigalitres per year or more). When compared to current licensed allocations for groundwater, the additional volume lost from groundwater due to plantations could be up to 25 per cent of what is currently licensed.

6 Peri-urban development

6.1 Introduction

6.1.1 Definition

Whilst there is no strict definition, the term ‘peri-urban’ generally refers to the transition zone between urban and rural areas (Buxton et al. 2006). Defining the physical bounds of this transition zone is difficult and so peri-urban regions are also defined by their structure or functional processes (Buxton et al. 2008). Structural features might include the proximity to metropolitan areas, population distribution and growth, lot and dwelling density and types of land uses. Functional processes include commuting time and production and consumption trends (Buxton et al. 2008). Regardless of how peri-urban areas are defined, the common trends identified include their low population density, high rates of change and the heterogeneous nature of land uses (Rigby 2007).

6.1.2 Government policy

Currently there is no national policy governing peri-urban expansion. Instead options for controlling the growth of peri-urban areas is the establishment of an urban growth boundary or green belt. An urban growth boundary defines the limit to urban growth whilst a green belt is an area of land not classed as urban or rural that extends around the periphery of an urban area (Buxton et. al. 2006). An undesirable effect of this type of regulation is the increase in urban land price that often occurs. In regards to water resources, there are no specific policies protecting water resources in peri-urban areas. They are instead managed through the state or regional policies described in previous sections of this report. These arrangements, however, will not necessarily address issues related to the high demand placed on water resources from peri-urban areas into the future. It is suggested that there is ultimately a lack of integrated policy development in peri-urban areas in relation to land management, natural resources and human activity, and a key issue is that land use planning and natural resource management (including water resources) are governed by separate legislation (Buxton et al. 2008).

6.1.3 Previous studies

Several previous studies have focused on peri-urban trends and impacts on particular regions around Australia. Buxton et al. (2008) undertook a study of trends in six peri-urban local government areas (Surf Coast; Moorabool; Macedon Ranges; Mitchell; Murrindindi; and Bass Coast) in Victoria. In regards to water resources within these areas, it was found that water demand is met either by the construction of stock and domestic farm dams or groundwater bores or through the expansion of the existing urban water supply system. In regards to farm dams, it was found that for catchments covering the study area, farm dams use approximately 5 per cent of the total water use in those catchments (based on *State Water Report 2005–06* figures). This figure is based on total farm dam capacity rather than use, so it is reasonable to assume that this number underestimates the actual impact of farm dams on water resources if they fill more than once a year. For individual catchments within the study area, it was found that farm dam water use varied between 2 per cent and up to a maximum of 47 per cent of total water use. Overall, farm dams were found to be a significant user of water in the study catchments, and indeed the impact on water resources will only be exacerbated as peri-urban areas expand.

In regards to groundwater use, it was found that stock and domestic bores account for 19 per cent of total groundwater use. Comparatively, it was found that irrigation is not a major water user in these peri-urban areas (Buxton et al. 2008).

Another key study into the peri-urban phenomenon in Australia was conducted from 2006 to 2008 by researchers from Griffith University's Urban Research Program, Griffith School of Environment and RMIT University's School of Global Studies, Social Science and Planning with funding by Land and Water Australia and the Commonwealth Department of Environment and Heritage. This study included a review of Australian and international research related to the peri-urban phenomenon and case studies of two Australian peri-urban regions (the extended Brisbane-Ipswich corridor to the west of Brisbane and the Bendigo corridor north-west of Melbourne). For both case studies, it was found that significant quantities of surface water are captured in farm dams, which affects natural hydrological systems and with increasing peri-urban development these issues will intensify (Buxton et al. 2007; Low Choy et al. 2007; Low Choy et al. 2008). There was also significant groundwater usage from stock and domestic bores within these areas. A further trend within the case study areas was the fragmentation of the landscape (i.e. splitting up of farms into smaller lots (Low Choy et. al. 2008)). This fragmentation leads to increased populations within the area and therefore an increased demand on water resources. Low Choy et. al. (2008) found that existing statutory planning attempts to prevent fragmentation of land is not enough to address this issue.

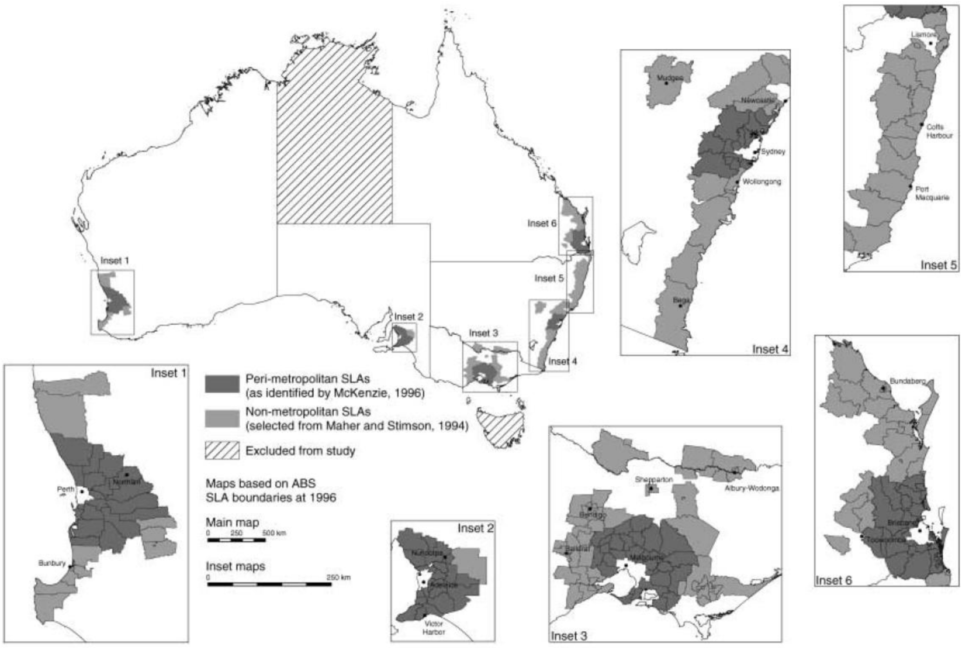
6.2 Methodology

6.2.1 Identification of SWMAs with peri-urban influence

Houston (2005) identified statistical local areas (from within the five mainland states) that are subject to peri-urban influence, based on findings from past studies (Figure 18). Despite the fact that the studies are based on old data, Houston (2005) suggests that the identified statistical local areas remain a reasonable representation of the likely peri-urban extent on mainland Australia. The surface water management areas that the identified statistical local areas lie within were therefore identified as having peri-urban influence.

Peri-urban influence in Tasmania was not assessed in the above study. Instead, population growth statistics (ABS 2009) for statistical local areas in Tasmania were reviewed, and those with a population change of greater than 1 per cent from 2007 to 2008 were selected as having peri-urban influence, which fits suggestions that peri-urban areas have a rapid population growth (Buxton et al. 2006). Unsurprisingly the selected statistical local areas were adjacent to large population centres (i.e. Launceston, Hobart) or along the coast. Using the statistical local areas as a guide, the SWMAs in Tasmania with peri-urban influence were identified. SWMAs with peri-urban influence were not identified in the Northern Territory because there were no data on stock and domestic bores and farm dams, and because farm dam impact was assumed to be negligible.

Figure 18: SLAs identified to have peri-urban influence



Source: Houston (2005)

6.2.2 Summary of tasks undertaken

Following identification of SWMAs subject to peri-urban influence, the following steps were undertaken. Note that only baseline peri-urban impact was determined for the reasons provided in Section 6.4.

- For the SWMAs identified, it was assumed that areas classed as 'rural residential' (based on land use classes in the land use datasets used and developed as part of this project, Appendix B) represented the peri-urban areas. Only the rural residential area within the SWMA covered by statistical local areas with peri-urban influence was included in the analysis (i.e. the whole rural residential area within the relevant SWMAs was not necessarily included). Only rural residential land use was assumed to represent peri-urban area, despite suggestion that peri-urban areas comprise a mix of land uses including rural residential, urban, commercial and agricultural (Buxton et al. 2006). Quantification, however, of the proportion of urban and agricultural areas (as an example) that are considered to be within the peri-urban region is difficult and furthermore would be likely to change for each SWMA. There can be reasonable confidence in the assumption that all rural residential areas are within the peri-urban region.
- Baseline farm dam volume densities within the relevant SWMAs for 'rural residential' areas were extracted. These densities were assumed to remain unchanged in the future (consistent with method used to project farm dam volumes).
- The farm dam volume densities were multiplied by the corresponding rural residential areas to determine the baseline farm dam volume for each relevant SWMA.
- Baseline farm dam impact was determined using the relationship (see Section 3):

  Farm Dam Impact = 1.1 x Farm Dam Volume

- Baseline bore numbers for rural residential areas within the relevant SWMAs were extracted. The proportion of 'peri-urban' rural residential area to total residential area was determined and applied to the bore numbers to estimate the number of bores within the peri-urban area of each SWMA.
- Baseline bore water usage was determined assuming 2 megalitres usage per bore per year (consistent with the methods used in Section 4). So combined farm dam and stock and domestic bore impact could be determined, bore usage was assumed to equal bore impact.
- The combined impact was determined by summing the farm dam impacts and bore usage reported in Sections 3 and 4 for the relevant regions.

6.3 Results

The baseline peri-urban impact in Australia is shown in Figure 19.

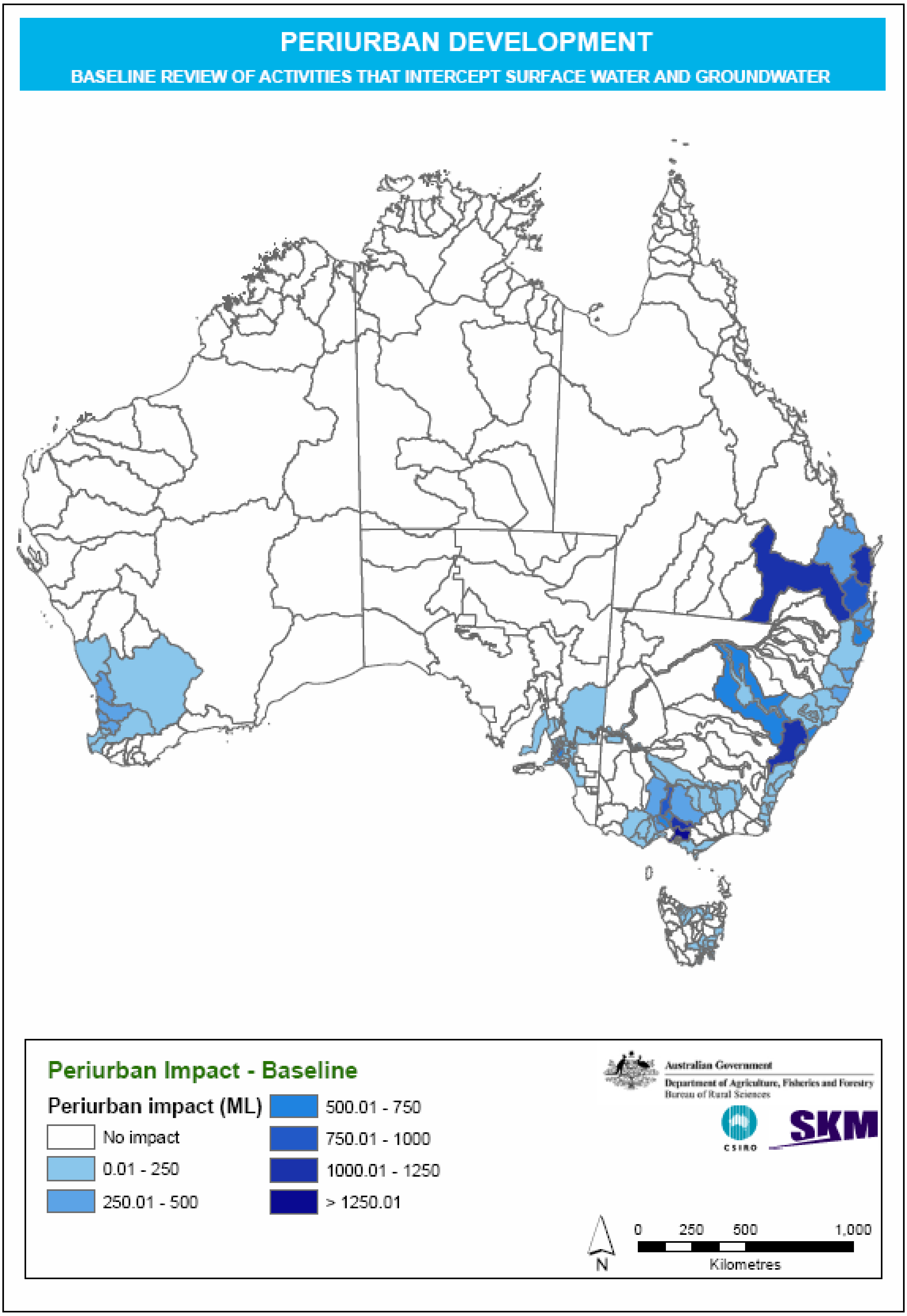
Table 17 summarises results for each state. It should be noted that peri-urban impact for Tasmania was estimated from farm dam impact only as information on stock and domestic bores was not available. No data are presented for the ACT or the Northern Territory, as peri-urban areas were not identified in these territories.

Table 17: Baseline peri-urban impact for each state

State	*Total peri-urban area (km^2)*	*Total baseline peri-urban impact (ML)*	*Total baseline peri-urban impact density (ML/km^2)*	*Total baseline farm dam impact and groundwater bore usage (ML)***	*Proportion of baseline impacts in peri-urban areas (%)*
NSW	2290	6000	2.6	415,000	1.4
Queensland	2560	4500	1.8	194,000	0.9
South Australia	417	3910	9.4	491,000	2.0
Victoria	1710	6360	3.7	459,000	1.4
Tasmania*	221	392	1.8	34,100	1.1
Western Australia	676	1640	2.4	431,000	0.4

*Farm dam impact only
**Groundwater bore usage was assumed to equal bore impact

Figure 19: Baseline peri-urban impact in Australia



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6.4 Discussion

Figure 19 shows those SWMAs with a peri-urban influence and the combined impacts of stock and domestic farm dams and bores in these areas. Whilst the whole SWMA is highlighted, it does not mean that the entire area of that SWMA is peri-urban. In fact only a small proportion is likely to be peri-urban. For this reason, peri-urban impact densities were not mapped.

The results suggest that South Australia has a very high peri-urban impact density relative to the other states. In fact, the Onkaparinga SWMA in this state has the highest peri-urban impact density of all of Australia with 22 ML/km^2.

Table 17 presents the proportion of farm dam and groundwater bore impacts in peri-urban areas compared with impacts for all land use areas for each state. South Australia exhibits the highest percentage of farm dam and groundwater bore impacts in peri-urban areas. These results, however, are likely to underestimate the actual peri-urban impact in each state for reasons discussed below.

Limitations of the methodology

The assumption that the rural residential land use in the land use datasets used and developed as part of this project (Appendix B) represents the total peri-urban area in each SWMA limits the accuracy of this study. Although there is confidence that rural residential areas are within peri-urban areas, rural residential areas do not represent the total peri-urban area, and it can be assumed that the results presented underestimate the actual peri-urban impact in each SWMA. As an example, for the land use data assessed, it was found that the ACT did not have any rural residential area and hence peri-urban impacts were not estimated in this area.

The use of only rural residential area presented another issue when attempting to estimate the projected 2015 and 2030 peri-urban impacts, as population increases were projected in urban centres and localities only. The land use projections for 2015 and 2030 merged the rural residential and urban classes and hence there was no way to determine the projected rural residential areas. As a result, projections of peri-urban impact were not estimated.

6.5 Findings

- South Australia was found to have a high baseline peri-urban impact density. It was found that approximately 2 per cent of the baseline (2008) farm dam impacts and groundwater bore usage occur within peri-urban areas in South Australia (see Table 17).
- Victoria and NSW were also assessed to have relatively high peri-urban impact densities, with 1.4 per cent of baseline (2008) farm dam impacts and groundwater bore usage occurring in peri-urban areas.
- Areas in Queensland have high peri-urban impact. However this impact is not as great as in other states when reviewed as a percentage of total baseline farm dam and groundwater bore impacts.
- The Onkaparinga SWMA in South Australia was found to have a peri-urban impact density of 22 ML/km^2. Other highly impacted SWMAs include Yarra and Bunyip SWMAs in Victoria, Hawkesbury River SWMA in NSW, and Mary SWMA in Queensland.

7 Integration

7.1 Introduction

This section combines the results from the individual intercepting land uses to examine the scale and patterns of water resource interception across Australia. A key question of this section is whether intercepting land uses potentially impact on the water balance of a SWMA. The NWI clauses on interception recognise several factors that need to be considered in determining whether interception is significant. The water balance is one of those factors, and it is the only factor considered here. Other factors are economic and environmental costs and benefits, which are beyond the scope of this report.

The question is first approached by summarising the results as a mean annual volumetric impact of each intercepting activity in each SWMA and examining patterns across Australia against the sustainable yield and water balance terms. An important consideration is that there are spatial and temporal patterns to hydrological impacts within a SWMA so that not all water users are impacted equally. Small overall impacts on volumes can have greater impacts on some uses of water, or some elements of the hydrological regime, or some subcatchments. There may be alternative metrics to total volume intercepted that should be considered as thresholds beyond which a response is required.

Lastly the confidence of future projections of intercepting activities is analysed. This shows that there is considerable uncertainty in future volumes of water intercepted. There are several possible responses to this uncertainty, including monitoring future land use developments, reducing uncertainty through better analysis, and precautionary policy responses.

7.2 Baseline results

The baseline results show the current distribution and magnitude of intercepting activities. They are useful for examining if these activities have an impact on water resources and how those impacts are expressed.

Appendix E shows, for each SWMA, the volumetric impact of the four intercepting activities that have been quantified. The four activities are:

- farm dams
- plantations
- floodplain harvesting
- stock and domestic bores.

Peri-urban impacts have not been included in this assessment as these impacts were obtained by combining the results for farm dams and stock and domestic bores and by including them again would effectively be double counting. For farm dams, plantations and floodplain harvesting, quantitative estimates were made for all SWMAs or for those SWMAs where the intercepting activity was found to occur. For stock and domestic bores, no data were available for the ACT, Tasmania, or for Western Australia beyond the three SWMAs surrounding Perth. The assessment for stock and domestic bores covers 227 of the 328 SWMAs.

Some summary statistics from across Australia are given in Table 18. Clearly all four intercepting activities are potentially impacting on hydrology at a national scale. Farm dams and stock and domestic bores occur in a majority of SWMAs, and plantations are found in just under half of the SWMAs. All four activities intercept very large volumes of water, from more than the estimated 1,000 gigalitres per year for stock and domestic bores (considering the partial coverage) to almost 2000 gigalitres per year for plantations.

Table 18: Summary of current baseline intercepting activities across SWMAs

Intercepting activity	*No. of SWMAs with activity*	*Total volume intercepted (GL/year)*	*No. of SWMAs potentially impacted by interception*
Farm dams	202	1,620	130
Plantations	153	1,990	120
Floodplain harvesting	12	887	9
Stock and domestic bores	217	1,086	62

NOTE: There were a total of 227 SWMAs with stock and domestic bore data.

It is beyond the scope of this project to do a full assessment of hydrological impacts of intercepting activities. Section 7.4 outlines the requirements for such an assessment. Nevertheless, the volumes of interception within each SWMA must be put in context of the broader water resources. An attempt was made to classify whether the mapped intercepting activities had the potential to impact on the hydrology of each SWMA. There are no objective criteria for defining indices of hydrological impact: there will always be an arbitrary element to the threshold. For this report, farm dams, plantations and floodplain harvesting were considered to have the potential to impact on hydrology if they met one or more of the following criteria:

1) the activity intercepted more than 1 gigalitre per year
2) the activity intercepted more than 5 per cent of the sustainable yield
3) the activity intercepted more than 2 per cent of the total runoff.

The aim was to identify SWMAs with little hydrological impact of interception and identify the SWMAs where more detailed investigation might be warranted to identify the precise impacts of interception on hydrology and on uses of water.

The first criterion was set at an order of magnitude of water that can be economically or environmentally valuable at the scale of a SWMA. Substantial funds have been invested to buy, use, save, or generate a gigalitre or more of water. Interception of similar volumes can undermine those investments. It can be argued that in a large SWMA, a gigalitre is an insignificantly small percentage of the overall water resource, but as is outlined below, large SWMAs are quite diverse, and intercepting activities tend to be concentrated in particular subcatchments or impact on particular uses of water to a far greater extent than is apparent from comparison to the total water resource. Therefore 1 gigalitre per year was set as a volume where further local investigation should be made to examine if there are uses that are affected (see Section 7.4 below).

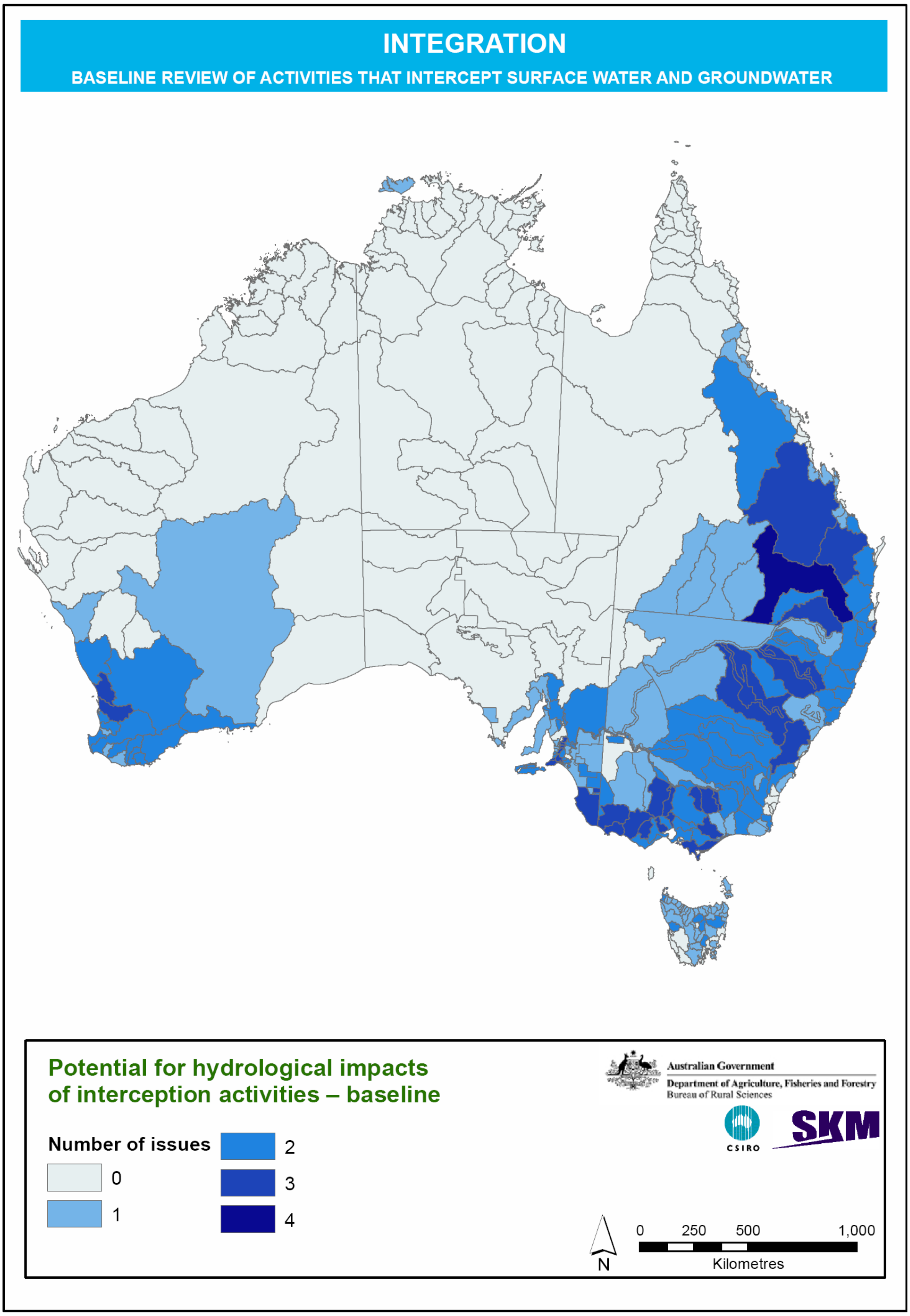
The second and third criteria are measures of the relative hydrological impact of interception. Intercepting activities are essentially an unlicensed use of water. Comparing them to the sustainable limit of water use is thus a good measure of their relative size. Sustainable yields obtained from the AWR2005 are listed in Appendix E. Sustainable yield has not been assessed for many SWMAs, so the third criterion, of hydrological impact compared to total runoff, is used for those cases. Total SWMA runoff was produced by the Water2010 landscape water balance model used for this project. The lower percentage for criterion three recognises that sustainable use is typically less than half of the total water availability, and the fact that landscape water balance models typically overestimate runoff (see Appendix E). Given the tendency to overestimate runoff, there could be more SWMAs where a substantial proportion of runoff is intercepted. The impact of stock and domestic bores was assessed by comparison to total recharge in the SWMA, using the same logic and value of 2 per cent that is used for surface runoff.

The full set of results for intercepted volume as a percentage of sustainable yield, runoff and recharge are given in Appendix E. The numbers of SWMAs where interception potentially impacts on hydrology or water use are summarised in Table 18, using the criteria above. There were 189 SWMAs with one or more activity that intercepted substantial volumes of water. Farm dams and plantations intercepted substantial volumes in more than one third of SWMAs. Stock and domestic bore use was substantial in almost one third of the SWMAs assessed. While floodplain harvesting was less frequent, where it did occur it consumes 10–30 per cent of sustainable yield. There were 72 SWMAs that had two activities that intercepted a substantial volume of water, and 29 with three or more. The most frequent combinations were farm dams and plantations (43), or those two activities combined with stock and domestic bores (26), or farm dams and stock and domestic bores (19). It is doubtful that other intercepting activities would have the same impact as farm dams, plantations and stock and domestic bores, nor would they use as large a volume per SWMA as floodplain harvesting.

The detailed results by SWMA given in Appendix E require some additional interpretation. There are cases where the interception by farm dams is greater than the sustainable yield. These occur where sustainable yield is a very low percentage of runoff. The most frequent situation is in dry catchments, where sustainable yield is low because of significant losses of water and disconnections throughout the catchment, so that the sustainable yield of the main river may be much less than the total amount of runoff in the catchment. In these catchments, runoff tends to be localised and farm dams are the most common way of storing and using the local runoff. The most extreme example is the Avon River in Western Australia, which is a very large but dry river basin. It has a very large number of farm dams but quite low sustainable yield because the vast majority of intermittent runoff from the arid east of the catchment does not contribute to river flow. This only reinforces the need to consider interception from farm dams when examining the water resources of the region. Other cases of low sustainable yield are in wetter regions, such as the Castlereagh River in NSW where the low yield relative to runoff is not explained. There are two cases where stock and domestic bore extractions are greater than the estimated recharge. These are at Patawalonga and Lower Torrens in South Australia, where there are a very large number of bores over a relatively small area. It is possible that the aquifers, and the recharge to them, cover a greater area than the SWMA, and thus recharge is underestimated.

Figure 20 shows the distribution of SWMAs where interception potentially impacts upon the water resources in that one or more activities intercept enough water to exceed the hydrological impact criteria outlined above. Not surprisingly those SWMAs with more than one intercepting activity with potential impact tend to be in the wetter areas with relatively high regional population density and more intensive agricultural land use. The drier areas with very extensive SWMAs tend just to have stock and domestic bores or farm dams as intercepting land uses. There is little hydrological impact from interception at present across northern Australia, although information is limited in those areas. Some SWMAs cover a large area and diverse environments. They can have a small area of relatively high rainfall, high population density and substantial volumes of interception but have a much larger area of low rainfall, low land use intensity and hence low levels of interception. These areas also generate only a small fraction of the water resource. Thus not all of the SWMA has intercepting activities, and not all water resources in the SWMA are necessarily impacted.

Figure 20: Distribution of SWMAs where interception activities potentially impact on hydrology for the baseline assessments



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Note: issues considered are overland flows, farm dams, plantations and stock and domestic bores.

The NWI notes that interception activities are of greatest importance when water resources are fully developed and use is close to the sustainable yield. It was hoped to highlight those SWMAs with substantial volumes intercepted and a high level of diversions. There is, however, currently no agreed definition of overallocation or full development of water resources. The only available data are from AWR2005, where only 18 SWMAs were rated as highly developed relative to sustainable yield (Appendix E, Table 33), 16 of which have substantial volumes of interception. The number of SWMAs that are highly developed and under environmental stress is likely to be much higher.

One of the areas that the NWI focuses on is how to manage future changes to land use to ensure the security of water resources, but it does not cover the consequences of current intercepting activities that are shown in Appendix C. The reduction in surface water resource availability from some of the current intercepting activities will be implicitly included in water plans through the assessment of water availability. The hydrological consequences of activities that have been present for decades will be reflected in the stream gauging data during that period, and it is this stream gauging data that are used to assess water availability. For example, the extent of runoff reduction as a consequence of afforestation by plantations that have existed for several decades will have been recorded by stream gauges. These data are then either analysed directly to determine water availability or used to calibrate rainfall–runoff models or river models as a part of water planning.

The impact of some of the current intercepting activities will not be incorporated in the assessment of water availability. Intercepting activities that have been introduced since the most recent data used to assess surface water availability are not included. Several models used for water plans in the Murray–Darling Basin for example were calibrated up to 1990 only, while others are calibrated to 2004, so in some cases intercepting activities that have occurred since 1990 are not included in the assessment of water availability. Some activities that had occurred towards the end of the calibration period are unlikely be fully accounted for. If the activity commenced after the start date used in either model calibration or the assessment of water availability its impact will not be fully included. For the Murray–Darling Basin, some models are calibrated from 1970, so interception activities which have developed since then are not fully incorporated into the assessment of water availability. They will have reduced flows for only part of the assessment or calibration period. Furthermore, for the impact of stock and domestic bores on surface water resources (through surface water and groundwater interactions), there are often lags of a decade or more between extraction and the resultant reduction in surface water yield. The Murray–Darling Basin Sustainable Yields project found, for example, that future consequences on surface water of current groundwater extraction totalled about 98 gigalitres per year.

7.3 Results of future interception

The projections of future growth of intercepting activities and their hydrological impacts help to form an appropriate policy response. The projections examine whether there is potential, if left unmanaged, for intercepting activities to reduce water availability, to erode the security of water entitlements, or to reduce the sustainability of water use.

Table 34 (Appendix E) lists the projected volumetric impact of possible growth to 2030 in farm dams, plantations, and stock and domestic bores for each SWMA. There are no quantitative projections for harvesting overland flow because there is no firm basis upon which to project growth in that intercepting activity. Most SWMAs that currently have floodplain harvesting have little potential for future expansion because of restrictions on the activity and little prospect of additional extractions being allowed. In other SWMAs there may be interest in developing floodplain harvesting, but that interest is too vague to be able to quantify.

The results shown in Table 34 (Appendix E) were generated by similar methods to those applied to the baseline summary of current intercepting activities, with a few important differences. First, the results for future volumetric impact show only the growth in volume intercepted, not the total impact of the activity. That is, the volumetric impact of current interception is subtracted from the projected 2030 impact to give results of the impact of future development only. Comparisons of volume intercepted to sustainable yield use the current estimate of sustainable yield, while comparisons to the volume of runoff or recharge use the projected 2030 runoff and recharge. In nearly all cases, future runoff and recharge are less than current runoff and recharge so the percentage of runoff or recharge that is intercepted is higher than if it had been compared to the baseline. However, the relative changes in runoff and recharge are small compared to the range of projections for growth in intercepting activities, so the choice of which period to compare against makes little material difference to the potential hydrological impacts of future interception. For plantations, the future runoff was used to project future impacts of plantations, so if there is no growth in plantation area, the volume of water intercepted is projected to decrease by a small percentage.

Projections were made for 2015 and 2030, but only the results for 2030 are shown for several reasons. Many of the projections, including those of climate change, are linear extrapolations to 2030 or beyond, so the 2015 results are just one third of the change expected between 2008 and 2030. The projections are highly uncertain, as explained below, and 2015 is such a short projection forward in time that many of the changes are within the error of uncertainty of what might happen, or are within natural interannual variability. Lastly, given that it is the potential for change in interception that is of interest, choosing too short a time period can give a false picture of a low potential for change if the changes are expected to continue at similar rates after the assessment period. Hence, the assessment of the sustainability of water resources should be based on a longer period than the next six years.

Some summary statistics from across Australia are given in Table 19. Each intercepting activity has potential to have a substantial impact on hydrology in the future. Growth of each intercepting activity is expected in over half of the SWMAs, and for stock and domestic bores it affects almost all SWMAs assessed. The projected additional volume of water intercepted ranges from 70 gigalitres per year for plantations to approximately 300 gigalitres per year for farm dams. These are large volumes of water, especially when it is considered that not all of the existing interception is incorporated into current water plans and into estimates of water availability and sustainable yield.

Table 19: Summary of projected new intercepting activities to 2030 across SWMAs

Intercepting activity	*Number of SWMAs with activity*	*Total volume intercepted (GL/year)*	*No. of SWMAs potentially impacted by interception*
Farm dams	192	299	61
Plantations	178	75	48
Stock and domestic bores	204	107	42

NOTE: There were a total of 227 SWMAs with stock and domestic bore data.

It is projected that by 2030, 131 SWMAs will have substantial additional interception from one or more activities. This is just over one third of SWMAs in Australia. There are 17 SWMAs predicted to have two activities—mostly plantations and farm dams—which intercept substantially more water. Again, it is doubtful that any other intercepting activities would have the same extent of hydrological impact.

Figure 21shows the distribution of SWMAs where new interception potentially impacts on hydrology at 2030. As with current interception, there is widespread coverage of interception across the more intensively used regions, and again some of the interception in the larger

SWMAs will probably be focused toward the wetter, more intensely used parts of the SWMA not the whole area. In future, interception may become an issue in northern Australia and parts of arid Australia. All three intercepting land uses that were projected to 2030 could intercept substantial volumes of water in Queensland, Western Australia and NSW. In other states, one or two issues are predicted to dominate: in Tasmania and Northern Territory it is plantations; in South Australia it is mainly stock and domestic bores; and in Victoria it is farm dams and plantations.

The limitations of the baseline assessment also apply to the future assessment, particularly the accuracy of future total runoff or recharge. Most cases of substantial interception exceeded the 1 gigalitre per year impact or were less than 5 per cent of sustainable yield. Few exceeded the criterion of 2 per cent of runoff, although many were more than 2 per cent of recharge, so inaccuracies in runoff prediction have little impact on the interpretations.

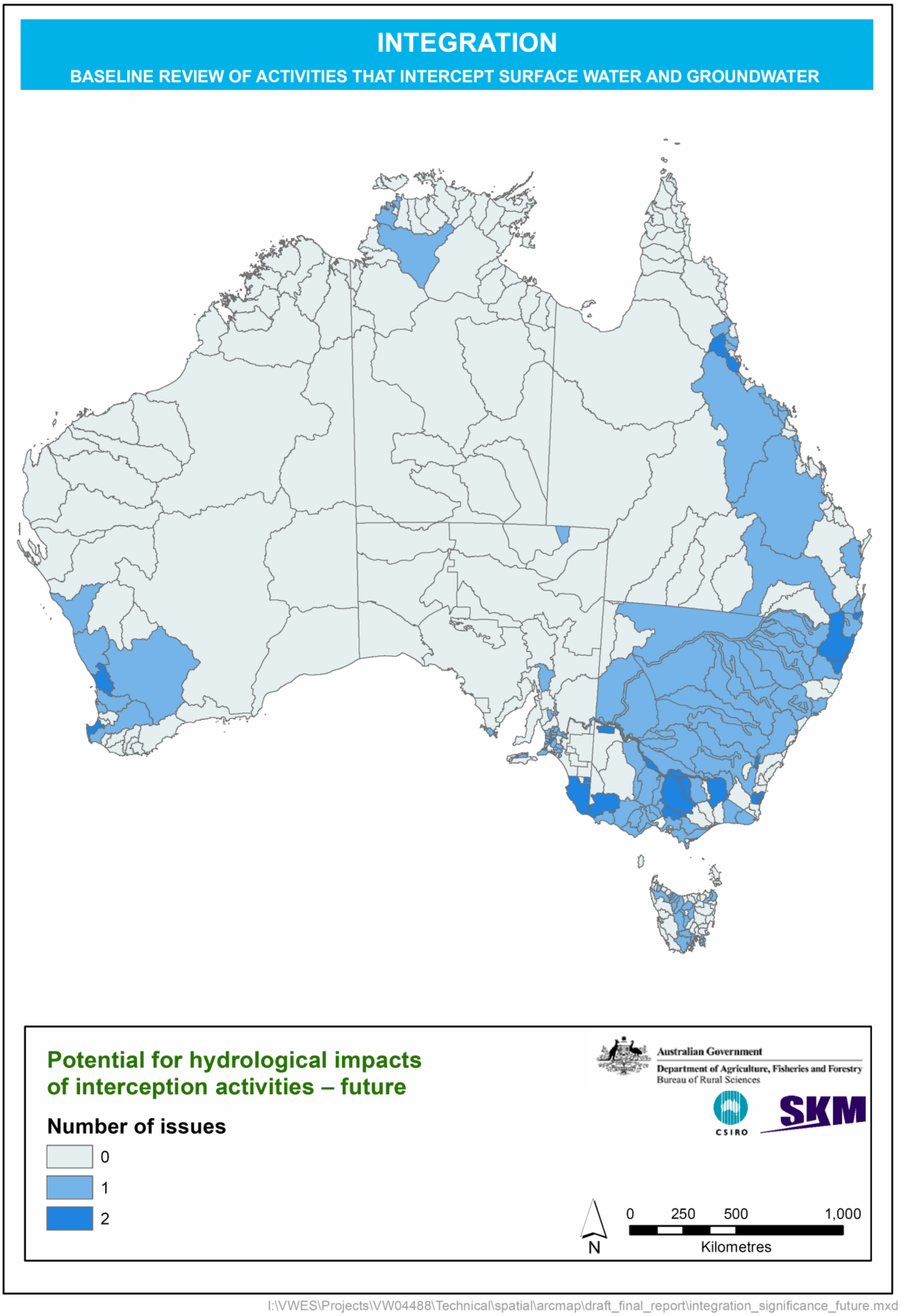
The most uncertain aspect of the projected future impacts is the projection of land use change, rather than the hydrological impact of that change. The projections for future impacts of farm dams and plantations were based directly on projected changes to land use, while those for stock and domestic bores relied upon extrapolation of past rates of growth in the number of bores. Land use changes were based upon extrapolation of short-term industry forecasts or on recent observed trends from census data. They are based mainly upon known current circumstances and are unable to incorporate future positive or negative shocks on agricultural industries. For example, future projections of land use do not include the impacts of droughts, water buybacks, new crop varieties, major changes in global markets, a carbon pollution reduction scheme or, for plantations, the recent collapses of managed investment schemes. Furthermore, the spatial allocation of the projected land use changes is based upon land suitability and population projections, but the precise location for future land use is uncertain and subject to other constraints such as planning and local economic conditions.

There are uncertainties in hydrological impacts, but overall these are low relative to the uncertainties in future land use change. The main hydrological uncertainty is over regional differences in hydrological impacts and the effects of local factors. At present, the hydrological impacts are based upon relationships developed for some environments, or simple global relationships that take just a couple of landscape factors into account. This is appropriate for a coarse risk assessment and overview scale, but for quantifying impacts and water use at the local SWMA scale, additional factors and local environmental conditions are likely to apply. For example, the extent of tropical plantations is increasing but most of our understanding of hydrological impacts of plantations comes from temperate environments. The temperate climate relationships may or may not apply to tropical plantations.

Given that predicting the future is inherently uncertain, a deterministic approach to the future is inherently limited. Risk frameworks, or examination of alternative futures scenarios provide broader or more probabilistic approaches where a wide range of scenarios can be considered and appropriate management responses can be set for each scenario within an overall framework, rather than relying upon a few deterministic futures.

The projections of future intercepting activities made here have not considered current or future policy responses. As such, the projections provide a baseline of what interception might occur without a policy response. Policy responses might be designed around those projections to reduce future impacts, but the assessment of the effectiveness of those measures on future interception should be a separate step to the original analysis of the scale of the problem. Of course, no change in management in areas where interception is not of concern is one possible response, as is continuation of existing measures where they have addressed the issue of intercepting activities. As well as uncertainty about the projections of future interception, there will be uncertainties over the effectiveness of the policy response. There is rarely full compliance to policy measures or no unintended consequences of policy. Thus there is a valuable role for monitoring the actual changes in future intercepting activities and periodic re-evaluation of water interception in light of the updated data. Even the assessments of current interception for farm dams, stock and domestic bores and floodplain harvesting were hampered by lack of data on the extent of existing activities, let alone their growth into the future. The patterns of intercepting activities and risks from interception assessed here can help determine priority regions for monitoring.

Figure 21: Distribution of SWMAs where interception activities potentially impact on hydrology at2030.



Note issues considered: farm dams, plantations and stock and domestic bores

Discussion

This reconnaissance study across Australia has focused upon simple measures of the hydrological impacts of intercepting activities. Past work though has shown that more comprehensive assessment methods are required in each SWMA to get an accurate picture of the impacts of intercepting activities. The work has shown that the impact on water users is more than the simple volumetric change to runoff in the catchment. The timing and spatial patterns of changes to water flow need to be considered to understand which particular users are most impacted. On a mean annual basis, the volumes of water intercepted by changes in land use are often small at a SWMA scale in comparison to the total available water resource. If interpretation of the results is based just on changes to mean annual water availability at a SWMA scale, there is a risk of falsely dismissing what could be a real problem for some users of water. This is because intercepting activities tend to be focused on particular subcatchments or have impacts on particular aspects of the flow regime. Local users in those subcatchments will be most impacted, while those who source their water from elsewhere will not be impacted.

Farm dams have the greatest concentration in urban fringe and other closely settled areas, while plantations are concentrated in high-rainfall areas, and they are relatively close to timber or paper mills. These activities will have the greatest impact on users of water in the local subcatchments affected. This might include run-of-river extractions from the local river or creek, where the intercepting activities will reduce flow and increase the amount of time where flow is too low for pumping to occur. Conversely, interception may have no measurable impact on the use of water in major irrigation developments, or urban centres. Typically irrigation districts and urban centres are supplied from large storages in the headwater catchments. If intercepting activities occur in unregulated subcatchments downstream of the storages, they will have almost no impact on allocations made from the storages. This is quite often the case as the catchments for many of the major storages are predominantly covered in native forest and have a low density of intercepting activities.

Similarly, not all temporal aspects of the flow regime are equally impacted by interception and some uses rely on the impacted aspects more than others. When considering the impact of flows into the main storage reservoirs then annual impacts are appropriate, as virtually all inflows are stored. For other uses, the precise nature of the impact needs to be considered. Plantations, farm dams and the surface water impacts of groundwater extraction have a high proportional impact on baseflow. Converting cleared catchments to plantations for example often converts perennial streams to ephemeral streams. This may have the consequence of much less frequent summer extraction by run-of-river pumpers, or have ecological impacts of increased frequency of flow falling below minimum ‘passing flow’ levels, or it may reduce the dilution of high salt concentrations. Plantations, farm dams and the surface water impacts of groundwater extraction have very little impact on higher flows. Thus in the Murray–Darling Basin, despite claims to the contrary, there is little capacity for these intercepting activities to undermine the provision of floodflows for The Living Murray Initiative. In contrast, floodplain harvesting has significant impact on high flows and their propagation downstream only, preventing those flows from watering environmental assets or other properties downstream. Floodplain harvesting has very little impact on baseflows. The main impact of stock and domestic bore use is on groundwater resources rather than surface water resources. As a result of their similarities, the impacts from farm dams and plantations are additive, whereas those from floodplain harvesting and stock and domestic bores are largely independent of that of the other intercepting activities.

It can be concluded that consumptive and environmental uses of water could be subjected to a greater or lesser impact from interception activities than would be expected from the average impact on total water availability. The only way to assess these differences in impact is through a full analysis of local hydrology and in highly regulated systems and through an analysis of the operating rules. This might be through a river model, rainfall-to-runoff model, or groundwater model. The CSIRO Sustainable Yields projects and the use of the Murray–Darling Basin results in the 2008 Murray–Darling Basin risks audit are examples of this type of analysis.

7.4 Findings

- Plantations, farm dams, floodplain harvesting and stock and domestic bores all intercept substantial quantities of water. They affect the majority of SWMAs across Australia and intercept hundreds to thousands of gigalitres of water per year on average.
- The timing and spatial patterns of changes to water flow need to be considered as well as total volume in order to understand which uses are most impacted. On a mean annual basis, the volumes of water intercepted by changes in land use are often small at a SWMA scale compared to the total available water resource.
- The temporal aspects of the flow regime are not equally impacted by interception and some uses will rely on the impacted aspects of the flow regime more than others. Plantations, farm dams and the surface water impacts of groundwater extraction have a proportionally high impact on baseflow. These three intercepting land uses have very little impact on high flows, but they can have significant impacts on low flows; whereas floodplain harvesting significantly impacts the high flows.
- The main impact of stock and domestic bore use is on groundwater resources rather than surface water resources. As a result, the impacts from farm dams and plantations are additive, whereas those from floodplain harvesting and stock and domestic bores are largely independent of the other activities.
- Integration of results from the analysis of plantations, farm dams, floodplain harvesting and stock and domestic bores highlight the following SWMAs as being potentially highly impacted: Condamine-Balonne (Queensland), Swan River (Western Australia), Onkaparinga and Limestone Coast (South Australia), Glenelg River and South Gippsland (Victoria) and Hawkesbury River (NSW).
- Integration of the 2030 results for plantations, farm dams, floodplain harvesting and stock and domestic bores highlight the following SWMAs as being potentially highly impacted: Swan River (Western Australia), Limestone Coast (South Australia), Glenelg River and Yarra (Victoria), Murray River (NSW) and Tweed River (Queensland).

8 Summary

The National Water Commission engaged Sinclair Knight Merz in partnership with the Bureau of Rural Sciences and CSIRO to develop a national baseline paper that documents the location of significant intercepting activities that fall outside the current entitlement framework; the potential rate of expansion of each activity over various time periods; and estimates of water usage of each activity in water management areas used in the AWR2005 (NWC 2007a,b). This report includes a definition and description of activities that intercept surface water and groundwater and identified the following activities for further analysis:

- overland flows
- farm dams
- stock and domestic bores
- plantations
- peri-urban development.

This project has undertaken analysis of available data for each of these activities throughout Australia in order to quantify the level of development of each of these activities according to the definition of intercepting activities. Analysis has then been undertaken to estimate the impact of the baseline assessment and projections of impacts for 2015 and 2030. Key findings from each of the analyses are provided below.

Overland flows

Almost all current floodplain harvesting in Australia occurs in the northern Murray–Darling Basin. The estimated total volume of floodplain harvesting storages nation-wide is approximately 2600 gigalitres; this volume is split between NSW (950 gigalitres) and Queensland (1625 gigalitres). Floodplain harvesting is not likely to expand, with moratoriums in place to restrict construction of new storages in the relevant river basins.

Farm dams

Based on available farm dam datasets, the total impact of farm dams nationally is 1600 gigalitres per year (in 2008), and the impact is projected to increase to 1840 gigalitres per year in 2015 and to greater than 1900 gigalitres per year in 2030. Baseline dam volume/impact densities are greatest at a river basin scale in central Victoria and the Mount Lofty Ranges, South Australia. Victoria is projected to experience increases in farm dam volume/impact across most of the state from 2008 to 2030.

Stock and domestic bores

Nationally, stock and domestic bore use is estimated at 1,100 gigalitres per year, which is equivalent to an additional 23 per cent of the current allocated volumes of 4,700 gigalitres per year. The highest density of extraction for stock and domestic purposes is in regions where there is no other available source of water (e.g. Lower Limestone Coast SWMA); in areas where surface waters have been capped and so users look to alternate water supplies (e.g. Lachlan River SWMA); and in urban centres where water restrictions have caused domestic users to source alternate water sources for garden watering (e.g. Swan Coast SWMA, Yarra SWMA). These three factors are probably the key indicators of where future growth in stock and domestic bores may occur. The Great Artesian Basin is a significant source for stock and domestic bore users, with an estimated 638 gigalitres usage, compared to the estimated 289 gigalitres of usage from other stock and domestic users in NSW, South Australia and Queensland. In these states, the Great Artesian Basin accounts for 69 per cent of the total stock and domestic use. There is no expected increase in stock and domestic bores in the Great Artesian Basin due to current policy and management initiatives.

Plantations

Plantations have currently been mapped in 156 SWMAs, with the total plantation area in Australia estimated to be more than two million hectares in 2008, with a median of 4000 hectares per SWMA. The most highly impacted SWMAs include Moore-Hill Rivers (Western Australia), Millicent Coast, Glenelg and Latrobe River (Victoria), Lower Limestone Coast (South Australia) and Mary (Queensland). The plantation area was predicted to increase to 2,300,000 hectares with a median of 5200 hectares by 2015. A further increase of 79,700 hectares was predicted by 2030 with a median of 5800 hectares. It is estimated that evapotranspiration from existing plantations is 2000 gigalitres per year greater than if this land was used for dryland agriculture or other non-forest. In addition, some plantations use groundwater in regions with shallow watertables, which may equate to several hundred gigalitres per year of additional water use across existing plantation estates.

Peri-urban development

South Australia was found to have a high baseline peri-urban impact density. It was found that approximately 2 per cent of the baseline (2008) farm dam impacts and groundwater bore usage occur within peri-urban areas in South Australia. Victoria and NSW were also assessed to have relatively high peri-urban impact densities, with 1.4 per cent of baseline (2008) farm dam impacts and groundwater bore usage occurring in peri-urban areas. The Onkaparinga SWMA in South Australia was found to have a peri-urban impact density of 22 ML/km^2. Other highly impacted SWMAs include Yarra and Bunyip SWMAs in Victoria, Hawkesbury River SWMA in NSW, and Mary SWMA in Queensland.

Conclusion

The baseline assessment and projected impacts of intercepting activities provides a national and regional context for assessing intercepting activities and highlights regions where particular risks may be posed by these activities. In assessing hydrological impacts, a number of factors need to be taken into account in addition to volume of impact. These include temporal impacts (in particular impacts during low flows), groundwater–surface water interactions and cumulative effects, which is most clearly indicated in the peri-urban regions. It should also be noted that it is difficult toquantify the baseline due to the limited availability of data relating to these activities and the required assumptions to provide a national dataset. This lack of data is to a large extent related to the definition and subject of this project, which is concerned with activities that are outside of current regulation and licensing regime. Because the activities are outside of the regulatory framework, there is no comprehensive monitoring of these activities and, therefore, a lack of data.

Further studies including local hydrological assessments are required at catchment scales to quantify and assess the significance of the temporal and spatial hydrological impacts of intercepting activities. This might be through a river model, rainfall–runoff model, or groundwater model.

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Appendix A—Intercepting activities

Table 20: List of intercepting activities

Type	*Activity*	*Comment*	*Meets definition criteria*
Water resource development	Floodplain harvesting / overland flows	Some licensing for very large direct diversions	Yes
	New farm dams (including capture of groundwater springs)	Some licensing controls—regulations concerning groundwater capture need to be assessed	Yes
	New direct diversions	Could include irrigation expansion, new irrigation districts, and mining where not licensed, but not possible to predict location	No
	Re-routing of rivers and creeks due to mining, urbanisation, other	Although this may cause some alteration of groundwater – surface water connectivity levels, there is no net change to the water balance. Not possible to model	No
	Groundwater extractions from unlicensed (either pre-licensing or outside current regulations (including some stock and domestic bores))	Can have significant localised impact on groundwater resources and baseflows	Yes
	Levee banks—bores, flood levees	Bank storage can be significant in some areas, especially in altered flood plains. Need to assess potential of interception in these areas	No
	Open cut mining	Groundwater dewatering, diversion impacts	Yes
	Pit lakes and mines wastewaters	Groundwater recharge, discharge, quality impacts	Yes
	Dewatering, mine voids (old mine workings)	Groundwater pumping—dewatering mines works and mine voids as a future source	Yes
Change in water management	Water quality impacts. For example: discharges remain same but improved salinity, increasing water lost through evaporation, or water quality prevents other uses	Small impacts, not possible to model	No
	Irrigation return flows, irrigation modernisation, efficiency (future)	Currently fit within water access and entitlement framework	No
	Changes in water delivery—e.g. Timing of environmental flows, use of weirs, storage of water	No net change in water balance, not possible to model (difficult to predict in the future)	No

Type	*Activity*	*Comment*	*Meets definition criteria*
Change in land management practices	Change in land management practice minimum tillage, clay spreading, contour banking	Difficult to predict in the future	Yes
	Change in forestry and plantation management (e.g. density, cycle of clearing & regrowth, selective logging vs. clear felling)	Difficult to ascertain how changes in management would increase water use. The expected impact would likely be small compared to the impact of forestry itself	No
	Change in native forest management (e.g. reduced grazing, thickening, thinning)	Difficult to ascertain if changes in management would increase water use. The expected impact would likely be small compared to the impact of forestry itself.	Yes
Change in rural land use	Afforestation—commercial plantations (both native and exotic) and for off-setting carbon emissions	Significant impacts on groundwater (removal of 100 per cent recharge and extraction from shallow watertable)	Yes
	Native revegetation (e.g. corridors for ecological benefit, riparian revegetation, other targeted plantings)	Includes working towards natural resource management targets, dependent on natural ecological vegetation classes (e.g. woodlands vs. grasslands). Philosophical problems in setting baseline, not easy to predict for the future	Yes
	Vegetation and land clearance—not an intercepting activity as increases surface water runoff	Reduces water use, provides additional water therefore not intercepting	No
	Farming land use change to high water use vegetation	Transition from pasture to horticulture, planting of deep rooted crops for grazing, and moving to perennial cropping	Yes
	Peri-urban expansion—increase in stock and domestic bores, farm dams, tree plantings, orchards	Activities may be modelled individually but also as a combined impact	Yes
Urban	Urban expansion, increase in impervious surfaces, drainage capture, includes development of water sensitive urban design, drainage water and sewerage pipes leak into groundwater—increasing recharge (but poor quality)	Future conditions include expansion into new urban areas and retrofit of existing urban areas	No
Other resource development	Oil and gas extraction, coal seam methane gas extraction	Significant impacts to water resources in a number of regions across Australia	Yes
Non-consumptive uses	Hydro-electricity	No net impact to water balance, however may present risk in the future due to changes in management regime	No
	Geothermal	Generally not net change and bores are normally licensed, including any extraction and injection bores.	No

Water resource development

Water resources development activities include activities that utilise both surface and ground water resources. A number of administrative frameworks are already in place to regulate the use of these resources, including entitlements and licenses. As a result, some potentially intercepting activities were identified as already having regulatory controls, and as such are not relevant for further analysis in this study, as per the definition in Section 1.2.1. Other potentially intercepting activities that are not currently licensed were evaluated using the criteria described previously in Section 1.2.1.

- *Farm dams*—which capture runoff within a localised catchment that would otherwise contribute to stream flow. These are often used for irrigation, domestic and stock purposes as well as for aesthetic purposes. The policy and administrative arrangements for farm dams differs across Australia, and is dependent on the use of the water. In general, farm dams used for stock and domestic consumption are not included within the existing entitlement regime. The impact of farm dams on the water balance depends on their location, and a range of factors such as climate and design. However, recent work undertaken for the Murray–Darling Basin Sustainable Yields Project (CSIRO 2008a) indicates that the impacts of future farm dam development can be up to 3 per cent of mean annual runoff. This study confirms that there is both capacity and likelihood for change in the existing farm dam density.
- *New direct surface water diversions*—which could be required for a range of uses such as irrigation, urban, and industrial demands. Many forms of diversions from waterways require a license to access and use the water, and hence are controlled through existing frameworks. However, as for farm dams, new stock and domestic water users can utilise direct access to water without a licence.
- *Water trading*—which allows the right to use water to be moved from one property to another. Water trading rules have been developed on a local and regional basis to ensure that there is no net impact on the water balance. Consequently, this is not considered to be an intercepting activity for analysis in the context of this project.
- *Floodplain harvesting and overland flows*—which capture water flowing across a floodplain from local runoff or channel overflows. This activity affects the water balance, as runoff is prevented from reaching the stream and recharge to aquifers can then be significantly reduced. There is both capacity and likelihood for an increase in the utilisation of floodplain harvesting activities.
- *The re-routing of streams* to allow the development of other land uses, such as urbanisation and mining—it is considered that there is some potential for this to occur; however, slight modification of the flow path of a river or stream is unlikely to have a significant impact on the water balance. Furthermore, it is not considered possible to model the impacts of this change. Consequently, this activity is not considered for inclusion in more detailed analysis in later stages of this project.
- *Groundwater extractions*—which occur mostly within the entitlement framework. However, there are some exceptions, which in some management areas, can have significant impacts on both the groundwater resource (and its current uses) and the surface water resources. This includes the following types of extractions:
  - bores unlicensed due to age, or construction type that are excluded from the current legislative requirements
  - stock and domestic bores where the extraction volume is not licensed (in most areas there is a nominal volume, however, in some states and territories stock and domestic bores do not come under the allocation frameworks)

  – disused bores, historically constructed for investigation or monitoring purposes, which could have collapsed or failed and are having an impact on the groundwater resource through pressure or level drops (difficult to quantify this impact).

    Where database information relating to the number and location of stock and domestic bores exists, a review of the likely impact on other users can be made by reviewing the current management plans and state and territory regulations. However, bores that are unlicensed are unlikely to be recorded systematically and therefore their impacts cannot be quantified as part of this project.

- *Mining activities*—which utilise water resources through groundwater dewatering for open cut mining, and impact on recharge through pit lakes and mine wastewater treatment areas.

Change in water management

Water resources are currently managed through a range of policy, legislation, agreements, and administrative arrangements. Changes to the way water resources are managed can impact on the availability of water, effectively intercepting water that would otherwise be available to downstream users. A number of possible water management related intercepting activities were evaluated for this briefing paper, including:

- *Water quality changes*—improving water quality could modify the water balance through potential increases in evaporation, particularly evident in locations where the salinity of discharge water is improved. For example, the freshening of a hypersaline wetland will increase the rate of evaporation. However, these potentially intercepting activities are considered to be of a very small in scale and not a significant impact on the overall water balance.
- *Reduction in irrigation return flows*—this is possible as a result of the modernisation of irrigation systems and on farm efficiency improvements. These fit within the current water access and entitlement framework. Quantification of existing outfalls resulting directly from irrigation return flows is difficult due to the lack of historical data and the incorporation of other losses in data that are available. However, there are clear policy drivers within various states that are working towards improved irrigation delivery systems, which will result in direct impacts on the water balance.
- *Changes in water delivery*—including the provision of environmental flows and the use of regulating structures—could modify the timing of water supply. However, as there is no net change in the average annual water balance, this is not considered to be an intercepting activity in the context of the definition applied for this project.
- *Salt interception schemes*—use groundwater bores to divert saline groundwater from rivers. Through this process it also removes groundwater fed baseflow from creeks and rivers that historically provided the majority of the low flows. Salt interception schemes are well regulated in terms of the environmental impact they have, especially evaporation disposal basins, but are not always assessed for the impact on the available water resources.

Change in land use

Modification of land cover to high water using vegetation occurs with the development of forestry, agriculture and native vegetation sectors. Increased plant water use has direct implications on the availability of water resources for other users and can occur through the following intercepting activities:

- *Afforestation*—which includes the development of commercial forestry plantations using either native vegetation or exotic species on land that has previously been cleared and utilised for agriculture. Plantations that are developed for carbon emissions offsetting are also included in this category. Plantations forests extract significant volumes of water from the available resources during the growth phase. This reduces the water available to other users of the surface and groundwater system. Given recent developments to minimise Australia's carbon emissions, forestry developments are likely to expand, with potential interception impacts to water resource availability.

- *Native revegetation*—which includes corridors for ecological benefit, riparian vegetation, and other revegetation activities to meet natural resource management targets. As for plantation vegetation, native forests utilise large volumes of water for vegetation growth. Some other native vegetation types (such as grasslands) are not as water intensive, but they can still intercept water from other users, depending on the water requirements of the original land cover. Modelling the interceptive impacts of native revegetation is difficult, and it is not easy to predict the location of future revegetation efforts.

- *Farming land use change to high water use vegetation*—changes in land cover to high water using vegetation can modify the water balance, with increases in vegetation uptake and evapotranspiration reducing the catchment runoff and groundwater recharge. The impact of the change will be driven by the vegetation type and catchment characteristics, but an understanding of these issues can be used to formulate modelling scenarios for consideration.

- *Urbanisation*—urban expansion includes the establishment of new urban areas as well as the modification of existing urban areas. Increases in impervious surfaces, drainage capture, rainwater tanks and development of water sensitive urban design all interact with the water balance. As the population grows, an expansion of urban areas is also anticipated. This includes modifications to the urban environment such as local wetlands, rainwater tanks, modified garden watering practices, and increased impervious surfaces. Current entitlement arrangements do not incorporate urban intercepting activities. Given the localised focus of urban development to few regions of Australia, and the estimated relative magnitude of the interception compared to other activities, urban expansion is not included in detail.

Change in rural land management practices

Land management practises in sectors such as forestry, agriculture and native vegetation management affect the current use of water resources. Modifications to these land management practices have the potential to cause impacts on the water balance, and reduce runoff and groundwater recharge. A number of interception activities related to land managementhave been evaluated through the development of this briefing paper, including:

- *Change in on-farm land management practices*—including minimum tillage, clay spreading and contour banking. Whilst these activities are likely to occur in the future and result in a change to the existing local water balance, it is difficult to predict the location and extent of these changes. Consequently, it is not considered feasible to determine a baseline and model the impacts of potential these on-farm land management changes at a regional scale.

- *Change in forestry plantation management*—which can alter the density, rotation cycle, and tree clearing practices. Whilst these activities will undoubtedly have an impact on the water balance through altered tree growth regimes, it is regarded as a secondary impact of the plantation forestry land use activity, and investigation of the impacts of likely management practices will be incorporated into analysis of general afforestation activities.
- *Change in native forest management*—which includes modifications to the forest density and stock grazing practices. As noted for changes in forestry plantation management practices, these activities are considered likely, yet are expected to have a secondary impact of native vegetation land uses. Furthermore, difficulties in being able to predict and model these management changes at a regional scale makes modelling impractical.
- *Peri-urban development*—which incorporates elements of land use change and water resource development. In particular, the development of farm dams and groundwater bores for stock and domestic purposes are expected to increase in conjunction with the establishment of small farm properties following lifestyle changes.

Other resource development

Mining and the resource industry use water in varying contexts. They extract groundwater through mining (dewatering) and oil and gas extraction with significant volumes of groundwater removed in the process (which is not licensed). The groundwater is then disposed within the mine water management plan framework or under license through the respective environmental protection authority. These regulations, though, do not include an entitlement for the groundwater volume displaced or disposed. Some elements of these activities also relate to the water resource development sector.

Non-consumptive uses

Activities identified within this sector that are potentially intercepting include hydro-electricity and geothermal power generation. Where water for a hydro-electricity development is not transferred across catchment boundaries, and where storage infrastructure for the power generation activities are reasonably small, it is considered unlikely that the development is one which intercepts water. Although there may be slight modifications of the timing of flows, the total volume will remain consistent with those observed prior to hydro-electricity generation. Recent studies on the Kiewa River confirm this, with hydro-electricity activities having no minimal effect on the overall water balance and annual flow pattern (SKM 2007a,). Some slight variations in the timing of water releases are likely to occur as a result of the power generation activities; however, these are evident on very short time scales only. Where water is transferred from one system to another, or a large storage is required for hydro-electricity generation, the existing entitlement framework would capture this activity. Evaporative losses may occur in hydro-power dams, however, most hydropower operations are currently located in areas where rainfall exceeds evaporation. Hence, it was determined that hydro-electricity generation currently has a low impact on water availability. There is a risk that changes in the management of water as part of hydro-electricity generation may have an increased impact on water availability if it is not accounted for, but this impact is difficult to model and quantify as part of this project.

Similarly, geothermal power generation also has no net change in the overall water balance as water extracted for this purpose is generally returned through injection bores. Bores required for water extraction and injection are licensed through existing administrative frameworks, and therefore, it was determined that interception of water resources as a result of geothermal generation is unlikely.

Exclusions

Activities that generate water

Drought and water shortages in recent times have led to technology developments that establish new sources of water or introduce more effective uses of existing water resources. As a result, a number of activities have been identified that appear to 'generate' water, or save water that would otherwise be considered as 'waste' and lost from the system (including water that discharges to the oceans or atmosphere through evaporation and evapotranspiration). This includes:

- *Cloud seeding*—technology that aims to increase rainfall has been established with varied success. Through cloud seeding, condensation nuclei are dispersed within the atmosphere to promote condensation, and subsequently increase precipitation.
- *Desalinisation*—this technology can be used to treat brackish and seawater for rural, industrial and urban uses. The desalination process can increase the water available in the terrestrial water cycle with high reliability, regardless of the climate conditions. Water used as the input stream for the desalination process is typically not considered useful for other purposes as a result of the poor water quality.
- *Recycled treated wastewater*—technology for the treatment of wastewater is now available to enable the treatment of ocean outfall sewerage for industrial, domestic or irrigation uses. This treatment process can increase the volume of water available in the terrestrial water cycle with high reliability, regardless of climate conditions. Water used as the input for the treatment process is typically not considered useful for other purposes as a result of the poor water quality.
- *Aquifer storage recovery and managed aquifer recharge*—this technology involves the injection of water into an aquifer for later extraction for consumptive use. In this context of water 'generation', the source of water to be injected can include stormwater and effluent. A net benefit in water availability is obtained if the source water would otherwise be lost as evaporation or evapotranspiration.

In general, since these activities seek to increase the total volume of water available for consumptive uses, and do not draw on water resources currently allocated to other users, they have been excluded from the analysis of intercepting activities.

However, where these activities transfer water from one licensed user to another they may be considered as intercepting activities. For example, reductions in wastewater discharge to rivers as a result of recycling activities can have a detrimental effect on downstream water users. Similarly, the injection of rainfall and surface runoff into an aquifer for later consumptive use can also have an impact on other users. In these instances, the activities are considered to be intercepting activities if they occur outside of the licensing system and could be considered relevant for discussion in the following sections of this report.

Interbasin transfers and water trading

Water trading is not defined as an intercepting activity, since policy and trading rules are designed to prevent impacts on other water users. However, water trading could have an indirect influence on interception. For example, if as a result of water trading a region changes its agricultural focus through the movement of water to a higher value commodity, the resulting land use change may cause increased 'interception' of water, and as such, this land use change would be assessed.

Natural processes

The NWI recognises there are environmental processes and events such as bushfires and climate change that significantly impact available water resources but are beyond the control of regulation and, as such, are external to the water management framework.

- Vegetation regrowth as part of bushfire recovery has been shown to have significant impact on surface water yields at broad catchment scales (Chiew et al. 2008). However, while the recovery process may be modelled, there would be no ability to regulate or set policy to manage the event of bushfires and is considered outside the scope of this project.
- Climate change is not an intercepting activity, however, the impact of climate change on runoff and recharge is an important consideration for water management planning. This study will use current climate in the scenarios of interception so that we can separate the land use effects from climate change effects.

Appendix B—Land use change

Methodology

The specific tasks relating to land use change were to:

- compile a one-kilometre resolution grid and a spreadsheet summary of the baseline land use for each surface water management area (SWMA) and future scenarios for 2015 and 2030
- changes in land use were based on historical trends and industry and government projections
- key land uses that were included in future projections were plantations, cropping, sugar, cotton, horticulture, urban areas and peri-urban areas
- compile one-kilometre resolution grids of annual evapotranspiration, runoff, deep drainage, irrigation and return flows and present as a spatial datasets and national maps summarised by land use and region using the Water 2010 modelling approach.

Population projections

Increases (or decreases) in residential areas were allocated first in the 2015 and 2030 land use/landcover datasets as it was assumed that urban uses would have a higher priority than any agricultural or plantation land uses if there were competition for the same location. It was also assumed that there would be no decrease in residential areas—even if the population of a community was to decline, the infrastructure would still remain. There was no distinction made between urban and rural residential areas, instead the Australian Bureau of Statistics Urban Centre/Locality dataset was used in conjunction with the baseline land use and landcover dataset to determine likely areas of expansion. Further details of the population projects are provided in BRS (2009).

Baseline land use dataset

The baseline land use/cover dataset created for this project built on the landcover dataset created for the Bureau of Rural Sciences Water 2010 project in 2007. The Water 2010 dataset was updated to include new catchment scale land use data from the Australian Collaborative Land Use and Management Program (ACLUMP) and National Forestry Industry data to provide a more accurate baseline dataset for 2008. Other input datasets include the National Vegetation Information System (NVIS) and MODIS NDVI imagery (2008) and are listed in detail in BRS (2009).

Agricultural projections

Key agricultural land use data (cropping, sugar, cotton and horticulture) were used as a starting point for researching projection information. It was also decided to add irrigated pastures as a key land use given the impact on water interception. Once projected increases were known, the number of extra pixels needed for each land use was determined and spatial data needed to assist in the allocation of pixels were collated.

Projection information was sourced mainly from the Australian Bureau of Resource and Agricultural Economics and industry organisations. The Australian Bureau of Resource and Agricultural Economics rarely provides estimates more than a few years into the future, and so where no other information was available, these estimates were used to determine a longer-term trend. Where no projection information could be found, past trends in the Australian Bureau of Statistics Agricultural Census data were used as surrogates.

It is important to note that the projections presented in this section assume a 'business as usual' approach. That is, these projections do not take into account the emergence of new crop types or farming techniques that could lead to greater areas being suitable for expansion. While it is noted that the 1994 Cap on water diversion for agriculture in the Murray–Darling Basin will limit the allocation available for irrigation, it is assumed that new developments will still occur due to improving water efficiency (MDBC 2008). This would allow irrigation to expand at the rates presented in this section. Increases for some of the industries may seem optimistic as most predictions have been made in isolation from other industries and do not take into account the trade-offs that would need to be made between competing land uses, in particular irrigation uses. Additionally, no modelling for a carbon pollution reduction scheme was undertaken.

A summary of the projection information collected as part of this project is presented in BRS (2009). It was also noted that these projections have been taken in isolation from each other, and in the real world there would be trade-offs between particular land uses. As a result, some crops would not expand as much as presented in the results. The projections are therefore optimistic targets for expansion for 2015 and 2030.

Historical trends

Agricultural Commodity Census data from 1986 to 2006 were analysed to determine area trends for the key land uses to support the industry derived projections. Data were aligned to the 2006 statistical local areas to allow for comparison. This information was useful in informing the key land use projections where no other data could be found. In particular, the percent increase for irrigated pastures was derived from an average of 0.7 per cent per year between 1987 (irrigation information was not collected in 1986) and 2006.

Prioritisation of projections

In order to determine the order in which agricultural land use projections would be allocated for 2015 and 2030, an analysis of the gross value of production per hectare for each land use was conducted. This used the Australian Bureau of Statistics 2005–06 Agricultural Census data and assumed that tree crops were at a modest density of 150 trees per hectare. The results of this analysis are presented in Table 21 (Appendix B) with vegetables having the having the highest priority in allocation and legumes having the lowest.

Table 21: Priority of increase assignments based on value per hectare

Priority	*Land use*	*GVAP per ha (assumed 150 trees per ha)*
1	Vegetables	21,677.63
2	Avocadoes	9,571.44
3	Grapes	8,160.96
4	Mangoes	6,925.59
5	Almonds	4,585.05
6	Irrigated pastures	3,341.30
7	Cotton	2,852.08
8	Sugar	2,637.84
9	Olives	1,045.62
10	Oilseeds	483.87
11	Cereals	392.73
12	Legumes	384.53

Source: Agricultural Commodities: Small Area Data, Australia, 2005–06 (Reissue), ABS, 9 June 2008

Plantation projections and input data

Projections were available as a breakdown of long rotation hardwoods, short rotation hardwoods and softwoods; but for the purposes of this report all plantations were grouped together as one class. Once projected increases were known, the number of extra pixels needed for each land use was determined and spatial data needed to assist in the allocation of pixels were collated.

Existing forecasts of forest plantation establishment rates were updated by the Bureau of Rural Sciences for this project because existing forecasts that had been developed for another project used less suitable timelines. The forecast provides low, medium and high levels of additional areas of each main type of plantation establishment separately for the periods 2009 to 2012, 2013 to 2015, and 2016 to 2030. The projections are based on current regional areas, recent rates of expansion, and estimates of areas of new plantations planned by major sectors and operators in the plantation forest industry. It is evident that many companies have reached or are reaching their targets in several regions and that estate areas are stabilising as harvesting of maturing stands increases. There will be some rationalisation following harvesting of the first crop on some sites. Some sites will be replanted while others may be used for other purposes. Alternative sites may be used instead if the total area is to be maintained and more suitable land is available.

The high-level forecast assumes that all currently planned managed investment scheme targets will be achieved and that industrial plantation programs will be continued at current planned levels until 2030. The medium and low projections assume that proportions of those targets will be achieved. Other key assumptions used to develop the forecast are:

- Current business circumstances that affect the amount of investment funds available are assumed to continue. A large majority of the funds available for the past several years has been raised by managed investment schemes. These schemes are currently being severely affected by difficulties in raising capital for land acquisition and the market for the schemes may contract for some years due to the general turmoil in financial markets. These factors add to the uncertainty of achieving the high level of expansion.
- The government programs that are financing plantation expansion in some states will continue at the planned rates until they reach their targets; all of these are planned to terminate by 2012 .

- It includes plantations planned primarily for production of sawlogs and pulpwood. For Western Australia this includes plantations established jointly for salinity control and sawlog production.
- It does not include plantations established primarily for production of biomass, carbon credits, sandalwood or other non-timber crops or crops established primarily for purposes such as salinity mitigation, land protection or biodiversity.
- It includes plantation forests planned to be established by public and private sector operators.

Creating land use datasets for 2015 and 2030

Analysis was carried out using the ACLUMP catchment-scale land use grid rather than the baseline land use/landcover dataset as it was at a finer resolution (50 metres), had more detailed horticulture classes, and could be converted to the land use/landcover codes at the end of the process when the 2015 and 2030 datasets were converted to one-kilometre grids. This approach is described in detail in BRS (2009).

Spatial allocation of key land use increases

The updated ACLUMP 2008 dataset (land use dataset updated with new population information) was combined with an available land grid, crop suitability grids for each of the key commodities, and a plantation suitability grid. This meant that for each cell in the updated ACLUMP 2008 dataset it was possible to see whether it was land available for agriculture (and if so how that land ranked in terms of slope and soil capability) and how suitable that land was for growing plantations, vegetables, olives, crops, etc. The combined suitability grids were used to allocate pixel increases for the key land uses for 2015 and 2030 in the order set out in Table 2.

WATER2010 water balance modelling

This project employed a static version of the Water 2010 modelling framework (see Welsh et al. 2006). The static version solves the water balance in terms of annual rainfall, evapotranspiration, drainage to ground and surface water, and runoff to rivers and storage components and an irrigation term (explained later). Water 2010 requires as inputs, average annual precipitation, potential evapotranspiration, land use and basic physical soil texture data. For this project, the water balance is to be estimated for two time periods in the future (2015, 2030) and expressed relative to a baseline period. In terms of weather and climate, the baseline is usually a period of significant length, whereas the baseline for landuse is usually a specific year. The Bureau of Meteorology, for example, uses 1961 to 1990 as their standard baseline (also known as *standard climatology*), and the Centre for Australian Weather and Climate Research uses 1980 to 1999. In terms of landuse, the Bureau of Rural Sciences has adopted 2008 as the baseline.

Water 2010, as used in this project, is described fully in Welsh et al. (2006). It is based on a steady-state catchment water balance modelling approach, where precipitation (P) is equal to actual evaporation (E) plus runoff (R) plus drainage (D), that is:

$$P = E + R + D$$

Precipotation (P) for 2015 and 2030 is as described above. Actual evapotranspiration is determined by water supply (rainfall) in dry environments and energy supply (radiation) in wet environments. A single-parameter hyperbolic function interpolates between dry (rainfall limited) and wet (energy limited) total evaporation rates. The value of this parameter describes the influence of catchment land characteristics on evapotranspiration and is used to convert potential evapotranspiration (as described earlier) to actual evapotranspiration; it is based on rainfall and land use. Thus, at this point in the description, we have P, E and R. As described in Welsh et al. (2006), D is calculated using a rule-based algorithm based on land use and physical soil properties, leaving R as the residual term.

An additional term is used for irrigated areas, based on the amount of water needed to be added to the crop (or pasture) to bring actual evaporation to the level of potential evaporation, the assumption here being that water will not be limiting growth in such a case. The extra term was used only where the landuse classification indicated irrigated agriculture.

Results

Table 22 shows the extent of each of the land use/landcover classes for 2008, 2015 and 2030 in square kilometres. Maps of land use for 2008, 2015 and 2030 are provided in Figure 22.

Table 22: Comparison of land use areas between the baseline 2008 land use/cover datasets and the projected 2015 and 2030 land use/cover datasets for Australia

Code	*Land use description*	*2008 area (km^2)*	*2015 area (km^2)*	*2030 area (km^2)*
110	Woodland	1,672,439	1,668,510	1,666,839
120	Open forest	378,602	376,482	375,887
130	Closed forest	53,180	52,974	52,962
140	Plantations	20,741	23,309	24,105
	Open Woodland	881,205	877,244	876,919
220	Shrubland	1,369,875	1,368,633	1,368,297
230	Native pastures	1,904,875	1,903,661	1,903,086
231	Irrigated native pastures	2	-	-
240	Sown pastures	860,120	779,783	744,949
241	Irrigated sown pastures	9,678	11,490	12,475
310	Summer cropping	101,609	23,249	22,623
311	Irrigated summer cropping	6,634	6,268	6,213
320	Winter cropping	260,467	56,856	55,101
321	Irrigated winter cropping	5,338	4,785	4,697
322	Winter or summer cropping (uncertain which season)	-	371,985	407,859
330	Sugarcane	1,486	1,443	1,388
331	Irrigated sugarcane	3,832	3,815	3,809
340	Cotton	318	297	297
341	Irrigated cotton	4,852	4,660	4,652
350	Horticulture	1,016	955	934
351	Irrigated horticulture	5,247	6,664	7,474
400	Bare	16,216	15,322	15,242
410	Urban	33,716	34,062	36,747
420	Rural residential	14,179	13,394	13,312
500	Water	79,060	78,923	78,907

The mean annual runoff and recharge for each SWMA are presented in Appendix E, Table 33 (for 2008) and Table 34 (Appendix E) (for 2030).

Discussion

Shaded classes in Table 22 are those that were explicitly increased based on the industry projections. Decreases in other classes may mean that these classes were used to convert to the expanding land uses. In particular, sown pastures have decreased substantially as this class was converted first when expanding other land uses. Agricultural land uses within the urban centre/locality areas were also converted, other classes such as water should not have changed during class allocation and so area differences are an artefact of resampling. Resampling in particular has affected smaller land use classes (such as cotton and rural residential) because, each time they are involved in a processing step, areas are likely to be 'swallowed up' by more dominant land uses.

In the 2015 and 2030 projections, it was not possible to differentiate between the majority of winter and summer cropping. As a result, most cropping in these years is allocated to a combined cropping class: 'Winter cropping or summer cropping'. Despite this, it is likely that the majority of cropping is winter cropping because this was the case in 2008. The intensification of cropping in the projected years is clear even when combined into one class.

In the 2030 dataset, dominant new cropping areas appear in Queensland (characterised by a doughnut shape) and south central Victoria. The concentration of these areas, in particular in Queensland, appears to be influenced by the distance to existing cropping input. This is most likely because all the other inputs were favourable (land capability, climate and tenure), and so areas closest to existing cropping were allocated first as a radius and then and then expanded from there.

Key Bureau of Rural Sciences land use mapping and crop experts were enlisted in a review. They agreed that the method used is defensible given the timeframe and the assumption of a 'business as usual' approach to the analysis (i.e. no change in tenure, crop types or farming techniques). Members of the Australian Collaborative Land Use and Management Program have also provided comments.

Limitations

Carbon pollution reduction scheme

No modelling for carbon pollution reduction scheme was undertaken. Plantation estimates do not include plantations established primarily for production of biomass, carbon credits, sandalwood or other non-timber crops or primarily for purposes such as salinity mitigation, land protection or biodiversity.

Input data limitations

Some of the input catchment-scale land use data are very dated (in particular for Western Australia). This means that cultivation may have already expanded into some of the future areas proposed in the 2015 and 2030 datasets. Also, given that distance to existing land uses was an important input into the allocation process, isolated cultivation areas that have appeared since mapping was completed will not be present and as a result, cultivation in these areas will not be predicted in 2015 and 2030.

Allocation of land use classes in the input catchment-scale land use mapping can differ between and within the states and so there could be regional differences. In particular the distinction between grazing native vegetation and grazing modified pastures can be an issue, and this project attempted to address this problem in Queensland.

Allocation limitations

A number of other methods for allocating the land use increases were suggested at the start of the project, in particular for the population projections, but processing and software constraints made these methodologies unsuitable given the timeframe of this project.

Where possible, the number of extra pixels allocated reflected the medium projections and where not possible the number of pixels allocated was as close to that total as practicable. Groups of pixels with similar availability, suitability and existing land use were allocated in one step as a pixel by pixel analysis was deemed to be far too complicated and time consuming.

Resampling of data

The allocation process tried to minimise the reprocessing steps needed, but datasets would have been re-sampled (using a nearest neighbour analysis) during the allocation process and so class areas may have changed slightly. In particular smaller areas (such as cotton and rural residential) were likely to decrease when this would not be the case in reality.

Predicted area increases in Table 22 may not match the actual areas in the projected land use datasets as the increases were applied at a 50-metre resolution and then re-sampled to one kilometre. As a result, some areas may have been lost while others may have increased, particularly for the smaller classes.

Distinguishing classes

As discussed above, in the 2015 and 2030 projections, it was not possible to differentiate between the majority of winter and summer cropping. As a result, most cropping in these years is allocated to a combined cropping class: 'Winter cropping or summer cropping'. Despite this, it is likely that the majority of cropping is winter cropping as this was the case in 2008. The intensification of cropping in the projected years is clear even when combined into one class.

Cropping in 2030

As discussed above, in the 2030 dataset, dominant new cropping areas appear in Queensland (characterised by a doughnut shape) and south central Victoria. The concentration of these areas, in particular in Queensland, appears to be influenced by the distance to existing cropping input. This is most likely because all the other inputs were favourable (land capability, climate and tenure) and so areas closest to existing cropping were allocated first and then and then expanded from there.

Water 2010 data limitations

Outputs representing climate change scenarios are available from the Centre for Australian Weather and Climate Research for the years 2030, 2050 and 2070.

The Centre for Australian Weather and Climate Research states (author date, p. n):

> Projections are given relative to the period 1980–99 (referred to as the 1990 baseline for convenience). The projections give an estimate of the average climate around 2030, 2050 and 2070, taking into account consistency among [the IPCC] climate models. Individual years will show variation from this average. The 50th percentile (the mid-point of the spread of model results) provides a best estimate result. The 10th and 90th percentiles (lowest 10% and highest 10% of the spread of model results) provide a range of uncertainty. Emissions scenarios are from the IPCC Special Report on Emission Scenarios. Low emissions is the B1 scenario, medium is A1B and high is A1FI. BRS obtained digital versions of the 2030 A1B (medium emissions) scenario for rainfall and potential evapotranspiration, noting that the contract specifies 2015 and 2030. These are at a spatial resolution of 100 km. BRS notes that the 2030 and 2050 fields are simply scaled versions of the 2070 calculations, a consequence of their 'pattern scaling' approach. The factor is 0.423 for 2030, and 0.718 for 2050. Consistent with this, BRS has applied a factor of 0.211 for 2015.

It is important to note that for 2015 and 2030, the differences between the (climate) models are generally larger than the climate change signal within them and this has important implications for the present work. While projections for 2015 and 2030 are consistent with longer term projections, they should be viewed as little more than plausible futures. For these reasons, they should not be regarded as predictions.

Figure 22: National land use 2008, 2015 and 2030

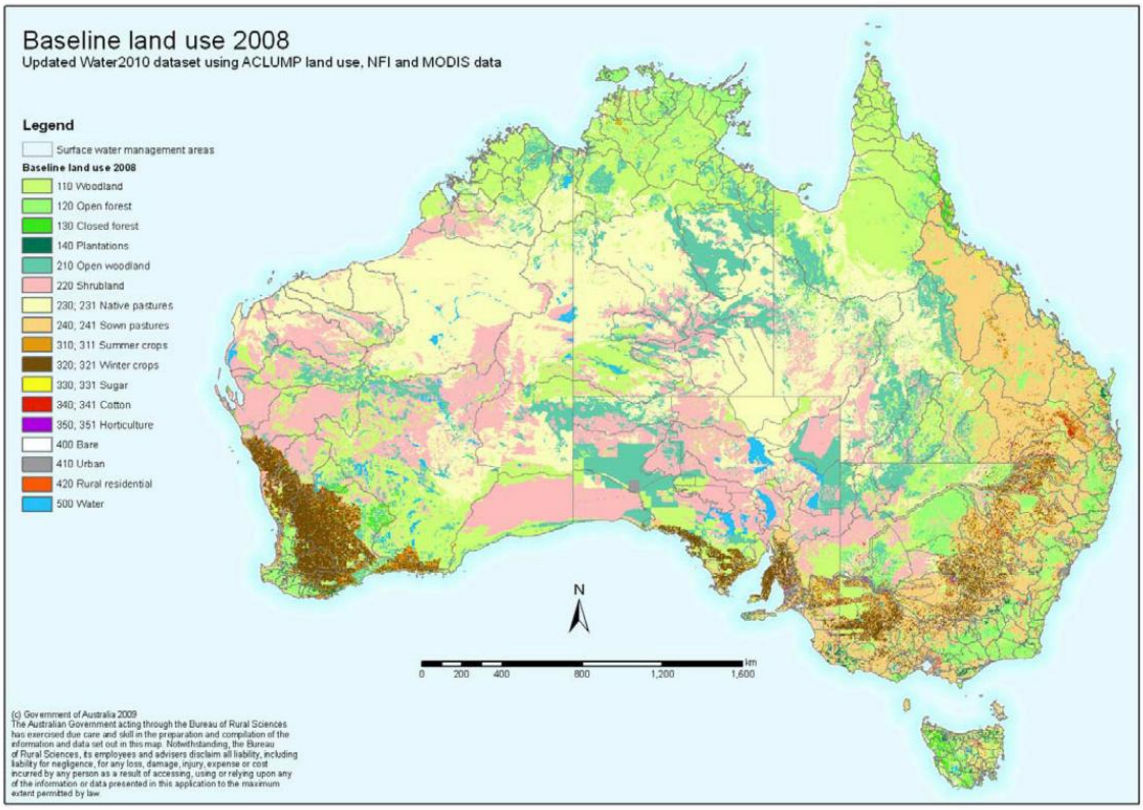

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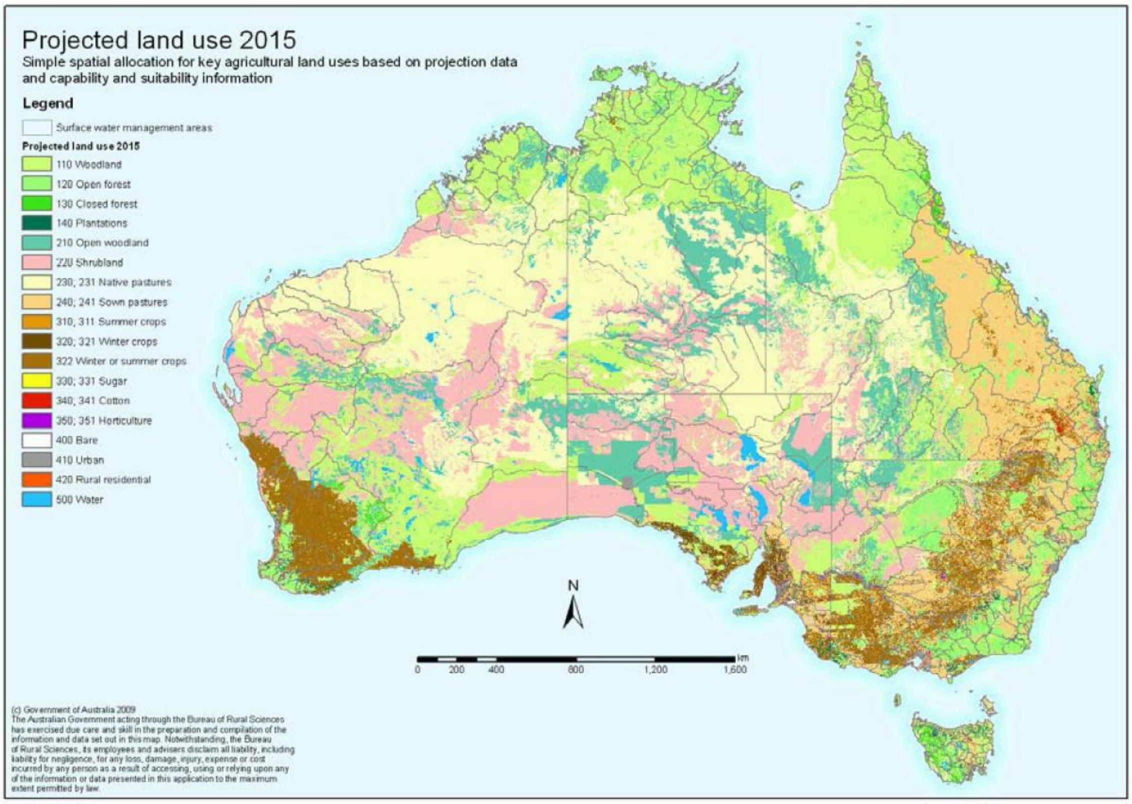
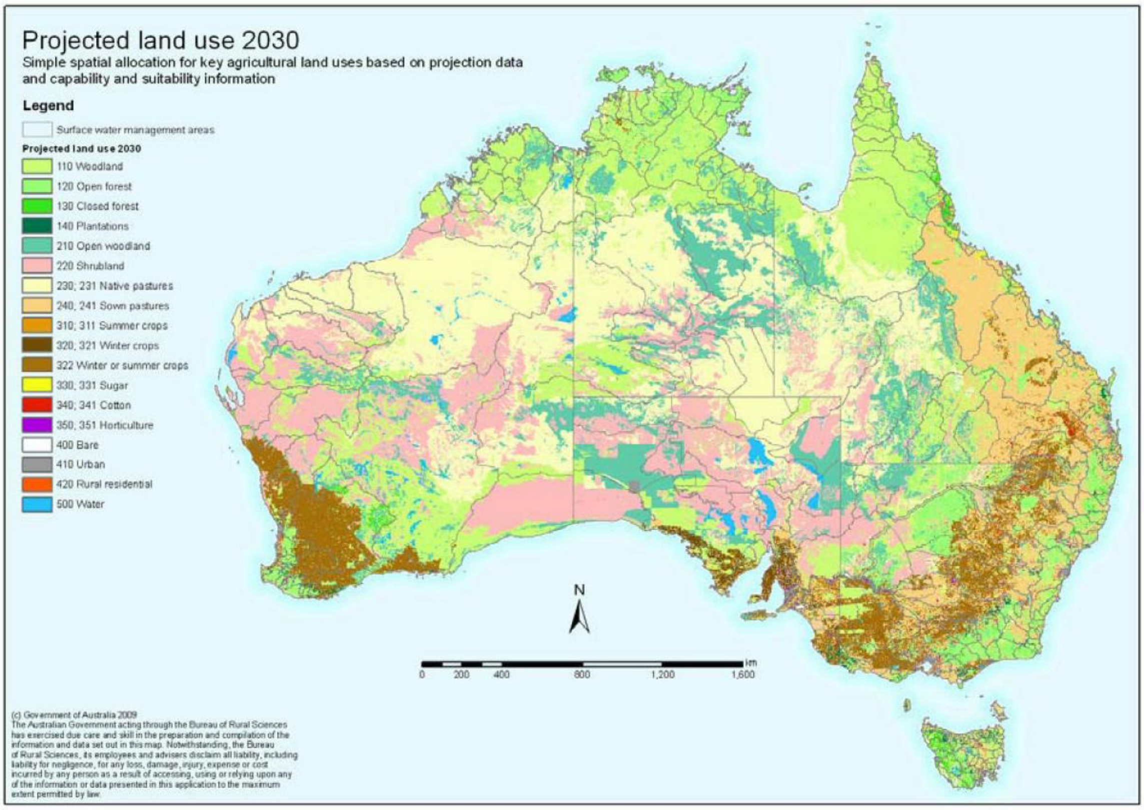
Figure 21 (continued)





Appendix C—Land management practices

Introduction

Farm management changes as a result of environmental degradation (including erosion and surface water logging) have become common practice within Australian farming region (Nelson et al. 2004). This review has established that there is active government intervention in both Queensland and South Australia that is well documented and researched. Other states have not reported on soil conservation techniques applied on farming land and it is therefore difficult to determine the extent of conservation techniques on the hydrologic balance.

The following land management practices have been considered:

- clay spreading
- minimum tillage
- constructing contour banks.

The following sections provide an overview of the available literature relating to these practices.

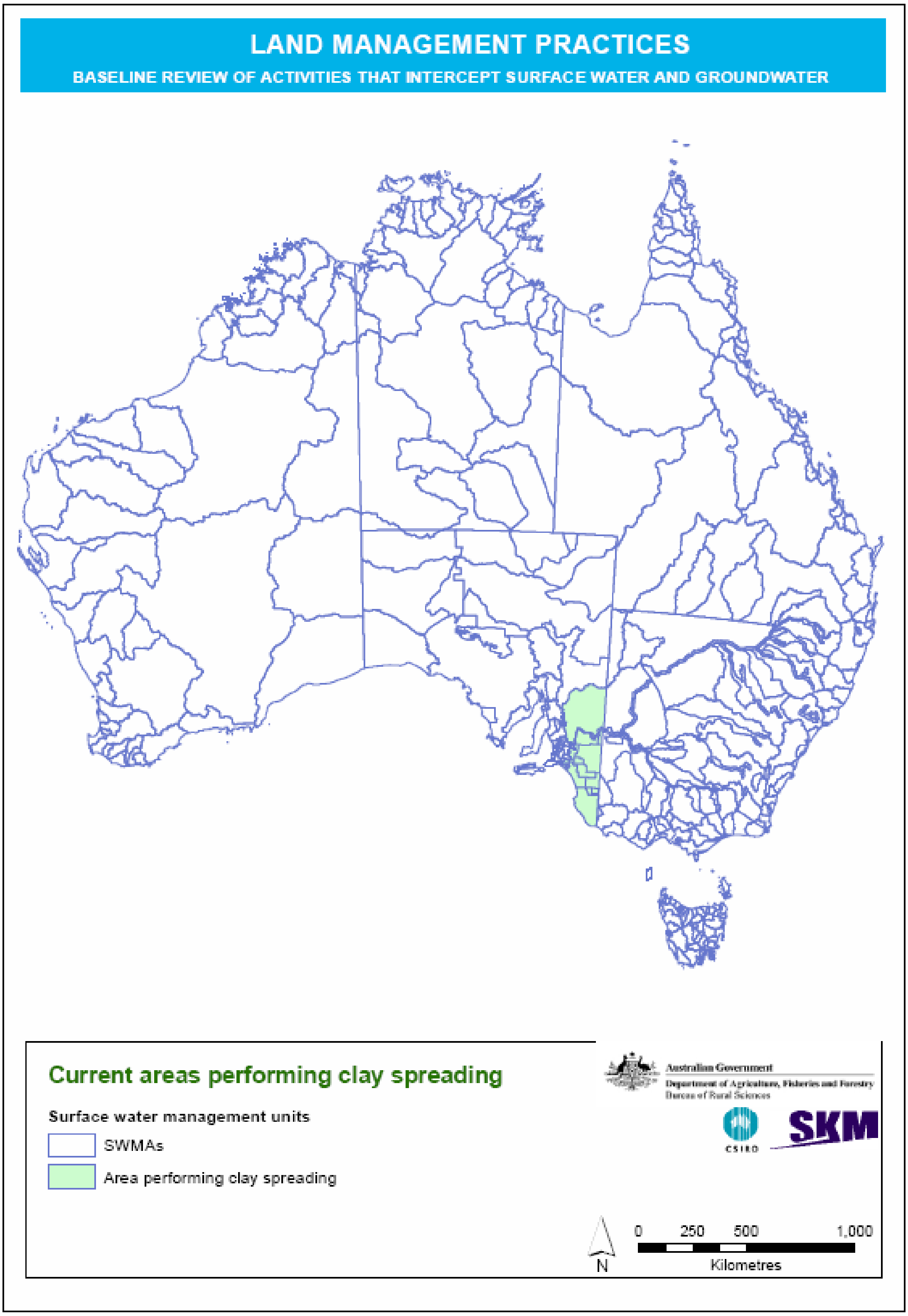
Clay spreading

Clay spreading is implemented in farming practices where soils are typically water repellent (hydrophobic). Areas with reported clay spreading are shown in Figure 23. Water repellence is commonly a ‘result of a waxy coating, derived from plant material on the soil particles’ (Munday 1999), which is most common on sands. Clay spreading involves the application of clay with a higher water absorbency (hydrophilic) over sands to increase water retention in the soils and decrease runoff. It is a common practice in the upper south-east of South Australia (Munday 1999). Additional benefits of clay spreading to a landscape are the enhancement of crop productivity (Cann 2000) as a result of more soil water availability, and reduced saline flooding. Clay spreading is advantageous as it is a one-off application in which the costs can be generally recovered in three years of grain production (Munday 1999).

Rates of clay spreading that have been reported in the South East of South Australia record ‘100–250t/ha clay on sandhills to 40-100t/ha on sand over clay flats’ (Cann 2000).

Documentation of the impacts of clay spreading to a hydrologic balance is minimal. It can be inferred that increased infiltration and therefore soil moisture will decrease water runoff into streams and across downstream landscapes.

Figure 23: Current areas recorded as performing clay spreading



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Minimum tillage

Farmers surveyed as part of the ABARE 2001–02 natural resources management survey reported that traditional cultivation of crops is still the most common method, although a significant number of farmers are applying minimum tillage practices (Table 23). Areas of reported uptake of minimum tillage are shown in Figure 24.

Table 23: Adoption of cultivation practices by Australian farmers

Cultivation practice	*Percentage of broad acre and dairy farms where each practice was relevant (%)*
Direct drilling	40
Minimum tillage	32
Traditional cultivation	52
Other	3

Note: the percentage can be added to more than 100 per cent because more than one type of cultivation method can be used on a farm; Source (Nelson et al. 2004)

The Darling Downs region of Queensland is an area of approximately 1.84 million hectares with an active cropping region. Land management practices are important in the conservation of soil quantity and quality, with the result that no-tillage and other conservation farming practices have become common practice in the area (Loch 2004).

On a wider Queensland scale, no-tillage and conservation farming practices have been adopted in 50 per cent of the cropping area, with the potential to increase to 85 per cent% in some areas (Thomas et al. 2007).

Site-specific runoff effects were presented that show a reduction in runoff between no tillage practices and other practices (see Table 24). In other site studies (Freebain and Wockner 1989; Radford and Key, undated) similar trends of no-till reducing runoff (see Figure 25) were observed.

Figure 24: Areas reported for minimum tillage

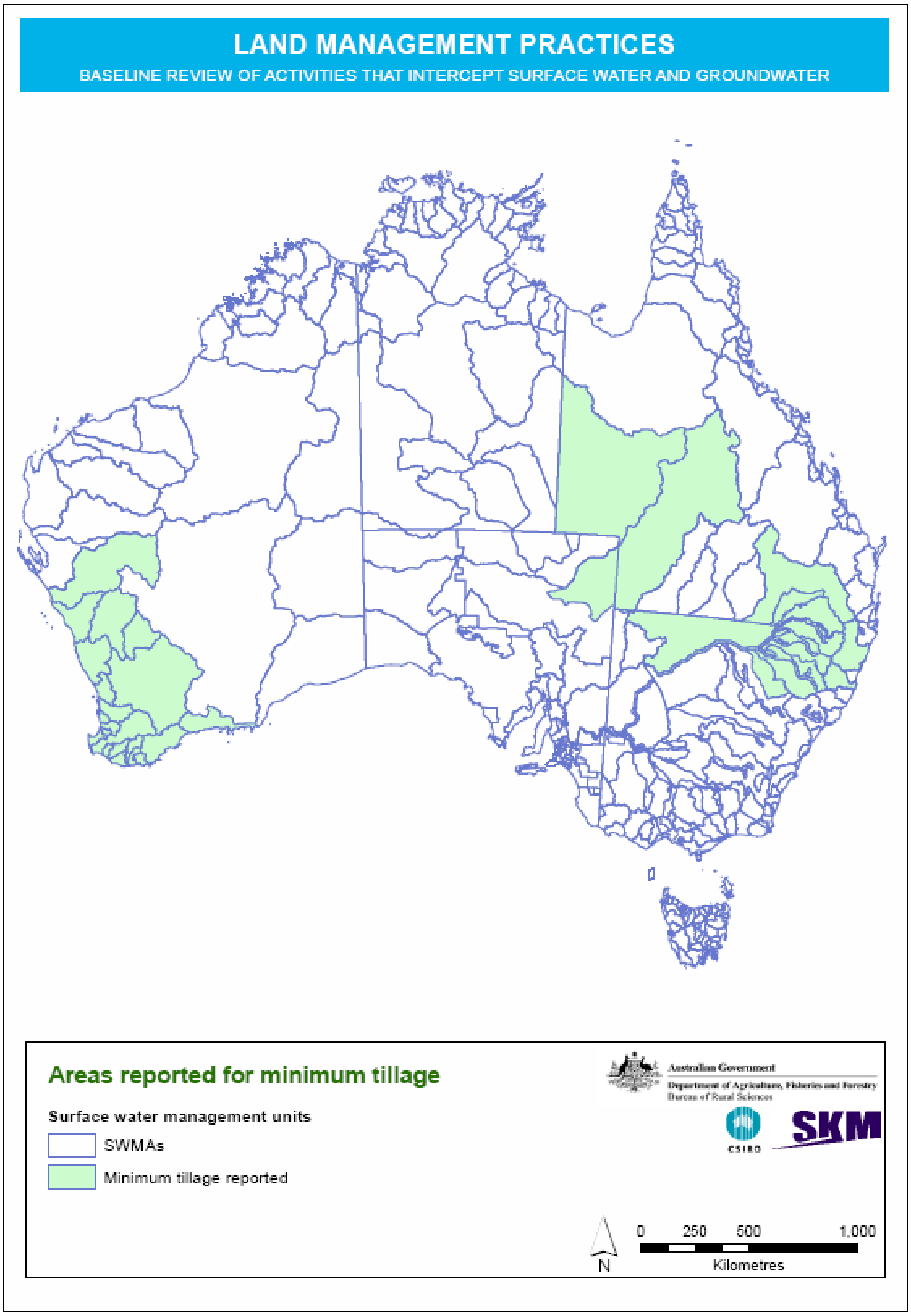

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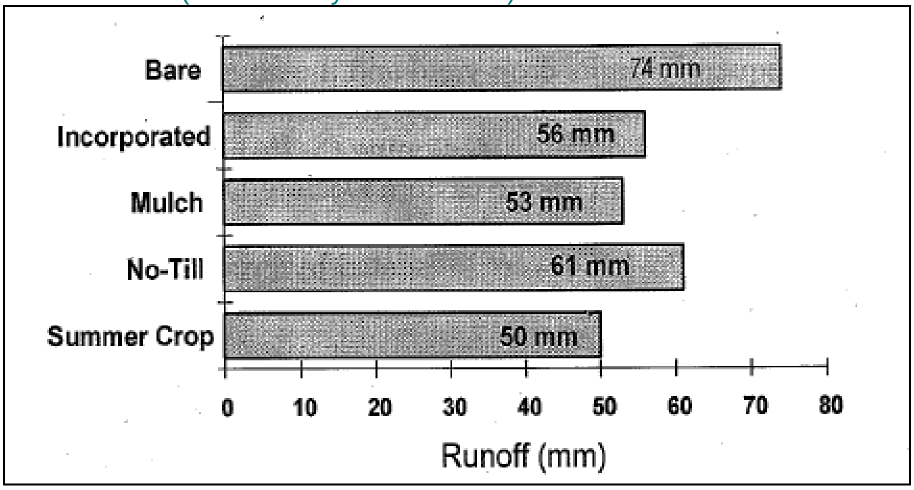
Table 24: Effect of fallow management practices on annual soil movement (t/ha) and runoff (mm; in parentheses) at four sites in Queensland

Fallow management practice	*Greenwood*	*Greenmount*	*Capella*			*Brigalow Research Station*
	Wheat 1978–82	*Wheat 1979–89*	*Wheat 1984–87*	*Sorghum 1983–87*	*Sunflower 1983–87*	*Wheat 1986–90*
No tillage	1 (31)	3 (61)	0.7 (6)	1.5 (54)	4.4 (46)	0.0 (62)
Stubble mulch	3 (27)	6 (53)	0.3 (8)	4.0 (59)	6.0 (66)	0.5 (56)
Stubble incorporation	31 (55)	16 (56)	1.8 (24)	8.0 (59)	7.4 (70)	n.d (n.d)
Stubble burnt	31 (55)	49 (74)	n.d (n.d)	n.d (n.d)	n.d (n.d)	n.d (n.d)

Source: (Thomas et al. 2007)

Figure 25: Mean annual runoff for five management options during the summer fallow period at Greenmount (mean of 11 years 1978–89)



Source: (Freebain and Wockner 1989)

Contour banks

Contour banks (also known as graded banks, terraces or bunds) are earthen banks constructed at intervals down a slope (Carey 2006b). They are used in farming with to reduce the length of slope of the land, and therefore reduce the flow of water and subsequent erosion of soil. They also control the flow direction of water through a catchment (Freebairn and Silburn 2004; Thomas et al. 2007). Areas of reported implementation of contour banks are shown in Figure 26.

Further, Harding (2008c), has identified five reasons for using contour banks:

- intercept surface water flows before they get large enough to cause erosion and direct the excess water to a safe disposal site
- direct surface runoff into water storage areas
- protect land reclamation works, such as the filling of old erosion gullies
- reduce waterlogging of flatter land
- moderate floodflows when used over the whole catchment.

It has been reported that, in Queensland, contour banks are designed to carry runoff water from a storm with the probability of occurring once in 10 years (Carey 2006b; Thomas et al. 2007).

Another factor in the amount of water that contour banks can contain and divert is the condition of the channel at the time of the storm. 'A contour bank with a smooth, bare channel can carry about five times more run-off than one with the channel choked with a close growing crop or dense stubble' (Carey 2006b).

In South Australia, the water that flows through a paddock with contour banks must leave the property where it would have prior to any works to avoid possible legal action (Harding 2008b). This suggests that the only impact to the hydrologic balance would be the differing infiltration rates as a result of water flow over a different path. The peak of the flow may be retained for a small period of time, and therefore decrease the peak flow through the receiving waterbody.

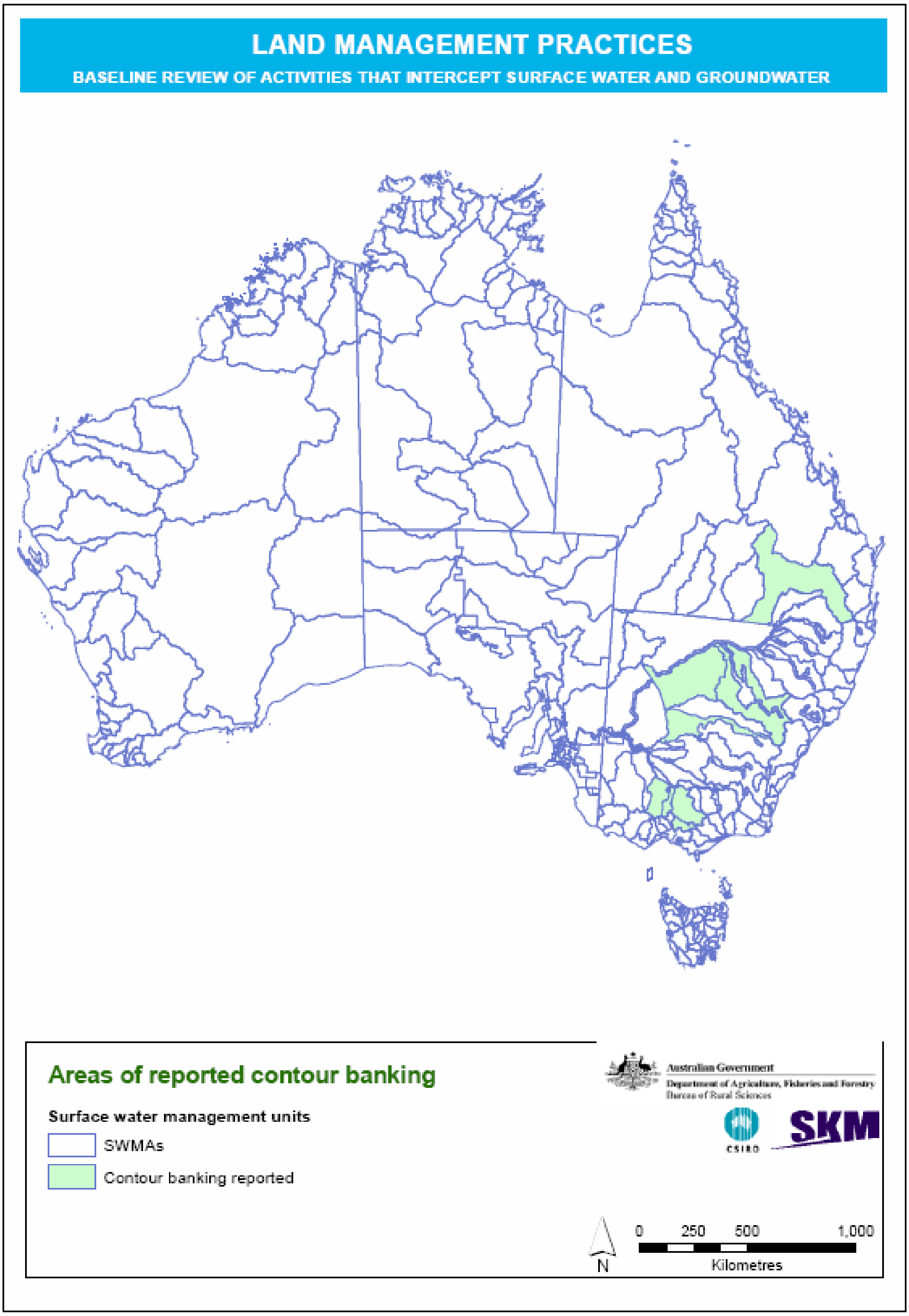
A mechanism by which no-tillage or reduced tillage reduces runoff is the increased water storage that results in fallows due to stubble retention, which in turn improves grain yield (Freebairn and Silburn 2004). This can in turn contribute to dryland salinity issues (Freebairn and Silburn 2004).

It has been found that the adoption to conservation tillage practices has been slow; and that barriers to change include: machinery costs, lack of need to change (perceived or real), insufficient skills and age (Freebairn and Silburn 2004).

Findings

Soil conservation management at a farming scale is occurring throughout Australia. Some states more actively implement management initiatives and report on the means of undertaking soil conservation management. There is no definite quantification of the impact that these soil conservation techniques will have on the hydrologic balance, and it should be noted that these impacts are site specific and would be expected to have greatest impact at the subcatchment scale.

Figure 26: Areas of reported contour banks



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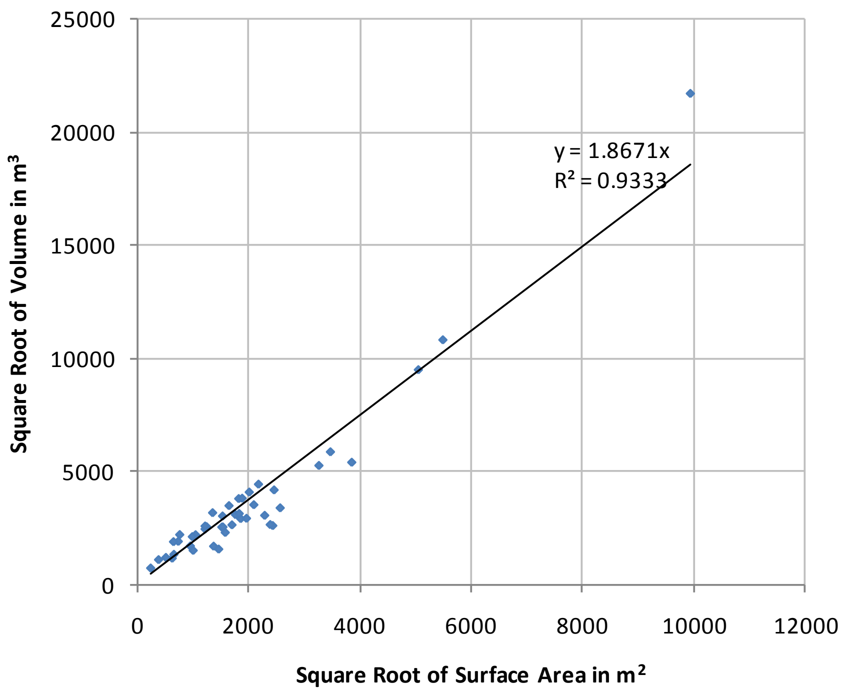
Appendix D—Detailed methodology

Overland flows

Volume – surface area relationship

A volume – surface area relationship was developed using data supplied by the Queensland Department of Natural Resources and Water, as shown in Figure 27. The Queensland government required landholders with existing works in the Lower Balonne basin to have their works certified by a registered professional engineer by February 2006. This yielded information about the volume and surface area of each dam, which the department has supplied for the purposes of this project. The data were supplied without reference to the location of individual dams.

Figure 27: Relationship between volume and surface area of floodplain harvesting dams in the Lower Balonne basin, Queensland



As shown in Figure 27, linear regression was performed on the square roots of each of volume and surface area. Standard linear regression (the least-squares method) tends to emphasise the impact of larger errors since the objective function minimises the sum of the squares of the errors. In this application, the square root was taken so that the estimating equation would be more likely to match the aggregate volume of the sample set.

The equation derived is as follows:

$$\sqrt{Volume\ (m^3)} = \sqrt{Surface\ Area(m^2)} \times 1.8671$$

Thus $$Volume\ (m^3) = Surface\ Area\ (m^2) \times 3.486$$

Estimating diversions of floodwaters

A map of the sample study area is given in Figure 28. A total of 27 floodplain harvesting storages have been identified within the study area.

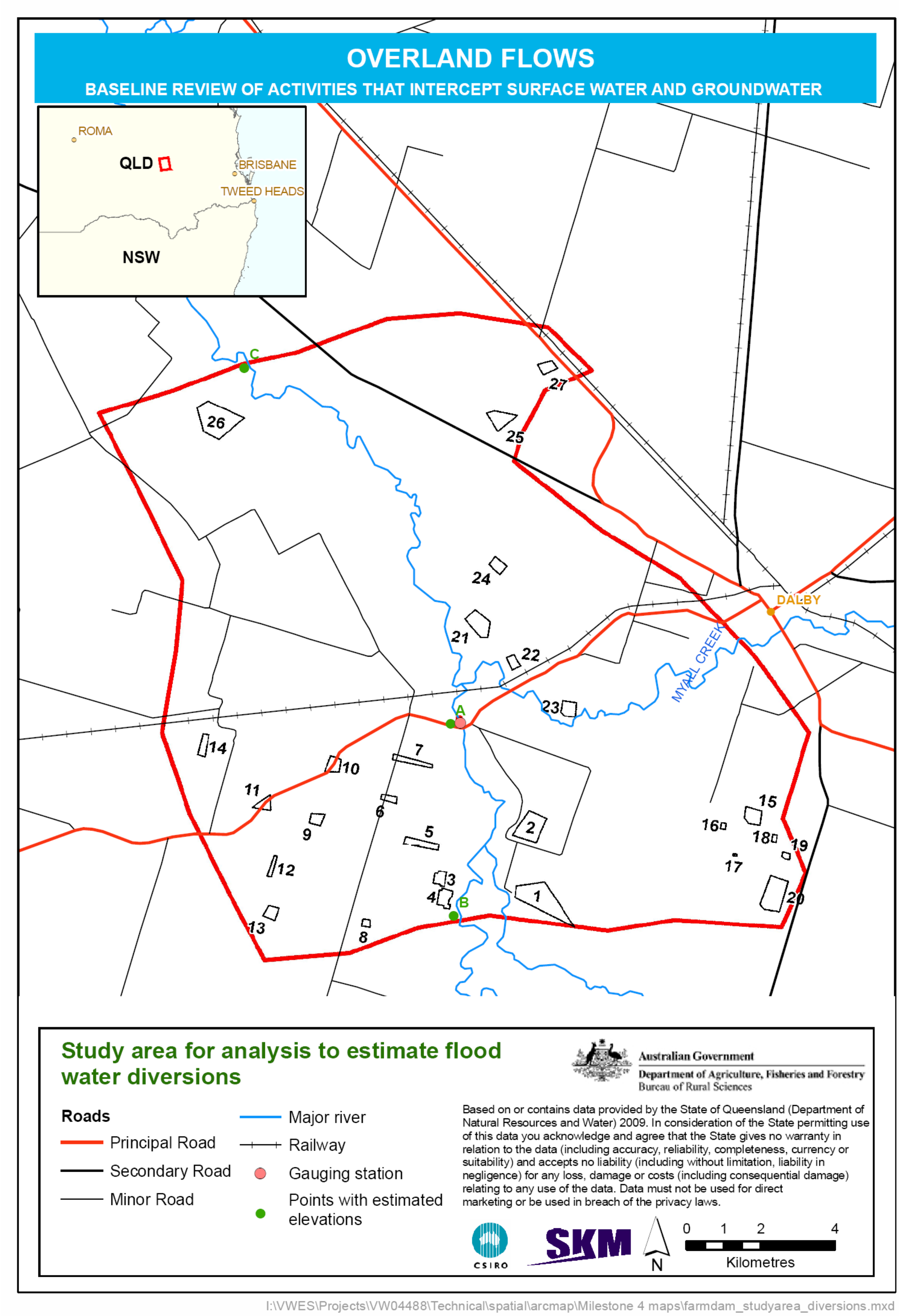
The study area centres on the gauging station at Loudoun Bridge (422333). The elevation of the floodplain is approximately 332 metres AHD adjacent to the gauging site (point A on Figure 28), and the upstream and downstream boundaries of the study area were chosen so that the change in elevation along the river was no greater than 5 metres. Thus, at point B the floodplain elevation is about 337 metres AHD, and at Point C the floodplain elevation is about 327 metres AHD.

The method used is summarised below. Each step was carried out for each of the 27 individual dams.

1) **Estimate the river level (at station 422333) required for floodwater to reach the base of the dam's embankment.** The elevation at the base of the embankment was found from the digital elevation model. This elevation was then adjusted according to the extent to which the dam was considered to be upstream or downstream of the gauging point. It is noted that this process was somewhat subjective. This is due to the difficulties of assigning a numerical value representing the extent to which a storage is upstream or downstream relative to the gauge, given the fact that some storages may be up to 10 kilometres away from the river channel.
2) **Identify periods in the historical record when the river level was at the level in (1) or higher.** This was done for the 30 year period March 1969 to January 2009.
3) **Calculate the hydrologic impact at these times under the following two assumptions:**
   a) *The dam fills by gravity.* In this scenario, the dam is assumed to have a floodgate that can be opened to allow floodwaters into the storage. After the flood recedes, the level in the storage is assumed to be the highest level that the floodwaters reached.
   b) *The dam is filled by pumping.* In this scenario, the landholders are assumed to pump water at a constant rate so long as the flood is above the level in (1). A filling period of 10 days is assumed. This means that for each day that the floodwaters are at the level in (1), the assumed hydrological impact is 10 per cent of the dam volume. The 10-day period was derived from data collected for the Murray–Darling Basin Commission (FSA/Aquatech 2007), which provided statistics for a sample of 14 properties. The median filling period for the sample was 10 days (although it is noted that five farms had filling period of longer than 25 days).

The *fills by gravity* scenario is expected to give lesser impacts than the *pumping* scenario. As such, the *fills by gravity* scenario will be referred to as a lower estimate of impact, and the *pumping* scenario as an upper estimate of impact.

Figure 28: Map of sample study area (a section of the Upper Condamine River floodplain) for analysis to estimate flood water diversions



Estimating diversions of rainfall–runoff

The method is summarised below:

Select sample areas containing numerous storages, from among the basins with relatively high density of floodplain harvesting (as shown in Figure 29 below).

1) **Calculate the total average annual runoff** from each of these areas by:
   a) estimating the amount of irrigated land in the sample using Bureau of Rural Sciences landuse data
   b) assuming that the average annual runoff from irrigated lands is 50 mm per year, and the average annual runoff from non-irrigated land is 18 mm per year, in line with estimates derived in the Condamine Basin by Porter and Delforce (2000).
2) **Estimate the rainfall-runoff diversion** by assuming a particular proportion of the runoff from (b) is diverted and does not reach the river. As a broad estimate, it will be assumed that 50 per cent of the runoff from non-irrigated lands is diverted,[3] based on the geometry of irrigation fields and rivers in the sample areas. It is assumed that all runoff from irrigated lands is diverted, through tailwater systems.
3) **Estimate the *ML diversion per ML of storage*** as the ratio of the estimated rainfall-runoff diversion from (2) and the total volume of storage within the sample area (repeat for each sample area).

As mentioned above, it was assumed that the runoff from irrigated and non-irrigated portions of the floodplain was 50 mm and 18 mm respectively. For comparison, the annual rainfall at Dalby in the Condamine River catchment is 676.4 mm per year. Therefore, runoff coefficients for irrigated and non-irrigated lands using these figures are 7.4 per cent and 2.7 per cent of rainfall respectively.

[3] It is noted that this assumption would not be valid unless sample areas are taken that are (a) completely contained with the floodplain; (b) storages are spread throughout the sample / have good spatial coverage

Figure 29: Sample areas used to estimate diversions of rainfall-runoff

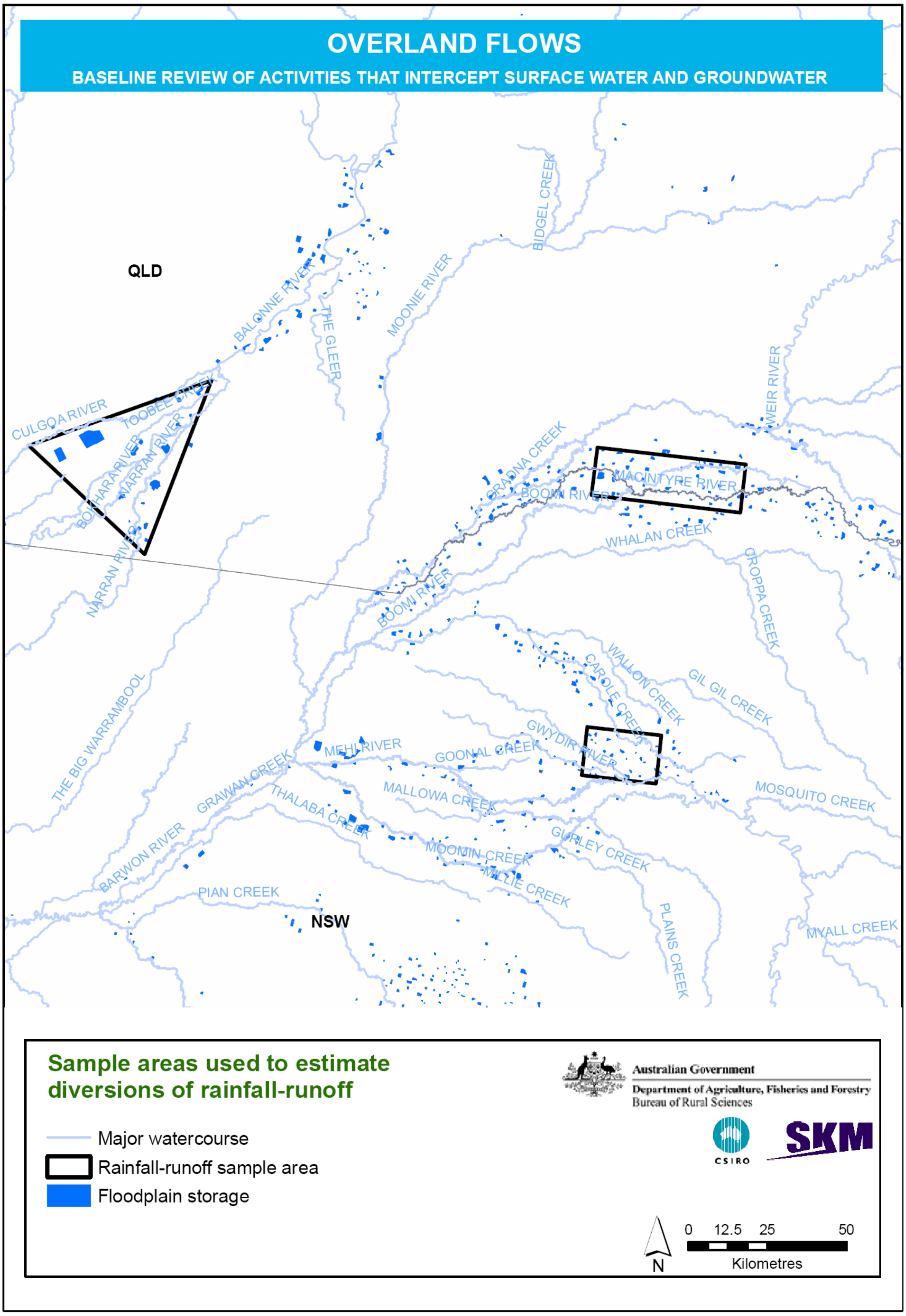


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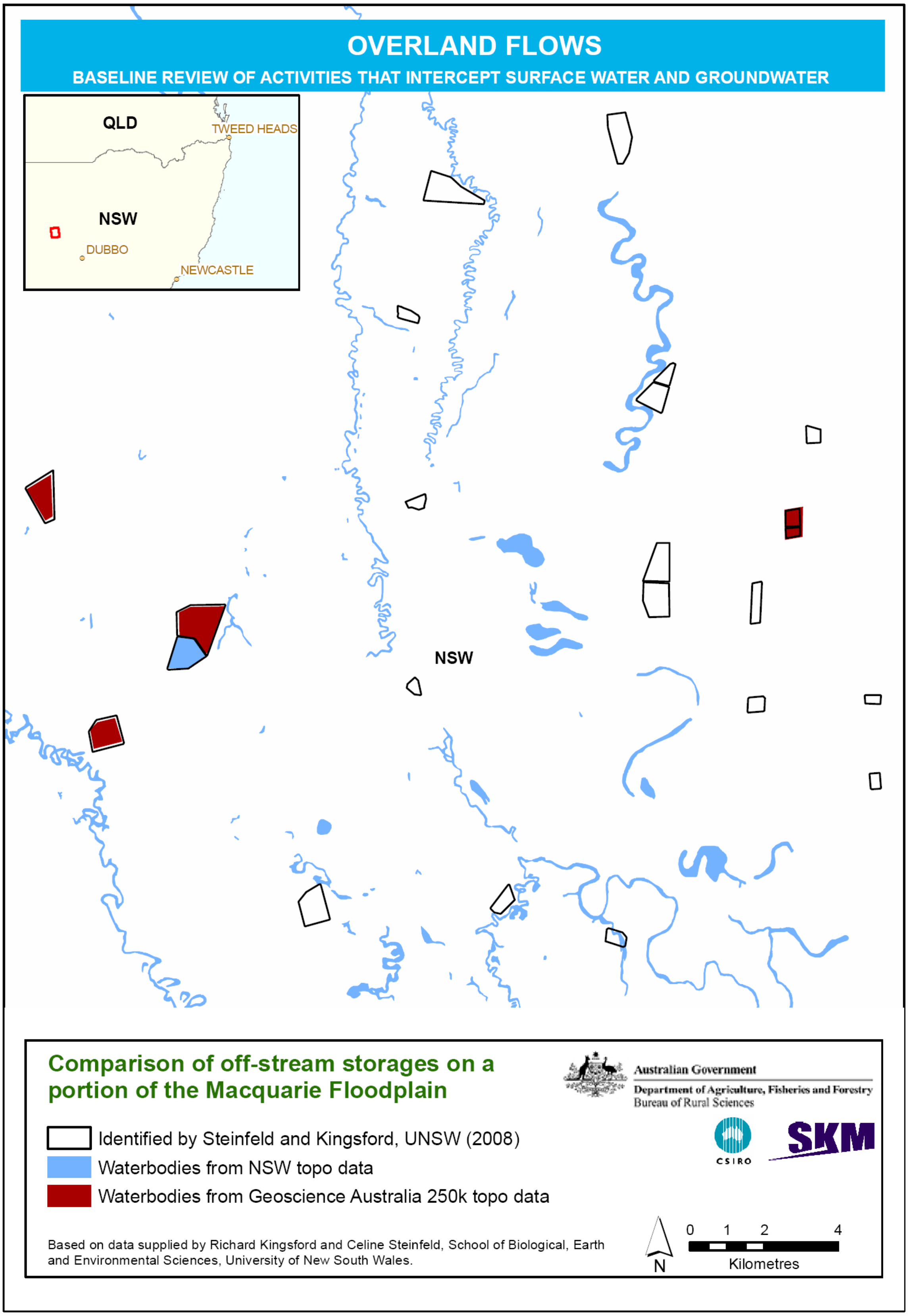
Figure 30: Comparison of off-stream storages on a portion of the Macquarie Floodplain



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Farm dams

Datasets utilised from the Murray–Darling Basin Sustainable Yields modelling (SKM 2007a) to develop a relationship between farm dam volume and impact were:

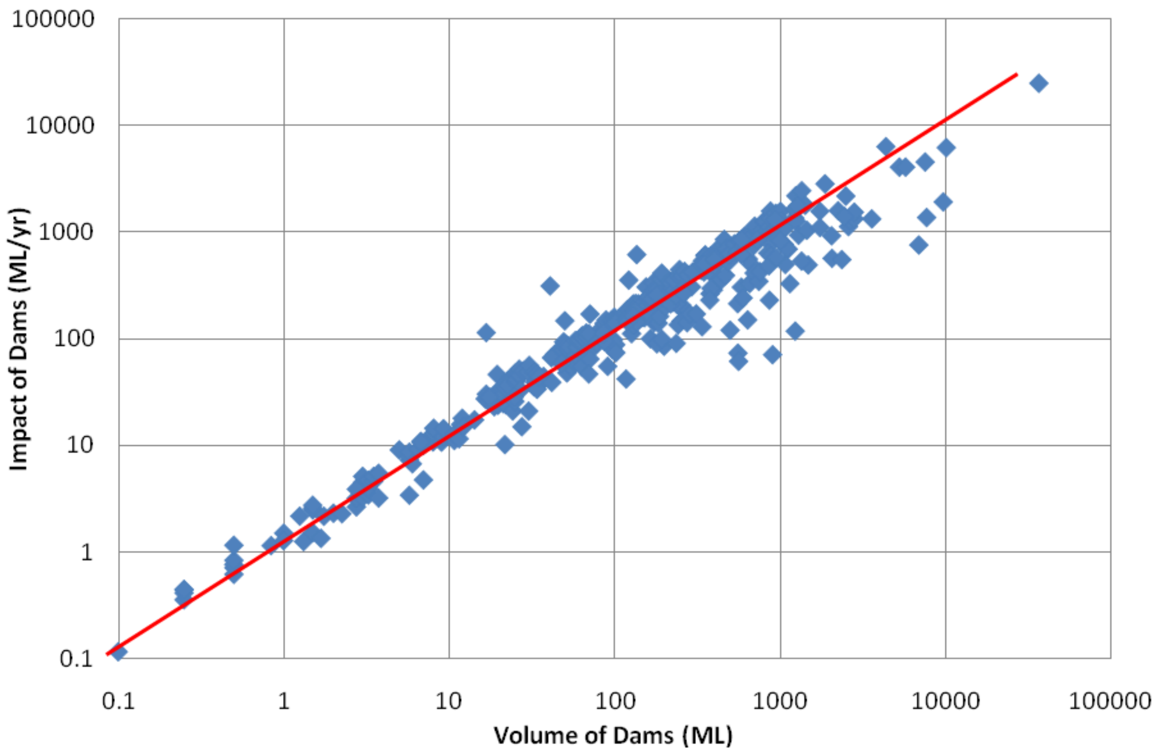
- projected volume of dams to 2030
- catchment areas for surface water gauging stations
- current runoff volume at each gauging station (i.e. 'unimpacted' runoff)
- projected runoff volume at each gauging station (i.e. 'impacted' runoff that takes into account projected dam volumes).

The relationship between dam volume and the reduction in runoff due to the dam was investigated to determine if the volume of a dam could be used to determine its impact on runoff. The 2030 projected dam volume for 445 catchments in the Murray–Darling Basin was plotted against the change in runoff occurring between current runoff levels and projected runoff levels (i.e. the dam impact) as seen in Figure 31.

A line of best fit was fitted to the datasets, which yielded Relationship 1:

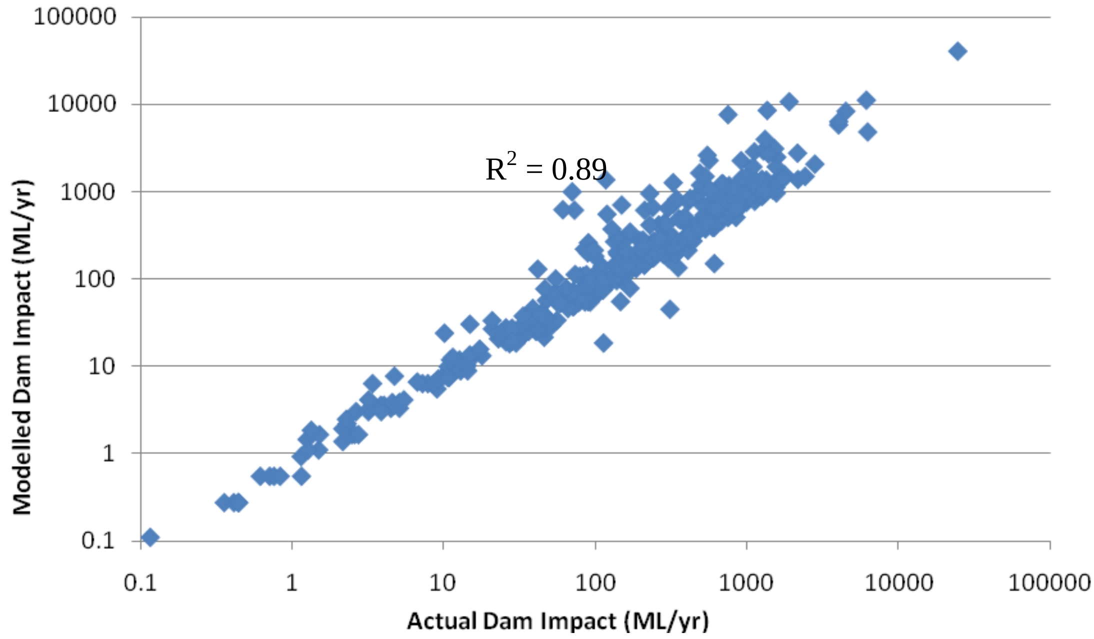
Impact of Dams (ML/yr) = 1.1 x Volume of Dams (ML)

Figure 31: Volume of dams versus the impact of dams



The 'actual' dam impact determined from the modelling undertaken in SKM (2007a) was compared with the dam impact determined from Relationship 1 as seen in Figure 32. The relationship yielded an R^2 value of 0.89.

Figure 32: Actual impact versus modelled impact from Relationship 1



Farm dam data

Farm dam data were collected from the sources listed in Table 25. An indication of the extent of farm dam data collected can be seen in Figure 33.

Table 25: Available farm dam data

State	Source	Type of data
South Australia	Department of Water, Land and Biodiversity Conservation	Farm dam volumes (ML)
Victoria	Data used from SKM (2007c)	Farm dam volumes (ML)
Western Australia	Department of Water	Farm dam surface areas (m^2)
New South Wales	Department of Land Information; Geosciences Australia	Farm dam surface areas (m^2)
Tasmania	Streetworks 2006, PSMA	Farm dam surface areas (m^2)

No farm dam data were available for Queensland and the Northern Territory. For those states that had farm dam surface area data available, volumes were determined using the following relationships:

New South Wales and Tasmania (SKM 2004c)[4]:

$$\text{Volume (ML)} = 0.000145 \times \text{Surface Area}^{1.314}\ (\text{m}^2)$$

Western Australia (Department of Water 2006):

$$\text{Volume (ML)} = 0.0007 \times \text{Surface Area}^{1.0709}\ (\text{m}^2)$$

[4] This relationship was originally developed for Victoria but is applicable to New South and Tasmania

Land use data

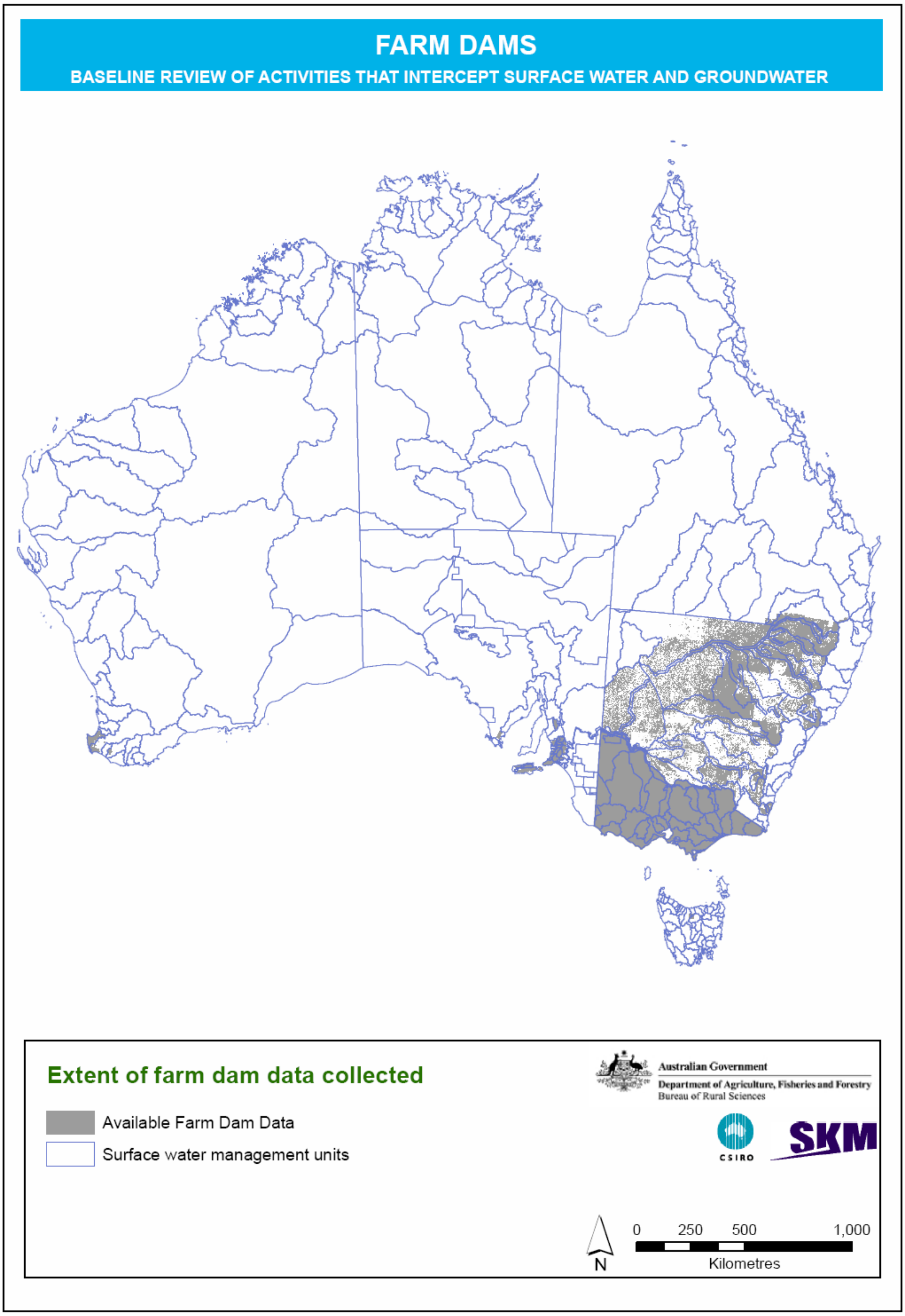
Land use area data for each SWMA in each state and territory were provided by the Bureau of Rural Sciences for 2008, 2015 and 2030. These data classified Australia into the land use classes listed below:

- 110 Woodland
- 120 Open forest
- 130 Closed forest
- 140 Plantation
- 210 Open woodland
- 220 Shrubland
- 230 Native pastures
- 240 Sown pastures
- 311 Irrigated summer crops
- 321 Irrigated winter crops
- 322 Summer or winter cropping
- 330 Sugar
- 331 Irrigated sugar
- 340 Cotton
- 341 Irrigated cotton
- 351 Irrigated horticulture
- 400 Bare
- 410 Urban
- 420 Rural residential
- 500 Water

Of these land use types it was assumed that no farm dams are present in:

- 110 Woodland
- 120 Open forest
- 130 Closed forest
- 140 Plantation
- 400 Bare
- 410 Urban
- 500 Water

Figure 33: Extent of farm dam data sourced for this project



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Stock and domestic bores

Table 26: Definition of stock and domestic bores according to state legislature

State or Territory	*Relevant Act*	*Definition of stock and domestic bores*
ACT	*Water Resources Act 2007*	• Domestic use for a person, their family or employees • Irrigating a garden no larger than 2 hectares, that is cultivated for domestic use and not for the sale, barter or exchange of goods • Watering stock of a number that would normally be depastured on the land where the water is found. Not for stock held in close concentration for a purpose other than grazing
NSW	*The Water Management Act 2000*	• Household purposes (non commercial uses around house and garden) • Water of stock
NT	*Water Act 1994*	• Domestic use for a person, their family or employees • Irrigating a garden no larger than 0.5 hectares, that is used in direct connection with the house • Drinking water for stock grazing on the land
QLD	*The Water Act 2000*	• Irrigating a garden no larger than 0.25 hectares, that is cultivated for domestic use and not for the sale, barter or exchange of goods. • Watering stock of a number that would normally be depastured on the land which the water is, or is to be used • Watering travelling stock on a stock route
SA	*Natural Resources Management Act*	• Irrigating a garden no larger than 0.4 hectares • Domestic use for a person, their family or employees' personal use • Providing drinking water for stock on the land that are not subject to intensive farming
TAS	*Water Management Act 1999*	• Drinking, cooking and washing but does not include water used in carrying on a business unless it is for personal employee use • Watering stock and normal husbandry practices associated with the keeping of livestock. Not providing water for livestock subject to intensive farming
VIC	*Water Act 1989*	• Watering of animals kept as pets • Watering of cattle or other stock • Household uses • Watering of a kitchen garden • Does not include water used for dairies, piggeries, feedlots, poultry or any other intensive commercial purpose
WA	*Rights in Water and Irrigation Act 1914*	• In house use and garden watering • Watering of stock under non-intensive conditions

Figure 34: Status of groundwater inclusion in cap as available in AWR2005

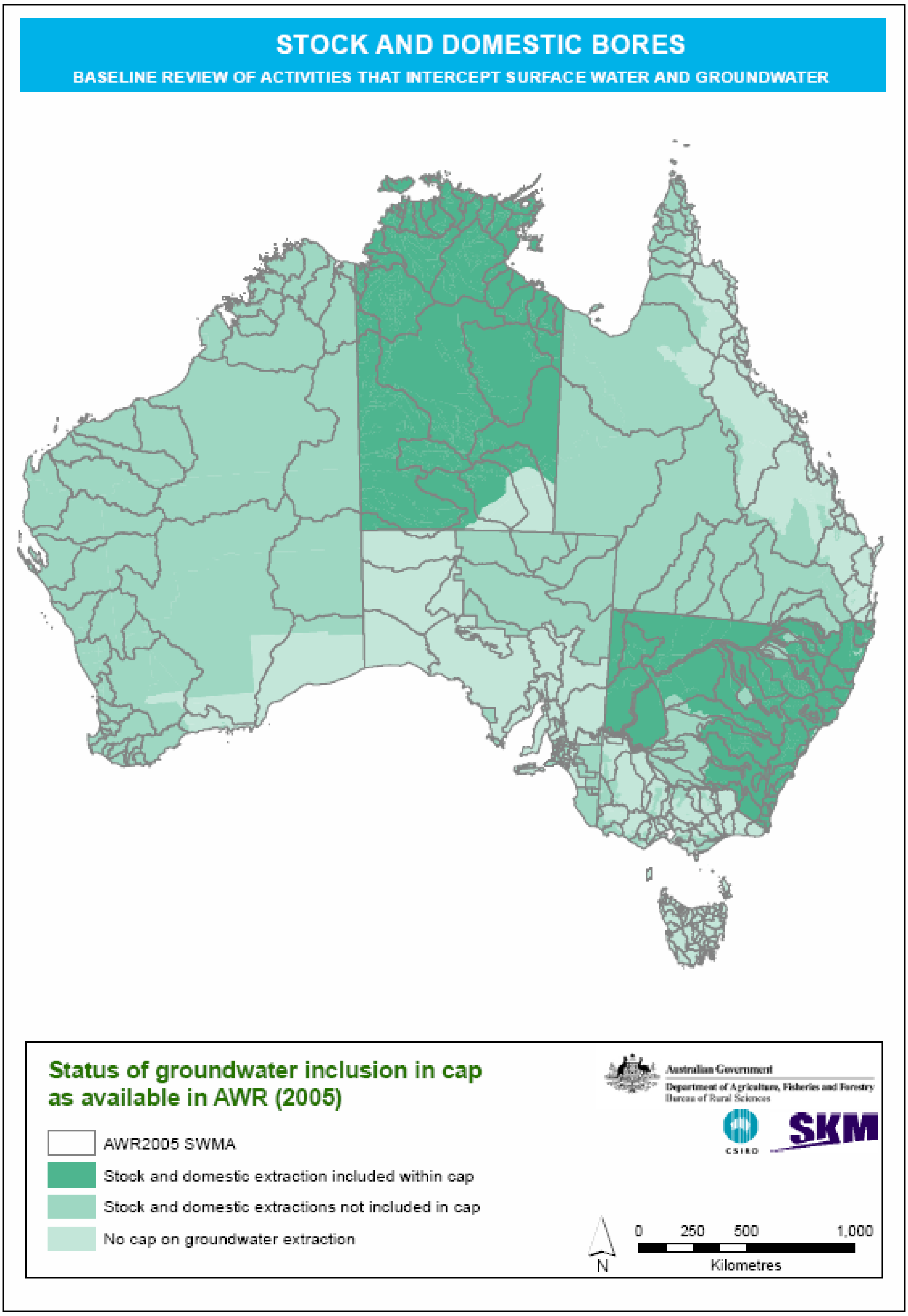

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Table 27: Water use statistics from Victorian state water reports

Water reporting year and component		*Total resource (ML)*	*Entitlement/allocation (ML)*	*Water used (ML)*
2003–2004	Surface water	1803900	5828000	4894000
	Groundwater (not including stock and domestic)	NA	85300	364910
	Stock and Domestic use is approximately 9% of overall groundwater use			36090
2004–2005	Surface water	17272000	5366000	4984000
	Groundwater (not including stock and domestic)	NA	85300000	384020
	Stock and Domestic use is approximately 9% of overall groundwater use			37980
2005–2006	Surface Water	15312200	6216340	4921360
	Groundwater (not including stock and domestic)	NA	879900	326007
	Stock and Domestic use is approximately 11% of overall groundwater use			40293

Source: SWR 03/04; SWR 04/05; SWR 05/06

Table 28: Water use statistics from Murray–Darling Basin Commission report (2003)

Groundwater users within the Murray–Darling Basin 1999–2000	*Urban Domestic Use (ML)*	*Rural Stock and Domestic (ML)*	*Irrigation*	*Industrial/ Commercial*
Great Artesian Basin Total	37420	367450	11840	-
Other groundwater management units	24423	54240	1132073	57772
Unincorporated areas	20599	74239	117913	29627
TOTAL	82442	495929	1261826	87399

Total groundwater used within the Murray–Darling Basin between 1999–2000 is 1,927,596 megalitres
Total percentage of use for all Stock and Domestic purposes is 30 per cent
Most stock and domestic use is concentrated in rural areas

Table 29: AWR2000 groundwater use statistics for 1996–97

State or territory	*Mean annual groundwater use for 96–97 from AWR2000 data (ML)*		*Total water use 96–97 from AWR2000 data (ML)*	*% of water use accounted for by rural stock and domestic bores (96–97)*	
	Rural stock and domestic bores	*All uses*		*% of total groundwater use*	*% of all water used*
VIC	54,000	622,000	5,777,000	9	0.93
NSW	205,000	1,008,000	10,008,000	20	2.05
SA	42,000	419,000	1,164,000	10	3.61
WA	37,000	1,138,000	1,796,000	3	2.06
NT	33,000	128,000	179,000	26	18.44
TAS	4,000	20,000	471,000	20	0.85
QLD	410,000	831,000	3,800,000	49	10.79
ACT	3,000	5,000	72,000	60	4.17
Total	788,000	4,171,000	23,267,000	19	3.39

Table 30: AWR 2000 groundwater use statistics for Victoria for 1996–97

Groundwater management area (GMA) or water plan area (WSPA)	*No. of stock & domestic bores*	*Estimated stock & domestic use (assuming 2ML/bore)*	*Groundwater extraction AWR2005 data (ML 2004–05)*	*Groundwater sustainable yields ML*	*% of groundwater extraction used by stock & domestic*
Kialla GMA	23	46	862	4770	5.34
Katunga WSPA	593	1186	27406	NA	4.33
Shepparton WSPA	1373	2746	80650	NA	3.40
Mullindolingong GMA	77	154	606	6980	25.41
Barnawartha GMA	28	56	226	2100	24.78
Murmungee GMA	1285	2570	6697	16710	38.38
Goorambat GMA	17	34	574	4888	5.92
Alexandra GMA	52	104	704	900	14.77
Kialla GMA	23	46	862	4770	5.34
Kinglake GMA	342	684	1328	3830	51.51
Campaspe Deep Lead	188	376	26089	NA	1.44
Katunga WSPA	593	1186	27406	NA	4.33
Nagambie GMA	78	156	4550	5650	3.43
Ellesmere GMA	27	54	830	1900	6.51
Bungaree WSPA	252	504	2862	NA	17.61
Mid Loddon WSPA	124	248	18050	37200	1.37
Spring Hill WSPA	64	128	1642	5000	7.80
Upper Loddon WSPA	198	396	6822	NA	5.80
Kaniva TCSA GMA	0	0	0	1100	NA
Murrayville WSPA	280	560	5200	10883	10.77
Telopea Downs WSPA	97	194	3976	13435	4.88
Balrootan (Nhill) GMA	51	102	446	980	22.87
Goroke GMA	0	0	0	2200	NA
Nhill GMA	0	0	0	1200	NA
Stratford GMA	410	820	18050	NA	4.54
Sale WSPA	919	1838	8599	13000	21.37
WyYung WSPA	116	232	906	9070	25.61
Rosedale GMA	1	2	9922	9000	0.02
Wa De Lock	482	964	10367	11500	9.30
Denison WSPA	297	594	6797	12000	8.74
Moe GMA	197	394	1478	8193	26.66
Yarram WSPA	970	1940	9070	26625	21.39
Corinella GMA	157	314	371	2550	84.64
Giffard GMA	171	342	2862	3000	11.95

Groundwater management area (GMA) or water plan area (WSPA)	*No. of stock & domestic bores*	*Estimated stock & domestic use (assuming 2ML/bore)*	*Groundwater extraction AWR2005 data (ML 2004–05)*	*Groundwate r sustainable yields ML*	*% of groundwater extraction used by stock & domestic*
Leongatha GMA	114	228	743	6500	30.69
Tarwin GMA	806	1612	256	1300	629.69
Frankston GMA	199	398	782	3200	50.90
Moorabbin GMA	238	476	1201	4305	39.63
Koo-Wee-Rup WSPA	600	1200	3670	14898	32.70
Nepean GMA	1162	2324	2466	5000	94.24
Wandin Yallock WSPA	163	326	463	3300	70.41
Cut Paw Paw WSPA	2	4	190	3650	2.11
Lancefield GMA	76	152	262	1485	58.02
Merrimu GMA	13	26	103	450	25.24
Deutgam WSPA	257	514	1217	2400	42.24
Cardigan GMA	481	962	NA	NA	NA
Gellibrand GMA	NA	NA	NA	NA	NA
Gerangamete GMA	5	10	10	NA	100.00
Bungaree WSPA	252	504	2862	NA	17.61
Colongulac GMA	208	416	1676	14271	24.82
Paaratte GMA	4	8	1125	4606	0.71
Warrion WSPA	461	922	4741	16500	19.45
Jan Juc GMA	NA	NA	1400	6804	NA
Newlingrook GMA	NA	NA	689	74970	NA
Nullawarre WSPA	1197	2394	10687	25100	22.40
Glenormiston	125	250	1129	5042	22.14
Yangery WSPA	1432	2864	5952	11500	48.12
Heywood GMA	1735	3470	5725	21763	60.61
Portland GMA	63	126	702	20683	17.95
Condah WSPA	58	116	3328	NA	3.49
Glenelg WSPA	N/A	NA	19950	NA	NA
Little desert GMA	NA	NA	NA	1100	NA
Apsley WSPA	134	268	1580	24355	16.96
Kaniva WSPA	112	224	2436	1100	9.20
Neuarpur WSPA	297	594	19760	24750	3.01
Kaniva GMA	NA	NA	NA	1100	NA
Total	19679	39358	381315	519566	
Median Value					17.78

Relationships examined for making future predictions

An appraisal of relationships, that might be used to estimate future growth areas for stock and domestic bores, was undertaken by plotting 'standalone' bores against the following datasets:

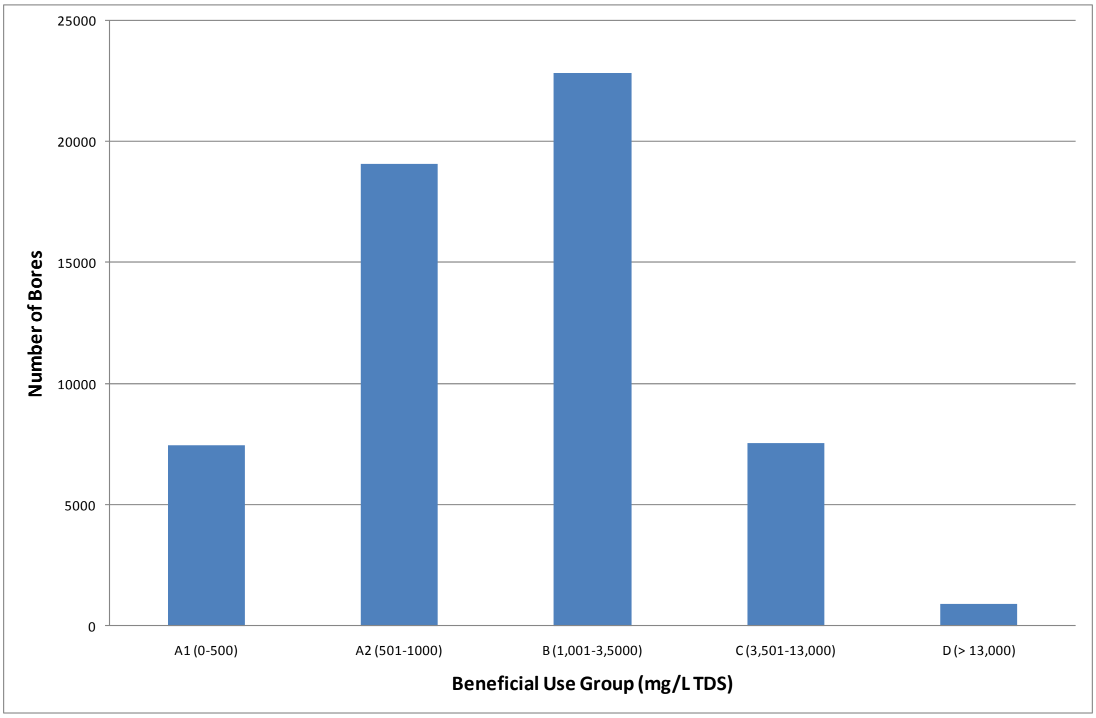
- groundwater salinity (beneficial use) data
- land use data (Bureau of Rural Sciences)
- population data (Australian Bureau of Statistics), in order to establish relationships that could be used to make future predictions regarding growth areas for standalone stock and domestic bores
- historical trends in bore completion (base on bore completion dates).

Groundwater salinity

Victorian bore data were plotted against available 'beneficial use' data, with the aim of identifying a relationship between groundwater quality and the number of stock and domestic bores. The results are presented in Figure 35 below.

As expected, most standalone stock and domestic bores are found in areas with better quality groundwater (less than 3500 milligrams per litre of total dissolved solids), although there are many bores constructed to extract more saline water where no other supply exists (e.g. for stock watering). This relationship, however, was not thought to be useful for making future predictions. The beneficial use dataset was readily available for Victoria only and not other states. For both these reasons, this relationship was not examined for other states.

Figure 35: Victorian bore data intersection with groundwater salinity (beneficial use) data



Land use

Bore data were plotted against land use data from the Bureau of Rural Sciences, for each state, with the aim of identifying a relationship between different land uses and the number of stock and domestic bores. It was thought that this relationship could then be applied to estimate the areas of high growth for stock and domestic bores. Spatial analysis utilising GIS-extracted data provided the number of bores present on each land use. A comparison was then made between the number of bores on each land use and the area that each land use covers, in order to calculate a bore density (bores per square kilometre value) for each land use. The results are summarised by state in Table 31, and they indicate that irrigated pastures and crops, horticulture, urban and rural residential and sown pasture land uses generally have the highest concentration of bores. As expected, populated land use areas (urban and rural residential) and land uses associated with rural residential (pasture and crops) are where most domestic and stock bores are found.

It is important to note that the accuracy of the bore density value is dependent upon the accuracy of the bore location data. The bore location datasets available for NSW, Victoria, Western Australia's PRAMS area, South Australia and Queensland contained some bores with no location data. It is also likely that there are more bores than presented in these datasets, as stock and domestic bores are often unregistered. So it can be assumed that the bore density values presented in Table 31 are lower than in reality, and any future predictions made using these values will be underestimates.

However, the extremely high bore density values found in the 'irrigated sown pasture' land use raised some concerns. The irrigated sown-pasture land use area increased from 492 square kilometres in 2008 to 11,489 in 2015 and 12,474 square kilometres in 2030. Any results based on these bore density values should, therefore, be regarded with caution. It is considered that this approach has a lower reliability, and other assessment methods should be used to estimate future trends in stock and domestic bore development.

Table 31: Results from bores per land use analysis

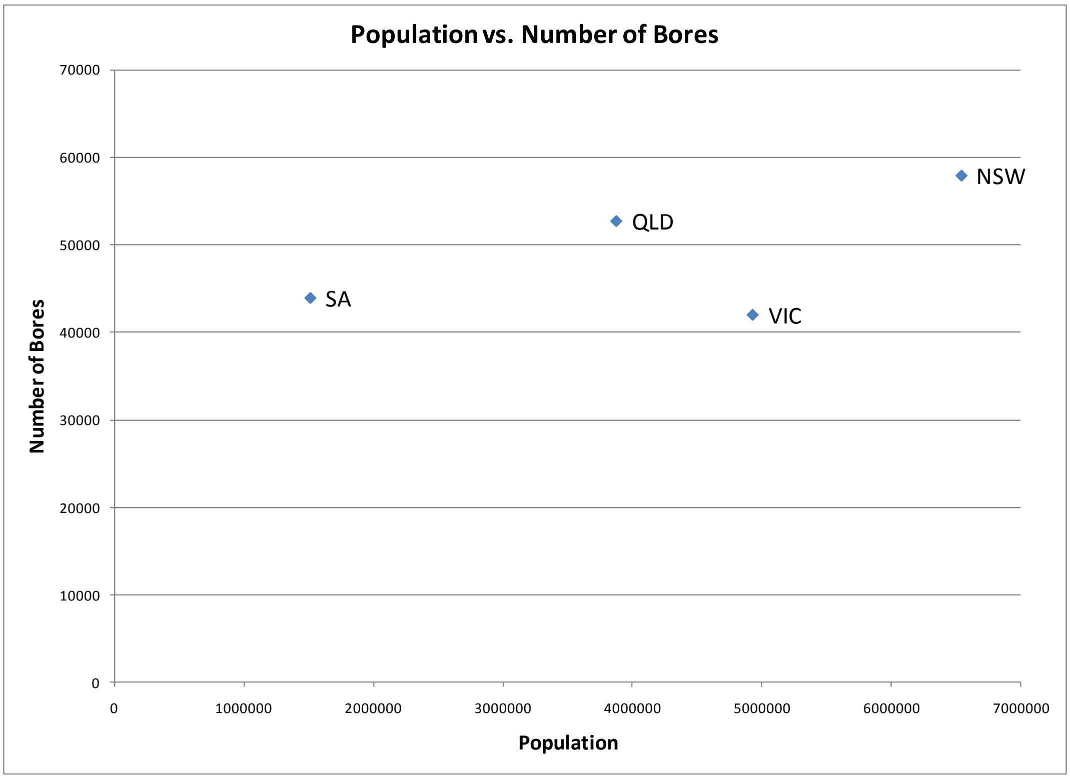
		NSW			QLD			SA			VIC			WA_Prams model area			Australia (Based on Data from NSW, QLD, SA, VIC, WA_Prams area)		
Land Use Code	Land Use Description	Km^2	No. of Bores	Bore Density (bores/km^2)	Km^2	No. of Bores	Bore Density (bores/km^2)	Km^2	No. of Bores	Bore Density (bores/km^2)	Km^2	No. of Bores	Bore Density (bores/km^2)	Km^2	No. of Bores	Bore Density (bores/km^2)	Km^2	No. of Bores	Bore Density (bores/km^2)
241	Irrigated sown pastures	12	907	75.58	NA	NA	NA	404	642	1.59	69	2270	32.90	5	164	32.80	490	3983	8.13
231	Irrigated native pastures	NA	NA	NA	NA	NA	NA	NA	NA	NA	2	2	1.00	NA	NA	NA	2	2	1.00
350	Horticulture	409	671	1.64	207	6	0.03	32	24	0.75	37	12	0.32	181	1	0.01	866	714	0.82
410	Urban	9187	4621	0.50	3681	1498	0.41	8218	7364	0.90	8192	5753	0.70	1682	6059	3.60	30960	25295	0.82
420	Rural residential	5273	4240	0.80	5643	1772	0.31	673	1480	2.20	2276	2401	1.05	548	80	0.15	14413	9973	0.69
351	Irrigated horticulture	1041	328	0.32	1024	299	0.29	1462	1329	0.91	1430	931	0.65	332	438	1.32	5289	3325	0.63
331	Irrigated sugar	NA	NA	NA	4672	1726	0.37	0	NA	NA	NA	NA	NA	NA	NA	NA	4672	1726	0.37
321	Irrigated winter crops	3137	390	0.12	623	185	0.30	284	373	1.31	1147	392	0.34	3	NA	NA	5194	1340	0.26
340	Cotton	90	3	0.03	234	78	0.33	0	NA	NA	NA	NA	NA	NA	NA	NA	324	81	0.25
311	Irrigated summer crops	4152	560	0.13	2516	749	0.30	166	176	1.06	333	101	0.30	2	2	1.00	7169	1588	0.22
341	Irrigated cotton	2888	457	0.16	2175	487	0.22	0	NA	NA	NA	NA	NA	NA	NA	NA	5063	944	0.19
330	Sugar	297	226	0.76	1308	55	0.04	0	NA	NA	NA	NA	NA	NA	NA	NA	1605	281	0.18
240	Sown pastures	240288	28399	0.12	250823	23911	0.10	54126	17501	0.32	84348	23557	0.28	5391	99	0.02	634976	93467	0.15
310	Summer crops	26304	3058	0.12	16925	3004	0.18	11009	1207	0.11	8364	331	0.04	22934	1065	0.05	85536	8665	0.10
320	Winter crops	48019	4581	0.10	8637	1090	0.13	42044	5544	0.13	28171	1580	0.06	99576	626	0.01	226447	13421	0.06
210	Open woodland	60263	1601	0.03	240541	4420	0.02	179423	1630	0.01	5629	1205	0.21	13754	225	0.02	499610	9081	0.02
230	Native pastures	36241	838	0.02	364422	6769	0.02	147620	578	0.00	6389	430	0.07	18037	120	0.01	572709	8735	0.02
	Totals	437601	50880	0.12	903431	46049	0.05	445461	37848	0.08	146387	38965	0.27	162445	8879	0.05	2095325	182621	0.09

Note: The following land uses were excluded from these tables as they had an insignificant number of bores (possibly due to changed land use since construction of the bore) or bores plotted in these land types only as a result of locality errors in location data: 110 Woodland, 120 Open forest, 130 Closed forest, 140 Plantation, 400 Bare, 500 Water, 220 Shrubland.

Population

An initial correlation was made between the number of bores (with data) for each state and population data (from the Australian Bureau of Statistics). Figure 36 demonstrates a general linear relationship between increasing population and increasing number of bores. The number of bores shown for Victoria (41,989) appears to be low and totals are expected to be high, given that there are approximately 15,000 bores with unknown use or location data.

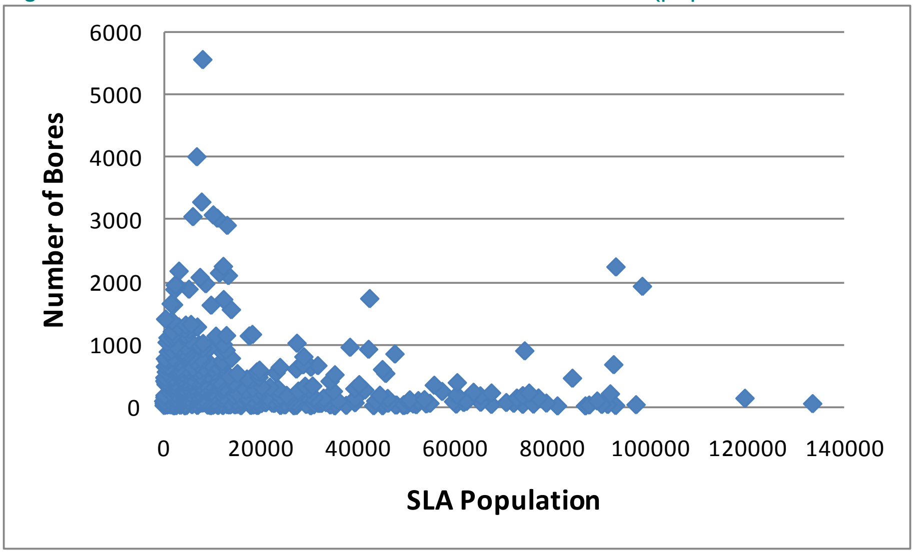
Figure 36: ABS (2006 Census) population data *versus* Number of bores (in 2007)



ABS = Australian Bureau of Statistics

This approximate correlation was studied in more detail by plotting bore data against Australian Bureau of Statistics population data, for statistical local areas (SLAs). This was done with the aim of identifying a relationship between population and number of bores in order to estimate areas of high growth for stock and domestic bores. Australia is divided into 1151 SLAs, of which only 496 have 10 or more bores. Figure 37 demonstrates that within these 496 SLAs, a larger population does not imply more standalone stock and domestic bores. This is possibly due to the fact that small densely populated SLAs have access to reticulated water, while SLAs that cover a more rural setting may not have access to reticulated water. These rural SLAs have a lower population, but a lack of access to reticulated water makes them more reliant on alternative water supplies, such as stock and domestic bores.

Figure 37: Statistical local areas with 10 bores or more (population *versus* bores)



Land use and population

GIS analysis was undertaken to enable the land uses within each SLA to be identified and quantified. This allowed for comparisons to be made between population, land use, and the number of bores. The SLAs with the highest number of bores were then examined in order to establish any patterns. Figure 38 examines the top ten SLAs with the largest number of bores and plots the percentage of area covered by each land use. Figure 39 plots the percentage of area covered by each land use type for the SLAs with the highest 'density of bores.' (i.e. the size of SLA is taken into consideration). Two points can be made from these figures:

- Sown pasture is the predominant land use within large SLAs with the highest number of bores (Figure 38).
- Urban land use type is the predominant land use within SLAs with the highest density of bores (i.e. highest bores per size of SLA in square kilometres).

Figure 38: Predominant land use types within SLAs with highest number of bores

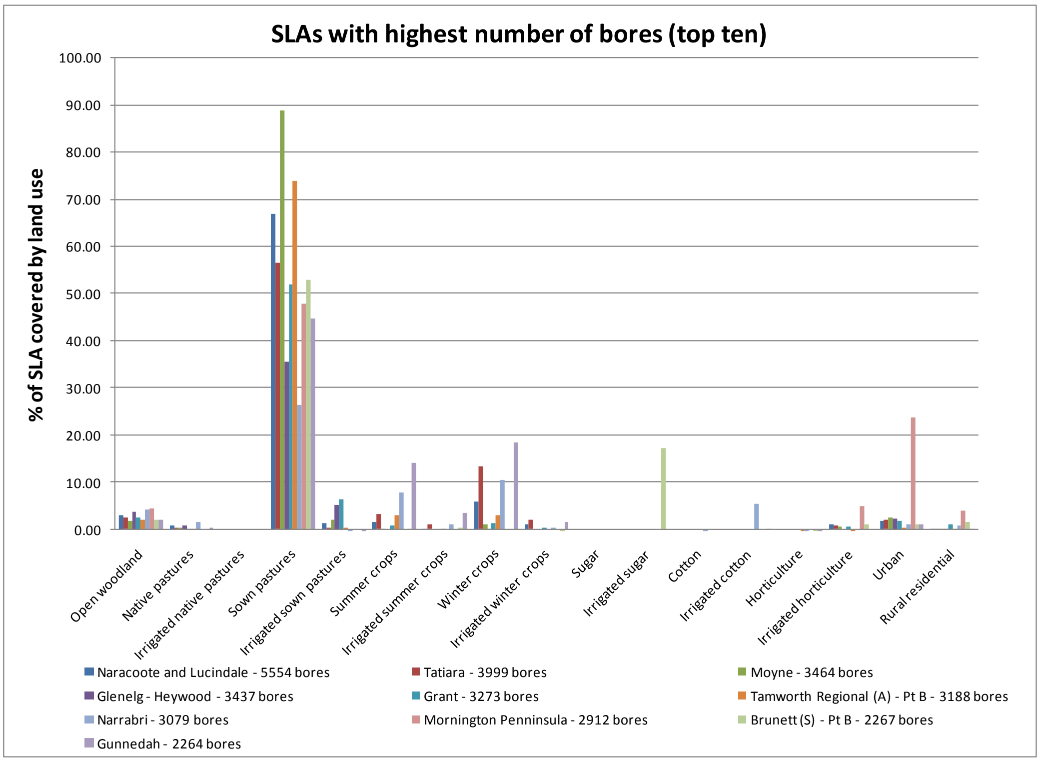
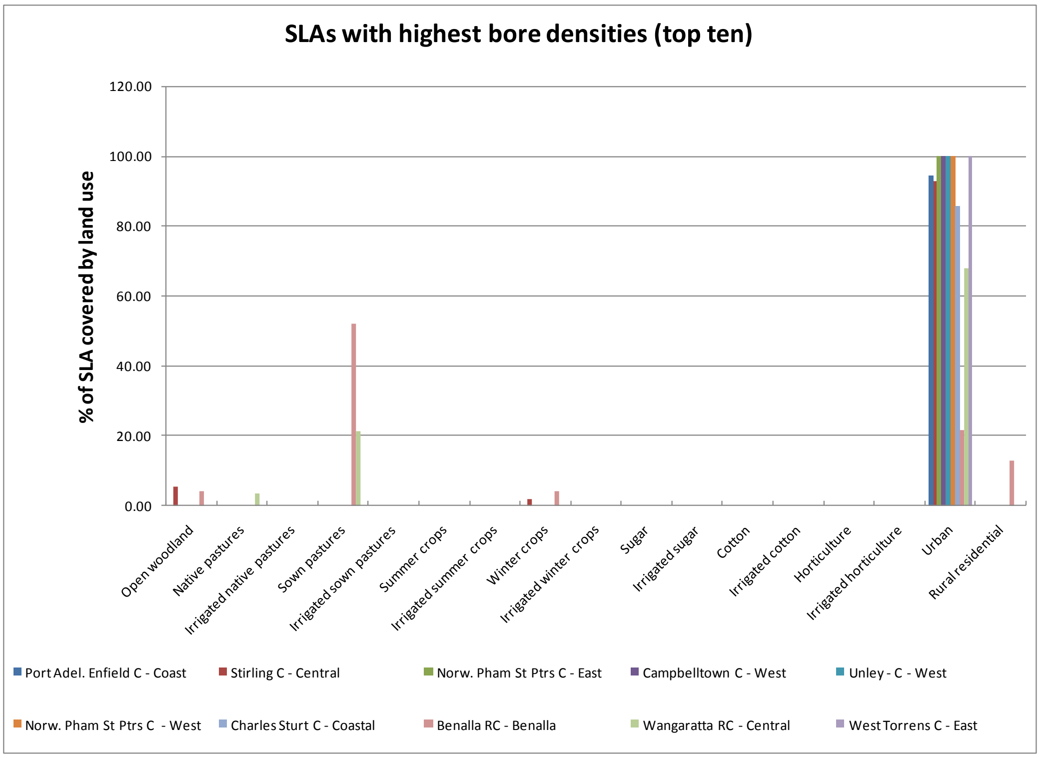


Figure 39: Predominant land use types within SLAs with highest bore density



Temporal increase of standalone stock and domestic bores

It was considered that analysis of bore-completion data on a SWMA basis would allow for the establishment of bore growth rates, which could then be used to predict future number of stock and domestic bores.

Completion dates were sourced for bore data from NSW, South Australia, Victoria and Western Australia and sorted into five-yearly time periods between the years 1903 and 2007. Figure 40 demonstrates the number of bores drilled for five-yearly time periods, from 1958 onwards in Victoria. Prior to 1958, the number of bores drilled is relatively small (642) and there are approximately 163 bores for which completion dates are unavailable. There is a clear drop in the rate of bores drilled after 1992. This pattern is also repeated in data from South Australia and Western Australia's PRAMS Model (Figure 41 and Figure 43). The low number of bores drilled in more recent years (after 2003) is, in part, due to a backlog of bore-completion reports that have not yet been uploaded into the state database management systems (e.g. GMS). In NSW, the rate of bore growth appears to have peaked in the late 1970s (Figure 42). For South Australia and NSW, bore growth rates were calculated only for bores outside the Great Artesian Basin.

Across all four states, it was considered that the period 1993 to 2002 was the most representative of current and future bore growth trends. Average 'bore growth rates' (bores per year) were calculated from this period, on a SWMA basis, and used to produce estimates of the number of bores in 2015 and 2030. For each SWMA in NSW, South Australia, Victoria and Western Australia:

- The average 'bore growth rate' (bores/year) was calculated for the period 1993–2002.
- For SWMAs where this value was less than five bores per year, a minimum of five bores per year was assigned.
- The number of bores in 2015 and 2030 is calculated for each SWMA.

The bore data obtained for Queensland did not include bore completion or drilled dates. It was therefore necessary to find an alternative means of assigning 'bore growth rates' for SWMAs in Queensland. Data from other states (NSW, Victoria, South Australia and Western Australia's PRAMS Model area) were analysed to establish a correlation between the number of bores in 2007 and the rate of bore growth (1993–2002).

Figure 44, Figure 45, Figure 46 and Figure A4.3-14 demonstrate that there is a clear relationship, where SWMAs with a large number of bores in 2007 also have a higher rate of bore growth (bores/year). A general trend can be fitted to the data to give the following relationships:

Equation 1 Rate of bore growth in VIC (bores/year) = 0.0038*number of bores in 2007 + 1.5597

Equation 2 Rate of bore growth in SA (bores/year) = 0.0096*number of bores in 2007 + 0.2579

Equation 3 Rate of bore growth in NSW (bores/year) = 0.007*number of bores in 2007 + 1.9456

Equation 4 Rate of bore growth in WA (bores/year) = 0.0268*number of bores in 2007 + 4.1054

As bore-completion-date data were unavailable for Queensland, 'bore growth rates' were assigned using data from NSW This was based on expected similarities between the two states in terms of stock and domestic bore use and some climatic and land use similarities (notwithstanding the strong climatic differences – it was felt that NSW was most appropriate for correlation). Equation 3 was used to calculate a 'bore growth rate' for each SWMA in QLD and a minimum threshold of 5 bores/year was applied. This method estimates that across QLD in 2015 and 2030 there will be 57,052 and 65,239 bores, respectively. It should, however, be noted that these estimates are less reliable than estimates for Victoria, NSW, South Australia and Western Australia's PRAMS Model area.

Figure 40: Victorian bore completion date data

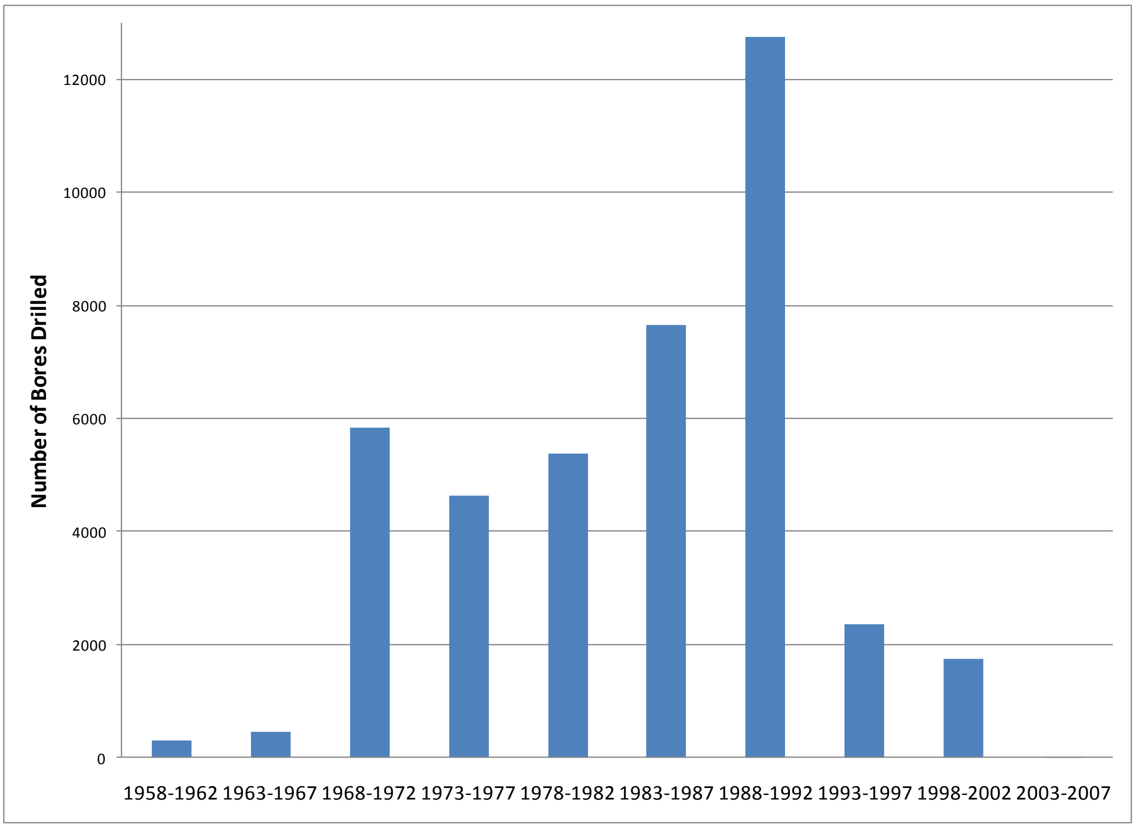


Figure 41: South Australian bore-completion-date data

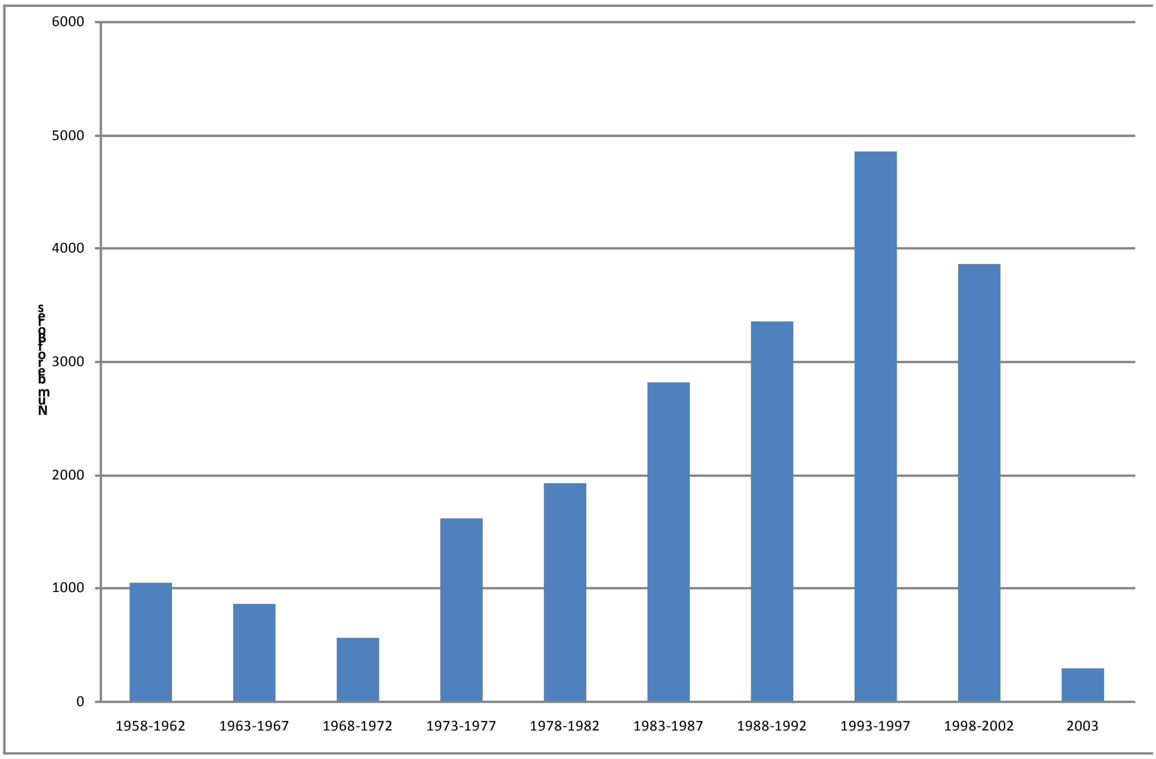


Figure 42: NSW bore-completion data

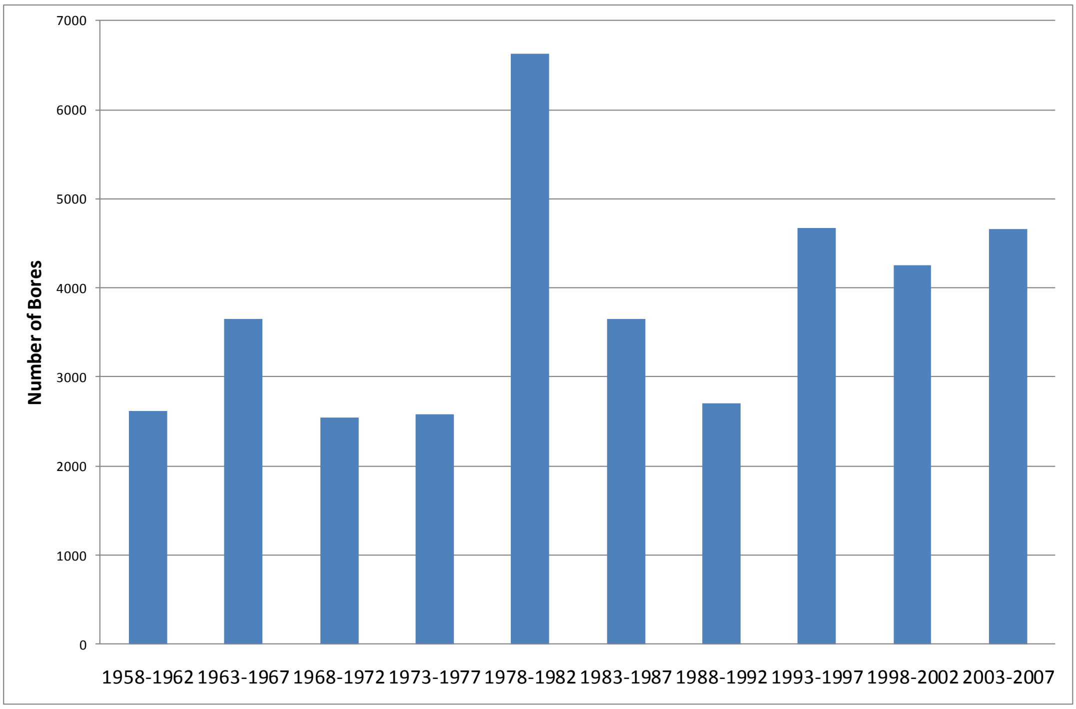
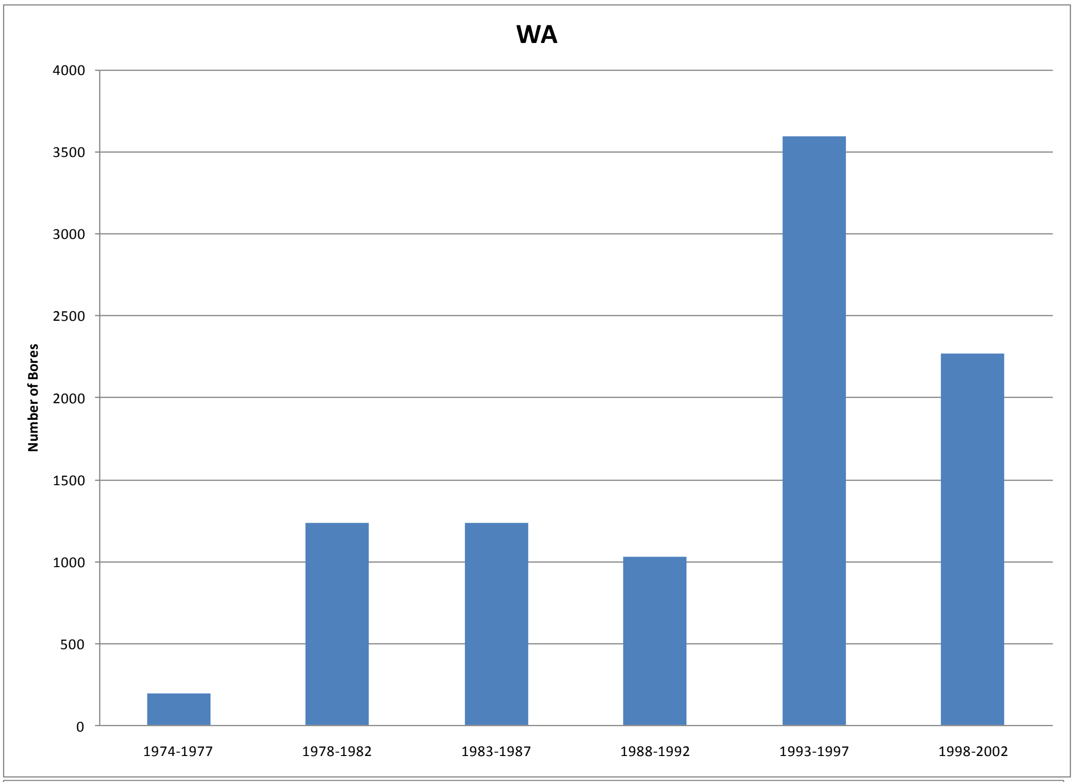


Figure 43: WA_PRAMS Model region and Northern Territory bore completion data



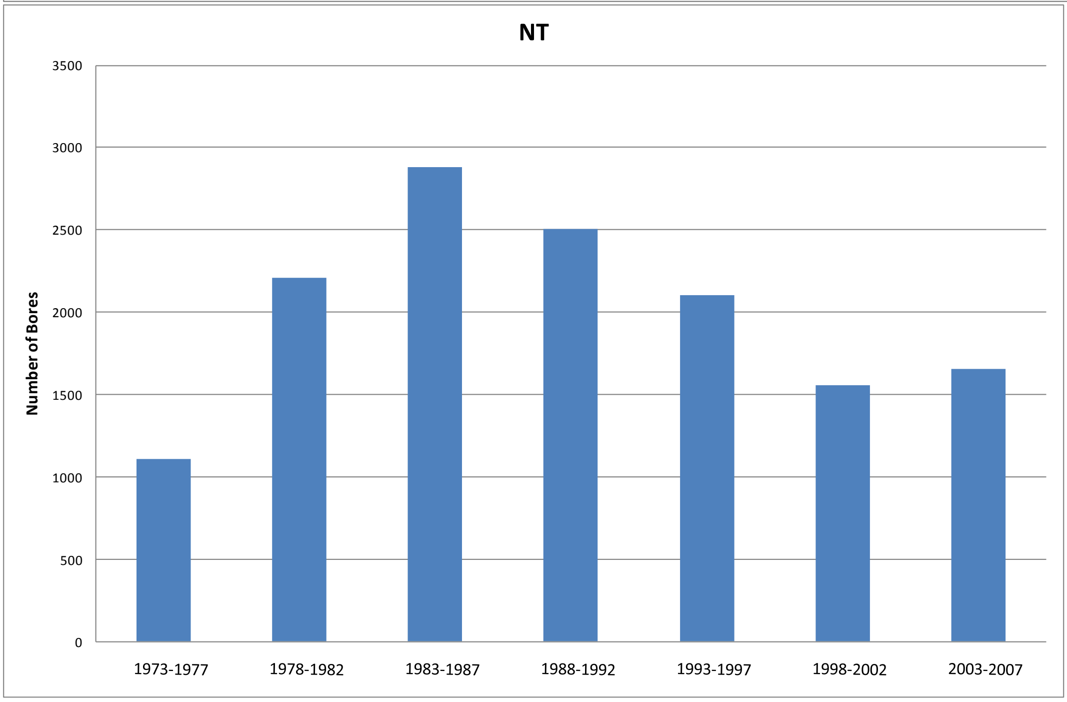


Figure 44: Victoria—Number of bores drilled *vs* total number of bores in SWMA in 2007

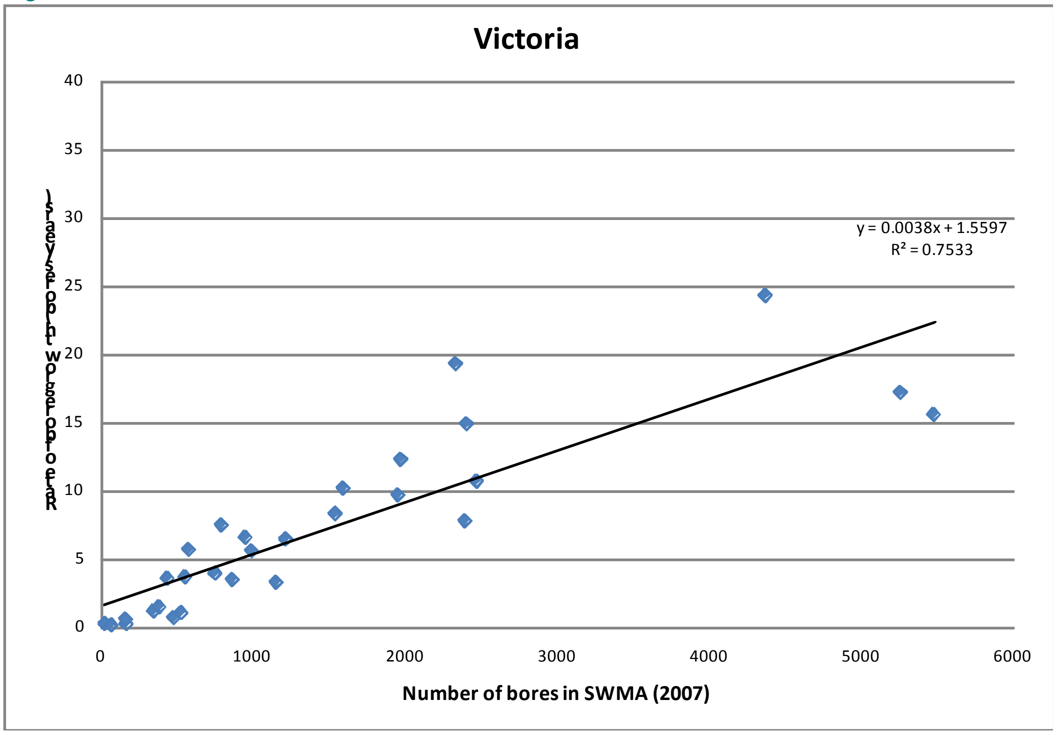


Figure 45: South Australia—Number of bores drilled *vs* total number of bores in SWMA in 2007

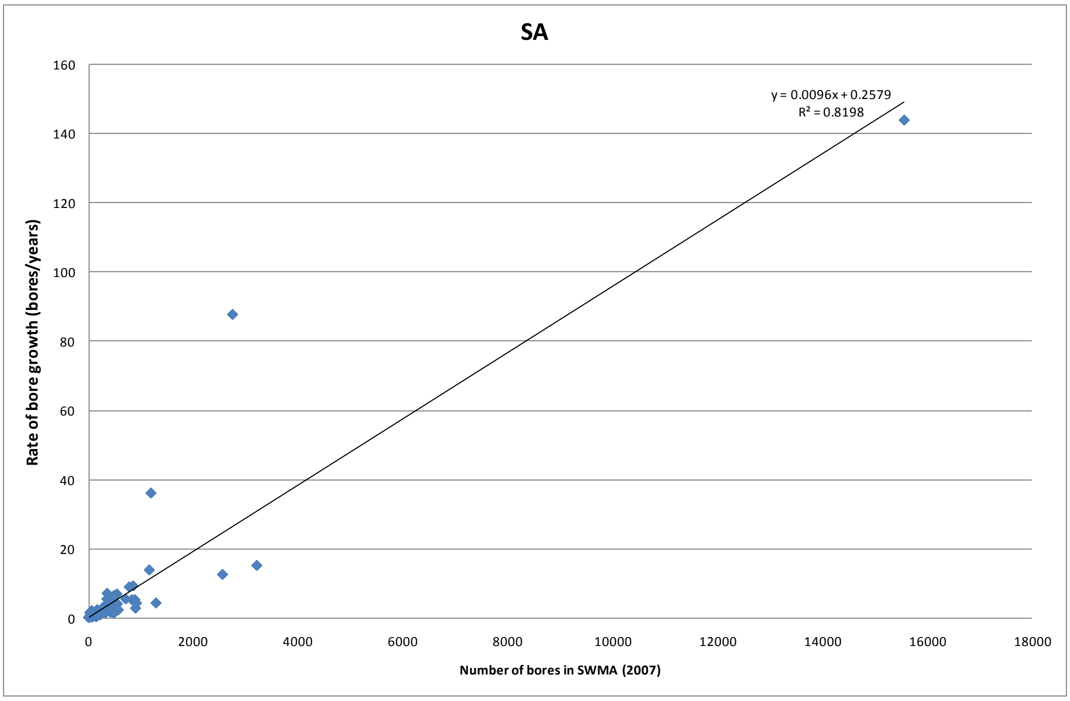


Figure 46: NSW—Number of bores drilled *vs* total number of bores in SWMA in 2007

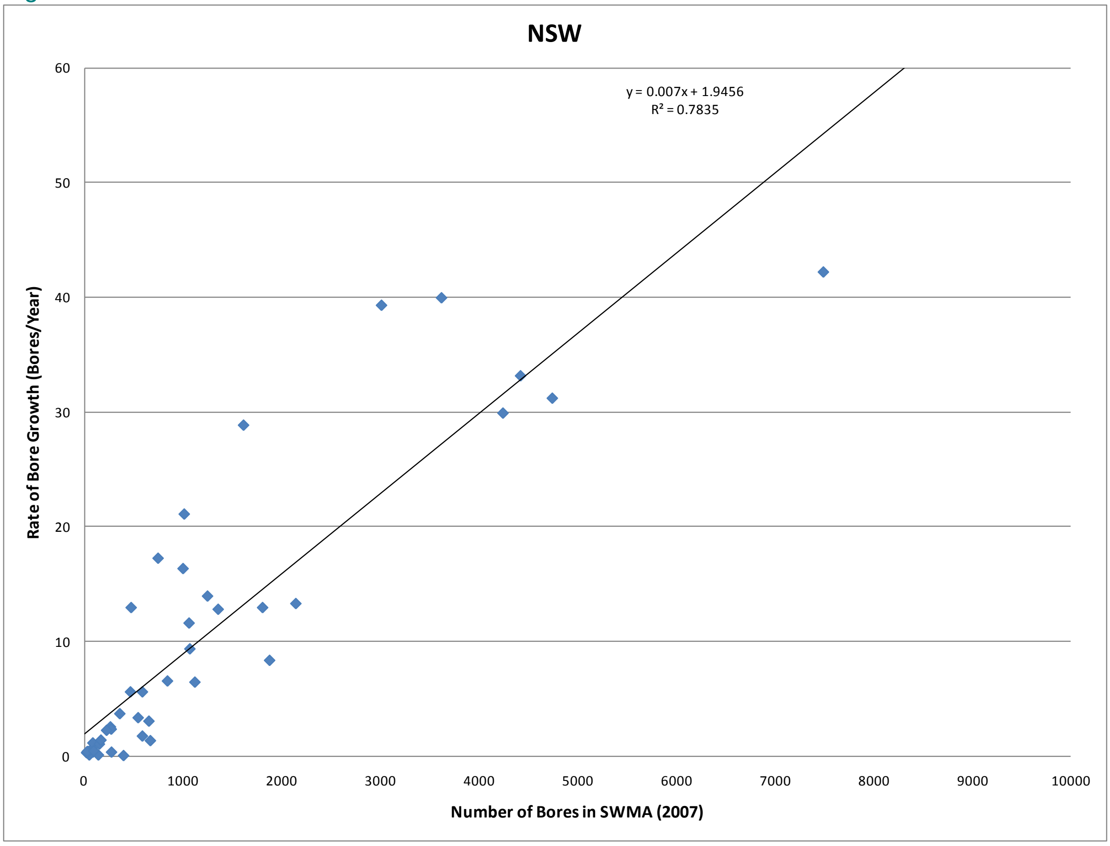


Figure 47: Western Australia—Number of bores drilled *vs* total number of bores in SWMA in 2007

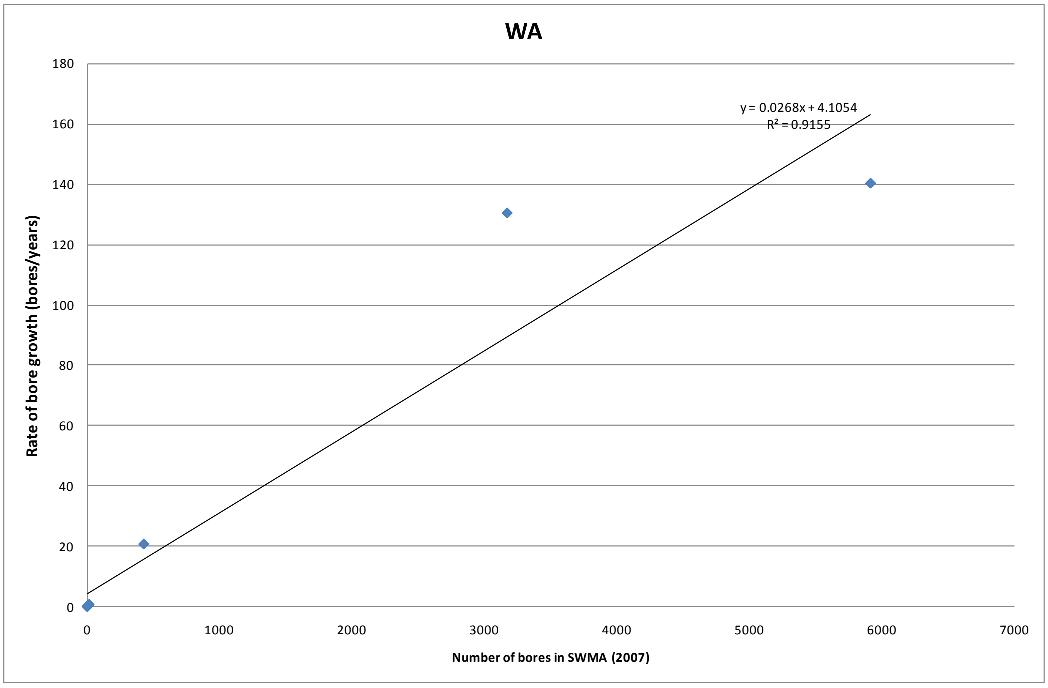


Table 32: Summary of Great Artesian (GAB) bore data by groundwater management unit and SWMA

State	*Groundwater management unit*	*No. of bores*	*Surface water management area (SWMA)*	*Number of GAB bores*
SA	Eucla	56	Eucla	56
	Far North PWA	757	South West Eromanga	150
			Hay River	1
			Georgina River	1
			Finke River	161
			Eyre & Frome	424
			Diamantina River	1
			Cooper Creek	19
	GAB—western	1	Finke River	1
	Unincorporated Area—Eromanga	479	Unincorporated Area - Eromanga	479
	SA TOTAL			1,293
NSW	GAB	4597	Border Rivers	1
			Border Rivers - Regulated	50
			Border Rivers - Unregulated	587
			Castlereagh River	1159
			Cooper Creek	8
			Far West	946
			Gwydir River - Regulated	4
			Gwydir River - Unregulated	322
			Lake Bancannia	145
			Lake Frome	154
			Macquarie River - Regulated	185
			Macquarie River - Unregulated	499
			Namoi River - Regulated	154
			Namoi River - Unregulated	381
			Paroo	1
			Warrego	1
	GAB Alluvial	1862	Barwon Darling Management Area	22
			Border Rivers - Regulated	9
			Border Rivers - Unregulated	141
			Castlereagh River	268
			Far West	141
			Gwydir River - Regulated	94
			Gwydir River - Unregulated	480
			Macquarie River - Regulated	150
			Macquarie River - Unregulated	487
			Namoi River - Regulated	16
			Namoi River - Unregulated	54
	NSW TOTAL			6,459

State	*Groundwater management unit*	*No. of bores*	*Surface water management area (SWMA)*	*Number of GAB bores*
QLD	GAB Management Area	15679	Barron	
			Black	
			Border Rivers	836
			Border Rivers - Regulated	
			Border Rivers - Unregulated	
			Boyne	
			Bulloo	100
			Burdekin	129
			Burnett	67
			Calliope	
			Castlereagh River	
			Coleman	22
			Condamine-Balonne	2569
			Cooper Creek	2885
			Don	0
			Embley	3
			Endeavour	0
			Far West	0
			Fitzroy	1990
			Fraser Island	0
			Georgina-Diamantina	1553
			Gold Coast	0
			Gwydir River - Unregulated	0
			Holroyd	0
			Jardine	0
			Jeannie	1
			Logan Basin	0
			Mary	0
			Mitchell	138
			Moonie	89
			Moreton	9
			Mossman	0
			Mulgrave-Russell	0
			Namoi River - Regulated	0
			Nebine	480
			Normanby	42
			O'Connell	0
			Olive-Pascoe	0
			Paroo	496
			Pioneer	0
			Plane	0
			Proserpine	0
			Richmond River - Regulated	0
			Richmond River - Unregulated	1
			Ross	0

State	*Groundwater management unit*	*No. of bores*	*Surface water management area (SWMA)*	*Number of GAB bores*
			Shoalwater	0
			Southern Gulf	3123
			Stewart	1
			Styx	0
			Warrego	1136
			Waterpark	0
			Wenlock	9
	QLD Total			15,679
NT	GAB Western		Finke	15
			Todd	12
	GAB Western Recharge		Hay	32
			Finke	9
			Todd	16
				84
	NT Total			*84*

Plantations

Relationships

Following Zhang et al. (2001), average annual evapotranspiration (ET) can be estimated by:

$$ET = P\left[\frac{1+w\dfrac{E_0}{P}}{1+w\dfrac{E_0}{P}+\left(\dfrac{E_0}{P}\right)^{-1}}\right] \qquad (1)$$

where P is precipitation, ET is actual ET, E_0 is potential evaporation, and w is the plant-available water coefficient.

Zhang et al. (2001) showed that the model predicts ET from forested catchments when w and E_0 are set to 2 and 1410, and ET from herbaceous plants when w and E_0 are set to 0.5 and 1100 (see Figure 48). These parameter values were obtained by a least squares fit based on the data from over 250 catchments worldwide listed by Zhang et al. (1999). The model predicts ET under different vegetation categories along a rainfall gradient. It should be emphasised that the water balance model developed by Zhang et al. (2001) is based on measured data and has been shown to be robust (Vertessy and Bessard 1999; Zhang et al. 2001, 2003, Brown et al. 2005). This model is simple, effective, and requires minimum inputs: hence it is well suited for investigating regional land cover-water resource management issues.

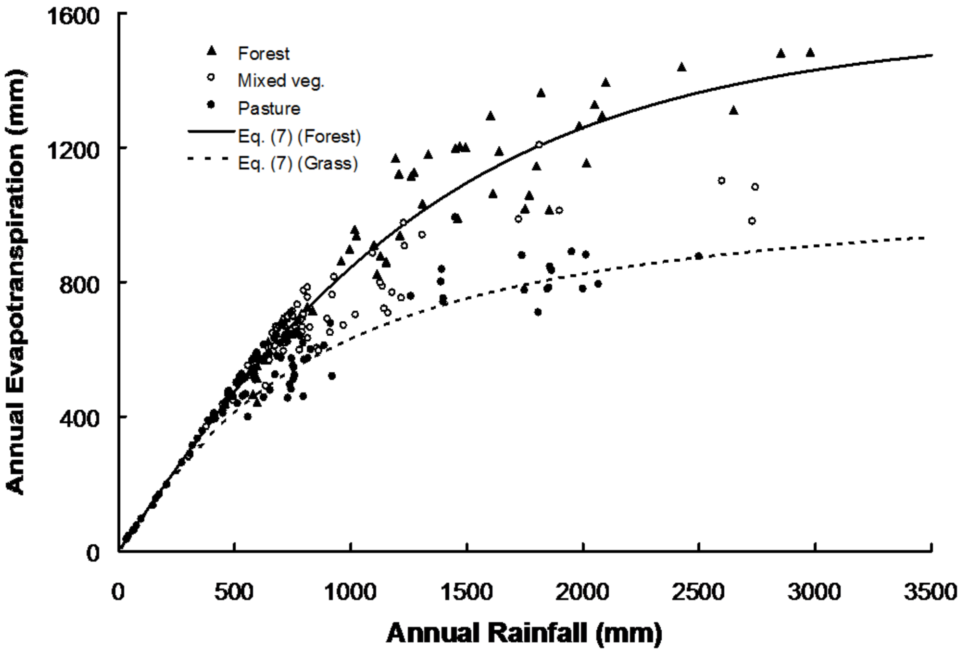
To extend the above method to catchments with varying proportions of forest cover, a simple catchment scale model is proposed. Following Eagleson (1982), annual ET from a catchment was assumed to be the sum of the annual ET from herbaceous vegetation (including soil evaporation) and that from forest, weighted linearly according to their areas. The general equation can be expressed as

$$ET = f\, ET_f + (1-f)\, ET_h \qquad (2)$$

where ET is the total annual ET in mm, f is the fractional forest cover, ET_f is the annual ET from forests in mm calculated by equation (1) with the parameter values set for forests; and ET_h is the annual ET from herbaceous plants in mm calculated by equation (1) with the parameter values set for herbaceous plants.

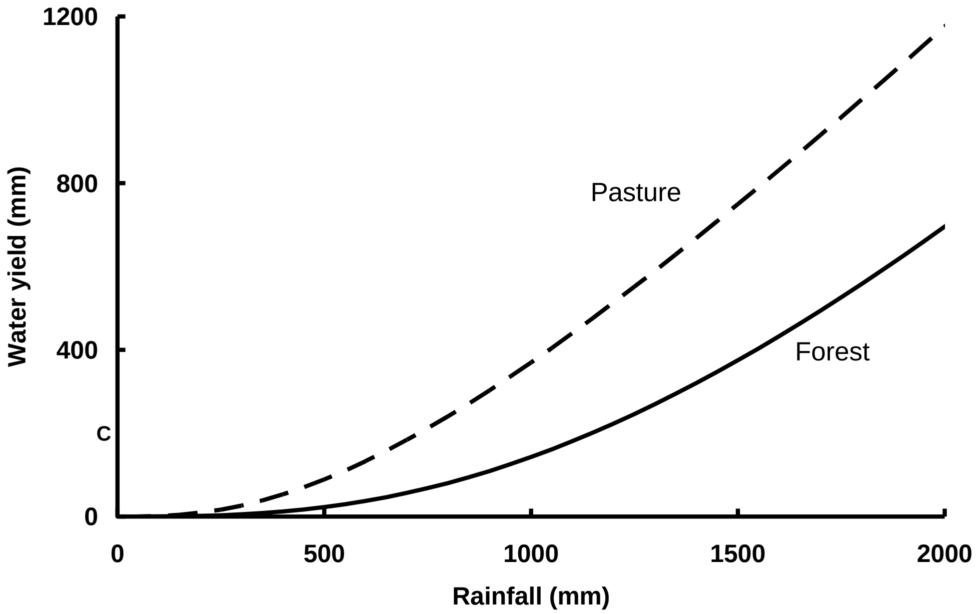
In estimating catchment water yield, it is assumed that there is no net change in catchment water storage over a long period of time. As a result, catchment water yield can be calculated as the difference between long-term average rainfall and evapotranspiration. Following Zhang et al. (2001), the average relationships between water yield and rainfall are shown in Figure 49 for grassland and forested catchments. It is clear that converting pasture to forest or plantation decreases mean annual water yield, and the reduction is greater in higher rainfall areas. For example, in an 800 mm rainfall zone, conversion from annual pastures to trees results in an average water yield reduction of 150 megalitres for each square kilometre planted.

Figure 48: Relationship between annual evapotranspiration and rainfall for different broad vegetation types



The relationship for *forested* catchments is indicated by the solid curve, for *pasture* catchments the dotted curve, and for *mixed vegetation* catchments somewhere between the two (Zhang et al. 2001).

Figure 49: Relationships between mean annual rainfall and water yield for different vegetation types



The relationship for *forested* catchments is indicated by the solid curve, for *pasture* catchments the dotted curve.

Appendix E—Interception in each surface water management area

Table 33 compiles the results from the individual intercepting activities to produce a baseline assessment of the volume of water intercepted per SWMA. Additional information on area, mean annual runoff, recharge and sustainable yield are shown. Some SWMAs in NSW and the SA portion of the Murray River have a regulated and unregulated component to the SWMA. For this assessment the two components were combined to produce a single total for the SWMA.

Sustainable yield was obtained from the NWC Australian Water Resources 2005 and mean annual runoff and recharge are from the results of the land use change modelling undertaken for this project. It would have been preferred to obtain surface water availability from stream gauging records rather than from landscape modelling of the water balance. However no such national database exists yet, thus the model results have been used for this assessment.

Modelling runoff from landscape water balance can result in over estimation of total runoff or of surface water availability for two reasons. Firstly it does not take into consideration transmission losses of runoff. Secondly, the calculated rates of runoff are of the same order as the errors in the model. A landscape water balance model is dominated by the large precipitation and evaporation terms, and recharge is inherently hard to estimate. Runoff is calculated as the residual of these terms, but is often less than 10 % of precipitation or evaporation. Thus a 10% underestimate in evaporation can lead to a 100% overestimate in runoff. Similarly errors in recharge are translated to errors in runoff. The errors in runoff tend to be greatest in dry catchments where the runoff coefficient is very low and hence small relative errors in other terms lead to larger relative errors in runoff. For example in the Wimmera River, Victoria, the mean annual runoff is modelled to be 821 gigalitres per year whereas gauged data report a mean annual surface water availability of 217 gigalitres per year (MDB Sustainable Yield project).

Table 33: Current volume and impact of intercepting activities by SWMA

SWMA_NAME	State or territory	Sust. Yield (GL/yr)	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
				ML/yr	%SY	% runoff	ML/yr	%SY	% runoff	ML/yr	%SY	% runoff		ML/yr	% Recharge
ACT	ACT	220	280	430	0.2	0.2	11000	4.8	3.8	-	-	-	29000	-	-
Bega River	NSW	19	370	750	4.0	0.2	-	-	-	-	-	-	0	220	-
Bellinger River	NSW	11	900	530	4.9	0.1	2400	22.2	0.3	-	-	-	58000	3230	5.6
Border Rivers	NSW	210	1400	16000	7.3	1.1	140	0.1	0.0	60000	28.1	4.2	-	25950	-
Brunswick River	NSW	2.3	240	250	10.9	0.1	150	6.7	0.1	-	-	-	12000	1500	12.5
Castlereagh River	NSW	4	560	16000	393.5	2.8	-	-	-	-	-	-	186000	43994	23.7
Clarence River	NSW	69	3800	3600	5.2	0.1	30000	43.9	0.8	-	-	-	342000	2000	0.6
Clyde River - Jervis Bay	NSW	3.5	600	210	5.9	0.0	-	-	-	-	-	-	46000	730	1.6
Cooper Creek	NSW	-	0.2	-	-	-	-	-	-	-	-	-	1600	240	15.0
East Gippsland	NSW	-	180	25	-	0.0	11000	-	6.4	-	-	-	15000	40	0.2
Far West	NSW	3	370	2400	80.5	0.7	0	0.0	0.0	-	-	-	433000	32900	7.6
Gwydir River	NSW	400	1400	20000	5.1	1.5	700	0.2	0.1	146000	36.3	10.7	-	31390	-
Hastings River	NSW	35	1400	650	1.9	0.0	3100	9.0	0.2	-	-	-	81000	2030	2.5
Hawkesbury River	NSW	-	3000	3400	-	0.1	13000	-	0.4	-	-	-	295000	6030	2.0
Hunter River	NSW	660	1600	5300	0.8	0.3	290	0.0	0.0	-	-	-	0	5110	-
Karuah River	NSW	3.4	870	680	20.0	0.1	1400	42.6	0.2	-	-	-	72000	540	0.7
Lachlan River	NSW	320	2500	57000	17.8	2.3	29000	8.9	1.2	-	-	-	-	13140	-
Lake Bancannia	NSW	-	12	-	-	-	0	-	0.0	-	-	-	74000	4460	6.0
Lake Frome	NSW	-	3.5	-	-	-	-	-	-	-	-	-	51000	4720	9.3
Lake George	NSW	0.2	79	730	366.0	0.9	200	99.5	0.3	-	-	-	9300	90	0.9
Lower Darling	NSW	140	250	5500	4.0	2.2	-	-	-	-	-	-	-	560	-
Macleay River	NSW	20	1900	2600	12.8	0.1	3700	18.5	0.2	-	-	-	154000	2500	1.6
Macquarie River	NSW	420	2700	94000	22.3	3.5	44000	10.5	1.7	8200	1.9	0.3	-	52740	-
Macquarie-Tuggerah Lakes	NSW	-	390	340	-	0.1	-	-	-	-	-	-	29000	1690	5.8
Manning River	NSW	83	1300	1400	1.7	0.1	7900	9.5	0.6	-	-	-	117000	1100	0.9
Moruya River	NSW	5.5	200	120	2.2	0.1	-	-	-	-	-	-	19000	180	0.9
Murray - Regulated	NSW	1800	270	8900	0.5	3.3	83	0.0	0.0	-	-	-	172000	2720	1.6
Murrumbidgee River	NSW	2000	3900	40000	2.1	1.0	116000	5.9	3.0	-	-	-	-	1628	-
Namoi River	NSW	320	2000	21000	6.6	1.1	5300	1.7	0.3	58000	18.4	3.0	-	41630	-
Richmond River	NSW	69	1500	2300	3.4	0.2	22000	32.2	1.5	-	-	-	248000	7800	3.1
Shoalhaven River	NSW	-	990	1300	-	0.1	2300	-	0.2	-	-	-	93000	940	1.0
Snowy River	NSW	-	1200	4000	-	0.3	28000	-	2.4	-	-	-	100000	340	0.3
Sydney Coast - Georges River	NSW	-	430	83	-	0.0	-	-	-	-	-	-	27000	1180	4.4
Towamba River	NSW	2.5	310	130	5.2	0.0	7400	297.5	2.4	-	-	-	29000	80	0.3
Tuross River	NSW	8.2	260	180	2.2	0.1	-	-	-	-	-	-	27000	70	0.2
Tweed River	NSW	35	440	340	1.0	0.1	1400	3.9	0.3	-	-	-	25000	960	3.8
Upper Darling	NSW	170	280	3300	1.9	1.2	-	-	-	51000	29.7	18.2	-	-	-
Upper Murray River	NSW	7.2	820	1300	18.0	0.2	24000	328.9	2.9	-	-	-	69000	460	0.7
Wollongong Coast	NSW	-	250	98	-	0.0	-	-	-	-	-	-	15000	200	1.3
Adelaide River	NT	310	1300	-	-	-	-	-	-	-	-	-	161000	4660	2.9
Barkly	NT	30	710	-	-	-	-	-	-	-	-	-	706000	4040	0.6
Bathurst and Melville Islands	NT	590	1400	-	-	-	5100	0.9	0.4	-	-	-	169000	460	0.3
Blyth River	NT	220	780	-	-	-	-	-	-	-	-	-	180000	110	0.1
Buckingham River	NT	440	920	-	-	-	-	-	-	-	-	-	182000	610	0.3
Burt	NT	3.8	40	-	-	-	-	-	-	-	-	-	171000	2460	1.4

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Calvert River	NT	180	220	-	-	-	-	-	-	-	-	-	108000	40	0.0
Daly River	NT	1100	4000	-	-	-	-	-	-	-	-	-	888000	5470	0.6
Darwin / Blackmore Rivers	NT	70	150	-	-	-	-	-	-	-	-	-	21000	3150	15.0
East Alligator River	NT	900	2300	-	-	-	-	-	-	-	-	-	347000	840	0.2
Finke River	NT	8	5	-	-	-	-	-	-	-	-	-	123000	2780	2.3
Finniss / Elizabeth / Howard Rivers	NT	480	1600	-	-	-	-	-	-	-	-	-	192000	15110	7.9
Fitzmaurice River	NT	280	770	-	-	-	-	-	-	-	-	-	157000	20	0.0
Georgina River	NT	130	180	-	-	-	-	-	-	-	-	-	395000	3130	0.8
Goomadeer River	NT	490	700	-	-	-	-	-	-	-	-	-	129000	60	0.0
Goyder River	NT	300	770	-	-	-	-	-	-	-	-	-	191000	80	0.0
Groote Eylandt	NT	130	180	-	-	-	-	-	-	-	-	-	43000	60	0.1
Hay River	NT	7	8.8	-	-	-	-	-	-	-	-	-	176000	1780	1.0
Keep River	NT	78	260	-	-	-	-	-	-	-	-	-	76000	210	0.3
Koolatong River	NT	310	640	-	-	-	-	-	-	-	-	-	149000	330	0.2
Limmen Bight River	NT	300	340	-	-	-	-	-	-	-	-	-	173000	190	0.1
Liverpool River	NT	570	920	-	-	-	-	-	-	-	-	-	187000	100	0.1
Mackay	NT	1.1	570	-	-	-	-	-	-	-	-	-	1037000	4010	0.4
Mary River	NT	400	1100	-	-	-	-	-	-	-	-	-	163000	490	0.3
McArthur River	NT	630	440	-	-	-	-	-	-	-	-	-	218000	390	0.2
Moyle River	NT	110	890	-	-	-	-	-	-	-	-	-	125000	160	0.1
Nicholson River	NT	130	150	-	-	-	-	-	-	-	-	-	125000	110	0.1
Ord River	NT	170	190	-	-	-	-	-	-	-	-	-	92000	280	0.3
Robinson River	NT	180	290	-	-	-	-	-	-	-	-	-	130000	60	0.0
Roper River	NT	950	2800	-	-	-	-	-	-	-	-	-	1031000	1880	0.2
Rosie River	NT	90	170	-	-	-	-	-	-	-	-	-	68000	30	0.0
Settlement Creek	NT	160	140	-	-	-	-	-	-	-	-	-	61000	70	0.1
South Alligator River	NT	-	1600	-	-	-	-	-	-	-	-	-	244000	320	0.1
Todd River	NT	4	8	-	-	-	-	-	-	-	-	-	178000	5290	3.0
Towns River	NT	100	130	-	-	-	-	-	-	-	-	-	63000	0	-
Victoria River	NT	560	2000	-	-	-	-	-	-	-	-	-	753000	2130	0.3
Walker River	NT	660	480	-	-	-	-	-	-	-	-	-	160000	80	0.0
Warburton	NT	1	1.1	-	-	-	-	-	-	-	-	-	31000	50	0.2
Wildman River	NT	60	750	-	-	-	-	-	-	-	-	-	97000	120	0.1
Wiso	NT	40	1700	-	-	-	-	-	-	-	-	-	1566000	5070	0.3
Archer	QLD	-	2600	-	-	-	-	-	-	-	-	-	298000	-	-
Baffle	QLD	-	450	1800	-	0.4	8000	-	1.8	-	-	-	59000	-	-
Barron	QLD	-	660	710	-	0.1	2700	-	0.4	-	-	-	109000	60	0.1
Black	QLD	-	110	170	-	0.2	-	-	-	-	-	-	17000	840	4.9
Border Rivers	QLD	210	970	16000	7.3	1.6	1400	0.6	0.1	90000	42.1	9.3	266000	17290	6.5
Boyne	QLD	-	210	1200	-	0.5	550	-	0.3	-	-	-	32000	2	0.0
Bulloo	QLD	-	180	28000	-	15.9	-	-	-	-	-	-	216000	2490	1.2
Burdekin	QLD	-	4800	52000	-	1.1	210	-	0.0	2400	-	0.1	1335000	4130	0.3
Burnett	QLD	-	2300	24000	-	1.0	15000	-	0.7	-	-	-	465000	5910	1.3
Calliope	QLD	-	160	1600	-	1.0	260	-	0.2	-	-	-	26000	1	0.0
Coleman	QLD	-	1900	-	-	-	-	-	-	-	-	-	263000	450	0.2
Condamine-Balonne	QLD	-	2900	61000	-	2.1	1100	-	0.0	454000	-	15.8	931000	62990	6.8
Cooper Creek	QLD	-	0.2	-	-	-	-	-	-	-	-	-	1600	59950	3746.6
Curtis Island	QLD	-	51	-	-	-	-	-	-	-	-	-	7200	-	-
Daintree	QLD	-	890	-	-	-	-	-	-	-	-	-	60000	-	-
Don	QLD	-	260	1300	-	0.5	-	-	-	-	-	-	56000	300	0.5
Ducie	QLD	-	1900	-	-	-	-	-	-	-	-	-	167000	-	-

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Embley	QLD	-	1400	-	-	-	-	-	-	-	-	-	114000	60	0.1
Endeavour	QLD	-	640	-	-	-	-	-	-	-	-	-	52000	40	0.1
Fitzroy	QLD	-	5700	93000	-	1.6	2400	-	0.0	12000	-	0.2	1410000	47370	3.4
Fraser Island	QLD	-	240	-	-	-	-	-	-	-	-	-	33000	1	0.0
Georgina-Diamantina	QLD	-	510	-	-	-	-	-	-	-	-	-	866000	32660	3.8
Gold Coast	QLD	-	460	480	-	0.1	-	-	-	-	-	-	28000	1	0.0
Herbert	QLD	-	1200	540	-	0.0	5000	-	0.4	-	-	-	206000	-	-
Hinchinbrook Island	QLD	-	170	-	-	-	-	-	-	-	-	-	11000	-	-
Holroyd	QLD	-	1600	-	-	-	-	-	-	-	-	-	211000	10	0.0
Jacky Jacky	QLD	-	760	-	-	-	-	-	-	-	-	-	81000	-	-
Jardine	QLD	-	900	-	-	-	-	-	-	-	-	-	84000	3	0.0
Jeannie	QLD	-	680	-	-	-	340	-	0.1	-	-	-	78000	20	0.0
Johnstone	QLD	-	1800	780	-	0.0	-	-	-	-	-	-	106000	-	-
Lockhart	QLD	-	480	-	-	-	-	-	-	-	-	-	58000	-	-
Logan Basin	QLD	-	680	2900	-	0.4	1200	-	0.2	-	-	-	65000	1	0.0
Mary	QLD	-	1900	6000	-	0.3	118000	-	6.2	-	-	-	228000	1	0.0
Misc other islands	QLD	-	130	-	-	-	-	-	-	-	-	-	19000	-	-
Mitchell	QLD	-	5800	-	-	-	-	-	-	-	-	-	1036000	2820	0.3
Moonie	QLD	-	390	11000	-	2.8	-	-	-	11000	-	2.7	140000	1850	1.3
Moreton	QLD	-	1600	9800	-	0.6	43000	-	2.6	-	-	-	216000	440	0.2
Mornington Island	QLD	-	63	-	-	-	-	-	-	-	-	-	17000	-	-
Mossman	QLD	-	120	28	-	0.0	-	-	-	-	-	-	14000	3	0.0
Mulgrave-Russell	QLD	-	1600	200	-	0.0	720	-	0.0	-	-	-	95000	2	0.0
Murray	QLD	-	390	140	-	0.0	8700	-	2.2	-	-	-	38000	-	-
Nebine	QLD	-	520	25000	-	4.9	-	-	-	480	-	0.1	236000	9830	4.2
Normanby	QLD	-	3000	-	-	-	-	-	-	-	-	-	437000	860	0.2
North Stradbroke Island	QLD	-	30	-	-	-	-	-	-	-	-	-	3600	-	-
O'Connell	QLD	-	380	540	-	0.1	-	-	-	-	-	-	47000	60	0.1
Olive-Pascoe	QLD	-	920	-	-	-	-	-	-	-	-	-	103000	2	0.0
Paroo	QLD	-	130	9700	-	7.6	-	-	-	-	-	-	151000	10090	6.7
Pioneer	QLD	-	410	410	-	0.1	97	-	0.0	-	-	-	81000	500	0.6
Plane	QLD	-	270	580	-	0.2	250	-	0.1	-	-	-	44000	200	0.4
Proserpine	QLD	-	210	330	-	0.2	590	-	0.3	-	-	-	27000	100	0.4
Ross	QLD	-	150	470	-	0.3	-	-	-	-	-	-	24000	520	2.2
Shoalwater	QLD	-	250	1400	-	0.5	-	-	-	-	-	-	45000	10	0.0
South Stradbroke Island	QLD	-	53	-	-	-	-	-	-	-	-	-	5800	-	-
Southern Gulf	QLD	-	8100	-	-	-	-	-	-	-	-	-	2825000	64040	2.3
Stewart	QLD	-	350	-	-	-	-	-	-	-	-	-	48000	20	0.0
Styx	QLD	-	160	1700	-	1.0	630	-	0.4	-	-	-	32000	1	0.0
Torres Strait Islands	QLD	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tully	QLD	-	700	230	-	0.0	-	-	-	-	-	-	57000	-	-
Warrego	QLD	-	920	33000	-	3.6	-	-	-	-	-	-	412000	23540	5.7
Waterpark	QLD	-	190	-	-	-	6000	-	3.1	-	-	-	30000	10	0.0
Watson	QLD	-	1300	-	-	-	-	-	-	-	-	-	109000	-	-
Wenlock	QLD	-	1800	-	-	-	-	-	-	-	-	-	173000	190	0.1
Whitsunday	QLD	-	0	-	-	-	950	-	-	-	-	-	0	210	-
Whitsunday Island	QLD	-	0	-	-	-	-	-	-	-	-	-	0	-	-
Adelaide	SA	-	14	380	-	2.7	130	-	0.9	-	-	-	1500	170	11.1
Angas-Bremer	SA	13	56	4300	33.0	7.6	-	-	-	-	-	-	12000	1080	9.0
Angas-Bremer Prescribed Well Area	SA	-	6.6	180	-	2.8	-	-	-	-	-	-	4500	280	6.3
Baroota	SA	-	1.7	230	-	13.2	-	-	-	-	-	-	930	40	4.7

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Barossa Prescribed Water Resources	SA	3	23	510	16.9	2.2	220	7.4	0.9	-	-	-	10000	820	8.2
Broughton River	SA	-	100	7800	-	7.6	980	-	1.0	-	-	-	80000	1650	2.1
Burra Creek	SA	-	16	800	-	5.0	-	-	-	-	-	-	7800	350	4.5
Clare Valley Prescribed Water Resources	SA	9.8	25	1600	16.3	6.5	-	-	-	-	-	-	14000	1700	12.1
Cooper Creek	SA	-	0.2	-	-	-	-	-	-	-	-	-	1600	1900	118.8
Coorong	SA	-	200	19	-	0.0	-	-	-	-	-	-	54000	1790	3.3
Cygnet River	SA	-	28	2900	-	10.4	920	-	3.3	-	-	-	6300	50	0.8
Diamantina River	SA	90	0	-	-	-	-	-	-	-	-	-	36000	100	0.3
Eucla	SA	-	35	-	-	-	-	-	-	-	-	-	190000	5600	2.9
Eyre & Frome	SA	-	8.9	-	-	-	-	-	-	-	-	-	219000	42400	19.4
Ferries-McDonald	SA	-	19	38	-	0.2	-	-	-	-	-	-	7800	40	0.5
Finke River	SA	8	5	-	-	-	-	-	-	-	-	-	123000	16200	13.2
Fleurieu Peninsula	SA	30	64	5900	19.6	9.2	2200	7.2	3.4	-	-	-	11000	540	4.9
Gawler	SA	-	10	98	-	0.9	-	-	-	-	-	-	5300	70	1.4
Gawler Craton	SA	-	400	620	-	0.2	-	-	-	-	-	-	795000	5100	0.6
Georgina River	SA	130	180	-	-	-	-	-	-	-	-	-	395000	100	0.0
Hay River	SA	7	8.8	-	-	-	-	-	-	-	-	-	176000	100	0.1
Kakoonie	SA	-	5.3	200	-	3.7	-	-	-	-	-	-	3200	130	4.2
Kangaroo Island	SA	-	160	7900	-	5.0	3700	-	2.3	-	-	-	37000	320	0.9
Lake Torrens	SA	-	29	-	-	-	-	-	-	-	-	-	78000	830	1.1
Light	SA	-	77	1	-	0.0	-	-	-	-	-	-	47000	650	1.4
Little Para	SA	11	7.4	440	4.0	5.9	-	-	-	-	-	-	1000	270	27.2
Lower Limestone Coast Prescribed Well	SA	50	1200	4500	8.9	0.4	131000	262.0	11.0	-	-	-	181000	31110	17.2
Lower Torrens	SA	-	24	57	-	0.2	-	-	-	-	-	-	2900	5490	189.2
Mackay	SA	1.1	570	-	-	-	-	-	-	-	-	-	1037000	110	0.0
Mallee Prescribed Well Area	SA	-	120	3400	-	2.8	-	-	-	-	-	-	116000	1550	1.3
Mambray Coast	SA	-	23	2400	-	10.4	110	-	0.5	-	-	-	27000	340	1.2
Marne-Saunders	SA	1.5	32	570	37.7	1.8	55	3.7	0.2	-	-	-	9800	970	9.9
McLaren Vale Prescribed Well Area	SA	-	20	1300	-	6.3	330	-	1.7	-	-	-	8000	690	8.7
Middle River	SA	-	7.4	590	-	8.0	880	-	11.9	-	-	-	1600	10	0.4
Morambro Creek Prescribed Surface	SA	0.9	9.8	77	8.6	0.8	-	-	-	-	-	-	3400	430	12.7
Murraylands	SA	-	49	2500	-	5.1	-	-	-	-	-	-	60000	880	1.5
Musgrave	SA	-	9.1	-	-	-	-	-	-	-	-	-	188000	700	0.4
Musgrave Prescribed Well Area	SA	-	53	54	-	0.1	-	-	-	-	-	-	28000	1090	3.9
Mypolonga Flat	SA	-	0.9	-	-	-	-	-	-	-	-	-	1200	10	0.8
Myponga	SA	17	13	1300	7.4	9.8	700	4.1	5.4	-	-	-	2100	150	7.1
Noora	SA	-	2.9	440	-	15.3	-	-	-	-	-	-	10000	2	0.0
Northern Adelaide Plains Prescribed Well	SA	-	28	110	-	0.4	-	-	-	-	-	-	10000	860	8.6
Northern Eastern Mount Lofty Ranges	SA	3.5	49	800	22.8	1.6	120	3.4	0.2	-	-	-	14000	220	1.5
Northern Flinders	SA	-	85	-	-	-	-	-	-	-	-	-	149000	1760	1.2
Onkaparinga	SA	60	37	3000	5.0	8.2	790	1.3	2.1	-	-	-	7000	2310	33.0
Padthaway Prescribed Well Area	SA	-	31	250	-	0.8	-	-	-	-	-	-	9400	1050	11.2
Parra Wirra	SA	-	22	1000	-	4.7	3700	-	16.8	-	-	-	3800	300	8.0
Patawalonga	SA	-	21	230	-	1.1	-	-	-	-	-	-	2300	2370	103.2
Peake-Roby-Sherlock Prescribed Well	SA	-	17	430	-	2.5	-	-	-	-	-	-	14000	280	2.0
River Murray	SA	1900	490	7700	0.4	1.6	-	-	-	-	-	-	0	10	-
Rocky River	SA	-	11	-	-	-	-	-	-	-	-	-	2400	2	0.1
South West Eromanga	SA	-	-	-	-	-	-	-	-	-	-	-	25000	15000	60.0
Southern Basins Prescribed Well Area	SA	-	25	-	-	-	-	-	-	-	-	-	7000	140	2.1
Southern Eastern Mount Lofty Ranges	SA	18	56	5000	27.5	8.9	1500	8.3	2.7	-	-	-	13000	970	7.5
Spencer Gulf	SA	-	36	6100	-	16.9	-	-	-	-	-	-	89000	630	0.7

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Tatiara	SA	-	100	1300	-	1.2	-	-	-	-	-	-	50000	6410	12.8
Tintinara-Coonalpyn Prescribed Well Area	SA	-	88	1100	-	1.3	-	-	-	-	-	-	36000	1130	3.1
Unincorporated Area - Eromanga	SA	-	0.1	-	-	-	-	-	-	-	-	-	67000	47900	71.5
Upper Torrens	SA	40	29	1600	4.0	5.5	930	2.3	3.2	-	-	-	4700	740	15.8
Wakefield	SA	-	32	2900	-	9.3	-	-	-	-	-	-	33000	340	1.0
Warburton	SA	6	1.1	-	-	-	-	-	-	-	-	-	31000	40	0.1
Willochra Creek	SA	3.9	56	12000	312.7	21.8	-	-	-	-	-	-	44000	1820	4.1
Yatla	SA	-	11	72	-	0.7	-	-	-	-	-	-	1600	320	20.1
Yorke Peninsula	SA	-	110	11000	-	10.2	-	-	-	-	-	-	134000	2570	1.9
Arthur	TAS	280	2000	170	0.1	0.0	47000	16.7	2.4	-	-	-	67000	-	-
Black-Detention	TAS	36	360	260	0.7	0.1	9600	26.6	2.7	-	-	-	14000	-	-
Blythe	TAS	8.9	330	220	2.5	0.1	7800	87.4	2.4	-	-	-	11000	-	-
Boobyalla-Tomahawk	TAS	100	200	540	0.5	0.3	1000	1.0	0.5	-	-	-	13000	-	-
Brumbys-Lake	TAS	-	280	1000	-	0.4	1300	-	0.5	-	-	-	22000	-	-
Cam	TAS	13	230	180	1.4	0.1	22000	169.4	9.3	-	-	-	7400	-	-
Clyde	TAS	-	180	590	-	0.3	1200	-	0.7	-	-	-	13000	-	-
Derwent Estuary-Bruny	TAS	-	270	570	-	0.2	-	-	-	-	-	-	15000	-	-
Duck	TAS	34	290	600	1.8	0.2	9800	29.0	3.3	-	-	-	11000	-	-
Emu	TAS	6.2	220	95	1.5	0.0	18000	290.2	8.2	-	-	-	6600	-	-
Forth-Wilmot	TAS	110	1100	280	0.3	0.0	18000	17.2	1.7	-	-	-	32000	-	-
Furneaux	TAS	-	270	1100	-	0.4	-	-	-	-	-	-	26000	-	-
George	TAS	36	150	160	0.4	0.1	5400	15.3	3.6	-	-	-	9000	-	-
Gordon-Franklin	TAS	-	4800	-	-	-	170	-	0.0	-	-	-	143000	-	-
Great Forester-Brid	TAS	250	240	400	0.2	0.2	5200	2.1	2.2	-	-	-	18000	-	-
Great Lake	TAS	-	130	-	-	-	-	-	-	-	-	-	5800	-	-
Huon	TAS	640	1500	690	0.1	0.0	19000	3.0	1.2	-	-	-	68000	-	-
Inglis	TAS	24	470	440	1.9	0.1	29000	121.8	6.1	-	-	-	15000	-	-
Jordan	TAS	24	160	1300	5.5	0.8	1400	5.8	0.8	-	-	-	13000	-	-
King Island	TAS	-	240	-	-	-	-	-	-	-	-	-	18000	-	-
King-Henty	TAS	-	2400	1600	-	0.1	4000	-	0.2	-	-	-	66000	-	-
Leven	TAS	58	710	300	0.5	0.0	24000	40.9	3.4	-	-	-	21000	-	-
Little Forester	TAS	85	91	200	0.2	0.2	13000	14.8	13.8	-	-	-	5700	-	-
Little Swanport	TAS	100	89	640	0.6	0.7	490	0.5	0.5	-	-	-	8400	-	-
Lower Derwent	TAS	-	520	800	-	0.2	24000	-	4.6	-	-	-	25000	-	-
Macquarie	TAS	300	250	2100	0.7	0.8	640	0.2	0.3	-	-	-	28000	-	-
Meander	TAS	590	540	1300	0.2	0.2	14000	2.4	2.6	-	-	-	29000	-	-
Mersey	TAS	240	1300	860	0.4	0.1	26000	10.8	2.0	-	-	-	42000	-	-
Montagu	TAS	27	220	160	0.6	0.1	4400	16.2	2.0	-	-	-	9600	-	-
Musselroe-Ansons	TAS	25	290	580	2.3	0.2	7000	28.1	2.4	-	-	-	17000	-	-
Nelson Bay	TAS	-	560	61	-	0.0	2500	-	0.5	-	-	-	20000	-	-
North Esk	TAS	280	190	540	0.2	0.3	15000	5.5	8.1	-	-	-	13000	-	-
Ouse	TAS	-	460	470	-	0.1	1200	-	0.3	-	-	-	22000	-	-
Pieman	TAS	-	5100	-	-	-	2800	-	0.1	-	-	-	140000	-	-
Pipers	TAS	230	160	500	0.2	0.3	10000	4.5	6.6	-	-	-	11000	-	-
Pitt Water-Coal	TAS	230	120	940	0.4	0.8	540	0.2	0.5	-	-	-	11000	-	-
Port Davey	TAS	-	1800	-	-	-	-	-	-	-	-	-	61000	-	-
Prosser	TAS	140	130	630	0.5	0.5	3400	2.4	2.6	-	-	-	12000	-	-
Ringarooma	TAS	350	300	350	0.1	0.1	14000	4.2	4.8	-	-	-	17000	-	-
Rubicon	TAS	39	260	450	1.1	0.2	9900	25.0	3.9	-	-	-	13000	-	-
Scamander-Douglas	TAS	12	120	93	0.8	0.1	4700	39.7	4.0	-	-	-	8700	-	-
South Esk	TAS	820	440	2000	0.2	0.4	22000	2.7	4.9	-	-	-	42000	-	-

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Swan-Apsley	TAS	36	130	410	1.1	0.3	320	0.9	0.2	-	-	-	14000	-	-
Tamar Estuary	TAS	-	250	790	-	0.3	6800	-	2.7	-	-	-	16000	-	-
Tasman	TAS	50	170	430	0.9	0.2	3700	7.3	2.1	-	-	-	12000	-	-
Upper Derwent	TAS	-	2000	-	-	-	22000	-	1.1	-	-	-	68000	-	-
Wanderer-Giblin	TAS	-	1400	-	-	-	-	-	-	-	-	-	42000	-	-
Welcome	TAS	5.3	290	320	6.0	0.1	5100	95.4	1.8	-	-	-	14000	-	-
Avoca River	VIC	17	210	10000	60.9	4.7	630	3.8	0.3	-	-	-	135000	320	0.2
Barwon River	VIC	92	540	13000	14.7	2.5	9200	10.0	1.7	-	-	-	51000	860	1.7
Broken River	VIC	47	430	11000	23.6	2.6	13000	27.3	3.0	-	-	-	56000	1710	3.1
Bunyip River	VIC	34	810	19000	54.4	2.3	230	0.7	0.0	-	-	-	60000	10510	17.5
Campaspe River	VIC	150	320	16000	10.4	4.9	1200	0.8	0.4	-	-	-	49000	3170	6.5
East Gippsland	VIC	-	180	25	-	0.0	11000	-	6.4	0	-	0.0	15000	40	0.2
Glenelg River	VIC	250	1200	30000	12.0	2.6	99000	39.1	8.3	-	-	-	133000	4770	3.6
Goulburn River	VIC	1900	2700	39000	2.0	1.5	23000	1.2	0.9	-	-	-	237000	4650	2.0
Hopkins River	VIC	75	1000	34000	45.5	3.4	11000	14.1	1.0	-	-	-	128000	8730	6.8
Kiewa River	VIC	200	480	4500	2.3	0.9	7100	3.6	1.5	-	-	-	28000	680	2.4
Lake Corangamite	VIC	15	560	12000	77.7	2.1	5000	33.6	0.9	-	-	-	52000	1970	3.8
Latrobe River	VIC	300	1200	15000	5.0	1.2	77000	26.1	6.3	-	-	-	77000	1490	1.9
Loddon River	VIC	160	570	26000	16.5	4.5	5200	3.3	0.9	-	-	-	140000	3890	2.8
Mallee	VIC	-	-	-	-	-	-	-	-	-	-	-	133000	940	0.7
Maribyrnong River	VIC	19	150	6400	34.4	4.3	990	5.3	0.7	-	-	-	15000	1560	10.4
Millicent Coast	VIC	-	380	0	-	0.0	24000	-	6.3	-	-	-	107000	2290	2.1
Mitchell River	VIC	130	600	5800	4.6	1.0	580	0.5	0.1	-	-	-	59000	750	1.3
Moorabool River	VIC	69	160	7000	10.2	4.3	3800	5.5	2.3	-	-	-	24000	1140	4.8
Murray River	VIC	2000	2300	10000	0.5	0.4	22000	1.1	1.0	-	-	-	252000	3930	1.6
Otway Coast	VIC	71	1000	13000	17.8	1.2	23000	33.0	2.3	-	-	-	60000	1090	1.8
Ovens River	VIC	400	1500	17000	4.2	1.2	32000	8.1	2.2	-	-	-	113000	4932	4.4
Portland Coast	VIC	46	490	5700	12.3	1.2	28000	61.6	5.8	-	-	-	48000	10950	22.8
Snowy River	VIC	-	1200	4000	-	0.3	28000	-	2.4	0	-	0.0	100000	120	0.1
South Gippsland	VIC	90	1400	32000	35.2	2.3	55000	61.3	4.0	-	-	-	103000	4800	4.7
Tambo River	VIC	17	420	6100	36.6	1.5	150	0.9	0.0	-	-	-	46000	310	0.7
Thomson River	VIC	470	1100	4300	0.9	0.4	6000	1.3	0.6	-	-	-	86000	3070	3.6
Werribee River	VIC	38	150	6900	18.3	4.6	680	1.8	0.5	-	-	-	21000	1890	9.0
Wimmera River	VIC	120	820	12000	10.0	1.4	710	0.6	0.1	-	-	-	376000	1040	0.3
Yarra River	VIC	490	900	14000	2.9	1.6	150	0.0	0.0	-	-	-	60000	2420	4.0
Albany Coast	WA	19	680	32000	166.0	4.6	58000	305.2	8.5	-	-	-	406000	-	-
Ashburton River	WA	28	49	-	-	-	-	-	-	-	-	-	267000	-	-
Avon River	WA	9.7	550	183000	1881.9	33.5	940	9.7	0.2	-	-	-	1507000	-	-
Blackwood River	WA	110	1300	41000	36.9	3.1	74000	66.1	5.6	-	-	-	489000	-	-
Busselton Coast	WA	140	580	3700	2.8	0.6	17000	12.3	2.9	-	-	-	50000	-	-
Cape Leveque Coast	WA	1	420	-	-	-	-	-	-	-	-	-	245000	-	-
Collie River	WA	170	450	1800	1.1	0.4	22000	13.5	5.0	-	-	-	53000	-	-
De Grey River	WA	120	150	-	-	-	-	-	-	-	-	-	266000	-	-
Denmark River	WA	37	390	2700	7.2	0.7	32000	87.0	8.2	-	-	-	64000	-	-
Donnelly River	WA	91	360	380	0.4	0.1	4800	5.3	1.3	-	-	-	31000	-	-
Drysdale River	WA	170	1400	-	-	-	-	-	-	-	-	-	380000	-	-
Esperance Coast	WA	4.2	330	33000	787.0	10.1	14000	323.6	4.1	-	-	-	384000	-	-
Fitzroy River	WA	740	1500	-	-	-	-	-	-	-	-	-	798000	-	-
Fortescue River	WA	10	120	-	-	-	-	-	-	-	-	-	219000	-	-
Frankland River	WA	6	350	8100	135.0	2.3	19000	321.0	5.6	-	-	-	118000	-	-
Gascoyne River	WA	200	0.2	-	-	-	-	-	-	-	-	-	182000	-	-

SWMA_NAME	State or territory	Sust. Yield	Runoff (GL/yr)	Farm dam impacts			Plantation impacts			Floodplain harvesting impacts			Recharge (ML/yr)	Stock & domestic bores impacts	
Greenough River	WA	38	75	38000	101.5	51.6	-	-	-	-	-	-	345000	-	-
Harvey River	WA	150	310	1800	1.2	0.6	6100	4.1	1.9	-	-	-	33000	-	-
Isdell River	WA	160	970	-	-	-	-	-	-	-	-	-	252000	-	-
Keep River	WA	78	260	-	-	-	-	-	-	-	-	-	76000	-	-
Kent River	WA	20	370	2200	10.8	0.6	27000	133.1	7.1	-	-	-	52000	-	-
King Edward River	WA	180	1300	-	-	-	-	-	-	-	-	-	281000	-	-
Lennard River	WA	280	410	-	-	-	-	-	-	-	-	-	157000	-	-
Lyndon-Minilya Rivers	WA	3.8	12	-	-	-	-	-	-	-	-	-	169000	-	-
Mackay	WA	1.1	570	-	-	-	-	-	-	-	-	-	1037000	-	-
Moore-Hill Rivers	WA	20	460	42000	203.9	9.0	9800	47.8	2.1	-	-	-	493000	3490	0.7
Murchison River	WA	0.5	26	-	-	-	-	-	-	-	-	-	305000	-	-
Murray River	WA	2000	2300	10000	0.5	0.4	22000	1.1	1.0	-	-	-	252000	25840	10.3
Ninghan	WA	1	59	-	-	-	-	-	-	-	-	-	120000	-	-
Nullarbor	WA	-	120	-	-	-	-	-	-	-	-	-	426000	-	-
Onslow Coast	WA	11	44	-	-	-	-	-	-	-	-	-	80000	-	-
Ord River	WA	170	190	-	-	-	-	-	-	-	-	-	92000	-	-
Pentecost River	WA	200	970	-	-	-	-	-	-	-	-	-	335000	-	-
Port Hedland Coast	WA	29	110	-	-	-	-	-	-	-	-	-	167000	-	-
Preston River	WA	50	170	870	1.7	0.5	6600	13.2	3.8	-	-	-	21000	-	-
Prince Regent River	WA	150	1200	-	-	-	-	-	-	-	-	-	229000	-	-
Salt Lake	WA	1	840	-	-	-	700	69.6	0.1	-	-	-	1851000	-	-
Sandy Desert	WA	-	1700	-	-	-	-	-	-	-	-	-	2372000	-	-
Shannon River	WA	58	630	270	0.5	0.0	7700	13.2	1.2	-	-	-	51000	-	-
Swan Coast	WA	130	710	5700	4.6	0.8	15000	12.3	2.2	-	-	-	165000	48190	29.2
Warburton	WA	6	1.1	-	-	-	-	-	-	-	-	-	31000	-	-
Warren River	WA	210	700	2700	1.3	0.4	31000	15.1	4.5	-	-	-	80000	-	-
Wooramel River	WA	-	13	-	-	-	-	-	-	-	-	-	129000	-	-
Yarra Yarra Lakes	WA	1	89	-	-	-	-	-	-	-	-	-	290000	-	-
TOTALS		39,000	225,000	1,600,000	4.1	0.7	2,020,000	5.2	0.9	900,000	2.2	0.3	52,500,000	*	-

*Please note a total value is not quoted here as it would not take into account the impact from states where data was not available on SWMA basis (i.e. ACT and Tasmania). Please see section 4.5 for discussion on the impact of stock and domestic use.

Table 34: Projected 2030 volume and impact of intercepting activities by SWMA

SWMA_NAME	State or territory	Sust. Yield (GL/yr)	Runoff 2008 (GL/yr)	Runoff 2015 (GL/yr)	Runoff 2030 (GL/yr)	Farm dams: increase in impact 2008 to 2030			Plantations: increase in impact 2008 to 2030			Recharge 2008 (GL/yr)	Recharge 2015 (GL/yr)	Recharge 2030 (GL/yr)	S & D Bores: increase in impact 2008 to 2030	
						ML/yr	%SY	% Runoff (2030)	ML/yr	%SY	% Runoff (2030)				ML/yr	% recharge (2030)
ACT	ACT	220	280	260	240	-	-	-	-786	-0.4	-0.3	29	29	28		**-**
Bega River	NSW	19	370	340	320	310	1.6	0.1	370	2.0	0.1	0	34	34	**460**	**1.4**
Bellinger River	NSW	11	900	850	790	180	1.7	0.0	3200	30.3	0.4	58	57	57	**1330**	**2.3**
Border Rivers	NSW	210	1400	1300	1200	3900	1.8	0.3	-11	0.0	0.0	-	360	360	**760**	**0.2**
Brunswick River	NSW	2.3	240	220	210	84	3.6	0.0	-8	-0.3	0.0	12	12	12	**800**	**6.6**
Castlereagh River	NSW	4	560	500	440	4800	120.5	0.9	-	-	-	190	200	210	**230**	**0.1**
Clarence River	NSW	69	3800	3500	3300	1200	1.8	0.0	16000	23.7	0.4	340	340	340	**750**	**0.2**
Clyde River - Jervis Bay	NSW	3.5	600	520	480	67	1.9	0.0	-	-	-	46	45	44	**230**	**0.5**
Cooper Creek	NSW	-	0.2	0.1	0.1	-	-	-	-	-	-	1.6	1.5	1.4	**0**	**0.0**
East Gippsland	NSW	-	180	160	150	3.3	-	0.0	930	-	0.5	15	15	15	-	**-**
Far West	NSW	3	370	310	260	1800	59.0	0.5	-	-	-	430	430	420	**230**	**0.1**
Gwydir River	NSW	400	1400	1200	1100	5700	1.4	0.4	-58	0.0	0.0	-	420	410	**730**	**0.2**
Hastings River	NSW	35	1400	1300	1200	220	0.6	0.0	-862	-2.5	-0.1	81	79	78	**970**	**1.2**
Hawkesbury River	NSW	-	3000	2800	2600	1100	-	0.0	-866	-	0.0	300	290	290	**1800**	**0.6**
Hunter River	NSW	660	1600	1400	1300	1900	0.3	0.1	-97	0.0	0.0	0	260	260	**610**	**0.2**
Karuah River	NSW	3.4	870	830	780	230	6.8	0.0	-78	-2.3	0.0	72	71	70	**230**	**0.3**
Lachlan River	NSW	320	2500	2100	1900	3500	1.1	0.1	-2095	-0.7	-0.1	-	900	950	**2140**	**0.2**
Lake Bancannia	NSW	-	12	7.6	4.4	-	-	-	-	-	-	74	71	68	**230**	**0.3**
Lake Frome	NSW	-	3.5	2	1	-	-	-	-	-	-	51	48	45	**230**	**0.5**
Lake George	NSW	0.2	79	73	66	170	87.1	0.2	-17	-8.5	0.0	9.3	9.4	10	**230**	**2.3**
Lower Darling	NSW	140	250	210	180	1900	1.3	0.7	-	-	-	-	-	-	-	**-**
Macleay River	NSW	20	1900	1700	1600	870	4.3	0.0	8600	42.6	0.5	150	150	150	**640**	**0.4**
Macquarie River	NSW	420	2700	2400	2100	21000	4.9	0.8	-3120	-0.7	-0.1	-	820	840	**2030**	**0.2**
Macquarie-Tuggerah Lakes	NSW	-	390	360	340	110	-	0.0	-	-	-	29	29	29	**300**	**1.0**
Manning River	NSW	83	1300	1200	1100	470	0.6	0.0	-355	-0.4	0.0	120	110	110	**230**	**0.2**
Moruya River	NSW	5.5	200	190	170	40	0.7	0.0	-	-	-	19	18	18	**230**	**1.3**
Murray - Regulated	NSW	1800	270	210	190	1200	0.1	0.4	-6	0.0	0.0	170	190	190	**590**	**0.3**
Murrumbidgee River	NSW	2000	3900	3400	3100	5300	0.3	0.1	-3383	-0.2	-0.1	-	970	1000	**460**	**0.0**
Namoi River	NSW	320	2000	1700	1600	6000	1.9	0.3	84	0.0	0.0	-	580	580	**3320**	**0.6**
Richmond River	NSW	69	1500	1400	1300	770	1.1	0.1	3500	5.1	0.2	250	130	130	**2070**	**1.6**
Shoalhaven River	NSW	-	990	790	730	420	-	0.0	-161	-	0.0	93	87	86	**260**	**0.3**
Snowy River	NSW	-	1200	1100	1000	530	-	0.0	160	-	0.0	100	99	98	**230**	**0.2**
Sydney Coast - Georges River	NSW	-	430	400	380	27	-	0.0	-	-	-	27	27	27	**260**	**1.0**
Towamba River	NSW	2.5	310	290	270	48	1.9	0.0	-27	-1.1	0.0	29	28	28	**230**	**0.8**
Tuross River	NSW	8.2	260	240	220	67	0.8	0.0	-	-	-	27	26	26	**230**	**0.9**
Tweed River	NSW	35	440	410	380	110	0.3	0.0	7100	20.5	1.6	25	25	24	**600**	**2.5**
Upper Darling	NSW	170	280	240	170	1200	0.7	0.4	-	-	-	-	-	-	-	**-**
Upper Murray River	NSW	7.2	820	740	690	170	2.4	0.0	1600	22.5	0.2	69	86	84	**230**	**0.3**
Wollongong Coast	NSW	-	250	240	220	33	-	0.0	-	-	-	15	15	14	**230**	**1.6**

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Adelaide River	NT	310	1300	1200	1200	-	-	-	140	0.0	0.0	160	160	160	**1920**	**1.2**
Barkly	NT	30	710	610	530	-	-	-	-	-	-	710	700	680	**650**	**0.1**
Bathurst and Melville Islands	NT	590	1400	1300	1200	-	-	-	-270	0.0	0.0	170	170	170	**400**	**0.2**
Blyth River	NT	220	780	710	650	-	-	-	-	-	-	180	180	170	**400**	**0.2**
Buckingham River	NT	440	920	850	790	-	-	-	-	-	-	180	180	180	**400**	**0.2**
Burt	NT	3.8	40	25	14	-	-	-	-	-	-	170	160	150	**400**	**0.3**
Calvert River	NT	180	220	190	170	-	-	-	-	-	-	110	110	110	**400**	**0.4**
Daly River	NT	1100	4000	3800	3500	-	-	-	15000	1.4	0.4	890	880	870	**1700**	**0.2**
Darwin / Blackmore Rivers	NT	70	150	150	140	-	-	-	-	-	-	21	22	21	**1340**	**6.4**
East Alligator River	NT	900	2300	2200	2000	-	-	-	-	-	-	350	340	340	**400**	**0.1**
Finke River	NT	8	5	2.5	1	-	-	-	-	-	-	120	110	99	**570**	**0.6**
Finniss / Elizabeth / Howard Rivers	NT	480	1600	1500	1400	-	-	-	1500	0.3	0.1	190	190	190	**5340**	**2.8**
Fitzmaurice River	NT	280	770	710	660	-	-	-	-	-	-	160	150	150	**400**	**0.3**
Georgina River	NT	130	180	140	120	-	-	-	-	-	-	390	380	370	**400**	**0.1**
Goomadeer River	NT	490	700	650	590	-	-	-	-	-	-	130	130	130	**400**	**0.3**
Goyder River	NT	300	770	700	640	-	-	-	-	-	-	190	190	190	**400**	**0.2**
Groote Eylandt	NT	130	180	0	0	-	-	-	-	-	-	43	0	0	**400**	**-**
Hay River	NT	7	8.8	4.2	1.8	-	-	-	-	-	-	180	160	150	**430**	**0.3**
Keep River	NT	78	260	240	220	-	-	-	-	-	-	76	75	74	**400**	**0.5**
Koolatong River	NT	310	640	590	550	-	-	-	-	-	-	150	150	150	**400**	**0.3**
Limmen Bight River	NT	300	340	300	270	-	-	-	-	-	-	170	170	170	**400**	**0.2**
Liverpool River	NT	570	920	840	770	-	-	-	-	-	-	190	180	180	**400**	**0.2**
Mackay	NT	1.1	570	460	370	-	-	-	-	-	-	1000	990	940	**430**	**0.0**
Mary River	NT	400	1100	1000	950	-	-	-	-	-	-	160	160	160	**400**	**0.3**
McArthur River	NT	630	440	410	370	-	-	-	-	-	-	220	220	210	**400**	**0.2**
Moyle River	NT	110	890	840	800	-	-	-	-	-	-	130	120	120	**400**	**0.3**
Nicholson River	NT	130	150	130	120	-	-	-	-	-	-	120	120	120	**400**	**0.3**
Ord River	NT	170	190	170	150	-	-	-	-	-	-	92	91	90	**410**	**0.5**
Robinson River	NT	180	290	260	240	-	-	-	-	-	-	130	130	130	**400**	**0.3**
Roper River	NT	950	2800	2600	2400	-	-	-	-	-	-	1000	1000	1000	**490**	**0.0**
Rosie River	NT	90	170	150	140	-	-	-	-	-	-	68	67	67	**400**	**0.6**
Settlement Creek	NT	160	140	120	110	-	-	-	-	-	-	61	61	60	**400**	**0.7**
South Alligator River	NT	-	1600	1500	1400	-	-	-	-	-	-	240	240	240	**400**	**0.2**
Todd River	NT	4	8	3.4	1.3	-	-	-	-	-	-	180	160	150	**500**	**0.3**
Towns River	NT	100	130	120	110	-	-	-	-	-	-	63	63	62	**-**	**-**
Victoria River	NT	560	2000	1800	1600	-	-	-	-	-	-	750	740	730	**400**	**0.1**
Walker River	NT	660	480	440	410	-	-	-	-	-	-	160	160	160	**400**	**0.3**
Warburton	NT	1	1.1	0.3	0.1	-	-	-	-	-	-	31	28	25	**400**	**1.6**
Wildman River	NT	60	750	660	630	-	-	-	-	-	-	97	98	97	**400**	**0.4**
Wiso	NT	40	1700	1400	1200	-	-	-	-	-	-	1600	1500	1500	**530**	**0.0**
Archer	QLD	-	2600	2400	2300	-	-	-	-	-	-	300	300	290	-	**-**
Baffle	QLD	-	450	390	350	670	-	0.1	-2688	-	-0.6	59	57	56	-	**-**
Barron	QLD	-	660	620	590	450	-	0.1	1100	-	0.2	110	110	110	**115**	**0.1**
Black	QLD	-	110	100	94	390	-	0.4	530	-	0.5	17	17	16	**115**	**0.7**
Border Rivers	QLD	210	970	860	730	290	0.1	0.0	-131	-0.1	0.0	270	280	320	**410**	**0.1**

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Boyne	QLD	-	210	190	180	270	-	0.1	-61	-	0.0	32	31	31	**115**	**0.4**
Bulloo	QLD	-	180	150	120	-	-	-	-	-	-	220	210	200	**115**	**0.1**
Burdekin	QLD	-	4800	4300	3900	77000	-	1.6	320	-	0.0	1300	1300	1300	**115**	**0.0**
Burnett	QLD	-	2300	2000	1800	29	-	0.0	-1629	-	-0.1	470	460	470	**115**	**0.0**
Calliope	QLD	-	160	150	130	0	-	0.0	-28	-	0.0	26	26	26	**115**	**0.4**
Coleman	QLD	-	1900	1700	1600	0	-	0.0	0	-	0.0	260	260	260	**115**	**0.0**
Condamine-Balonne	QLD	-	2900	2600	2300	71	-	0.0	-107	-	0.0	930	930	910	**460**	**0.1**
Cooper Creek	QLD	-	0.2	0.1	0.1	-	-	-	-	-	-	1.6	1.5	1.4	**510**	**36.4**
Curtis Island	QLD	-	51	47	43	-	-	-	-	-	-	7.2	7.1	7	-	**-**
Daintree	QLD	-	890	830	780	-	-	-	380	-	0.0	60	59	59	-	**-**
Don	QLD	-	260	240	220	1600	-	0.6	-	-	-	56	55	54	**115**	**0.2**
Ducie	QLD	-	1900	1800	1800	-	-	-	-	-	-	170	170	170	-	**-**
Embley	QLD	-	1400	1400	1300	-	-	-	-	-	-	110	110	110	**115**	**0.1**
Endeavour	QLD	-	640	590	550	0	-	0.0	-	-	-	52	51	50	**115**	**0.2**
Fitzroy	QLD	-	5700	5100	4500	30	-	0.0	740	-	0.0	1400	1400	1500	**370**	**0.0**
Fraser Island	QLD	-	240	230	210	0	-	0.0	-	-	-	33	32	31	**115**	**0.4**
Georgina-Diamantina	QLD	-	510	430	360	-	-	-	-	-	-	870	840	800	**300**	**0.0**
Gold Coast	QLD	-	460	430	400	-	-	-	9000	-	2.0	28	28	27	**115**	**0.4**
Herbert	QLD	-	1200	1100	1000	6000	-	0.5	1300	-	0.1	210	210	200	-	**-**
Hinchinbrook Island	QLD	-	170	160	150	-	-	-	-	-	-	11	11	11	-	**-**
Holroyd	QLD	-	1600	1500	1400	-	-	-	-	-	-	210	210	210	**115**	**0.1**
Jacky Jacky	QLD	-	760	710	690	-	-	-	-	-	-	81	82	82	-	**-**
Jardine	QLD	-	900	850	820	-	-	-	-	-	-	84	80	80	**115**	**0.1**
Jeannie	QLD	-	680	690	640	-	-	-	-22	-	0.0	78	78	77	**115**	**0.1**
Johnstone	QLD	-	1800	1700	1700	0.8	-	0.0	4000	-	0.2	110	110	110	-	**-**
Lockhart	QLD	-	480	460	440	-	-	-	-	-	-	58	58	58	-	**-**
Logan Basin	QLD	-	680	630	580	19	-	0.0	7300	-	1.1	65	64	63	**115**	**0.2**
Mary	QLD	-	1900	1800	1700	1.2	-	0.0	6300	-	0.3	230	220	220	**115**	**0.1**
Misc other islands	QLD	-	130	110	100	-	-	-	-	-	-	19	18	18	-	**-**
Mitchell	QLD	-	5800	5400	5000	-	-	-	-	-	-	1000	1000	1000	**115**	**0.0**
Moonie	QLD	-	390	350	310	0.6	-	0.0	-	-	-	140	140	140	**115**	**0.1**
Moreton	QLD	-	1600	1500	1400	8.4	-	0.0	-1171	-	-0.1	220	210	210	**115**	**0.1**
Mornington Island	QLD	-	63	59	54	-	-	-	-	-	-	17	17	17	-	**-**
Mossman	QLD	-	120	120	110	-	-	-	-	-	-	14	14	13	**115**	**0.9**
Mulgrave-Russell	QLD	-	1600	1500	1500	-	-	-	750	-	0.0	95	95	94	**115**	**0.1**
Murray	QLD	-	390	370	350	43	-	0.0	-8	-	0.0	38	38	38		**-**
Nebine	QLD	-	520	460	400	-	-	-	-	-	-	240	230	230	**122**	**0.1**
Normanby	QLD	-	3000	2800	2600	-	-	-	-	-	-	440	430	430	**115**	**0.0**
North Stradbroke Island	QLD	-	30	28	26	-	-	-	-	-	-	3.6	3.6	3.5	-	**-**
O'Connell	QLD	-	380	350	320	5.5	-	0.0	540	-	0.1	47	46	46	**115**	**0.3**
Olive-Pascoe	QLD	-	920	890	860	-	-	-	-	-	-	100	100	100	**115**	**0.1**
Paroo	QLD	-	130	110	86	-	-	-	-	-	-	150	150	140	**125**	**0.1**
Pioneer	QLD	-	410	370	330	510	-	0.1	-9	-	0.0	81	81	80	**115**	**0.1**
Plane	QLD	-	270	240	220	540	-	0.2	1900	-	0.7	44	44	44	**115**	**0.3**
Proserpine	QLD	-	210	200	190	160	-	0.1	1500	-	0.7	27	26	26	**115**	**0.4**

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Ross	QLD	-	150	140	130	640	-	0.4	-	-	-	24	23	23	**115**	**0.5**
Shoalwater	QLD	-	250	220	200	460	-	0.2	-	-	-	45	44	43	**115**	**0.3**
South Stradbroke Island	QLD	-	53	49	44	-	-	-	-	-	-	5.8	5.7	5.6	-	**-**
Southern Gulf	QLD	-	8100	7400	6800	-	-	-	-	-	-	2800	2800	2800	**550**	**0.0**
Stewart	QLD	-	350	320	300	-	-	-	-	-	-	48	47	47	**115**	**0.2**
Styx	QLD	-	160	140	130	82	-	0.1	-80	-	0.0	32	32	31	**115**	**0.4**
Torres Strait Islands	QLD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Tully	QLD	-	700	660	630	41	-	0.0	1200	-	0.2	57	57	57	-	**-**
Warrego	QLD	-	920	820	720	-	-	-	-	-	-	410	400	400	**230**	**0.1**
Waterpark	QLD	-	190	170	160	-	-	-	-571	-	-0.3	30	29	28	**115**	**0.4**
Watson	QLD	-	1300	1200	1200	-	-	-	-	-	-	110	110	110	-	**-**
Wenlock	QLD	-	1800	1700	1700	-	-	-	-	-	-	170	170	170	**115**	**0.1**
Whitsunday	QLD	-	0	0	0	-	-	-	12000	-	-	0	0	0	**115**	**-**
Whitsunday Island	QLD	-	0	0	0	-	-	-	-	-	-	0	0	0	-	**-**
Adelaide	SA	-	14	13	12	-	-	-	-72	-	-0.5	1.5	1.6	1.5	**230**	**15.3**
Angas-Bremer	SA	13	56	49	44	300	2.3	0.5	120	0.9	0.2	12	14	13	**313**	**2.4**
Angas-Bremer Prescribed Well Area	SA	-	6.6	5.5	4.8	22	-	0.3	-	-	-	4.5	4.4	4.1	**230**	**5.6**
Baroota	SA	-	1.7	1.5	1.4	0	-	0.0	-	-	-	0.9	0.9	0.9	**23**	**25.6**
Barossa Prescribed Water Resources Area	SA	3	23	18	16	58	1.9	0.2	-24	-0.8	-0.1	10	12	11	**23**	**2.1**
Broughton River	SA	-	100	84	72	530	-	0.5	-169	-	-0.2	80	84	82	**240**	**0.3**
Burra Creek	SA	-	16	14	13	1.1	-	0.0	-	-	-	7.8	7.7	7.5	**230**	**3.1**
Clare Valley Prescribed Water Resources Area	SA	9.8	25	21	18	120	1.2	0.5	-	-	-	14	14	14	**420**	**3.0**
Cooper Creek	SA	-	0.2	0.1	0.1	-	-	-	-	-	-	1.6	1.5	1.4	-	**-**
Coorong	SA	-	200	180	160	0	-	0.0	-	-	-	54	60	58	**230**	**0.4**
Cygnet River	SA	-	28	20	18	-	-	-	110	-	0.4	6.3	11	11	**230**	**2.1**
Diamantina River	SA	90	0	0	0	-	-	-	-	-	-	36	33	30	-	**-**
Eucla	SA	-	35	22	13	0	-	0.0	-	-	-	190	180	170	-	**-**
Eyre & Frome	SA	-	8.9	5.8	3.9	-	-	-	-	-	-	220	200	190	-	**-**
Ferries-McDonald	SA	-	19	17	15	0.1	-	0.0	-	-	-	7.8	7.7	7.5	**230**	**3.1**
Finke River	SA	8	5	2.5	1	-	-	-	-	-	-	120	110	99	-	**-**
Fleurieu Peninsula	SA	30	64	54	49	-	-	-	390	1.3	0.6	11	12	12	**230**	**1.9**
Gawler	SA	-	10	8.8	7.8	7.1	-	0.1	-	-	-	5.3	5.5	5.2	**230**	**4.4**
Gawler Craton	SA	-	400	300	240	13	-	0.0	-	-	-	790	760	730	**570**	**0.1**
Georgina River	SA	130	180	140	120	-	-	-	-	-	-	390	380	370	-	**-**
Hay River	SA	7	8.8	4.2	1.8	-	-	-	-	-	-	180	160	150	-	**-**
Kakoonie	SA	-	5.3	4.7	4.1	6.1	-	0.1	-	-	-	3.2	3.1	3	**230**	**7.7**
Kangaroo Island	SA	-	160	130	110	-	-	-	-95	-	-0.1	37	52	51	**230**	**0.5**
Lake Torrens	SA	-	29	24	19	0	-	0.0	-	-	-	78	75	72	**230**	**0.3**
Light	SA	-	77	67	58	0	-	0.0	-	-	-	47	47	46	**230**	**0.5**
Little Para	SA	11	7.4	6.3	5.7	9.4	0.1	0.1	-	-	-	1	1.3	1.3	**230**	**17.7**
Lower Limestone Coast Prescribed Well Area	SA	50	1200	930	800	2900	5.7	0.2	-20413	-40.8	-1.7	180	300	320	**6620**	**2.1**
Lower Torrens	SA	-	24	22	20	16	-	0.1	-	-	-	2.9	3	2.9	**4030**	**139.0**

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Mackay	SA	1.1	570	460	370	-	-	-	-	-	-	1000	990	940	**230**	0.0
Mallee Prescribed Well Area	SA	-	120	110	92	15	-	0.0	-	-	-	120	110	110	**410**	**0.4**
Mambray Coast	SA	-	23	19	16	130	-	0.5	-13	-	-0.1	27	26	26	**230**	**0.9**
Marne-Saunders	SA	1.5	32	28	25	20	1.3	0.1	-6	-0.4	0.0	9.8	11	10	**230**	**2.3**
McLaren Vale Prescribed Well Area	SA	-	20	14	12	160	-	0.8	-34	-	-0.2	8	11	11	**250**	**2.2**
Middle River	SA	-	7.4	5.7	5.1	210	-	2.9	-92	-	-1.2	1.6	2.6	2.5	**230**	**9.2**
Morambro Creek Prescribed Surface Water Area	SA	0.9	9.8	8.7	6.2	42	4.7	0.4	-	-	-	3.4	3.4	4.9	**230**	**4.7**
Murraylands	SA	-	49	42	36	28	-	0.1	-	-	-	60	57	54	**230**	**0.4**
Musgrave	SA	-	9.1	3.9	1.5	-	-	-	-	-	-	190	170	150	**320**	**0.2**
Musgrave Prescribed Well Area	SA	-	53	41	29	16	-	0.0	-	-	-	28	31	36	**230**	**0.6**
Mypolonga Flat	SA	-	0.9	0.7	0.6	-	-	-	-	-	-	1.2	1.2	1.1	**230**	**20.9**
Myponga	SA	17	13	10	9.3	530	3.1	4.1	-294	-1.7	-2.3	2.1	3.4	3.3	**230**	**7.0**
Noora	SA	-	2.9	2.5	2.2	7	-	0.2	-	-	-	10	9.4	8.8	**230**	**2.6**
Northern Adelaide Plains Prescribed Well Area	SA	-	28	25	23	14	-	0.0	-	-	-	10	10	9.7	**230**	**2.4**
Northern Eastern Mount Lofty Ranges	SA	3.5	49	43	38	15	0.4	0.0	-12	-0.3	0.0	14	14	14	**230**	**1.6**
Northern Flinders	SA	-	85	69	49	0	-	0.0	-	-	-	150	150	150	**240**	**0.2**
Onkaparinga	SA	60	37	31	27	680	1.1	1.8	-76	-0.1	-0.2	7	9.2	9.1	**630**	**7.0**
Padthaway Prescribed Well Area	SA	-	31	28	18	170	-	0.5	-	-	-	9.4	9.5	16	**230**	**1.4**
Parra Wirra	SA	-	22	19	17	190	-	0.9	-494	-	-2.3	3.8	4.6	4.5	**230**	**5.1**
Patawalonga	SA	-	21	20	18	0	-	0.0	-	-	-	2.3	2.3	2.2	**1660**	**75.3**
Peake-Roby-Sherlock Prescribed Well Area	SA	-	17	15	12	5.5	-	0.0	-	-	-	14	14	14	**230**	**1.6**
River Murray	SA	1900	490	390	340	-	-	-	-	-	-	11	9.9	9.7	**-**	**-**
Rocky River	SA	-	11	10	9	-	-	-	-	-	-	2.4	2.3	2.3	**230**	**10.0**
South West Eromanga	SA	-	-	0	0	-	-	-	-	-	-	25	23	21	**-**	**-**
Southern Basins Prescribed Well Area	SA	-	25	22	19	0	-	0.0	-	-	-	7	6.8	7.3	**230**	**3.2**
Southern Eastern Mount Lofty Ranges	SA	18	56	46	41	560	3.1	1.0	-156	-0.9	-0.3	13	17	17	**290**	**1.7**
Spencer Gulf	SA	-	36	28	21	230	-	0.6	-	-	-	89	78	76	**230**	**0.3**
Tatiara	SA	-	100	91	77	150	-	0.1	-	-	-	50	50	53	**690**	**1.3**
Tintinara-Coonalpyn Prescribed Well Area	SA	-	88	74	65	85	-	0.1	-	-	-	36	39	38	**230**	**0.6**
Unincorporated Area - Eromanga	SA	-	0.1	0.1	0.1	-	-	-	-	-	-	67	61	55	**-**	**-**
Upper Torrens	SA	40	29	24	21	72	0.2	0.3	-93	-0.2	-0.3	4.7	6.7	6.6	**230**	**3.5**
Wakefield	SA	-	32	26	21	270	-	0.9	-	-	-	33	33	32	**230**	**0.7**
Warburton	SA	6	1.1	0.3	0.1	-	-	-	-	-	-	31	28	25	**230**	**0.9**
Willochra Creek	SA	3.9	56	48	38	660	16.8	1.2	-	-	-	44	44	48	**230**	**0.5**
Yatla	SA	-	11	9.8	9	0.1	-	0.0	-	-	-	1.6	1.7	1.7	**230**	**13.5**
Yorke Peninsula	SA	-	110	79	64	230	-	0.2	-	-	-	130	130	130	**230**	**0.2**
Arthur	TAS	280	2000	1900	1800	-	-	-	2800	1.0	0.1	67	67	66	**-**	**-**
Black-Detention	TAS	36	360	340	330	3.8	0.0	0.0	880	2.4	0.2	14	14	14	**-**	**-**
Blythe	TAS	8.9	330	310	300	6.1	0.1	0.0	1500	16.5	0.5	11	10	10	**-**	**-**
Boobyalla-Tomahawk	TAS	100	200	-	-	5.3	0.0	0.0	-97	-0.1	0.0	13	0	0	**-**	**-**
Brumbys-Lake	TAS	-	280	270	250	9.1	-	0.0	8600	-	3.0	22	22	22	**-**	**-**

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Cam	TAS	13	230	220	210	4.9	0.0	0.0	690	5.4	0.3	7.4	7.3	7.2	-	-
Clyde	TAS	-	180	170	160	1.1	-	0.0	-24	-	0.0	13	13	13	-	-
Derwent Estuary-Bruny	TAS	-	270	260	260	-	-	-	1500	-	0.5	15	15	15	-	-
Duck	TAS	34	290	280	270	1.5	0.0	0.0	4400	12.9	1.5	11	11	11	-	-
Emu	TAS	6.2	220	210	200	4.2	0.1	0.0	550	8.9	0.3	6.6	6.5	6.4	-	-
Forth-Wilmot	TAS	110	1100	1100	1000	1.1	0.0	0.0	3300	3.0	0.3	32	32	32	-	-
Furneaux	TAS	-	270	-	-	0	-	0.0	0	-	0.0	26	0	0	-	-
George	TAS	36	150	-	-	2.7	0.0	0.0	26	0.1	0.0	9	0	0	-	-
Gordon-Franklin	TAS	-	4800	4700	4500	-	-	-	3	-	0.0	140	140	140	-	-
Great Forester-Brid	TAS	250	240	190	180	19	0.0	0.0	-67	0.0	0.0	18	16	16	-	-
Great Lake	TAS	-	130	130	120	-	-	-	-	-	-	5.8	5.7	5.7	-	-
Huon	TAS	640	1500	1500	1500	3	0.0	0.0	5000	0.8	0.3	68	67	67	-	-
Inglis	TAS	24	470	450	430	11	0.0	0.0	270	1.2	0.1	15	15	15	-	-
Jordan	TAS	24	160	150	150	-	-	-	-26	-0.1	0.0	13	13	13	-	-
King Island	TAS	-	240	0	0	-	-	-	-	-	-	18	0	0	-	-
King-Henty	TAS	-	2400	2300	2300	-	-	-	740	-	0.0	66	65	65	-	-
Leven	TAS	58	710	680	660	4.2	0.0	0.0	1300	2.2	0.2	21	20	20	-	-
Little Forester	TAS	85	91	85	80	0.8	0.0	0.0	-418	-0.5	-0.5	5.7	5.6	5.5	-	-
Little Swanport	TAS	100	89	84	78	-	-	-	-104	-0.1	-0.1	8.4	8.3	8.2	-	-
Lower Derwent	TAS	-	520	510	490	0.4	-	0.0	1700	-	0.3	25	25	25	-	-
Macquarie	TAS	300	250	240	220	-	-	-	-35	0.0	0.0	28	28	27	-	-
Meander	TAS	590	540	520	490	9.5	0.0	0.0	13000	2.3	2.5	29	28	28	-	-
Mersey	TAS	240	1300	1200	1200	15	0.0	0.0	8700	3.6	0.7	42	42	41	-	-
Montagu	TAS	27	220	210	200	27	0.1	0.0	-49	-0.2	0.0	9.6	9.6	9.5	-	-
Musselroe-Ansons	TAS	25	290	-	-	6.1	0.0	0.0	3900	15.8	1.4	17	0	0	-	-
Nelson Bay	TAS	-	560	540	510	-	-	-	350	-	0.1	20	20	19	-	-
North Esk	TAS	280	190	160	150	13	0.0	0.0	-2839	-1.0	-1.5	13	13	13	-	-
Ouse	TAS	-	460	440	420	1.9	-	0.0	2000	-	0.4	22	22	22	-	-
Pieman	TAS	-	5100	5000	4900	-	-	-	540	-	0.0	140	140	140	-	-
Pipers	TAS	230	160	150	140	1.5	0.0	0.0	-295	-0.1	-0.2	11	11	11	-	-
Pitt Water-Coal	TAS	230	120	120	120	11	0.0	0.0	-187	-0.1	-0.2	11	11	11	-	-
Port Davey	TAS	-	1800	1700	1700	-	-	-	-	-	-	61	61	61	-	-
Prosser	TAS	140	130	110	100	-	-	-	-3044	-2.2	-2.4	12	12	11	-	-
Ringarooma	TAS	350	300	-	-	30	0.0	0.0	2500	0.7	0.8	17	0	0	-	-
Rubicon	TAS	39	260	240	230	5.3	0.0	0.0	-226	-0.6	-0.1	13	13	13	-	-
Scamander-Douglas	TAS	12	120	77	72	0.4	0.0	0.0	-4085	-34.3	-3.4	8.7	7.4	7.3	-	-
South Esk	TAS	820	440	360	330	13	0.0	0.0	-8746	-1.1	-2.0	42	41	41	-	-
Swan-Apsley	TAS	36	130	120	120	-	-	-	-17	0.0	0.0	14	14	13	-	-
Tamar Estuary	TAS	-	250	240	220	1.5	-	0.0	440	-	0.2	16	16	16	-	-
Tasman	TAS	50	170	0	0	-	-	-	6900	13.7	4.0	12	0	0	-	-
Upper Derwent	TAS	-	2000	1900	1800	0	-	0.0	3700	-	0.2	68	67	67	-	-
Wanderer-Giblin	TAS	-	1400	1400	1400	-	-	-	-	-	-	42	42	42	-	-
Welcome	TAS	5.3	290	270	260	22	0.4	0.0	-64	-1.2	0.0	14	13	13	-	-
Avoca River	VIC	17	210	170	140	1000	6.3	0.5	-58	-0.4	0.0	130	150	150	**230**	**0.2**
Barwon River	VIC	92	540	420	390	3600	3.9	0.7	-2758	-3.0	-0.5	51	79	78	**230**	**0.3**

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Broken River	VIC	47	430	360	330	2700	5.8	0.6	1100	2.4	0.3	56	90	89	**230**	**0.3**
Bunyip River	VIC	34	810	750	700	4000	11.6	0.5	-14	0.0	0.0	60	61	61	**790**	**1.3**
Campaspe River	VIC	150	320	270	250	3800	2.5	1.2	-90	-0.1	0.0	49	73	72	**470**	**0.7**
East Gippsland	VIC	-	180	160	150	3.3	-	0.0	930	-	0.5	15	15	15	**230**	**-**
Glenelg River	VIC	250	1200	990	900	1000	0.4	0.1	3200	1.2	0.3	130	220	220	**360**	**0.2**
Goulburn River	VIC	1900	2700	2400	2200	9400	0.5	0.4	3700	0.2	0.1	240	310	300	**890**	**0.3**
Hopkins River	VIC	75	1000	810	740	1100	1.5	0.1	-1343	-1.8	-0.1	130	230	220	**1120**	**0.5**
Kiewa River	VIC	200	480	450	420	970	0.5	0.2	-194	-0.1	0.0	28	33	33	**230**	**0.7**
Lake Corangamite	VIC	15	560	470	430	3100	20.8	0.6	-732	-4.9	-0.1	52	93	91	**260**	**0.3**
Latrobe River	VIC	300	1200	1100	1000	2400	0.8	0.2	-4305	-1.5	-0.4	77	97	95	**230**	**0.2**
Loddon River	VIC	160	570	480	430	6700	4.2	1.2	-558	-0.4	-0.1	140	180	170	**440**	**0.3**
Mallee	VIC	-	-	190	160	180	-	-	-	-	-	130	170	170	**230**	**0.1**
Maribyrnong River	VIC	19	150	130	120	1400	7.3	0.9	82	0.4	0.1	15	22	22	**340**	**1.6**
Millicent Coast	VIC	-	380	310	260	-	-	-	-2241	-	-0.6	110	140	140	**230**	**0.2**
Mitchell River	VIC	130	600	550	510	420	0.3	0.1	-47	0.0	0.0	59	63	62	**230**	**0.4**
Moorabool River	VIC	69	160	140	120	1500	2.2	0.9	-521	-0.8	-0.3	24	37	36	**260**	**0.7**
Murray River	VIC	2000	2300	2100	2000	2200	0.1	0.1	1300	0.1	0.1	250	280	270	**570**	**0.2**
Otway Coast	VIC	71	1000	670	620	3400	4.8	0.3	-20013	-28.3	-1.9	60	63	62	**230**	**0.4**
Ovens River	VIC	400	1500	1300	1200	3600	0.9	0.3	-628	-0.2	0.0	110	150	150	**500**	**0.3**
Portland Coast	VIC	46	490	440	400	190	0.4	0.0	4300	9.3	0.9	48	47	47	**720**	**1.5**
Snowy River	VIC	-	1200	1100	1000	530	-	0.0	160	-	0.0	100	99	98	**230**	**0.2**
South Gippsland	VIC	90	1400	1300	1200	5100	5.7	0.4	-7555	-8.4	-0.5	100	110	110	**690**	**0.6**
Tambo River	VIC	17	420	380	350	440	2.7	0.1	-12	-0.1	0.0	46	48	48	**230**	**0.5**
Thomson River	VIC	470	1100	960	880	310	0.1	0.0	-579	-0.1	-0.1	86	110	100	**380**	**0.4**
Werribee River	VIC	38	150	130	120	1500	3.9	1.0	-119	-0.3	-0.1	21	30	29	**300**	**1.0**
Wimmera River	VIC	120	820	640	550	-	-	-	-64	-0.1	0.0	380	430	440	**230**	**0.1**
Yarra River	VIC	490	900	830	770	3100	0.6	0.3	2700	0.5	0.3	60	62	62	**300**	**0.5**
Albany Coast	WA	19	680	550	470	15	0.1	0.0	-13682	-72.0	-2.0	410	410	390	**-**	**-**
Ashburton River	WA	28	49	33	20	-	-	-	-	-	-	270	250	230	**-**	**-**
Avon River	WA	9.7	550	340	260	3000	30.5	0.5	-153	-1.6	0.0	1500	1400	1200	**-**	**-**
Blackwood River	WA	110	1300	1100	940	1100	1.0	0.1	-2316	-2.1	-0.2	490	490	470	**-**	**-**
Busselton Coast	WA	140	580	500	440	1200	0.9	0.2	6900	5.1	1.2	50	61	59	**-**	**-**
Cape Leveque Coast	WA	1	420	380	340	-	-	-	-	-	-	250	240	240	**-**	**-**
Collie River	WA	170	450	390	340	330	0.2	0.1	-1492	-0.9	-0.3	53	55	53	**-**	**-**
De Grey River	WA	120	150	120	91	-	-	-	-	-	-	270	260	250	**-**	**-**
Denmark River	WA	37	390	350	310	32	0.1	0.0	-4327	-11.7	-1.1	64	66	64	**-**	**-**
Donnelly River	WA	91	360	320	280	34	0.0	0.0	800	0.9	0.2	31	31	30	**-**	**-**
Drysdale River	WA	170	1400	1300	1200	-	-	-	-	-	-	380	380	370	**-**	**-**
Esperance Coast	WA	4.2	330	270	220	-	-	-	-2769	-65.9	-0.8	380	360	350	**-**	**-**
Fitzroy River	WA	740	1500	1400	1200	-	-	-	-	-	-	800	790	770	**-**	**-**
Fortescue River	WA	10	120	88	64	-	-	-	-	-	-	220	210	200	**-**	**-**
Frankland River	WA	6	350	290	250	-	-	-	-2716	-45.3	-0.8	120	120	110	**-**	**-**
Gascoyne River	WA	200	0.2	0.1	0	-	-	-	-	-	-	180	160	140	**-**	**-**
Greenough River	WA	38	75	29	20	980	2.6	1.3	-	-	-	340	310	280	**-**	**-**
Harvey River	WA	150	310	270	240	120	0.1	0.0	4500	3.0	1.4	33	33	32	**-**	**-**

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Isdell River	WA	160	970	880	810	-	-	-	-	-	-	250	250	250	-	-
Keep River	WA	78	260	240	220	-	-	-	-	-	-	76	75	74	-	-
Kent River	WA	20	370	330	290	-	-	-	-3399	-17.0	-0.9	52	53	51	-	-
King Edward River	WA	180	1300	1200	1100	-	-	-	-	-	-	280	280	270	-	-
Lennard River	WA	280	410	370	340	-	-	-	-	-	-	160	150	150	-	-
Lyndon-Minilya Rivers	WA	3.8	12	6.3	3.3	-	-	-	-	-	-	170	150	140	-	-
Mackay	WA	1.1	570	460	370	-	-	-	-	-	-	1000	990	940	-	-
Moore-Hill Rivers	WA	20	460	300	230	1500	7.2	0.3	-2209	-10.8	-0.5	490	490	460	**960**	**0.5**
Murchison River	WA	0.5	26	17	10	-	-	-	-	-	-	300	270	250	-	-
Murray River	WA	2000	2300	2100	2000	2200	0.1	0.1	1300	0.1	0.1	250	280	270	**6000**	**0.5**
Ninghan	WA	1	59	44	33	-	-	-	-	-	-	120	110	100	-	-
Nullarbor	WA	-	120	67	45	-	-	-	-	-	-	430	400	380	-	-
Onslow Coast	WA	11	44	32	22	-	-	-	-	-	-	80	78	74	-	-
Ord River	WA	170	190	170	150	-	-	-	-	-	-	92	91	90	-	-
Pentecost River	WA	200	970	880	800	-	-	-	-	-	-	340	330	330	-	-
Port Hedland Coast	WA	29	110	88	67	-	-	-	-	-	-	170	160	160	-	-
Preston River	WA	50	170	150	130	180	0.4	0.1	16	0.0	0.0	21	22	22	-	-
Prince Regent River	WA	150	1200	1100	990	-	-	-	-	-	-	230	230	220	-	-
Salt Lake	WA	1	840	670	530	-	-	-	-92	-9.2	0.0	1900	1700	1600	-	-
Sandy Desert	WA	-	1700	1400	1100	-	-	-	-	-	-	2400	2300	2200	-	-
Shannon River	WA	58	630	520	460	24	0.0	0.0	-3362	-5.8	-0.5	51	49	47	-	-
Swan Coast	WA	130	710	600	520	1000	0.8	0.1	-1057	-0.8	-0.1	160	170	160	**6460**	**0.5**
Warburton	WA	6	1.1	0.3	0.1	-	-	-	-	-	-	31	28	25	-	-
Warren River	WA	210	700	580	520	130	0.1	0.0	840	0.4	0.1	80	84	82	-	-
Wooramel River	WA	-	13	7.3	3.6	-	-	-	-	-	-	130	120	110	-	-
Yarra Yarra Lakes	WA	1	89	59	42	-	-	-	-	-	-	290	260	240	-	-
Totals		39,000	225,000	202,000	187,000	239,000	0.6	0.1	74,000	0.2	0.03	52,500	56,100	55,000	*	-

*Please note a total value is not quoted here as it would not take into account the impact from states where data was not available on SWMA basis (i.e. ACT and Tasmania). Please see section 4.5 for discussion on the impact of stock and domestic use.