Technical supplement

1. Previous water resources assessments in Australia

1.1 Introduction

The Australian Water Resources Assessment 2010 (the 2010 Assessment) is the first of its kind produced by the Bureau of Meteorology (the Bureau). The report presents assessments of Australia's climate and water resources in 2009–10 (July 2009 to June 2010). It discusses regional variability and trends in water resources and patterns of water use over recent seasons, years and decades, based on currently accessible data.

This technical supplement to the Australian Water Resources Assessment Report 2010 provides additional information on particular aspects of the report, including background information on:

- the context of the report particularly in relation to previous water resources assessments
- the choice of landscape water balance modelling methods used
- the analysis methods used
- the data selection procedures.

The supplement is organised into four chapters incorporating the above topics in the order in which they are listed.

1.2 Australian Water Resources Assessment 2010 region boundaries

The 2010 Assessment is structured around 13 regions covering the Australian continent, based on drainage division boundaries. Drainage divisions represent the catchments of major surface water drainage systems, generally comprising a number of river basins. Drainage divisions provide a scientifically robust framework for assessing hydrological flows in the landscape while also allowing information to be presented and discussed in broadly identifiable regional and climatic contexts.

The 13 regions were derived from the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2011f). This is a specialised geographic information system that identifies the spatial relationships of important hydrological features such as rivers, lakes, reservoirs, dams, canals and catchments.

Hierarchically-nested catchments were derived using an automated drainage analysis procedure based on a nine second digital elevation model (Bureau of Meteorology 2010c). Twelve drainage divisions were defined at the highest level of the hierarchy. At the next level, there are 191 catchment units. This work builds on and approximates the drainage boundaries developed by Geoscience Australia (1997) which were the result of a joint State, Territory and Australian Government project to create a national spatial database of major hydrological basins.

For the Australian Water Resources Assessment 2010 report, one drainage division, the South East Coast, was split in two, using selected catchment boundaries at the second level of the hierarchy. This division was chosen to best approximate the border between New South Wales (NSW) and Victoria, creating the 'South East Coast (NSW)' and 'South East Coast (Victoria)' regions.

The differences between the original Geoscience Australia boundaries and those used in the 2010 Assessment are illustrated in Figure 1-1.

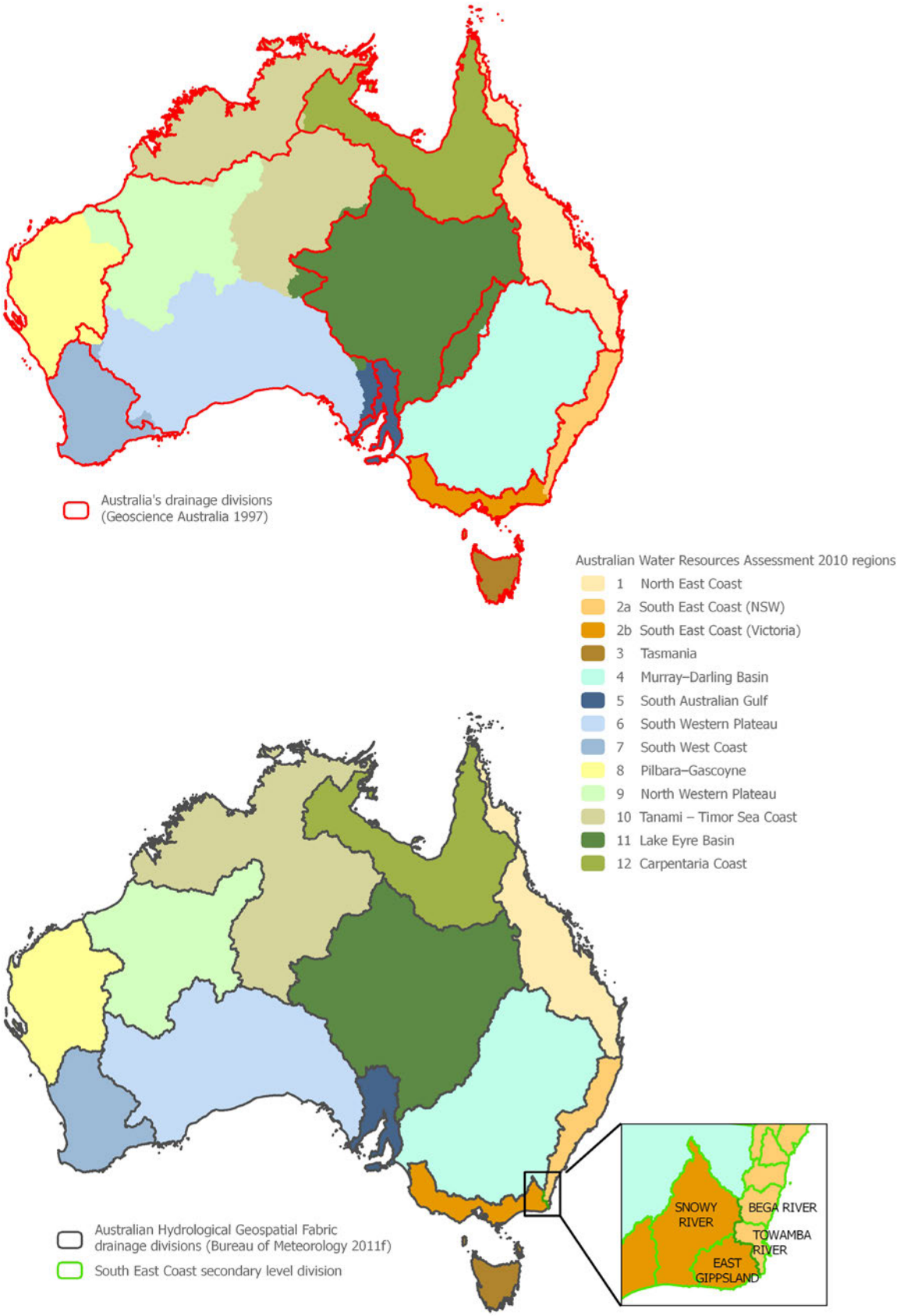


Figure 1-1. Comparison of drainage division boundaries of Geoscience Australia (1997) and the Australian Water Resources Assessment 2010 regions.

1.3 Jurisdictional water reporting products

There are many existing water information products already in the public domain in Australia. Links to key websites for these products are summarised in Table 1-1 and Table 1-2.

Table 1-1. Links to key Australian Government water reporting products

Organisation	Report name	Report link
Australian Bureau of Agricultural and Resource Economics and Sciences	Water Balance Reporting Tool	http://adl.brs.gov.au/water2010/water_balance_month/index.phtml
Australian Bureau of Statistics	ABS Water Accounts	www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4610.02004-05?OpenDocument
Australian Bureau of Statistics	Water Use on Australian Farms	www.abs.gov.au/AUSSTATS/abs@.nsf/mf/4618.0
Australian Bureau of Statistics	Water and the Murray–Darling Basin	www.abs.gov.au/ausstats/abs@.nsf/mf/4610.0.55.007
Commonwealth Scientific and Industrial Research Organisation	Sustainable Yields Projects	www.csiro.au/partnerships/SYP.html
Murray–Darling Basin Authority	Water Audit Monitoring Report	www.mdba.gov.au/services/publications/more-information?publicationid=88
National Water Commission	Australian Water Resources 2005	http://water.gov.au/IntroductiontoAWR2005/index.aspx?Menu=Level1_2
National Water Commission	National Performance Reports	www.nwc.gov.au/
National Water Commission	Biennial Assessment Report	www.nwc.gov.au/www/html/147-introduction---2009-biennial-assessments.asp?intSiteID=1

Table 1-2. Links to key State and Territory water reporting products

Jurisdiction	Organisation	Report name	Report link
Australian Capital Territory	Department of the Environment, Climate Change, Energy and Water	Water Report	www.environment.act.gov.au/__data/assets/pdf_file/0003/175206/DECCEW_Water_Report_FINAL_FINAL.pdf
New South Wales	New South Wales Office of Water	Water supply and sewerage performance monitoring	www.water.nsw.gov.au/Urban-water/Country-Towns-Program/Best-practice-management/Performance-monitoring/Performance-monitoring/default.aspx
Northern Territory	Natural Resources, Environment, The Arts and Sport	Water Allocation Plans	www.nt.gov.au/nreta/water/manage/water_allocation.html
Queensland	Department of Environment and Resource Management	Water Resources Planning Annual Catchment Reports	www.derm.qld.gov.au/wrp/annual_reports.html
Tasmania	Department of Primary Industries, Parks, Water and Environment	Waterway Monitoring Report and Water Management Plans	www.dpiw.tas.gov.au/inter.nsf/WebPages/JMUY-6BV8GJ?open
South Australia	South Australia Water	Annual Report, Drinking Water Quality and Water Sustainability Reports	www.sawater.com.au/sawater/whatsnew/publications/annual+reports.htm
Victoria	Department of Sustainability and Environment	Victorian Water Accounts	www.water.vic.gov.au/monitoring/accounts
Western Australia	Department of Water	Allocation Plans	www.water.wa.gov.au/Managing+water/Allocation+planning/default.aspx

The following sections provide explanations of major jurisdictional products.

1.3 Jurisdictional water reporting products (continued)

1.3.1 Australian Bureau of Agricultural and Resource Economics and Sciences

The 'Rural Water' website of the Australian Bureau of Agricultural and Resource Economics and Sciences contains landscape water balance reports for every river basin and drainage division in Australia (average annual and for some historical months). Data were drawn from a large range of information sources, including: CSIRO, Bureau of Meteorology, Australian Bureau of Statistics, Geoscience Australia, the National Land and Water Resources Audit, the Australian National Committee on Large Dams, the Australian National Committee – International Commission on Irrigation and Drainage, the Murray–Darling Basin Commission, State Agencies and the Australian Water Resource Council.

1.3.2 Australian Bureau of Statistics

Water Account Australia

The Australian Bureau of Statistics Water Account Australia integrates annual data from different sources, including Australian Bureau of Statistics surveys, into a consolidated data-set. The account links physical water data to economic data, such as that in Australia's National Accounts. The 2004–05 Water Account Australia was partly funded by the National Water Commission and is a component of the Australian Water Resources 2005 project. Earlier Water Accounts were created for 1993–94 to 1996–97 and 2000–01.

Water Use on Australian Farms

The *Water Use on Australian Farms* publications provide estimates of agricultural water use, irrigated pastures and crops, water sources for agricultural use, irrigation water management and financial data relating to irrigation. Estimates are presented for Australia, State and Territories and regions, as well as for the Murray–Darling Basin. These estimates are compiled from data collected as part of the agricultural census, which is conducted every five years with sample agricultural surveys carried out during the inter-census years.

Water and the Murray–Darling Basin

This publication provides environmental, economic and social information for the Murray–Darling Basin, which is presented in five chapters. Chapter 3 describes water use in the Murray–Darling Basin including:

- water consumption
- irrigation application rates
- area irrigated
- water storage.

1.3.3 Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Projects to investigate likely sustainable water yields in the Murray–Darling Basin, Tasmania, northern Australia and in southwest Western Australia were commissioned in response to shortages, and potential development opportunities in water resources. Policy-makers are the primary audience for Sustainable Yields projects. The findings will be used in the development of water sharing plans as specified in the Commonwealth *Water Act 2007*.

The Sustainable Yields projects assessed the current and future availability of water resources. Four scenarios of climate and water resource development were considered:

- Scenario A – current development and historic climate
- Scenario B – current development and recent climate
- Scenario C – current development and future climate
- Scenario D – future development and future climate.

Scenario A used 1895–2006 rainfall data while Scenario B was based on rainfall for the ten years between 1997 and 2006. Scenarios C and D used the 2030 climate predictions from global climate models in the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. In terms of water resource development, Scenarios A, B and C replicated the conditions specified in current water sharing plans, whereas Scenario D considered the expansion of farm dams, plantation forestry and groundwater extraction.

Eighteen new reporting units were developed for the Murray–Darling Basin Sustainable Yields projects. The new units were based on a combination of surface hydrology and river system models. They differ from previous spatial units, such as surface water management areas, river basins and Murray–Darling Basin Cap regions.

The results from the Sustainable Yields projects are presented in a series of regional and summary reports, which can be accessed from the CSIRO website. Regional reports generally contain the following water information:

- contextual information (hydrology, hydrogeology and water management)
- climate and drought assessment
- modelled run-off
- modelled groundwater recharge
- water balance (from river systems modelling)
- groundwater balance (from groundwater modelling)
- water accounts (based on measurement and estimation)
- environmental assessments.

1.3 Jurisdictional water reporting products (continued)

1.3.4 National Water Commission

Australian Water Resources 2005

The primary purpose of Australian Water Resources 2005 was to provide a baseline assessment of water resources and management prior to national water reforms. Baseline information on water availability, water use and river/wetland health was assembled for future comparisons measuring the success of the National Water Initiative reform process.

Under the National Water Initiative, the National Water Commission is required to: 'undertake a baseline assessment of the water resource and governance arrangements, based on existing work by the Parties and undertaking further work only where required.' (National Water Commission 2011c)

Regional water resources assessments were undertaken for surface water management areas and groundwater management units. Depending on the region, these assessments can include:

- contextual information
- water resources
- water balance
- water use
- assessment of river and wetland health
- management indicators.

National Performance reports

Urban and rural performance benchmarking reports for the most significant water suppliers have been published by the National Water Commission since 2005. Three annual reports were completed for 88 urban water utilities and two annual reports were done for the 13 rural water service providers. Indicators for both reports were developed, covering:

- water resources
- system characteristics
- customer service
- environment
- health
- asset management
- finance and pricing.

Australian Water Markets report

The National Water Commission released its inaugural water markets report in December 2008. The report provides a range of data relating to entitlements, allocations, trading and economic activity occurring in each State and Territory. Data are presented by regulated and unregulated management areas.

Biennial Assessment report

Biennial Assessments by the National Water Commission report on all aspects of progress with respect to the objectives and outcomes of the National Water Initiative. This includes reporting on progress with respect to:

- the level of understanding of our water resources and their use
- ensuring the health of river and groundwater systems
- increasing the productivity and efficiency of water use
- dealing with challenges for rural and urban communities.

One of the means by which the Biennial Assessments achieve this is to report against performance indicators approved by the Natural Resource Management Ministerial Council, including indicators such as:

- water application rates for irrigated agriculture
- gross value of irrigated agricultural production by State per unit volume
- household water use per annum
- percentage of water supplied to users by source
- percentage of water losses in distribution systems
- proportion of water use for consumptive and non-consumptive purposes.

1.3 Jurisdictional water reporting products (continued)

1.3.5 Murray–Darling Basin Authority

The Murray–Darling Basin Authority took over many of the responsibilities of the former Murray–Darling Basin Commission. Their functions under the Commonwealth *Water Act 2007* include:

- establishment of a Basin Plan
- measuring, monitoring and recording the quality and quantity of water resources in the Murray–Darling Basin
- management of Murray–Darling water resources
- operation of a Murray–Darling Basin Water Rights Information Service.

Water Audit Monitoring report

Water Audit Monitoring reports are produced annually by the Murray–Darling Basin Authority. They report on compliance with diversion limits as well as water and climate conditions for the year including:

- diversions
- water trading
- environmental flows
- storages and streamflow
- allocation
- losses
- groundwater use.

Most data are annual and presented in tables and graphs.

1.3.6 Australian Capital Territory (ACT)

The key water publication in the ACT is the annual *ACT Water Report* published by the Environment Protection Authority. This report is environmentally driven and focuses on the waterways of the ACT with the exception of Lake Burley Griffin, which is a federal responsibility. These reports have been produced yearly since 1996–97 with the most recent being the 2007–08 report (Australian Capital Territory Government 2008). Values recorded throughout the reporting year (for example, streamflow or water quality indicators) are compared to the long-term averages.

Recent reports are divided into three sections: (i) Water Resources; (ii) Water Quality and Condition; and (iii) Research and Community Activities.

The Water Resources section relates to the volume of water available for use within the ACT and provides an overview of water allocation and water availability. Water allocation is tabulated as total water volume and number of surface, groundwater and surface plus groundwater licences from 14 water management areas. Water availability is graphed as the previous year's rainfall and inflow against long-term averages.

The Water Quality and Condition section relates to water quality measured in water courses throughout and near the ACT during the year.

The Research and Community Activities section outlines research programs and community activities that were conducted during the reporting year. Groundwater levels are monitored at 14 bore sites in the ACT. Research and monitoring of groundwater are reported in Section 3 of the *ACT Water Report*.

The annual report of the State-owned water company, ACTEW, is the only other annual publication currently produced in the ACT that contains water information. The ACTEW Annual Report is published as a requirement under section 6(1) of the ACT *Annual Reports (Government Agencies) Act 2004* and contains a review of drinking water consumption in the ACT and treated wastewater effluent discharge into the Murrumbidgee system. This report makes a brief statement as to whether environmental flow guidelines were met for the year.

1.3 Jurisdictional water reporting products (continued)

1.3.7 New South Wales (NSW)

A dedicated annual water report covering a broad range of water related issues and statistics across all of NSW is not currently published. However, individual organisations responsible for different jurisdictions do produce water information products (e.g. annual reports) covering a range of issues.

The NSW Office of Water produces the Water Supply and Sewerage Performance Monitoring Report. This report provides a broad range of data for 107 non-metropolitan and four metropolitan water utilities with annual information for comparison over the previous six years. Information relating to utility characteristics, health, water resources and usage, pricing and economics, and effluent management is presented.

The Sydney Catchment Authority Annual Report provides several water information products. Bulk water supplied over the past five years to customers (Sydney Water, Wingecarribee Shire Council, Shoalhaven City Council, direct users and others) is reported as a table and bulk water stored over the past ten years is reported graphically. The annual report also details releases from storages in the Sydney catchment for the previous year. Releases are categorised as being for customer, the environment or other purposes. The annual report also contains rainfall data.

1.3.8 Northern Territory

There is no annual, high profile public report on the status of water resources in the Northern Territory. Water Allocation Plans are gradually being developed for various priority catchments across the Northern Territory where the need for more intensive management of water resources is identified.

The Water Allocation Plans were developed to maintain environmental flow in areas where groundwaters are seasonally recharged and drawn down. There is generally high recharge, but also high discharge rates which can be monitored each year, allowing for an adaptive management approach. There is no standard template for a Plan. The level of detail is based upon the population, the importance of the resource to the community and the complexity of the hydrological system. The objectives of the plans can be summarised as:

- to manage water resources in a way that balances social and environmental protection with economic growth
- to provide an understanding of the water resources and water demands
- define water allocations and establish mechanisms for community involvement in water resource management
- set a strategic work plan for management of water resources for the next ten years.

1.3 Jurisdictional water reporting products (continued)

1.3.9 Queensland

In Queensland, a Water Resource Plan establishes a framework for sustainable water resource management for domestic, irrigation and industrial purposes, and environmental water requirements. It specifies the outcomes that must be met under sustainable water management arrangements in the plan area, and how they will be achieved. It is typically implemented through a resource operations plan, which establishes the operating rules for water supply systems to meet the Water Resource Plan's objectives.

Under section 53 of the Queensland *Water Act 2000*, the minister must report periodically on the implementation of each plan. The Water Resource Plan Annual Report 2009–10 provides the annual flow conditions and realised extractions, which vary year to year. The Annual Report contains one chapter for each plan. It covers the period from 1 July 2009 to 30 June 2010 for 19 catchments (Barron, Border, Boyne, Burdekin, Burnett, Calliope, Condamine and Balonne, Cooper Creek, Fitzroy, Georgina and Diamantina, Gold Coast, Great Artesian Basin, Gulf, Logan, Mitchell, Moonie, Moreton, Pioneer Valley and Warrego–Paroo–Bulloo–Nebine).

Generally this report provides information for each catchment under the following headings:

- overview
- background on plan area
- hydrologic year in review
- plan implementation
- plan outcomes
- water allocation and use
- water sharing rules and critical water supply arrangements
- water trading
- water service provider operations and monitoring
- impact monitoring
- ecological monitoring
- planning processes and changes to the plan.

1.3.10 Tasmania

While there are a number of water data and information products developed for Tasmania, no annual, high profile public report on the status of water resources in the State is undertaken. The Department of Primary Industries, Parks, Water and Environment is the major custodian for Government water information and hydrological water assessment in Tasmania. Water Information Systems of Tasmania provides public access to streamflow, groundwater, water quality, water licence and river health data for the State's catchments.

Between 2004 and 2008, Waterway Monitoring Reports were produced on an annual basis for 40 of the State's 48 catchments. These annual reports provided streamflow and water allocation information and interpretations on the status of water quality and river health in each catchment. Prior to this, more detailed State of Rivers Reports were completed for 13 catchments in agriculturally developed areas of the State.

More detailed water resource assessments are undertaken to support the development of catchment water management plans. Information on catchment hydrological characteristics, the current status of water allocation and water availability on a sub-catchment basis is provided through hydrological reports. This information is used with environmental and socio-economic information to develop the water management plan. To date, six water management plans have been formally adopted with a further seven plans in various stages of development.

Hydro Tasmania undertakes water management reviews as a mechanism to review environmental performance and water management practices. The process is undertaken on a catchment by catchment basis. Various scientific studies support the review including hydrological assessments.

1.3 Jurisdictional water reporting products (continued)

1.3.11 South Australia (SA)

There is no annual, publicly available, comprehensive water publication or water balance for South Australia. The State's major water utility, South Australia Water, produces several regular reports based on its jurisdiction. Its Annual Report provides:

- annual water consumption statistics (e.g. total volume supplied, average household consumption, highest daily consumption)
- water source derivation (i.e. River Murray, surface water, groundwater)
- wastewater figures and a comparison of these values over the previous five years.

South Australia Water also produces a Drinking Water Quality Report and a Water Sustainability Report, the latter of which has been incorporated into the Annual Report since 2008.

Under the National Water Initiative, South Australia Water is required to provide statistical data on water use for metropolitan Adelaide and South Australian regional centres (Mount Gambier, Whyalla, Murray Bridge, Port Augusta, Port Lincoln and Port Pirie). This is compiled by the National Water Commission in production of its National Performance Report.

1.3.12 Victoria

The State Water Report presents accounts of water in each of Victoria's 29 river basins for the financial year. Information presented for each basin includes:

- a seasonal overview, factors influencing water availability, comparison with the previous years data
- a map of the river basin
- current water resources summary
- surface water (water balance, small catchment dams, entitlement transfers, diversions)
- groundwater
- seasonal allocations and restrictions on water use, diversions and extractions
- recycled water
- water for the environment (environmental water reserve, entitlements, passing flow compliance requirements, streamflow management plans, water leaving the basin).

A methodology for calculating water balances is detailed in this report. In summary:

- The spatial unit for water accounts is the river basin as defined by the Australian Water Resource Council.
- Groundwater information is reported within a river basin to give an indication of total resource use.
- The accounts detail diversions and extractions rather than use.
- Diversion types include urban, irrigation district, regulated licensed, environmental water and small catchment dams.
- Diversion figures are recorded at the off-take and therefore include all transmission losses prior to water reaching the user.

1.3 Jurisdictional water reporting products (continued)

1.3.13 Western Australia (WA)

There are a number of water data and information products generated by various organisations in Western Australia. The Department of Water has published several reports outlining water resources across the State including allocation plans which are available on their website. Published water balance studies by the Water Corporation focus mainly on groundwater resources.

Helping underpin the sustainable planning and management of this State's water resources is the South West Sustainable Yields project undertaken by the Department of Water and CSIRO. This project involves an assessment of the water yield of 13 catchments and 24 groundwater areas in the southwest, particularly in irrigation areas, under a changing climate.

2. Landscape water balance methods

2.1 Introduction

A major component of the Australian Water Resources Assessment 2010 report is the estimation of the dominant landscape water flows and stores on a national scale. These are not directly measured across all parts of Australia. Spatial interpolation techniques and modelling simulations were used to generate this information.

This chapter explains the reasoning for the choice of the WaterDyn and AWRA-L as the models for simulating the spatial and temporal variability of the non-measured water balance components. These include actual evapotranspiration, soil moisture and landscape water yield (run-off and groundwater discharge).

2.2 Considerations for choice of methods

The Bureau's Water Information Services Branch was formed in 2008 to produce various retrospective water reporting products. Since then, Bureau and CSIRO staff have been working on establishing systems and methods to support this new role. Two new major information products will be regularly produced. These are the Australian Water Resources Assessment report and the National Water Account (www.bom.gov.au/water/nwa). The National Water Account contains water accounting reports for nationally significant regions. It provides information on water stores and flows, water rights and water use.

Both products require continental scale water balance estimation, according to the conceptual water balance framework defined by Barratt (2008) as illustrated in Figure 2-1. As observations are not available for all of these stores and flows at sufficient frequency and resolution across the continent, various models or methods are required to estimate the required values.

The methods for estimating components of the water balance for the 2010 Assessment and the National Water Account 2010 were chosen according to the following considerations:

- **consistency**: the methods could be applied consistently to both products
- **timeliness**: the methods could be implemented in time for both product deadlines subject to available Bureau resources
- **robustness**: the methods are demonstrably robust compared with other available methods.

The choice of methods for rainfall, actual evapotranspiration, landscape water yield and soil moisture storage are discussed below.

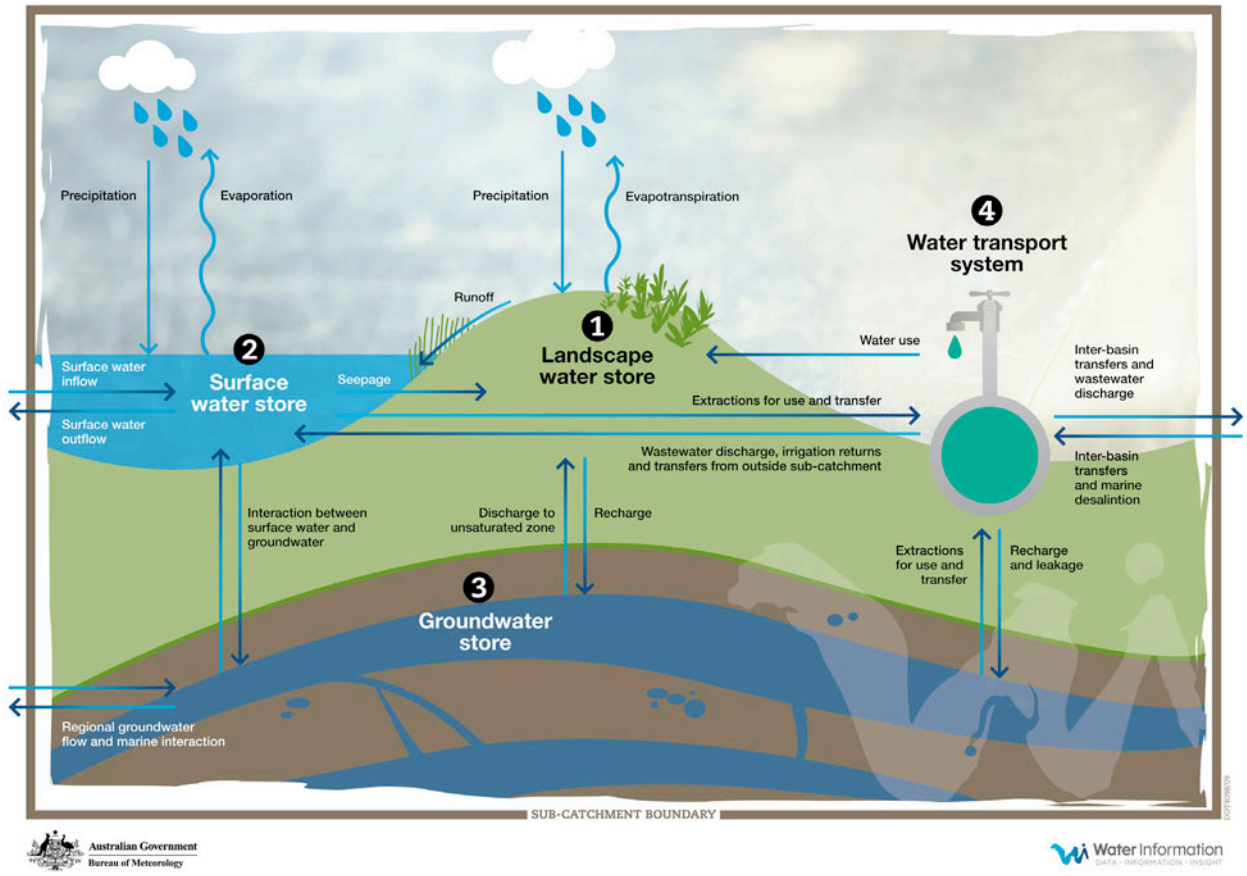


Figure 2-1. Conceptual water balance framework of Barratt (2008)

2.3 Modelling concepts

2.3.1 Input climate data requirements

Rainfall measurements are required for estimation of the rainfall term (Barratt 2008) and for input into water balance models. Gridded rainfall produced by the Bureau (Jones et al. 2009) was used. The data-set is derived from spatial interpolation of available daily rainfall readings collected by the Bureau.

Solar radiation and temperature serves as input for the models used in this report. Daily gridded estimates provided under the Australian Water Availability Project were used (see www.bom.gov.au/jsp/awap/).

Modelled landscape water balance estimates

The 2010 Assessment includes estimates of actual evapotranspiration, landscape water yield (run-off and groundwater discharge) and soil moisture storage. The AWRA-L model version 0.5 (Van Dijk 2010; Van Dijk & Warren 2010) and WaterDyn version 25M (Raupach et al. 2008) produce modelled estimates of all these components. Figure 2-2 shows a diagram of the conceptual processes contained in each of these models that were implemented within the Bureau.

Other methods exist that can be used to produce estimates of individual components of the water balance, but these have yet to be adopted by the Bureau. For example, the conceptual rainfall run-off models (e.g. as employed within the various Sustainable Yields projects; www.csiro.au/partnerships/SYP.html; Chiew et al. 2008) can be used to produce estimates of run-off. Furthermore, satellite empirical-based methods can be used to estimate actual evapotranspiration (e.g. the CSIRO Modis Reflectance Scaling ET (CMRSET) algorithm; Guerschman et al. 2009).

Comparisons of the various modelling methods available against observed streamflow (Viney 2010) and evapotranspiration (King et al. 2011) and relative to one another (Bacon et al. 2010) provide information about the accuracy of the estimates for the various model outputs.

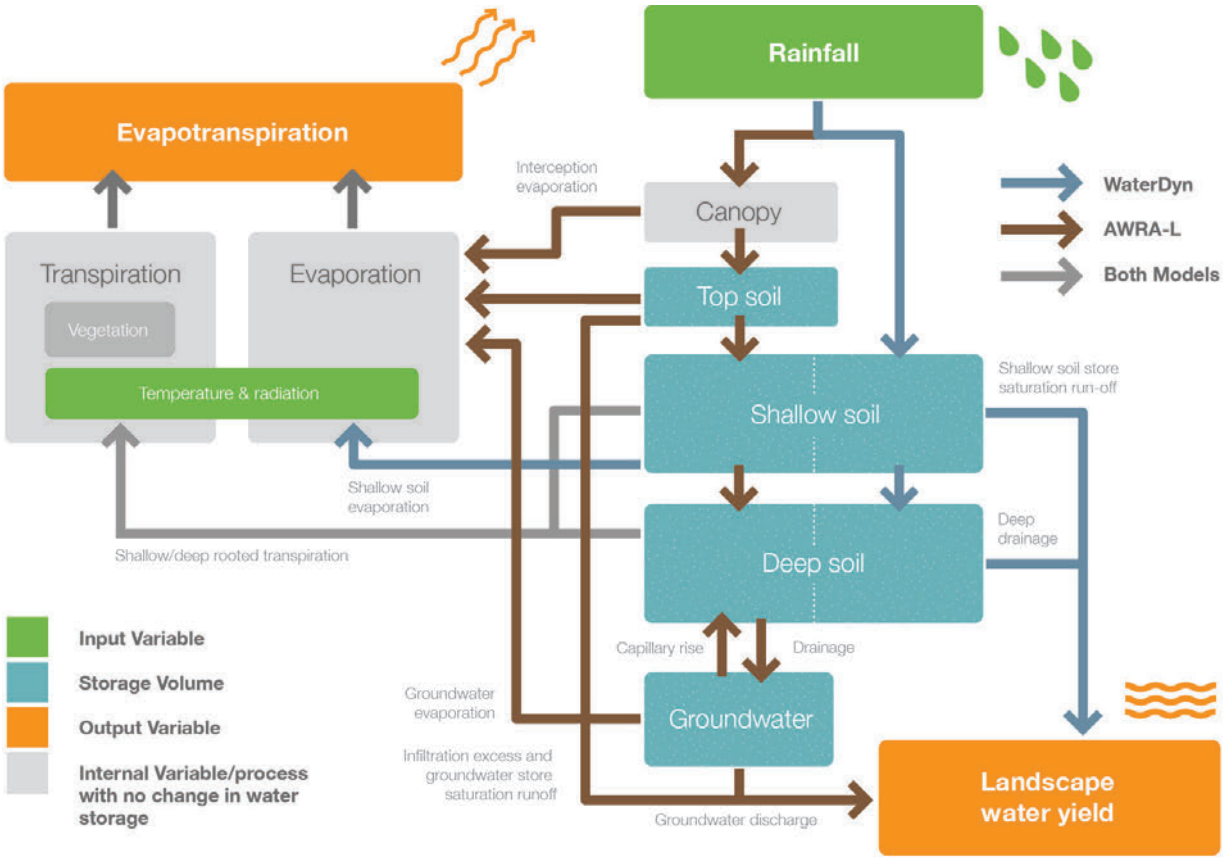


Figure 2 2. Conceptual diagram of AWRA-L and WaterDyn model processes

2.3 Modelling concepts (continued)

Landscape water yield

Rainfall run-off models calibrated to local streamflow tend to perform best. Furthermore, an ensemble of run-off estimates from the various models available tends to produce a better estimate overall. Also, the national gridded models AWRA-L and WaterDyn perform at a similar standard, although not as well as locally calibrated models. Model performances are of varying quality depending on location as illustrated in Figure 2-3 and Figure 2-4 by the annual bias and Nash-Sutcliffe efficiency values for the various regions used in the Sustainable Yields projects. In these graphs, the Australian Water Availability Project represents the WaterDyn model results.

Evapotranspiration

Evapotranspiration estimates provided from AWRA-L and WaterDyn are reasonable compared to other available methods in uplands areas. Satellite-based methods perform better in irrigation/inflow receiving areas, as the models do not currently allow for sources of water into a grid pixel other than rainfall (e.g. flooding, irrigation). The CMRSET algorithm was recommended for use in inflow receiving areas, with AWRA-L or WaterDyn recommended for upland areas. Application of such a quilted product was not possible in time for the Australian Water Resources Assessment 2010 report.

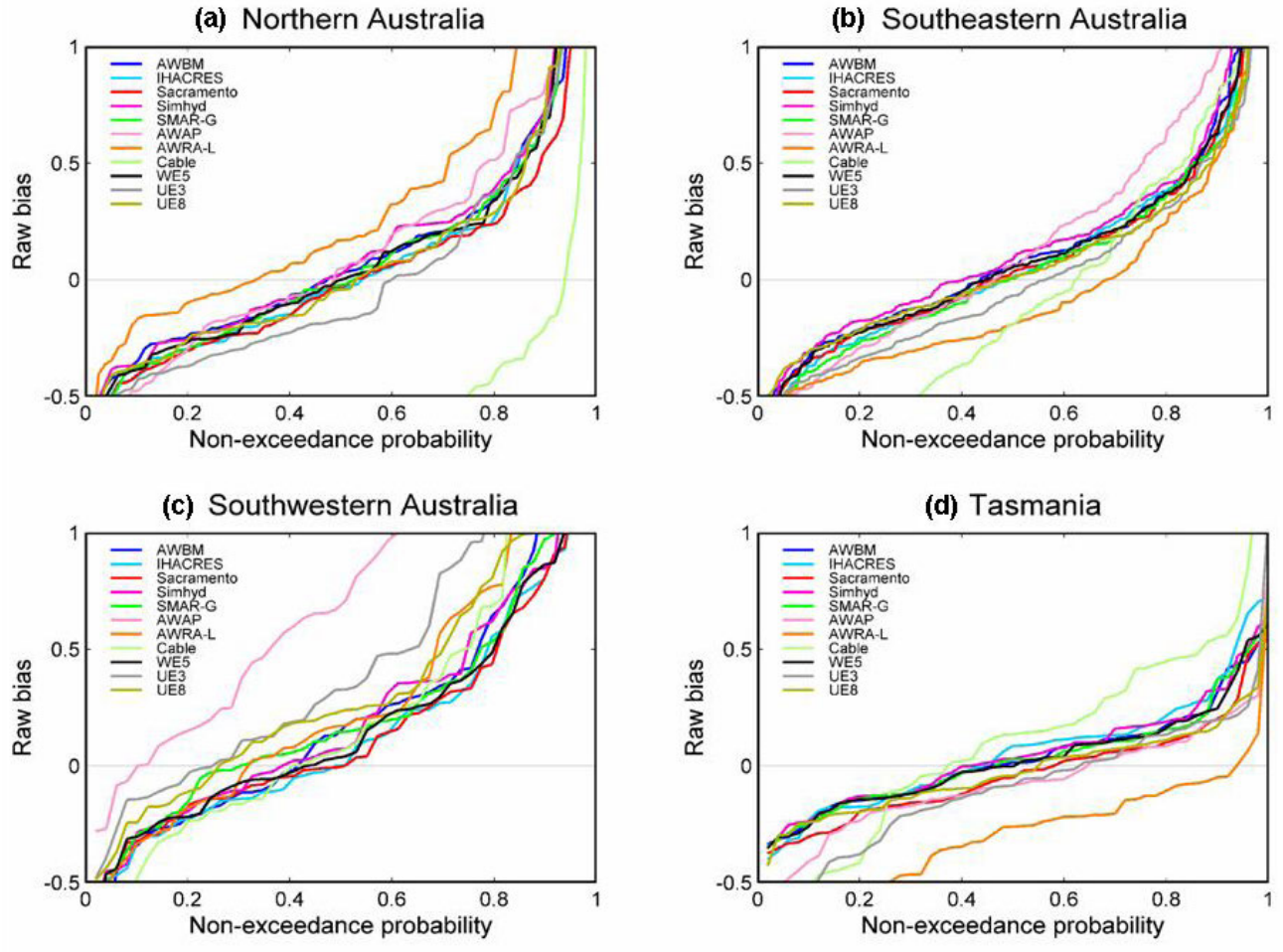


Figure 2-3. Cumulative distribution of raw average bias of annual streamflow predictions in validation mode for: (a) northern Australia, (b) south-eastern Australia, (c) south-western Australia and (d) Tasmania (Viney 2010)

2.3 Modelling concepts (continued)

Soil moisture storage

Soil moisture estimates derived from AWRA-L and WaterDyn differ greatly in magnitude when compared in absolute terms across the reporting regions (Figure 2-5). This difference is predominantly due to the differing assumptions in each of the models regarding upper and lower soil store capacity. WaterDyn uses available soil depth mapping to spatially vary the soil depth around Australia within the model. Spatially explicit soil properties for the two WaterDyn soil layers are based on the McKenzie and Hook (1992) and McKenzie et al. (2000) interpretations of the Digital Atlas of Australian Soils (Northcote et al. 1960–68). AWRA-L currently uses a constant soil storage capacity across Australia. Neither approach is perfect, as (a) for WaterDyn: the soil mapping will contain errors and (b) for AWRA-L: soil depth (and hence water holding capacity) varies spatially. Comparison of relative performance at reproducing observed field and satellite data is yet to be undertaken.

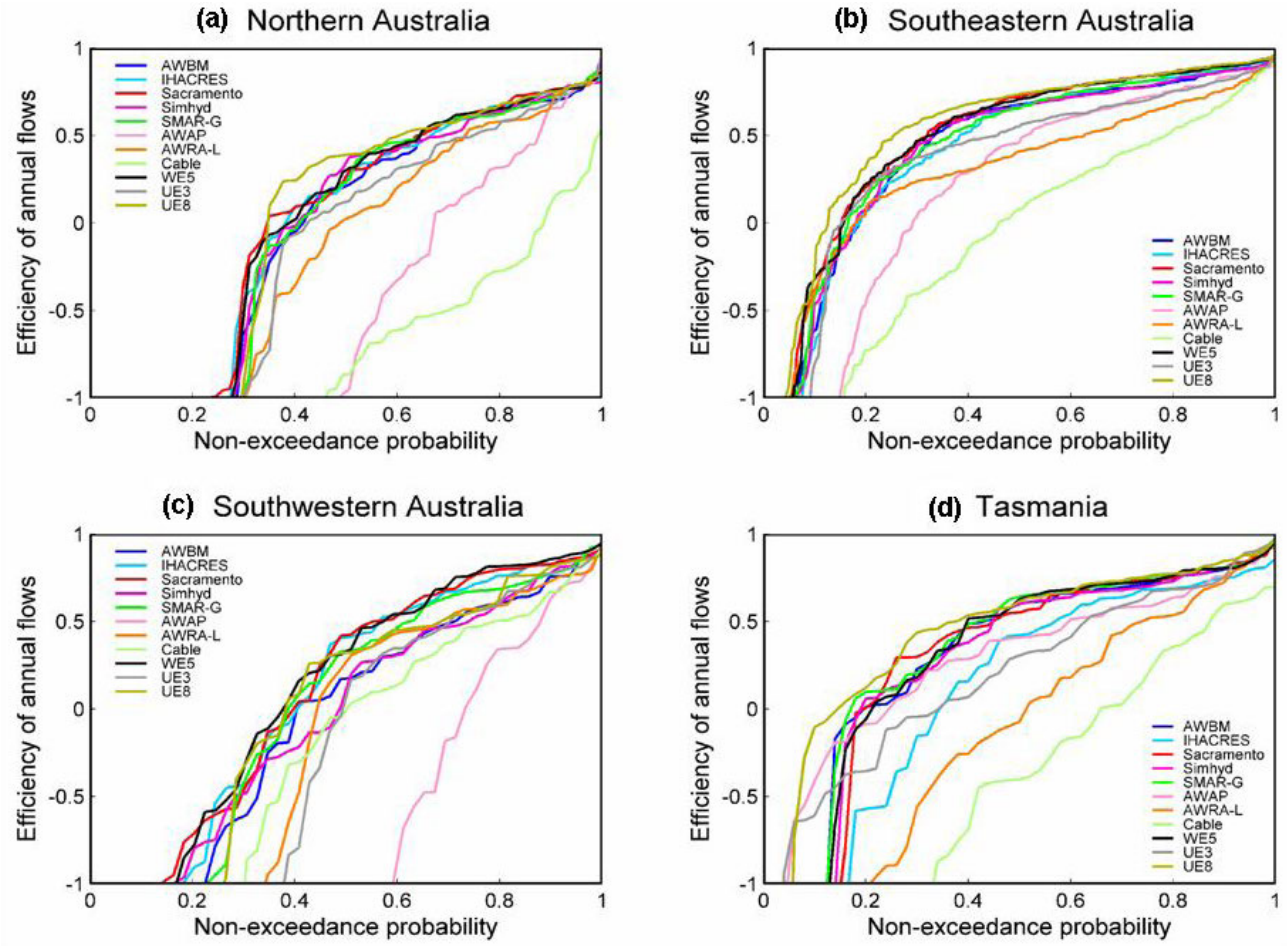


Figure 2-4. Cumulative distribution of Nash-Sutcliffe Efficiency of annual streamflow predictions in validation mode for (a) northern Australia, (b) south-eastern Australia, (c) south-western Australia and (d) Tasmania (Viney 2010)

2.3 Modelling concepts (continued)

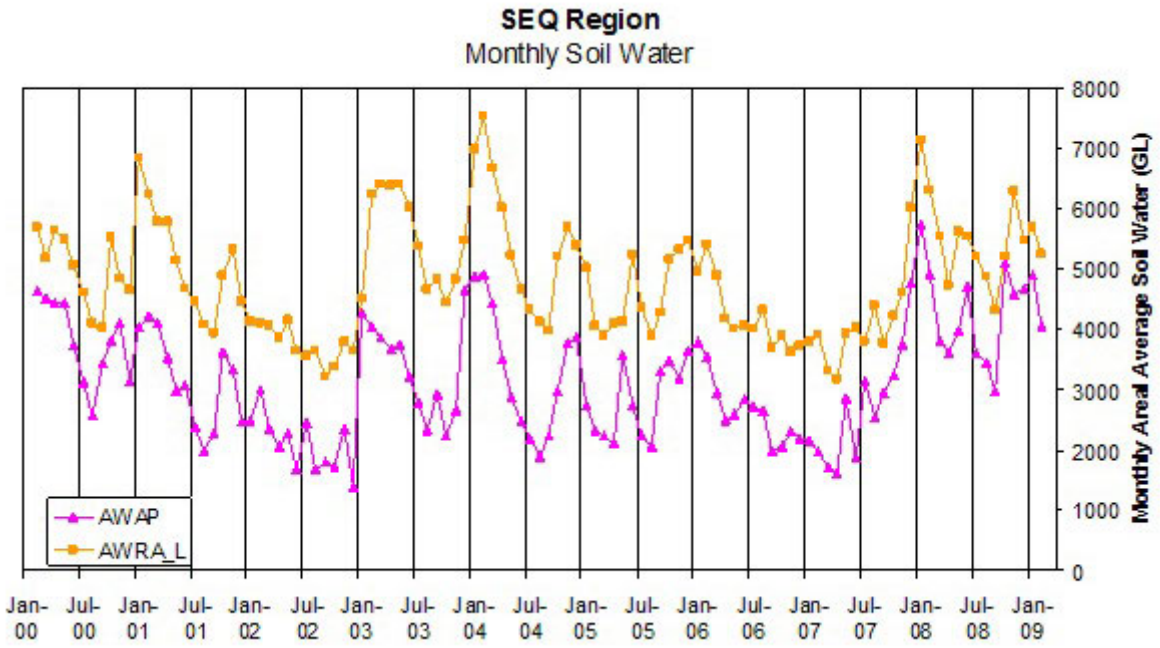


Figure 2-5. Monthly aggregated soil moisture for South East Queensland comparing WaterDyn (AWAP) and AWRA-L (Bacon et al. 2010)

2.4 Adopted approach

The following decisions were made as the most comprehensive approach to estimate the required water balance components for the 2010 Assessment.

Landscape water yield

As there was insufficient time for calibration/regionalisation of standard rainfall run-off models for use in the National Water Account 2010 and the Australian Water Resources Assessment 2010, an average of WaterDyn and AWRA-L, defined below, was selected to generate estimates of modelled landscape water yield for this report. That estimate was shown by Bacon et al. (2010) to be better than either model alone when compared to available unimpaired catchment streamflow data.

$LWY = (F_{WDis} + Q_{Tot}) / 2$

Where:

- LWY is modelled landscape water yield
- F_{WDis} is modelled catchment discharge/outflow from WaterDyn [surface run-off (F_{WRun}) + deep drainage (F_{WLch2})]
- Q_{Tot} is modelled streamflow from AWRA-L (surface run-off + groundwater discharge).

Soil moisture storage

As the WaterDyn soil store varied according to available soil depth mapping (albeit flawed due to mapping errors), the WaterDyn model was chosen for calculation of soil moisture storage. Averaging of soil store estimates (as used for streamflow) was not considered appropriate, as the conceptual structure and capacity of AWRA-L and WaterDyn soil and groundwater storages are different.

Actual evapotranspiration

As the satellite-based algorithms, compared by King et al. (2011), were not available to the Bureau for the Australian Water Resources Assessment 2010, and as WaterDyn was used for soil moisture storage, WaterDyn was also used for evapotranspiration calculation.

It should be noted that, as an AWRA-L and WaterDyn average was used for landscape water yield in the Australian Water Resources Assessment 2010, and WaterDyn was used for evapotranspiration and soil moisture storage, a mass balance is not maintained.

2.5 Current development: the AWRA modelling system

As part of the Water Information Research and Development Alliance (WIRADA) between the Bureau and CSIRO, the AWRA modelling system (Van Dijk et al. 2011; see Figure 2-6) is the preferred model for use in future editions of this report. It is under development to support the Bureau's National Water Account and Australian Water Resources Assessment reporting requirements. This development will improve the robustness of the estimation methods and will facilitate timely reporting by the Bureau.

The AWRA modelling system includes the following components:

- A holistic **water balance model** (AWRA-LRG): this consists of landscape, river and groundwater balance components, also allowing dynamic linkages between them. Development has focused on the landscape component to date (Van Dijk & Warren 2010). AWRA-LRG will provide a consistent water balance estimation system.
- A **model-data fusion system** to update and constrain model estimates according to observations where appropriate. Model-data fusion includes calibration/parameterisation of model components (e.g. calibration of a rainfall run-off model according to streamflow data), assimilation of observations to update model states/parameters (updating model soil store states according to satellite observations) and other blending methods (e.g. averaging differing model estimates of run-off).
- A **benchmarking system** to test that the model and input data are accurately reflecting observations. The benchmarking system refers to a set of (partly or wholly automated) tests designed to assess how well the simulations from a modified system version (in comparison to a previous system version) reproduce a standard set of observations following a standard set of criteria. This also needs to include ongoing evaluation of system forcing data where possible.

Other components are under development as well, which is further described by Stenson et al. (2011). It is expected that through this research and development, over the remainder of the WIRADA (ending June 2013), estimates provided within Australian Water Resources Assessment reports will significantly improve.

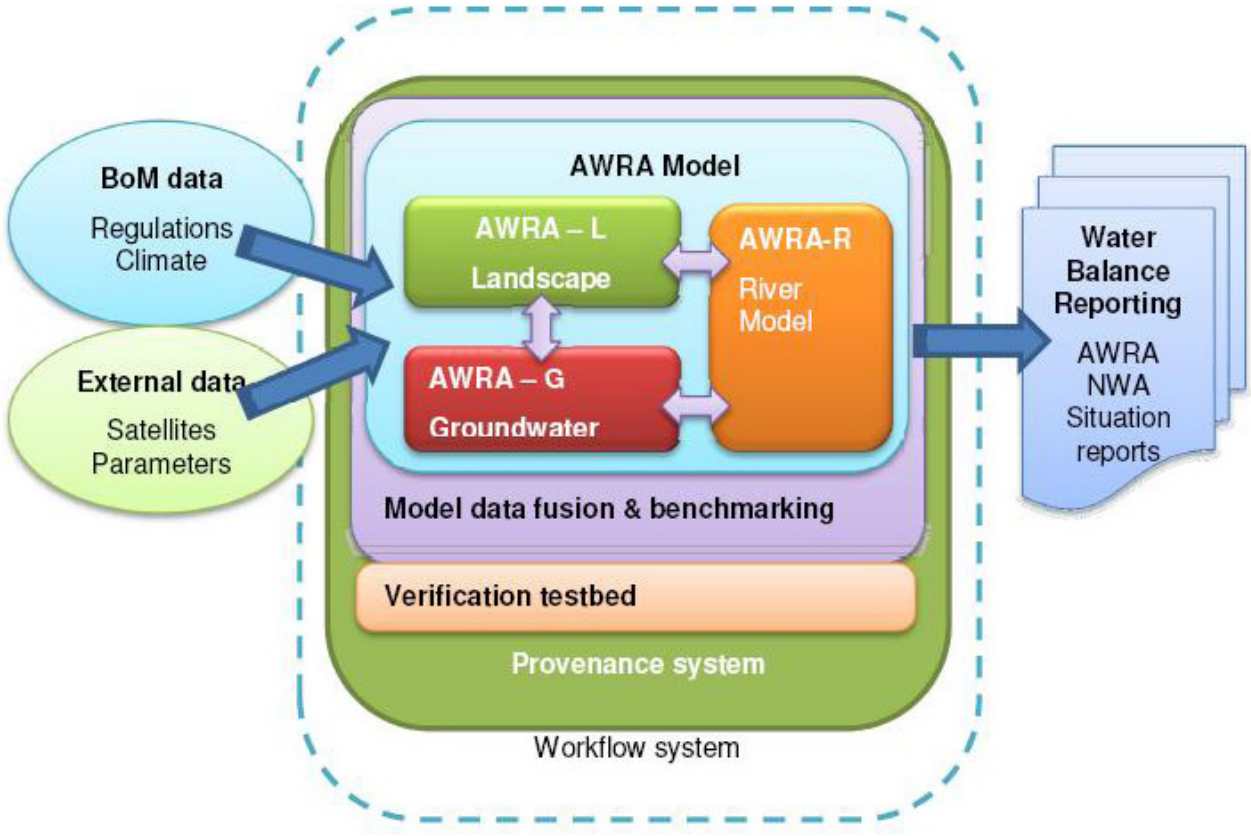


Figure 2-6. AWRA modelling system conceptual diagram

3. Methods review summary

The 2010 Assessment includes many different analysis methods, most of them specifically focusing on particular components of the water resources (i.e. groundwater, storages or streamflow). These methods were selected with care, based on a sound investigation of similar assessments previously performed in Australia and overseas.

This summary is to provide a list of references and peer reviews of the analysis methods used in this report, to demonstrate the validity of the methods.

For each method used in the report, the consequent tables provide the following information:

- a reference to the section in which the method is used
- a short description of the input data for the analysis
- a short description of the applied method
- the resolution (temporal and spatial) of the output data
- references to other work in which the method was applied
- an example illustration of the output.

More information on each individual report figure can be found in the metadata for the figure in question. This is provided on the Australian Water Resources Assessment 2010 website.

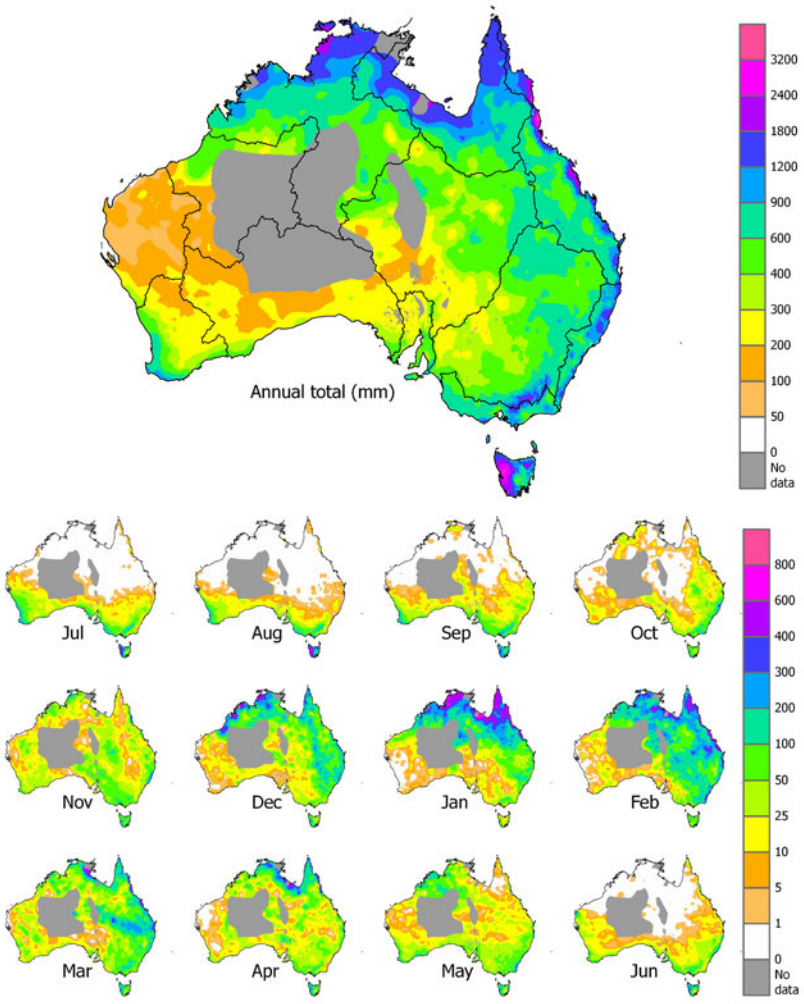
For further details of Categories of Water Information defined in the Methods review summary, please refer to the following webpages:

- Categories of water information www.bom.gov.au/water/regulations/categoriesWaterAuxNav.shtml
- Sub-categories of water information www.bom.gov.au/water/regulations/subCategoriesWaterAuxNav.shtml

3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Annual and monthly national rainfall surfaces National Overview/ Landscape water flows in 2009–10 (Section 2.3)	**Description** 5 x 5 km rainfall grid data derived using an anomaly-based approach applying the Barnes successive correction method and smoothing spline approach. **Source** Bureau (National Climate Centre)	**Description** Bureau standard spatial climate data presentation method. Monthly and annual total rainfall grids (July–June) presented. Monthly data summed to generate annual rainfall grid. **Resolution (Output)** **Temporal** – Annual/Monthly **Spatial** – 5 x 5 km grid (National coverage)	Bureau of Meteorology 2010, Annual Climate Summary 2009, www.bom.gov.au/climate/annual_sum/2009/AnClimSum09_HR1.1.pdf Bureau of Meteorology 2011, Annual Climate Summary 2010, www.bom.gov.au/climate/annual_sum/2010/AnClimSum10_HR1.0.pdf Jones, DA, Wang, W and Fawcett, R 2009, 'High-quality spatial climate data-sets for Australia', *Australian Meteorological and Oceanographic Journal*, vol. 58, pp. 233–248.

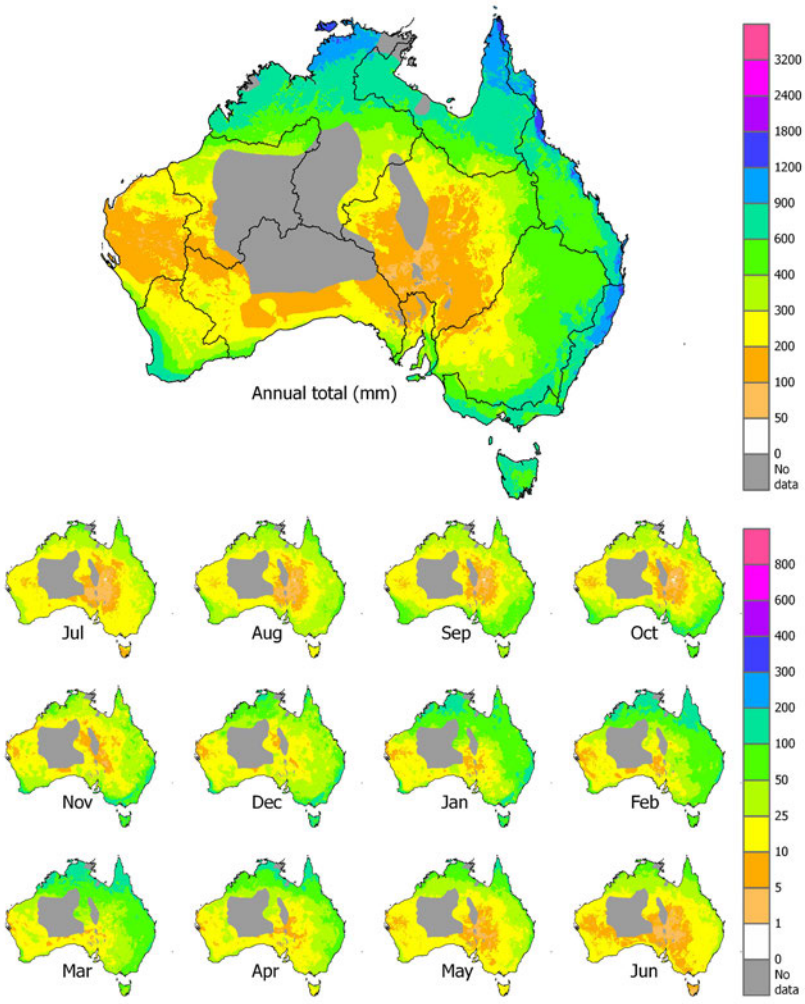
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Annual and monthly national modelled actual evapotranspiration surfaces National Overview/ Landscape water flows in 2009–10 (Section 2.3)	**Description** 25 x 5 km actual evapotranspiration grid data from national water balance model (WaterDyn). Based on the Priestly-Taylor equation. **Source** CSIRO (WaterDyn V26)	**Description** Bureau standard spatial climate data presentation method. Monthly and annual total modelled actual evapotranspiration grids (July–June) presented. Monthly data summed to generate annual evapotranspiration grid. **Resolution (Output)** **Temporal** – Annual/Monthly **Spatial** – 5 x 5 km grid (National coverage)	Raupach, MR, Briggs, PR, Haverd, V, King, EA, Paget, M and Trudinger, M 2009, *Australian Water Availability Project: CSIRO Marine and Atmospheric Research Component: Final Report for Phase 3*, CAWCR Technical Report No. 013, Centre for Australian Weather and Climate Research, Australia.

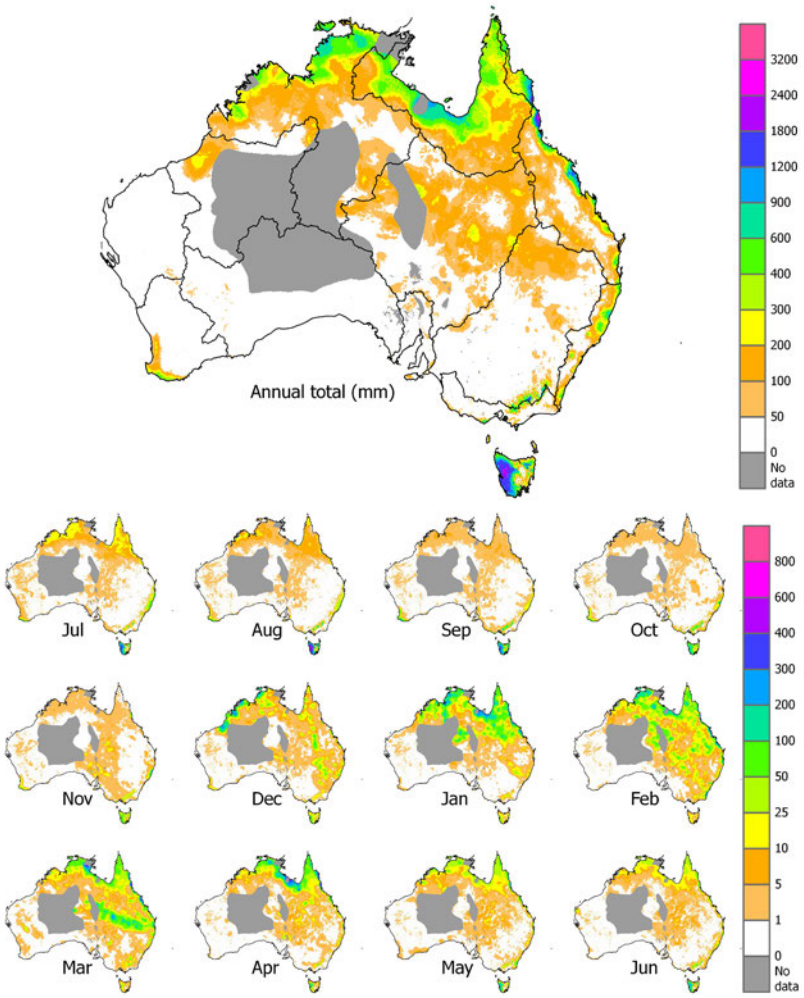
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Annual and monthly national modelled landscape water yield surfaces National Overview/ Landscape water flows in 2009–10 (Section 2.3)	**Description** 5 x 5 km modelled landscape water yield grid data derived from average of model generated outputs from two national water balance models (WaterDyn and AWRA-L). **Source** CSIRO (WaterDyn V26/AWRA-L)	**Description** Bureau standard spatial climate data presentation method. Monthly and annual total modelled landscape water yield grids (July–June) presented. Monthly data summed to generate annual landscape water yield grid. **Resolution (Output)** **Temporal** – Annual/Monthly **Spatial** – 5 x 5 km grid (National coverage)	Raupach, MR, Briggs, PR, Haverd, V, King, EA, Paget, M and Trudinger, M 2009, *Australian Water Availability Project: CSIRO Marine and Atmospheric Research Component: Final Report for Phase 3*, CAWCR Technical Report No. 013, Centre for Australian Weather and Climate Research, Australia. Van Dijk, A 2010, *The Australian Water Resources Assessment System: Technical Report 3; Landscape Model (version 0.5), Technical Description*, CSIRO National Research Flagships: Water for Healthy Country, Canberra. Viney, NR 2010, *A comparison of modelling approaches for continental stream flow prediction*, CSIRO National Research Flagships: Water for Healthy Country, Canberra.

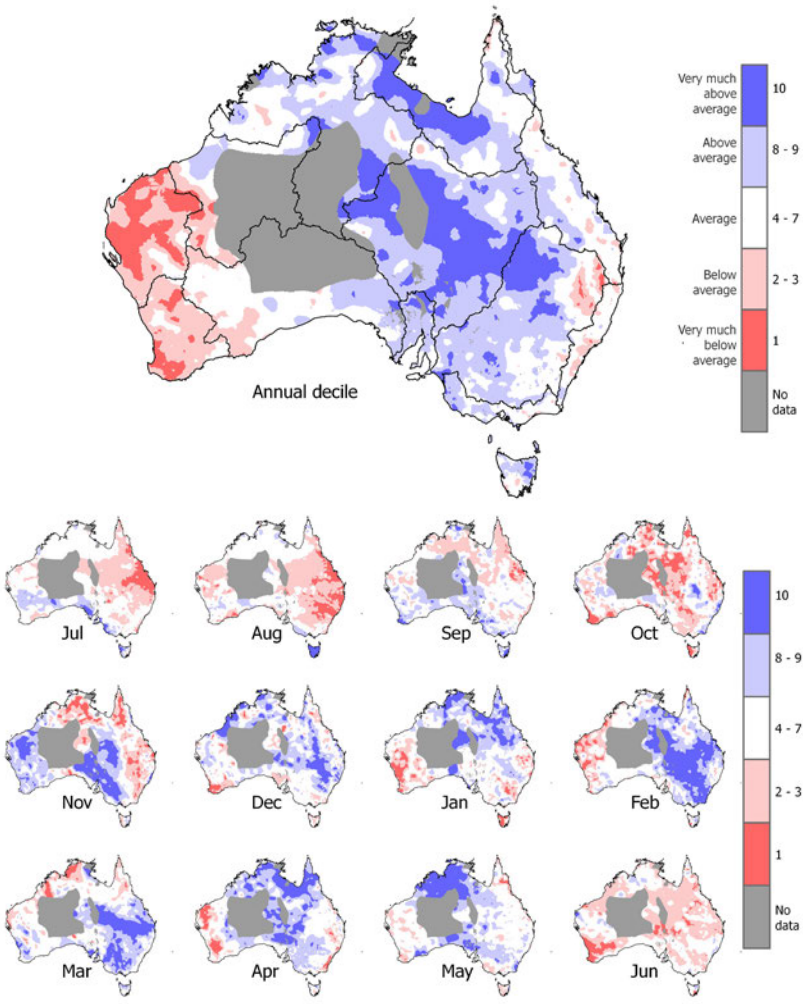
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Annual and monthly national deciles (rainfall, evapotranspiration and landscape water yield) National Overview/ Landscape water flows in 2009–10 (Section 2.3)	**Description** 5 x 5 km annual and monthly deciles grid data generated for each of the landscape water flows. Deciles calculated from long-term gridded data (July 1911 to June 2010) from two national water balance models (WaterDyn and AWRA-L). **Source** Bureau (National Climate Centre) CSIRO (WaterDyn V26/AWRA-L)	**Description** Bureau standard spatial climate data analysis and presentation method. Monthly and annual deciles grids (July–June) presented based on the long-term record (July 1911 to June 2010). **Resolution (Output)** **Temporal** – Annual/Monthly **Spatial** – 5 x 5 km grid (National coverage)	Bureau of Meteorology 2011, Annual Climate Summary 2010, www.bom.gov.au/climate/annual_sum/2010/AnClimSum10_HR1.0.pdf Bureau of Meteorology 2010, Annual Climate Summary 2009, www.bom.gov.au/climate/annual_sum/2009/AnClimSum09_HR1.1.pdf Bureau Climate Statements www.bom.gov.au/climate/current/statements/scs22.pdf www.cawcr.gov.au/publications/researchletters/CAWCR_Research_Letters_2.pdf

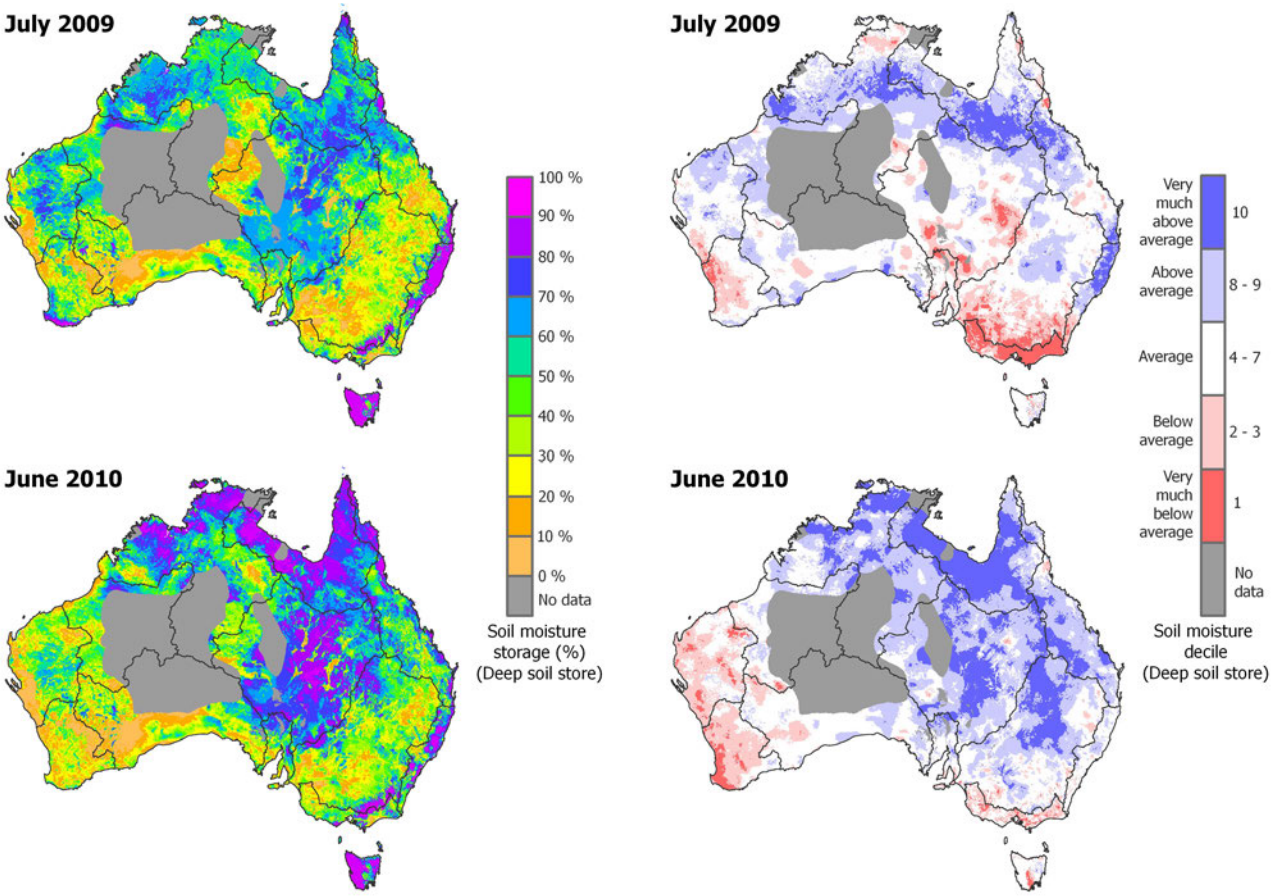
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Annual variation in national soil moisture surfaces National Overview/ Soil Moisture Store in 2009–10 (Section 2.4)	**Description** 5 x 5 km gridded monthly soil moisture index data from national water balance model (WaterDyn). Deciles calculated from long-term gridded data (July 1911 to June 2010). **Source** CSIRO (WaterDyn V26)	**Description** Spatial soil moisture data analysis and presentation method for WaterDyn model outputs. Monthly deep soil store moisture storage (0–100%) – based on soil moisture index (0–1) – and deciles presented for the beginning and end of the reporting year (July 2009 to June 2010). Deciles classes are derived from the relevant monthly values from the long-term (July 1911 to June 2010) record. **Resolution (Output)** **Temporal** – Monthly **Spatial** – 5 x 5 km grid (National coverage)	Australian Water Availability Project www.csiro.au/awap/cgi/awap2.pl?ser=Australia_run26c_monthly Raupach, MR, Briggs, PR, Haverd, V, King, EA, Paget, M and Trudinger, M 2009, *Australian Water Availability Project: CSIRO Marine and Atmospheric Research Component: Final Report for Phase 3*, CAWCR Technical Report No. 013, Centre for Australian Weather and Climate Research, Australia.

Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Monthly Pacific Ocean temperature maps and profiles National Overview/ Australian climate drivers in 2009–10 (Section 2.8)	**Description** Pacific Ocean 150 m depth-averaged temperature anomalies and monthly vertical temperature anomaly at the equator. Data presented as four-month sequences covering July 2009 to June 2010. **Source** Bureau (National Meteorological and Oceanographic Centre)	**Description** Standard Bureau and International presentation of surface and sub-surface Pacific Ocean temperature anomalies for the assessment and analysis of Pacific Ocean ENSO conditions. **Resolution (Output)** **Temporal** – Monthly sequence for 2009–10 **Spatial** – Pacific Ocean	Bureau of Meteorology Seasonal Outlooks – El Niño/La Niña www.bom.gov.au/climate/enso/ Temperature anomaly sequences http://reg.bom.gov.au/cgi-bin/wrap_fwo.pl?IDYOC006.gif http://reg.bom.gov.au/cgi-bin/wrap_fwo.pl?IDYOC007.gif

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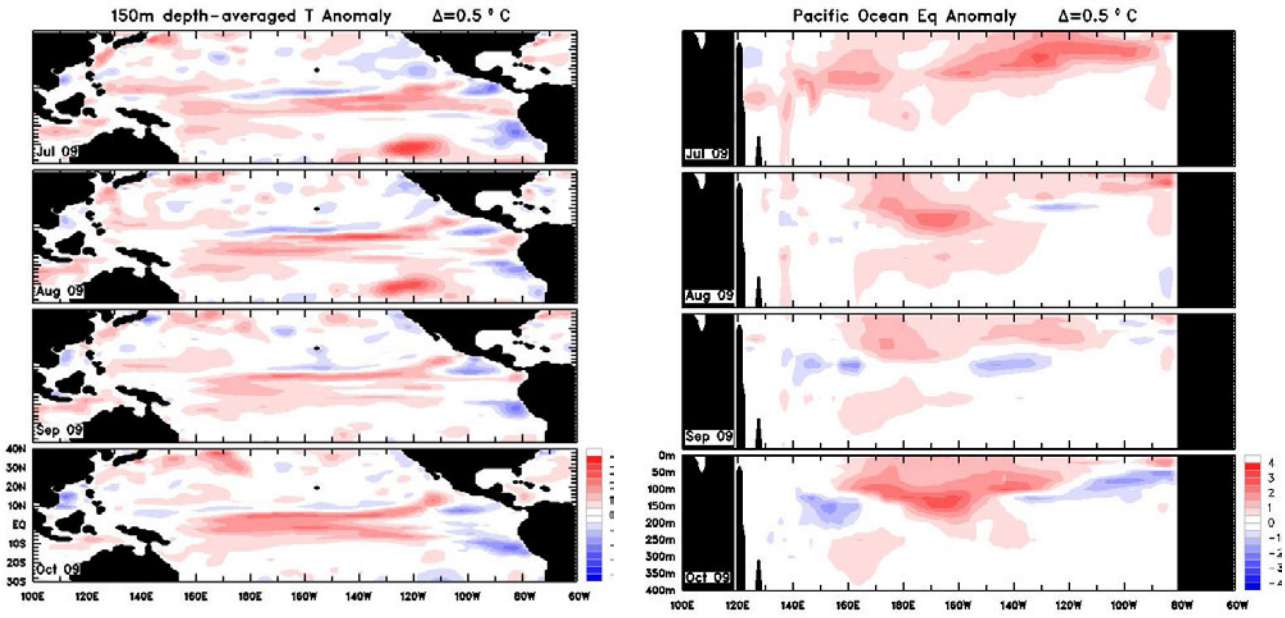
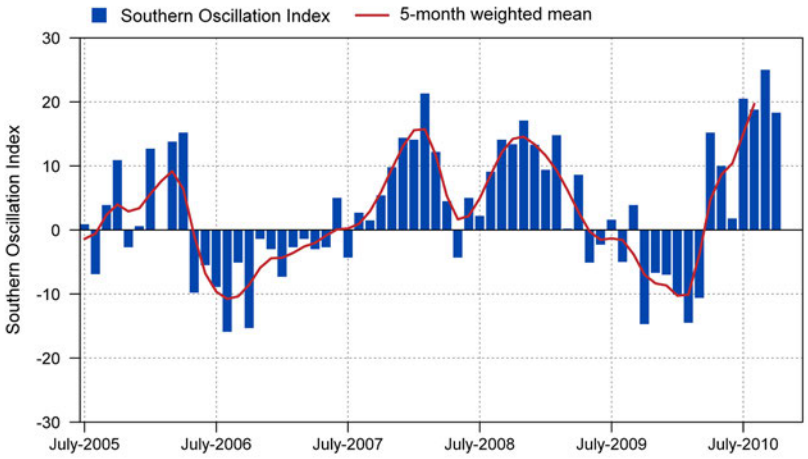
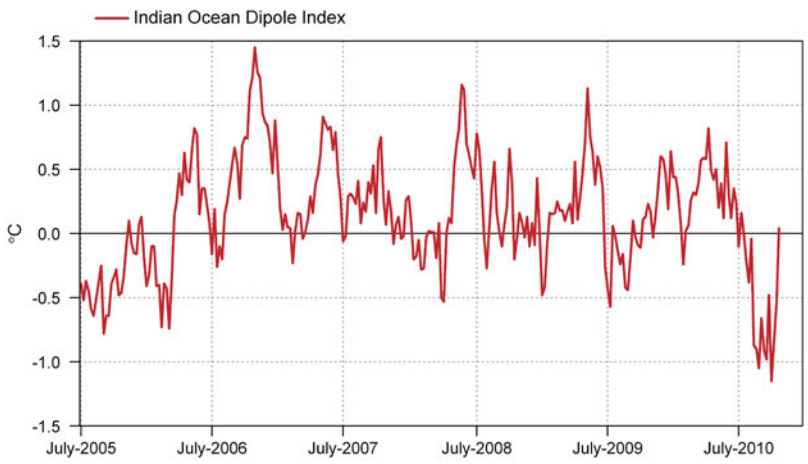


3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD) Time-series National Overview/ Australian climate drivers in 2009–10 (Section 2.8)	**Description** Monthly Southern Oscillation Index (SOI) time-series data (July 2005 to October 2010). Weekly Indian Ocean Dipole (IOD) time-series data (July 2005 to October 2010). **Source** Bureau (National Climate Centre)	**Description** Standard presentation of historic SOI and IOD time-series data. SOI data presented at monthly resolution with a five-month binomial weighted mean. The five-month mean for month x = (SOI_{x-2} + $4SOI_{x-1}$ + $6SOI_x$ + $4SOI_{x+1}$ + SOI_{x+2}) / 16 IOD Index data presented at weekly resolution. **Resolution (Output)** **Temporal** – Monthly (SOI) and weekly (IOD)	Bureau of Meteorology Seasonal Outlooks – El Niño/La Niña www.bom.gov.au/climate/enso/ SOI and IOD time-series www.bom.gov.au/climate/current/soi2.shtml www.bom.gov.au/climate/enso/indices.shtml Troup, AJ 1965, 'The Southern Oscillation', *Quarterly Journal of Royal Meteorological Society*, vol. 91, pp. 490–506. Saji, NH, Goswami, BN, Vinayachandran, PN and Yamagata, T 1999, 'A dipole mode in the tropical Indian Ocean', *Nature*, vol. 401, pp. 360–363.

Example figures

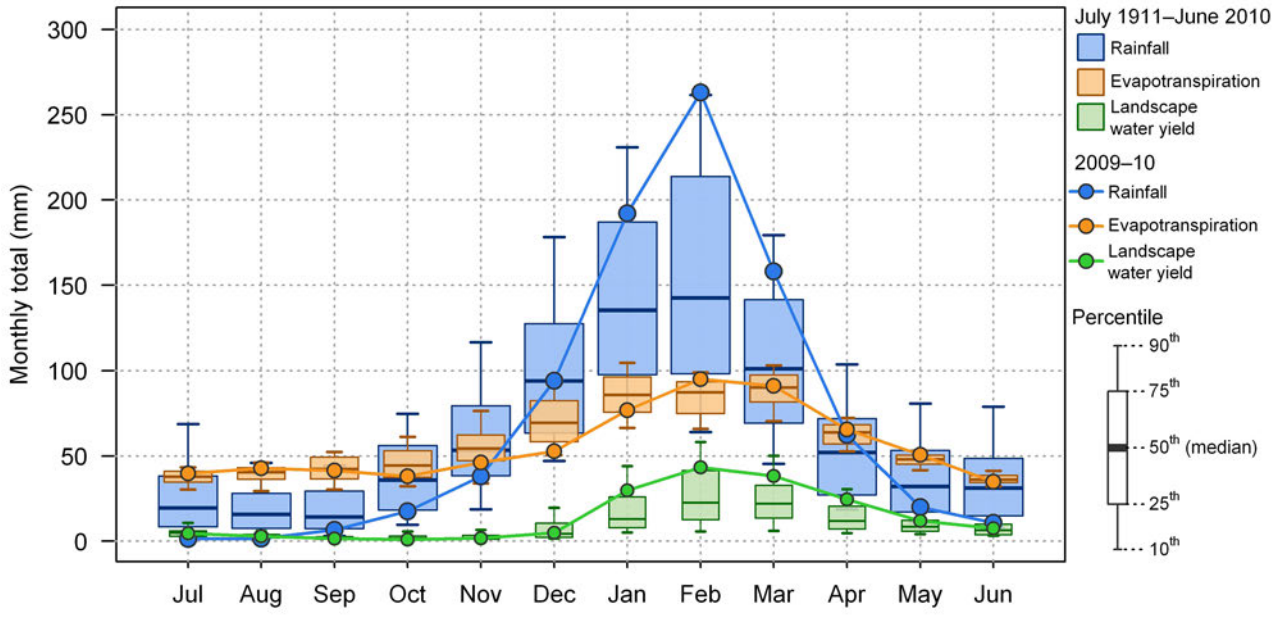




3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Monthly box plots of regional landscape water balance model flows Regional water resources assessments/Recent patterns in landscape water flows (Section 4 of the regional chapters)	**Description** Regionally averaged monthly landscape water flow data from national landscape water balance models (WaterDyn and AWRA-L). Data presented are rainfall, evapotranspiration and landscape water yield. **Source** Bureau (National Climate Centre) CSIRO (WaterDyn V26/AWRA-L)	**Description** Monthly data for the current year (2009–10) are presented relative to long-term record. Monthly distributions (box and whiskers) are calculated from long-term model run data (July 1911 to June 2010). Landscape water flow variables presented are: 1) rainfall 2) actual evapotranspiration 3) landscape water yield. **Resolution (Output)** **Temporal** – Monthly **Spatial** – Australian Water Resources Assessment reporting region (spatially averaged)	Example for the interpretation of the Bureau's Streamflow Forecasts www.bom.gov.au/water/ssf/forecasts.shtml#drainage=murray_darling&basin=upper_murray&catchment=Q_HUME_TOT&productType=DT_1&productGroup=data

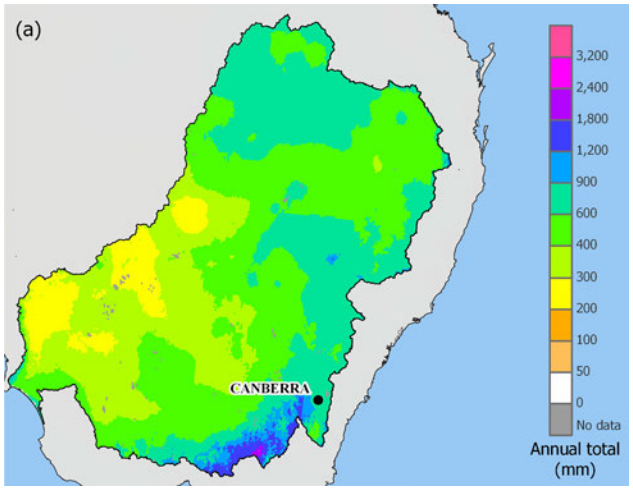
Example figures

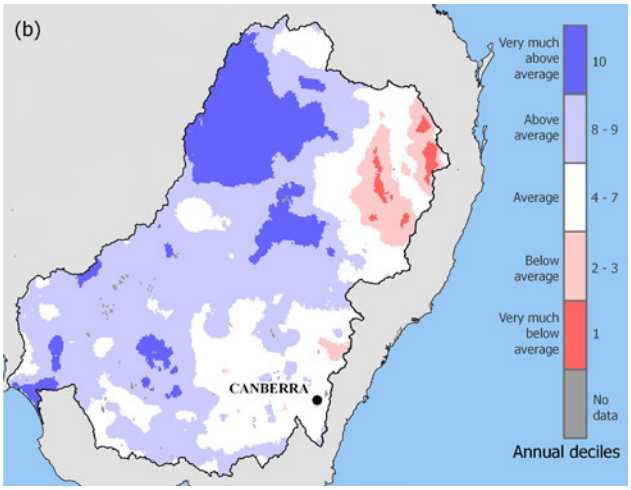


3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Regional summary of annual landscape water flows (mapped annual totals and deciles) Regional water resources assessments/Recent patterns in landscape water flows (Section 4 of the regional chapters)	**Description** 5 x 5 km gridded annual landscape water flows data (July–June) from national landscape water balance models (WaterDyn and AWRA-L). Deciles calculated from long-term gridded data (July 1911 to June 2010) The underlying data are the same as presented for the national water flow surfaces in Section 2.3. **Source** Bureau (National Climate Centre) CSIRO (WaterDyn V26/AWRA-L)	**Description** Bureau standard spatial climate data presentation method. Annual total and annual deciles landscape water flow grids (July–June) presented. Annual deciles grids (July–June) calculated based on the long-term record (July 1911 to June 2010). Landscape water flow variables presented are: 1) rainfall 2) actual evapotranspiration 3) landscape water yield. **Resolution (Output)** **Temporal** – Annual **Spatial** – 5 x 5 km grid for each Australian Water Resources Assessment reporting region	Bureau of Meteorology 2011, Annual Climate Summary 2010, www.bom.gov.au/climate/annual_sum/2010/AnClimSum10_HR1.0.pdf Bureau of Meteorology 2010, Annual Climate Summary 2009, www.bom.gov.au/climate/annual_sum/2009/AnClimSum09_HR1.1.pdf Raupach, MR, Briggs, PR, Haverd, V, King, EA, Paget, M and Trudinger, M 2009, *Australian Water Availability Project: CSIRO Marine and Atmospheric Research Component: Final Report for Phase 3*, CAWCR Technical Report No. 013, Centre for Australian Weather and Climate Research, Australia

Example figures

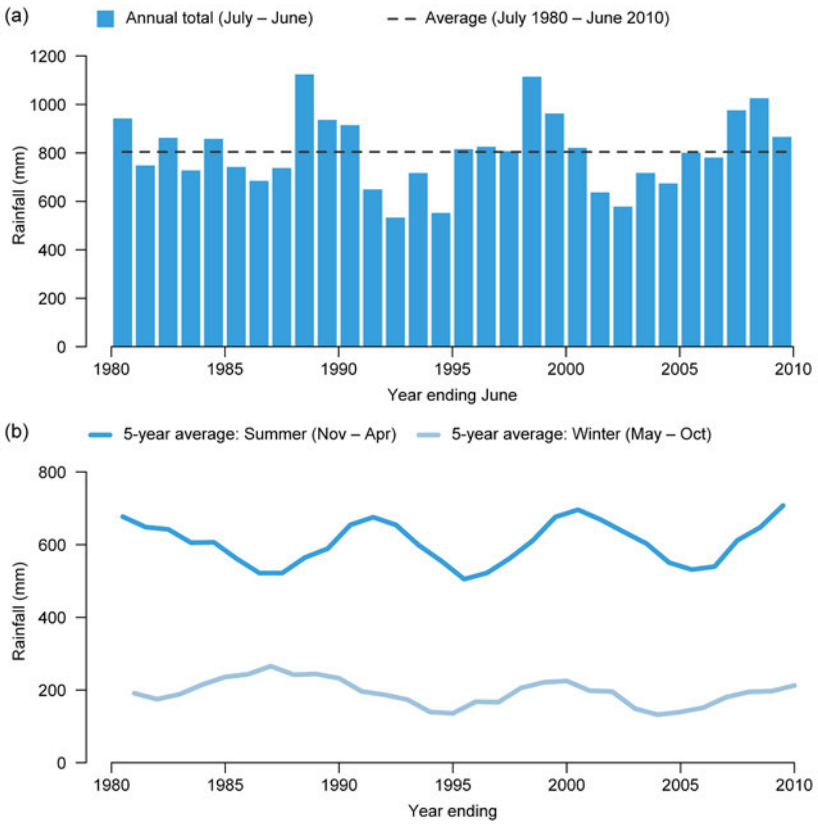




3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Time-series of landscape water flows over the past 30 years (annual and seasonal) Regional water resources assessments/Recent patterns in landscape water flows (Section 4 of the regional chapters)	**Description** Spatially averaged monthly and annual landscape water flow data (July–June) from national landscape water balance models (WaterDyn and AWRA-L). Summer (November–April) and winter (May–October) season totals calculated from monthly model output data. **Source** Bureau (National Climate Centre) CSIRO (WaterDyn V26/AWRA-L)	**Description** Simple time-series plot of annual data presented for past 30 years (July 1980 to June 2010). Simple time-series plot of seasonal five-year moving averages (backward looking) data presented for past 30 years (November 1980 to October 2010). Landscape water flow variables presented are: 1) rainfall 2) actual evapotranspiration 3) landscape water yield. **Resolution (Output)** **Temporal** – Annual (July–June) and six-month seasons (November–April and May–October) Spatial – Australian Water Resources Assessment reporting region (spatially averaged)	Example of the Bureau's climate variability and change time-series: **Annual plot** www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=aus&season=0112&ave_yr=A **Seasonal plot** www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=aus&season=0411&ave_yr=5 Jones, DA, Wang, W and Fawcett, R 2009, 'High-quality spatial climate data-sets for Australia', *Australian Meteorological and Oceanographic Journal*, vol. 58, pp. 233–248.

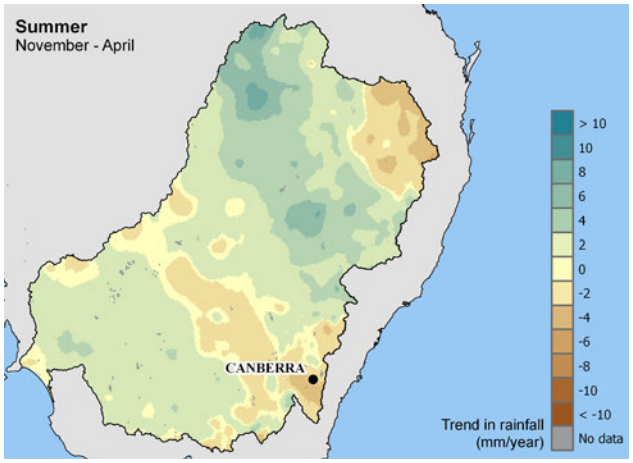
Example figures

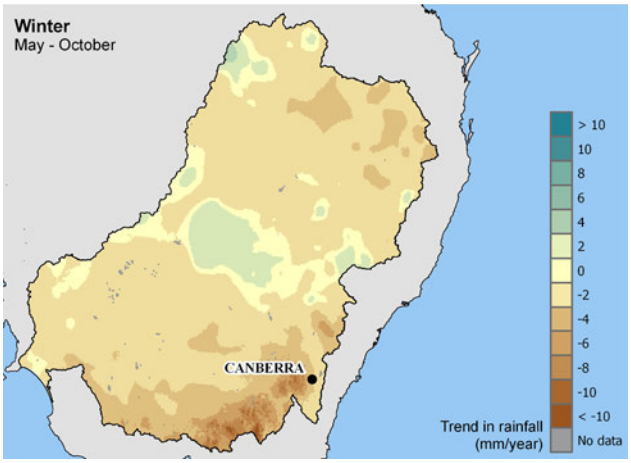


3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Regional maps trends in seasonal landscape water flows over the past 30 years (seasonal) Regional water resources assessments/Recent patterns in landscape water flows (Section 4 of the regional chapters)	**Description** 5 x 5 km gridded landscape water flow data from national landscape water balance models (WaterDyn and AWRA-L). Trend analysis applied to summer (November–April) and winter (May–October) season totals. Analysis applied to the past 30 seasonal periods (November 1980 to October 2010). **Source** Bureau (National Climate Centre) CSIRO (WaterDyn V26/AWRA-L)	**Description** Simple linear regression trend calculated for summer and winter totals at each 5 x 5 km grid cell over the past 30 years (November 1980 to October 2010). Slope of linear regression line (mm/year) presented to reflect the strength and direction of potential trends. The statistical significance (regression analysis p-values) was calculated (see Section 4.3.1 of the Technical supplement). **Resolution (Output)** **Temporal** – six-month seasons (November–April and May–October) **Spatial** – 5 x 5 km grid for each Australian Water Resources Assessment reporting region	Example of the Bureau's climate variability and change trend analysis www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi?map=rain&area=aus&season=1202&period=1970 Kundzewicz, ZW and Robson, AJ 2004, 'Change detection in hydrological records – a review of the methodology', *Hydrological Sciences Journal/Journal des Sciences Hydrologiques*, vol. 49, no. 1.

Example figures

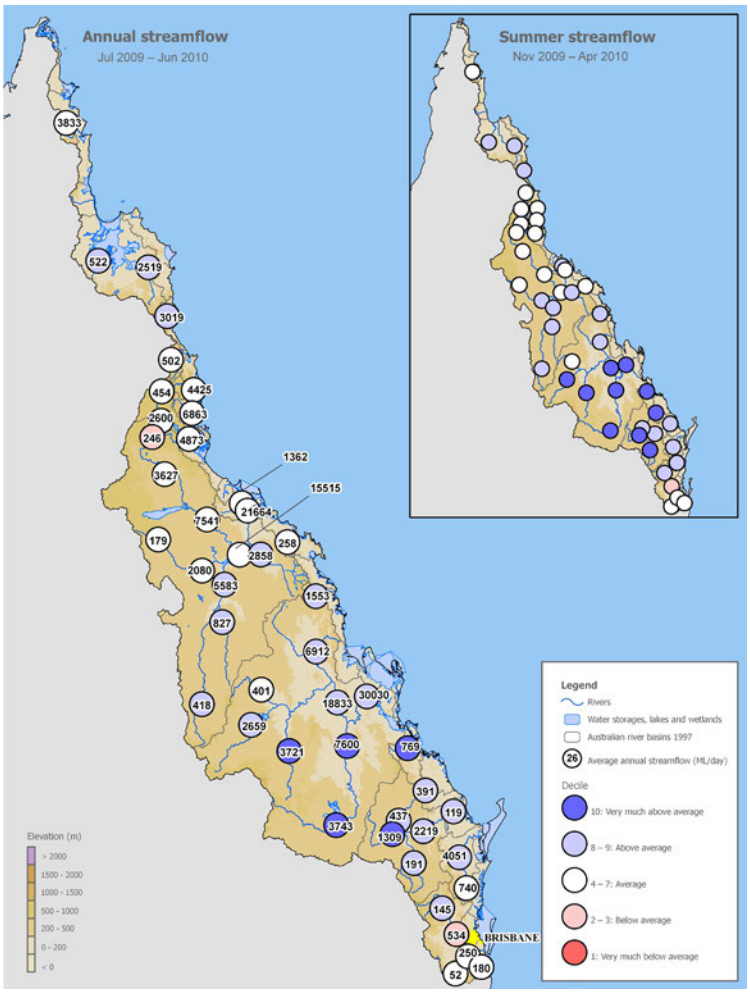




3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based seasonal streamflow anomaly analyses Regional water resources assessments/Rivers, wetlands and groundwater (Section 5 of some regional chapters)	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational reference streamflow gauges with records available for at least the past 30 years (July 1980–June 2010). **Source** Bureau (Hydstra database)	**Description** Decile ranking of annual discharge for the reporting year (July 2009 to June 2010) compared to long-term (July 1980 to June 2010) annual time-series. Decile ranking of summer discharge for the reporting year (November 2009–April 2010) compared to long-term (November 1980–April 2010) seasonal time-series. **Resolution (Output)** **Temporal** – Annual/Summer season (November–April) **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Marsh, T and Sanderson, F 2009, *UK Hydrological Review 2008*, NERC/Centre for Ecology and Hydrology, United Kingdom. http://nora.nerc.ac.uk/10839/1/UK_Hydrological_Review_2008.pdf

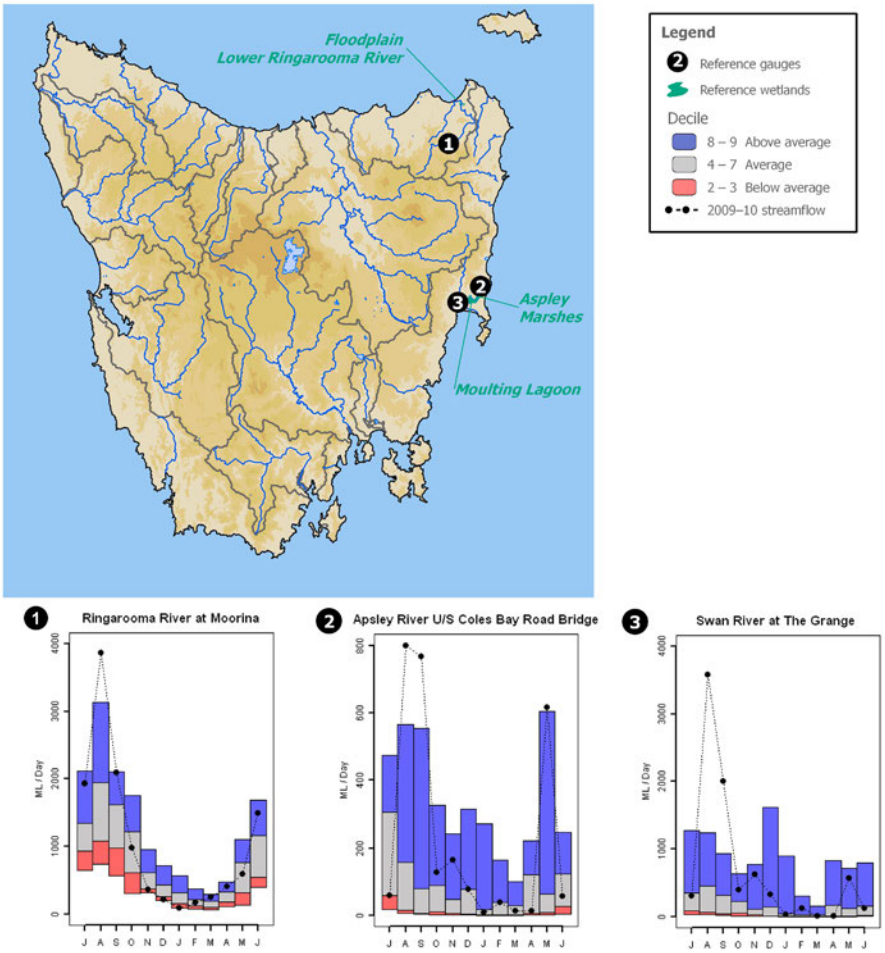
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of monthly streamflow Regional water resources assessments/Rivers, wetlands and groundwater (Section 5 of some regional chapters)	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational reference streamflow gauges with records available for at least the past 30 years (July 1980 to June 2010). **Source** Bureau (Hydstra database)	**Description** Graphical presentation of measured monthly streamflow for 2009–10 plotted against derived monthly decile ranges (2–3, 4–7 and 8–9). Decile ranges calculated from 30-year (July 1980 to June 2010) record. Plots are presented on a map of the reporting region linked to the location of reference streamflow gauges. **Resolution (Output)** **Temporal** – Monthly **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Standard graphical presentation of hydrological information Reference not required

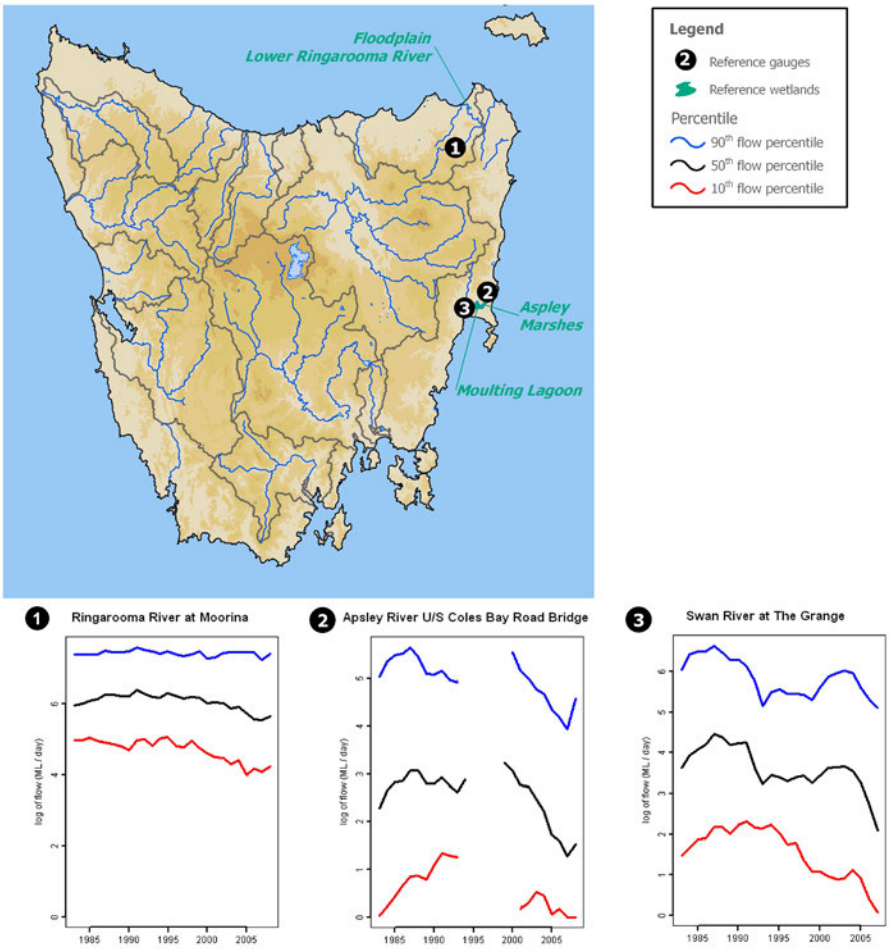
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of changes in streamflow over the past 30 years Regional water resources assessments/Rivers, wetlands and groundwater (Section 5 of some regional chapters)	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational reference streamflow gauges with records available for at least the past 30 years (July 1980 to June 2010). **Source** Bureau (Hydstra database)	**Description** Graphical presentation of measured daily streamflow percentiles (10 per cent, 50 per cent and 90 per cent) based on a five-year moving window for the available 30-year record. Plots are presented on a map of the reporting region linked to the location of the reference streamflow gauges. **Resolution (Output)** **Temporal** – Annual **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Standard analysis and presentation of hydrological information Reference not required

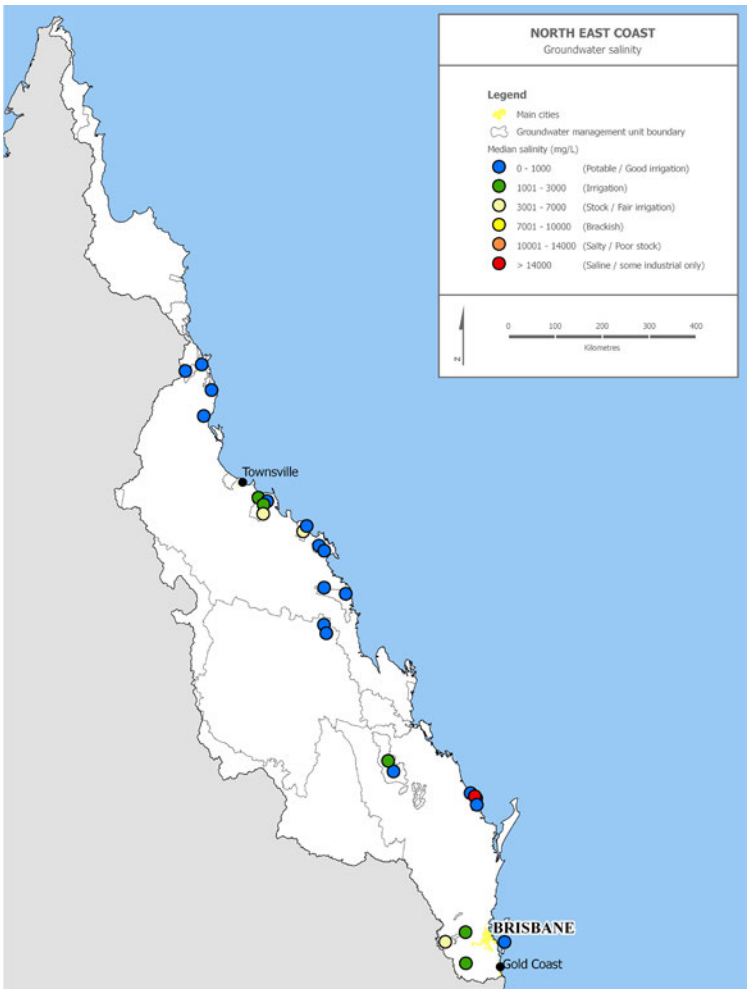
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based summary of groundwater salinity Regional water resources assessments/Rivers, wetlands and groundwater (Section 5 of some regional chapters)	**Description** Electrical conductivity of a groundwater sample (µS/cm). Data collated for currently operational monitoring bores for the past 20 years (July 1990 to June 2010). **Source** Bureau (Groundwater database)	**Description** Standard map presentation of calculated median salinity (mg/L) over the 20-year period (July 1990 to June 2010). Median values classified based on quality and potential use. Empirical equation (below) used to convert units of Electrical Conductivity (EC) (µS/cm) to Total Dissolved Solids (TDS) (mg/L). TDS (mg/L) = EC(µS/cm at 25°C) x 0.6 **Resolution (Output)** **Temporal** – Median of period (20 years) **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Victorian Resources Online: Victoria's Groundwater Resource www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/water-ground-res

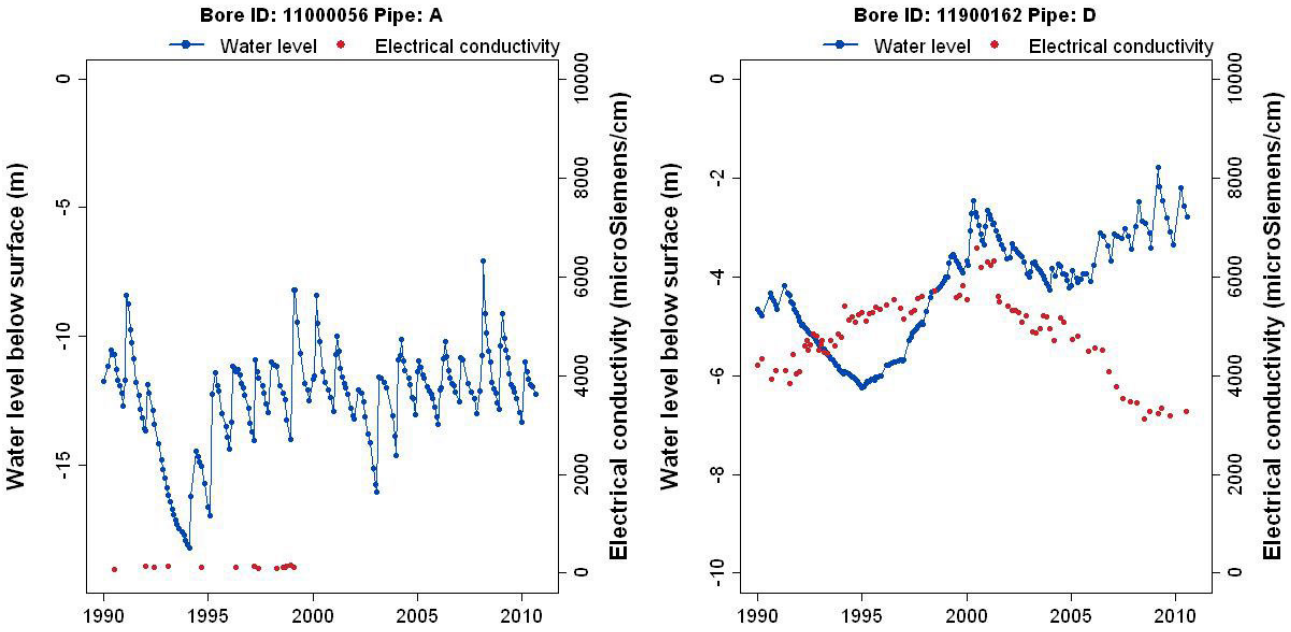
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of changes in groundwater levels and salinity Regional water resources assessments/Rivers, wetlands and groundwater (Section 3.5)	**Description** Groundwater level of a bore (relative to datum) and electrical conductivity of a groundwater sample (µS/cm). Data collated for currently operational monitoring bores for the past 20 years (July 1990 to June 2010). **Source** Bureau (Groundwater database)	**Description** Graphical presentation of variations and changes in groundwater level (and quality) over the 20-year period (July 1990 to June 2010) Empirical equation (below) used to convert units of Electrical Conductivity (EC) (µS/cm) to Total Dissolved Solids (TDS) (mg/L). TDS (mg/L) = EC(µS/cm at 25°C) x 0.6 **Resolution (Output)** **Temporal** – Variable (dependent upon frequency of measurement) **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Murray–Darling Basin Commission 2008, *Groundwater Status Report 2000-2005; Technical Report*, Murray–Darling Basin Commission, Canberra. Victorian Resources Online: Victoria's Groundwater Resource www.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/water-ground-res

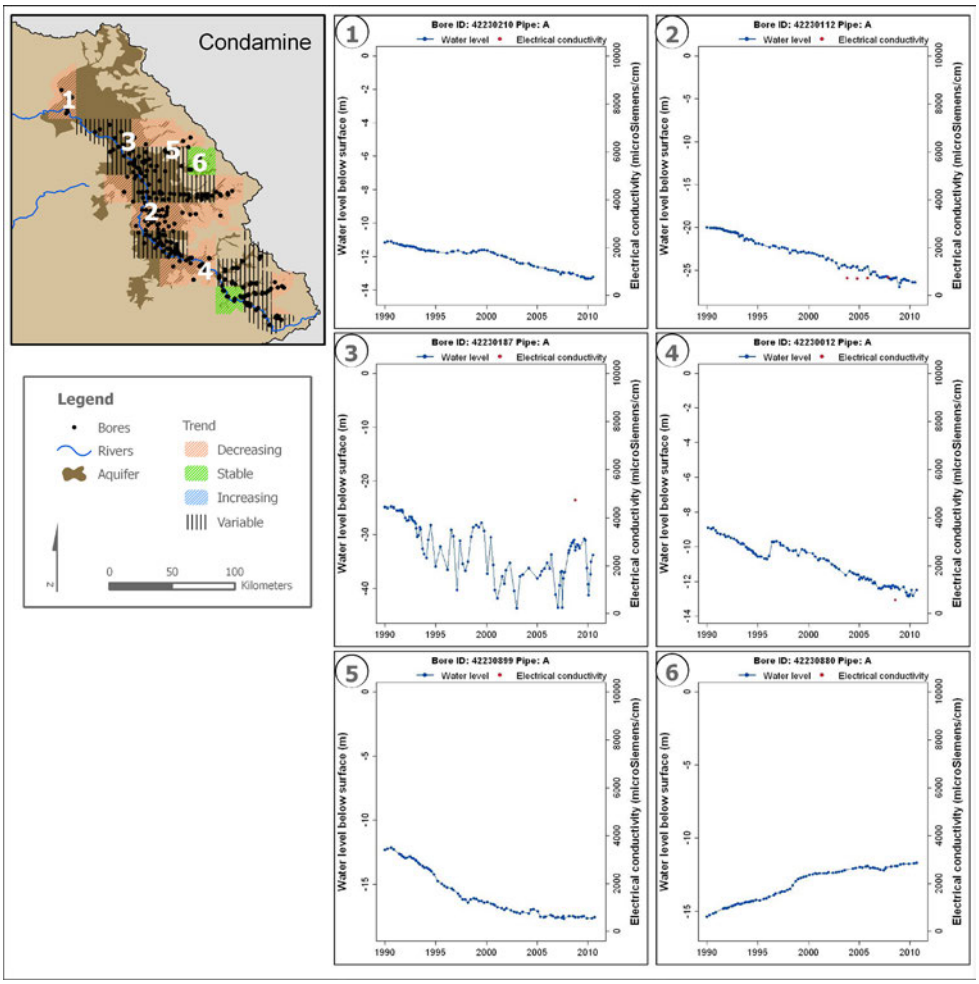
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Trends in groundwater levels Regional water resources assessments/Rivers, wetlands and groundwater (Sections 7.5 and 8.5)	**Description** Groundwater level of a bore (relative to datum). Data collated for currently operational monitoring bores for the past 20 years (July 1990 to June 2010). **Source** Bureau (Groundwater database)	**Description** Standard map presentation of trends in groundwater levels over the period 2005 to 2010 using 20 x 20 km grids across selected aquifers. The linear trend in groundwater levels for a 20 x 20 km grid is assessed as decreasing, stable, increasing or variable. **Resolution (Output)** **Temporal** – Variable (dependent upon frequency of measurement) **Spatial** – 20 x 20 km grids for selected aquifer(s)	Murray–Darling Basin Commission 2008, *Groundwater Status Report 2000-2005; Technical Report*, Murray–Darling Basin Commission, Canberra.

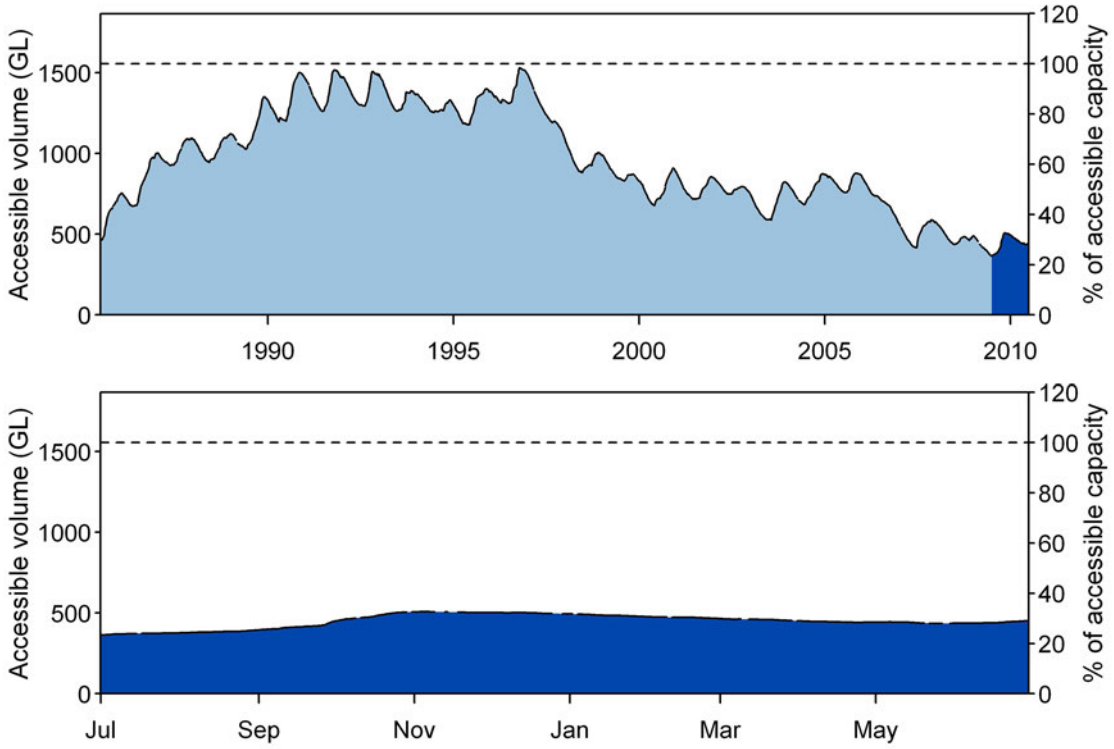
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of changes in surface water storage (urban/ irrigation) Regional water resources assessments/Water for cities and towns (Section 6 of some regional chapters) Regional water resources assessments/Water for agriculture (Section 7 of some regional chapters)	**Description** Volume of water held in a major storage (GL). **Source** Bureau (AWRIS)	**Description** Graphical presentation of observed long-term and reporting year storage data (2009–10). Graphical axes represent data as both storage volume (GL) and per cent full (per cent of maximum capacity). **Resolution (Output)** **Temporal** – Daily **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Standard presentation of water storage information http://water.bom.gov.au/waterstorage/awris/index.html www.bom.gov.au/water/about/publications/document/factsheet_waterstorage.pdf

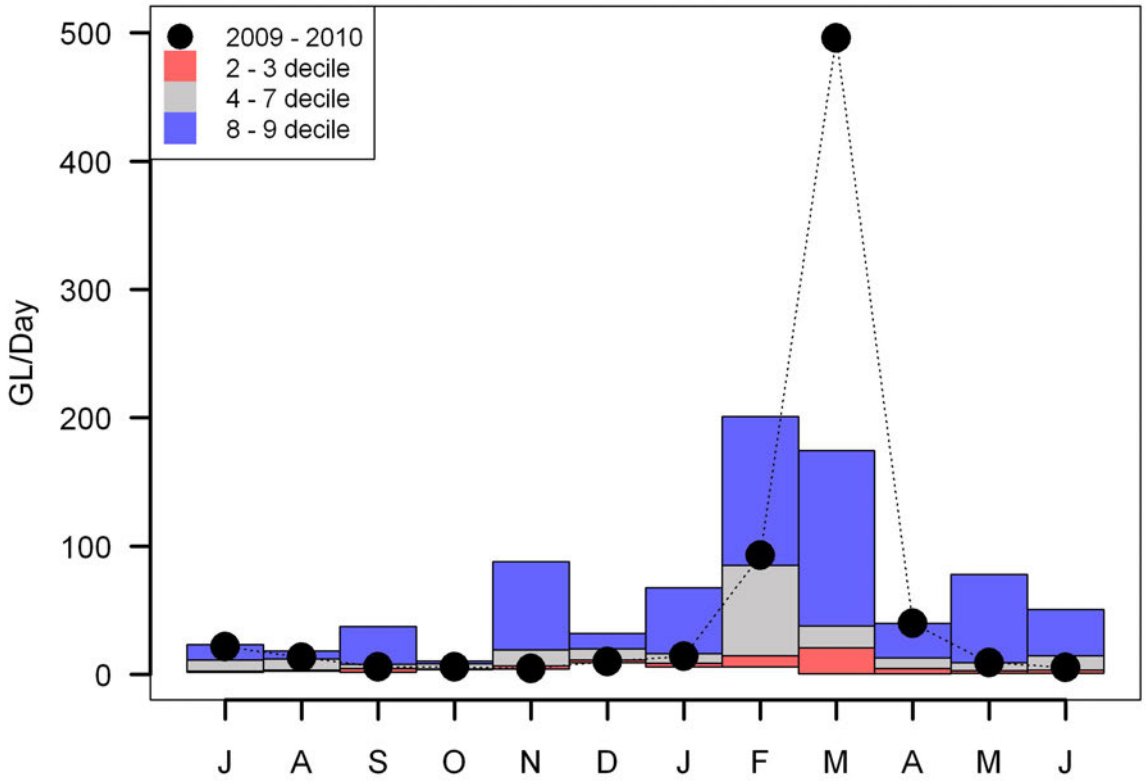
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of monthly inflows into selected storages (urban/irrigation) Regional water resources assessments/Water for cities and towns (Section 6 of some regional chapters) Regional water resources assessments/Water for agriculture (Section 7 of some regional chapters)	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational reference streamflow gauges with records available for at least the past 30 years (July 1980 to June 2010). **Source** Bureau (Hydstra database)	**Description** Graphical presentation of measured monthly streamflow for 2009–10 plotted against derived monthly percentile classes (10–30, 30–70 and 70–90). Percentiles calculated from 30-year (July 1980 to June 2010) record. **Resolution (Output)** **Temporal** – Monthly **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Standard graphical presentation of hydrological information Reference not required

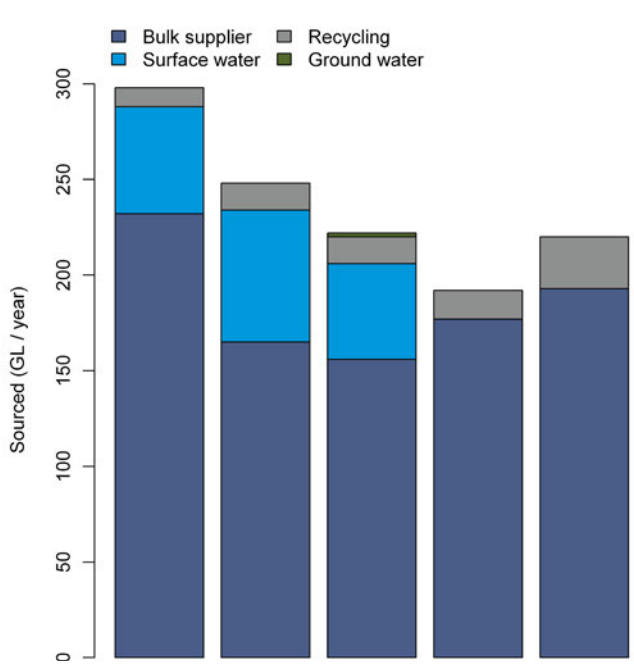
Example figures

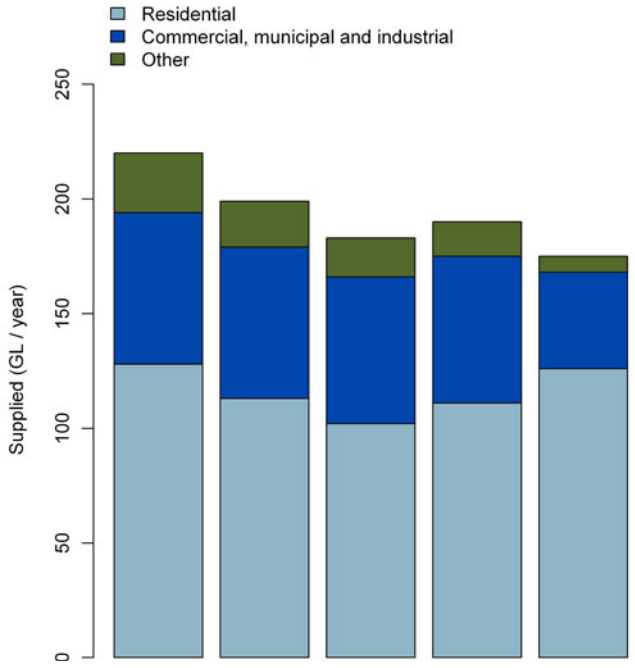


3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Time-series of annual urban water supply by source Regional water resources assessments/Water for cities and towns (Section 6 of some regional chapters)	**Description** Information about Urban Water Management. For more details refer to Definitions of Sub-Categories of Water Information: www.bom.gov.au/water/regulations/subCategoriesWaterAuxNav.shtml#urbanWater **Source** Bureau (Hydstra database)	**Description** Plot of total annual water volume sourced and description of sources (e.g. surface water, groundwater, recycled, desalinated). Also water volume delivered to different groups of users. **Resolution (Output)** **Temporal** – Annual (July to June) **Spatial** – Urban water supply area within relevant Australian Water Resources Assessment reporting region	Standard graphical presentation of hydrological information Reference not required

Example figures

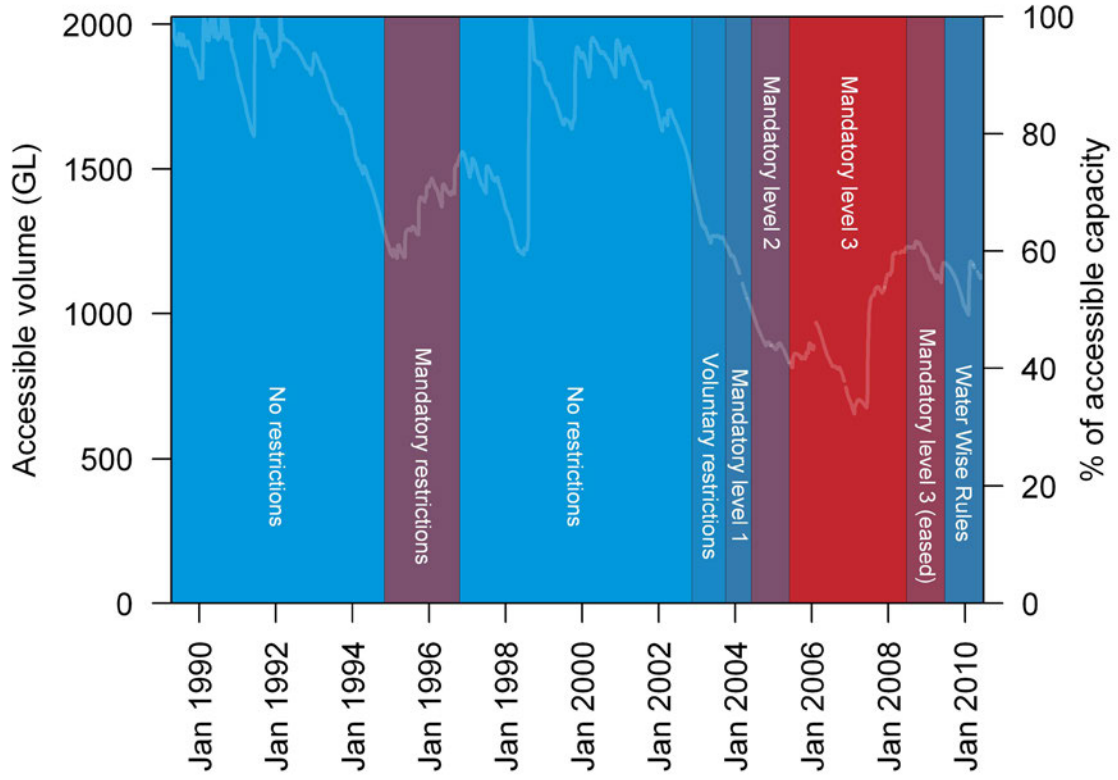




3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Changes in urban water restrictions over time Regional water resources assessments/Water for cities and towns (Section 6 of some regional chapters)	**Description** Water use restriction announcements indicating level, commencement and termination dates, a description of water restriction levels and where they apply. **Source** Bureau (Hydstra database)	**Description** Graphical representation of water restriction levels over time plotted against a relevant measure of water availability, i.e. reservoir storage. Only applied where restrictions may be defined relative to a defined storage level or other resource availability variable. **Resolution (Output)** **Temporal** – Variable – dependent on announcements of changes to restriction levels **Spatial** – Water supply area within relevant Australian Water Resources Assessment reporting region	Standard graphical presentation of hydrological information Reference not required

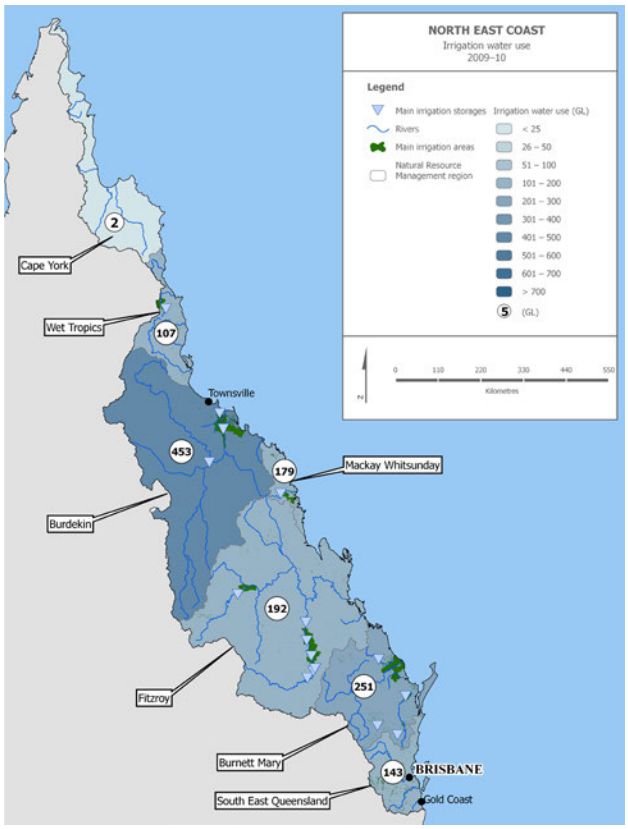
Example figures

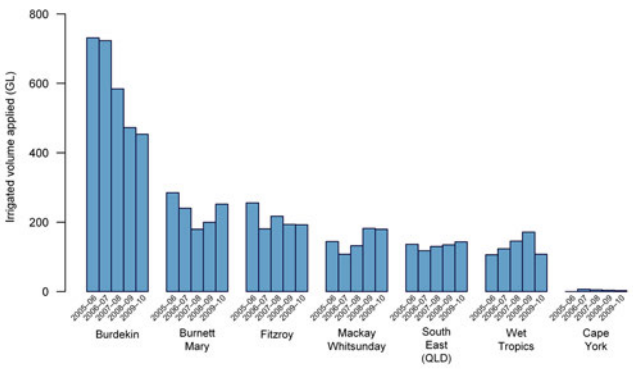


3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Patterns in annual irrigation water use Regional water resources assessments/Water for agriculture (Section 7 of some regional chapters)	**Description** Annual (July–June) irrigation water use data from ABS *Water Use on Australian Farms* reports. Data are summarised at a national resource management (NRM) level for the four years between 2005–06 and 2008–09. Data for 2009–10 were not available at the time of publication. **Source** Australian Bureau of Statistics (ABS) – *Water Use on Australian Farms* reports	**Description** Mapped and graphical representation of annual irrigation water use for each NRM region within the reporting region. **Resolution (Output)** **Temporal** – Annual **Spatial** – NRM regions within relevant Australian Water Resources Assessment reporting region	Australian Bureau of Statistics (ABS) 2010a, *Water Use on Australian Farms* 2009-10, ABS, Canberra, www.abs.gov.au/ausstats/abs@.nsf/mf/4618.0

Example figures

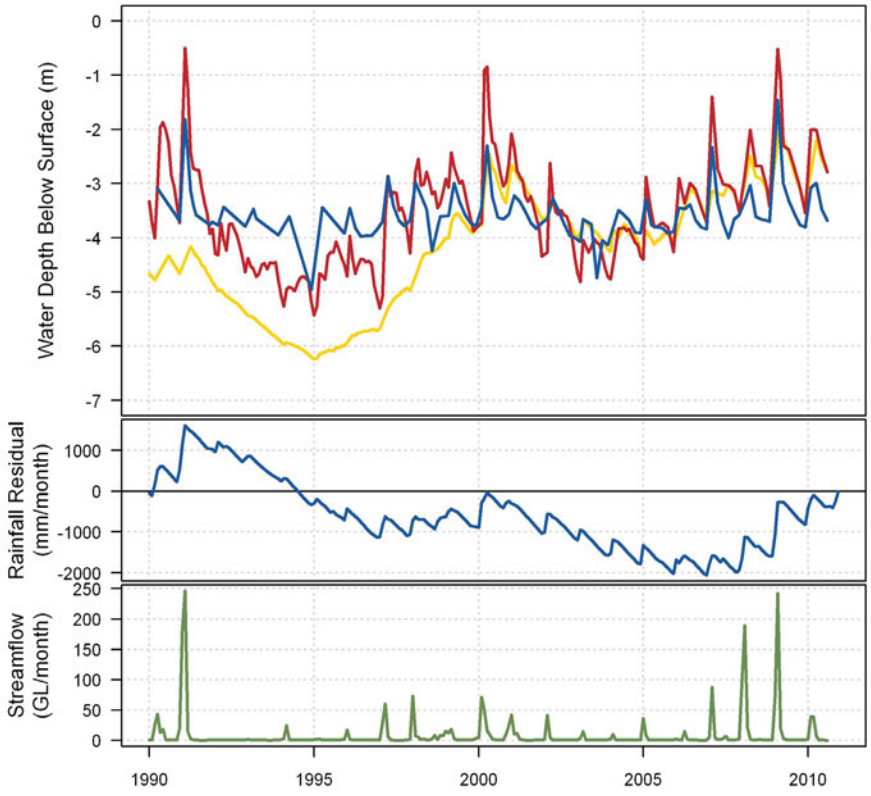




3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based time-series of variations in shallow groundwater levels, residual rainfall and streamflow Regional water resources assessments/Water for agriculture (Sections 3.7, 7.7 and 8.7)	**Description** Groundwater level of a bore (relative to datum) and measured streamflow discharge (ML/day). Data collated for currently operational monitoring bores for the past 20 years (July 1990 to June 2010). **Source** Bureau (Groundwater database) Bureau (Hydstra database) Bureau (Climate data online)	**Description** Graphical presentation of the relationship between monthly variations in shallow groundwater levels (m), local residual rainfall (mm/month) and measured streamflow (GL/month). The rainfall residual mass curve is based on the following equation. Rainfall residual mass for month(x) = (Actual rainfall for month(x) – average rainfall for month(x) + (the cumulative sum of (Actual rainfall for month – average rainfall for month) for all previous months). **Resolution (Output)** **Temporal** – Monthly **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Modified from: Murray–Darling Basin Commission 2008, *Groundwater Status Report* 2000–2005: Technical Report, ed. Murray–Darling Basin Commission, Canberra.

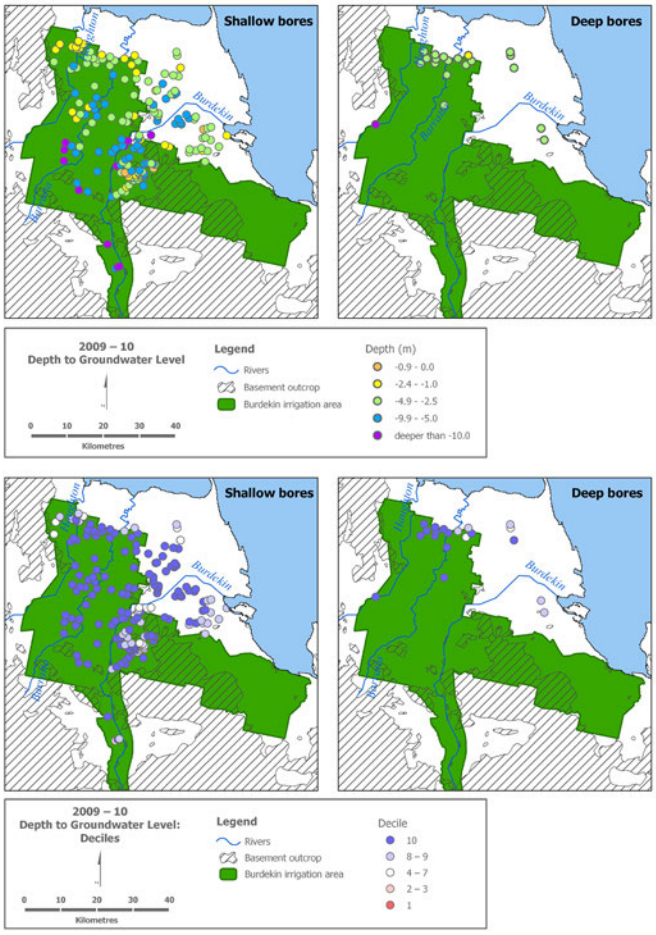
Example figures



3. Methods review summary (continued)

Analysis	Data	Method	Reference/peer review
Site-based analysis of groundwater depth Regional water resources assessments/Water for agriculture (Sections 3.7, 7.7 and 8.7)	**Description** Groundwater level of a bore (relative to datum). Data collated for currently operational monitoring bores for the past 20 years (July 1990 to June 2010). **Source** Bureau (Groundwater database)	**Description** Standard map presentation of calculated median depth to groundwater (m) for the reporting year (July 2009 to June 2010). Decile ranking of median depth to groundwater (m) for the reporting year (July 2009 to June 2010) compared to long-term (July 1980 to June 2010) levels. **Resolution (Output)** **Temporal** – Annual (median level and decile rank) **Spatial** – Sites within relevant Australian Water Resources Assessment reporting region	Reference not required

Example figures



4. Data and analysis

4.1 Introduction

The Bureau's Australian Water Resources Assessment reporting is a work in progress with regards to the methods used and results presented. Data sourcing and methods will improve over time. This section gives background information on data sources, methods applied to produce the figures in the report and the data available for download from the website.

4.2 Data selection procedures

A number of different selection procedures were employed to identify the most suited data for the 2010 Assessment. At the time of writing, suitable quality controlled and assured data from the Australian Water Resources Information System (Bureau of Meteorology 2011a) were not available. To overcome this, other sources of information were used. The following sections give an overview of the selection of information sources.

4.2.1 Estimated flows 'No Data' areas

The Australian landscape water balance modelling uses gridded daily rainfall data as a primary model input variable along with a number of gridded meteorological data-sets for the calculation of potential and actual evapotranspiration, i.e. maximum and minimum temperature, humidity and incoming solar radiation.

In order to run the model and perform the required analysis for the 99-year period (July 1911 to June 2010) a review of the reliability and quality of model input data was required, particularly for rainfall data that exhibit high levels of spatial variability.

The effects of the expansion of the rain-gauge network between 1990 and 2006 on the reliability of the interpolated rainfall surfaces were assessed to identify areas of poor quality data. Interpolation failures are generated as a result of sparse gauge networks and are particularly prominent in the central and western deserts. The analysis produced surfaces of rainfall interpolation reliability ranging from 100 per cent unreliable (data show consistent interpolation failure) to zero per cent unreliable, where data are defined to be reliable throughout the record within the constraints of the interpolation scheme (Jones, Wang & Fawcett 2009).

Australian Water Resources Assessment 2010 areas identified to be greater than 20 per cent unreliable (or less than 80 per cent reliable) were excluded from the landscape water balance modelling. The extent of areas of unreliable data (blue) are shown in Figure 4-1. The map also indicates additional areas (grey) that are not modelled due to absent parameter data, including oceans, salt lakes, salt pans, inland water, and some coastal features. All modelled areas (white) are reported in the landscape water flows analysis sections of the 2010 Assessment.

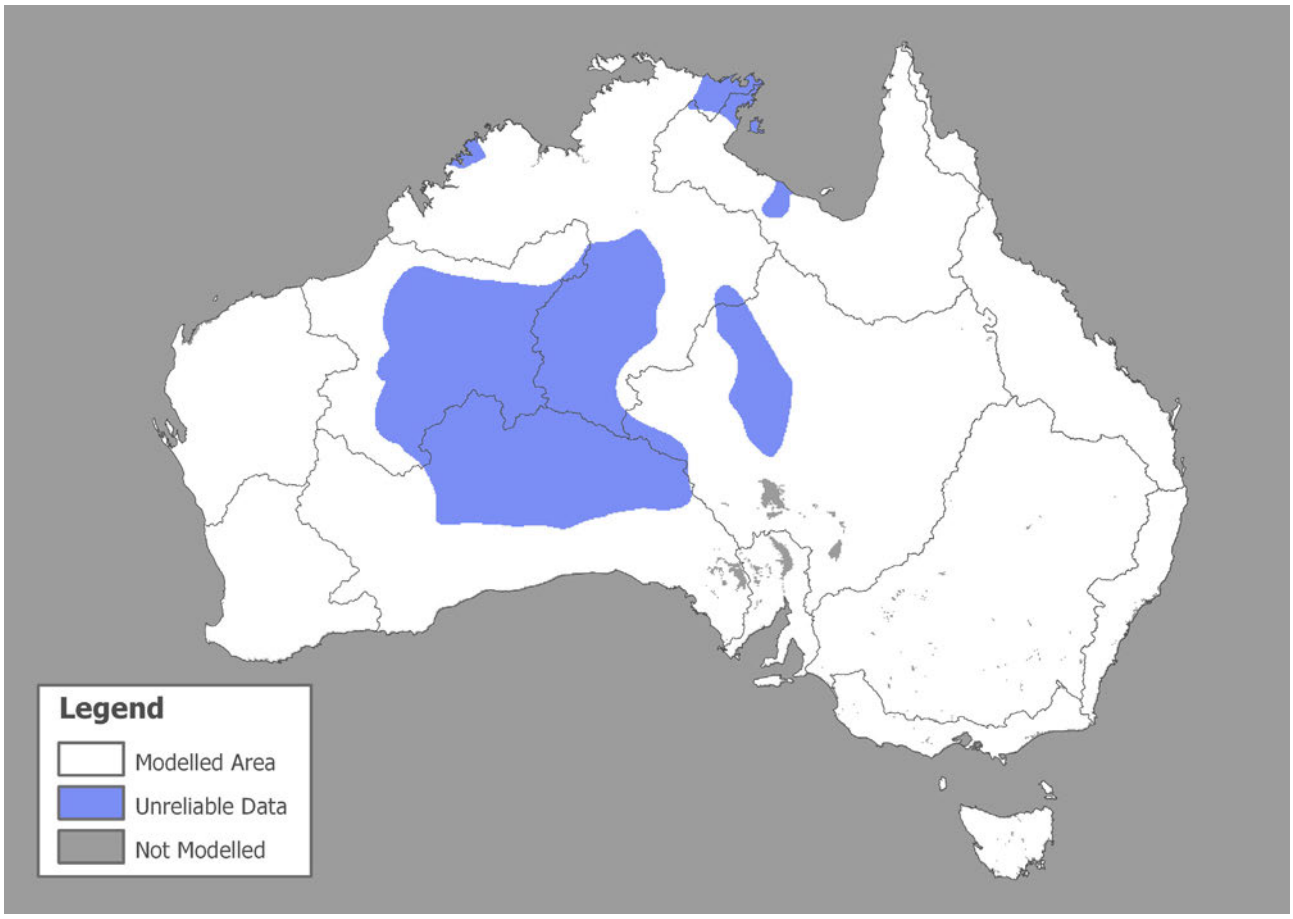


Figure 4 1. Map of areas included in the 2010 Assessment landscape water balance modelling and areas excluded from the model due to unreliable data and absent parameter data

4.2.2 Streamflow gauge selection

Gauges were selected for all relevant river basins to represent the lower reaches of each basin (i.e. to approximate total basin outflow). In the case of larger basins, additional gauges were selected to represent the major 'middle' and 'upper' basin tributaries to enable a monitoring of the varying status of river flow as water passes from the upper catchment tributaries to the downstream part of the basin. The reference gauges selected are provided in the data files accompanying the report chapters.

Gauges were selected which:

- were in ongoing operation in 2010
- possessed greater than or equal to 30 years of data record
- have data records available within the Bureau of Meteorology's data archives.

In selecting gauges for the wetland sections, these needed to be geographically close to the upstream side of the wetland (so as to represent variability in river inflow to the wetland site).

A visual quality check was performed on the run-off hydrographs to exclude unsuitable data from the analysis. The data were scanned for outliers and unusual patterns in the long-term discharge. Where long gaps exist in the data and unusual patterns were found, the site was excluded from the analysis for this report.

Since some distinct patterns can be caused by human actions (e.g. construction of new weirs/dams or deviation of river beds), not all unusual patterns are the result of data errors. The datasets will, therefore, be re-examined for potential use in future reports.

4.2 Data selection procedures (continued)

4.2.3 Flood information

Flood tables – site selection

A set of generic criteria were used in the selection and reporting of flood warning monitoring sites for the production of regional flood table summaries for the 2009–10 year. The selection criteria were adopted for each of the regions where flood summary tables are reported. Sites were selected:

- from the Bureau's Australian Integrated Forecast System database
- to give a maximum of 20 sites per Australian Water Resources Assessment reporting region
- to provide good spatial coverage across the reporting region
- based on reasonable data coverage and quality for the 2009–10 period
- based primarily on proximity to population centres (large cities/towns) where possible/relevant
- where the Bureau provides a quantitative flood forecast as part of the flood warning responsibilities that were prioritised (these sites usually correspond with populated centres and better quality data)
- where possible, to give approximately two sites per catchment (upper and lower catchments).

4.2.4 Selection of water storages

Water storages were selected based on their representation of the total system storage and system behaviour, and upon suitable data availability for 2009–10.

4.2.5 Selection of groundwater bores

The sources of groundwater data used for analyses carried out for this report were obtained from the main government agencies responsible for data collection within the different States. These agencies are the Department of Environment and Resource Management in Queensland, the NSW Office of Water and the Department for Water in South Australia. Other States were not considered in this report as, at the time of writing, suitable quality controlled data were not available from the Bureau's data stores.

The relevant aquifers for bores located within NSW and within the Murray–Darling Basin were identified based on the Geographical Information System data connected with the Groundwater Status Report 2000–2005 (Murray–Darling Basin Commission 2008). The aquifer information for bores located within the States of Queensland and South Australia were obtained either from the relevant databases or reports.

4.2.6 National Resource Management regions and irrigation water use

There are 56 natural resource management (NRM) regions identified for Australia, based on catchments and bioregions. The boundaries were established in agreements between the Commonwealth, State and Territory Governments between December 2002 and June 2004 (www.nrm.gov.au/nrm/region.html).

The irrigation water use figures available from the Australian Bureau of Statistics and used in this publication are summarised according to natural resource management regions.

These boundaries do not coincide with those of the Australian Water Resources Assessment 2010 reporting region boundaries. In areas close to the boundaries, population densities are relatively low and the use of these natural resource management regions provides a fair approximation to the situation in the Australian Water Resources Assessment 2010 regions. The areas used are shown in Figure 4-2 against a backdrop of the reporting regions.

The Wimmera natural resource management region, for example, spans both the South East Coast (Victoria) and Murray–Darling Basin reporting regions. For the purposes of this publication, the same irrigation water use amount per natural resource management region was allocated to both reporting regions, with no partitioning attempted.

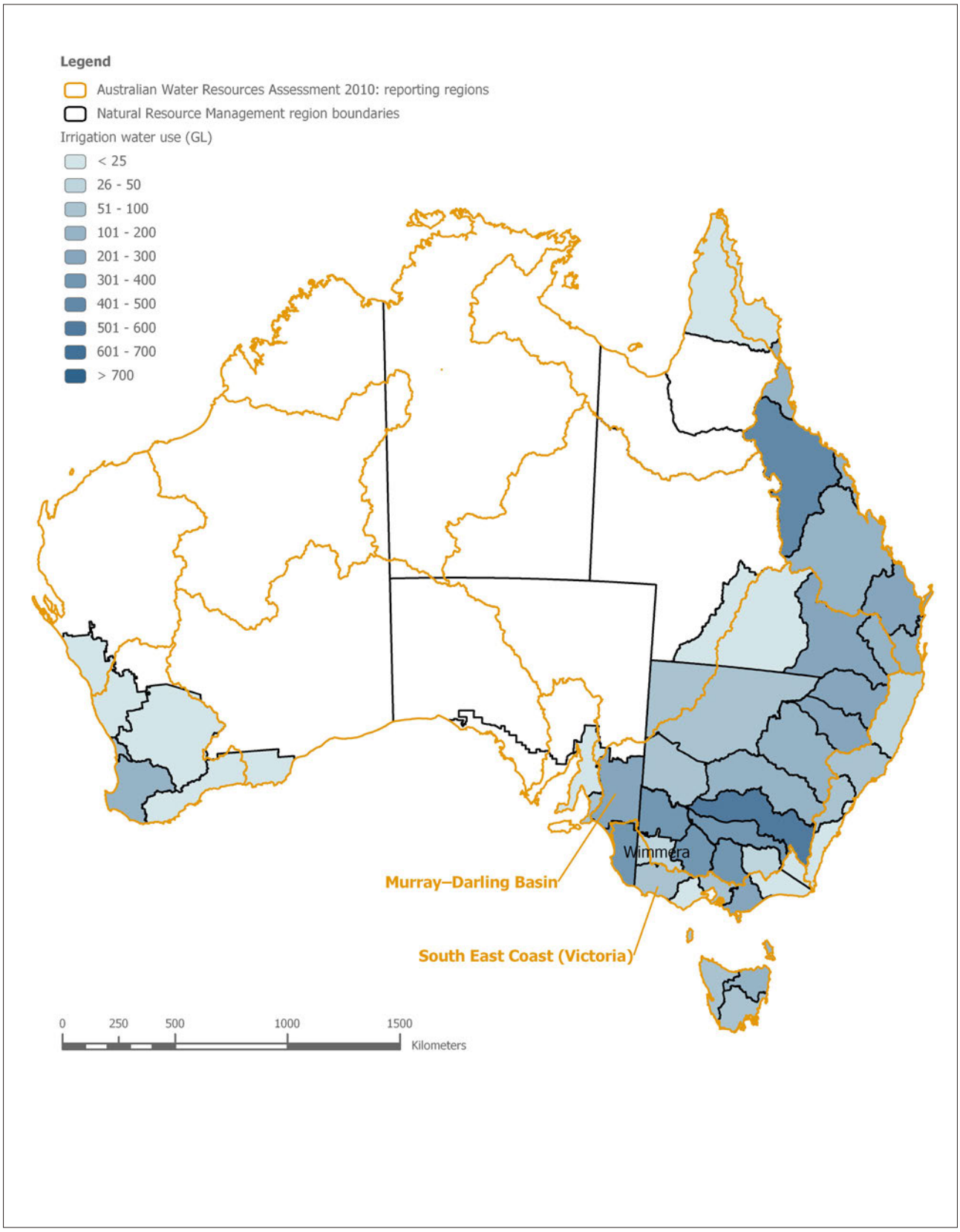


Figure 4-2. The Australian Water Resources Assessment 2010 reporting region and natural resource management region boundaries

4.3 Data analysis procedures

4.3.1 Guide to landscape flows trend analysis results

A simple analysis of trends in landscape water flow time-series was performed in order to provide an assessment of potential long-term movement and changes in modelled variables over time. As noted by Radziejewski and Kundzewicz (2004), many statistical trend and change tests are not able to detect a weak trend or a change which is not sufficiently long, but this cannot be interpreted as a demonstration of the absence of change.

The test statistic for simple linear regression was used to estimate trends across Australia applying the ordinary least squares estimator to fit a straight line between the n points (n = 30). The analysis provides an estimate of whether water flow variables increased or decreased over the defined time period (30 years) by calculating the gradient of the best fit regression line.

Data

The simple trend analysis was applied to the following national level landscape flows:

- rainfall
- modelled evapotranspiration
- modelled landscape water yield.

These data represent modelled inputs or outputs associated with the landscape water balance models applied. The data are generated as a monthly time-series for each 5 x 5 km model grid cell giving almost full coverage of Australia. Each data-set was aggregated to seasonal totals for the summer (November to April) and winter (May to October) periods, providing seasonal totals for the 30 years from November 1980 to October 2010. Regression trends are also presented for annual data (July to June) in this section, but are not presented in the regional chapters.

Simple linear regression

Simple linear regression fits a straight line through the set of n points in such a way that minimises the sum of square of residuals. The residuals are the vertical distances between the modelled points and the fitted line. The objective of the analysis is to determine the equation of the straight line (given below) that would provide the 'best' fit for the data.

$$Y = B_0 + B_1X$$

B_0 is a constant, B_1 is the slope (also called the regression coefficient), X is the value of the independent variable, and Y is the value of the dependent variable.

For the purpose of the Australian Water Resources Assessment report, the slope coefficient (B_1) was calculated for both the summer (November–April) and winter (May–October) season at each grid cell for all three flow variables. Figure 4-3 provides a summary of regression analysis for rainfall, evapotranspiration and landscape water yield for selected grid cell locations in the Murray–Darling Basin and Tanami – Timor Sea Coast regions.

Significance of estimated regression trend

An assessment of the significance of seasonal trends was also carried out as part of the statistical trend analysis process, although the results of the significance tests were not included in the regional chapters. The trend analysis was carried out to illustrate the potential directional trends in landscape water flows over the past 30 years, i.e. has seasonal rainfall tended to increase or decrease over the 30-year period, rather than to explicitly determine whether these changes are statistically significant.

If there is a significant linear relationship between the independent variable X and the dependent variable Y, the slope will not equal zero. Therefore, the null hypothesis (H_0) states that the slope of the linear regression is equal to zero, and the alternative hypothesis (H_a) states that the slope is not equal to zero.

$$H_0: B_1 = 0$$

$$H_a: B_1 \neq 0$$

Significance levels of five per cent and ten per cent were chosen for the presentation of results. A five per cent significance level means that an error will be made, on average, for five per cent of the time, i.e. if the null hypothesis was true then one in 20 test results will be significant and incorrect. It should be noted that any level of significance can be chosen between zero and 100 per cent, although the significance levels chosen here are widely used in statistics.

A linear regression t-test was applied to determine whether the slope of the regression line differs significantly from zero. The test statistic is a t-score (t) defined by the following equation:

$$t = b_1 / SE$$

where b_1 is the slope of the sample regression line, and SE is the standard error of the slope.

The P-value is the probability of observing a sample statistic as extreme as the test statistic and can be used to assess whether the statistical test satisfies the test hypotheses based on the defined levels of significance. The test statistic is based on the t-score and the t-distribution is used to assess the probability associated with the test statistic. The degrees of freedom (DF) associated with the test statistic is equal to:

$$DF = n - 2$$

where n is the number of observations in the sample.

If the test indicates a significant trend in a data series, based on the calculated P-value, the null hypothesis (H_0), (i.e. there is no linear trend identified in the slope of the regression line ($B_1 = 0$)), is rejected.

National maps of the calculated linear regression slopes (in mm/year) and statistical significance are presented for seasonal rainfall, evapotranspiration and landscape water yield in Figure 4-4, Figure 4-5 and Figure 4-6. Trend gradients are also presented on an annual basis (July to June).

Assumptions and limitations

The analysis of national trends in seasonal and annual rainfall, evapotranspiration and landscape water yields presented in this report include a number of assumptions and limitations. The analysis provides only a simplified assessment of (linear) trends in landscape model variables and should, therefore, only be interpreted as providing an indication of the directional tendencies in these variables over the past 30 years. The strength and magnitudes of these trends should only really be taken to be indicative as a consequence of the simple nature of the statistical test and the inherent variability, spatially and temporally, of the underlying data.

Some (not all) of the relevant assumptions and limitations of the statistical analysis are identified below.

Assumptions

- Trends in seasonal and annual rainfall, modelled evapotranspiration and landscape water yield are assumed to be linear over the past 30 years.
- The data points are assumed to be independent with no serial correlation, i.e. no short-term correlation between samples.
- The measurement and calculation of the data is assumed to be consistent over space and time, i.e. the method used for the generation of rainfall surfaces is the same over the 30-year period.
- The data are assumed to be normally distributed. Data transformations to compensate for undesirable data properties, i.e. high skewness or strong departure from normality, were not applied.

Limitations

- Only very limited exploratory data analysis and visual assessment was applied to the data and therefore the depth of understanding of the underlying data is also limited. The large volume of data involved in the analysis and time and resource constraints proved highly prohibitive in the further analysis and understanding of the data and results of statistical analysis. It is acknowledged that without a rigorous exploratory data analysis process, the quality, robustness and reliability of the analysis and its interpretation will be weakened.
- The simple linear regression test does not effectively identify more complex characteristics of trends. For instance, this approach does not identify break points and step changes in the time-series or changes in trend direction or period trends within the data period.
- The 30-year time period was assumed to be sufficient for the analysis of statistical trends and represents a good standard period for analysis. The analysis of much longer term records, i.e. up to 100 years, may provide additional values and support to the results and interpretation of statistical trends and change over time.
- Potential implications of spatial statistics and spatial independence were not considered.

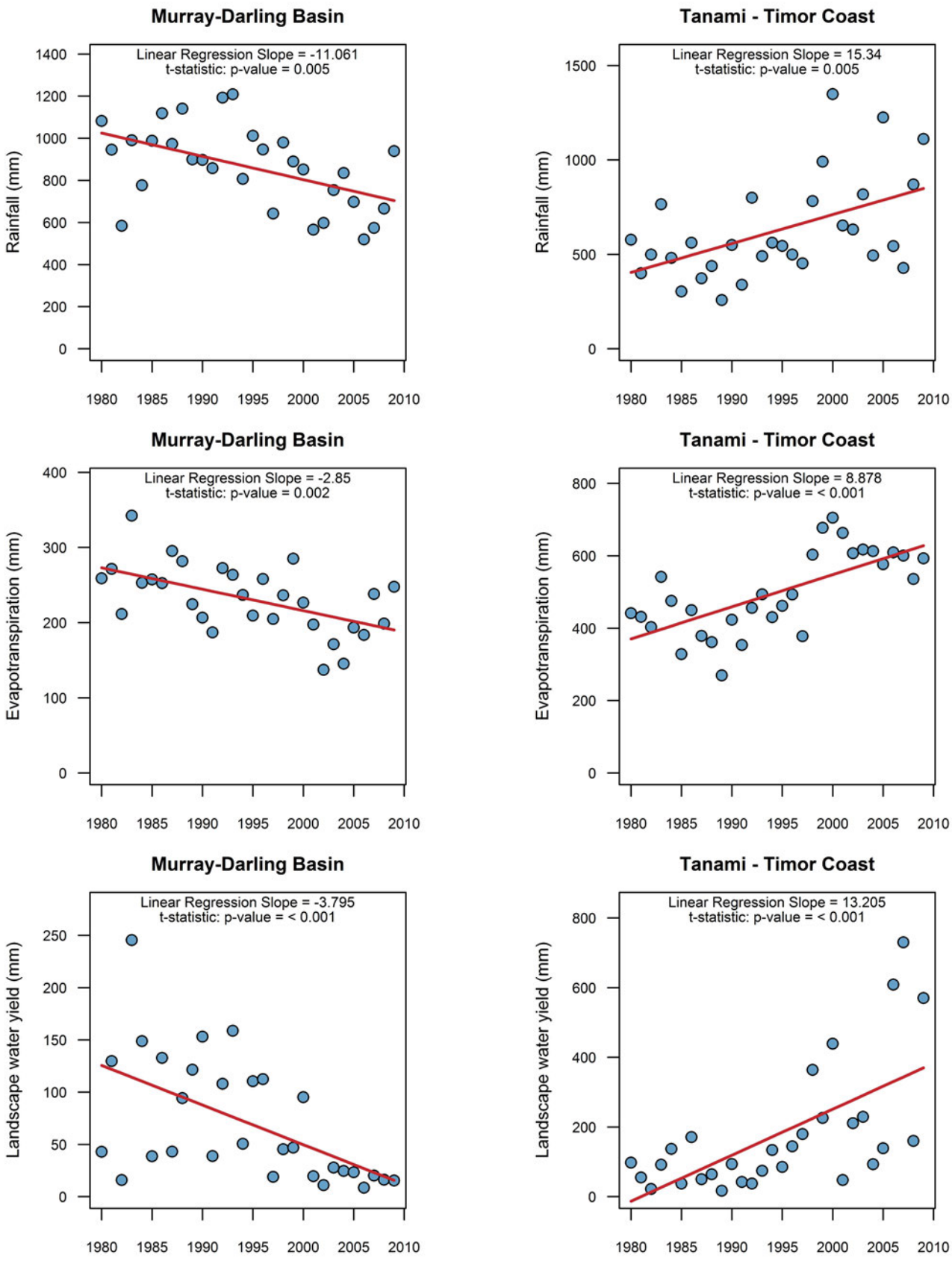


Figure 4-3. Regression analysis for selected grid cell locations in the Murray–Darling Basin and Tanami – Timor Sea Coast regions

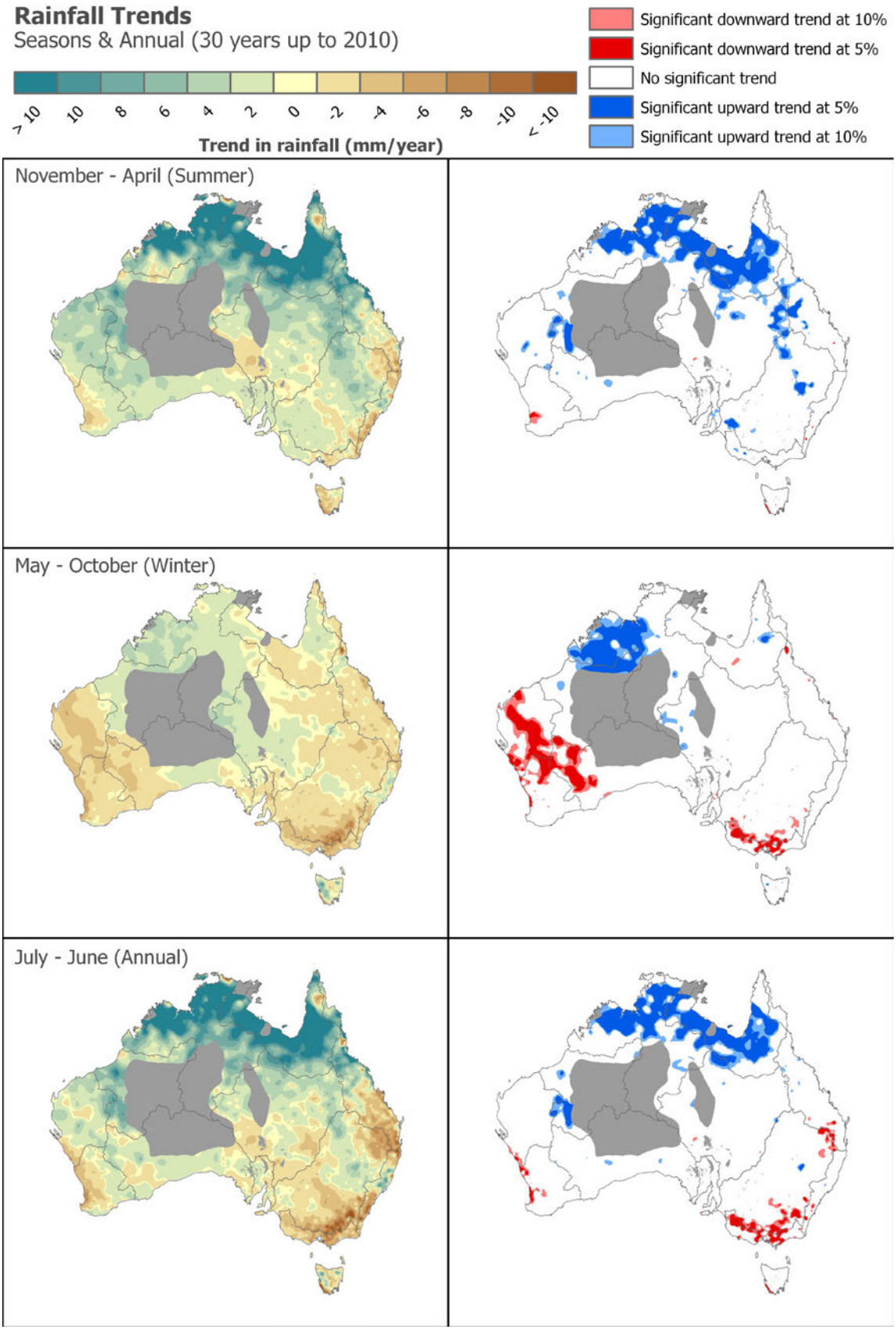


Figure 4-4. Maps of estimated trends in summer, winter and annual rainfall (for 30 years up to 2010) and associated levels of statistical significance (at 5% and 10% significance)

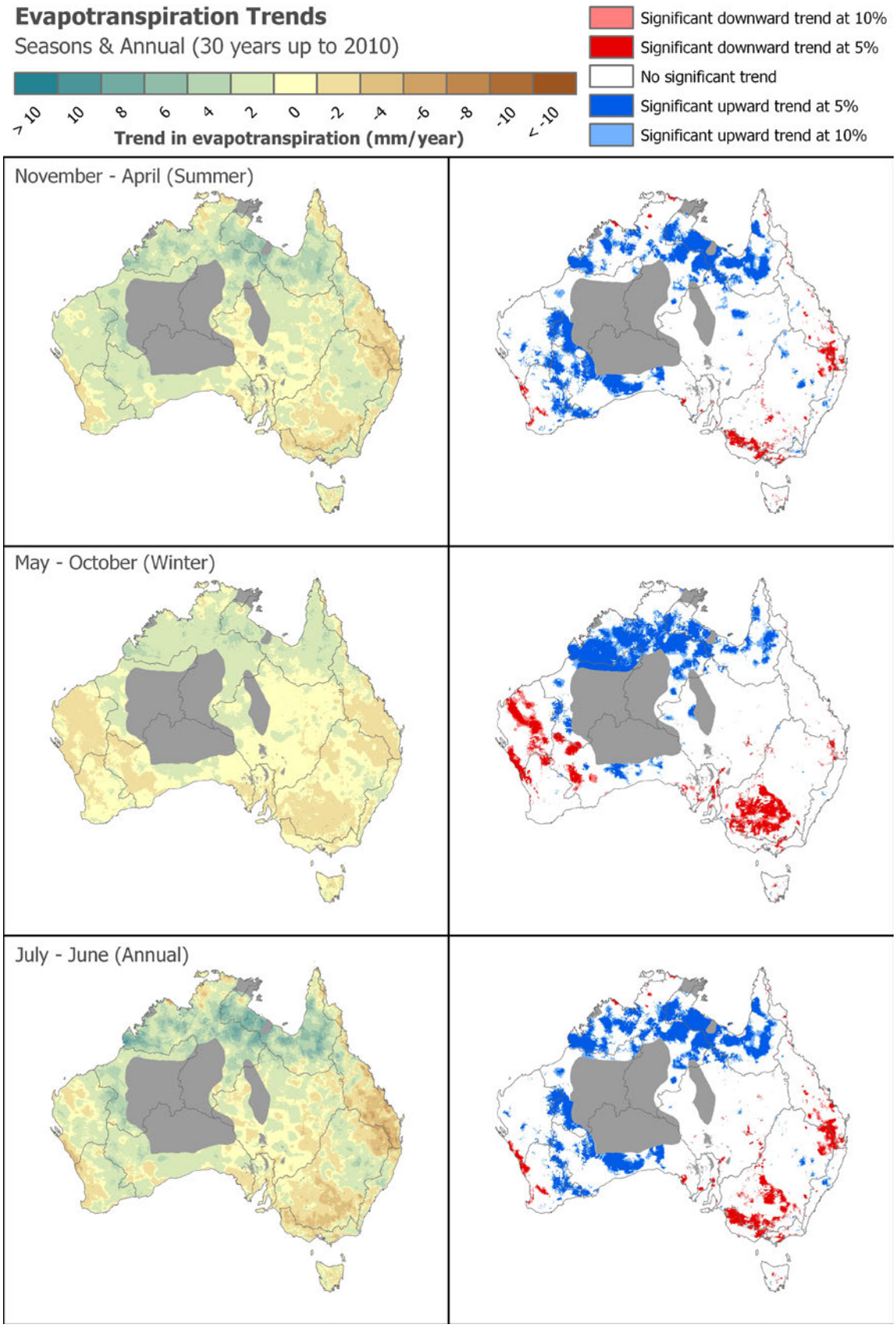


Figure 4-5. Maps of estimated trends in summer, winter and annual evapotranspiration (for 30 years up to 2010) and associated levels of statistical significance (at 5% and 10% significance)

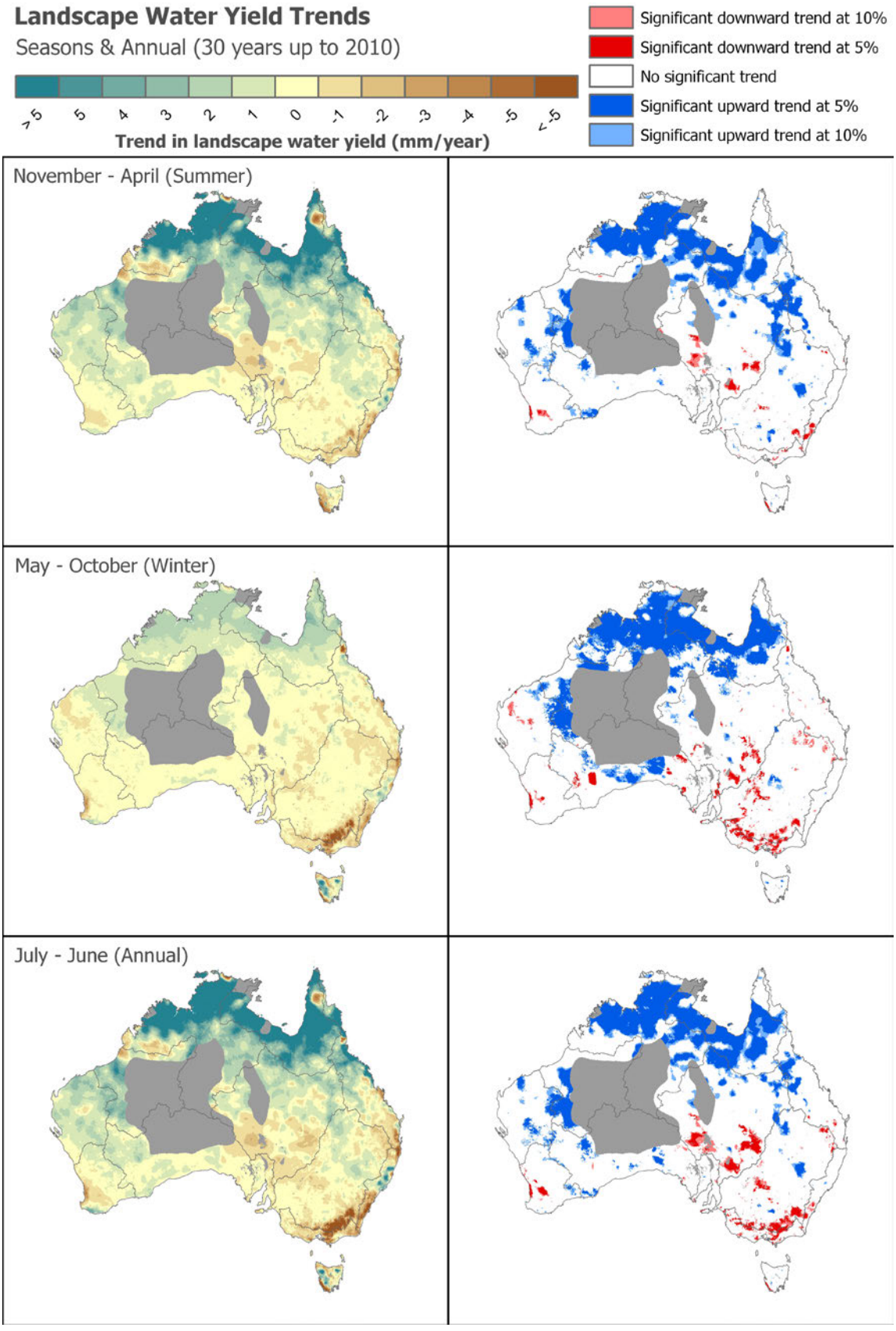


Figure 4-6. Maps of estimated trends in summer, winter and annual landscape water yield (for 30 years up to 2010) and associated levels of statistical significance (at 5% and 10% significance)

4.3.2 Guide to surface water storages information

This section provides information relating to the water storage figures presented in the Australian Water Resources Assessment report. This is general information regarding terminology, understanding storage graphs and data, copyright and data supply information and general data processing information. Storage specific information and data are available within the storage figures' metadata.

Water storage terminology

The following terms are used for the water storage volume figures and are visually explained by Figure 4-7:

- **per cent of accessible capacity** – the volume of water in storage as a percentage of accessible storage capacity. Note that the percentage full may exceed 100 per cent due to floods
- **accessible storage capacity** – the volume of water a storage can hold between the minimum supply level and full supply level; equal to total storage capacity excluding dead storage capacity. This is the capacity that is reported for all storages and the sum of this capacity that is reported for systems of storages
- **accessible storage volume** – the volume of water stored at a particular time and date. It excludes the dead storage volume and hence is the volume of water that can be accessed under normal circumstances without the installation of additional infrastructure
- **dead storage capacity** – the portion of a water storage's capacity that is equal to the volume of water below the level of the lowest outlet (the minimum supply level). This water cannot be accessed under normal operating conditions.

Storage data graphs in the Australian Water Resources Assessment report give an indication of accessible storage, excluding dead storage.

The mean daily accessible storage for a storage or system of storages is shown by a black line, which may contain gaps where data of one or more storages are unavailable. There are no gaps in the blue shading as data were linearly interpolated over the gaps.

During periods of high river flow or flood, storages can hold more than 100 per cent of their rated capacity.

Percentages are calculated based on the accessible capacity of the storage as per 30 June 2010. Therefore, the storage volume in previous years may also exceed 100 per cent if the storage capacity decreased. Changes in storage capacity can occur for a variety of reasons including: sediment accumulation or changes to the height of the dam or outlet structures.

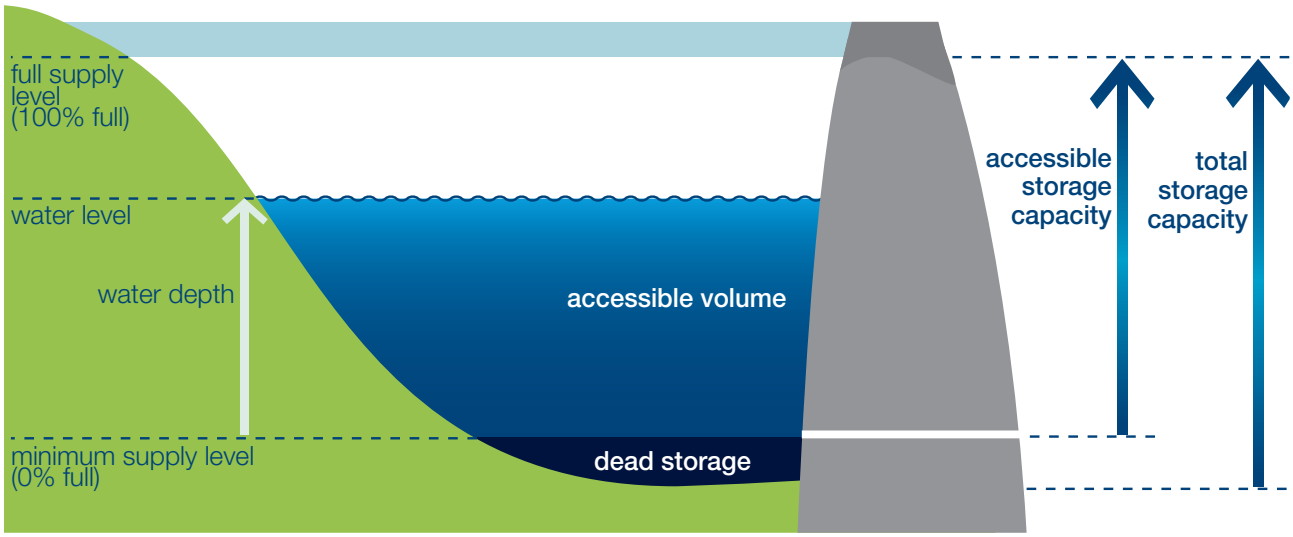


Figure 4-7. Conceptual representation of a water storage

4.3.2 Guide to surface water storages information (continued)

Data processing

Corresponding volume/level pairs are created using a capacity table, the established relation between water level and storage volume. Depending on the provided data and configuration of the storage, either level or volume will be specified as the primary data feed from which to calculate values.

Where historical capacity tables were not available, the capacity table as at 1 January 2009 was used to calculate storage volume for the period prior to this date.

Standardisation

All data that are received from a data provider for a storage is converted to the Bureau standard (e.g. meters above Australian Height Datum (mAHD) and Accessible Volume). Where required, the reference data as at 1 January 2009 were used to standardise data back to the beginning of the period of record.

Calculate mean daily values

Mean daily storage volume values were calculated in one of two ways:

- Simple average – mean daily volume values are calculated from sub-daily data by calculating the mean of all the measurements received for the day
- Time weighted average – mean daily volume values are calculated from sub-daily data by linearly interpolating between points and calculating the average volume over the entire day from midnight to midnight.

4.4 Data available with the report

Introduction

Data files will be available for download from the Bureau's website www.bom.gov.au/water/awra/2010/metadata.shtml for most of the figures contained in the report. Readily available background information (particularly for the maps) is referenced only, as are a few data-sets considered sensitive by the data providers.

Only information shown in the figures is included together with its associated metadata. The original data used to derive this information are described in the metadata. Information is grouped into zip files associated with each chapter. PDF metadata files are associated with the data for each figure. For ease of identification, a small JPG file of the figure is also included.

Spatial information

The raster data that are provided with the national overview chapter are not repeated in the regional chapters. A shapefile of regional boundaries is provided to enable selection of regional data subsets. Legend information is provided linking numerical ranges to associated colours used in the report. The raster data are provided in ASCII grid format.

All publicly available background information is available from the Bureau's Geofabric website (www.bom.gov.au/water/geofabric/index.shtml) and Geoscience Australia (www.ga.gov.au/products-services/data-applications.html). Spatial information on groundwater unit boundaries is not included but will be available in the near future from the Bureau's website.

Graphed information

The graphed information in the figures is provided in zip files associated with each of the individual chapters. Information is provided in CSV format.