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Australian Water Resources Assessment 2012

Water Information
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Foreword

The Commonwealth *Water Act 2007* created a number of additional functions for the Bureau of Meteorology (the Bureau), including the provision of 'regular reports on the status of Australia's water resources and patterns of usage of those resources'.

The *Australian Water Resources Assessment 2012* (the 2012 Assessment) is the second of these reports. It presents assessments of Australia's water resources and climatic conditions in 2011–12 and discusses regional variability and trends in water resources and patterns of water use over seasons, years and decades. It extends the content presented in the first assessment report (2010 Assessment) by including additional information about streamflow salinity, land use, population, soil types, physiographic regions, rainfall zones and rainfall deficits.

The Bureau's water resources assessments are repeated on a regular basis (currently every two years), with a focus on consistency in reporting of particular streams of modelled and measured water resources data. The 2012 Assessment is intended to assist understanding of the impact and sustainability of current water management practices and inform the design of water resource policies and plans. This will support the goals of the National Water Initiative and contribute to the water reform agenda.

The 2012 Assessment uses data provided from organisations across the country and research outputs of the Bureau's Water Information Research and Development Alliance with CSIRO. It has required significant effort from a large number of people and I am proud of the dedication and professionalism of the teams involved.

Graham Hawke

Deputy Director
Environment and Research Division
Bureau of Meteorology

September 2013

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1. Introduction

1.1 Background

The Commonwealth *Water Act 2007* gave the Bureau of Meteorology (the Bureau) responsibility for compiling and delivering comprehensive water information across Australia. This includes conducting timely, rigorous and independent assessments of the status of Australia's water resources.

The Bureau's first national water resources assessment was published in 2011 for the 2009–10 year (July 2009–June 2010). It built on earlier assessments undertaken by various Australian Government agencies and partners at irregular intervals over the last 50 years, each with a slightly different purpose and approach.

The Bureau's water resources assessments are undertaken at regional and national spatial scales and time scales ranging from months to decades. These reports are intended to assist assessment of the impact and sustainability of current water management practices and inform the design of future water resource plans, supporting the goals of the National Water Initiative and contributing to the water reform debate.

The Bureau's water resources assessments provide:

1. consistency in reporting across the nation and over time, enabling spatial and temporal comparisons of water resources by end users;
2. free access to water information via the web;
3. comparable information at regional and national scales;
4. a high level of transparency about the information and data used, and the modelling and analysis techniques employed;
5. scientifically robust analyses of changes in water availability, quality, and use over time-scales of months to decades; and
6. a presentation of Australia's water resources without reference to jurisdictional boundaries.

1.2 Scope and purpose

The *Australian Water Resources Assessment 2012* (the 2012 Assessment) presents assessments of Australia's climate and water resources over the 2011–12 year (July 2011–June 2012). It discusses regional variability and trends in water resources and patterns of water use over recent seasons, years and decades, using currently accessible data.

The 2012 Assessment is focused on aspects of national and regional water availability rather than water allocation, trading or quality (though salinity of surface streamflow and groundwater is included). Water use is addressed for various selected urban centres and irrigation schemes.

The 2012 Assessment includes the:

- Introduction;
- National Overview;
- 13 regional assessments;
- Glossary;
- Technical Supplement; and
- References.

A summary report and the data used to develop the figures is available from the Bureau's website.

The National Overview provides a continent-wide assessment of climate and water flows and stores across Australia in 2011–12. This includes national landscape water balance model outputs for the year, including rainfall, evapotranspiration, landscape water yield and change in soil moisture, as well as consideration of changes in surface water storage in each region. The National Overview examines important Australian climate drivers and their impact on rainfall over the year. It also provides an overview of urban and agricultural water use in 2011–12 for selected areas. Information on relevant nationally significant weather and flooding experienced in 2011–12 is also presented.

The regional chapters highlight changes in water availability and use in 13 regions that cover the Australian continent and Tasmania. Analyses presented include climate impacts on water resources over 2011–12 and also in recent decades (1980–2012). Modelled regional spatial data and time series data from selected monitoring sites provide more detail at particular locations.

With each assessment the same sites are used for data analysis. As new data becomes available the data used in analyses is updated for these selected sites. This allows clear comparisons to be made between assessments.

Finally, the Technical Supplement provides background on the landscape water balance modelling techniques, methods, the data and the analyses used to generate information in the report.

Information and data provided in the 2012 Assessment reflect the quantity and quality of data currently available for analysis. It is expected that as data supplied to the Bureau under the *Water Act* and the Water Regulations 2008 are further stored, standardised and quality assured by the Bureau, analysis and reporting will be enhanced. Feedback from users will also be used to improve future reports in terms of methods used, interpretation and content.

1.3 Focal questions

The 2012 Assessment aims to provide information to help address a variety of questions at a range of spatial and temporal scales subject to the availability of appropriate data. The scales vary from national in the National Overview to regional and local in subsequent chapters. Time scales also vary depending on the data used and the intent of the analysis. The types of questions addressed include:

1. Which ocean and atmospheric circulation patterns influenced rainfall in different parts of the country in 2011–12? (section 9 in the National Overview).
2. How much of the rainfall received in 2011–12 ended up in rivers and groundwater and how does this compare with the past? (section 3 in the National Overview; section 4 in the regional chapters)
3. Was there any significant flooding or dry periods in 2011–12 as a result of particular weather conditions? (section 11 in the National Overview; section 5 in the regional chapters)
4. How much of the rainfall received in 2011–12 was evaporated or used by plants and how does this compare with the past? (section 3 in the National Overview; section 4 in the regional chapters)
5. How moist were soil profiles across the country in 2011–12 and how does this compare with the past? (section 4 in the National Overview; section 7 of the regional chapters)
6. Are there any regional trends evident in seasonal rainfall, evapotranspiration, soil moisture, landscape water yield or groundwater levels? (sections 4, 5 and 7 in the regional chapters)
7. How do seasonal inflows to and outflows from selected nationally significant wetlands vary from year to year and are they changing? (section 5 in the regional chapters)

Tyto wetlands, near Townsville | Andrew Rankin (Queensland Image Gallery)

8. Where does the water for cities and irrigation areas come from and is this changing? (sections 6 and 7 in the regional chapters)
9. What seasonal to decadal patterns and trends are evident in water storage inflows and volumes, and in groundwater levels, particularly in relation to rainfall? (sections 5, 6 and 7 in the regional chapters)
10. How does water use in cities and irrigation areas vary from year to year, particularly in relation to water availability? (sections 6 and 7 in the regional chapters)

1.4 Assessment approach

The techniques used to produce the 2012 Assessment are explained in this section. The descriptions provide context to the information presented in the regional chapters.

Further information about the methods used to derive and analyse water and climate data is provided in the Technical Supplement.

1.4.1 Reporting units

The 2012 Assessment report is structured around 13 regions covering the Australian continent and Tasmania that are based on drainage division boundaries (Figure 1.1).

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 biophysical regional and climatic contexts.

In Australia, 12 drainage divisions were first defined in the 1960s by the Australian Water Resources Council and the boundaries were formally published in the 1990s (Hutchinson and Dowling 1991). They were recently modified by the Bureau and its research partners at Geoscience Australia and the Australian National University, based on the most current topographical data. This dataset is described in the *Geofabric Product Guide* (The Bureau 2013b).

In the new drainage divisions, the South East Coast has been split into two regions to distinguish New South Wales coastal river basins from Victorian and

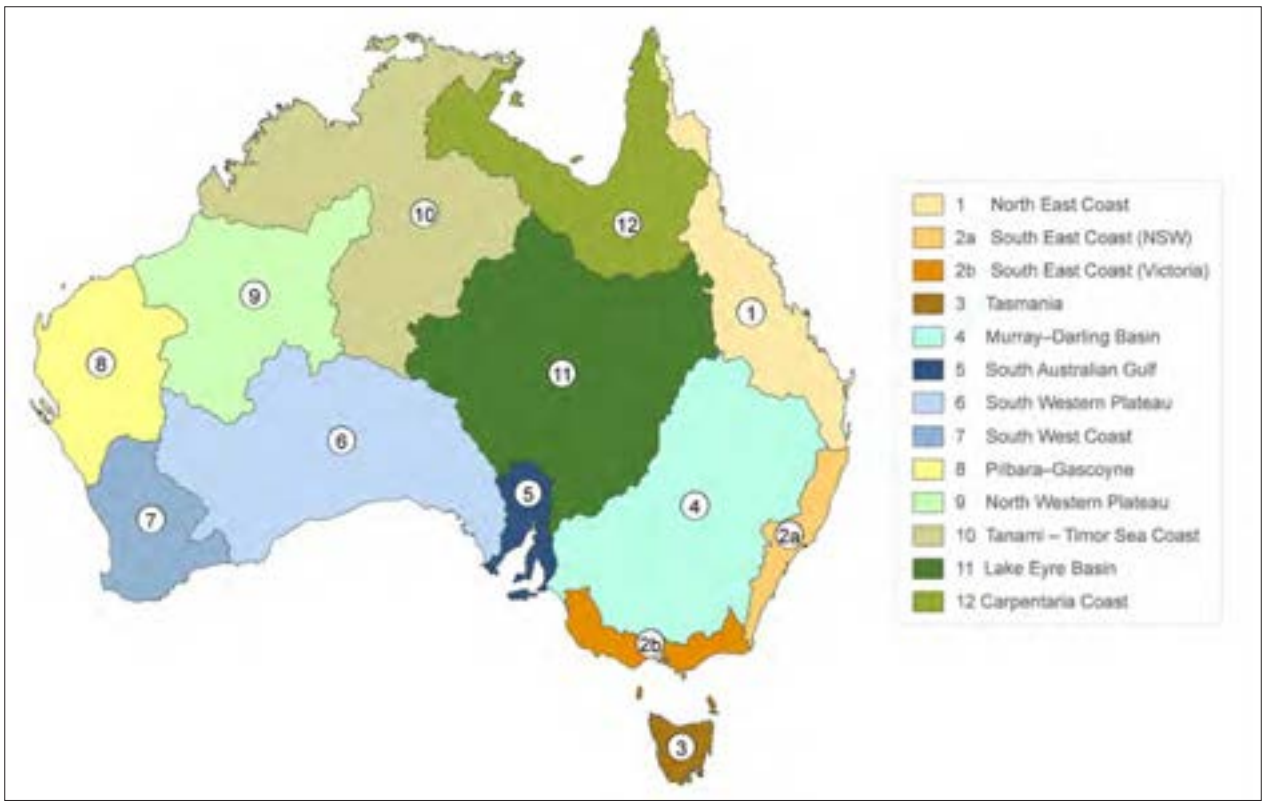


Figure 1.1 2012 Assessment reporting regions

southeastern South Australian coastal river basins (Figure 1.1), to further establish a manageable heterogeneity within and between reporting units.

Within the reporting regions shown in Figure 1.1, various time-series analyses and reporting techniques have been applied depending on the availability of data. Analysis and reporting units at the sub-regional level include hydrological units (surface catchments and groundwater aquifers), water management and planning areas, water supply systems and monitoring sites or clusters of sites (for example, stream gauges on tributaries flowing into a reservoir).

1.4.2 Reporting period

The data and information presented focuses on the 12 months from July 2011 to June 2012 and/or months and seasons therein. Time-series analyses are restricted to consideration of data from 1980, in order to place the 2011–12 period in the context of the variability and trends in recent decades, with the exception of the landscape water balance flows, which are related to the rainfall data and generated model results from 1911 onwards.

Trends in groundwater levels for major aquifers in the regions are reported for the past five years (2007–08 to 2011–12).

1.4.3 Landscape water balance

Water balances are used as a consistent and repeatable means of reporting on water availability. A water balance has a number of standard variables:

- inflows, for example, rainfall;
- outflows, for example, evaporation, transpiration, run-off; and
- change in storage, for example, soil moisture.

Key terms used in the 2012 Assessment are presented in Figure 1.2. The spatially dispersed landscape water flow components, besides rainfall, include:

- Evapotranspiration: the combination of modelled evaporation from the soil and modelled transpiration from vegetation.
- Landscape water yield: the sum of modelled surface run-off and groundwater discharge to surface waters. This approximates streamflow at monthly to annual time scales in high rainfall areas and areas with steep slopes. It is an indication of potential water availability, especially groundwater, in low rainfall or topographically low profile areas.

Together with soil moisture, these are the only terms that are assessed through the use of a landscape water balance model. All other terms are assessed through the use of measured data.

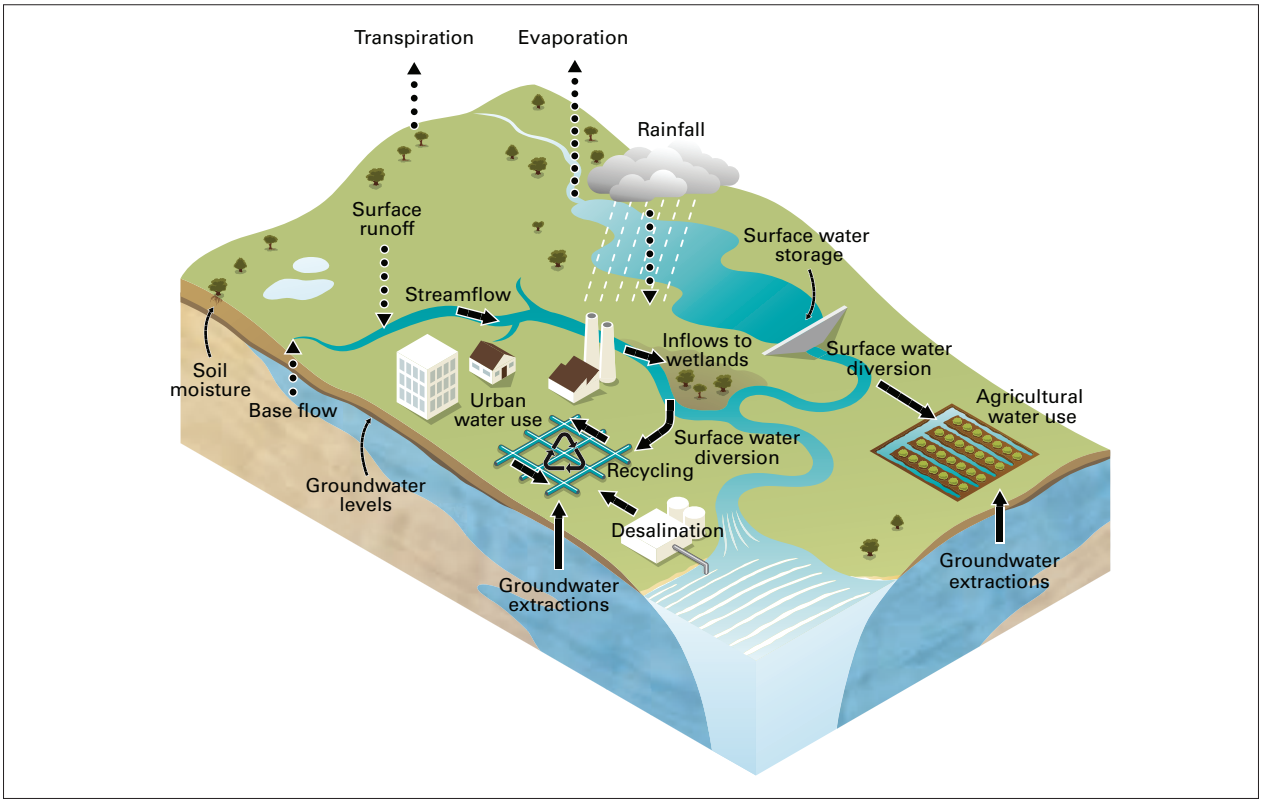


Figure 1.2 Water balance terms reported on in the 2012 Assessment

1.4.4 Mapped rainfall data

This 2012 Assessment uses daily rainfall data to drive the landscape water balance model. National daily rainfall grids were generated using rainfall station data from a network of persistent, high-quality sites managed by the Bureau. The grid resolution is constrained by the density of the network of rainfall stations across Australia, and is approximately 5 km x 5 km (0.05° grid).

For monthly and annual aggregate rainfall information presented on the Bureau website and in other Bureau products (for example, the National Water Account), the Bureau applies a post processing analysis method. This analysis uses rainfall ratios (daily rainfall divided by monthly averages) to incorporate the general influence of topography on prevailing weather systems, which is reflected in the monthly averages (Jones et al. 2009). The analysis provides an objective estimate of rainfall in each grid square and thus enables useful estimates of rainfall in areas with few rainfall stations, such as Central Australia. This accounts for small differences in the rainfall information shown in the 2012 Assessment as compared to other Bureau products.

Areas where rainfall interpolation was assessed to be unreliable have been marked in the maps to assist the reader in identifying the relevance of the spatial information. More detail is provided in the Technical Supplement (section data and analysis).

1.4.5 National landscape water balance modelling

A newly developed nationally consistent landscape water balance model, the Australian Water Resources Assessment Modelling System (AWRAMS) was used to generate estimates of landscape water flows and stores across the country in the 2012 Assessment. The AWRAMS was developed for the Bureau's water-reporting purposes through the Water Information Research and Development Alliance between the Bureau and CSIRO. The purpose of the AWRAMS is to provide up-to-date, credible, accurate and relevant information about the history, present state and future trajectory of the water balance in Australia to inform water resources management policy. The 2012 Assessment is the first in its series that uses a nationally consistent landscape water balance model.

The landscape water component of the AWRAMS is referred to as AWRA-L and simulates water stores and flows in the landscape: the vegetation, soil and local catchment groundwater systems (van Dijk 2010). AWRA-L incorporates a catchment water balance that takes account of vegetation ecohydrology and phenology. AWRA-L is a national, distributed model and runs at a daily time-step. Figure 1.3 shows a schematic representation of the components (inputs, stores, flows and outputs) of the AWRA-L model.

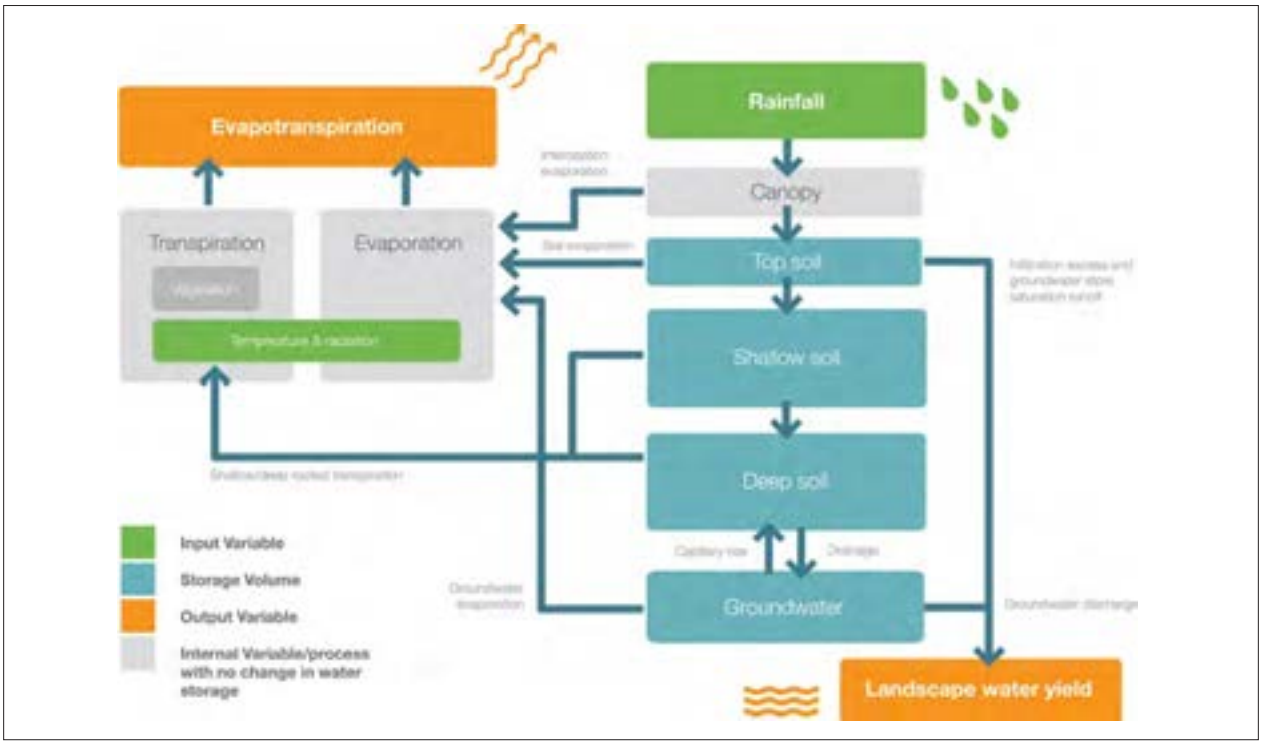


Figure 1.3 Schematic representation of inputs, outputs, flows and stores in the AWRA-L landscape water balance model

AWRA-L simulates water stores and flows on the landscape based on the following principles:

- Net rainfall is determined after accounting for interception and direct evaporation losses.
- Run-off occurs from the surface top soil through saturation or infiltration excess processes.
- Soil moisture storage and fluxes are described in three soil layers: surface top soil, shallow, and deep soil. They include evaporation, transpiration and drainage processes. Root uptake of water occurs from both the shallow and deep soil layers.
- Groundwater balance typically comprises drainage from the deep soil layer, capillary upward flow, discharge into streams and change in storage.

AWRA-L was run nationally on a 0.05° grid (approximately 5 km x 5 km), consistent with the resolution of available climate data required as input to the model.

For the 2012 Assessment, the model was used to derive estimates of monthly and annual landscape evapotranspiration and water yield for each grid cell. These estimates don't include estimates of the impact of surface water bodies or human activities such as irrigation. Estimates of landscape water yield were produced by taking the total of modelled surface run-off and groundwater discharge estimates. The model was also used to provide estimates of changes in the soil moisture store over 2011–12.

The 2012 Assessment differs from the 2010 Assessment in that an improved calibration of the AWRA-L model was used in analyses in the 2012 report. The 2010 Assessment used combined outputs of the Waterdyn and AWRA-L models. The combined model outputs were not required for the 2012 Assessment as the new calibration has resulted in a more satisfactory representation of the landscape water flows (see Technical Supplement for more information on the model choice). The annual and seasonal patterns in total flows given in the regional chapters of the 2012 report supersede those in the 2010 report.

1.4.6 Percentiles, deciles and anomalies

National rainfall and landscape water balance analysis outputs are presented in the form of monthly and annual totals for the 2011–12 water year in conjunction with their decile rankings when compared with the historical record.

Percentiles and deciles show the ranking of the observations or estimated water balance terms for the year relative to all values in the historical record. They provide a clear indication of above or below average estimates relative to the long-term record.

The advantage of presenting percentiles and deciles in addition to absolute values is that a given estimate may vary considerably at different locations due to variations in climate and landscape characteristics whereas percentiles and deciles express this variability relative to the long-term average at a particular location.

As observations and, in particular, estimated model outputs can be imprecise both spatially and temporally, it is more credible to give relative indications of spatial and temporal differences and trends.

Using these statistical tools to relate current year data relative to history avoids putting undue emphasis on the absolute difference between years.

Calculation of percentiles, deciles values and variability in climate datasets held by the Bureau typically use all years of record to best describe pronounced conditions in these datasets.

For example, to calculate the 'wettest month on record', data from all years in the record are required; however, limitations in the temporal and spatial extent, as well as the quality of data, also have a bearing on the most appropriate reference period.

With this in mind, the 101-year period from July 1911–June 2012 was used to calculate percentiles and deciles for rainfall and modelled landscape water balance terms.

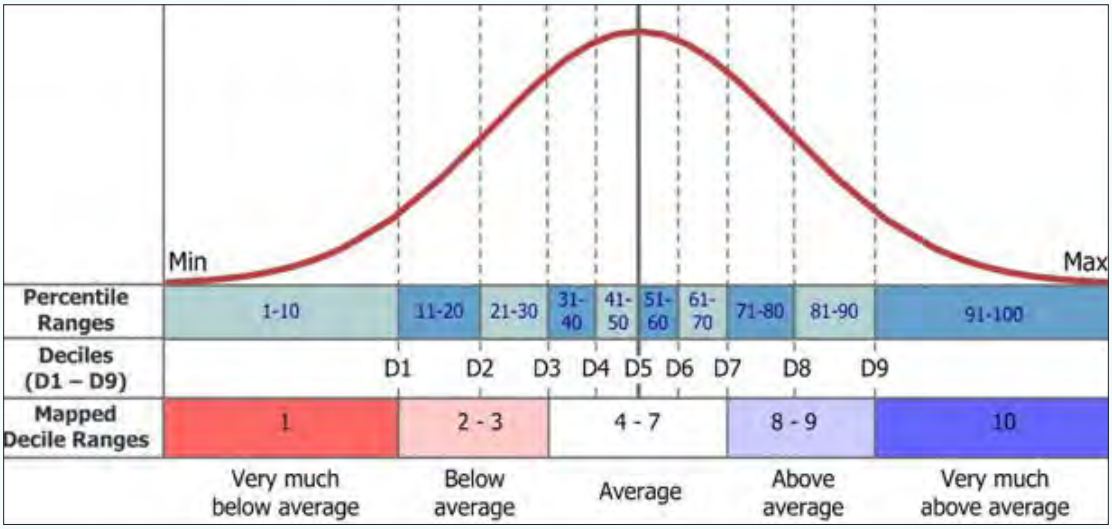
Box 1.1 Deciles and percentiles

Deciles and percentiles are forms of descriptive statistics widely used in science to provide an easily interpretable and standardised summary of the position, or scale, of a value, measurement or observation relative to the full distribution of the long-term record.

A decile represents any of the nine values that divide a ranked dataset into ten groups with equal frequencies, so that each part represents a tenth of the record. Percentiles simply split the data into 100 equal parts; therefore, a decile is the aggregation of a set of ten percentiles.

If the graph presented in the figure below is assumed to represent the ordered distribution of a long-term record of observations (for example annual rainfall totals), then:

- Decile 1 (D1) is the highest value of the first (lowest) grouping; therefore in 10% of the years on record the annual rainfall total did not exceed the D1 value. This is equivalent to the 10th percentile value.
- Decile 9 (D9) is the highest value of the ninth (highest) grouping; therefore in 10% of the years on record the annual rainfall total exceeded the D9 value. This is equivalent to the 90th percentile value.
- The median, or decile 5 (D5), is that value which marks the level dividing the ordered dataset in half, that is, the midpoint of the ordered annual rainfall totals. This median value is equivalent to the 50th percentile value.
- This example also illustrates the classification of decile ranges used in this report to define values relative to the average (median) range that is within the 'average' range, 'above / below average' or 'very much above / below average'. For example, Decile range 10 is the grouping of values that exceed Decile 9.



1.4.7 Flood classification analyses

National and regional flood peak analyses for the 2011–12 period are presented. The Bureau definitions of minor, moderate and major flooding are defined on a State-by-State basis in consultation with stakeholders for key monitoring sites based on impacts on infrastructure and properties (see www.bom.gov.au/water/awid/index.shtml for the definitions of the flood classes).

A national analysis in the National Overview shows locations where peak river levels exceeded the major flood threshold during 2011–12. Flood maps are also provided in the regional chapters presenting all key flood gauging sites within each region and the maximum flood level that occurred during 2011–12.

1.4.8 Trend analyses

Climate and landscape water balance analysis for the regional scale (chapters 3–15) is the same as that used at the national scale. However, spatial trend analyses are also included at the regional scale. Trend values were determined from a linear or straight line fit using ordinary least square regression. Trend maps enable comparisons of how rainfall and other water balance terms have changed in different regions of Australia over time.

These trend maps need to be interpreted with caution. Readers are advised to interpret the trend maps in the context of the accompanying time-series. For example, a calculated trend could be due to a relatively rapid 'step' change, with the remainder of the series showing no trend. Spatial surfaces such as rainfall are based on point observations and, therefore, the removal or addition of a station in the network can affect the temporal analysis (particularly if it is located in an area with significant topographical influence) and may introduce an artificial 'step change'.

The maps aim to provide a very simple spatial assessment of the general direction and, to a limited degree, the scale or magnitude of the fitted linear trends in the climate and landscape water balance time-series. The significance of estimated trends is often low as is presented in the regional trend analyses. The trend estimates are constrained by the assumptions associated with the statistical analysis that are described in the Technical Supplement.

The trend map values should not be used to imply future rates or directions of change. Due to the complex interactions between natural and human drivers of climate change and variability, the climate of any location is always changing. Future rates of change will depend on how these drivers interact in the future, which will not necessarily be the same as in the past.

1.4.9 Site-based anomaly and time-series analyses

Water data from a wide range of organisations across Australia are currently being received by the Bureau (under the *Water Act* and Water Regulations 2008). This includes data and information on:

- climate (including rainfall);
- streamflow;
- surface storage levels and volumes;
- groundwater;
- agricultural water supply and use;
- water allocations and trade;
- urban water supply and use;
- urban water restrictions; and
- water quality.

At the time of publication, only a subset of data pertaining to these categories had been received, stored and checked by the Bureau and made available for analysis and presentation in this report. This included datasets on climate, streamflow and surface storage, and selected datasets related to groundwater, urban and irrigation water supply and use.

The location of monitoring sites for rainfall, streamflow, storage volumes, flood heights and groundwater level and salinity addressed in this report are shown in figures 1.4 and 1.5. A total of 292 river gauges, 315 flow salinity gauges, 25 wetland gauges, approximately 3,000 rainfall stations, 13,644 groundwater bores, 280 storages and 1,244 flood sites have been used in this report.

Where possible, selected sites, stations and datasets were identified to help present temporal variability in water availability and use around the country over the past 12 months in comparison to the past three decades.

Seasonal and annual discharges at selected river monitoring sites for 2011–12 are compared to the deciles of the datasets at these sites for the years following 1980. Variation of the annual river salinity at selected river monitoring sites for 2011–12 is also presented.

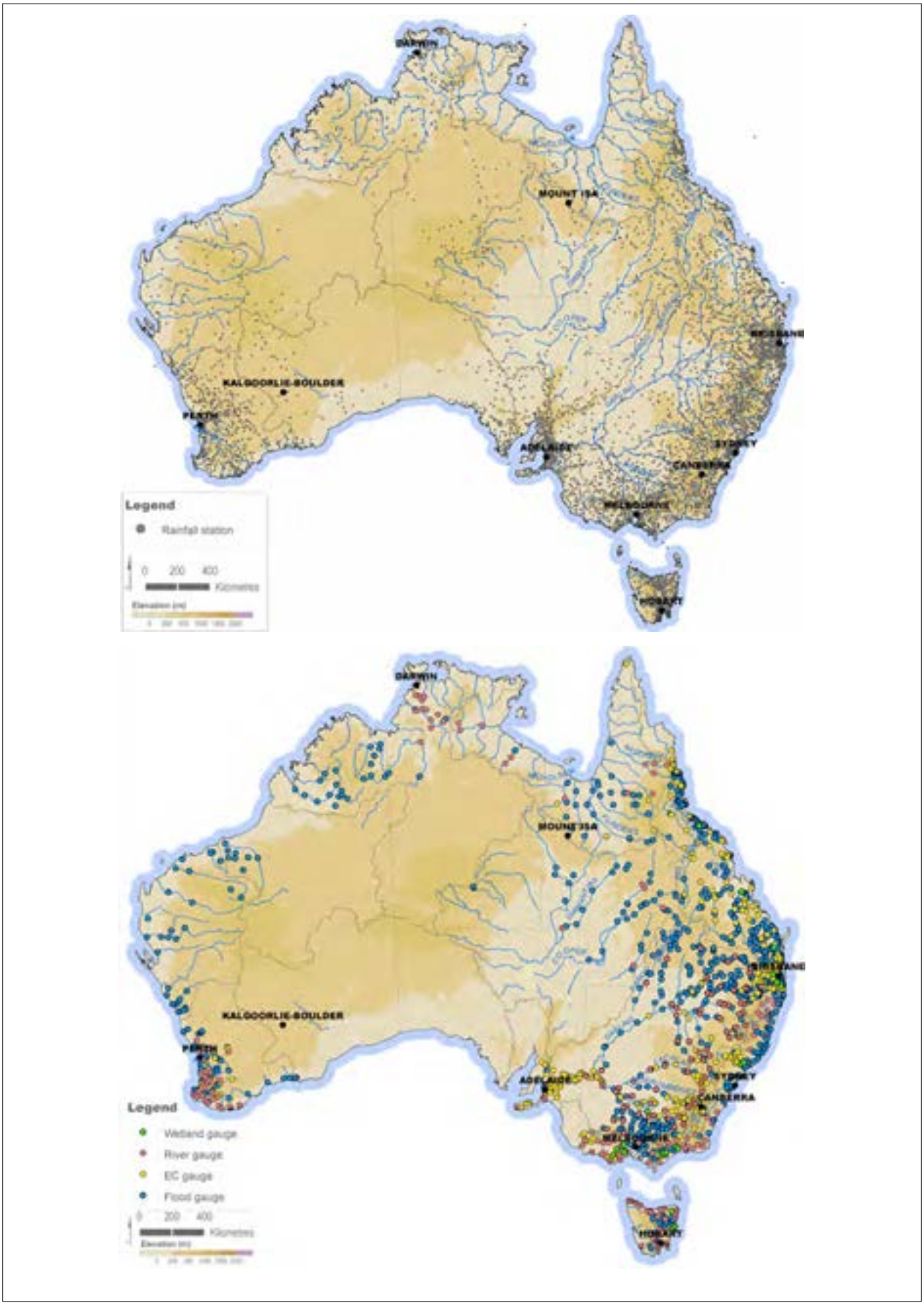


Figure 1.4 Location of (a) rainfall stations, and (b) river gauges selected for analysis in this report

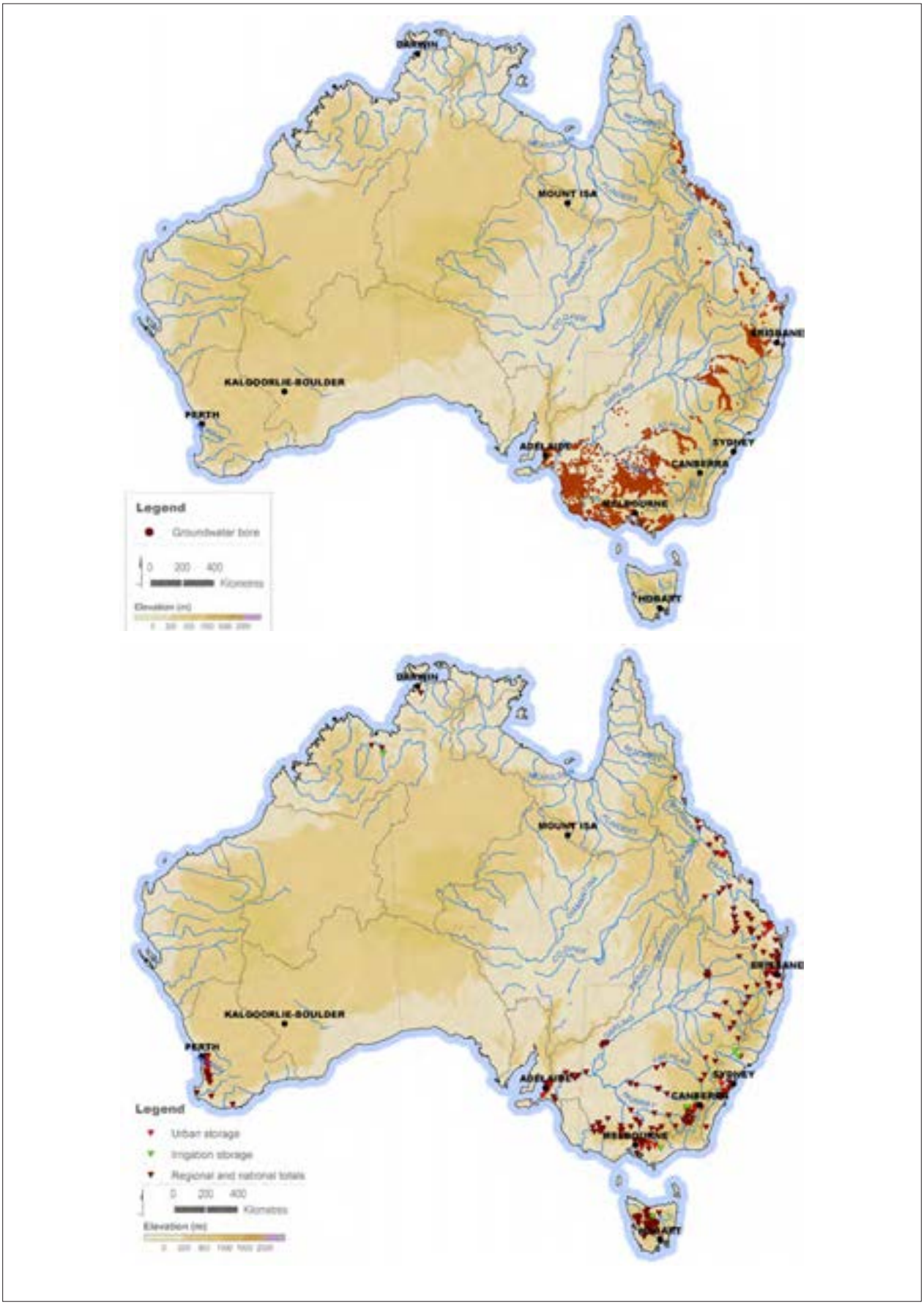


Figure 1.5 Location of (a) groundwater bores, and (b) surface water storages selected for analysis in this report

At river monitoring sites important for describing wetland inflows or outflows, decile ranges for each month were determined based on the monthly flows from 1980 onwards. Results for daily distribution of streamflow decile rankings over time are also presented.

Water quality, particularly river water salinity levels for 2011–12, were plotted for selected river salinity monitoring sites in selected regions where sufficient suitable data were available for this report.

Groundwater level and electrical conductivity readings over the past 20 years were plotted for monitoring bores in selected groundwater management units in regions where suitable data were available for this report.

Urban and irrigation water supply and use level and trends for the major cities and irrigation district within the region were presented where suitable data were available for this report.

1.5 Quality control and review: Who was involved?

Specialist reviewers comprising water domain and regional experts were invited to review the report before publication. These specialists, both from within and external to the Bureau, have expertise in a variety of fields, including hydrology, climatology and water resources modelling.

These reviewers were requested to examine the report with the aim of improving its quality and credibility by evaluating:

- the suitability of data used;
- the validity and robustness of the methods used;
- the appropriateness and presentation of figures and tables;
- the extent to which information is accurate, clear, complete and unbiased;
- whether information is presented within a proper context;
- the clarity of conclusions and findings;
- the extent to which conclusions are unambiguous and supported by results;
- whether any important issues or data were omitted; and
- the overall quality, style and presentation of the material.

Overall, comments and suggestions were received from over 40 reviewers. Stakeholder comments and suggestions that were not able to be implemented in this report will be considered in the evaluation process for future water information products and water resources assessments.

1.6 Terminology

In addition to definitions in the Bureau's *Australian Water Information Dictionary* (see www.bom.gov.au/water/awid/index.shtml), additional frequently and consistently used terminology in this report is defined as follows:

Very much above average	Values are among the highest 10% of the time-series in question (10th decile range).
Above average	Values lie above the highest 30% (70th percentile) but below the highest 10% (90th percentile) of the time-series in question (8th and 9th decile ranges).
Average	Values lie between the 30th percentile and the 70th percentile of the time-series in question (4th to 7th decile ranges).
Below average	Values lie above the lowest 10% (10th percentile) but below the lowest 30% (30th percentile) of the time-series in question (2nd and 3rd decile ranges).
Very much below average	Values are among the lowest 10% of the time-series in question (1st decile range).

1.7 Future reports

The Bureau's water resources assessments will develop over time as the availability and quality of data and modelling systems improve and as analytical and reporting methods are automated. Future reports will benefit from greater access to a range of water information progressively being stored and delivered through the Australian Water Resources Information System: www.bom.gov.au/water/about/wip/awris.shtml

Monitoring sites will be added as the coverage of the report is expanded and as additional information becomes available. In particular, it is anticipated that analysis and reporting of groundwater and water quality will be increasingly evident in future reports as data availability improves.

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2 National Overview

2.1 Introduction

This chapter of the *Australian Water Resources Assessment 2012* (the 2012 Assessment) presents an assessment of climatic conditions and water flows, stores and use in the Australian landscape during 2011–12. It provides an overview at the national scale and discusses the variations in water availability and use between the reporting regions (see Figure 2.1).

The assessment presents an overview of rainfall and landscape water balance terms for the year including evapotranspiration, landscape water yield, and change in soil moisture. It also considers changes in surface water storage, use, and supply in the regions.

The important drivers of climatic conditions in Australia are also examined and their impact on rainfall over the year is evaluated. Information on notable rainfall and flood events experienced during 2011–12 is presented.

Long-term average annual rainfall across Australia varies from less than 300 mm per year in central Australia to over 4,000 mm per year in parts of far northern Queensland. Of this rainfall, about 85–95% evaporates directly from the land surface or from the upper soil layer or is transpired by plants into the atmosphere. These two processes are collectively referred to as evapotranspiration. The remaining water (5–10%) finds its way into streams and other surface water features like storages and wetlands, or drains below the soil root zone into groundwater aquifers that may subsequently discharge to surface water features.

The proportion of rainfall used by vegetation depends on soil type and depth, vegetation type and condition and the stage of the growth cycle of the vegetation. Annual crops and pasture use less water than perennial vegetation, such as trees, primarily due to their shallower root systems and the reduced interception of water by leaves and branches.

The processes mentioned above are represented conceptually in the landscape water balance model used in this report (see Introduction for a description of the AWRA-L model) to provide estimates of the dominant water balance components.

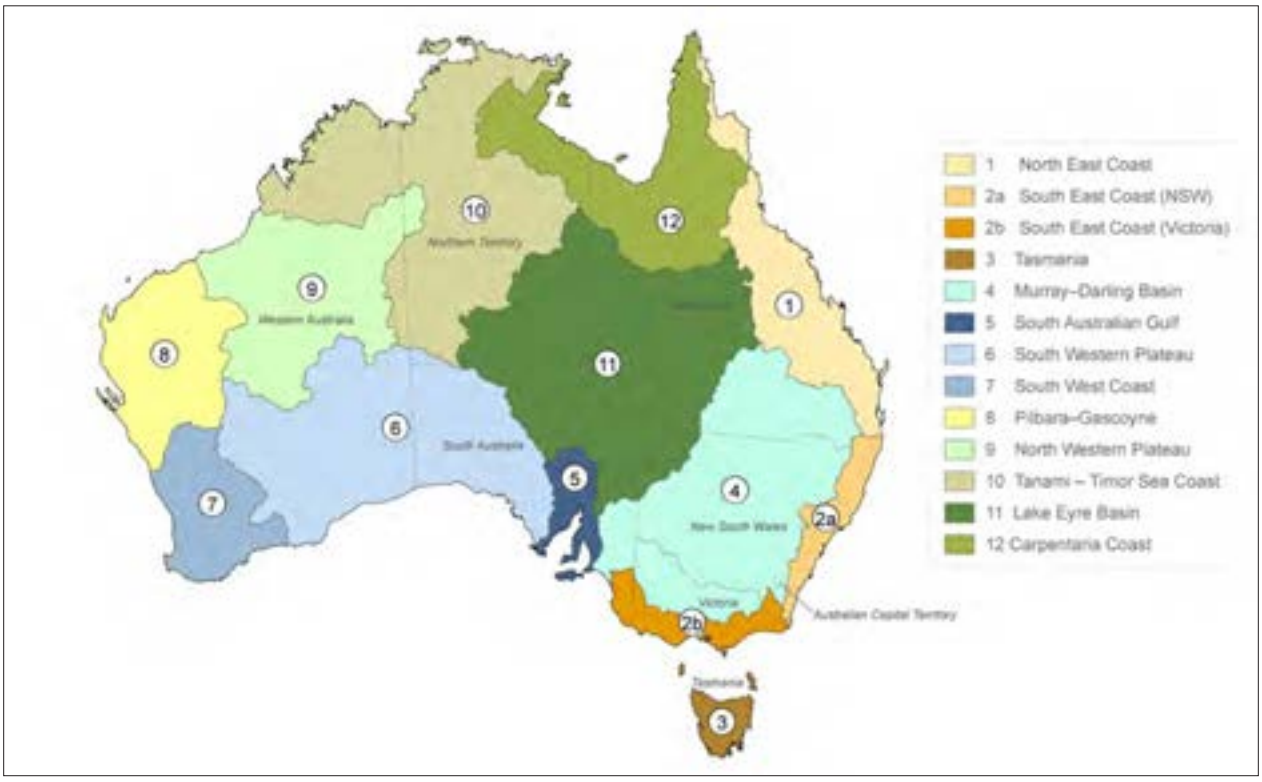


Figure 2.1 2012 Assessment reporting regions

2.2 National key findings

Climate drivers

The Australian climatic condition during 2011–12 was characterised by a moderately strong La Niña event.

The year started with neutral conditions in the Pacific. This followed the very strong La Niña event of 2010–11, which decayed to neutral conditions by the beginning of the 2011–12. During July–September 2011, average to below average rainfall was recorded over much of the country.

A La Niña developed again in spring 2011 with markedly above average rainfall across most of the country. The La Niña event was declared over in late March 2012 and, after Australia's third wettest March on record, below average rainfall was seen over large areas of the country for the remainder of the 2011–12 period.

For more information on the drivers of Australian climatic conditions in 2011–12, see section 2.9.

Landscape water flows

The year 2011–12 began with wet soil moisture conditions throughout most of the country, except for southwest Australia. Total annual rainfall for 2011–12 was 33% above the long-term average for 1911–2012, most of which fell between November 2011 and March 2012. This increased the soil moisture substantially, particularly across the southeast of the country. With elevated water availability in most regions, evapotranspiration was 30% above the long-term average and landscape water yield was 57% above the long-term average.

The Pilbara–Gascoyne and South West Coast regions had low soil moisture conditions at the start of the year. The above average rainfall for these regions during 2011–12 substantially elevated the soil moisture conditions for Pilbara–Gascoyne region; however, in the South West Coast region soil moisture conditions increased only marginally. In this region, soils were dry and remained well below long-term average levels as evapotranspiration processes reduced much of the absorbed rainwater. As a result, landscape water yield remained below average in this region.

Surface water

The relatively high landscape water yield of 2011–12 contributed to above average streamflow in large parts of the country. Many surface water storages received substantial inflows, causing the total water in major storages to increase from 75% at the end of 2010–11 to 83% at the end of June 2012. Increases were particularly significant in the Murray–Darling Basin and Tasmania, as well as in the storages supplying drinking water to Sydney in the South East Coast (NSW) region.

Despite the below average landscape water yield in the South West Coast, the total accessible volume of water held in surface water storages increased as a result of greater inputs of desalinated water and above average coastal rainfall in the first half of 2011–12 in this region.

Groundwater

Rising trends in groundwater levels were present in most of the selected aquifers within the North East Coast, South East Coast (Victoria) and Murray–Darling Basin regions. This reflects the high rates of recharge to groundwater due to the average to above average rainfall, streamflow and soil moisture in 2010–11 and 2011–12.

Trends in groundwater levels in the South Australian Gulf region were more variable, reflecting the local groundwater extraction and rainfall.

Urban and agricultural water use

Urban water consumption in 2011–12 remained consistent with that of the previous year for all State and Territory capitals considered in this assessment. Total urban water use in 2011–12 was 1,530 GL, a rise of just 1% from 1,513 GL in 2010–11.

Irrigation water use increased since 2010–11, but did not reached the 2005–06 levels.

Major rainfall and flooding

Widespread flooding occurred as the wet La Niña-influenced summer period (November 2011–April 2012) brought high rainfall particularly to the South East Coast (NSW) and Murray–Darling Basin regions. Major rainfall events in November 2011, January and March 2012 caused widespread flooding in parts of the South East Coast (NSW), Murray–Darling Basin, North East Coast and Lake Eyre Basin regions.

A localised rainfall event in June 2012 caused extensive flooding in eastern parts of the South East Coast (Victoria) region.

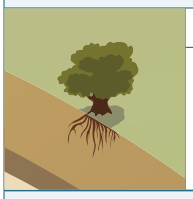
Table 2.1 gives an overview of the key components of the information in this chapter.

Table 2.1 Key information on national water flows, stores and use indicators for 2011–12

Landscape water flows

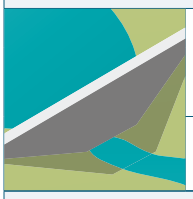
	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	567 mm	+33%	10th—very much above average
Evapo-transpiration	483 mm	+30%	10th—very much above average
Landscape water yield	83 mm	+57%	10th—very much above average

Mean annual soil moisture (decile ranking with respect to the 1911–2012 record averaged over Australia)



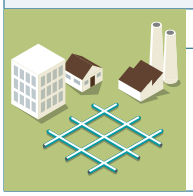
2011–12	2010–11
10th—very much above average	10th—very much above average

Surface water storage (comprising about 94% of the region's total capacity of all major storages)



Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
79,700 GL	66,300 GL	83%	60,100 GL	75%	+6,200 GL	+8%

Urban water use (for all State and Territory capitals, excluding Hobart due to data unavailability)



Total use in 2011–12	Total use in 2010–11	Change
1,530 GL	1,513 GL	17 GL (+1%)

2.3 Landscape water flows

Table 2.2 gives an overview of the regions' average annual totals of the three water balance components (rainfall, evapotranspiration and landscape water yield) for 2011–12 and their percentile rankings with respect to the 1911–2012 record. The values on the left side of the table show how the regions relate to each other in absolute terms for the year 2011–12. Values to the right show how 2011–12 compares to the reference period 1911–2012.

For most regions the annual rainfall was approximately equal to the annual evapotranspiration and landscape water yield combined; however, in two regions (the South Western Plateau and Pilbara–Gascoyne) the total evapotranspiration exceeded the rainfall. In these two regions, soil moisture levels at the beginning of the year were above average due to high rainfall during the preceding months.

The regional totals for 2011–12 are all ranked above median, except for the landscape water yield in the South West Coast region. With relatively low soil moisture levels at the start of the year in this region, the above average rainfall in the first half of the year was largely absorbed by the soil. For the rest of 2011–12, landscape water yield in this region was generally low.

The Murray–Darling Basin region had the highest ranked rainfall and landscape water yield of all regions in 2011–12. This was the third highest estimate of landscape water yield on record for this region and contributed to a substantial increase in total water volume in the storages across the region (see section 2.5).

Rainfall in Tasmania was the highest of all regions though this was close to average for the region, itself. Annual rainfall in Tasmania is normally higher than for the other regions.

Similarly, the landscape water flows in the South Western Plateau region were lower than those for the other regions. The flows were, however, relatively high in 2011–12 with respect to the long-term record.

Table 2.2 Average rainfall, evapotranspiration and landscape water yield as well as its percentile ranking in 2011–12 by region, with highest (blue) and lowest (red) values shown

Region	Region average in 2011–12 (mm)			Percentile ranking with respect to the 1911–2012 record		
	Rainfall	Evapo-transpiration	Landscape water yield	Rainfall	Evapo-transpiration	Landscape water yield
North East Coast	1,041	814	223	84	87	83
South East Coast (NSW)	1,265	**919**	352	87	89	92
South East Coast (Victoria)	842	648	180	88	**64**	**97**
Tasmania	**1,396**	769	**632**	**62**	72	54
Murray–Darling Basin	651	559	65	**95**	93	**97**
South Australian Gulf	331	306	9	74	70	53
South Western Plateau	**256**	**268**	**6**	89	94	92
South West Coast	499	455	28	77	86	**32**
Pilbara–Gascoyne	338	341	19	82	89	91
North Western Plateau	319	291	26	91	92	90
Tanami – Timor Sea Coast	754	646	142	90	94	87
Lake Eyre Basin	337	327	25	88	93	93
Carpentaria Coast	992	775	237	89	**95**	87

2.3.1 Rainfall

Average Australian rainfall for 2011–12 is estimated to be 567 mm, which is 33% above the estimated national long-term average of 426 mm (calculated from July 1911–June 2012). Large areas of the country received very much above average rainfall although these areas are not the areas with the highest rainfall totals (Figure 2.2).

Close to 50% of the Murray–Darling Basin region received very much above average rainfall in 2011–12.

In contrast, the Wimmera and Mallee areas in the southwest of this region received relatively low rainfall.

Towards the south of the continent, the Limestone Coast areas in South Australia, the South East Coast (Victoria), particularly the Barwon coastal area in southwestern Victoria, also received below average rainfall. Most of Tasmania, the Nullabor Plain in the southwest and the west coast of Western Australia experienced average rainfall.

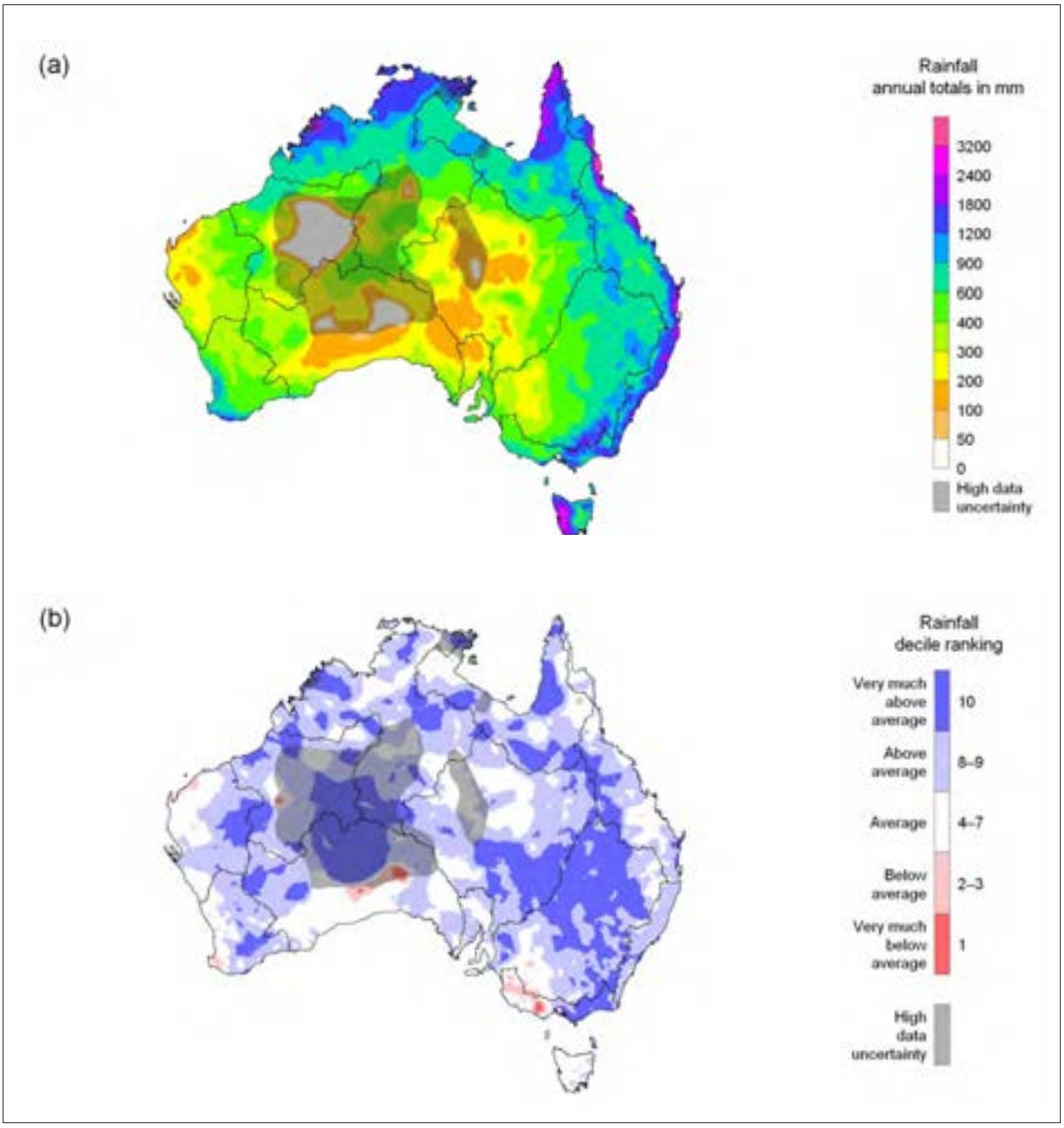


Figure 2.2 (a) Annual total rainfall in 2011–12, and (b) its decile range with respect to the 1911–2012 record

Figure 2.3 shows the monthly rainfall totals for 2011–12 and Figure 2.4 shows the monthly rainfall decile ranking of 2011–12 with respect to the 1911–2012 record. The first three months of the 2011–12 year showed a varying pattern of both above average and below average rainfall. From October 2011 onwards very much above average rainfall prevailed over large parts of the country as a La Niña event was established in the Pacific Ocean (see Section 2.9 for a description of the major drivers of Australian climate). This period of widespread above average rainfall continued until March 2012 when a relatively dry period ensued, predominantly across the southern half of Australia. In June 2012 most of the country returned to average rainfall conditions with the exception of some areas in the northeast and southwest which received above average rainfall.

The South West Coast, South Australian Gulf, South East Coast (Victoria) and Tasmania regions mostly received average rainfall during July–September 2011. Following this period, the South West Coast region had above average rainfall, with the fifth highest monthly rainfall total on record for October. Above average sea surface temperatures were evident in the Indian Ocean during spring 2011, which generated many thunderstorms over the whole of Western Australia. From November 2011–April 2012 the southern regions, except Tasmania, all experienced above average rainfall. From October–December 2011 the South West Coast region had the highest rainfall on record. During May–June 2012 average rainfalls occurred in these regions, with only the South East Coast (Victoria) experiencing above average rainfall, including the sixth wettest June on record.

The regions with summer dominant rainfall (that is, Tanami – Timor Sea Coast, Carpentaria Coast, North East Coast and South East Coast [NSW]) also received above average rainfall over the November 2011–April 2012 period. March 2012 recorded the third highest March rainfall on record for the Carpentaria Coast region, fourth highest for the North East Coast region, and seventh highest for the Tanami – Timor Sea Coast region.

The arid regions (that is, the Pilbara–Gascoyne, North Western Plateau, South Western Plateau, and Lake Eyre Basin) and extensive parts of the Murray–Darling Basin region experienced above average to very much above average rainfall in the summer period (November 2011–April 2012). The Murray–Darling Basin region had its third highest rainfall total on record for the period November 2011–April 2012. All these regions had one or more of these months ranking in the top five monthly rainfall events. For the Murray–Darling Basin region, the months of November and December 2011, and January, February and March 2012, were all in the top ten monthly rainfalls. Rainfall during July–October 2011 was average for the eastern regions and above average for the western regions. During May–June 2012, rainfall was also average for the eastern regions, but generally below average for the more western regions. For example, rainfall in May 2012 was the sixth lowest May rainfall on record for the Pilbara–Gascoyne region.

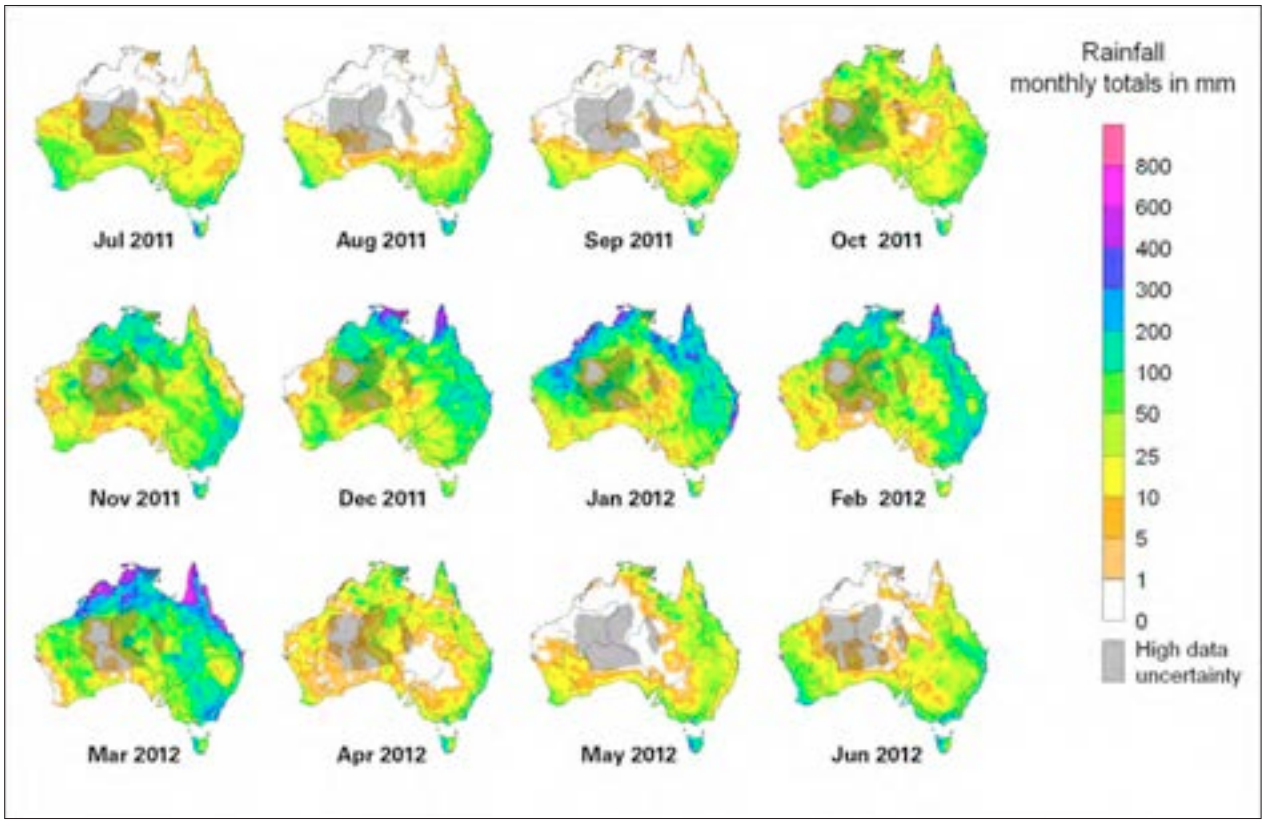


Figure 2.3 Monthly rainfall totals for 2011–12

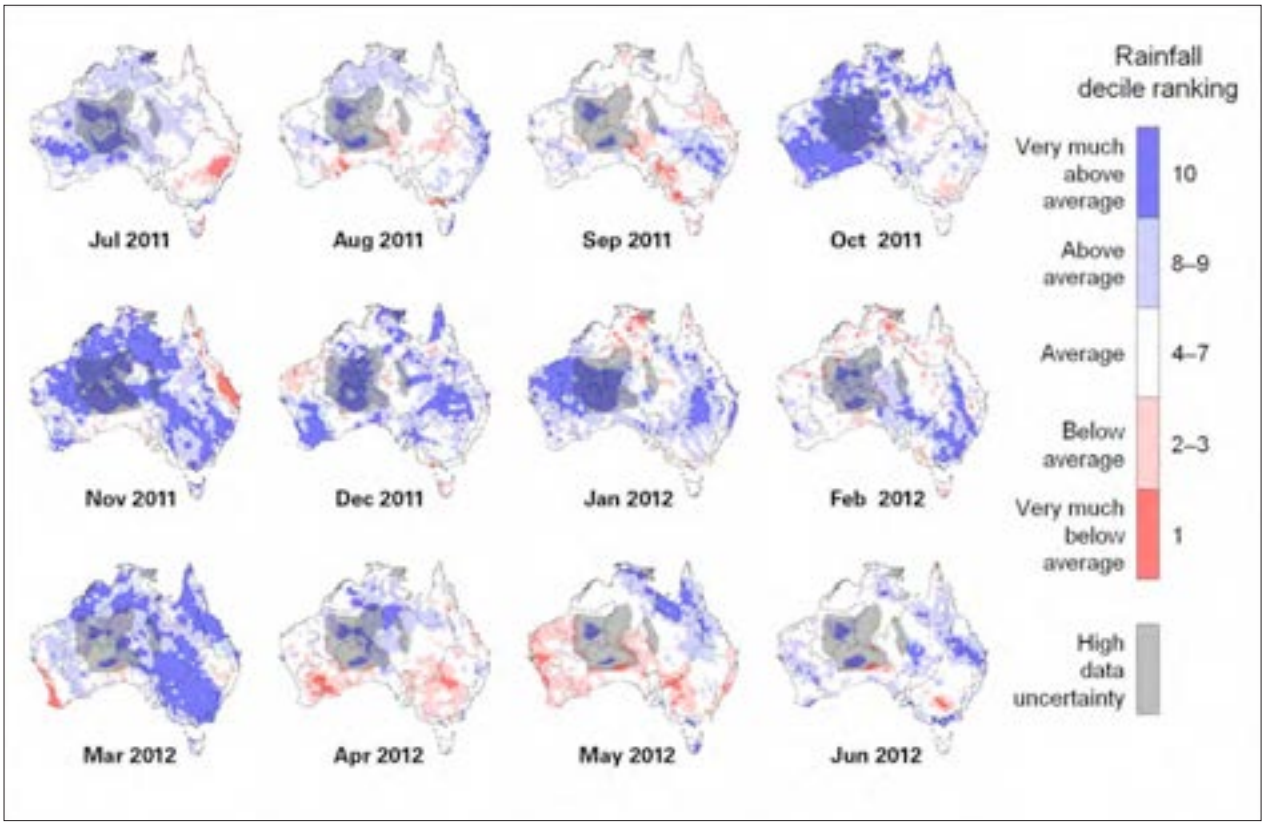


Figure 2.4 Monthly rainfall deciles for 2011–12 with respect to the 1911–2012 record

2.3.2 Evapotranspiration

Average Australian evapotranspiration for 2011–12 is estimated to be 486 mm, which is 32% above the estimated national long-term average of 368 mm (calculated from July 1911–June 2012). Large areas of the country experienced very much above average evapotranspiration, particularly in the inland areas of the continent where water availability is normally limited and evapotranspiration is generally lower than in the coastal areas (Figure 2.5).

Exceptions to this pattern were in several areas along the west and south coast and along the north east coast. As with rainfall (section 2.3.1), low evapotranspiration occurred in the western part of the South East Coast (Victoria) region and in the southwestern tip of the South West Coast region. Evapotranspiration was close to average in Tasmania.

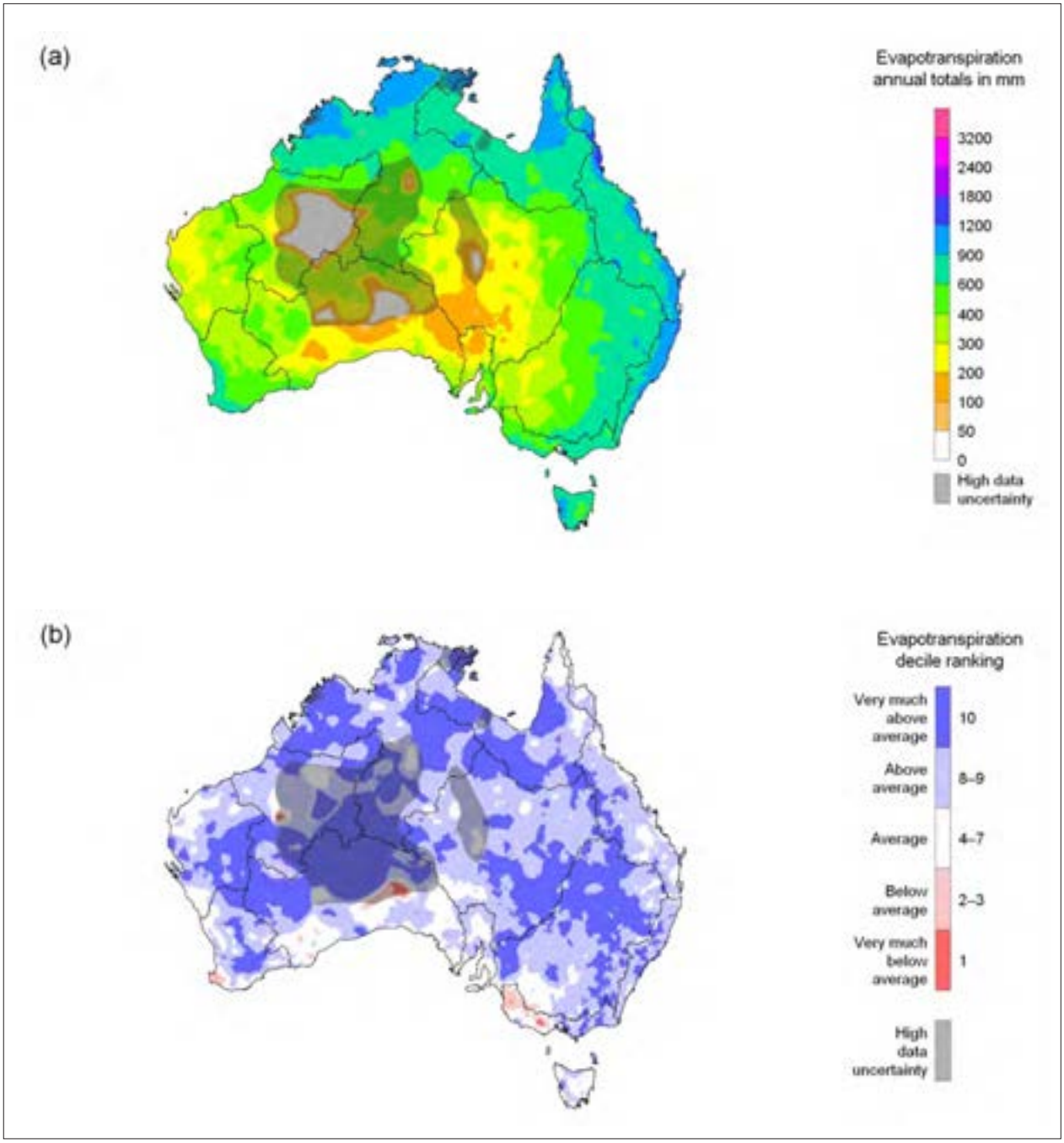


Figure 2.5 (a) Modelled annual total evapotranspiration in 2011–12, and (b) and its decile range with respect to the 1911–2012 record

Figure 2.6 shows modelled monthly evapotranspiration for 2011–12 which is highest during the months of November 2011 through to March 2012. This is strongly related to the temperature and the above average rainfall during this period as identified in subsection 2.3.1. For some months, even the arid areas in the centre of the country experienced evapotranspiration rates of more than 25 mm per month (effectively reaching 1 mm per day).

Figure 2.7 shows the modelled monthly evapotranspiration decile ranking of 2011–12 with respect to the 1911–2012 record. Throughout 2011–12, evapotranspiration was very much above average in different parts of the country for several months. November, December 2011 and March 2012 stand out as months with extensive areas experiencing very much above average evapotranspiration. The North Western Plateau, South Western Plateau and Tanami – Timor Sea Coast regions experienced their highest November evapotranspiration on record. In addition, the South West Coast and Pilbara–Gascoyne regions experienced their second highest November evapotranspiration on record. The South West Coast region also experienced their highest evapotranspiration on record for December while the Murray–Darling Basin region experienced their third highest evapotranspiration on record for December.

Evapotranspiration was also particularly high for the Murray–Darling Basin, South Australian Gulf and Lake Eyre Basin regions during March 2012.

Despite the general pattern of above average evapotranspiration throughout 2011–12, some regions had prolonged periods of below average evapotranspiration. Most affected was the South West Coast region, where evapotranspiration was consistently below average for the last four months of 2011–12. This is in contrast to the first half of the year, which had the highest evapotranspiration on record for this region. In May 2012, many of the southern and western regions recorded below average evapotranspiration. This is directly associated with the shortage of rainfall for this month and the previous month (see Figure 2.4).

An interesting feature of the northern regions is that evapotranspiration is normally highest during the months of January and February. The average to below average evapotranspiration in these regions during January and February 2012 reflects the rainfall pattern (see Figure 2.4).

In the northern regions, the evapotranspiration is normally highest during the months of January and February. Interestingly, in January and February 2012 the evapotranspiration was average to below average, similar to the rainfall pattern (see Figure 2.4).

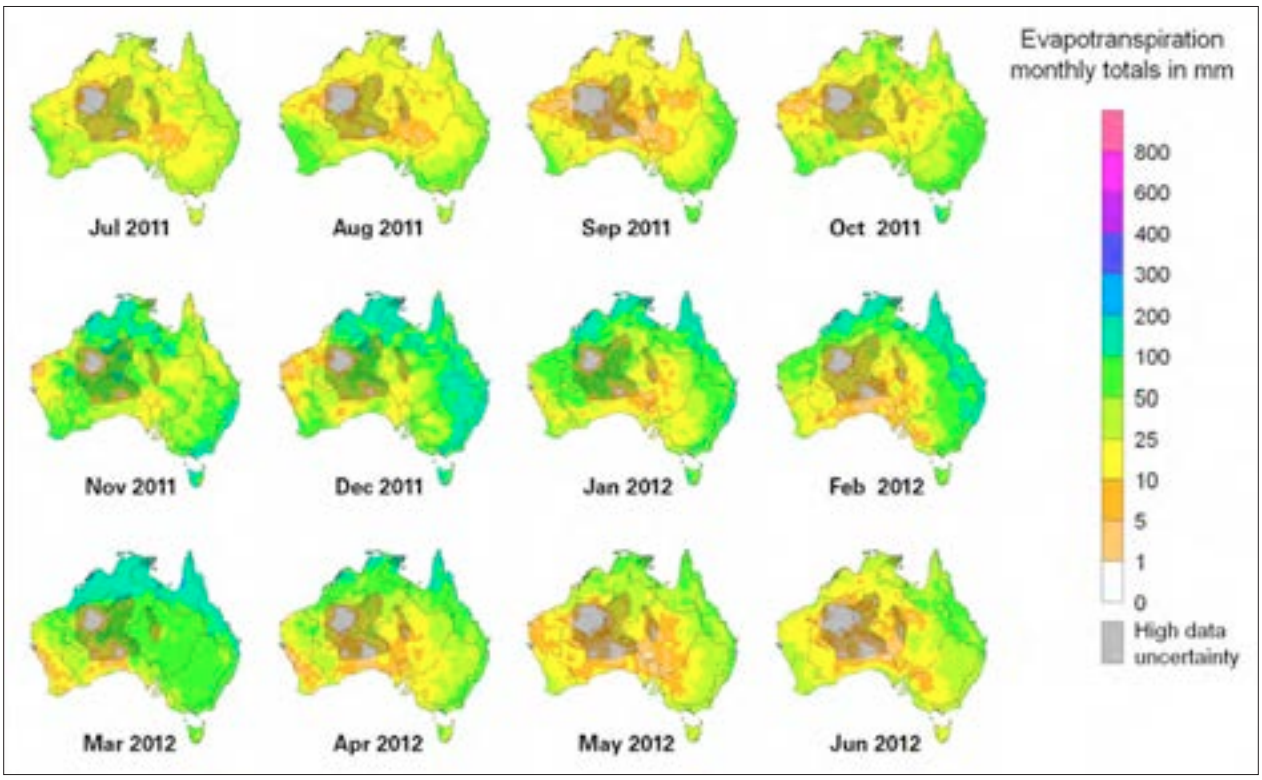


Figure 2.6 Modelled monthly evapotranspiration totals for 2011–12

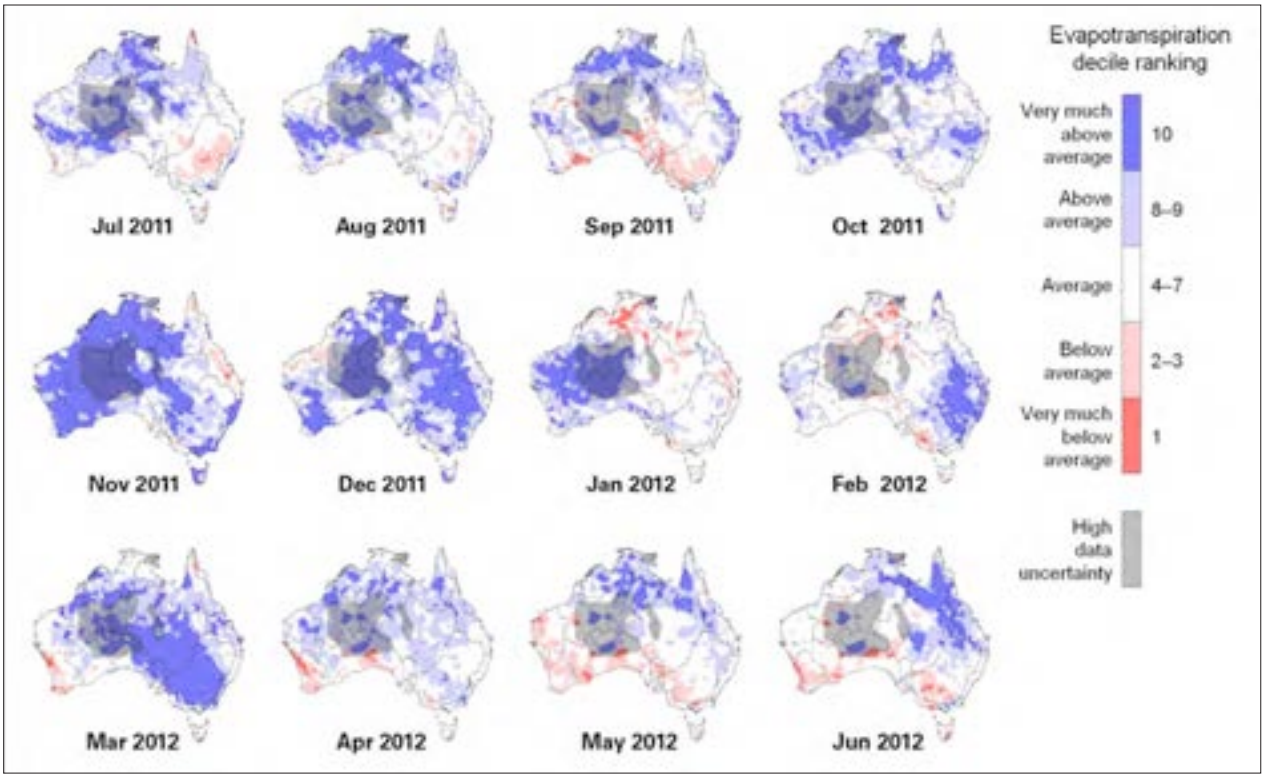


Figure 2.7 Modelled monthly evapotranspiration deciles for 2011–12 with respect to the 1911–2012 record

2.3.3 Landscape water yield

Average Australian landscape water yield for 2011–12 is estimated to be 87 mm, which is 56% above the estimated national long-term average of 56 mm (calculated from July 1911– June 2012). Large areas of the country had very much above average landscape water yield, although mostly this was in areas where total landscape water yield itself was low (Figure 2.8).

Landscape water yield was very much above average across most of the Murray–Darling Basin region. In contrast, landscape water yield was relatively low for the South West Coast region.

Decile rankings along the north coast of the country were average to above average with only some areas within the highest decile ranking. Landscape water yield was generally average throughout Tasmania.

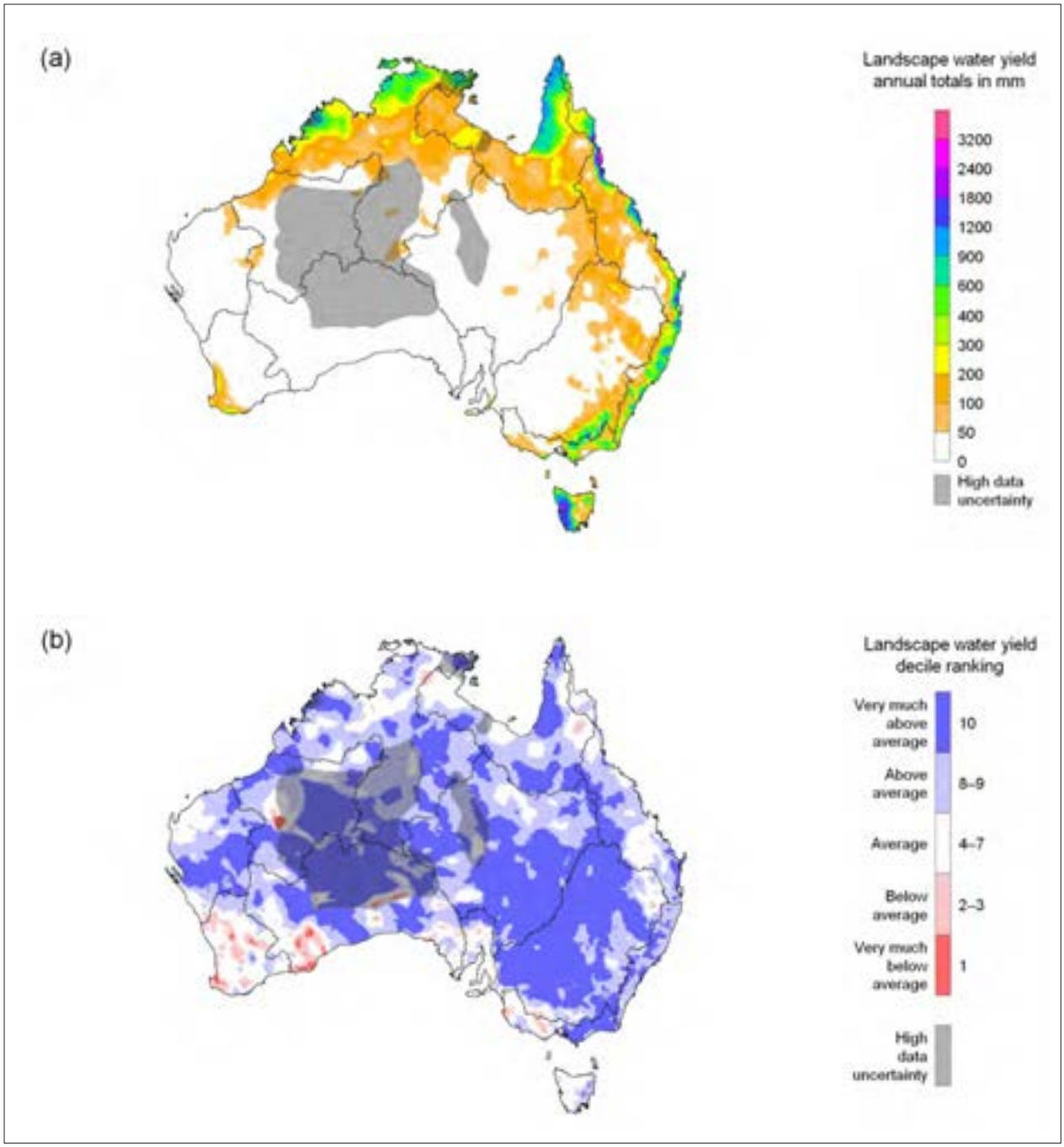


Figure 2.8 (a) Modelled annual total landscape water yield in 2011–12, and (b) its decile range with respect to the 1911–2012 record

Monthly modelled landscape water yield, shown in Figure 2.9, indicates that for large parts of the centre of the country total landscape water yield remained below 1 mm per month throughout most of 2011–12 including large portions of the South West Coast, Pilbara–Gascoyne, North Western Plateau, South Western Plateau, South Australian Gulf, Lake Eyre Basin regions and even some areas of the Murray–Darling Basin region. Notable landscape water yield occurs consistently throughout the year only in the South East Coast (Victoria), South East Coast (NSW), and Tasmania regions. Conversely, particularly low landscape water yield occurs during the dry season in the northern regions.

Figure 2.10 shows the modelled monthly landscape water yield decile rankings. During 2011–12, very much above average landscape water yields were experienced during each month in many regions. Very much above average landscape water yields were experienced in November 2011 and March 2012 for more than 50% of the country. Very much above average landscape water yield also occurred throughout most of the year in the arid regions in the centre and west of the country; however, as can be seen from Figure 2.9, the landscape water yield for these areas did not exceed 5 mm. The frequently above average landscape water yield during most months in these regions distinguishes the year from previous years.

In contrast, landscape water yields were below average in the southwest of the country. From July–September 2011 and from March–May 2012, the South West Coast region in particular had below average landscape water yield, with the latter period having the eighth lowest landscape water yields on record (1911–2012).

The southeast of the country was most affected by widespread rainfall. In March, landscape water yield was the highest on record for both the Murray–Darling Basin region as well as the South East Coast (Victoria) region. The month had also the third highest on record landscape water yield for the North East Coast region. November 2011– March 2012 as a whole had the second highest landscape on record water yield for the Murray–Darling Basin region, fourth highest on record for the South East Coast (NSW) region and sixth highest on record for the South East Coast (Victoria) region.

In January 2012, two tropical cyclones affected the Pilbara–Gascoyne region and provided it with almost half its average annual rainfall. As a result, landscape water yields were the highest on record for the month. The North Western Plateau region also experienced the fifth highest landscape water yield on record.

The only region without any top-ten months of highest landscape water yield for 2011–12 was Tasmania.

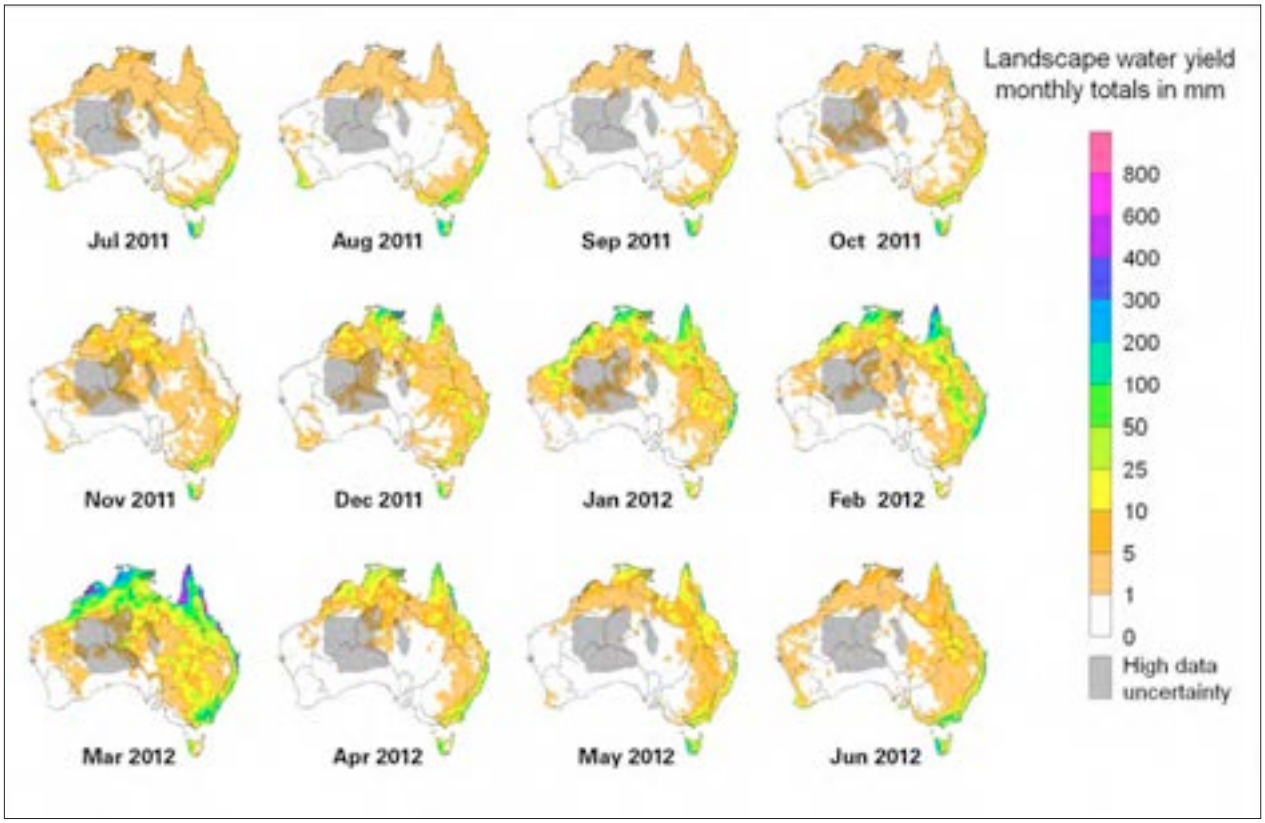


Figure 2.9 Modelled monthly landscape water yield totals for 2011–12

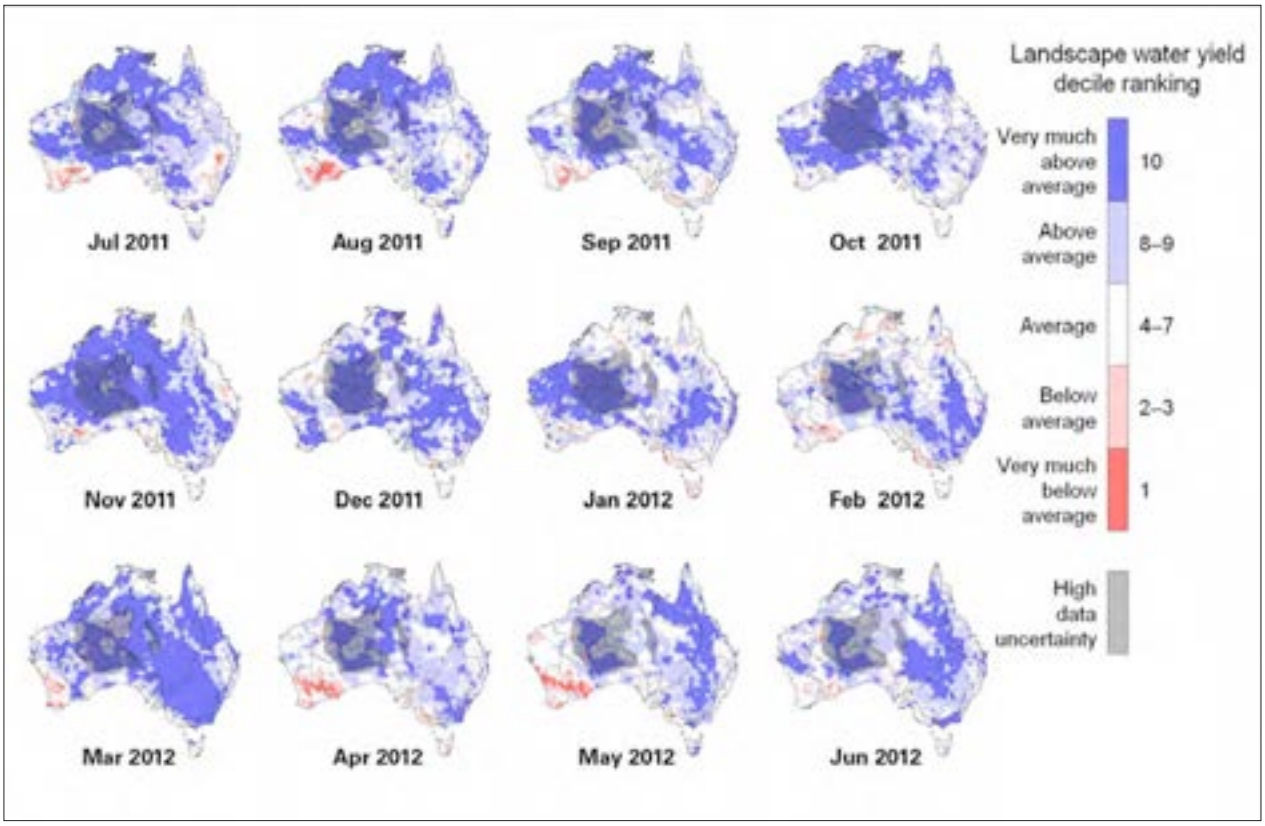


Figure 2.10 Modelled monthly landscape water yield deciles for 2011–12 with respect to the 1911–2012 record

2.4 Soil moisture

The AWRA-L landscape water balance model derives soil moisture volumes at daily time steps. The model conceptualisation of soil water storage and transfer processes is relatively simple. Since the modelled outputs are not verified against local soil moisture measurements, they are presented in relative terms only.

Figure 2.11 shows the decile ranking of the 2011–12 modelled annual average soil moisture with respect to the 1911–2012 period.

In 2011–12, soil moisture volumes were very much above average in most regions of the country, with the exception being the South West Coast region. Very low soil moisture volumes were experienced in this region at the start of the year. Even the relatively high rainfall during the year (Figure 2.2) could not lift the overall soil moisture to average levels.

The large areas of very much above average soil moisture volumes cover many important agricultural areas. For the regions in the highly cultivated southeast of the country, soil moisture was high.

The soil moisture deciles of Figure 2.11 correspond mostly to the landscape water yield deciles of Figure 2.8. This is because of the way the flow processes correlate with each other in the model. Both rainfall infiltration excess (that is, rainfall that is not infiltrating into the soil) and groundwater discharge are dependent on soil moisture levels. The model is designed so that with higher soil moisture levels both infiltration excess and deep percolation into the groundwater system becomes higher. Both processes generate higher landscape water yield.

As there is a temporal variability in soil moisture volumes, an additional monthly analysis is presented separately for each region (see the regional chapters).

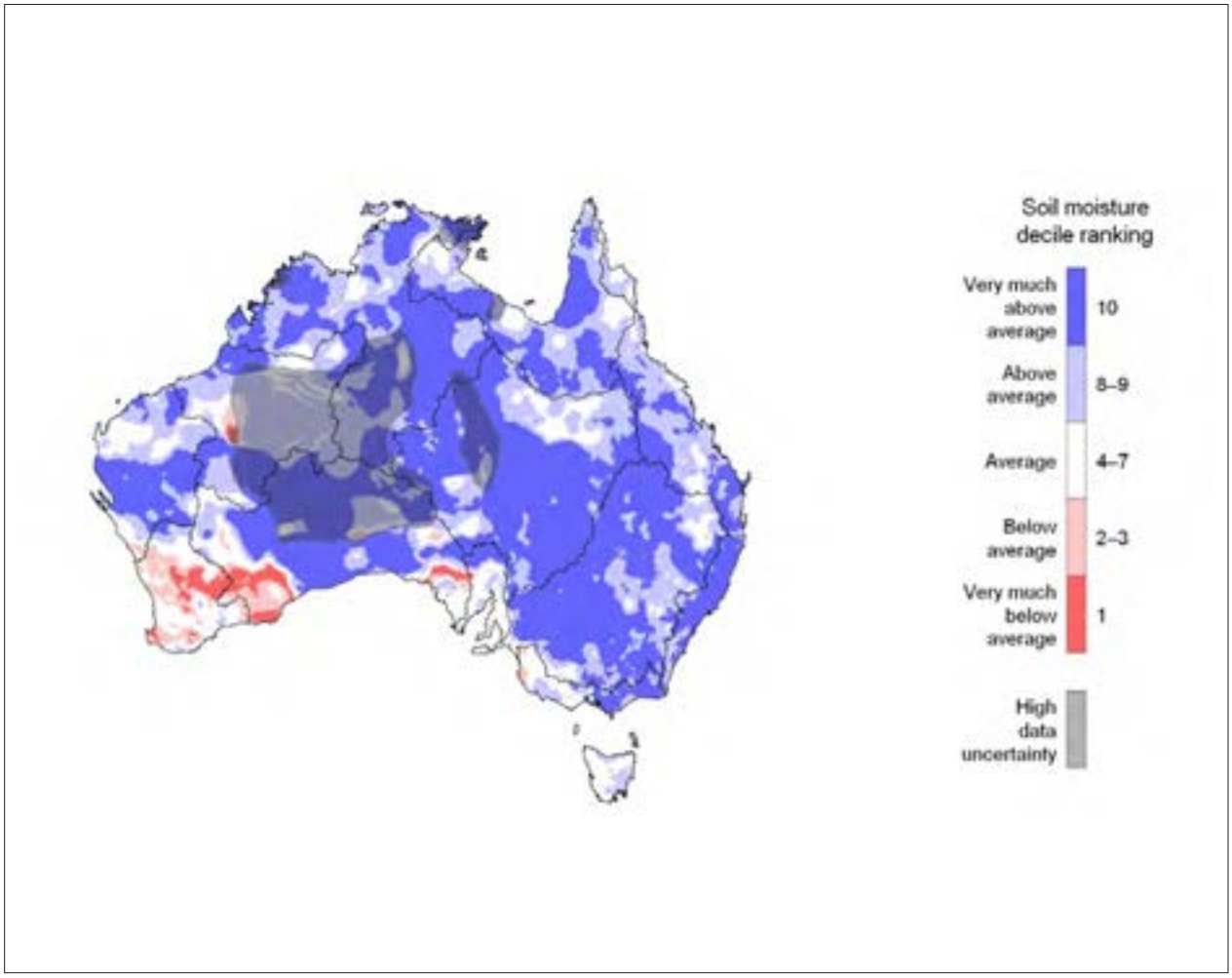


Figure 2.11 Decile rankings of modelled annual average soil moisture for 2011–12 with respect to the 1911–2012 record

2.5 Surface water storage

The total volume of water stored in major public water storages in Australia at the end of 2011–12 was at 83% of their total accessible capacity. This represents an 8% increase on the previous year (Table 2.3). The increase is largely due to storage volume increases in the Tasmania and Murray–Darling Basin regions.

Surface water storage in the South Australian Gulf, Carpentaria Coast, Pilbara–Gascoyne and Tanami – Timor Sea Coast regions decreased over this period. The changes in the Tanami – Timor Sea Coast region (mainly Lake Argyle) and the Carpentaria Coast region (Lake Julius) are negligible in comparison to their total storage volumes, especially as the storage volumes were close to full capacity.

After substantial increases in storage volumes in most regions during 2010–11, storage volumes continued to rise during 2011–12. Storage volumes in the eastern regions, which had not reached full capacity the previous year, increased substantially. The highest relative increase in storage volume occurred in the South East Coast (NSW) region, where the Warragamba storage reached full capacity and spilled on several occasions during the year. The Warragamba storage accounts for more than 50% of the total storage capacity in the region.

While landscape water yield for the year was average and locally below average in the South West Coast region, the volume of water in surface storage in this region increased from 22% of accessible volume to 32% of accessible volume. This was as a result of a number of significant coastal rainfall events (in July, August and September 2011) and the steady provision of other sources of water (such as groundwater and desalinated water).

Water restrictions in metropolitan areas also contributed to the observed increase in surface water storage in the South West Coast region.

Table 2.3 Change in surface water storage over 2011–12 by region

Region	Accessible volume in storage (GL)			% of total accessible capacity		
	30 June 2011	30 June 2012	Difference	30 June 2011	30 June 2012	Difference
North East Coast	9,135	9,301	+166	96	**98**	+2
South East Coast (NSW)	3,049	3,658	+609	79	95	**+16**
South East Coast (Victoria)	1,078	1,346	+268	57	71	+14
Tasmania	13,576	15,672	+2,096	61	71	+10
Murray–Darling Basin	22,006	25,230	+3,224	73	84	+11
South Australian Gulf	135	96	–39	69	49	–20
South Western Plateau[1]	—	—	—	—	—	—
South West Coast	210	309	+99	**22**	**32**	+10
Pilbara–Gascoyne	62	36	–26	98	57	**–41**
North Western Plateau[2]	—	—	—	—	—	—
Tanami – Timor Sea Coast	10,710	10,549	–161	**100**	**98**	–2
Lake Eyre Basin[3]	—	—	—	—	—	—
Carpentaria Coast	93	92	–1	94	93	–1
Total Australia	**60,054**	**66,289**	**+6,235**	**75**	**83**	**+8**

[1–2] No major public storages exist in the South Western Plateau, North Western Plateau, and Lake Eyre Basin regions.

2.6 Groundwater levels

A complete national overview of groundwater availability cannot be presented in this report due to the limited amount of quality-controlled data available in a suitable form at this time.

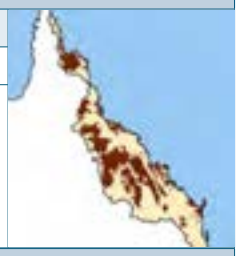
Nationally-significant groundwater systems in Western Australia, the Northern Territory and Tasmania have not been assessed. They are expected to be reported on in future assessments. No analysis has been attempted for aquifers of the Great Artesian Basin (GAB) in this report; however, the CSIRO has recently led a GAB Water Resource Assessment (Smerdon et al. 2012). Interested readers are referred to the reports of this study.

The status of groundwater levels was evaluated in a number of aquifers in four regions where data were available. The data is presented as linear trends for the period of 2007–08 to 2011–12. The trends in groundwater levels within large aquifers are categorised as decreasing, increasing, stable or variable for each 20 km x 20 km grid (for the Murray–Darling Basin and South East Coast [Victoria] regions), and for 5 km x 5 km grid (for intermediate to local flow systems within smaller aquifers in the North East Coast and South Australian Gulf regions).

The available results are summarised in Table 2.4. The maps on the right present the location and spatial distribution of the aquifers identified for trend analysis in the four regions. Colours used to represent aquifers in the maps correspond to colours in the first column of the table; note that some aquifers overlie others and are shown with hatching. More details on aquifer extent and location are given in the groundwater status section of the regional chapters.

Table 2.4 Groundwater level trends for the 2007–08 to 2011–12 period

North East Coast	
Region aquifers	**Trend**
Alluvial and Tertiary basalts	rising ↗



Murray–Darling Basin	
Region aquifers	**Trend**
Condamine alluvial	rising ↗
Condamine basalts	rising ↗
Narrabri and Gunnedah	stable or rising →↗
Cowra and Lachlan	rising ↗
Shepparton	no prevalent trend
Calivil	declining ↘
Murray Group	stable →
Renmark	no prevalent trend

South East Coast (Victoria)	
Region aquifers	**Trend**
Quarternary and upper Tertiary	rising ↗
Upper middle and lower middle Tertiary	stable or rising →↗
Lower Tertiary	no prevalent trend

South Australian Gulf	
Region aquifers	**Trend**
Adelaide Plains watertable	rising ↗
Tertiary aquifer (T1)	declining ↘
Tertiary aquifer (T2)	rising ↗
McLaren Vale watertable	stable →
Port Willunga	stable or declining →↘
Maslin Sands	no prevalent trend

2.7 Urban water use

Average water consumption per property for the nation along with a number of major cities is presented in Figure 2.12.

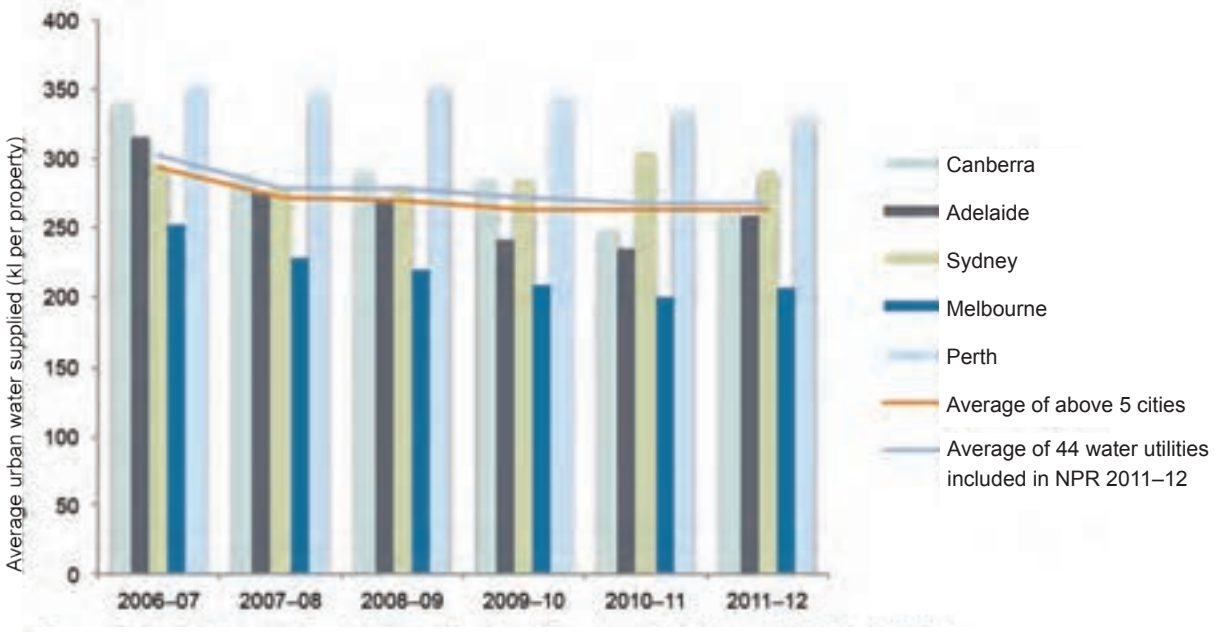
Water conservation and demand management have seen a reduction in the nation's urban water consumption over the past six years. Significantly above average rainfalls in many parts of Australia over the past two years has seen increased water storage levels and an easing of water restrictions across much of the country. The exception is southwest Western Australia, including Perth, which continued to experience low rainfall.

Capital city urban water consumption continued to fall with the exception of the southeast where above average rainfalls and increased water storage volumes has seen a shift in consumer behaviour and a rise in urban water consumption.

While continuing its downward trend, Perth remains the highest urban user of water on a per property basis.

Total urban water supplied to the capital cities increased by 1.4% from 2010–11 to 2011–12, with increases in the total amount supplied observed in Melbourne, Perth, Adelaide and Canberra.

In 2011–12 residential water use accounted nationally for 63% of the total volume supplied to urban areas. Commercial, municipal and industrial uses comprised 25% and the remaining 12% was attributed to uses categorised as 'other' (National Water Commission, 2013).



Source: National Performance Report 2011–12

Figure 2.12 Total urban water supplied per property from 2006–07 to 2011–12 (Brisbane, Darwin and Hobart have been excluded from the individual and capital city analysis due to data unavailability)

Figure 2.13 presents the volume of water sourced from major supply sources for each capital city. With the exception of Perth, surface water continues to be the major source of supply. With ongoing drought in southwest Western Australia, groundwater usage and desalination are increasing to meet the cities' needs.

On a per property basis, residential recycled water use continued on its flat trend in 2011–12. At 22 kL per connected property, it remains consistent with 2009–10 and 2010–11 figures of 22 and 21 kL per connected property.

2.8 Agricultural water use

Average agricultural water use in Australia between 2005–06 and 2010–11 was 8,232 GL (Australian Bureau of Statistics 2011a), 90% of which (7,400 GL) was used for irrigation of crops and pasture. Annual water use for irrigation over the 2010–11 period was 6,645 GL. The highest use of water for irrigation occurred in New South Wales (2,745 GL), which also showed the greatest reduction in irrigation water use between 2005–06 and 2007–08 at the peak of the drought. Victoria and Queensland showed notable decreases in total irrigation water use during the same period. The Northern Territory used the lowest irrigation volume (22 GL in 2010–11) of any Australian State or Territory (data of the State's irrigation water use for 2011–12 was not available at the time of preparing the report). Figure 2.14 compares water use for irrigation between the Murray–Darling Basin region and the rest of Australia. In 2005–06, irrigation water use in the Murray–Darling Basin was more than double that of the rest of the country, but by 2007–08 water use in this basin was approximately equal to the rest of Australia. Water allocation and use has increased gradually since. Although the proportion of water use in the basin compared to the rest of Australia during the last two years was the same as that in 2005–06, the total water use had not increased as such.

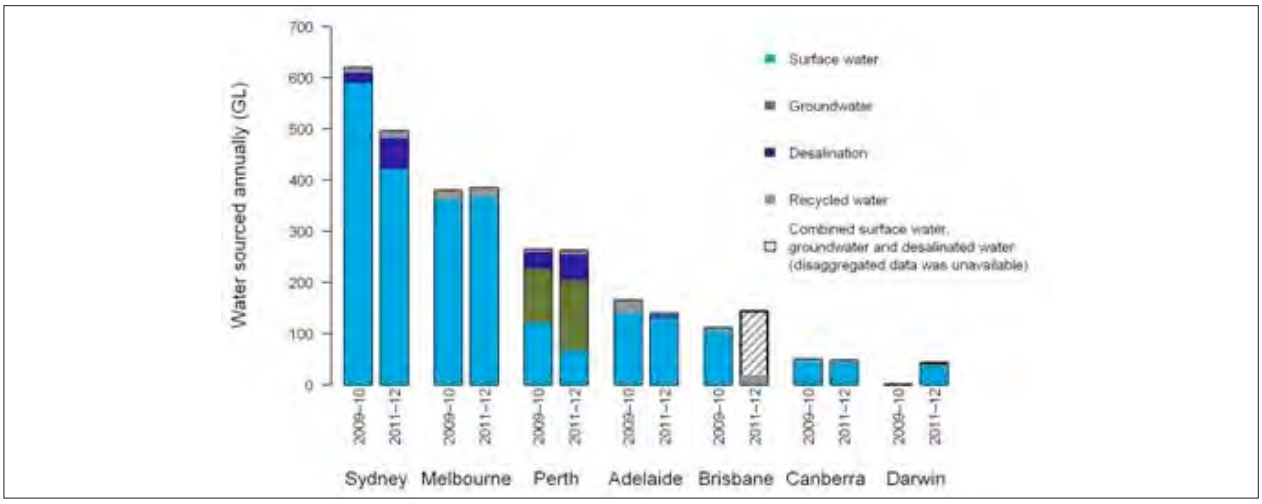


Figure 2.13 Sources of water supplied in capital cities, 2011–12 (National Water Commission 2011a, 2013)

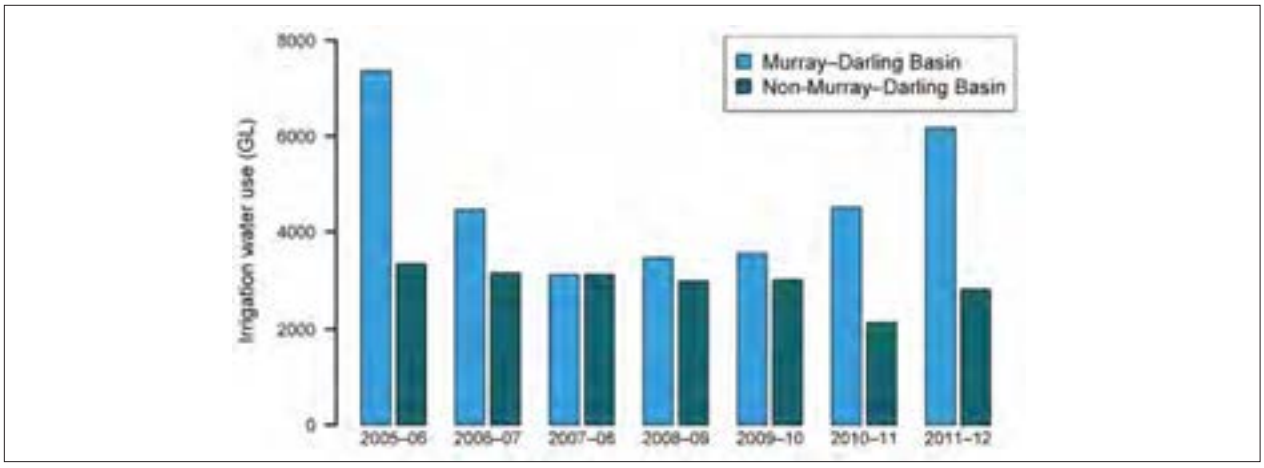


Figure 2.14 Irrigation water use between 2005–06 and 2011–2012

2.9 Drivers of climatic conditions

There are a number of broad-scale influences on the climate of Australia. The climate observed in Australia during 2011–12 can be largely explained by variations in two of the main drivers: conditions in the tropical Pacific Ocean and the eastern Indian Ocean. Tropical Pacific climate indicators include the Southern Oscillation Index (SOI), trade winds, cloudiness and sea temperatures. Of these two drivers, the La Niña conditions that established in the Tropical Pacific by October 2011 dominated Australian rainfall patterns. See Box 2.1 for more on the influence of Pacific Ocean temperatures on rainfall in Australia.

In the first half of 2011 a positive SOI and the corresponding strong La Niña conditions brought very much above average rainfall to most of Australia. These conditions receded in later months and much of the country recorded average to below average rainfall for the months July–September (Figure 2.15).

A La Niña developed again in spring 2011, causing above average rainfall across large parts of the country. To the northwest of Australia, the Indian Ocean Diopole (IOD) index was positive from August–November 2011, peaking at 0.9 °C in late August 2011 (Figure 2.16). This may have moderated the above average rainfall, especially in southeastern Australia; however, spring generally had above average rainfall over large parts of Australia, with large parts of Western Australia receiving very much above average rainfall. Averaged over Australia as a whole, spring 2011 was in Australia's top-ten wettest springs on record. See Box 2.2 for more on the influence of Indian Ocean temperatures on rainfall in Australia.

The positive SOI declined at the start of autumn to be in the neutral range by the end of autumn. During March 2012, much of northern and eastern Australia recorded average to very much above average rainfall (Australia's third wettest March on record). Conditions then turned drier as the La Niña waned. Averaged as a whole, autumn was still wetter than average across Australia, largely due to the very wet March.

More information on the drivers of climatic conditions in Australia can be found on the Bureau's website at: www.bom.gov.au/lam/climate/levelthree/analclim/analclim.html and at: www.bom.gov.au/water/newEvents/presentations/ncwbriefings/index.shtml

Storm over the approach to Canberra Airport | Nathan Campbell

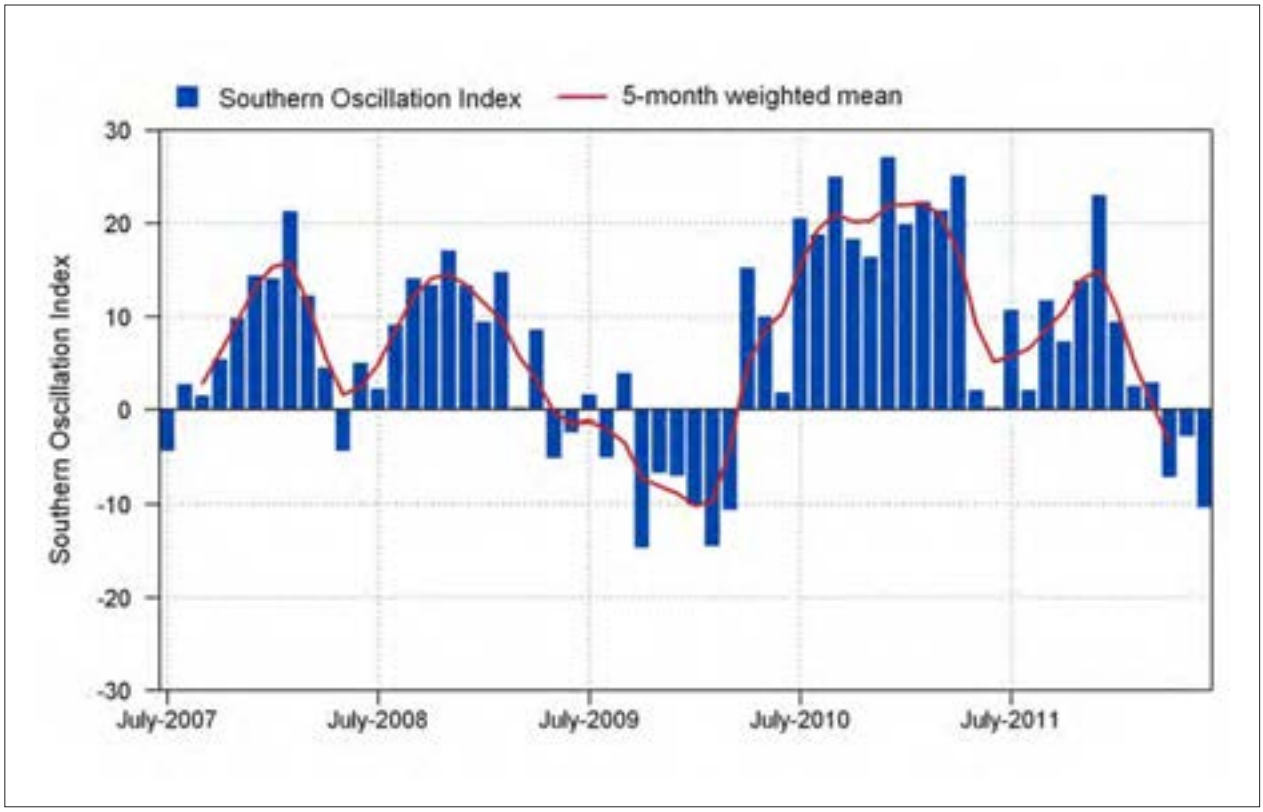


Figure 2.15 Southern Oscillation Index monthly time-series from July 2007–June 2012 (data available at: www.bom.gov.au/climate/enso/indices.shtml)

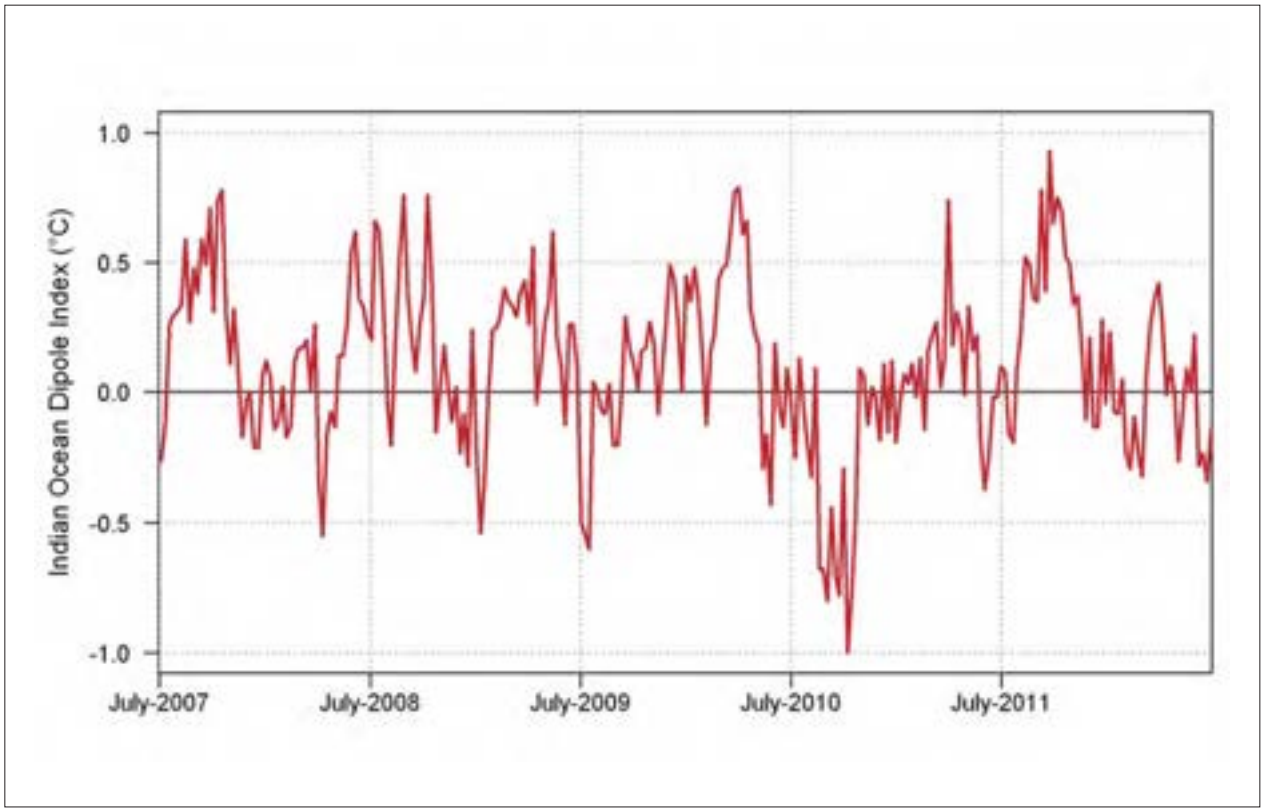


Figure 2.16 Indian Ocean Dipole index time-series from July 2007–June 2012 (data available at: www.bom.gov.au/climate/enso/indices.shtml)

Box 2.1 The Southern Oscillation and El Niño / La Niña

Much of the variability in Australia's climate is connected with the atmospheric phenomenon called the Southern Oscillation, a major see-saw of air pressure and rainfall patterns between the Australian/Indonesian region and the eastern tropical Pacific. The Southern Oscillation Index (SOI) is calculated from the monthly mean air pressure difference between Tahiti and Darwin and provides a simple measure of the strength and phase of the Southern Oscillation and Walker Circulation.

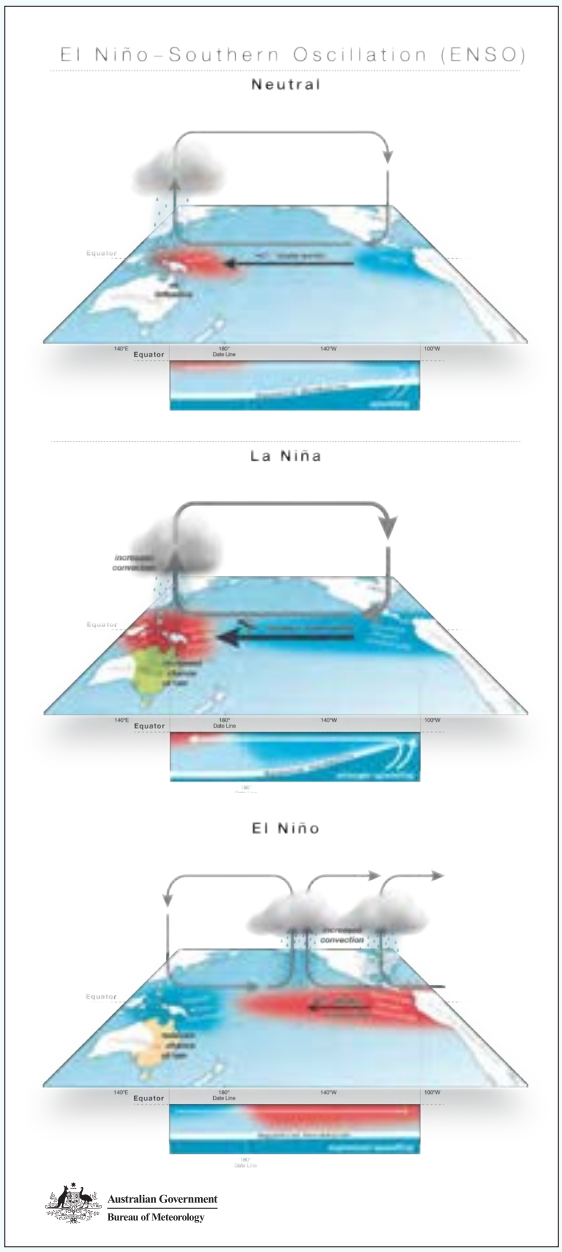
The typical Walker Circulation patterns shown in the first panel of the schematic has an SOI close to zero (that is, the Southern Oscillation is close to the long-term average, or neutral, state). Positive values of the SOI are associated with stronger than average Pacific trade winds blowing from east to west and warmer sea temperatures to the north of Australia. Together these give a high probability that eastern and northern Australia will be wetter than normal.

During El Niño episodes, the Walker Circulation weakens, seas around Australia cool, and slackened trade winds feed less moisture into the Australian/southeast Asian region (bottom panel of schematic). Air pressure is higher over Australia and lower over the central Pacific in line with this shift in the Walker Circulation, and the SOI becomes persistently negative (for example, below −7). Under these conditions, there is a high probability that eastern and northern Australia will be drier than normal. In addition to its effect on rainfall, the El Niño phenomenon also has a strong influence on temperatures over Australia. During winter/spring, El Niño events tend to be associated with warmer than normal daytime temperatures. Conversely, reduced cloudiness means that the air tends to cool very rapidly at night, often leading to widespread and severe frosts.

When the Pacific trade winds and Walker Circulation are stronger than average, the eastern Pacific Ocean is cooler than normal and the SOI is usually persistently positive. This enhancement of the Walker Circulation, also called La Niña, often brings widespread rain and flooding to Australia.

The effect of La Niña on Australian rainfall patterns is generally more widespread than that of El Niño. During La Niña phases, temperatures tend to be below normal, particularly over the northern and eastern parts of Australia. The cooling is strongest during the October–March period.

For more information, see: www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.shtml?bookmark=enso



The three phases of the Southern Oscillation and Walker Circulation patterns

Box 2.2 The Indian Ocean Dipole

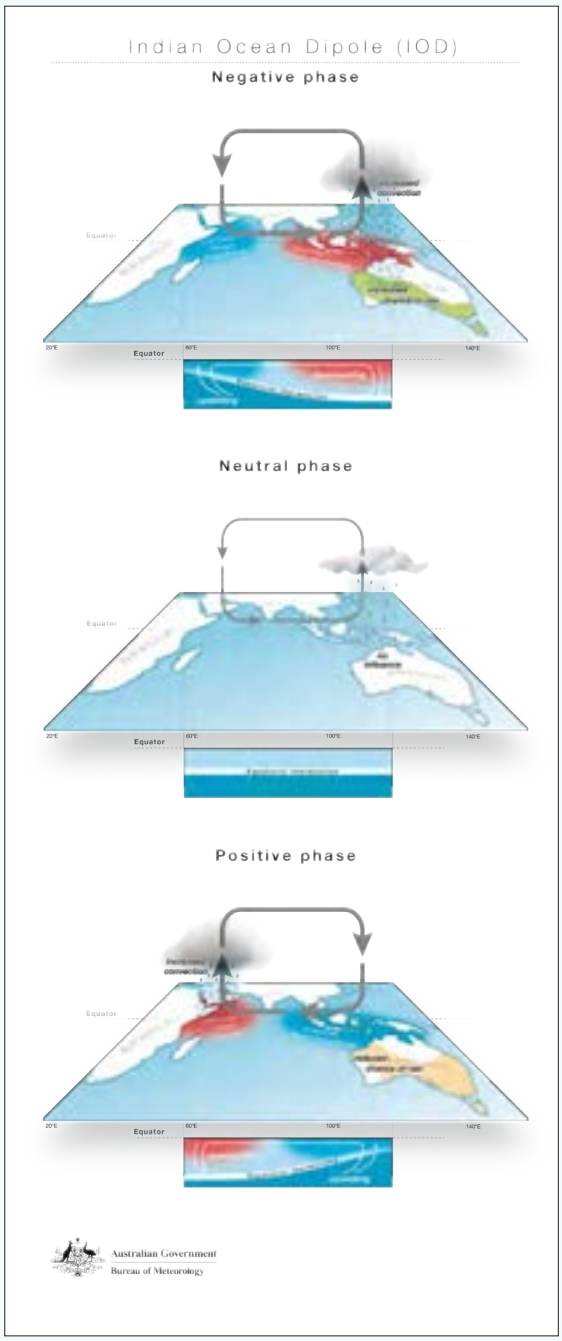
The Indian Ocean Dipole (IOD) is a coupled oceanic and atmospheric phenomenon in the equatorial Indian Ocean that affects the climatic conditions in Australia and other countries that surround the Indian Ocean basin.

The IOD is commonly measured by an index that is the difference in sea surface temperature (SST) between the western and eastern equatorial Indian Ocean. The images below show the east and west poles of the IOD and the phases the index can be in.

A negative IOD period is characterised by warmer than normal water in the tropical eastern Indian Ocean and cooler than normal water in the tropical western Indian Ocean. A negative IOD SST pattern can be associated with an increase in rainfall over parts of southern Australia.

A positive IOD phase is characterised by cooler than normal water in the tropical eastern Indian Ocean and warmer than normal water in the tropical western Indian Ocean. A positive IOD SST pattern can be associated with a decrease in rainfall over parts of central and southern Australia.

For more information see:
www.bom.gov.au/climate/IOD/about_IOD.shtml



The three phases of the Indian Ocean Dipole (IOD)

2.10 Notable rainfall periods

The wet La Niña-influenced summer period (November 2011–April 2012) brought high rainfall, particularly to the South East Coast (NSW) and Murray–Darling Basin regions.

A slow-moving trough brought heavy rainfall in the north of the Murray–Darling Basin region and throughout South East Coast (NSW) region in late November 2011 (Figure 2.17). Rainfall totals were highest on record for a few areas in the northeast of the Murray–Darling Basin region. These heavy rainfalls caused major flooding to occur in some rivers which continued into December.

A major summer rainfall event occurred in late January 2012 which mainly impacted rivers in the north of the South East Coast (NSW) and Murray–Darling Basin regions and the south of the North East Coast region (Figure 2.18). Heavy rainfall continued into February, particularly in the northeast of the Murray–Darling Basin region. A near-stationary trough produced daily rainfall totals up to 200 mm in some areas.

Figure 2.19 shows a major rainfall event, caused by a slow moving low pressure trough, which happened in early March 2012. The Murray–Darling Basin recorded its wettest seven-day period for any month. The Murrumbidgee River basin received seven-day rainfall totals that were double the previous highest on record (> 200 mm). It resulted not only in high river levels and local flooding in rivers across large areas of the region, but large areas of the Tanami – Timor Sea Coast, Lake Eyre Basin and the south of South East Coast (NSW) regions were also affected.

In the north, three tropical cyclones (*Grant*, *Heidi* and *Iggy*) passed through the north and western parts of the Australian continent in December 2011 through to February 2012. Tropical cyclone *Grant* crossed the northern part of the Northern Territory in late December 2011, producing heavy rainfall near the town of Katherine. The highest rainfall total was 385 mm, measured at Edith Falls Ridge on 27 December 2011. Tropical cyclone *Heidi* made landfall on the Pilbara coast near Port Hedland in mid-January 2012. Tropical cyclone *Iggy* briefly affected the coast of Western Australia in the Pilbara and Kimberley areas in late January and early February 2012.

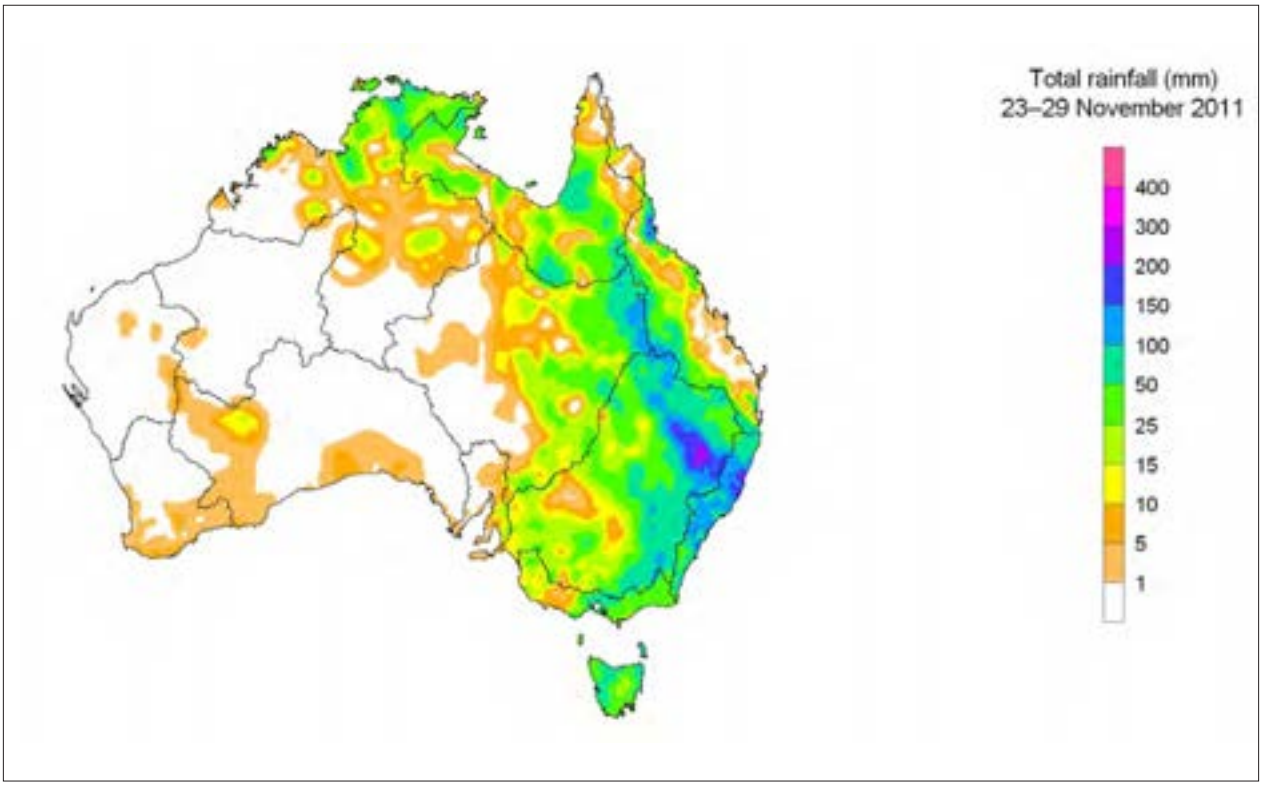


Figure 2.17 Rainfall that contributed to flooding in the Murray–Darling Basin and South East Coast (NSW) regions in late November and early December 2011

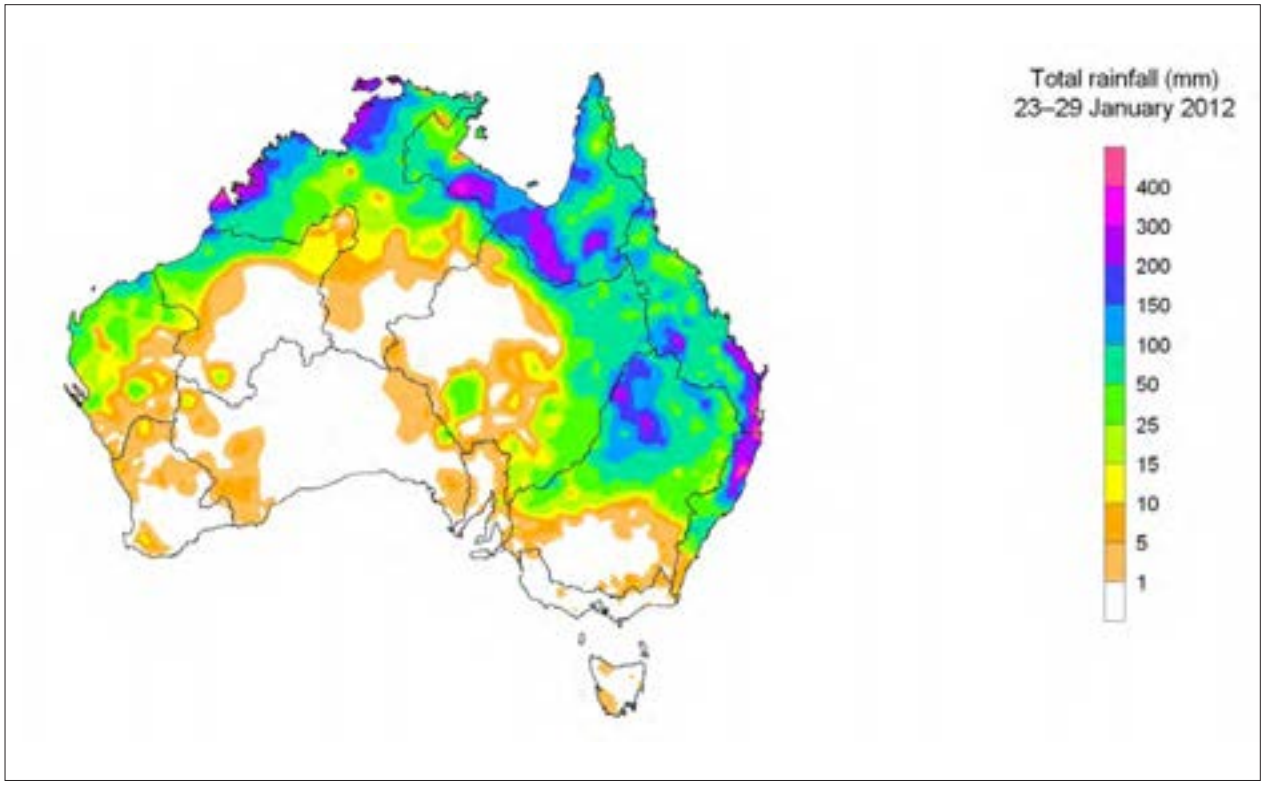


Figure 2.18 Rainfall that contributed to flooding in South East Coast (NSW), Murray–Darling Basin and North East Coast regions in late January 2012

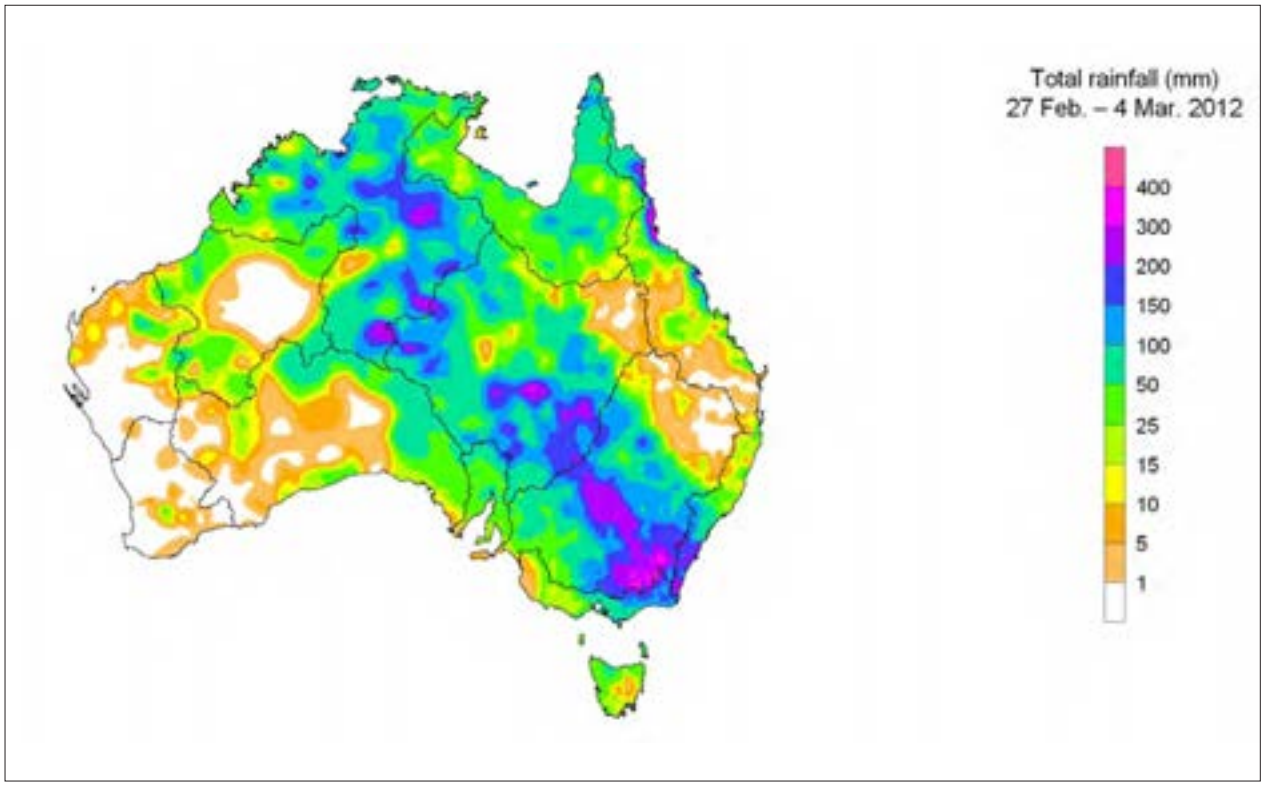


Figure 2.19 Rainfall that contributed to flooding in Tanami – Timor Sea Coast, Lake Eyre Basin, Murray–Darling Basin and South East Coast (NSW) regions in early March 2012

2.11 Major flood events

Major floods are events that cause large infrastructural disturbance and extensive inundation of rural or urban areas. Following on from a very wet preceding year, Australia experienced more widespread major flood events during 2011–12 than typically occurs. This was predominantly in rivers in the eastern part of the country (Figure 2.20).

Heavy rainfall in August generated floods in the northeast part of the Tasmania region. The resulting highly saturated soils caused many landslides.

In the northeast part of the Murray–Darling Basin region, floods were recorded in the Gwydir and Namoi river basins in November 2011.

In these two basins, the floodwaters moved downstream during December 2011 and, with additional high rainfall at the end of January 2012, many rivers in the Darling River basin experienced flooding through to April 2012.

The coastal rivers of the North East Coast region flooded during March. During this month in the Murray–Darling Basin region, a large rainfall event caused widespread flooding, particularly in the Lachlan and Murrumbidgee rivers.

The South East Coast (Victoria) region experienced major floods in June 2012 that were the result of a rare local rainfall event. Most of the east of the region received rainfall of over 100 mm on 5 June, resulting in a rapid rise in river levels and flash flooding.

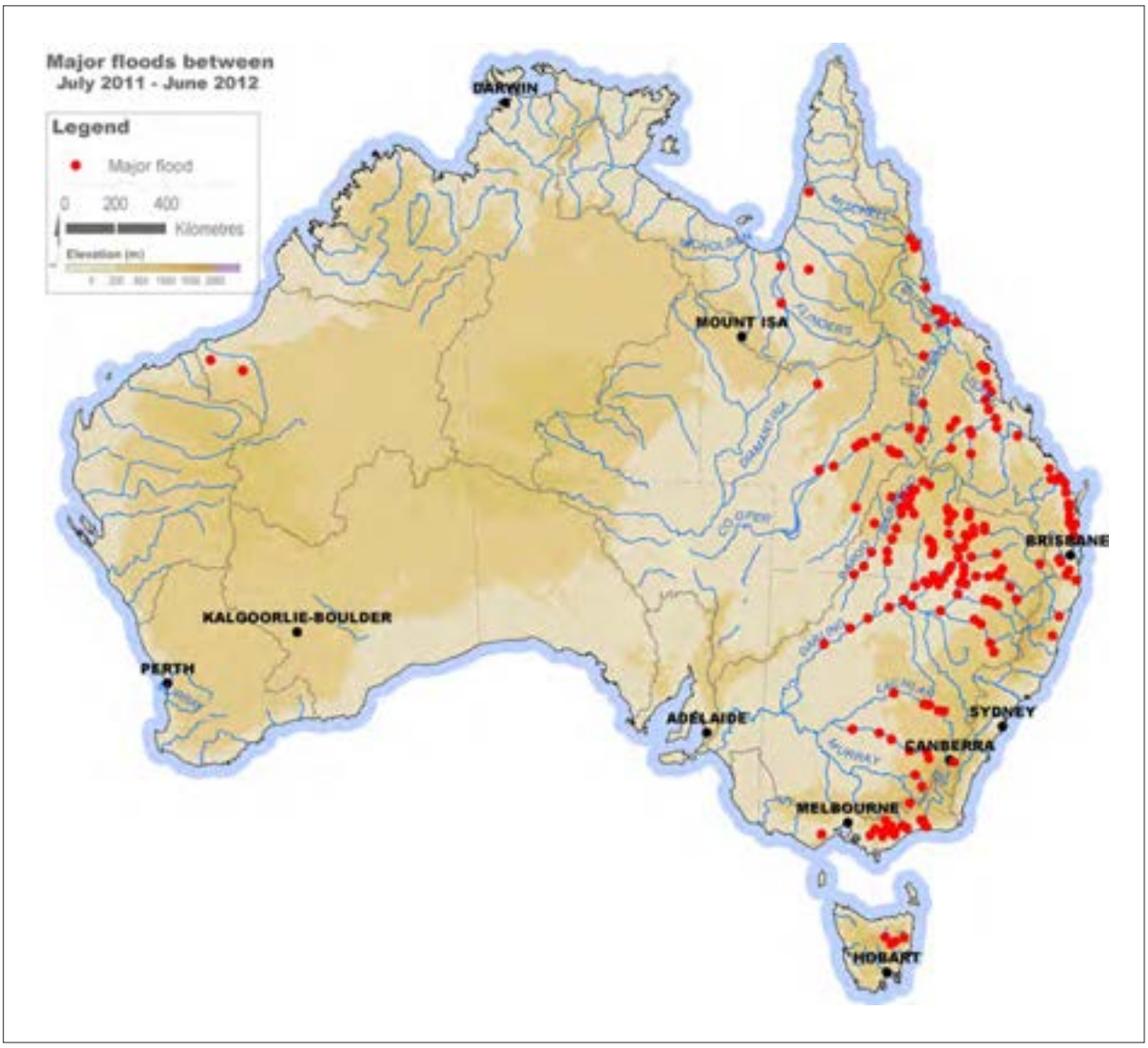


Figure 2.20 Major floods in 2011–12, as monitored by the Bureau's Flood Forecasting and Warning Service

2.12 Regional water resources assessments

Chapters 3–15 detail assessments of water availability and use at regional scales. Within each reporting region, patterns, variability and trends in water availability and use are considered.

Topics addressed include the impacts of the climatic condition on water resources over 2011–12 and between 1980 and 2012.

The report focuses on presentation of annual to decadal trends in water resources and over monthly and seasonal periods.

Particular consideration is given to describing the hydrological state of rivers within each region during 2011–12 and over recent years. Groundwater resources are also described where data were available. Water availability and use in selected cities and irrigation areas is also presented. Information is conveyed in general descriptions of each region and the results of analysis are presented in graphs, tables and diagrams.

Modelled landscape water balance data provide a spatially explicit regional perspective, and data from selected monitoring sites give more detail at particular locations.

North East Coast

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3 North East Coast

3.1 Introduction

This chapter examines water resources in the North East Coast region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information including the physiographic characteristics, soil types, population, land use and climate of the region.

Spatial and temporal patterns in landscape water flows are presented, and surface and groundwater resources examined. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The Technical Supplement details the sources and methods used in developing the diagrams and maps.

3.2 Key information

Table 3.1 gives an overview of the key components of the data and information in this chapter.

Table 3.1 Key information on water flows, stores and use in the North East Coast region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	1,041 mm	+22%	9th—above average
Evapo-transpiration	814 mm	+18%	9th—above average
Landscape water yield	223 mm	+42%	9th—above average

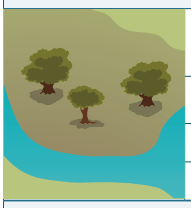
Streamflow (at selected gauges)

Annual total flow:	Predominantly average to above average flow throughout the region
Salinity:	Annual median electrical conductivity predominantly below 1,000 µS/cm throughout the region
Flooding:	Major floods in many parts of the region

Surface water storage (comprising about 92% of the region's total capacity of all major storages)

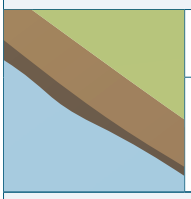
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
9,516 GL	9,301 GL	98%	9,135 GL	96%	+166 GL	+2%

Wetlands inflow patterns (for selected wetlands)



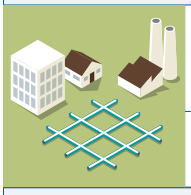
Bowling Green Bay:	Average flows throughout the year, but very much above average flows in March
Fitzroy River floodplain:	Very much above average flows during February and March 2012
Great Sandy Strait:	Very much above average flows over the January to March 2012 period
Moreton Bay:	Very much above average flows in January and March 2012

Groundwater (in selected aquifers)



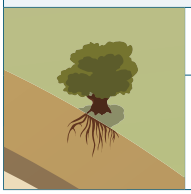
Levels:	Predominantly rising trends in the selected watertable aquifers over the 2007–08 to 2011–12 period
Salinity:	Scattered areas of saline groundwater (≥3,000 mg/L) throughout the region

Urban water use (Brisbane and Gold Coast)



Total use in 2011–12	Total use in 2010–11	Change	Restrictions
176 GL	180 GL	−4 GL (−2%)	Permanent Water Conservation Measures

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly above average annual mean soil moisture with large inland areas of very much above average soil moisture
Temporal patterns in regional average:	Above average to very much above average soil moisture throughout the year

3.3 Description of the region

The North East Coast region is a 451,000 km² area in Queensland surrounded by the Great Dividing Range in the west, the Coral Sea in the east, Torres Strait in the north and the Queensland–New South Wales border in the south.

River basins in the region vary in size from 400–143,000 km². Major river basins include the Burdekin, Fitzroy, Burnett, Brisbane, Mary and Johnstone, Mulgrave, Barron, Daintree, Bloomfield and Normanby.

The largest river basins are the Burdekin and the Fitzroy (Figure 3.1), which together comprise 64% of the Great Barrier Reef catchment area and impact upon the offshore reef's ecosystems through discharges of sediments and nutrients.

The region includes some of the most topographically diverse terrain in Australia, including high altitudes associated with coastal ranges and tablelands and a retreating escarpment with outcrops on the coastal alluvial plains. The highest mountains in Queensland and the highest rainfall areas in Australia are north of Innisfail. Subsections 3.3.1–3.3.4 give more detail on the physical characteristics of the region.

With a population in excess of 4 million people the region is home to just over 19% of all Australians and 92% of all Queensland residents (Australian Bureau of Statistics [ABS] 2011b). Major population centres within the region include Brisbane, the Gold Coast and the Sunshine Coast as well as the regional centres of Hervey Bay, Bundaberg, Gladstone, Rockhampton, Mackay, Townsville and Cairns (Figure 3.1). Further discussion of the region's population distribution and urban centres can be found in subsection 3.3.6 and section 3.6 respectively.

Most of the region outside the urban centres is used for grazing. In the north this occurs on native rangelands with fewer management inputs and pasture improvement than occur in the southern river basins. Dryland and irrigated agriculture accounts for approximately 0.4% of the land use of the area. Areas of intensive land use such as in urban areas account for 0.2% of the area. Section 3.7 has more information on agricultural activities.

The region's climate is subtropical to tropical with hot, wet summers and cooler, dry winters. The monsoonal summer rainfall is more predictable in the north than in the south. Subsections 3.3.7 and 3.3.8 provide information on the rainfall patterns across the region.

A large area of outcropping fractured basement rock dominates the hydrogeology of the region. The groundwater systems in fractured rock typically offer restricted low-volume groundwater resources. In contrast, large groundwater resources are localised in alluvial valley systems and coastal sand deposits. The status of surface water and groundwater is presented in section 3.5.

Tropical landscape with tree ferns and rain forest, Queensland Tablelands | Dirk Ercken, Dreamstime

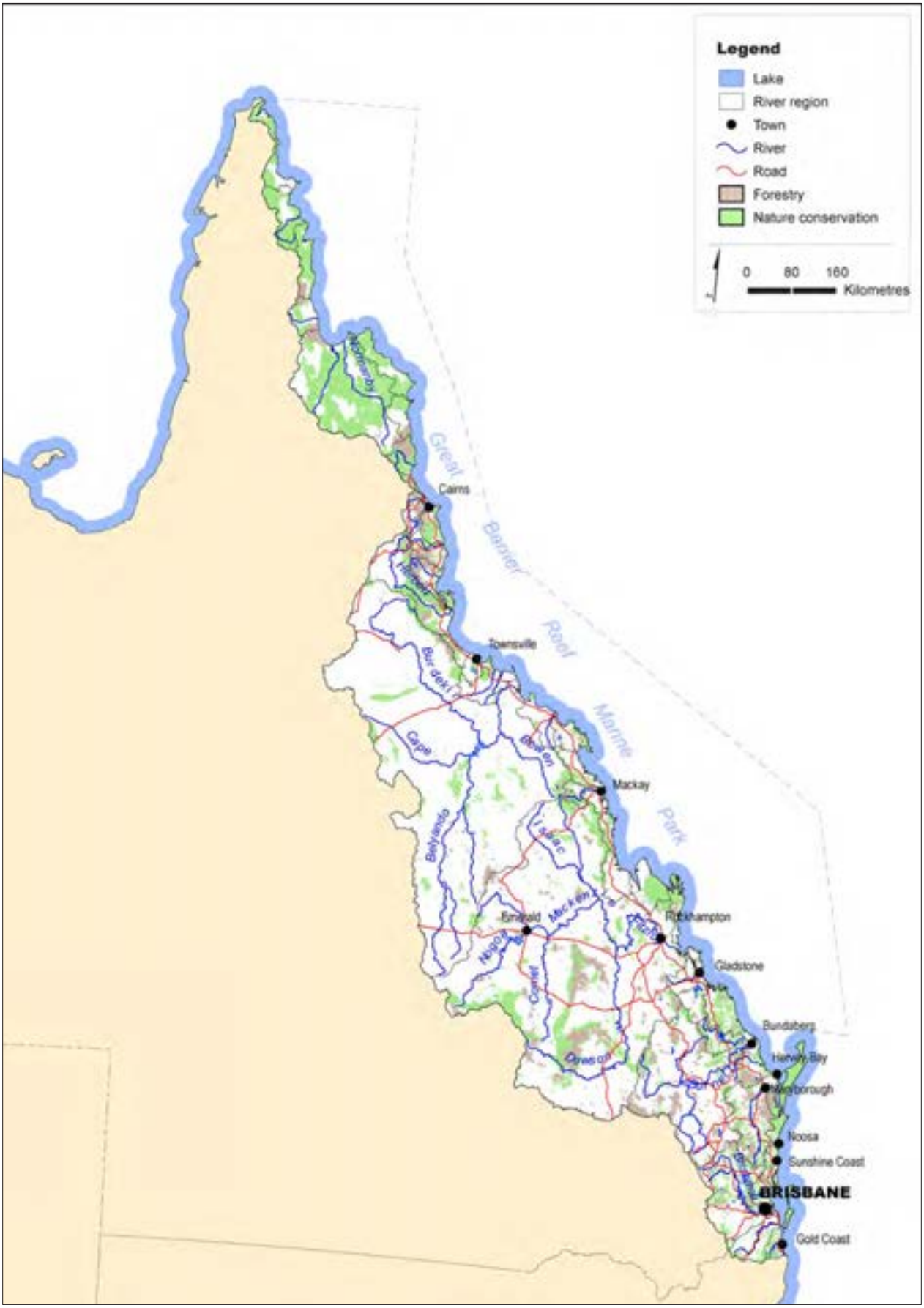


Figure 3.1 The North East Coast region

3.3.1 Physiographic characteristics

Figure 3.2 is a physiographic map indicating areas with similar landform evolutionary histories (Pain et al. 2011). These are related to similar geology and climatic impacts defining the extent of erosion processes.

The areas have distinct physical characteristics that influence hydrological processes.

The North East Coast region has four physiographic provinces. These are described in the following list with the proportion of the region they cover shown in brackets.

- Burdekin Uplands (21%): mixture of hills, plateaus and plains with the highlands chiefly on granite and metamorphic rocks with some young basaltic plateaus;
- Fitzroy Uplands (43%): mixture of hills, plateaus and plains with highlands of sandstone, basalt, granite and metamorphic rocks;
- New England–Moreton Uplands (23%): sandstone and igneous highlands with sedimentary and metamorphic lowlands; and
- Peninsular Uplands (13%): mixture of hills, plateaus and plains with highlands of sandstone as well as volcanic, granitic and metamorphic rocks.

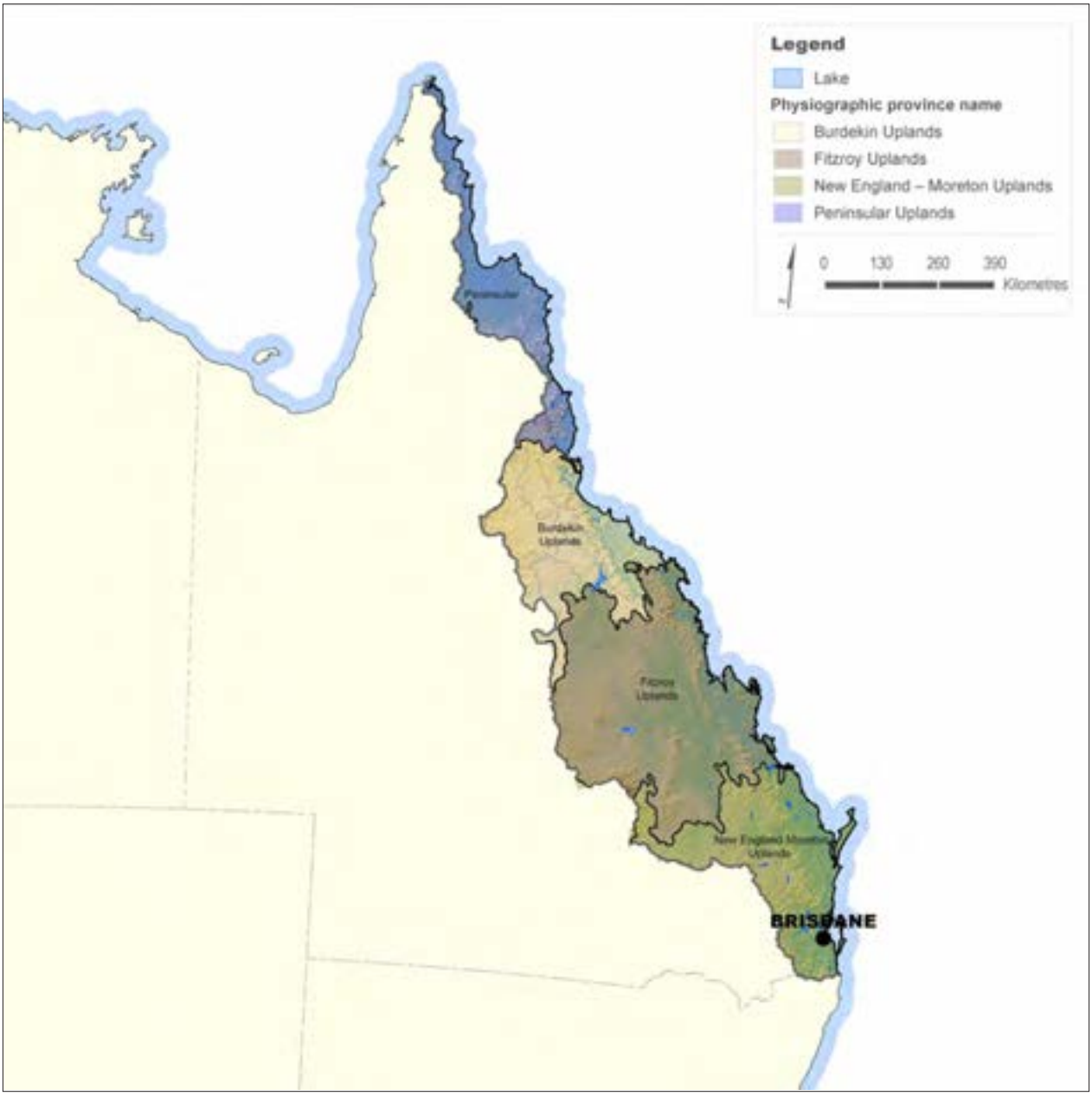


Figure 3.2 Physiographic provinces of the North East Coast region

3.3.2 Elevation

Figure 3.3 presents ground surface elevations in the North East Coast region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).

The North East Coast region has a very diverse topography and includes high altitudes associated with coastal ranges and tablelands, and a retreating escarpment with residual outliers on the coastal alluvial plains.

The region contains many mountains from part of the Great Dividing Range. It also contains large plateaus and low-lying coastal areas.

The highest mountains in the region can be found south of Cairns, with peaks reaching altitudes of 1,600 m above sea level.

Further south, the peaks of various coastal mountain ranges form water divides between the smaller coastal river basins and the few inland river basins.

The crest of the Great Dividing Range forms the western border of the region. Altitudes on this boundary vary from less than 200 m to more than 1,200 m.

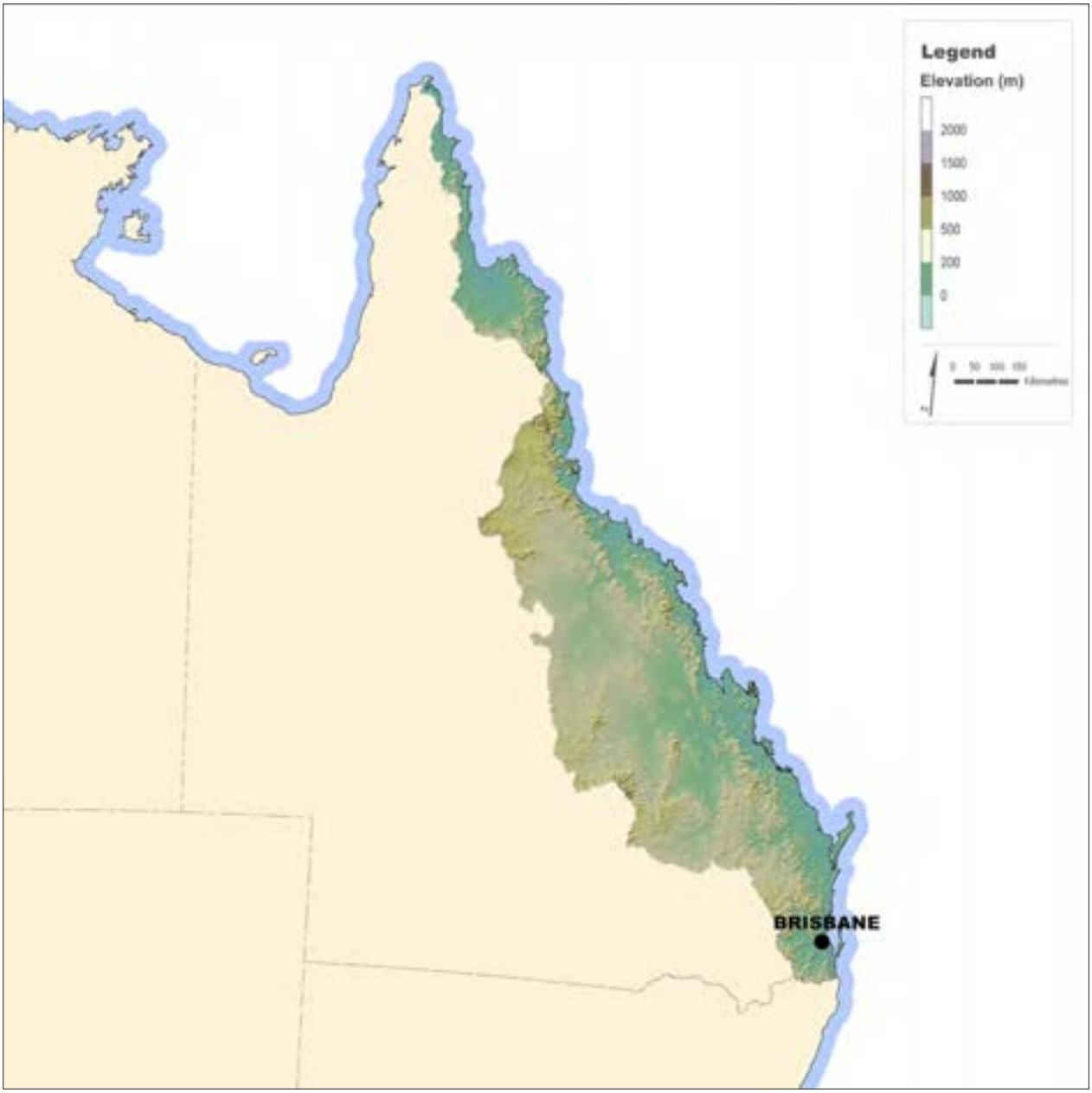


Figure 3.3 Ground surface elevations in the North East Coast region

3.3.3 Slopes

Table 3.2 summarises the proportions of slope classes for the region while Figure 3.4 shows the spatial distribution of the surface slopes. Areas with steep slopes provide higher run-off generating potential than flat areas. The North East Coast region has high slope variability with larger expanses of steeper slopes than most other parts of Australia. The slopes were derived from the elevation information used in the previous section.

Table 3.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	19.0	16.4	43.8	20.8

Slopes are particularly steep along the coastal escarpment. Rivers in both the north and south of the region often have flash flooding under high intensity rainfall. The January 2011 flood in the Brisbane River and March 2012 flood in the Haughton River are examples of such events.

Further inland, slopes are rather gentle (Figure 3.4). At some locations large lakes have formed, both naturally as well as through the construction of dams for water supply.

In the flatter coastal areas many larger rivers form extensive floodplains. These are often identified as wetland areas of conservation significance.

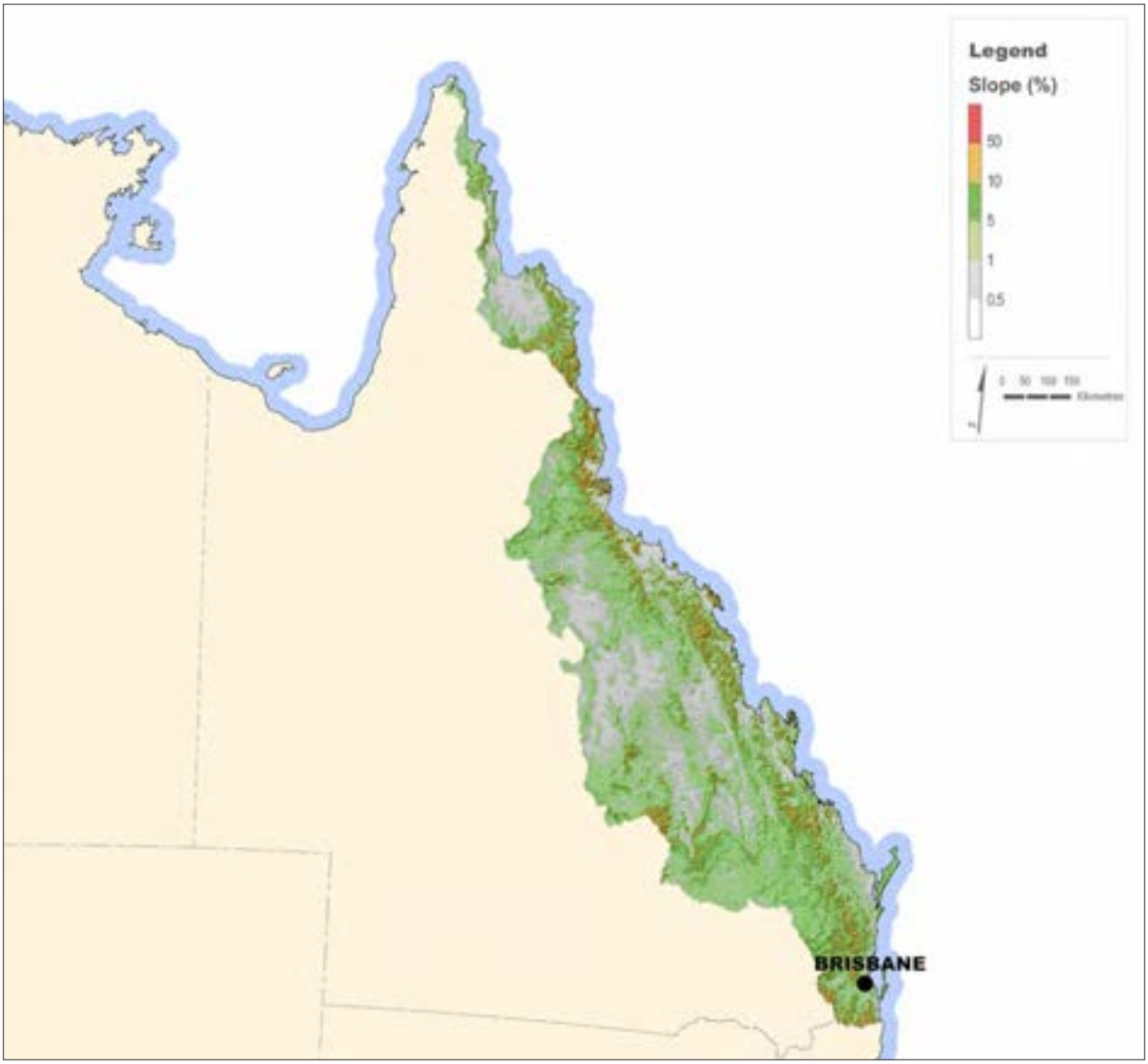


Figure 3.4 Surface slopes in the North East Coast region

3.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics.

Soil type information was obtained from the Australian Soil Resource System website (www.asris.csiro.au).

Figures 3.5–3.6 show the distribution of soil types within the North East Coast region. About 80% of the land surface is covered by five soil types, namely sodosols, kandosols, kertosols, tenosols and chromosols. With the exception of vertosols, these soils are widespread across the region, are low in fertility and are mostly used for grazing, dryland agriculture, horticulture and forestry.

Soil types with clear texture contrasts in this region are sodosols and chromosols. These soils can have a propensity to become waterlogged.

Sodosols have impermeable, sodic subsoil due to elevated sodium concentrations. They are susceptible to dryland salinity as well as erosion if vegetation is removed. Chromosols also have an impermeable subsoil that is not strongly sodic or acidic.

Vertosols, only distributed through the middle part of the region, are soils with a high clay content. These are brown, grey or black soils with large water-holding capacity, but can develop large cracks when drying. They are highly fertile and self-mulching.

Soils with little or no changes in soil texture in the region are kandosols and tenosols. Kandosols are usually red, yellow and grey massive earthy soils with a low water-holding capacity; however, a wide range of crops can be grown on them where rainfall is high or irrigation is available. Similarly, tenosols have a weak profile development. Their agricultural use is limited due to their low water-holding capacity and their often shallow or stony material. Soil types with small area coverage in the region are rudosols, dermosols, ferrosols, hydrosols, kurosols, and podosols (1–6%).

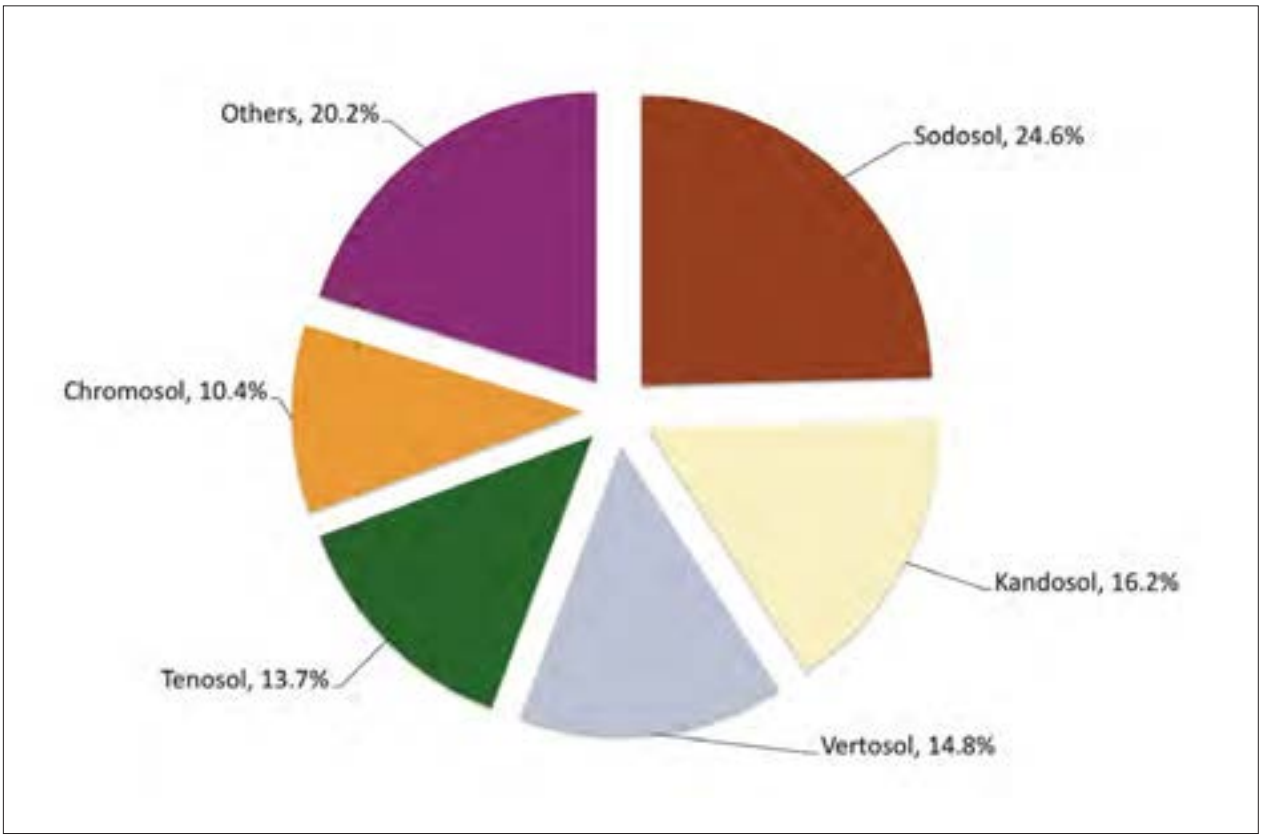


Figure 3.5 Soil types in the North East Coast region

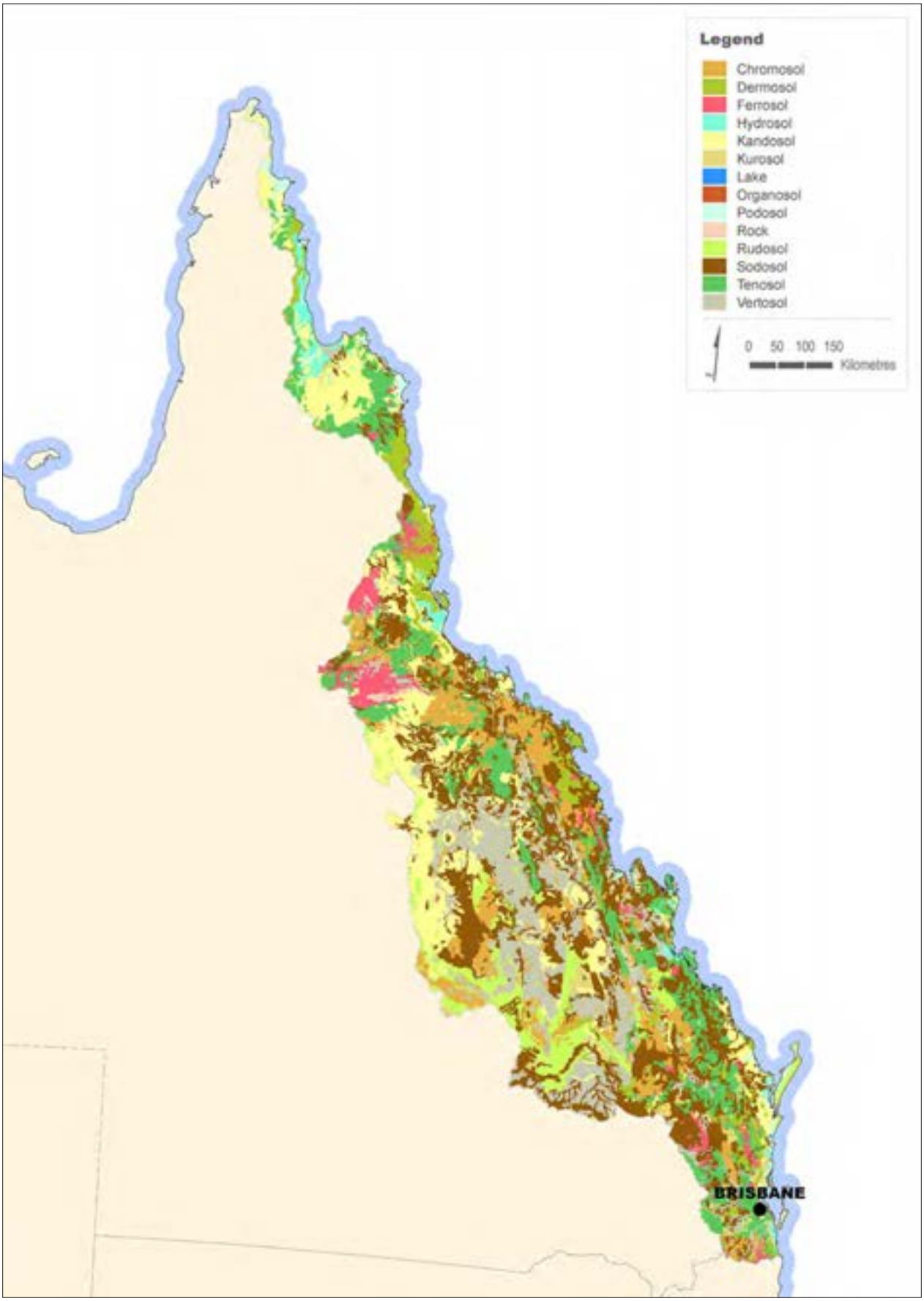


Figure 3.6 Soil type distribution in the North East Coast region

3.3.5 Land use

Most of the North East Coast region is used for grazing. In the north this occurs on native rangelands with fewer management inputs and pasture improvements than in southern river basins.

Figure 3.7 presents land use in the region. Dryland and irrigated agriculture account for approximately 4% of land use, while intensive land uses such as that of urban areas account for 1% of the region (information from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml).

As seen in Figure 3.8 nature conservation areas, such as those on Cape York are an important part of the land cover in the north, where the largest areas of unspoilt rainforests in Australia can be found.

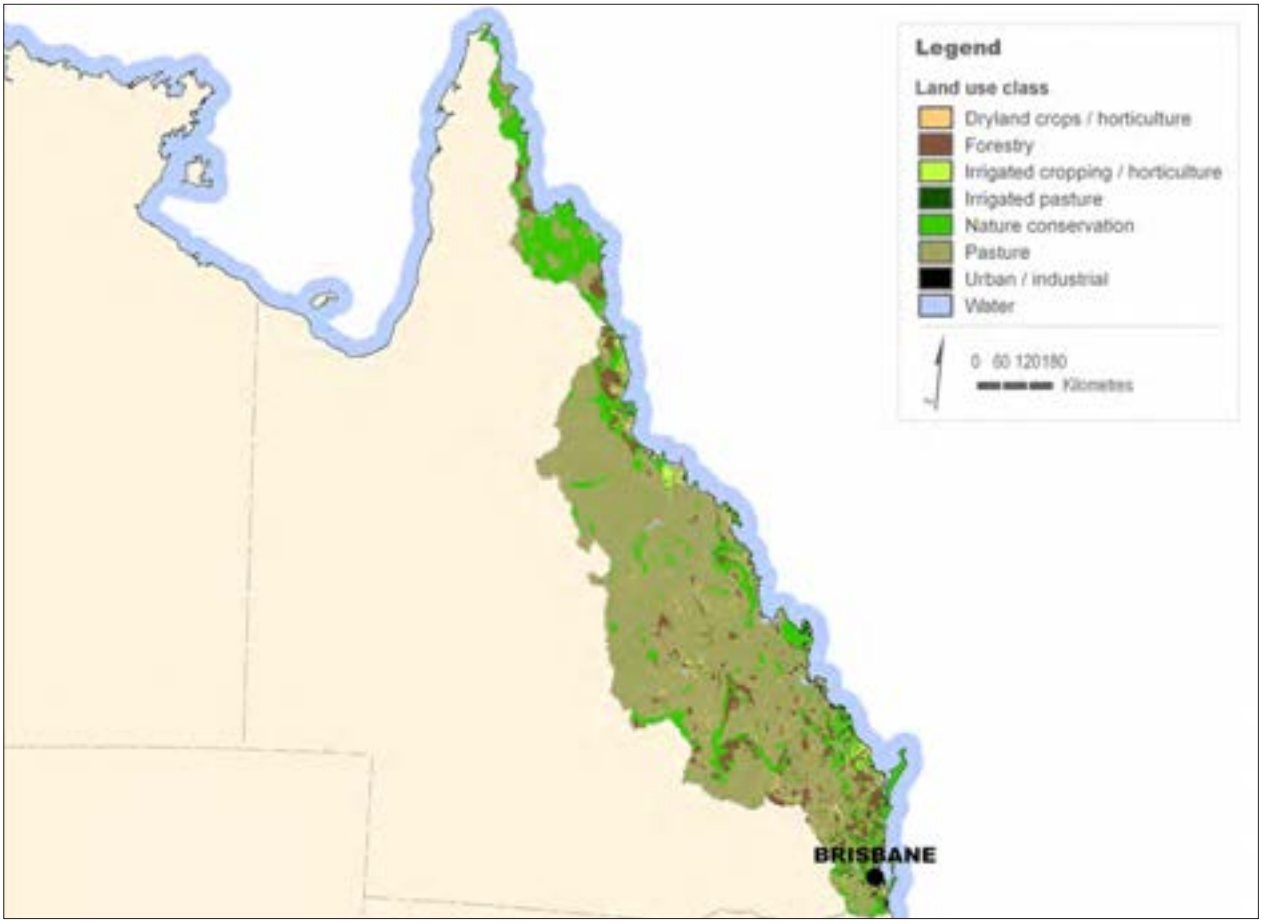


Figure 3.7 Land use distribution in the North East Coast

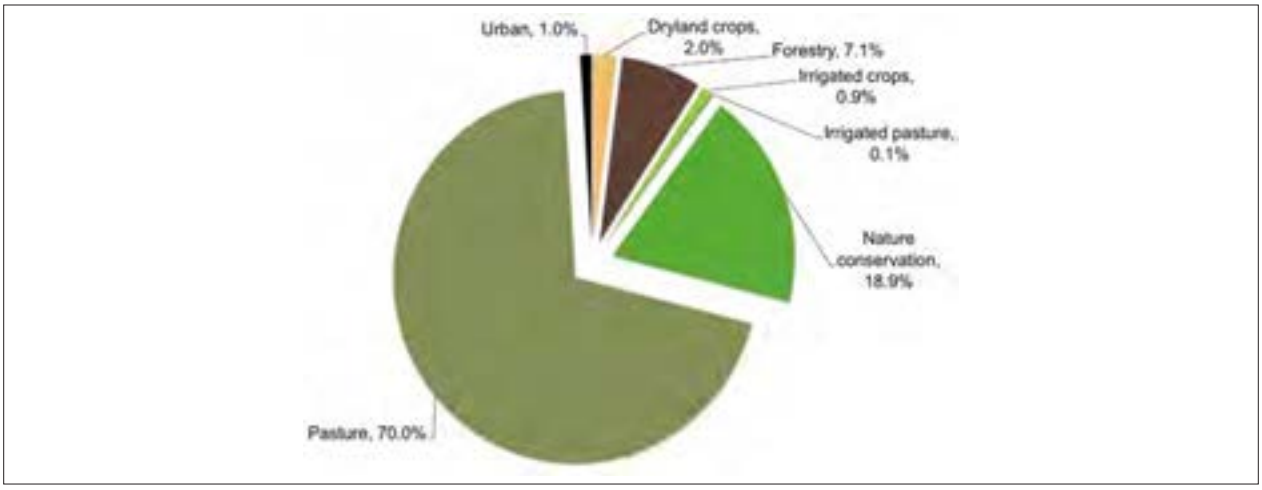


Figure 3.8 Land use in the North East Coast region

3.3.6 Population distribution

Figure 3.9 shows the population density and distribution in the North East Coast region. Urban areas account for less than 1 % of the total land area of this region. South East Queensland, which includes Brisbane, Gold Coast, and the Sunshine Coast, is the most heavily urbanised and populated area and constitutes over 65% of the region's total population.

Agriculture, fishing, mining and tourism are the major drivers for the many population centres in the north and largely along the coastal fringes, estuaries and alluvial plains of the region. Coal mining in the Bowen basin in the central eastern part of the region has been a major driver for many small inland towns as well as the larger coastal regional cities that lie on or adjacent to its eastern boundary (Gladstone, Rockhampton and Mackay).

Further north, the coastal cities of Townsville and Cairns provide the focal points for the major population concentrations of the region's northern population.

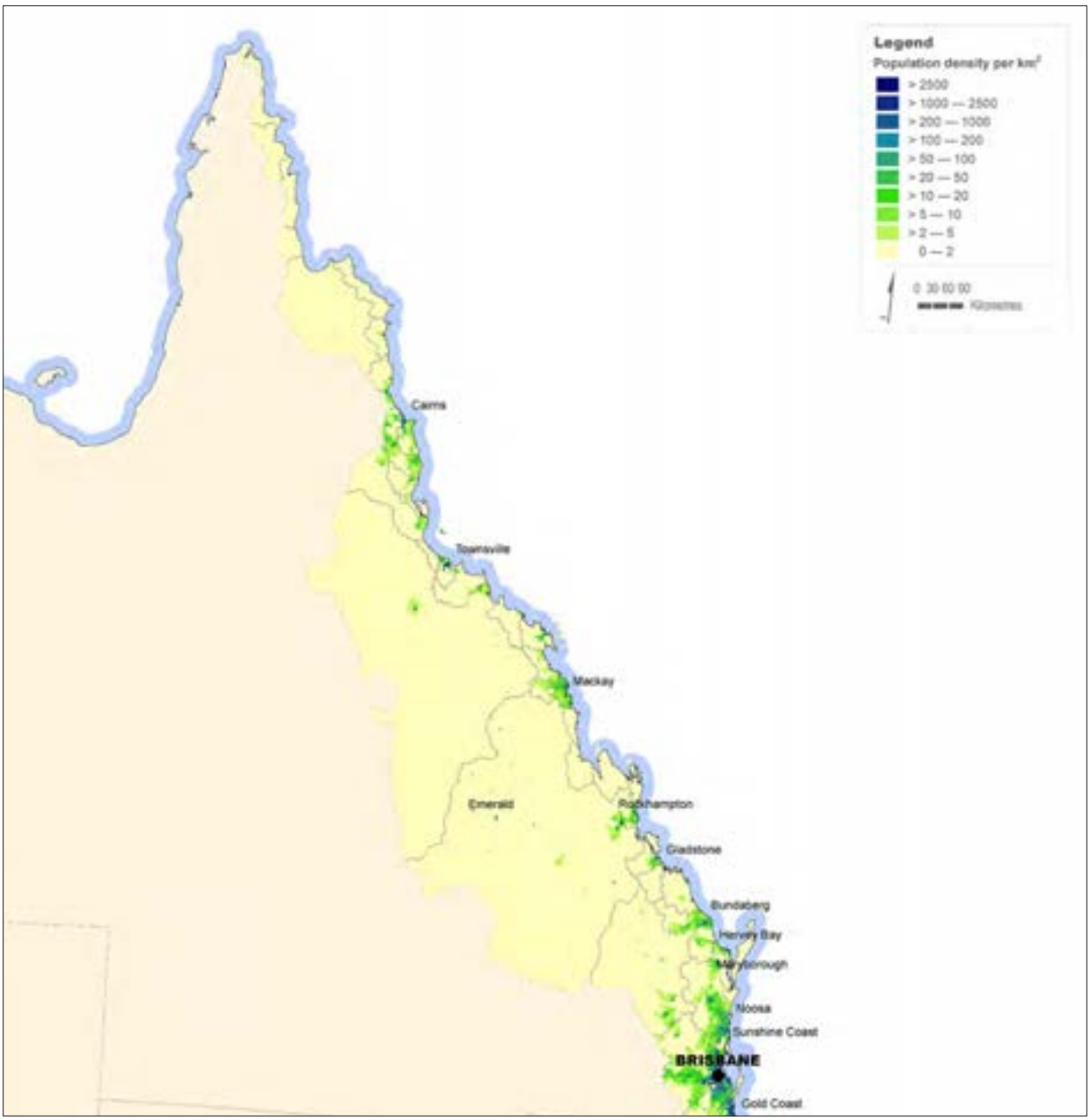


Figure 3.9 Population density and distribution in the North East Coast region

3.3.7 Rainfall zones

Figure 3.10 represents median rainfall zones in the North East Coast region, which has a subtropical to tropical climate and receives most of its rainfall in summer. Median rainfall exceeds 350 mm throughout the region.

The northern half of the region receives summer dominant rainfall with a marked wet summer and dry winter as well median rainfall decreasing westwards from over 1,200 mm per annum along the coast to between 350 mm and 650 mm inland.

The southern part of the region has a summer rainfall season (wet summer and low winter rainfall) with localised areas along the coast north of Brisbane having average annual rainfalls of over 1,200 mm. For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications

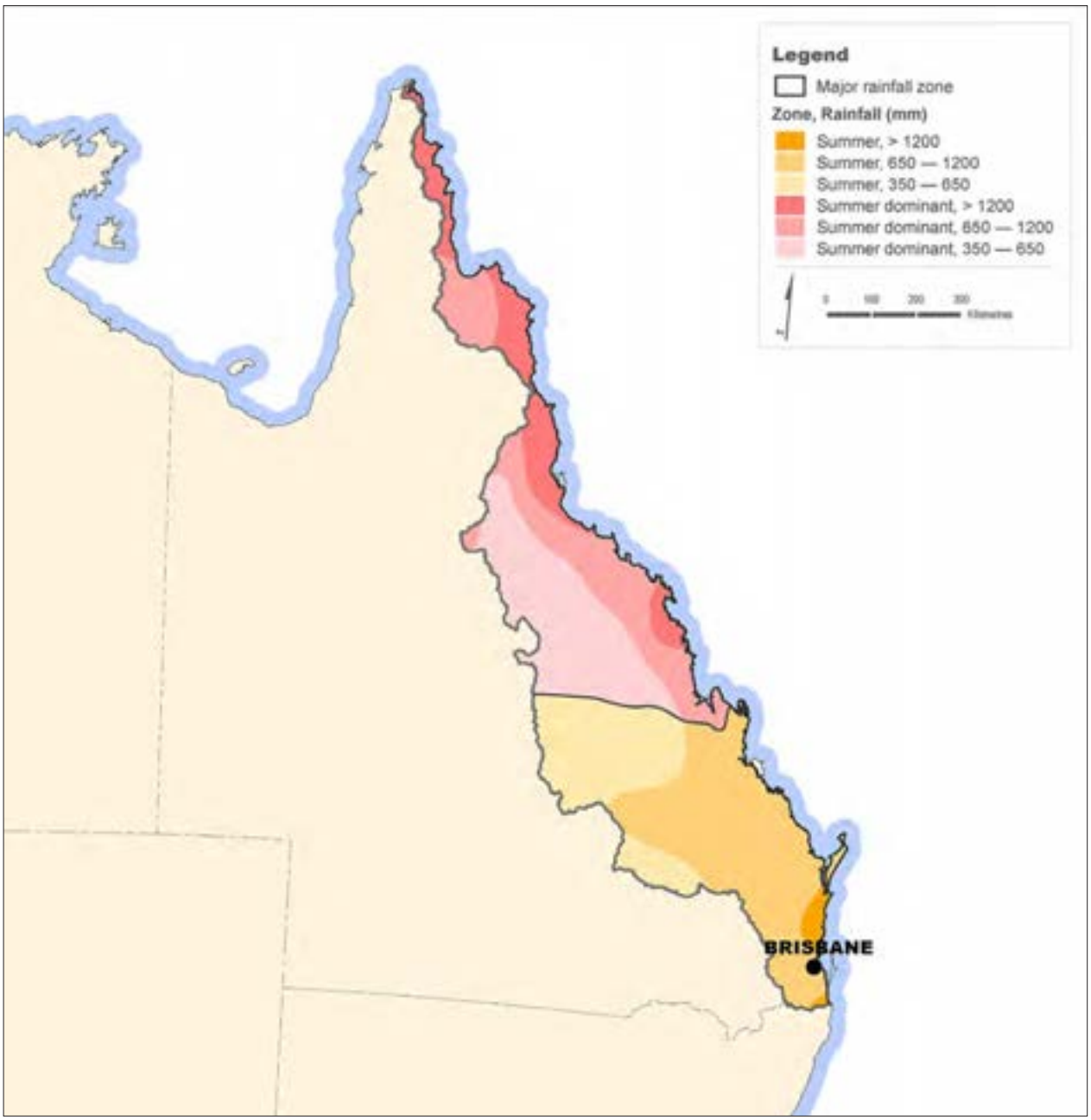


Figure 3.10 Rainfall zones in the North East Coast region

3.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The North East Coast has a distinct rainfall deficit pattern.

As shown in Figure 3.11, serious deficits can be expected in large parts of the inland areas where the major land use is grazing.

Along the coast, some areas experience abundant water over the year. Rivers carry this water to the Coral Sea and are an important source of fresh water for many estuarine wetlands.

For more information on rainfall and evapotranspiration, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

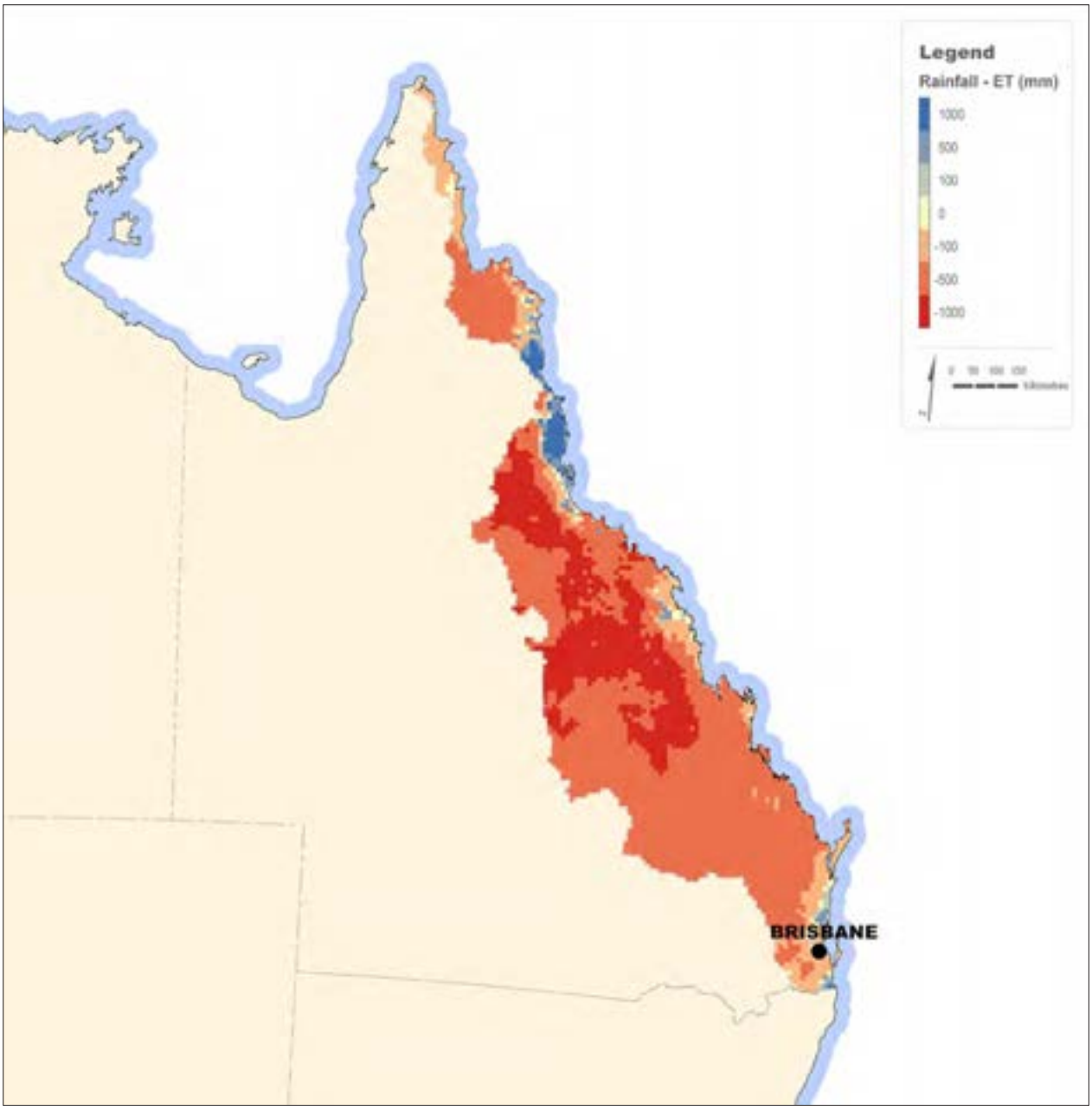


Figure 3.11 Rainfall deficit distribution in the North East Coast region

3.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the North East Coast region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau.

Figure 3.12 shows the region has a highly seasonal rainfall pattern with a wet period from December–March and a particularly dry period from July–September. Evapotranspiration in the dry period generally exceeds rainfall. After the wet period the soils normally contain moisture that is available for evapotranspiration.

The monthly landscape water yield history for the region shows a stable pattern of very low yield in the dry period. It gradually increases during summer months and subsides during autumn.

The 2011–12 year was relatively wet, particularly between December 2011 and March 2012, when rainfall was much greater than the historic median. An active monsoon in the north of the region contributed to particularly high rainfall totals for March 2012.

With wet soil conditions present at the start of the year, evapotranspiration rates were higher than rainfall rates for the first five months of 2011–12. With the exception of January 2012, evapotranspiration rates remained above the 75th percentile for the rest of the year as a result of the higher than usual rainfall in most parts of the region.

The landscape water yield for 2011–12 closely followed the historic pattern with the exception of March 2012, when very high rainfall generated a much higher landscape water yield than the historic average.

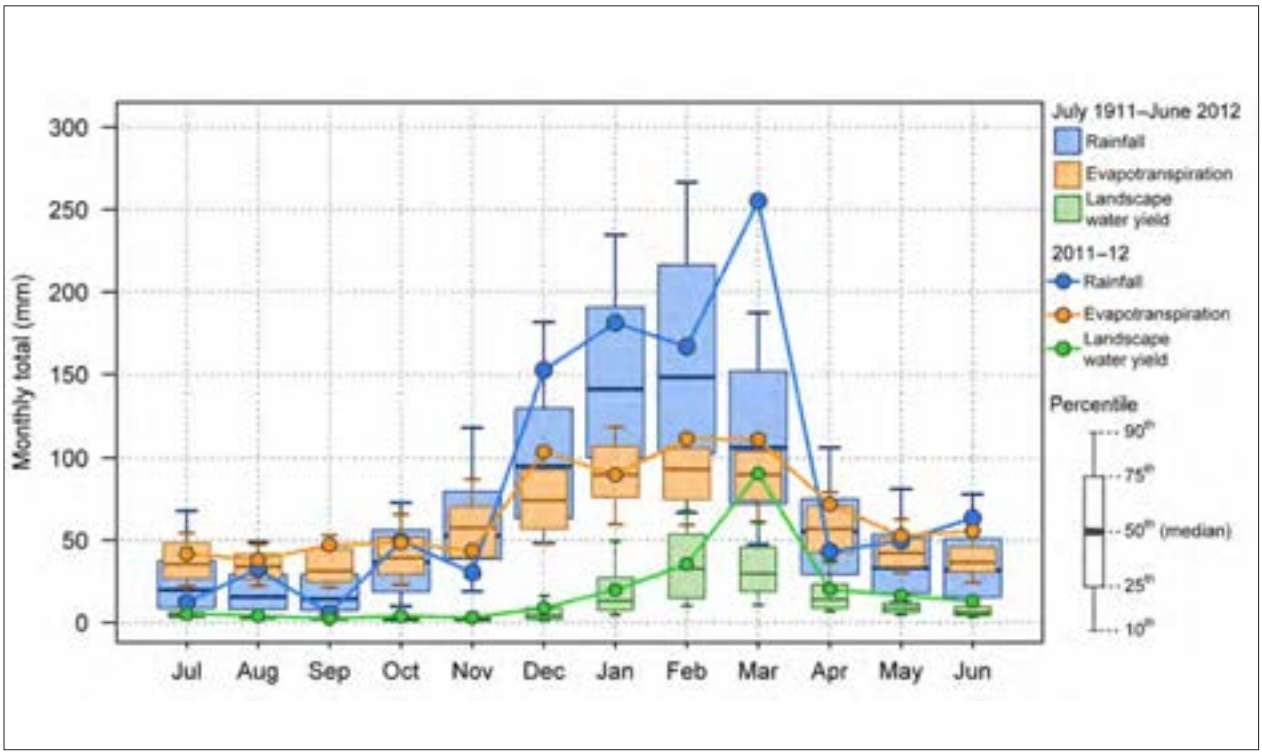


Figure 3.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911– June 2012) for the North East Coast region

3.4.1 Rainfall

Rainfall for the North East Coast region for 2011–12 is estimated to be 1,041 mm. This is 22% above the region's long-term average (July 1911–June 2012) of 853 mm. Figure 3.13a shows that the highest rainfall occurred along the coastal areas with annual totals exceeding 2,400 mm in many areas for 2011–12. The majority of the inland areas had rainfall ranging from 600–900 mm for 2011–12. However, in some areas along the western border, rainfall exceeded 900 mm.

Rainfall deciles for 2011–12 indicate average to above average rainfall for the entire region (Figure 3.13b). Most of the inland parts of the region received above average rainfall with some parts in the west receiving very much above average rainfall. The southern coastal area north of Brisbane, including Fraser Island, also received very much above average rainfall.

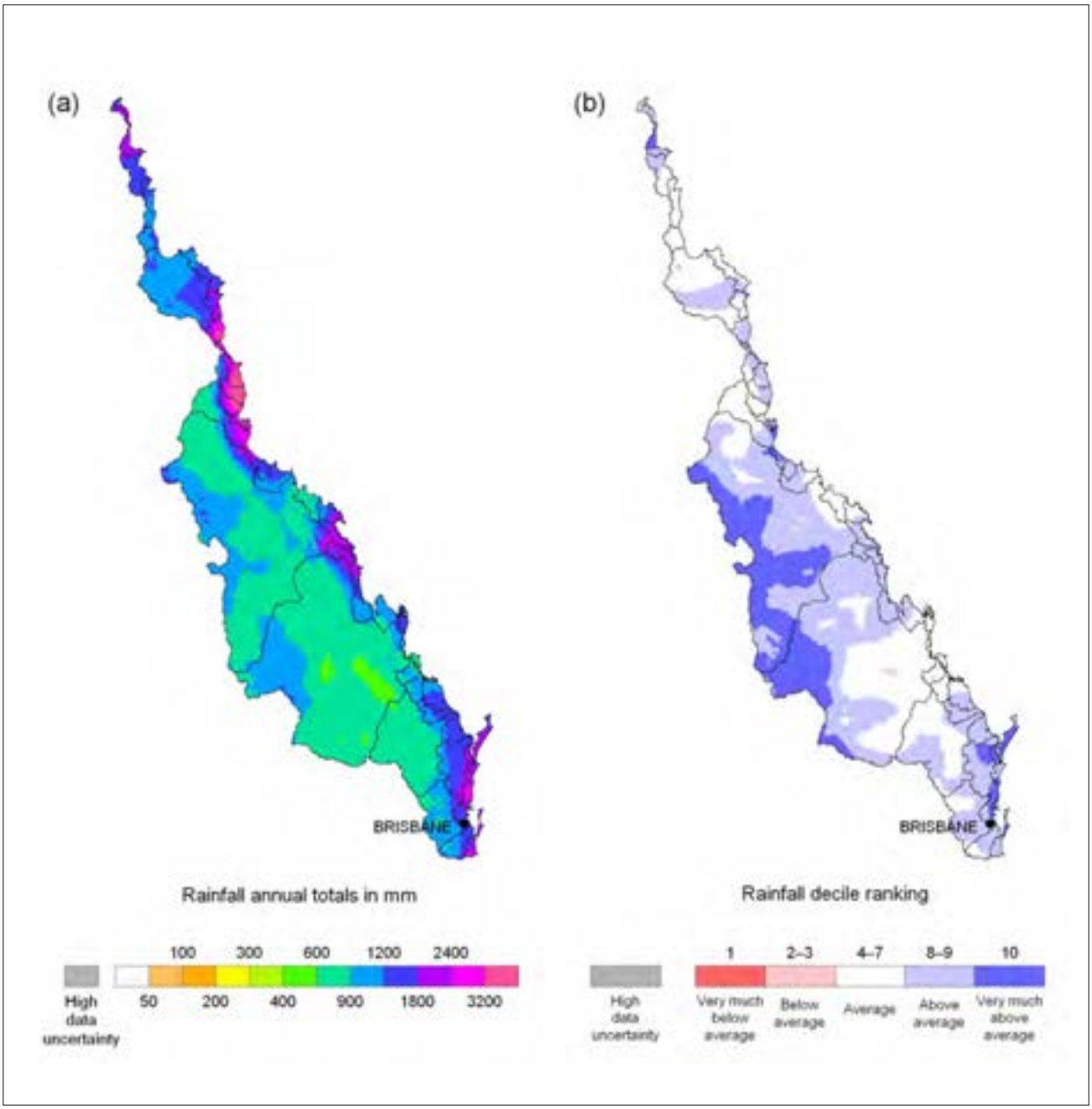


Figure 3.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North East Coast region

Rainfall variability in the recent past

Figure 3.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 851 mm, varying from 551 mm (1992–93) to 1,586 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 3.14b. The graphs indicate the presence of cyclical patterns typical of the region's annual rainfall over these 32 years, which are particularly noticeable in the summer period. This pattern is closely linked to the occurrence of El Niño and La Niña periods and correlates well with the Southern Oscillation Index (see National Overview chapter).

A strong La Niña period typically delivers above average rainfall to this region, which is clearly highlighted by the recent 2010–11 La Niña period.

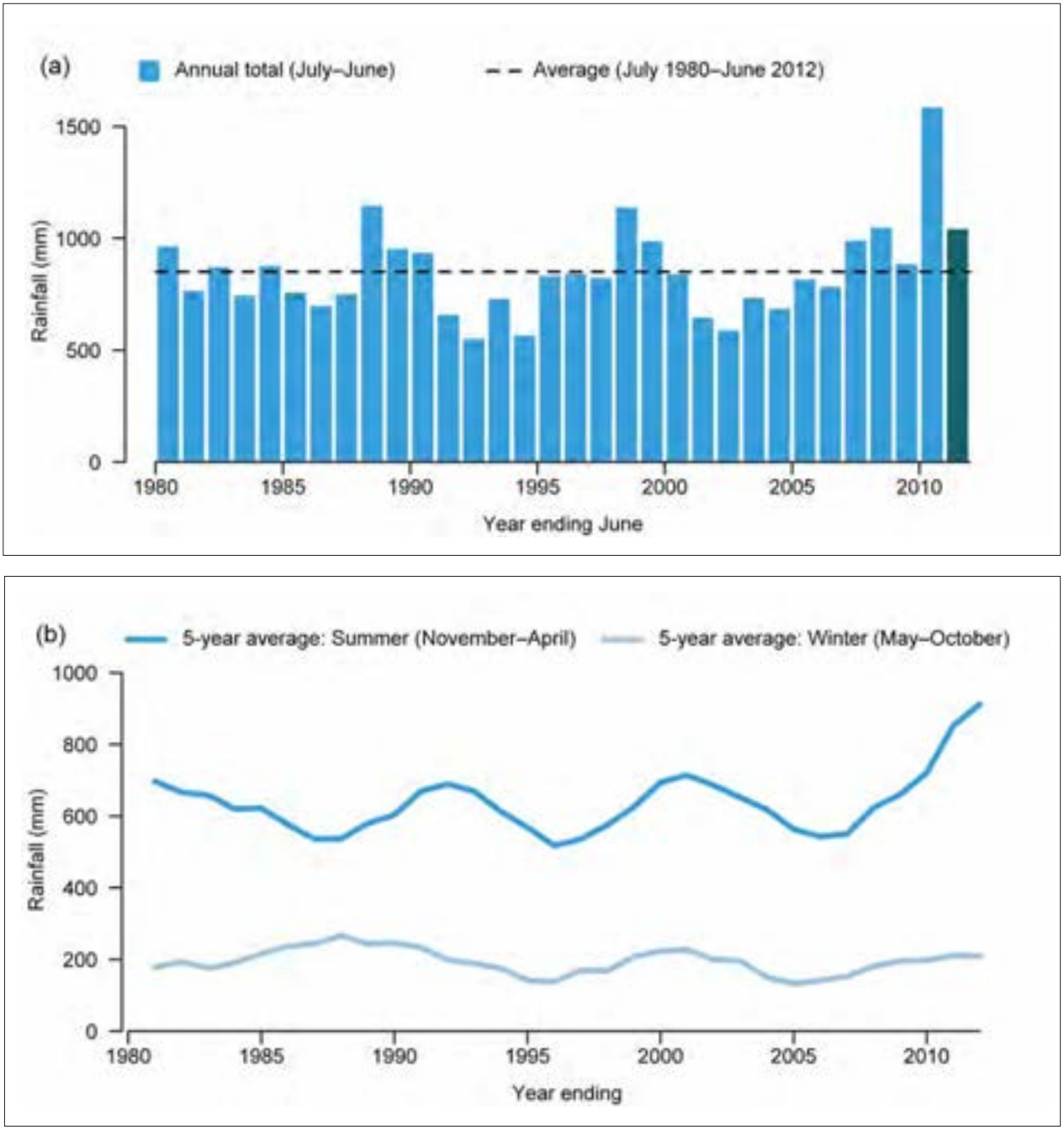


Figure 3.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North East Coast region

Recent trends in rainfall

Figure 3.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 3.15b.

Figure 3.15a shows that since 1980 a strong increase in rainfall has occurred in large parts of the region particularly towards the north. These trends are strongly significant in 22% of the region (Figure 3.15b).

The trends are largely a result of the cyclic rainfall pattern shown in Figure 3.14 and the particularly high rainfall of the past two years.

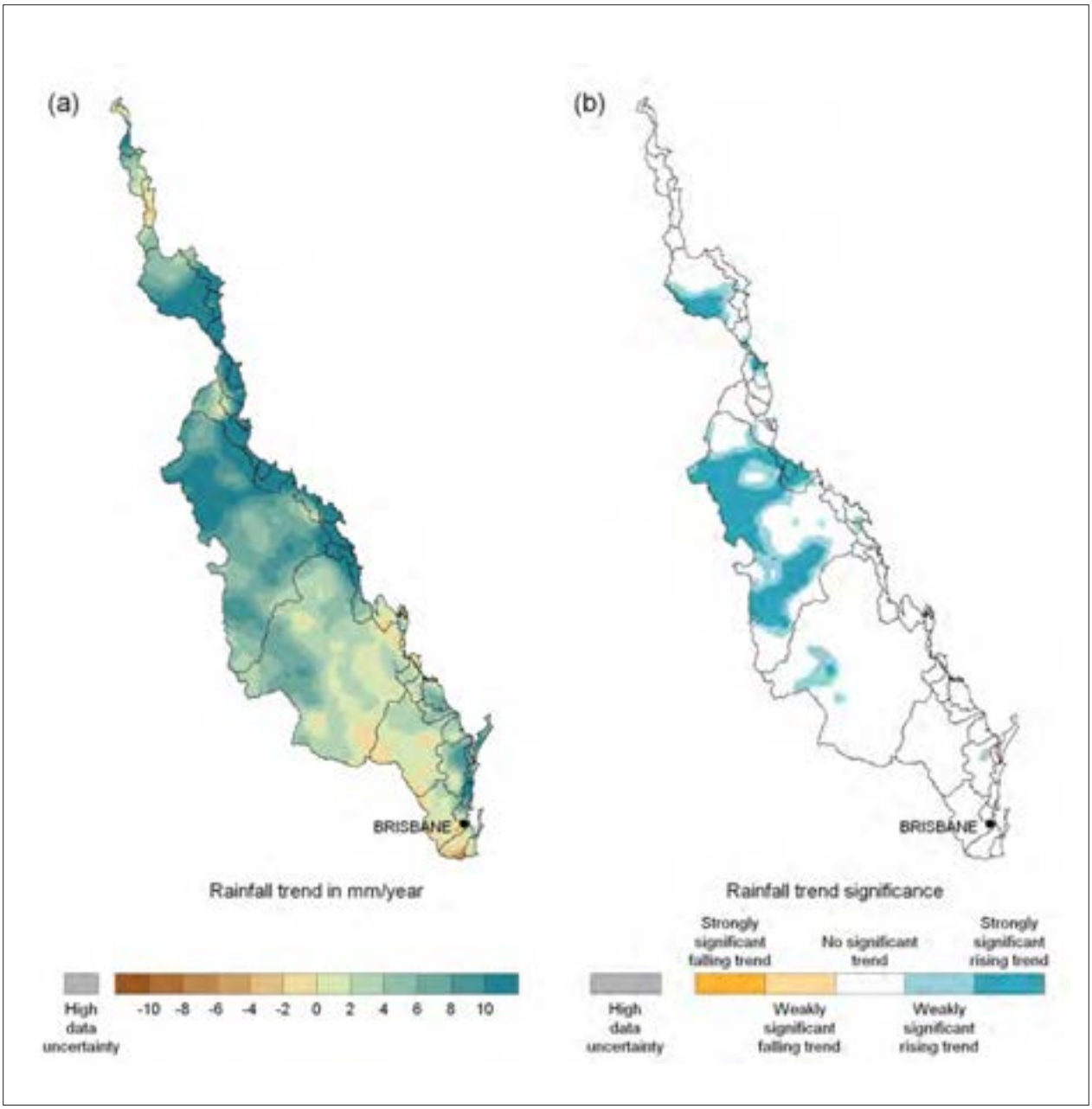


Figure 3.15 Spatial distribution of (a) trends in annual rainfall from 1980– 2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North East Coast region

3.4.2 Evapotranspiration

Modelled annual evapotranspiration for the North East Coast region for 2011–12 is estimated to be 814 mm. This is 18% above the region's long-term (July 1911– June 2012) average of 692 mm.

Figure 3.16a shows that spatial distribution of annual evapotranspiration in 2011–12 is similar to that of rainfall Figure 3.13a. Evapotranspiration rates are highest along the coast with annual totals exceeding 1,200 mm in some areas for 2011–12. Evapotranspiration averaged around 750 mm for the inland parts of the region.

Figure 3.16b shows that evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region. This coincides with the very much above average rainfall observed largely along the western border (Figure 3.15b). Most coastal areas are estimated to have had average evapotranspiration.

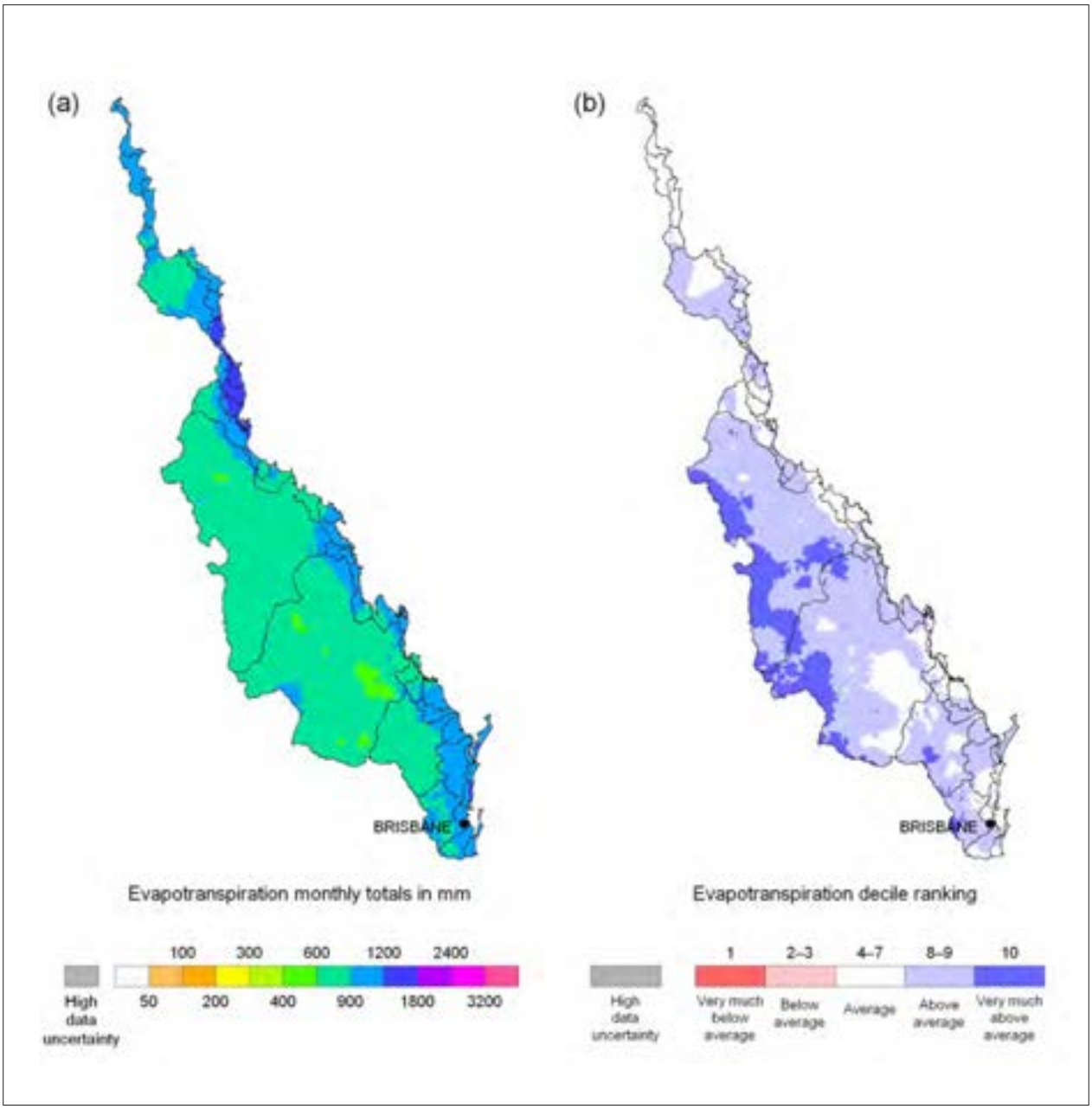


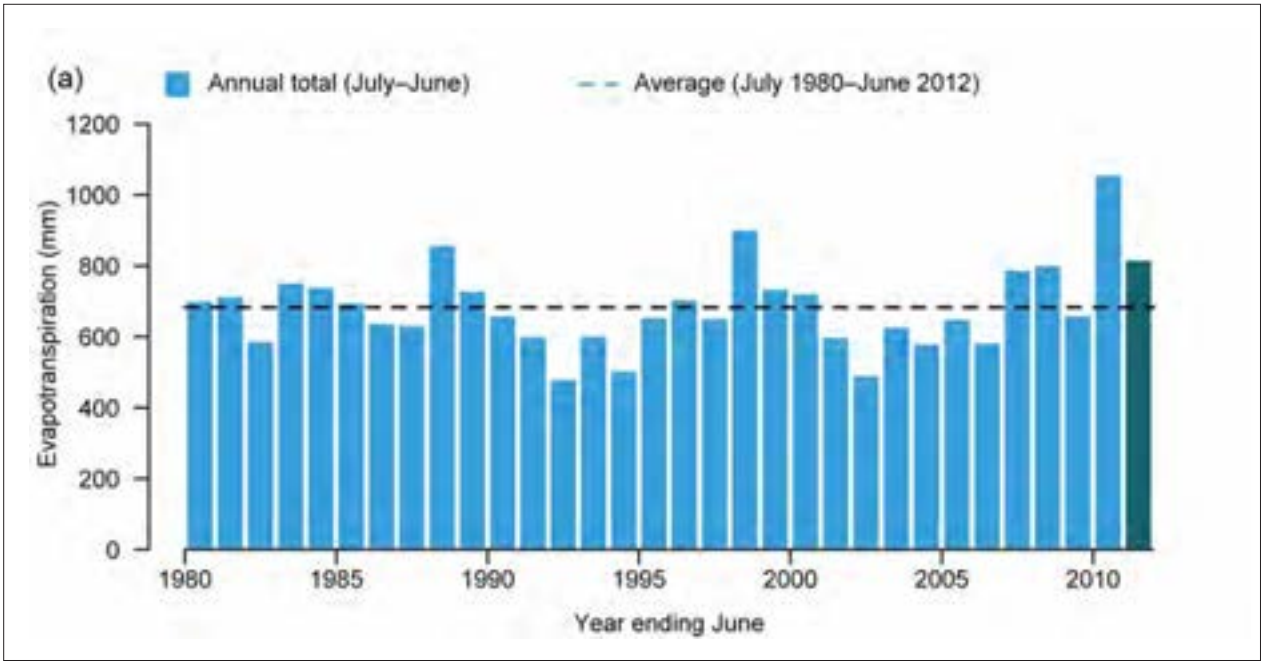
Figure 3.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North East Coast region

Evapotranspiration variability in the recent past

Figure 3.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 682 mm, varying from 477 mm (1992–93) to 1,054 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 3.17b.

Summer periods showed consistently higher evapotranspiration rates than the winter period.

The higher temperatures and the higher rainfall amounts during these periods contribute to this. Compared with the seasonal rainfall (Figure 3.14b), the cyclical time-series of seasonal evapotranspiration is less pronounced (Figure 3.17b).



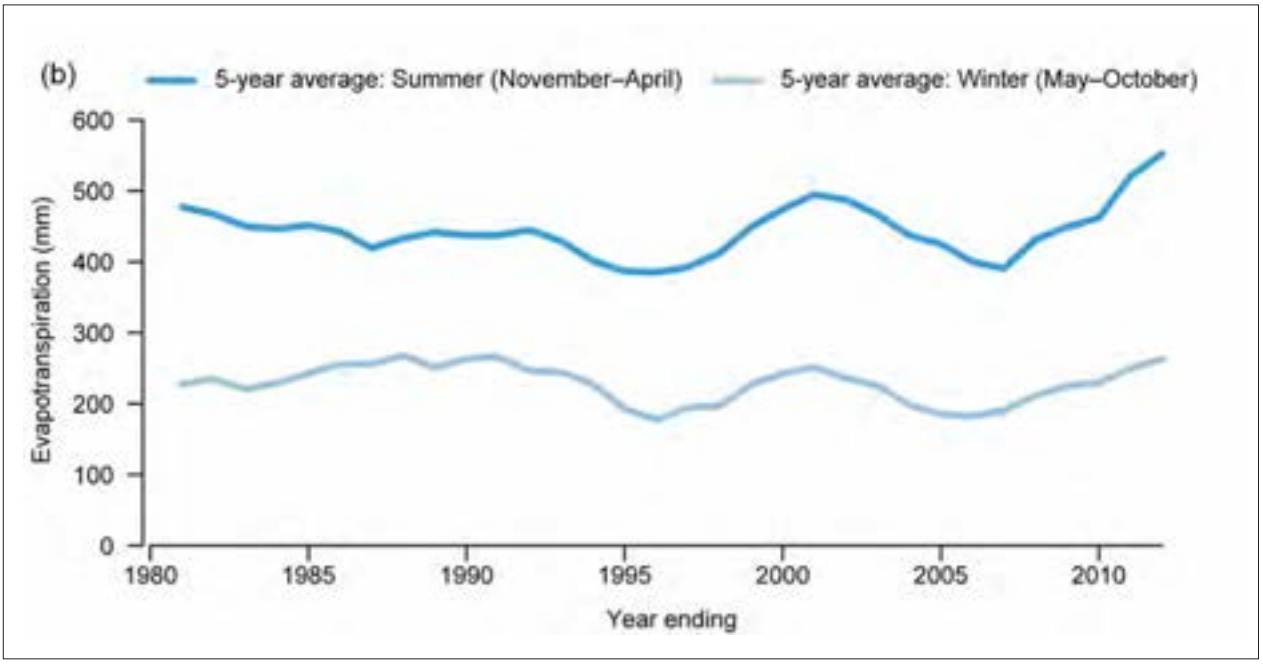


Figure 3.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North East Coast region

Recent trends in evapotranspiration

Figure 3.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980– 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 3.18b.

Figure 3.18a shows that since 1980 trends are mostly rising in the central northern part of the region. In the south, the trends are more neutral to weakly falling.

As shown in Figure 3.18b, the trends are generally only statistically significant in some inland parts of the region. In the south of the region the falling trends have no statistical significance.

As evapotranspiration is driven by the availability of moisture, the trends are related to the cyclic pattern in the rainfall shown in Figure 3.14 and the particularly high rainfall of 2010–11 and 2011–12.

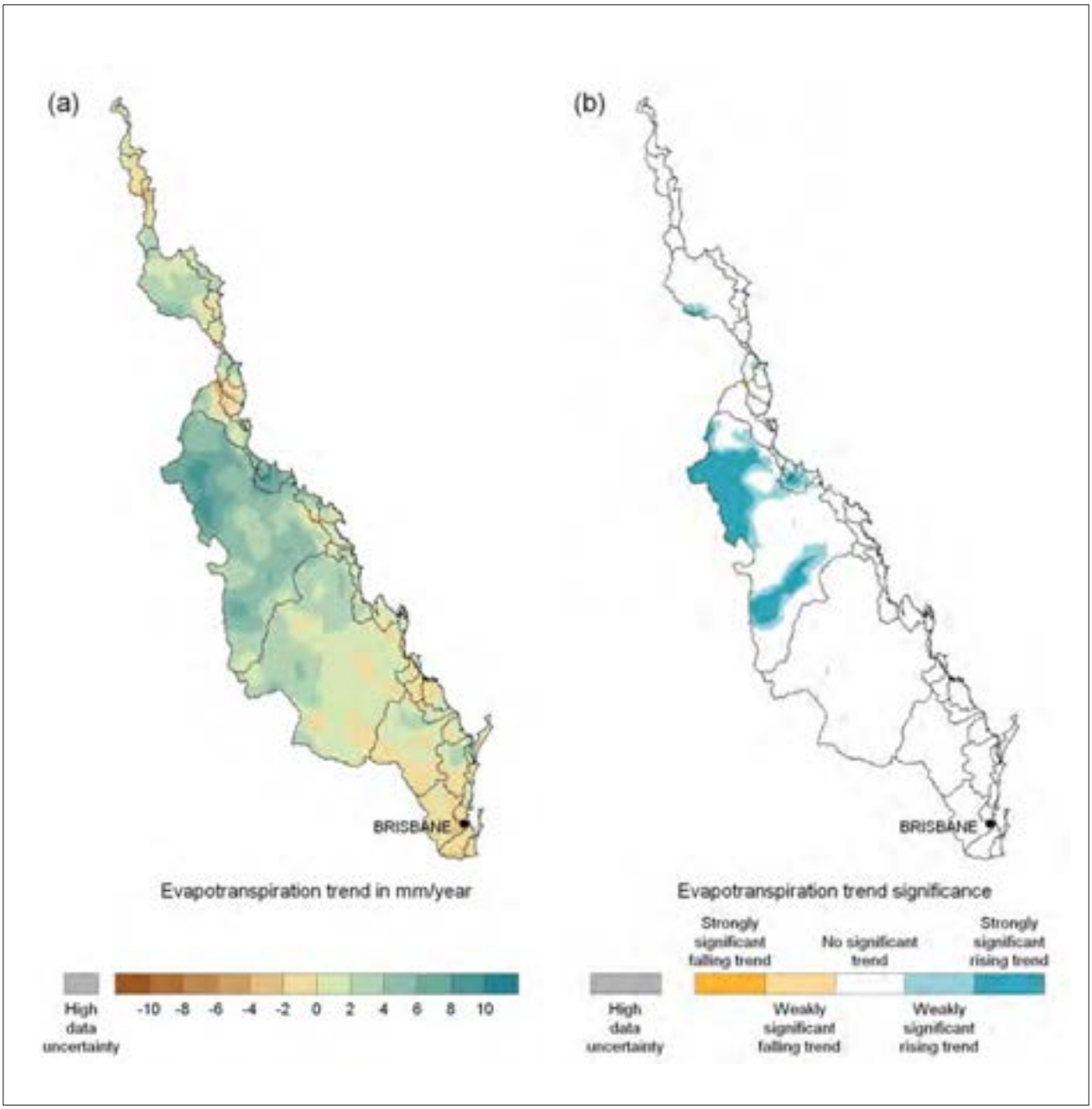


Figure 3.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North East Coast region

3.4.3 Landscape water yield

Modelled landscape water yield for the North East Coast region for 2011–12 is estimated to be 223 mm. This is 42% above the region's long-term (July 1911–June 2012) average of 157 mm.

Figure 3.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to that shown in Figure 3.14a, annual rainfall distribution. This is a result of rainfall intensity and volume being the dominant drivers for generating landscape water yield.

The highest landscape water yields in 2011–12 are observed in areas along the mid-north and south coast, locally exceeding 1,200 mm. For the rest of the region, the landscape water yield did not exceed 400 mm.

Figure 3.19b is the decile-ranking map for 2011–12 and shows average to very much above average landscape water yields.

Above average water yields are found across much of the inland areas, with very much above average yields along the western border, as well as along the southern coast.

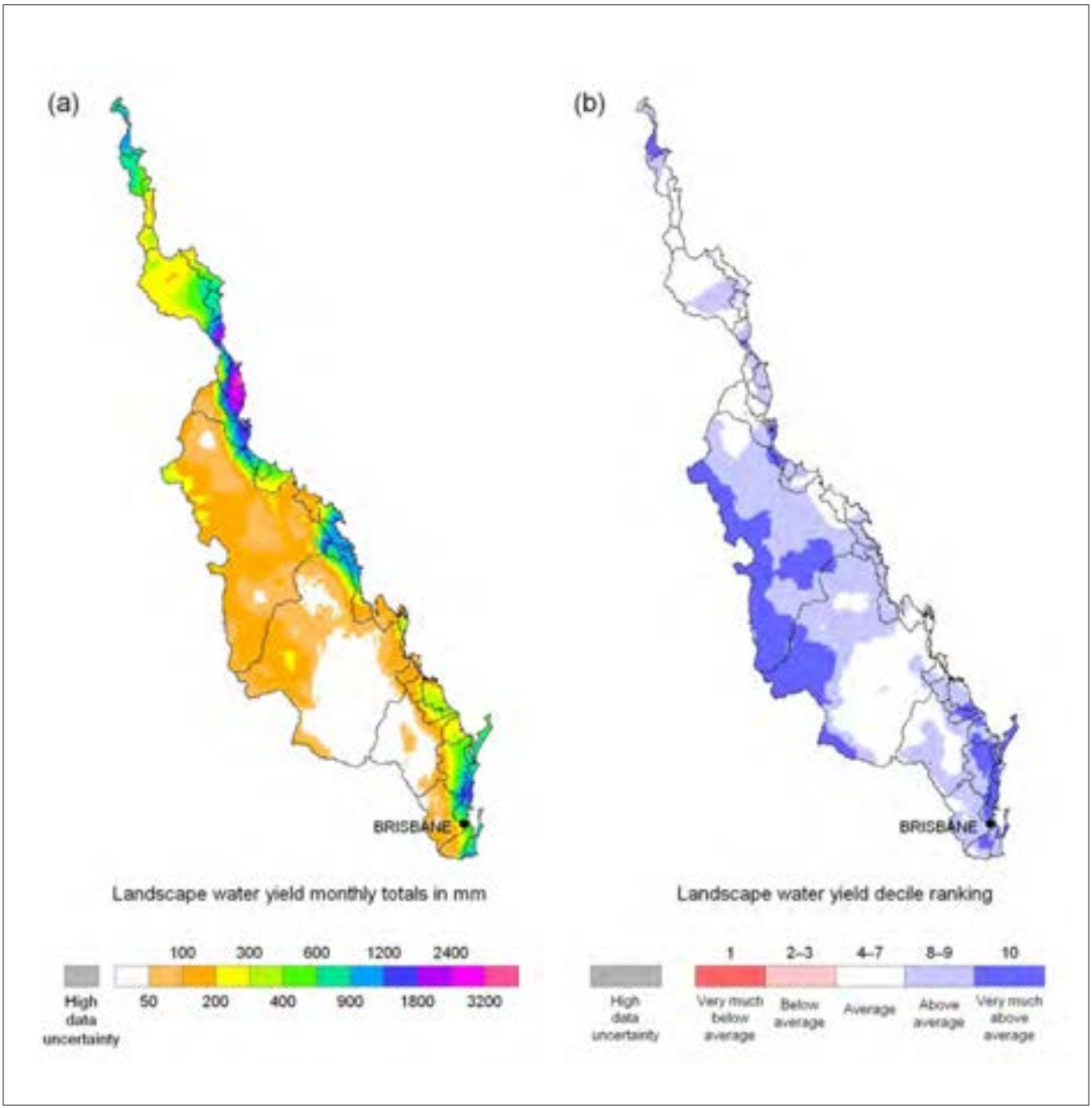


Figure 3.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North East Coast region

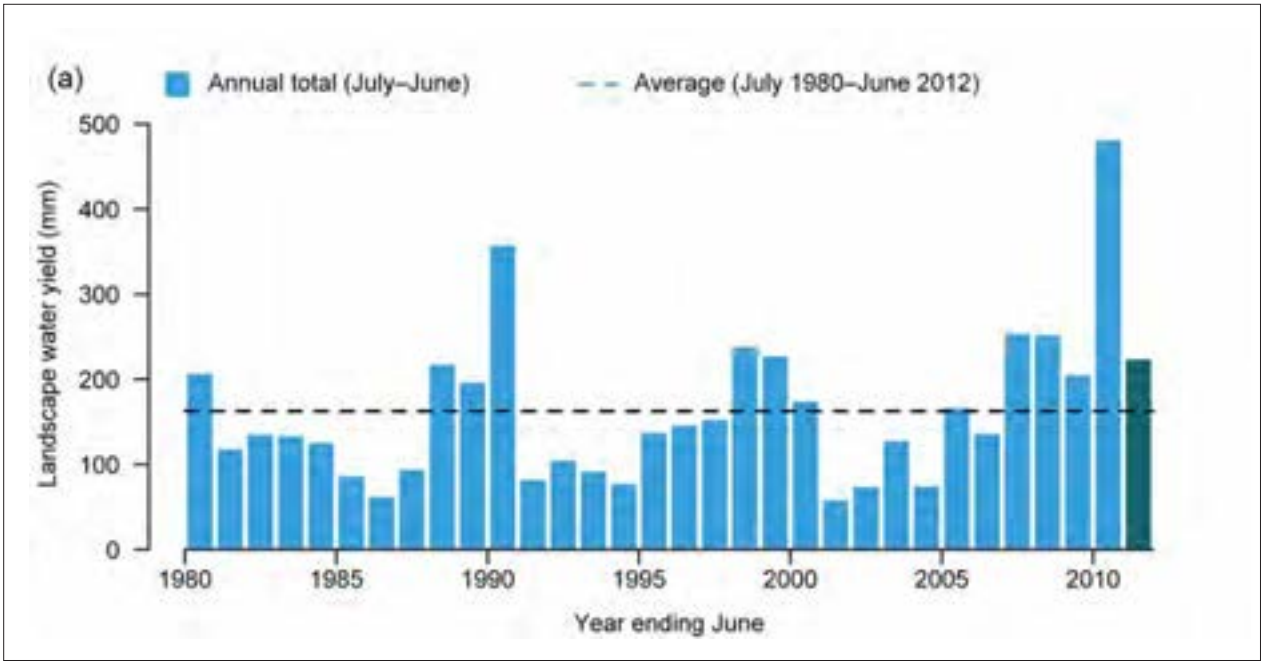
Landscape water yield variability in the recent past

Figure 3.20a shows annual landscape water yield for the North East Coast region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 162 mm, varying from 58 mm (2001–02) to 481 mm (2010–11).

Temporal variability and seasonal patterns since 1980 are presented in Figure 3.20b.

As shown in Figure 3.20b, landscape water yield is consistently higher during the summer period compared to the winter period.

The summer period's average also exhibits a greater inter-annual and cyclical variability driven by the region's rainfall dynamics.



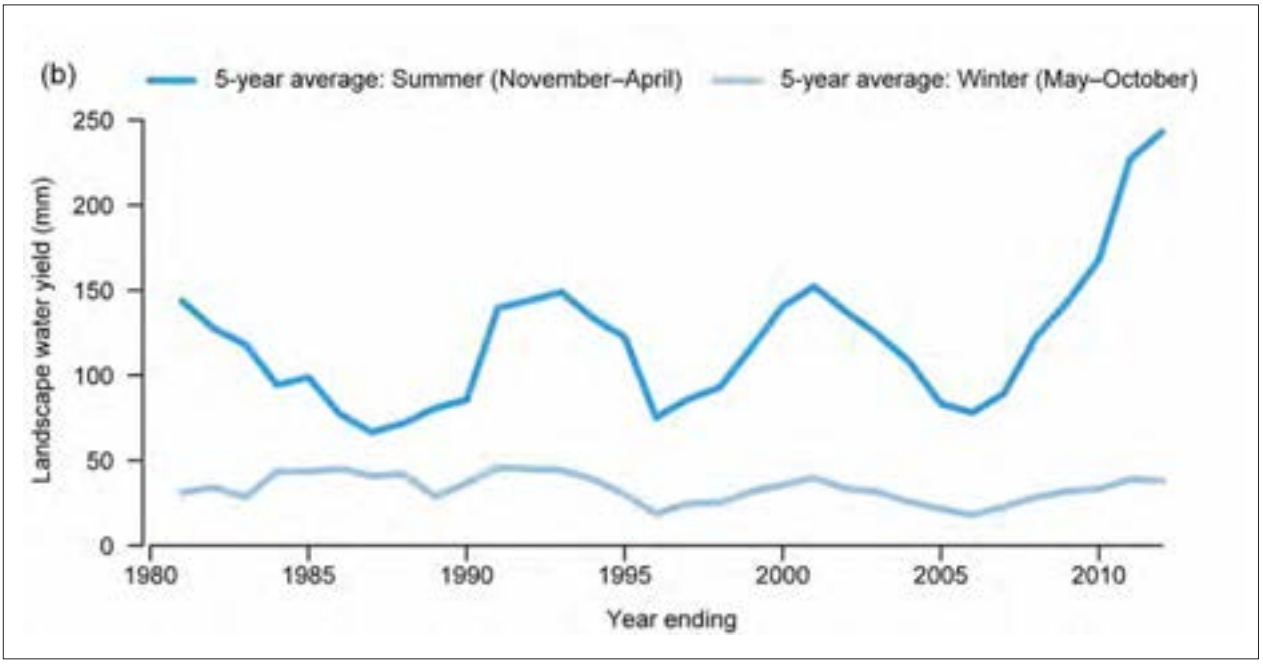


Figure 3.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North East Coast region

Recent trends in landscape water yield

Figure 3.21a presents the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 3.21b.

Figure 3.21a shows that since 1980 rising trends occur along the coast, particularly in areas where annual rainfall normally exceeds 1,200 mm. In the inland part of the region, weaker rising trends occur.

Figure 3.21b shows strongly significant trends occur mainly in the inland parts of the region. The high landscape water yields between 2007–08 and 2011–12 (Figure 3.20a) contributed appreciably to these rising trends.

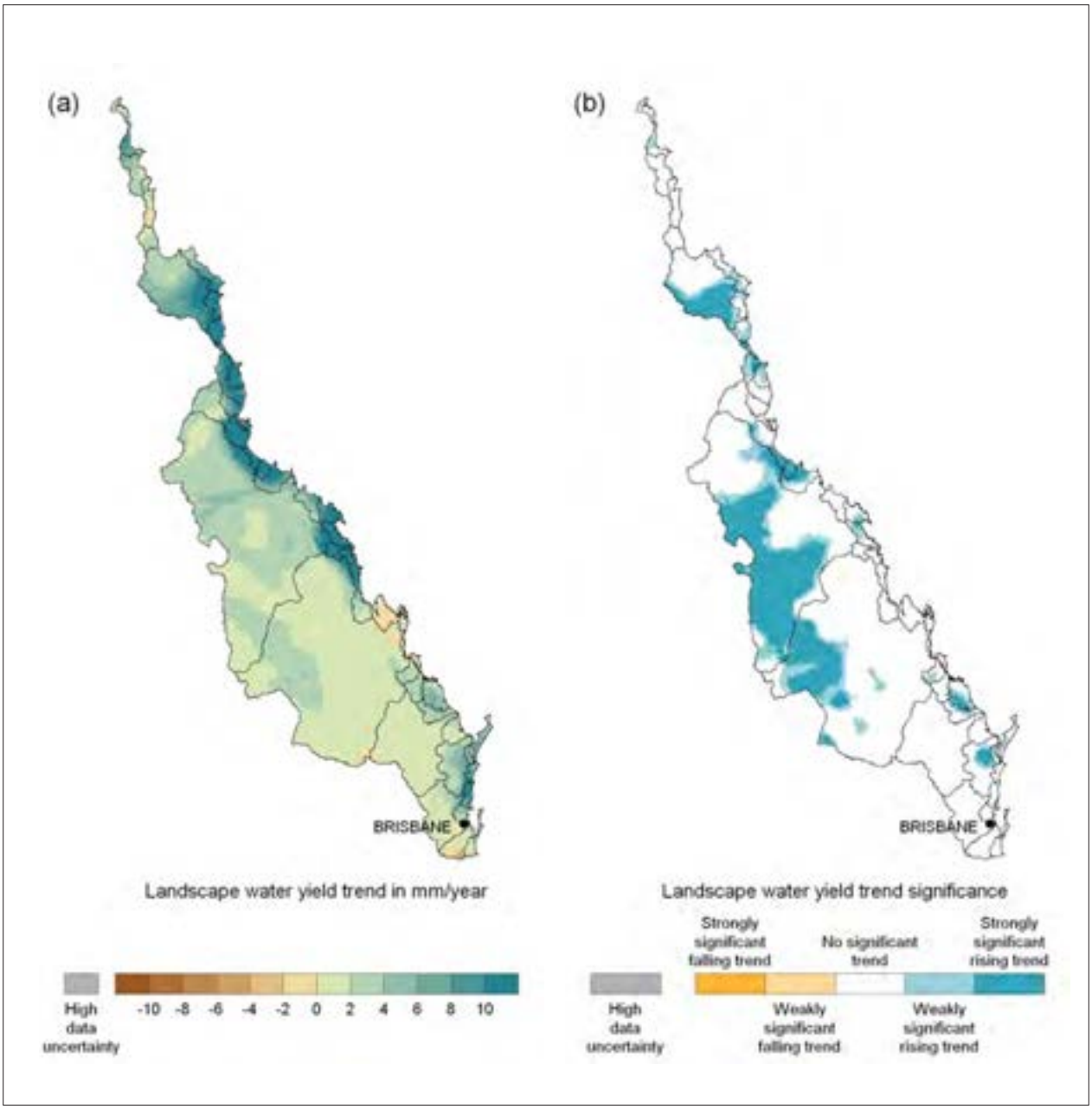


Figure 3.21 Spatial distribution of (a) trends in annual landscape water yield from 1980– 2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North East Coast region

3.5 Surface water and groundwater

This section examines surface water and groundwater resources in the North East Coast region in 2011–12. An analysis of rivers, wetlands and water storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described and the groundwater status is illustrated by showing changes in groundwater levels at selected sites.

3.5.1 Rivers

All the rivers in this region drain to the Coral Sea with many of the rivers having outflows that can impact on the Great Barrier Reef.

Figure 3.22 shows the 45 river basins in the region, which vary in size from 400–143,000 km^2.

Many of the rivers have high summer flows with relatively long periods of low or zero flows in winter, especially to the mid-north of the region. Streams in the southeast of the region generally flow all year round but still show distinct seasonal variation.

The Burdekin and the Fitzroy rivers are amongst the largest Australian rivers in terms of their total flow volumes. The Burdekin River is a south-flowing ephemeral river which often dries to just a series of disconnected water holes, and runs over 300 km before turning east to the sea.

The lower reaches of the Fitzroy River are perennial but a large proportion of the tributaries in the catchment are ephemeral.

The lower Burdekin, Nogoa and Mackenzie rivers run through highly modified catchments. The Burnett River basin is the third largest basin in the region.

The Fitzroy River, east of Rockhampton | John Casey, Dreamstime

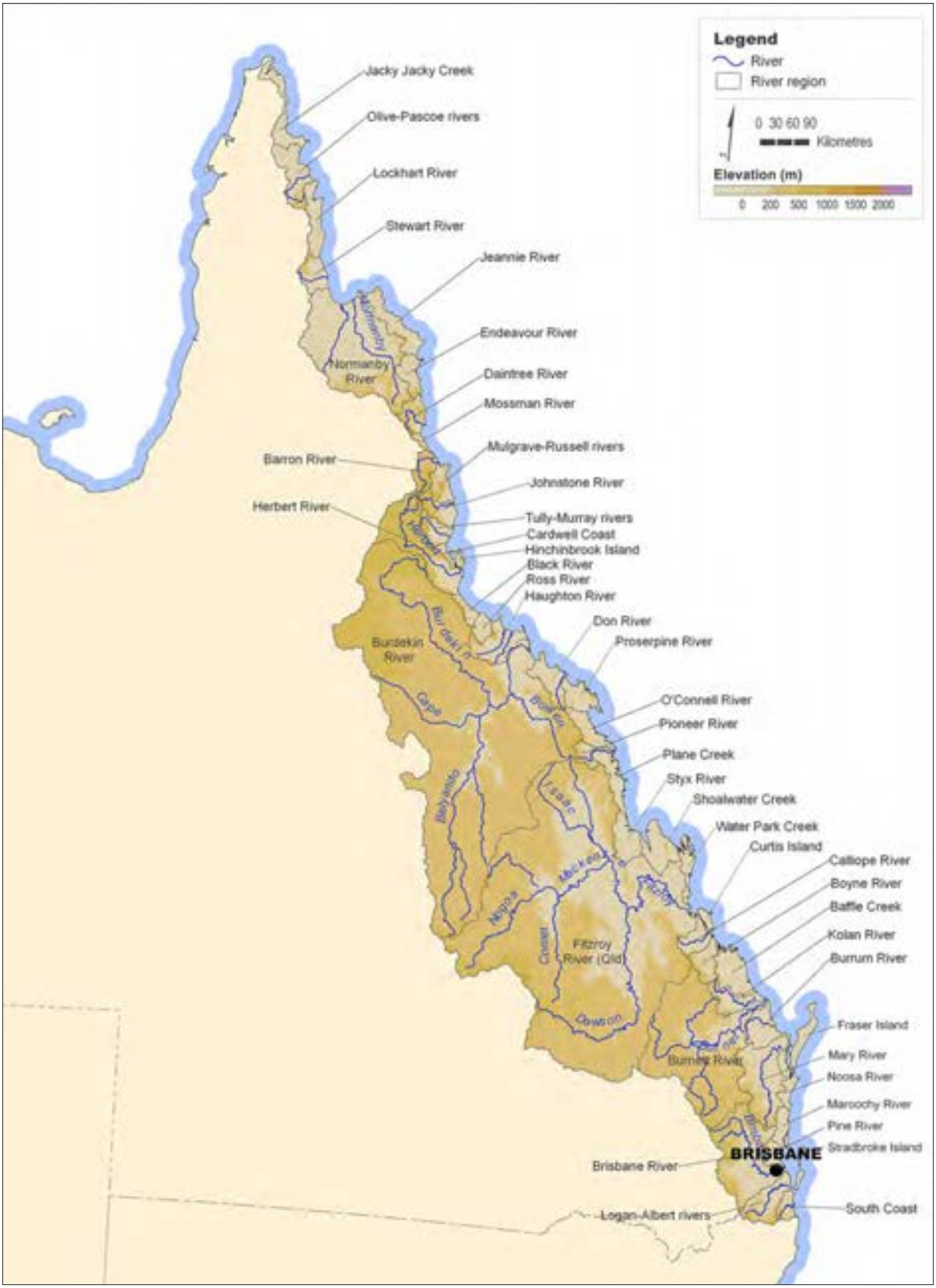


Figure 3.22 Rivers and catchments in the North East Coast region

3.5.2 Streamflow volumes

Figure 3.23 presents an analysis of flows at 46 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across 20 geographically representative rivers were selected (see Technical Supplement for details).

The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period. The flows generally reflect the mostly average to above average modelled landscape water yield results shown in Figure 3.19b.

High run-off, generated in the upstream reaches of the rivers, caused above average to very much above average flows in many rivers in the central part of the North East Coast region.

Very much above average flows were observed at five monitoring sites located on rivers in the west: the north Johnstone River in the central north and the Gregory River in the southeast of the region.

Above average total flows were recorded at 23 monitoring sites. These were mainly located on the rivers to the south, some centrally located rivers, and in some river basins to the central north of the region.

Average flows occurred at 17 sites in the region that were on the rivers in the southwest and far south of the region, and among river basins in the central north and far north of the region.

There was only one below average flow recorded for the 46 monitoring sites examined across the region. This was on the Normanby River in the north.

As shown in Figure 3.23, deciles in the summer (November 2011–April 2012) were very similar to total annual flows for 2011–12. This is not surprising given that the greatest volume of flows in the region, particularly in the central north, occurred over the summer months. There are a few monitoring sites that did not show this pattern, such as the relatively low flows observed in the summer period on the Stewart River in the far north of the region.

3.5.3 Streamflow salinity

Figure 3.24 shows an analysis of streamflow salinity for 2011–12 at 79 monitoring sites throughout the North East Coast region. Monitoring sites with at least a five-year data record were selected for analysis. The results are shown as electrical conductivity (EC, µS/cm). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The circle size depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

The median EC values for most of the selected monitoring sites fall in the range 0–1,000 µS/cm, an amount that is suitable for most irrigation uses. Some results for small rivers and creeks in the Fitzroy River basin and the Logan River basin fall outside this range (see Figure 3.24). Of the 79 monitoring sites, 53% had median EC values below 500 µS/cm and 33% were between 500–1,000 µS/cm. Only 14% of the monitoring sites had a median EC above 1,500 µS/cm.

Rivers with higher (>1,000 µS/cm) median salinities all occur in the southern half of the region. They are typically associated with low annual flows. Median stream salinity was above 2,000 µS/cm at three of the 79 monitoring sites. These were from one monitoring site on the Dee River that is a tributary of the Dawson River, and two creeks in the Fitzroy River basin. High salinity in the Dee River is influenced by the decommissioned Mount Morgan gold mine, from which leachates enter the Dee River.

The salinity CV values vary widely across the North East Coast region. The CV is high at a few monitoring sites in the south and northwest, and in the Dee River in the east. In contrast, the CV is relatively low for most rivers in the south, northeast, and central parts of the region. The CV of salinity is typically related to the variability in annual flow at the monitoring site.

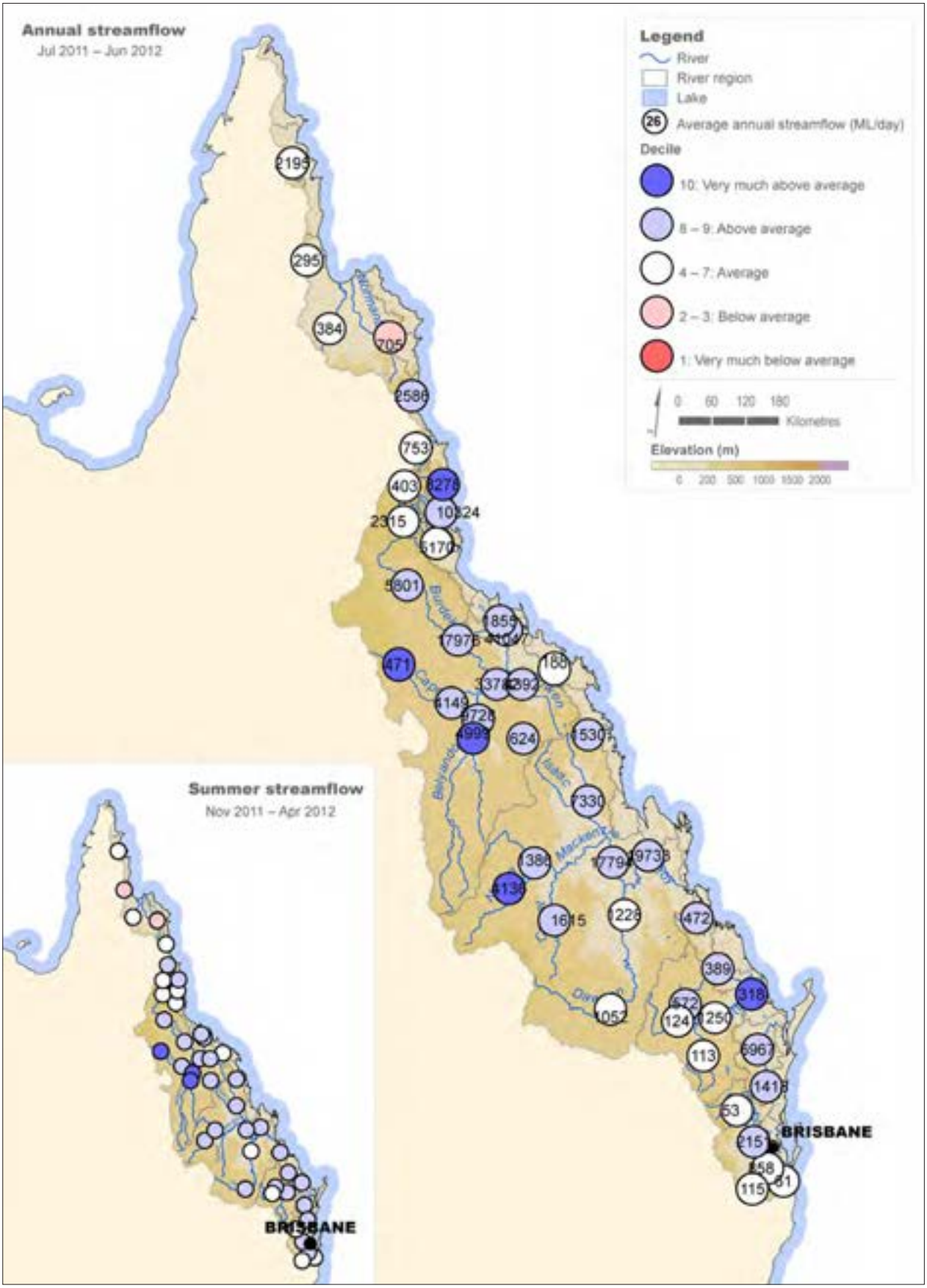


Figure 3.23 Average annual and summer period flow volumes of selected gauges for 2011–12 and their decile rankings over the 1980–2012 period in the North East Coast region

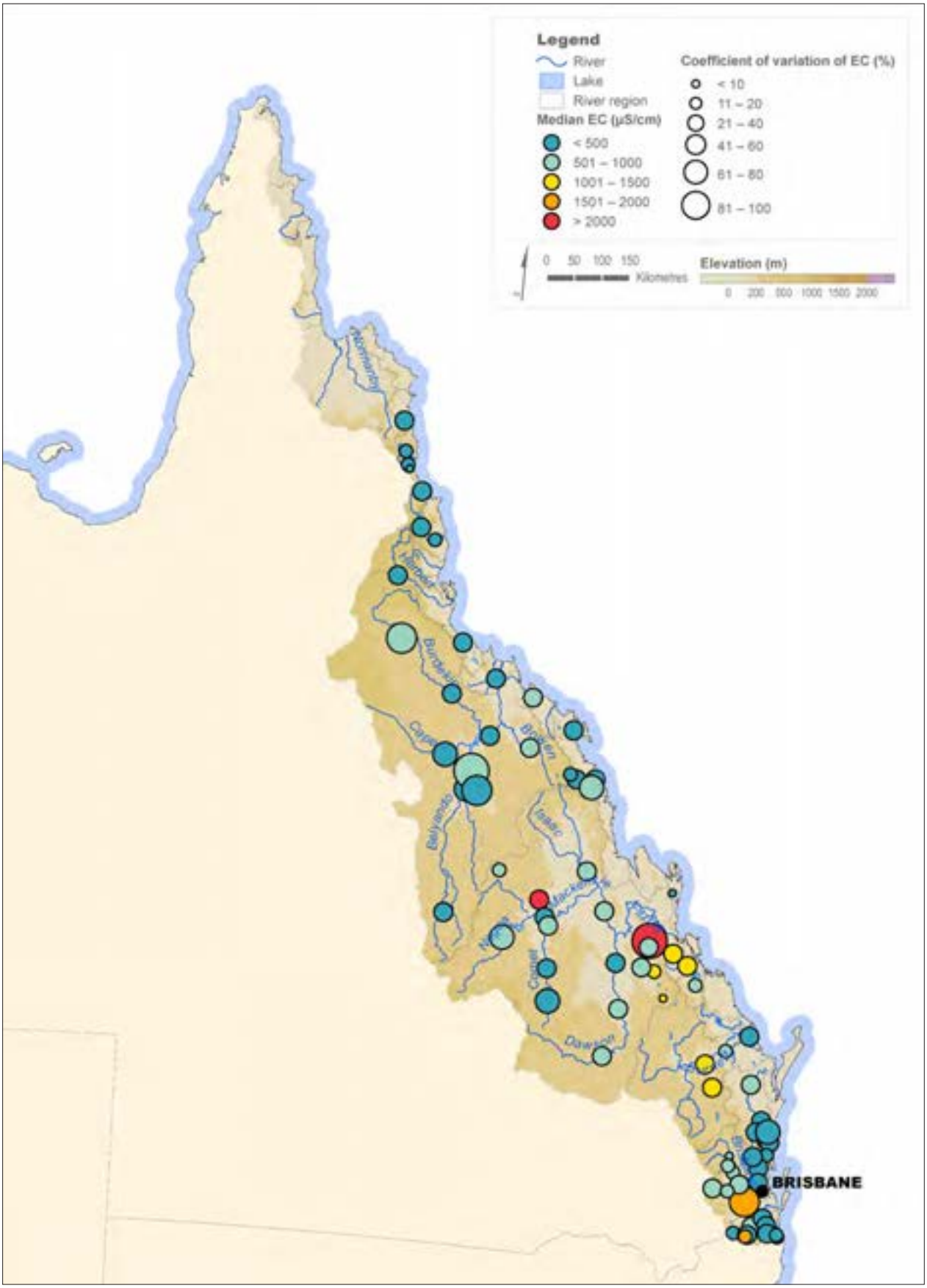


Figure 3.24 Salinity as electrical conductivity and its associated coefficient of variation for 2011–12 in the North East Coast region

Of the 79 monitoring sites, 27% had a coefficient of variation below 20%; 67% of the sites had CV between 20% and 60%; and only 6% of the sites had CV above 60%. These were on the Suttor River in the Burdekin River basin in the centre of the region, Dee River in the central east and Purga Creek in the Brisbane River basin in the south of the region.

Stream salinity variation was above 80% at one of the 79 monitoring sites. This was on the Suttor River in the Burdekin River basin in the centre of the region.

3.5.4 Flooding

Floods in the North East Coast region are mainly caused by two rainfall types. These are localised high intensity rainfall (for example, thunderstorms) or prolonged periods of rainfall (for example, frontal rainfall, monsoon, tropical storms). While the first rainfall type often results in localised flash flooding, the prolonged rainfall can cause sustained floods over large areas.

The region has a seasonal pattern of rainfall, with most rainfall occurring in summer, in which both rainfall types occur frequently.

Figure 3.25 shows the locations where the Bureau monitors river levels in the region as part of its flood forecasting services. The highest flood levels experienced during 2011–12 are shown in terms of the flood classification levels established in consultation with emergency management and local agencies to describe flood impacts at each location (see Technical Supplement).

A large number of major floods occurred in 2011–12 (Figure 3.25). In large rivers to the central west of the region major floods were observed during January and February 2012. The prolonged rainfall in the last week of January resulted in high water levels in the southern tributaries of the Burdekin River and most of the upstream tributaries of the Fitzroy River.

The prolonged January rainfall also impacted the rivers around Brisbane in the southern part of the region. Although not as severe as the January 2011 floods, some areas in the Brisbane and Logan river basins experienced major flooding; however the impacts in suburban Brisbane and surrounds were less severe with only minor to moderate flooding.

In March, the monsoon in the northern part of the region delivered large amounts of rainfall to the coastal areas of north Queensland. Major flooding occurred in many small rivers. Flooding also occurred further south in some rivers between Brisbane and Rockhampton, where rainfall for this month was up to 400 mm.

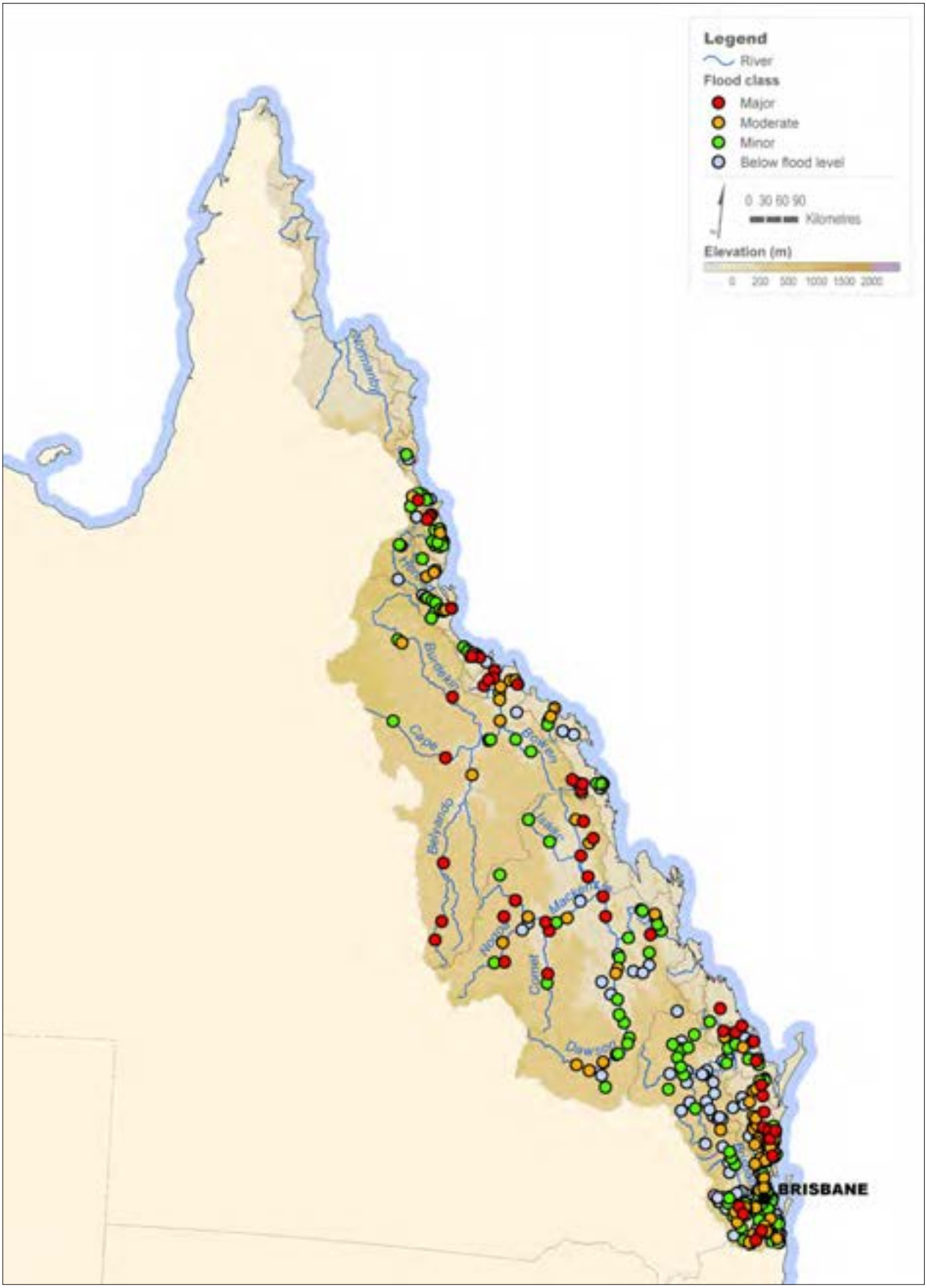


Figure 3.25 Flood occurrence in 2011–12 for the North East Coast region, with each dot representing a river level monitoring station and the colour of the dot representing the highest flood class measured

3.5.5 Storage systems

There are over 100 major, publicly-owned water storages in the North East Coast region with a total accessible capacity in excess of 10,400GL.

The Bureau's water storage information (as at August 2012) covers approximately 92% of the region's publicly owned storage capacity. Storages supply 17 irrigation areas as well as the city of Brisbane.

Table 3.3 gives a summary of the major storage systems together with an overview of the storage levels at the end of 2010–11 and the end of 2011–12. The location of all the systems and associated storages are shown in Figure 3.26.

Total accessible storage in the region for the 2011–12 year increased marginally, with most storages close to full capacity. The major increase was in the Brisbane system, where volumes went up from 85 to 94%. The only substantial drop in storage levels was in the Callide system.

More details on the Brisbane and Burdekin Haughton systems is provided in the 'Water for cites and towns' and 'Water for agriculture' sections in this chapter.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

Table 3.3 Major public storage systems in the region as identified in the Bureau's water storage website (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume 30 June 2012
Brisbane	urban	2,220 GL	1,882 GL — 85%	2,093 GL — 94%
Burdekin Haughton	rural	1,868 GL	1,866 GL—100%	1,868 GL—100%
Nagoa Mackenzie	rural	1,305 GL	1,296 GL—99%	1,297 GL—99%
Bundaberg	rural	909 GL	908 GL—100%	906 GL—100%
Proserpine	rural	490 GL	490 GL—100%	480 GL—100%
Mareeba Dimbulah	rural	438 GL	433 GL—99%	437 GL—99%
Boyne Tarong	rural	196 GL	195 GL—100%	196 GL—100%
Upper Burnett	rural	187 GL	182 GL—97%	182 GL—97%
Callide	rural	148 GL	140 GL—95%	105 GL—71%
Pioneer	rural	147 GL	146 GL—99%	146 GL—99%
Barker Barambah	rural	134 GL	134 GL—100%	134 GL—100%
Bowen Broken	rural	116 GL	115 GL—99%	116 GL—100%
Three Moon Creek	rural	88 GL	88 GL—100%	88 GL—100%
Warrill valley	rural	86 GL	83 GL—97%	82 GL—95%
Eton	rural	62 GL	61 GL—98%	62 GL—100%
Mary river	rural	56 GL	56 GL—100%	56 GL—100%
Logan river	rural	44 GL	44 GL—100%	44 GL—100%
Non-allocated	—	1,022 GL	1,016 GL—99%	1,009 GL—99%
Total		**9,516 GL**	**9,135 GL—96%**	**9,301 GL—98%**

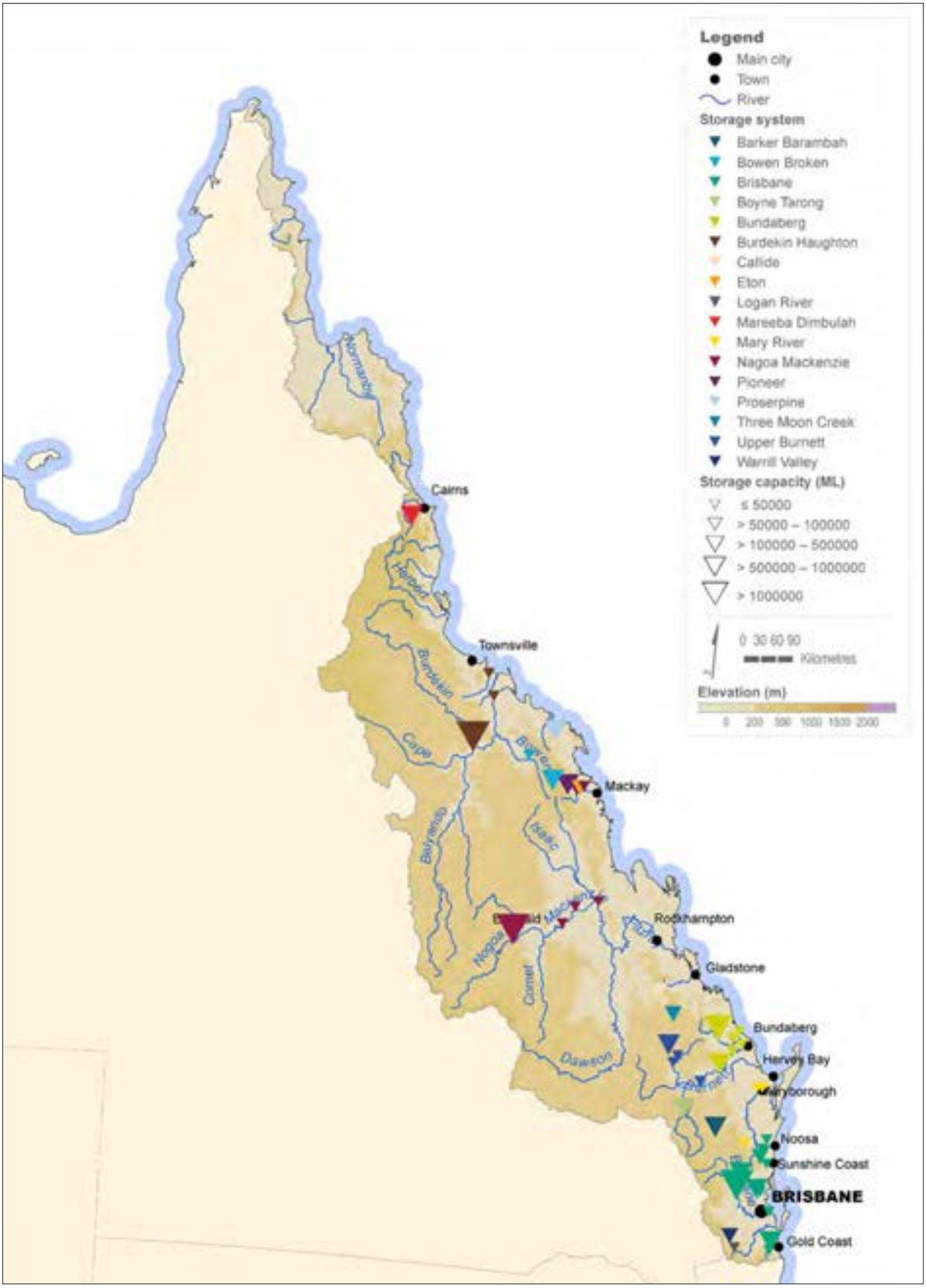


Figure 3.26 Storage systems in the North East Coast region (information extracted from the Bureau of Meteorology's water storage website in August 2012)

3.5.6 Wetlands

Important wetlands

As seen in Figure 3.27, there are a large number of wetlands of national and international importance in the North East Coast region that encompass a wide diversity of wetland types, from coastal floodplains to higher altitude freshwater streams and waterfalls. The wetlands create a mosaic of temporally and spatially dynamic habitats within this part of Australia. The most spatially extensive wetland types in the region are artificial freshwater storages and the marine-influenced coastal flats and mangroves.

The artificial wetlands, despite being constructed from dammed watercourses for urban and rural water supply and flood retardation purposes, provide recreational and ecosystem values such as aquatic habitat for a number of important flora and fauna species. The brackish to saline coastal wetlands in this region provide ecosystem services such as mangrove and salt-marsh habitat as well as acting as filters reducing sediment discharges to the Great Barrier Reef.

Inflows to selected wetlands

The state of the biodiversity in a wetland is linked to the way water is stored within the area and the temporal variability of inflows. An analysis of historic and recent inflows into wetlands forms an informative picture of potential changes.

Three internationally-recognised Ramsar wetland sites (Bowling Green Bay, Great Sandy Strait and Moreton Bay) and one nationally-listed freshwater wetland (the Southern Fitzroy River wetland complex) were selected for hydrological analysis of major inflows. More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html)

Seven upstream monitoring gauges were selected to enable the analyses and interpretation of inflows to these four wetlands. The gauges used in the analyses are the closest upstream gauges that have largely continuous discharge records since 1980.

Though the analyses do not capture the total inflows, they are indicative of the temporal patterns of freshwater surface flows to these wetlands.

Woodhouse Lagoon | NQ Dry Topics

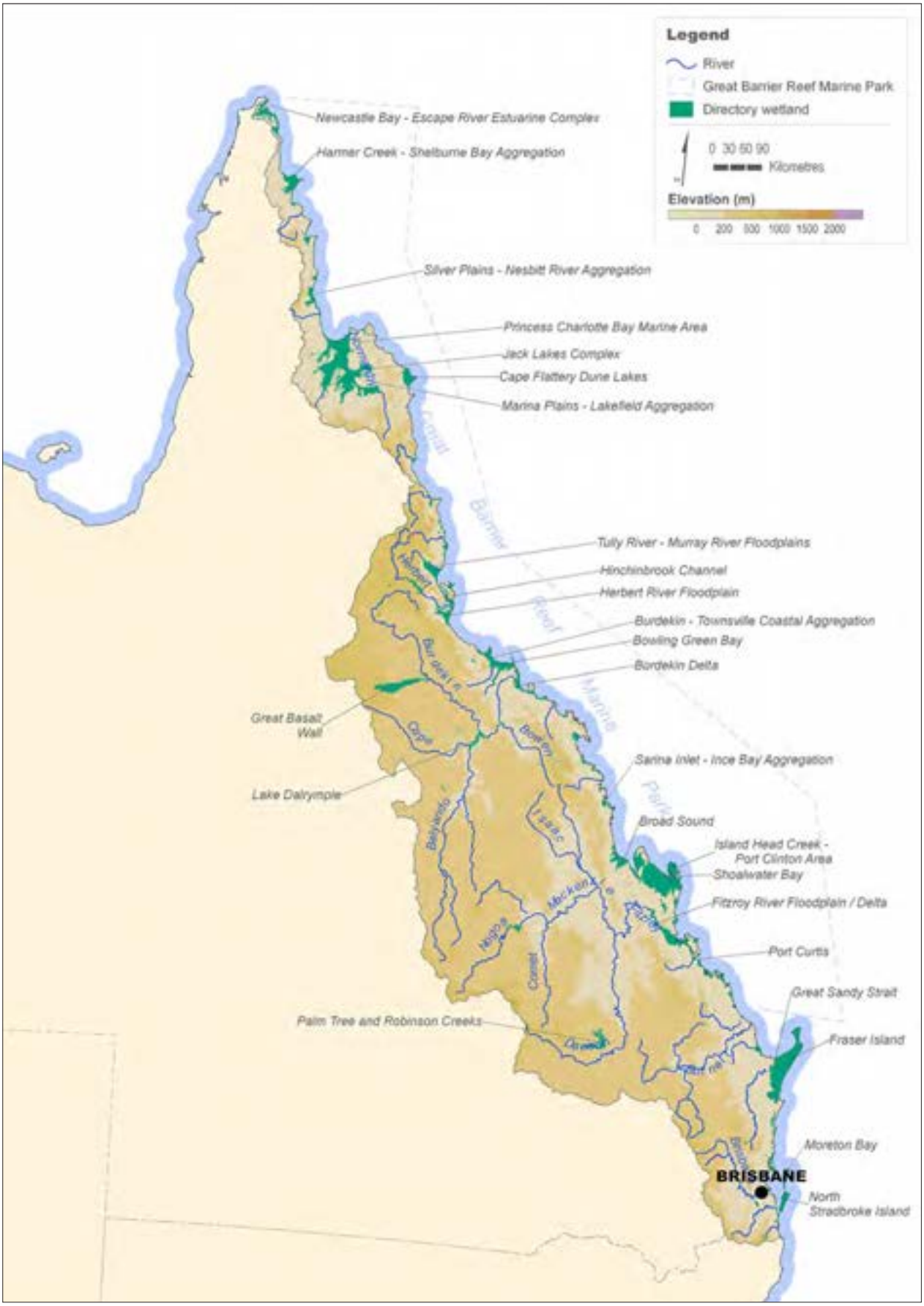


Figure 3.27 Location of important wetlands in the North East Coast region

Bowling Green Bay

Wetlands centred on Bowling Green Bay, south of Townsville, form one of tropical Australia's largest and most diverse coastal wetlands. The wetlands are mostly coastal plains covered in tidal mudflats, mangrove forest and salt marshes. River channels and freshwater marshes also form part of this large wetland complex.

Daily discharge data for the monitoring gauges on the Haughton River at Powerline and on the Barratta Creek at Northcote have been combined to provide a temporal pattern of freshwater inflows into Bowling Green Bay (Figure 3.28).

Figure 3.28 Location of the monitoring sites in relation to Bowling Green Bay

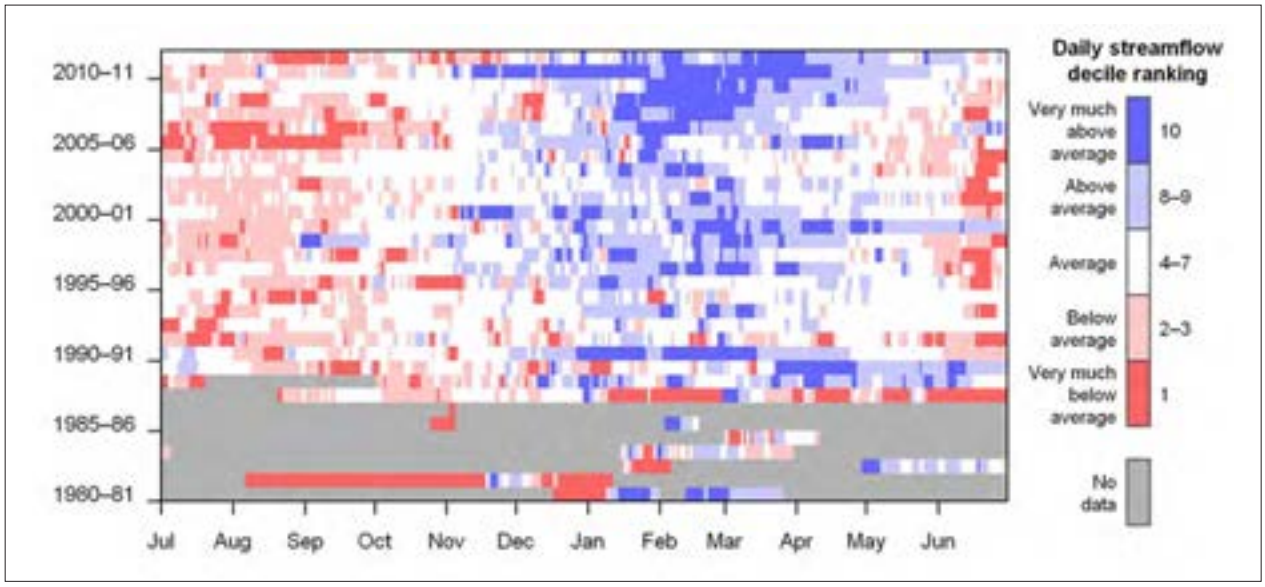


Figure 3.29 Daily flows of the Haughton River at Powerline and on the Barratta Creek at Northcote between 1980 and 2012, ranked in decile classes

Figure 3.29 presents an overview of the distribution of daily streamflow decile rankings for the period between 1980 and 2012. The data is fairly sparse until 1987. Thereafter one can see a pattern of wet periods in blue of varying length usually between November and May. From 2008–09 there has been an increase in the length of the period of very much above average flows.

Figure 3.30 compares monthly discharges from 2011–12 with the flow statistics from 1980 onwards. The March 2012 flows well exceeded the ninth decile of the 32-year record and contributed a substantial amount of freshwater to Bowling Green Bay.

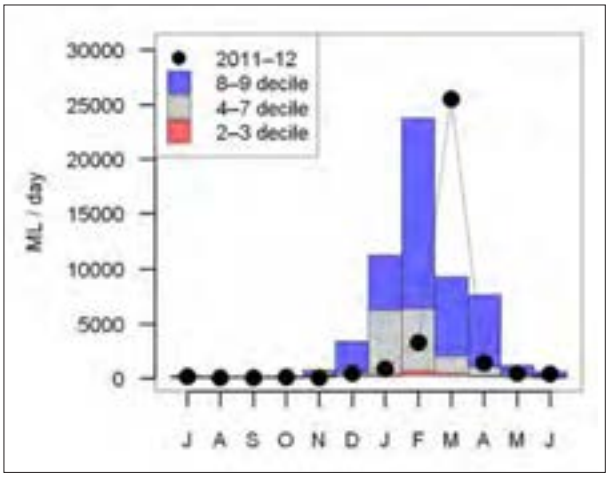


Figure 3.30 Combined monthly flows at Haughton River and Barratta Creek from 2011–12 compared with the 1980–2012 decile rankings

Southern Fitzroy River floodplain complex

The Fitzroy catchment is the second largest in the region, at nearly 150,000 km^2, and is dominated by agriculture and mining including coal mining. Inter-tidal wetlands are present particularly around the lower reaches of the river and south of the mouth. These wetlands typically consist of extensive saltpans fringed by mangroves.

Daily discharge data for the monitoring gauge on the Fitzroy River at The Gap provides a temporal pattern of freshwater inflows into the southern Fitzroy River floodplain complex (Figure 3.31).

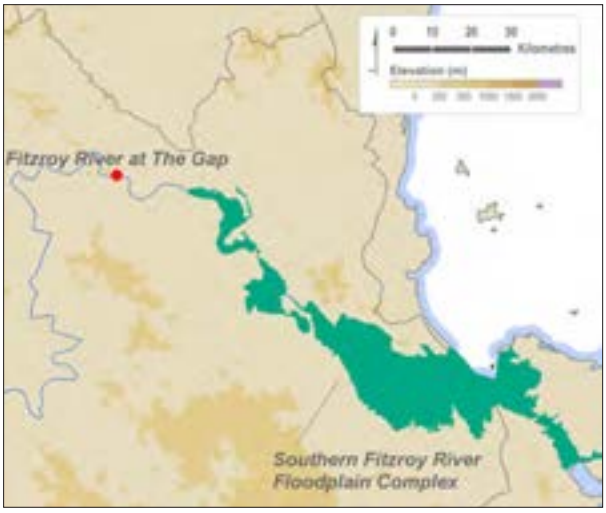


Figure 3.31 Location of the monitoring site in relation to the southern Fitzroy River floodplain complex

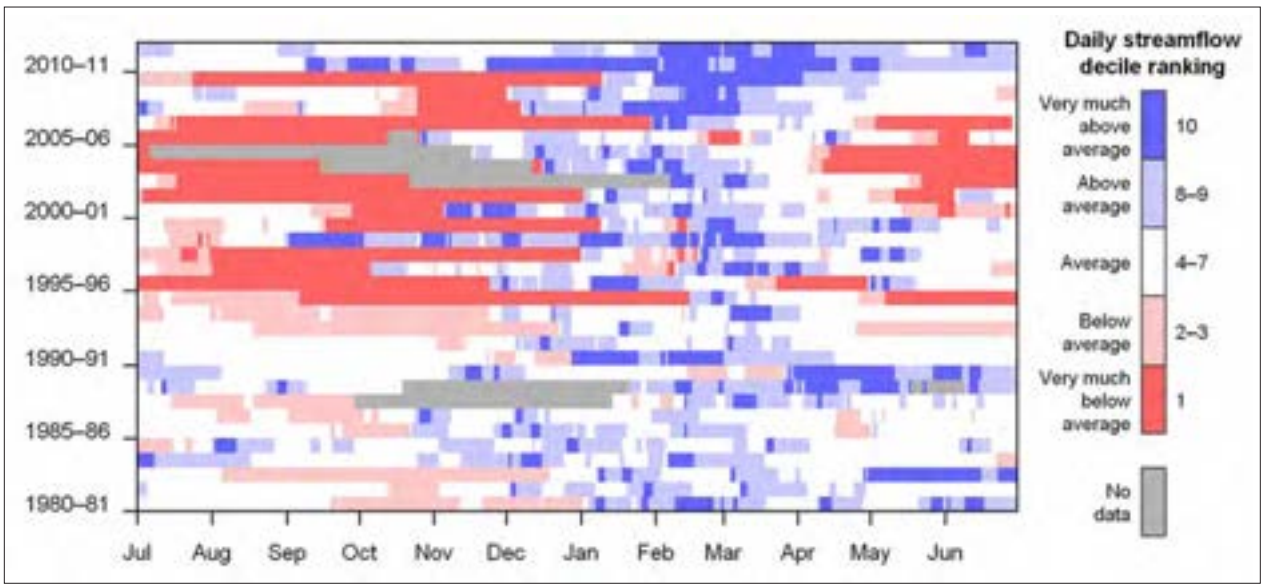


Figure 3.32 Daily flows of the Fitzroy River at The Gap between 1980 and 2012, ranked in decile classes

Figure 3.32 presents an overview of the distribution of daily streamflow decile rankings for the period between 1980 and 2012. From 1994 onwards, flows were generally very much below average during the dry period, except for the last two years. Additionally, there were extended periods of very much above average flows during the wet months of 2009–10 to 2011–12.

Figure 3.33 compares monthly discharges from 2011–12 with the flow statistics from 1980 onwards. The February and March 2012 flows contributed a substantial amount of freshwater to the floodplain complex.

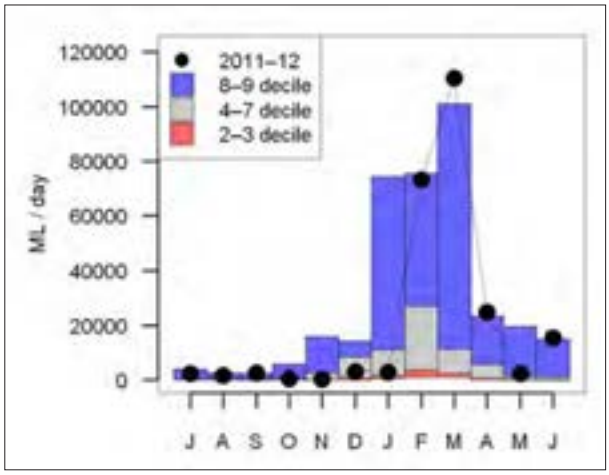


Figure 3.33 Monthly flows at the Fitzroy River monitoring site at The Gap from 2011–12 compared with its 1980–2012 decile rankings.

Great Sandy Strait

The Great Sandy Strait is enclosed between the Australian mainland and Fraser Island. The Mary River enters the strait at River Heads. The Strait is a complex landscape of mangroves, sandbanks, inter-tidal sand, mud islands, salt marshes and sea grass beds. It forms an important habitat for breeding fish, crustaceans, dugongs, dolphins and marine turtles.

Daily discharge data for the monitoring gauge on the Mary River at Miva (see Figure 3.34) provide a temporal pattern of freshwater inflows into the Great Sandy Strait.

Figure 3.34 Location of the monitoring site in relation to the Great Sandy Strait

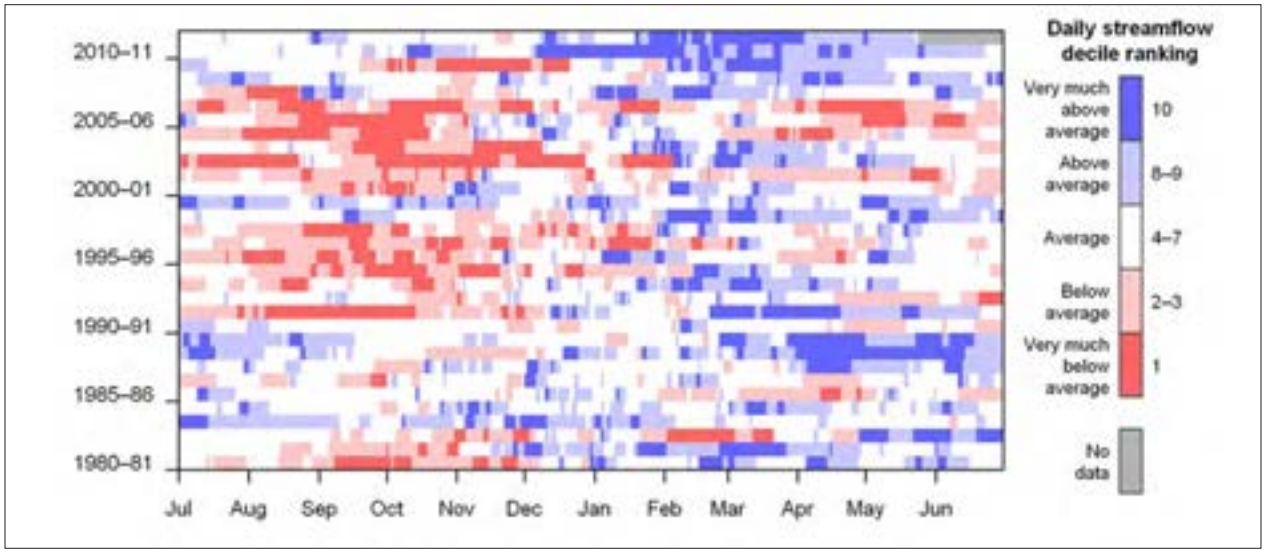


Figure 3.35 Daily flows of the Mary River at Miva between 1980 and 2012, ranked in decile classes

Figure 3.35 presents an overview of the distribution of daily streamflow decile rankings for the period between 1980 and 2012. An irregular pattern of high and low flows occurs throughout most years. There were extended periods of very much above average flows during the wet months of 2010–2012. Extended periods of very much below average flows occurred during 2002–03 to 2006–07.

Figure 3.36 compares monthly discharges from 2011–12 with the flow statistics from 1980 onwards. The January–March 2012 flows well exceeded the ninth decile of the 32-year record and contributed a substantial amount of freshwater to the wetland.

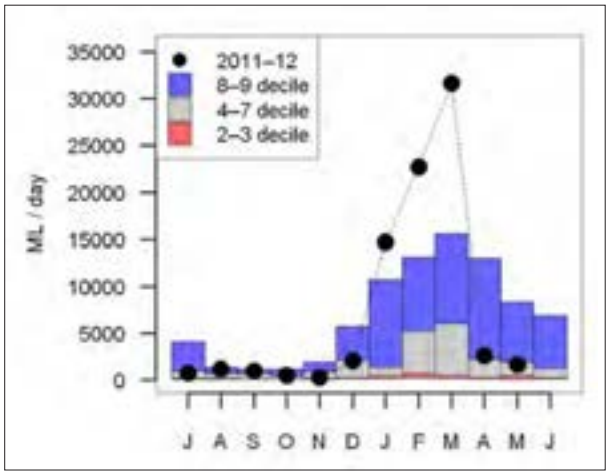


Figure 3.36 Monthly flows at the Mary River monitoring site at Miva from 2011–12 compared with its 1980–2012 decile rankings

Moreton Bay

Because of the existence of a series of off-shore barrier islands that restrict the flow of oceanic water, Moreton Bay acts similar to a lagoon. The wetlands in the bay range from perched freshwater lakes and sedge swamps on the offshore sand islands, to inter-tidal mudflats, marshes, sandflats and mangroves on the shores of the bay's islands and the mainland. The major rivers flowing into the bay pass through Brisbane.

Daily discharge data for the monitoring gauges on the Brisbane, Logan and Nerang rivers (Figure 3.37) have been combined to provide a temporal pattern of freshwater inflows into Moreton Bay.

Figure 3.37 Location of the monitoring sites in relation to Moreton Bay

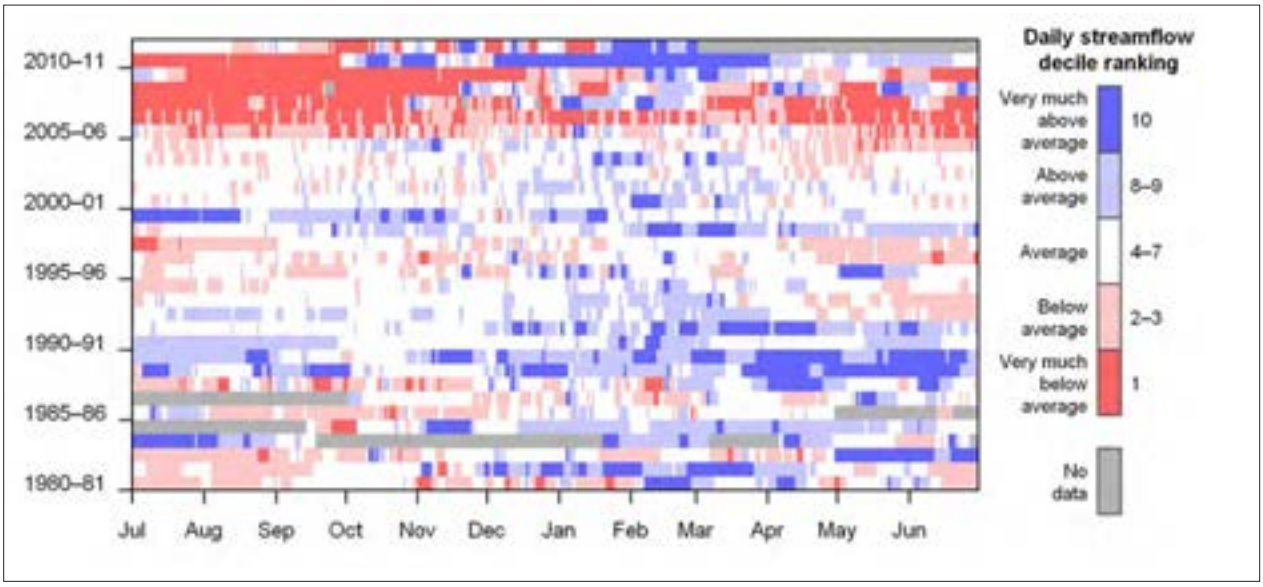


Figure 3.38 Combined daily flows of Brisbane, Logan and Nerang rivers between 1980 and 2012, ranked in decile classes

Figure 3.38 presents an overview of the distribution of daily streamflow decile rankings for the period between 1980 and 2012, ranked in decile classes. The Wivenhoe Dam in the Brisbane River was completed in 1985 and from then onwards flows in the river became increasingly regulated. Prolonged periods of very much below average inflows to the bay occurred between 2006–07 and 2010–11. The Brisbane floods of December 2010 broke this pattern.

Figure 3.39 compares monthly discharges from June 2011–March 2012 with the flow from 1980 onwards. Data was not available beyond March 2012. The March 2012 flows contributed a substantial amount of freshwater to the wetland.

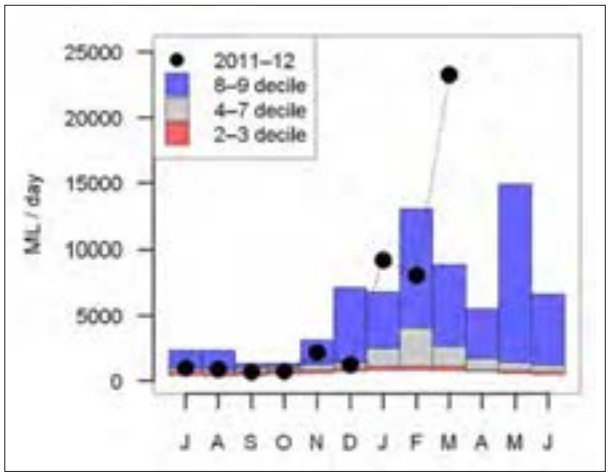


Figure 3.39 Combined monthly flows of Brisbane, Logan and Nerang rivers from 2011–12 compared with the 1980–2012 decile rankings

3.5.7 Hydrogeology

As seen in Figure 3.40, the North East Coast region is dominated by fractured rock groundwater systems that provide a low-volume groundwater resource. Greater resource potential is associated with the following aquifer groups:

- Surficial sediment aquifer (porous media—unconsolidated);
- Tertiary basalt aquifer (fractured rock); and
- Mesozoic sediment aquifer (porous media —consolidated).

Figure 3.40 shows that sediments of the Great Artesian Basin, which is one of Australia's largest and most significant groundwater basins, are present along the western border of the region; however, these sediments are not extensive in the North East Coast region.

3.5.8 Watertable salinity

Figure 3.41 shows the classification of watertable aquifers as fresh (total dissolved solids (TDS) < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L). The salinity was interpolated from bores less than 40 m deep using the long-term average groundwater salinity for all bores. Most parts of the region have fresh groundwater. Salty groundwater occurs in localised areas in the central highlands and the coast.

3.5.9 Groundwater management units

In Queensland, a number of groundwater areas have been established by the State government to protect underground water resources.

A groundwater area in Queensland is an area identified in the Water Regulation 2002 as a water resource plan or a wild river declaration. Within these areas authorisation is required to access groundwater or construct works to take groundwater for certain purposes.

The groundwater management units within the region are presented in Figure 3.42. This dataset is extracted from the Bureau's Interim Groundwater Geodatabase as compiled in 2009 (currently under revision).

Most groundwater management units are relatively small in area. In large areas, groundwater resources are used outside of groundwater management units (unincorporated areas). This pattern of groundwater use reflects the hydrogeology in the region, which is dominated by a large area of outcropping fractured basement rock typically offering restricted low-volume groundwater resources.

In contrast, significant groundwater resources are localised in alluvial valley systems and coastal sand deposits.

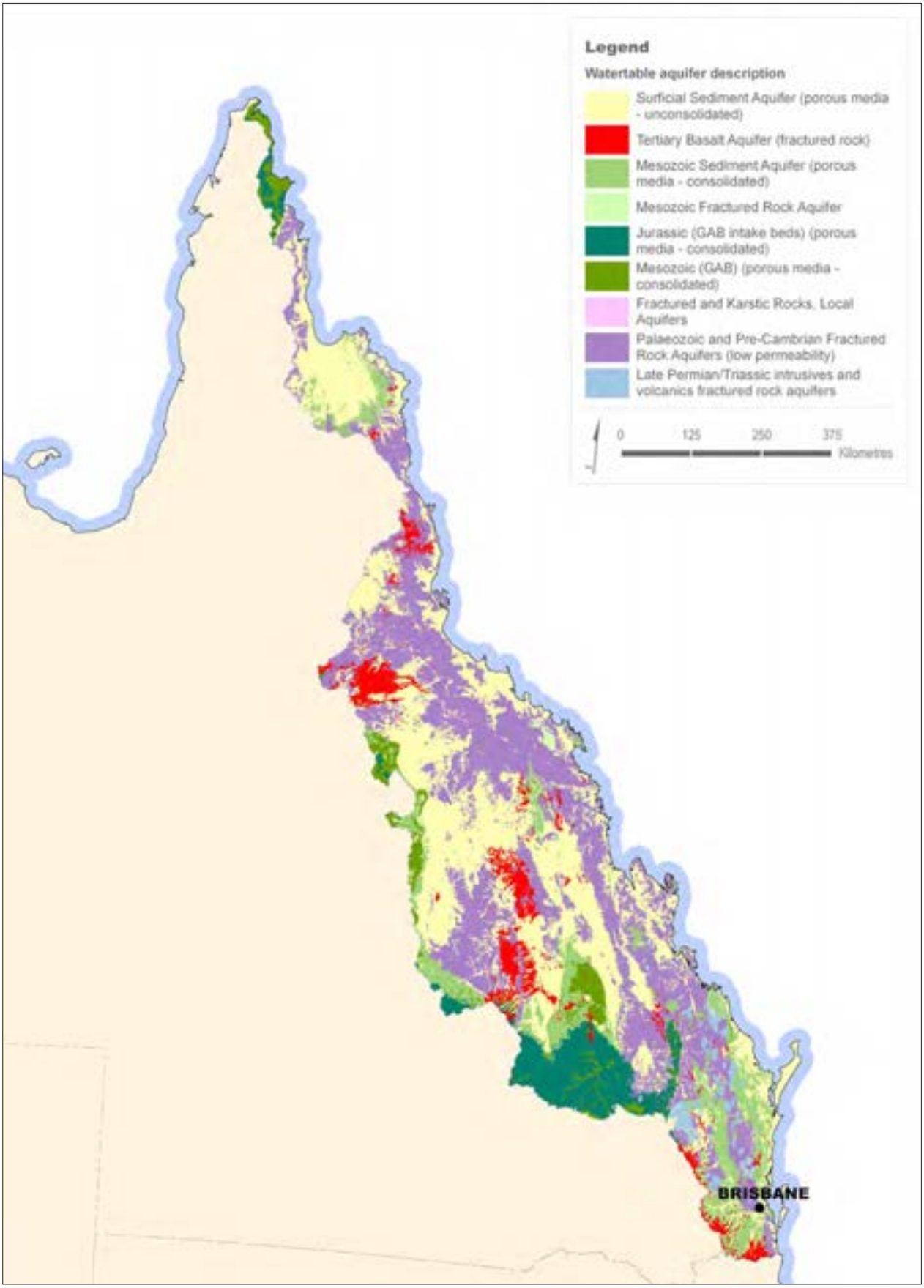


Figure 3.40 Watertable aquifers of the North East Coast region, data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

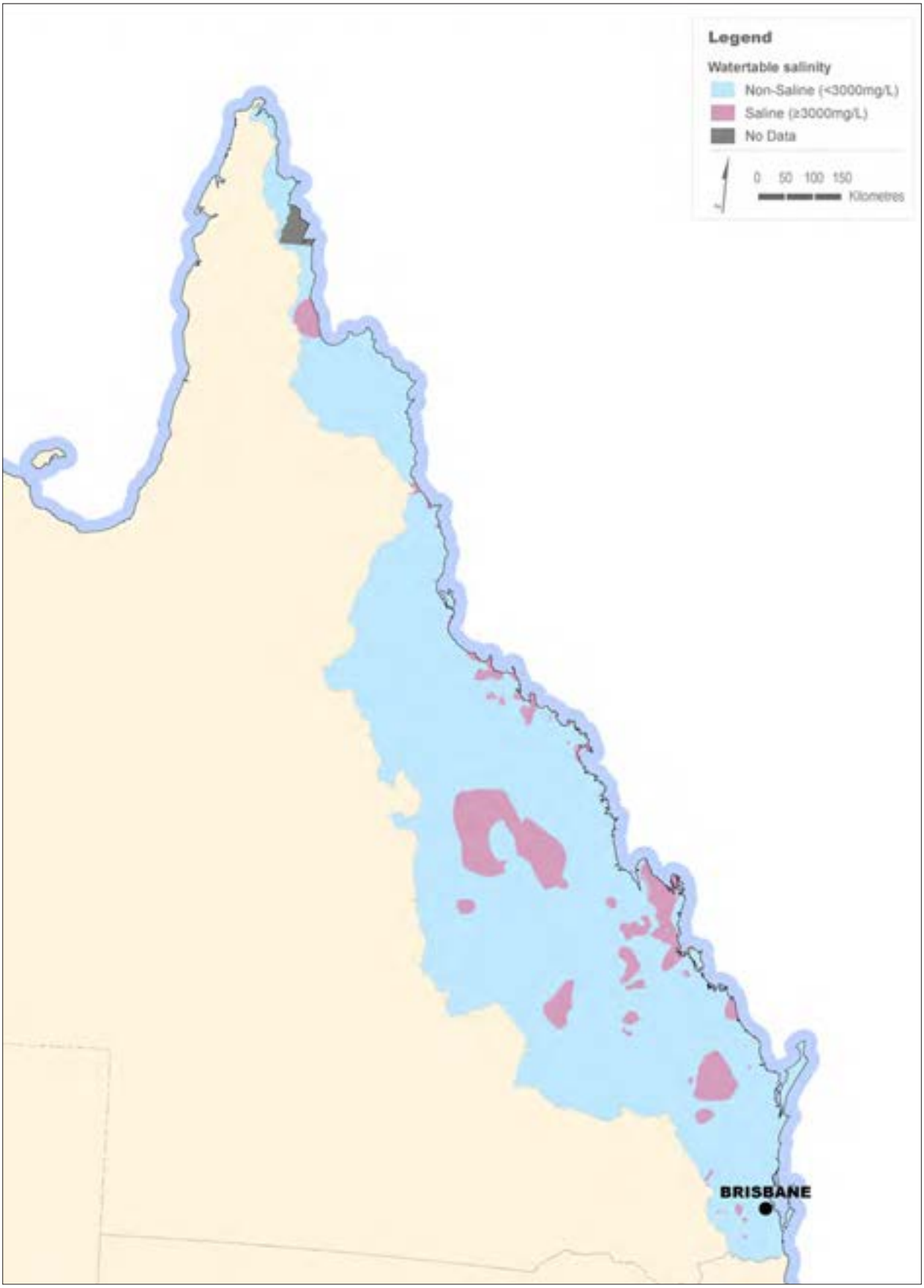


Figure 3.41 Watertable salinity classes in the North East Coast region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

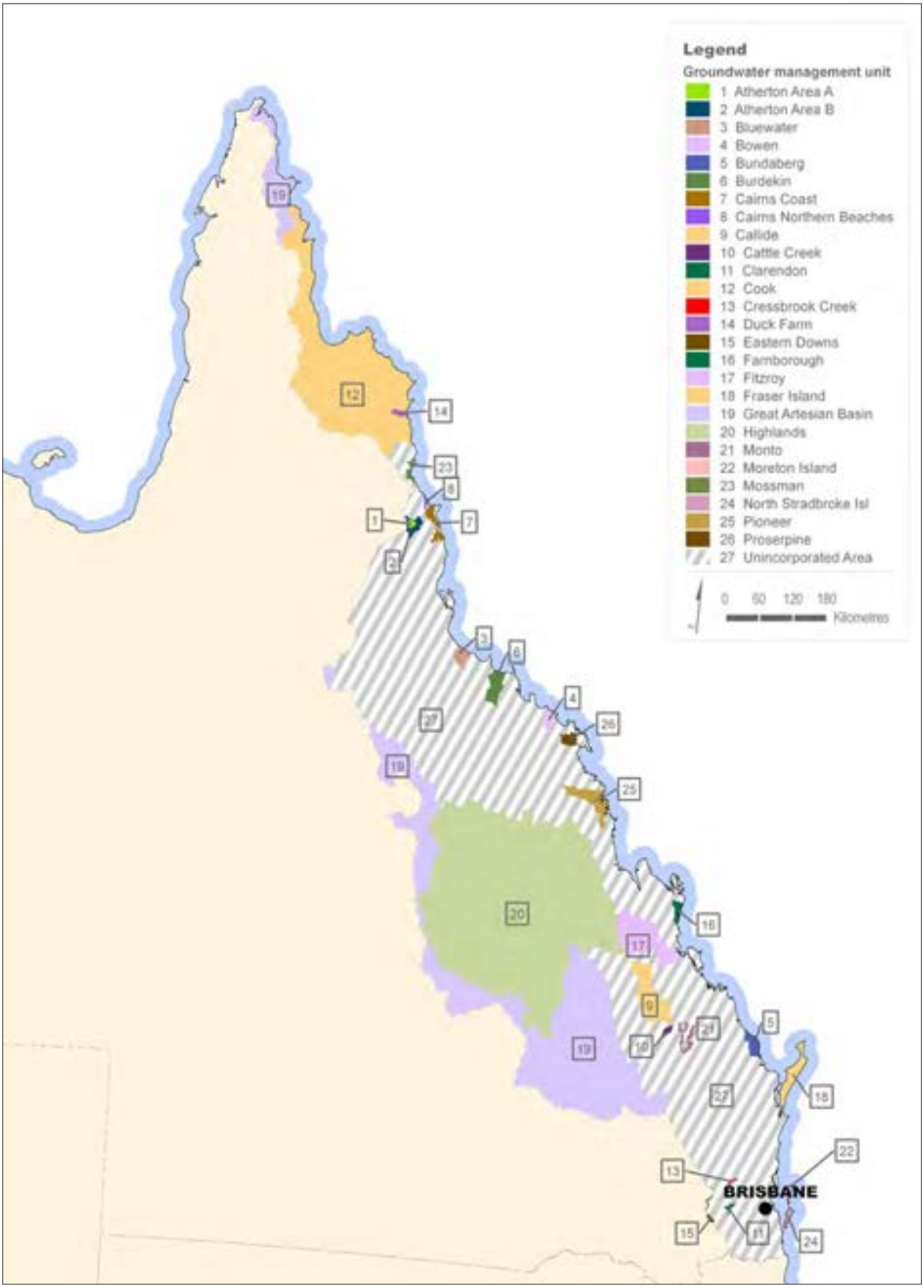


Figure 3.42 Groundwater management units in the North East Coast region, data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

3.5.10 Groundwater status of selected aquifers

The status of groundwater levels is analysed at each bore throughout the North East Coast region. This assessment evaluates trends in groundwater levels over the five-year period 2007–08 to 2011–12.

The trends in groundwater levels over the five years are investigated using a 5 km x 5 km grid across data rich areas usually associated with the major groundwater management units (see Figure 3.42). This scale reflects the mostly local to intermediate flow system of the alluvial and tertiary basalts aquifers in the region.

The linear trend in groundwater levels for a grid cell is assessed as:

- decreasing (where more than 60% of the bores have a negative trend in levels lower than –0.1 m/year);
- stable (where more than 60% of the bores have a trend lower than 0.1 m/year and higher than –0.1 m/year);
- increasing (where more than 60% of the bores have a positive trend in levels higher than 0.1 m/year); and
- variable (where there is no dominant trend in groundwater levels amongst the bores within a grid cell).

Example bore hydrographs are presented for each sub-region over the entire record length and trends are discussed with a focus on the 2007–08 to 2011–12 period. The selected bore hydrographs represent mostly bores with high data density that were used in the 2010 Assessment.

Northern aquifers

The map in Figure 3.43 illustrates the spatial and temporal trends in groundwater levels in the major alluvial aquifers along the coast (shown in brown) and in the main inland basalt aquifer (shown in pink), over the 2007–08 to 2011–12 period, in the north of the region. Many of the grid cells show a rising trend with a minority of cells showing a stable trend.

Selected Bore 1 shows a stable trend while bores 2 and 3 show a rising trend in groundwater levels over the last five years. This reflects the local groundwater use and the rising trend in rainfall for the northern part of the region. Irrigation in the Burdekin irrigation area may also be affecting groundwater levels in Bore 2. Groundwater levels in the last five years are within the shallowest levels on record.

Central aquifers

The map in Figure 3.44 illustrates the spatial and temporal trends in groundwater levels in the major alluvial (shown in brown) and basalt aquifers (shown in pink), over the 2007–08 to 2011–12 period, in the central area of the region. Many of the grid cells show either a rising or stable trend.

Selected Bore 4 shows a rising trend in groundwater levels over the analysis period. The Bore 4 hydrograph is similar in nature to the behaviour of groundwater levels in the northern coastal aquifers. Bores 5 and 6, located in the inland alluvium of the Callide groundwater management unit, show an increase in groundwater level from end 2010 to early 2011 in contrast to the long-term declining trend suggesting recent high recharge to groundwater. This reflects the high rainfall and flooding that occurred since 2010.

Southern aquifers

The map in Figure 3.45 illustrates the spatial and temporal trends in groundwater levels in the major alluvial (shown in brown) and basalt (shown in pink) aquifers inland and along the coast, over the 2007–08 to 2011–12 period. Many of the grid cells show a rising trend with a minority of cells showing a stable trend.

Selected bores 7, 8 and 9 show a rising trend in groundwater levels over the analysis period, especially in Bore 9, representing the Lockyer valley alluvium aquifer; this is in contrast to the long-term declining trend. It suggests recent high recharge to groundwater, reflecting the high rainfall and flooding since 2010.

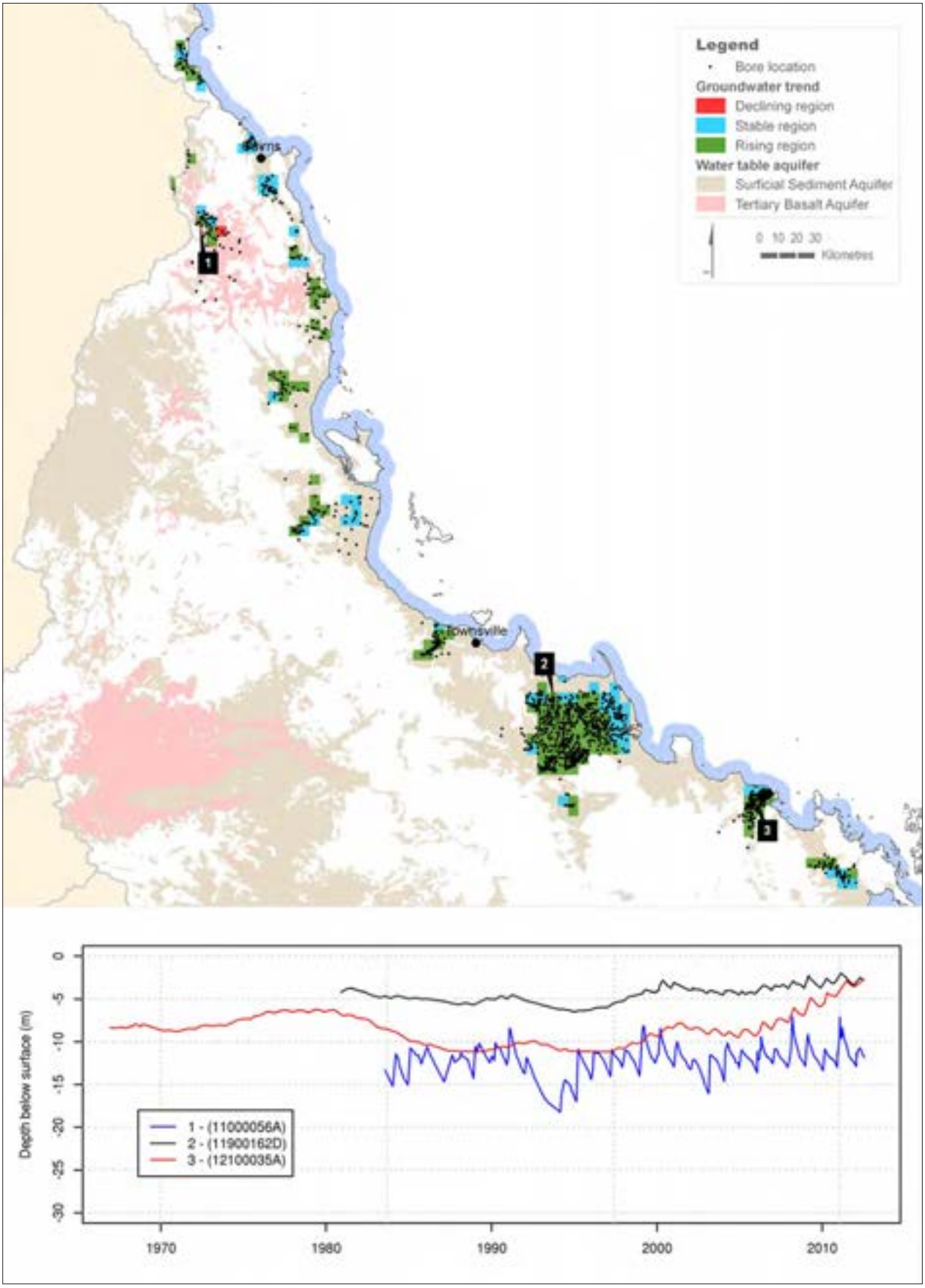


Figure 3.43 Spatial distribution of trends in groundwater levels for the surficial sediments and tertiary basalt aquifers in the northern North East Coast region for 2007–08 to 2011–12 with selected hydrographs showing groundwater levels

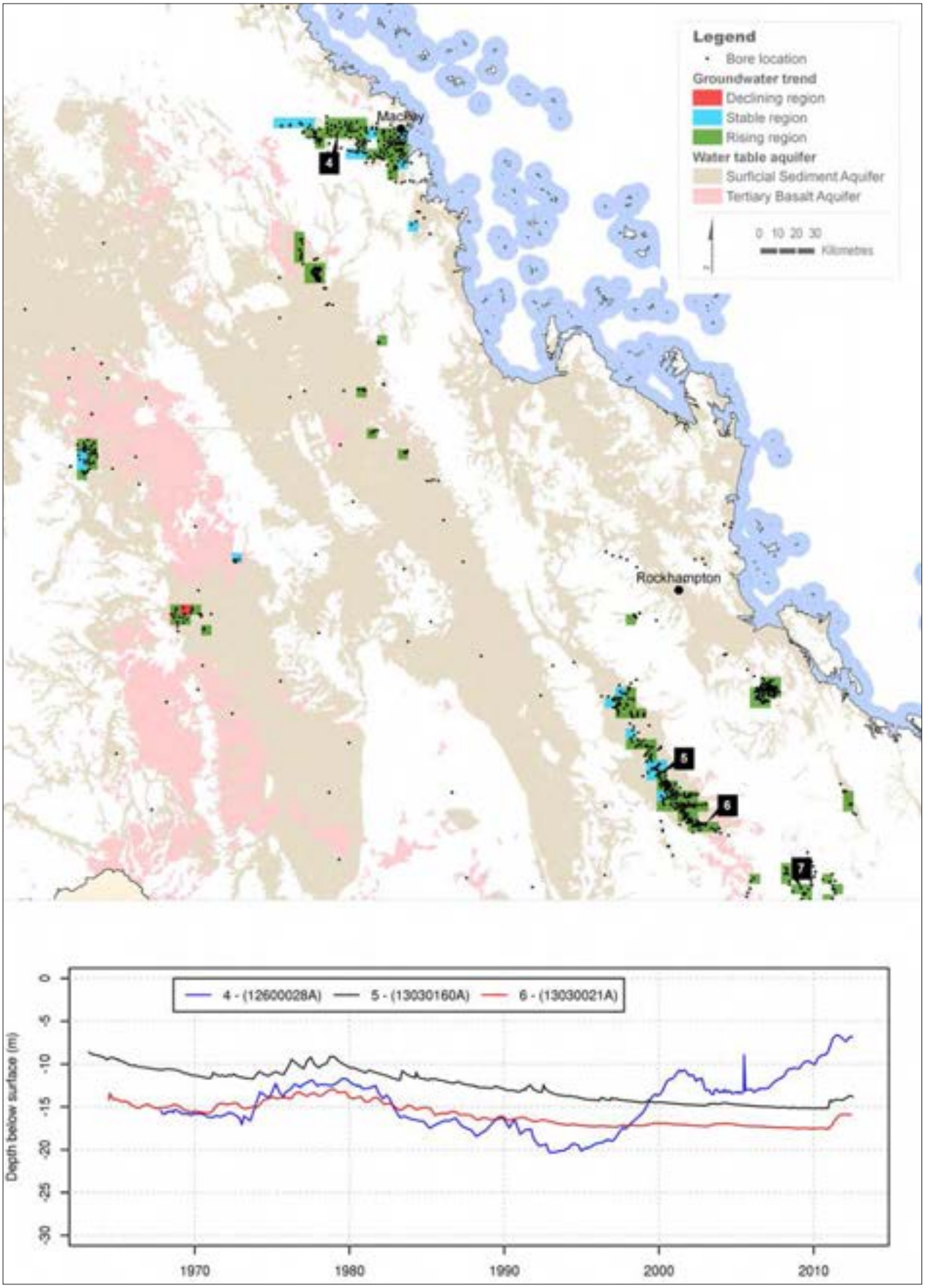


Figure 3.44 Spatial distribution of trends in groundwater levels for the surficial sediments and tertiary basalt aquifers in the central North East Coast region for 2007–08 to 2011–12 with selected hydrographs showing groundwater levels

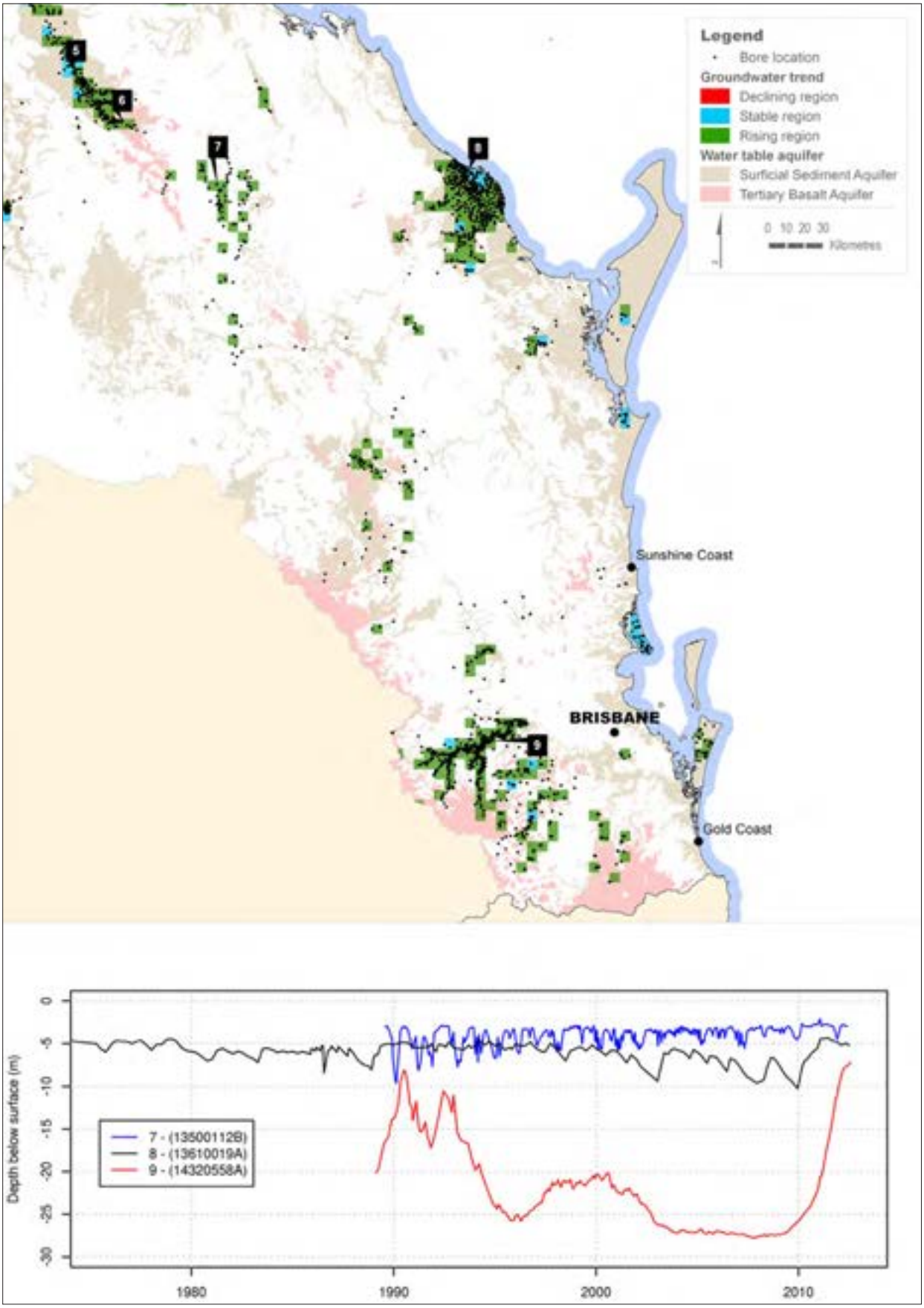


Figure 3.45 Spatial distribution of trends in groundwater levels for the surficial sediments and tertiary basalt aquifers in the southern North East Coast region for 2007–08 to 2011–12 with selected hydrographs showing groundwater levels

3.6 Water for cities and towns

This section examines urban water in the North East Coast region in 2011–12. The large urban centres in the region, their water supply systems and water storage situations are briefly described. The main urbanised area, southeast Queensland, is addressed in more detail and the history of water restrictions over recent years is discussed. A breakdown is provided for water obtained for and delivered to Brisbane and the Gold Coast.

3.6.1 Urban centres

Straddling the Brisbane River, the city of Brisbane is the largest city in the region and with a population of over 1.8 million people it is the third largest in Australia. The Sunshine Coast and Gold Coast, to the respective north and south of Brisbane, are home to a further 743,000 people.

Outside of the heavily populated southeast coast, the region has a large number of urban centres and towns. In particular, a number of coastal cities that support adjoining areas within the region.

Cairns is the northern most and second largest of these cities. From north to south between Cairns and Brisbane these cities include Townsville, the largest regional city outside of southeast Queensland, Mackay, Rockhampton, Gladstone and Bundaburg. These cities, along with Brisbane, The Gold Coast and the Sunshine Coast are shown in Figure 3.46 in conjunction with their population ranges.

Table 3.4 summarises the major urban centres of the region with populations of over 25,000 people and provides information on the population, surrounding river basin and significant water storages for each of the major urban centres.

Table 3.4 Cities and their water supply sources in the North East Coast region

City	Population[1]	River basin	Major supply sources
Brisbane	1,874,000	Brisbane River	Wivenhoe, Somerset and North Pine reservoirs (part of SEQ Water Grid)
The Gold Coast	534,000	South Coast	Hinze reservoir (part of SEQ Water Grid)
The Sunshine Coast	209,000	Mary River	Lake Macdonald, Baroon Pocket, Ewen Maddock, Cooloolabin and Wappa reservoirs
Townsville	158,000	Ross River	Ross River and Paluma reservoirs
Cairns	134,000	Mulgrave–Russell Rivers	Tinaroo Falls and Copperlode reservoirs
Mackay	74,000	Pioneer River	Teemburra and Kinchant reservoirs
Rockhampton	62,000	Fitzroy River	Fitzroy River Barrage and Eden Bann Weir
Bundaberg	50,000	Burnett River	Ben Anderson Barrage, Ned Churchward Weir, Paradise and Fred Haigh reservoirs
Hervey Bay	49,000	Mary River	Lake Lenthall
Gladstone	32,000	Calliope River	Awoonga Reservoir

[1] Australian Bureau of Statistics (2011b)

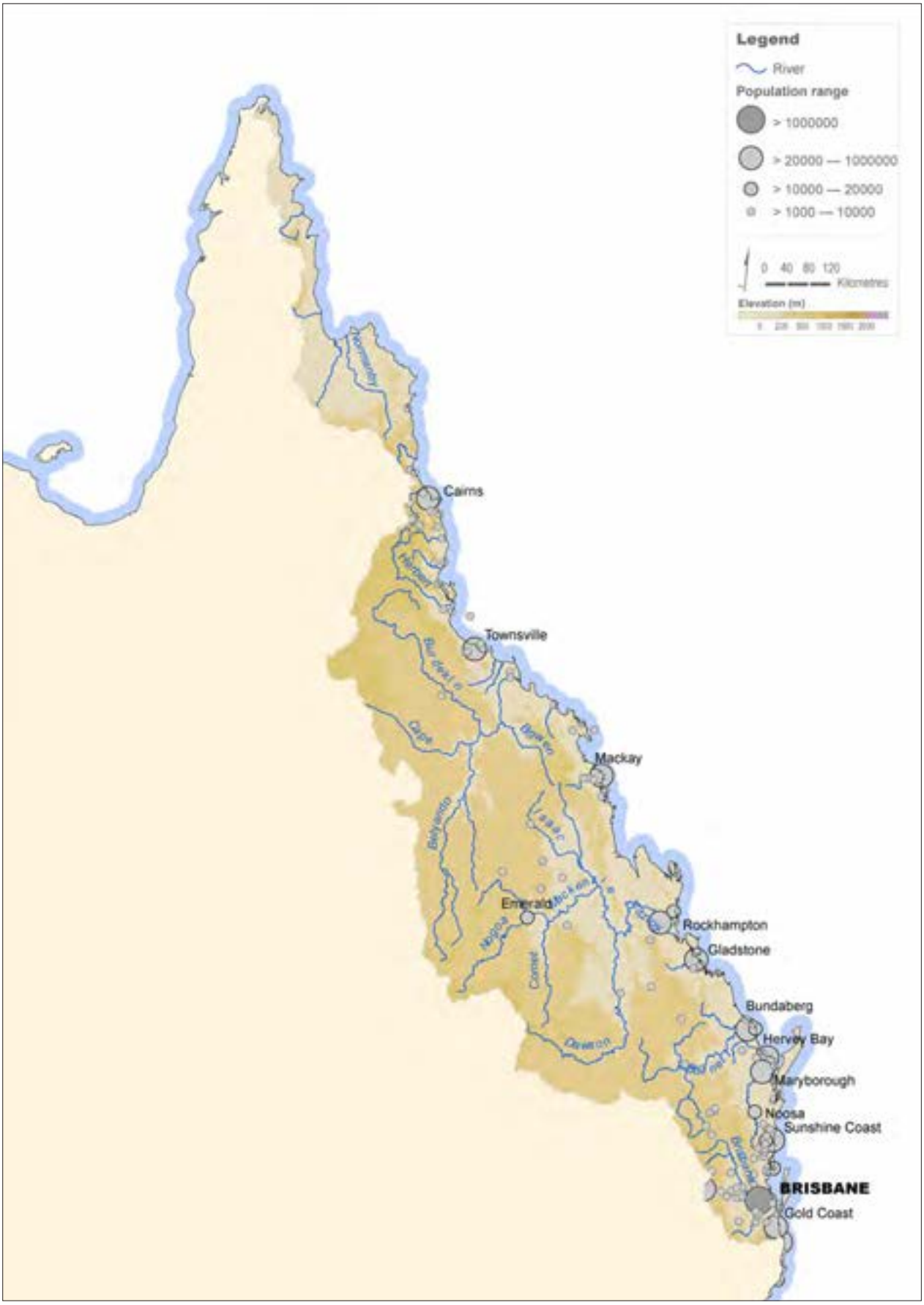


Figure 3.46 Population range of major urban centres in the North East Coast region

3.6.2 Sources of water supply

Surface water is the major source of supply for the cities and towns of the region. It has over 70 major water storages, each with a capacity of over 1 GL, that supply a combination of urban, agricultural, industrial and mining demands.

Supplying Brisbane and surrounding populations, Wivenhoe is arguably the most well known surface water storage in the region; however, with respect to size it ranks third behind Fairbairn and Burdekin Falls. The latter, being the largest surface water storage in the region, supplies both irrigation and urban demands, including those of the City of Townsville.

Figure 3.47 shows major surface water storages in the region, including Wivenhoe and Burdekin Falls, that are partly in use for urban water supply.

In addition to surface water storages the region utilises direct river extractions (including extractions of upstream storage releases), groundwater, desalination, recycled water, and harvested storm and rainwater to supply its urban demands.

3.6.3 Southeast Queensland

Southeast Queensland (SEQ) is serviced by what is arguably the most complex water supply system in Australia. Known as the SEQ Water Grid, the supply area it covers is about 22,000 km^2, extending 240 km from the Shire of Noosa in the north to the Gold Coast and the New South Wales border in the south. It encompasses the ten local government areas of Brisbane, the Gold Coast, Ipswich, Lockyer Valley, Logan, Moreton Bay, Redland, Scenic Rim, Somerset and the Sunshine Coast.

New institutional arrangements for the management and operation of the region's water services came into effect on 1 January 2013. Seven separate authorities and utilities are collectively responsible for the SEQ Water Grid and are comprised of a bulk water authority (Seqwater), a network controller for bulk supplies (Link Water) a water grid operator (SEQ Water Grid Manager), an operator for the region's desalination and recycled water plants (Secure Water), and three retail suppliers (Unity Water, Queensland Urban Utilities and Allconnex Water).

Seqwater is responsible for the collection and storage of surface water, extraction of groundwater, operation of the desalination facilities and the area's Western Corridor Recycled Water Scheme. In addition, Seqwater is the catchment manager for the area's surface water and groundwater supply catchments.

Link Water operates and maintains the bulk water supply network and is responsible for the transportation of water supplies to treatment plants and between storages.

As the owner of urban water entitlements in the SEQ region the SEQ Water Grid Manager operates the SEQ Water Grid to supply the council-owned retail authorities and industry with potable water.

Secure Water operates the Gold Coast desalination plant and the Western Corridor Recycled Water Scheme.

The region's urban water utilities are Unity Water (Moreton Bay and Sunshine Coast), Queensland Urban Utilities (Brisbane, Scenic Rim, Ipswich, Somerset and the Lockyer Valley) and Allconnex Water (Gold Coast, Logan and Redland). In addition to the provision of water supply services these utilities are responsible for the collection and treatment of wastewater.

Figure 3.47 Urban supply storages in the North East Coast region

Supply system

The region's water supplies are drawn from a complex network of surface water storages, water treatment plants, groundwater bore fields and recycled and desalinated water plants.

Over ten major surface water storages, including Wivenhoe, Somerset and North Pine, a series of small storages and weirs, the Stradbroke Island and Bribie Island bore fields, the Tugan desalination plant, the Western Corridor Recycled Water Scheme and a complex network of pipes, service reservoirs, pump stations and treatment plants make up the SEQ Water Grid.

Figure 3.48 outlines the major water infrastructure in southeast Queensland and illustrates urban flow pathways between local government and other main customers.

Some water is exported to costumers beyond this system, the largest being the Tarong Power Station.

Storage volumes

In combination, the Wivenhoe, Hinze, Somerset and North Pine storages provide over 90% of the total accessible surface water storage for SEQ, with Wivenhoe contributing over half of this total.

Figure 3.49 presents the total accessible volume held in these storages over the past 18 years (1984–2012) and clearly illustrates the impacts of the millennium drought with storages levels reaching critically low levels in 2008. A shift in climatic conditions in 2009 and a series of wetter years, including Australia's wettest two-year period on record in 2010 and 2011, saw storage levels recover from their historic lows. Continued good rainfall in the region's catchments has seen storage levels maintained at or near capacity throughout 2011–12.

The observed step change in the accessible volumes of the Hinze storage is explained by an increase in the storage's total capacity. Coming into effect in December 2011, the Hinze Dam was raised to increase the total accessible storage from 161 GL to 311 GL.

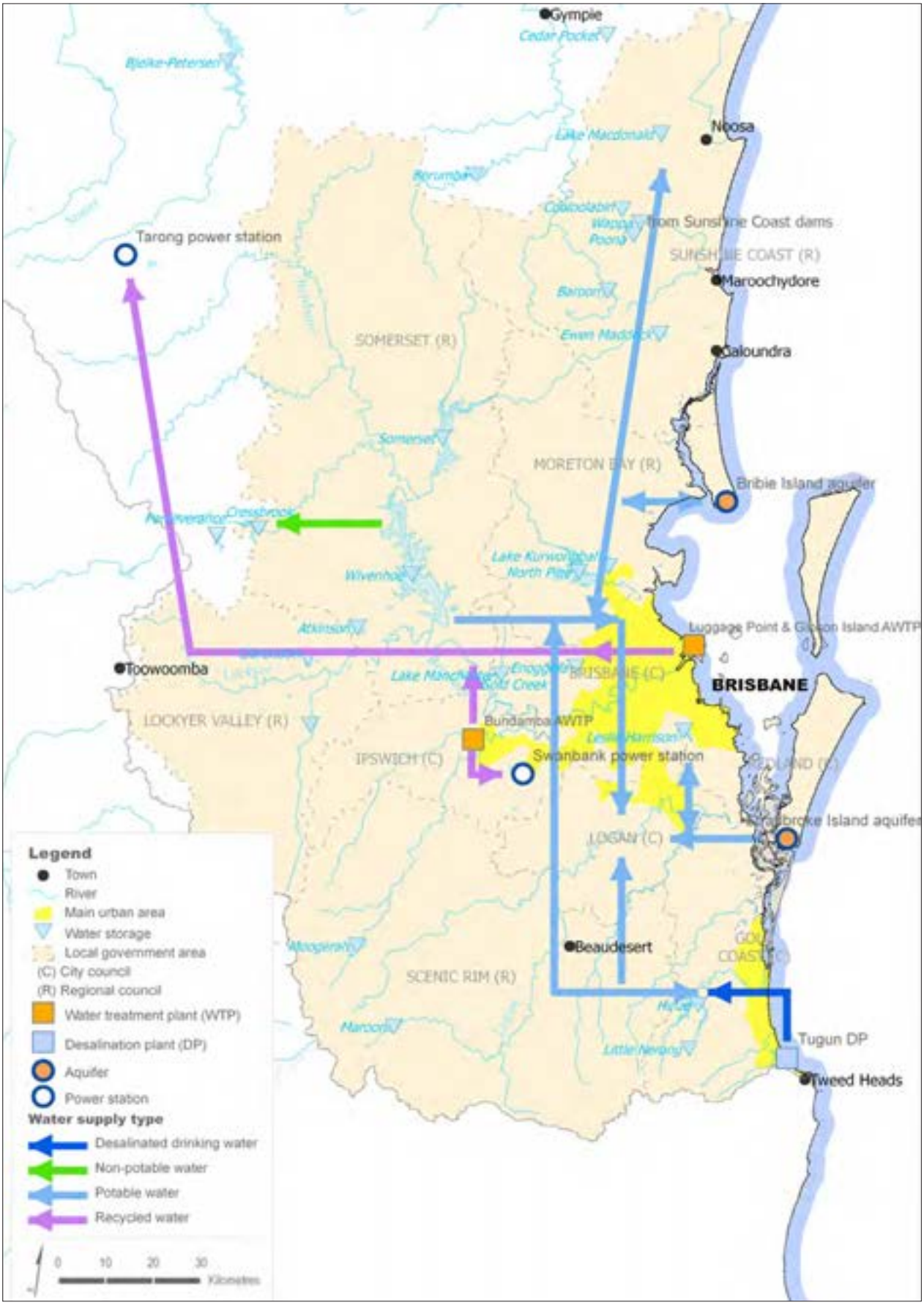


Figure 3.48 Water supply schematic for southeast Queensland

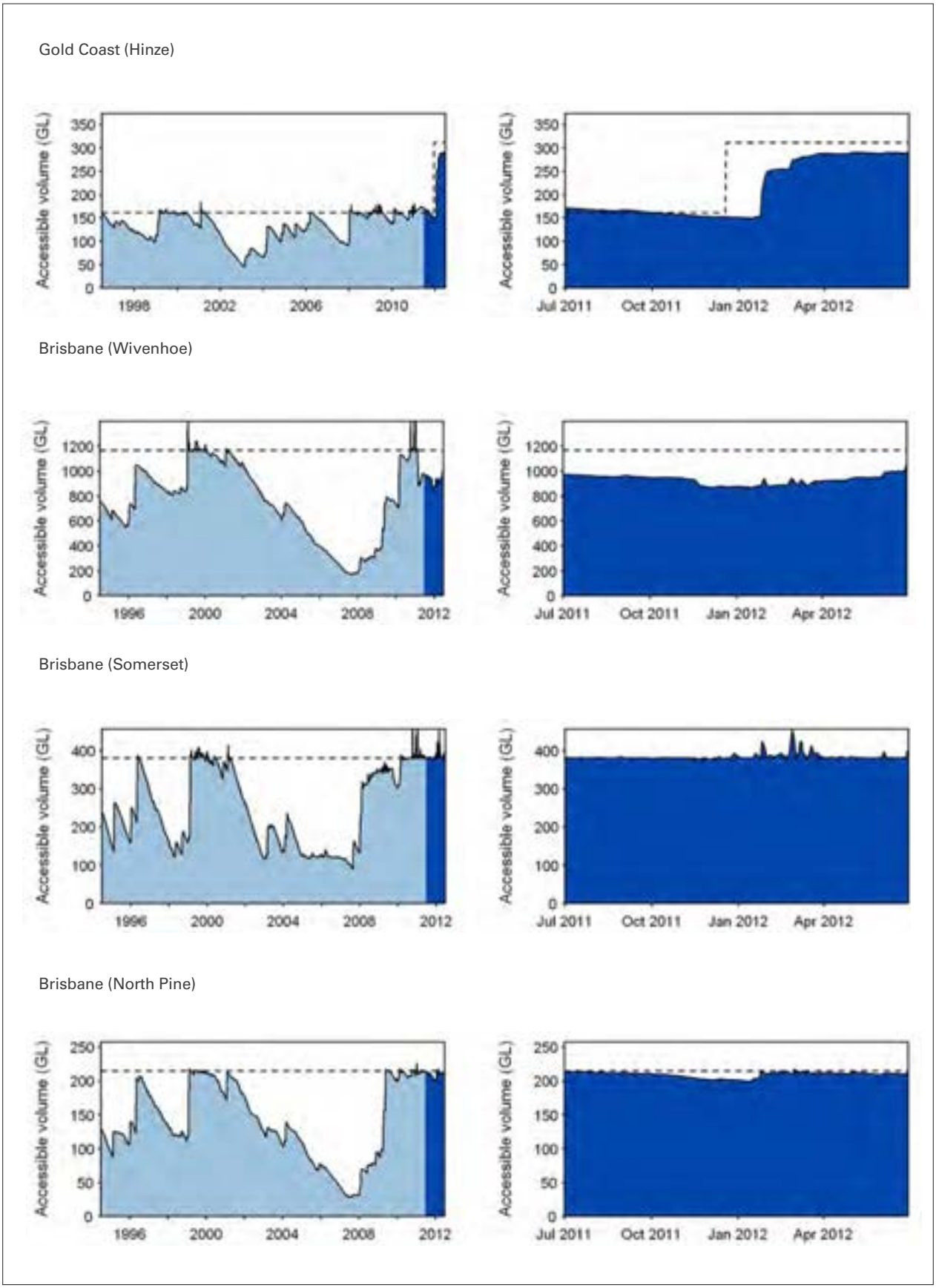


Figure 3.49 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for the Hinze, Wivenhoe, Somerset and North Pine storages, as well as total accessible storage capacity (dashed line)

Water restrictions

Following its formation on 1 January 2013, Seqwater has taken over the water security and efficiency responsibilities previously performed by the Queensland Water Commission.

Water restrictions have been in place since 2005, and applied throughout SEQ, excluding Redland, Sunshine Coast Council and Toowoomba until December 2009. They are shown with the combined storage levels in Figure 3.50.

Between 2005 and 2008 combined storage levels steadily decreased resulting in the introduction of more stringent water restrictions.

Permanent water conservation measures (PWCM) were introduced in December 2009 across southeast Queensland including the Sunshine Coast. Although the combined storage level remained above 80% during 2011–12, PWCM remained in place. These measures encouraged the use of a maximum of 200 litres per person per day.

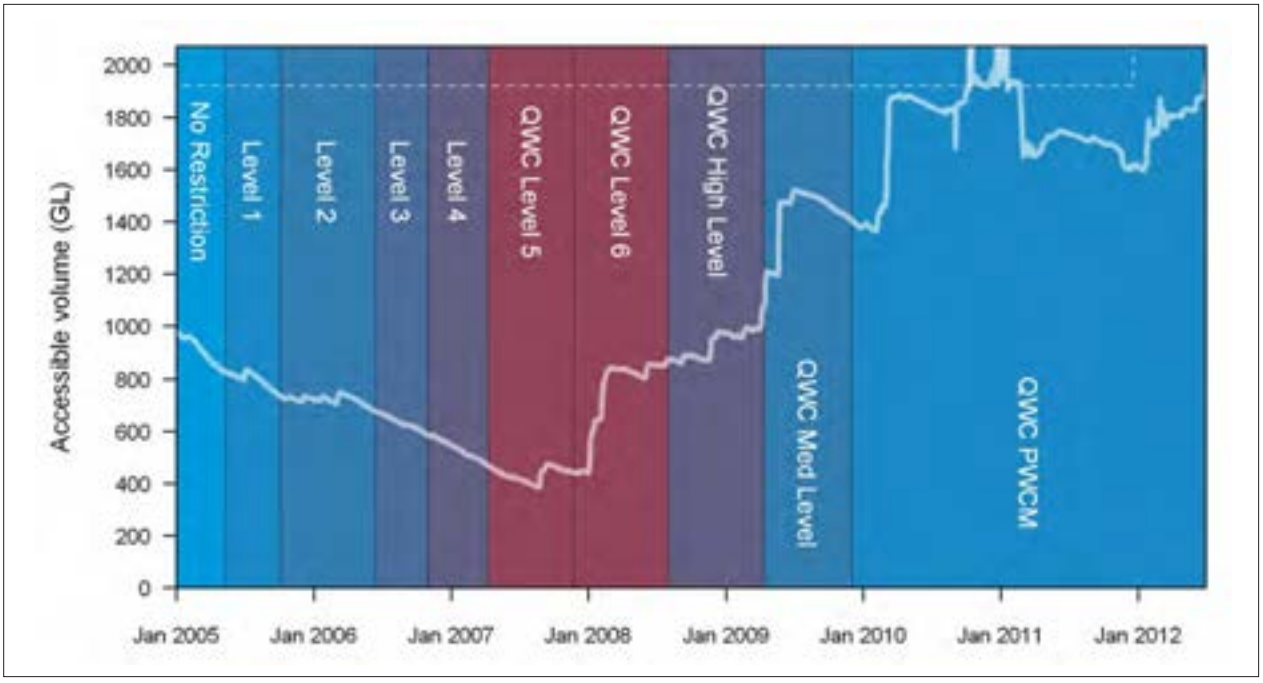


Figure 3.50 Urban water restriction levels across southeast Queensland since 2005 shown against the combined accessible water volume of Wivenhoe, Somerset and North Pine storages

Sources of water obtained

Because of data limitations the following discussion of sources of water obtained pertains only to the Brisbane, Logan and Gold Coast City Council areas. For the purposes of this and the following sections this supply area is referred to as the 'combined area' and represents the central and southern extents of the SEQ Water Grid.

Figure 3.51 shows the total volume of water sourced from surface water extractions, groundwater, recycling, and bulk water transfers to the combined area for the last eight years (2005–06 to 2011–12).

Following changes to the management of bulk water resources in SEQ with the creation of the SEQ Water Grid in 2008, reported data no longer distinguishes between locally sourced surface water and surface water imported to the area.

The observed downward trend in the total volume of water sourced for urban supply is attributable to demand management and water conservation measures put in place in response to dwindling surface water storage levels.

A shift in climatic conditions in 2009 and a series of wetter years has seen storages in SEQ recover to at or near full supply levels and resulted in an easing of water restrictions. These conditions have seen a gradual increase in the total amount of water sourced for urban supply to the area and a reduction in the volume of recycled water used to meet the areas demand.

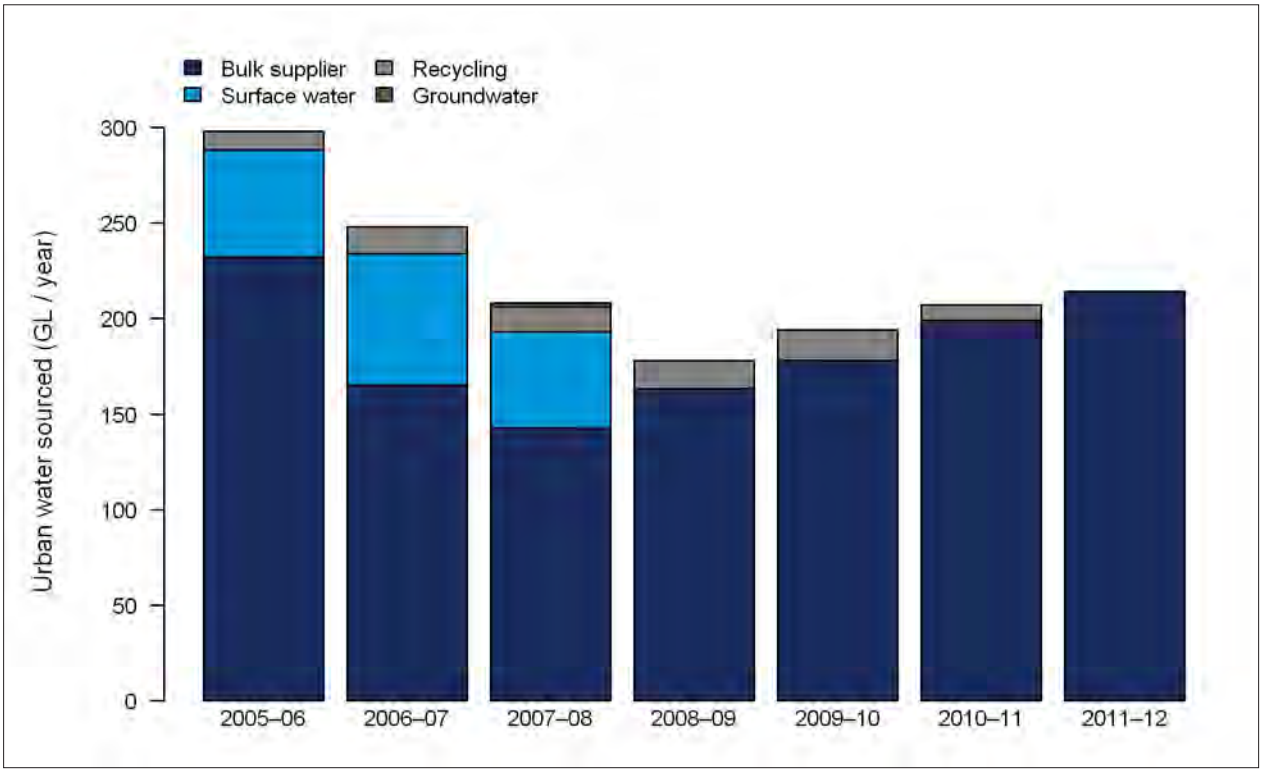


Figure 3.51 Total urban water sourced for the combined area from 2005–06 to 2011–12

Categories of water delivered

As in the previous discussion this section reports on water usage for the 'combined area' comprising Brisbane, Logan and Gold coast councils.

Figure 3.52 shows the total volume of water delivered to residential, commercial, municipal, industrial, and other consumers, such as nurseries, parks, gardens and cemetaries, in the combined area.

Total water supplied was 220 GL in 2005–06 that then decreased for two consecutive years due to water restrictions. Between 2007–08 and 2009–10, total water supplied increased slightly due to the easing of water restrictions and the reintroduction of outdoor watering. The total volume of water supplied to urban customers in 2011–12 was 176 GL. Recent water use is low compared to that in 2005–06.

Average total residential water consumption of the combined area in 2011–12 was 297 ML/d or 158 litres per person per day (L/p/d). The residential sector accounted for 62% of total potable water consumption (similar to the previous year when residential consumption was estimated to be 59%). The commercial, municipal and industrial sectors accounted for 26% of urban water consumption.

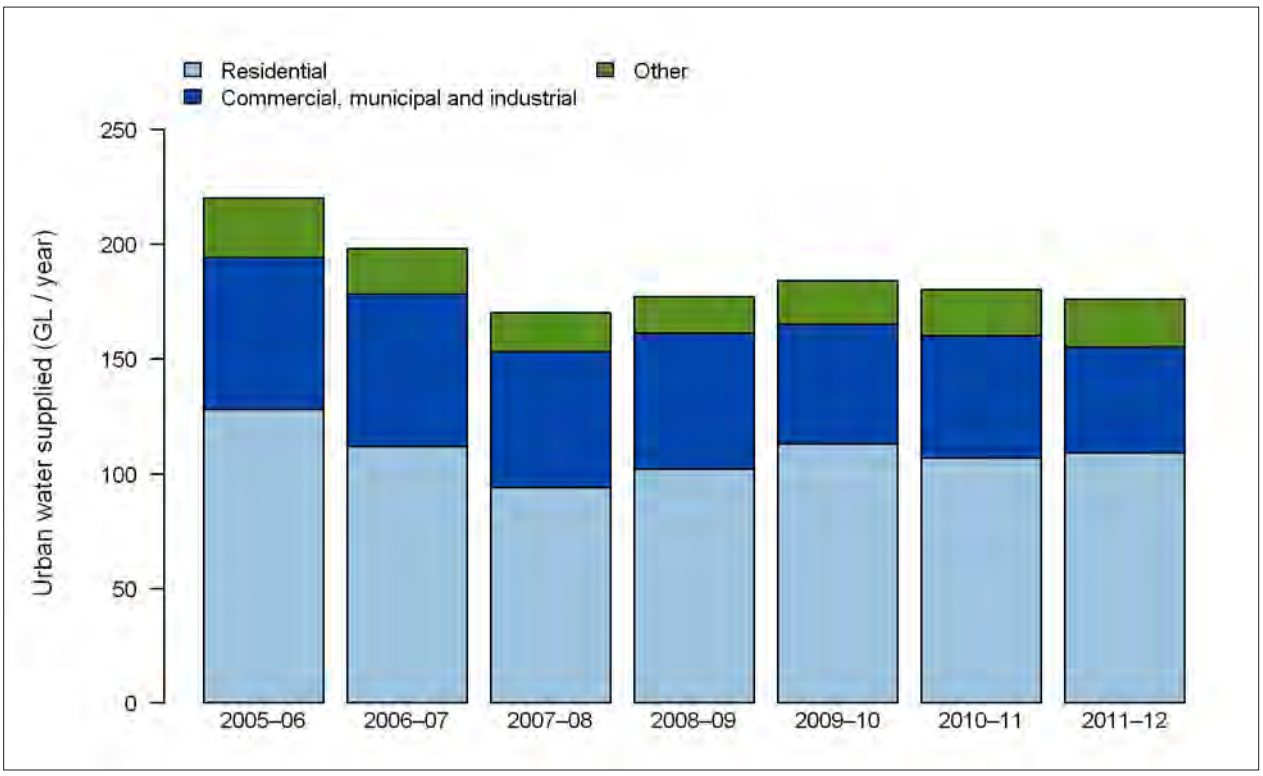


Figure 3.52 Total urban water supplied to the combined area from 2005–06 to 2011–12

3.7 Water for agriculture

This section describes the water situation for agriculture in the North East Coast region during the 2011–12 year compared with the past. Soil moisture conditions are presented and important irrigation areas are identified. The Burdekin irrigation area is described in more detail and information is provided regarding surface water storage and groundwater.

3.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5km x 5km grid cell, they are not suitable for comparison with locally measured soil moisture volumes. This analysis, therefore, presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

Figure 3.53 gives an overview of the decile ranking of modelled annual average soil moisture for 2011–12 with respect to the 1911–2012 period. It shows that the majority of the region had above average or very much above average soil moisture conditions. The latter conditions were more prominent in the western pastoral and cropping areas of the region where very much above average rainfalls occurred in that period.

Above average soil moisture conditions in the region were dominant in the wet months of November 2011–March 2012 (Figure 3.54). Soil moisture remained very much above average in all other months of the year. It created beneficial water conditions for dryland cropping across the inland and western parts of the region which are normally drier.

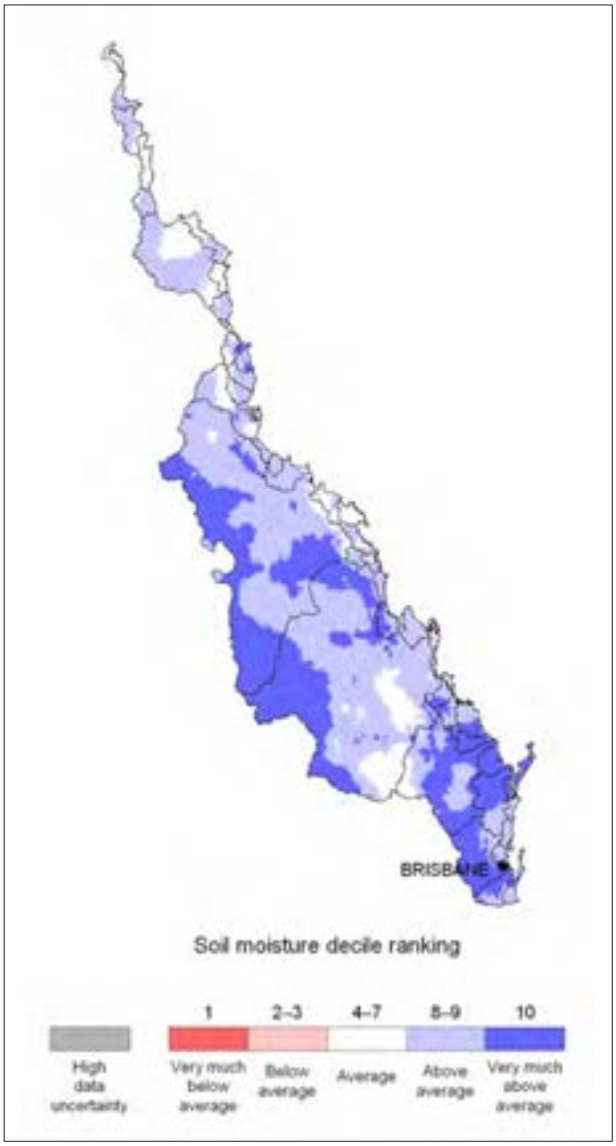


Figure 3.53 Deciles rankings of annual average soil moisture for 2011–12 with respect to the 1911–2012 period for the North East Coast region

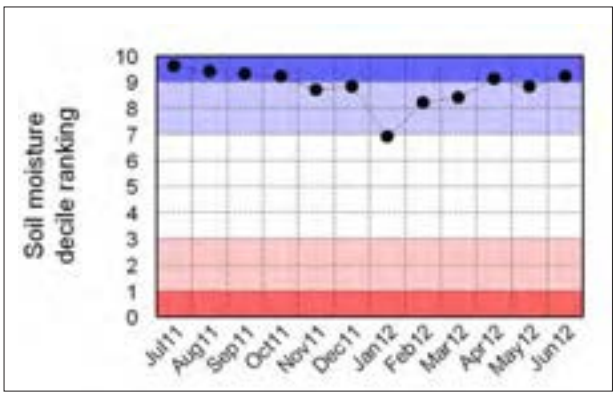


Figure 3.54 Decile ranking of the monthly soil moisture conditions during the 2011–12 period with respect to the 1911–2012 period in the North East Coast region

3.7.2 Irrigation water

The Department of Energy and Water Supply, established in April 2012, provides policy and regulation for the delivery of water to Queensland.

SunWater is a government-owned corporation, which is the main supplier of bulk water, bulk water storage and delivery of services for regional Queensland. In the southeast, Seqwater provides bulk water supply and services to around 1,000 rural communities in five water supply schemes in the Upper Mary, Logan, Central Brisbane, Warrill valley and Lockyer valley areas.

A comparison of water use in irrigated catchments by natural resource management (NRM) regions in the region over the period 2005–06 to 2010–11 is shown in Figure 3.55. Figure 3.56 shows the map of the water use per NRM region in 2010–11.

As with the previous years Burdekin had the highest irrigation water consumption among other NRM regions, but the water use during the 2010–11 in all regions had dropped due to increased availability of water through rainfall. At the time of writing the report data was not available for 2011–12.

The Burdekin River Irrigation Area is described in more detail in subsection 3.7.4

3.7.3 Irrigation areas

Most of the North East Coast region is used for grazing. Dryland and irrigated agriculture account for only 0.4% of the land use of the region. The greatest area of dryland agriculture, 1.8 million hectares, is located in the Fitzroy River basin.

As shown in Figure 3.57, the largest irrigation areas are located in the Brisbane, Mary, Burnett, Burrum and Kolan river basins in the south; the Fitzroy, Plane Creek and Pioneer river basins in the centre of the region; and the Haughton and Burdekin river basins in the north.

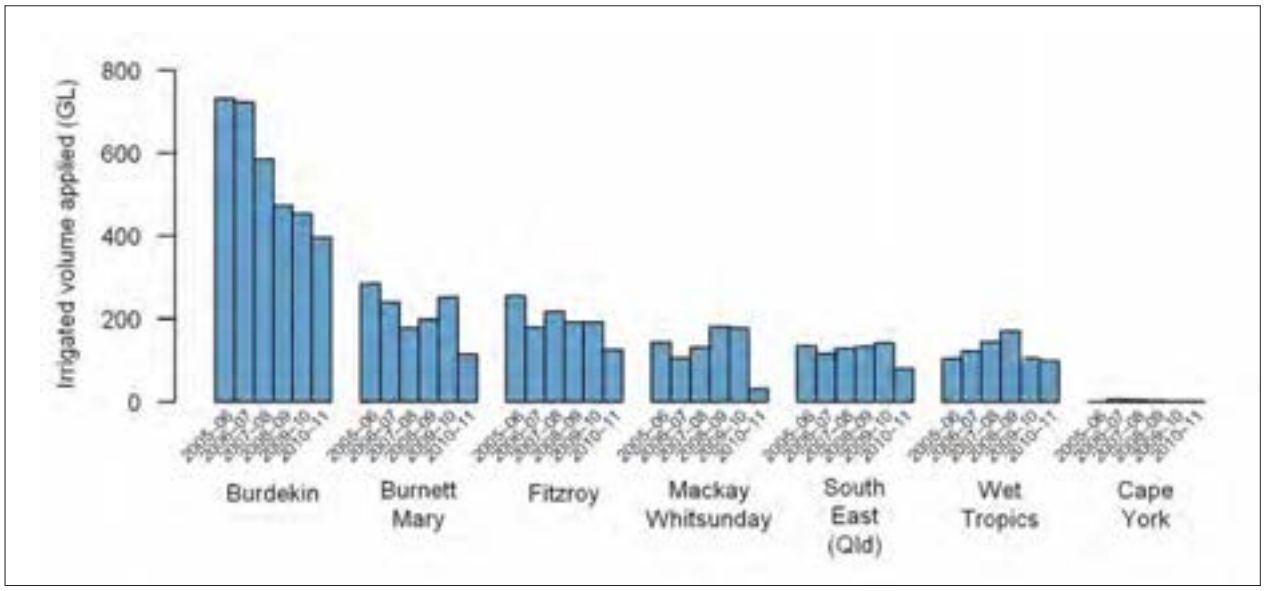


Figure 3.55 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the North East Coast region (ABS 2006–2010; 2011a)

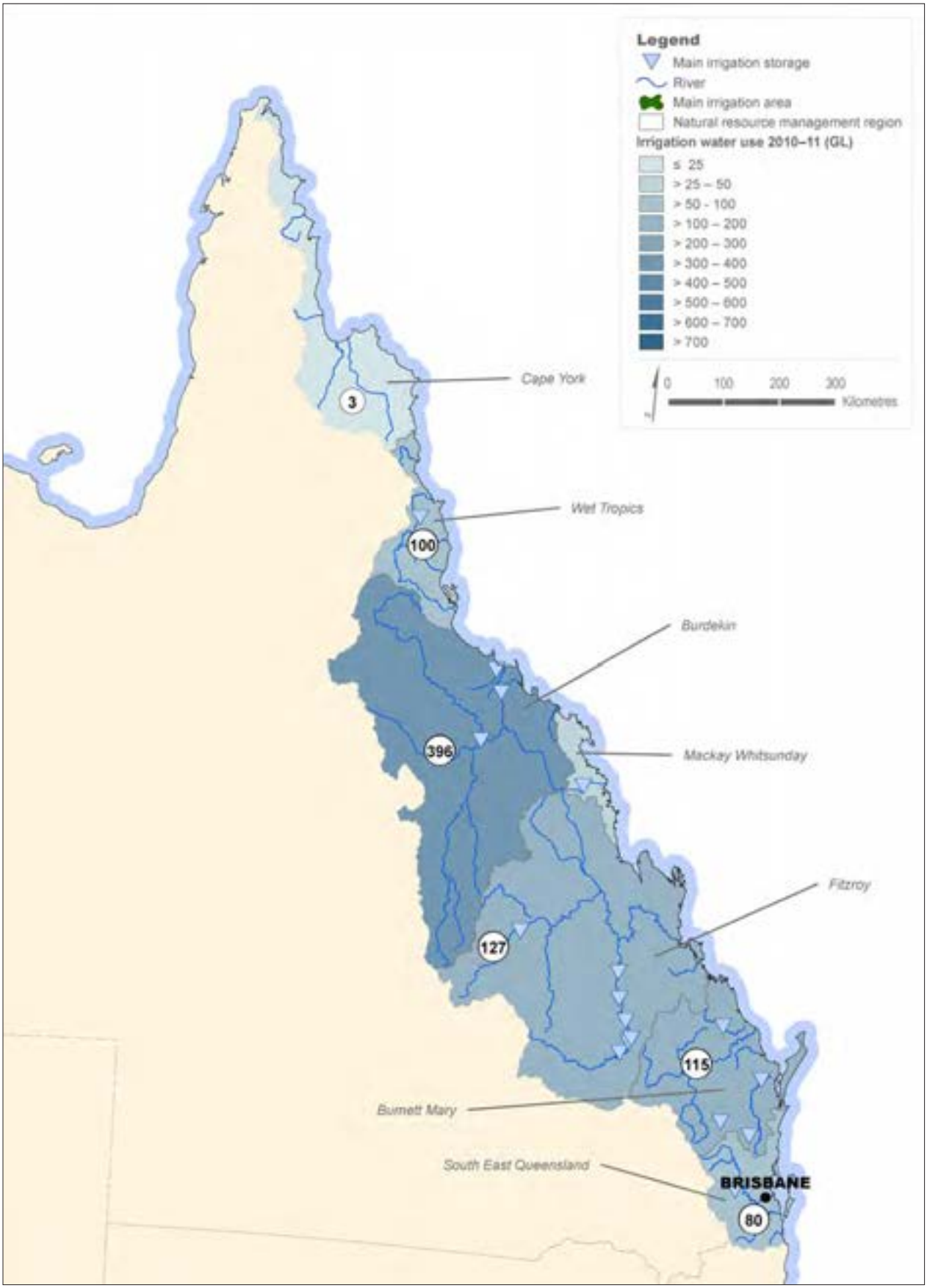


Figure 3.56 Annual irrigation water use (GL) per natural resource management region for 2010–11 in the North East Coast region (ABS 2011a)

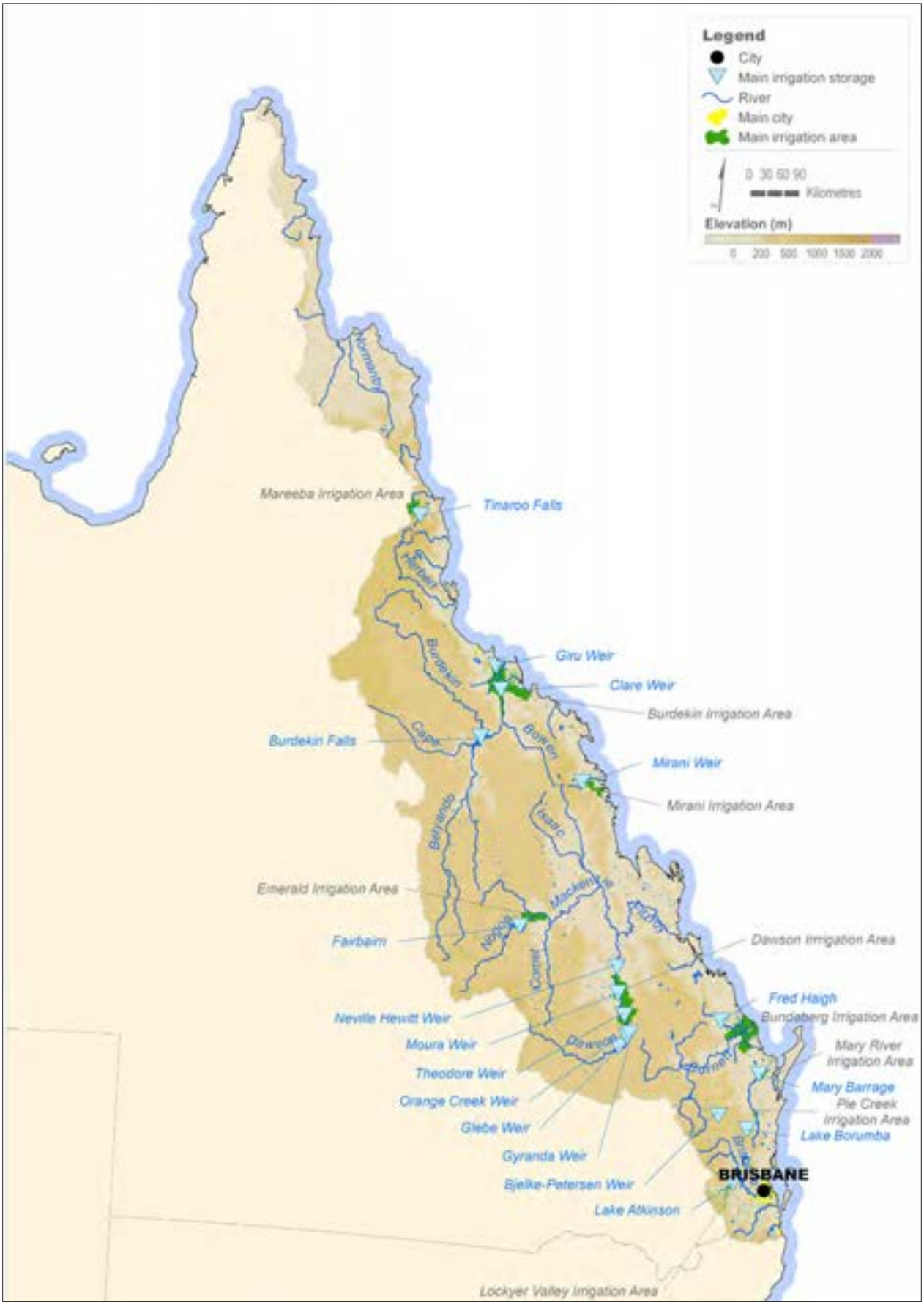


Figure 3.57 Irrigation areas in the North East Coast region

3.7.4 Burdekin River Irrigation Area

The Burdekin River basin is located in the dry tropics on the North East Coast region, covering a total catchment area of approximately 133,000 km^2.

The basin's assets include water, biodiversity, national parks, grazing, fertile soil and crops (Figure 3.58).

The Lower Burdekin in the basin is the largest irrigation area in northern Australia, predominantly growing sugarcane. This part of the region can receive more than 300 days of sunshine each year, which is a primary reason for the highly productive agricultural sector. This can be tempered, however, by the traditional wet season, which runs from November–March each year with the wettest months typically being January and February.

Lower Burdekin comprises two schemes: the Burdekin River Delta, and the Burdekin–Haughton Water Supply Scheme.

The Burdekin Delta downstream of the Burdekin River is a groundwater-dominated scheme, with more than 35,000 ha of irrigated sugarcane and other crops. This system overlies major groundwater supplies.

The Burdekin–Haughton Water Supply Scheme is surface water dominated and receives significant volumes of water from Burdekin Falls storage. Groundwater supplies supplement irrigation.

Burdekin Falls on the Burdekin River is one of the largest surface water storages in Queensland covering 22,000 ha and is supplied by an upstream catchment area of approximately 120,000 km^2. The total accessible storage capacity of Burdekin Falls is 1,850 GL.

Total water delivery in the Burdekin–Haughton scheme in 2011–12 was 455 GL, which was 41 per cent of the water available to the scheme (SunWater 2012).

For the purpose of this report, the Burdekin River Irrigation Area was selected as an example of groundwater use for irrigation in the North East Coast region.

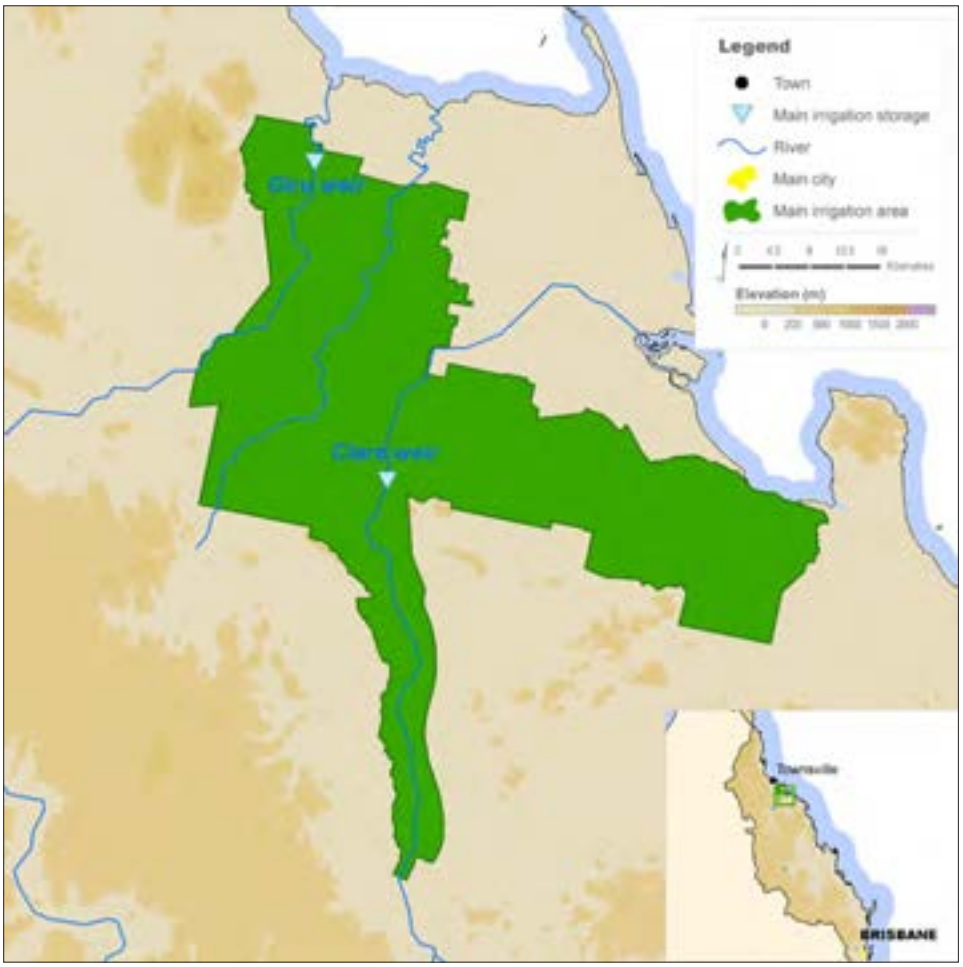


Figure 3.58 Burdekin River Irrigation Area

Surface water storage inflows

The highly seasonal rainfall pattern of the region, which is characteristic of the tropics of northern Australia, is highlighted by the historical streamflow discharge records of gauging stations on the Suttor River at St Anns, Cape River at Taemas and Burdekin River at Sellheim (Figure 3.59).

The seasonal rainfall pattern is linked to the El Niño Southern Oscillation, tropical cyclones and monsoonal activity.

The majority of the recorded discharge in the three catchments upstream of Burdekin Falls for the period 1980–2012 occurred during the months of January through to the end of March, which is the wet season in the region.

The discharge hydrographs of 2011–12 show a lag in peak flow compared with the historical patterns. This is consistent with the overall pattern of rainfall in the region; showing gradual ascent with a peak in March that subsides afterwards.

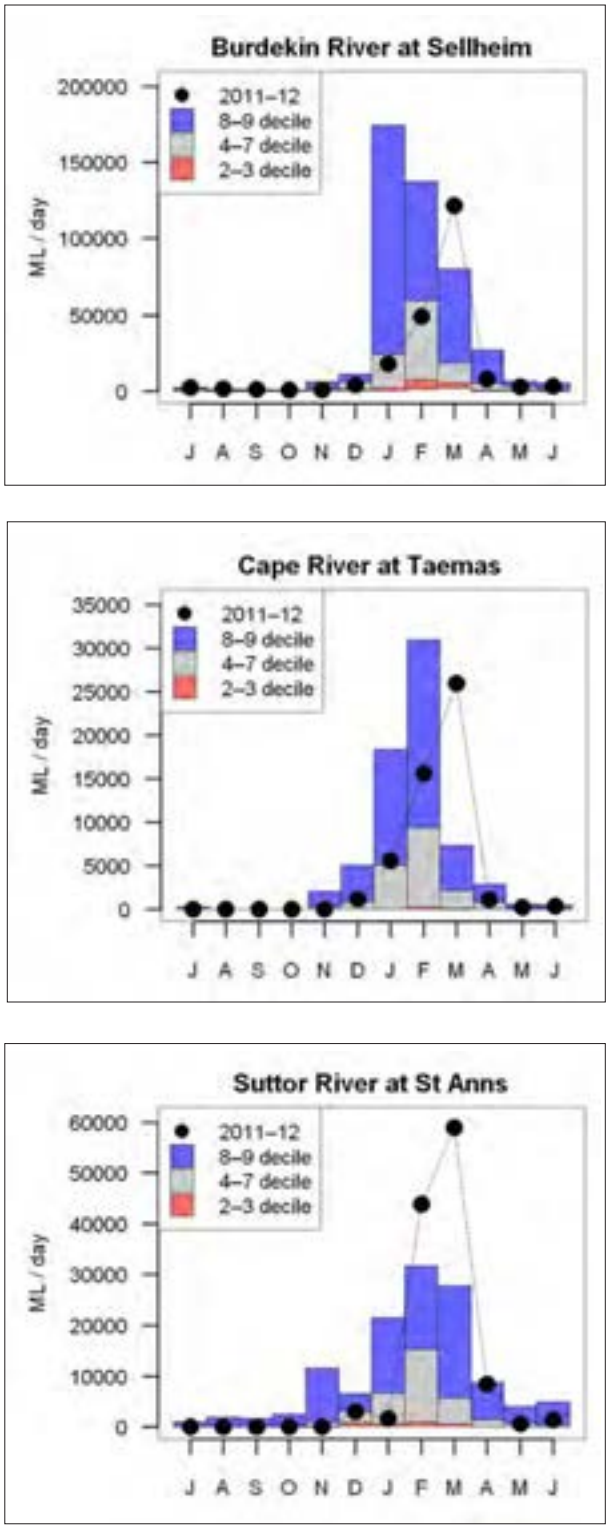


Figure 3.59 Monthly inflows to Burdekin Falls for 2011–12 with respect to the 1980–2012 decile rankings

Surface water storage volumes

Despite the large storage capacity of Burdekin Falls, the significant seasonal discharge from the upstream catchments has resulted in an almost periodic spilling of the dam every wet season since construction (Figure 3.60). In wet years, the spilling can continue for months. In 2011–12, the dam overflowed from January 2012 and continued to spill in June 2012.

Between January and June 2012, more than 29,000 ML of water passed over the spillway. The full storage and wet weather conditions ensured 100% of water allocations were available to local irrigators.

Local hydrogeology

Irrigation areas in the Burdekin River Delta are underlain by a relatively shallow watertable. Lower Burdekin Water manages a groundwater-dominated irrigation system downstream and east of Mount Kelly (Figure 3.61). More than 1,400 groundwater pumps are in operation applying 10–40 ML/ha/yr to crops (McMahon et al. 2002). This is equivalent to 1,000–4,000 mm/year.

The water source used for irrigation (groundwater or surface water) depends on proximity to the river or irrigation channels and on groundwater salinity and yield.

The coastal floodplain is mostly unconfined and has up to 100 m of sediments overlying the basement. The shallow groundwater in this system is in direct hydraulic connection with the Burdekin River.

Typically, during the dry season, groundwater elevation is higher than surface water levels in the river upstream of the Rocks weir allowing groundwater discharge into the river. During occasional high flows in the wet season, the direction of flow is reversed allowing surface water to recharge groundwater (Lenahan and Bristow 2010). This activity indicates a high connectivity between surface water and groundwater.

Lateral groundwater flow is northerly towards the coast. However, groundwater pumping causes large fluctuations in groundwater levels that can change the local groundwater flow direction.

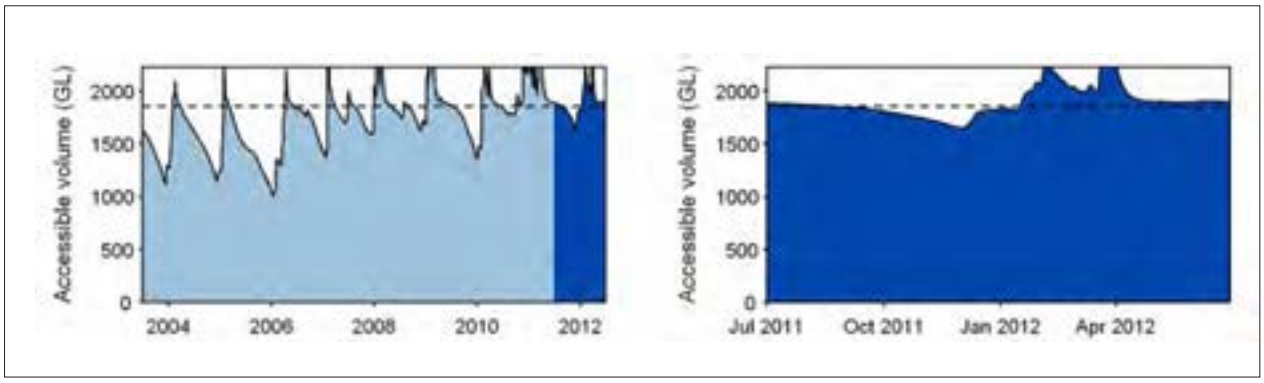


Figure 3.60 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Burdekin Falls storage, as well as total accessible storage capacity (dashed line)

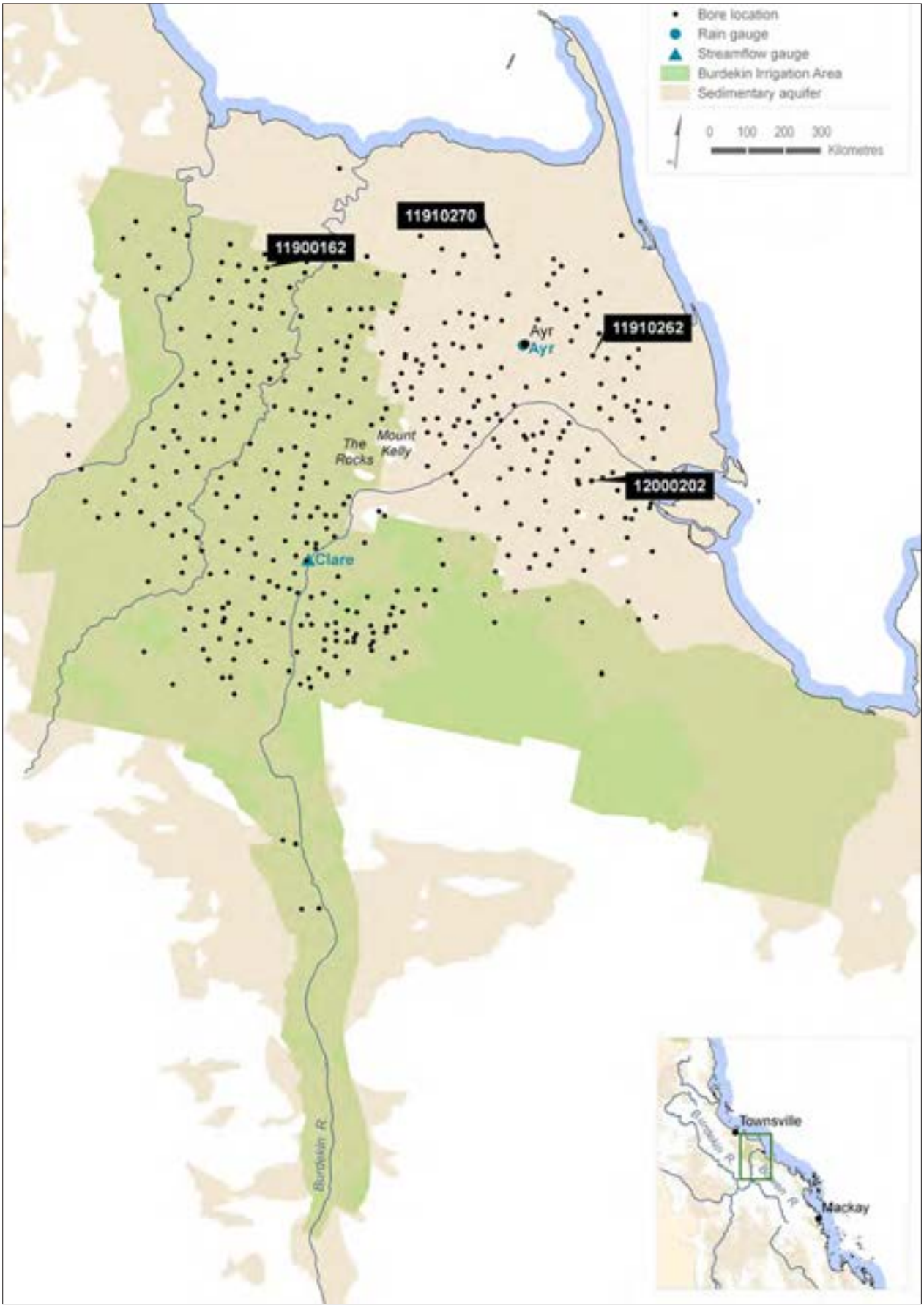


Figure 3.61 The Burdekin River Irrigation Area showing the location of groundwater bore sites, river gauge and rain gauge

Influences on shallow groundwater

Figure 3.62 shows the fluctuations in shallow groundwater levels at selected sites. From 2003 groundwater levels show a rising trend.

Figure 3.62 also illustrates the drivers of the groundwater level by comparing fluctuation in shallow groundwater levels with the monthly cumulative rainfall residual at Ayr and the monthly discharge of the Burdekin River at Clare (Figure 3.62). The location of gauges and bores is shown in Figure 3.61.

Periods in which the cumulative rainfall residual curve rises indicate wetter than average conditions. Periods with a falling trend indicate drier than average conditions.

Figure 3.62b shows a drier than average period up to 2007, followed by a wetter than average period.

Both rainfall and streamflow appear to be drivers for groundwater levels. Peaks in streamflow and in the rainfall residual curve correspond to peaks in groundwater. There are, however, some inconsistencies between the rainfall and groundwater level cycles. For example, groundwater levels start rising in 1995 and 2003 even though the rainfall residual mass curve is still falling.

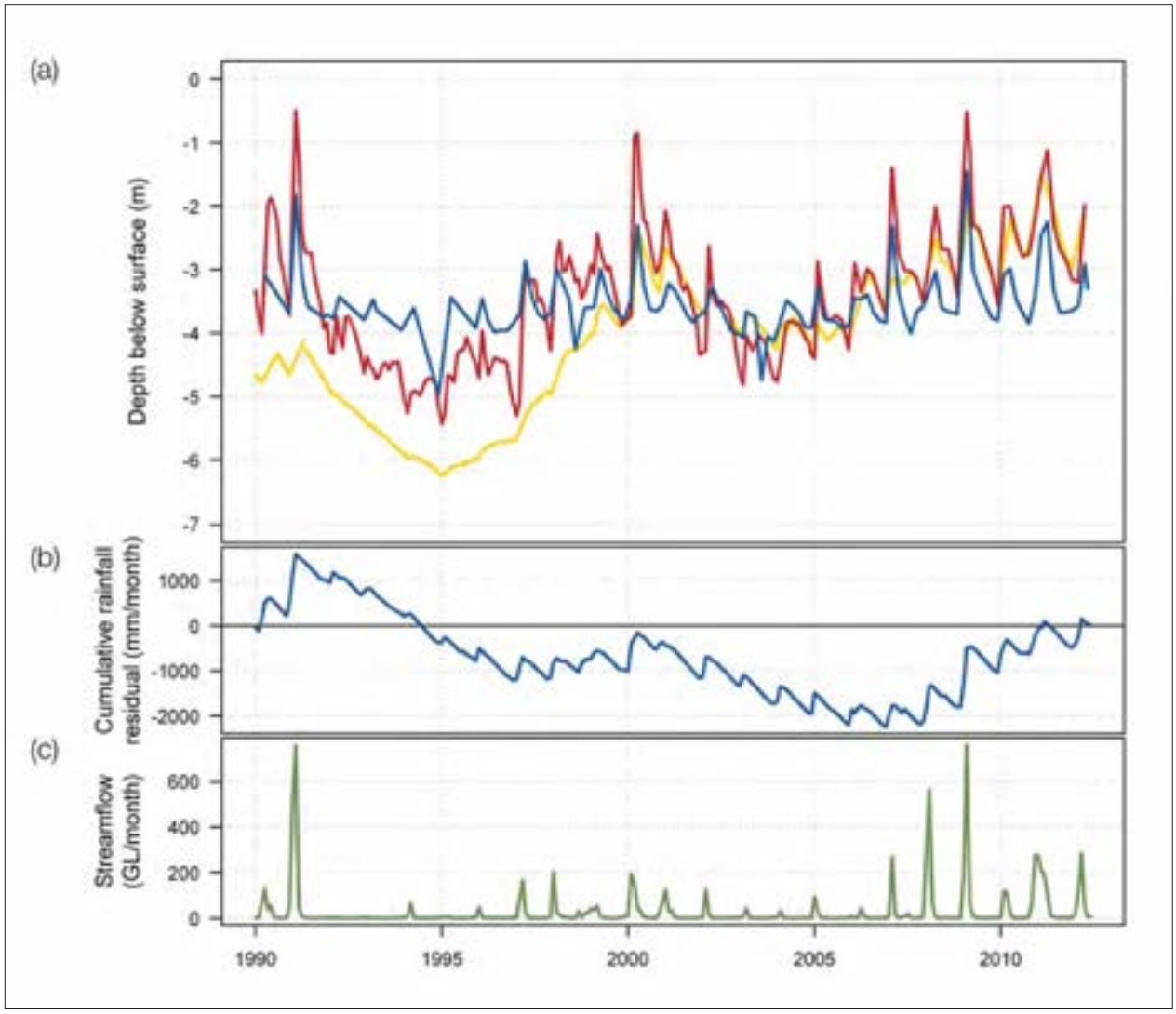


Figure 3.62 Comparison of shallow groundwater levels recorded at nested bore sites with rainfall and streamflow in the Burdekin River Irrigation Area to June 2012, showing (a) top panel: Bore 11910262 pipe D (red), Bore 12000202 pipe D (blue), Bore 11900162 pipe D (yellow); (b) cumulative rainfall residual mass at Ayr, Station 33002; and (c) lower panel: Burdekin River discharge at Clare, Station 120006B)

Groundwater level

Groundwater level measurement is an important source of information about hydrological and anthropogenic influences on the groundwater in an area, including recharge.

Figure 3.63 presents groundwater levels recorded in bores of different depth at the same site, a nested bore site, in the Lower Burdekin area. Groundwater level fluctuations are similar at all depths indicating that deeper and shallower groundwater is hydraulically connected. Vertical groundwater gradients are mostly downward indicating possibility of flow from the watertable to the deepest part of the aquifer.

Figure 3.64(a) shows the median groundwater depths in the upper groundwater aquifer in the Burdekin River Delta in 2011–12; Figure 3.64(b) shows the decile ranks of 2011–12 median groundwater levels compared to annual median groundwater levels in the last 22 years (1990–2012).

In general, in the upper aquifer, groundwater levels vary from quite shallow near the coast to deeper than 10 m further inland. Median groundwater depths in the upper aquifer in 2011–12 are mostly above the average of recorded levels within the irrigation area and are a mix of above average and below average northeast of the irrigation areas.

As shown in Figure 3.65(a), groundwater levels in the lower aquifer are generally between one and five meters below the surface. Median groundwater levels in the lower aquifer in 2011–12 are mostly above the average of recorded levels of the last 22 years Figure 3.65(b).

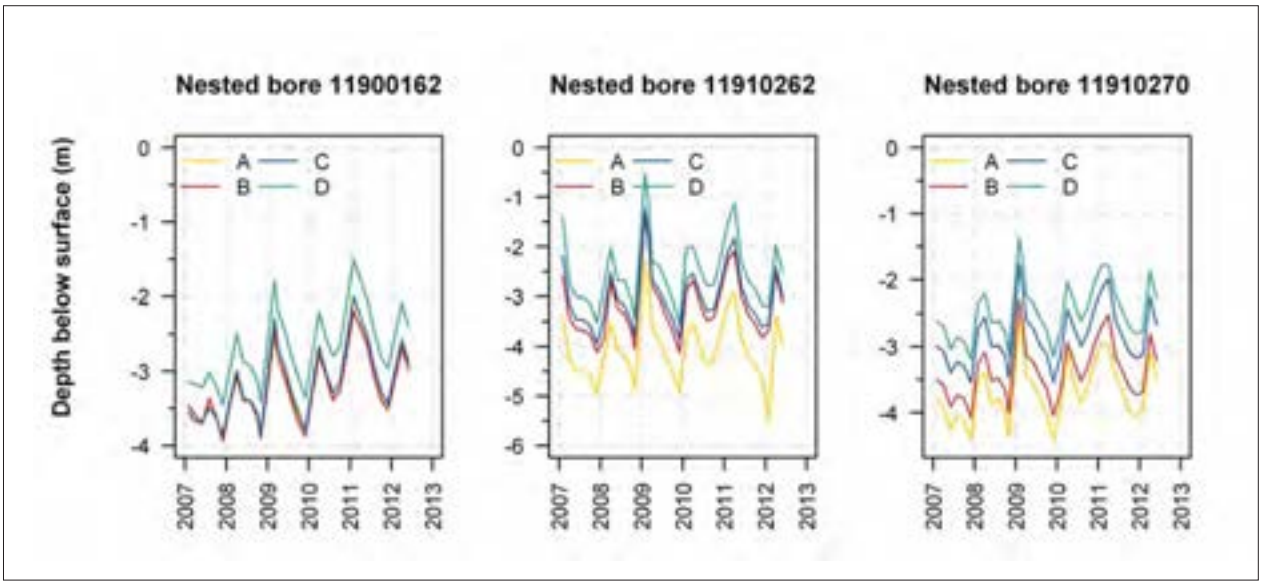


Figure 3.63 Groundwater levels between 2007 and 2012 recorded at selected nested bore sites in the Lower Burdekin area, depth of the screen interval increases from pipe D (shallow) to pipe A (deep)

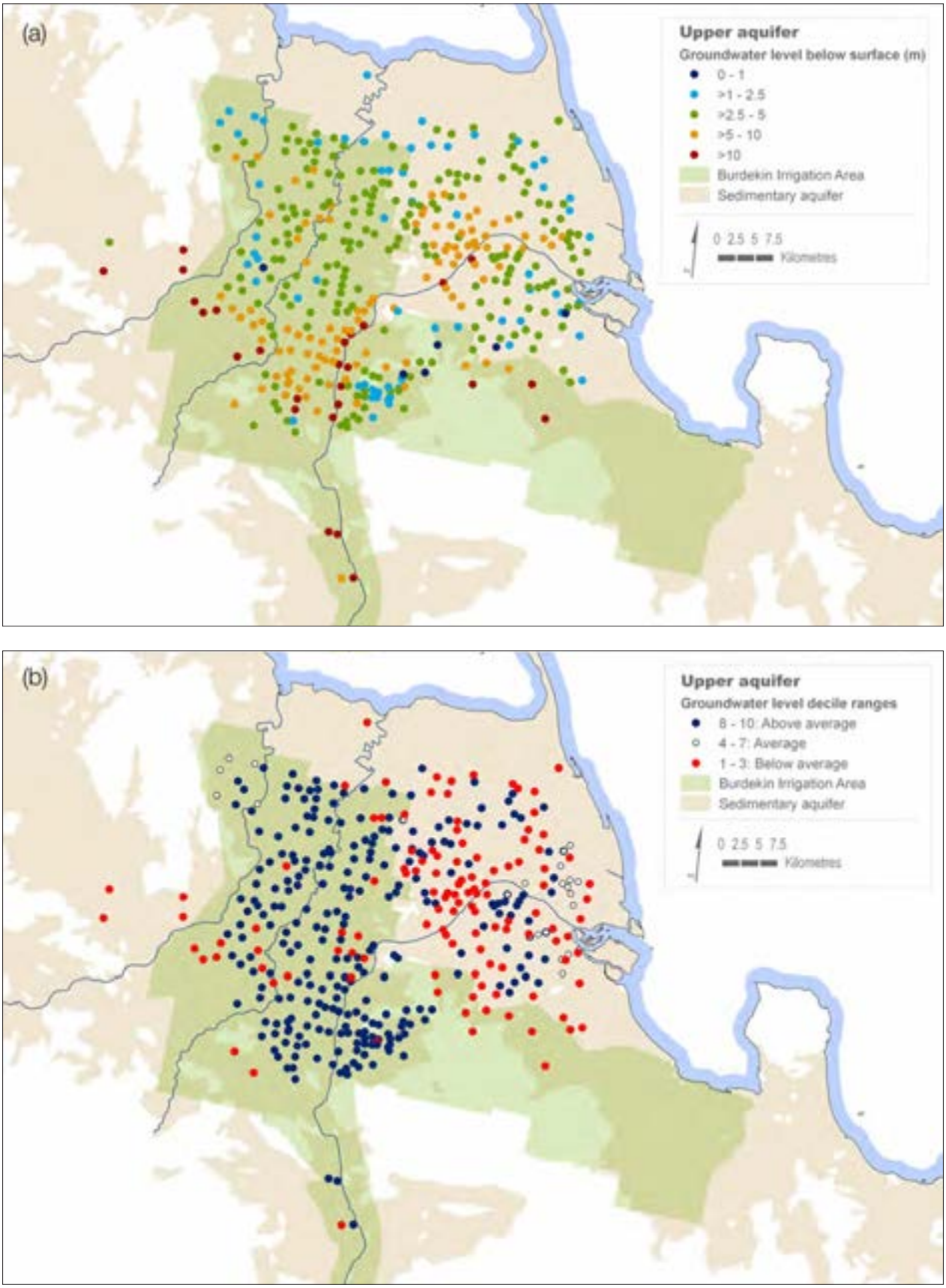
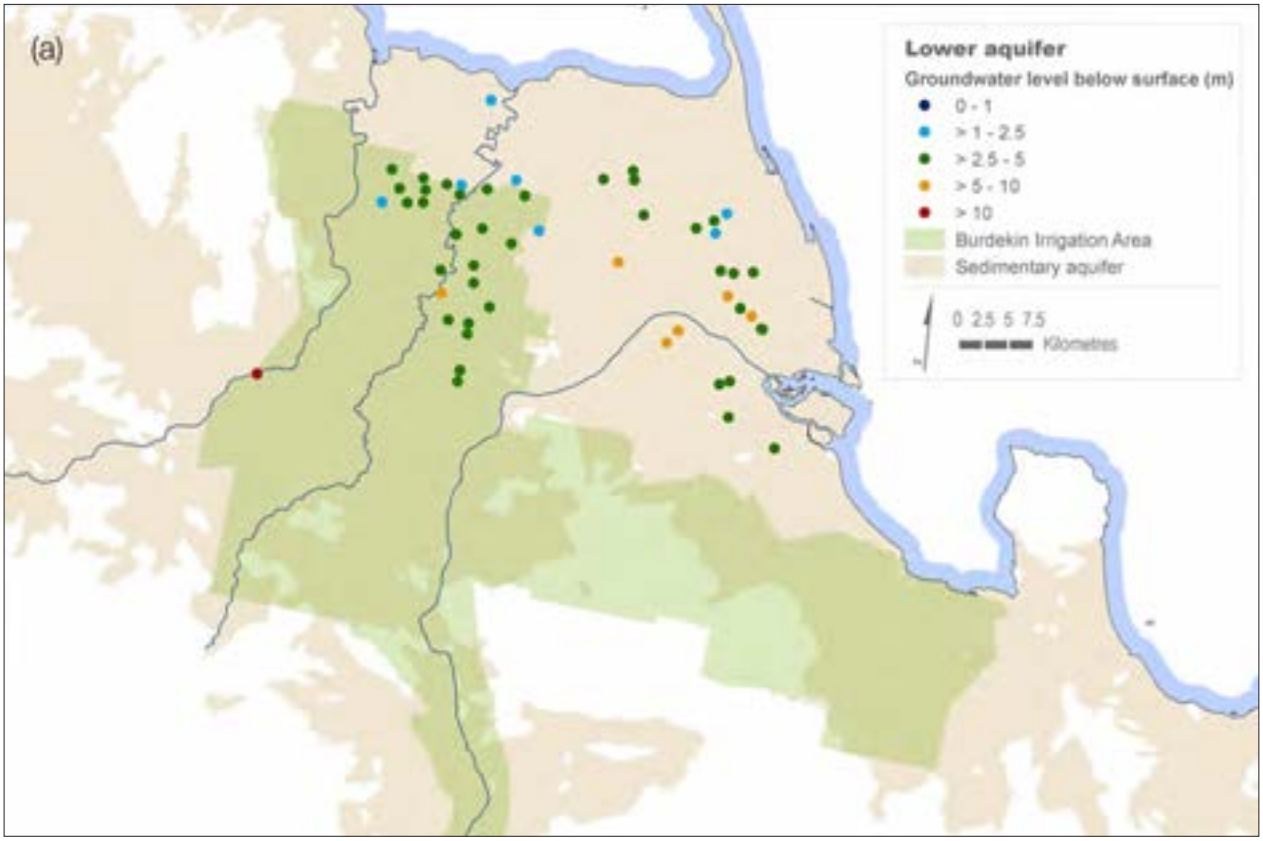


Figure 3.64 (a) Upper aquifer median groundwater depths for the Burdekin River Delta in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average



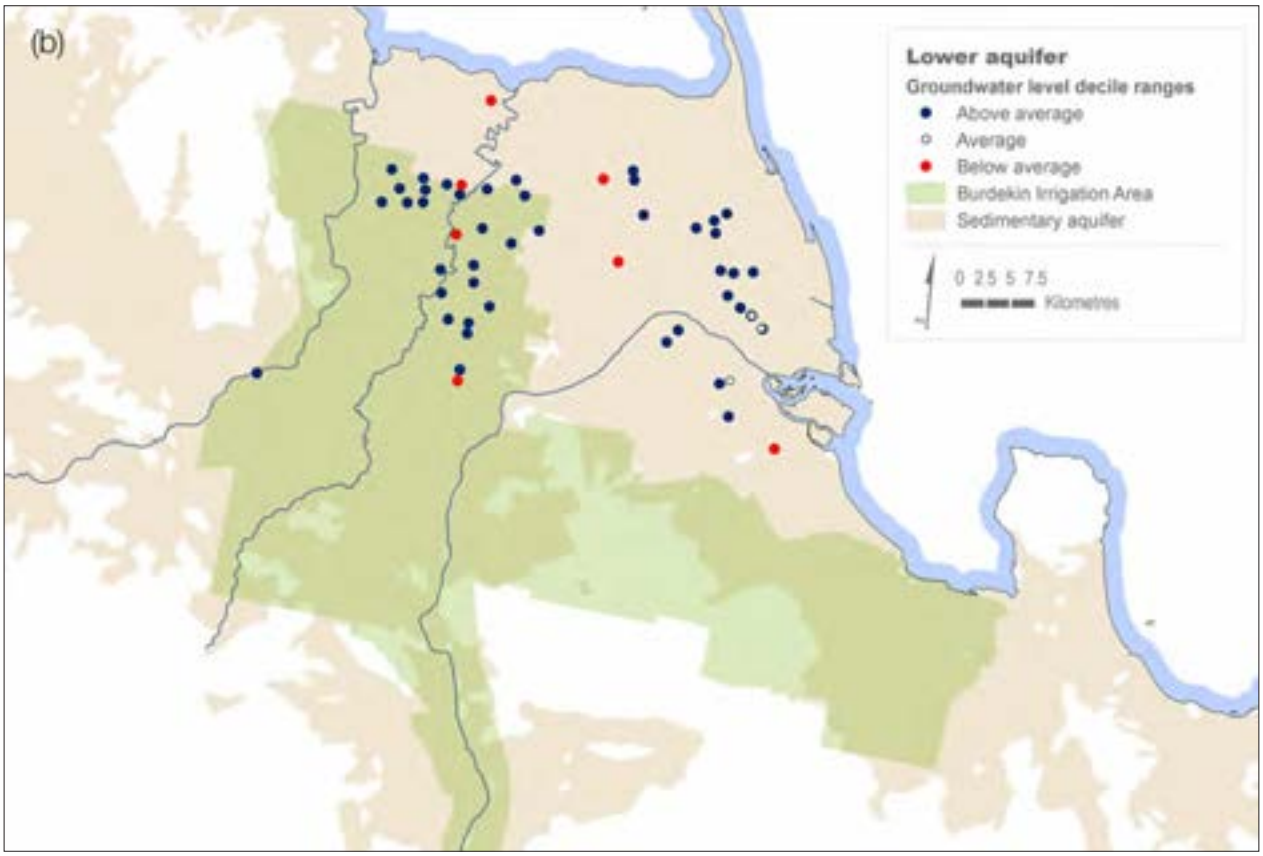


Figure 3.65 (a) Lower aquifer median groundwater depths for the Burdekin River Delta in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above

Groundwater salinity

Since the 1960s, when the Queensland Government commenced regular monitoring of groundwater quality, an increase in salinity has been reported at many sites. Two main issues linked to degrading groundwater quality highlighted by Lenahan and Bristow (2010) are:

- an increase in groundwater salinity beyond irrigated crop tolerance level reducing the groundwater resource volume available for irrigation; and
- ecosystems in decline due to greater influx of solutes from the aquifers into the surface water and ultimately into the Great Barrier Reef.

Increasing groundwater salinity at some locations is caused by influences on the hydrological cycle, such as land clearing and irrigation, which mobilise subsurface solute stores.

Increases in groundwater pumping can result in seawater intrusion or upward movement of deeper salty groundwater. In contrast, decreasing groundwater salinities in the shallow system can result from dilution by irrigation drainage or leakage from the river.

Figure 3.66 shows groundwater salinity, expressed in units of electrical conductivity, at four depths for each of three nested bore sites in the lower Burdekin River Delta (for bore locations, see Figure 3.61).

Groundwater salinity in the deep bores is usually very high compared to the shallow bores. At these nested sites, the shallow groundwater salinity is more than an order of magnitude lower than salinity in deeper bores.

Figure 3.66 also shows that groundwater salinity at these sites has been relatively stable since 2007. In general groundwater salinity is slow to change.

Figure 3.67 and Figure 3.68 show the median groundwater salinities in the upper and lower groundwater aquifers in 2011–12 and the ranking of these salinities compared to 22-year annual averages for the 1990–2012 period.

The Burdekin River Delta groundwater in the upper aquifer is saltier in the north, in the southeast near the coast and close to the bedrock outcrops in the south. Median groundwater salinities in the upper aquifer in 2011–12 do not show any consistent trend from the long-term averages.

In the lower aquifer, salty groundwater appears to define the distance from the coast where seawater intrusion may have occurred. Median groundwater salinities in the lower aquifer in 2011–12 again do not show any consistent trend from the long-term average.

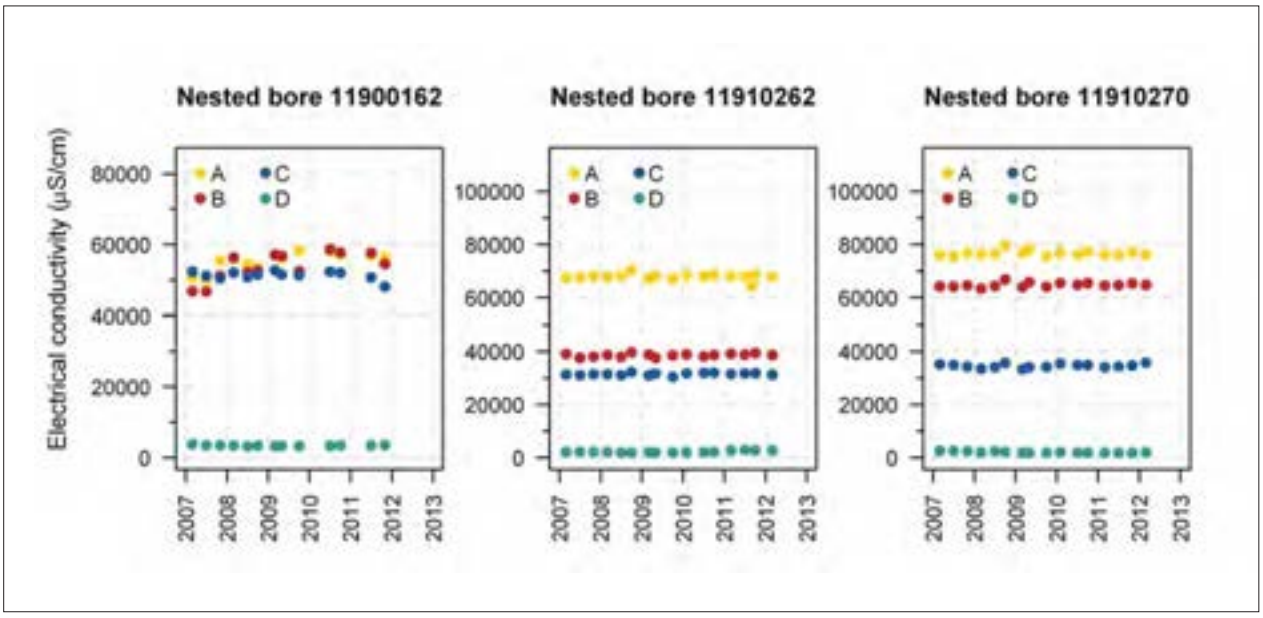
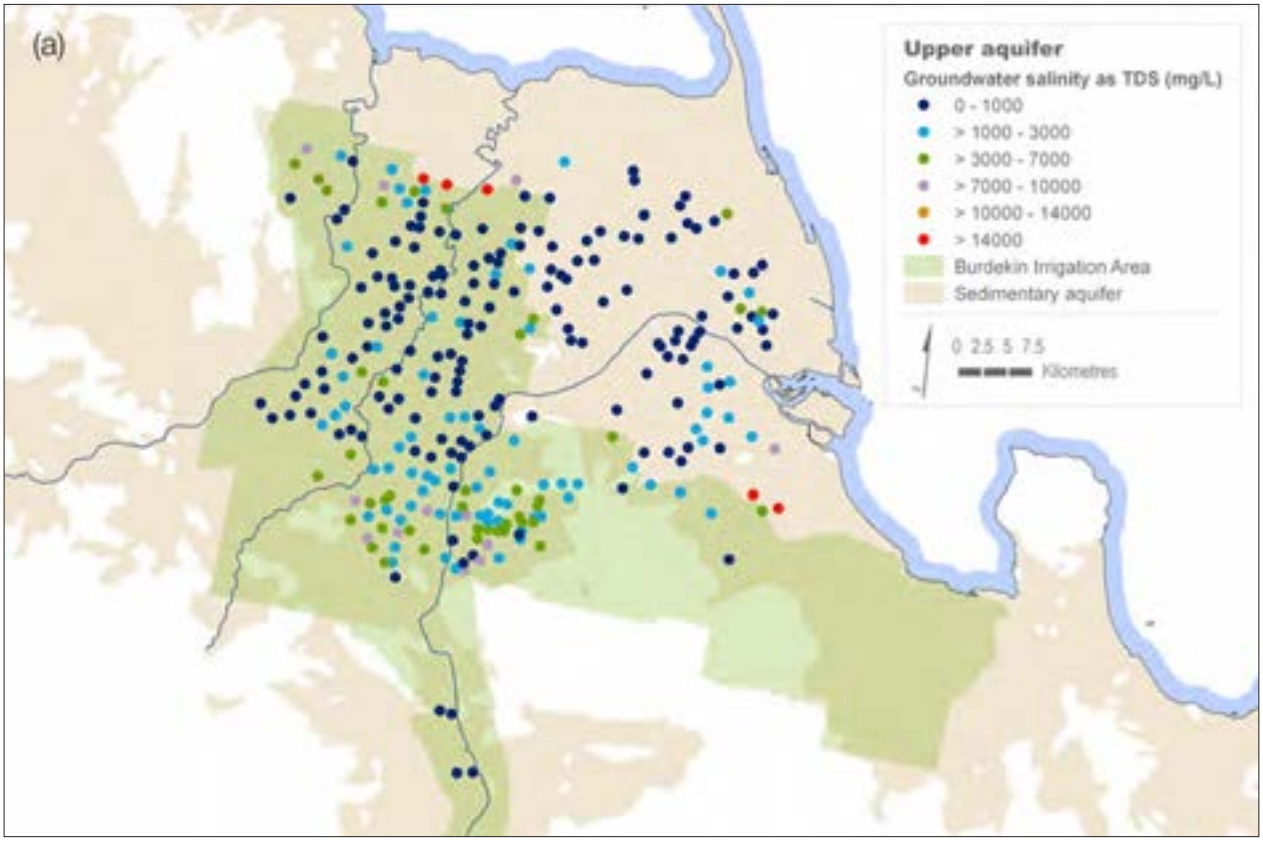


Figure 3.66 Groundwater salinity recorded at selected nested bore sites in the lower Burdekin area between 2007 and 2012, with depth of the screen increasing from pipe D (shallow) to pipe A (deep)



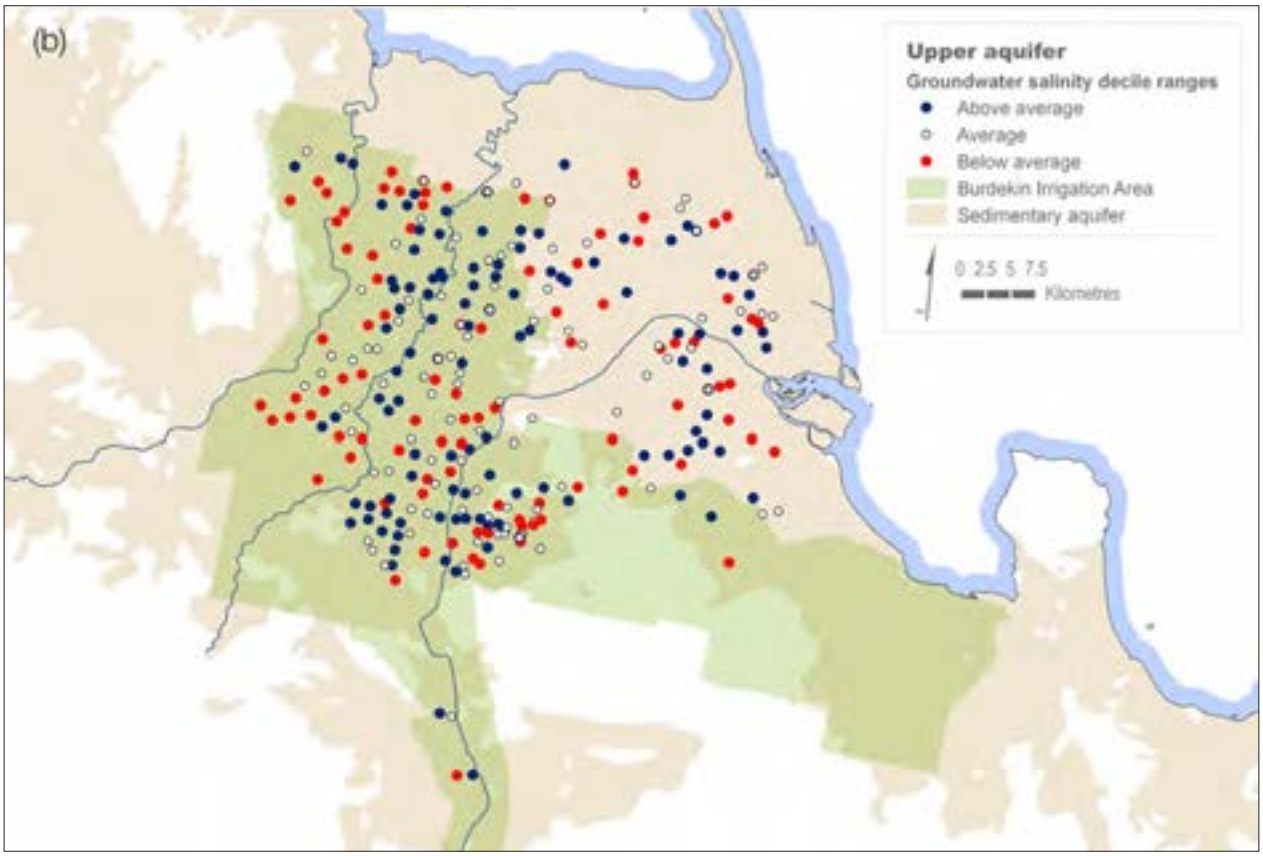


Figure 3.67 (a) Upper aquifer median groundwater salinity for the Burdekin River Delta in 2011–12, and (b) groundwater salinity in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), 4–7 as average and deciles 8–10 as above average

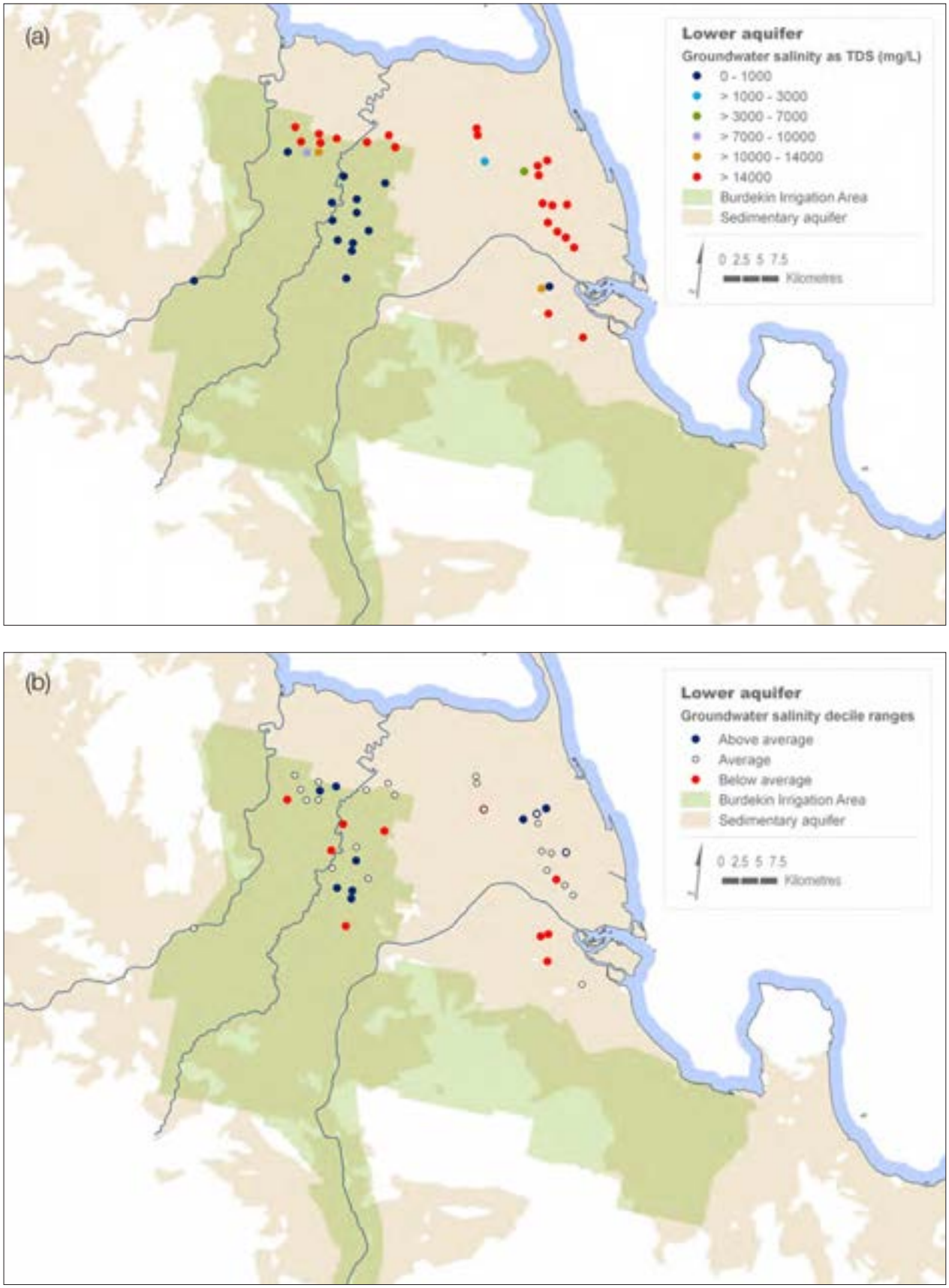


Figure 3.68 (a) Lower aquifer median groundwater salinity for the Burdekin River Delta in 2011–12, and (b) groundwater salinity in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

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4 South East Coast (NSW)

4.1 Introduction

This chapter examines water resources in the South East Coast (NSW) region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

4.2 Key information

Table 4.1 gives an overview of the key components of the data and information in this chapter

Table 4.1 Key information on water flows, stores and use in the South East Coast (NSW) region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	1,265 mm	+25%	9th—above average
Evapo-transpiration	919 mm	+12%	9th—above average
Landscape water yield	352 mm	+84%	10th—very much above average

Streamflow (at selected gauges)

Annual totals:	Above average flow throughout the region, locally very much above average
Salinity:	Annual median electrical conductivity predominantly below 1,000 µS/cm (Hunter River basin only)
Flooding:	Minor to moderate flooding in many rivers, locally major flooding in the north

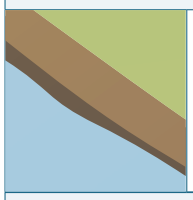
Surface water storage (comprising about 83% of the region's total capacity of all major storages)

Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
3,853 GL	3,658 GL	95%	3,049 GL	79%	+609 GL	+16%

Wetlands inflow patterns (for selected wetlands)

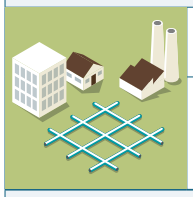
Hunter Estuary wetlands:	Above average flows throughout the year, with particularly high flows in November, February and March

Groundwater (in selected aquifers)



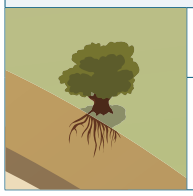
Salinity:	Scattered areas of saline groundwater (≥3,000 mg/L), particularly in coastal aquifers

Urban water use (Sydney)



Total use in 2011–12	Total use in 2010–11	Change	Restrictions
528 GL	544 GL	–16 GL (–3%)	Water Wise Rules

Annual mean soil moisture (model estimates)



Spatial patterns:	Very much above average soil moisture levels in the centre and north of the region, above average in the south
Temporal patterns in regional average:	Above average to very much above average regional average soil moisture throughout the year

4.3 Description of the region

The South East Coast (NSW) region covers all of coastal New South Wales, and has a total area of 129,500 km². The western and eastern boundaries of the region are defined by the Great Dividing Range and the coast. The northern boundary is defined as the New South Wales–Queensland border, and the southern boundary reflects the dividing line between the Towamba and East Gippsland river basins.

The southern part of the region has extensive forested headwaters, large areas of national park and state forest, important wetlands, river estuaries and fresh water swamps. The main catchments are those of the Shoalhaven, Clyde, Deua, Tuross, Bega and Towamba rivers. Subsections 4.3.1–4.3.4 give more detail on physical characteristics of the region.

The region has a population of over 6 million people, just under one third of Australia's total population (Australian Bureau of Statistics [ABS] 2011b), and includes Australia's largest and most densely populated city, Sydney.

Figure 4.1 highlights the major population centres in the region. These include Newcastle, the Central Coast and Wollongong, Further discussion of the region's population distribution and urban centres can be found in subsections 4.3.6 and 4.6 respectively.

Nature conservation is the main feature of the region (44%) followed by dryland pasture (37%). In the north of the region, subtropical cropping is common, and a mix of irrigated and dryland cropping is practised depending on the frequency of rainfall. In the mid-coast area, irrigated agriculture is common and mostly occurs in the Hunter River basin. Irrigation concerns mainly wine grapes and dairy pasture. In the south of the region, irrigation of broadacre and dairy farming enterprises occurs in the Hawkesbury–Nepean and Bega river basins. Section 4.7 has more information on the region's agricultural activities.

The region has a warm temperate climate with a moderate and generally reliable rainfall due to the presence of the Great Dividing Range. The proximity of the coast moderates weather extremes. Subsections 4.3.7 and 4.3.8 provide more information on the rainfall patterns and deficits across the region.

The Clarence River is the largest in the region in terms of annual discharge into the sea (Figure 4.1). The Hawkesbury and Hunter river basins are similar in size and form two important systems in the region in terms of urban and irrigation water supply.

Groundwater systems in the region that generally provide good potential for extraction include:

- Surficial sediment aquifer (porous media— unconsolidated);
- Tertiary basalt aquifer (fractured rock); and
- Mesozoic sediment aquifer (porous media—consolidated).

A more detailed description of the surface water and groundwater status in the region is given in section 4.5.

Figure 4.1 Major rivers and urban centres in the South East Coast (NSW) region

4.3.1 Physiographic characteristics

The physiographic map in Figure 4.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes.

The South East Coast (NSW) region has three physiographic provinces, namely:

- Kosciuszkan Uplands (13%): dissected high uplands on various resistant rocks, with isolated high plains;
- Macquarie Uplands (34%): deeply dissected sandstone plateaus over most of the area with rolling basalt uplands and sandstone cliffs in the northwest; and
- New England–Moreton Uplands (53%): dissected plateau margin on igneous and metamorphic rocks with coastal lowlands on weak sedimentary rocks, with littoral and alluvial plains.

Figure 4.2 Physiographic provinces of the South East Coast (NSW) region

4.3.2 Elevation

The western border of the South East Coast (NSW) region is clearly defined by the crest of the Great Dividing Range. The crest runs almost parallel with the coastline, with the exception of the western borders of the Hunter River basin.

As shown in Figure 4.3, the region contains many mountain ranges that belong to the Great Dividing Range (information was obtained from the Geoscience Australia website, www.ga.gov.au/topographic-mapping/digital-elevation-data.html). It also contains some plateaus and an almost continuous stretch of low-lying coastal areas.

The highest mountains in the region can be found west of Coffs Harbour, with peaks reaching altitudes of 1,500 m above sea level.

The crest of the Great Dividing Range forms the western border of the region, all the way from the north to the south. Altitudes on this crest line vary between less than 600 m at the western part of the Hunter River basin to more than 1,200 m in both the north and the south.

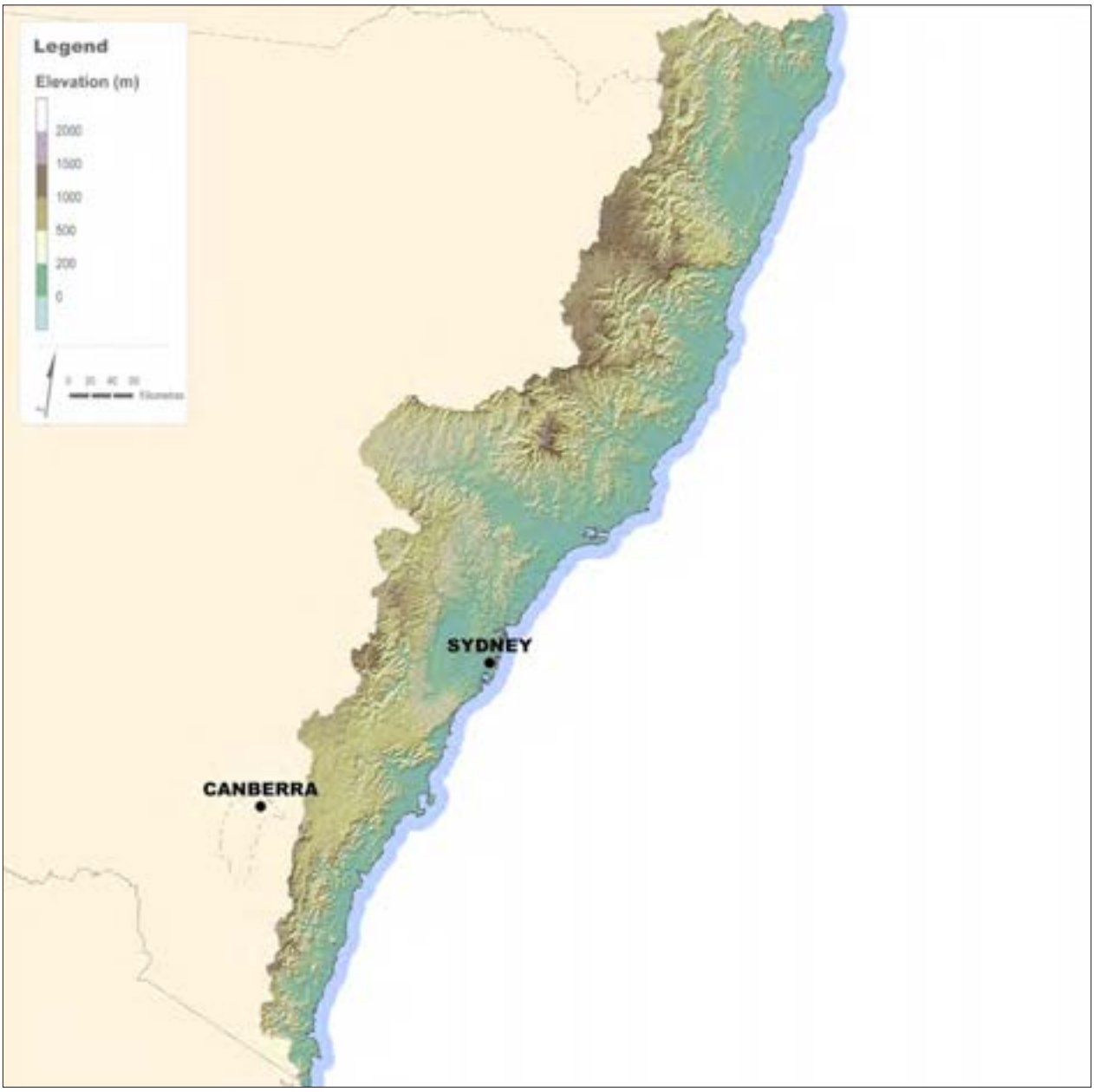


Figure 4.3 Ground surface elevations in the South East Coast (NSW) region

4.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. Table 4.2 shows the extent of steep slopes in the South East Coast (NSW) region. This is greater than for other regions in mainland Australia. The slopes were derived from the elevation information used in the previous section.

Table 4.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	4.9	4.5	29.9	60.7

The steep slopes in Figure 4.4 in particular show the wide escarpments of the western plateau. The eastern part of the plateau forms most of the water divide of the river basins. In fact, the highest peaks of the Great Dividing Range in this region are not necessarily located on the border of the region.

The steep slopes of the Great Dividing Range only come close to the coast around Sydney and Coffs Harbour. Also, the coastal plains of the south coast are relatively narrow.

Due to the steep slopes in the region, rivers rapidly accumulate run-off. As a consequence, high intensity rainfall often cause flash flooding in the narrow flat coastal strip. Recent years have provided clear examples of such flood in the region.

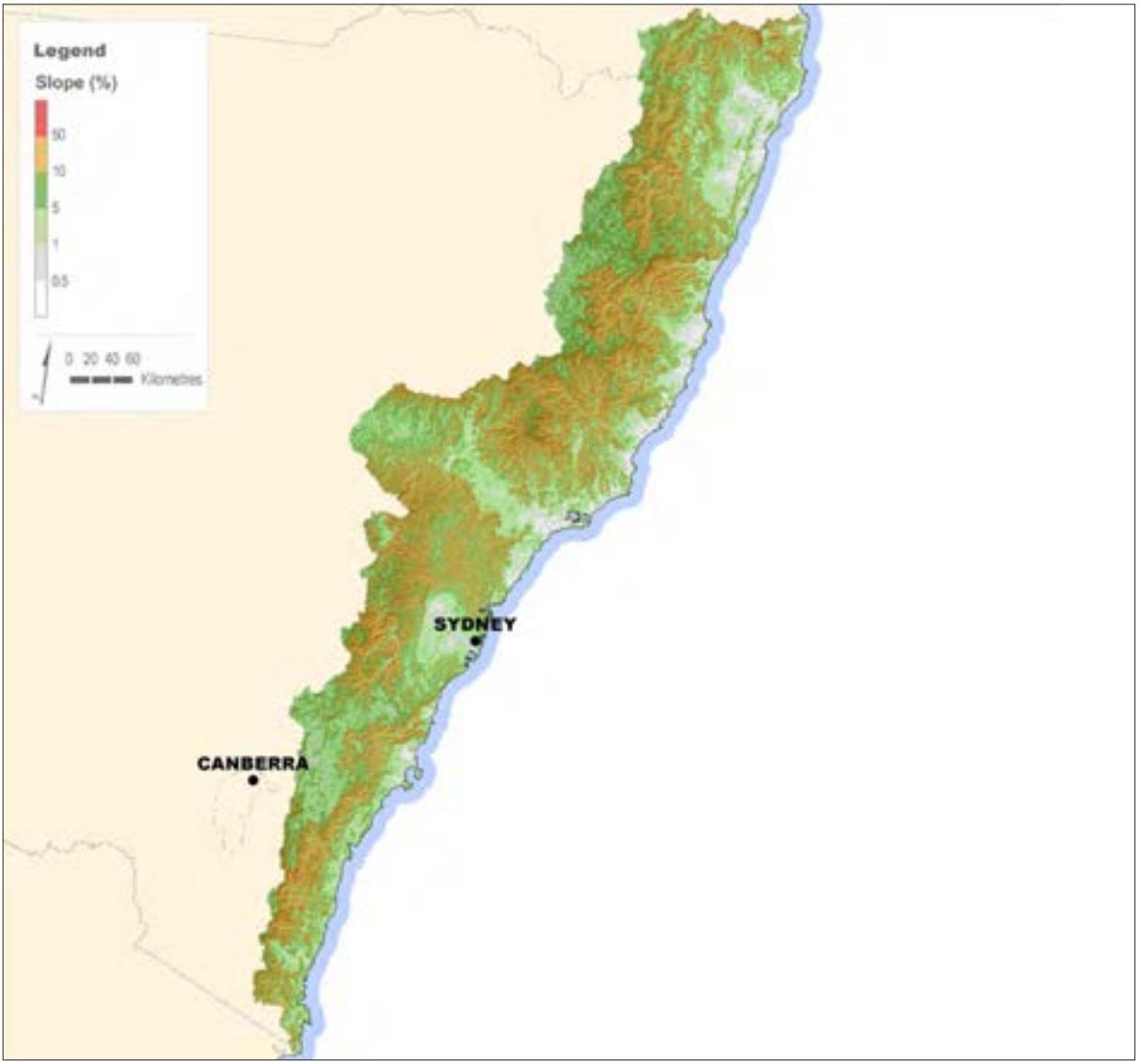


Figure 4.4 Surface slopes in the South East Coast (NSW) region

4.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 87% of the South East Coast (NSW) region is covered by five soil types, namely kandosols, dermosols, kurosols, sodosols and tenosols (Figure 4.5 and Figure 4.6).

Kandosols are structureless soils and are often very deep (up to three metres or more). They do not have a strongly contrasting texture and do not contain carbonate throughout their profile. They are low in chemical fertility and are well drained. With only moderate water-holding capacity compared with other soil types, they only have low to moderate agricultural potential. In this region, they are mostly present in pastures and areas used for nature conservation.

Soils with higher agricultural potential and moderate to high chemical fertility are dermosols. These soils are mostly present in the northern and southern parts of the region. They are well structured and have a high water-holding capacity, and they are mostly present in areas used for forestry and nature conservation.

Another soil type common in this region is kurosol. Soils of this type are strongly acidic (pH < 5.5) and have an abrupt increase in clay in the soil profile. Their use for agriculture is limited due to low chemical fertility and low water-holding capacity. Kurosols are mostly present in improved dairy pastures and areas used for forestry.

Sodosols are widely distributed across the region and have low agricultural potential due to a low nutrient status and low permeability. They present a clear change in texture as the clay and sodium content increases with depth. This can cause soil dispersion and instability which can give rise to a high risk of erosion (tunnel and gully erosion) as well as dryland salinity.

In the central to northern part of the region, tenosols are the common soil type. They have a weak profile development and, due to their low chemical fertility and water-holding capacity, limited agricultural potential.

The other soil types that have minimal representation in the South East Coast (NSW) region are chromosols, vertosols, hydrosols, ferrosols, podosols and rudosols (0.5–4%).

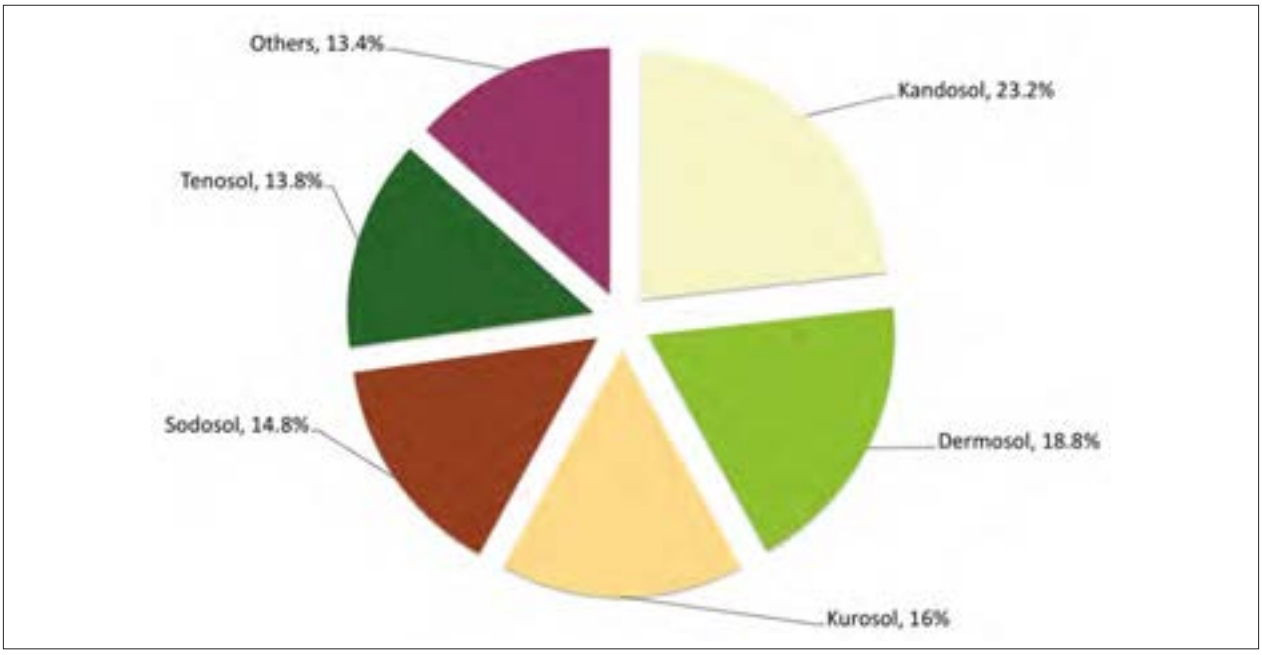


Figure 4.5 Soil types in the South East Coast (NSW) region

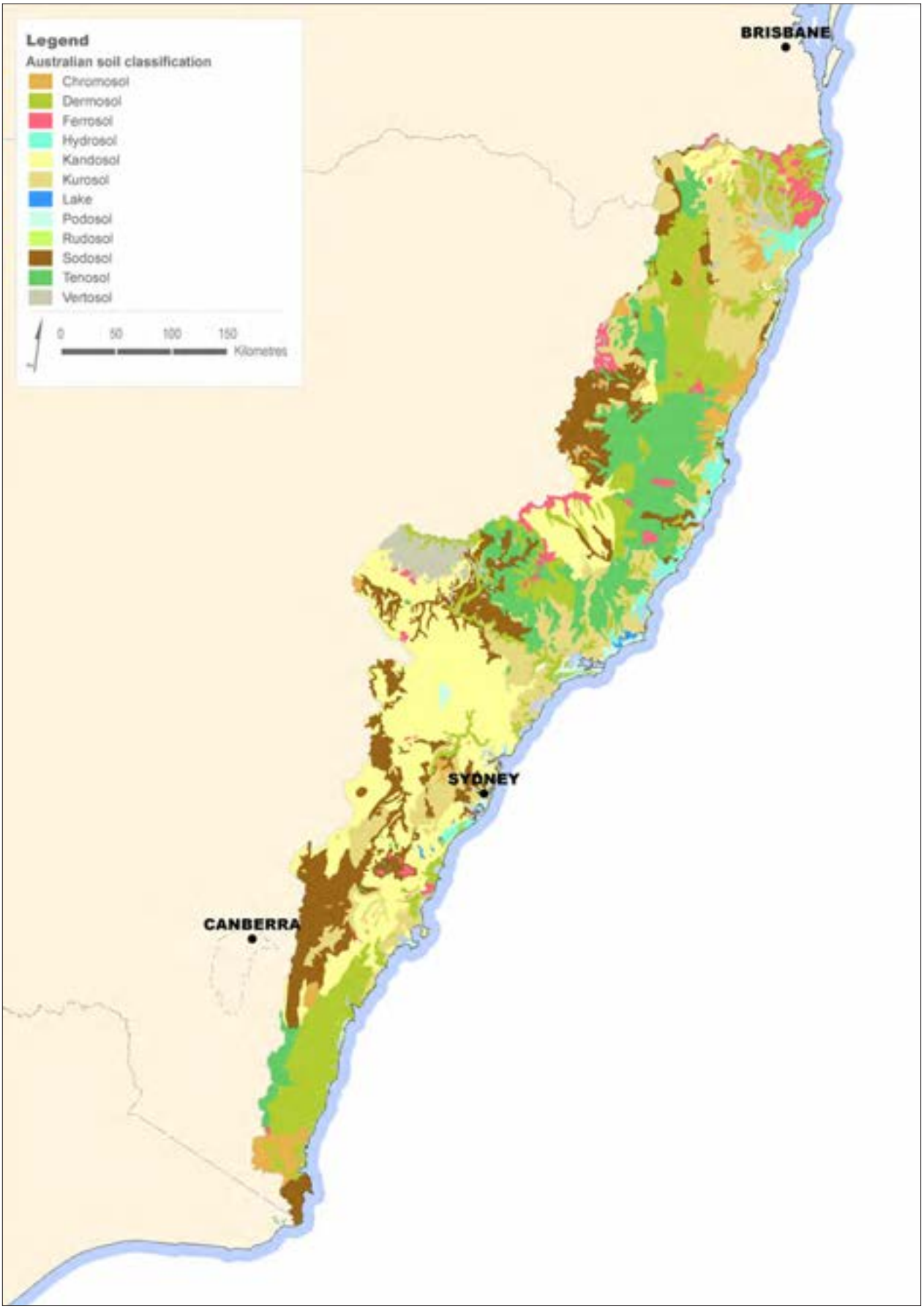


Figure 4.6 Soil type distribution in the South East Coast (NSW) region

4.3.5 Land use

Figure 4.7 presents land use in the South East Coast (NSW) region (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). The main feature of the region is nature conservation (44%) followed by dryland pasture (38%).

In the north of the region, subtropical cropping is common and a mix of irrigated and dryland cropping is practised depending on the reliability of rainfall.

In the mid-coast area, irrigated agriculture is common and mostly occurs in the Hunter River basin. This mainly consists of wine grapes and dairy pasture (Figure 4.8).

In the south of the region, irrigation of broadacre and dairy farming enterprises occurs in the Hawkesbury–Nepean and Bega river basins.

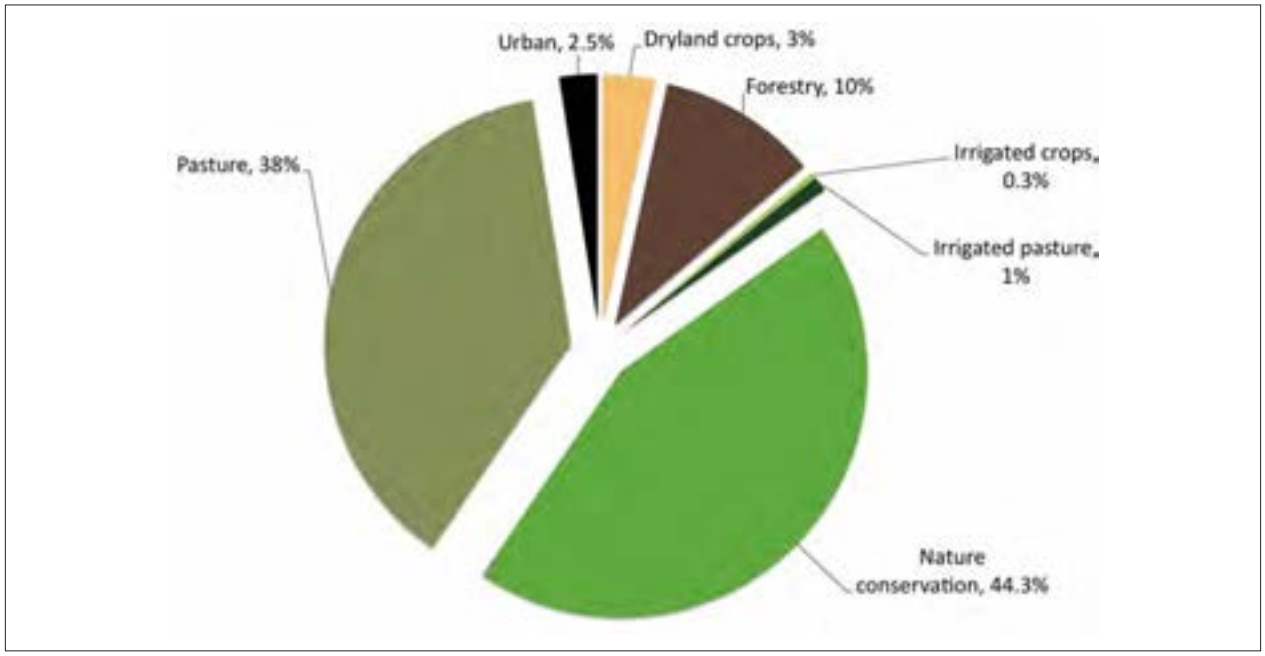


Figure 4.7 Land use in South East Coast (NSW) region

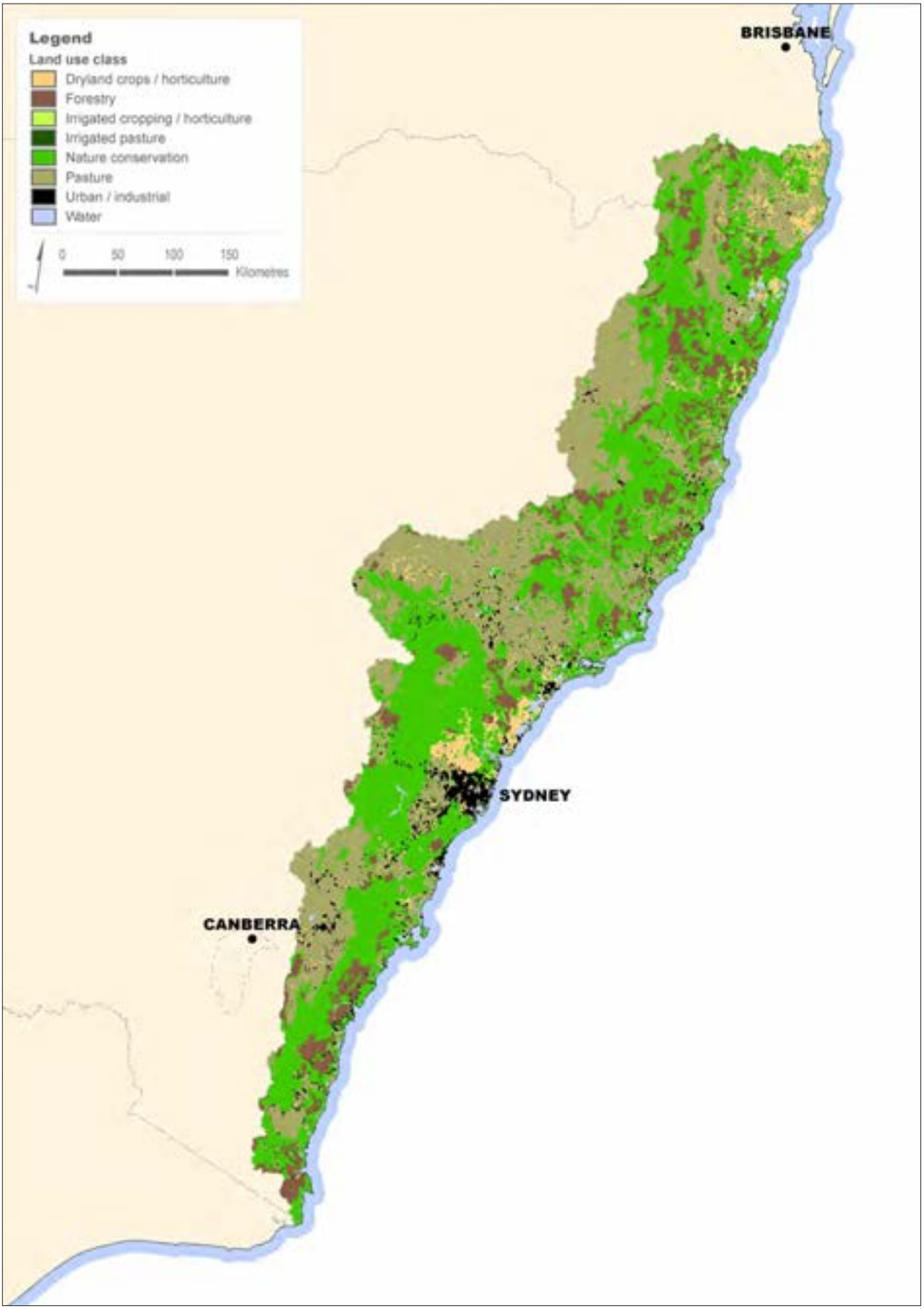


Figure 4.8 Land use distribution in the South East Coast (NSW) region

4.3.6 Population distribution

The South East Coast (NSW) region has over 6 million people which constitutes almost 33 % of all Australians (ABS 2011b). The most densely populated areas are along the coastal fringes (Figure 4.9).

Sydney is Australia's largest and most densely populated city. Other major urban areas such as Newcastle, the Central Coast and Wollongong are located in a narrow coastal strip in the north and south of Sydney.

Newcastle and Wollongong have strong links with mining and heavy industries such as steel production.

In the Hunter Valley, agricultural and mining are major drivers for a number of small urban centres.

The coastal centres of Port Macquarie, Coffs Harbour, Ballina and Byron Bay are supported by large agricultural production, tourism, fisheries and mining. In the north, Taree, Kempsey, Grafton and Lismore support large agricultural districts, mostly located adjacent to major rivers. Armidale is a major population centre near the western boundary of the region.

South of Wollongong and the Illawarra district agriculture, fisheries and tourism are key drivers for population centres.

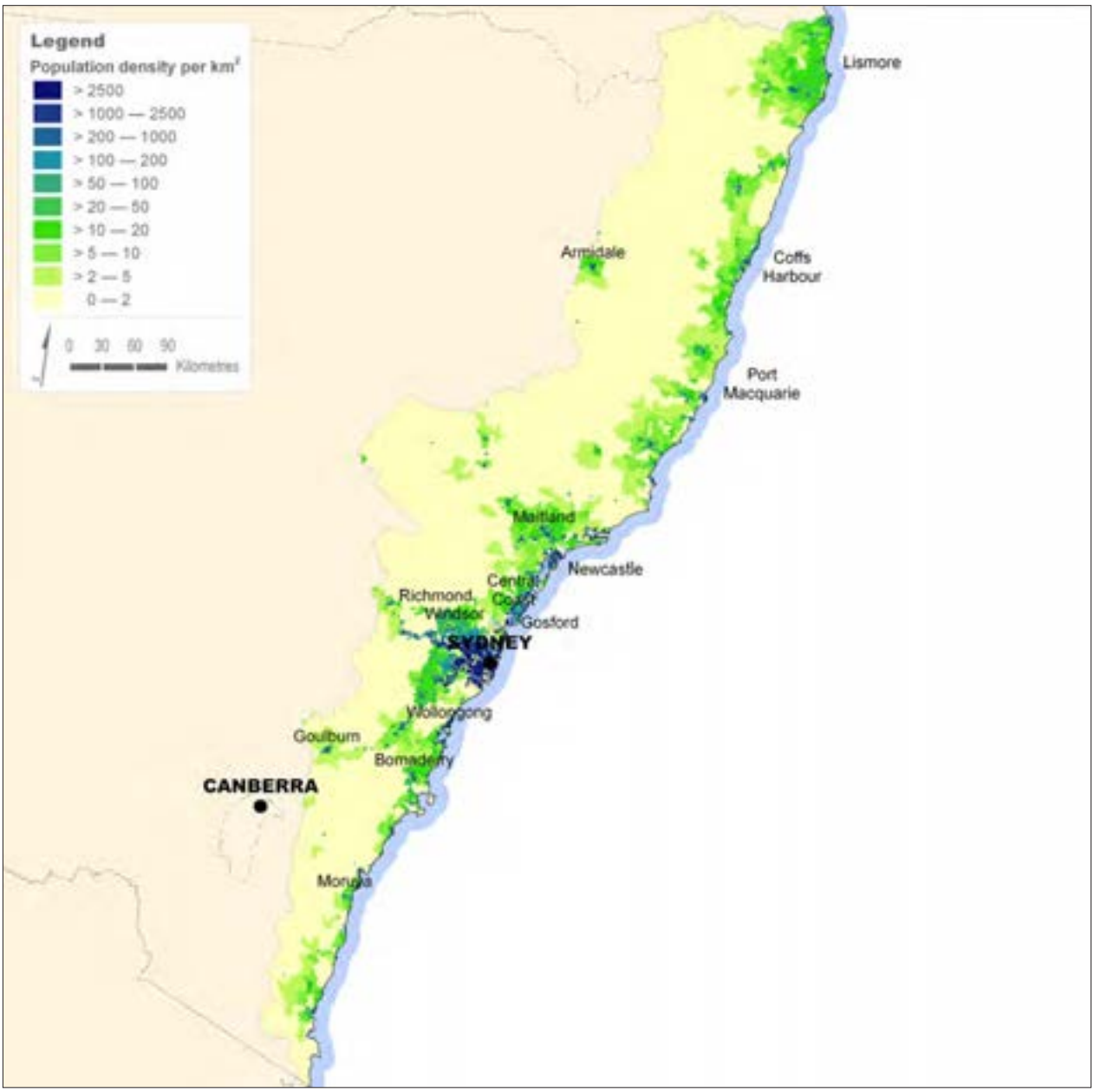


Figure 4.9 Population density and distribution in the South East Coast (NSW) region

4.3.7 Rainfall zones

The South East Coast (NSW) region has a warm temperate climate with moderate and generally reliable rainfall due to the presence of the Great Dividing Range in the west. The proximity of the coast moderates weather extremes. Median rainfall exceeds 350 mm throughout the region (Figure 4.10).

The northern half of the region has summer dominant rainfall, with median rainfall remaining high but decreasing westwards from patches with over 1,200 mm per year along the coast to between 650 mm and 1,200 mm inland.

The southern part of the region has a mixture of summer dominant rainfall amongst more uniform rainfall zones. The coastal mountains and plateaus are a major influence on the rainfall patterns that cause substantial climatic differences on a small spatial scale.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

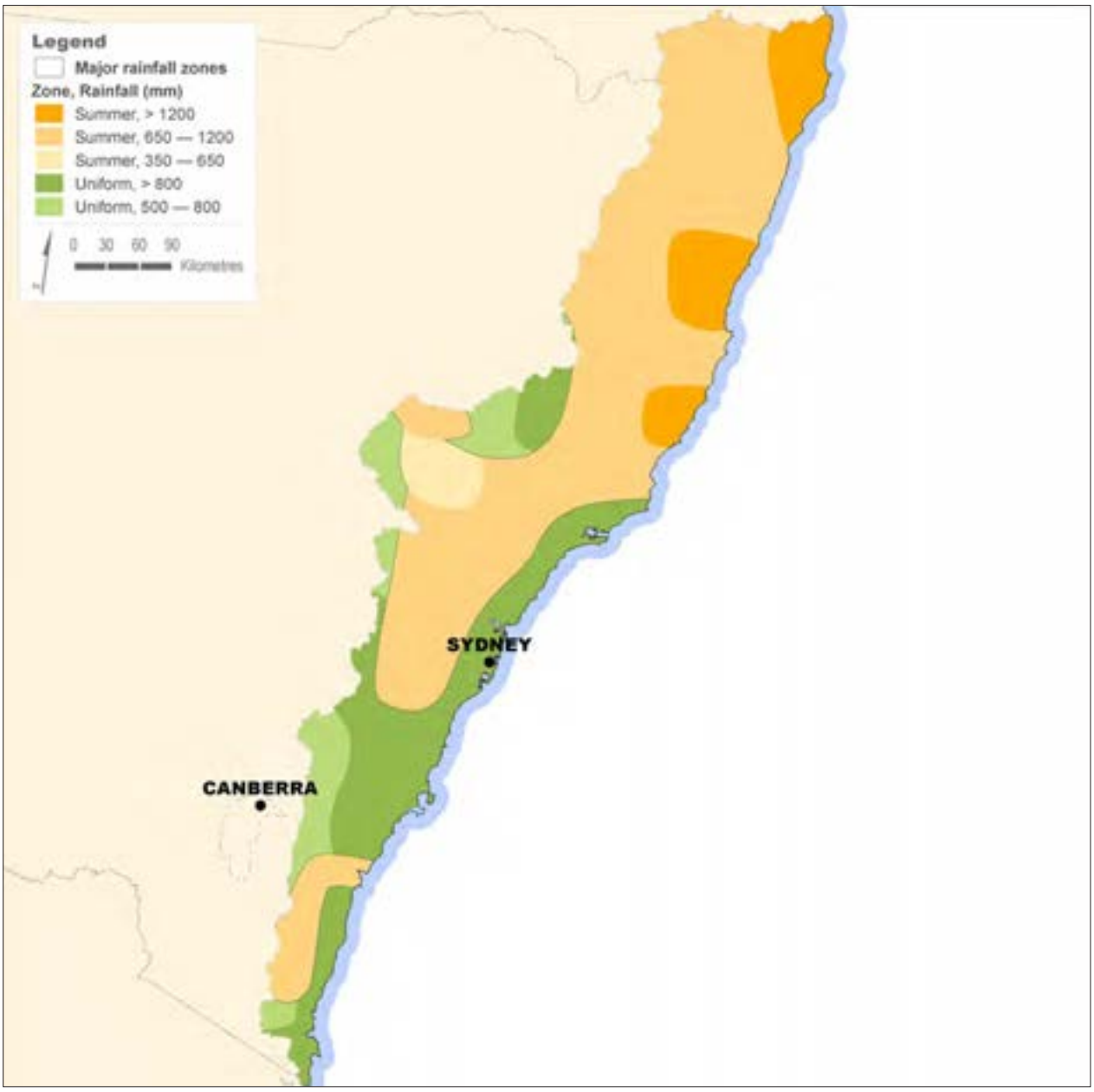


Figure 4.10 Rainfall zones in the South East Coast (NSW) region

4.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The South East Coast (NSW) has a distinct rainfall deficit pattern.

Most inland areas experience a deficit of water over the year (Figure 4.11). Substantial deficits can be expected in the Hunter River basin. This basin contains major irrigation areas that must rely on surface water storages to supply enough water to the crops.

Along the coast, many areas experience an abundance of water over the year. In these areas, the land cover is mainly dominated by forests (either production forests or subtropical rainforests).

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

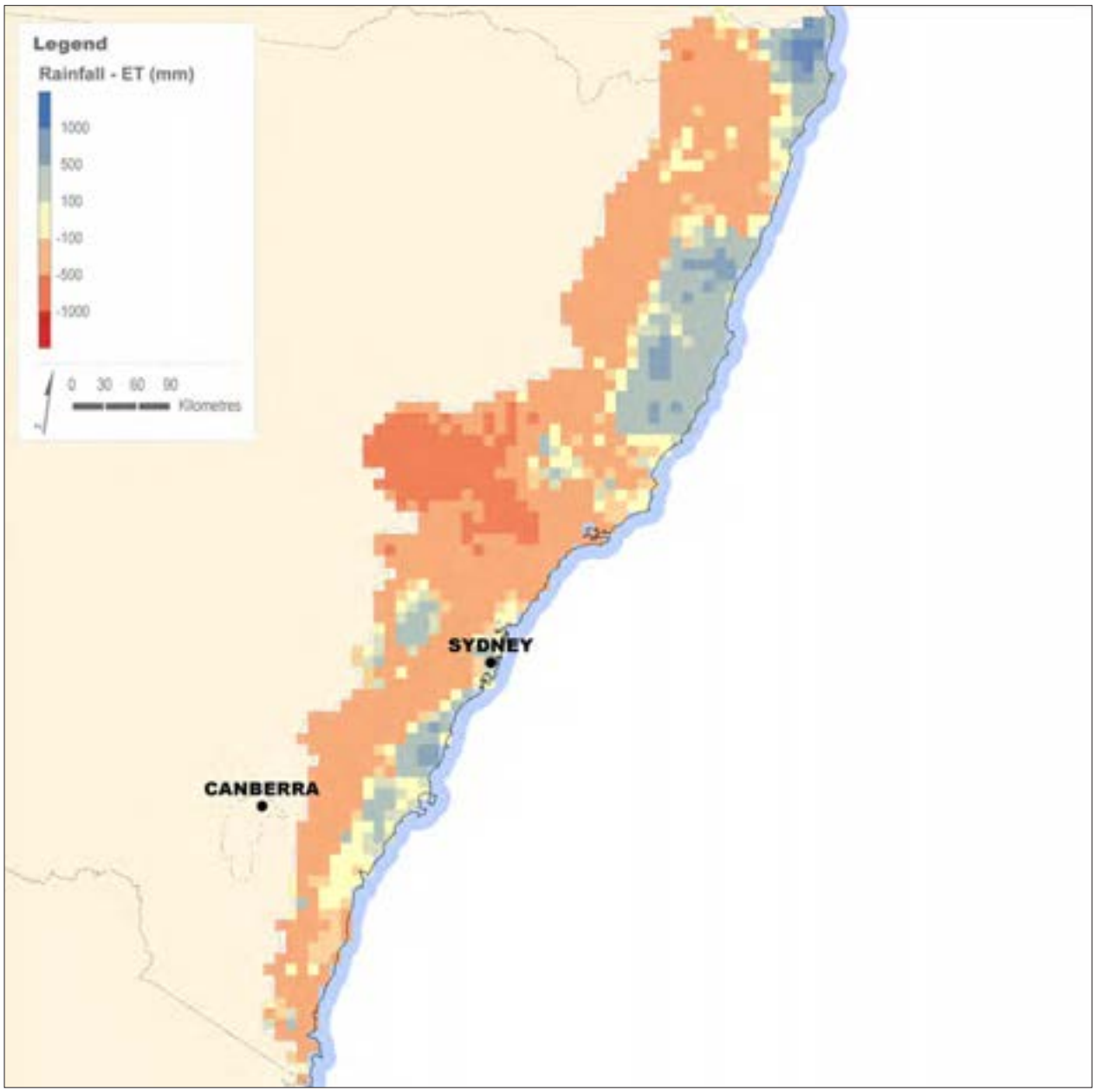


Figure 4.11 Rainfall deficit distribution for the South East Coast (NSW) region

4.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the South East Coast (NSW) region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in Introduction and addressed in more detail in the Technical Supplement.

Figure 4.12 shows the region has a seasonal rainfall pattern with a wetter summer and a drier winter period. Average monthly evapotranspiration totals generally follow those of rainfall. The region's monthly landscape water yield history shows a pattern of low yield in the period September–December, which increases during January–March and remains higher throughout April–July.

The 2011–12 year was a relatively wet year throughout. Rainfall was only below the historic median in May 2012. The wet La Niña-influenced summer period (November 2011–April 2012) contributed to particularly high monthly rainfall.

Evapotranspiration also remained above the historic median throughout the year. The monthly totals mainly stayed between the 50th and 90th percentile of the historic records.

The monthly landscape water yield for 2011–12 exceeded the 75th percentile in the first ten months of the year, only returning back to historic median levels in May 2012, due to the relatively low rainfall in that month. February and March, in particular, had very much above average high landscape water yields that coincided with the many floods that occurred in the region's north (early February) and in the central and southern parts of the region (early March).

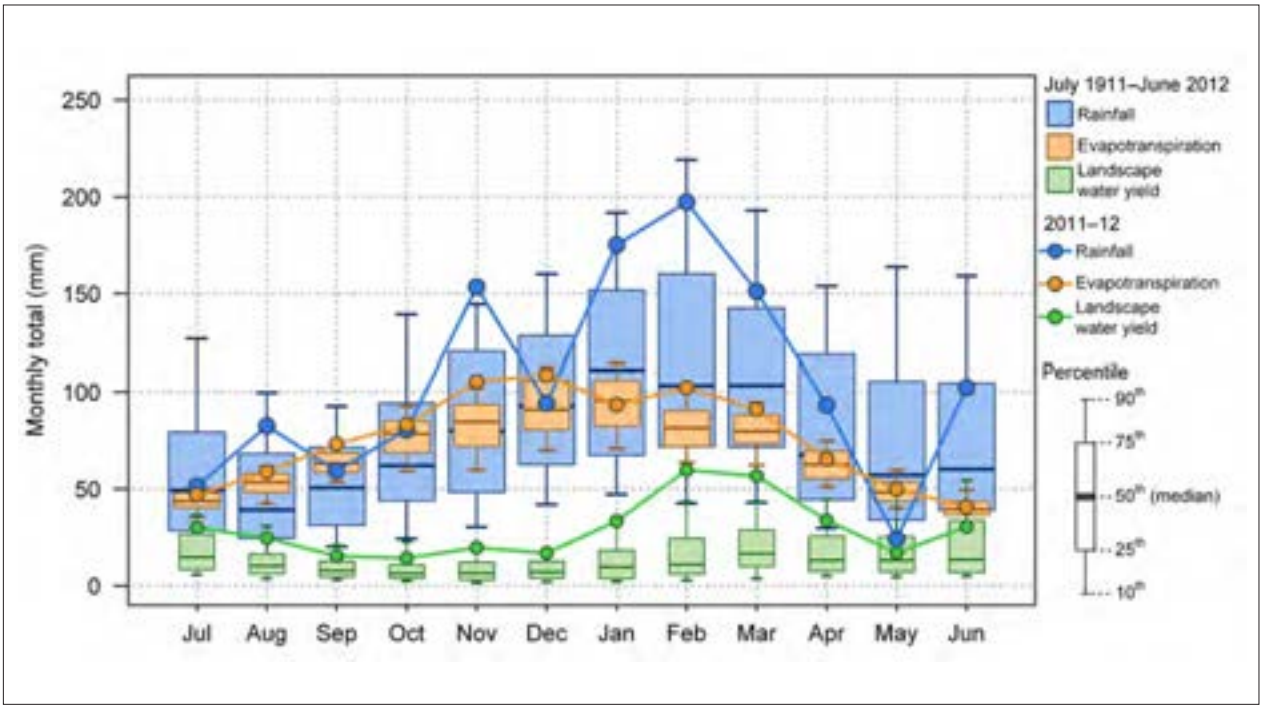


Figure 4.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the South East Coast (NSW) region

4.4.1 Rainfall

Rainfall for the South East Coast (NSW) region for 2011–12 is estimated to be 1,265 mm. This is 25% above the region's long-term average (July 1911–June 2012) of 1,013 mm. Figure 4.13a shows that the highest rainfall occurred adjacent to the coast with annual totals exceeding 1,800 mm in many areas for 2011–12, especially in the north. The majority of the inland areas had rainfall ranging between 600 mm and 1,200 mm for 2011–12.

Rainfall deciles for 2011–12 indicate above average rainfall for the majority of the region over the course of the year (Figure 4.13b). Some inland areas in the region's north received average rainfall. Very much above average rainfall was recorded in the uphill areas of the central west, including large parts of the Blue Mountains, and in the coastal zone surrounding Sydney.

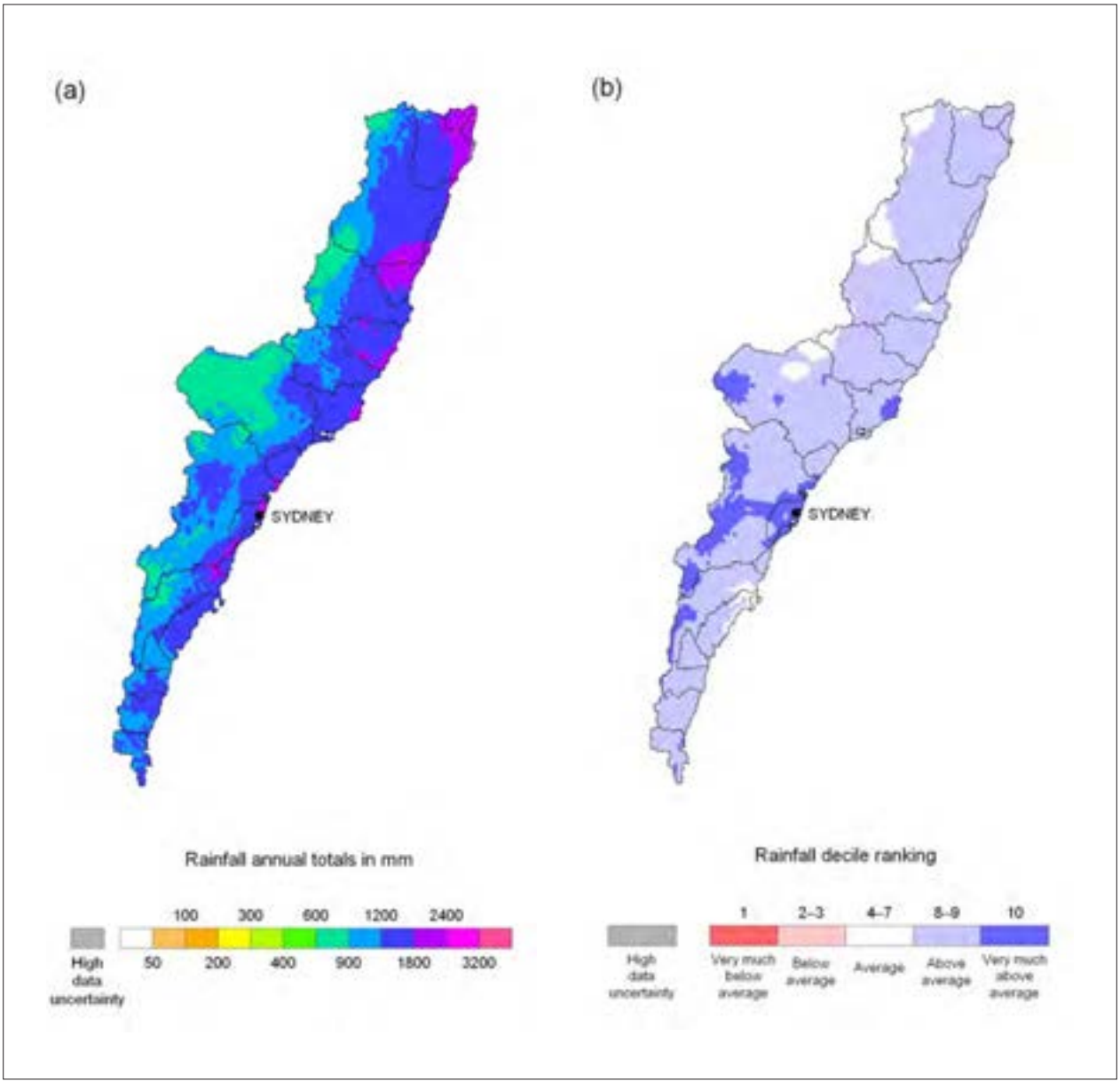


Figure 4.13 Spatial distribution of (a) annual rainfall in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South East Coast (NSW) region

Rainfall variability in the recent past

Figure 4.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 1,014 mm, varying from 772 mm (2002–03) to 1,508 mm (1988–89). Temporal variability and seasonal patterns since 1980 are presented in Figure 4.14b.

Figure 4.14a also indicates the presence of cyclical patterns in annual rainfall over these 32 years. The pattern is apparent in the summer and winter periods' moving averages (Figure 4.14b), although the pattern is less evident in the summer period than it is for the winter period.

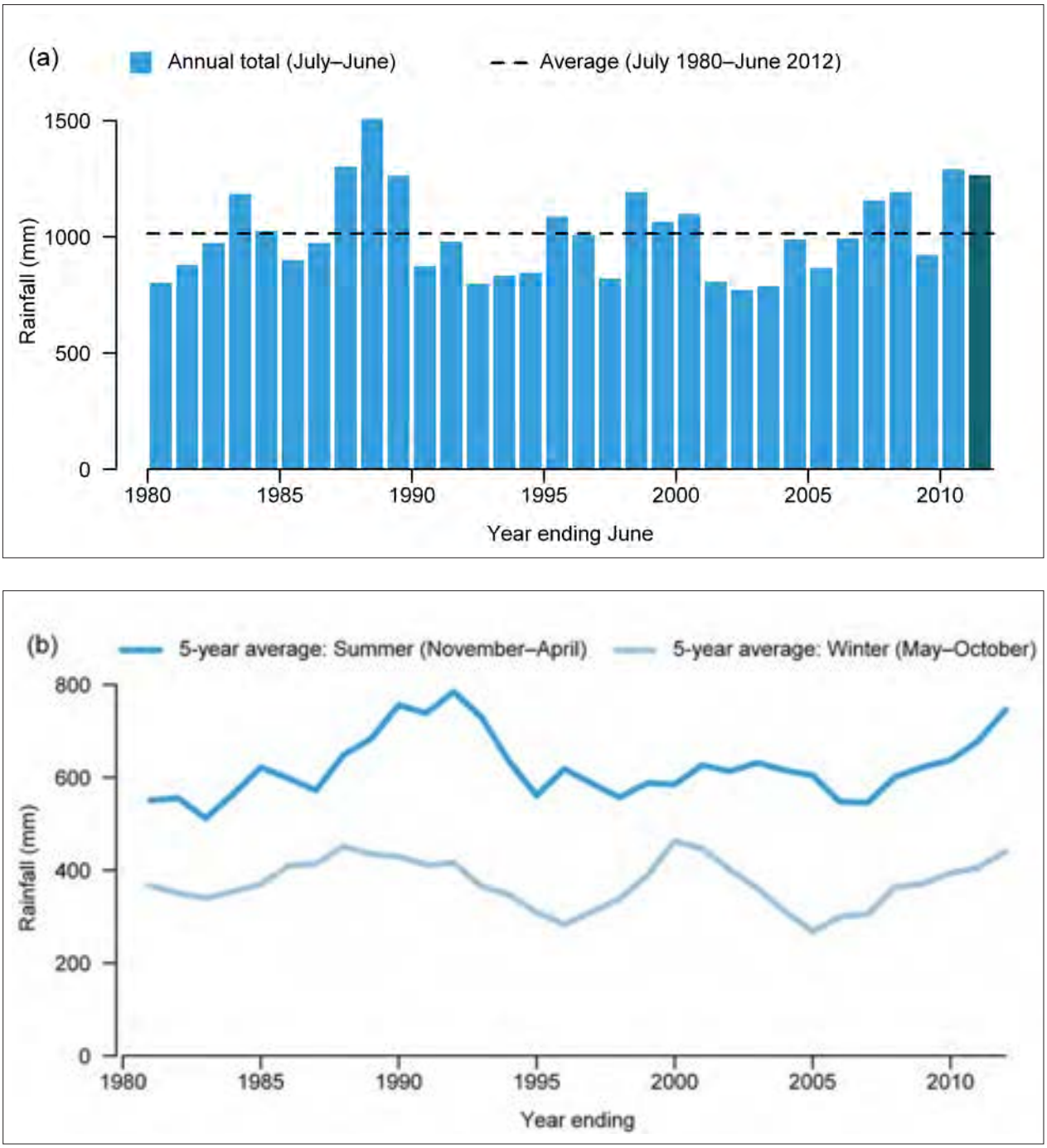


Figure 4.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (NSW) region

Recent trends in rainfall

Figure 4.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 4.15b.

Figure 4.15a shows that since 1980 a strong increase in rainfall has occurred in large parts of the north of the region. In contrast, the south has a pattern of predominantly decreasing rainfall.

Figure 4.15b, however, indicates that with the exception of some relatively small areas in the northern half of the region the trends are not statistically significant.

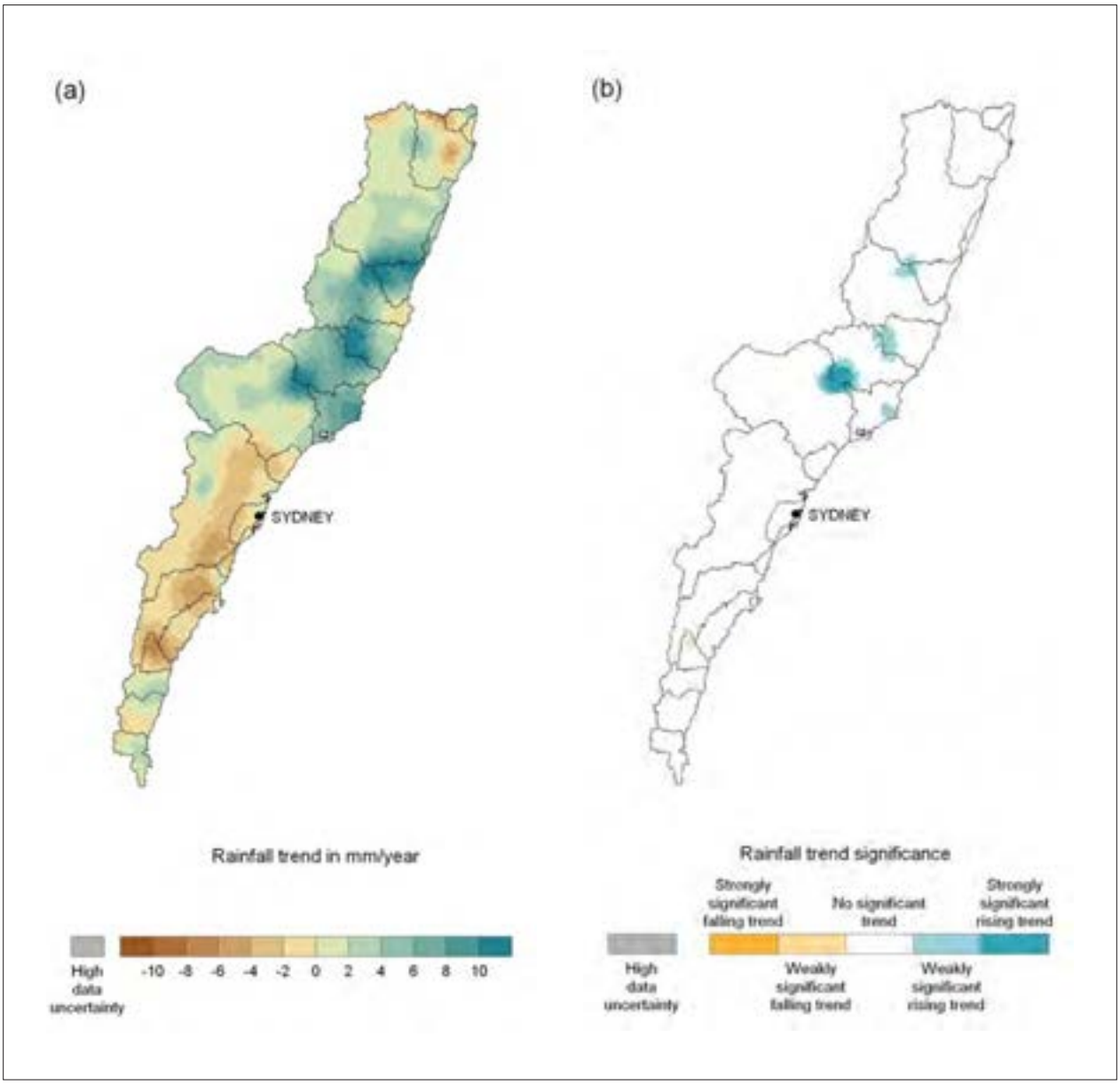


Figure 4.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (NSW) region

4.4.2 Evapotranspiration

Modelled annual evapotranspiration for the South East Coast (NSW) region for 2011–12 is estimated to be 919 mm. This is 12% above the region's long-term (July 1911– June 2012) average of 819 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 4.16a) shows a west–east gradient of increasing totals. Evapotranspiration was highest along the north coast with annual totals exceeding 1,200 mm in some areas for 2011–12.

Evapotranspiration deciles for 2011–12 indicate above average totals across most of the region (Figure 4.16b) with very much above average totals along the Sydney and central coast and more to the north. The high evapotranspiration was possible due to the high rainfall (Figure 4.13b) and the resulting high wetness levels of the soils.

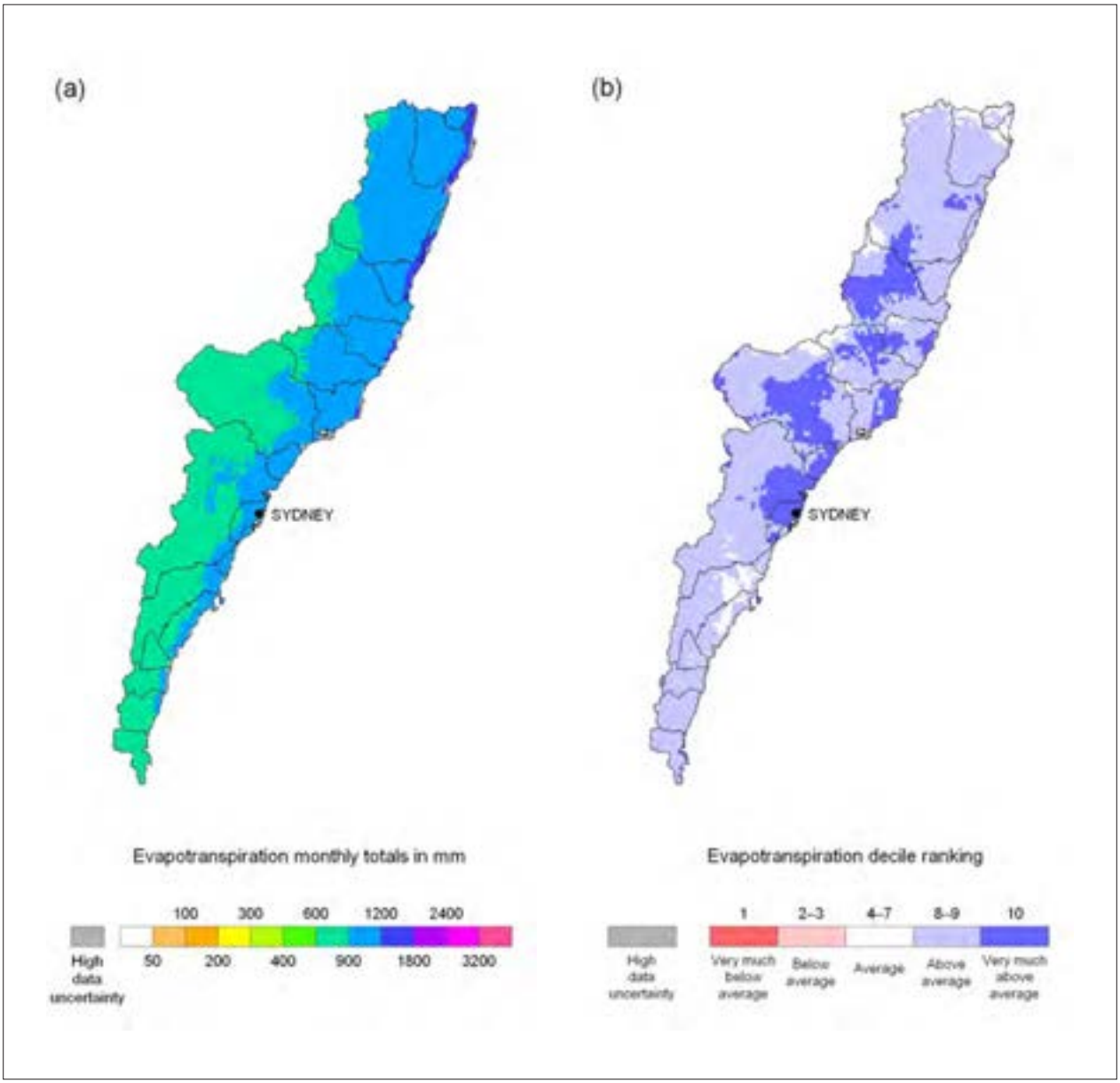


Figure 4.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South East Coast (NSW) region

Evapotranspiration variability in the recent past

Figure 4.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 814 mm, varying from 636 mm (2002–03) to 964 mm (1988–89). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 4.17b.

Summer periods showed consistently higher evapotranspiration than the winter period. The higher temperatures and the higher rainfall amounts during these periods contribute to this. Compared with the seasonal rainfall (Figure 4.14b), the cyclical time-series of seasonal evapotranspiration is less pronounced (Figure 4.17b).

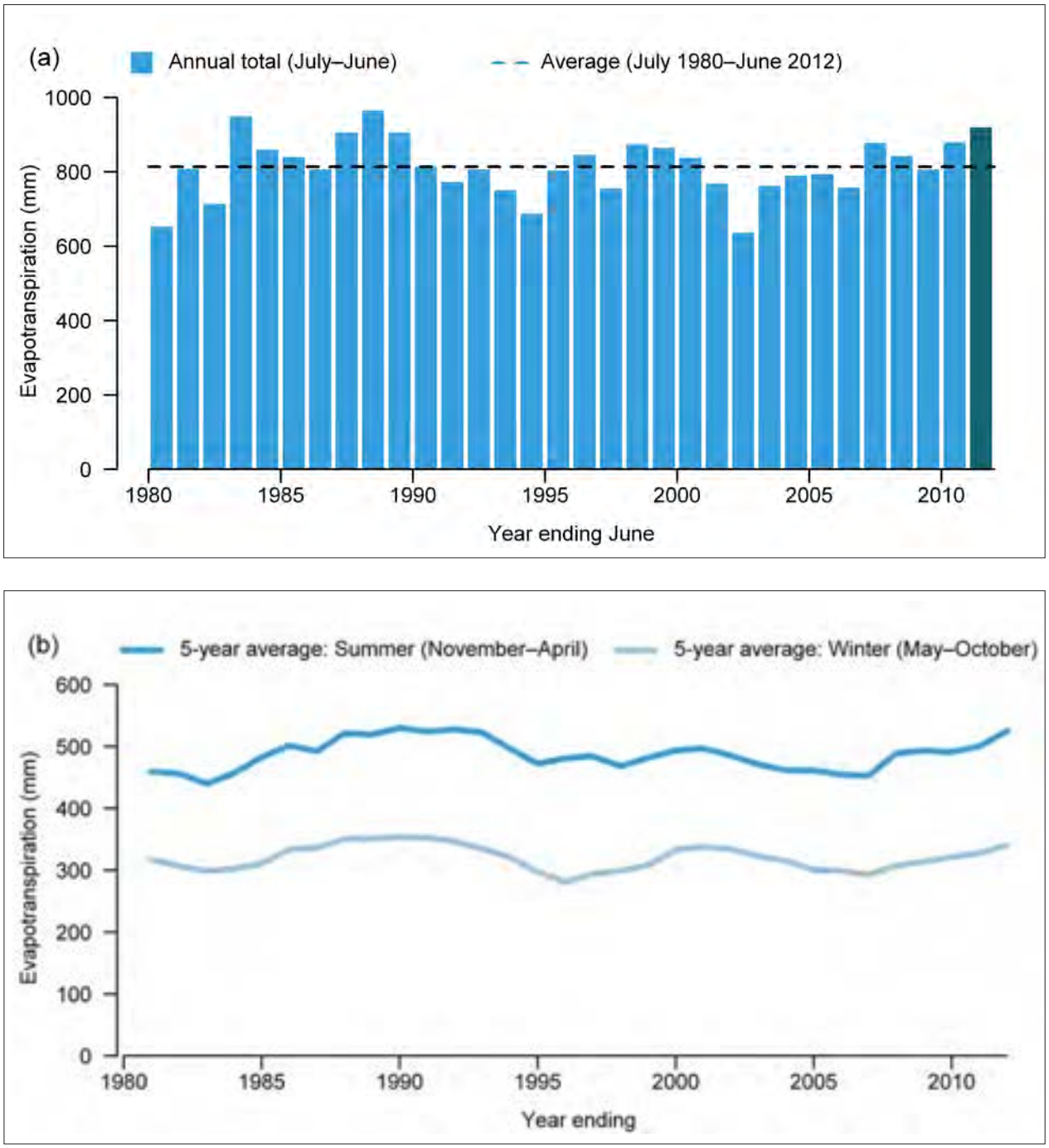


Figure 4.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (NSW) region

Recent trends in evapotranspiration

Figure 4.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 4.18b.

Figure 4.18a shows that since 1980 trends are weakly positive in the central northern part of the region. In the south and the far north, the trends are mostly neutral to weakly falling.

As shown in Figure 4.18b, the trends are generally only statistically significant in small parts of the region where trends are generally showing increasing evapotranspiration. In most of the area, however, the trends have no statistical significance.

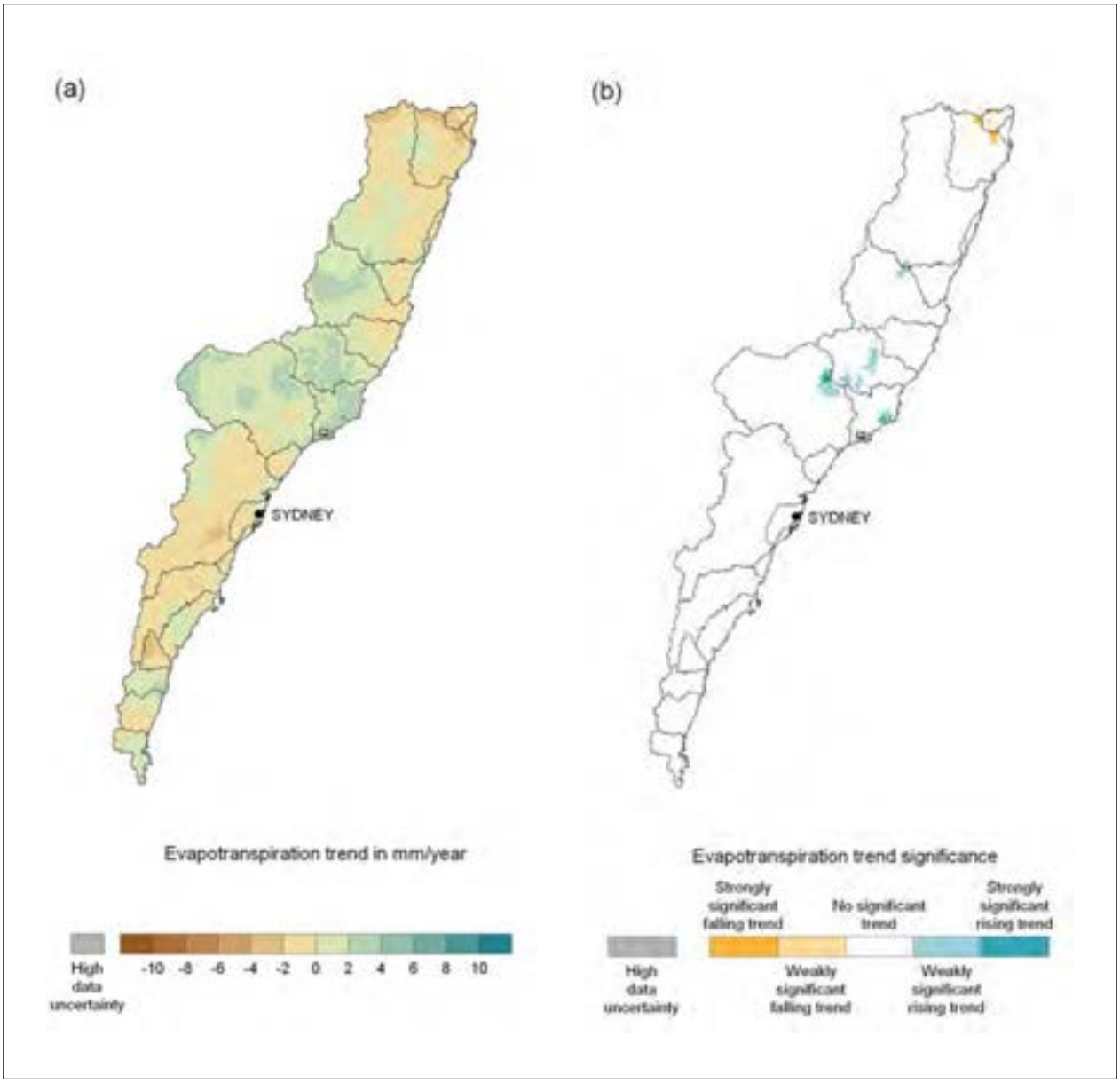


Figure 4.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (NSW) region

4.4.3 Landscape water yield

Modelled landscape water yield for the South East Coast (NSW) region for 2011–12 is estimated to be 352 mm. This is 84% above the region's long-term (July 1911–June 2012) average of 191 mm.

Figure 4.19a shows the spatial distribution of landscape water yield for 2011–12. The highest landscape water yields are observed in areas adjacent to the coast, locally exceeding 900 mm.

The landscape water yield was substantially lower inland, with some areas not exceeding 50 mm (especially in the Hunter Valley).

The decile-ranking map for 2011–12 (Figure 4.19b) shows above average landscape water yields throughout the region. Some areas recorded very much above average landscape water yield, partly reflecting the pattern of rainfall deciles in Figure 4.13b.

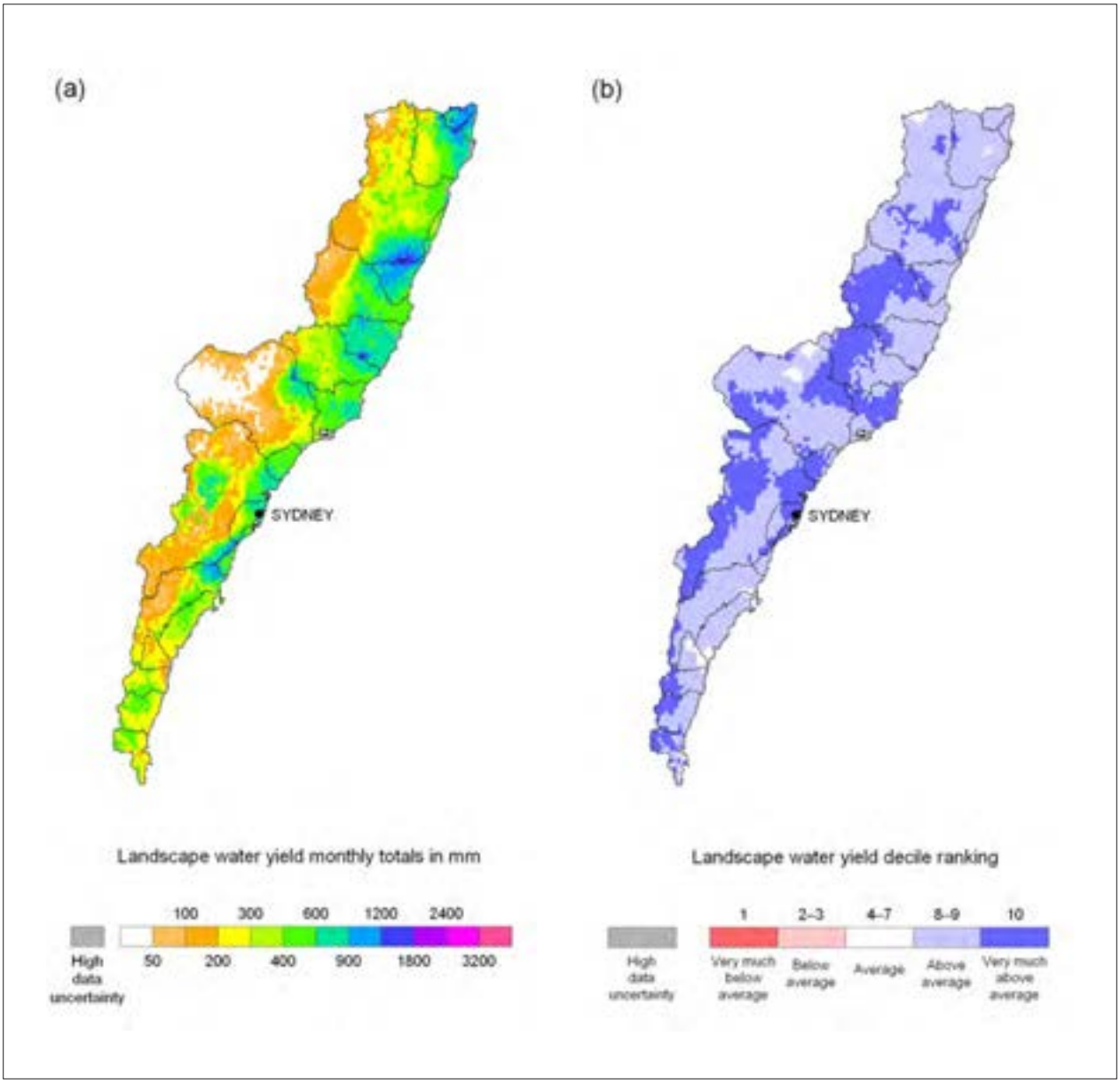


Figure 4.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South East Coast (NSW) region

Landscape water yield variability in the recent past

Figure 4.20a shows annual landscape water yield for the South East Coast (NSW) region from July 1980 onwards. Over this 32-year period, average annual landscape water yield was 193 mm, varying from 82 mm (1992–93) to 441 mm (1988–89). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 4.20b.

Landscape water yield is equally distributed between the summer and winter periods. This is a result of higher landscape water yields in the south in the winter period, and in the north in the summer period.

Both periods show a distinct inter-annual cyclic variability driven by the region's rainfall dynamics (see Figure 4.14b).

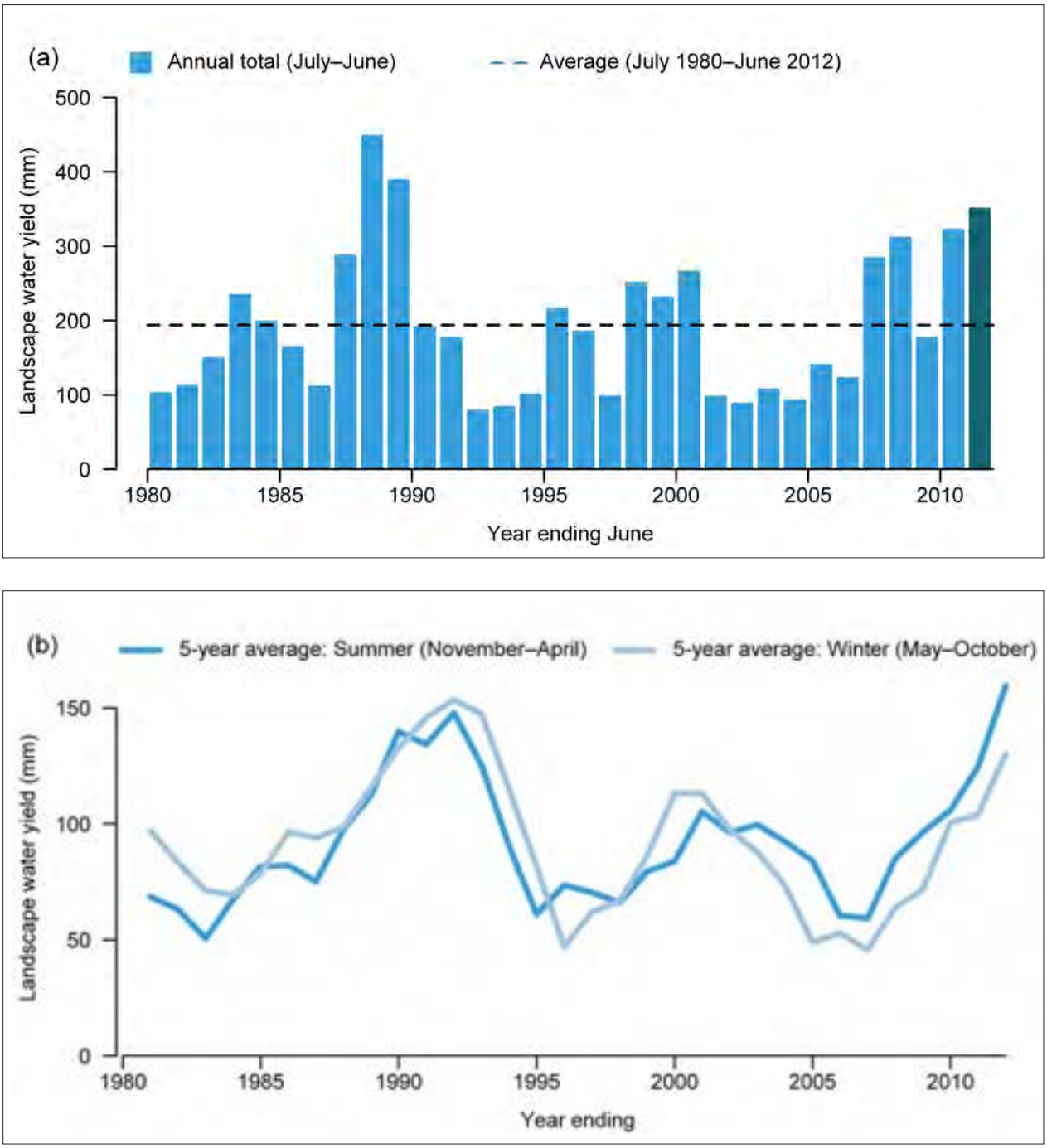


Figure 4.20 Time-series of (a) annual landscape water yield and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (NSW) region

Recent trends in landscape water yield

Figure 4.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 4.21b.

Figure 4.21a shows that since 1980, trends are rising in the central northern part of the region. In the south and the far north the trends are mostly neutral to weakly falling.

As shown in Figure 4.21b, the trends are generally only statistically significant in some central northern parts of the region, where trends are generally showing increasing landscape water yield. In most of the area, however, the trends have no statistical significance. A minor exception can be found in the Moruya River basin in the south, where a strongly significant falling trend is identified.

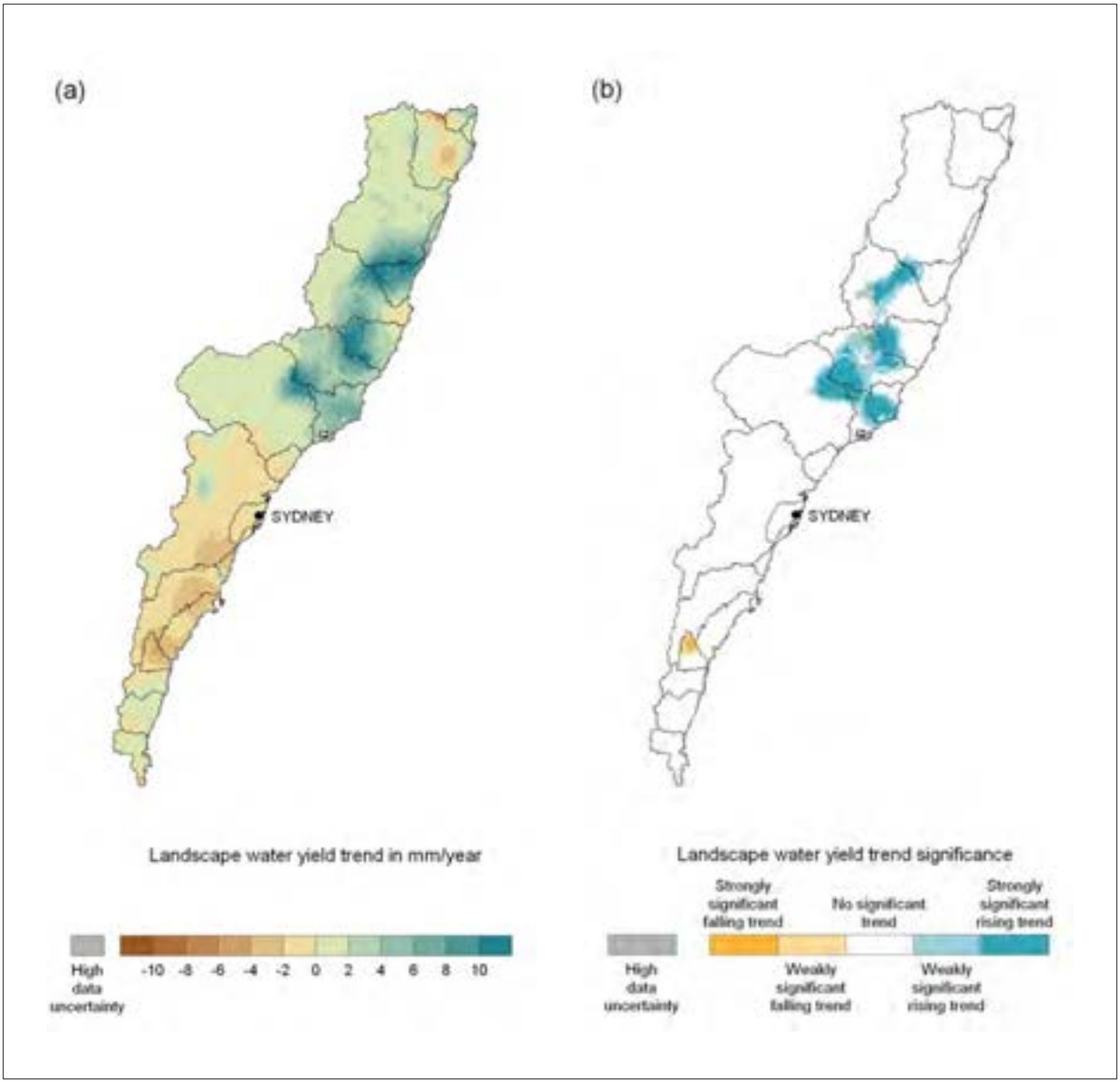


Figure 4.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (NSW) region

4.5 Surface water and groundwater

This section examines surface water and groundwater resources in the South East Coast (NSW) region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources.

The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis of individual aquifers.

4.5.1 Rivers

There are 20 river basins in the South East Coast (NSW) region, varying in size from 500–22,000 km^2 (Figure 4.22).

The Clarence River is the largest in the region in terms of annual discharge into the sea. The Hawkesbury and Hunter rivers are two important systems in the region in terms of urban and irrigation water supply.

The rivers are all perennial, although in times of drought some may almost stop flowing. River flows in the region generally show distinct seasonal variations.

Hawkesbury River at Little Wobby, New South Wales | Catherine Marshall

Figure 4.22 Rivers and catchments in the South East Coast (NSW) region

4.5.2 Streamflow volumes

Figure 4.23 presents an analysis of flows at 31 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across 15 geographically representative river catchments were selected (see Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows from monitoring gauges generally reflect the mostly above average to very much above average modelled landscape water yield results shown in Figure 4.19b.

High run-off, generated in the upstream reaches of the rivers, caused above average to very much above average flows in all rivers. Very much above average flows were observed at five sites located on rivers in the northwest, central east and south of the region. Above average total flows were recorded at 26 monitoring sites distributed across the entire region.

Flow deciles for summer (November 2011–April 2012) are similar to total annual flows for 2011–12 as shown in Figure 4 23. This is not surprising given that the greatest volume of flows in the region, particularly in the north and some areas in the south, occurs over the summer months. While flows in the region's centre and central north were above average over the year, flows in most of these rivers were relatively high over the summer period. There are a few monitoring sites that did not show this pattern, such as low flows observed in the summer period on the Hunter River in the centre of the region.

4.5.3 Streamflow salinity

Figure 4.24 presents an analysis of streamflow salinity for 2011–12 at 20 monitoring sites in the region. The sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC, µS/cm at 25 °C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation, are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean. Stream salinity data were only available in the Hunter River basin.

The median EC values for most of the selected monitoring sites in the main rivers fall in the range 0–1,000 µS/cm, an amount that is suitable for most irrigation uses. Some creeks in the Hunter River basin fall outside of this range (see Figure 4.24).

Of the 20 monitoring sites, 40% had median EC values below 500 µS/cm, and 45% were between 500–1,000 µS/cm. Only 5% of the monitoring sites had a median EC above 1,500 µS/cm. The higher median salinities all occurred in the centre and central west of the Hunter River basin.

Stream salinity was above 2,000 µS/cm at only one of the 20 monitoring sites. This was in Bayswater Creek at Liddell in the Hunter River basin. High salinity in the Bayswater Creek is due to saline discharges from coal mining, and wastewater from power generation (Environmental Protection Agency 2001) and saline groundwater input in the river.

The CV was relatively low for the most of the sites. The CV in EC is typically related to the variability in annual flow at the monitoring site.

Of the 20 monitoring sites, 10% of them had a CV below 20%, and 90% of the sites had a CV between 20% and 60%. These monitoring sites were located on the Hunter River basin towards the central part of the region.

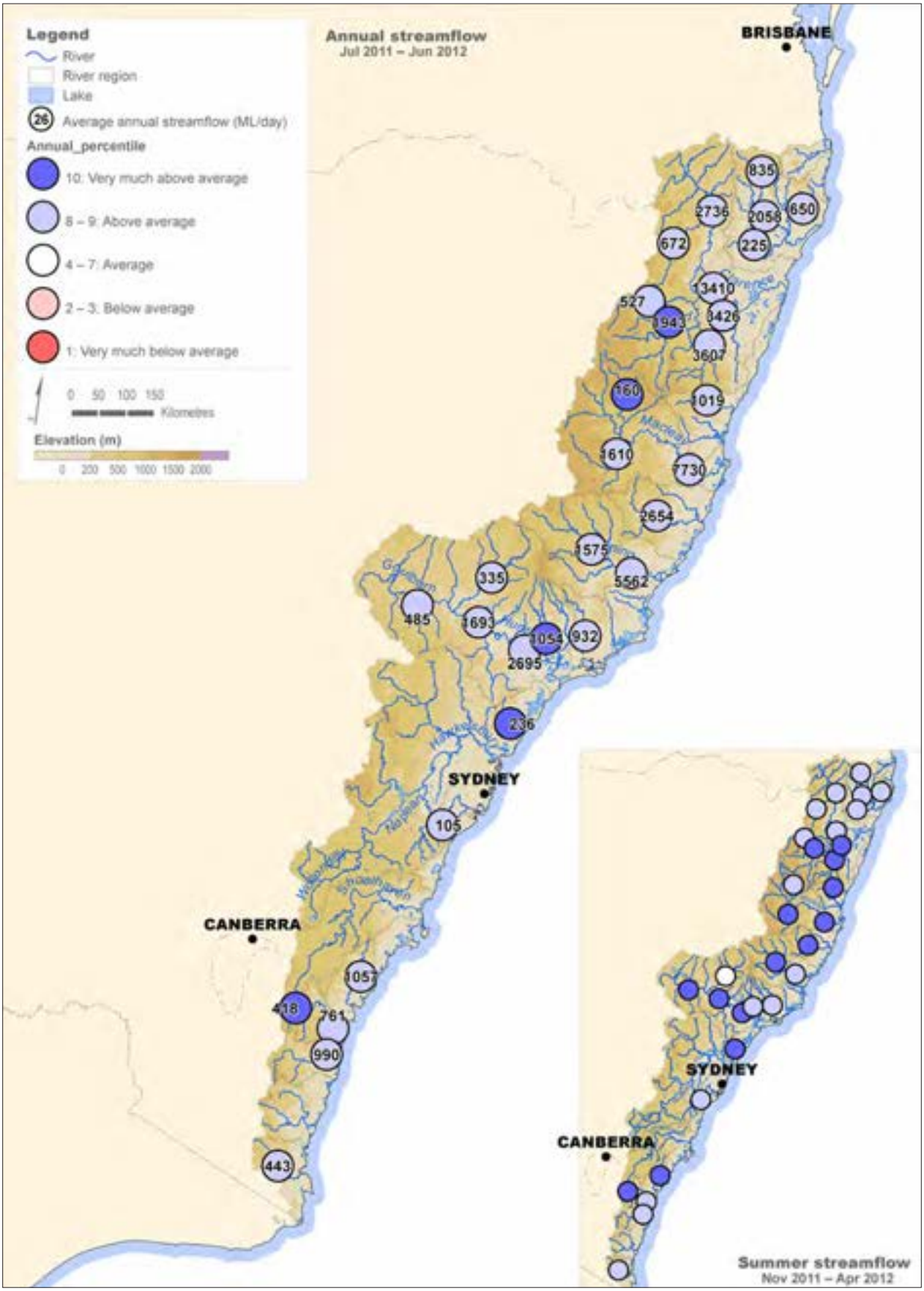


Figure 4.23 Average annual and summer period flow volumes at selected sites for 2011–12 and their decile rankings over the 1980–2012 period in the South East Coast (NSW) region

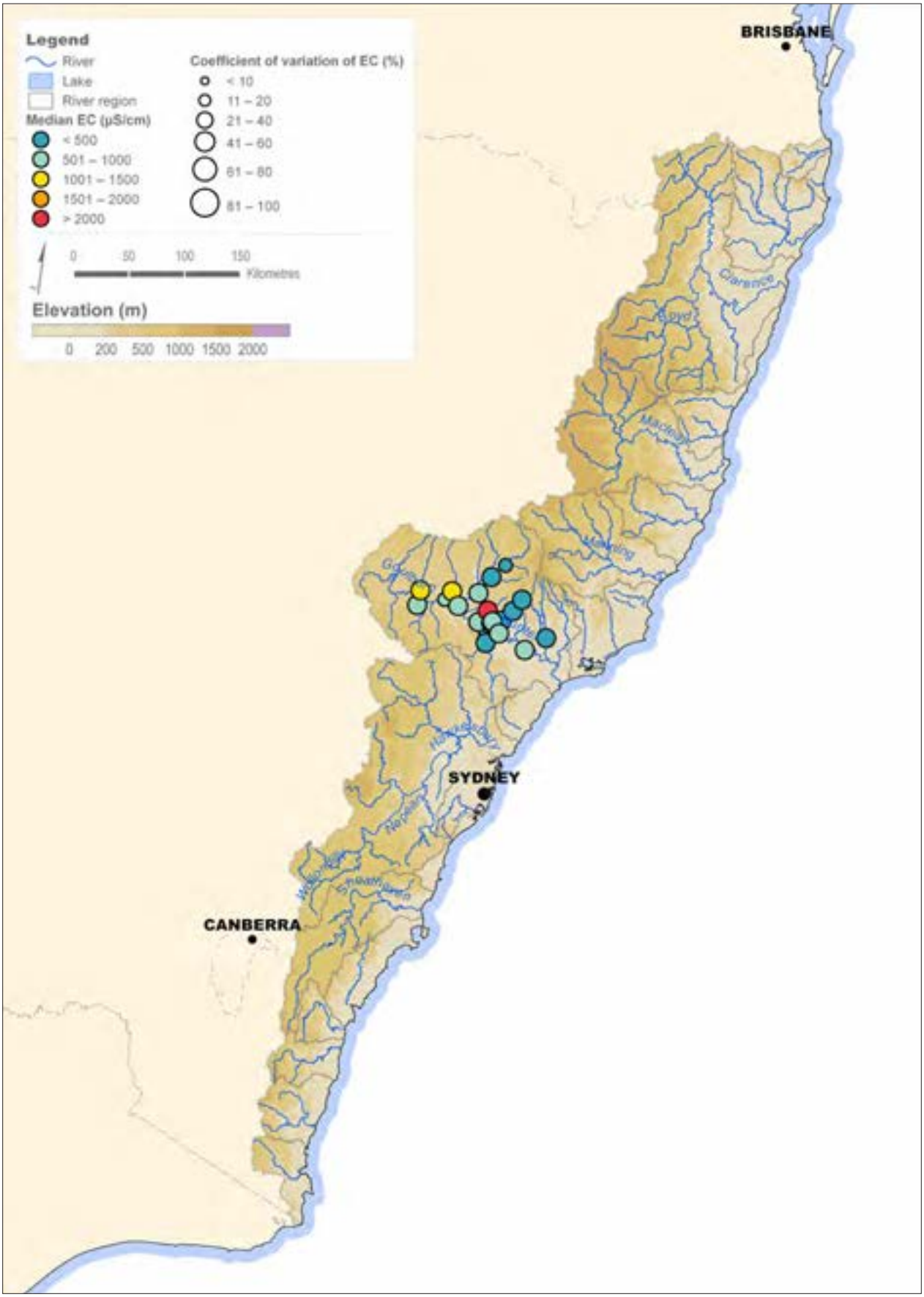


Figure 4.24 Salinity as electrical conductivity and its associated coefficient of variation for 2011–12 in the South East Coast (NSW) region

4.5.4 Flooding

Floods can be caused by either localised high intensity rainfall, for example thunderstorms, or prolonged periods of heavy rainfall, for example, during frontal rainfall, monsoon, and tropical storms. While the first rainfall type often results in localised flash flooding, the prolonged rainfall can cause sustained floods spreading over larger areas.

Floods in the region are particularly common in the north of the South East Coast (NSW) region. Most of the region's south has a uniform rainfall pattern while the northern part receives the majority of rainfall during summer. Both types of rainfall can occur across the region, with heavy rainfalls often associated with easterly troughs and frontal systems.

Figure 4.25 shows selected locations where the Bureau is monitoring river levels as part of its flood forecasting service and the highest level reached during the year is expressed in terms of flood classification level. These classification levels are established in consultation with emergency management and local agencies and are further described in the Technical Supplement.

A three-day period of torrential rainfall along the north coast of New South Wales produced totals of about 500 mm of rain from 23–27 January 2012, causing significant flooding in some of the northern rivers. Major flooding occurred along the Tweed River, with approximately 4,200 people evacuated from this area. Rain also led to localised landslides in some areas.

Minor to moderate flooding also occurred along several other rivers, isolating more than 12,000 people in areas including Goodooga, Bellingen, Thora, Darkwood, Upper Macleay, Mullumbimby and the Brunswick and Clarence valleys.
On 1 February 2012, natural disasters were declared in 11 local government areas in the north of the region as a result of the flooding. The damage due to this flooding was assessed to be several million dollars.

Bellingen River Floods | Greg McLagan

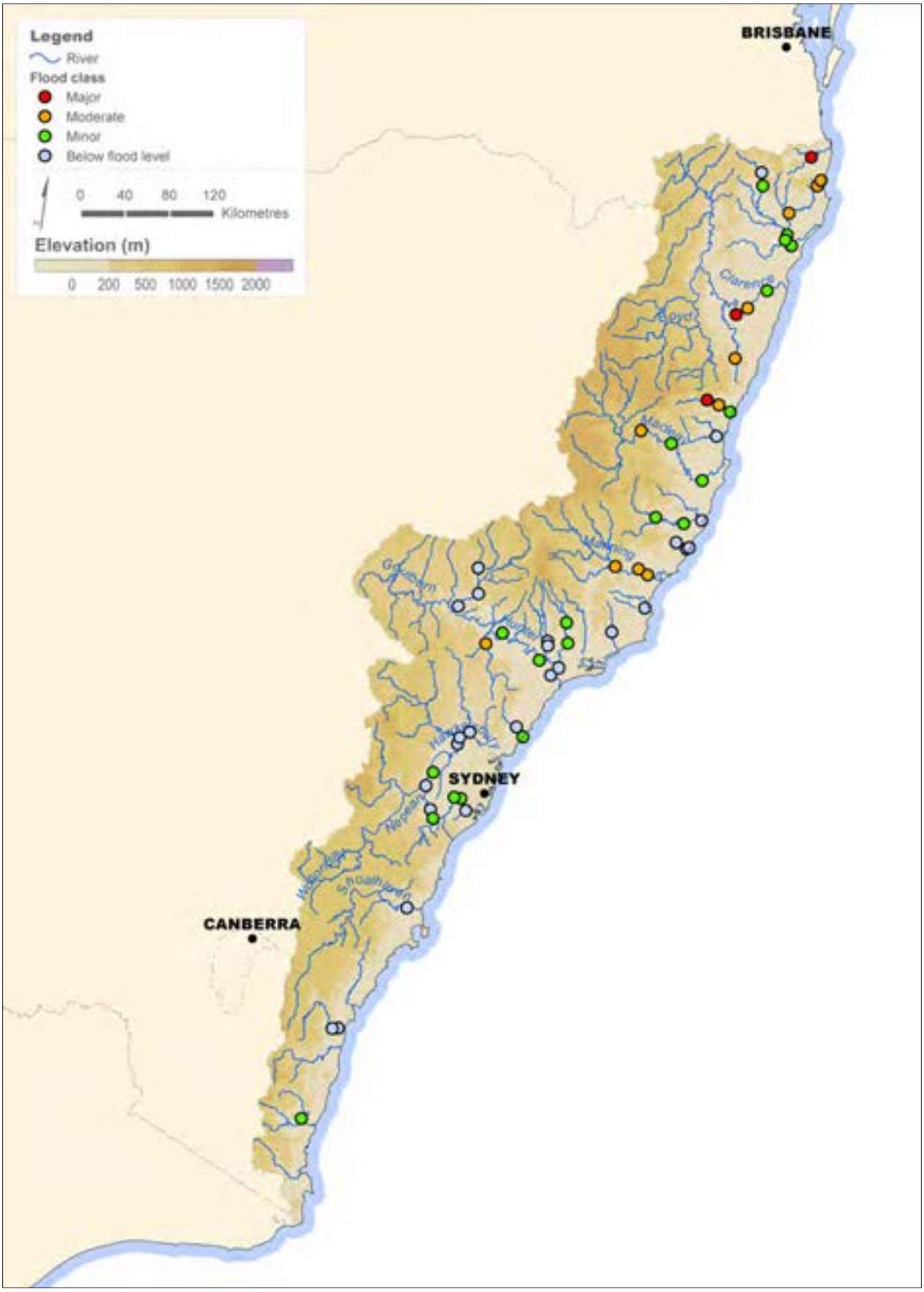


Figure 4.25 Flood occurrence in 2011–12 for the South East Coast (NSW) region, with each dot representing a river level monitoring station and the colour of the dot representing the highest flood class measured

4.5.5 Storage systems

There are approximately 50 major publicly owned storages in the South East Coast (NSW) region with a total capacity in excess of 4,600 GL. The Bureau's water storage information includes approximately 83% of the region's publicly owned storage capacity.

Storages in the region supply the irrigation areas in the Hunter Valley as well as the city of Sydney. Table 4.3 gives a summary of the region's major storage systems together with an overview of the storage levels at the end of 2010–11 and 2011-12. The location of all the systems and associated storages are shown in Figure 4.26.

Table 4.3 indicates that the above average rainfall upstream of most storages has resulted in a substantial increase in the accessible volumes region-wide. The Sydney supply storages, especially, have received large amounts of water, with Sydney's largest storage, Warragamba, spilling in March, April and June. The Hunter storages reached full supply level in November 2011 and have been full since. More details on the Sydney and Hunter systems is provided in subsections 4.6–4.7.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

4.5.6 Wetlands

Important wetlands

There are a large number of wetlands of national and international importance in the South East Coast (NSW) region (Figure 4.27). Most of these are coastal wetlands of various types, including salt and freshwater marshes, mangrove forests, reed beds, lakes and lagoons.

The region is the most densely populated region in Australia. As a consequence, most wetlands are impacted by human activities upstream of the wetland or in the wetland area itself. The coastal estuaries and lakes are important refuges for many migrating and threatened bird species as well as many types of fish and amphibians, including several threatened species of frogs.

Inflows to selected wetlands

The state of the biodiversity in a wetland is linked to the way water is stored within the area and the temporal variability of inflows. An analysis of historic and recent inflows into wetlands forms an informative picture of potential changes.

One internationally recognised Ramsar wetland site (Hunter Estuary wetlands) was selected for hydrological analysis of major inflows.

More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html).

Two upstream stream monitoring gauges were selected to enable the analyses and interpretation of inflows to these wetlands. The gauges used in the analyses are the closest upstream gauges that have largely continuous discharge records since 1980. Although the analyses do not capture the total inflows, they are indicative of the temporal patterns of freshwater surface flows to these wetlands.

Table 4.3 Major public storage systems in the region as identified in the Bureau's water storage information (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Sydney	urban	2, 582 GL	1,973 GL—76%	2,496 GL—97%
Hunter	rural	1,031 GL	965 GL—94%	1,026 GL—100%
Non-allocated	—	240 GL	111 GL—46%	137 GL—57%
Total		**3,853 GL**	**3,049 GL—79%**	**3,658 GL—95%**

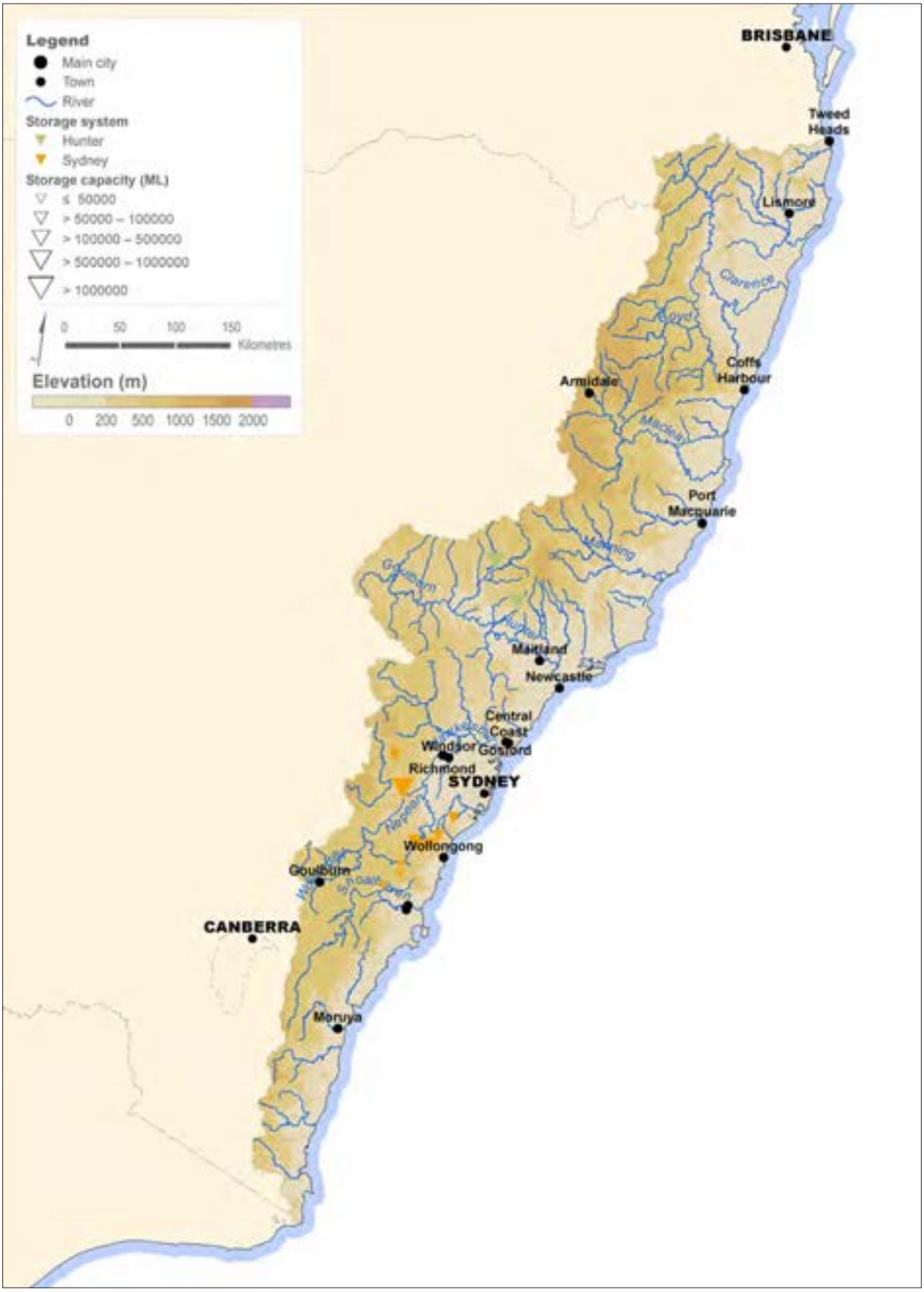


Figure 4.26 Storage systems in the South East Coast (NSW) region; information extracted from the Bureau's water storage information website in August 2012

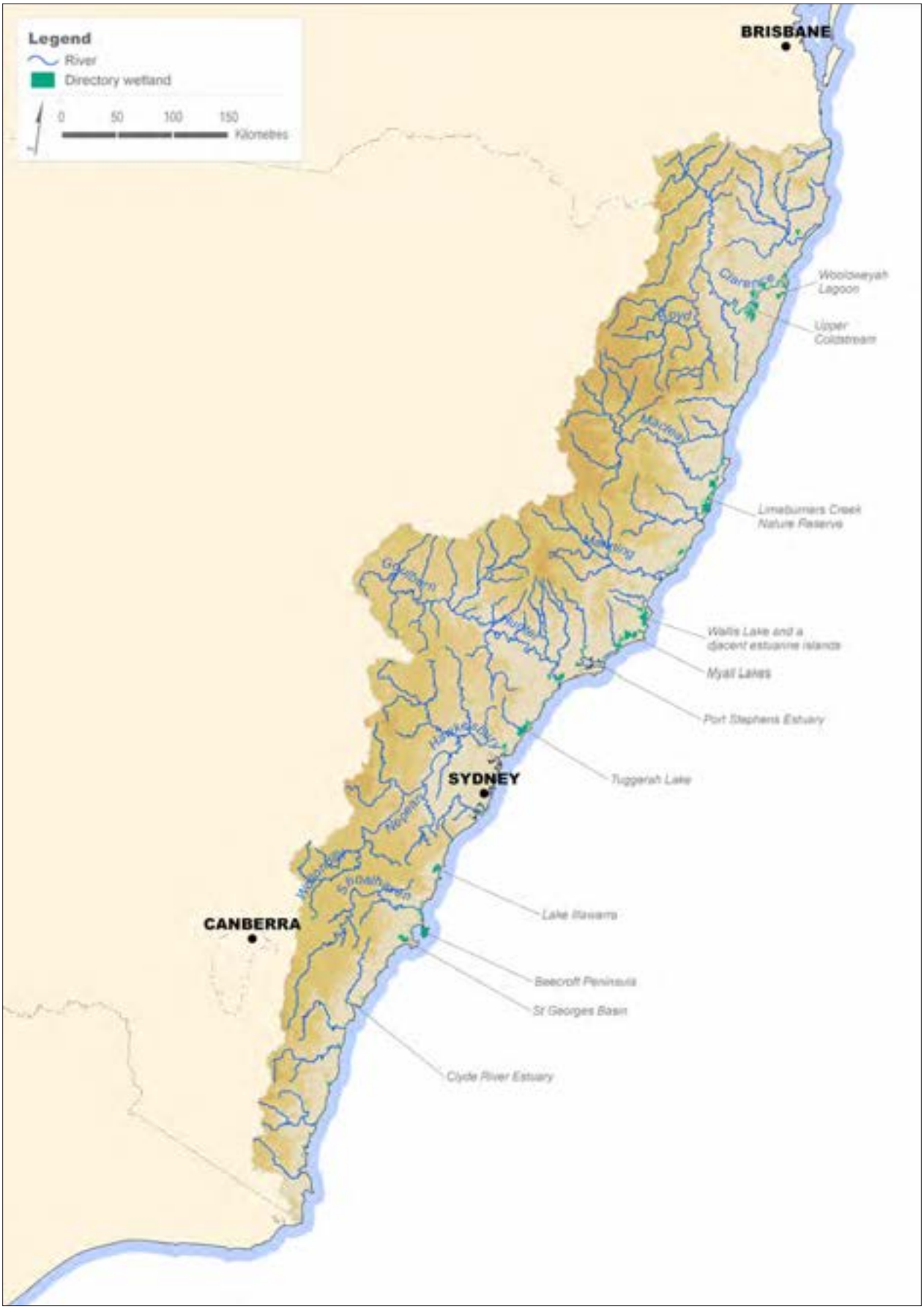


Figure 4.27 Location of important wetlands in the South East Coast (NSW) region

Hunter Estuary wetlands

The Hunter Estuary wetlands are downstream of one of the most intensely irrigated areas of the region. The Hunter River and its tributaries contain a number of dams that catch much of the streamflow. Also, the wetlands themselves are impacted by human activities as the surrounding river branches are frequently dredged and are progressively controlled by flood mitigation structures.

Daily discharge data for the monitoring gauges on the Hunter River at Greta and on the Patterson River at Gostwyck have been combined to provide a temporal pattern of freshwater inflows into Hunter Estuary wetlands (Figure 4.28).

Figure 4.28 Location of the monitoring site in relation to the Hunter Estuary wetlands

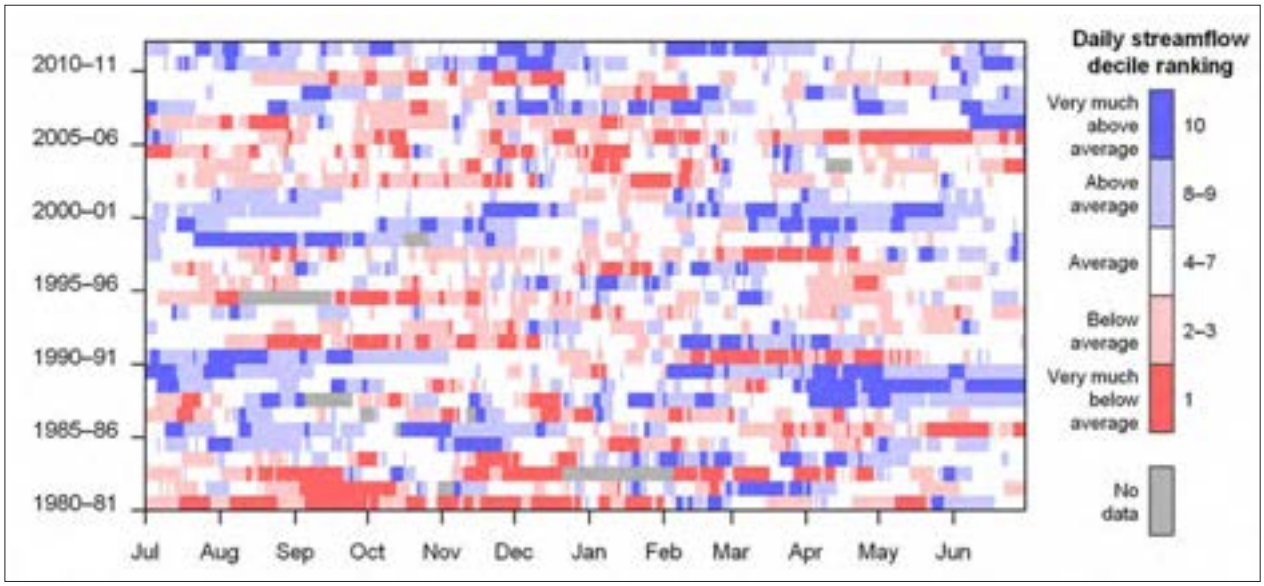


Figure 4.29 Combined daily flows of the Hunter and Patterson rivers between 1980–81 and 2011–12, ranked in decile classes

Figure 4.29 presents an overview of the distribution of daily streamflow decile rankings. With the absence of a distinct rainfall season, the flow pattern is qutie heterogeneous. Some years appear to have less flow than others, but no clear indication can be found that points towards a change in flow regime for the Hunter Estuary wetlands.

Figure 4.30 compares monthly discharges from 2011–12 with the statistics of flows from July 1980 onwards. The November, February and March flows exceeded the ninth decile of the 32-year record and contributed a substantial amount of freshwater to the Hunter Estuary wetlands.

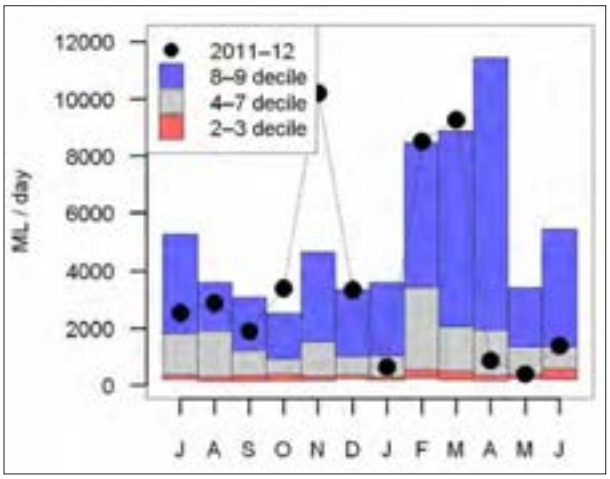


Figure 4.30 Combined monthly flows of the Hunter and Patterson rivers from 2011–12 compared with the July 1980—June 2012 decile rankings

4.5.7 Hydrogeology

The hydrogeology of the South East Coast (NSW) region is dominated by a large area of outcropping fractured basement rock. Aquifer systems in fractured rock typically offer restricted low-volume groundwater resources. Productive groundwater resources are localised in alluvial valley and coastal sand aquifers.

The watertable aquifers present in the region are shown in Figure 4.31. Groundwater systems in the region that generally provide more potential for extraction include:

- Surficial sediment aquifer (porous media —unconsolidated); and
- Tertiary basalt aquifer (fractured rock).

4.5.8 Watertable salinity

Figure 4.32 shows a classification of the watertable aquifer as either fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) according to salinity levels.

As shown in the figure, quality-assured salinity data are not available for most of the region. Where data are available, as in the central part of the region southwest, west and northwest of Sydney, groundwater is generally fresh. Areas with known high salinity values in the region are relatively small in area.

4.5.9 Groundwater management units

Groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 4.33 shows large groundwater management units located within the fractured and consolidated sedimentary rocks that typically provide low-volume groundwater resources. In contrast, the smaller units represent local coastal sand, alluvial valley or tertiary basal aquifers which are usually better yielding aquifers.

The Tomago Sandbeds unit (no. 5 in Figure 4.33) within coastal sand aquifers in the eastern part of the region is important as it provides 20% of the drinking water supply to the Hunter area.

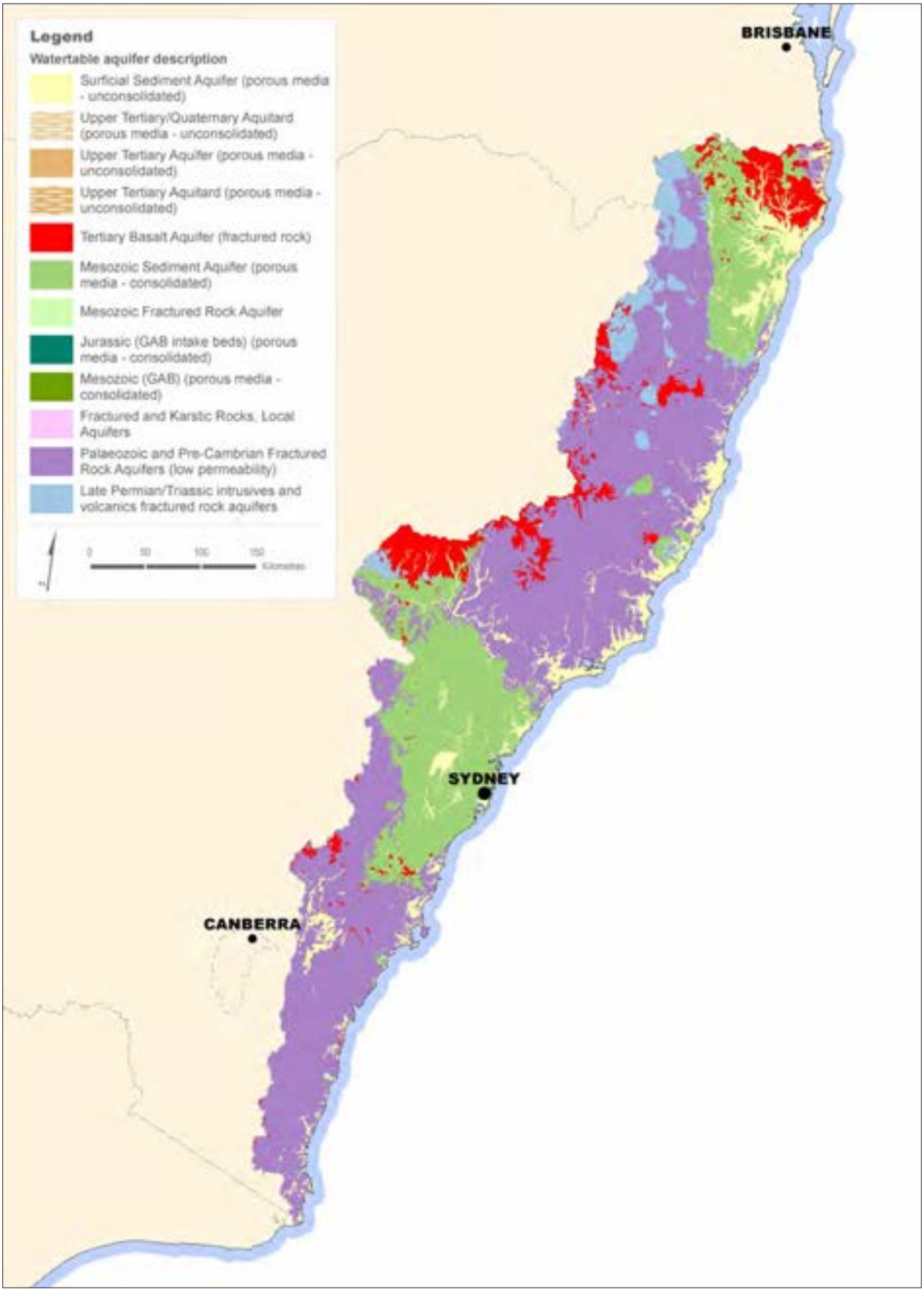


Figure 4.31 Water table aquifers of the South East Coast (NSW) region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

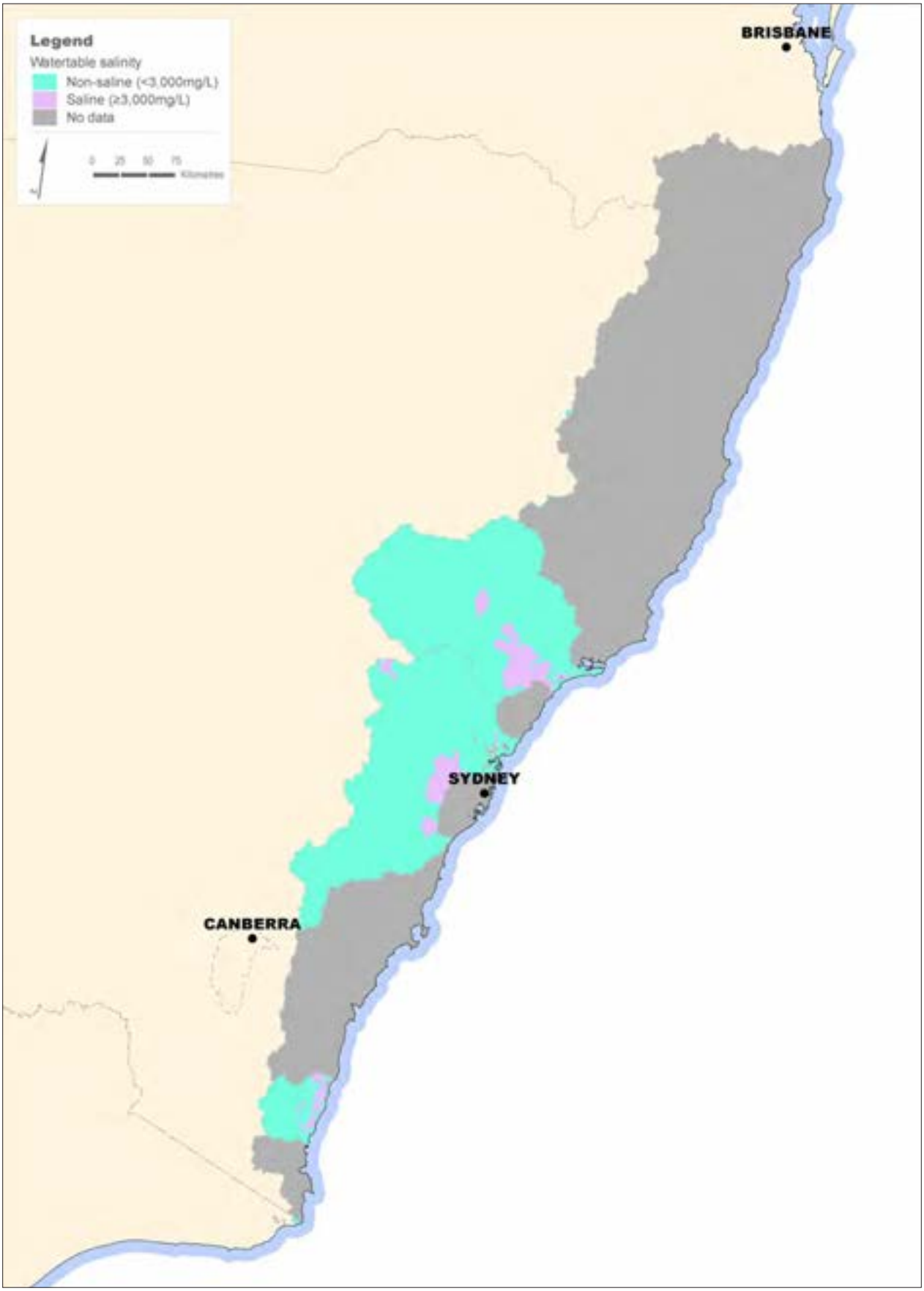


Figure 4.32 Water table salinity classes in the South East Coast (NSW) region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

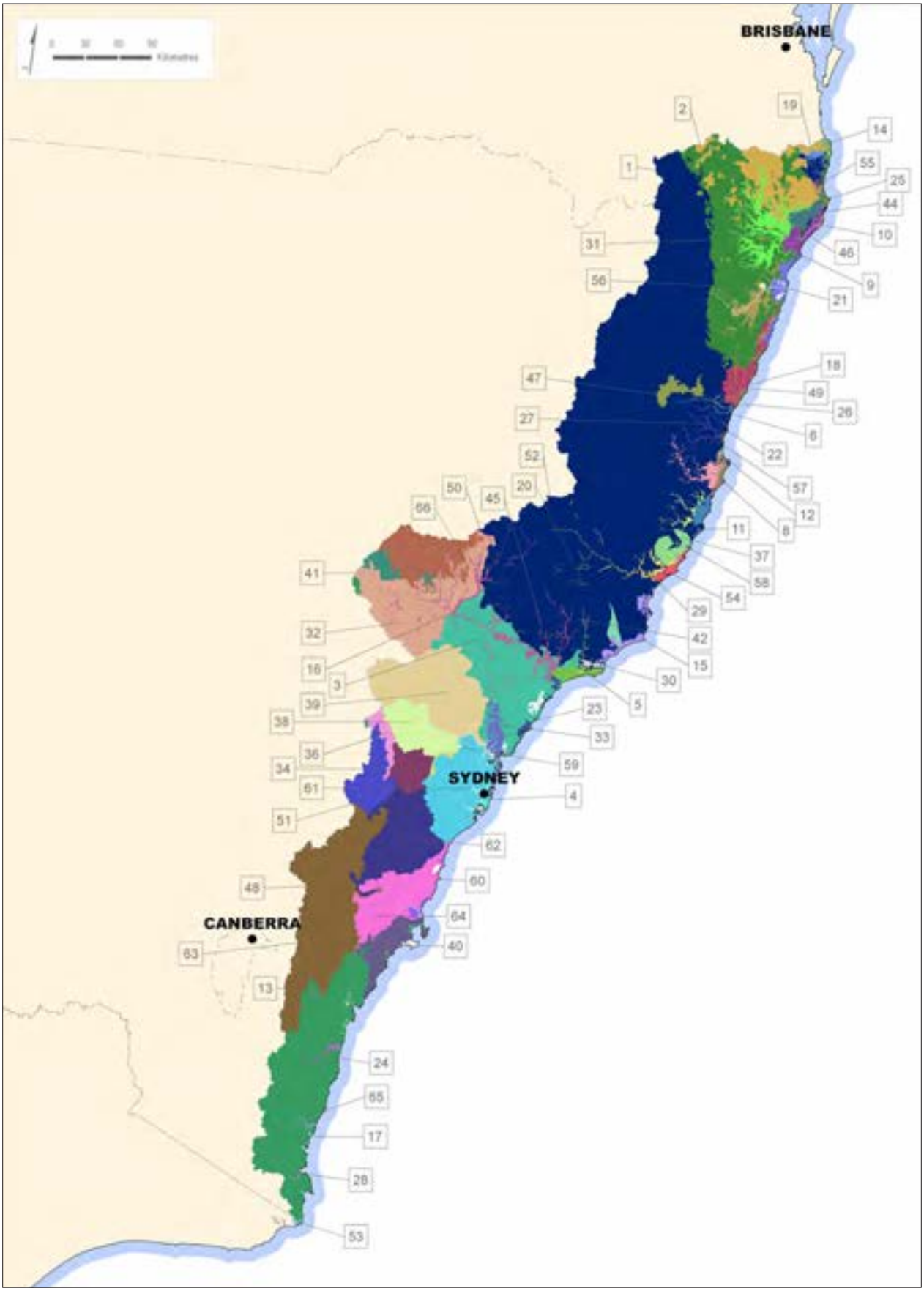


Figure 4.33 Groundwater management units in the South East Coast (NSW) region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

Legend to Figure 4.33 Groundwater management units in the South East Coast (NSW) region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

4.6 Water for cities and towns

This section examines the urban water situation in the South East Coast (NSW) region in 2011–12. The large urban centres in the region, their water supply systems and the storage situations are briefly described. The analysis includes the most populous city in Australia, Sydney, and for this centre further details are provided on the water supply system, storage volumes, water sources and water delivered.

4.6.1 Urban centres

Sydney is the most populous city in Australia. It is located on Australia's southeast coast. As of June 2012, the metropolitan area had a population of 3.9 million people (ABS 2011b). Sydney's urban area is in a coastal basin, which is bordered by the Pacific Ocean to the east, the Blue Mountains to the west, the Hawkesbury River to the north, and the Royal National Park to the south.

Newcastle, situated 162 km north of Sydney, has a population of just over 300,000 people and is the second most populated city in region.

The Central Coast is a peri-urban area located north of Sydney and south of Lake Macquarie. It has a population of 298,000 and is the third largest urban area in the region. The Central Coast is generally considered to include the area bounded by the Hawkesbury River in the south, the Watagan Mountains in the west and the southern end of Lake Macquarie in the north. It is reported to be growing at 1% per year.

Wollongong, located in the Illawarra district, has a population of 246,000 people. It is a coastal city that lies on the narrow strip between the Illawarra Escarpment and the Tasman Sea. It is situated 80 km south of Sydney.

Outside of its two major cities, the region has a large number of other 'regional' urban centres and towns. These, along with Sydney, Newcastle, the Central Coast and Wollongong, are shown Figure 4.34 in conjunction with their population ranges.

Sydney CBD | Malcolm Watson

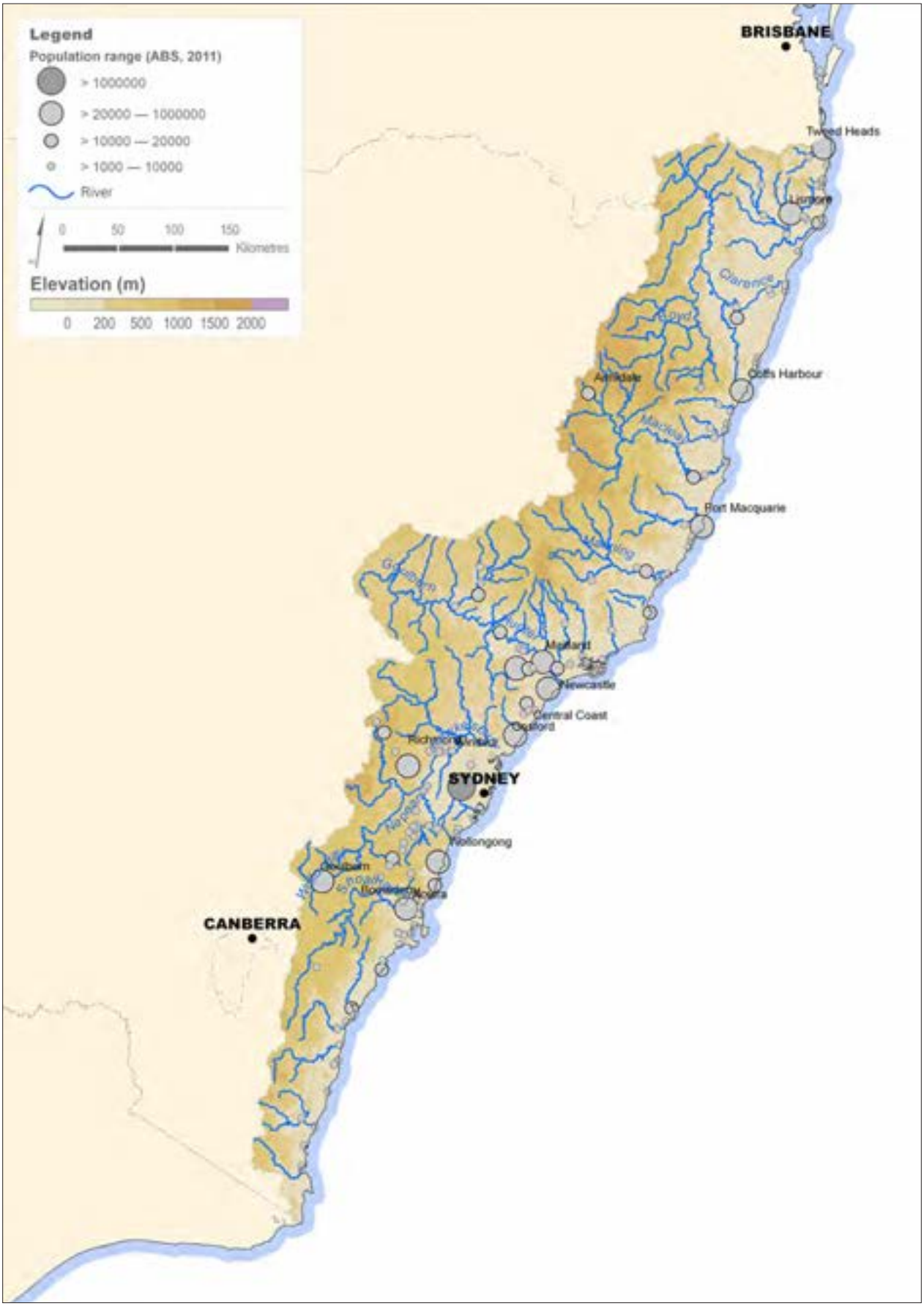


Figure 4.34 Population range of urban centres in the South East Coast (NSW) region

The major urban centres of the region, with populations of over 25,000 people, are summarised in Table 4.4. This table provides information on the population, surrounding river basin and significant water storages for each of the major urban centres.

4.6.2 Sources of water supply

All major cities and towns in the region are predominantly supplied with drinking water coming from surface water storages, or in some cases from direct river extractions, partly fed by upstream storage releases.

The region is home to over 20 major surface water storages that supply its many cities and towns. This includes the major Sydney metropolitan storage, Warragamba. With a total accessible storage capacity of over 2,000 GL it provides almost 85% of Sydney's total surface water storage.

Major surface water storages, predominantly used for urban water supply, are shown in Figure 4.35.

In addition to surface water storages, the region utilises direct river extractions, including extractions of upstream storage releases, groundwater, desalination, recycled water, and harvested stormwater and rainwater to supply the urban demands of the region.

Groundwater extractions form a reliable source of supply in the region and are an important source of water for Newcastle and the Port Stephens area.

Recycled water is an important source of water in the region, in particular in Sydney where dedicated recycling schemes such as Rouse Hill operate to provide 'third pipe' recycled water to consumers.

Table 4.4 Major urban centres and their water supply sources in the South East Coast (NSW) region

City	Population[1]	River basin	Major supply sources
Sydney	3,908,000	Hawkesbury River	Warragamba (Lake Burragorang) Upper Nepean storages (Cataract, Avon, Cordeaux and Nepean) Shoalhaven system storages (Wingecarribee, Fitzroy Falls, Tallowa [Lake Yarrunga] and Bendeela Pondage) Woronora storage Blue Mountains storages (Lower Cascade, Middle Cascade, Upper Cascade, Lake Medlow and Lake Greaves) Lake Oberon Prospect Reservoir
Newcastle	308,000	Hunter River	Grahamstown and Chichester storages, Tomago Sandbeds
Central Coast	298,000	Macquarie–Tuggerah Lakes	Mangrove Creek, Mardi and Mooney Mooney storages
Wollongong	246,000	Wollongong Coast	Avon storage
Maitland	67,000	Hunter River	Grahamstown and Chichester storages, Tomago Sandbeds
Coffs Harbour	45,500	Clarence River Bellinger River	Karangi storage, Orara River
Port Macquarie	41,500	Hastings River	Port Macquarie and Cowarra off-creek storages
Nowra–Bomaderry	28,000	Shoalhaven River	Shoalhaven River with water released from Lake Yarrunga (Tallowa)
Lismore	27,500	Richmond River	Rocky Creek storage

[1] Australian Bureau of Statistics (2011b)

Figure 4.35 Urban supply storages in the South East Coast (NSW) region

4.6.3 Greater Sydney

Sydney, with a built up area of 4,000 km², is one of the largest cities in the world. The urban centres of Sydney and Wollongong account for nearly 60% of the population of New South Wales and are part of the Greater Sydney area, which also includes the Blue Mountains. Greater Sydney is the urban water supply reporting area addressed in this subsection.

The State Government-owned Sydney Water Corporation, Sydney Water, is the urban water utility that supplies Greater Sydney. It services a population of 3.9 million people. Sydney Water operates the bulk water supply and distribution systems, wastewater collection system and drainage assets.

Water supplies are mainly sourced from catchment areas occupying approximately 16,000 km², managed by the Sydney Catchment Authority (SCA).

Supply systems

Sydney's water supply catchments include the Warragamba, Upper Nepean, Blue Mountains, Woronora and Shoalhaven river basins, which provide water for Sydney's storages as well as for the Southern Highlands and Shoalhaven areas. Parts of these water supply catchments are protected to help maintain water quality and provide habitat for a variety of rare and endangered flora and fauna.

The Fish River Water Supply Scheme, originating in Oberon, supplements Sydney's water supply by providing water to the Blue Mountains area. Water from Tallowa (Lake Yarrunga), Fitzroy Falls and Wingecarribee storages is used to supply local communities and supplement SCA water storages during drought (NSW Government 2011b).

While water from the storages provide most of Greater Sydney's drinking water needs, the 2006 Metropolitan Water Plan (New South Wales Government 2006) introduced measures to diversify Sydney's water supply through water recycling and desalination. Recycled water has become important in securing supply for the residential, commercial and industrial needs of Sydney.

The major water components of the water supply system for the Greater Sydney area is shown in Figure 4 36. Sydney is known to have one of the highest per capita water storage capacities in the world (NSW Government 2011c). The inter-connected network represents a complex urban water system and includes a total of 21 storages that can hold more than 2,500 GL of water. Water taken from the Hawkesbury River is used to supply Richmond–Windsor. The water supply for Wollongong is sourced from the Avon storage.

Figure 4.36 also shows the water treatment plants and the treated water delivery systems for the Greater Sydney area. Water sourced from the storage network, the Hawkesbury River and the Kurnell desalination plant is treated and delivered to customers by Sydney Water. The water supply system includes ten water treatment plants and a network of about 21,000 km of water mains (National Water Commission 2011a). Most of the water is treated at privately owned water filtration plants operating under contract to Sydney Water.

The major surface water storage in the network, Warragamba, collects water from the Wollondilly and Coxs rivers. Its catchments cover an area of 9,000 km². It is the largest urban water storage in Australia and accounts for about 80% of water supplies to Greater Sydney (SCA 2011b).

The storages of the Upper Nepean collect water from the catchments of the Cataract, Cordeaux, Avon and Nepean rivers. The catchments of the Upper Nepean lie in one of the highest rainfall areas in New South Wales. Together with the Shoalhaven River basin, they provide more reliable inflows than the Warragamba catchments. The Upper Nepean transfer system can provide the equivalent of 30% of Sydney's water supply (NSW Government 2010b). Upper Canal, a 64-km long combination of open channels, tunnels and aqueducts, transfers water from Upper Nepean storages to the Prospect water filtration plant.

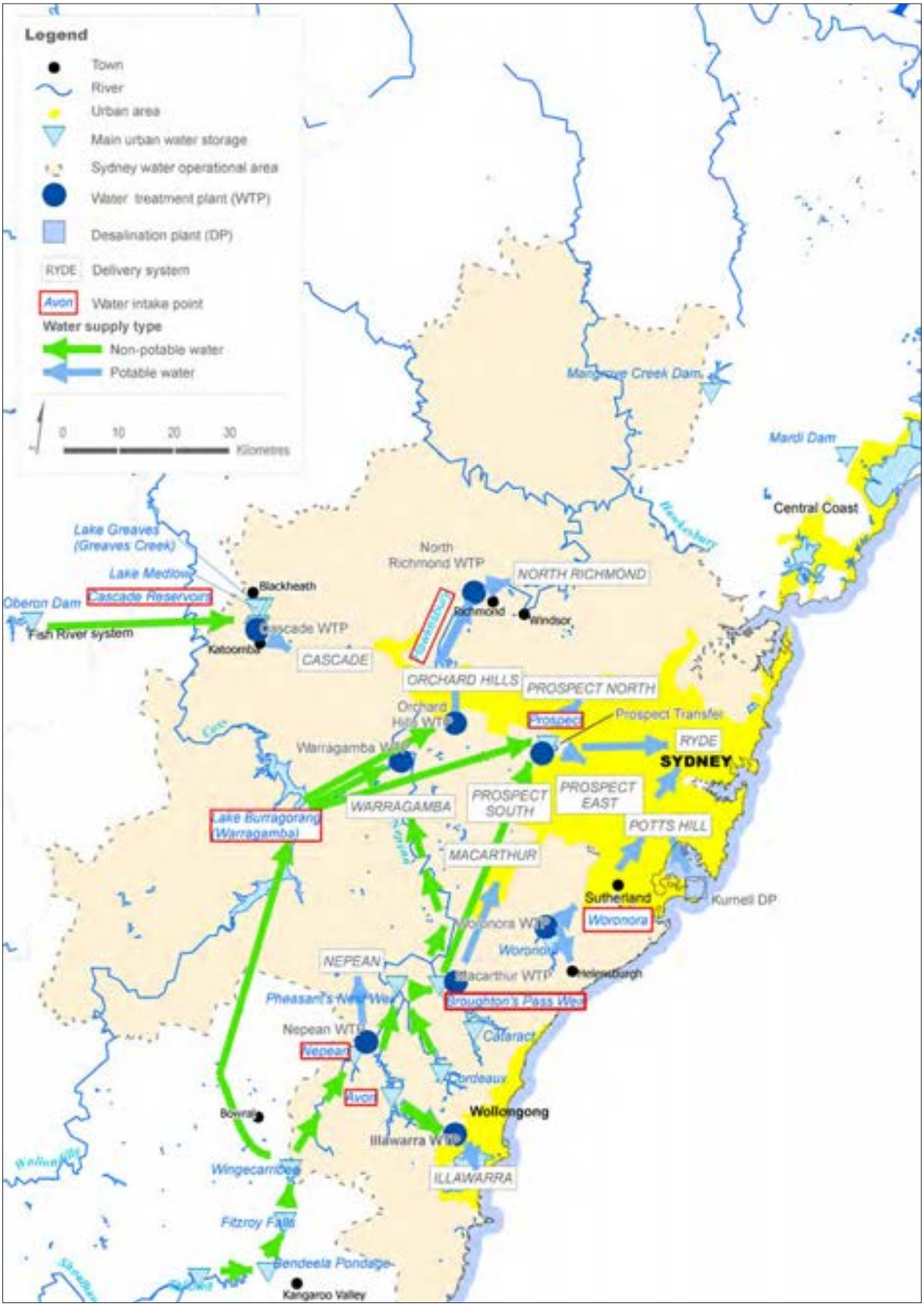


Figure 4.36 Water supply schematic for Greater Sydney

The Blue Mountains storage system comprises three small catchments feeding six storages that provide water for the Blue Mountains region. Water can also be sourced from the Fish River Water Supply Scheme (SCA 2011a). Due to a continuing water shortage in the Oberon and surrounding regions, this scheme has not recently been used to supply the Blue Mountains.

Woronora storage, the water supply source for the Sutherland Shire in Sydney's southeast, collects water from the Woronora River catchment.

The Shoalhaven system in the south, which includes the storages of Wingecarribee, Fitzroy Falls, Bendeela Pondage and Tallowa, is an integral part of Sydney's water supply system. The Shoalhaven system serves as a dual-purpose water supply and hydro-electric power generation scheme. Since the 1970s, Sydney and the Illawarra have relied on water pumped from Tallowa on the Shoalhaven River to supplement water supplies in times of drought. The system can provide around 30% of supply to the Greater Sydney region. Water is transferred using the river system to provide additional water into Warragamba (Lake Burragorang) or the upper Nepean storages (NSW Government 2010b).

The Kurnell desalination plant was constructed in response to low water storage inflows from 2000 onwards and began supplying water to Sydney in January 2010. When operating at full capacity, the desalination plant can produce 90 GL of water per year, enough water to supply up to 15% of Sydney's current water needs. Water from the desalination plant is distributed to approximately 1.5 million people across the Sydney central business district, inner west, eastern suburbs, south Sydney, as well as parts of the Sutherland Shire.

In addition to water sourced from surface water and desalination, water recycling is an important source for securing water for residential, commercial and industrial needs. Sydney Water operates 17 recycled water schemes including Australia's largest recycled water scheme at Rouse Hill. The Wollongong recycled water scheme supplies water for industrial and irrigation use. The remaining recycled water schemes mainly supply agricultural areas and sports fields.

Storage volumes

Figure 4.37 shows the total accessible storage volumes for Sydney's major storage, Warragamba and three of the four upper Nepean storages over the period 1989–90 to 2011–12. These plots clearly illustrate the significant draw down to critical levels during the latter stages of the Millennium Drought and the dramatic recovery to near full supply levels during the above average rainfall years post 2009–10.

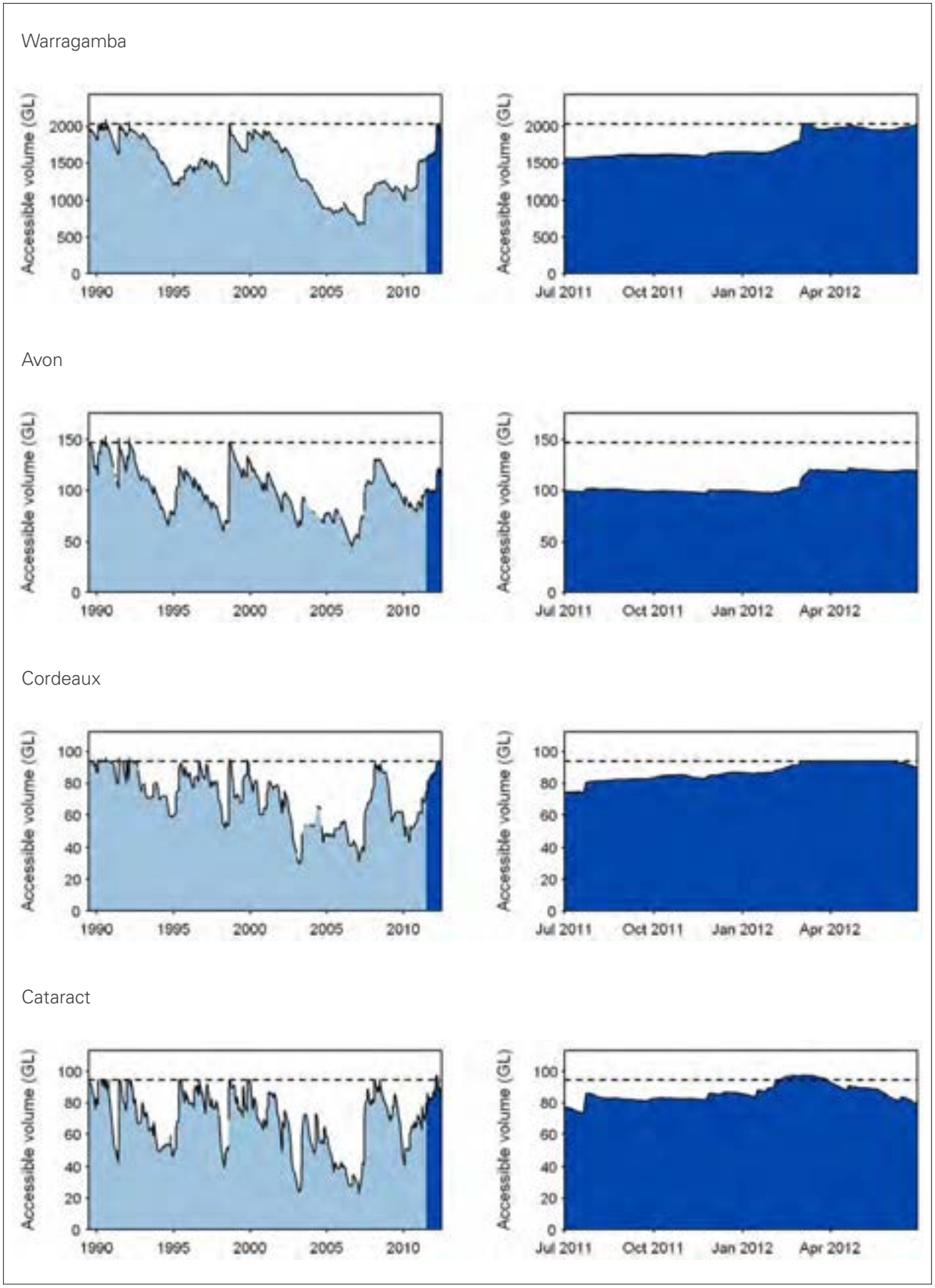


Figure 4.37 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Sydney's major storage, Warragamba, and three of the four upper Nepean storages, as well as total accessible storage capacity (dashed line).

Water restrictions

Figure 4.38 shows the accessible storage volume and the water restrictions implemented for Sydney in recent years. Water restrictions are used as a measure to reduce the demand on water supplies. On 1 November 1994, mandatory water restrictions were introduced for Sydney in response to a decreasing accessible volume at Warragamba. Above average rainfall during 1995 led to an increase in storage volume, and on 16 October 1996 the restrictions were lifted.

During 2002, Sydney experienced one of the worst periods of drought on record. Surface water storage levels began to decline rapidly and, as a strategy to reduce water consumption, voluntary water restrictions were introduced in Sydney in November 2002 (Sydney Water Corporation 2010). Despite this, the volume of water in Warragamba continued to decrease under the ongoing drought conditions.

With the total combined storage volume of Sydney's supply network falling below 60% of its capacity, Sydney Water introduced mandatory water restrictions level 1 at the beginning of October 2003.

When Sydney's total storage volume dropped below 50% of capacity, mandatory water restrictions were elevated on 1 June 2004 to level 2. Water restrictions were elevated to level 3 on 1 June 2005 when the total storage volume dropped below 40% of capacity.

In May 2007, Warragamba reached the lowest water level in recent years. Above average rainfall increased storage volumes to about 60% of its accessible storage capacity. As a consequence, Level 3 water restrictions were eased out by June 2008.

Combined storage volumes remained at around 60% over the following 12 months and water restrictions were replaced by 'Water Wise Rules' in June 2009 to encourage continued water saving. Water Wise Rules have remained in place since then as storage levels have continued to rise to near full capacity during early 2012.

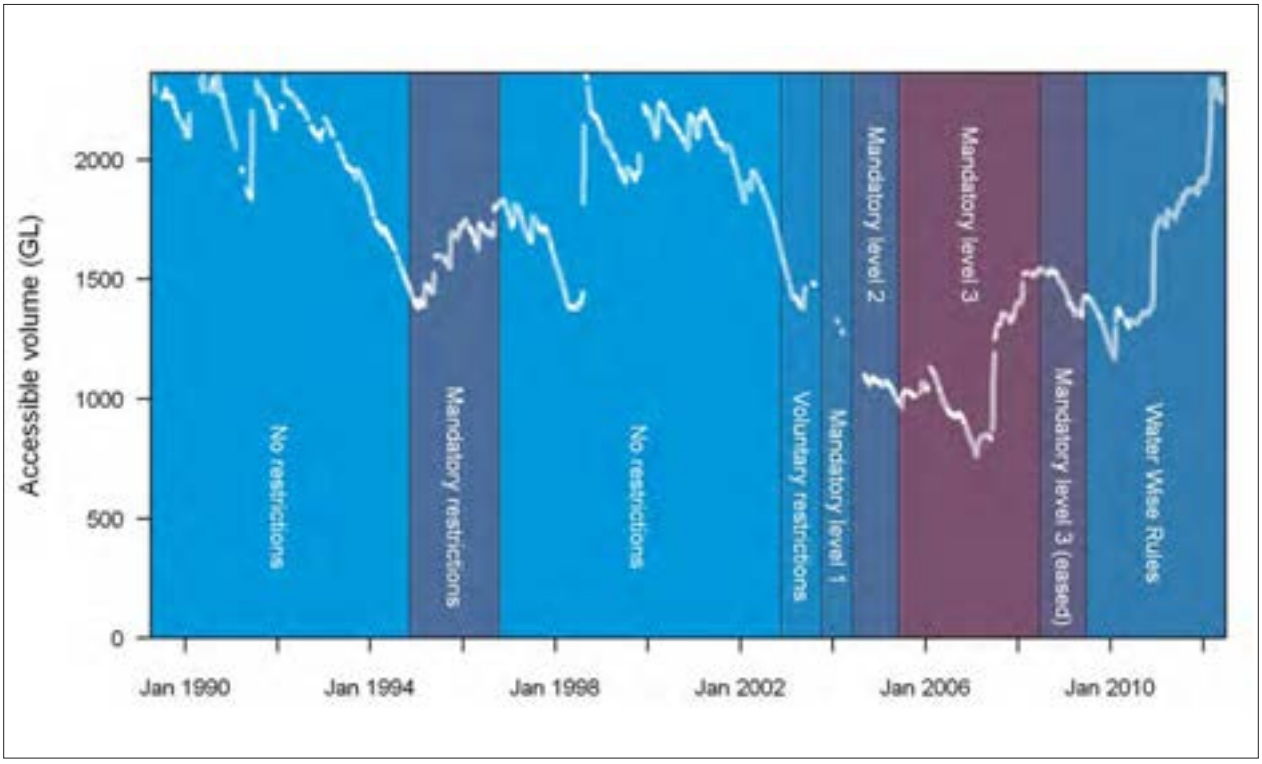


Figure 4.38 Water restrictions in the Greater Sydney area

Sources of water obtained

Figure 4.39 shows the total volume of water sourced from surface water, recycling, and desalination by Sydney Water from 2006–07 to 2011–12 (National Water Commission 2011a). The volume sourced from surface water includes water received from the bulk supplier (SCA) and surface water taken from the Hawkesbury River for supply to Richmond–Windsor.

The total volume of water sourced in 2011–12 was 495 GL. Over the past five years, the highest volume of water sourced, 517 GL, was in 2006–07. The following year annual volumes decreased to 491 GL in 2007–08 and 506 GL in 2008–09. This decrease can be attributed to, in part, the easing of water restrictions from June 2008.

The main source of water supply for the Greater Sydney region is surface water, which ranged from 97% of the total water sourced in 2006–07 to 81% in 2010–11. The decrease in surface water sourced coincides with an increase in desalination water supplied.

The Kurnell desalination plant was commissioned in January 2010. Water sourced from desalination accounted for 3.9% of total water sourced in 2009–10. The share of desalinated water increased to 15% for the 2010–11 year and 12% for 2011–12 year.

Water from recycling comprises a small yet significant component of water sourced, ranging from 1.5% in 2006–07 to 2.1% in 2010–11. In 2011–12, water sourced from recycling accounted for 2.7%.

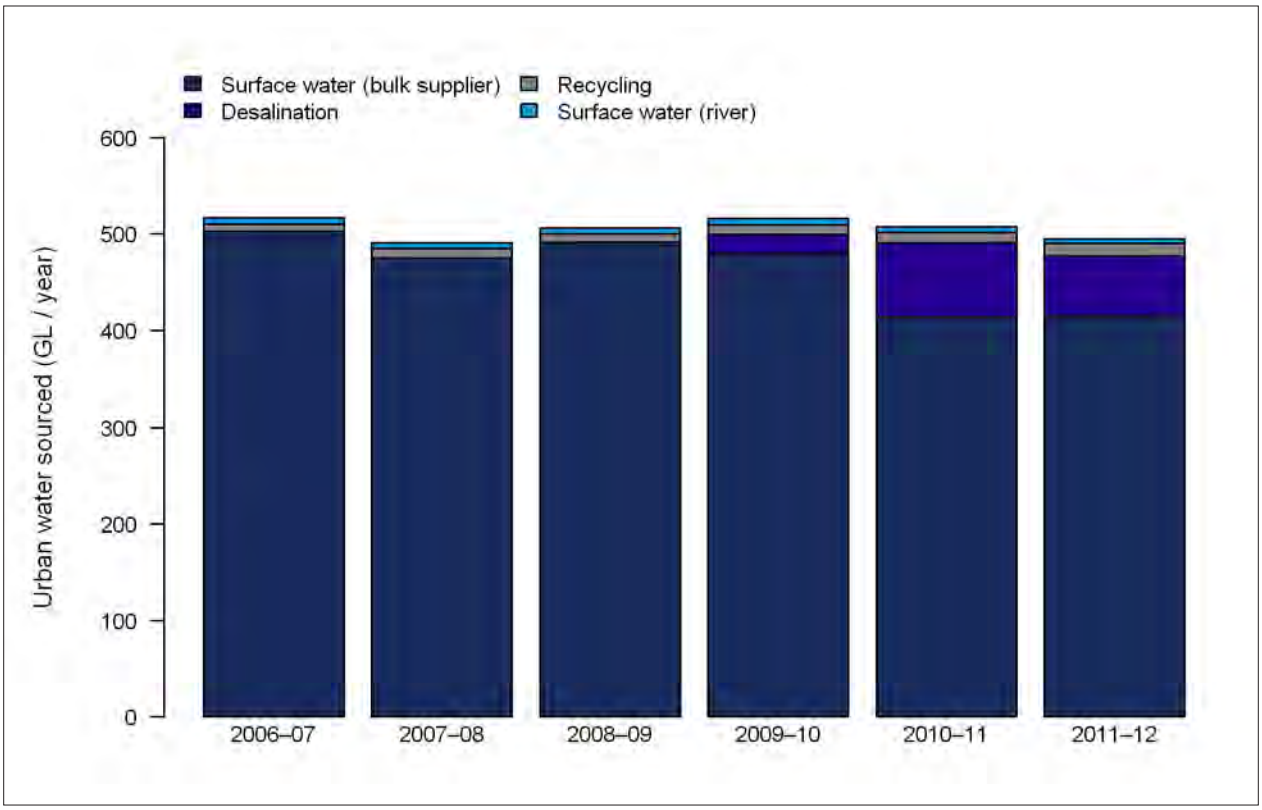


Figure 4.39 Total urban water sourced for the Greater Sydney area from 2006–07 to 2011–12

Categories of water delivered

Figure 4.40 shows the total volume of water delivered to residential, commercial, municipal and industrial consumers in the Greater Sydney region from 2006–07 to 2011–12 (National Water Commission 2012). The total volume of water delivered to the residential sector in 2011–12 accounted for 61% of total potable water consumption.

Total water supplied has gradually increased since the 2007–08 year and was highest in 2010–11 at 544 GL. While residential and commercial use has remained consistent over the last three years, there has been a significant growth in water supplied for other uses.

Based on the data obtained from the National Performance Reports (National Water Commission 2012), the average water supplied by Sydney Water, per property for residential use was estimated to be 196 kL from 2006–07 to 2011–12. The maximum residential water use per property was 205 kL in 2009–10 and the minimum was 182 kL in 2007–08.

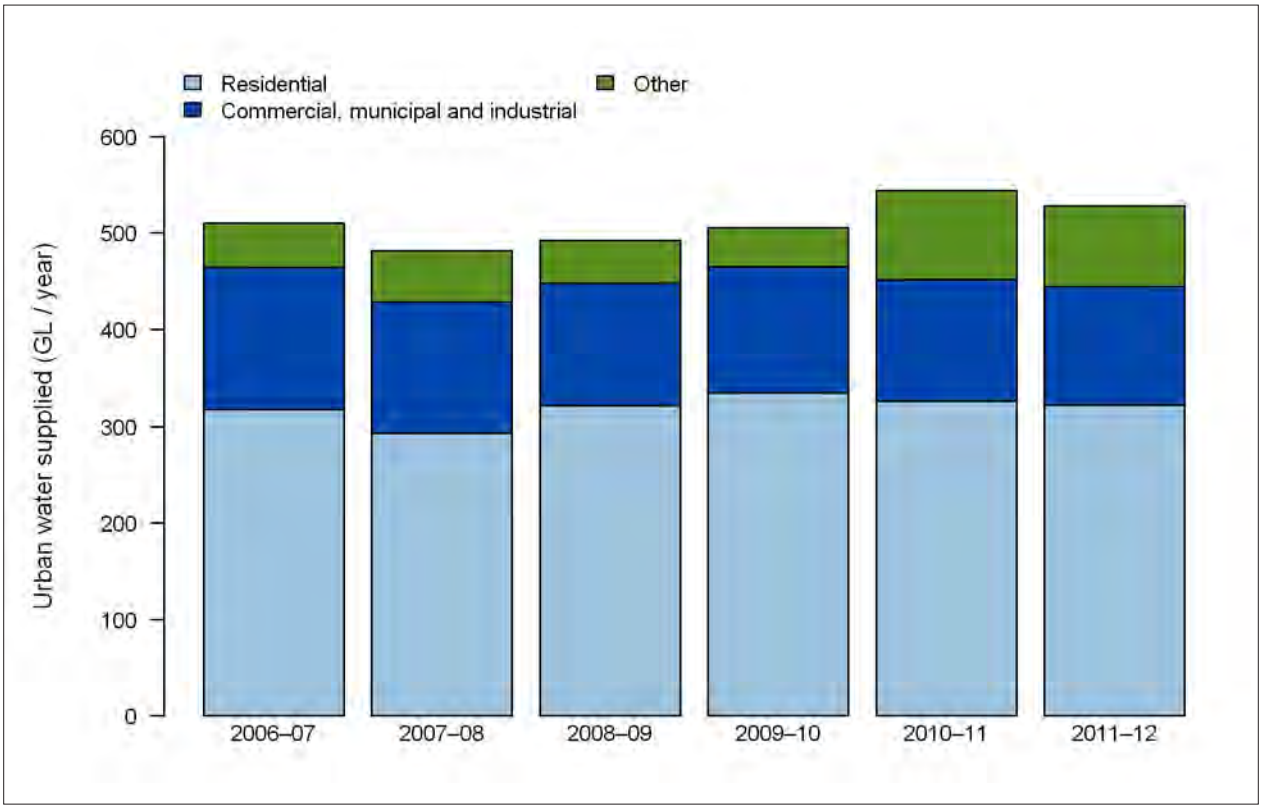


Figure 4.40 Total urban water supplied to the Greater Sydney area from 2006–07 to 2011–12

4.7 Water for agriculture

This section describes the water situation for agriculture in the South East Coast (NSW) region in 2011–12. Soil moisture conditions are presented and important irrigation areas are identified. The Hunter River irrigation area is described in more detail and information is provided regarding surface storage.

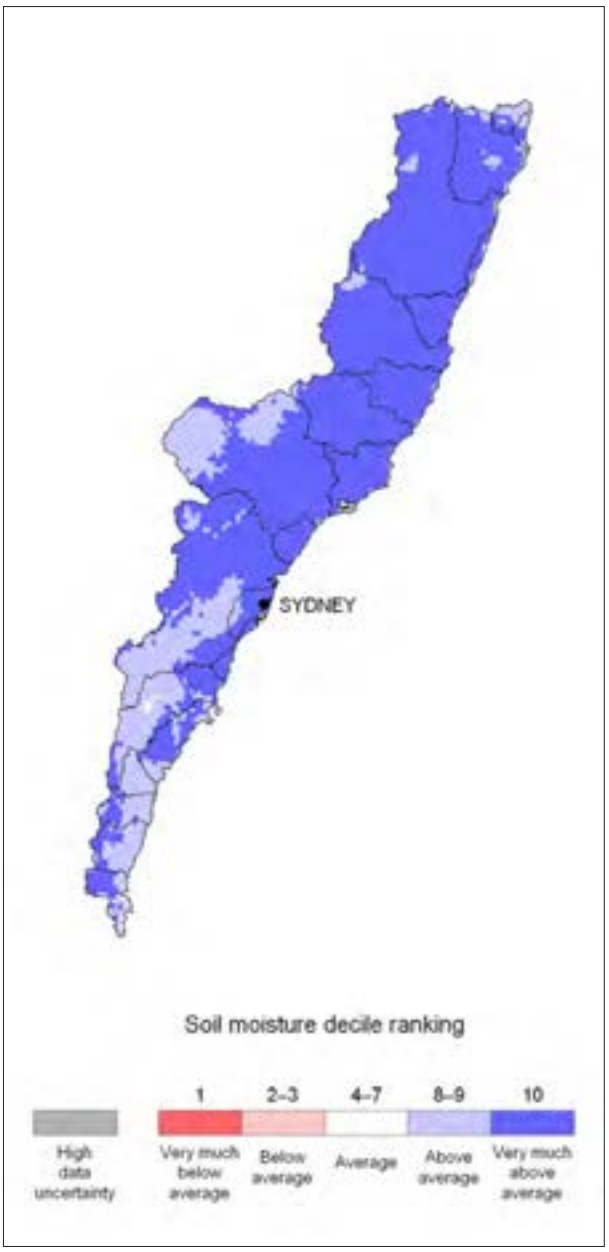


Figure 4.41 Deciles rankings of the soil moisture over the 1911–2012 period in the South East Coast (NSW) region

4.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 km x 5 km grid cell, they are not suitable to compare with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to those of the 1911–2012 period, expressed in decile rankings.

The above average rainfall in the region during 2011–12 favoured wet conditions in the soils, which ranked as very much above the long-term average for most areas. In the southern parts, the soils were generally at above average conditions (Figure 4.41).

Temporal variation of the decile rankings show very much above average soil moisture conditions for most of 2011–12 (Figure 4.42). This was a result of the high rainfall in the region, which sustained the wet conditions in the soil.

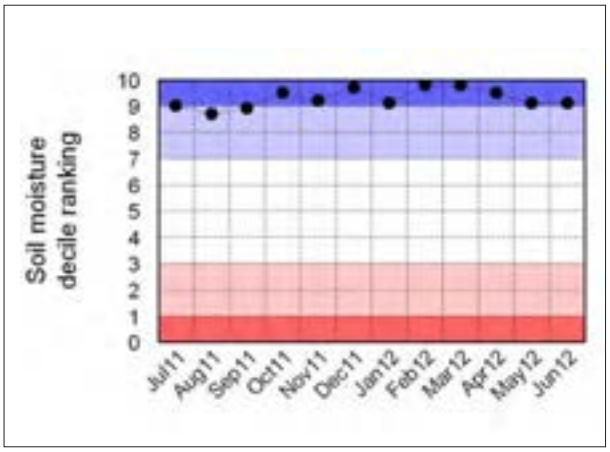


Figure 4.42 Decile ranking of the monthly soil moisture conditions during the 2011–12 period in the South East Coast (NSW) region

4.7.2 Irrigation water

Irrigation water use in the region between 2005–06 and 2010–11 is shown in Figure 4.43 and Figure 4.44 by natural resource management (NRM) region. Data for the 2011–12 year was not available at the time of preparing this report.

The data show that the highest irrigation water use occurs in the regulated Hunter River basin, followed by the Hawkesbury–Nepean river basin.

Figure 4.44 shows the variation in the irrigation water use during the 2010–11 year. The Hunter River basin with 86 GL was the major consumer of irrigation water.

In the next section, the Hunter River basin is used as an example for water resource conditions and irrigated agriculture in 2011–12.

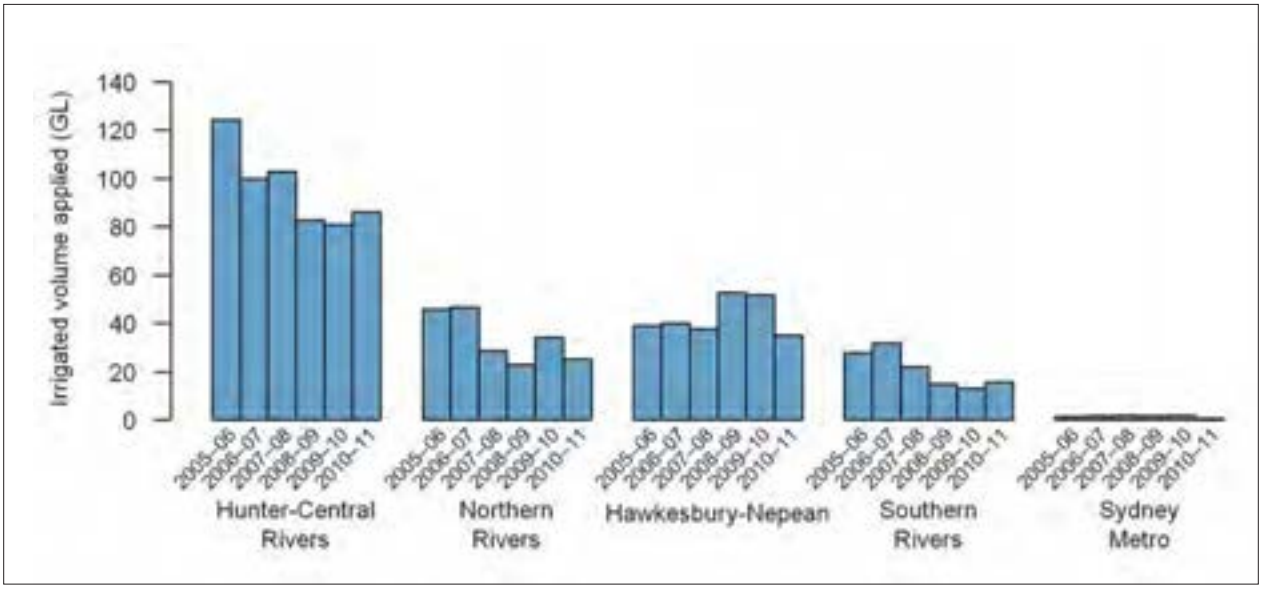


Figure 4.43 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the South East Coast (NSW) region (ABS 2006–10; 2011a)

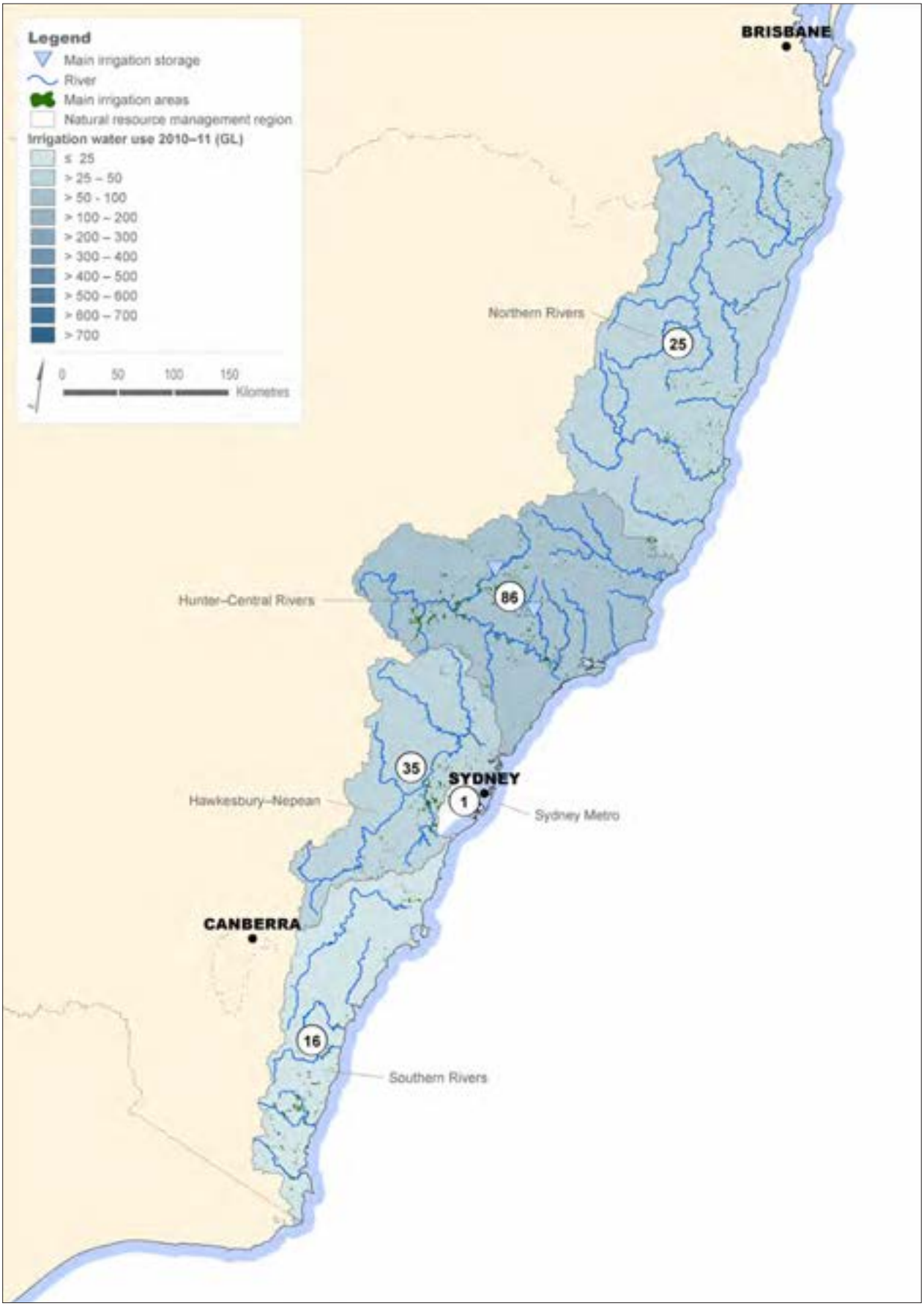


Figure 4.44 Annual irrigation water use per natural resource management region for 2010–11 (ABS 2011a)

4.7.3 Irrigation areas

In the subtropical north, where dairy is the largest industry, irrigation is necessary during spring and early summer. Mild winters and warm hot summers in the north are conducive also to avocado, banana, citrus and other fruit production.

In the mid-coast catchments, wine grapes and dairy pasture are the two most important irrigated industries. In these areas, most of the licences for irrigation are located in the Hunter catchment (Figure 4.45) along the Williams and Goulburn rivers and Wollombi Brook (Hope 2003b).

The southern coast has extensive forested headwaters, wetlands, river estuaries and freshwater swamps. Irrigated agriculture occurs mainly in the Hawkesbury–Nepean and Bega river basins (Hope 2003c). Dairy production is the main industry followed by vegetables and floriculture.

Unregulated rivers are the major source of water for the irrigation industry in most parts of the region. Irrigation from farm storages is widespread and provides a level of security during droughts. Irrigation from groundwater is very limited (Hope 2003a).

The Hunter River basin irrigation areas are described in more detail in subsection 4.7.4.

Hunter Valley vineyards, New South Wales | Christopher Howey (Dreamstime)

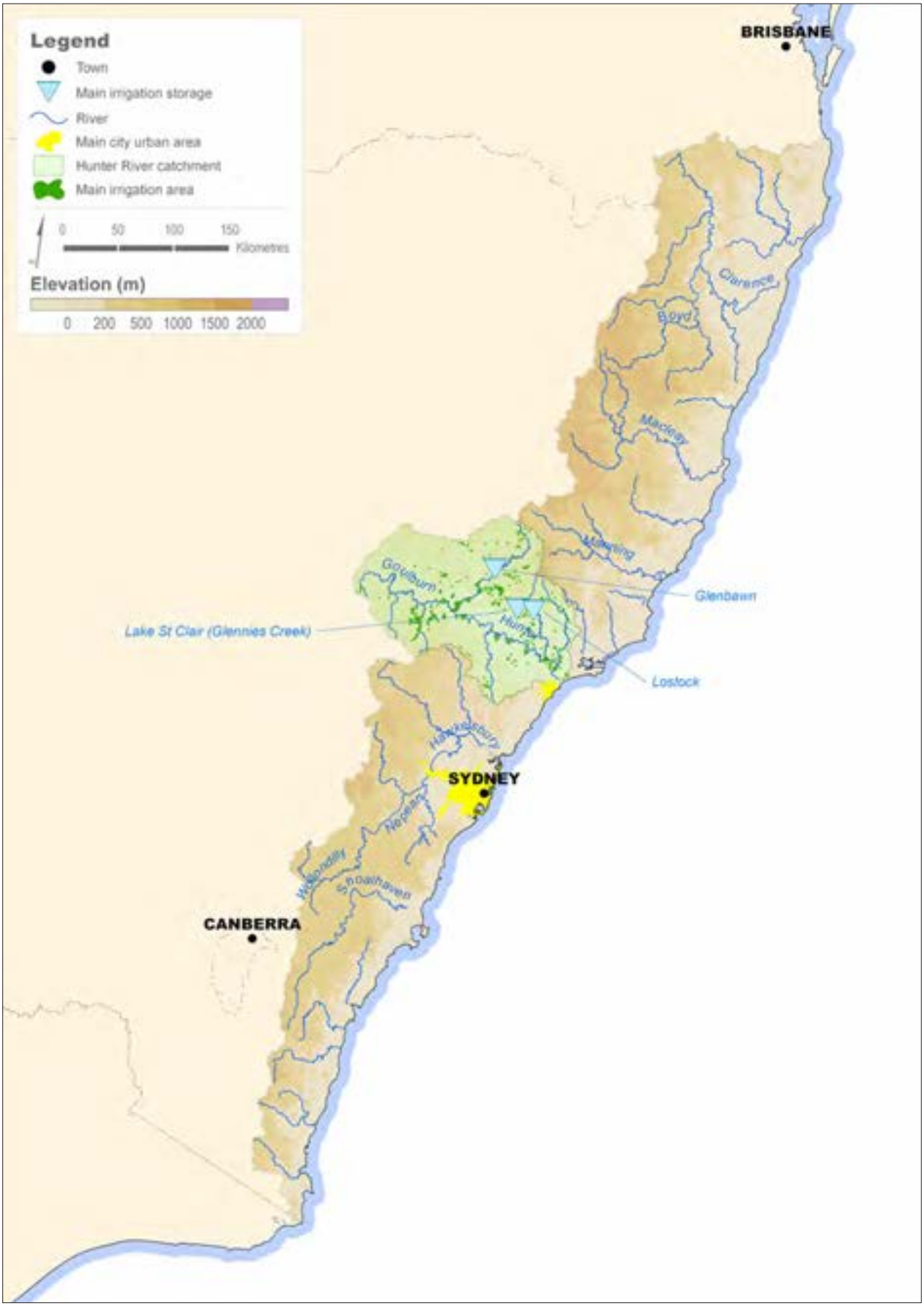


Figure 4.45 The Hunter River basin in the South East Coast (NSW) region

4.7.4 Hunter River basin

The Hunter River drains the largest coastal catchment in New South Wales (22,000 km^2) and provides the only regulated water supplies in the mid-coast part of the South East Coast (NSW) region (Figure 4.46).

The Hunter River basin contains approximately 80% of the irrigated area in the mid-coast. Irrigation is used to grow pasture and lucerne for dairy farms. Vineyards are the second most important irrigated enterprise in the river basin and are located along the Goulburn River and Wollombi Brook. The river basin also supports a diversity of other agricultural activities, such as beef cattle, dairy, poultry, wool and sheep, cereal crops and horse and cattle studs.

Most of the water in the Hunter Valley irrigation area comes from the north-eastern part of the catchment. Water is controlled by three storages: Glenbawn, Lake St Clair, behind Glennies Creek dam, and Lostock.

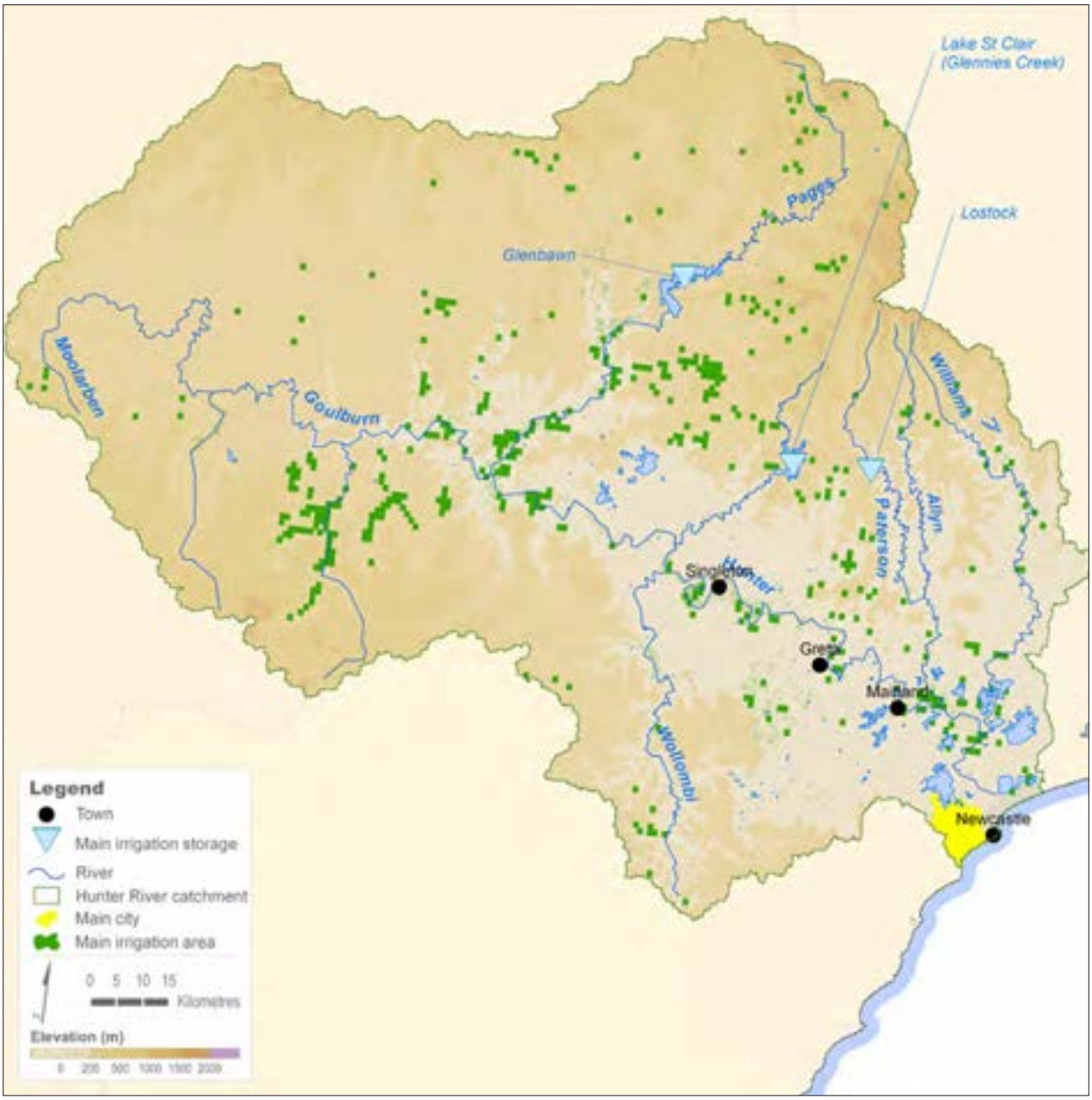


Figure 4.46 Irrigated areas in the Hunter River basin

Glenbawn storage, with an accessible capacity of 750 GL plus 120 GL for flood control, is located behind the largest earth-filled dam in Australia. It regulates flows in the Hunter River downstream of Maitland. The storage has an area of 26 km^2 with a maximum depth of 85 m. It provides water for towns, stock, irrigation, industry and environmental flows.

Glenbawn is operated in conjunction with Glennies Creek storage. The latter has an accessible storage capacity of 283 GL with surface and catchment areas of 15 km^2 and 233 km^2, respectively. It supplies water for the town of Singleton as well as for irrigation, stock and industries such as coal mining (State Water Corporation 2011).

The Hunter Regulated River Water Sharing Plan contains rules for how water is shared between the environment and water users with different categories of licences. The plan establishes a long-term average annual extraction limit estimated as 217 GL per year, out of an annual natural average flow estimated at 1,042 GL (New South Wales Department of Water and Energy 2009). This ensures a minimum level of flow in the Hunter River at Liddell, just upstream of the Glennies Creek junction, and Greta (near the end of the regulated river system).

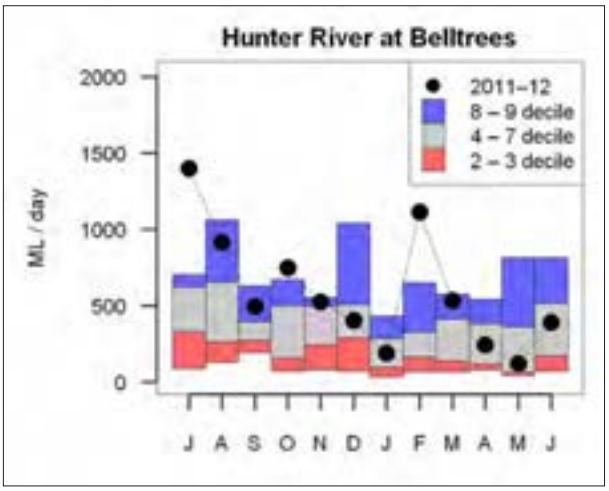


Figure 4.47 Monthly discharge hydrographs compared to discharge deciles of Hunter River at Belltrees, representing inflows into Glenbawn

The plan also establishes water reserves (or environmental contingency allowances) of 20 GL per year in both Glenbawn and Glennies Creek. The rules for how water is shared between extractive users are set by the plan.

The Hunter regulated river water source is divided into three management zones and five supplementary water reaches for the management of extractions by supplementary water access licences. An actual volumetric allocation scheme was introduced in 1981 which is based on 6 ML/ha. In most years, water allocation for general security use was 100% or more.

Surface water storage inflows

In 2011–12, the flows in the catchments upstream of the Glenbawn storage were at medium to high levels compared with their historic record. The maximum flows at the Hunter River occurred in February that coincided with the high incidents of rainfall in the region (Figure 4.47). The flows gradually declined during spring and early summer, with a sudden rise during February following the rainfall pattern in the region.

Surface water storage volumes

Combined inflows to the Glenbawn and Glennies Creek storages and total regulated water use in the Hunter region since 1985 are shown in Figure 4.48. The inverse relationship between the two indicates diversions increased in drought years in response to greater irrigation water demand. The combined inflows to Glenbawn and Glennies Creek in 2011–12 were much above the average (184 GL).

The storage volume for both the Glenbawn and Glennies Creek storages remained at 100% of their accessible capacity for most parts of the year (Figure 4.49).

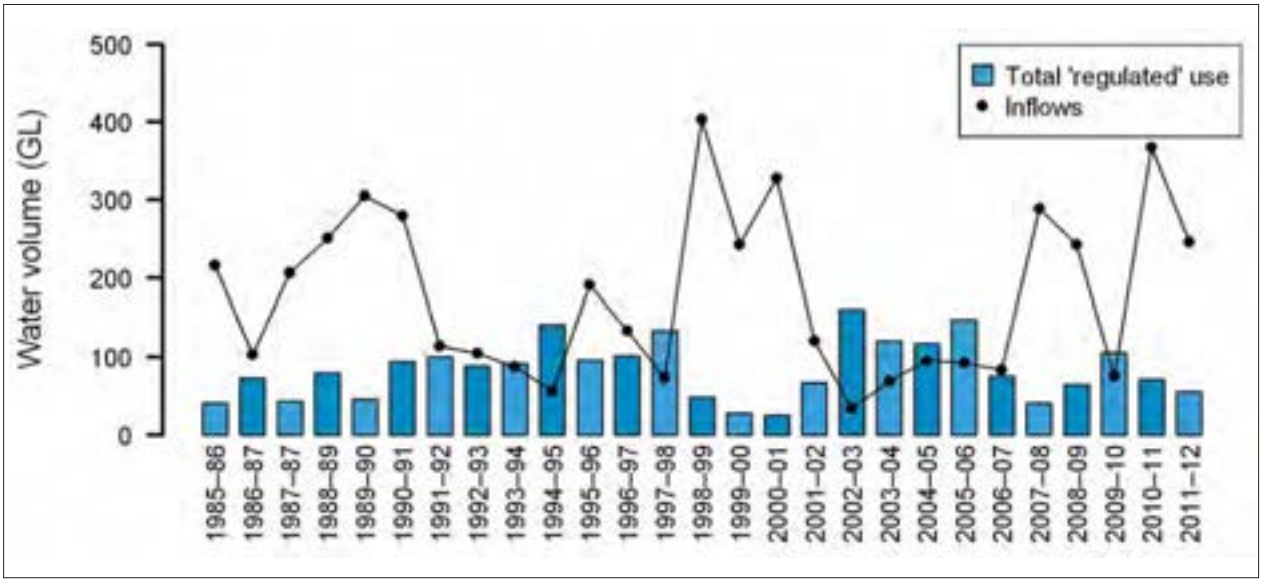


Figure 4.48 Combined inflows to the Glenbawn and Glennies Creek storages and total regulated water use in the Hunter region between 1985–86 and 2011–2012

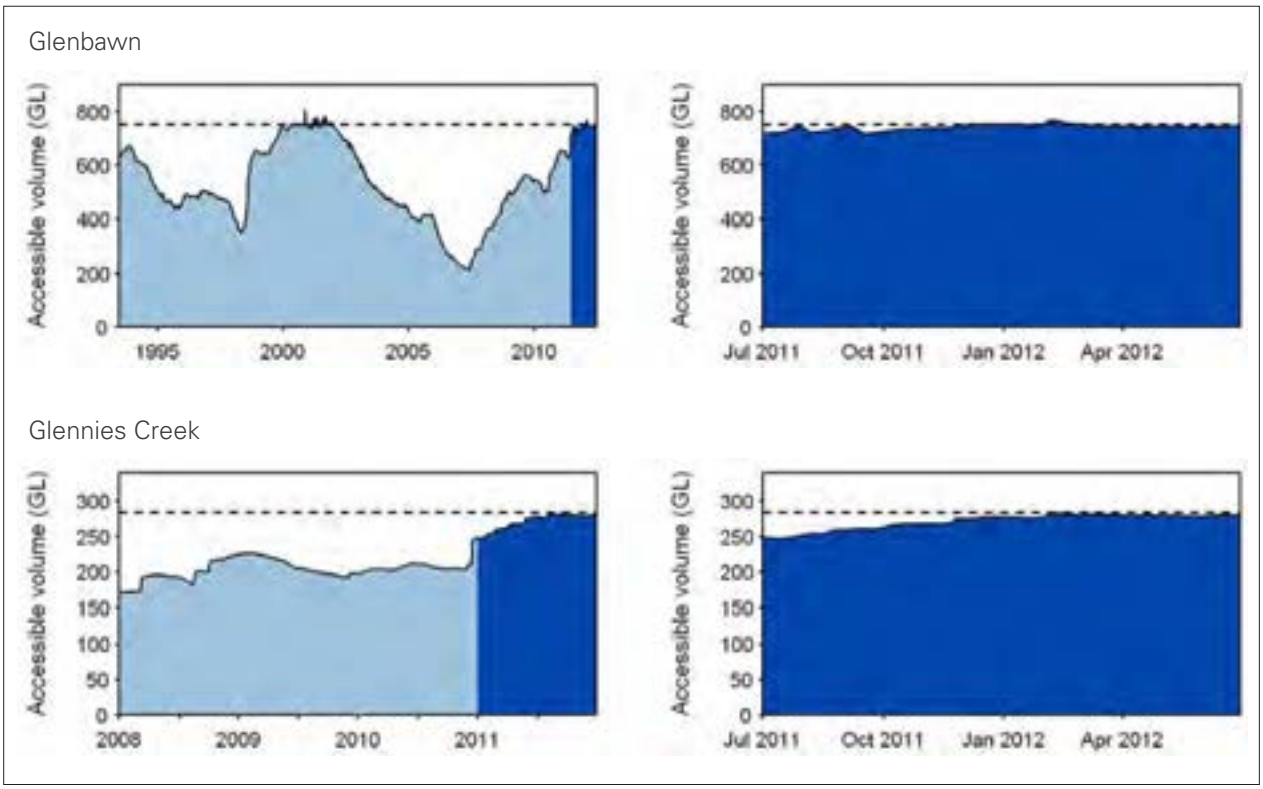


Figure 4.49 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Glenbawn and Glennies Creek storages, as well as total accessible storage capacity (dashed line)

South East Coast (Victoria)

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5 South East Coast (Victoria)

5.1 Introduction

This chapter examines water resources in the South East Coast (Victoria) in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well an examination of the surface water and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

5.2 Key information

Table 5.1 gives an overview of the key components of the data and information in this chapter.

Table 5.1 Key information on water flows, stores and use in the South East Coast (Victoria) region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	842 mm	+14%	9th—above average
Evapo-transpiration	648 mm	+3%	7th—average
Landscape water yield	180 mm	+68%	10th—very much above average

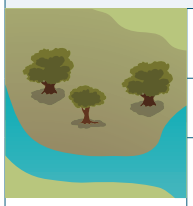
Streamflow (at selected gauges)

Annual total flow:	Very much above average flow in the eastern half of the region, predominantly average in the western rivers
Salinity:	Annual median electrical conductivity below 1000 µS/cm in the few gauges in the east and many rivers in the west with higher than 2000 µS/cm
Flooding:	Major flooding in the eastern rivers in June 2012

Surface water storage (comprising about 73% of the region's total capacity of all major storages)

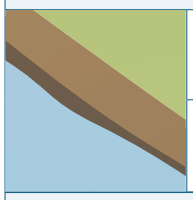
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
1,907 GL	1,346 GL	71%	1,078 GL	57%	+268 GL	+14%

Wetlands inflow patterns (for selected wetlands)



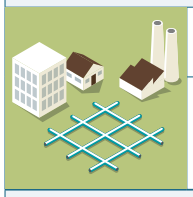
Western District Lakes:	Below average flows, particularly in the wet season (August to October)
Gippsland Lakes:	Very much above average flows for much of the year
Reedy Lake–Lake Connewarre:	Predominantly average flows, with high flows in June 2012

Groundwater (in selected aquifers)



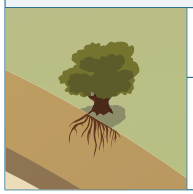
Levels:	Variable groundwater levels in the various aquifers throughout the region
Salinity:	Large areas of saline groundwater (≥3,000 mg/L), particularly in the eastern aquifers

Urban water use (Melbourne)



Total use in 2011–12	Total use in 2010–11	Change	Restrictions
361 GL	343 GL	+18 GL (+5%)	Eased to Stage 1

Annual mean soil moisture (model estimates)



Spatial patterns:	Above average soil moisture levels in the east, predominantly average in the west
Temporal patterns in regional average:	Above average in July 2011, dropping to average between October 2011 and February 2012, then returning to above average in March 2012

5.3 Description of the region

The South East Coast (Victoria) region covers approximately 134,600 km² of land area in southern Victoria, bordered in the south by the Victorian and South Australian coastlines. It is set between the Great Dividing Range in the north, the eastern boundaries of the East Gippsland and Snowy River basins in the east and Mount Gambier and the Millicent coast of South Australia in the west.

The region's river basins vary in size from 1,400 km² to 12,000 km². The region's landscape varies from densely-forested mountainous areas in East Gippsland, undulating with numerous volcanic cones in the Hopkins River basin and flat with alluvial deposits in the Werribee River basin. Subsections 5.3.1 and 5.3.4 give more detail on the physical characteristics of the region.

The region has a population of in excess of 4.8 million people, almost one quarter of Australia's total population, and includes the Victorian State capital, Melbourne (Australian Bureau of Statistics [ABS] 2011b).

Figure 5.1 highlights the major population centres in the region which include Geelong, Ballarat, Melton, Warrnambool and Sunbury. Further discussion of the region's population distribution and urban centres can be found in subsection 5.3.6 and section 5.6 respectively.

Although national parks and State forests occupy large portions (Figure 5.1), a significant amount of the region is cleared for grazing sheep and cattle. Hardwood timber production is a major industry in some river basins such as the Snowy, East Gippsland and Barwon. Dryland agriculture, particularly cereal cropping, is a major land use in some areas such as the Millicent coast. Irrigated agriculture is concentrated around storages in the Thomson and Werribee river basins. This includes irrigation districts at Lake Glenmaggie, Bacchus Marsh and Werribee.

Extensive parts of some river basins, such as the Yarra River basin, are urbanised with agricultural production such as viticulture and market gardening. Section 5.7 has more information on agricultural activities in the region.

The climate of the region is affected by a seasonal movement of the major atmospheric systems in Australia, which brings warm temperate conditions. This merges with a moderate Mediterranean climate in the south. Subsections 5.3.7 and 5.3.8 provide more information on the rainfall patterns and deficits across the region.

There are numerous rivers and tributaries in the region, of which the Thomson, Macalister and Snowy rivers constitute the major streams. Others include the Glenelg, Bunyip, Latrobe, Hopkins and Maribyrnong rivers. Most of the river basins in the region have at least one major storage. Thomson storage in the Thomson River basin is the largest storage supplying surface water to the region.

The groundwater systems of the South East Coast (Victoria) region are relatively varied and complex. Hydrogeological features include the Otway basin, Port Phillip and Westernport basins, Gippsland basin and Tarwin basin, basement outcrops of fractured rock, and the karstic limestone area of the Murray Group aquifer in the northwest of the region. The basement fractured rock typically provides low groundwater yield. The basins can provide significant groundwater resources from permeable layers of sediments, limestone and fractured basalt. A more detailed description of the rivers and groundwater status in the region is given in section 5.5.

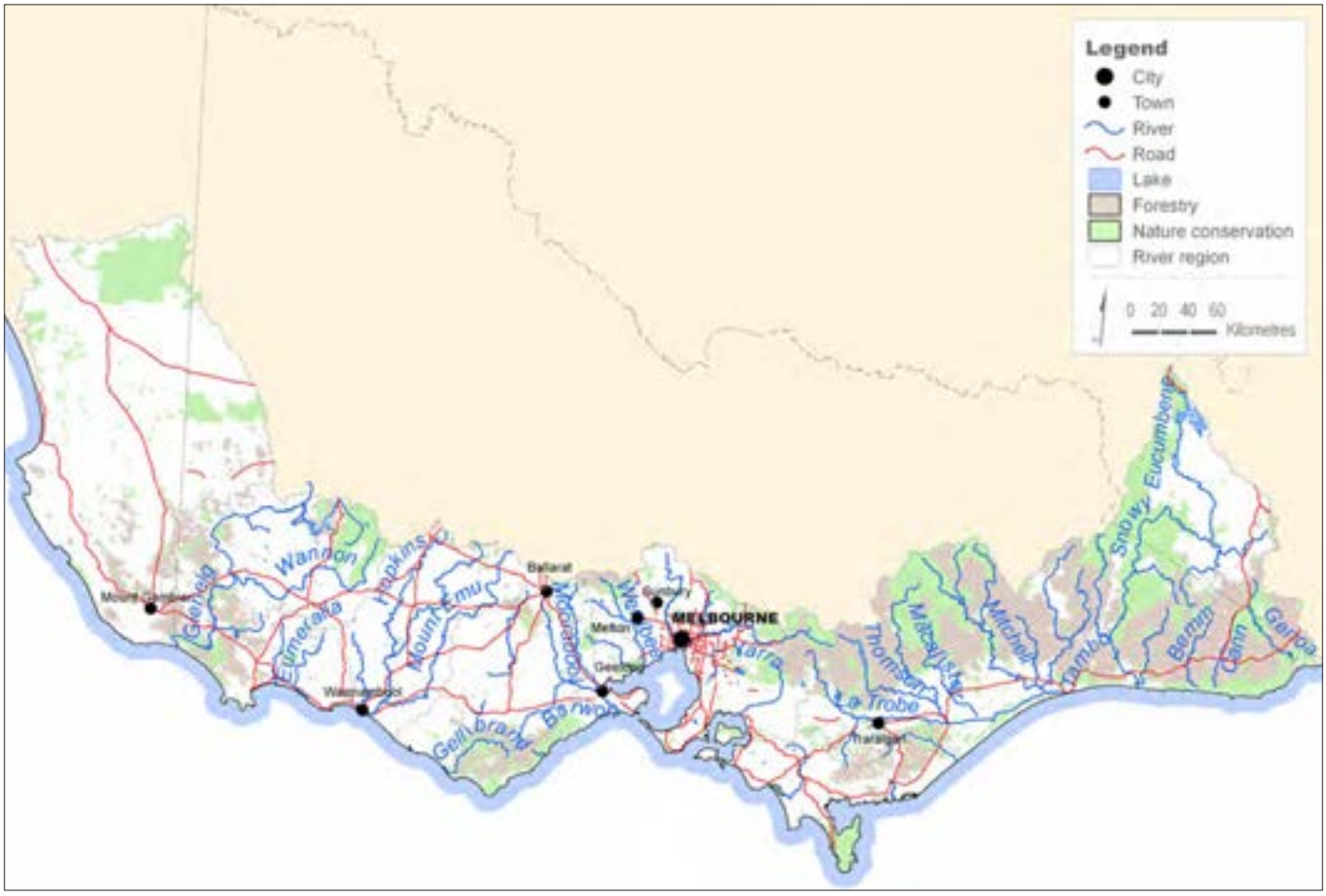


Figure 5.1 Major rivers and urban centres in the South East Coast (Victoria) region

Yarra River, Melbourne | MoMorad (iStockphoto)

5.3.1 Physiographic characteristics

The physiographic map in Figure 5.2 shows areas with similar landform evolutionary histories (Pain et al 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes. The South East Coast (Victoria) region has two physiographic provinces, the Kosciuszkan Uplands and the Murray Lowlands.

The Kosciuszkan Uplands province occupies 73% of the region and has undulating upland plains with some tabular basalt relief and granitic rock outcrops in the northeast. The central portion comprises dissected high plateaus on various resistant rocks, with isolated high plains. The south coast has sandstone and granite hills with terraced plains on weak sedimentary and basalt rocks. The northwest has moderately high plateaus and ridges.

The Murray Lowlands province occupies 27% of the area and, in the southeast, has parallel dune limestone ridges with intervening swamps, closed karst depressions and young volcanoes. In the northeast there are aeolian and alluvial sand plains, minor low sandstone ridges. In the northwest there are coastal barriers, lagoons and calcareous dunes.

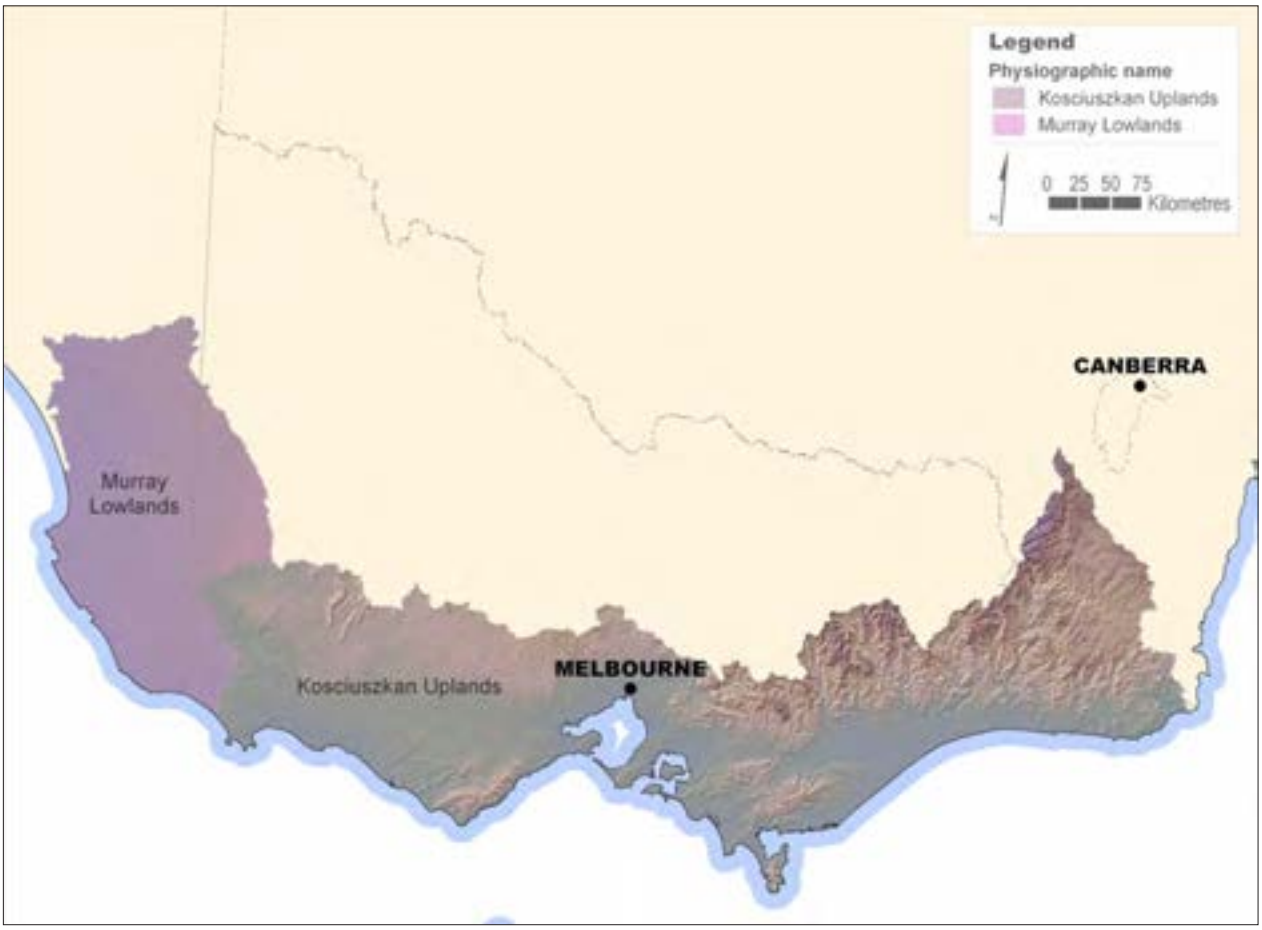


Figure 5.2 Physiographic provinces of the South East Coast (Victoria) region

5.3.2 Elevation

Figure 5.3 presents the topography in the South East Coast (Victoria) region, which varies from alpine mountains in the northeast to low-lying coastal zones. The northwest is called the Limestone Coast and includes large plains lined by rows of sand hills parallel to the coast.

Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The region contains the most southern part of the Great Dividing Range on the Australian mainland. It includes some of the highest mountains in the Great Dividing Range, including Australia's highest mainland mountain, Mount Kosciuszko.

To the west, the tilted sandstone formations of the Grampians form a north–south orientated series of parallel ridges, reaching altitudes of over 800 m. Only the southern parts of these ridges are located in the region.

The crest of the Great Dividing Range forms the northwest border of the region. Moving to the west, the altitude of the water divide that forms the border of the region gradually reduces to less than 100 m in the far west.

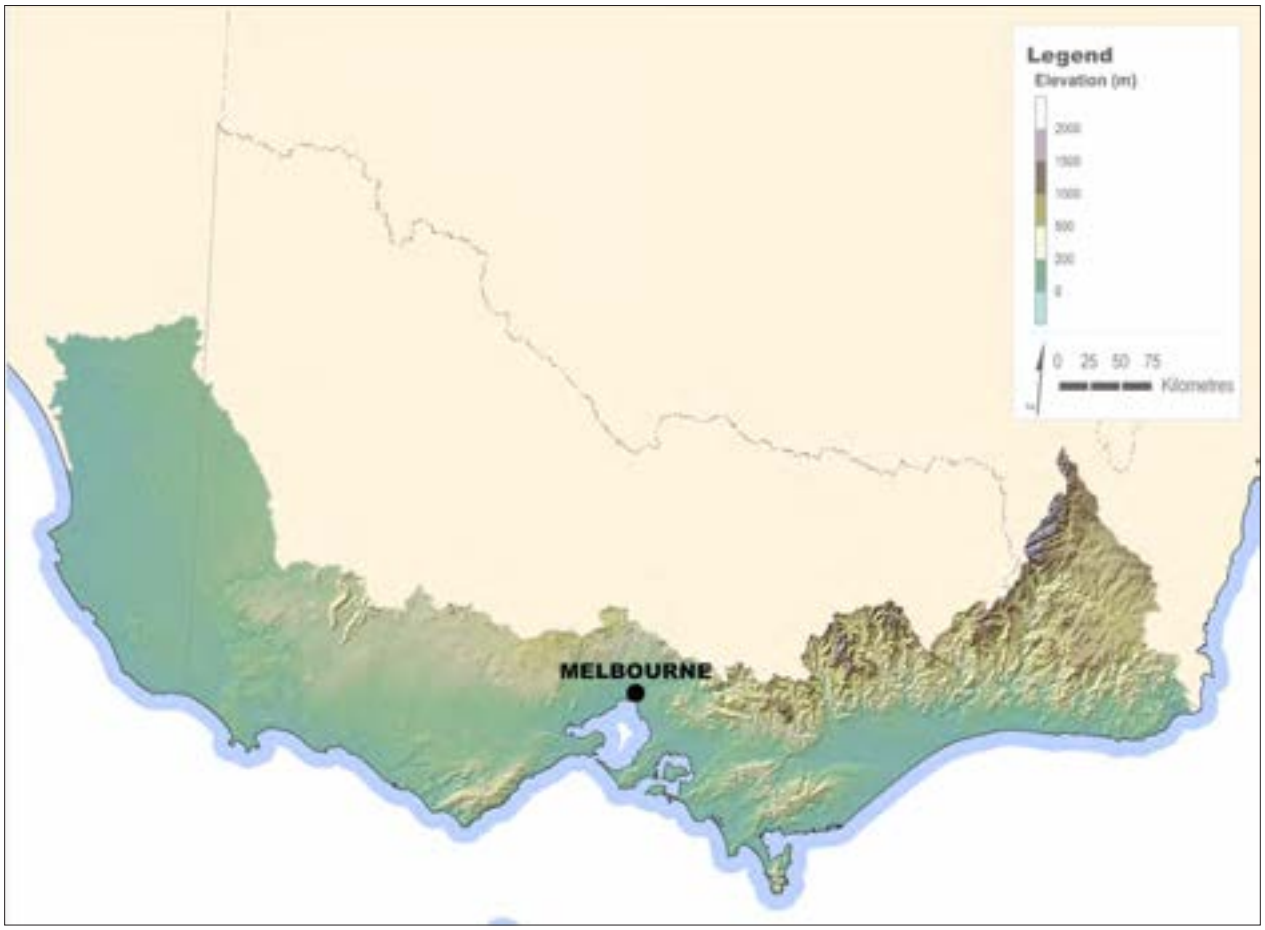


Figure 5.3 Ground surface elevations in the South East Coast (Victoria) region

5.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The South East Coast (Victoria) region has high variability in slopes (Table 5.2), with generally large areas of steeper slopes in relation to the rest of Australia. The slopes were derived from the elevation information used in the previous section.

Table 5.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1– 5	> 5
Proportion of region (%)	27.4	15.3	30.1	27.2

Particularly in the northeast, the slopes in the Great Dividing Range are steep. Streamflow runs quickly into the many storages located in the area. South of this area, in the flat coastal areas, rivers form floodplains and coastal lakes (Figure 5.4).

To the west of Melbourne, many inland areas are rather flat. Water does not run off into large rivers, but rather forms small lakes and swamps. This landscape is even more distinct in the Limestone Coast, where the many swamps and lakes needed to be drained to transform the land into exploitable farmland.

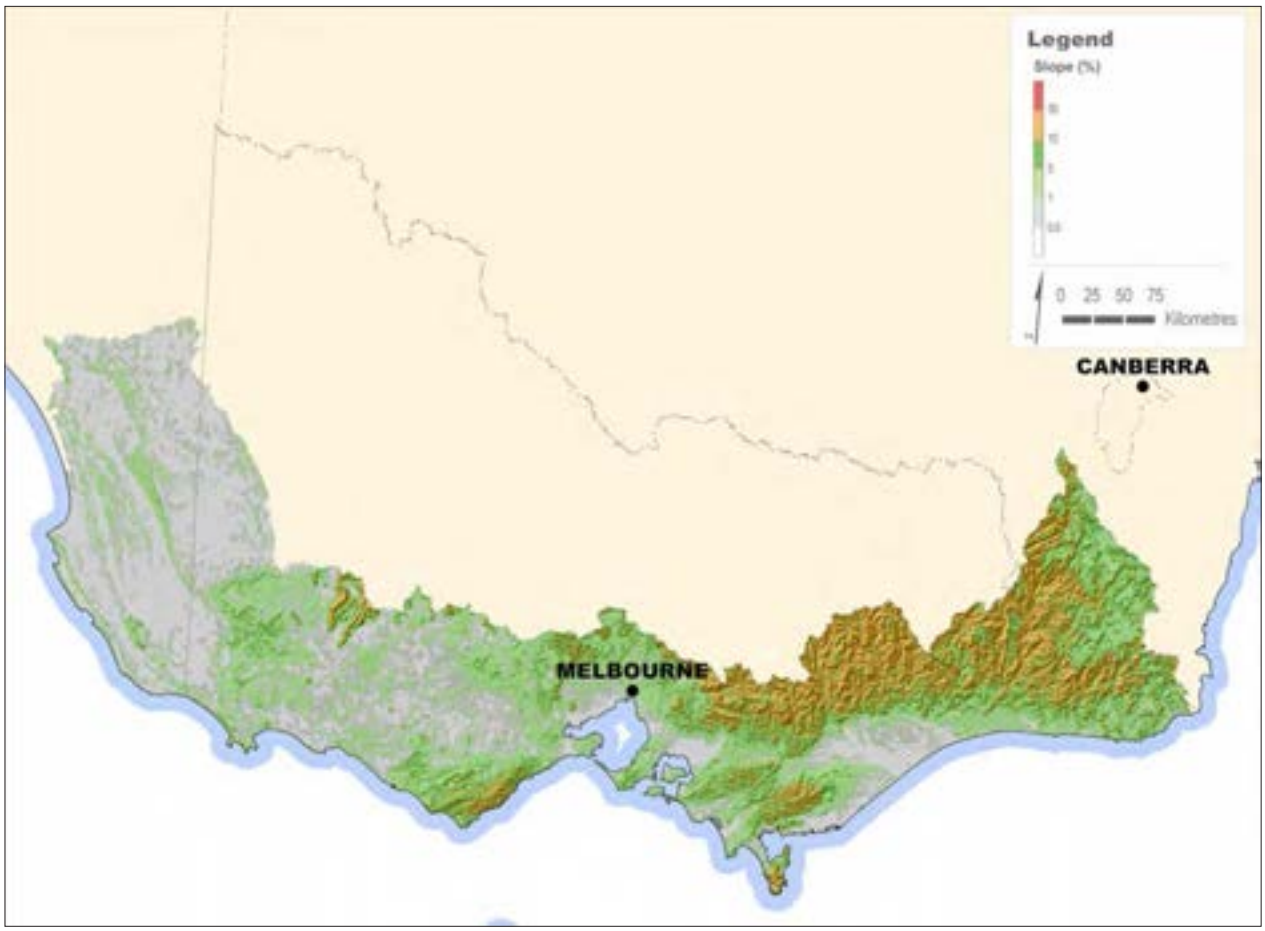


Figure 5.4 Surface slopes in the South East Coast (Victoria) region

5.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge. The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 83% of the South East Coast (Victoria) region is covered by five soil types, namely sodosols, chromosols, tenosols, dermosols and vertosols (Figure 5.5 and Figure 5.6).

The most common and widely spread soils for this region are sodosols (38%). They are characterised by an abrupt increase of clay as well as sodium with depth leading to dispersion and instability. Sodosols are prone to erosion, especially tunnel and gully erosion as well as dryland salinity. Due to the high sodicity and low permeability they have a low agricultural potential.

Chromosols are mainly found in the eastern part of the region, but also to some extent in the central western part of this region. Similarly to sodosols, chromosols have an abrupt increase in clay content in the soil profile. They have moderate chemical fertility, water-holding capacity and a moderate agricultural potential often used for wheat cropping as well as for grazing. Soil acidification and soil structural decline may occur on these soils.

Dermosols also have moderate and partly high agricultural potential due to their moderate chemical fertility, well structured and high water-holding capacity. They are widely spread in the central and eastern parts of the region.

In the central to northern parts of the region tenosols are also common soil types. They have a weak profile development and with a low chemical fertility and water-holding capacity their agricultural potential is low.

Vertosols, soils with high clay contents throughout the profile are mainly found in western parts and to a small extent in central parts of the region. They have tendencies for soil cracks when dry and swelling during wetting, are highly fertile and have a large water-holding capacity. They, however, require a significant amount of water before it becomes available to plants.

Other soil types with small area coverage in this region are kurosols, podosols, ferrosols, rudosols, calcarosols as well as kandosols (Figure 5.6).

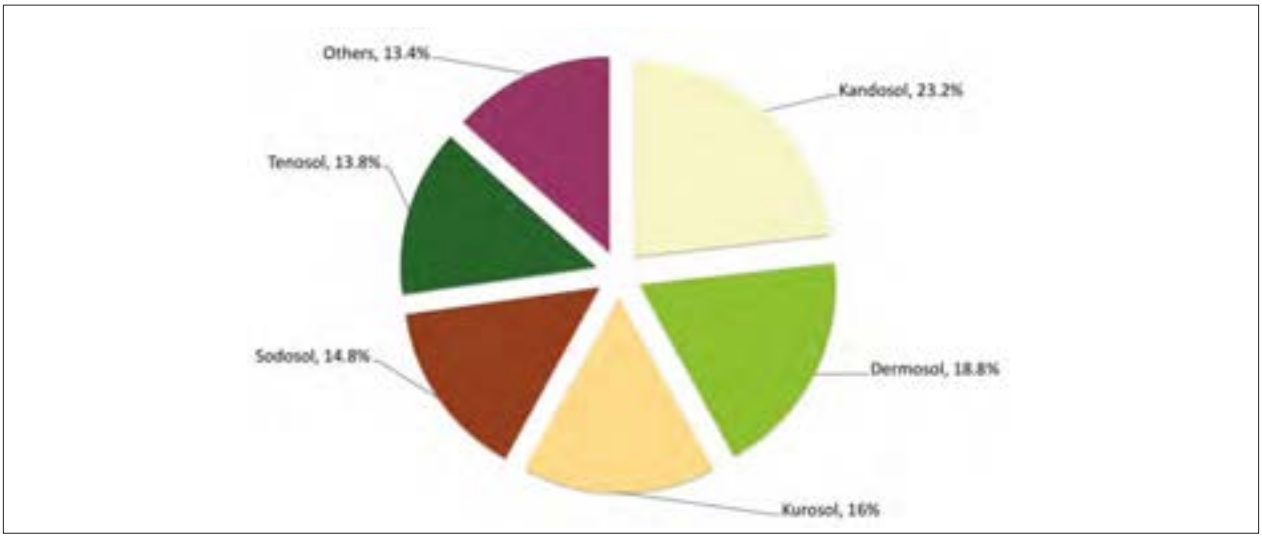


Figure 5.5 Soil types in the South East Coast (Victoria) region

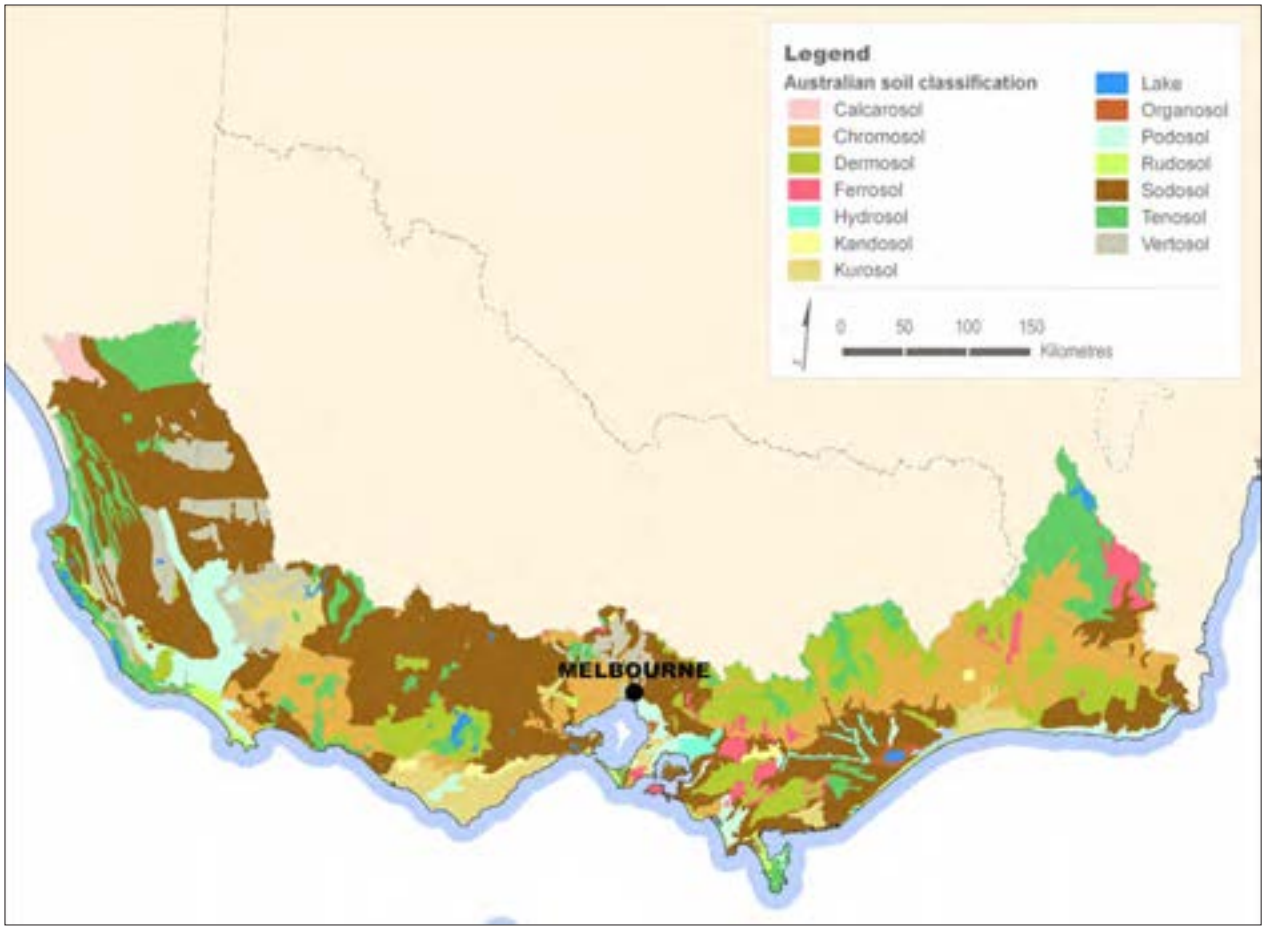


Figure 5.6 Soil type distribution in the South East Coast (Victoria) region

5.3.5 Land use

National parks and State forests occupy large portions of the region, although the majority of the region is cleared for grazing sheep and cattle. Figure 5.7 presents land use in the regions (information from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Hardwood timber production is a major industry in some river basins such as the Snowy, East Gippsland and Barwon river basins (Figure 5.8).

Dryland cropping such as cereals is scattered across the South East Coast (Victoria) region, mostly in the western part of the region.

Irrigation districts at Lake Glenmaggie, Bacchus Marsh and Werribee are the largest irrigated areas in the region. Viticulture and market gardening can be found in the Yarra district.

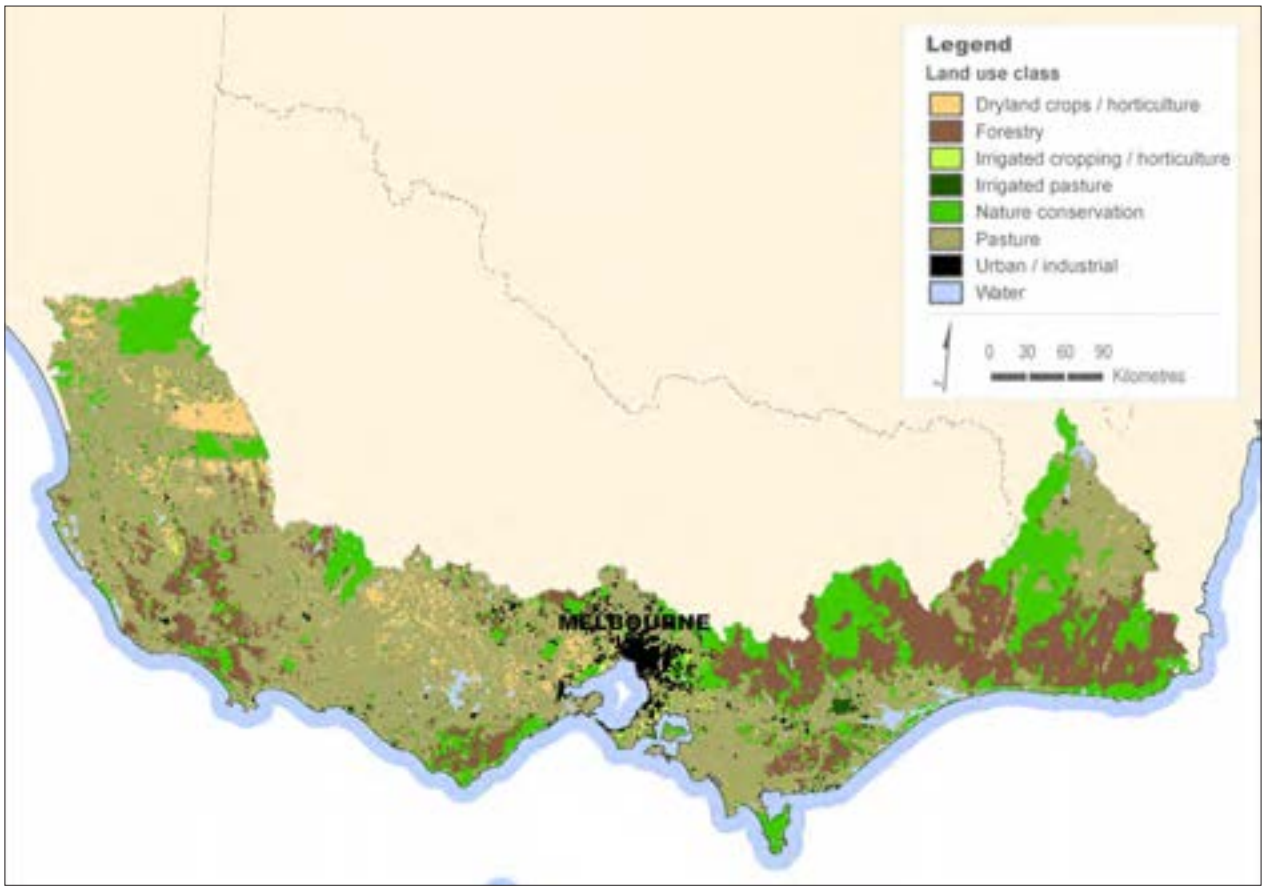


Figure 5.7 Land use distribution in the South East Coast (Victoria) region

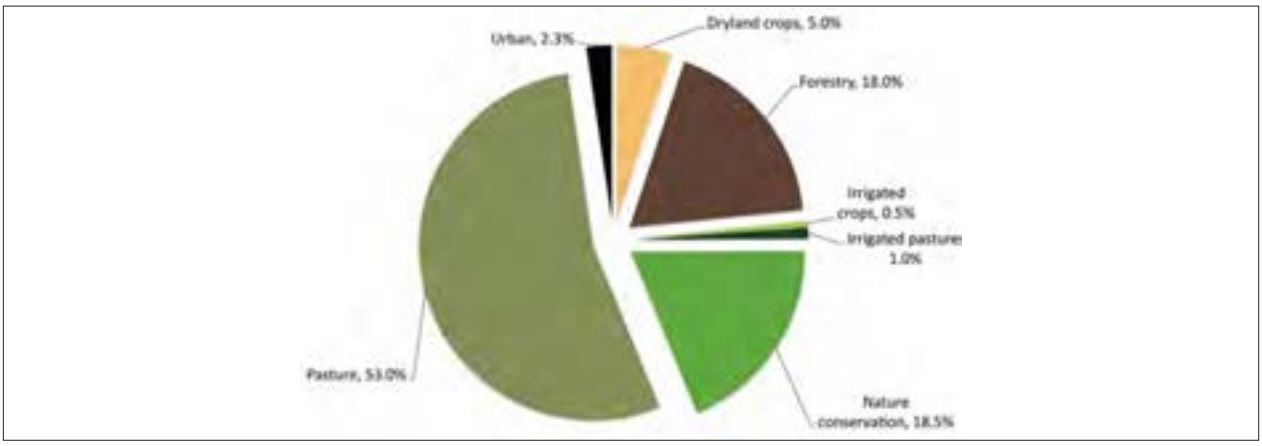


Figure 5.8 Land use in the South East Coast (Victoria) region

5.3.6 Population distribution

The South East Coast (Victoria) region has a population of just over 4.8 million people, with the largest concentrations located through its central corridor, and southern coastal areas. In particular the areas adjacent to Port Phillip and Westernport bays, which include the cities of Geelong, Melbourne and Frankston, are the most densely populated areas in the region. Figure 5.9 shows the spatial distribution of population density based on data from the Australian Bureau of Statistics [ABS 2011b].

Beyond the many towns dotted along the coastal fringe, the populations of the western and eastern extents of the region are clustered around centres supporting the major agriculture districts as well as mining and forestry. Ballarat, in the central north and Warrnambool in the coastal west are two major non-metropolitan cities in the region.

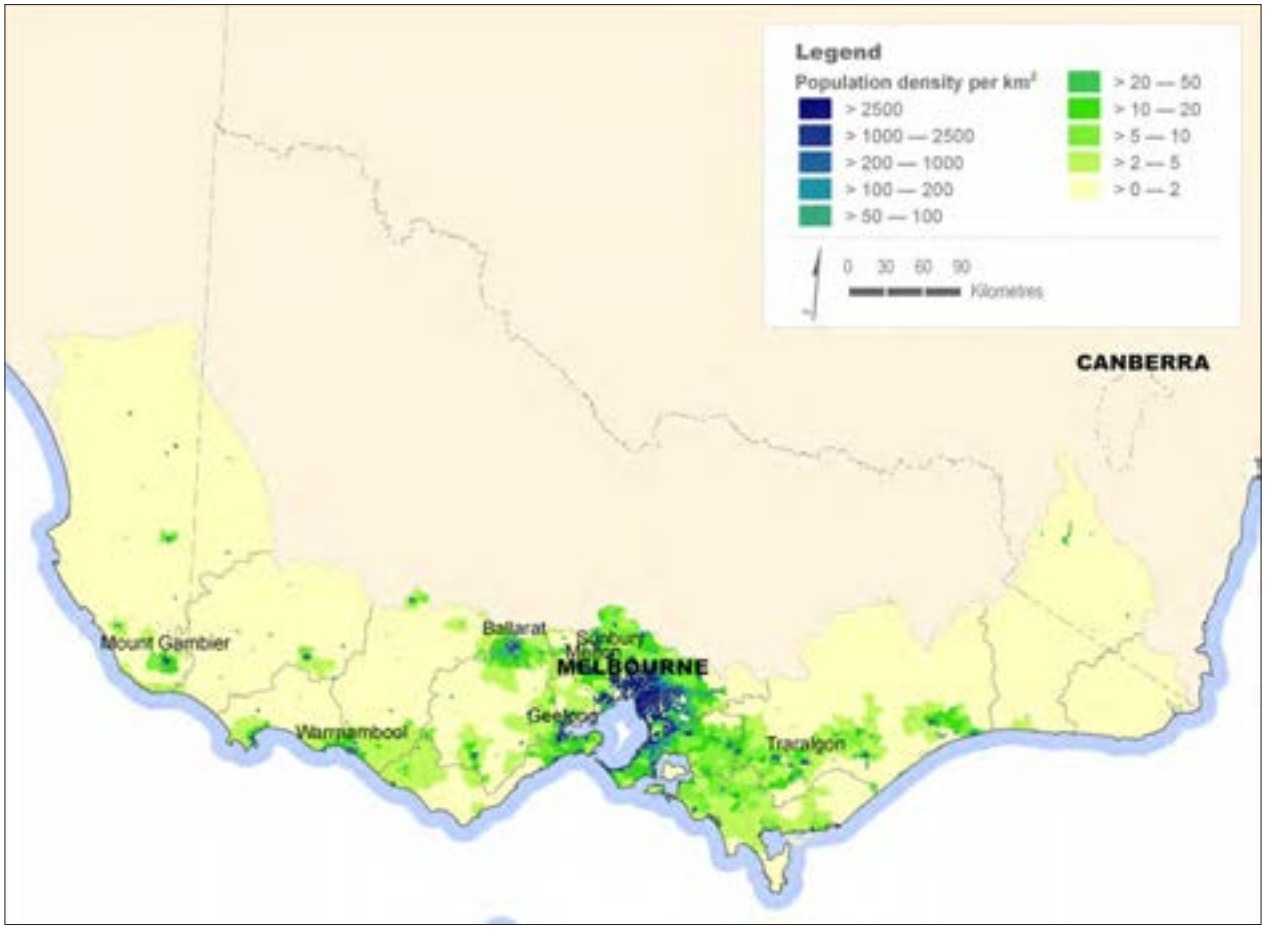


Figure 5.9 Population density and distribution in the South East Coast (Victoria) region

5.3.7 Rainfall zones

The climate of the region is affected by a seasonal movement of the major atmospheric systems in Australia that brings warm temperate conditions. This merges with a moderate Mediterranean climate in the south.

This region receives most of its rainfall in winter. Median rainfall exceeds 250 mm throughout (Figure 5.10).

In the centre of the region, median annual rainfall is reasonably high (>800 mm) and is generally uniform throughout the year. The western half of the region receives winter dominant rainfall, ranging from 250 mm in the northwest to over 800 mm in the east. The mountainous eastern part of the region receives a more uniform rainfall pattern over the year. Median rainfall amounts are moderate (500–800 mm) to high (>800 mm).

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

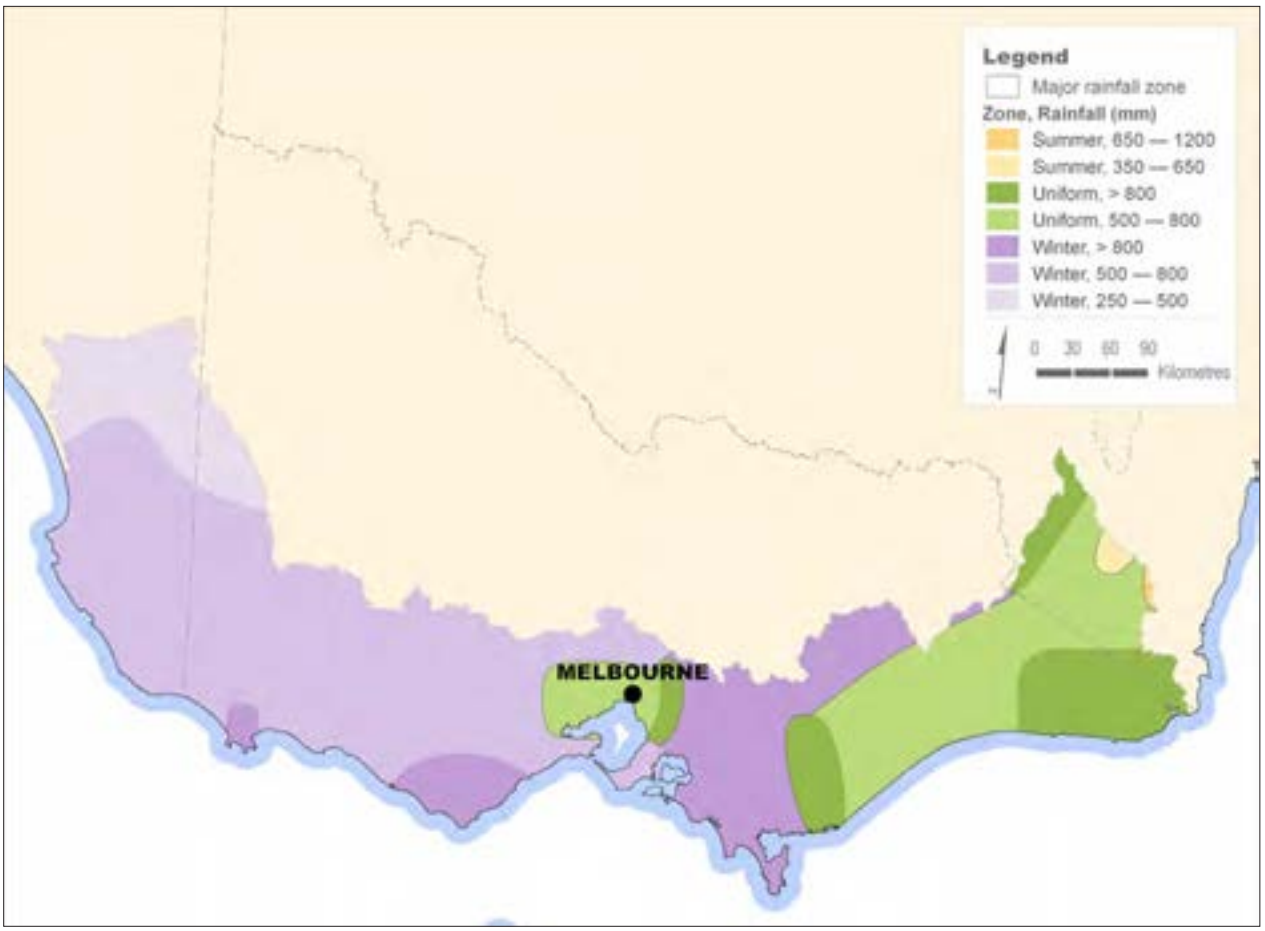


Figure 5.10 Rainfall zones in the South East Coast (Victoria) region

5.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The South East Coast (Victoria) region has a distinct rainfall deficit pattern.

Serious deficits can be expected in areas in the northwest. This area is mainly in use for dryland crop growing and pasture. Dryland crop growers in this area often face serious risks of water shortage. More centrally, rainfall deficits are less substantial.

Along the northeast border, most areas receive an abundance of water over the year (Figure 5.11). Rivers carry this water to the major storages in the region, which form a reliable source of water for the irrigation areas along the coast where slight deficits normally occur. They also form the major source of water for the city of Melbourne.

For more information on rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

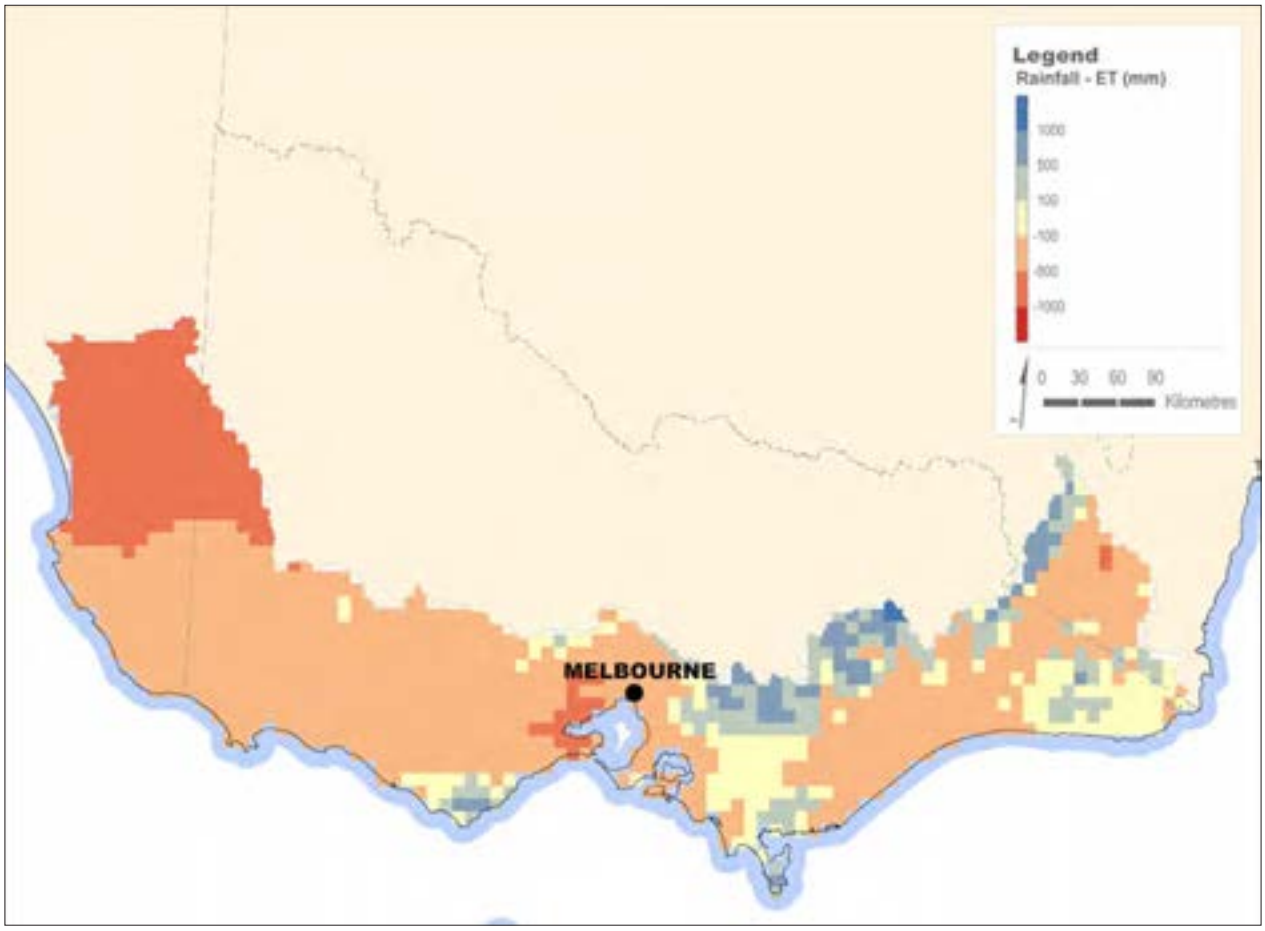


Figure 5.11 Rainfall deficit distribution in the South East Coast (Victoria) region

5.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the South East Coast (Victoria) region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 5.12 shows that the region has a seasonal rainfall pattern with a wetter winter and a drier summer period. Average monthly evapotranspiration totals show a different pattern from those of rainfall, particularly in the period between April and August. In this colder and wetter part of the year the energy availability for generating evapotranspiration is low. In spring, the energy levels increase and evapotranspiration normally exceeds rainfall. In summer, water availability becomes the limiting factor in large parts of the region. From March onwards, the evapotranspiration is limited by energy availability again. The monthly landscape water yield history for the region shows a pattern similar to rainfall.

The 2011–12 year was a year with high variability in all of the landscape water flows. Rainfall exceeded the 90th percentile in March and June 2012, but also had six months recording below median rainfall.

Evapotranspiration in 2011–12 also shows some variability compared with the historic pattern. The majority of the variability is related to rainfall, especially for the months in which water availability is typically limiting evapotranspiration.

The monthly landscape water yield for 2011–12 exceeded the 75th percentile in seven months of the year. Two distinct periods stand out in March and June 2012, which are the highest and third highest totals for these months in the 101-year period. Many floods occurred in June, particularly in the eastern rivers.

Figure 5.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the South East Coast (Victoria) region

5.4.1 Rainfall

Rainfall for the South East Coast (Victoria) region for 2011–12 is estimated to be 842 mm. This is 14% above the region's long-term average (July 1911–June 2012) of 737 mm. Figure 5.13a shows that the highest rainfall occurred in the mountainous east of the region with annual totals exceeding 1,800 mm in some areas. The majority of the western areas had rainfall not exceeding 900 mm for 2011–12.

Rainfall deciles for 2011–12 indicate very much above average rainfall for the majority of the east of the region over the course of the year (Figure 5.13b). In contrast, the west of the region had a distinctly dry year with large areas of below average rainfall and very much below average rainfall for the Hopkins River basin and the Victorian Volcanic Plains in the western part of the Barwon River–Lake Corangamite basin.

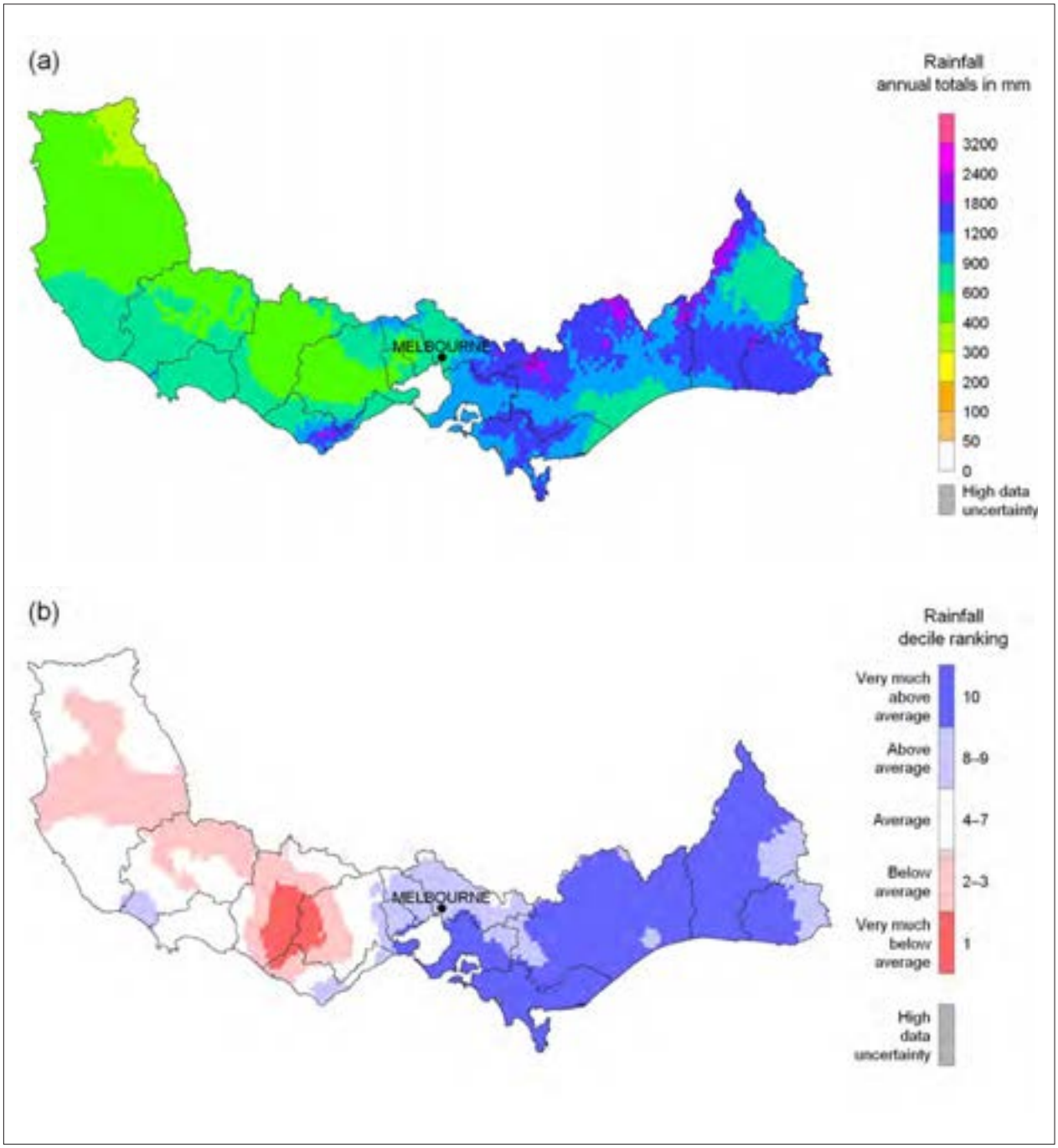
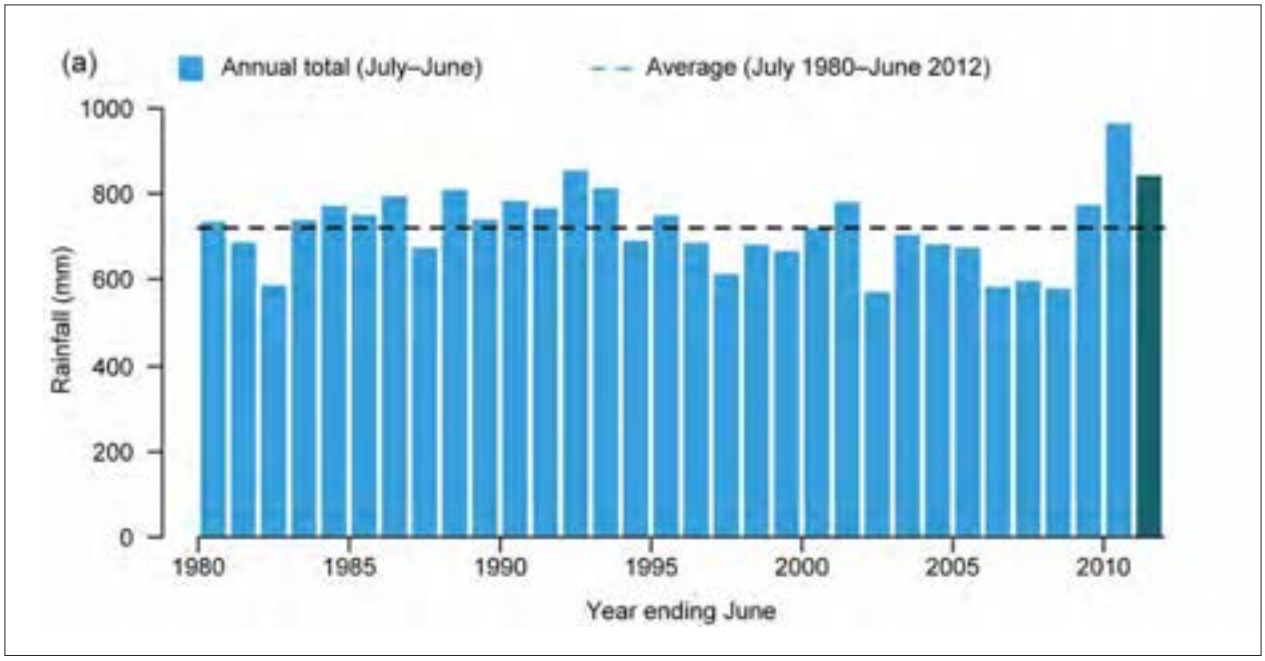


Figure 5.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South East Coast (Victoria) region

Rainfall variability in the recent past

Figure 5.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 720 mm, varying from 570 mm (2002–03) to 964 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 5.14b.

Figure 5.14a indicates that 2010–11 produced the highest and 2011–12 the third highest rainfall totals over the past 32 years. Figure 5.14b shows that the increase in rainfall over these years mainly happened in the summer period. The five-year moving average for the winter period shows a distinctly lower average for the years between 1997 and 2012 in relation to the first part of the 32-year reference period.



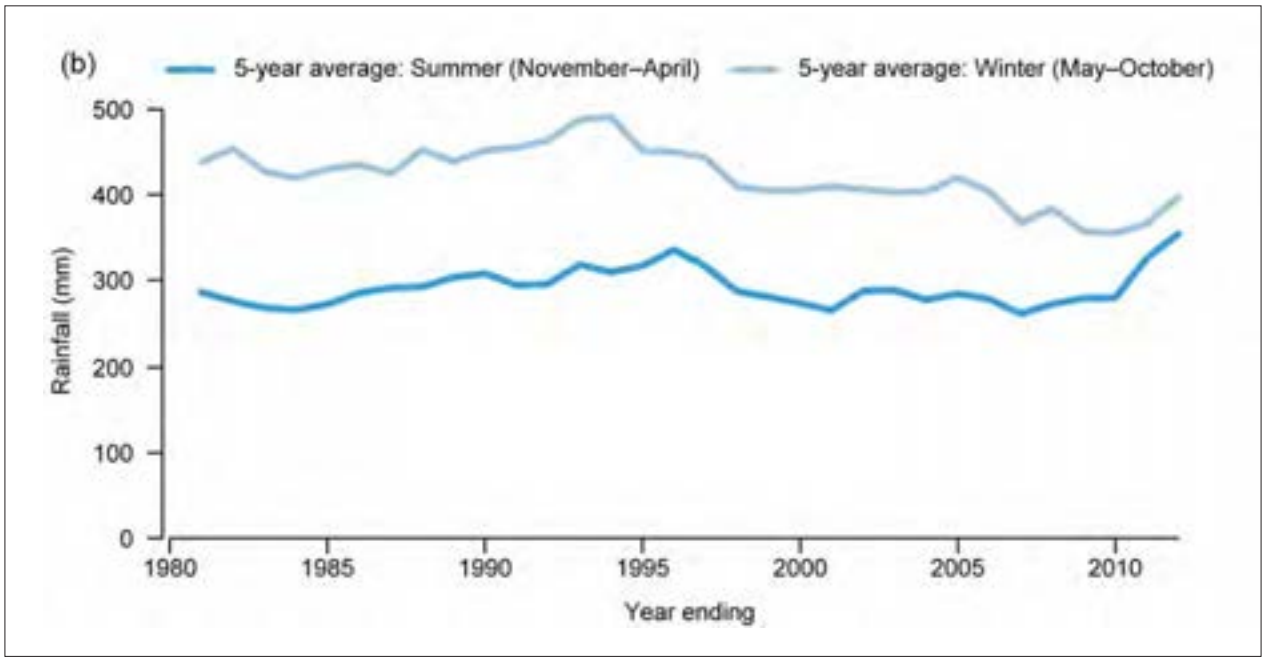


Figure 5.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (Victoria) region

Recent trends in rainfall

Figure 5.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 5.15b.

Figure 5.15a shows that trends in rainfall are only moderately decreasing in some areas in the centre of the region with a general pattern of marginal change in most parts of the region.

Figure 5.15b indicates that the trends are not statistically significant with the exception of a small area in the south of the Barwon River basin, where a strongly significant falling trend is identified.

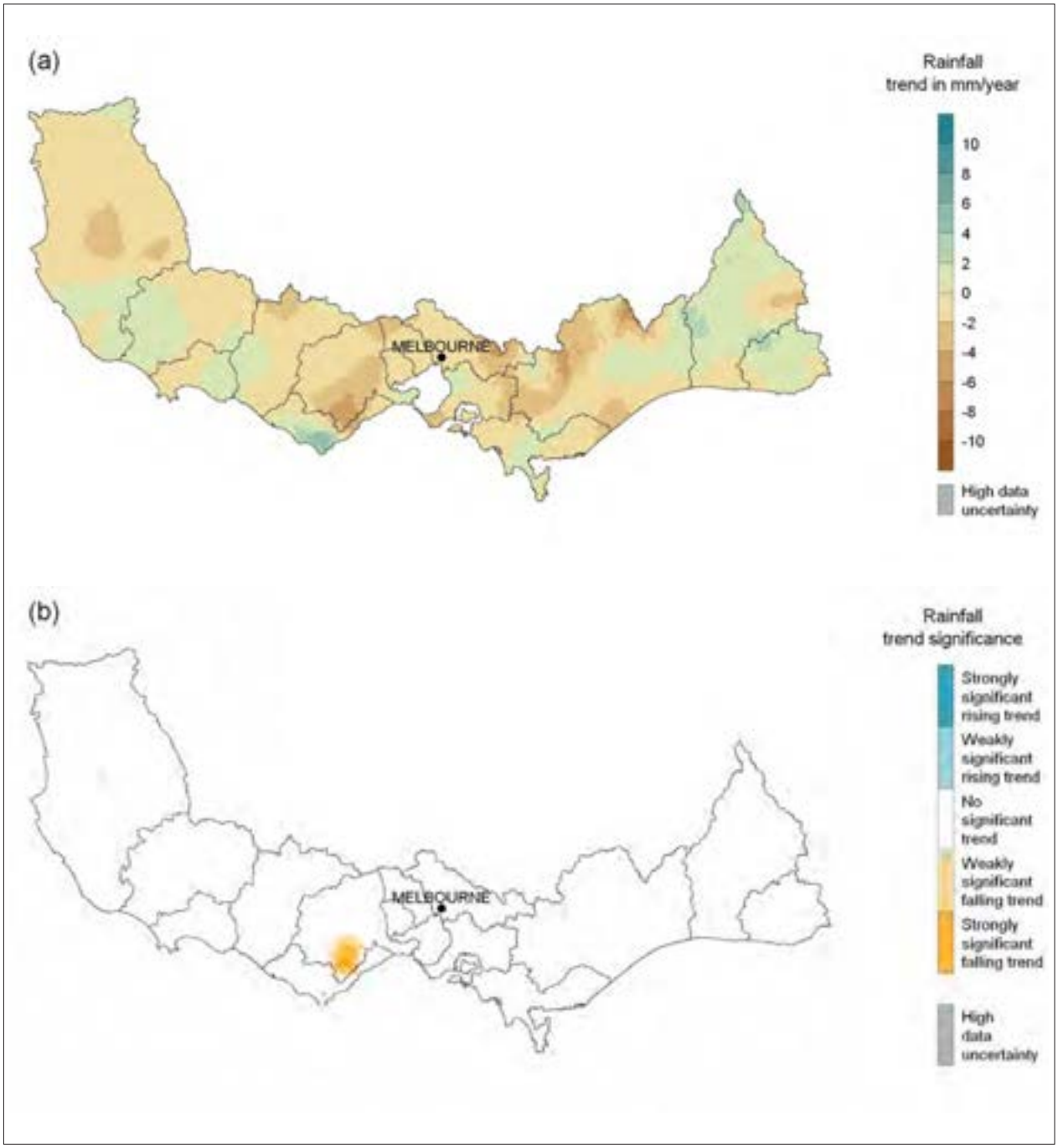


Figure 5.15 Spatial distribution of (a) trends in annual rainfall from 1980– 2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (Victoria) region

5.4.2 Evapotranspiration

Modelled annual evapotranspiration for the South East Coast (Victoria) region for 2011–12 is estimated to be 648 mm. This is 3% above the region's long-term (July 1911–June 2012) average of 629 mm. Similar to the spatial patterns in rainfall (Figure 5.13a), evapotranspiration was higher in the east than in the west (Figure 5.16a).

Evapotranspiration deciles for 2011–12 indicate large areas of very much above average totals to the east of the region (Figure 5.16b). Large areas in the west experienced average evapotranspiration, with some distinct areas of below average evapotranspiration present.

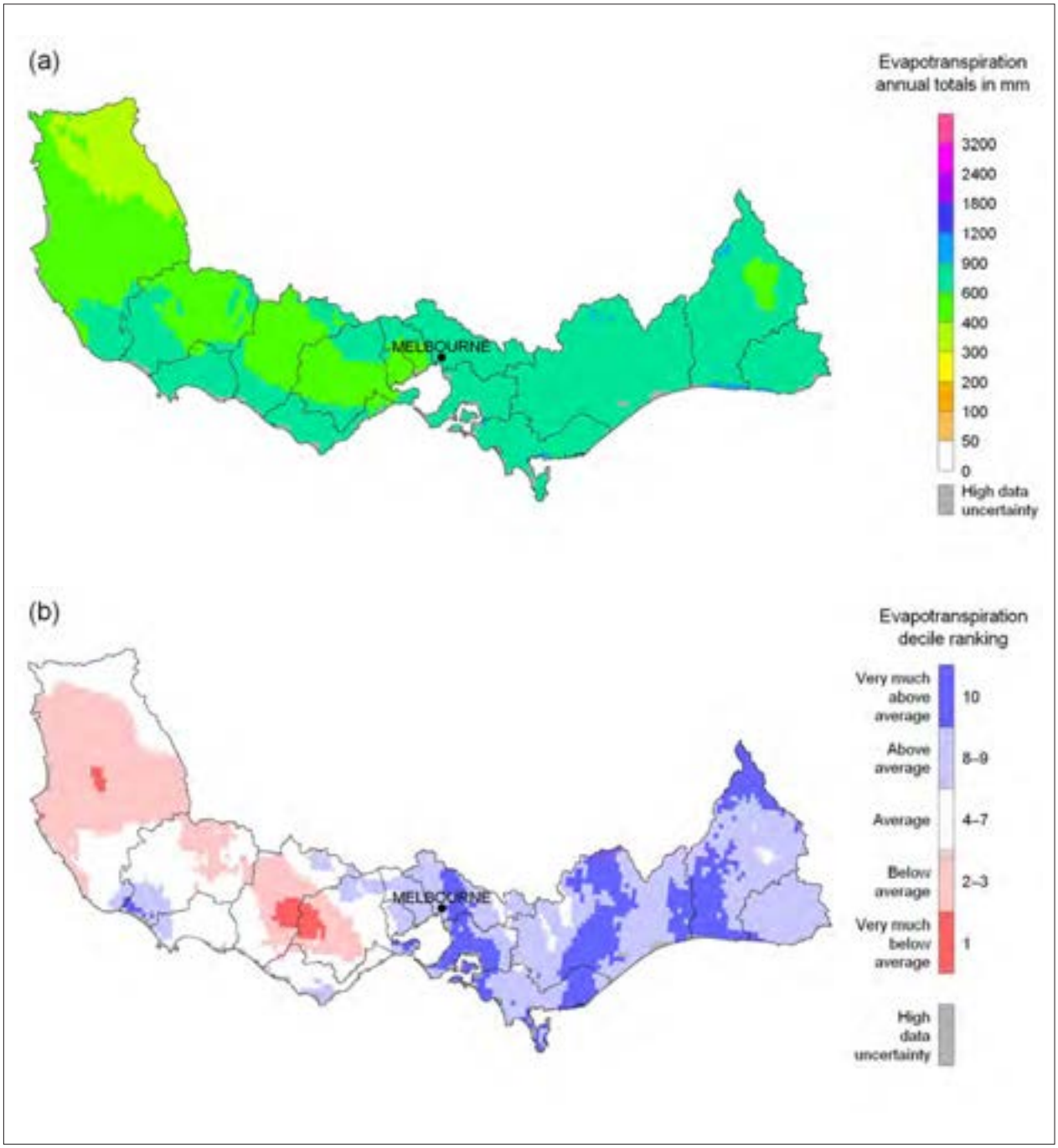
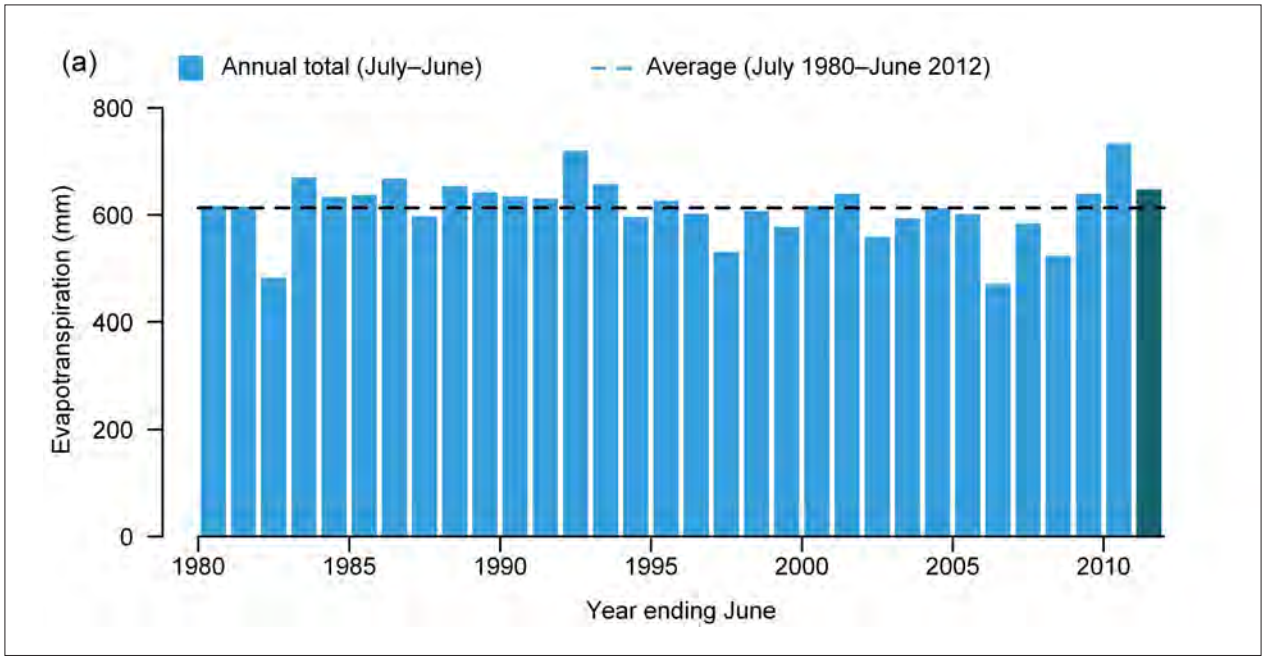


Figure 5.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South East Coast (Victoria) region

Evapotranspiration variability in the recent past

Figure 5.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 613 mm, varying from 470 mm (2006–07) to 733 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 5.17b.

Annual evapotranspiration totals reflect those of rainfall, although with less variability. Summer periods only have marginally higher evapotranspiration than winter periods with no cyclic pattern identifiable. In contrast to rainfall, evapotranspiration is higher in the summer period, meaning that in the winter period, the lack of energy substantially limits evapotranspiration.



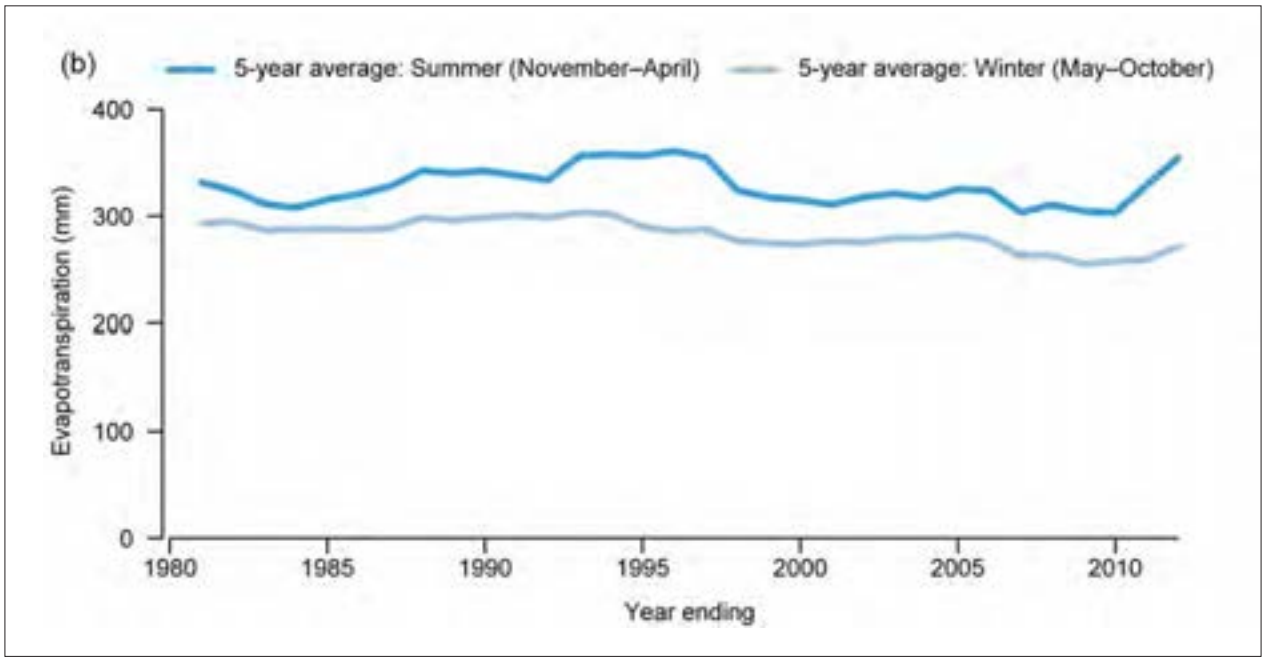


Figure 5.17 Time-series of (a) annual evapotranspiration and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (Victoria) region

Recent trends in evapotranspiration

Figure 5.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 5.18b.

Figure 5.18a shows that since 1980, trends are weakly negative in the central part of the region and variable, but mainly neutral elsewhere.

As shown in Figure 5.18b, the trends are generally only statistically significant in small parts of the region, where trends are generally showing decreasing evapotranspiration. A particular case is Phillip Island, where Figure 5.18a indicates a weakly significant positive trend. In most of the area though, the trends have no statistical significance.

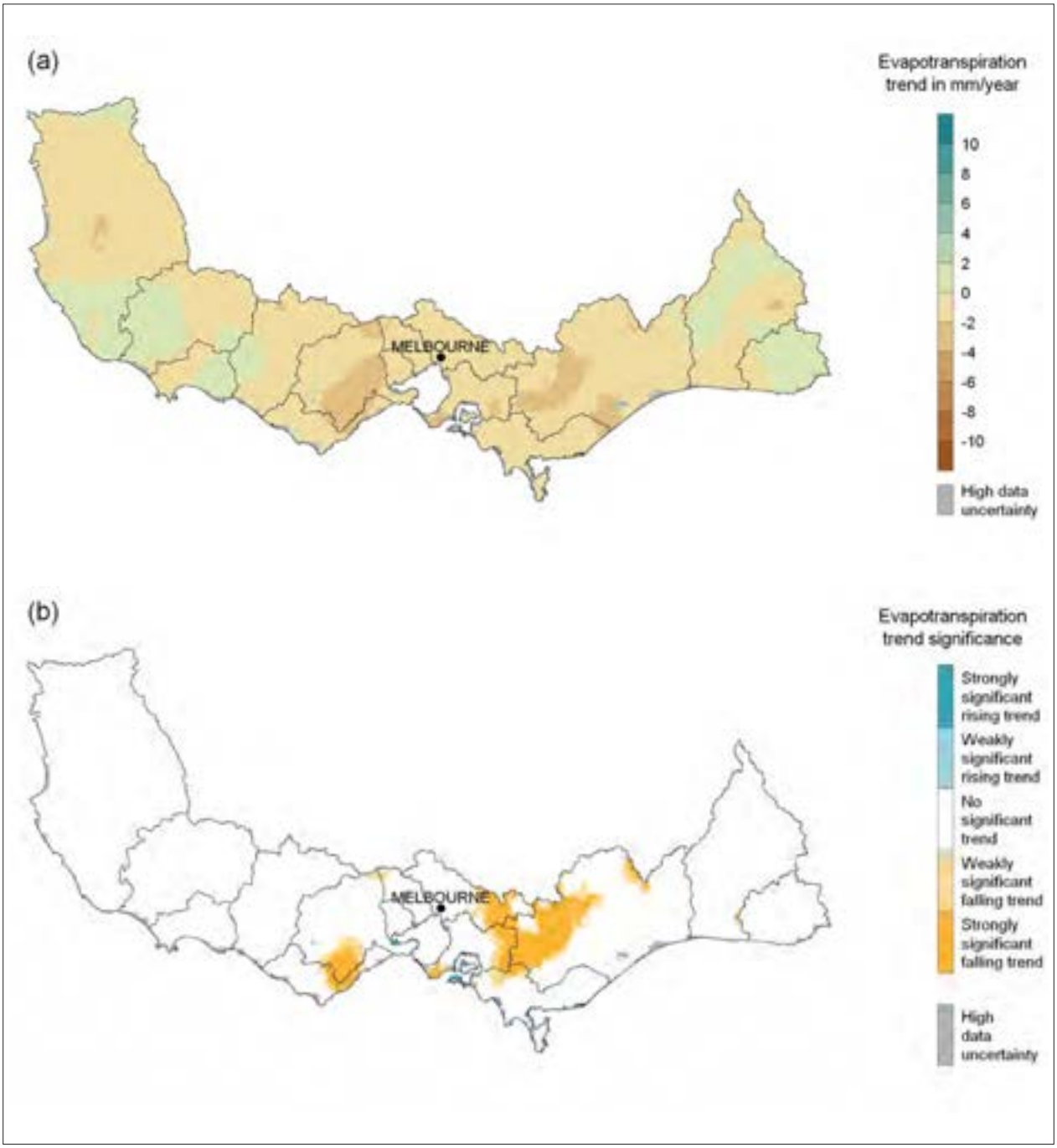


Figure 5.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (Victoria) region

5.4.3 Landscape water yield

Modelled landscape water yield for the South East Coast (Victoria) region for 2011–12 is estimated to be 180 mm. This is 68% above the region's long-term (July 1911–June 2012) average of 107 mm.

Figure 5.19a shows the spatial distribution of landscape water yield for 2011–12.

In the mountainous east of the region, the landscape water yield relates directly to rainfall, which in turn relates closely to elevation (Figure 5.4).

The decile-ranking map for 2011–12 (Figure 5.19b) shows very much above average landscape water yields in the east. To the west, a more variable pattern is observed, with relatively higher decile rankings throughout, in comparison to the rainfall deciles in this part of the region.

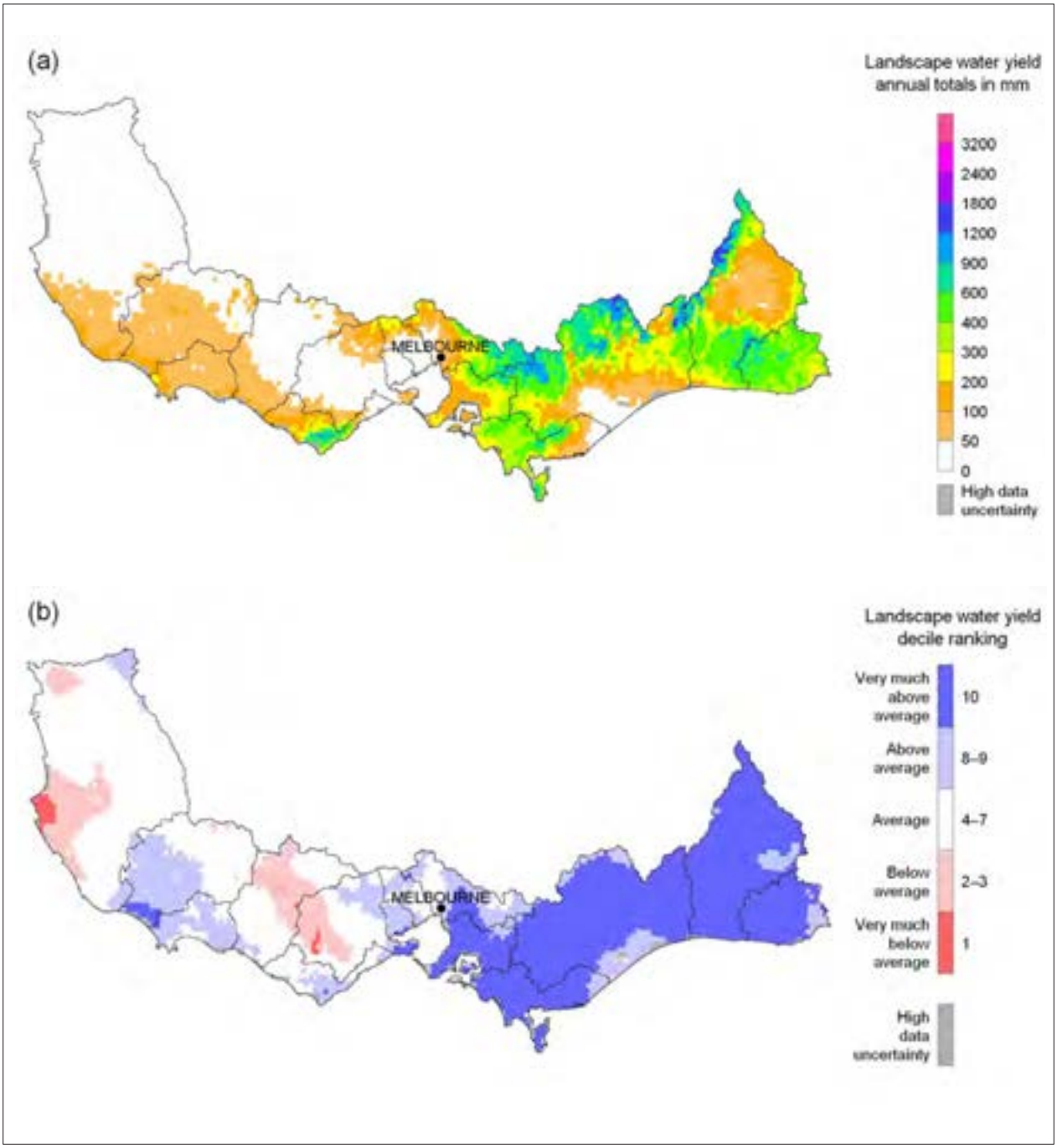
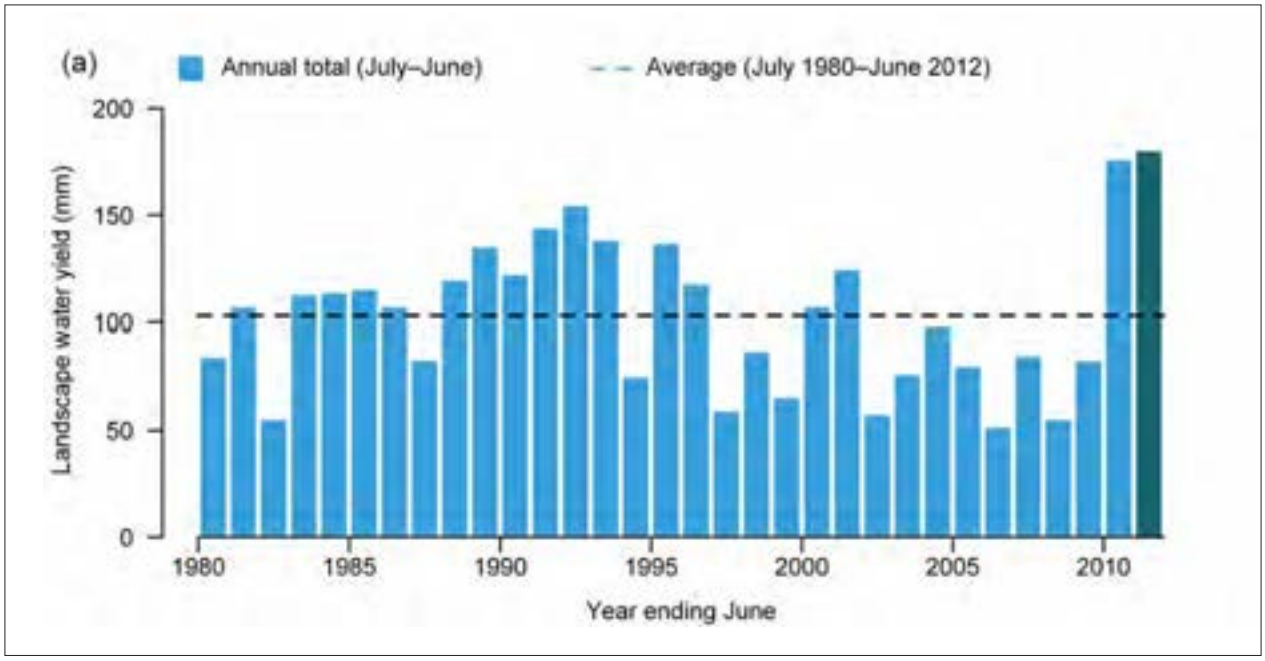


Figure 5.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South East Coast (Victoria) region

Landscape water yield variability in the recent past

Figure 5.20a shows annual landscape water yield for the South East Coast (Victoria) region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 103 mm, varying from 51 mm (2006–07) to 180 mm (2011–12). Temporal variability and seasonal patterns since 1980 are presented in Figure 5.20b.

As most landscape water yield is generated in the east of the region, both graphs generally refer to this area only. Many of the last 15 years have seen lower than average landscape water yields, which are mainly reflected in the substantially lower landscape water yields in the winter period, shown in Figure 5.20b.



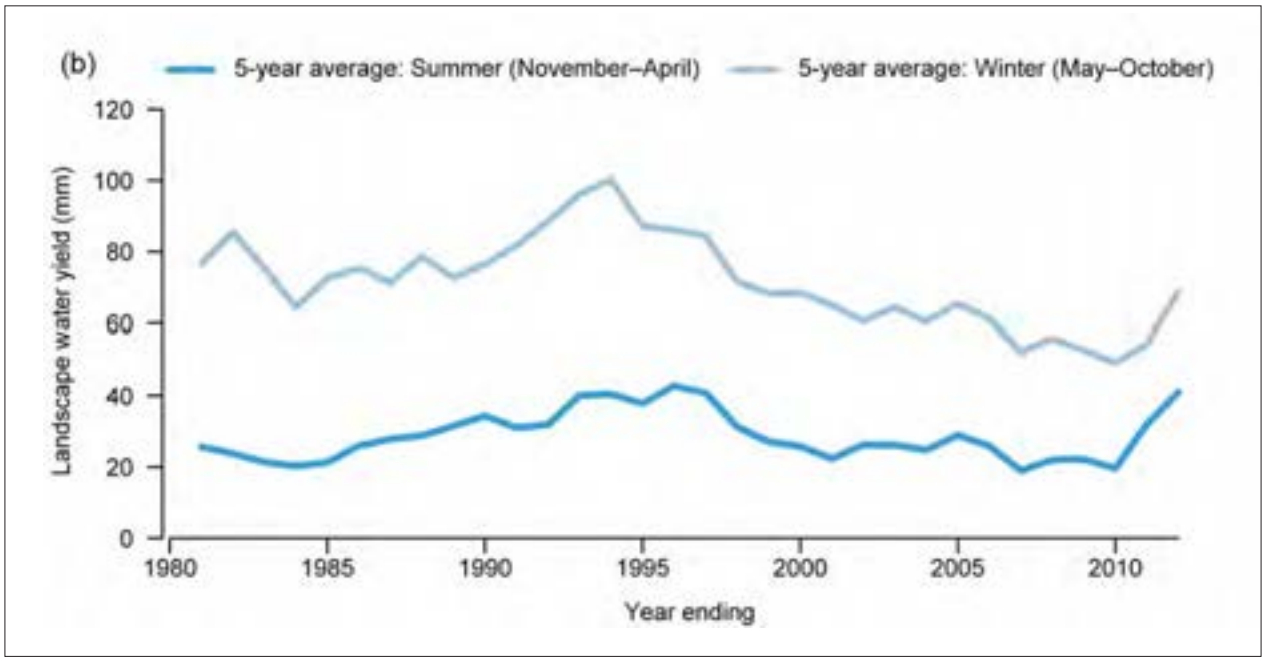


Figure 5.20 Time-series of (a) annual landscape water yield and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South East Coast (Victoria) region

Recent trends in landscape water yield

Figure 5.21a shows the spatial distribution of the trends in modelled annual landscape water yield for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 5.21b.

Figure 5.21a shows that since 1980, trends are mostly in the neutral range between –2 and 2 mm/year.

As shown in Figure 5.21b, the trends are generally only statistically significant in some small parts scattered throughout the region. In these areas trends are mostly falling, but considering their extent, they can be local artefacts in the input data of the model, such as rainfall, temperature or solar radiation.

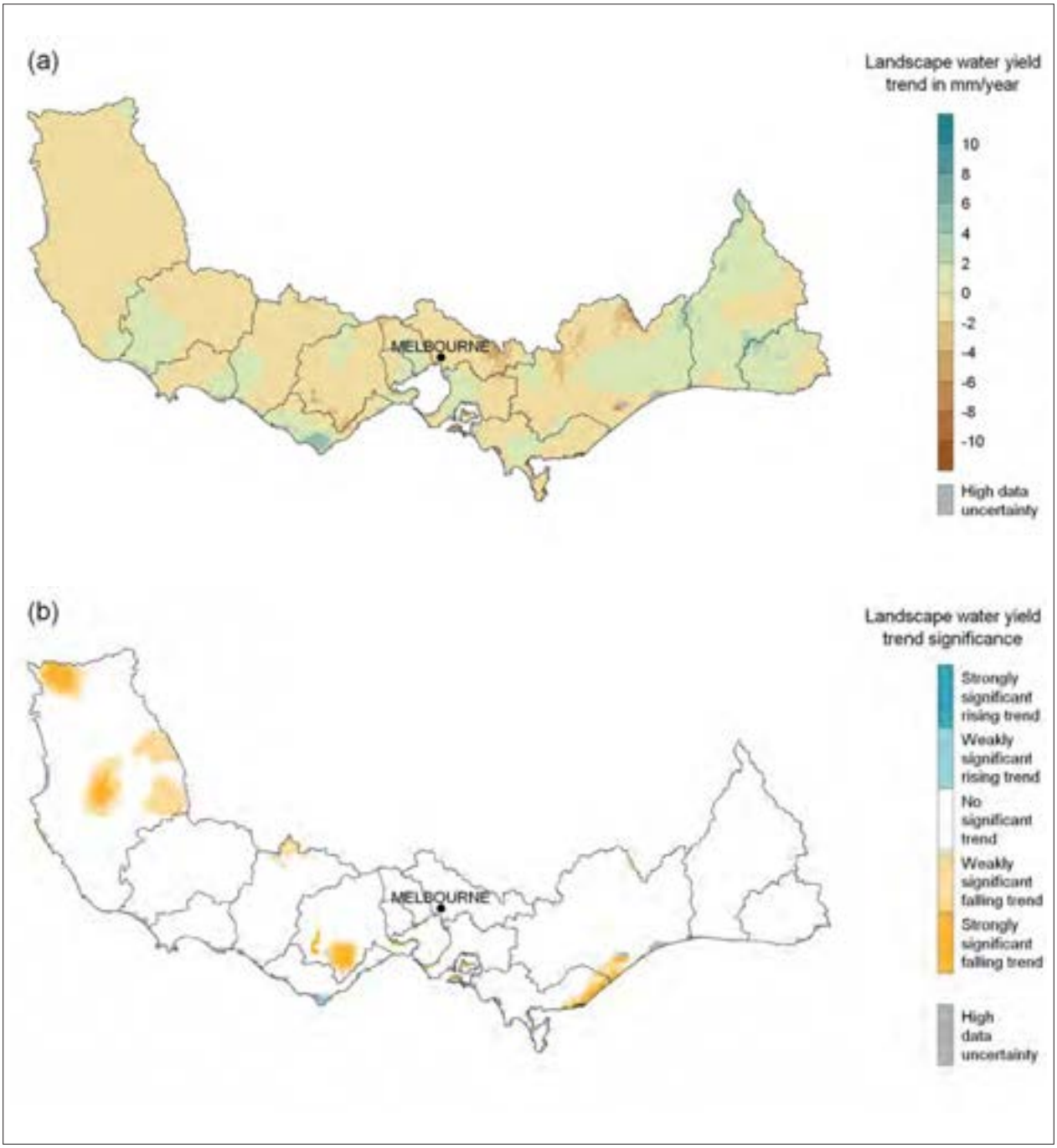


Figure 5.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South East Coast (Victoria) region

5.5 Surface water and groundwater

This section examines surface water and groundwater resources in the South East Coast (Victoria) region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described and the groundwater status is illustrated by showing changes in groundwater levels at selected sites.

5.5.1 Rivers

There are 14 river basins in the South East Coast (Victoria) region, varying in size from 1,000 to 33,000 km^2 (Figure 5.22).

The Thomson, Macalister and Snowy constitute the major rivers. Others include the Glenelg, Bunyip, Latrobe, Hopkins, Mitchell, Yarra and Maribyrnong rivers.

River flows in the region generally show distinct variations in time, with streamflows showing both a seasonal pattern and substantial year-on-year variability in discharge. In all areas of the region, river flows decrease during the summer and autumn months. Rivers originating from the higher mountain ranges in the Great Dividing Range generally are perennial (that is, flow for most of the year) and are fed largely by interflow or groundwater flow. Ephemeral streams in the northwest of the region usually flow only from surface run-off after heavy rain.

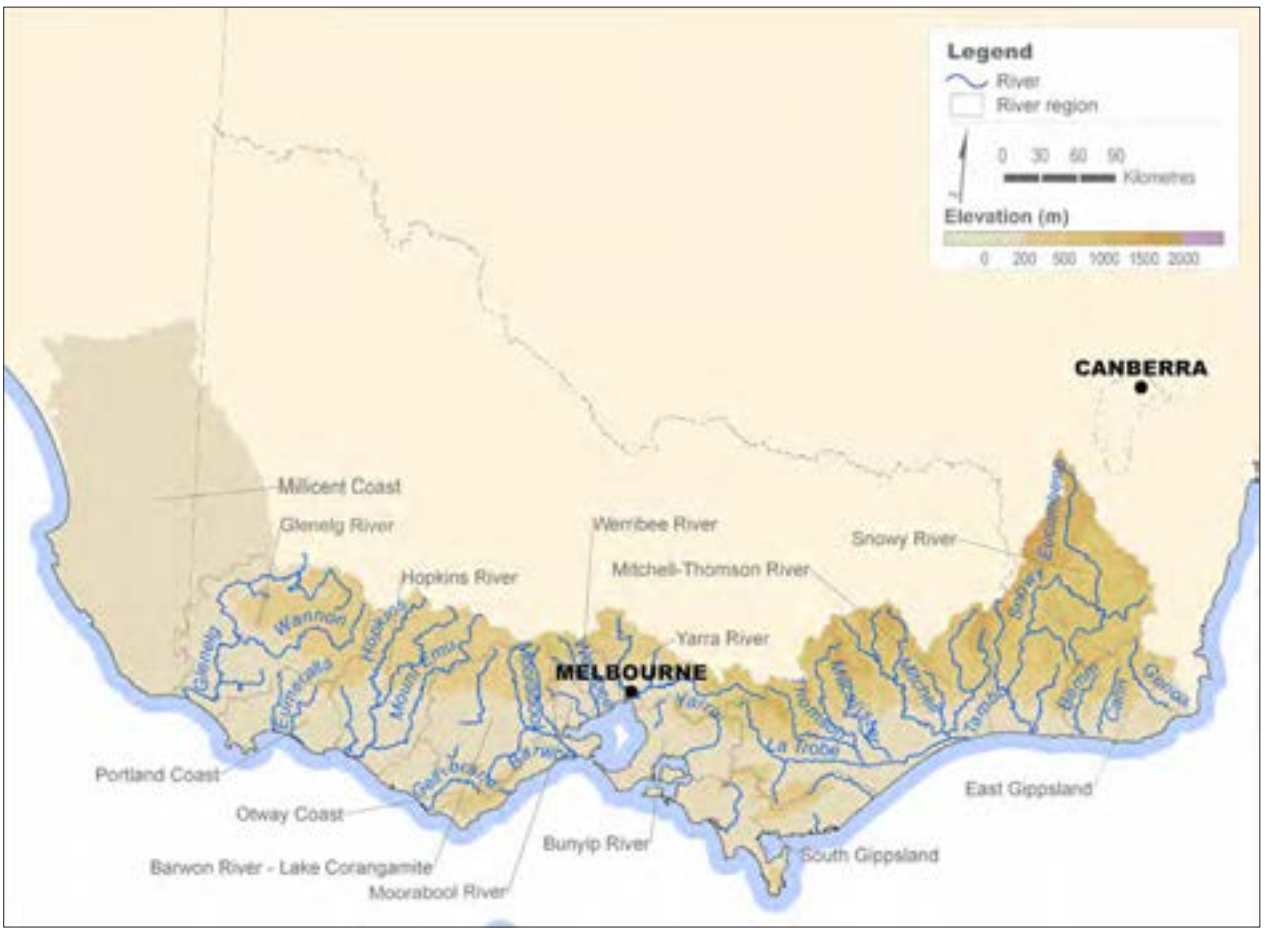


Figure 5.22 Rivers and catchments in the South East Coast (Victoria) region

5.5.2 Streamflow volumes

Figure 5.23 presents an analysis of flows at 38 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across 16 geographically representative rivers were selected (see Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows are mostly above average in the east and mostly average in the west and are commensurate with the modelled landscape water yield results shown in Figure 5.19b.

The flows recorded in the Glenelg River are not reflected in the modelled landscape water yield results.

High run-off, generated in the upstream reaches of the rivers, caused above average to very much above average flows in many rivers in the east and southeast of the South East Coast (Victoria) region. Very much above average flows were observed at 17 monitoring site located on rivers in the eastern half of the region, which are fully reflected by the modelled landscape water yields. Above average total flows were recorded at five monitoring sites. These were mainly located on the rivers east and north of Melbourne as well as two sites in the west of the region.

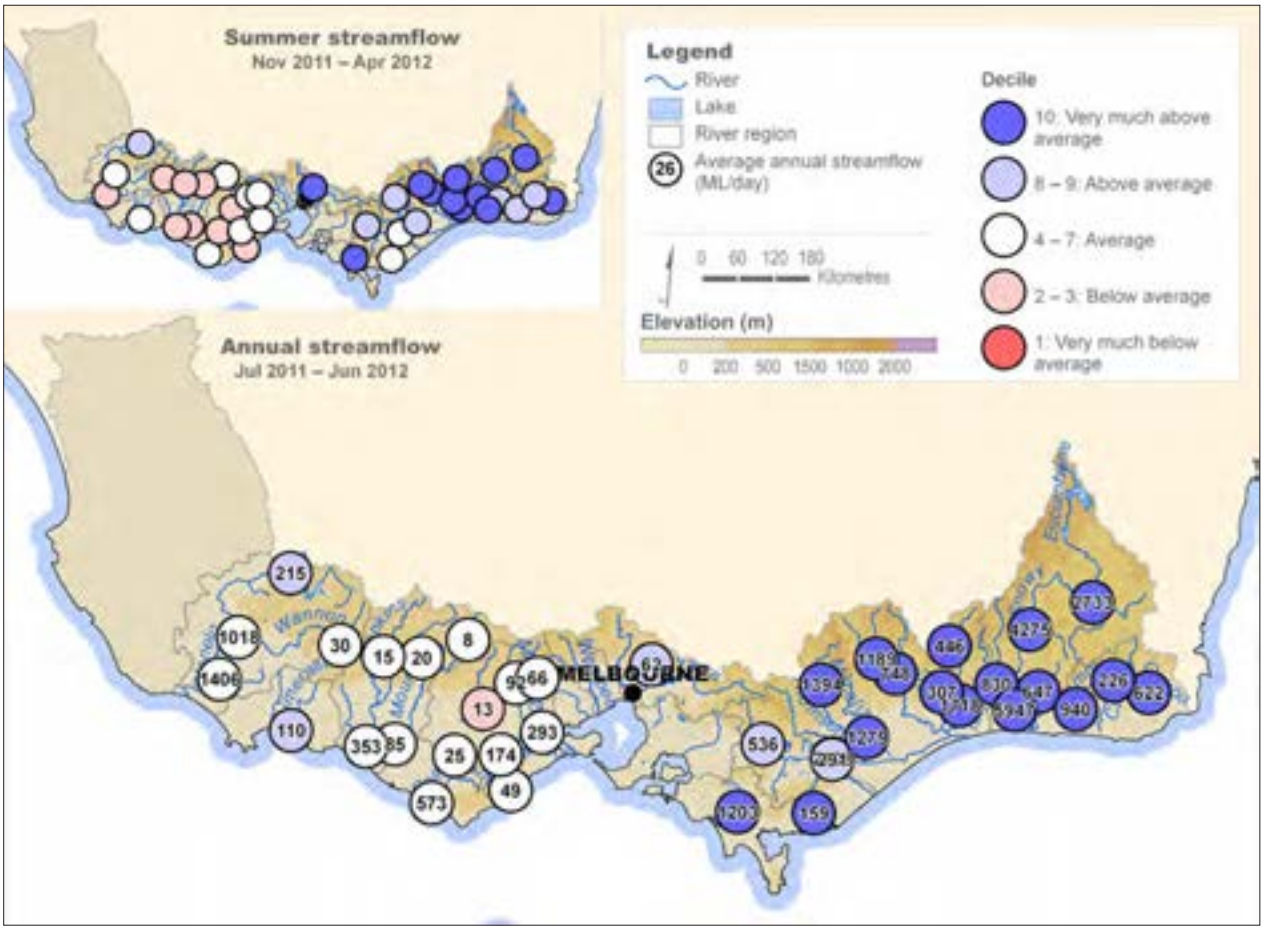


Figure 5.23 Average annual and summer period flow volumes of selected sites for 2011–12 and their decile rankings over the 1980– 2012 period in the South East Coast (Victoria) region

Average flows occurred at 15 sites in the western half of the region. This is consistent with the average landscape water yields shown in Figure 5.19b. Of the 38 monitoring sites, there was only one where below average flows were recorded in 2011–12. This one site was located on the Woady Yalock River in the central headlands west of Melbourne.

The pattern of flow deciles for the summer period (November 2011–April 2012) is similar to that for the total annual flows for 2011–12 as shown in Figure 5.23. Though the pattern is similar, the decile values are lower in many instances, such as slightly lower flows observed in the summer period of 2011–12 in the western half of the region and some rivers to the east of Melbourne.

5.5.3 Streamflow salinity

Figure 5.24 presents an analysis of streamflow salinity for 2011–12 at 25 monitoring sites throughout the South East Coast (Victoria) region. The monitoring sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC, µS/cm at 25°C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

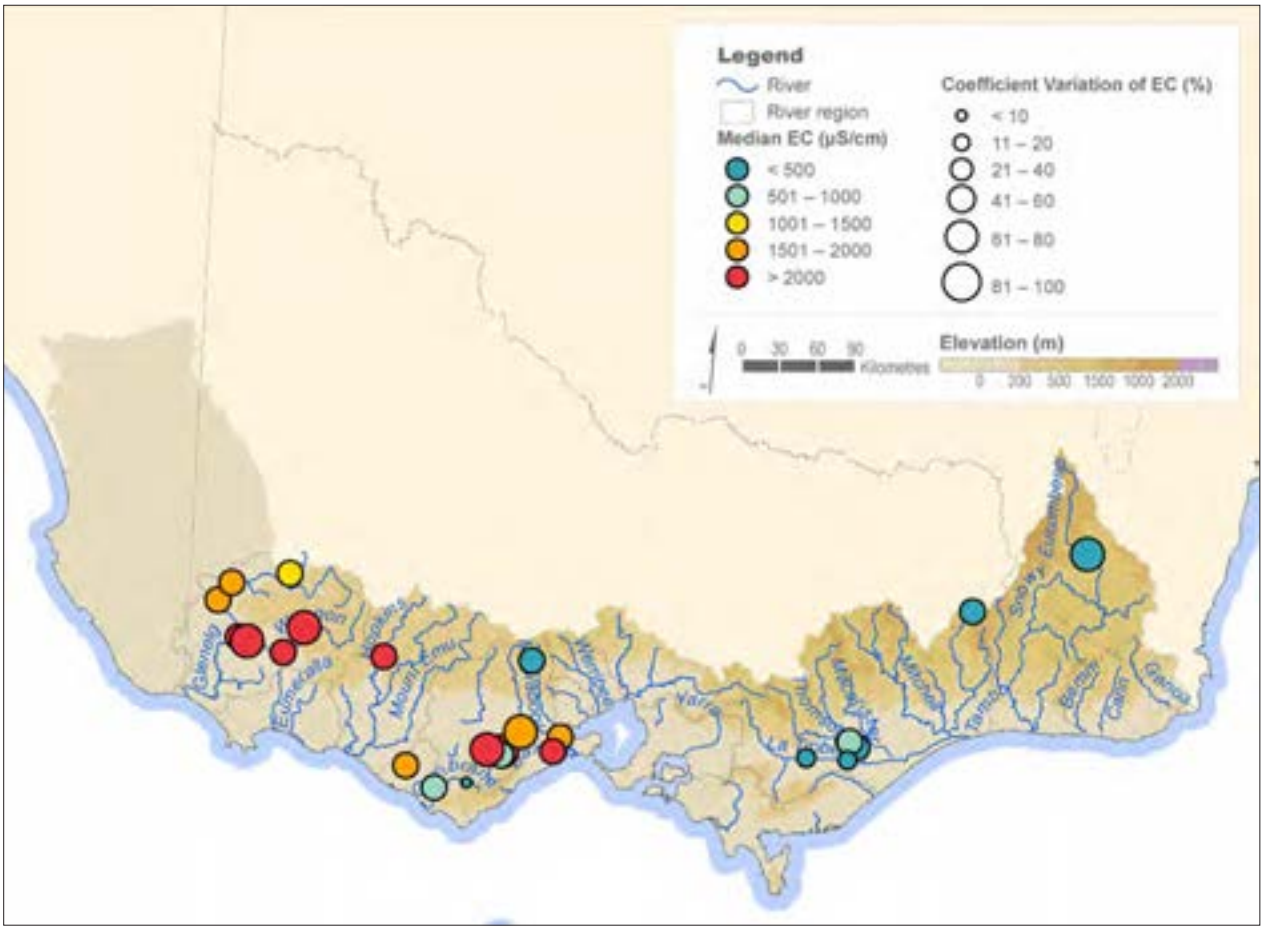


Figure 5.24 Salinity as electrical conductivity and its associated coefficient of variation for 2011–12 in the South East Coast (Victoria) region

The median EC values for 44% of the monitoring sites in the main rivers fall in the range 0–1,000 µS/cm (suitable for most irrigation uses). More than half of the rivers and creeks shown for the region fall outside of this range (Figure 5.24) and the flows are less suitable for irrigation and many aquatic ecosystems.

Of the 25 monitoring sites included in the analysis, 32% had median EC values below 500 µS/cm and 12% between 500–1,000 µS/cm. The other monitoring sites had median EC values above 1,500 µS/cm. The higher median salinities occur in the western half of the region.

Stream salinity was above 2,000 µS/cm at eight of the 25 monitoring sites. These eight monitoring sites were located on the rivers in central southwest and central west of the region. The high salinity in the western river sites particularly Glenelg, Wannon, Dundas, Hopkins rivers, and Thompson and Birregurra creeks is influenced by saline aquifers, draining of wetlands, low flows, evaporation and poor agricultural practices (Metzeling 2001).

The CV is the expected variability of a measurement of EC value, relative to the annual mean of EC. The CV is high at some monitoring sites in the central southwest, west and in the Snowy River in the northeast. The CV is relatively low in the rivers of the central southeast and Lander Creek in the southwest of the region. The CV in EC in is typically related to the variability in annual flow at the monitoring site. Of the 25 monitoring sites 16% had a CV below 20%. Eighty-four percent of the sites had a CV between 20% and 60%.

5.5.4 Flooding

Floods are mainly caused by either localised high intensity rainfall (for example, thunderstorms) or prolonged periods of heavy rainfall (for example, frontal rainfall). While the first rainfall type often results in localised flash flooding, the prolonged rainfall events can cause sustained floods over larger areas.

The west and central parts of the South East Coast (Victoria) region typically have a seasonal winter dominated rainfall pattern whereas the eastern part of this region has a more uniform rainfall distribution. Flooding however can occur at any time during the year from rainfall associated with fronts and cut-off low pressure systems. Both systems produce sustained rainfall and which can be often heavy at times, especially when these systems are slow moving. Thunderstorms can occur throughout the region.

Figure 5.25 shows locations where the Bureau monitors river levels as part of its flood forecasting service and the highest level reached during the year expressed in terms of flood classification level. These classification levels are established in consultation with emergency management and local agencies and are further described in the Technical Supplement.

A number of heavy rainfall events were recorded in this region over the period March–June 2012 causing several episodes of major flooding in the central and eastern part of this region.

Major flooding was observed for the Snowy River in March 2012. It was caused by two consecutive rain events occurring between the first to the ninth of March 2012, with a total rainfall of approximately 260 mm.

A localised, but short-lived major flooding event occurred on the Barwon River at Ricketts Marsh in the eastern part of the region. It was caused by a strong torrential rainfall event with totals of approximately 280 mm rainfall between the 3–5 June 2012.

Major to moderate flooding also occurred during this time in the eastern part of the region. Floods were caused by an intense east coast low pressure system which formed over the Tasman Sea. Rainfall totals on the 5 June 2012 exceeded 120 mm and triggered major flooding in the Latrobe, Thomson, Macalister, Mitchell and Snowy rivers damaging infrastructure and housing. A major impact of this event occurred when the bank of the Latrobe River broke and floodwaters flowed into the Yallourn open-cut coal mine with a significant interruption to its operation.

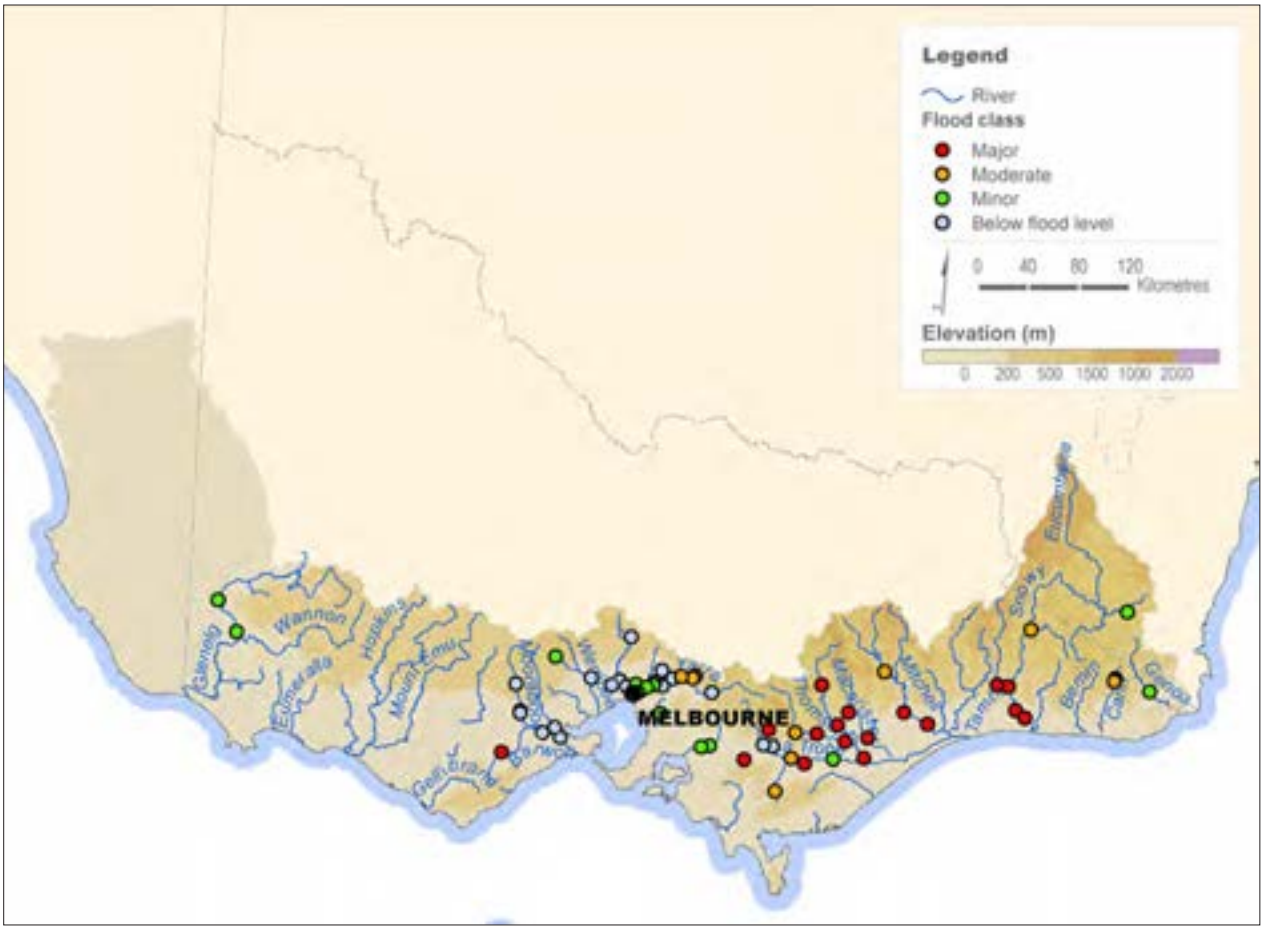


Figure 5.25 Flood occurrence in 2011–12 for the South East Coast (Victoria) region, with each dot representing a river level monitoring station and the colour of the dot representing the highest flood class measured

5.5.5 Storage systems

There are approximately 50 major, publicly owned, storages in the South East Coast (Victoria) region with a total capacity in excess of 8,400 GL. Some major storages that are part of the Snowy Hydro storage system are located in the region, but are not accounted for in the region as the majority of the water from the Snowy Hydro scheme is transferred into the River Murray and Tumut River, which is part of the Murrumbidgee River basin. A similar structure is present in the Wimmera–Mallee irrigation scheme, which is located in the Murray–Darling Basin region, but is supplied by several storages located outside the region.

Excluding the contribution of the Snowy Hydro and Wimmera–Mallee storages to the South East Coast (Vic) region results in a total capacity of about 2,600 GL. The Bureau's water storage website includes information on approximately 73% of the region's publicly owned storage capacities (as at August 2012) These storages are mostly allocated to supply the city of Melbourne. Table 5.3 gives a summary of the major storage systems in the region together with an overview of the storage levels at the end of 2010–11 and 2011–12. The location of the systems and associated storages are shown in Figure 5.26.

During 2011–12, the Melbourne supply system storage volumes increased by 14%. In particular, the Thomson, which comprises 68% of this system, has shown a persistent rise in water levels since June 2010. For the 2011–12 year, Thomson storage volumes rose from 41% to 64% of total accessible capacity.

Further information on the past and present volumes of the storage systems and the individual storage can be found on the Bureau's water storages website: water.bom.gov.au/waterstorage/

Table 5.3 Major public storage systems in the region as identified in the Bureau of Meteorology's water storage information (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Melbourne*	urban	1,812 GL	1,010 GL—56%	1,268 GL—70%
Non-allocated	—	95 GL	68 GL—72%	77 GL—81%
Total		1,907 GL	1,078 GL—57%	1,346 GL—71%

*The Melbourne system includes Thomson, which also has an important rural supply function

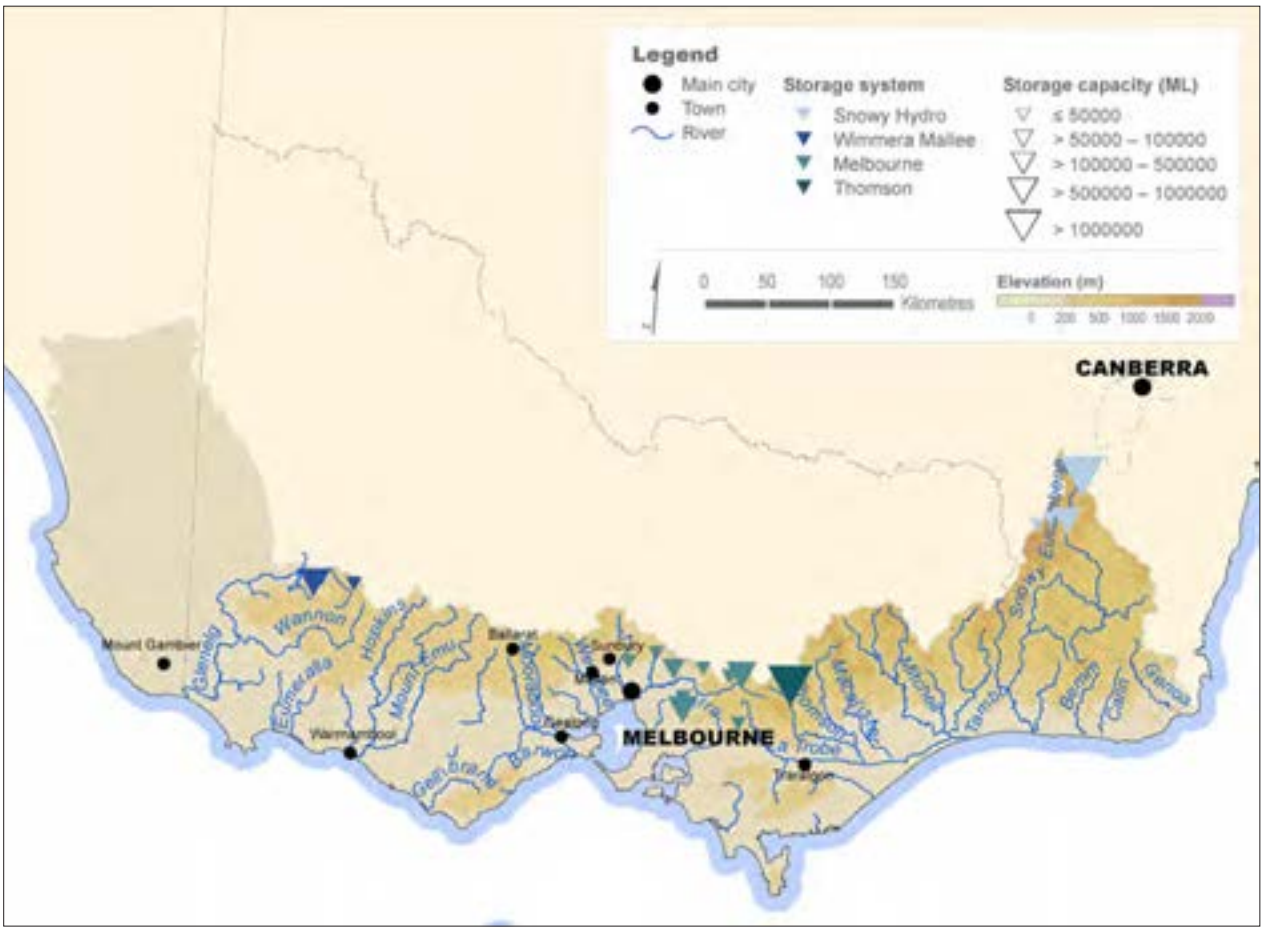


Figure 5.26 Storage systems in the South East Coast (Victoria) region (information extracted from the Bureau of Meteorology's water storage information in August 2012)

5.5.6 Wetlands

Important wetlands

There are a large number of wetlands of national and international importance in the South East Coast (Victoria) region (Figure 5.27), encompassing several wetland types. Wetlands in the region include alpine bogs, fresh and saline lakes, coastal estuaries and bays.

The coastal lakes, lagoons and bays form the largest wetlands and attract a large number of common and threatened bird species. They also form the habitat for some rare fish and dolphins, in particular the recently-described Burrunan dolphin. The other major types of wetlands are the lakes and lagoons in the west of the region, which are mainly fed by small rivers and creeks. These provide important habitat for water birds, including a large number of duck species.

Inflows to selected wetlands

The state of biodiversity in a wetland is linked to the way water is stored within the area and the temporal variability of inflows. An analysis of historic and recent inflows into wetlands forms an informative picture of potential changes.

Two internationally recognised Ramsar wetland sites, Western District Lakes and Gippsland Lakes, as well as one nationally important wetland (Reedy Lake–Lake Connewarre wetland complex) were selected for hydrological analysis of major inflows. More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html).

Nine upstream stream monitoring gauges were selected to enable analyses and interpretation of inflows to these three wetlands. The gauges used in the analyses are the closest upstream gauges that have largely continuous discharge records since 1980. Though the analyses do not capture the total inflows, they are indicative of the temporal patterns of freshwater surface flows to these wetlands.

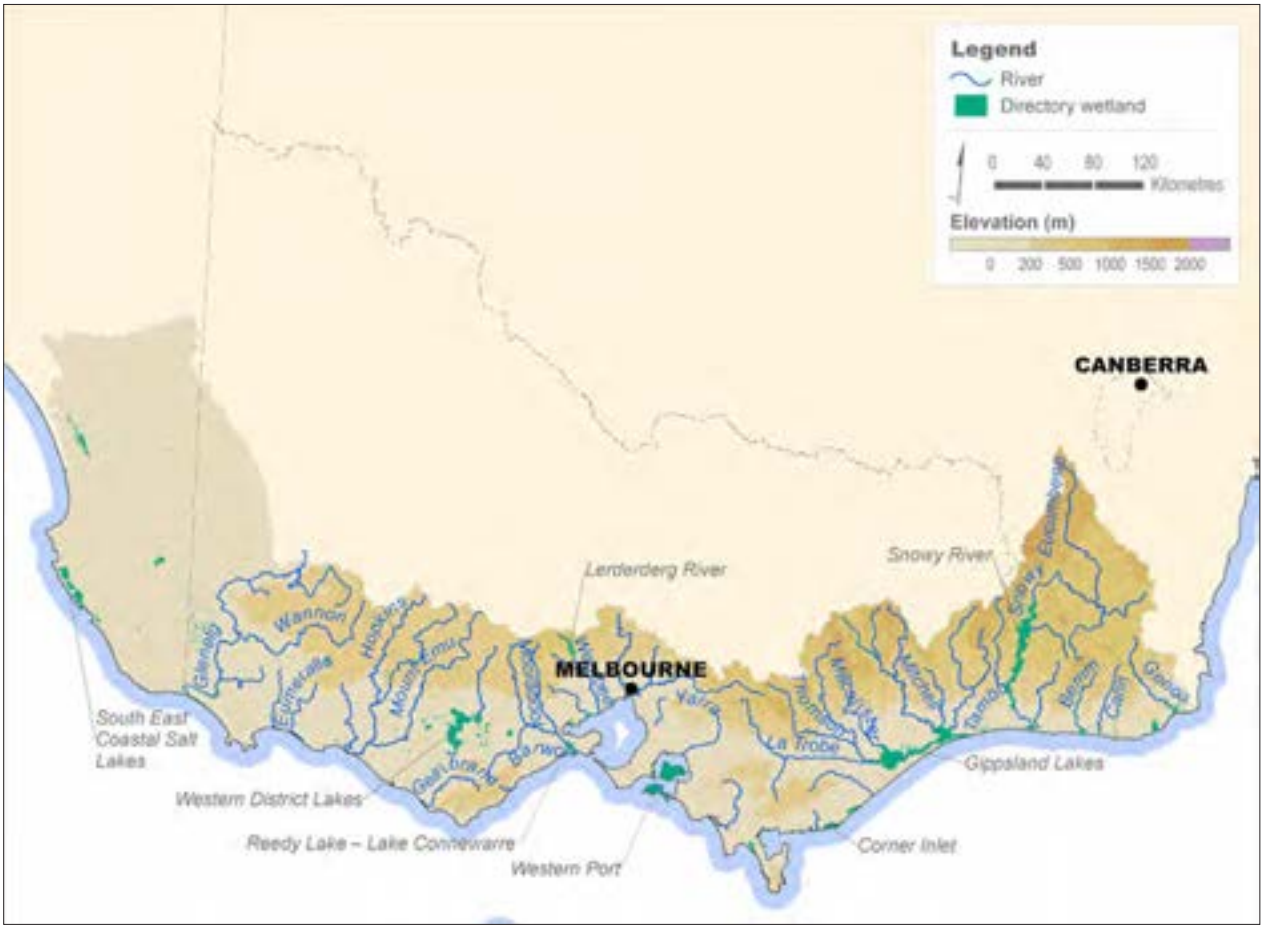


Figure 5.27 Location of important wetlands in the South East Coast (Victoria) region

Western District Lakes

The Ramsar-listed Western District Lakes form a combination of freshwater and hyper-saline lakes fed by local creeks and rivers. The wetlands are important habitats for many different species of waterbirds. Amongst the shores of the lakes, many different plant species cover vast areas of flat land.

Daily discharge data for the monitoring gauges on the Woady Yaloak River and Pirron Yallock Creek are combined to provide a temporal pattern of freshwater inflows into the Western District Lakes (Figure 5.28).

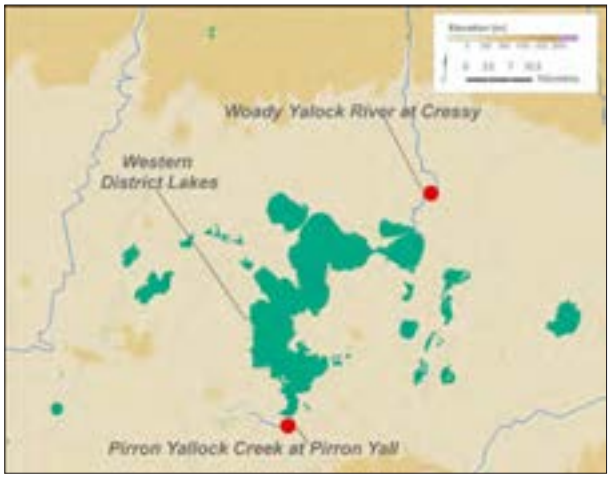


Figure 5.28 Location of the monitoring sites in relation to Western District Lakes

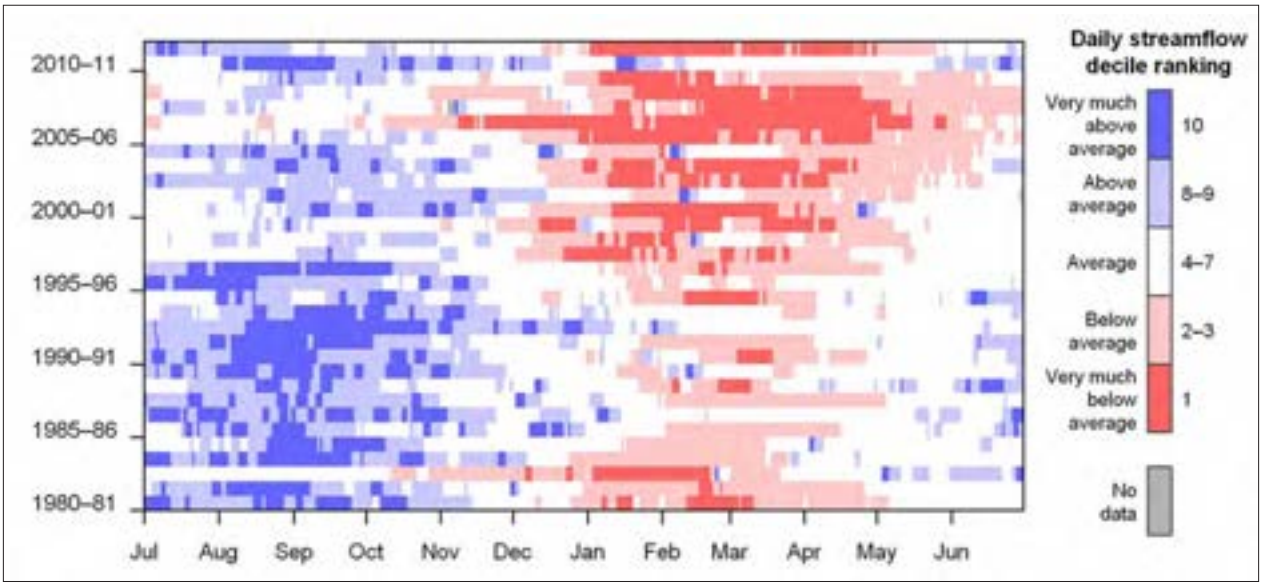


Figure 5.29 Combined daily flows of Woady Yaloak River and Pirron Yallock Creek between 1980 and 2012, ranked in decile classes

Figure 5.29 presents an overview of the distribution of daily streamflow decile rankings. Since 1997, the normally very much above average flows in late winter and early spring have become substantially less. Additionally, the summer and autumn low flows became much more pronounced from this year onwards. The year 2010–11 was the only real exception to this pattern.

Figure 5.30 compares monthly discharges from 2011–12 with the statistics of flows from 1980 onwards. The 2011–12 flows were particularly low in the normally high flow season from August–October and failed to contribute a significant amount of freshwater to the lakes.

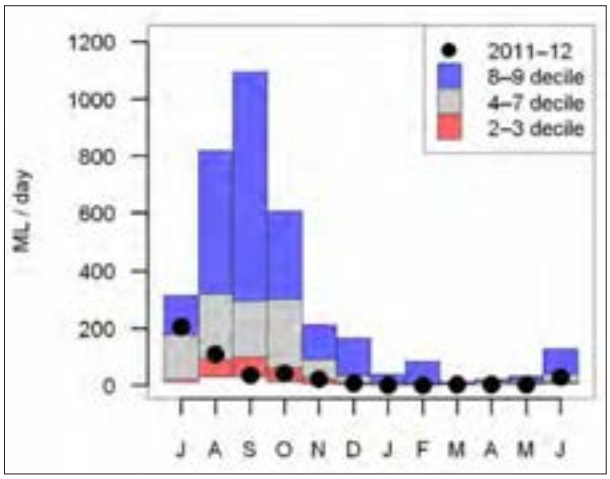


Figure 5.30 Combined monthly flows of the Woady Yaloak River and Pirron Yallock Creek from 2011–12 compared with its 1980–2012 decile rankings

Gippsland Lakes

The Gippsland Lakes are a Ramsar-listed complex of lakes supplied by a number of rivers. Land-use change and river regulation have reduced the original wetland dynamics substantially, but due to the large size of the complex the original biodiversity remains largely intact. The lakes are home to many water birds as well as the rare Burrunan dolphin.

Daily discharge data for the monitoring gauges on the Latrobe, Thomson, Avon, Nicholson and Tambo rivers are combined to provide a temporal pattern of freshwater inflows into the lakes (Figure 5.31).

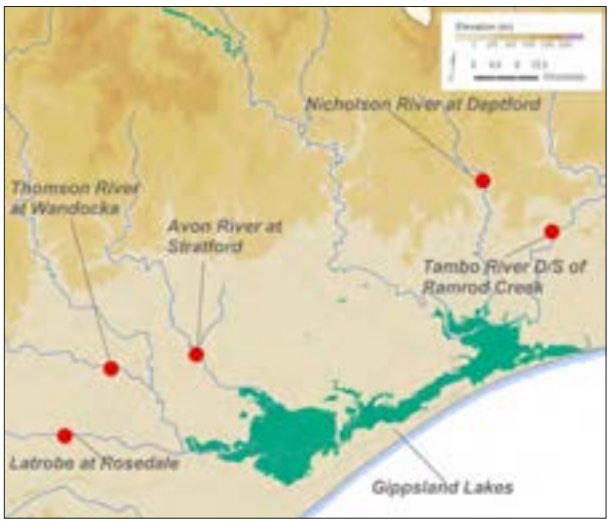


Figure 5.31 Location of monitoring sites in relation to the Gippsland Lakes

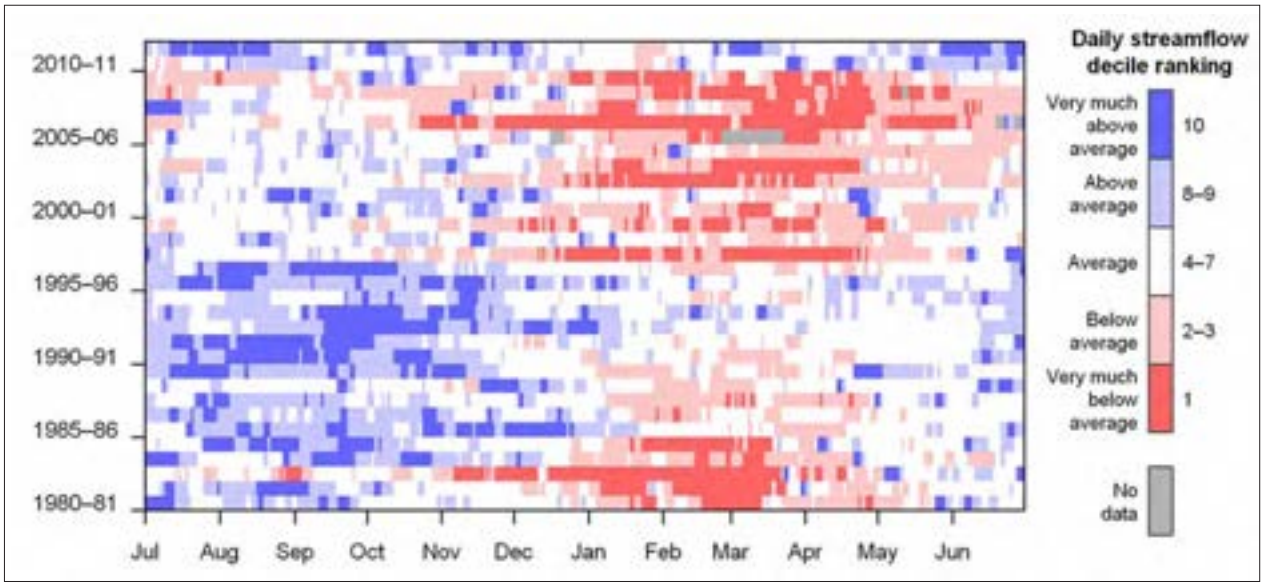


Figure 5.32 Combined daily flows of Latrobe, Thomson, Avon, Nicholson and Tambo rivers between 1980 and 2012, ranked in decile classes

Figure 5.32 presents an overview of the distribution of daily streamflow decile rankings. The last two years have seen much higher flows than the period 1997–08 and 2009–10. Before this flows were noticeably higher, particularly between July and December. Figure 5.33 compares monthly discharges from 2011–12 with the statistics of flows from 1980 onwards. The flows have been particularly high throughout most of the year and contributed a large amount of freshwater to the lakes.

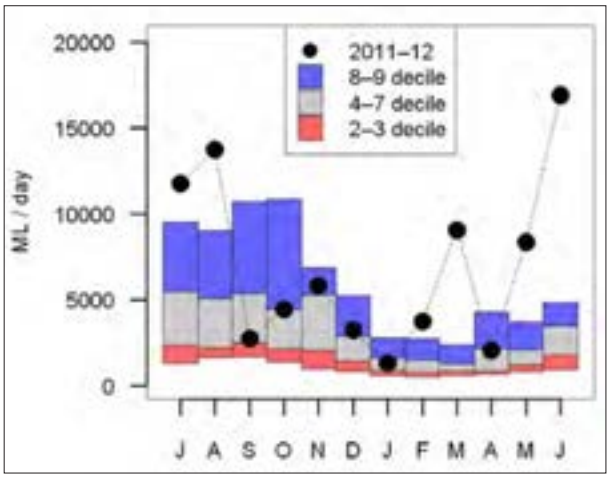


Figure 5.33 Combined monthly flows of the Latrobe, Thomson, Avon, Nicholson and Tambo rivers from 2011–12 compared with its 1980–2012 decile rankings

Reedy Lake–Lake Connewarre wetlands

The nationally recognised Reedy Lake–Lake Connewarre wetlands form a combination of freshwater swamps and shallow lakes, fed by the Barwon River. The estuary has been blocked off with a weir to prevent inflows of saline water. The lakes form the habitat for many common as well as some threatened waders and waterbird species.

Daily discharge data for the monitoring gauge on the Barwon and Moorabool rivers are combined to provide a temporal pattern of freshwater inflows into the lakes (Figure 5.34).

Figure 5.34 Location of the monitoring sites in relation to the Reedy Lake–Lake Connewarre wetlands

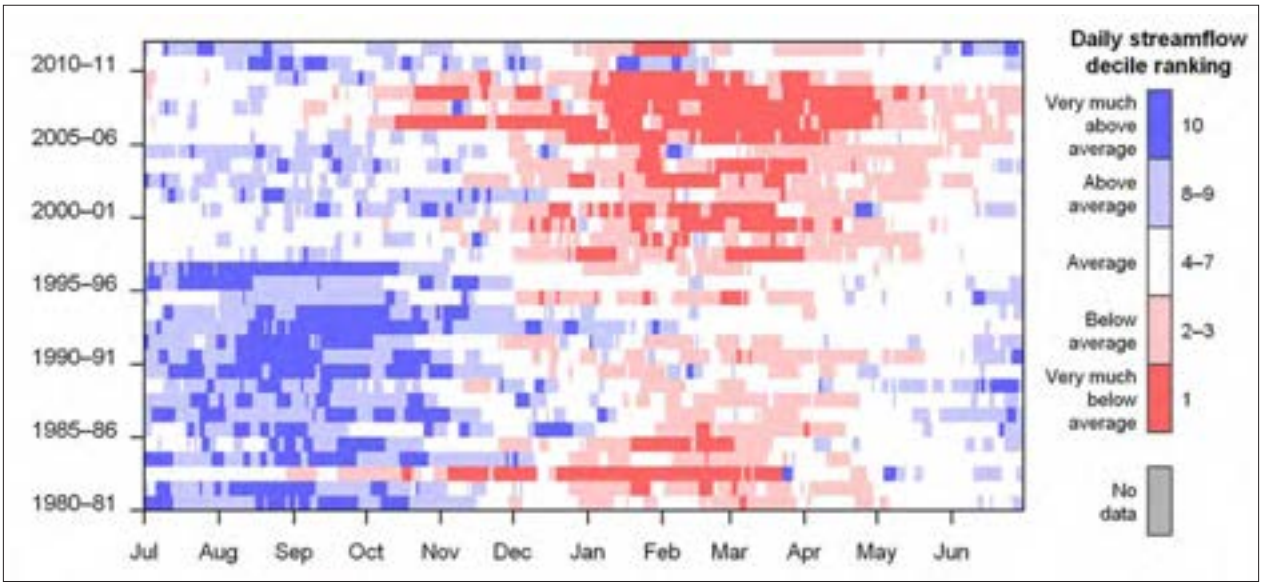


Figure 5.35 Combined daily flows of the Barwon and Moorabool rivers between 1980 and 2012, ranked in decile classes

Figure 5.35 presents an overview of the distribution of daily streamflow decile rankings. Since 1997–98, the normally very much above average flows in late winter and early spring have become substantially less. Additionally, the summer and autumn low flows became much more pronounced from this year onwards. From 2010–11, the pre-1997–98 flow patterns returned to some extent.

Figure 5.36 compares monthly discharges from 2011–12 with the flow statistics from 1980 onwards. The 2011–12 flows were particularly low in the normally high flow season from August–October and only contributed a substantial amount of freshwater to the lakes in July 2011 and June 2012.

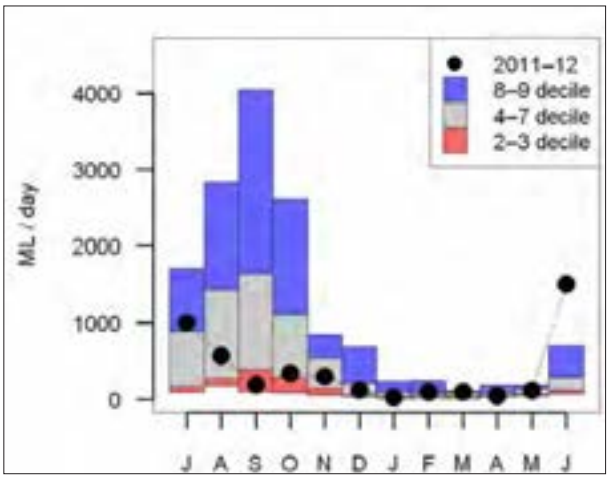


Figure 5.36 Combined monthly flows of the Barwon and Moorabool rivers from 2011–12 compared with their 1980–2012 decile rankings

5.5.7 Hydrogeology

The groundwater systems of the South East Coast (Victoria) region are varied and complex as shown in Figure 5.37. Hydrogeological features include, basement outcrops of fractured rock, sedimentary basin and the karstic limestone area of the Murray Group aquifer in southeast South Australia.

The region is bounded in the north by fractured rock groundwater systems that typically provide a low volume groundwater resource with the exception of the northwest area. In this part of the region the Murray Group aquifer provides a valuable groundwater resource.

High potential for groundwater extraction is provided by the aquifers associated with the Otway basin, Port Phillip and Westernport basins, Gippsland basin, and Tarwin basin in Southern Victoria (Southern Rural Water 2009). The volcanic basalt plains to the west of Melbourne are also a significant feature.

These aquifers are grouped in Figure 5.37 as:

- lower Tertiary aquifer (porous media—unconsolidated);
- lower mid-Tertiary aquifer (porous media—unconsolidated);
- upper mid-Tertiary aquifer (porous media—unconsolidated);
- upper Tertiary aquifer (porous media—unconsolidated); and
- upper Tertiary/Quaternary aquifer (porous media—unconsolidated).

5.5.8 Watertable salinity

Figure 5.38 shows the classification of watertable aquifers as fresh (total dissolved solids ([TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L). Most parts of the region are considered to have fresh water. No data are available for the New South Wales part of the region, which is primarily the fractured rock of the Lachlan Fold Belt.

5.5.9 Groundwater management units

In the region, a number of groundwater areas have been established to protect underground water resources. Within these areas authorisation is required to access and/or construct works to take groundwater for certain purposes.

The groundwater management units within the region are presented in Figure 5.39. Most of the units are relatively small in area and are located near the coast, with the exception of some larger units at the western and eastern ends of the region.

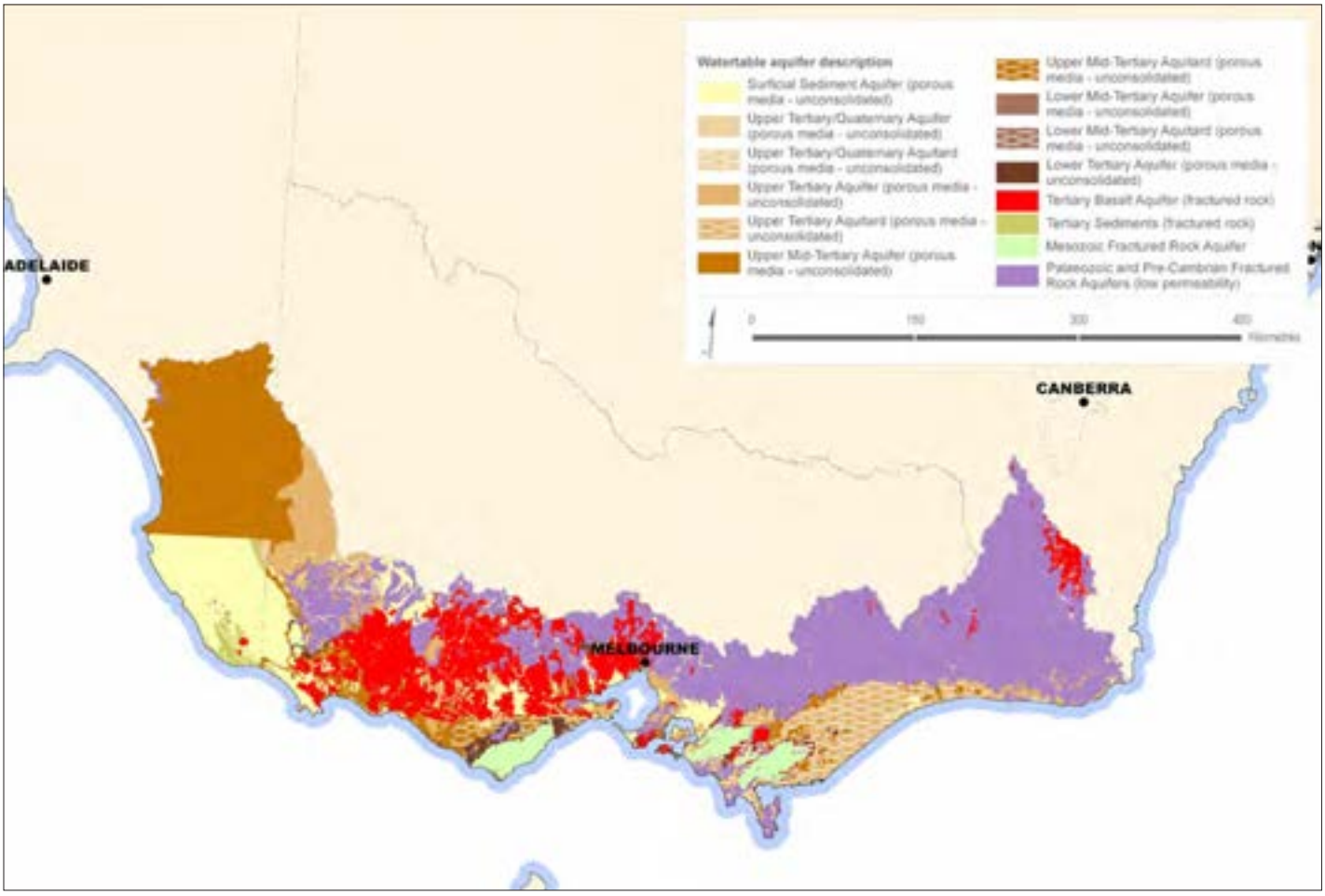


Figure 5.37 Watertable aquifers of the South East Coast (Victoria) region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

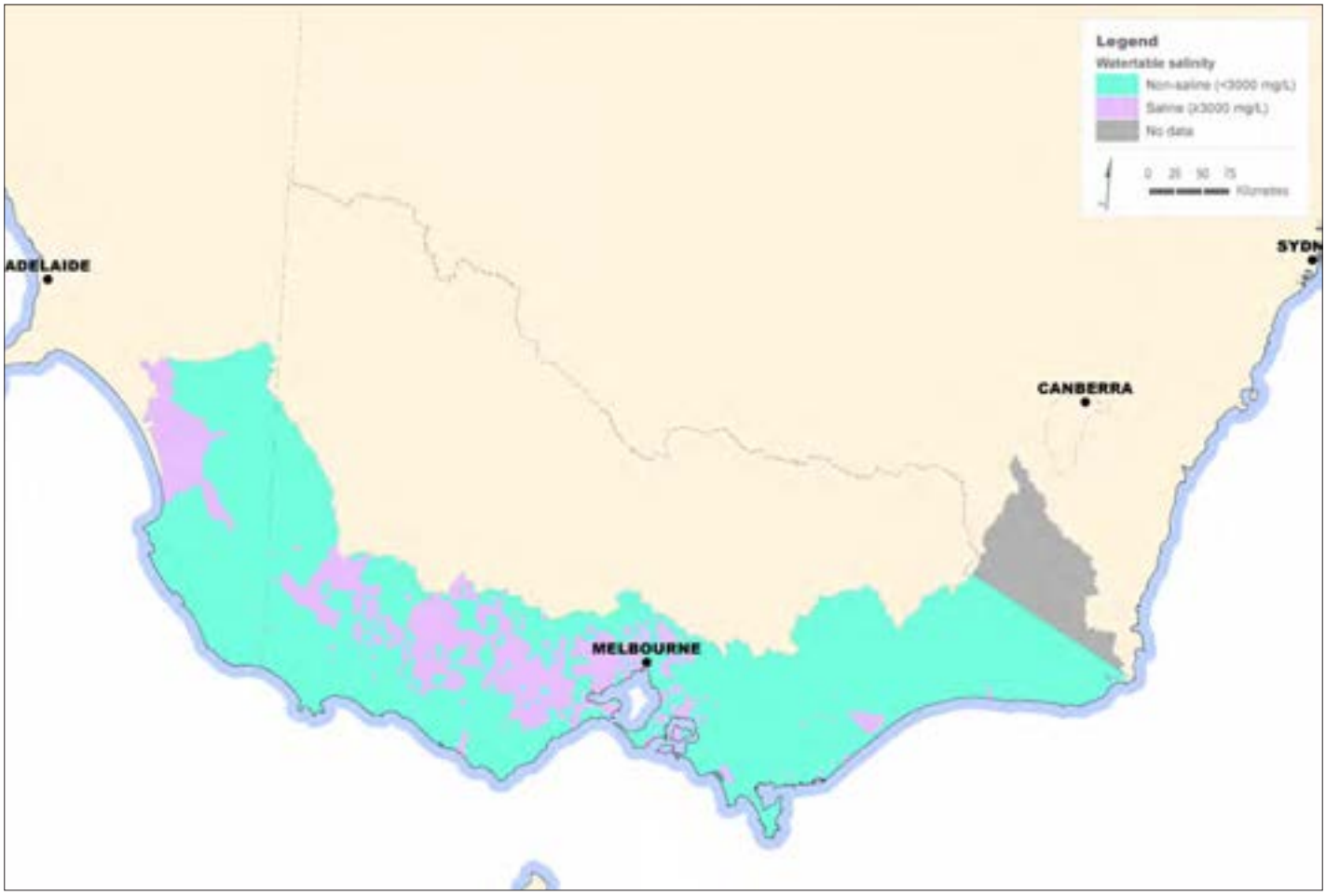


Figure 5.38 Watertable salinity classes in the South East Coast (Victoria) region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

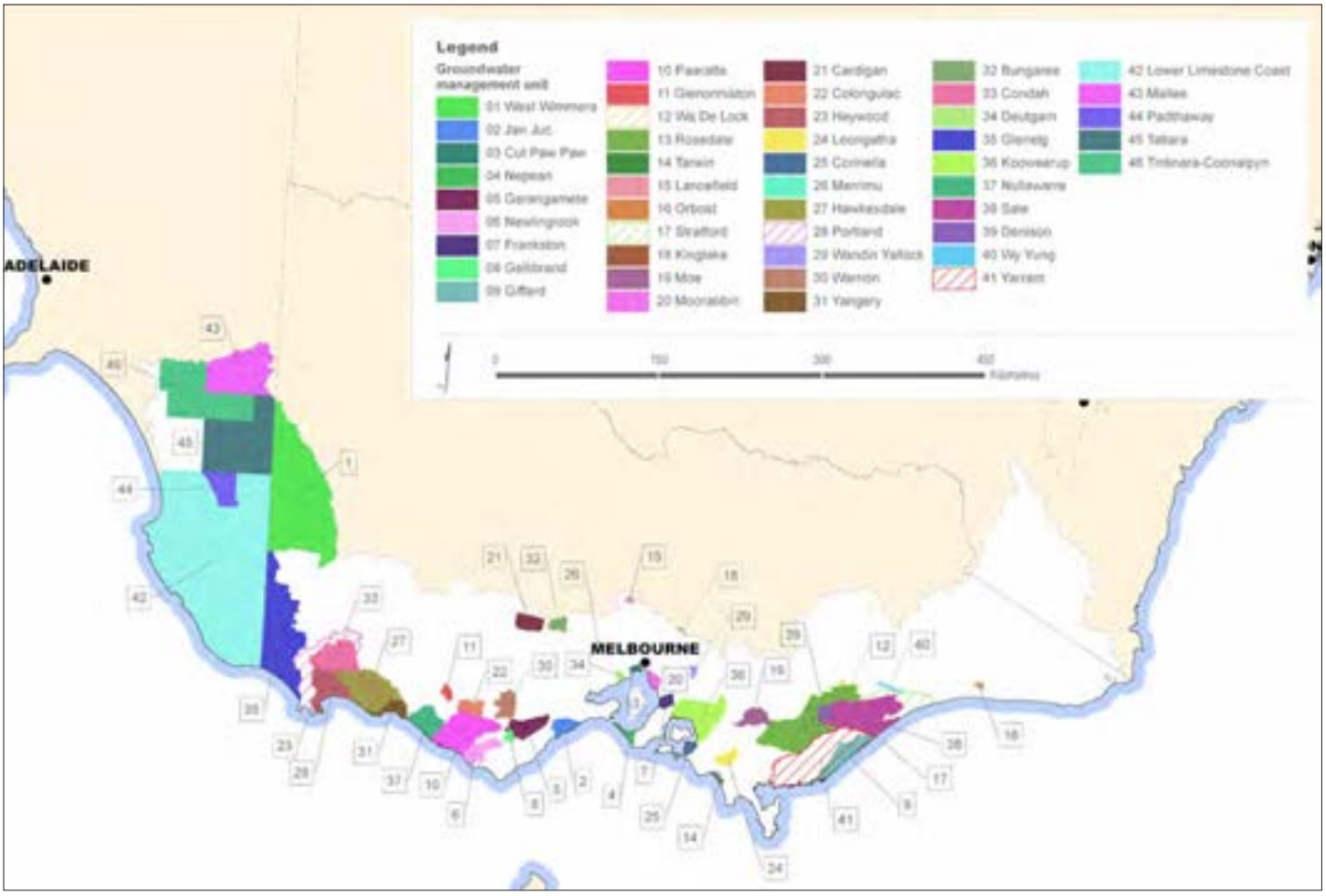


Figure 5.39 Groundwater management units in the South East Coast (Victoria) region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013). Management units identified by hatched areas are for deeper aquifers that may be confined

5.5.10 Status of selected aquifers

The status of groundwater levels is analysed at each bore throughout the South East Coast (Victoria) region. The assessment of groundwater levels evaluates trends in groundwater levels over the five-year period 2007–08 to 2011–12.

The trends in groundwater levels over the last five years are investigated using a 20 km x 20 km grid across data rich areas usually associated with the major groundwater management units (see Figure 5.39). This scale reflects the mostly regional flow system of the aquifers in the region. The linear trend in levels for a grid cell is assessed as:

- decreasing (where more than 60% of the bores have a negative trend in levels lower than –0.1 m/year);
- stable (where more than 60 % of the bores have a trend lower than 0.1 m/year and higher than –0.1 m/year);
- increasing (where more than 60% of the bores have a positive trend in levels higher than 0.1 m/year); and
- variable (where there is no dominant trend in groundwater levels amongst the bores within a grid cell).

Example bore hydrographs are presented for each aquifer type over the entire record length and trends are discussed with a focus on 2007–08 to 2011–12. The hydrographs are for key bores that have been selected to assist in the analysis and reporting of groundwater trends by the Department of Sustainability and Environment across Victoria, by Southern Rural Water for the Gippsland and South West Victoria Groundwater Atlas and by the South Australian Department for Water for the Lower Limestone Coast Prescribed Wells Area.

Upper aquifers

Figure 5.40 illustrates the spatial and temporal trends in groundwater levels, over 2007–08 to 2011–12, in the upper aquifers group which includes Quaternary and upper Tertiary aquifers. This grouping is based on the National Aquifer Framework (the Bureau 2012a) that builds on the Victorian Aquifer Framework. Many of the grid cells show a rising trend with some cells showing either a variable or stable trend with only a minority of cells showing a decreasing trend.

Selected bores 1 (Gippsland basin) and 3 (Otway basin) show a rising trend in groundwater levels over the last five years. This reflects the high rainfall and floods that occurred. Overall these bores show a long-term stable trend in groundwater levels with seasonal rises and falls which indicate good level recovery in the aquifer. Some winter peaks are more subdued in response to low rainfall. Step rises indicate groundwater response to recharge in high rainfall periods and to floods. In contrast, Bore 2 shows a declining trend until 2010 and then a sharp rising trend in groundwater levels over the last two years. This reflects the local groundwater use and the high rainfall and floods that occurred in this period.

Middle aquifers

Figure 5.41 illustrates the spatial and temporal trends in groundwater levels over 2007–08 to 2011–12, in the middle aquifers group which include upper middle and lower middle Tertiary aquifers. In the west of the region many of the grid cells show a stable trend, while in the rest of the region most of the grid cells show a rising trend with a minority of cells showing a variable or decreasing trend.

Selected bores 4 and 6 show a long-term declining trend in groundwater levels. The main factor driving this declining trend is likely to be reduced recharge. It should be noted that extraction and land use change may also contribute to localised declines. Bore 5 shows overall a stable trend. Wetter conditions during 2009–10 to 2010–11 have led to some recovery of water levels in all bores.

Lower aquifers

Figure 5.42 illustrates the spatial and temporal trends in groundwater levels, over 2007–08 to 2011–12, in the lower aquifers group which include the lower Tertiary aquifers. The grid cells do not show a clearly prevalent trend throughout the region. This probably reflects the low bore density in this aquifer group. However, there is a known long-term declining trend in the Gippsland lower Tertiary aquifer. Selected Bore 7 shows a decline in groundwater level in the late 1990s followed by a recovery in levels, and a more recent slow decline over the last five years. Bores 8 and 9 show a long- term minor declining trend. Wetter conditions during 2009–10 to 2010–2011 have not led to any substantial recovery in groundwater levels, probably due to the slow response of these deep confined groundwater systems.

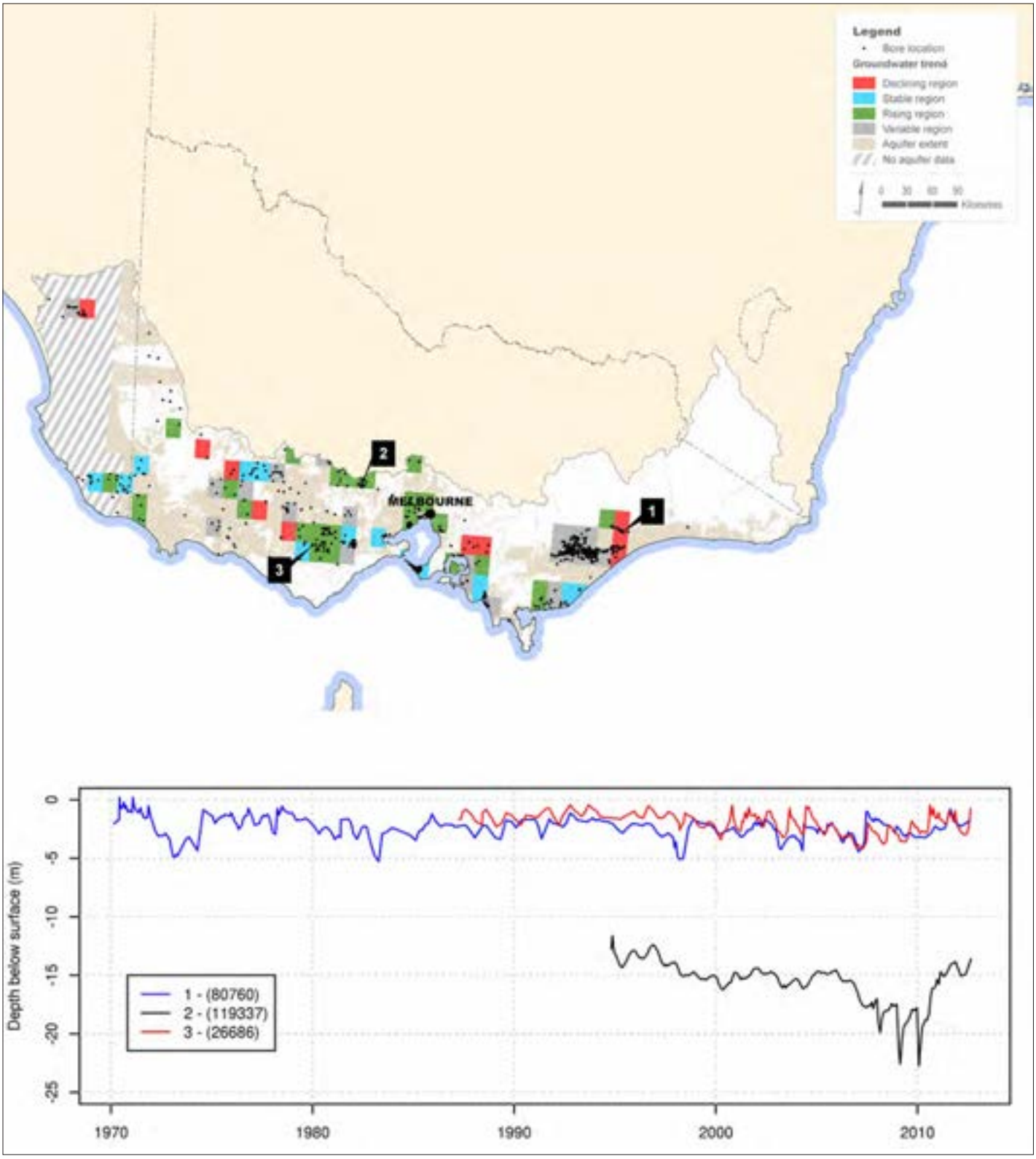


Figure 5.40 Spatial distribution of trends in groundwater levels for the upper aquifers in the South East Coast (Victoria) region for 2007–12, with selected hydrographs showing groundwater levels

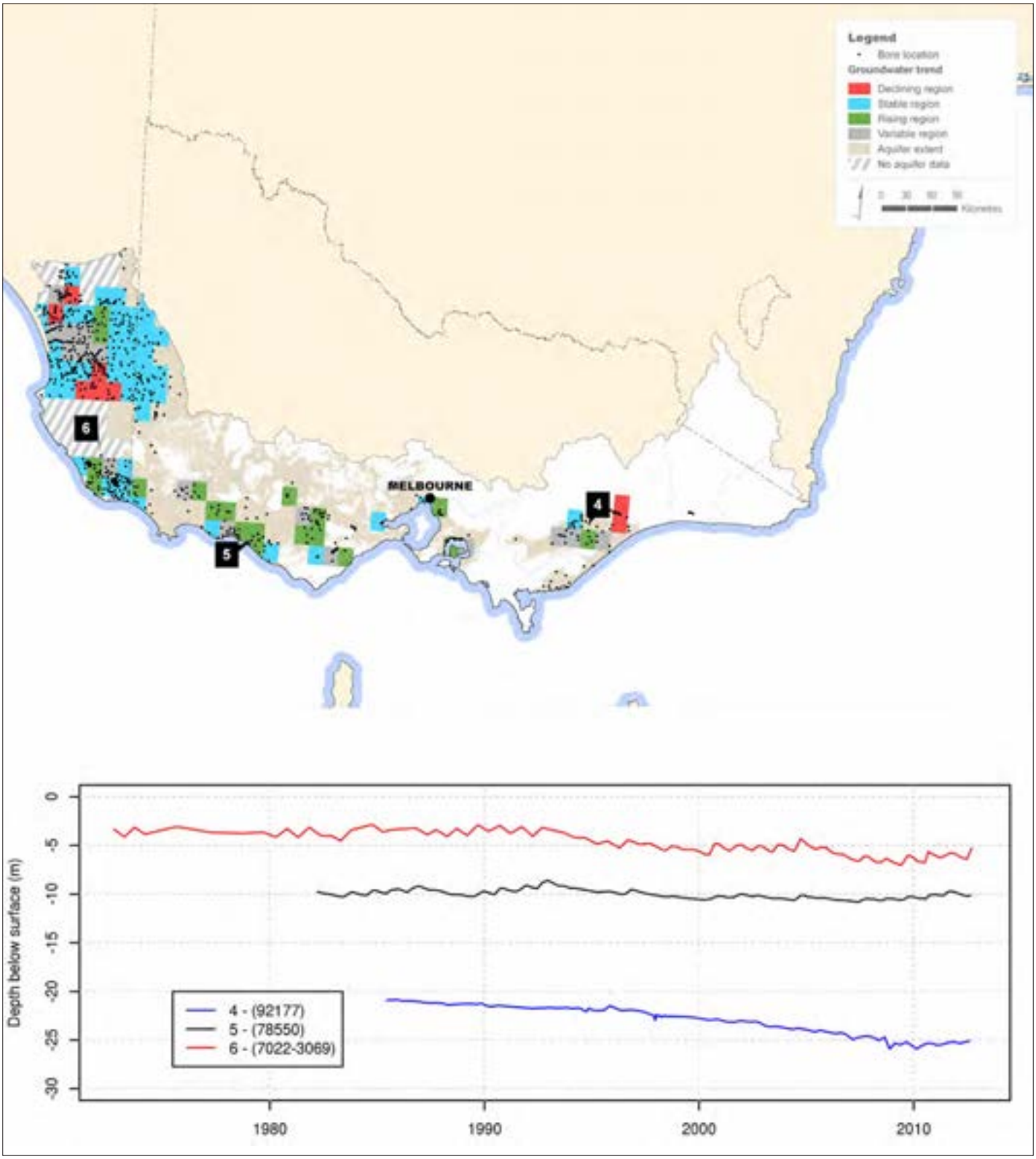


Figure 5.41 Spatial distribution of trends in groundwater levels for the middle aquifers in the South East Coast (Victoria) region for 2007–12, with selected hydrographs showing groundwater levels

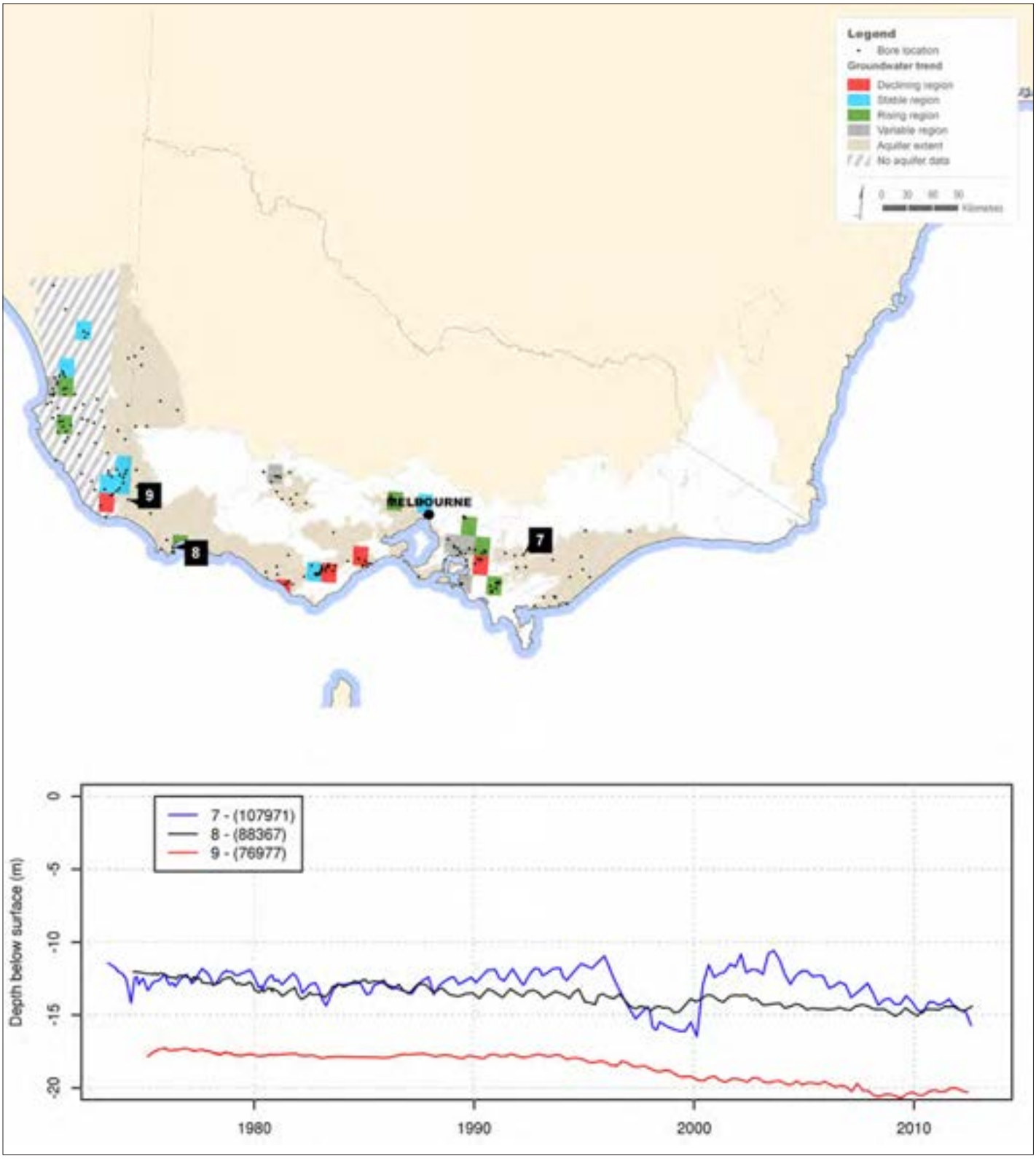


Figure 5.42 Spatial distribution of trends in groundwater levels for the lower aquifers in the South East Coast (Victoria) region for 2007–12, with selected hydrographs showing groundwater levels

5.6 Water for cities and towns

This section examines the urban water situation in the South East Coast (Victoria) region in 2011–12. The large urban centres in the region, their water supply systems and storage situations are briefly described. The main urbanised portion, the Melbourne water supply area, is presented in detail including its water supply systems, storage position, historical and current water restrictions, water sources and supply information.

5.6.1 Urban centres

With a population of about 3.7 million people, Melbourne is the largest and most populous city in the region and the second most populous city in Australia. The metropolitan area extends south from the city centre, along the eastern and western shorelines of Port Phillip Bay, and towards the north.

Geelong, located 75 km southwest of Melbourne, has a population of 144,000 people and is the region's second most populous city.

Outside of its two major cities the region has a large number of other regional urban centres and towns. These, along with Melbourne and Geelong, are shown in Figure 5.43 in conjunction with their population ranges.

The major urban centres of the region with populations of over 25,000 people are summarised in Table 5.4, which provides information on the population, surrounding river basins and significant water storages for each of the major urban centres in the region.

After Geelong the most notable of the major non-metropolitan urban centres in the region are Ballarat and the Latrobe Valley.

The Latrobe Valley has a population of 125,000 people and is located to the east of Melbourne. It has four major urban centres: Warragul, Moe, Morwell, and Traralgon. Population figures for the Latrobe Valley are not included in this table.

Ballarat with a population of 86,000 people is located in the lower western plains of the Great Dividing Range, about 100 km northwest of Melbourne.

Table 5.4 Population in major towns and cities in the South East Coast (Victoria) region

City	Population[1]	River basin	Major supply sources
Melbourne	3,707,000	Yarra, Werribee, Maribyrnong and Bunyip	Thomson, Upper Yarra, Cardinia
Geelong	144,000	Barwon	Wurdee Boluc
Ballarat	86,000	Barwon	Coliban storages, Lake Eppalock
Melton	46,000	Werribee	Melton Reservoir
Sunbury	33,000	Maribyrnong	Rosslyne Reservoir
Warrnambool	29,000	Hopkins	Via pipeline from the Gellibrand River and various diversion weirs on creeks in the Great Otway National Park
Mount Gambier	25,000	Millicent Coast	Blue Lake

[1]Australian Bureau of Statistics (2011b)

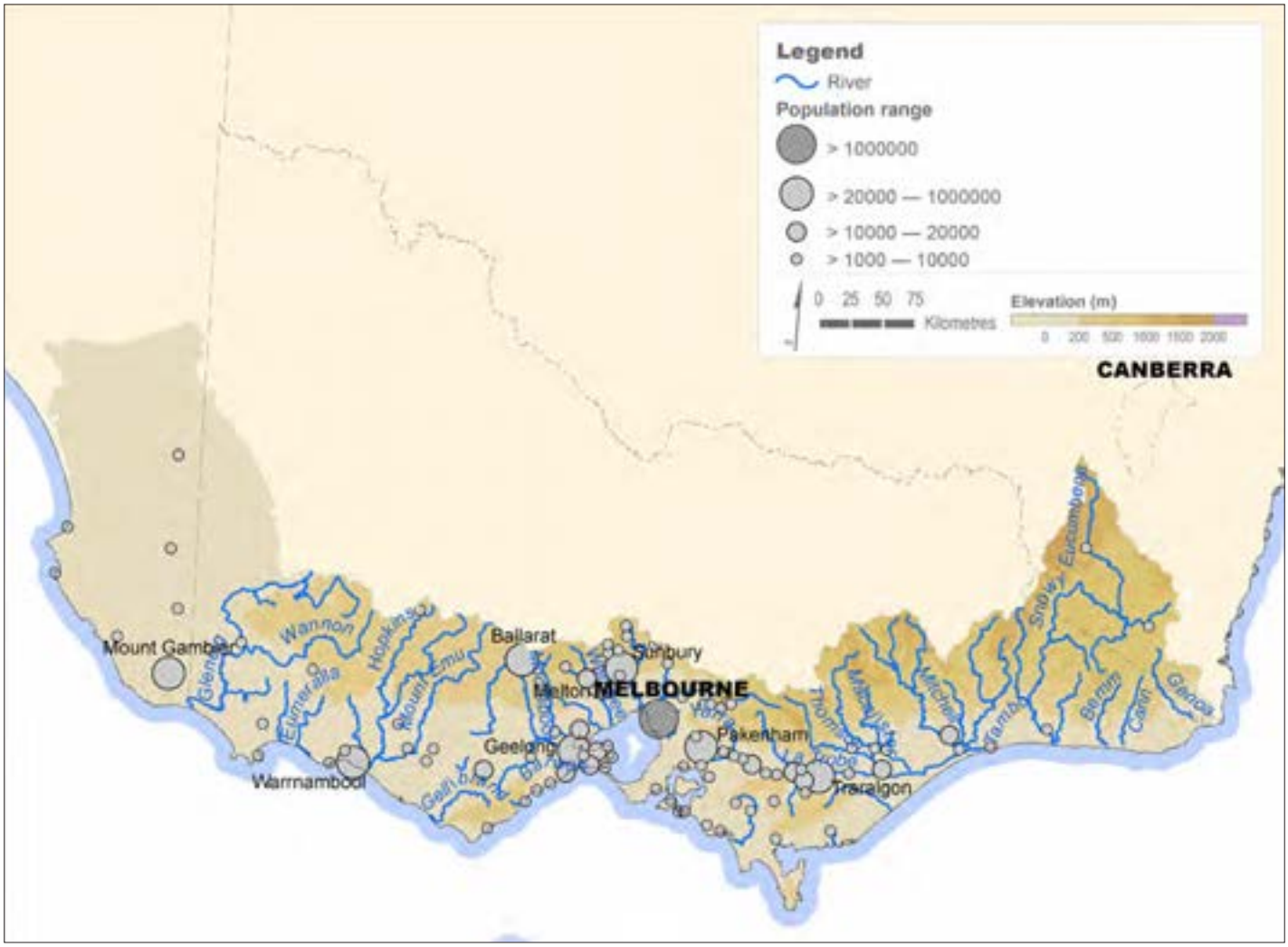


Figure 5.43 Population range of major urban centres in the South East Coast (Victoria) region

5.6.2 Sources of water supply

Like much of Australia, the cities and towns of the South East Coast (Victoria) region rely on surface water as the major source of supply. The region has over 20 major water storages, each with a capacity greater than 1 GL, and the majority of these are within Victoria.

While Lake Eucumbene, located in the northwest, is the largest storage in the region and the third largest in Australia, the Thomson storage in the central north is the largest storage of the region with the primary use being for urban supply.

The Thomson primarily supplies the Melbourne metropolitan region and is the third largest water storage connected to a major city in Australia. The storage also supplies a number of small towns and, more significantly, irrigation demands across a number of the regions irrigation districts. The Thomson, along with other major surface water storages in the region, is shown in Figure 5.44.

In addition to surface water storages the region utilises direct river extractions (including extractions of upstream storage releases), groundwater, desalination, recycled water, and harvested storm and rainwater to supply the urban demands of the region.

Groundwater extractions form a reliable source of supply in the western part of the region where surface water extractions from the Grampians and Otway Ranges catchments can be variable.

Two major wastewater treatment plants on the eastern and western extremities of metropolitan Melbourne supply significant quantities of recycled water to adjacent areas.

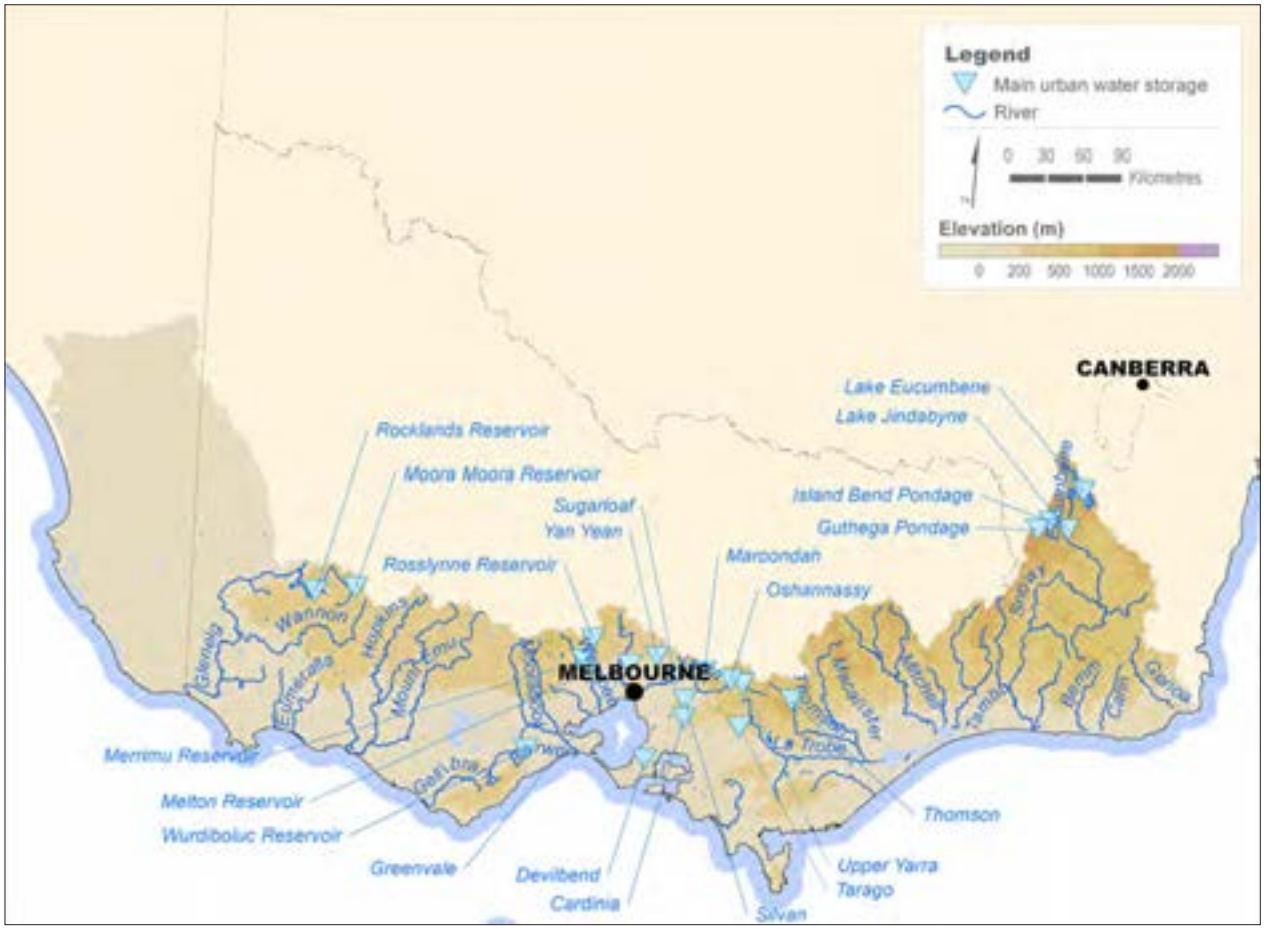


Figure 5.44 Urban supply storages in the South East Coast (Victoria) region

5.6.3 Melbourne

The Melbourne metropolitan area is serviced by four major water corporations. These comprise three retail suppliers (City West Water, Yarra Valley Water and South East Water) and a bulk water supplier (Melbourne Water). Melbourne's water supply and wastewater system are summarised in Figure 5.45.

Formed under Victoria's *Water Act 1989*, these corporations manage Melbourne's surface water supply catchments, storages, water treatment plants, storages and supply networks. These corporations are owned by the Victorian Government but managed by independent boards of directors.

Melbourne Water supplies bulk water to the metropolitan retailers as well as selling water to the regional urban water corporations of Western Water and Gippsland Water.

In addition to its bulk water supply role Melbourne Water operates a number of Melbourne's wastewater treatment plants, including its two largest, the Eastern and Western treatment plants, and manages waterways and major drainage systems in the Port Phillip Bay and Westernport areas.

Yarra Valley Water is the largest of the three retail water utilities and provides water supply and sewerage services to over 1.6 million people and over 50,000 businesses in the Yarra River basin part of the Melbourne water supply area

City West Water is the second largest of the three retail water utilities in the Melbourne water supply area. It provides drinking water and recycled water services to customers in Melbourne's central business district as well as to the inner and western suburbs, and manages sewerage and trade waste.

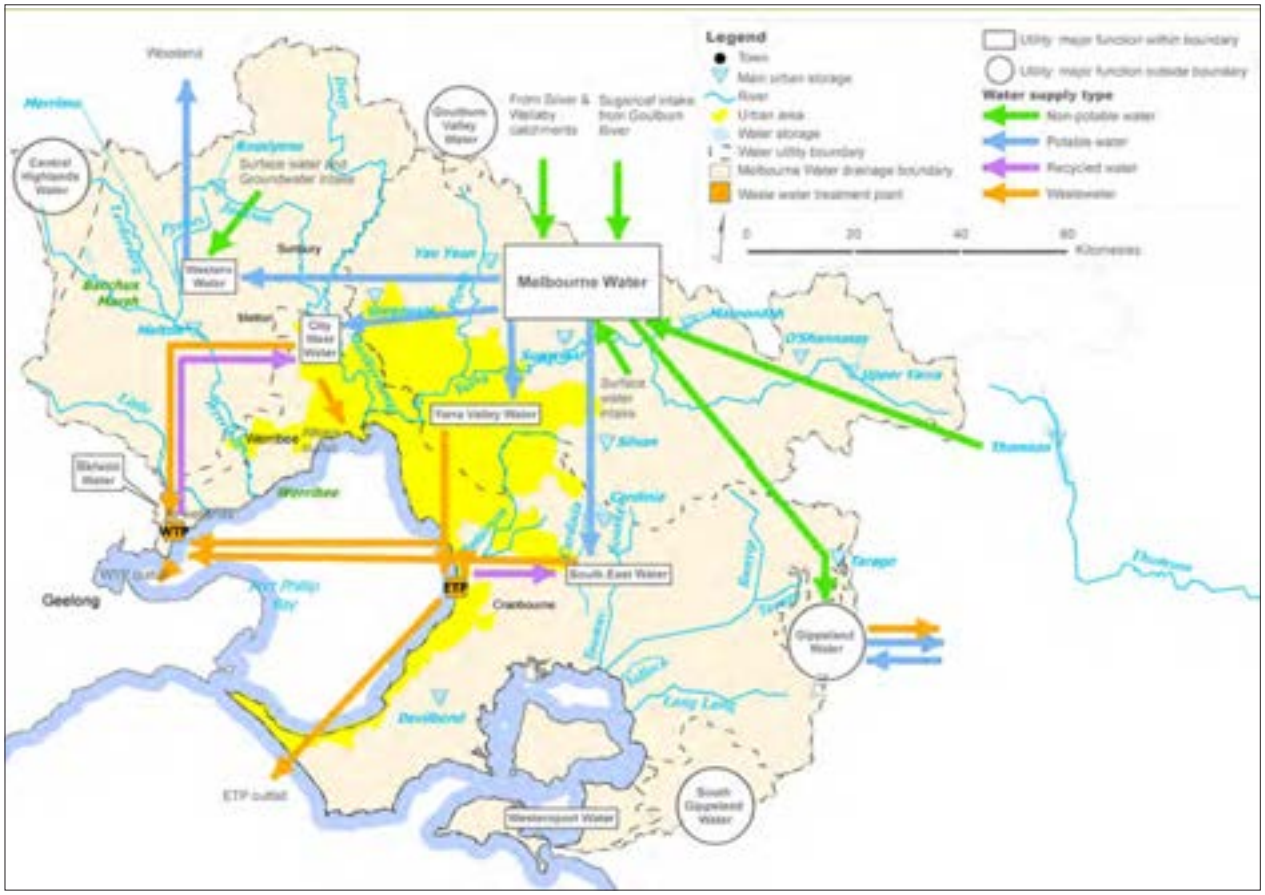


Figure 5.45 Melbourne's major water supply and waste water system

South East Water provides water supply services including recycled water to residents, businesses, industry and councils in Melbourne's southeast. It manages and maintains the water and sewerage networks and some treatment plants. It also manages a network of parks as well as cultural assets, bays and waterways.

In addition to the major metropolitan suppliers, Western Water services the area within the Maribyrnong and Werribee River basins that extend into Melbourne's Western growth area, while Gippsland Water delivers water to a small area in the southeast of Melbourne and has its major service area outside Melbourne.

Supply system

Melbourne's surface water supplies are drawn from catchments that feed six main storages. These storages are Thomson, Upper Yarra, Tarago, Maroondah, O'Shannassy and Yan Yean.

In addition to these storages a further four major storages without a significant catchment area are used in the operation of the Melbourne system. These storages are Cardinia, Sugarloaf, Silvan and Greenvale.

While no longer in operation, the North South Pipeline facilitates the bidirectional transfer of water between the Goulburn River and Melbourne Water's Sugarloaf storage.

Again, not in operation during 2011–12, the Wonthaggi desalination plant can provide potable water for Melbourne and based on current consumption is capable of supplying up to 40% of the cities potable water demand. Water supplied from the plant is transferred by pipe to Cardinia.

Storage volumes

At approximately 60% of Melbourne's total accessible storage capacity the Thomson plays a major role in the security of the city's water supply. Thomson constitutes 1,068 GL of the 1,812 GL total accessible storage capacity. As such, the historical storage volume shown in Figure 5.46 provides insight into Melbourne's surface water supply resources over the past 18 years.

Figure 5.46a shows the accessible storage volumes of Thomson from 1985–2012 and exhibits three distinct trends.

The sustained increase in the accessible storage volume between 1985 and 1990 is explained by the completion of the Thomson Dam in 1984 and the subsequent filling of the storage during successive years of good rainfall and inflows.

Below average rainfall between 1997 and 2008 saw drought conditions develop throughout much of the region. The corresponding reduction in inflows to Melbourne's major storages saw a significant decline in the accessible storage. This trend was reflected throughout the system.

A shift in climatic conditions in 2009 and a series of wetter years (including Australia's wettest two-year period on record in 2010–11) saw the storage level recover from their 2008 low of less than 200 GL. This filling trend is highlighted in Figure 5.46b which shows the accessible storage for Thomson for 2011–12.

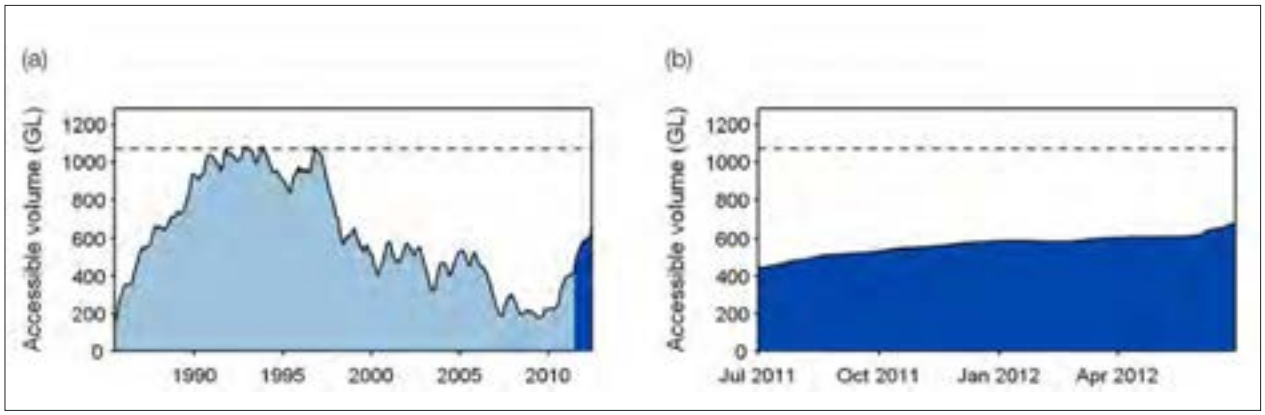


Figure 5.46 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Thomson storage, as well as total accessible storage capacity (dashed line)

Water restrictions

Drought response plans (DRPs), developed by Melbourne's three water retailers (City West Water, South East Water and Yarra Valley Water) in consultation with Melbourne Water, are an important mechanism in the management of Melbourne's water resources in times of shortage.

The DRPs require the three retailers and Melbourne Water to jointly prepare and publish, by 1 December each year, an annual Water Outlook for Melbourne that provides an overview of the total system storage with reference to three zones: High, Medium and Low, as well as an annual and medium term action plans which may include water restrictions.

Announcements to lift or introduce water restrictions are made by the Victorian Government based on the annual Water Outlook that considers a range of factors including storage over the Water Outlook period; past and forecast weather/climate, catchment conditions; inflows and trends in demand; as well as planned investments and actions. In times of water shortages, the urban water utilities can implement water restrictions ranging from Stage 1 (mild/alert) to Stage 4 (severe/critical).

These restriction levels and the Permanent Water Saving Rules which is a set of commonsense rules that applies all the time to ensure water efficient practices in the community were developed following a State-wide review in 2011 by the Victorian Water Industry Association in consultation with the water industry.

Figure 5.47 shows there were no water restrictions in the Melbourne water supply area until August 2006 since the previous restrictions were lifted in March 2005. Due to the low rainfall and inflow in 2006, in September 2006 Stage 1 restrictions were introduced. This was quickly followed by Stage 2 restrictions introduced in spring 2006 and Stage 3 restrictions introduced in summer 2007. Stage 3a restrictions, which increase limitations on residential water use even further, were introduced before winter 2007.

Rainfall between 2007 and 2009 was not enough to increase water storage volumes and Stage 3a restrictions remained in place. Because of above average rainfall in the upstream sections of the supply catchments in 2009–10, water restrictions were eased to Stage 3 in April 2010. Following the above average rainfall in 2010–11 and 2011–12, the water restrictions were eased progressively, falling back to Stage 1 in December 2011.

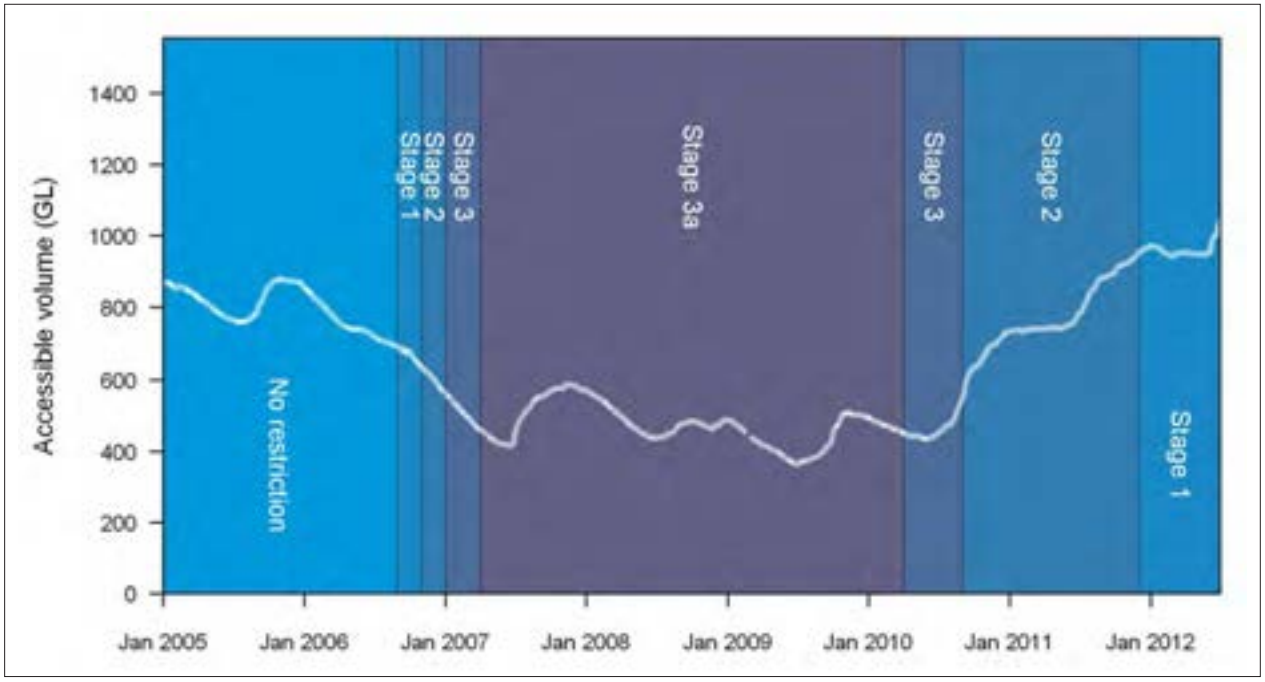


Figure 5.47 Urban water restriction levels for Melbourne since 2005 shown against the combined accessible water volume of the Thomson, Upper Yarra and Cardinia storages

Source of water obtained

Surface water is the main source of water supplied to the Melbourne water supply area. Figure 5.48 illustrates that over the last six years approximately 96% of bulk water delivered was derived from surface water supplies and 4% from recycled water (National Water Commission 2013).

The total volume of water supplied to Melbourne decreased from 431 GL in 2006–07 to 384 GL in 2011–12. This significant 18% reduction can be attributed to water efficiency gains, the implementation demand management strategies (including water restrictions and the installation of water efficient appliances), and the augmentation of domestic supplies with locally sourced water from storm and rainwater.

Following its broad scale introduction as a supply source in 2005–06, Melbourne has sourced approximately 14 GL of water per year from recycled water. Recycled water is supplied to consumers through various schemes operated by the water authorities. It is used to meet a broad range of end-uses that include including broad scale agriculture, market gardens and the maintenance of conservation areas and golf courses.

Once commissioned, the Wonthaggi desalination plant will provide a new source of water for Melbourne. The plant will have the capacity to meet up to 40% of Melbourne's current demand.

Groundwater does not play a significant role in the Melbourne water supply system.

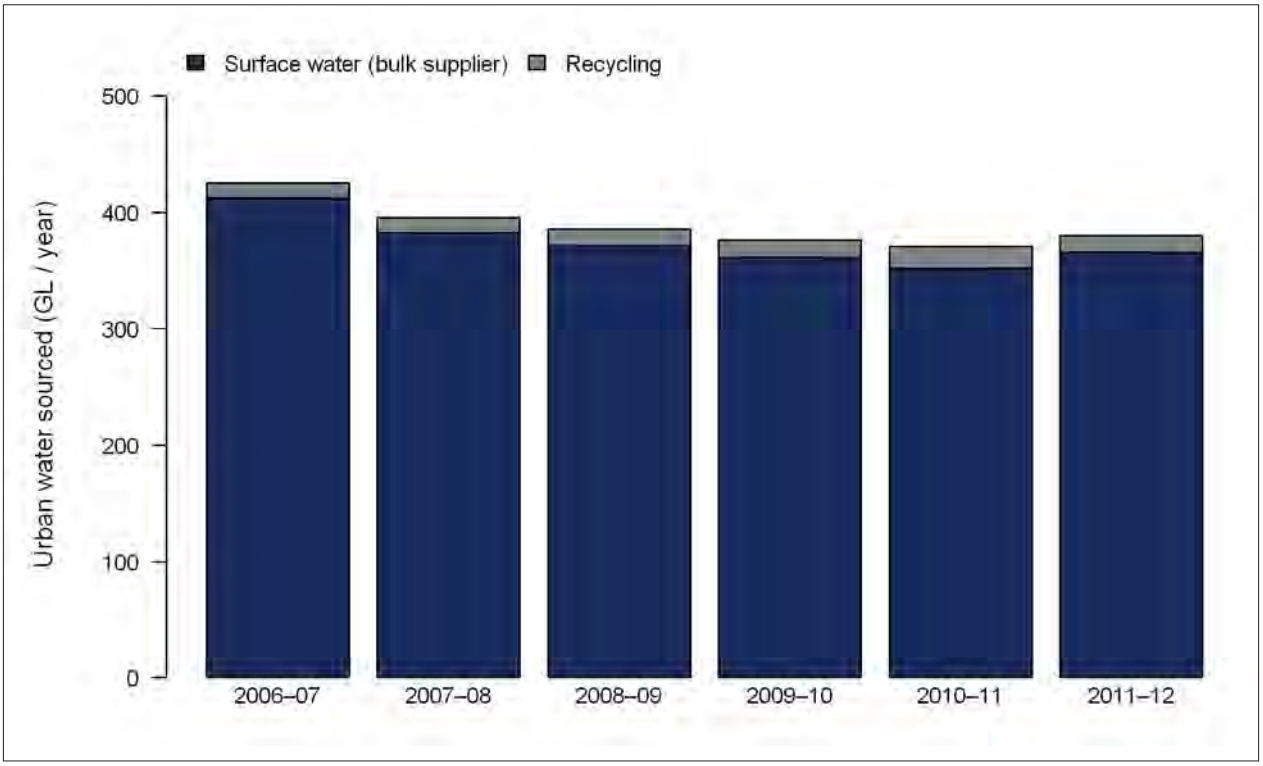


Figure 5.48 Total urban water sourced for the Melbourne water supply area from 2006–07 to 2011–12

Categories of water delivered

Figure 5.49 shows the total volume of water delivered to residential, commercial, municipal and industrial consumers by the three utilities from 2006–07 to 2011–12 financial years. Approximately 60% of the total volume supplied was for residential use and 27% for commercial, municipal and industrial use (National Water Commission 2013).

Most significantly this figure illustrates that while demand management strategies in the residential sector achieved a reduction in water consumption (approximately 8%) the most significant savings were achieved in the commercial, industrial and municipal sectors, which collectively achieved a 16% reduction in water consumption across the 2006–07 to 2011–12 financial year period.

At individual property scale, the observed reductions in residential water consumption translate to an estimated 7 kL per year per property saving of water, with use falling from an average 148 kL per property in 2006–07 to 141 kL in 2011–12 (National Water Commission 2013).

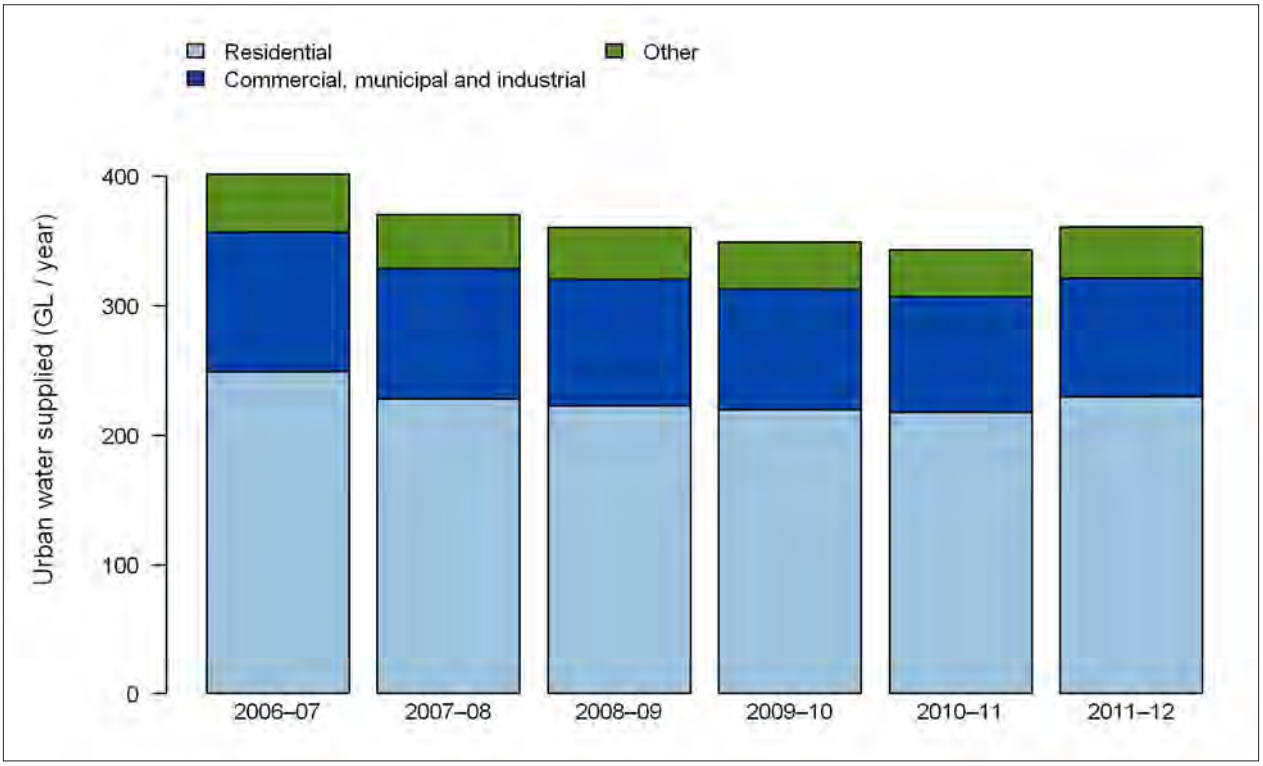


Figure 5.49 Total urban water supplied to the Melbourne water supply area from 2006–07 to 2011–12

5.7 Water for agriculture

This section describes the water situation for agriculture in the South East Coast (Victoria) region in 2011–12. Soil moisture conditions are presented and important irrigation areas are identified. The Macalister, Werribee and Bacchus Marsh irrigation areas are described in more detail and information is provided regarding surface storage and groundwater.

5.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 25 km x 25 km grid cell, they are not suitable to compare with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

Soil moisture deciles for 2011–12 show very much above average conditions for most of the eastern part of the region (Figure 5.50). This was as a result of high rainfall events in the east which was in sharp contrast to the western part of the region which generally received average to very much below average rainfall during the year.

The decile ranking of monthly changes of soil moisture (Figure 5.51) shows that availability of soil moisture dropped to near average levels during the spring and summer months, partly due to very high evapotranspiration in two months of this period. The above average rainfalls that followed this period kept the soil moisture conditions at very much above average in the autumn and winter months.

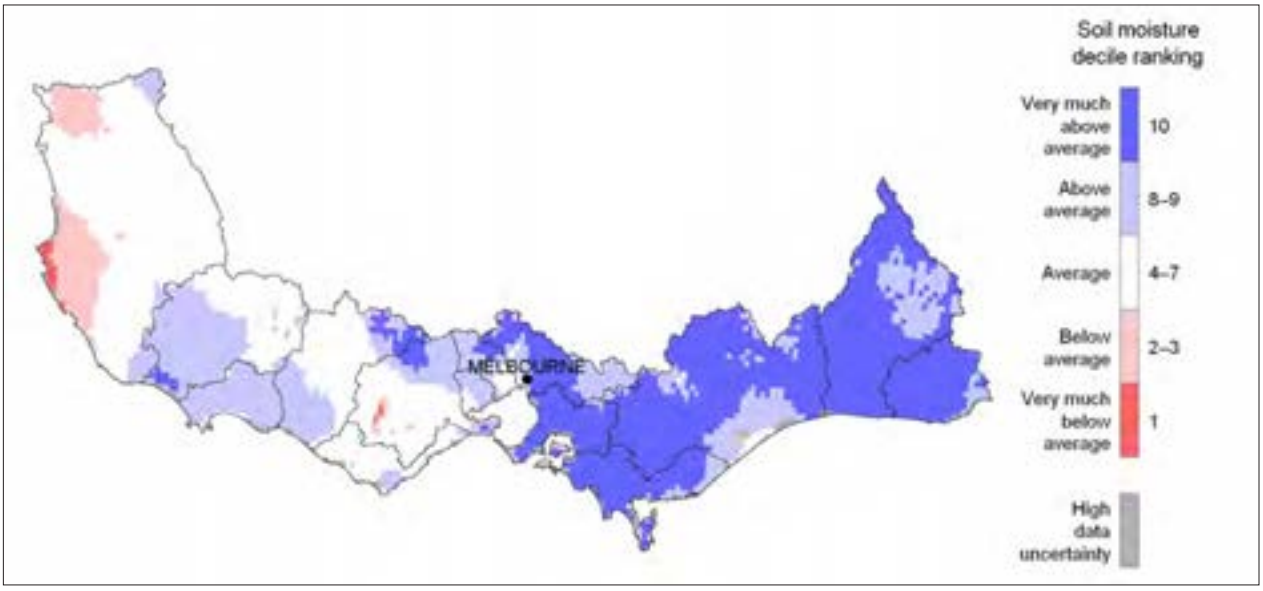


Figure 5.50 Deciles rankings of annual average soil moisture for 2011–12 with respect to the 1911–2012 period in the South East Coast (Victoria) region

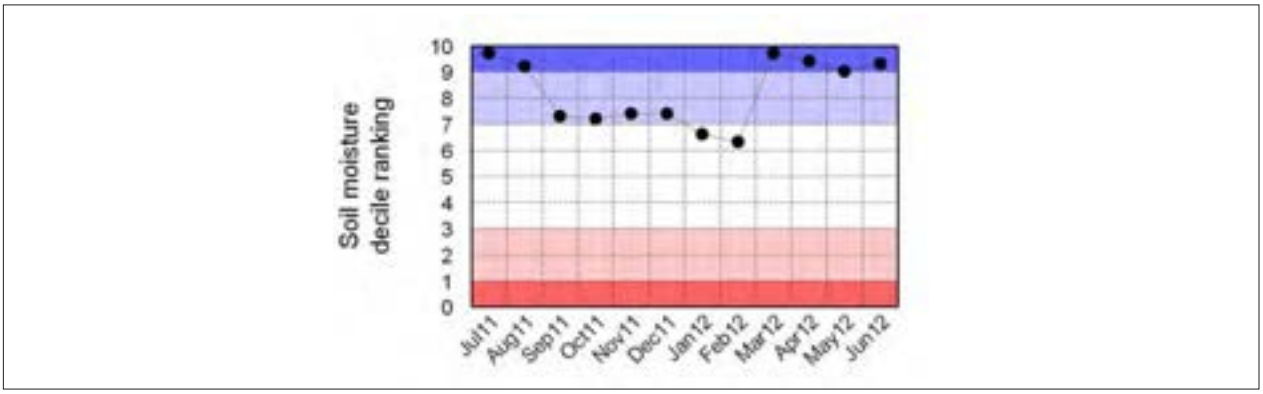


Figure 5.51 Decile ranking of the monthly soil moisture conditions during the 2011–12 period in the South East Coast (Victoria) region

5.7.2 Irrigation water

Irrigation water use in the region between 2005–06 and 2010–11 is shown in Figure 5.52 and Figure 5.53 by natural resource management (NRM) region. The southeast (South Australia) and West Gippsland districts showed the highest irrigation water use during this period.

At the time of writing the report data was not available for 2011–12.

Water resource availability for Macalister Irrigation District in West Gippsland and Werribee and Bacchus Marsh in the Port Phillip Bay and Westernport regions are discussed in more detail in the following sections.

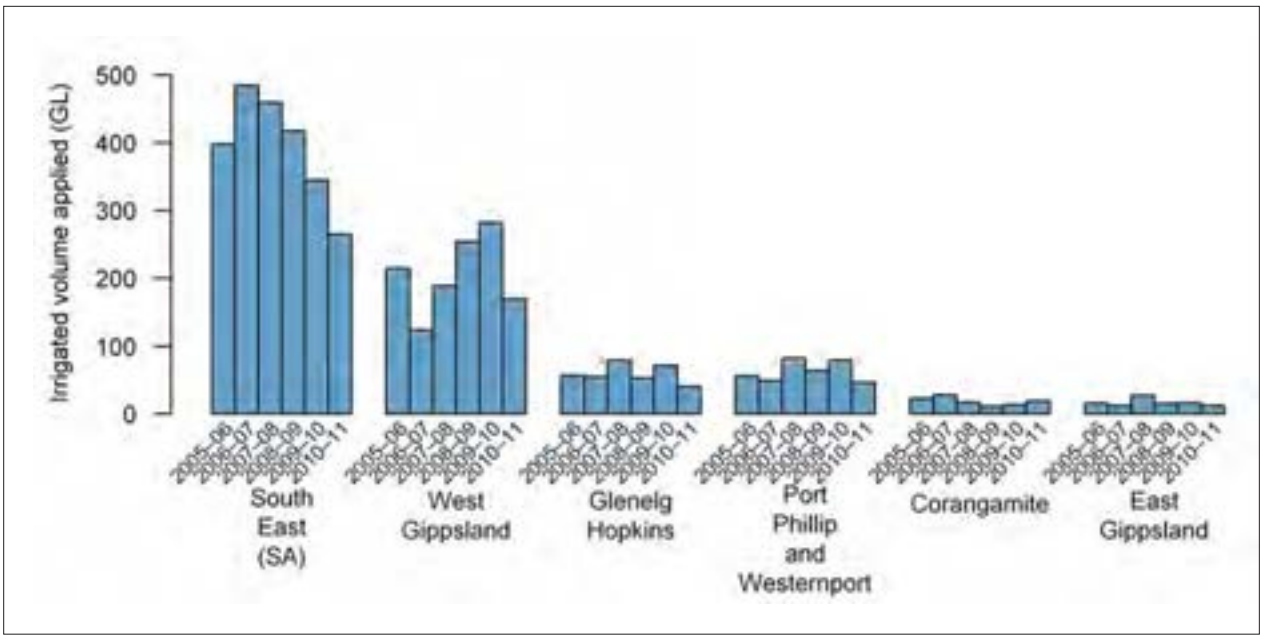


Figure 5.52 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the South East Coast (Victoria) region (ABS 2006–2010; 2011a)

Agricultural water use in the Bacchus Marsh irrigation district, Victoria | Southern Rural Water

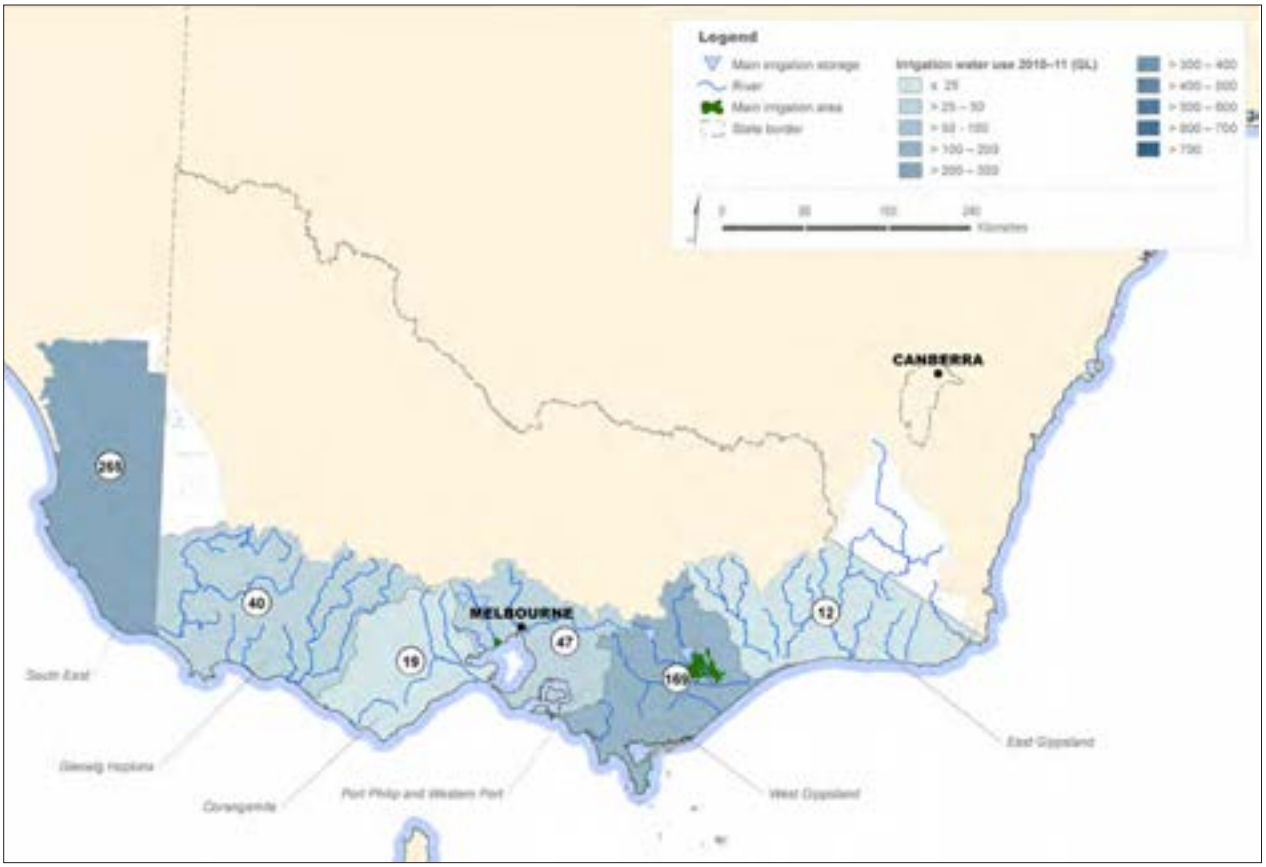


Figure 5.53 Annual irrigation water use per natural resource management region for 2010–11 (ABS 2011b)

5.7.3 Irrigation areas

More than half the land in the South East Coast (Victoria) region is used for grazing sheep and cattle. Dryland cropping is concentrated in the central and western parts of the region. Hardwood timber production is a major industry in the Snowy, East Gippsland and Barwon River basins. The region contains a green triangle of more than five million hectares with the largest area of plantations in Australia including pine (softwood).

Irrigated agriculture constitutes only a small portion (0.5%) of the land use in the region (Figure 5.54). Major irrigation districts are concentrated around Lake Glenmaggie in the Thomson River basin and Bacchus Marsh and Werribee in the Werribee River basin. The most significant irrigation area in the region is the Macalister Irrigation District that contains both irrigated pasture and horticulture. The Werribee irrigation area is important for irrigated agricultural and dairy farming. Market gardens are the dominant industry in both areas.

Water in the region is managed by the Gippsland and Southern Rural Water Corporation that delivers water to the Macalister, Werribee and Bacchus Marsh districts. These districts use about 145 GL and 330 GL from surface and groundwater each year. The storages in four major catchments, such as the Macalister, Werribee, Maribyrnong and Latrobe, are also managed by this corporation. The Werribee, Bacchus Marsh and Macalister irrigation areas are described in more detail in subsections 5.7.4–5.7.5.

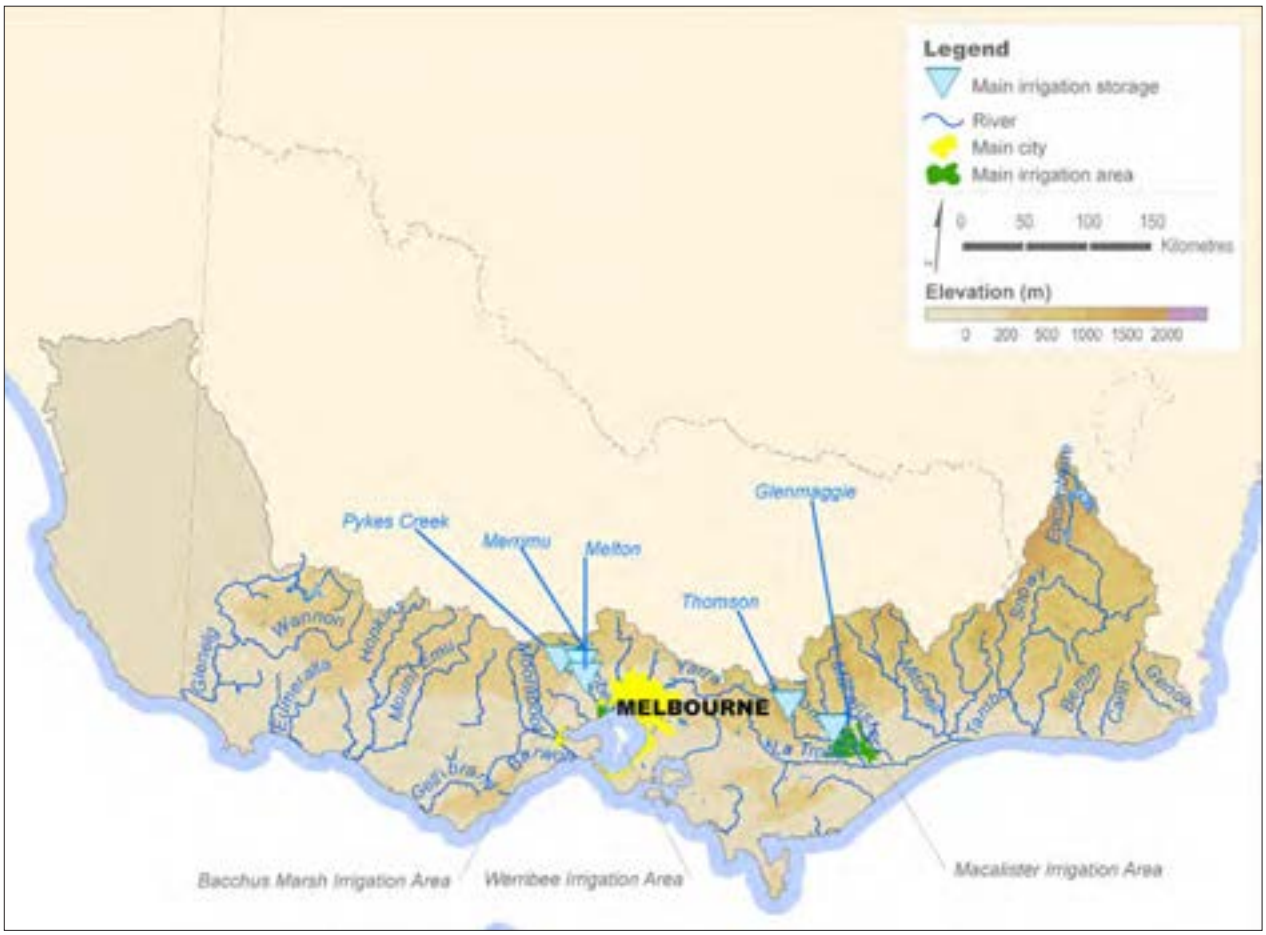


Figure 5.54 Irrigation areas in the South East Coast (Victoria) region

5.7.4 Werribee and Bacchus Marsh irrigation districts

The Werribee and Bacchus Marsh irrigation districts are located in the Werribee basin that has a temperate climate with most rain in winter and spring (Figure 5.55). The combined capacity of the Werribee system storages is approximately 69 GL (Melton, Pykes Creek and Merrimu storages). This capacity is allocated between irrigation (62%) and urban (28%) water use, with the remaining 10% retained as an unallocated share.

The Werribee system has some of the highest percentages of water trading in Victoria and trading occurs across the whole system between Werribee and Bacchus Marsh irrigators and river diverters. River entitlements have been in place in the Werribee basin since 2001 as a further source of water.

Most farms in the Bacchus Marsh district have on-farm dams to store water prior to irrigation, which provides flexibility to manage crop water demands. The Bacchus Marsh irrigation district receives its irrigation supply via a weir on the Werribee River east of Ballan as well as a second diversion weir located west of Bacchus Marsh on the Werribee River. The maximum capacity of the supply system is 105 ML/d at the Bacchus Marsh Weir, although during the millenium drought it rarely operated at flows higher than 70 ML/d.

Treated recycled water from Melbourne's Western Treatment Plant has been available to the Werribee district irrigators since 2004. Melbourne Water supplies up to 65 ML/d of recycled water as a supplementary water source. Recycled water is mixed with river water to reduce salinity levels before it is supplied to irrigators. However, heavy rainfall, turbidity-related issues caused by wind, and algal outbreaks affect reliability of river water for mixing.

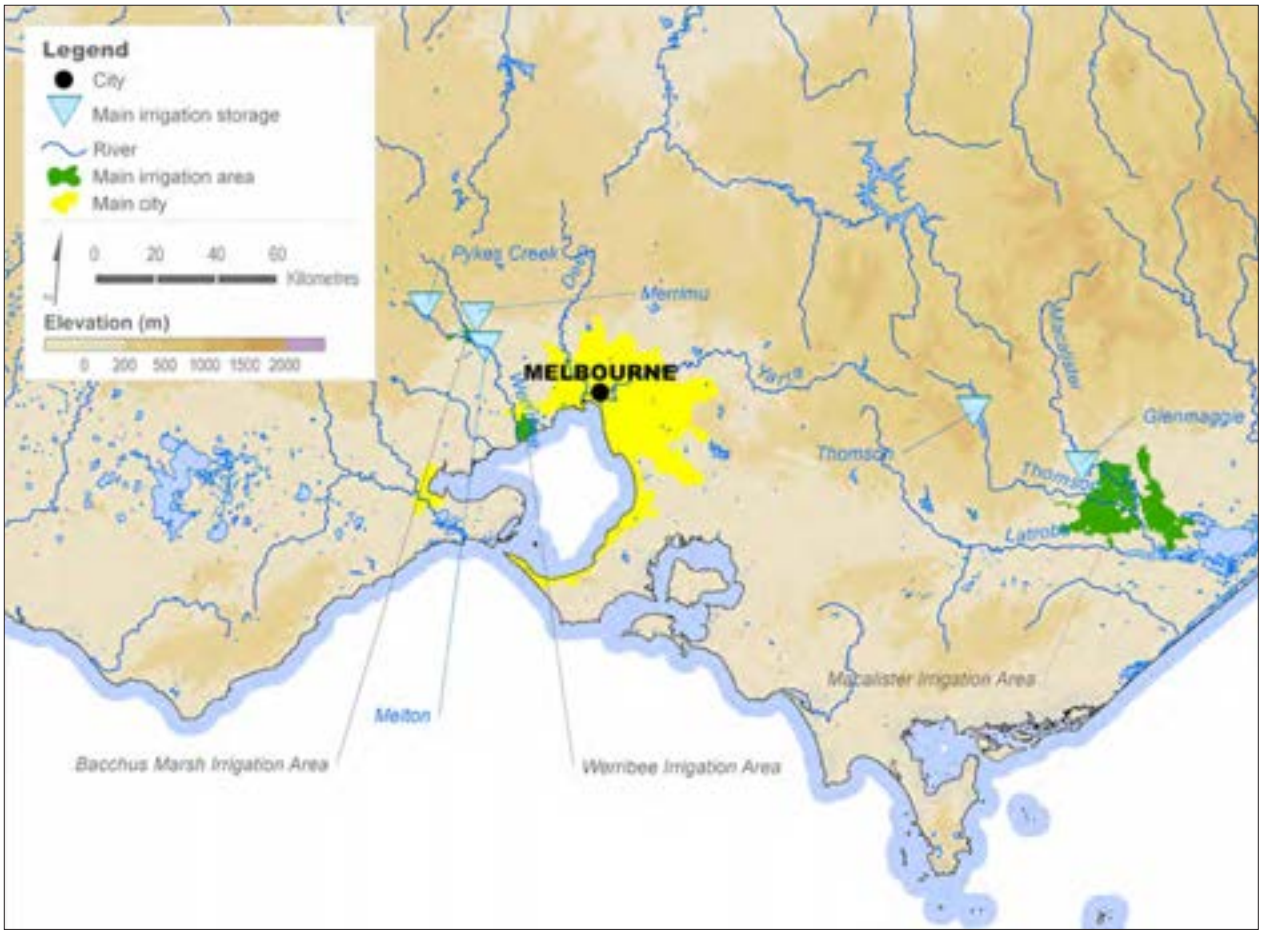


Figure 5.55 The Macalister, Werribee and Bacchus Marsh irrigation districts

The following example of Pykes Creek storage shows the storage had reached full capacity in 2010 which continued for half of the 2011–12 year. The inflows to the storage was not adequate enough to keep it full for the rest of the period (Figure 5.56).

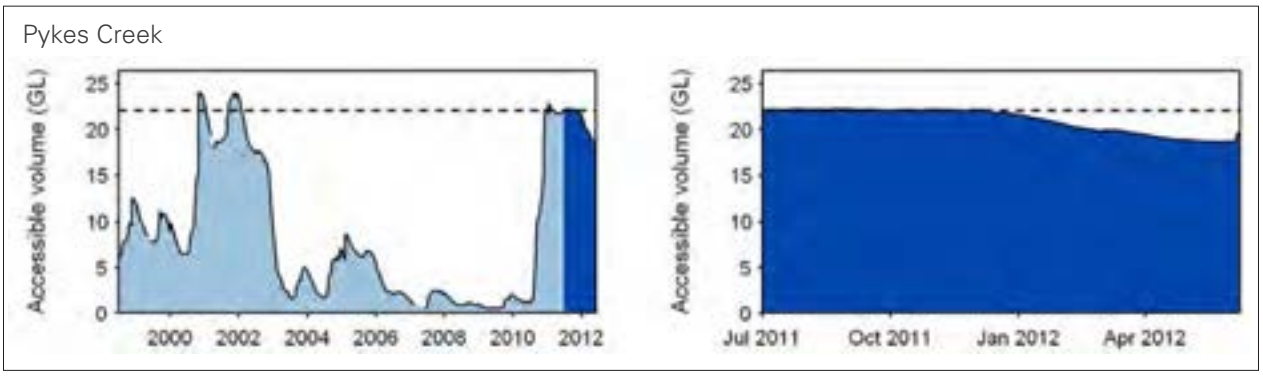


Figure 5.56 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for the Pykes Creek, as well as total accessible storage capacity (dashed line)

5.7.5 Macalister Irrigation District

The Macalister Irrigation District is the largest irrigation area south of the Great Dividing Range, extending from Lake Glenmaggie to near Sale along the Macalister River (Figure 5.55). The majority of the land used for irrigation is under pasture.

Lake Glenmaggie is the main source of supply for the Macalister Irrigation District, situated on the Macalister River. It covers an area of 1,760 ha and has an accessible storage capacity of 190 GL. The lake usually fills up during winter and spring and levels decline gradually during the summer months. Thomson, with an accessible storage capacity of 1,068 GL, also partially supplies the Macalister Irrigation District.

Irrigation allocations from Lake Glenmaggie each year are a function of three phases: a filling phase starting at the beginning of the irrigation season on 1 July; a spilling phase when the lake has filled (October–December); and an emptying phase when the drawdown of lake levels begins. If the dam spills, all water used from the start of the season is referred to as Spill Entitlement or off-quota and allocation use is reset to zero. The maximum volume of Spill Entitlement is 62,000 ML/yr. During the emptying phase, a high reliability water share (HRWS) and a low reliability water share (LRWS) are announced depending on the magnitude of the inflows to the storage.

There is some limited groundwater use in the Macalister Irrigation District.

Surface water storage inflows

Historically, streamflow in the Macalister River peaks during late winter and spring. The flow upstream of Lake Glenmaggie, monitored at the river gauge on the Macalister River at Stringy Bark Creek, peaked in August before it dropped to historic low levels, but maintained average to high flows afterwards. During March and July 2012 the flows were much above historic average flows (Figure 5.57). This situation coincided with a period when rainfalls exceeded the 90th percentile in the region and resulted in landscape water yields that were at historically high levels.

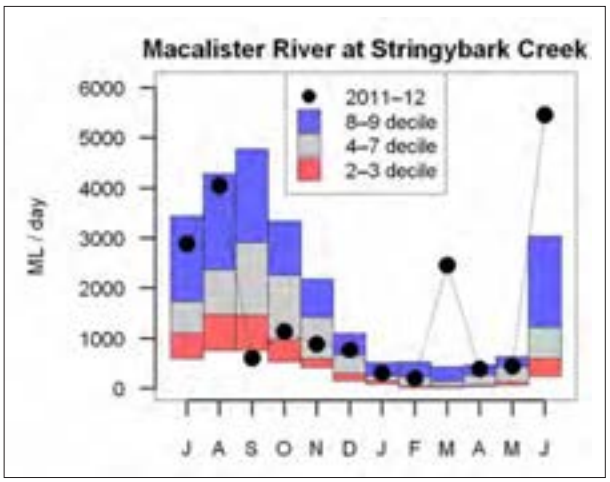


Figure 5.57 Monthly discharge hydrographs compared to discharge deciles at a reference gauge for inflows to Lake Glenmaggie

All this caused the water availability from Lake Glenmaggie in 2011–12 to be at its highest on record. The seasonal allocation opened at 90% HRWS with Lake Glenmaggie spilling. The allocation increased to 100 per cent HRWS in February 2012. In addition, 15.8 GL of spill entitlement was delivered between July and December 2011.

High rainfall during February and March caused total water deliveries for the season to be 86 GL, which is below the average delivery and below delivery budget of 163 GL. (Southern Rural Water 2012).

Surface water storage volumes

Historical data of stored water volume in Lake Glenmaggie show that storage levels reach their maximum capacity during winter and spring in each year (Figure 5.58).

High inflows into Lake Glenmaggie in 2011–12, coupled with low irrigation demand, resulted in the volume in storage remaining at 138 GL or 78% of the full capacity in May 2012 at the end of the irrigation season. This situation provided a good start for the 2012–13 season (Southern Rural Water 2012).

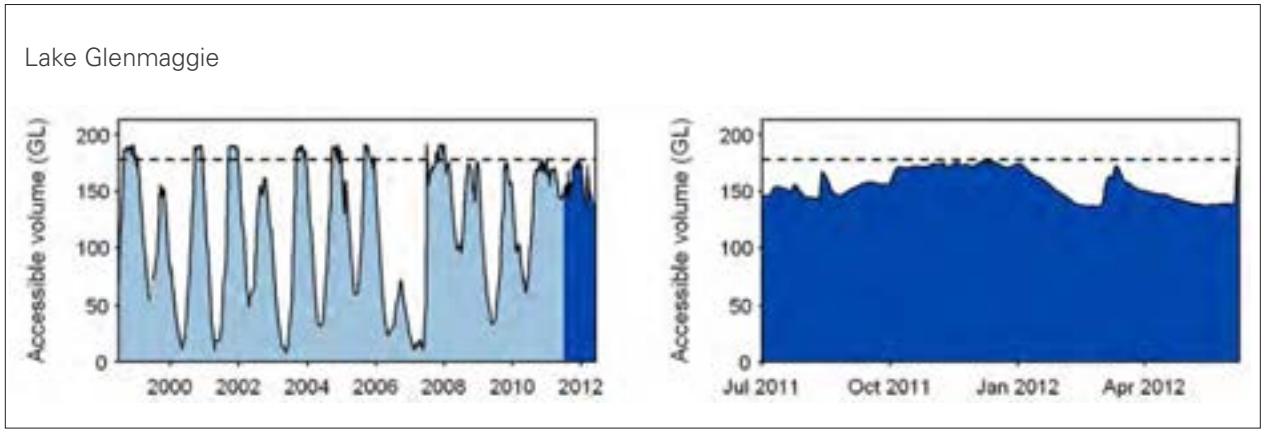


Figure 5.58 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for the Lake Glenmaggie storage as well as total accessible storage capacity (dashed line)

Local Hydrogeology

The Macalister Irrigation District (shown in Figure 5.59) is underlain by relatively complex groundwater systems. This is also reflected in the large number of groundwater management areas that overlay the irrigation area. There are at least five management units that regulate groundwater extraction at various depths for different aquifers.

The Boisdale Aquifer (upper middle aquifer) that occurs throughout the area provides a valuable source of water for irrigation of pasture for dairy production, vegetable cropping and stock and domestic supply. The Boisdale aquifer is underlain by the Latrobe Valley Group (lower middle and lower aquifer), grading easterly into the Balook Formation (lower middle aquifer) and the Gippsland Limestone aquifer (lower middle aquifer). Declining groundwater levels in these deeper aquifers as well as in the Boisdale aquifer is a well documented phenomenon resulting from the combined effects of offshore gas and oil extraction, dewatering of the Latrobe Valley coal mines and pumping for irrigation.

The degree of interaction between surface water and groundwater is high. The Latrobe, Thomson, Macalister and Avon are the major rivers in the area and they gain groundwater during low flow; by contrast rivers recharge the alluvial aquifers during floods (Southern Rural Water 2012). The eastern portion of the area includes Lake Wellington, Lake Victoria and Lake Reeve, which are part of the Gippsland Lake systems. The current accepted view is that groundwater discharges into the lakes as well as to the sea.

Groundwater quality overview

Clearing and irrigation has significantly altered the hydrogeological regime in the irrigation area, increasing the infiltration to the shallow watertable and causing discharge of shallow saline groundwater. In addition, the recent lowering of the groundwater levels near Lake Wellington below the lake level has focused attention on the potential to draw saline water from the lake and the sea into the aquifer.

Influences on shallow groundwater

Fluctuations in shallow groundwater levels at selected sites are shown in Figure 5.60. To investigate the drivers of the shallow groundwater levels, fluctuations in the groundwater levels '(a)' are compared to the monthly rainfall trend, shown by cumulative residuals from the historic average at Sale '(b)', the monthly discharge of the Macalister River '(c)' and the monthly average level of Lake Wellington '(d)'. Locations of gauges and bores are shown in Figure 5.59.

Periods in which the cumulative rainfall residual mass curve rises indicate wetter than average conditions. Periods with a falling trend indicate drier than average conditions.

Panel two in Figure 5.60, shows a wetter than average period up to 1996, followed by drier that average period until 2010 and since then wetter than average condition. This is reflected by groundwater levels which are lower on average after 1996 compared to before 1996 and show a rise in level at two bores after 2010.

Seasonal pumping and recovery cycles are also visible in all bores except Bore 92297. Step rises indicates groundwater response to flooding, for example in 2007. Although some of the groundwater levels show some degree of correlation with the river discharge there is no major correlation to lake levels.

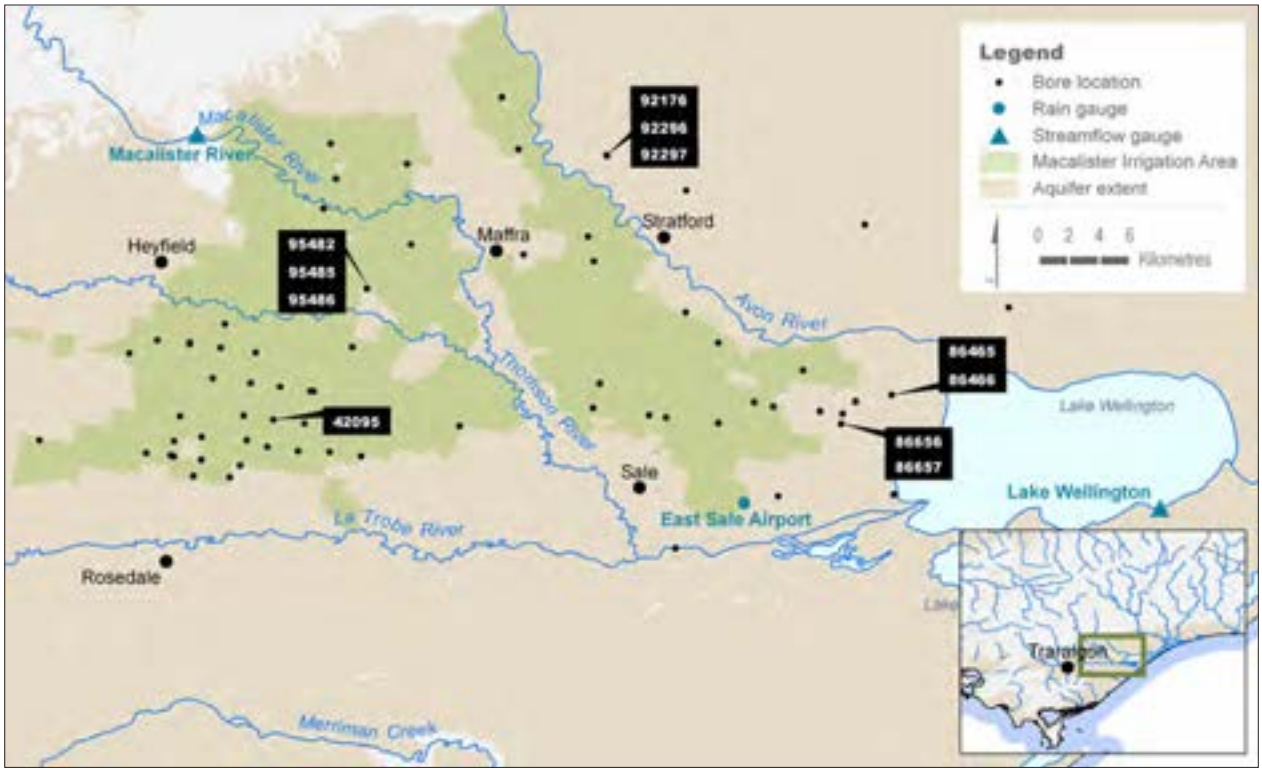


Figure 5.59 The Macalister Irrigation District showing the location of groundwater bore sites, river gauges, lake gauges and rain gauges

A telemetered bore in Glenelg-Hopkins | Thiess Services

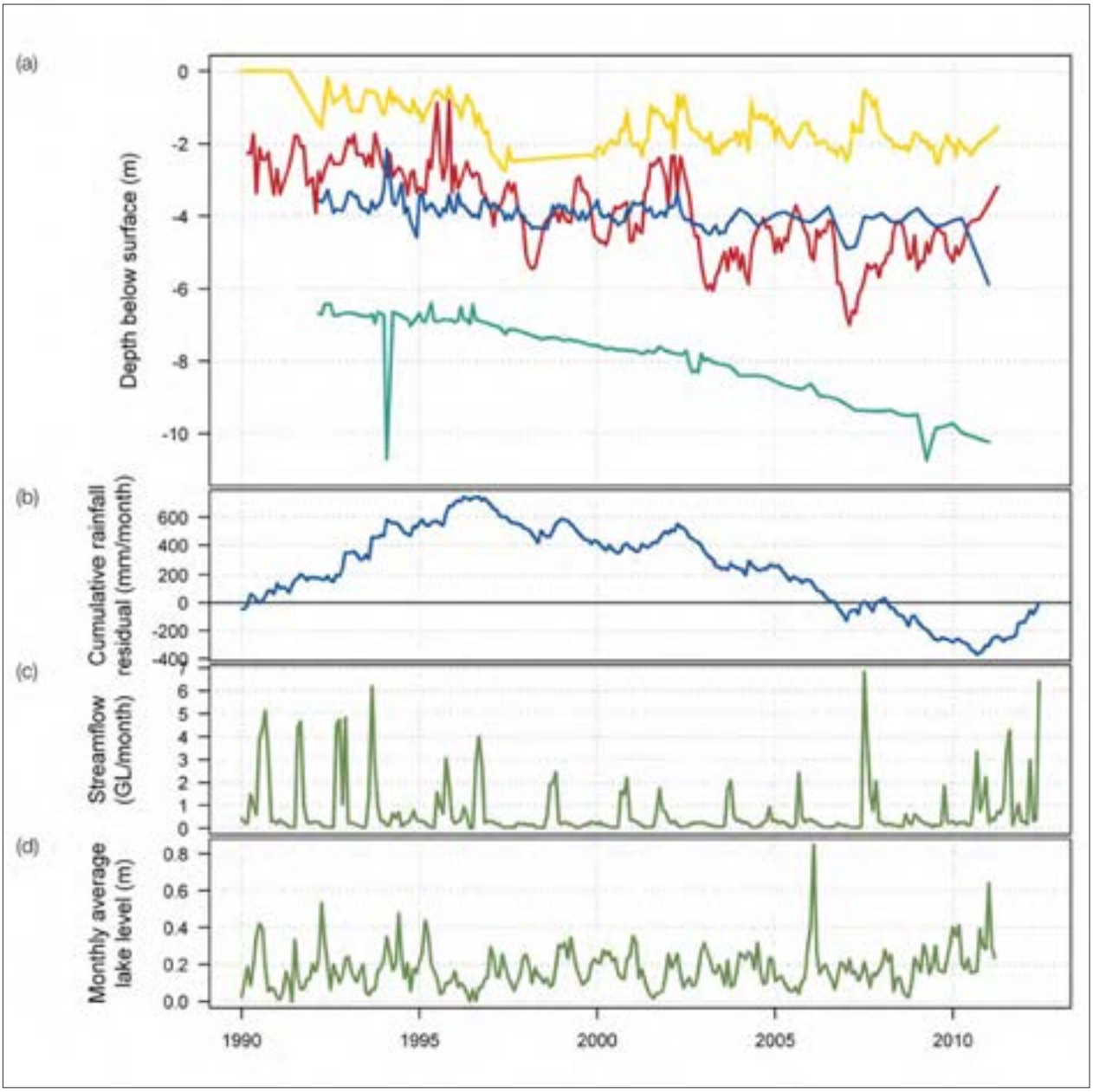


Figure 5.60 (a) Comparison of shallow groundwater levels recorded at nested bore sites with rainfall, streamflow and Lake Wellington water levels in the Macalister Irrigation District (Bore 86657—yellow, Bore 42095—red, Bore 95486—blue, and Bore 92297—green; (b) cumulative rainfall residual mass at Sale Station no. 85072; (c) Macalister River discharge at Glenmaggie, Station no. 225204; and (d) Lake Wellington level at Bull Bay, Station no. 226041.

Groundwater level

Groundwater level measurements are an important source of information about hydrological and anthropological influences on the groundwater in an area, including recharge. Figure 5.61 illustrates groundwater levels recorded in bores of different depth at the same site in the Macalister Irrigation District in the last five years.

Groundwater level fluctuations in the area generally indicate upward gradients and potentially groundwater flow from the deeper aquifers (blue lines) to the shallower aquifers (red and yellow lines). However, gradients and potentially groundwater flow can be reversed during intense pumping from the lower aquifer (for example, blue line in site 1) as in 2010 and 2012. Figure 5.61 also shows in general poor connectivity between various aquifers at various depths. Groundwater levels show different patterns at different location and depth except for shallow bores 95485 and 95486.

Figure 5.62 and Figure 5.63 show the spatial distribution of depth to groundwater in bores located in the upper and middle aquifers in the Macalister Irrigation District. They also give the ranking of 2011–12 median groundwater levels compared to annual median groundwater levels in the last 22 years (1990–2012).

As shown in Figure 5.62, typically groundwater levels in the upper aquifer are mostly within 5 m of the surface. Median groundwater depth below surface in 2011–12 is typically above average or average in the southwest and in the rest of the area is average or below average.

Groundwater levels below surface in the middle aquifer vary from greater than 10 m away from Lake Wellington to above the surface (flowing artesian) near the lake (Figure 5.63). Median groundwater depth in 2011–12 is mostly below average or average, indicating that groundwater levels are the deepest or within the average of the past 22 years.

Groundwater levels from bores screened in the lower aquifer are not shown as there are not enough data available to provide a useful assessment of groundwater conditions in this aquifer.

Groundwater salinity

At the time of writing, suitable quality controlled and assured time-series data on groundwater salinity were not available from the Australian Water Resources Information System (the Bureau of Meteorology 2011).

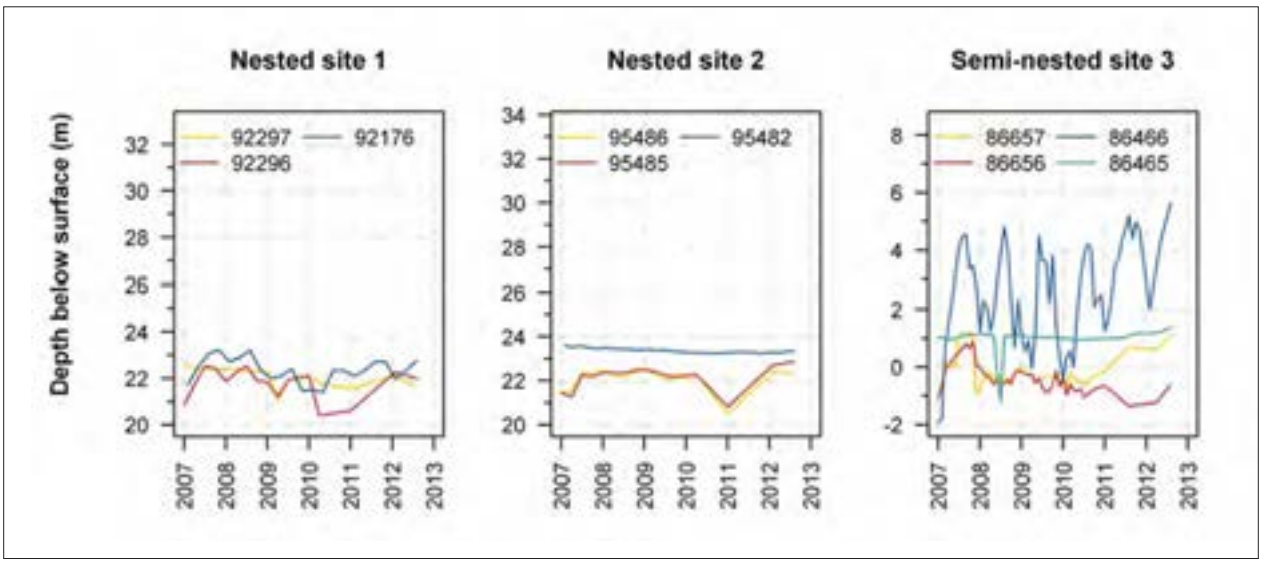


Figure 5.61 Groundwater levels between 2007 and 2012 recorded at selected nested bore sites in the Macalister Irrigation District

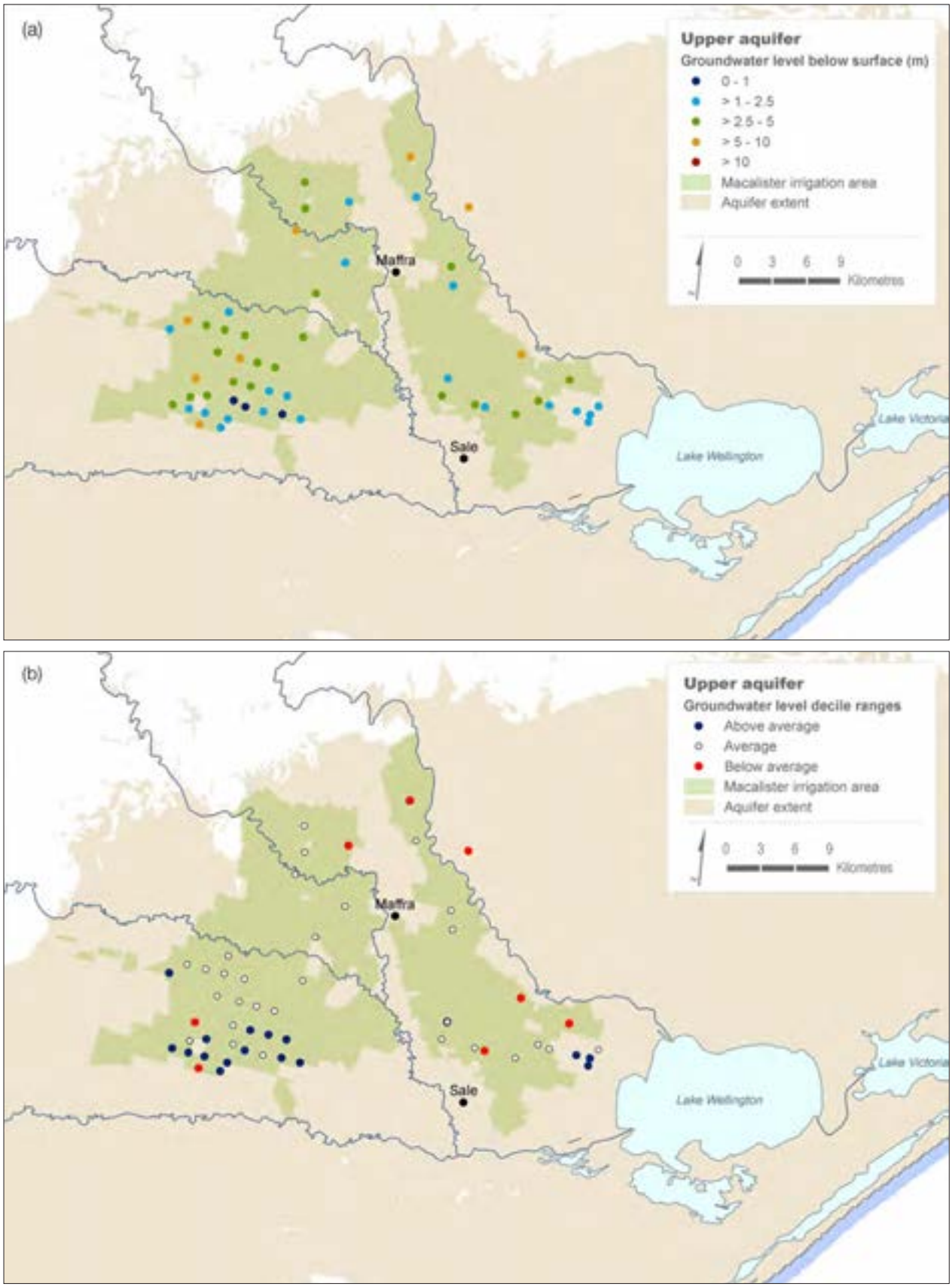


Figure 5.62 (a) Upper aquifer median groundwater depth for the Macalister Irrigation District in 2011–12; and (b) decile rank of depth in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

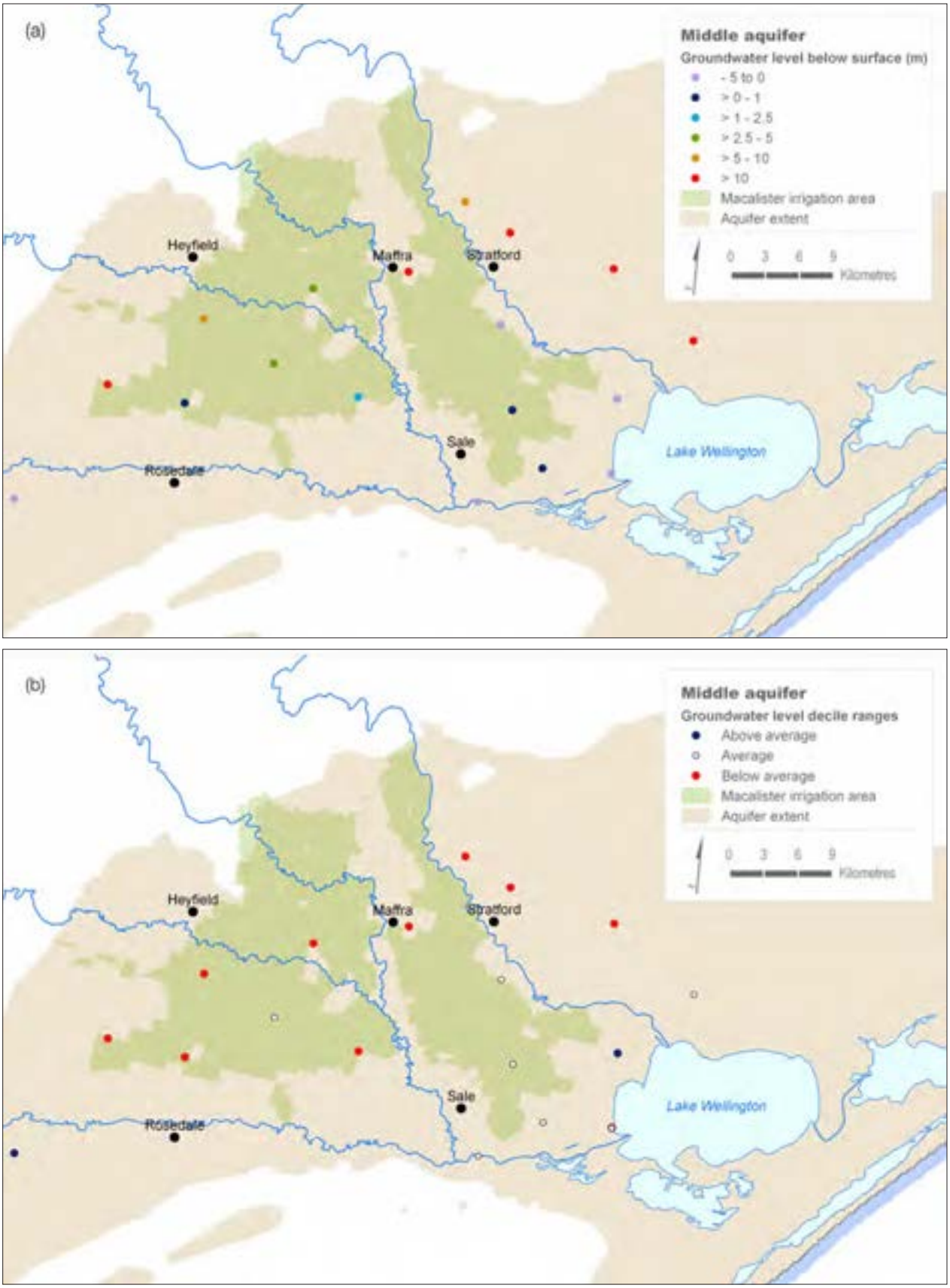


Figure 5.63 (a) Middle aquifer median groundwater depth for the Macalister Irrigation District in 2011–12; and (b) decile rank of depth in 2011–12 compared to the 1990–2012 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

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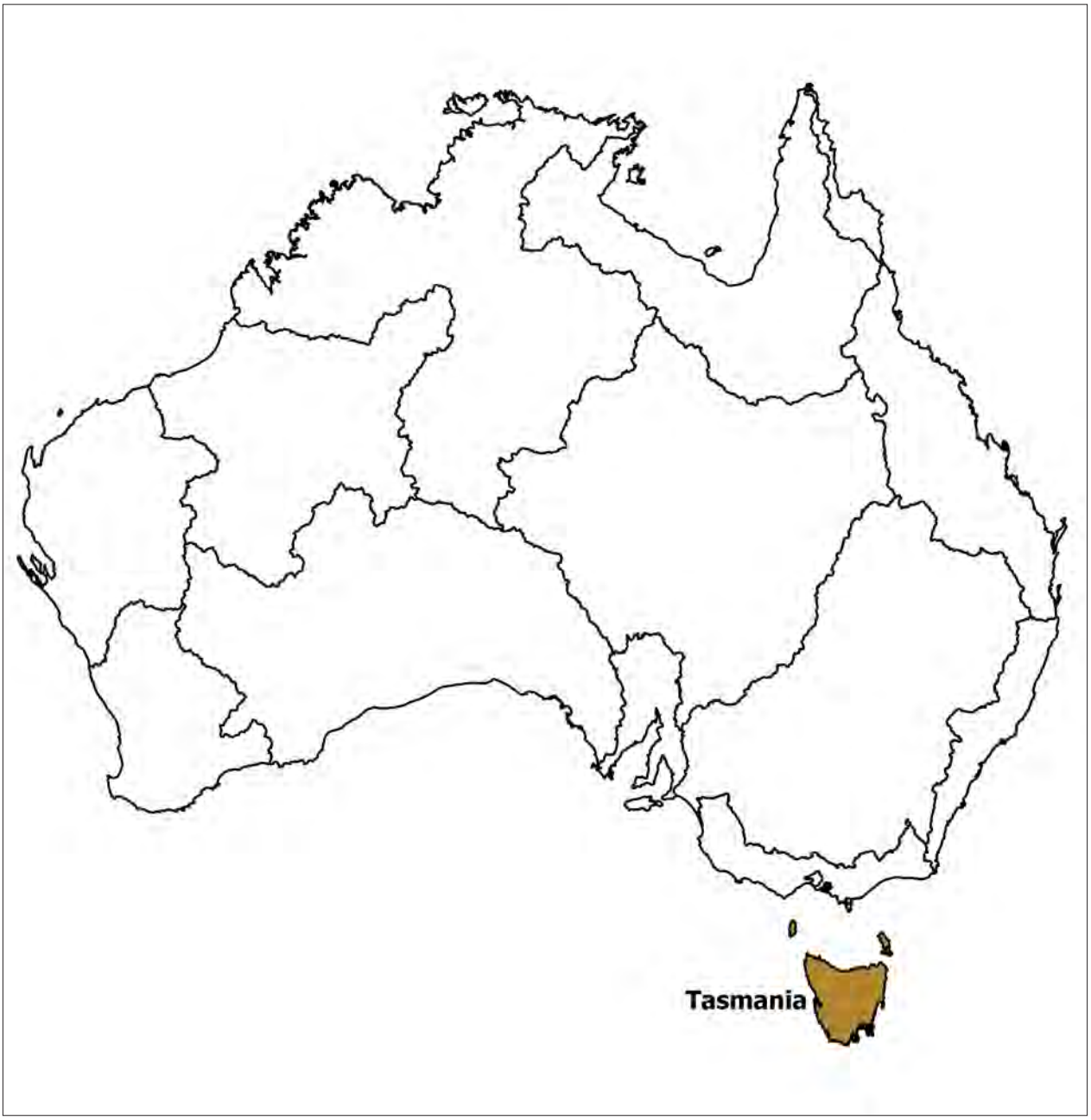
6 Tasmania

6.1 Introduction

This chapter examines water resources in the Tasmania region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.



6.2 Key information

Table 6.1 gives an overview of the key components of the data and information in this chapter.

Table 6.1 Key information on water flows, stores and use in the Tasmania region

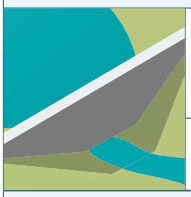
Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	1,396 mm	+2%	7th—average
Evapo-transpiration	769 mm	+3%	8th—above average
Landscape water yield	632 mm	+1%	6th—average

Streamflow (at selected gauges)

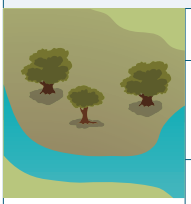
Annual total flow:	Predominantly average flow in the northern and southern rivers, mostly above average flow in the central east of the region
Flooding:	Moderate to major floods in the central east of the region

Surface water storage (comprising about 86% of the region's total capacity of all major storages)



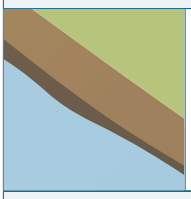
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
22,141 GL	15,672 GL	71%	13,576 GL	61%	+2,096 GL	+10%

Wetlands inflow patterns (for selected wetlands)



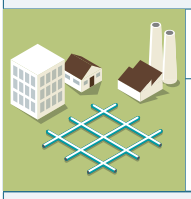
Lower Ringarooma River:	Average flows, but above average flow in August 2011
Apsley Marshes:	Very much above average flows in August 2011 and above average in May and June 2012, generally average to below average flows in the other months
Moulting Lagoon:	Very much above average flows in August 2011 and above average in May and June 2012, generally average flows in the other months

Groundwater (in selected aquifers)



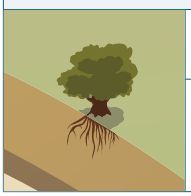
Salinity:	Non-saline groundwater (<3,000 mg/L) in most aquifers, locally some small areas with saline (≥3,000 mg/L) groundwater in the east

Urban water use (Hobart)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
40 GL	42 GL	−2 GL (−4%)	No restrictions

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly average with large areas of below average in the southwest and above average soil moisture mainly in the southeast
Temporal patterns in regional average:	Above average soil moisture at the start of the year, gradually dropping to below average in January and returning to above average by June 2012

6.3 Description of the region

The island of Tasmania is the smallest of Australia's states with a total land size of approximately 68,000 km². Though it is less than 1% of Australia's surface area the region contains about 12% of Australia's freshwater resources. It is separated from the Australian mainland by Bass Strait.

The region is largely composed of relatively fertile agricultural land, dense forests and rugged mountainous areas. The geologically and florally diverse northern regions of Tasmania include a wide variety of terrestrial, estuarine and marine ecosystems. The terrestrial ecosystems range from the vegetation and wildlife of the mountain plateaus to the wet forests and swamps of the middle elevations, the drier forests and woodlands of the lower-rainfall slopes down to the sandy hills and plains of the coast. Fertile agriculture land is also present. In the west and southwest of the region, rugged mountains, extensive forests and uninhabited coastlines are found. Subsections 6.3.1 to 6.3.4 give more detail on physical characteristics of the region.

The State-based region of Tasmania has a population of just over 0.5 million people (Australian Bureau of Statistics [ABS] 2011b). Major population centres include the State's capital, Hobart, as well as the cities of Launceston, Devonport and Burnie.

Figure 6.1 shows the major population centres for the region, while further discussion of the region's population distribution and urban centres can be found in subsection 6.3.6 and section 6.6 respectively.

The majority of Tasmania is under nature conservation land management (50%, see Figure 6.1). This is followed by forestry (23%) and pasture (21%). Irrigated and dryland cropping and horticulture makes up only a small portion (1.2%) of the land use. Section 6.7 has more information on agricultural activities in the region.

Tasmania has a cool temperate climate with high rainfall in the western highlands, and low rainfall in the lowlands and east. The northeast highlands also have high rainfall compared to their surrounds. Snowfall normally occurs in late winter and early spring. Subsections 6.3.7 and 6.3.8 provide more information on the rainfall types and deficits across the region.

Approximately 150,000 km of waterways, 8,800 wetlands and 94,000 water bodies exist in the region (Department of Primary Industries, Parks, Water and Environment 2009). River basins on the island vary in size from 685–11,700 km².

Tasmania has extensive groundwater resources located in igneous, sedimentary and metamorphic rocks, as well as unconsolidated sediments. The region's hydrogeology is dominated by large areas of outcropping fractured basement rock. The groundwater systems in fractured rock typically offer restricted low to moderate volume groundwater resources. Groundwater quality and yield is highly variable. A more detailed description of the rivers and groundwater status in the region is given in section 6.5.

Figure 6.1 Major rivers and urban centres in the Tasmania region

6.3.1 Physiographic characteristics

The physiographic map in Figure 6.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes.

The Tasmania region has two large physiographic regions that account for 75% of the total area, namely:

- East Tasmanian Hills (37%): fault block hills and mountains on dolerite, sandstone, and mudstone, with coastline formed from submerged river valleys; and
- West Tasmanian Ridge (35%): ridges of folded quartzite and conglomerate, glaciated in places, parallel valleys on weaker rocks.

Four physiographic regions occupy the remaining area. They are:

- Lakes Plateau (9%): high dolerite plateau with many lakes;
- Midlands Plain (6%): lowland on weathered sediments;
- Bass Coastal Platforms (6%): low coastal platforms; and
- North West Ramp (3%): incised basalt ramp including coastal cliffs.

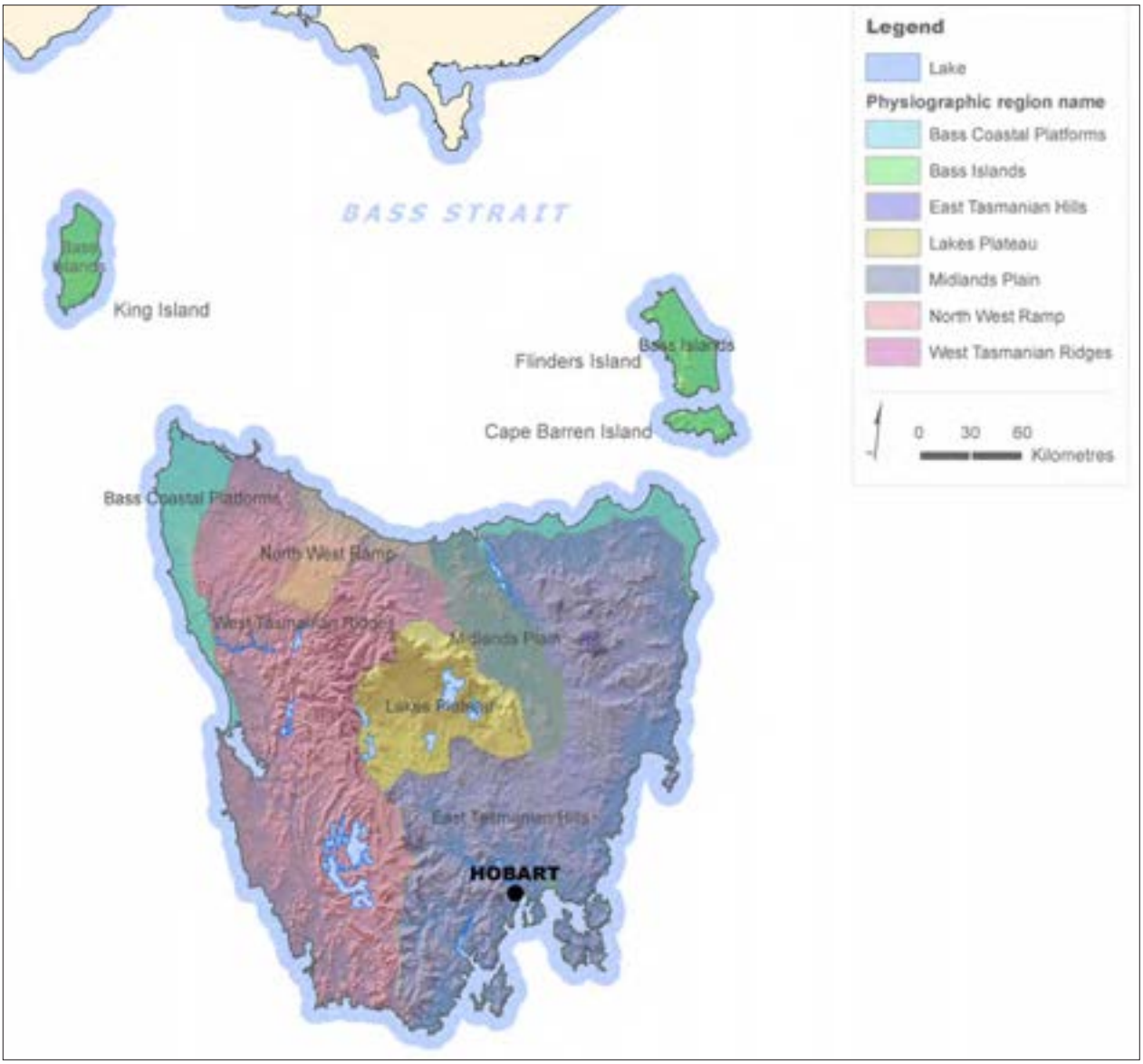


Figure 6.2 Physiographic provinces of the Tasmanian region

6.3.2 Elevation

Figure 6.3 presents ground surface elevations in the Tasmania region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The centre of Tasmania forms the highest part of the region, with peaks exceeding 1,500 m above sea level. It contains a plateau called the Central Highlands, on which a substantial number of lakes have formed.

Coastal plains are generally absent. The north coast is the most accessible, which is noticeable by the many harbour towns along the coast. The city of Hobart is built on the flanks of the Derwent River.

Much of the western part of the island is in use for hydroelectricity generation by Hydro Tasmania. The abundance of rainfall and the presence of deep valleys form an ideal landscape for this particular industry. The area is almost totally protected under nature conservation regulations.

The three major islands north of Tasmania, that is, Flinders and Cape Barren islands to the east and in particular King Island to the west, are less mountainous.

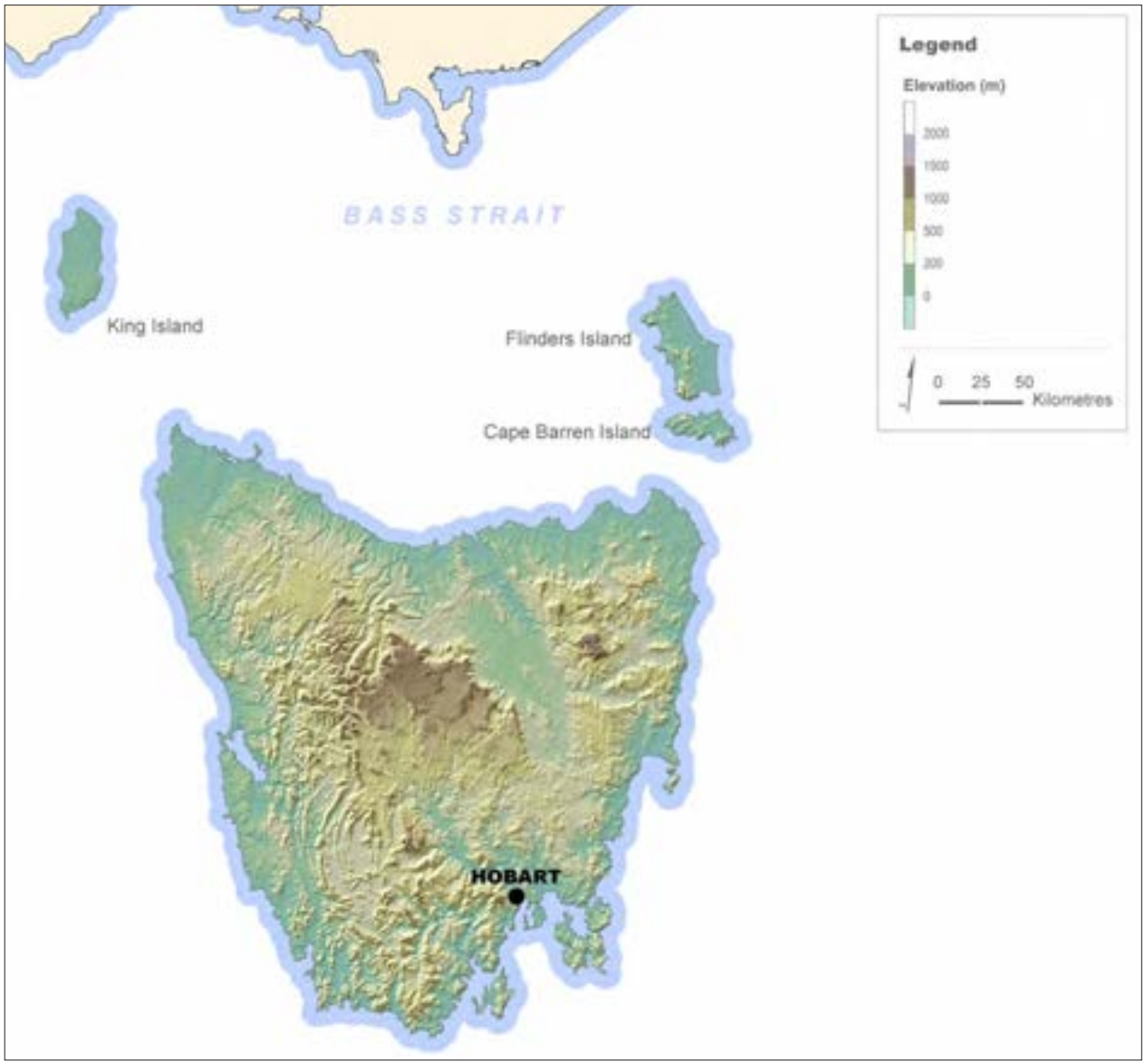


Figure 6.3 Ground surface elevations in the Tasmania region

6.3.3 Slopes

Table 6.2 summarises the proportions of slope classes for the region, while Figure 6.4 shows the spatial distribution for the surface slopes. Areas with steep slopes provide higher run-off generating potential than flat areas. The Tasmania region has the highest coverage of steep slopes in relation to the rest of Australia. The slopes were derived from the elevation information used in the previous section.

Table 6.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	3.4	4.6	29.9	62.1

Figure 6.4 presents surface slopes in the Tasmania region. Steep slopes generally inhibit commercial use of the land other than forestry and natural conservation/recreation. This is partly why almost 75% of the land use in the region falls in these categories.

In between the steep slopes some flat areas can be noticed. Most of these are very large lakes, with the exception of the larger area in the central northeast, which are the alluvial plains of the Macquarie and South Esk rivers.

Figure 6.4 Surface slopes in the Tasmania region

6.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 85% of the Tasmania region is covered by five soil types, namely tenosols, dermosols, sodosols, kurosols as well as organosols (Figure 6.5 and Figure 6.6).

Tenosols, sodosols and kurosols soils have a low agricultural potential due to low chemical fertility and water-holding capacity.

Tenosols are distributed along the west coast as well as in central to northern parts and scattered around the east coast of the region.

Sodosols are only common in the east of the region. These soils have a strongly contrasting texture, with a relatively impermeable sodic and clay enriched subsoil. They are prone to tunnel and gully erosion due to soil dispersion and structural instability. They are also at risk of dryland salinity.

Kurosols are common in the northeast and southeast of the region. They are usually strongly acidic (pH < 5.5).

Dermosols have higher agricultural potential. They have moderate to high chemical fertility and are common in the northwest and northeast of the region. These soils are well structured and have a high water-holding capacity. They co-exist with highly fertile and well-drained ferrosols that together with the moderate climate, result in a very productive agricultural zone.

Organosols soils are rich in organic material throughout the profile and are found in the wet and forested southwest of the region.

The other soil types that have minimal representation in the region are ferrosols, chromosols, podosols and rudosols (0.5–5% of the total area).

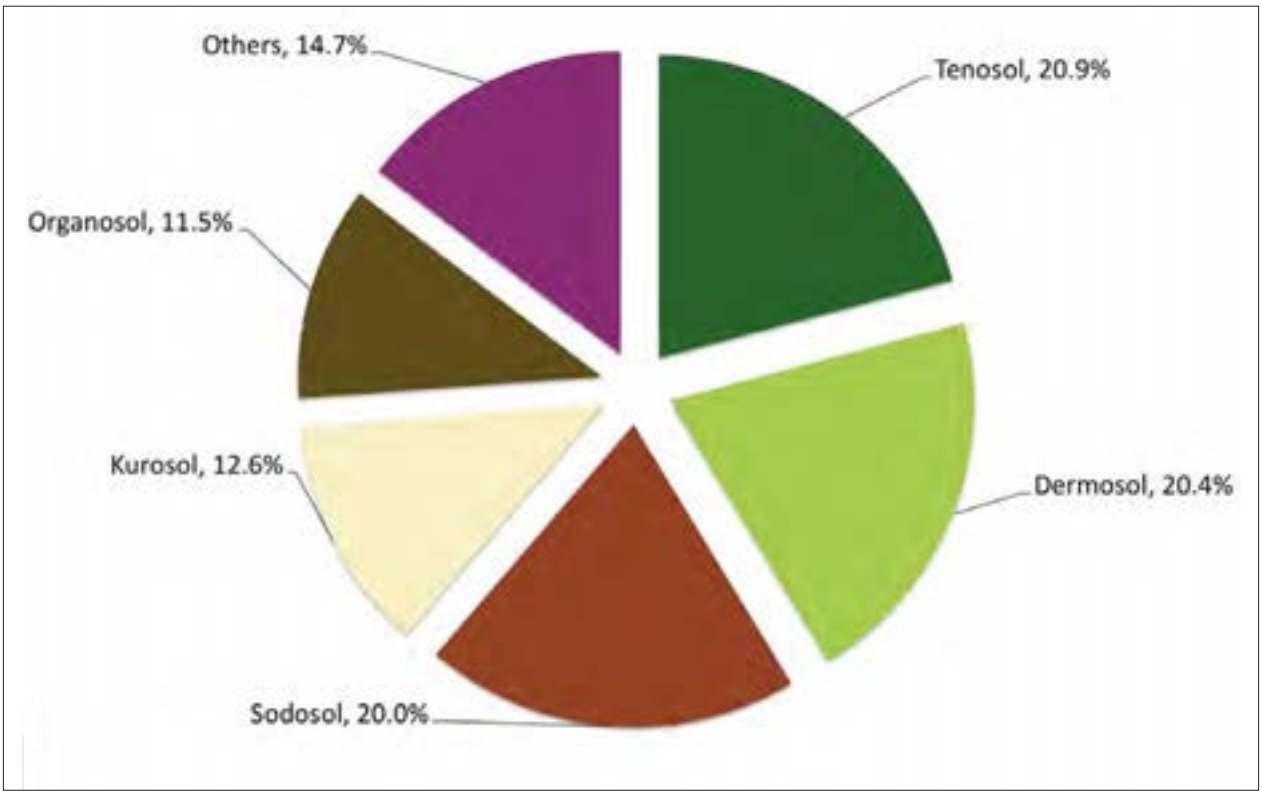


Figure 6.5 Soil types in the Tasmania region

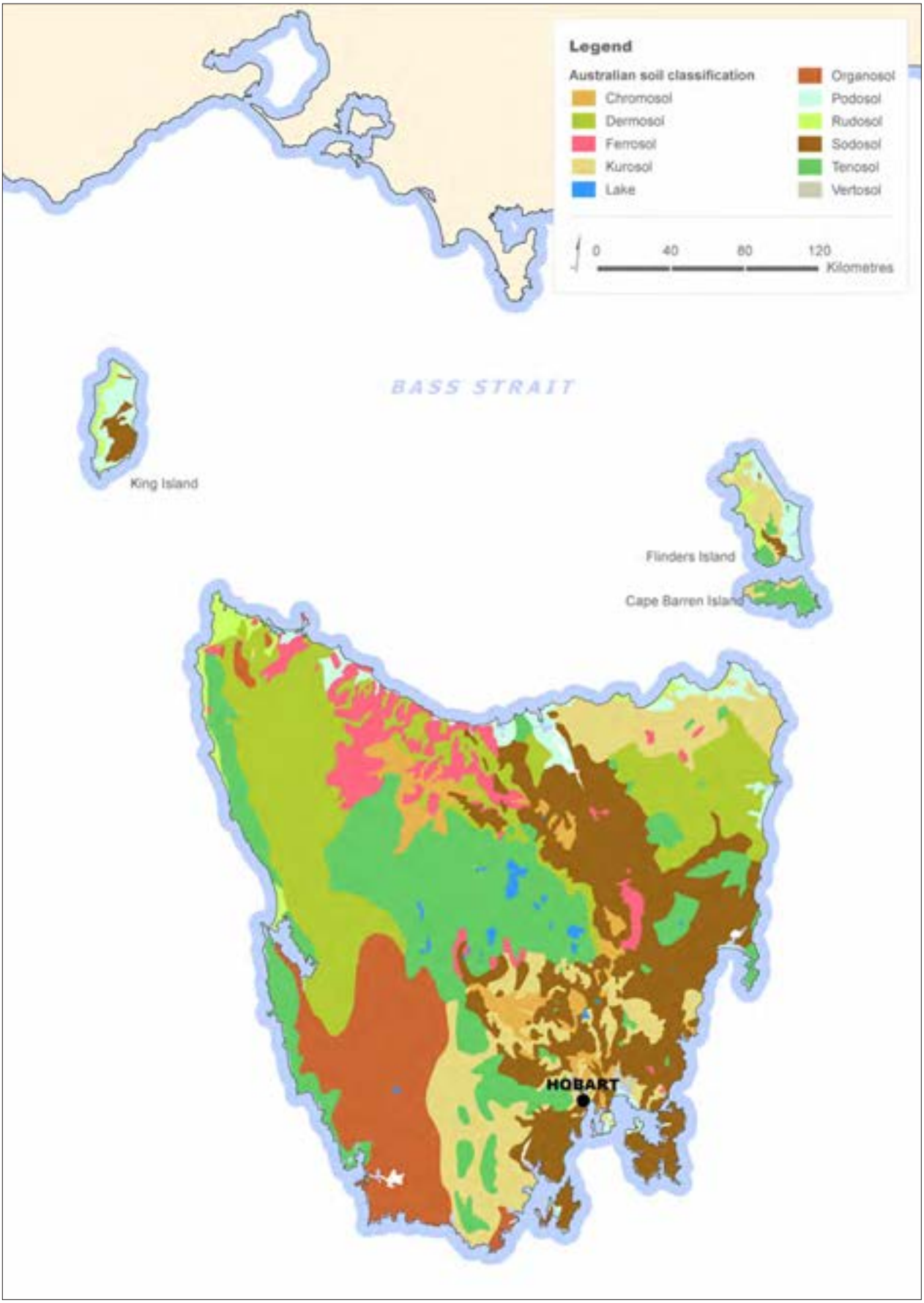


Figure 6.6 Soil type distribution in the Tasmania region

6.3.5 Land use

Figures 6.7 and 6.8 presents land use in the region (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). The majority of the region is under nature conservation, and this is followed by forestry and pasture. Irrigated and dryland cropping and horticulture make up only a small portion of the land use.

The landscape is heavily forested and mountainous. In the north, a wide variety of terrestrial, estuarine and marine environments can be found that include:

- the vegetation and wildlife of the mountain plateaus;
- the wet forests and swamps of the middle elevations; and
- the drier forests and woodlands of the lower-rainfall slopes; and sandy coastal hills and plains.

Fertile agriculture land is also present in the north. The west and southwest of the region is covered with rugged mountains, extensive forests and uninhabited coastlines.

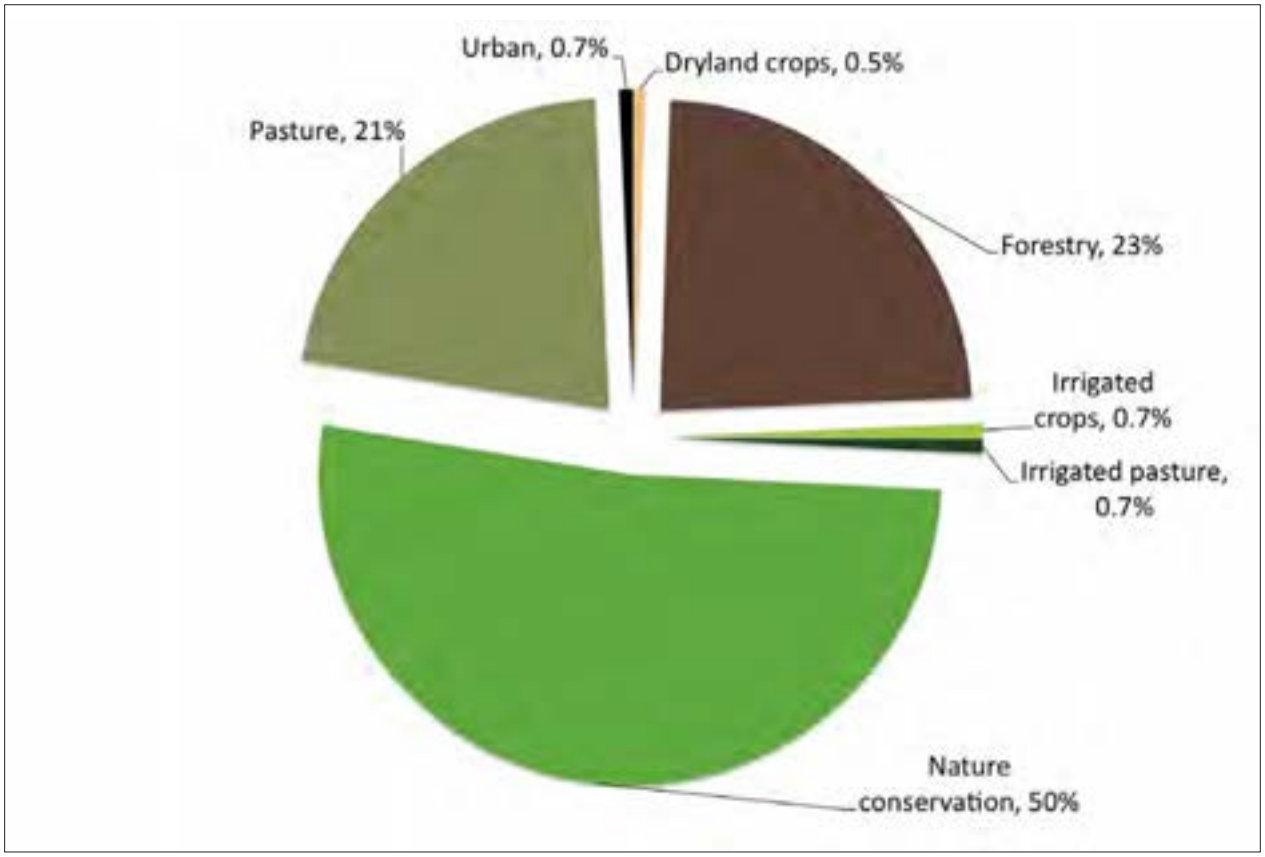


Figure 6.7 Land use in the Tasmania region

Figure 6.8 Land use distribution in the Tasmania region

6.3.6 Population distribution

The Tasmania region, with a total population of 494,000 people, represents just over 2% of Australia's total population. Figure 6.9 shows the spatial distribution of population density (ABS 2011b).

The region's population is divided in two major concentrations. In the south, the population is concentrated mainly around Hobart, and in the north around the north coast that includes the major towns of Launceston, Devonport and Burnie.

Agriculture is a major driver for many communities, and Launceston, Devonport and Burnie provide important ports for exporting the produce to the Australian mainland and beyond.

The central and western districts are sparsely populated and mostly devoted to nature conservation. Mining, forestry and tourism are the major drivers for many of the more remote towns located throughout the west of the State.

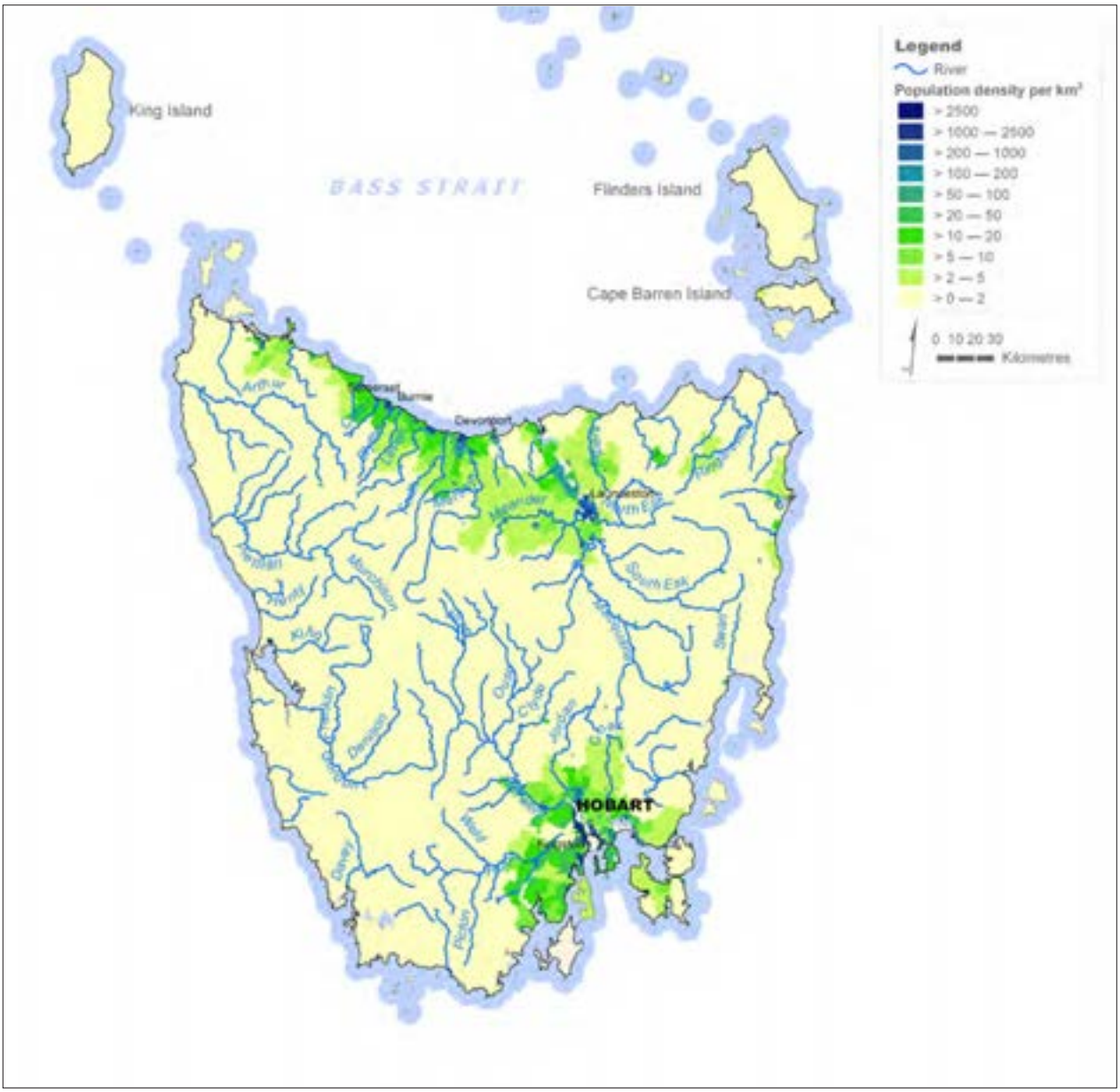


Figure 6.9 Population density and distribution in the Tasmania region

6.3.7 Rainfall zones

Tasmania has a cool temperate climate with high rainfall and snowfall in the western highlands, and low rainfall in the lowlands and east. The northeast highlands also have high rainfall (partly as snowfall) compared to their surrounds. Median rainfall exceeds 500 mm throughout (Figure 6.10).

Median annual rainfall exceeds 1,000 mm in the west. In the southeast, the rainfall is more uniformly distributed over the year and the median annual totals are mostly below the 800 mm, with the exception of highlands in the northeast.

For more information on this and other climate classifications, visit the Bureau's climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

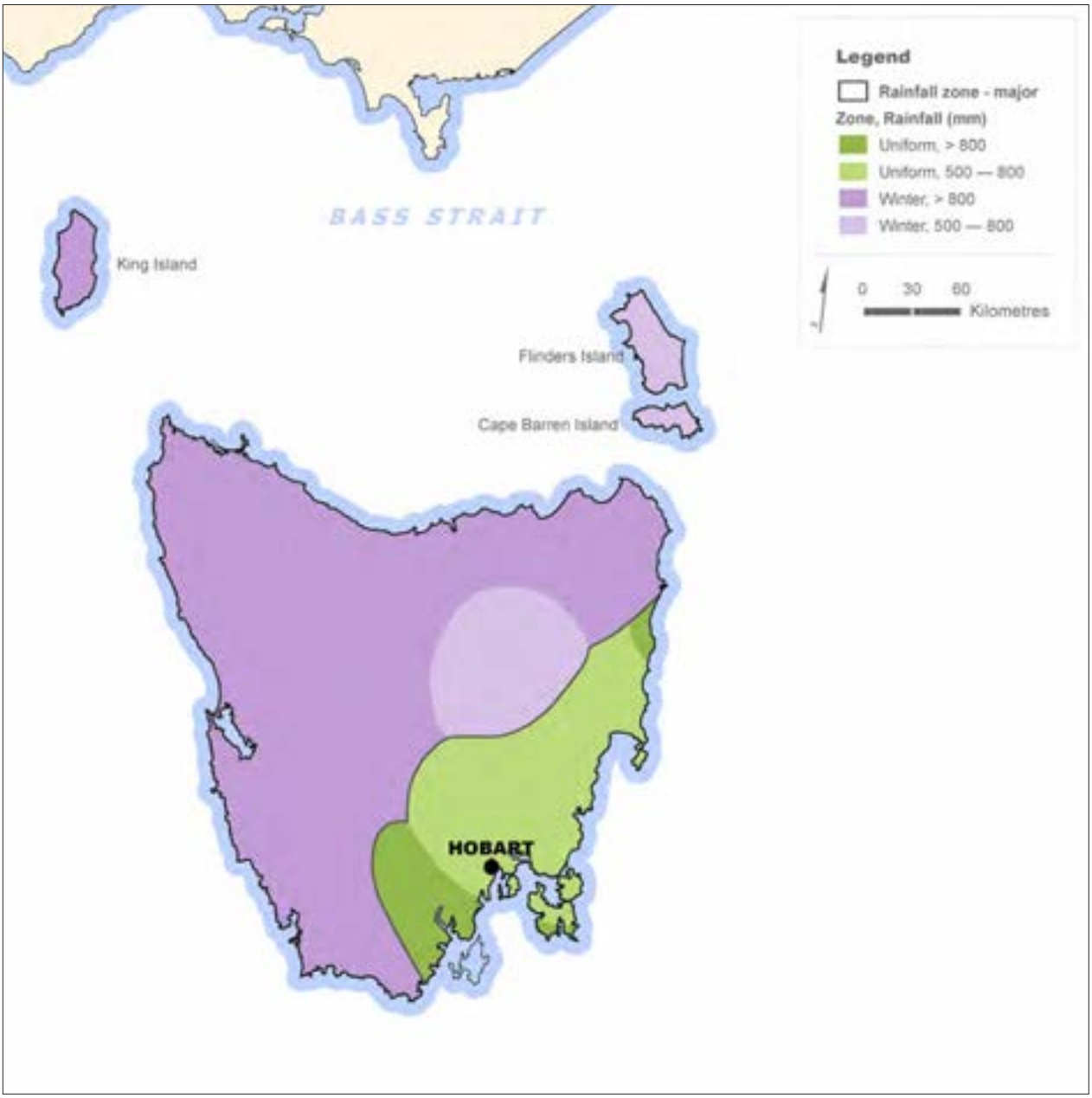


Figure 6.10 Rainfall zones in the Tasmania region

6.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The Tasmania region in general has relatively limited areas of minor moisture deficit potential (Figure 6.11) in comparison to the rest of Australia.

Due to the lower temperatures and solar radiation levels, potential evapotranspiration in the region is relatively low. Hence, rainfall deficits mostly occur only in those areas where rainfall itself is a limiting factor.

In the west and central areas, the general abundance of water over the year is used to generate hydroelectricity. Hydro Tasmania uses this energy source to supply the majority of Tasmania's electricity. Major reservoirs are located in the area.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

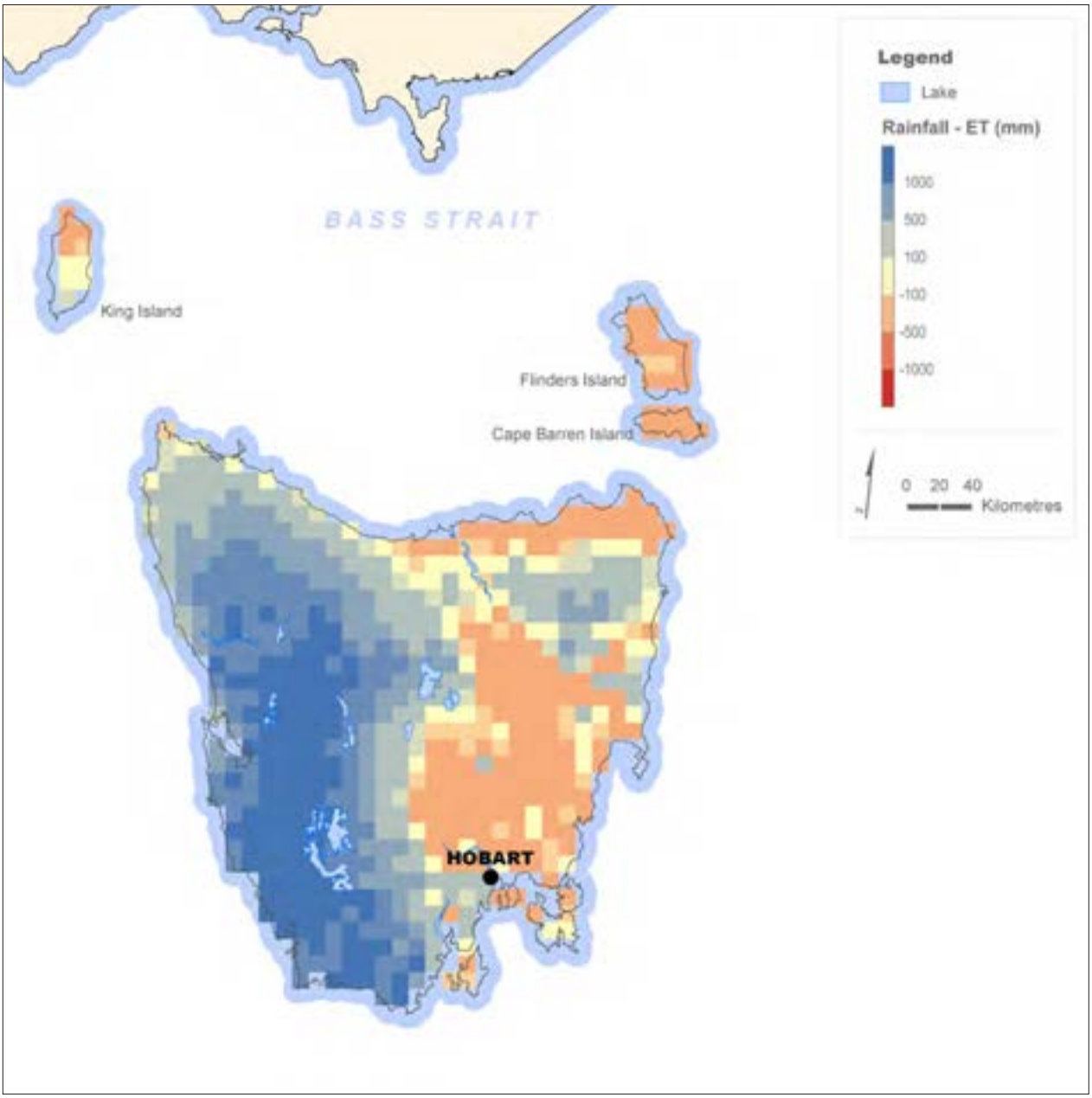


Figure 6.11 Rainfall deficit distribution for the Tasmania region

6.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Tasmania region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 6.12 shows the region has a seasonal rainfall pattern with a wet winter and a drier summer period. However, in particular in this region, local anomalies can occur. The bandwidth of historic evapotranspiration data is small, which indicates that the constraint on evapotranspiration is mainly energy-driven. Evapotranspiration in the summer period occasionally exceeds rainfall, as the soils normally contain moisture available for evapotranspiration. The monthly landscape water yield history for the region shows a pattern that is closely linked to rainfall.

The 2011–12 year was relatively average, with no major extremes in the monthly rainfall exceeding the 10th–90th percentile range. There was also no dry or wet period identifiable for consecutive months.

Evapotranspiration rates were relatively high for the months of November and December. Very much above average temperatures were measured throughout the region for November, which provided additional energy for the evapotranspiration processes. For the rest of the year, the evapotranspiration closely followed the historic pattern.

As with the historic records, the landscape water yield for 2011–12 closely followed the rainfall pattern with the exception of November, when the higher rainfall was largely absorbed by the soil and consequently evaporated back to the atmosphere. The landscape water yield was consistently below average or average from September–February.

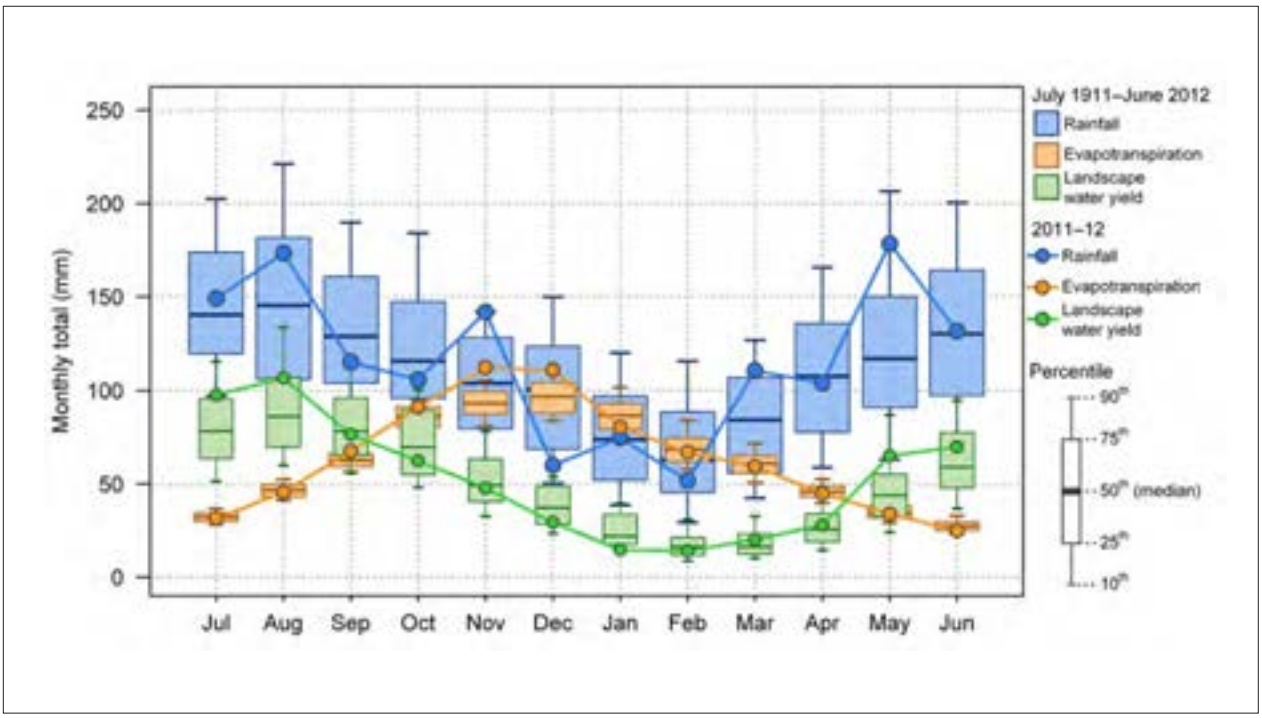


Figure 6.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the Tasmania region

6.4.1 Rainfall

Rainfall for the Tasmania region for 2011–12 is estimated to be 1,396 mm. This is 2% above the region's long-term average (July 1911–June 2012) of 1,365 mm.

Figure 6.13a shows that the highest rainfall for 2011–12 occurred in the western part of the region with annual totals exceeding 2,400 mm in large areas.

Rainfall deciles for 2011–12 indicate generally average conditions, with some areas of above average rainfall in the southern and eastern coastal areas (Figure 6.13b). The Flinders and Cape Barren islands in the northeast received above average rainfall.

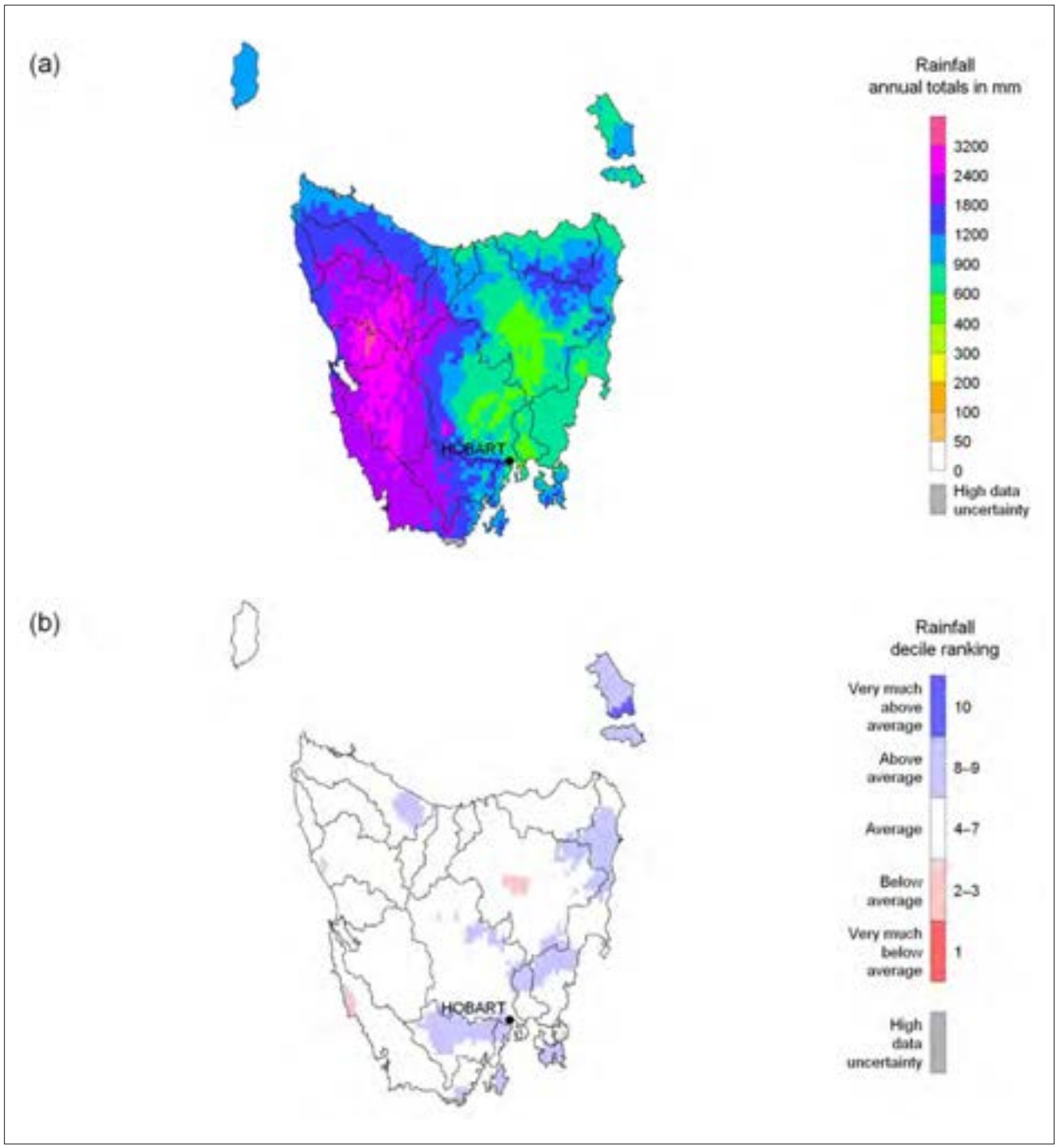
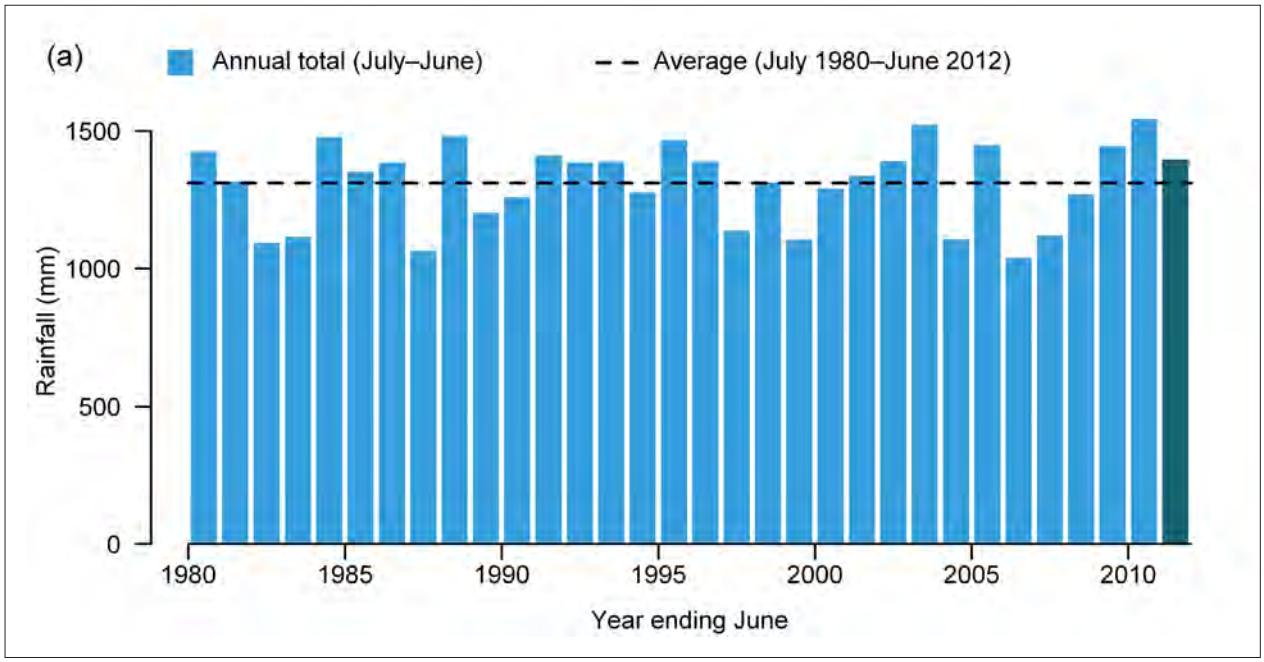


Figure 6.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Tasmania region

Rainfall variability in the recent past

Figure 6.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 1,311 mm, varying from 1,039 mm (2006–07) to 1,543 mm (2010–11). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 6.14b.

The graphs indicate that regional average rainfall is not very variable. The coefficient of variation (standard deviation divided by the mean) over the annual rainfall and data of Figure 6.14a is 0.11, the lowest of all regions in Australia. Both the summer and winter periods in Figure 6.14b show no signs of trends or cyclic patterns.



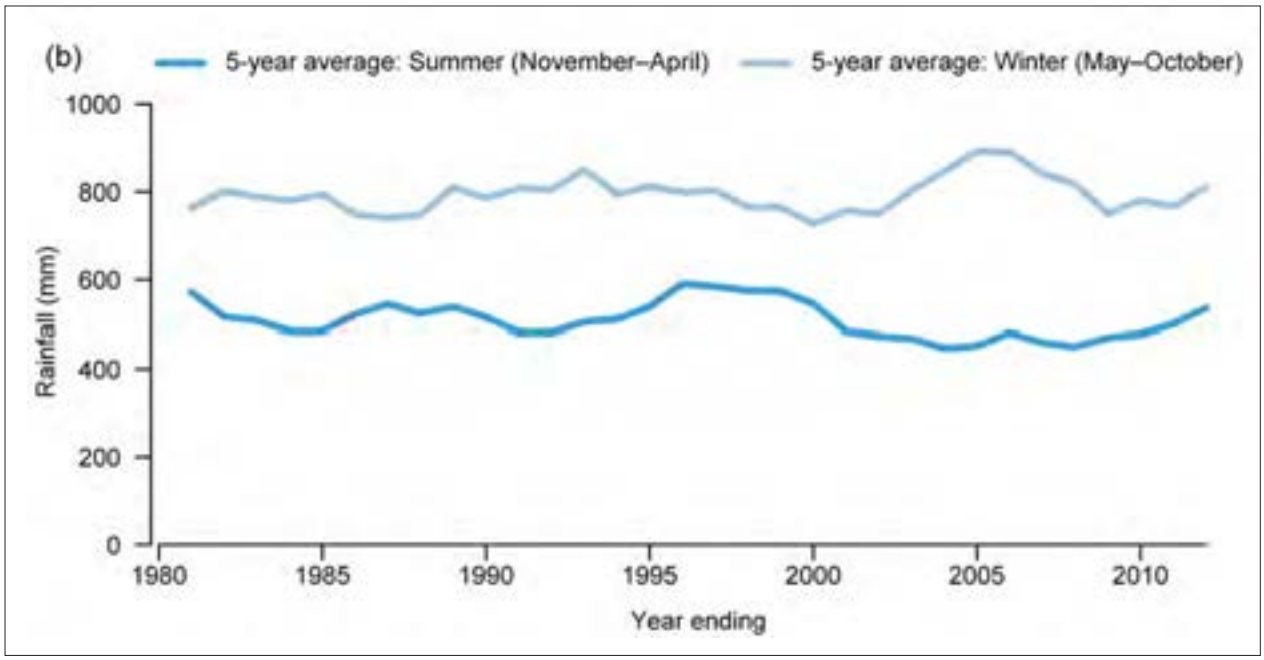


Figure 6.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Tasmania region

Recent trends in rainfall

Figure 6.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 6.15b.

Figure 6.15a shows that since 1980 a strong decrease in rainfall has occurred on the southwestern coast of the region. This falling trend appears to be strongly statistically significant (Figure 6.15b), but this can be influenced by the low rain gauge density. On the other hand, a strongly significant rising trend is found in the northeast (covering the Ben Lomond National Park area) of the region.

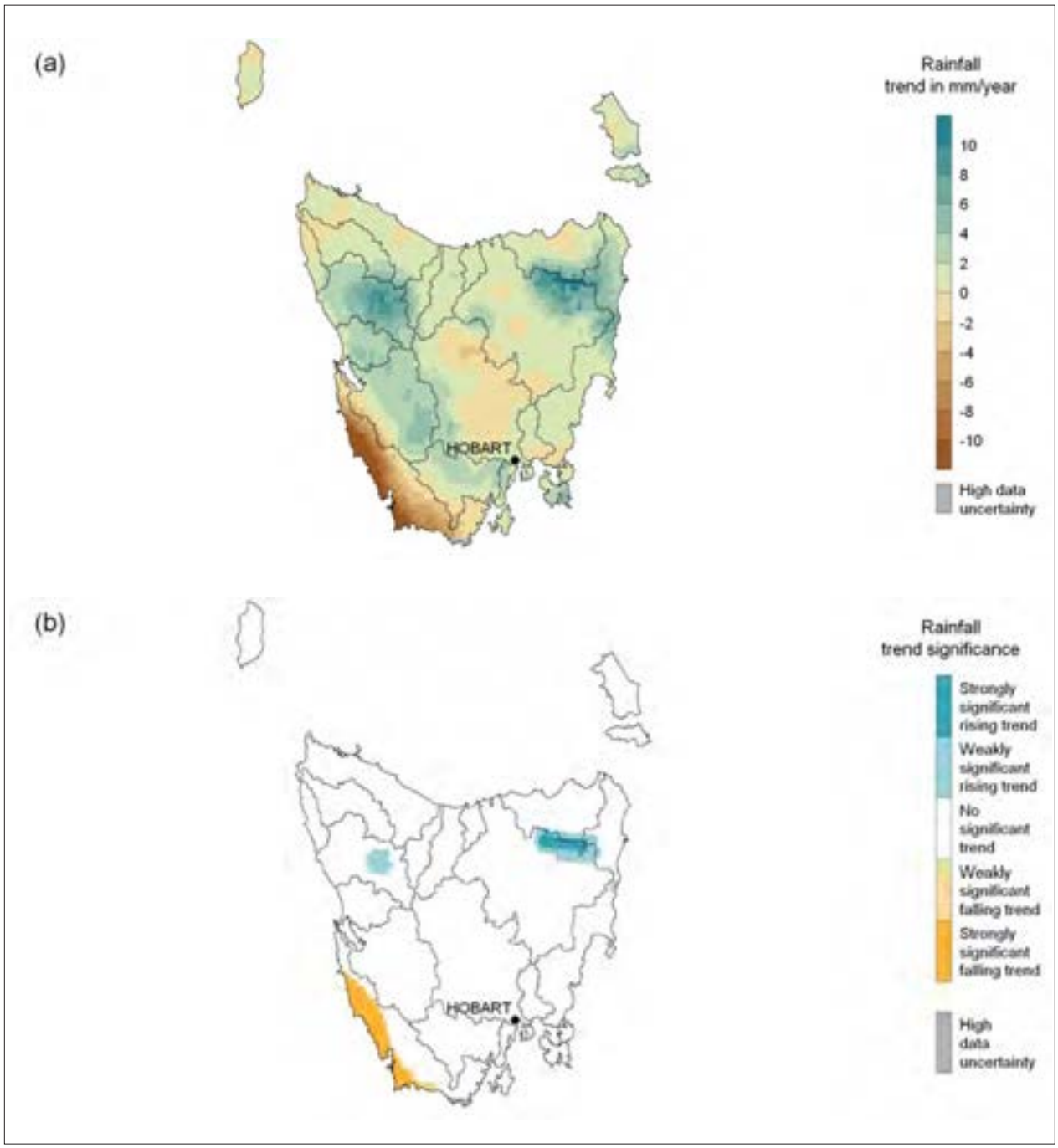


Figure 6.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tasmania region

6.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Tasmania region for 2011–12 is estimated to be 769 mm (Figure 6.16). This is 3% above the region's long-term (July 1911–June 2012) average of 744 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 6.16) is similar to that of rainfall (Figure 6.13) and was highest along the west coast with annual totals exceeding 900 mm.

Evapotranspiration deciles for 2011–12 indicate above average or average totals across most of the region (Figure 6.16b). This spatial distribution is very different to the rainfall distribution (Figure 6.13b). The highly localised areas of very much above average evapotranspiration appearing mainly around major lakes are currently known artefacts of the model and need to be considered with care.

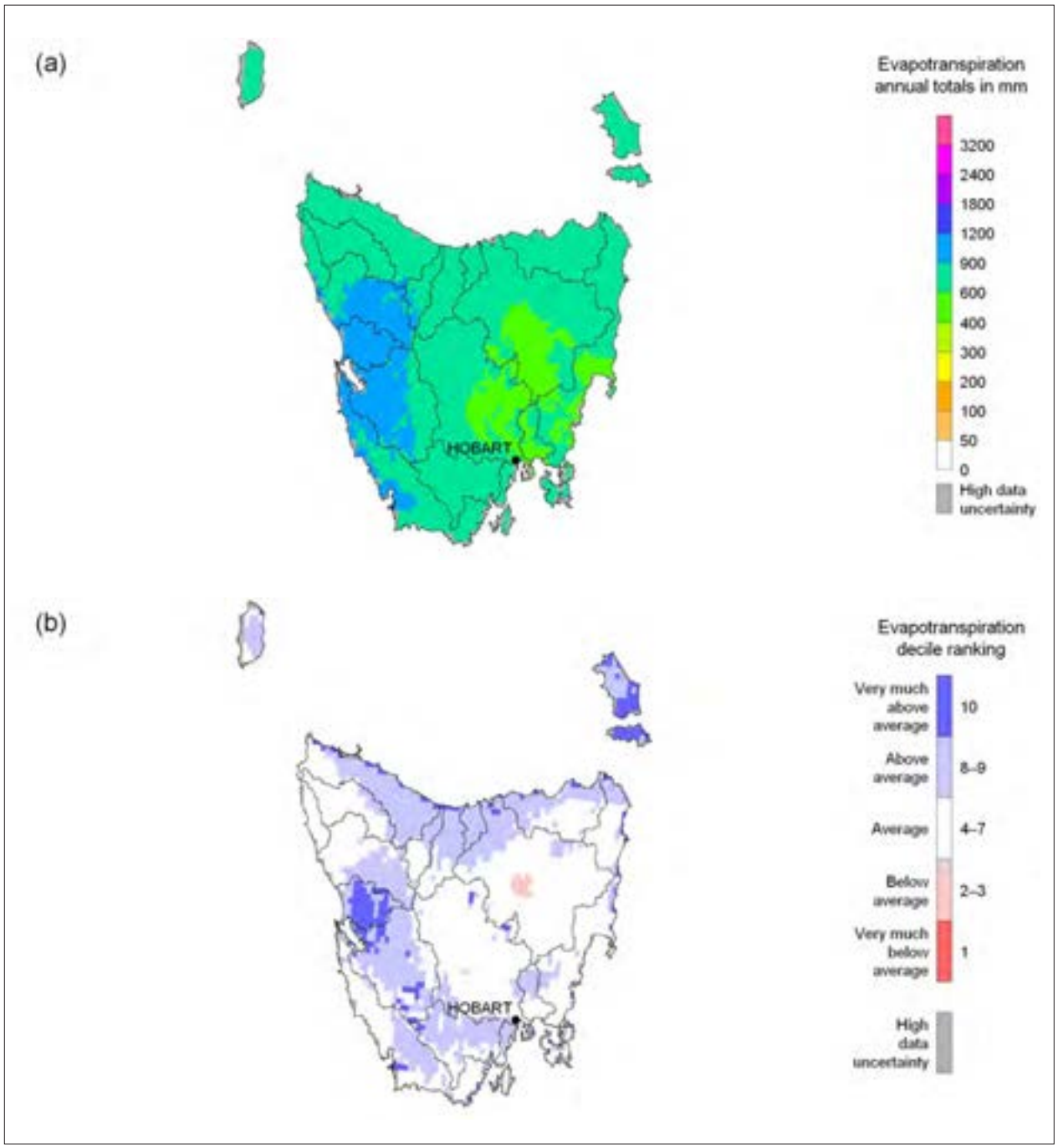
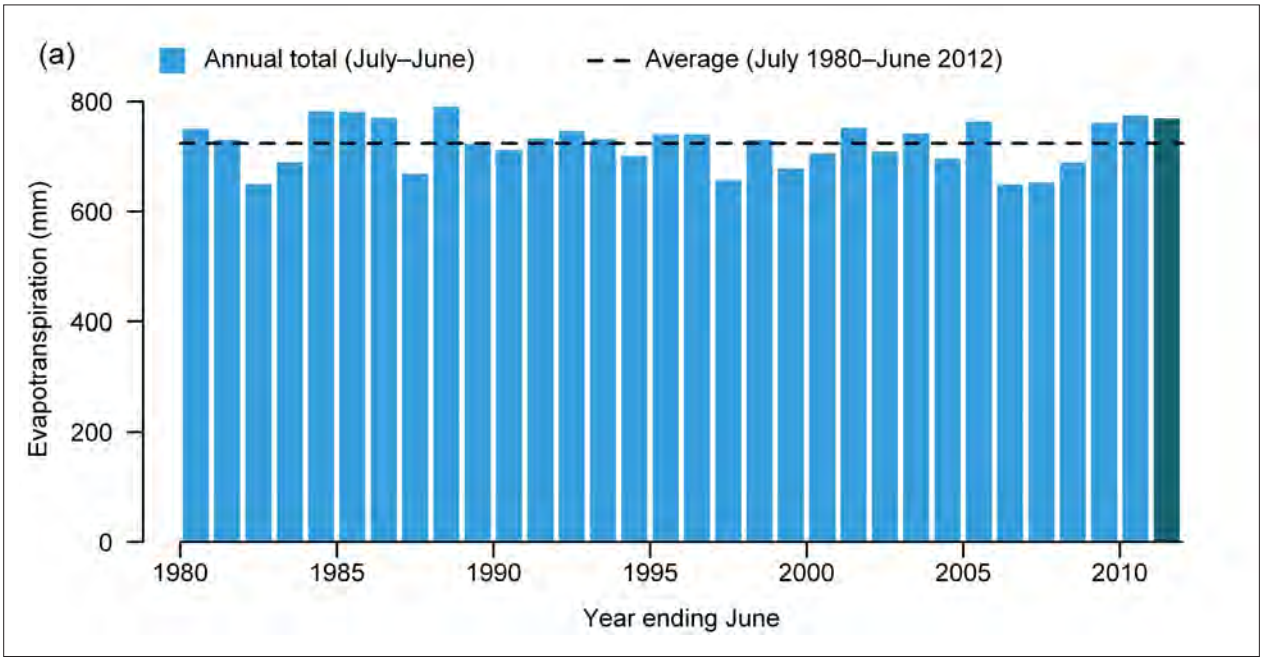


Figure 6.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Tasmania region

Evapotranspiration variability in the recent past

Figure 6.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 724 mm, varying from 649 mm (2006–07) to 791 mm (1988–89). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 6.17b.

The graphs indicate that regional average evapotranspiration is even less variable than rainfall. The coefficient of variation over the annual data of Figure 6.17a is 0.06, the lowest of all regions in Australia. Both the higher summer and lower winter periods in Figure 6.17b show no obvious signs of trends or cyclic patterns.



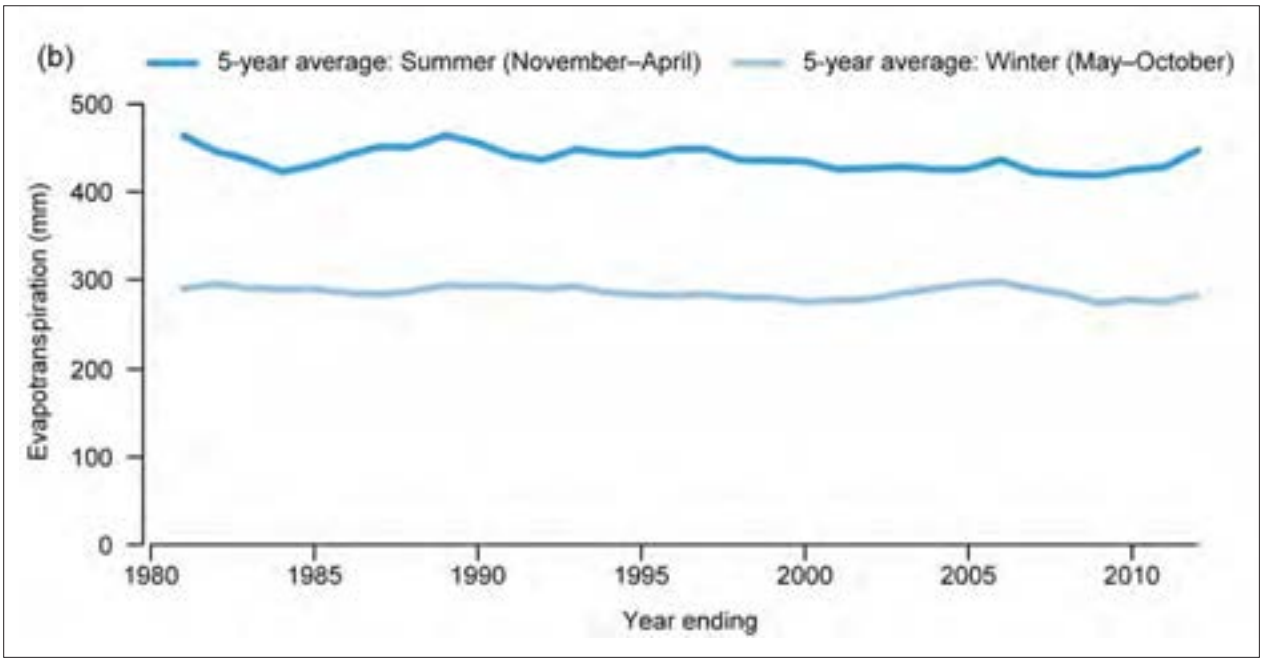


Figure 6.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Tasmania region

Recent trends in evapotranspiration

Figure 6.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980 to 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 6.18b.

Figure 6.18a shows that since 1980 trends are mostly neutral, with the exception of the southwest part of the region. Besides the same artefacts on the lakes, Figure 6.18b shows significant falling trends for only the southwest and south coast.

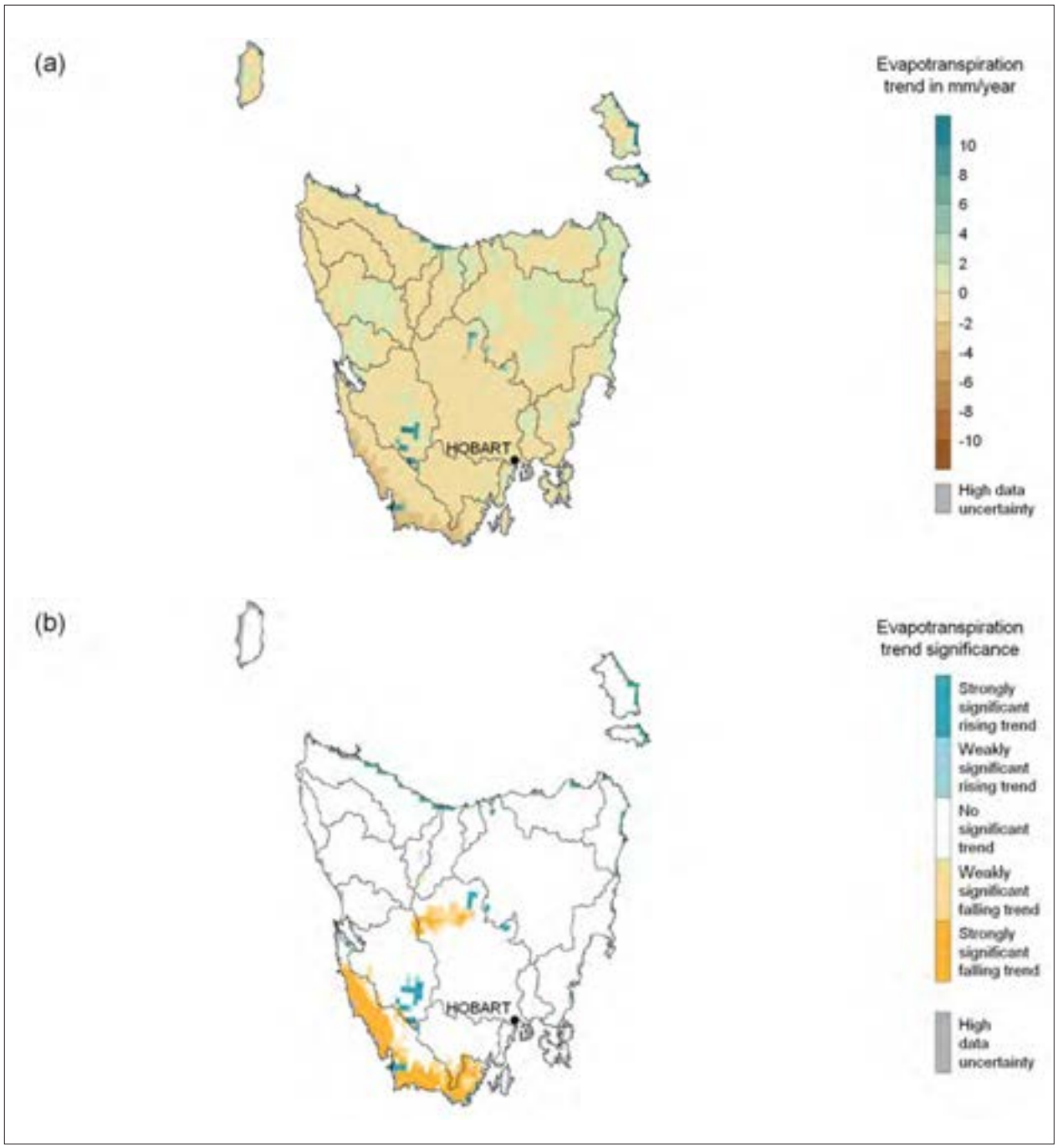


Figure 6.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tasmania region

6.4.3 Landscape water yield

Modelled landscape water yield for the Tasmania region for 2011–12 is estimated to be 632 mm. This is just above the region's long-term (July 1911–June 2012) average of 627 mm. Figure 6.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to that of rainfall (Figure 6.13a).

The highest landscape water yields in 2011–12 are observed along the west coast, exceeding 1,200 mm in most of the area. In contrast, the inland areas in the Midlands and the Derwent Valley had annual landscape water yield totals below 50 mm. The decile ranking map for 2011–12 (Figure 6.19b) shows mostly above average landscape water yields to the east, average landscape water yields in the centre and western part of the region and some areas of below average landscape water yield on the west coast.

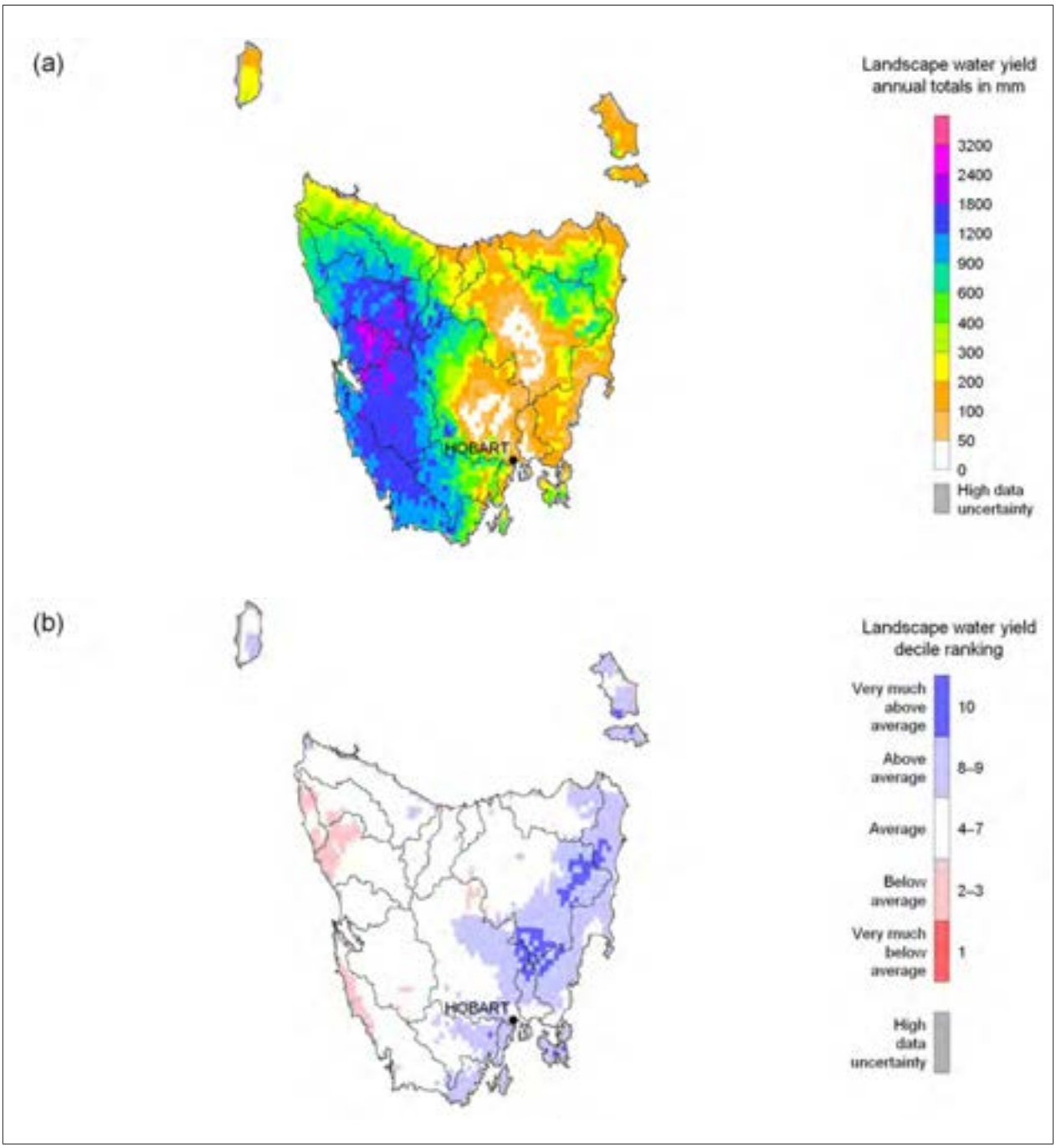
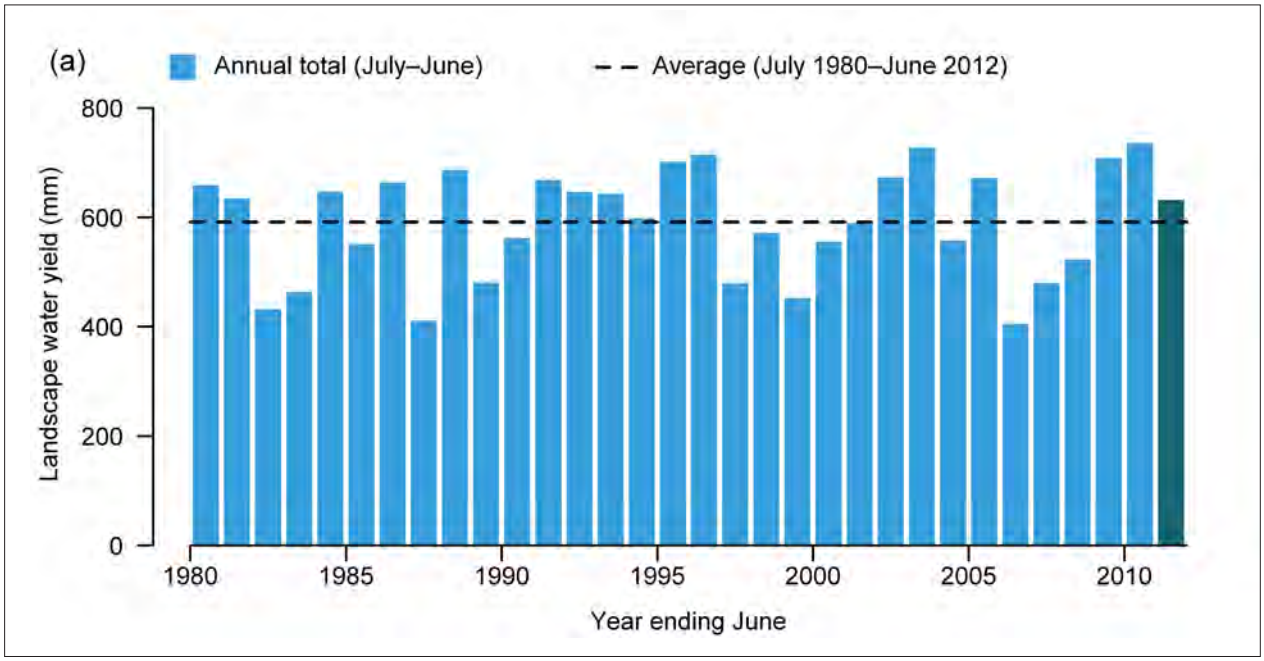


Figure 6.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for Tasmania region

Landscape water yield variability in the recent past

Figure 6.20a shows annual landscape water yield for the Tasmania region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 591 mm, varying from 405 mm (2006–07) to 735 mm (2010–11). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 6.20b.

The graphs indicate that regional average landscape water yield is more variable than rainfall and evaporation, but the coefficient of variation is still the lowest of all regions in Australia. Both the summer and winter period in Figure 6.20b show no signs of trends or cyclic patterns. Landscape water yield is generally high in the winter period due to the combination of higher rainfall and the lower evapotranspiration producing more saturated soils.



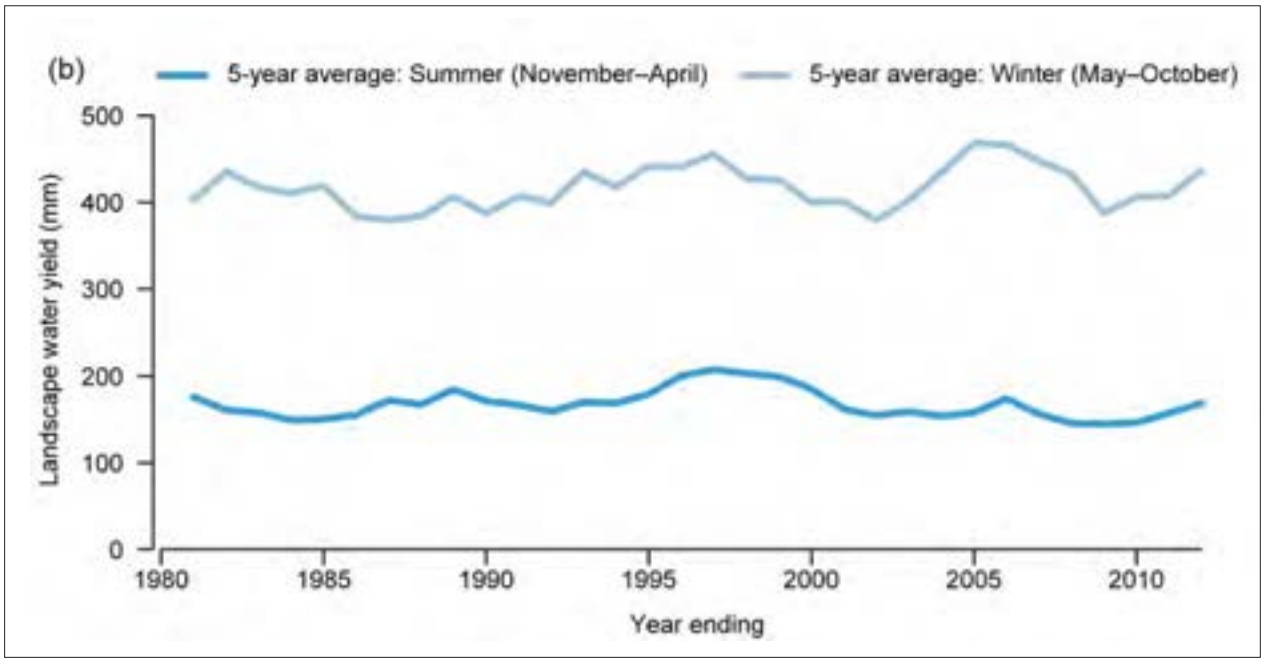


Figure 6.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Tasmania region

Recent trends in landscape water yield

Figure 6.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 6.21b.

Figure 6.21a is consistent with the rainfall trends of Figure 6.15a. However, Figure 6.21b shows that the strongly significant falling trends on the southwest coast are less pronounced than those of rainfall. Conversely, the strongly significant rising trends in landscape water yield in the northeast cover a larger area than the area of significantly increased rainfall.

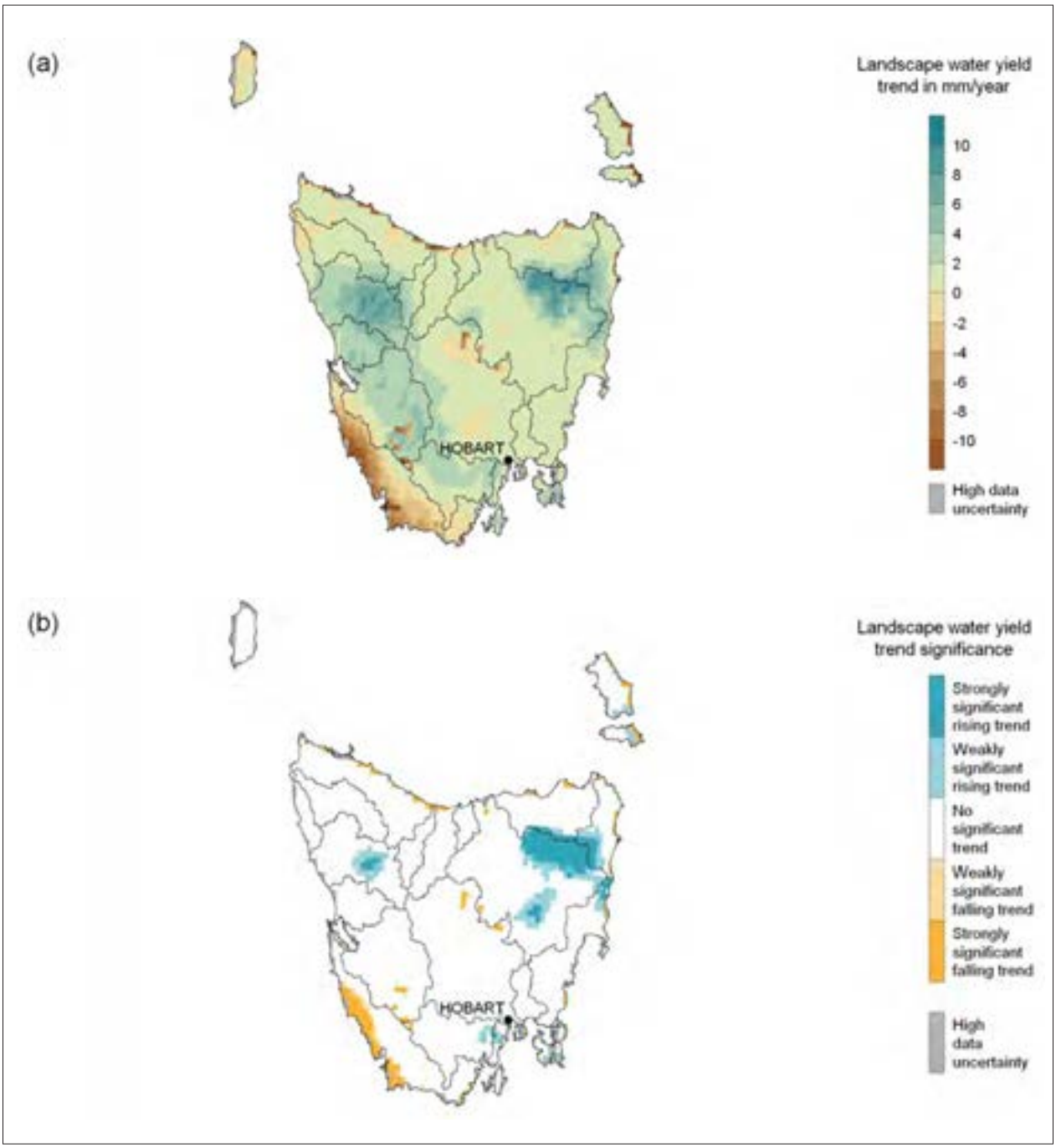


Figure 6.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tasmania region

6.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Tasmania region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources.

The region's water table aquifers and salinity are described and the groundwater management units are illustrated. No data was available to the Bureau in a suitable format for a detailed analysis of individual aquifers.

6.5.1 Rivers

There are 19 river basins in the Tasmania region, varying in size from 650 to 11,000 km^2 (Figure 6.22).

The main river basins within the region are the Tamar and Derwent river basins. The region includes some of the largest permanent lakes in Australia such as Lake Pedder and Lake Gordon.

Most of the major rivers are perennial except on the east coast where a variety of river types can be found. The rivers are seasonal and those fed from the highlands have increased flow during snow melt. Many rivers are fast-flowing with many rapids, dropping quickly over short distances from the source to the sea. Many, like the Gordon and Tamar, have fine estuaries before entering the ocean.

Gordon River, Tasmania | A41cats, Dreamstime.com

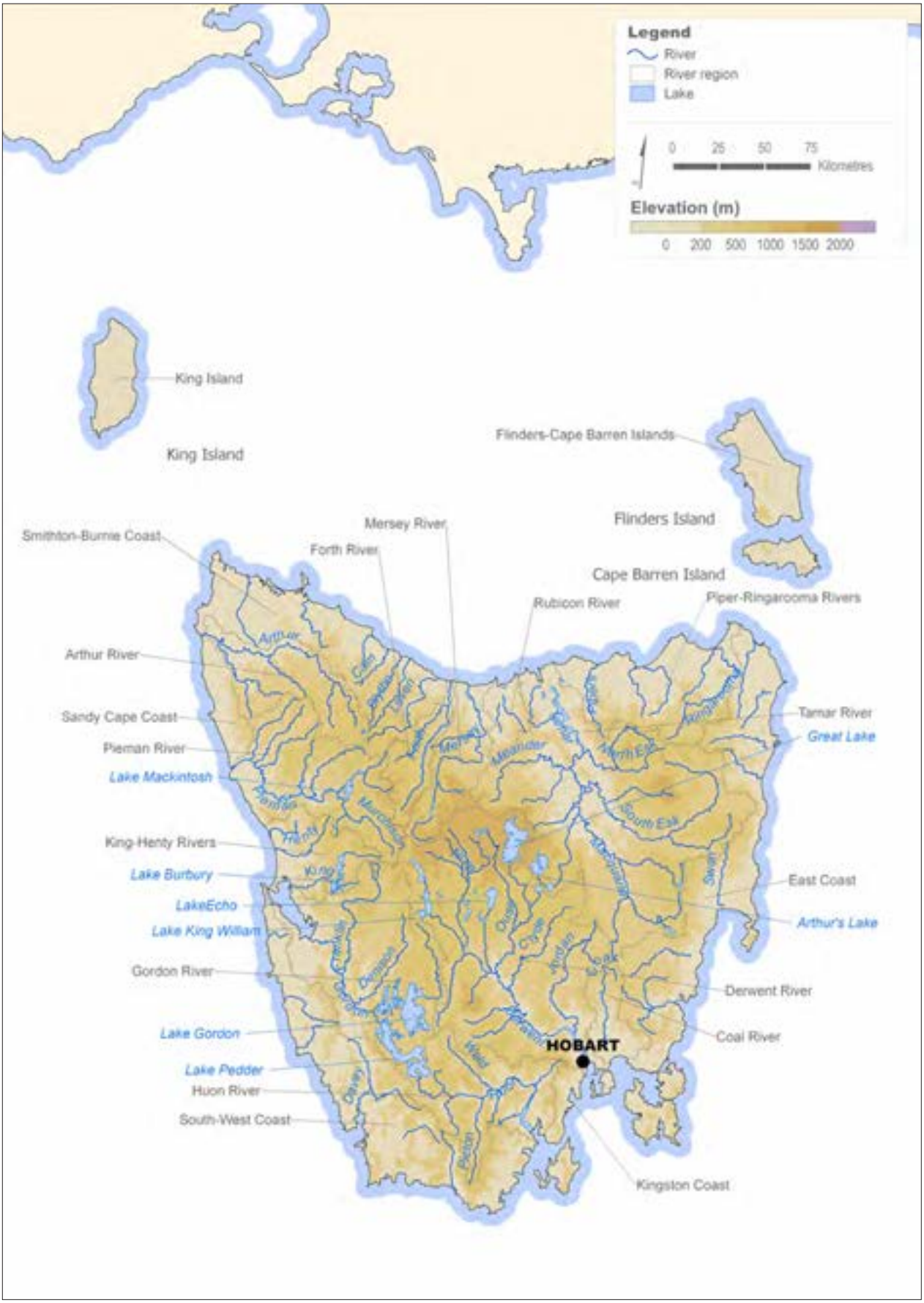


Figure 6.22 Rivers and catchments in the Tasmania region

6.5.2 Streamflow volumes

Figure 6.23 presents an analysis of flows at 25 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long flow records across 11 geographically representative river catchments were found in the north and eastern area of the region and selected for analysis. The annual flows for 2011–12 are colour-coded according to the decile ranking at each site over the 1980–2012 period.

High flows volumes are usually generated in the headwaters of rivers and their tributaries where rainfall is often relatively high. Very much above average flows were observed at three sites located on the Clyde River in the centre and the Scamander River in the northeast of the Tasmania region. Above average total flows were recorded at five monitoring sites located on the rivers in the centre and east of the region. Above average flows in these rivers were mostly generated during major rainfall events in August 2011.

Average flow occurred at 16 sites in the region that were located on the rivers in the south and most of the rivers in the north of the region. Of the 25 monitoring sites there was only one where below average flows were recorded. This site is located on the Pipers River in the north of the region.

Flow deciles in the summer (November 2011–April 2012) were very different to the total annual flows for 2011–12 as shown Figure 6.23. The main differences are the relatively low flows in the summer period in the centre and along the east coast and the relatively higher flows on the north coast. The most contrasting flow pattern can be seen in the centre of the region, especially on the Clyde River downstream of Lake Crescent (see Figure 6.23, sites with flow values of 282 and 132 ML/day). As a consequence of large winter inflows in early 2011–12, water was released for irrigation in the summer period.

6.5.3 Streamflow salinity

Suitable streamflow salinity data were not available during this period. Therefore, streamflow salinity analysis is not included in this chapter.

6.5.4 Flooding

Floods can be caused mainly by localised high intensity rainfall (for example, during thunderstorms) or prolonged periods of heavy rainfall (for example, frontal rainfall). While the first rainfall type often results in localised flash flooding, the prolonged rainfall events can cause floods over larger areas.

While thunderstorms can occur at any time, most of the Tasmania region has a seasonal pattern of rainfall with the majority of rainfall occurring in winter. Flooding is most commonly associated with cold fronts crossing Tasmania as well as coastal low pressure systems.

Figure 6.24 shows selected locations where the Bureau is monitoring river levels as part of its flood forecasting service and the highest level reached during the year expressed in terms of flood classification level. These classification levels are established in consultation with emergency management and local agencies and are further described in the Technical Supplement.

Significant flooding occurred in the northeast of the Tasmania region following two separate periods of heavy rainfall in August 2011 causing moderate to major flooding of the South Esk and Macquarie rivers. The first event, from 7–10 August 2011, was caused by a low pressure system that slowly moved to the north of the region with a trough extending down over the northeast. Rainfall totals for the four days exceeded 100 mm at sites in the South Esk and Macquarie rivers.

The second event, from 16–19 August 2011, was another significant flooding event in the northeast. Four-day rainfall totals again exceeded 100 mm at several sites. The South Esk River reached major flood level, and the North Esk and Macquarie rivers both reached moderate flood level. Flood volumes for this event were exacerbated by already wet ground and high water levels following the earlier event.

There were landslips and several roads were closed with both events. The township of St Helens was isolated. Infrastructure damage totalled several hundred thousand dollars and flooding disrupted freight services, closing the North-South and Fingal railway lines.

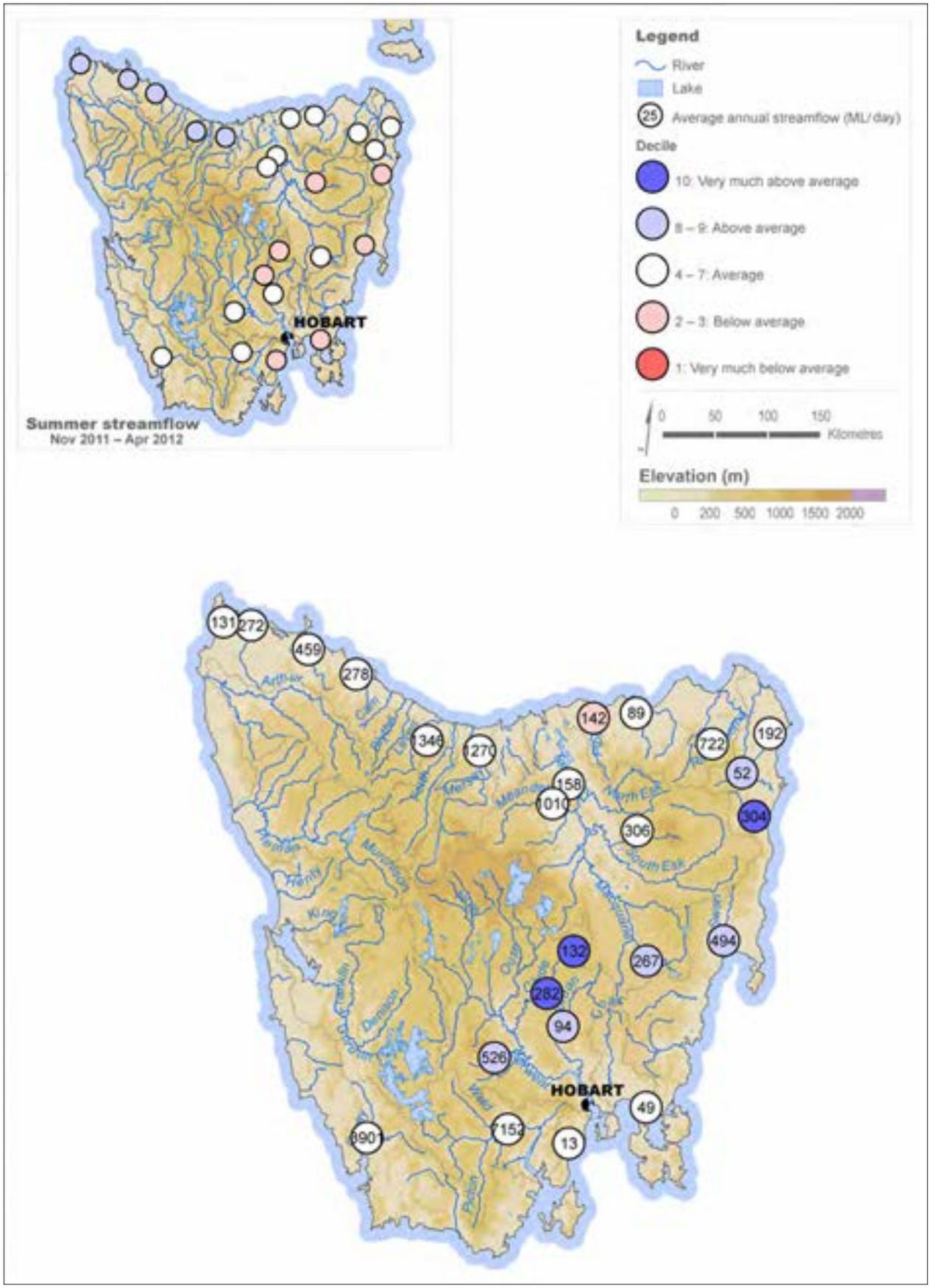


Figure 6.23 Average annual and summer period flow volumes of selected sites for 2011–12 and their decile rankings over the 1980–2012 period in the Tasmania region

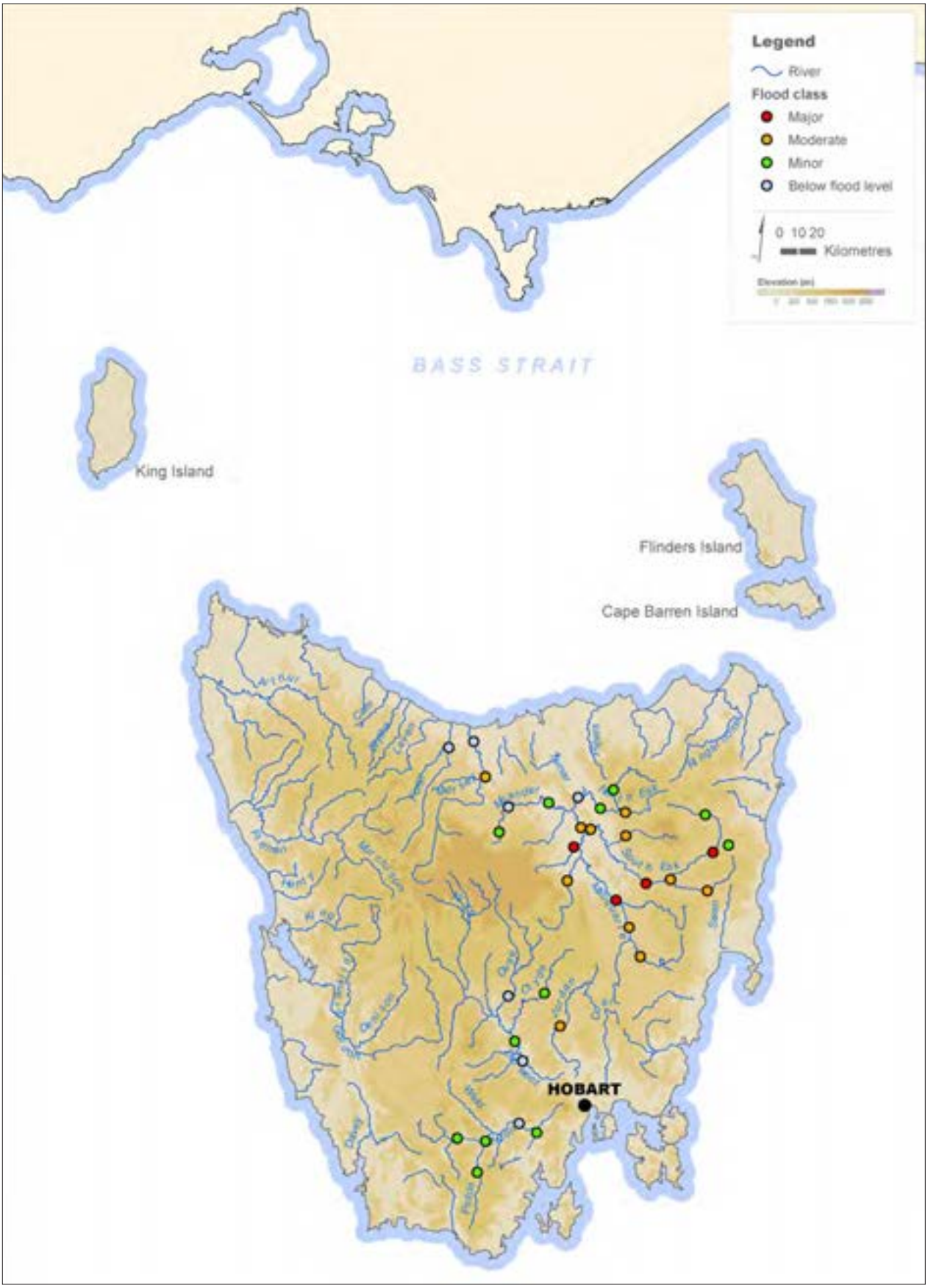


Figure 6.24 Flood occurrence in 2011–12 for the Tasmania region, with each dot representing one gauging station and the colour of the dot representing the highest flood class measured

6.5.5 Storage systems

There are approximately 57 major publicly owned storages in the Tasmania region with a total capacity in excess of 25,700 GL. The Bureau's water storage website provides information for more than 86% of the region's publicly owned storage capacity (as at August 2012). Storages in the region supply ten systems used for hydro-electric power generation. They also supply the urban centre of Hobart.

Table 6.3 gives a summary of the major storage systems in the region together with an overview of the storage levels at the end of 2010–11 and 2011–12. The location of all the systems and associated storages are shown in Figure 6.25.

A mixed pattern of storage volume increases and decreases took place in the systems in 2011–12. The substantial increase in the total storage volume can mostly be ascribed to the increase in storage volume in Lake Gordon.

Since most systems are used for hydro-electrical power generation, some water release patterns are highly irregular. For example, the significant drop in volumes of the storages in the Anthony system were balanced out again in July 2012, when storage volumes were back at those volumes measured in July 2011.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

Table 6.3 Major public storage systems in the region as identified in the Bureau's water storage website (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Gordon	hydro	14,029 GL	8,432 GL—60%	10,527 GL—75%
South Esk—Great Lake	hydro	3,619 GL	1,604 GL—44%	1,665 GL—46%
Pieman	hydro	1,434 GL	1,368 GL—95%	1,179 GL—82%
Burbury	hydro	1,082 GL	795 GL—73%	959 GL—89%
Upper Derwent	hydro	755 GL	504 GL—67%	573 GL—76%
Nive	hydro	728 GL	478 GL—66%	408 GL—56%
Mersey	hydro	157 GL	102 GL—65%	86 GL—55%
Lower Derwent	hydro	142 GL	120 GL—85%	115 GL—81%
Forth	hydro	141 GL	130 GL—92%	128 GL—91%
Anthony	hydro	36 GL	22 GL—61%	14 GL—39%
Hobart	urban	3.6 GL	3.6 GL—100%	3.6 GL—100%
Non-allocated	—	15 GL	15 GL—100%	14 GL—93%
Total		22,141 GL	13,576 GL—61%	15,672 GL—71%

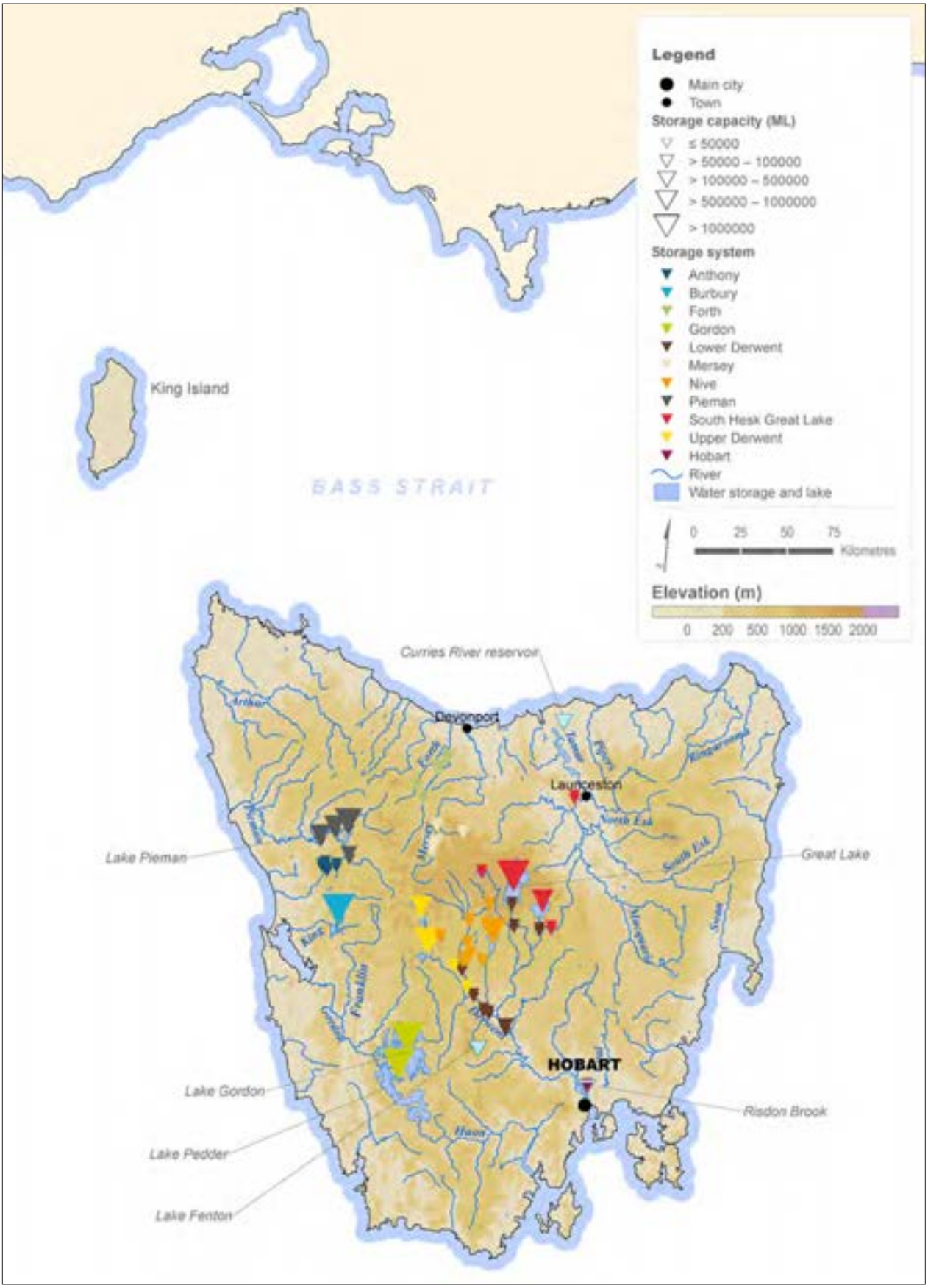


Figure 6.25 Storage systems in the Tasmania region (information extracted from the Bureau's water storage website in August 2012)

6.5.6 Wetlands

Important wetlands

There are a large number of wetlands of national and international importance in the Tasmania region (Figure 6.26), encompassing a wide diversity of wetland types, from coastal floodplains and lagoons to higher altitude freshwater streams and lakes. Dominant features in the region are the coastal lagoons. Six of the ten Ramsar-listed wetlands in the region are lagoons, each with their own characteristic biodiversity. Other dominant wetland types are river deltas and estuaries.

The coastal lagoons comprise a diverse range of seasonal and permanent marshlands, grass, forests and woodlands. They are recognised as important sites for resident and migratory birds, including some threatened bird species. The river deltas and estuaries are predominantly characterised by marshes and swamps and provide a different type of habitat for birds and plants.

Inflows to selected wetlands

The state of the biodiversity in a wetland is linked to the way water is stored within the area and the temporal variability of inflows. An analysis of historic and recent inflows into wetlands forms an informative picture of potential changes.

Three internationally recognised Ramsar wetland sites (Lower Ringarooma River, Moulting Lagoon and Apsley Marshes) were selected for hydrological analysis of major inflows. The Moulting Lagoon and Apsley Marshes form a linked system of wetlands, with the Apsley Marshes performing important nutrients-filtering of the Apsley River before it flows into the Moulting Lagoon. More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html)

Three upstream stream monitoring gauges were selected to enable the analyses and interpretation of inflows to these three wetlands. The gauges used in the analyses are the closest upstream gauges that have largely continuous discharge records since 1980. Though the analyses do not capture the total inflows, they are indicative of the temporal patterns of freshwater surface flows to these wetlands.

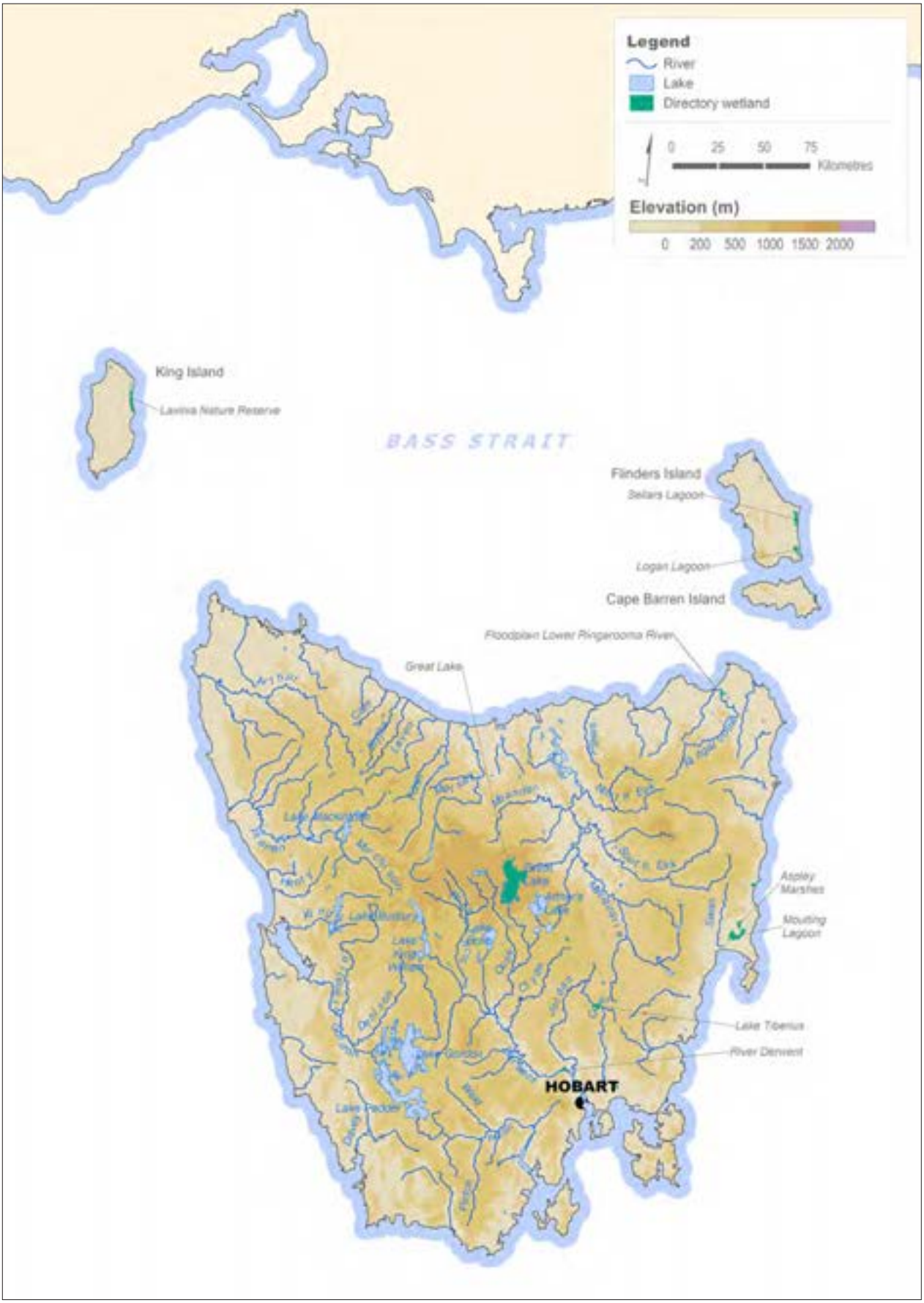


Figure 6.26 Location of important wetlands in the Tasmania region

Lower Ringarooma River

The Lower Ringarooma River wetlands encompass a variety of wetland types, including estuary, river and floodplain wetlands. Much of the listed wetland area has been altered from its natural state (Newall and Lloyd 2012). Mining in the 1800s and early 1900s has contributed to large scale sedimentation entering the Ringarooma River.

Daily discharge data for the monitoring gauge on the Ringarooma River at Moorina provides a temporal pattern of freshwater inflows into the Lower Ringarooma River wetlands (Figure 6.27).

Figure 6.27 Location of the monitoring site in relation to the Lower Ringarooma River wetlands

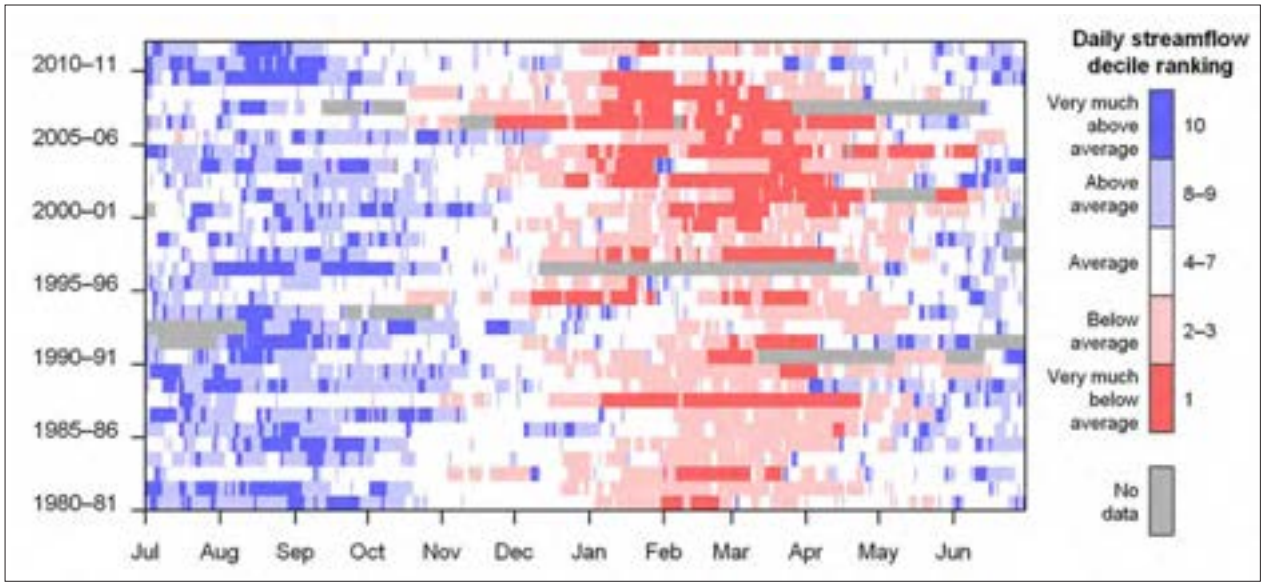


Figure 6.28 Daily flows of Ringarooma River at Moorina between 1980 and 2012, ranked in decile classes

Figure 6.28 presents an overview of the distribution of daily streamflow decile rankings. The data provides a clear pattern of a seasonal flow regime with high flows from June up to October and low flow from December through to April. From 1999 onwards the low flows appear to be lower than before, but the wet summer of 2010–11 broke this pattern. The flows of 2011–12 were back to pre-1999 conditions.

Figure 6.29 compares monthly discharges from 2011–12 with the statistics of flows from 1980 onwards. The normally high August flows were above average in 2011–12. The remaining 2011–12 flows are close to the average flows of the past 32 years.

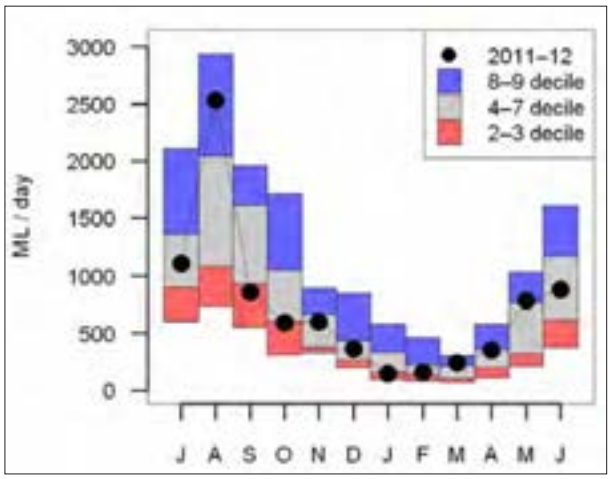


Figure 6.29 Monthly flows of the Ringarooma River monitoring site at Moorina from 2011–12 compared with the 1980–2012 decile rankings

Apsley Marshes

The Apsley Marshes are located in the floodplain of the Apsley River, just upstream of the Moulting Lagoon. The Apsley Marshes contain areas of woody vegetation, some salt marshes, large areas of reed and freshwater aquatic herbs. The marshes form an important habitat for some threatened bird species and support many plant and animal species considered internationally important.

Daily discharge data for the monitoring gauge on the Apsley River upstream of the Coles Bay Road bridge provides a temporal pattern of freshwater inflows into the marshes (Figure 6.30).

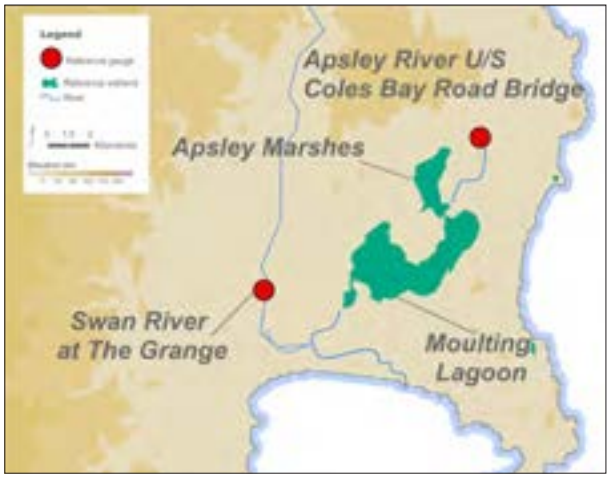


Figure 6.30 Location of the monitoring sites in relation to the Apsley Marshes

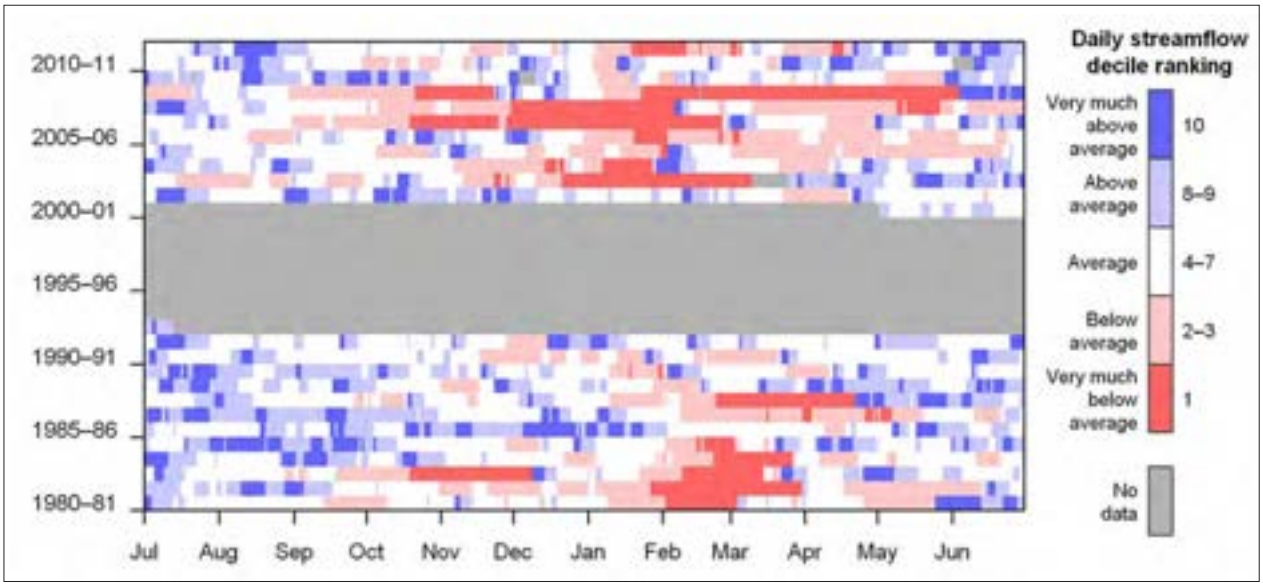


Figure 6.31 Daily flows of Apsley River upstream of Coles Bay Road bridge between 1980 and 2012, ranked in decile classes

Figure 6.31 presents an overview of the distribution of daily streamflow decile rankings. Although data are missing from 1992–93 to 2000–01, it can be noted that the flows have no distinct seasonal pattern. Flows can be low between November and April, but as a result of east coast lows, large rainfall events have occurred during this period that resulted in high flow peaks throughout this period for many years.

Figure 6.32 compares monthly discharges from 2011–12 with the statistics of flows from 1980 onwards. The August flows contributed a substantial amount of freshwater to the floodplain complex.

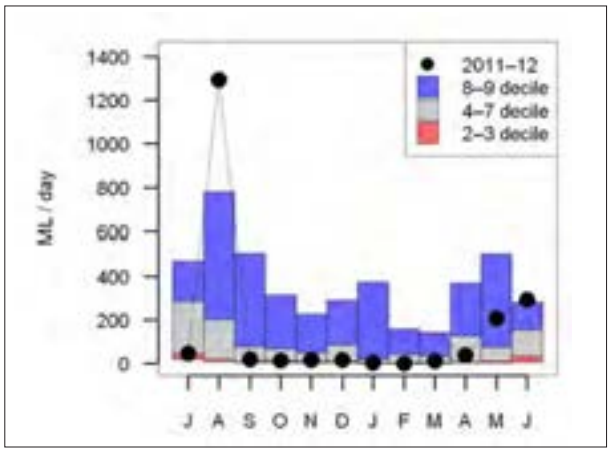


Figure 6.32 Monthly discharges at the Apsley River monitoring site upstream of Coles Bay Road bridge from 2011–12 compared with its 1980–2012 decile rankings

Moulting Lagoon

The Moulting Lagoon is located downstream of the Apsley Marshes on the Apsley River, but also has substantial inflows from the Swan River. The lagoon is surrounded by tidal mudflats and salt marsh that provide important feeding areas for many water bird species. The Swan River provides important inflows of freshwater to the system during peak flows.

Daily discharge data for the monitoring gauge on the Swan River at The Grange provide a temporal pattern of freshwater inflows into the lagoon (Figure 6.33).

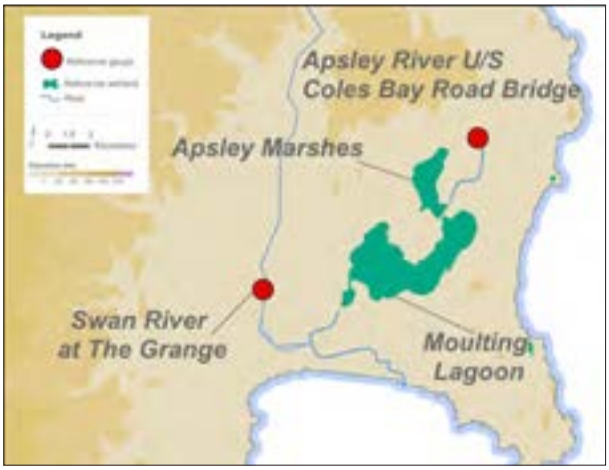


Figure 6.33 Location of the monitoring sites in relation to the Moulting Lagoon

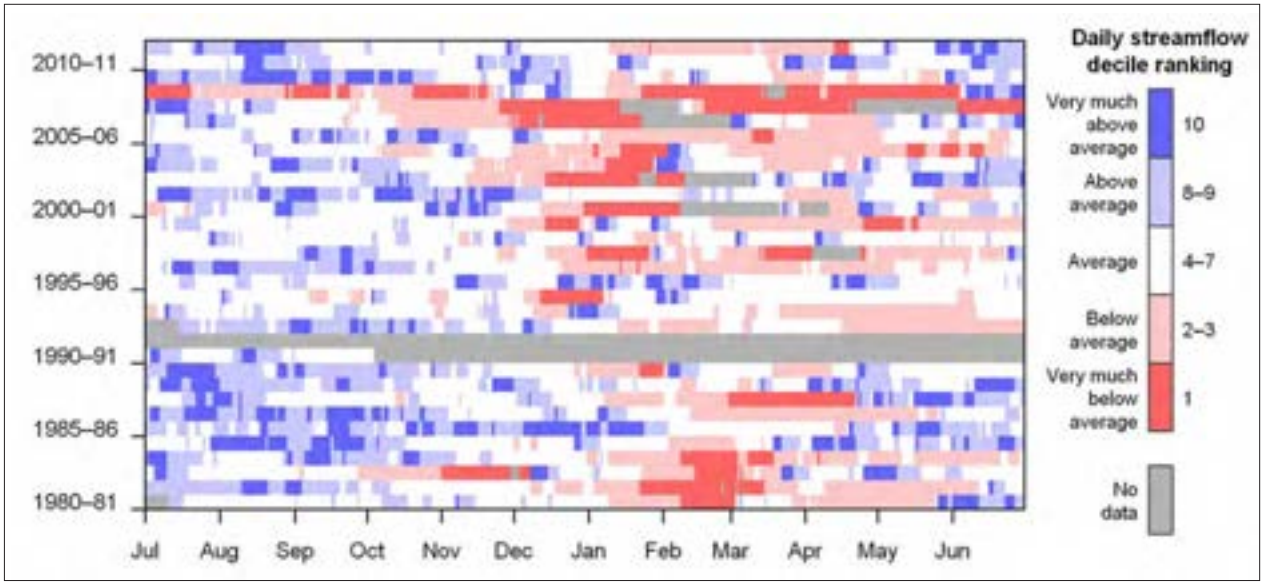


Figure 6.34 Daily flows of the Swan River at The Grange between 1980 and 2012, ranked in decile classes

Figure 6.34 presents an overview of the distribution of daily streamflow decile rankings. The raster visualisation shows an irregular pattern of high and low flows occurring throughout most years. There were extended periods of very much below average flows during the dry years of 2007–08 and 2008–09. In general, however, flood peaks occurred frequently throughout the 32 years, providing frequent freshwater inflows into the lagoon.

Figure 6.35 compares monthly discharges from 2011–12 with the statistics of flows from 1980 onwards. The August flows well exceeded the ninth decile of the 32-year record and contributed a substantial amount of freshwater to the wetland.

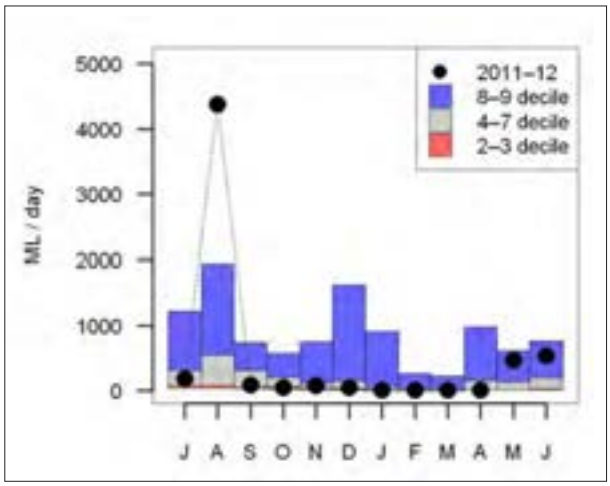


Figure 6.35 Monthly flows at the Swan River monitoring site at The Grange from 2011–12 compared with its 1980–2012 decile rankings

6.5.7 Hydrogeology

Tasmania has extensive groundwater resources located in igneous, sedimentary and metamorphic rocks, as well as unconsolidated sediments. Groundwater quality and yield is highly variable, depending on the aquifer type, the topographic location and the rainfall.

The classification of water table aquifers based on the geology within the region is presented in Figure 6.36. Greater resource potential is associated with the following aquifer groups:

- Surficial Sediments aquifers, porous media—unconsolidated;
- Upper Tertiary aquifer, porous media—unconsolidated;
- Fractured and Karstic Rocks, local aquifers; and
- Fractured Rock aquifers.

6.5.8 Water table salinity

Figure 6.37 shows the salinity of the water table aquifer as fresh (total dissolved solids [TDS] <3,000 mg/L) and saline (TDS≥3,000 mg/L). Data on groundwater salinity is not available for most parts of Tasmania, however, where data do exist, the water table is mainly fresh.

6.5.9 Groundwater management units

There are approximately 8,000 operating bores in Tasmania supplying water for irrigation, domestic use, town supplies, stock watering, mining and other commercial purposes. They are predominantly located in agricultural areas along the north coast, midlands, east coast and southeast.

Estimated sustainable annual groundwater yield across the state is in the order of 500–2,500 GL (Department of Infrastructure Energy and Resources 2001); however, a significant proportion is located in undeveloped terrain in the high rainfall areas of the west coast (generally reserved land).

A smaller proportion is available from aquifers in the developed areas. A number of these areas, poorly served by reliable surface water, and where the density of bores and demand on groundwater are relatively high, are currently experiencing pressure on groundwater and connected surface water resources (Sheldon 2011).

Estimated State-wide groundwater use is approximately 14% of the total current annual consumptive surface water allocation of 950 GL/year. In those parts of the State where groundwater and surface water use coincide, this ratio is significantly higher.

A regulatory framework for the management of groundwater in Tasmania is being introduced by the Department of Primary Industries, Parks, Water and Environment, through the development and implementation of policy to underpin sustainable management of connected groundwater and surface water resources. Introduction of a well-driller's licensing system and a well works permit system occurred in October 2009, and the State's first proclaimed groundwater area was appointed at Sassafras-Wesley Vale in August 2012 (Figure 6.38). Further groundwater areas will be considered through a formal risk assessment process likely to lead to more appointments.

While provision for active management of groundwater is made in all currently active water management plans if monitoring reveals emerging issues, a formal provision to appoint a statutory groundwater area and to licence and allocate groundwater is presently only made in the Sassafras-Wesley Vale water management plan (Department of Primary Industries, Parks, Water and Environment 2012).

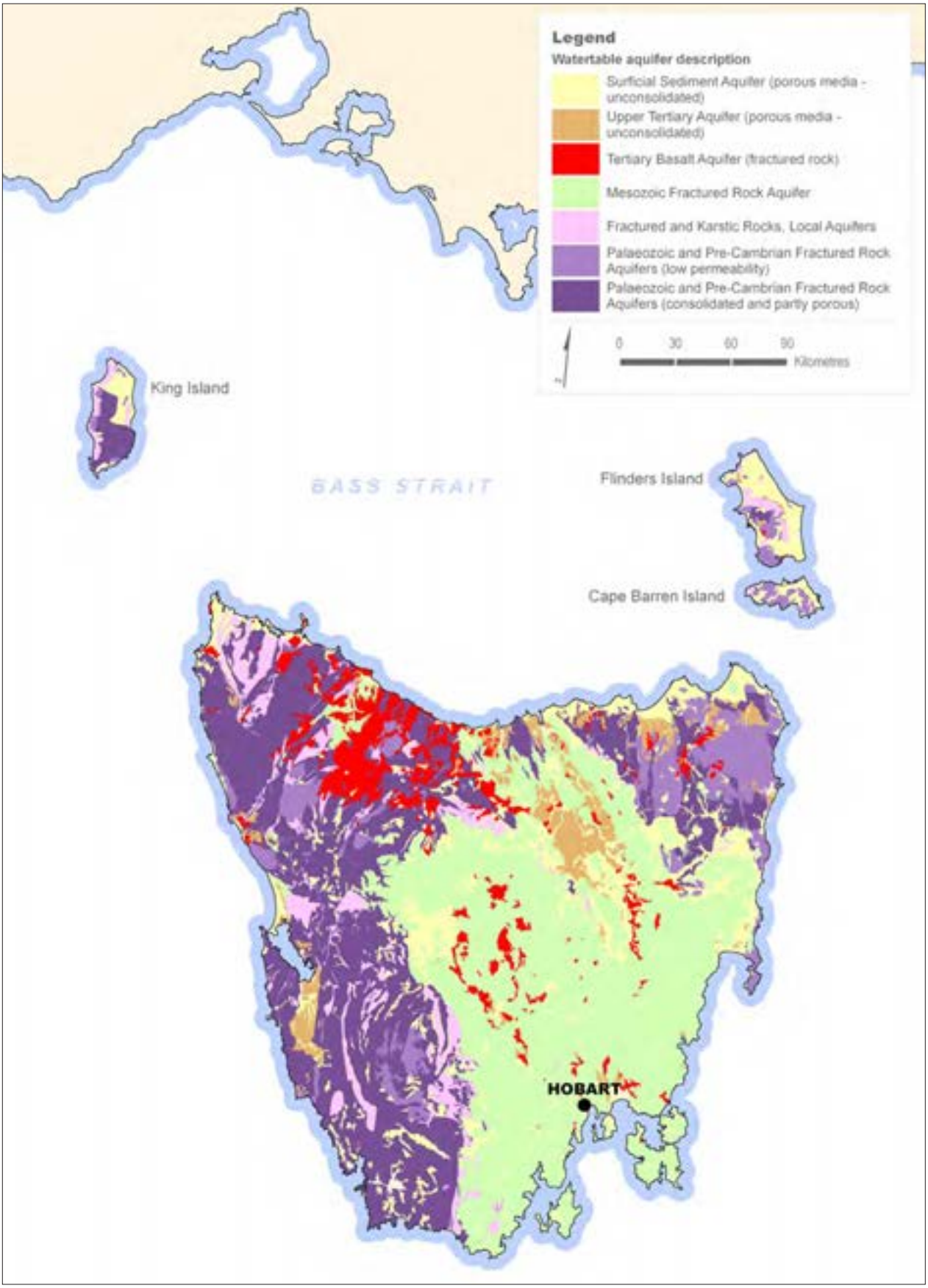


Figure 6.36 Water table aquifers of the Tasmania region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

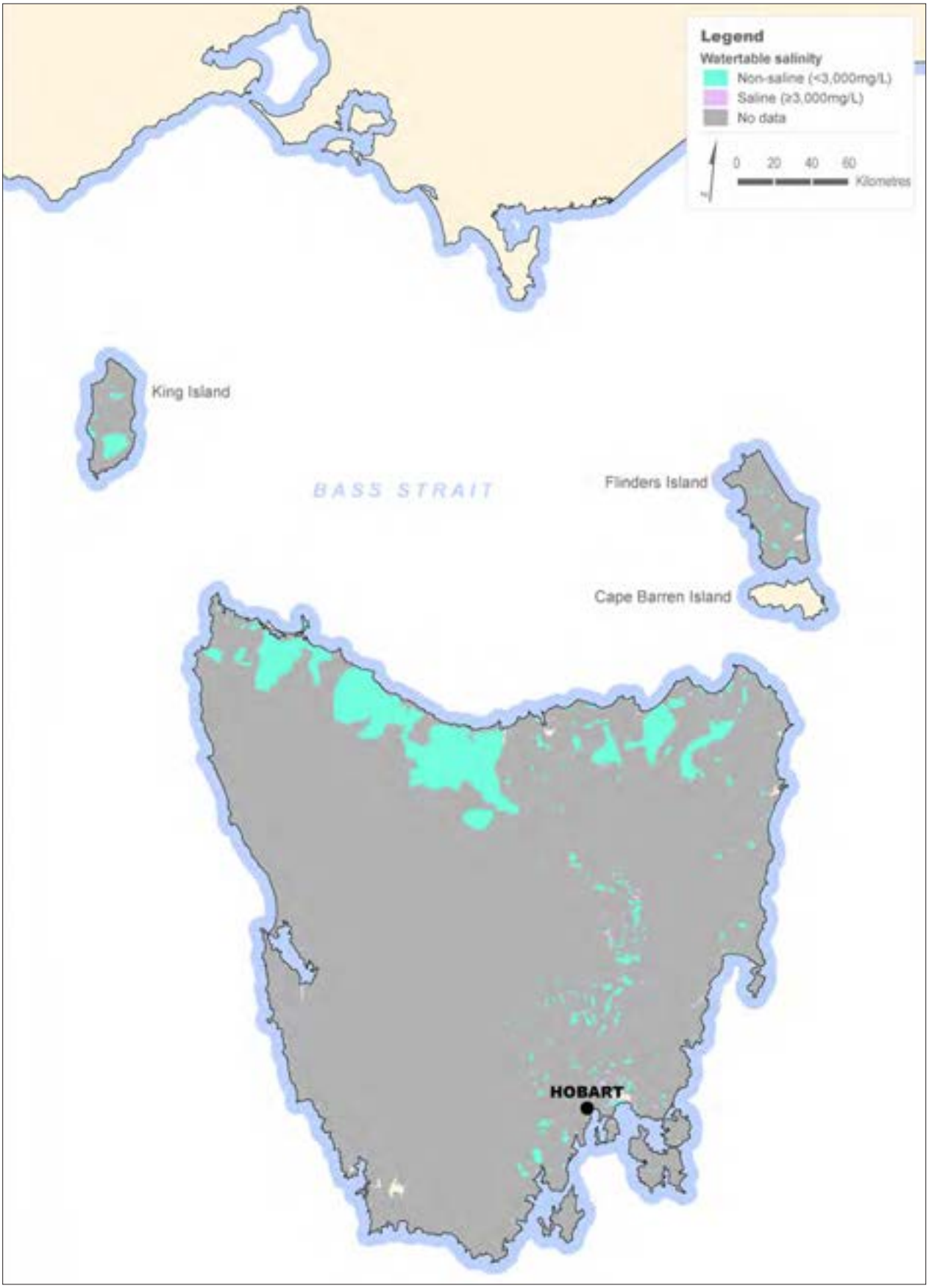


Figure 6.37 Water table salinity classes of the Tasmania region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

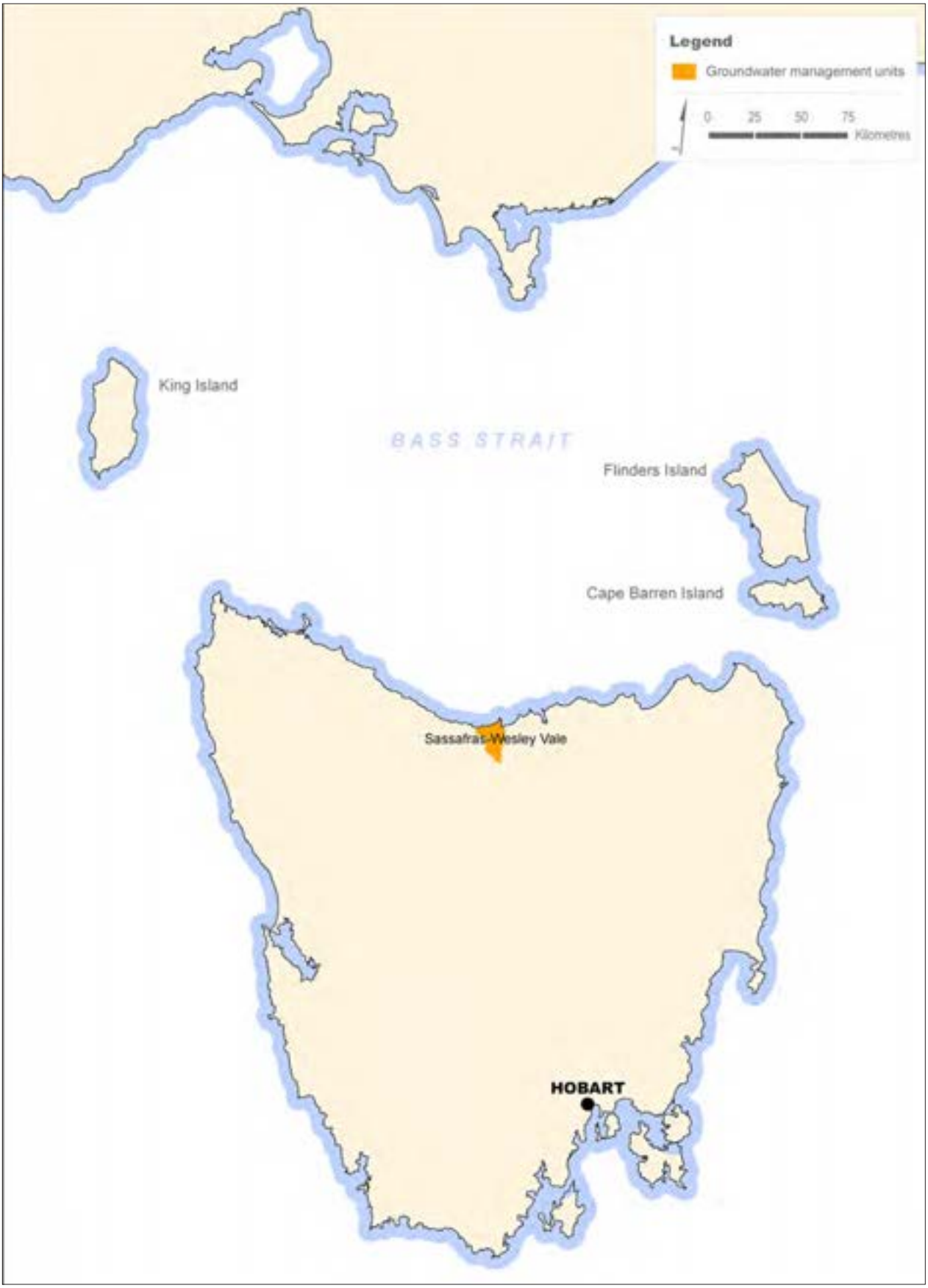


Figure 6.38 Groundwater management units in the Tasmania region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

6.6 Water for cities and towns

This section examines urban water situation in Tasmania in 2011–12. The large urban centres in the region and their water supply systems are briefly described. The main urbanised area, Greater Hobart, is addressed in more detail.

6.6.1 Urban centres

With over one quarter of the region's population, Hobart is the largest city in the region; yet, with only 171,000 residents Hobart ranks just outside Australia's top ten largest cities.

Launceston, in the north is the second largest city in the region is and has a population of 74,000 people. The city is located at the southern end of the Tamar River estuary.

Devonport, on the northwest coast, has a population of 23,000 people and supports the surrounding agricultural areas as a local commercial centre and provides a harbour for exporting the produce to the Australian mainland and beyond.

Burnie, with a population of just below 20,000, has a similar function further west on the north coast, serving the forestry industry in particular.

While its number of large urban centres is small, Tasmania is characterised by numerous small towns and communities scattered throughout its many river valleys and coastal plains Figure 6.39 shows the location and population ranges of towns and communities with populations in excess of 1000 people.

The major urban centres of the region (populations over 20,000 people) are summarised in Table 6.4. This table provides information on the population, surrounding river basin and significant water storages for each of the major urban centres.

Table 6.4 Cities and their water supply sources in the Tasmania region

City/town	Population[1]	River basin	Major supply sources
Hobart	171,000	Derwent River, Kingston Coast	Derwent River, Mount Wellington streams, Lake Fenton
Launceston	74,000	South Esk River, North Esk River, Tamar River	North Esk River, St Patricks River, Curries River storage
Devonport	23,000	Forth River, Mersey River	Forth River and Lake Paloona

[1] Australian Bureau of Statistics 2011b

Figure 6.39 Population range of urban centres in the Tasmania region

6.6.2 Sources of water supply

With its many river valleys and high rainfall, Tasmania relies almost entirely on surface water to meet its urban supply needs.

The State has a total accessible storage capacity of over 22,000 GL, approximately one quarter of Australia's total surface water storage capacity. Lake Gordon, in the southwest, comprises over half of the region's total storage capacity. While the majority of this storage is used for the generation of hydro-electricity, the networks of dams, transfer channels and pipe plays an important role in the supply of the region's urban water resources.

Urban supplies are typically drawn from river extractions from a combination of catchment inflows and storage releases. The region has a number of smaller dedicated urban storages, such as Lake Travallyn; these, however, are typically much smaller than storages used in many other regions because of the region's reliable rainfall. Figure 6.40 shows the location of the few storages that are specifically functioning as water supply sources to the urban centres of the region.

While only playing a minor role in urban supply in the region, recycled water and groundwater are used to meet only a small proportion of the region's demands. Harvested storm and rainwater are also used on a very local basis to supply urban demand within the region.

6.6.3 Greater Hobart

Hobart is located on the southeast coast of Tasmania on the Derwent River estuary. It occupies the foothills and low lying slopes of Mt Wellington.

Water supply and sewerage services for Hobart and the broader southern Tasmanian area are provided by the Tasmanian Water and Sewerage Corporation (Southern Region) that trades as Southern Water. The cooperation functions as both the bulk water authority and retail supplier.

Supply System

Water supplied to the greater Hobart area (Derwent and Kingston Coast river basins) are drawn from three primary sources, that is, the middle reaches of the Derwent River (upstream of New Norfolk), Lake Fenton/Lady Barron Creek (Mount Field in the Derwent River basin) and from several Mount Wellington streams (Hobart Water 2008).

Water sourced from the Derwent River is treated at the Bryn Estyn plant, transferred to water storages and then delivered to customers throughout Greater Hobart. Water sourced from Mount Wellington and Lake Fenton is used for supply to consumers in Hobart City and Kingborough local government areas.

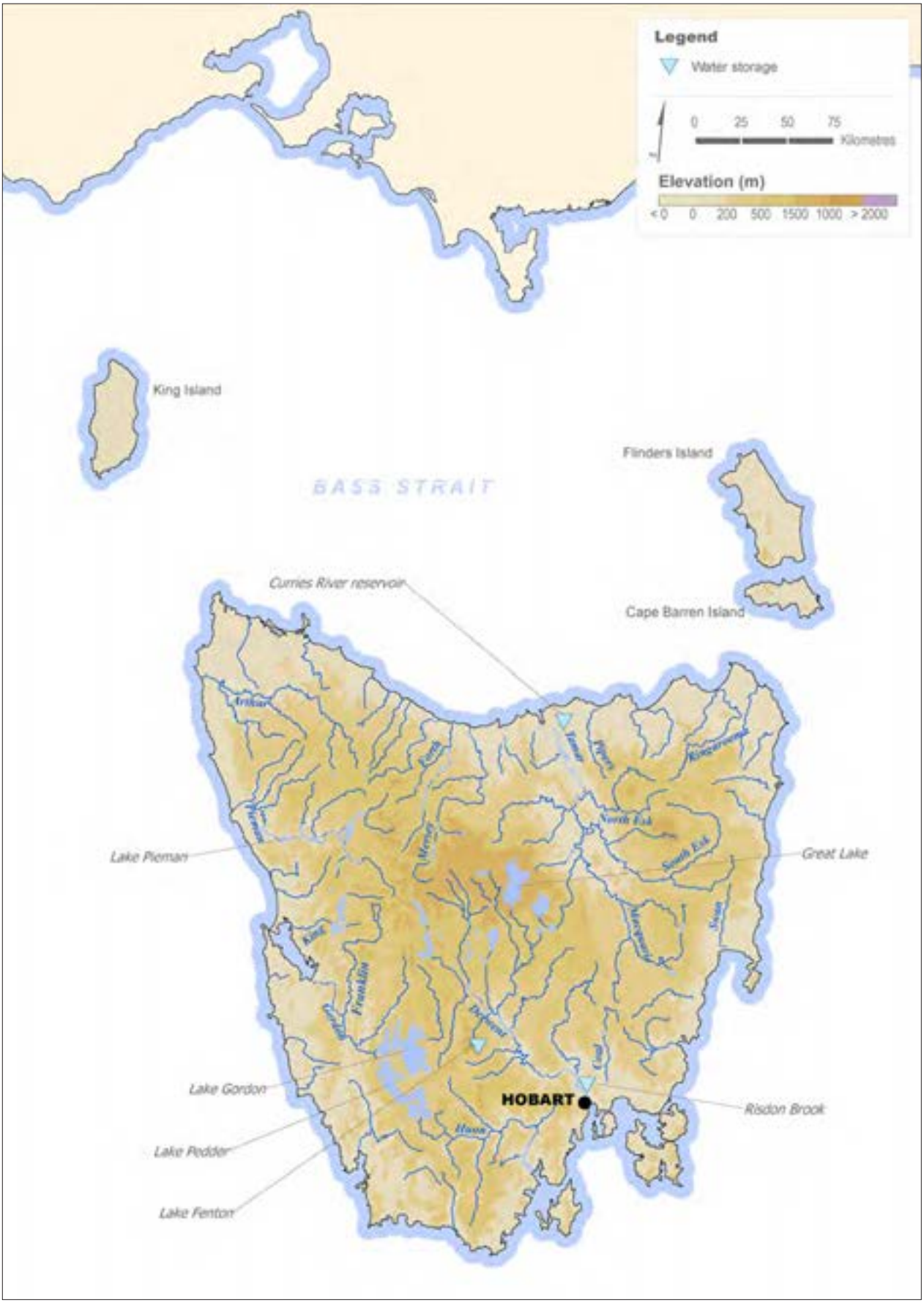


Figure 6.40 Urban supply storages in the Tasmania region

Water restrictions

The reliable and comparatively secure nature of water resources available for supplying the Greater Hobart area have negated the need to enforce water restrictions; however, restrictions on outdoor watering are automatically imposed during periods of total fire ban so that sufficient water is available for fire-fighting purposes (Southern Water 2012).

Storage volumes

While the majority of the city's water supplies are drawn from direct river extractions, Lake Fenton, in the Mount Field National Park, was constructed in 1939. The dam and transfer tunnel is capable of releasing 18 million litres of water per day into the Lady Barron Creek for transfer by pipe to Hobart's water treatment facilities.

Sources of water obtained

The following paragraph contains data relating to the source of water to Greater Hobart from 2006–07 to 2011–12. For the period from 2006–07 to 2008–09, data was extracted from a National Performance Report (National Water Commission 2009a).

Figure 6.41 presents the total volume of water sourced from surface water for supply to Greater Hobart area. A downward trend in the water drawn is emerging with an 8% reduction over the past two years in total water supplies.

Consumption data for Greater Hobart was not available.

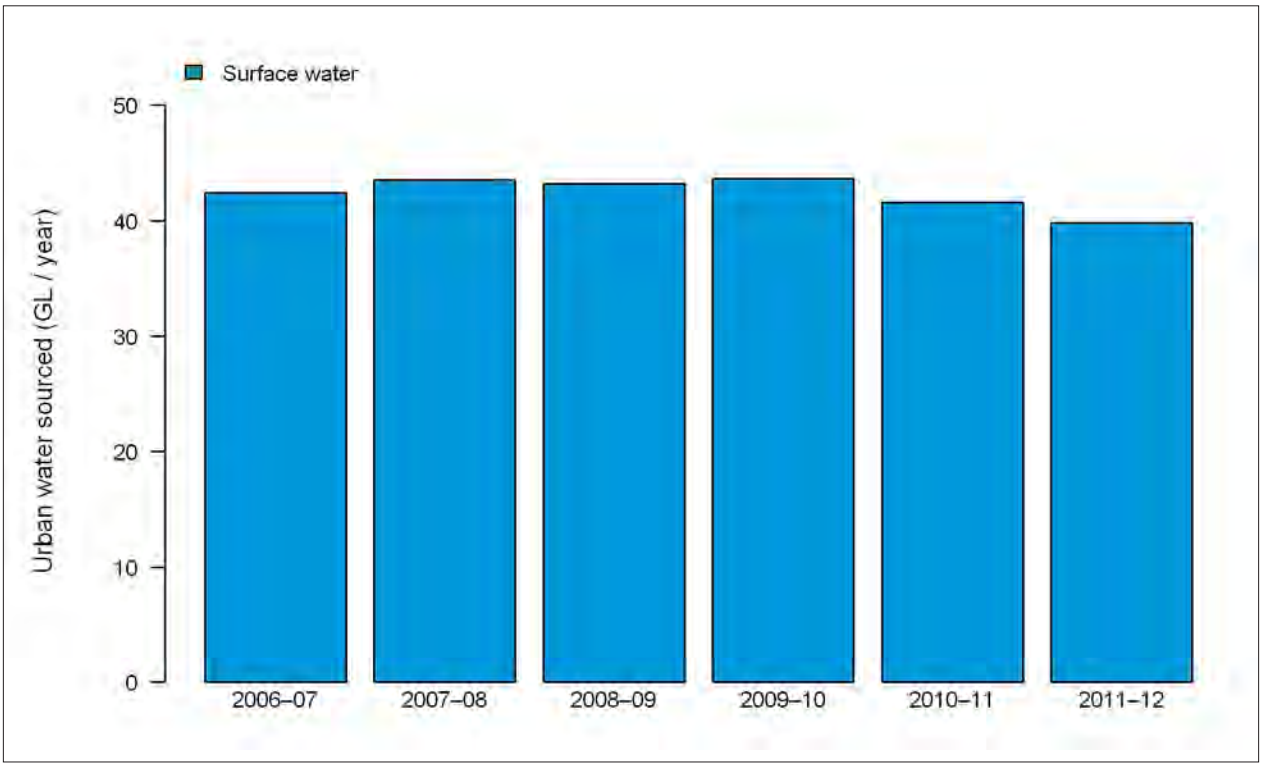


Figure 6.41 Total urban water sourced for Greater Hobart from 2006–07 to 2011–12

6.7 Water for agriculture

This section describes the water situation for agriculture in the Tasmania region during 2011–12 year compared with the past. Soil moisture conditions are presented and important irrigation areas are identified. The South East and Meander irrigation areas are described in more detail and information is provided regarding surface storage.

6.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 x 5 km grid cell, they are not suitable to compare with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

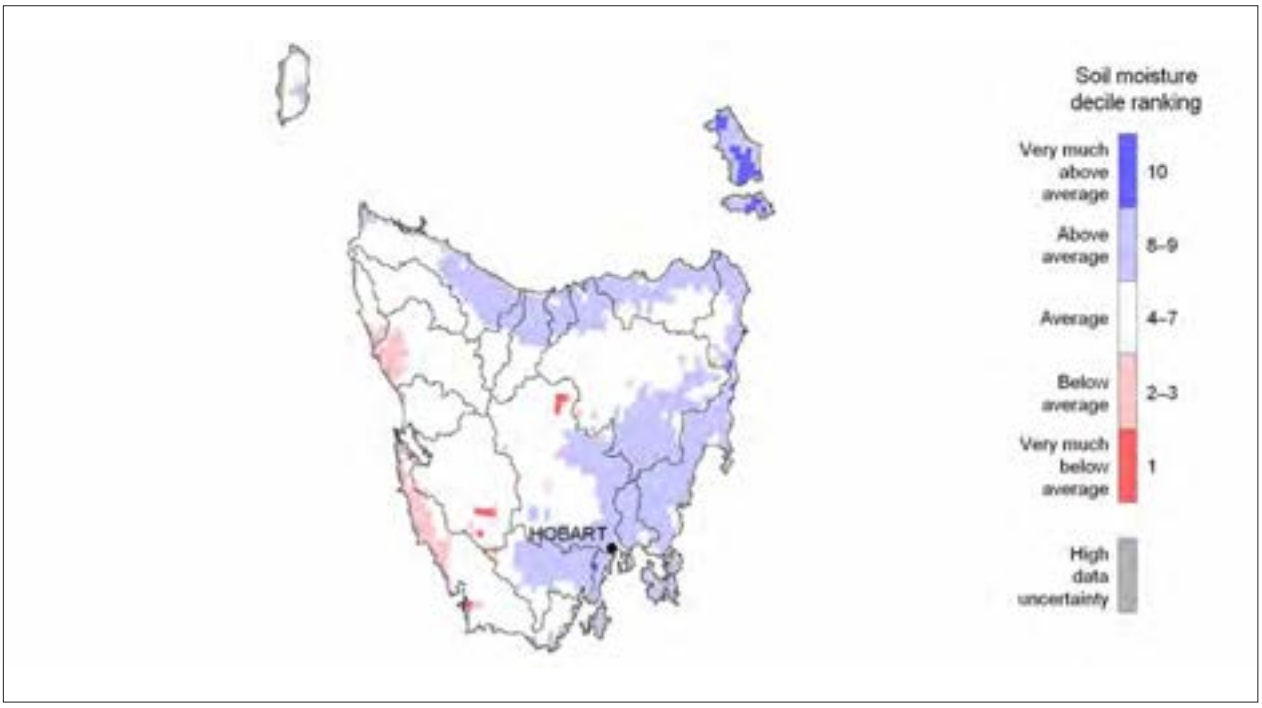


Figure 6.42 Deciles rankings of annual average soil moisture for 2011–12 with respect to the 1911–2012 period for the Tasmania region

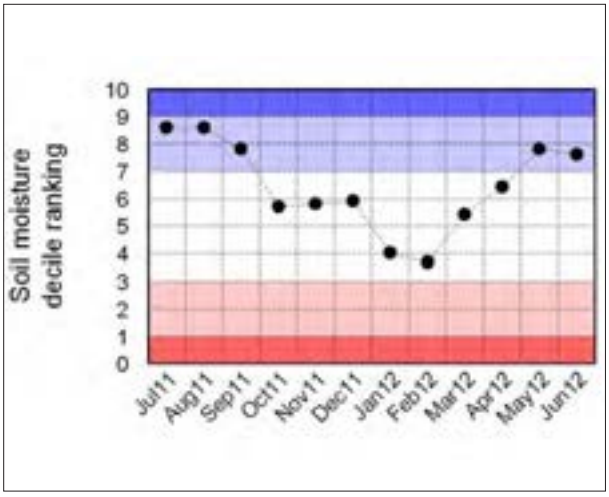


Figure 6.43 Decile ranking of the monthly soil moisture conditions during the 2011–12 period with respect to the 1911–2012 in the Tasmania region

The decile ranking of soil moisture in the region indicates average and below average soil moisture conditions throughout the region in 2011–12 (Figure 6.42). The region experienced much drier conditions in the west compared with the eastern areas, which received above average rainfall in many parts of the area.

The region had above average soil moisture conditions at the start of the year, but this dropped to below average in summer, due to the combination of average rainfall and very much above average evapotranspiration in spring (Figure 6.43). Moisture levels returned back to above average in June 2012 as rainfall in the second half of the year was above average.

6.7.2 Irrigation water

Average annual irrigation water use in the region's three natural resource management regions over the period 2005–06 to 2010–11 is illustrated in Figure 6.44. Figure 6.45 shows the irrigation water use in each region for the year 2010–11. At the time of preparing this report, the data for 2011–12 year was not available.

The South East Irrigation Scheme (in the Coal River catchment), and Meander Irrigation District will be discussed in more detail in the following subsections.

6.7.3 Irrigation areas

Due to highly uneven rainfall distribution, the Tasmania region has a diverse range of hydrological characteristics, and as a consequence a variety of land uses is observed in the region. More than 70% of the land is covered by nature conservation and forestry. Pasture covers more than 20%. Irrigated agriculture is a developing industry in Tasmania. In spite of this, agriculture is an important component of the region's economy, contributing to about 16% of the gross state product (Tasmanian Farmers and Graziers Association 2010). It consumes about 60% of total water use in the State (ABS 2010). Figure 6.46 shows the irrigation areas in the region.

Allocation of water resources in the region is governed by water management plans and through water licence approval processes under the State's *Water Management Act 1999*. The design of policy and regulatory frameworks for allocation and sustainable use of surface and groundwater resources, as well as infrastructure construction in the region is the responsibility of the Department of Primary Industries, Parks, Water and Environment (DPIPWE).

The government-owned Hydro Tasmania is a major hydropower operator in Australia and is responsible for water management under a Special Water Licence for many major lakes and rivers in the region.

Operational service includes mechanisms to allow transfer of water for irrigation purposes and town water supply responsibilities in addition to electricity generation.

Tasmanian Irrigation is responsible for the development and operation of various irrigation schemes in the region through a public-private partnership. The Meander Irrigation District (in the Meander River catchment) is the largest scheme operated by Tasmanian Irrigation. The irrigation industry in the region is changing rapidly with a number of new schemes commencing operation.

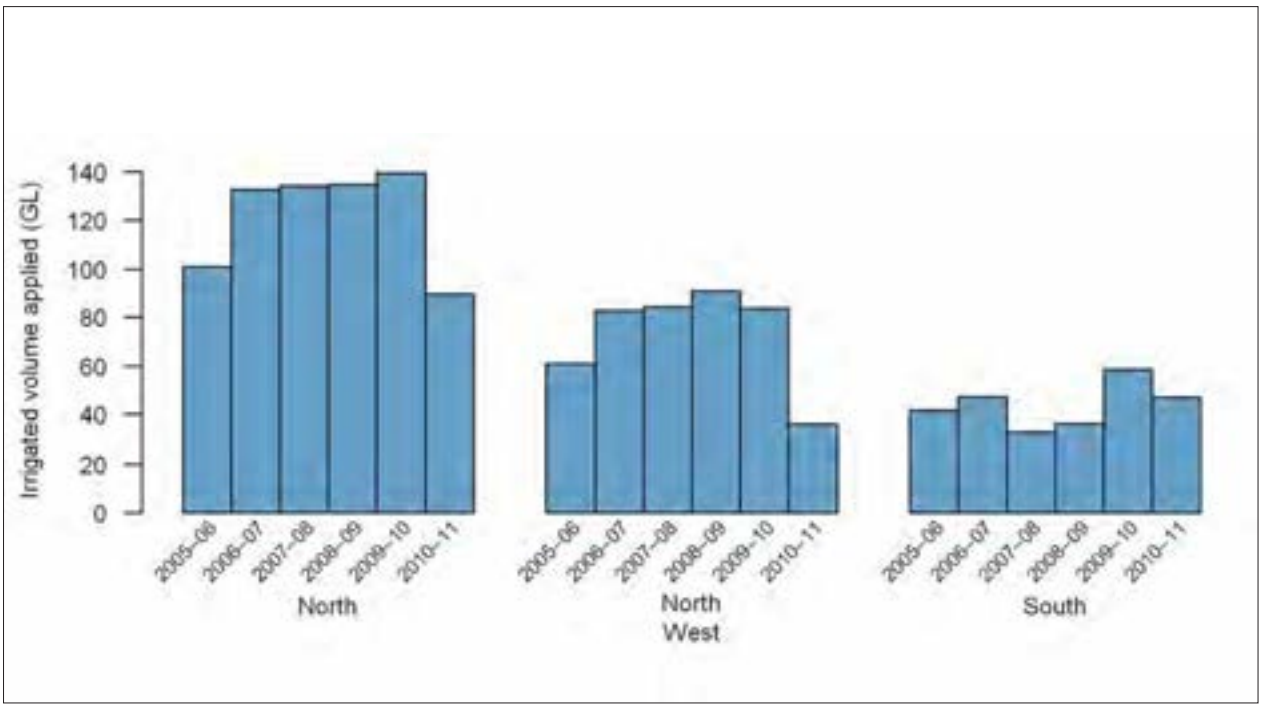


Figure 6.44 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the Tasmania region (ABS 2006-2010; 2011a)

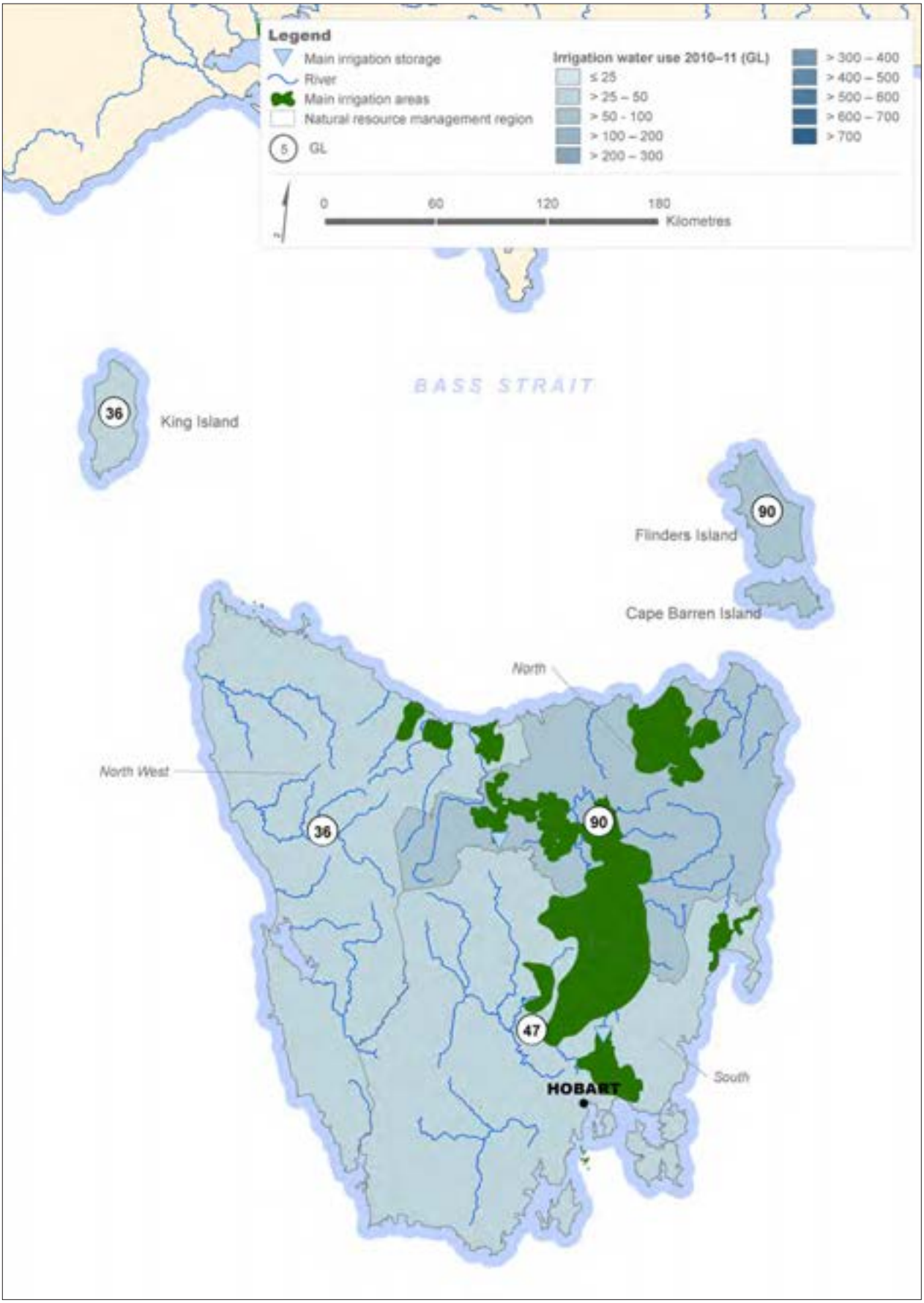


Figure 6.45 Annual irrigation water use per natural resource management region for 2010–11 (ABS 2011a)

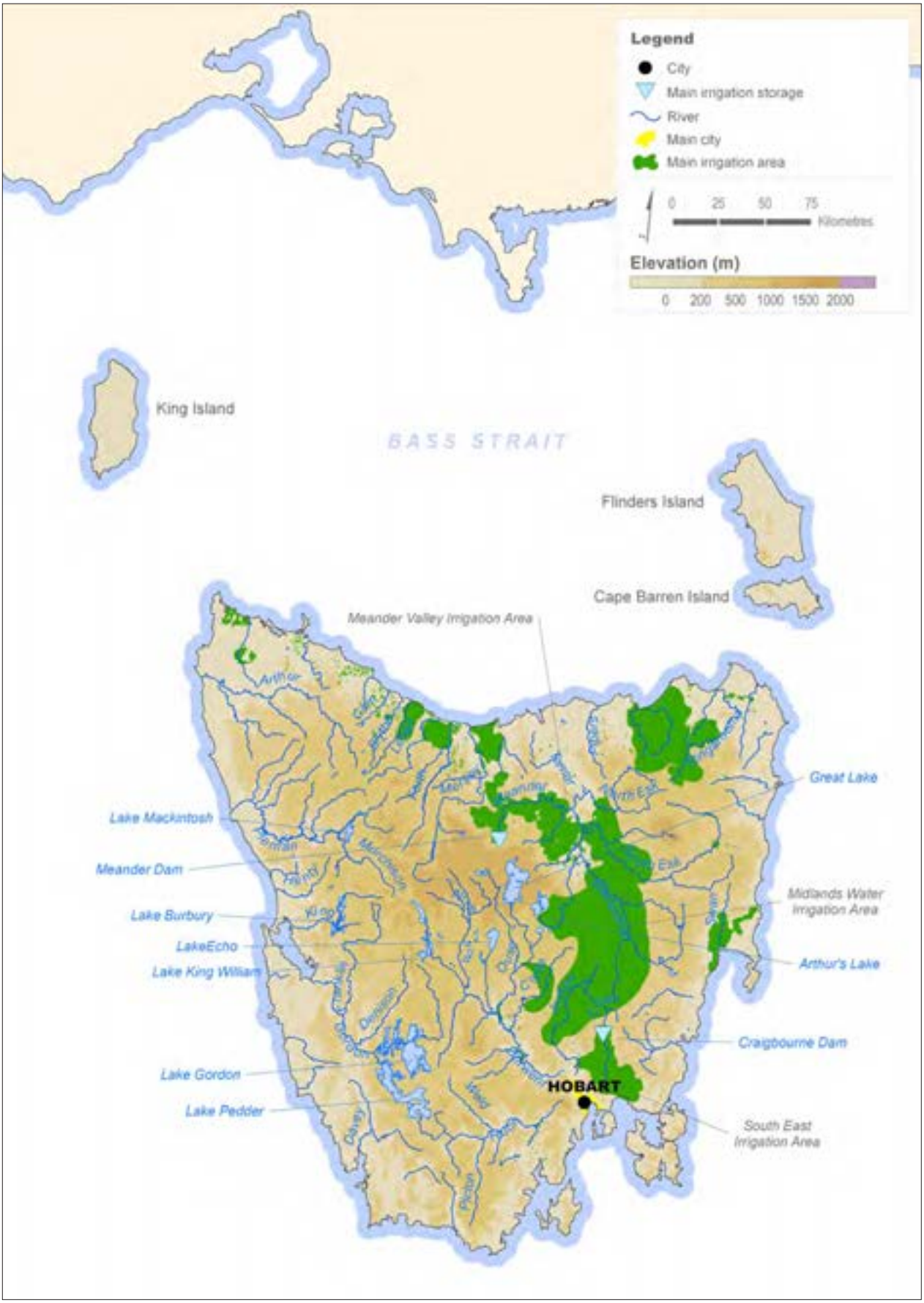


Figure 6.46 Irrigation areas in the Tasmania region

6.7.4 South East and Meander irrigation schemes

Figure 6.47 presents a map of the South East and Meander Valley irrigation schemes.

South East Irrigation Scheme

The South East Irrigation Scheme controls water distribution and usage in the Coal River catchment through stages 1 and 2 of the irrigation scheme. Stage 1 of the scheme comprises the Craigbourne storage at upper Coal River near Colebrook. Stage 2 of the scheme consists of 4,200 ha, most of which is located downstream of Craigbourne and has received regulated flows since 1986.

Craigbourne Dam was built in 1986 and the storage has an accessible capacity of 12.5 GL with a lake surface area of approximately 6.2 km^2 and a catchment area of around 247 km^2. The dam is built primarily for irrigation water storage, but is an important and popular fishery because of its proximity to Hobart.

In 2011–12, 12.6 GL of water was allocated to the operation of the Coal River Irrigation District (stage 1); however, only a minimal amount of 112 ML was pumped into the South East Irrigation Water District Stage 2. The urban water supplier Southern Water supplied 1.2 GL into Daisy Bank reservoir for irrigation purposes of the district (DPIPWE pers. comm.).

Meander Valley Irrigation Scheme

The Meander Valley Irrigation Scheme was established in 2007–08 (Meander Valley Council 2010). The Meander Dam (and associated Huntsman Lake) was officially operational in 2008. Huntsman Lake has a storage capacity of 43 GL. Water available for irrigation is 36 GL (Tasmanian Irrigation 2013).

In 2011–12, 4.3 GL of water was delivered for the purposes of irrigation during the operation of the Meander Valley Irrigation District (DPIPWE pers. comm.). Water delivery for irrigation in the two districts has reduced in recent years due to high rainfall inputs (Figure 6.48).

Meander River, Tasmania | Dennis Harding

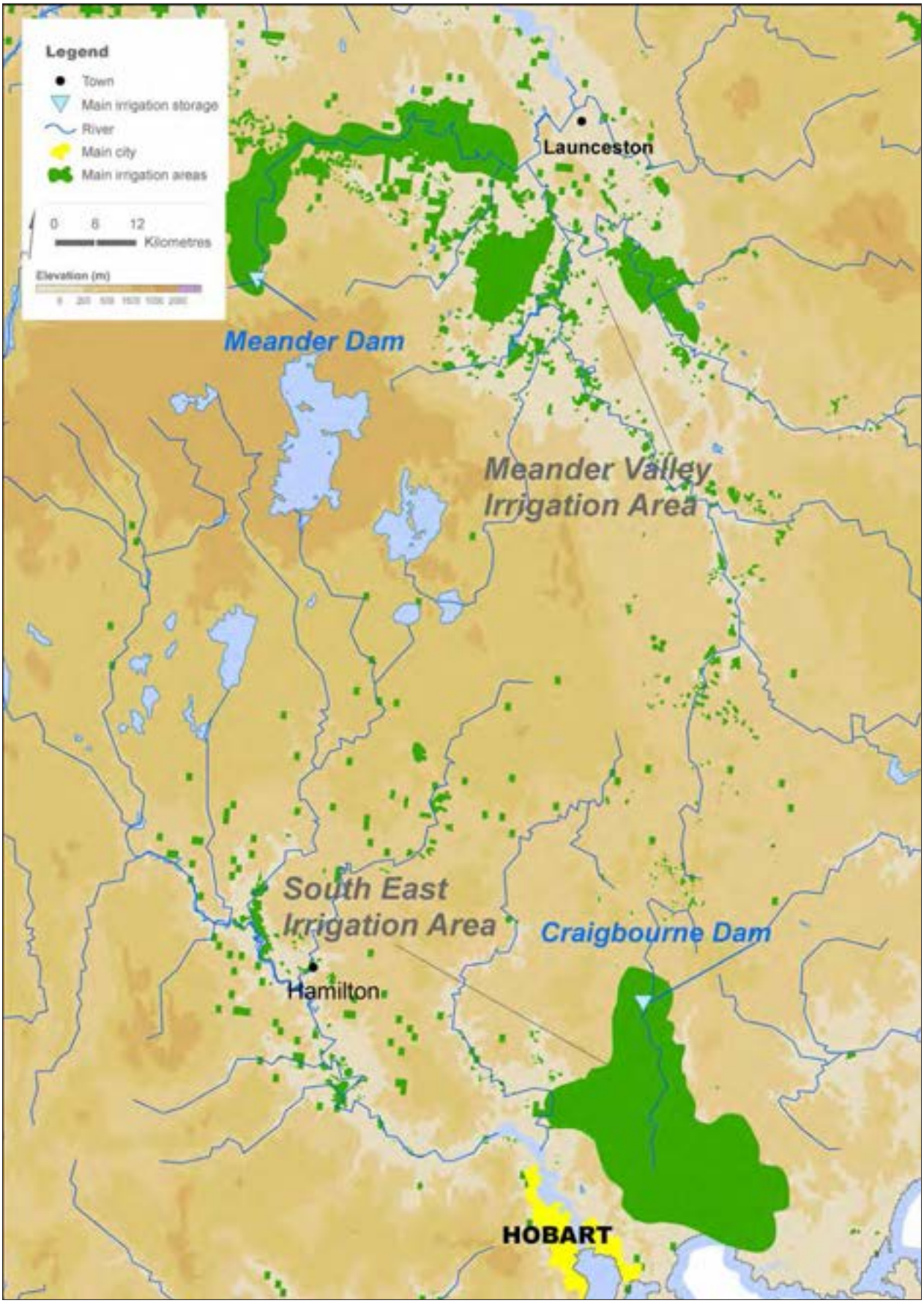


Figure 6.47 Meander and South East irrigation schemes

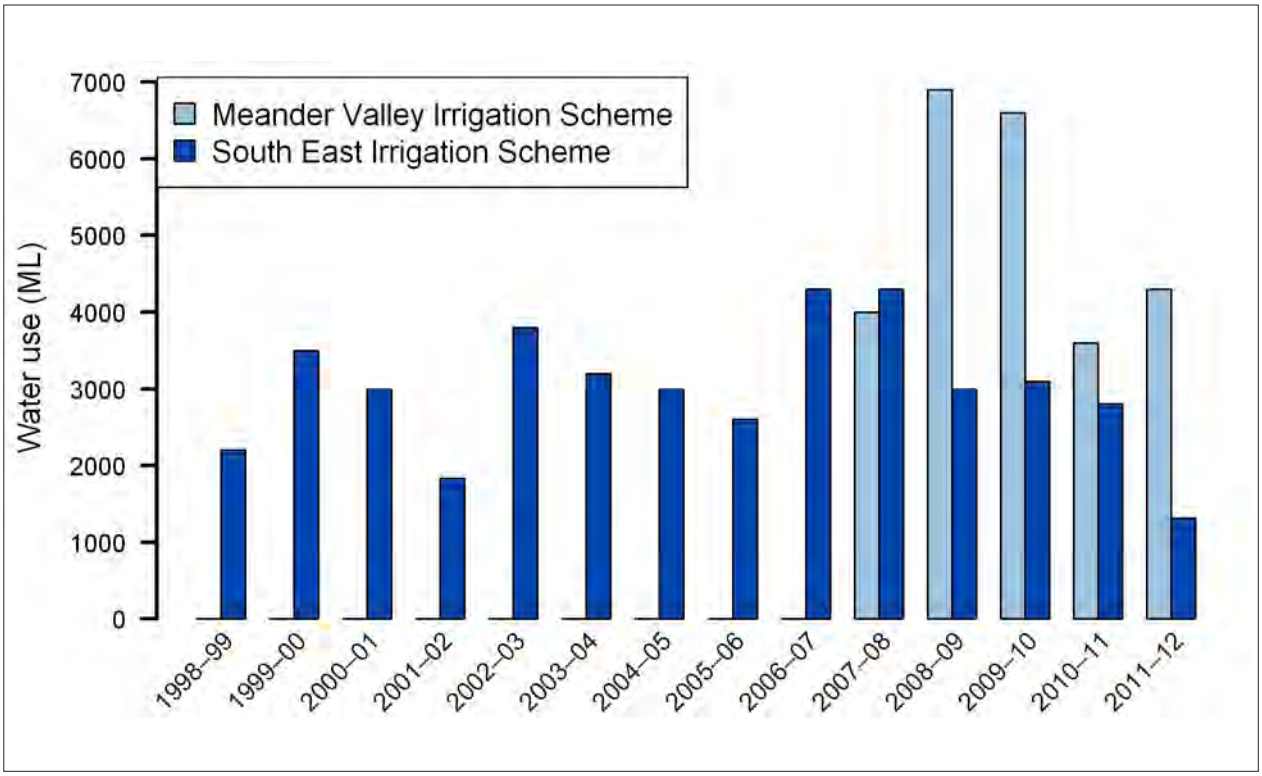


Figure 6.48 Water use in Meander and South East irrigation schemes between 1998–99 and 2011–12

Surface water storage inflows

The seasonal flow patterns in the Coal River, shown in Figure 6.49, show flow volumes are generally low with long periods of zero flow. The rainfall in the region is generally highest in winter and subsides during summer when evapotranspiration is at its highest. The inflows to Craigbourne were average to very much above average at the beginning of 2011–12 and dropped to almost nil afterwards before it rose again through the end of the period due to above average rainfalls that occurred in the region. The historic inflows to Huntsman Lake are much higher than that of Craigbourne, reflecting the higher rainfall in the former area. Compared with their historic average, the flow in the Meander River was average for the most part of the year.

Surface water storage volumes

The storage volume change in the Huntsman Lake is shown in Figure 6.50, which follows the inflow pattern to the lake in Figure 6.49. The historic data shows a cyclic pattern in the availability of water in the storage that follows the seasonality of rainfall in the region.

The data for the 2011–12 year, which covers only up to February 2012, shows a gradual drop in the storage volume after winter season.

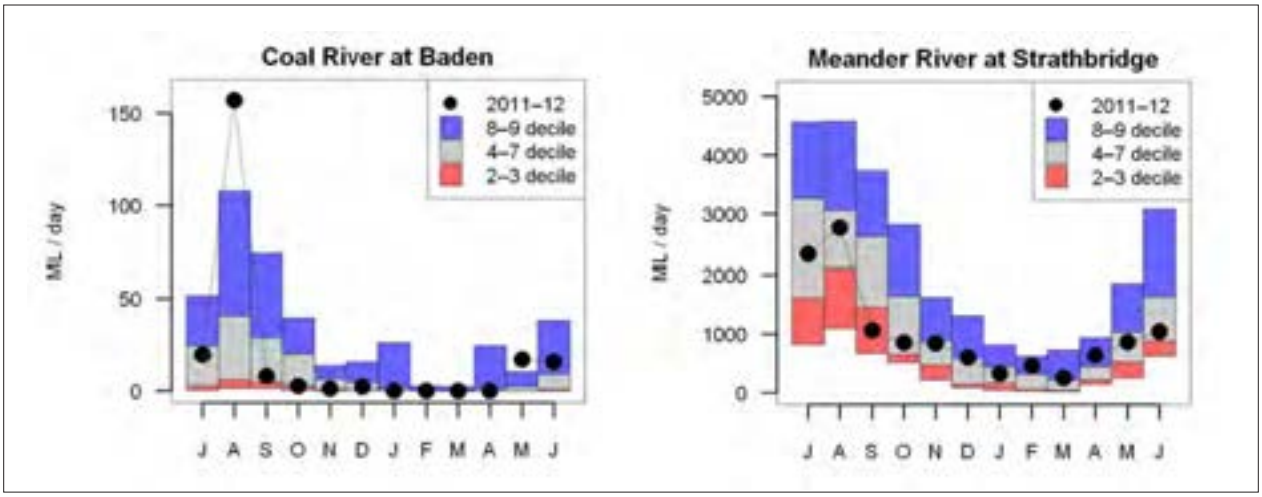


Figure 6.49 Monthly discharge hydrograph compared to discharge deciles for inflows into Craigbourne (Coal River) and Huntsman Lake (Meander River) storages

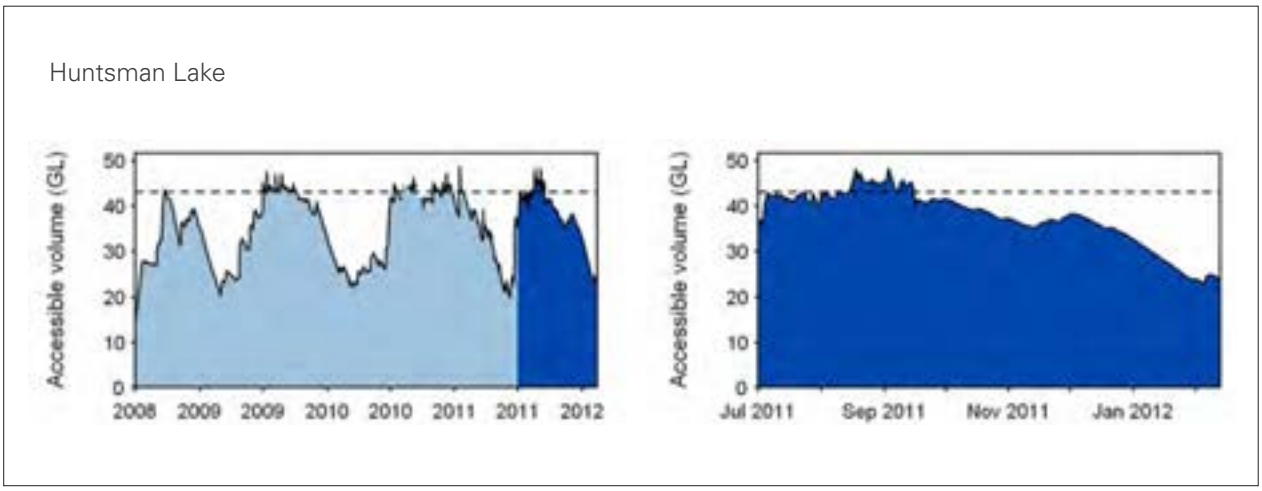


Figure 6.50 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Huntsman Lake storage, as well as total accessible storage capacity (dashed line)

Murray–Darling Basin

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7. Murray–Darling Basin

7.1 Introduction

This chapter examines water resources in the Murray–Darling Basin region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented, as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

7.2 Key information

Table 7.1 gives an overview of the key components of the data and information in this chapter.

Table 7.1 Key information on water flows, stores and use in the Murray–Darling Basin region

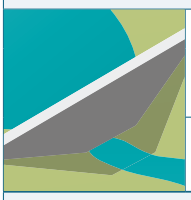
Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	651 mm	+40%	10th—very much above average
Evapo-transpiration	559 mm	+29%	10th—very much above average
Landscape water yield	65 mm	+110%	10th—very much above average

Streamflow (at selected gauges)

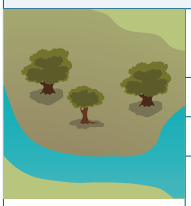
Annual total flow:	Predominantly above average flow throughout the region and numerous stream gauges in the upper Darling River with very much above average flow
Salinity:	Annual median electrical conductivity predominantly below 1,000 µS/cm throughout the region
Flooding:	Major floods in the upper Darling River and in the Lachlan and Murrumbidgee rivers

Surface water storage (comprising about 88% of the region's total capacity of all major storages)



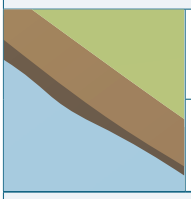
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
30,192 GL	25,230 GL	84%	22,006 GL	73%	+3,224 GL	+9%

Wetlands inflow patterns (for selected wetlands)



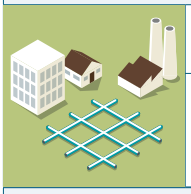
Currawinya Lakes and Paroo River wetlands:	Very much above average flows in the normally wettest month of February and above average flows in December and March
Gwydir wetlands:	Very much above average flows in November, December and February
Macquarie Marshes:	Very much above average flows in March and April
Barmah–Millewa Forest:	Very much above average flows in March, above average flows in July and August

Groundwater (in selected aquifers)



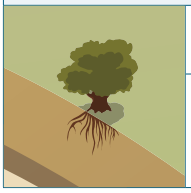
Levels:	Predominantly rising groundwater levels in the northern aquifers, variable to stable groundwater level trends in the southern aquifers
Salinity:	Non-saline groundwater < 3,000 mg/L) in most aquifers in the uphill areas, mostly saline (≥3,000 mg/L) in the downhill basin aquifers

Urban water use (Canberra)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
44 GL	41 GL	+3 GL (+7%)	Permanent Water Conservation Measures

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly very much above average throughout the region, with some areas of above average in the south and east of the region
Temporal patterns in regional average:	Consistently very much above average during the year

7.3 Description of the region

The Murray–Darling Basin region covers more than 1,000,000 km^2, one-seventh of mainland Australia, including all of the Australian Capital Territory and parts of Queensland, New South Wales, Victoria and South Australia (Figure 7.1). The region is bounded in the south and east by the Great Dividing Range. In the northwest and southwest, the boundaries are much less distinct, particularly in the Wimmera River basin to the southwest and the Paroo River basin in the northwest, which borders the Bulloo River basin of the Lake Eyre Basin region.

Vast inland plains, including the Darling and Riverine plains, and large areas of undulating hills dominate the region's landscape. The region also includes the three longest rivers in Australia: the River Murray, Murrumbidgee River and Darling River. Subsections 7.3.1 to 7.3.4 give more detail on the physical characteristics of the region.

The region has a population of over 2 million people or approximately 10% of Australia's total population (Australian Bureau of Statistics [ABS] 2011b). The major population centre is Canberra/Queanbeyan. Other major towns are mostly located along the southeast of the region (Figure 7.1). Further discussion of the region's population distribution and cities and towns can be found in subsections 7.3.6 and 7.6.1 respectively.

Agriculture is the dominant economic activity in the region. Pasture, predominantly for livestock production, accounts for 75% of the land area of the basin. Important cropping activities include cereals (particularly wheat, barley and rice), oilseed, cotton, and horticulture (particularly citrus, stone and pome fruits, grapes and vegetables). Irrigated agriculture occupies a relatively small proportion of the region (2%) but is the major water user. More than half of all irrigation in Australia takes place in the region, which supports an agricultural industry that contributes about 40% to the gross value of irrigated agricultural production in Australia (ABS 2010). Section 7.7 has more information on agricultural activities in the region.

The region has a diverse range of climatic conditions and natural environments, from the cool temperate rainforests of the eastern uplands, to the drier more sparsely vegetated Mallee country of the southwest. There are subtropical areas to the northeast of the region and the far western plains are hot and semi-arid to arid. Subsections 7.3.7 and 7.3.8 provide more information on the rainfall patterns and deficits across the region.

Monsoonal events in the north of the Murray–Darling Basin region and rainfall along the western slopes of the mountains in the northern part of the Great Dividing Range contribute to the flow in the Darling River. Much of the flow in the various tributaries of the River Murray originates from rainfall run-off and snowmelt in the south and southeast of the region. The headwaters of the Murrumbidgee River are in the Snowy Mountains area of the Kosciuszko National Park, whereas the headwaters of the River Murray, the Mitta Mitta River, and the Ovens River are in the Victorian Alps. The Broken and Goulburn rivers also contribute a substantial proportion to the flow in the middle reaches of the River Murray.

The region is divided into three broad hydrogeological subdivisions (Murray–Darling Basin Commission 2008), namely:

- the basinal aquifers in sedimentary deposits (Murray Basin and Great Artesian Basin) within the flatter landscapes;
- the fractured rock aquifers in areas where the basement rock outcrops are present; and
- valley-fill alluvium (including the mid-Murrumbidgee and upper Namoi) in the highlands bordering the basin.

Figure 7.1 Major rivers and urban centres in the Murray–Darling Basin region

7.3.1 Physiographic characteristics

The physiographic map in Figure 7.2 indicates areas with similar landform histories that can be related back to similar geology and climatic impacts that influence erosion processes (Pain et al. 2011). The areas have distinct physical characteristics that impact on hydrological processes.

The Murray–Darling Basin region has five major physiographic provinces, namely:

- Central Lowlands (37%): sand, clay and stony plains with low sandy hills;
- Kosciuszkan Uplands (10%): moderately high mountains and detached hills with intervening alluvial valley floors;
- New England–Moreton Uplands (7%): mainly undulating granitic plateaus and metamorphic ridges and shale lowlands; and
- Macquarie Uplands (6%): granitic and basaltic tablelands with detached hills in the west.

The remaining two provinces occupy less than 3% of the region (Gulfs Ranges and Fitzroy Uplands).

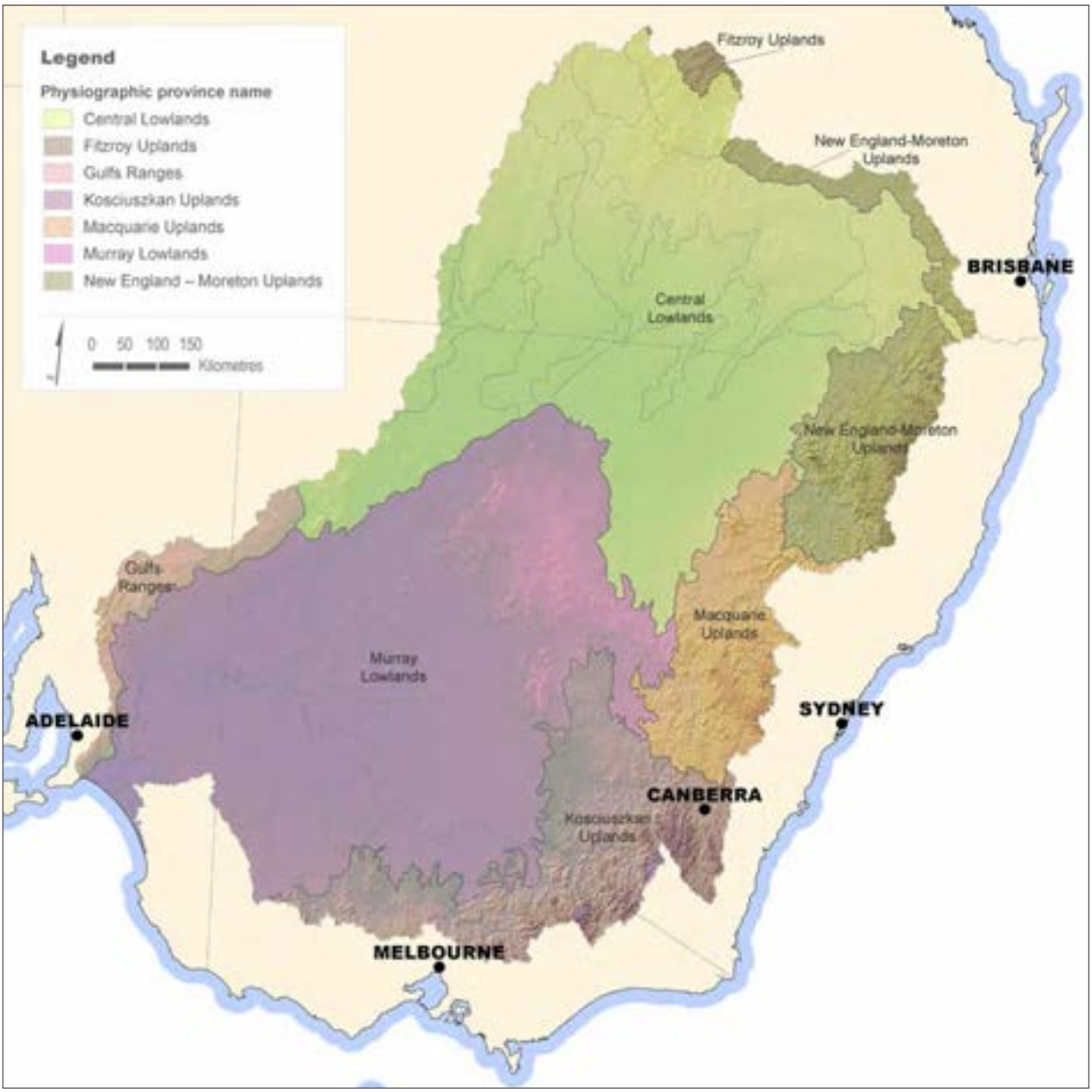


Figure 7.2 Physiographic provinces of the Murray–Darling Basin region

7.3.2 Elevation

Most of the region's landscape is dominated by vast inland plains and large areas of undulating hills, almost all lower than 200 m above sea level. The largest plains are the Darling Plain in the north, drained by the Darling River and its tributaries, and the Riverine Plain in the south, drained by the Murray and Murrumbidgee rivers and their tributaries.

The Murray–Darling Basin region has clear water-divide boundaries in the south and east of the region formed by the Great Dividing Range. To the northwest and southwest, the boundaries are much less distinct, due to very low topography. Elsewhere, areas of low to medium altitude determine the region's boundaries (Figure 7.3). Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).

The region includes a large portion of the western flanks of the Great Dividing Range. It is here where most of the run-off is generated.

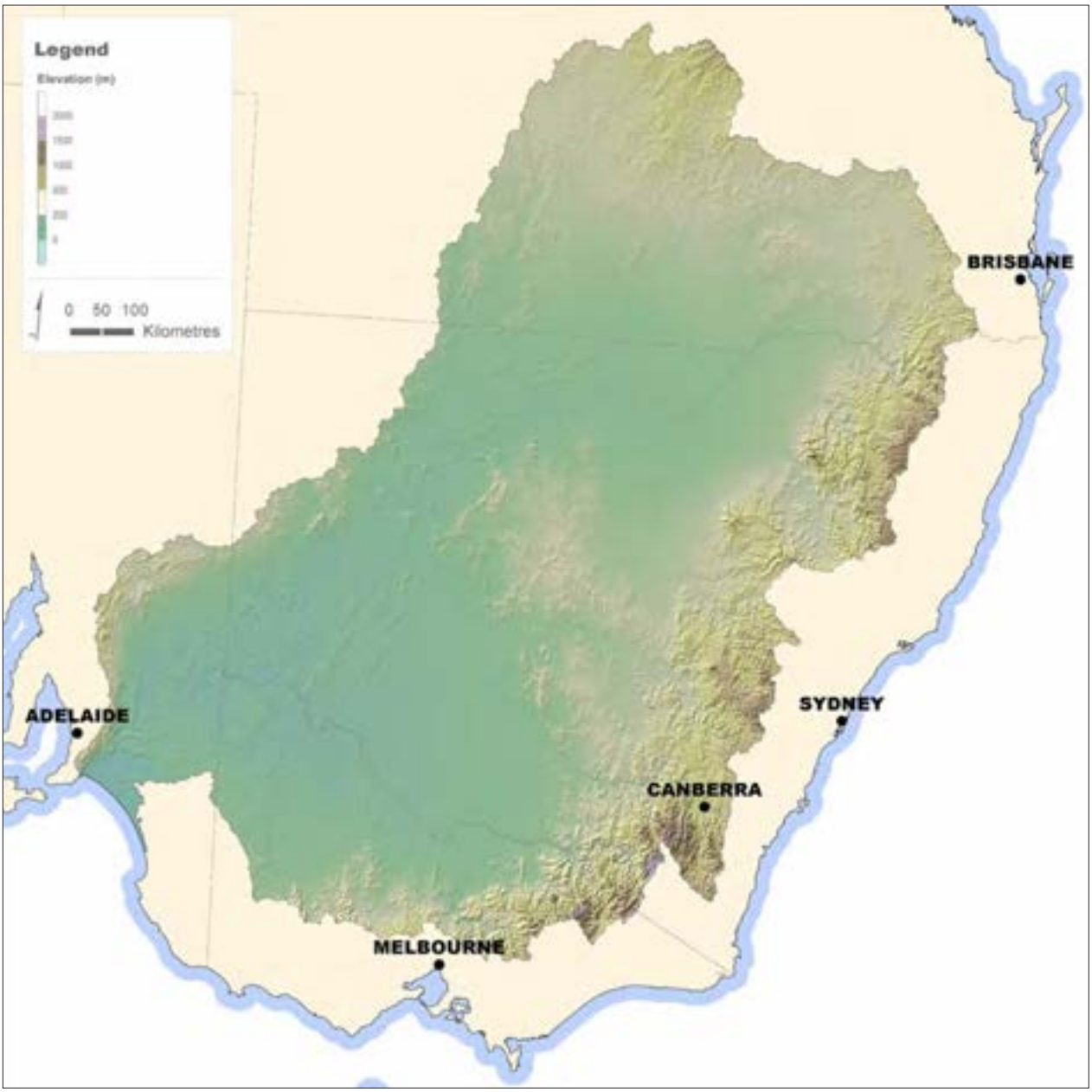


Figure 7.3 Land surface elevations in the Murray Darling Basin region

7.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The Murray–Darling Basin region is generally flat, with some areas of steeper slopes along the southeast border (Table 7.2 and Figure 7.4). The slopes were derived from the elevation information used in the previous section.

Table 7.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	51.4	16.2	22.7	9.7

These steep slopes provide opportunities to create large storages through the construction of relatively small dams. Major storages like Lake Hume, Lake Dartmouth and Lake Eildon now serve as an essential source of fresh water for the irrigation areas in the upper and lower River Murray.

Several large rivers flow through the flat plains of the region. In times of high flow volumes, water moves slowly and these rivers form vast floodplains over longer periods of time. When the flood waters retreat, what remains are numerous wetlands and lakes of various types that are distributed throughout the region, but are particularly prominent along the lower Darling River.

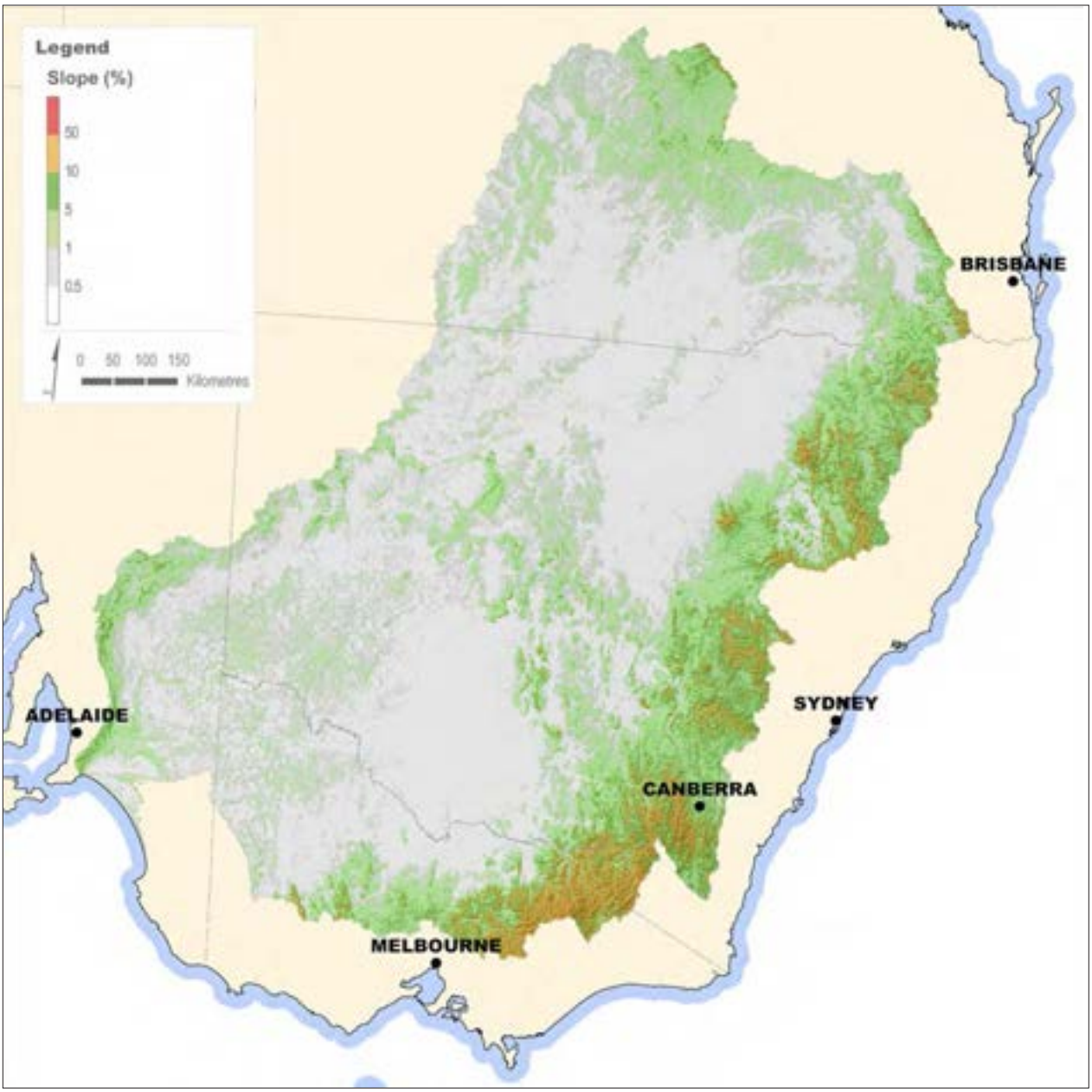


Figure 7.4 Surface slopes in the Murray–Darling Basin region

7.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge. The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 85% of the Murray–Darling Basin region comprises four soil types, namely sodosols, kandosols, vertosols, and calcarosols (Figure 7.5).

Sodosols are widely found in the south, southcentral as well as eastern part of the region (Figure 7.6). These soils have a clear texture contrast, with a relatively impermeable, sodic and clay-enriched subsoil. Due to their soil dispersion and structural instability they are susceptible to tunnel and gully erosion as well as dryland salinity, if vegetation is cleared. Sodosols are mostly used for dryland crops and horticulture in the area.

Kandosols are dominant in the northwest of the Murray–Darling Basin region, but are also widely represented in the southeast of the region. These soils are often very deep (up to three metres or more), but do not have a strong texture contrast and colour change, and do not contain carbonate throughout their profile. Kandosols have a low to moderate agricultural potential with moderate water-holding capacity and chemical fertility. These soils are mostly used for grazing in this region. When grazed, these soils are susceptible to surface soil degradation, such as hardsetting and crusting even under low grazing intensities.

Vertosols are stretched around the southcentral to north-central part of the region. These are brown, grey or black soils with high clay contents. They are highly fertile and have a large water-holding capacity. They, however, require a significant amount of water before it becomes available to plants. In the region they are used for dryland agriculture and horticulture.

Calcarosols are the dominate soil type in the lower parts of the region and are mostly used for dryland crops and horticulture. These soils are often shallow with low water-holding capacity. They are characterised by a high calcium carbonate content, which occurs as soft or hard white fragments, or as solid layers. They have low to moderate agricultural potential and often high salinity levels. Alkalinity and boron toxicity may cause issues.

The soil types that have minimal representation in the Murray–Darling Basin region are tenosols, rudosols, dermosols, kurosols and ferrosols (between 0.5–4% of the total area).

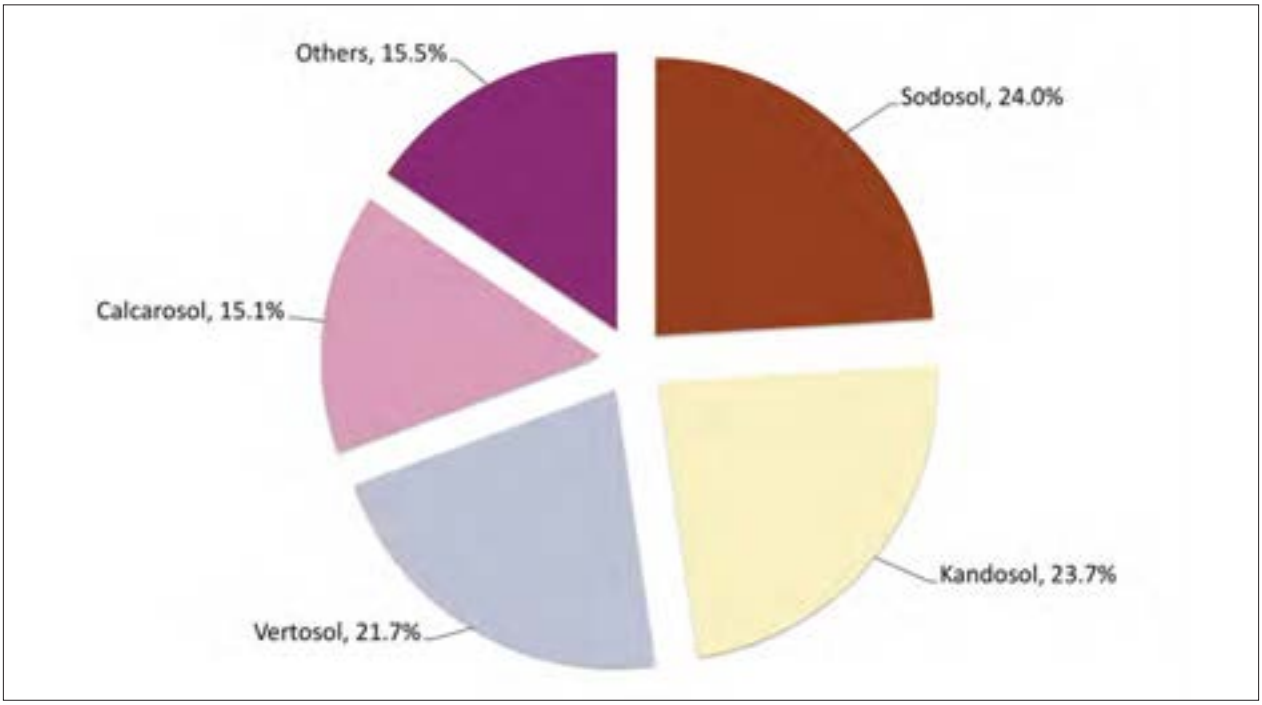


Figure 7.5 Soil types in the Murray–Darling Basin region

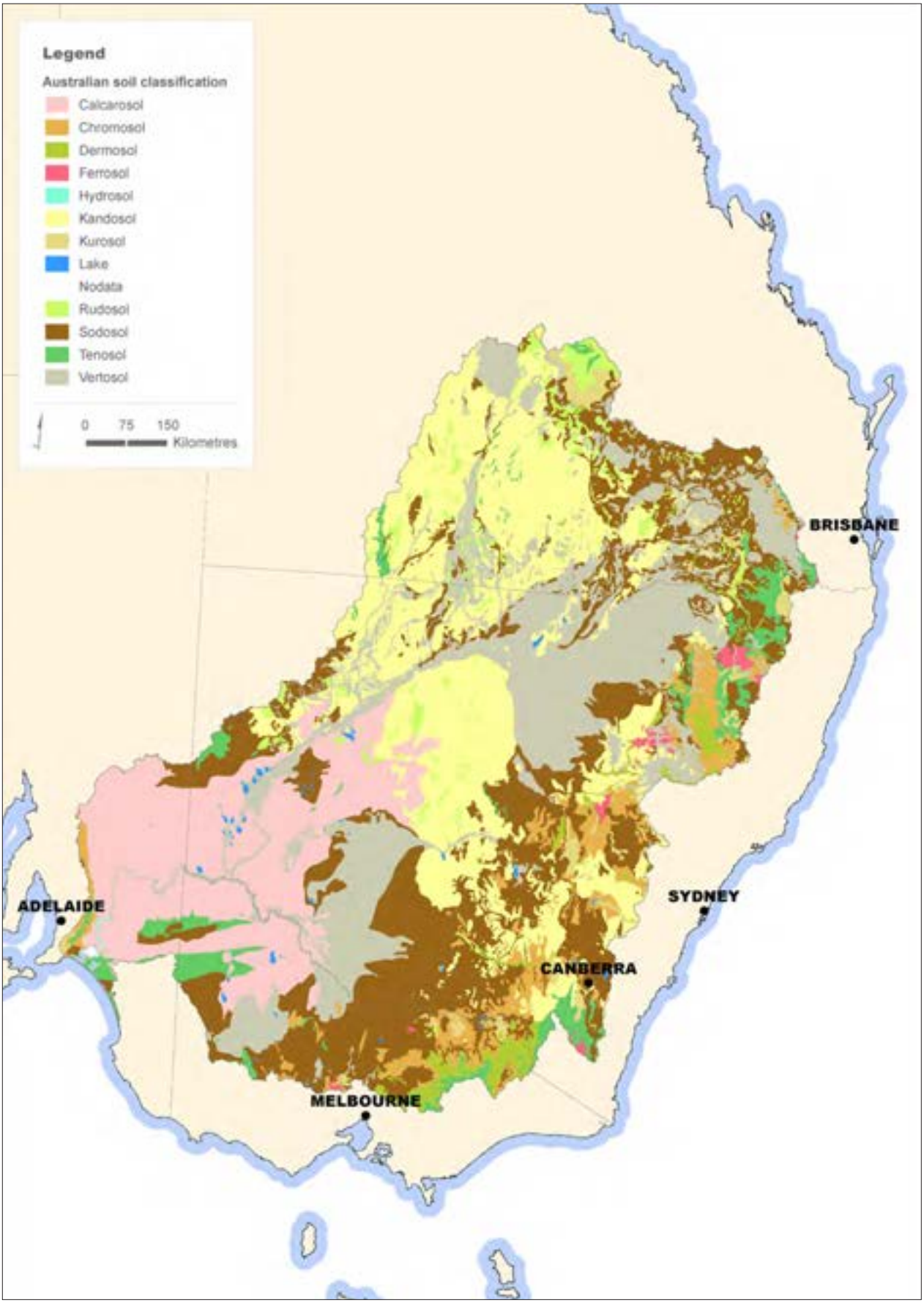


Figure 7.6 Soil type distribution in the Murray–Darling Basin region

7.3.5 Land use

Agriculture is the dominant economic activity in the Murray–Darling Basin region. Pasture, predominantly for livestock production, particularly dryland sheep and cattle production, accounts for 75% of the land area of the basin (Figure 7.7 and Figure 7.8; data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Important cropping activities include cereals, oilseed, cotton, and horticulture such as fruits and vegetables.

Although irrigated agriculture occupies a relatively small portion of the region (2%), it is the major water user in the basin.

More than 60% of all irrigation in Australia takes place in the Murray–Darling Basin region. This contributes to more than 40% of the total gross value of irrigated agricultural production in Australia (ABS 2010).

In 2011–12, cotton production accounted for the largest area of irrigated land in the region. Cotton production also used the largest volume of irrigation water. Irrigation areas are located in the Murrumbidgee, Murray, Lachlan, Goulburn, Broken, Loddon and lower Murray river basins to the south of the region, and the Condamine, Border, Gwydir, Namoi and Macquarie river basins to the north of the region.

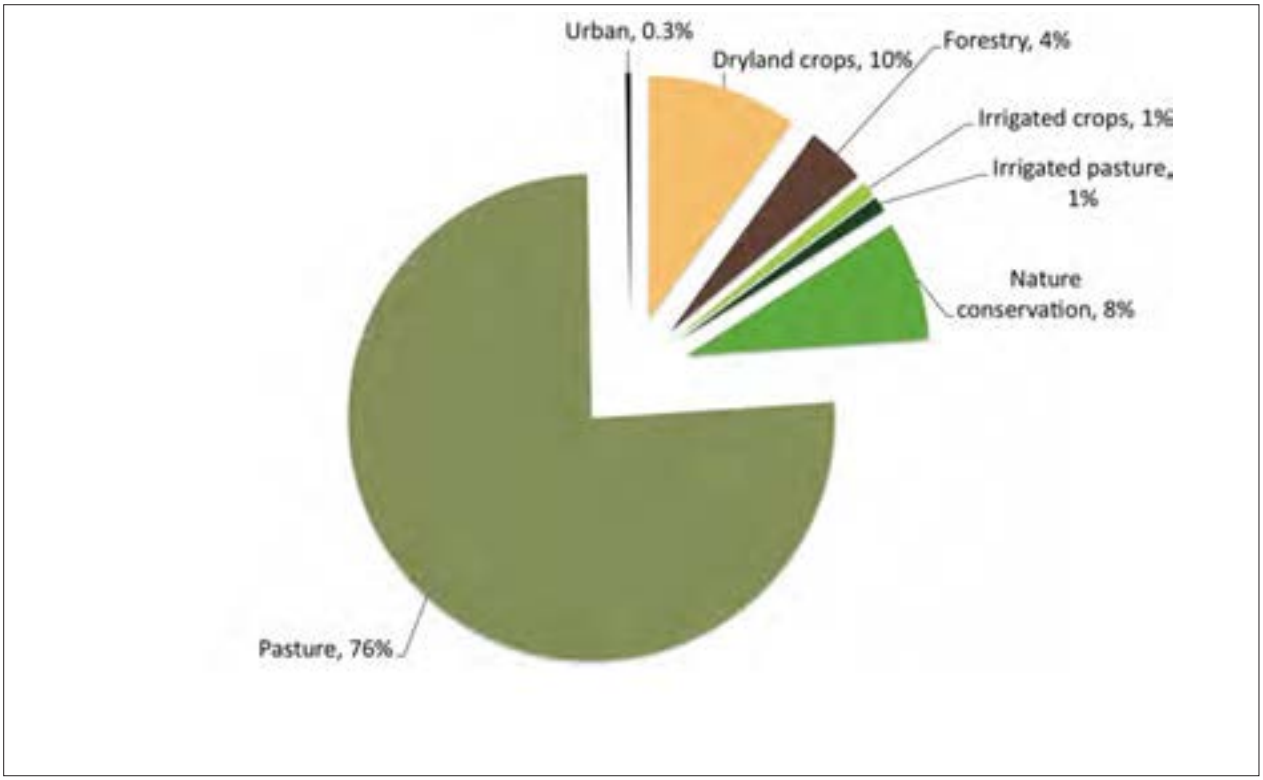


Figure 7.7 Land use in the Murray–Darling Basin region

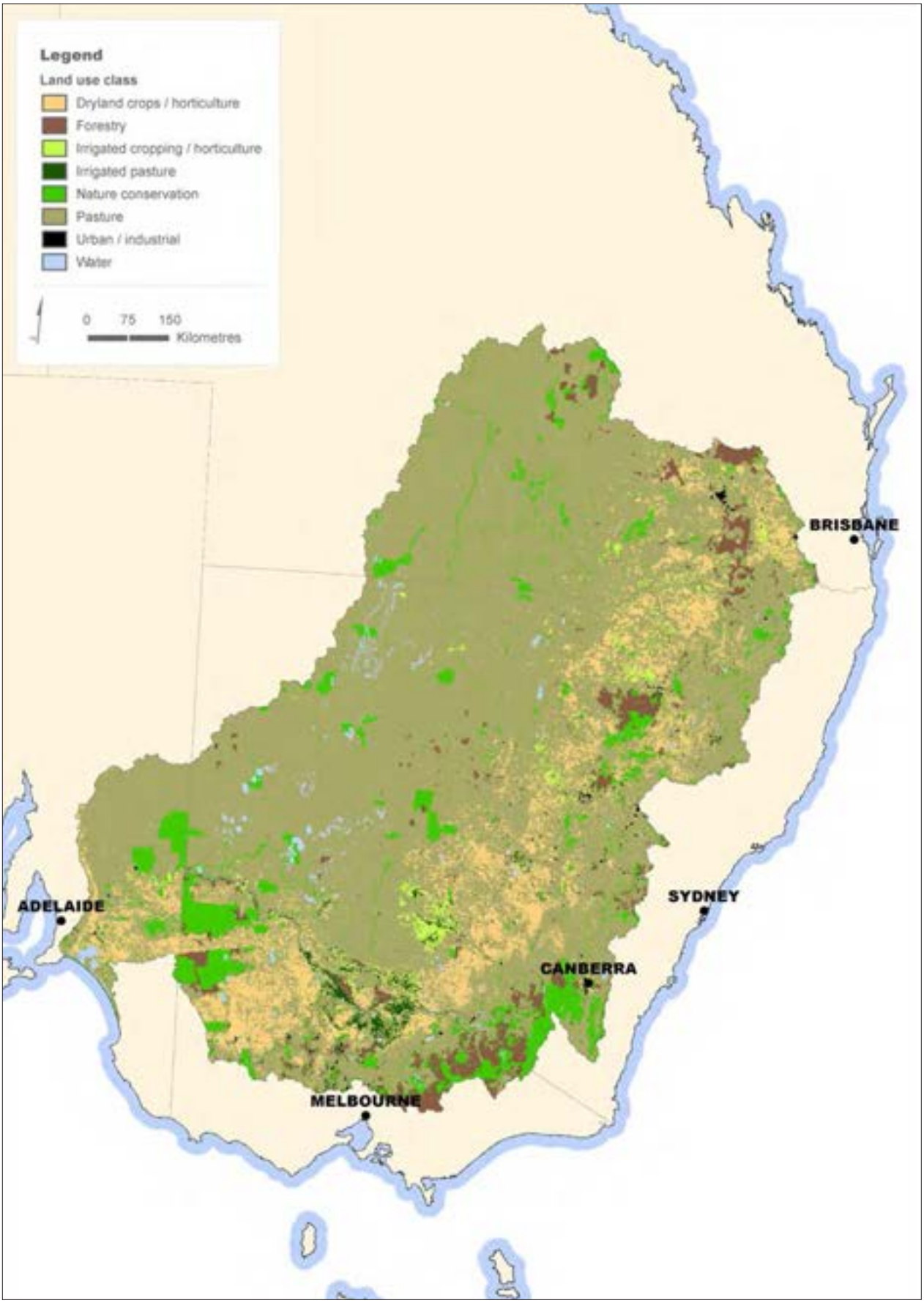


Figure 7.8 Land use distribution in the Murray–Darling Basin region

7.3.6 Population distribution

The Murray–Darling Basin region has a population of over 2 million people, approximately 10% of Australia's total population. It is home to Australia's national capital, Canberra, which makes up 17% of the region's total population. Figure 7.9 shows the spatial distribution of population density (ABS 2011b).

Many of the large population centres near the eastern and southern boundaries of the region provide support to the numerous agricultural districts of the basin.

These population centres are generally located in the valleys and on the alluvial plains of the many major rivers that feed the Murray–Darling River system.

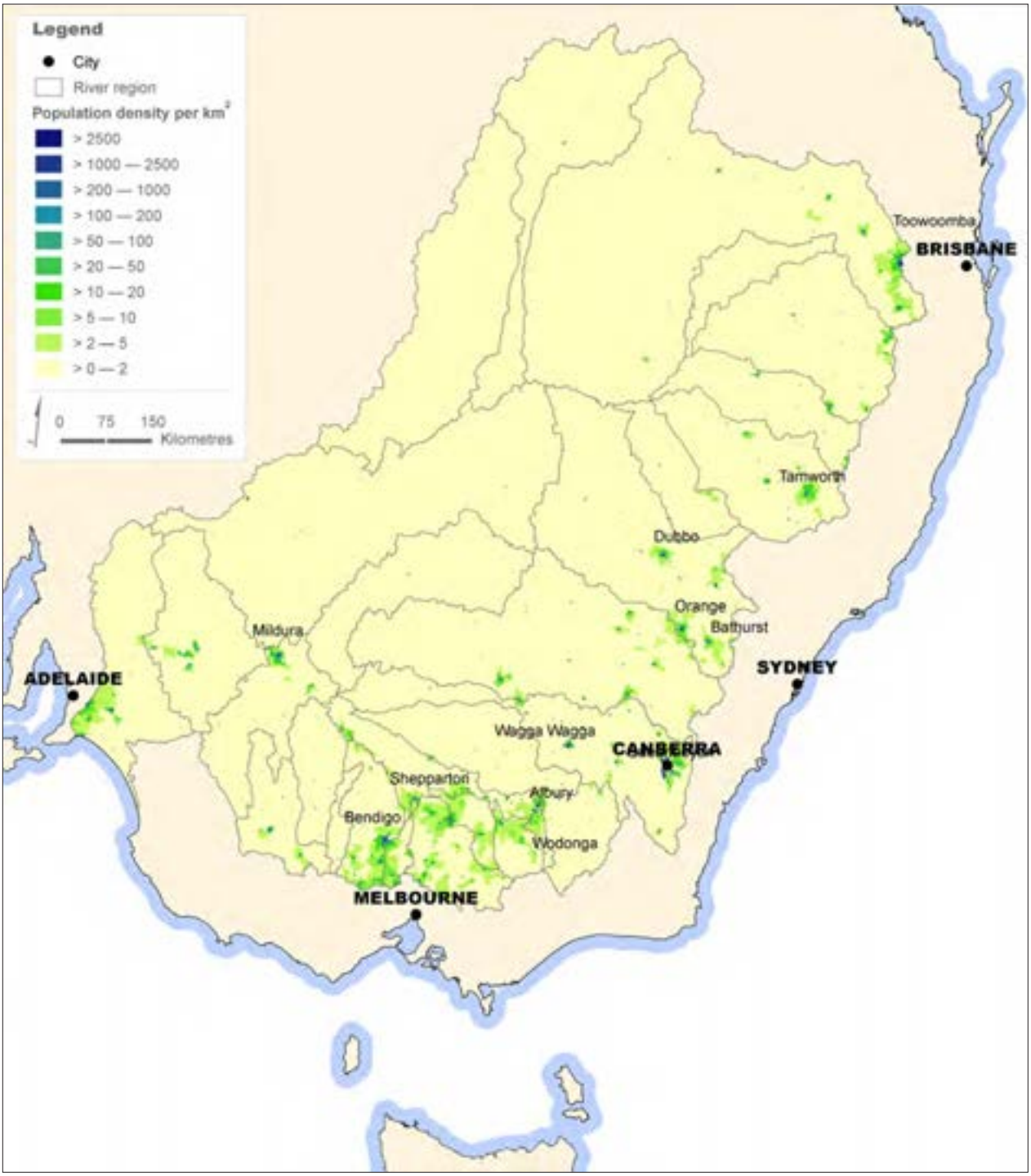


Figure 7.9 Population density and distribution in the Murray–Darling Basin region

7.3.7 Rainfall zones

The Murray–Darling Basin region has a large range of climatic conditions and natural environments, from the rainforests of the cool and humid eastern uplands, the temperate Mallee country of the southwest, the subtropical areas of the northeast, to the hot and dry, semi-arid and arid lands of the far western plains. Median rainfall varies throughout the region.

As the region covers a large part of the continent, the rainfall zones correspond to a number of the major climate zones of Australia (Figure 7.10).

There is a north–south pattern of summer dominant to uniform to winter dominant annual rainfall. A second pattern in the rainfall zones is the high annual total rainfall in the east contrasted with the low annual total rainfall in the west. Higher rainfall totals in the west are directly related to the presence of the Great Dividing Range in this area and its proximity to the coast.

For more information on this and other climate classifications, visit the Bureau's climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

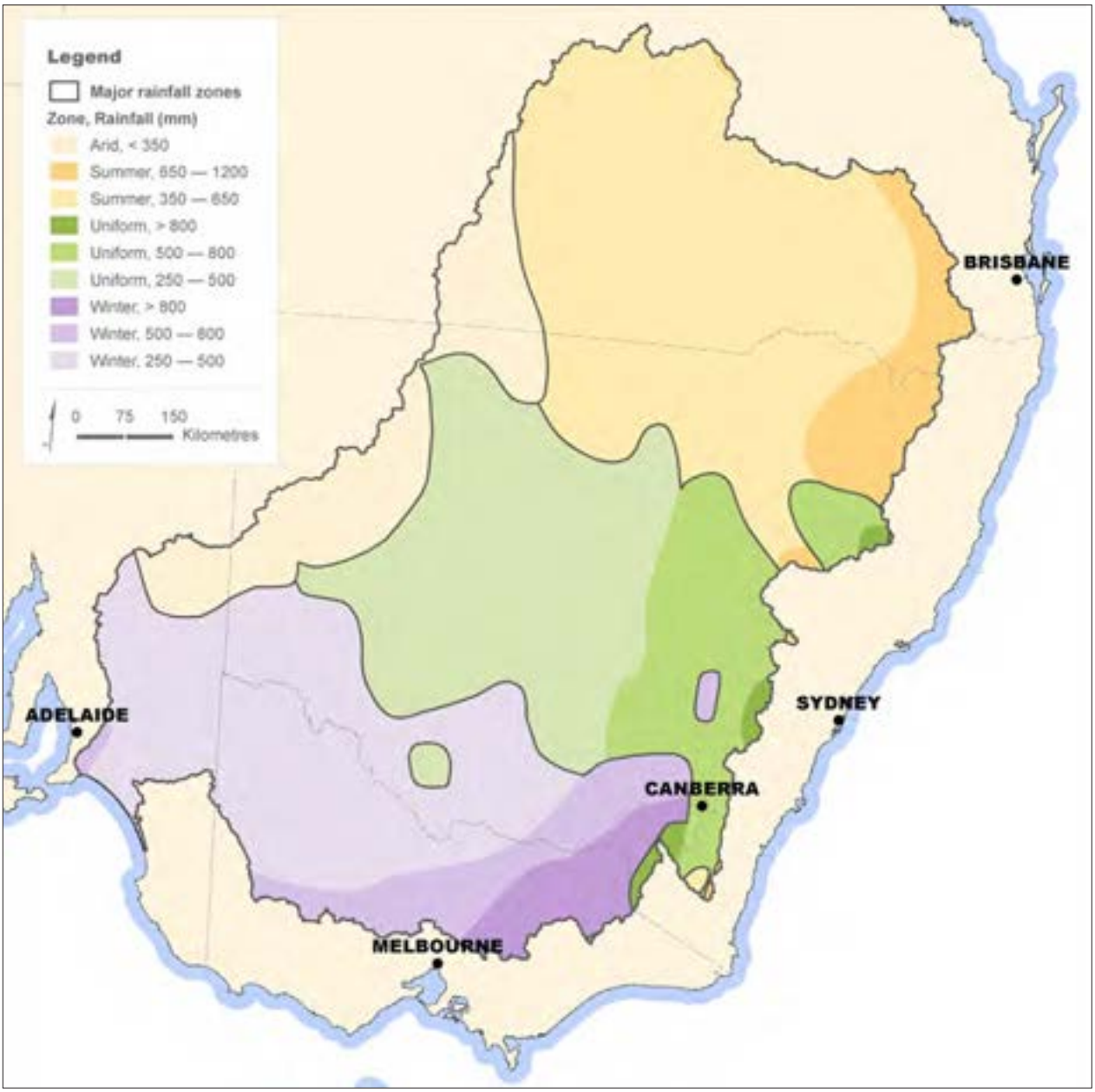


Figure 7.10 Rainfall zones in the Murray–Darling Basin region

7.3.8 Rainfall deficit

The rainfall deficit indicator (rainfall minus potential evapotranspiration) gives a general indication of which parts of the region are likely to experience moisture deficits over the period of a year. The Murray–Darling Basin region generally has a rather uniform pattern of substantial deficits over the whole region (Figure 7.11).

The only areas of rainfall excess are located in the southern ranges of the Great Dividing Range. It is where the major storages are located for the surface water supply of the Murrumbidgee and Murray irrigation areas. The irrigation areas themselves are located in the – 500 to –1,000 mm deficit range. The northern irrigation areas are also reliant on surface water to a large extent, but the overall lower availability of surface water has limited the potential of intensive irrigated agriculture in these areas compared to the south of the region.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

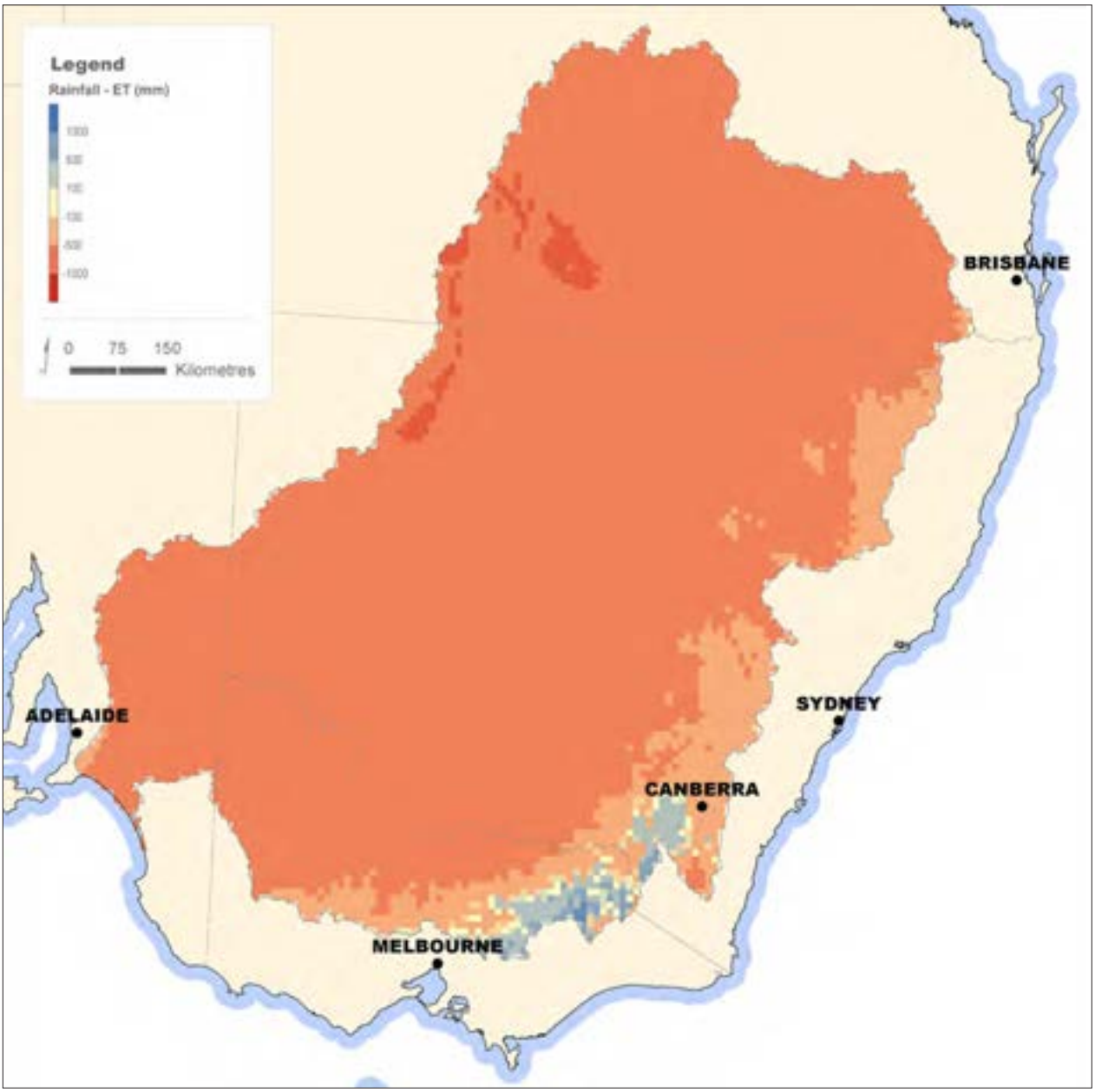


Figure 7.11 Rainfall distribution in the Murray–Darling Basin region

7.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Murray–Darling Basin region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 7.12 shows that the region has two rainfall maxima present in the historical rainfall data. This can be attributed to a wetter summer period in the north and a wetter winter period in the south. Evapotranspiration follows a similar pattern to rainfall, although it is also related to energy availability (temperature and solar radiation), which is higher in the summer period. The monthly landscape water yield history for the region shows a stable pattern of very low yield in all months, although it moderately increases over the July–September period.

The 2011–12 year started with four months of mostly average rainfall, which were followed by five wet months. For the remaining three months of the year rainfall was again close to average. The above average rainfall between November and March was a result of three major frontal systems, one at the end of November, one in the last week of January and a final one in late February/early March (see the National Overview chapter for more details).

Evapotranspiration in 2011–12 was generally consistent with rainfall, with close to median values for July–October, high values for November– March, returning to near median values for April–June. Despite high rainfall January recorded median evapotranspiration due to lower soil moisture levels.

The landscape water yield for 2011–12, relative to historical values, was very high for November–January and also high for February–March. The February and March peaks coincided with the end of the wet period when soil saturation levels were high.

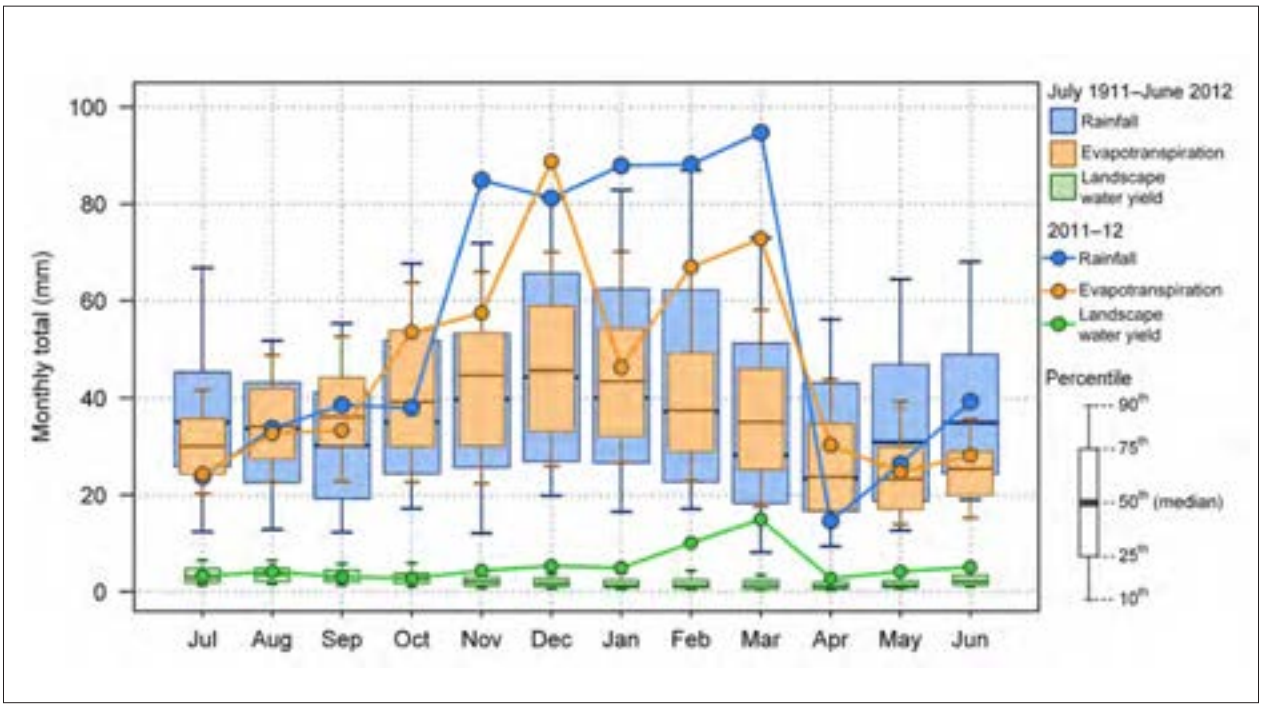


Figure 7.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the Murray–Darling Basin region

7.4.1 Rainfall

Rainfall for the Murray–Darling Basin region for 2011–12 is estimated to be 651 mm. This is 40% above the region's long-term average (July 1911–June 2012) of 465 mm.

Figure 7.13a shows that the highest rainfall occurred along the slopes of the Great Dividing Range in the east of the region, with annual totals for 2011–12 exceeding 1,200 mm in some areas.

Rainfall in the western part of the region did not exceed 600 mm for 2011–12.

Rainfall deciles for 2011–12 indicate very much above average rainfall for 48% of the region over the course of the year (Figure 7.13b). Many of the region's irrigation areas received above and very much above average rainfall, as did the upstream catchment areas from which they extract the water. An exception to this was the Wimmera district in the southwest of the region.

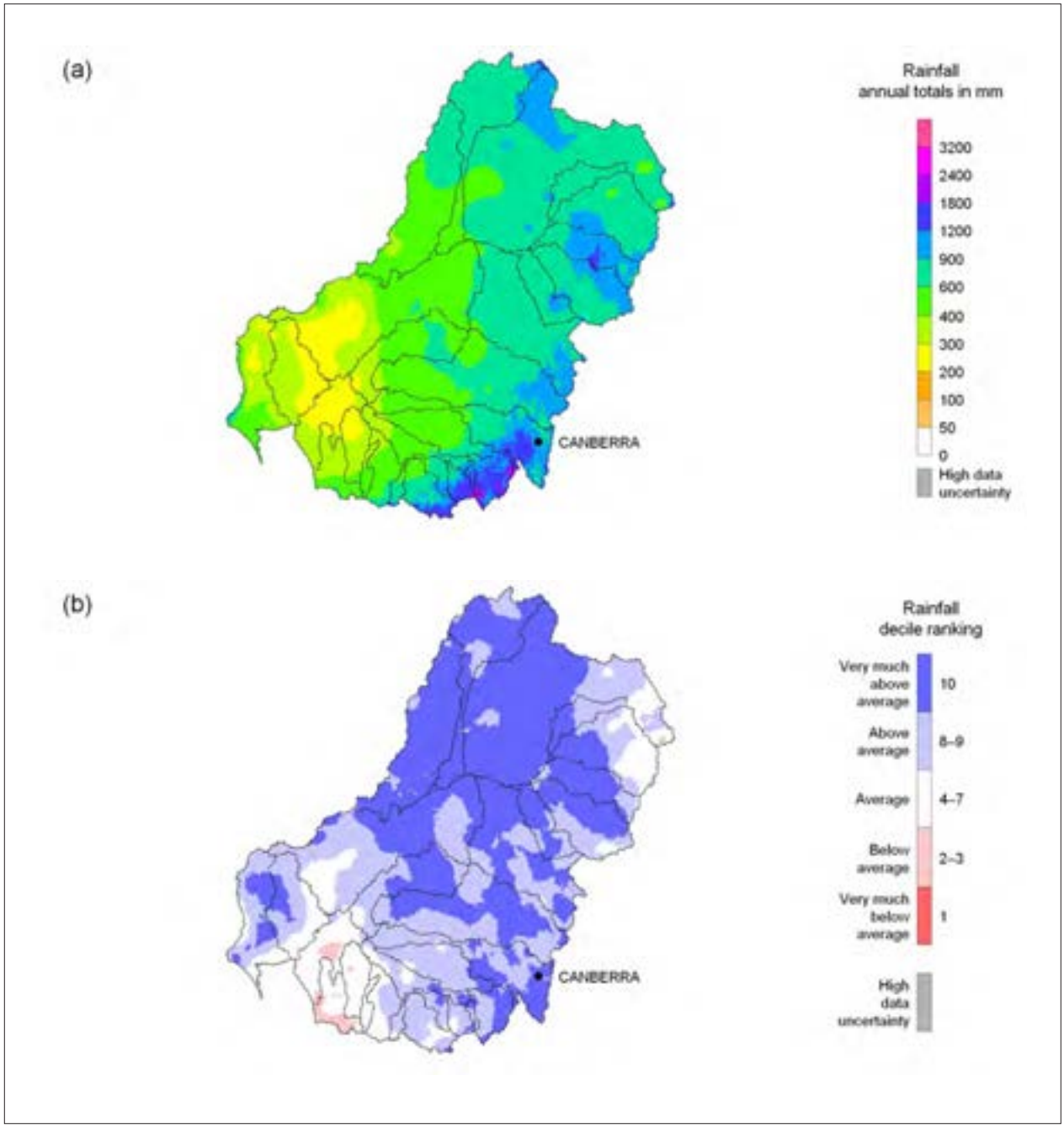


Figure 7.13 Spatial distribution of (a) annual rainfall in 2011–12 and (b) their decile rankings over the 1911–2012 period for the Murray–Darling Basin region

Rainfall variability in the recent past

Figure 7.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 482 mm, varying from 305 mm (2002–03) to 780 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 7.14b.

Total rainfall for 2011–12 was the second highest since 1980. As can be noted from Figure 7.14b, there has been an increase in rainfall in the summer period in recent years. This is in part attributed to a strong La Niña event in 2010–11 and the return of a slightly weaker La Niña event in 2011–12.

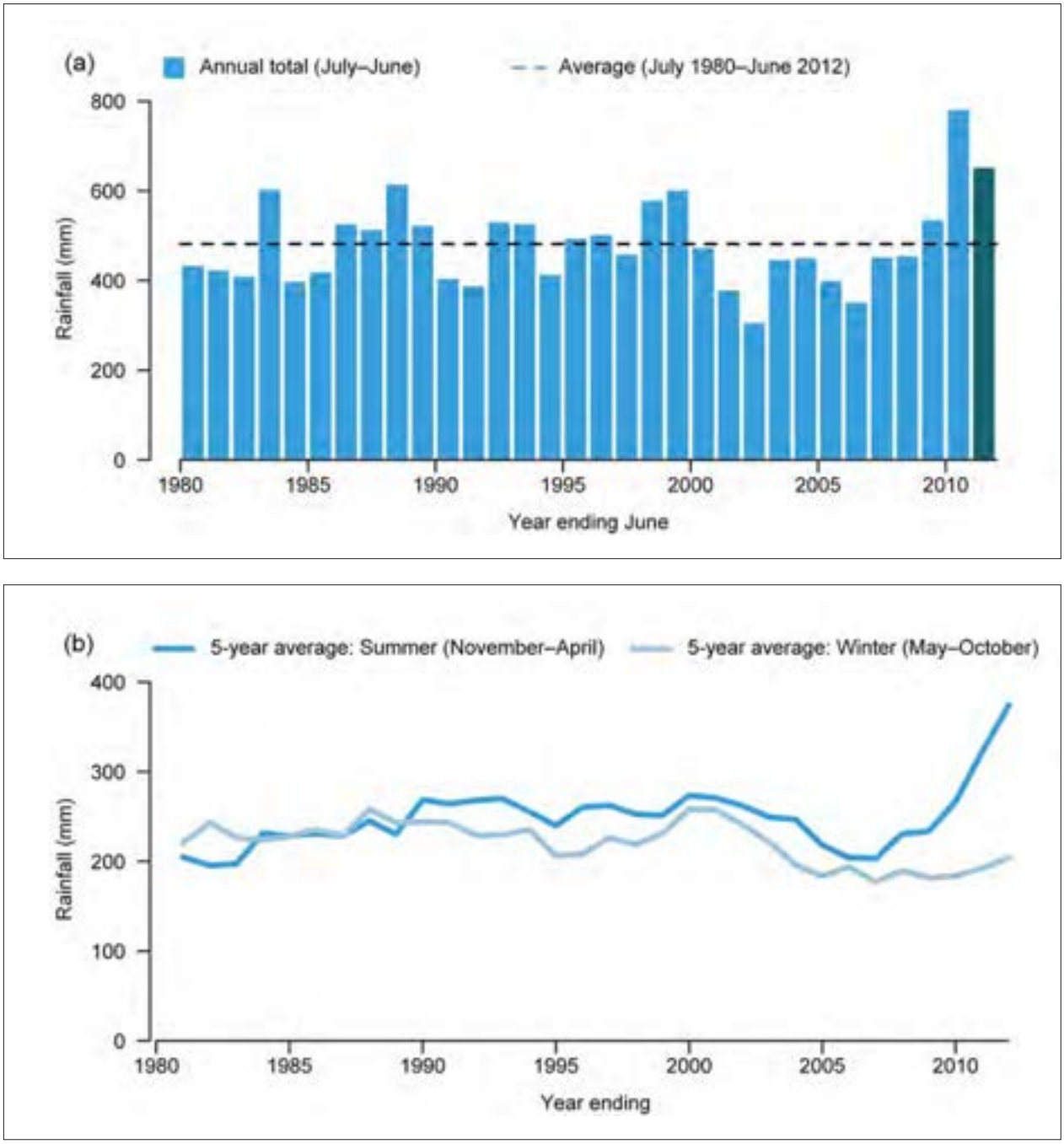


Figure 7.14 Time-series of (a) annual rainfall and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Murray–Darling Basin region

Recent trends in rainfall

Figure 7.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 7.15b.

The trend patterns indicate a decrease in rainfall for the southeastern border areas, which are areas with the highest rainfall totals.

In these areas, most of the rivers that feed the southern irrigation areas originate in the upper Murray and Murrumbidgee river basins.

The rising trends indicated as statistically significant in Figure 7.15b are largely a result of the high rainfall of the past two years.

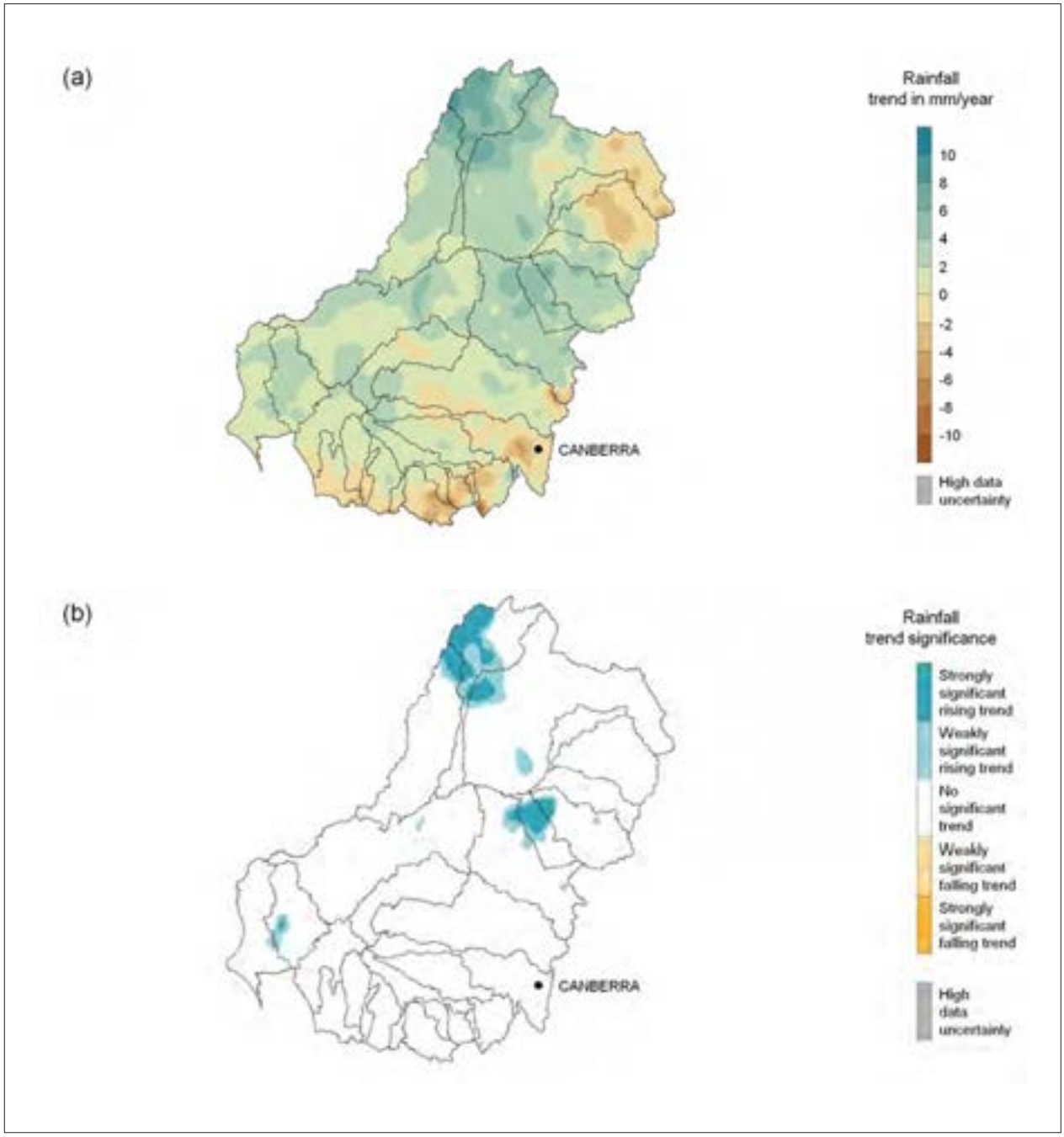


Figure 7.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Murray–Darling Basin region

7.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Murray–Darling Basin region for 2011–12 is estimated to be 559 mm. This is 29% above the region's long-term (July 1911–June 2012) average of 434 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 7.16a) is similar to that of rainfall (Figure 7.13a).

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 7.16b). This coincides with the very much above average rainfall observed largely along the north and centre of the region (Figure 7.13b). Evapotranspiration is normally limited by water shortage in these areas; however, the very much above average rainfall of the last two years altered this pattern.

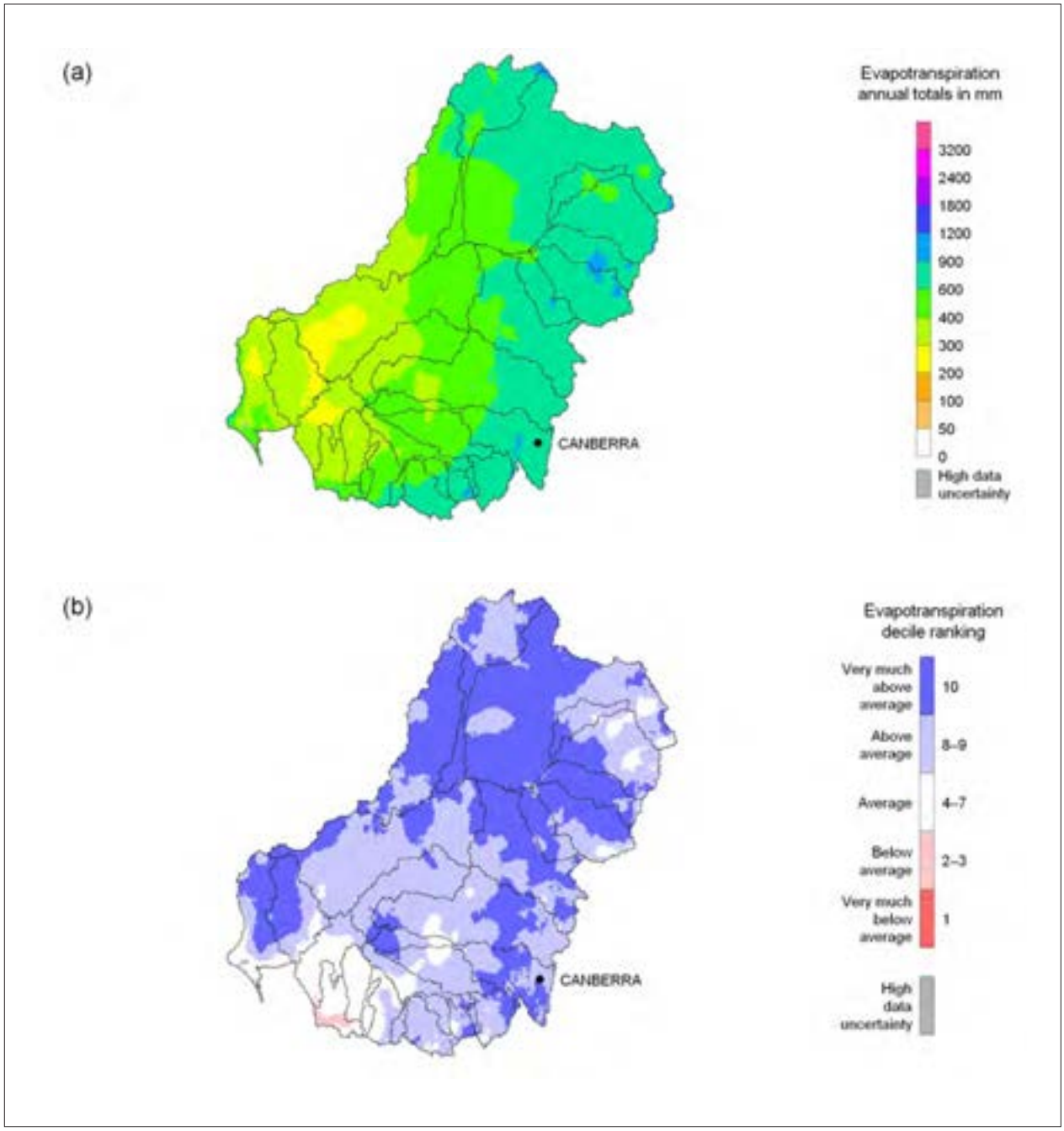


Figure 7.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12 and (b) their decile rankings over the 1911–2012 period for the Murray–Darling Basin region

Evapotranspiration variability in the recent past

Figure 7.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 446 mm, varying from 284 mm (2002–03) to 691 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 7.17b.

Evapotranspiration shows a similar pattern as rainfall with the highest and third highest annual totals of the last 32 years for 2010–11 and 2011–12 respectively. The greatest increase occurred in the summer period with the five-year retrospective moving average of evapotranspiration peaking much higher than in the winter period (Figure 7.17b).

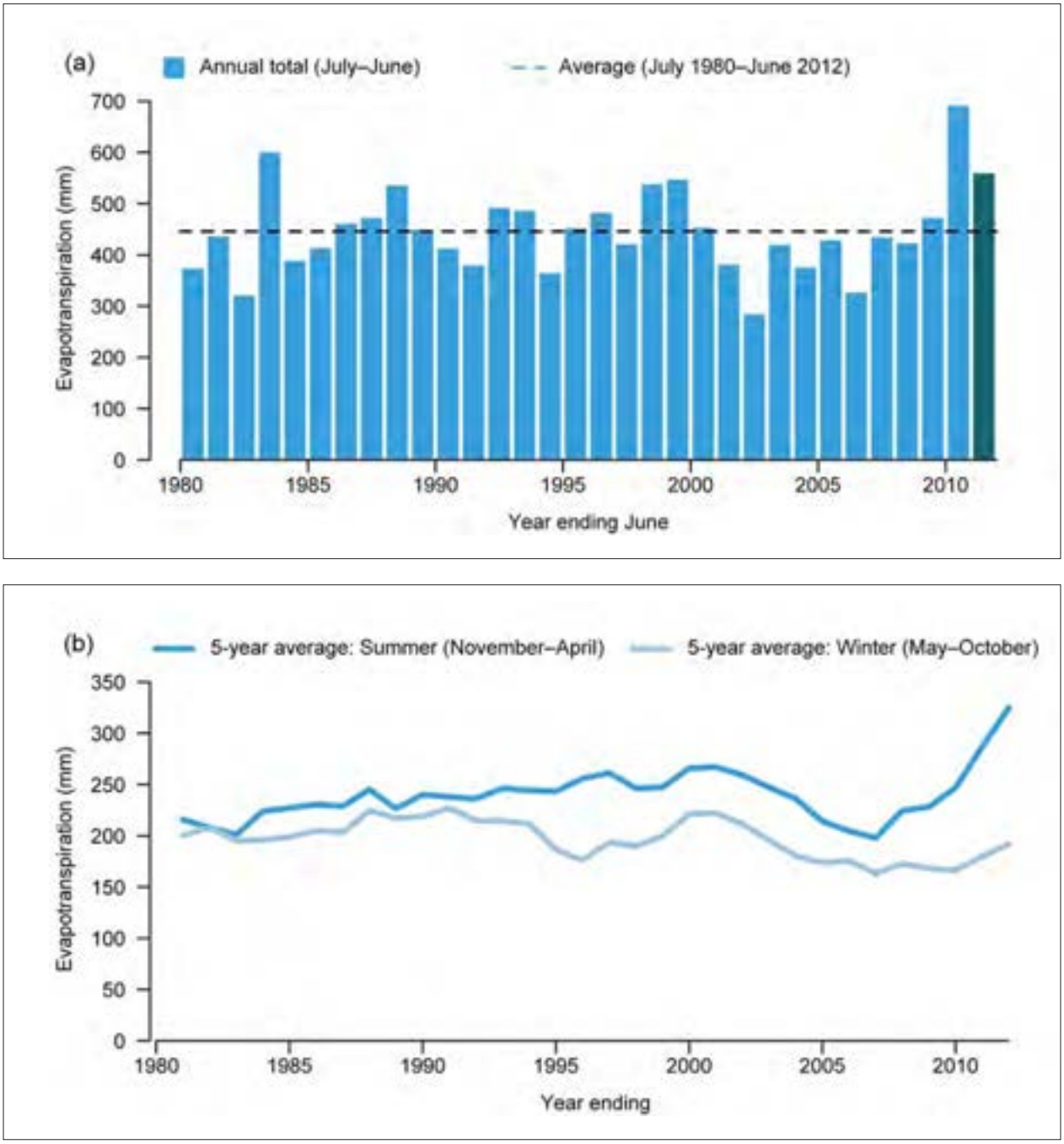


Figure 7.17 Time-series of (a) annual evapotranspiration and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Murray–Darling Basin region

Recent trends in evapotranspiration

Figure 7.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 7.18b.

Figure 7.18a shows that since 1980 trends are mostly rising in the centre and north of the region and more neutral in the rest of the region.

As shown in Figure 7.18b, the trends are generally only statistically significant in the far north and some smaller central parts of the region. In the south and northeast of the region the falling trends have no statistical significance.

As evapotranspiration is driven by the availability of moisture, the trends are related to the trend pattern in the rainfall shown in Figure 7.15a, especially with the high rainfall of the past two years.

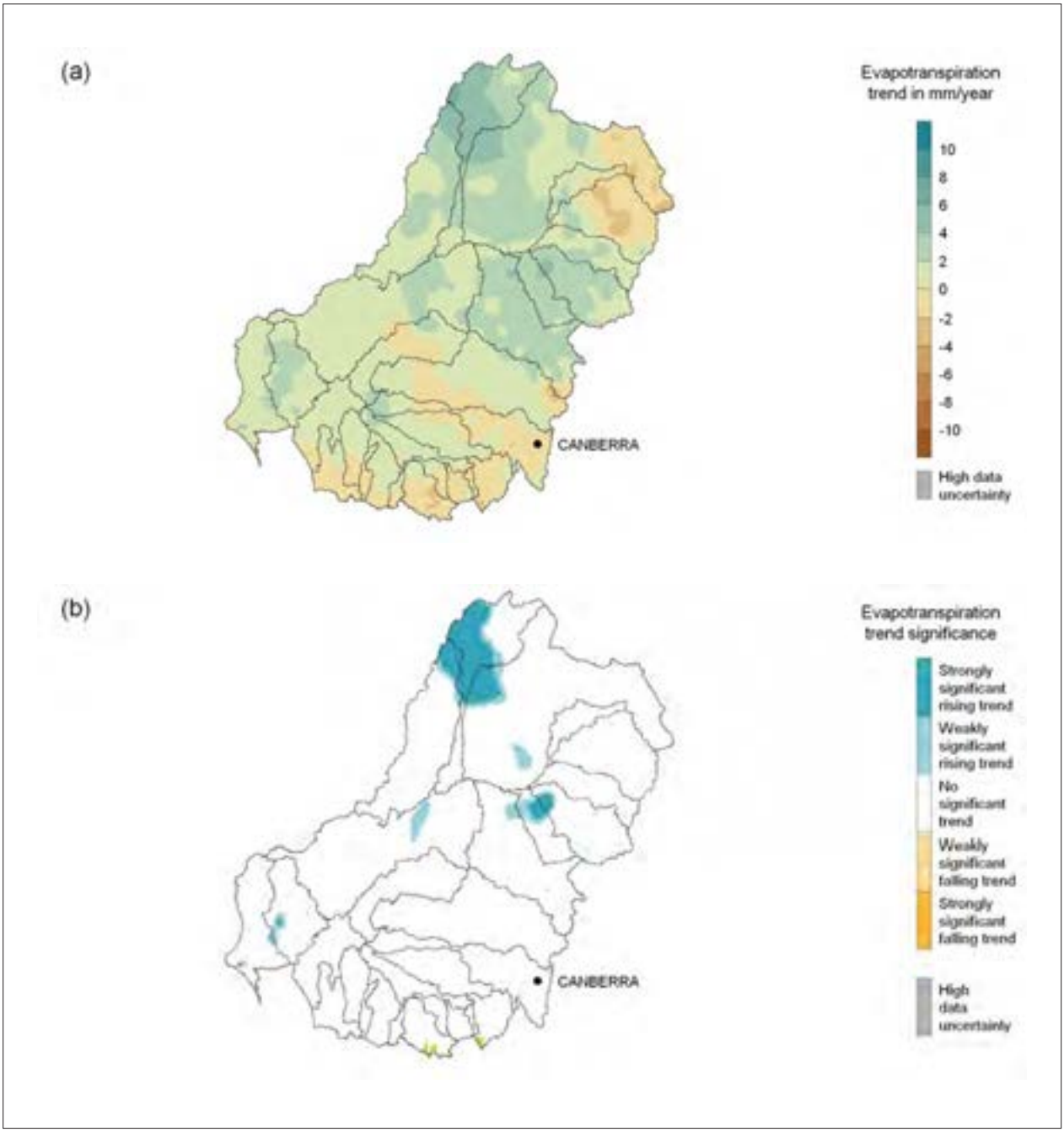


Figure 7.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Murray–Darling Basin region

7.4.3 Landscape water yield

Modelled landscape water yield for the Murray–Darling Basin region for 2011–12 is estimated to be 65 mm. This is 110% above the region's long-term (July 1911–June 2012) average of 31 mm. Figure 7.19a shows the spatial distribution of landscape water yield for 2011–12. Most landscape water yield is generated in the mountainous southeast of the region with large areas exceeding 400 mm.

The decile-ranking map for 2011–12 (Figure 7.19b) shows very much above average landscape water yields for 72% of the region; however, although very much above average, the largest proportion of the region remained below 50 mm of annual landscape water yield. Additionally, large parts of those areas that historically have the highest landscape water yields (the mountains in the southeast) only generated average to above average landscape water yields.

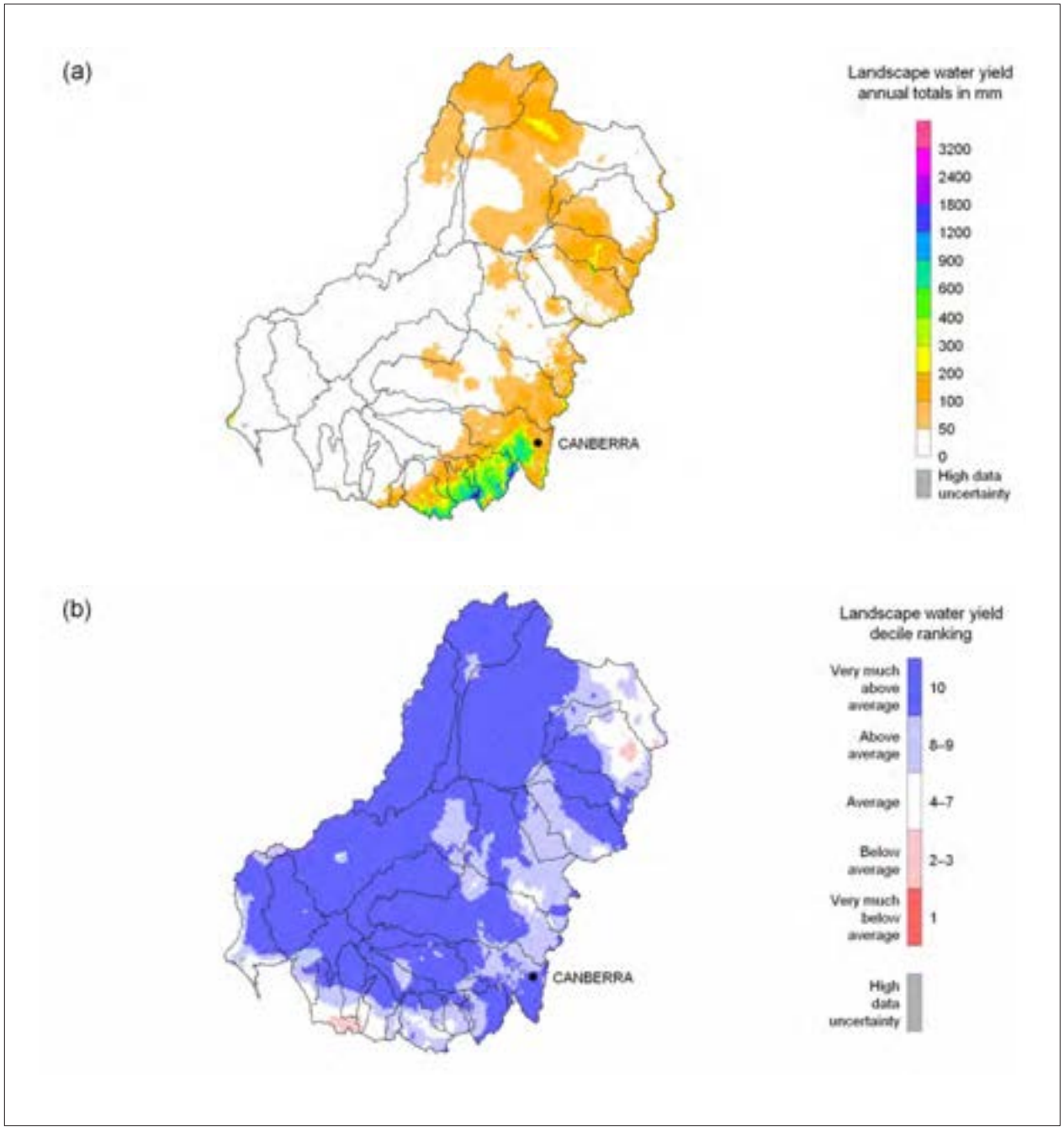


Figure 7.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12 and (b) their decile rankings over the 1911–2012 period for the Murray–Darling Basin region

Landscape water yield variability in the recent past

Figure 7.20a shows annual landscape water yield for the Murray–Darling Basin region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 34 mm, varying from 9 mm (2006–07) to 84 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 7.20b.

The last two years have seen exceptionally high landscape water yield. Historically, most of the landscape water yield for the region is generated in the winter dominant rainfall areas in the southeast. It is therefore not surprising that the yields were consistently higher during the winter period compared to the summer period; however, the last two years have seen some very high intensity rainfall events in the summer period, which sparked the generation of landscape water yield throughout the whole region, including the southeast.

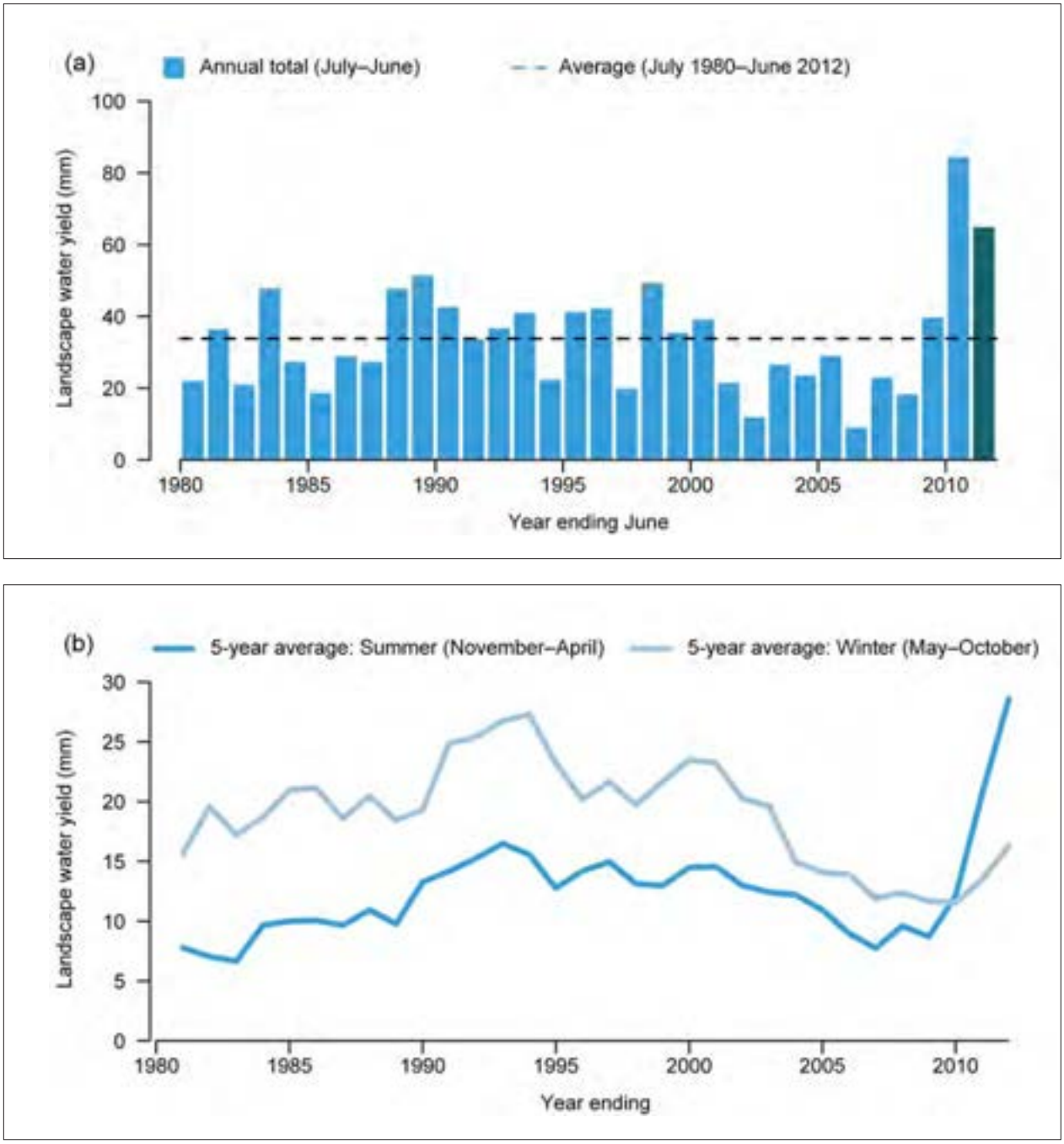


Figure 7.20 Time-series of (a) annual landscape water yield and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Murray–Darling Basin region

Recent trends in landscape water yield

Figure 7.21a shows the spatial distribution of the trends in modelled annual landscape water yield for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 7.21b.

Since 1980, marginally rising trends are present over most of the region; however, they are not present in the normally high landscape water yield generating areas in the mountainous southeast.

The rising trends in landscape water yield are generally strongly significant in more extensive areas than those of rainfall and evapotranspiration. This is a consequence of the very much above average high annual totals of the last two years, which were unusual and therefore may have caused an overestimation of the trend. A more important change from a water availability point of view is that in the southeast some falling trends occurred, though these were not statistically significant.

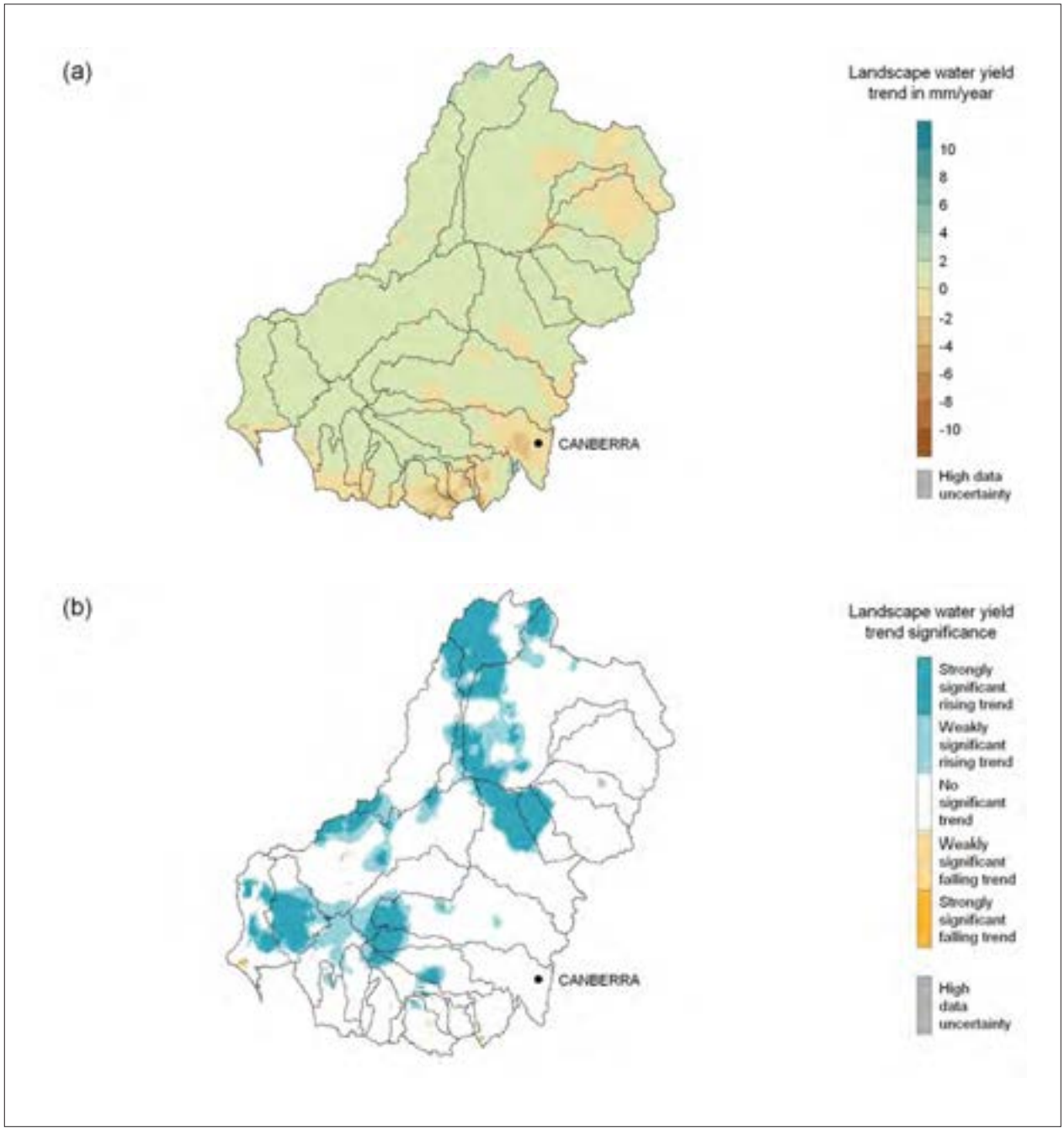


Figure 7.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Murray–Darling Basin region

7.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Murray–Darling Basin region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers are described and the groundwater status is illustrated by showing changes in groundwater levels at selected sites.

7.5.1 Rivers

There are 28 river basins in the Murray–Darling Basin region, varying in size from 1,700 to 166,000 km^2 (Figure 7.22). The region is named after its two major rivers, the River Murray, which drains water from inland areas of southern New South Wales and northern Victoria, and the Darling River, which drains inland through southern Queensland and northern New South Wales. The River Murray and Darling River combine near Wentworth before discharging to the ocean via the Lower Lakes system in South Australia.

The Darling River (2,740 km), the River Murray (2,510 km) and the Murrumbidgee River (1,490 km) are the three longest rivers in Australia. Monsoonal events in the north of the basin contribute to a large portion of the flow from the north in the Darling River. The flow in the various rivers and tributaries of the River Murray originate from rainfall run-off or from snowmelt in the Great Dividing Range to the south and southeast of the region. This includes the headwaters of the River Murray and the Mitta Mitta, Kiewa, Ovens, Broken and Goulburn rivers in the Victorian Alps. The headwaters of the Murrumbidgee River lie in the Snowy Mountains area of the Kosciuszko National Park.

There are two types of rivers in the region: ephemeral and perennial. Ephemeral rivers, including the Paroo, Warrego and Culgoa rivers, generally originate in southwestern Queensland, whereas the perennial rivers usually start in the southeastern slopes of the Great Dividing Range. Ephemeral rivers in the Murray–Darling Basin region are usually slow-flowing and almost always carry notable silt loads.

Confluence of Murray and Darling rivers at Wentworth, New South Wales | Ashley Whitworth, Dreamstime

Figure 7.22 Rivers and catchments in the Murray–Darling Basin region

7.5.2 Streamflow volumes

Figure 7.23 presents an analysis of flows at 74 monitoring sites during 2011–12 relative to annual flows for the July 1980–July 2012 period. Sites with relatively long records across 20 geographically representative rivers were selected (see Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

High run-off, generated in the upstream reaches of the rivers, caused above average to very much above average flows in many rivers in the central north and east of the Murray–Darling Basin region, whereas flows to the south and southeast tended to be more variable, and were sometimes average with some below average flows (Figure 7.23).

Very much above average flows were observed at 14 monitoring sites located on rivers in the central north and some catchments in the central south of the region. Above average flows were recorded at 35 monitoring sites distributed across the Murray–Darling Basin region.

Average flows occurred at 19 sites in the region, which are mainly located on the eastern rivers and some rivers in the south of the region. Of the 74 monitoring sites, there were only six below average flows recorded across the region in 2011–12. These six monitoring sites were located on the Avoca and Loddon rivers in the south, the Macintyre Brook and the Gwydir River in the northeast, and the Mitta Mitta River in the southeast of the region.

Flow deciles in the summer (November 2011–April 2012) were very similar to total annual flows for 2011–12 as shown in Figure 7.23. This is not surprising, given that the greatest volume of flows in the Murray–Darling Basin region occurred over the summer months. While flows in the central and eastern rivers of the region were above average over 2011–12, flows in these rivers were even higher over the summer months compared with annual average conditions. There are a few monitoring sites that did not show this pattern, such as the lower flows observed in summer on the Tumut River and the River Murray downstream of the Hume Dam in the southeast of the region.

7.5.3 Streamflow salinity

Figure 7.24 presents an analysis of streamflow salinity at 142 monitoring sites throughout the Murray–Darling Basin region. Monitoring sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC), µS/cm at 25 °C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation, are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

The median EC values for most of the selected monitoring sites fall in the range 0–1,000 µS/cm (suitable for most irrigation uses). Of the 142 sites, 80% had median EC values below 500 µS/cm and 13% were between 500–1,000 µS/cm. Only 3% of the monitoring sites had a median EC above 1,500 µS/cm (Figure 7.24).

Stream salinity was above 2,000 µS/cm at four of the 142 monitoring sites. These were from three monitoring sites on rivers and creeks in the southwest, and Houlaghans Creek in the Murrumbidgee River basin in the southeast of the region.

The salinity CV is typically related to the variability in annual flow at the monitoring site. It is high at some monitoring sites in the central, central south and eastern rivers in the Murray–Darling Basin region, whereas it is relatively low in many of the eastern rivers and at some monitoring sites in the River Murray in the central southwest of the region.

Of the 142 sites, 25% had a CV below 20%; 75% of the sites had a CV between 20% and 60%; and the CV was above 60% at only one of the 142 monitoring sites, on the Wakool River in the central south of the region.

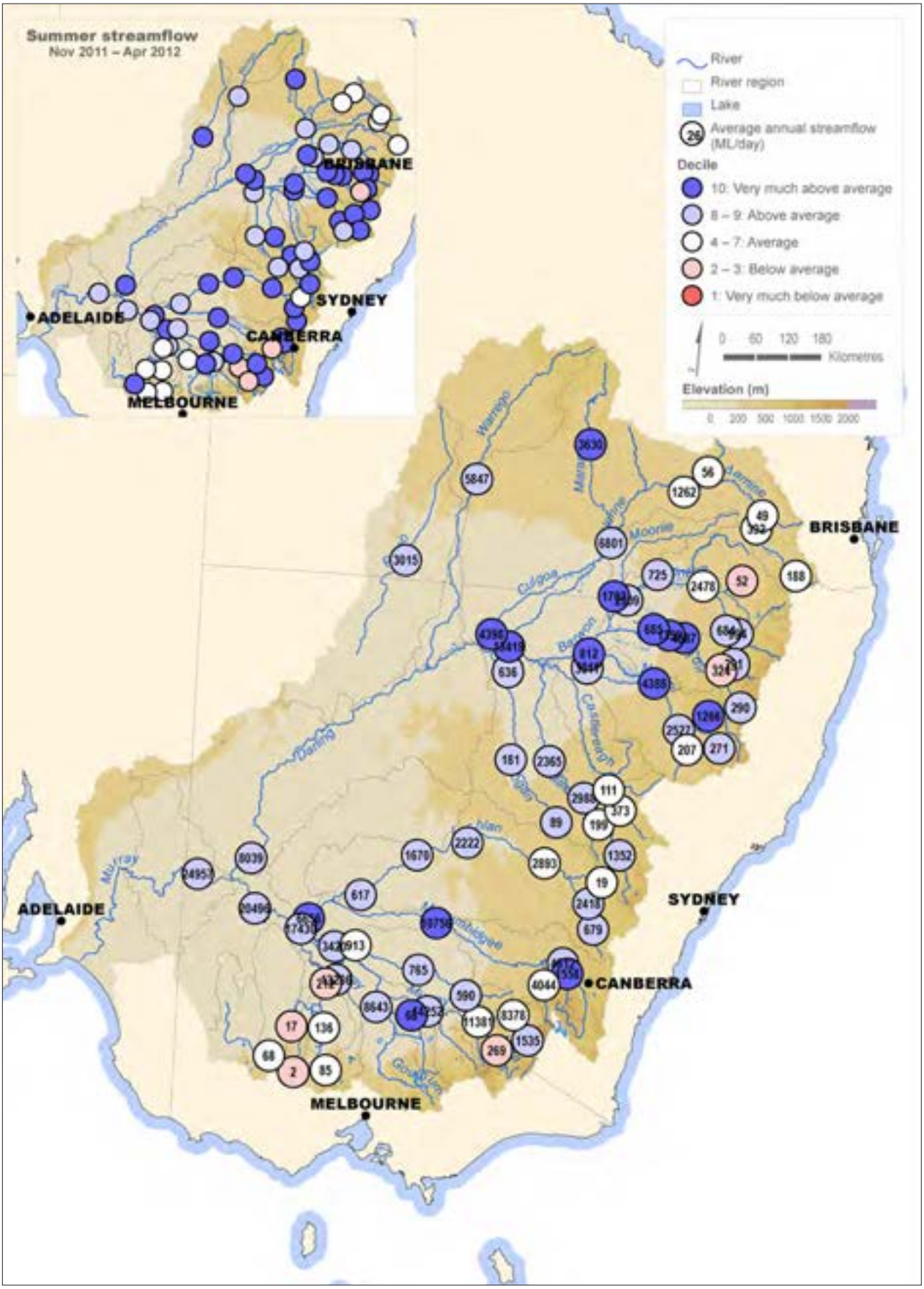


Figure 7.23 Average annual and summer period flow volumes of selected monitoring sites for 2011–12 and their decile rankings over the 1980–2012 period in the Murray–Darling Basin region

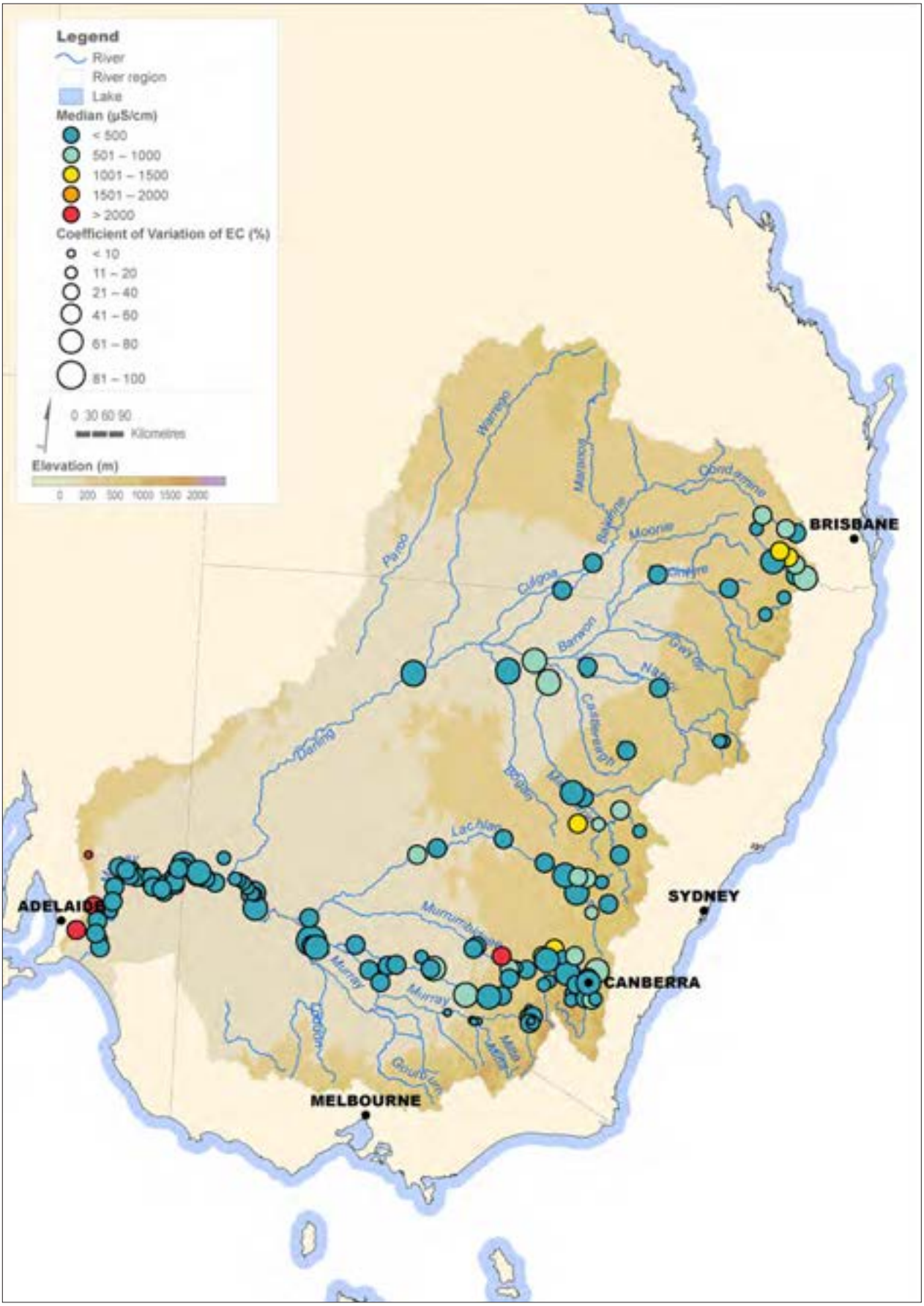


Figure 7.24 Salinity as electrical conductivity and its associated co-efficient of variation for 2011–12 in the Murray–Darling Basin region

7.5.4 Flooding

Figure 7.25 presents an overview of the monitoring sites where the Bureau of Meteorology is measuring river levels in the Murray–Darling Basin region as part of the flood forecasting service. The highest river level reached during the year is expressed as one of four flood classification levels. These classification levels are established in consultation with emergency management and local agencies (see the Technical Supplement for details).

A number of major floods occurred during 2011–12 mostly in the north and southeast parts of the region. The most significant flooding occurred during November 2011–March 2012, where catchments in inland southern Queensland and the upper to mid River Murray catchments received well above average rainfall.

In late November heavy rainfalls lead to flooding in northwestern New South Wales with floodwaters moving downstream towards the west and southwest along tributaries of the Darling River.

Major floods also occurred in the northern catchments of the Condamine, Warrego and Paroo rivers during December 2011 through to February 2012 as a result of well above average rainfall in these areas.

In March 2012 high intensity, well above average rainfall in the south and west of the region resulted in major floods in the Lachlan, Murrumbidgee and the upper Murray rivers. These rivers flooded again in late June 2012. The Goulburn River and the upper and mid River Murray had a number of minor to moderate floods during much of the year.

River Murray floods, early 2012 | murrayriverguide.com.au

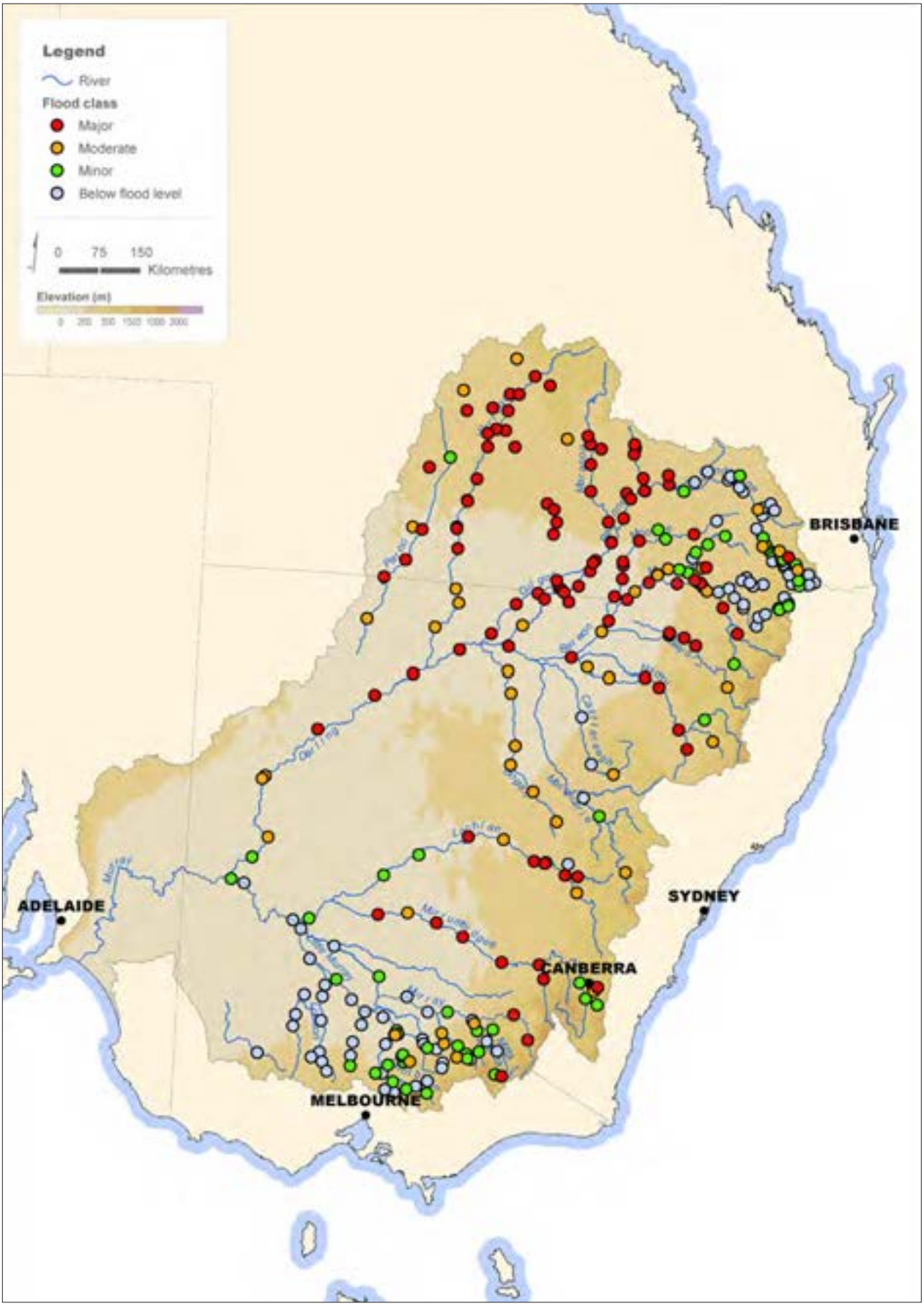


Figure 7.25 Flood levels for the Murray–Darling Basin region in 2011–12

7.5.5 Storage systems

There are over 70 major publicly owned storages in the Murray–Darling Basin region. In total, the capacity of all these storages exceeds 34,000 GL. This includes the storage systems of Snowy Hydro Limited and the Grampians Wimmera–Mallee (GWMW) Corporation, which are partly located outside the region but transfer most of their water to the Murray–Darling Basin region. The Bureau's water storage information covers more than 88% of the region's publicly owned storage capacity (as at August 2012). Storages in the region supply 17 rural water supply systems as well as the city of Canberra.

Table 7.3 is a summary of the major water supply and associated storage systems in the region, together with an overview of the storage levels at the end of 2010–11 and 2011–12. The location of all the water supply systems and associated storages are shown in Figure 7.26.

Table 7.3 indicates that the larger systems experienced significant increases in storage volumes. This resulted in an 11% increase in total storage volume over the region. This is an important improvement in water supply security for most irrigation areas in the region. Some increases could also be partly caused by environmental water holders carrying over their allocations to be released some time in the future.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

Table 7.3 Major publicly owned storage systems in the Murray–Darling Basin region (as at August 2012). 'Non-allocated' means storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Murray	rural	7,441 GL	5,627 GL—76%	6,554 GL—88%
Snowy Hydro	hydro /rural	5,302 GL	1,711 GL—32%	2,960 GL—56%
Goulburn	rural	3,559 GL	3,056 GL—86%	3,159 GL—89%
Murrumbidgee	rural	2,633 GL	2,454 GL—93%	2,485 GL—94%
Macquarie	rural	1,523 GL	1,208 GL—79%	1,371 GL—90%
Gwydir	rural	1,343 GL	671 GL—50%	1,282 GL—95%
Lachlan	rural	1,253 GL	1,144 GL—91%	1,197 GL—96%
Namoi	rural	873 GL	548 GL—63%	803 GL—92%
Wimmera–Mallee	rural	662 GL	294 GL—44%	266 GL—40%
Border rivers	rural	563 GL	559 GL—99%	520 GL—92%
Campaspe	rural	304 GL	293 GL—96%	271 GL—89%
Loddon	rural	213 GL	194 GL—91%	186 GL—87%
Canberra	urban	205 GL	199 GL—97%	204 GL—100%
Upper Condamine	rural	104 GL	103 GL—99%	87 GL—84%
St George	rural	95 GL	94 GL—99%	91 GL—96%
Macintyre	rural	69 GL	60 GL—87%	42 GL—61%
Broken	rural	40 GL	40 GL—100%	40 GL—100%
Ovens	rural	32 GL	23 GL—72%	24 GL—75%
Non-allocated	—	3,979 GL	3,728 GL—94%	3,689 GL—93%
Total		**30,192 GL**	**22,006 GL—73%**	**25,230 GL—84%**

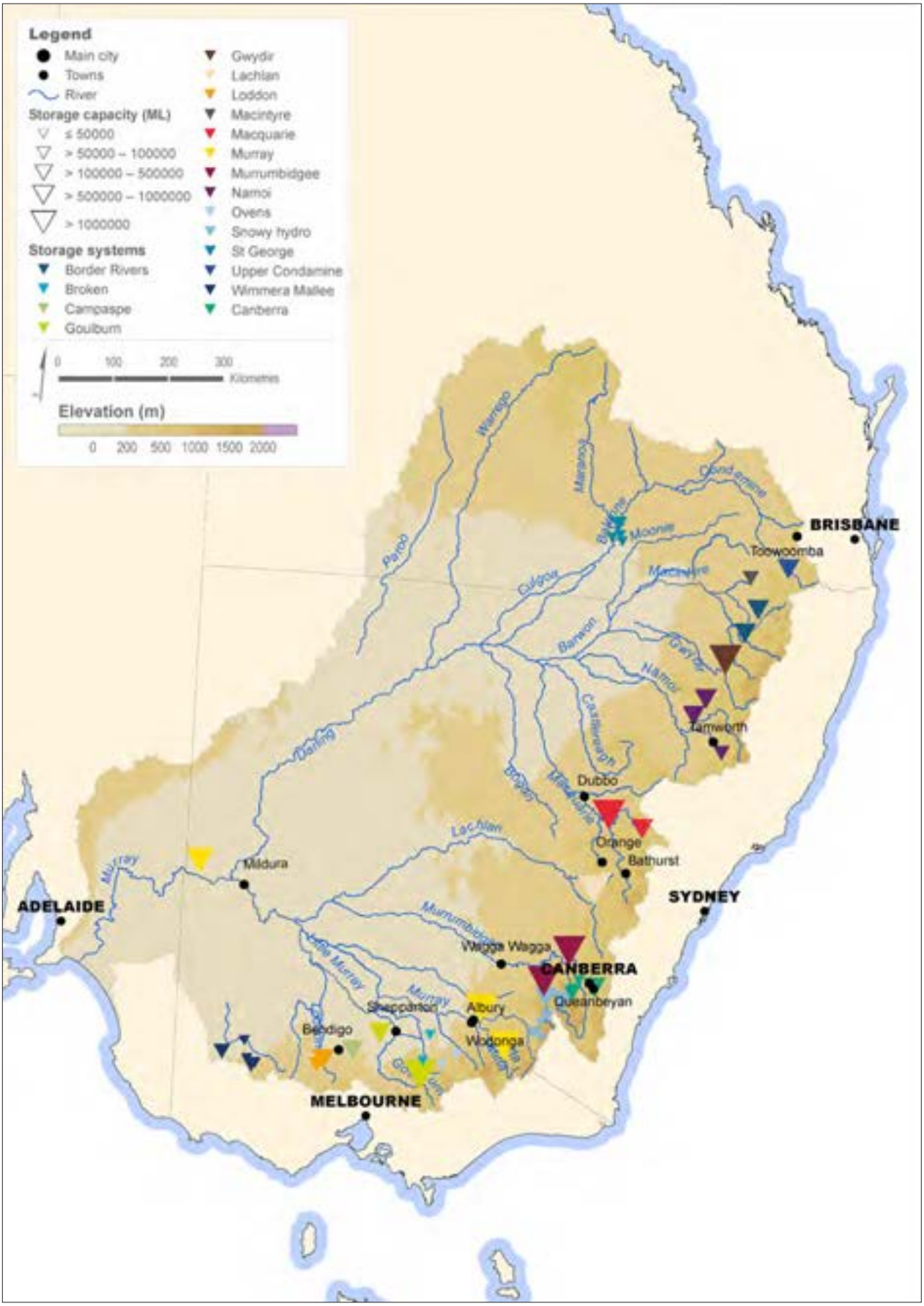


Figure 7.26 Major water supply and associated storage systems in the Murray–Darling Basin region (as at August 2012)

7.5.6 Wetlands

Important wetlands

There are a large number of wetlands of national and international importance in the Murray–Darling Basin region (Figure 7.27), encompassing a wide diversity of wetland types. The wetlands create a mosaic of temporally and spatially dynamic habitats within this part of Australia. The most spatially extensive wetland types in the region are river floodplains, which include lakes, swamps, lagoons and flooded forests. Another dominant type of wetland present in the region is the terminal wetland system of ephemeral rivers.

The river floodplains are particularly important for the conservation of large areas of river red gum forests as well as other woodland species. They are also important breeding grounds for threatened bird species. The swamps and lakes of the terminal wetland systems contain large areas of common reed and other water plant species that form ideal breeding and feeding grounds for many bird species as well as some rare fish species.

Inflows to selected wetlands

The state of the biodiversity in a wetland is linked to the way water is stored within the area and the temporal variability of inflows. An analysis of historic and recent inflows into wetlands provides an informative picture of potential changes.

Five internationally recognised Ramsar wetland sites (Currawinya Lakes, Paroo River wetlands, Gwydir wetlands, Macquarie Marshes and the Barmah Forest) were selected for hydrological analysis of major inflows. More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html)

Four upstream monitoring sites were selected to enable analyses and interpretation of inflows to these five wetlands. The monitoring sites used in the analyses are the closest upstream monitoring sites that have suitable continuous, or almost continuous, discharge records since 1980, providing a comprehensive dataset for much of the freshwater surface-inflows to the wetlands. Though the analyses do not capture the total inflows they are indicative of the temporal patterns of flows to these wetlands.

Barmah Forest | Malcolm Watson

Figure 7.27 Location of important wetlands in the Murray–Darling Basin region

Currawinya Lakes and Paroo River wetlands

The Ramsar-listed Currawinya Lakes and Paroo River wetlands form a combination of wetlands fed by the largest free-flowing river in the region, the Paroo River (Figure 7.28). The wetlands are important nesting and feeding places for migrating birds. Since the area is semi-arid to arid, some unique flora is present amongst the permanent waterholes.

Daily flow data for the monitoring site on the Paroo River at Caiwarro provide a temporal pattern of freshwater inflows into parts of the Currawinya Lakes area and the Paroo River wetlands (Figure 7.29).

Figure 7.28 Location of the monitoring site in relation to Currawinya Lakes and Paroo River wetlands

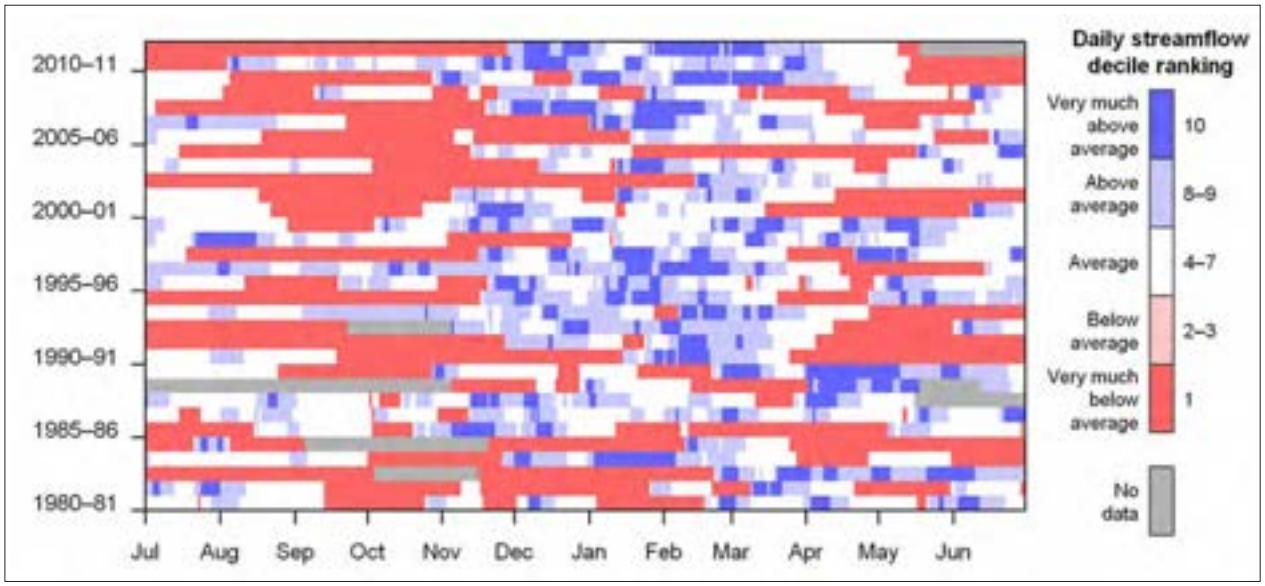


Figure 7.29 Daily flows of the Paroo River at Caiwarro between 1980 and 2012, ranked in decile classes

Figure 7.29 presents an overview of the distribution of daily streamflow decile rankings. Since 1990, above average flows from December through to March provide a reliable source of inflows into the wetlands. This pattern was only interrupted by some dry years between 2000 and 2005. Before 1990, the very much above average flows had a more irregular pattern of occurrence with more frequent periods of very much below average flows during these months.

Figure 7.30 compares monthly flows from 2011–12 with the statistics of flow statistics from 1980 onwards. The February flows well-exceeded the ninth decile of the 32-year record and contributed substantial inflows to the wetlands.

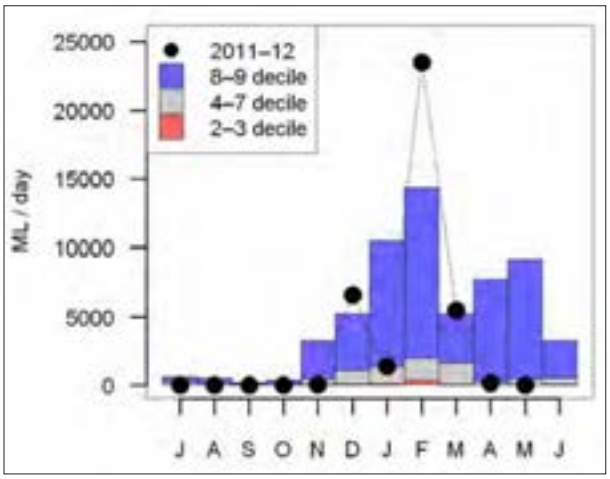


Figure 7.30 Monthly flows at the Paroo River monitoring site at Caiwarro from 2011–12 compared with its 1980–2012 decile rankings

Gwydir wetlands

The Gwydir wetlands are a terminal delta wetland complex of which a small area is Ramsar-listed (Figure 7.31). Land use change and river regulation have substantially reduced the extent of the original wetlands. The Ramsar-listed parts of the Gwydir wetlands mainly consist of grass/sedge meadows and wooded swamps and support some threatened bird species. The wetlands are important nesting and feeding places for migrating birds.

Daily flow data for the monitoring site on the Gwydir River at Pallamallawa shows the temporal pattern of inflows to the wetlands (Figure 7.32).

Figure 7.31 Location of the monitoring sites in relation to the Gwydir wetlands

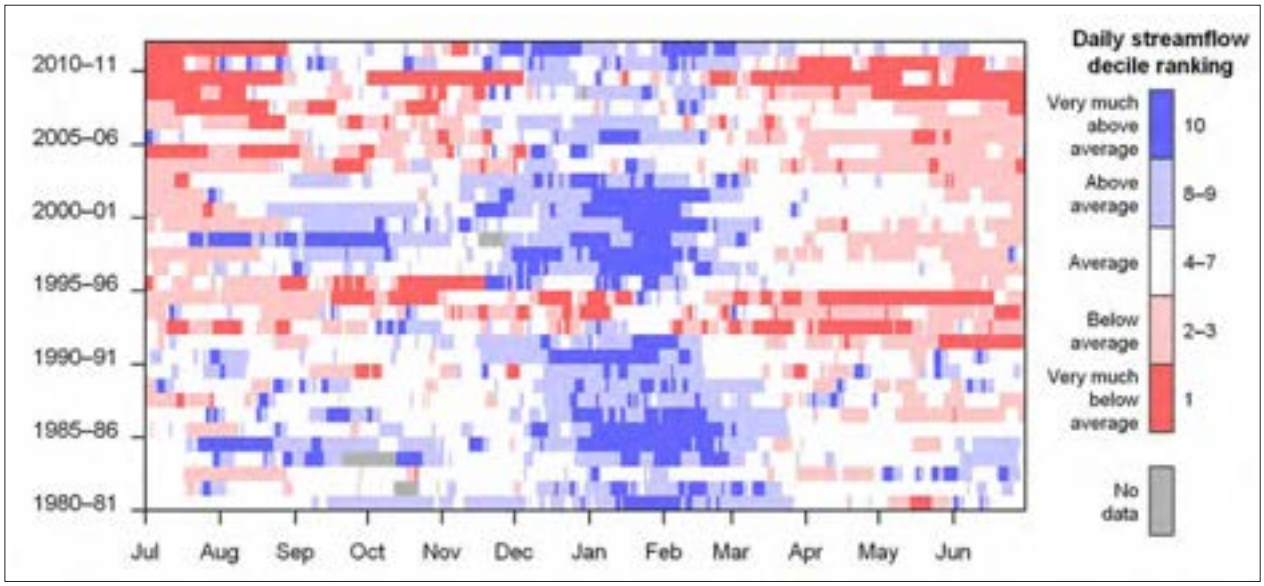


Figure 7.32 Daily flows of the Gwydir River at Pallamallawa between 1980 and 2012, ranked in decile classes

Figure 7.32 presents an overview of the distribution of daily streamflow decile rankings. Although sometimes interrupted, a period of high summer flows was present between 1980 and 2003. Since the summer of 2003–04 this pattern of inflows has been interrupted for most of the eight years to 2011–12. Inflows in the summer of 2011–12 eventually reverted back to longer periods of very much above average flows.

Figure 7.33 compares monthly flows from 2011–12 with flow statistics from 1980 onwards. The November, December and February inflows well-exceeded the ninth decile of the 32-year record and contributed a substantial amount of inflows to the wetlands.

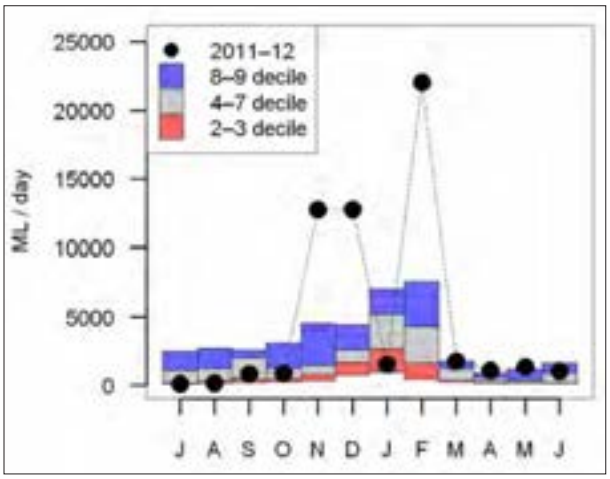


Figure 7.33 Monthly discharges at the Gwydir River monitoring site at Pallamallawa from 2011–12 compared with its1980–2012 decile rankings

Macquarie Marshes

The Ramsar-listed Macquarie Marshes form a combination of various wetland types, supporting a variety of habitats for various ecological communities (Figure 7.34). The marshes support river red gum woodlands, extensive reed beds and water couch marsh, all of which form large breeding grounds for many common as well as threatened bird species.

Daily flow data for the monitoring site on the Macquarie River at Warren Weir shows a temporal pattern of freshwater inflows into the marshes (Figure 7.35).

Figure 7.34 Location of the monitoring site in relation to the Macquarie Marshes

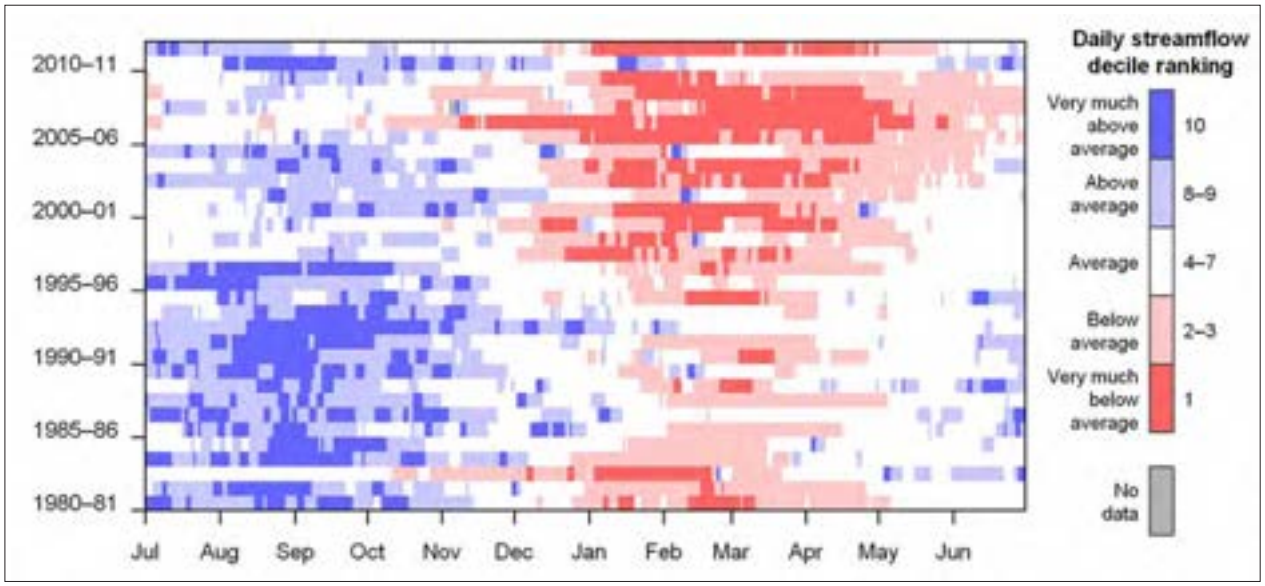


Figure 7.35 Daily flows of the Macquarie River at Warren Weir between 1980 and 2012, ranked in decile classes

Figure 7.35 presents an overview of the distribution of daily streamflow decile rankings. From autumn 2001, flows were frequently average or below average until August 2010. Prolonged low flow periods are not unusual, but over 2000–01 to 2011–12 longer than usual periods of very much below average flows occurred.

Figure 7.36 compares monthly discharges from 2011–12 with flow statistics of flows from 1980 onwards. As can be seen, the flows for 2011–12 were particularly low during the normally high flow months of August–October.

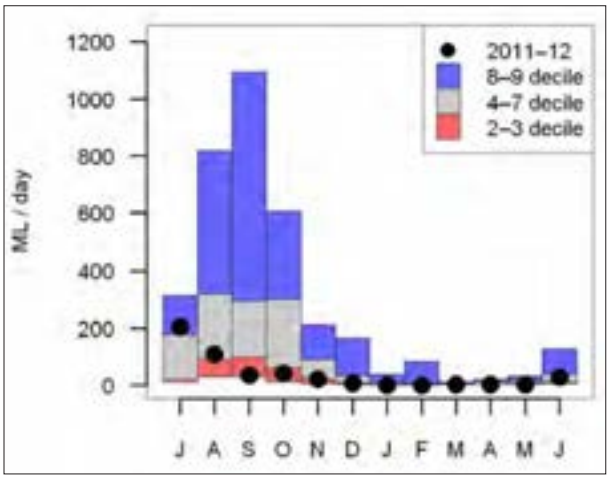


Figure 7.36 Monthly discharges at the Macquarie River monitoring site at Warren Weir from 2011–12 compared with its 1980–2011 decile rankings

Barmah–Millewa Forest wetlands

The Barmah–Millewa Forest wetlands are separately listed as Ramsar sites for the Victorian and New South Wales sides of the River Murray (Figure 7.37). The wetlands contain the largest river red gum forest in Australia. They depend particularly on the irregular flooding of the River Murray. The wetlands include lakes, swamps, lagoons and flooded forest and they provide habitat for a large number of bird species.

Daily flow data for the monitoring site on the River Murray at Tocumwal provides a temporal pattern of inflows into the Barmah–Millewa Forest wetlands, particularly the frequency of potential flooding (Figure 7.38).

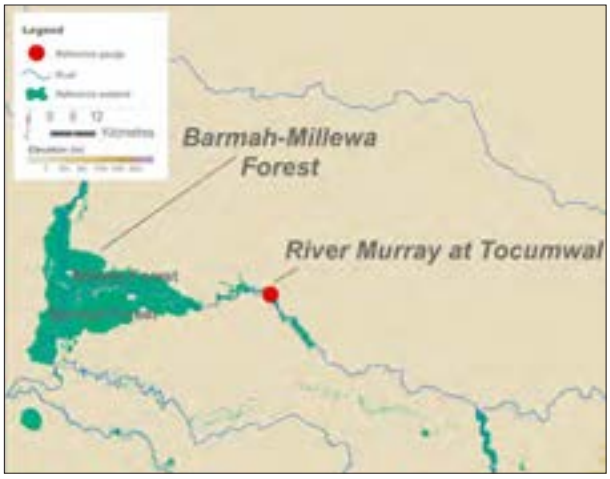


Figure 7.37 Location of the monitoring site in relation to Barmah–Millewa Forest wetlands

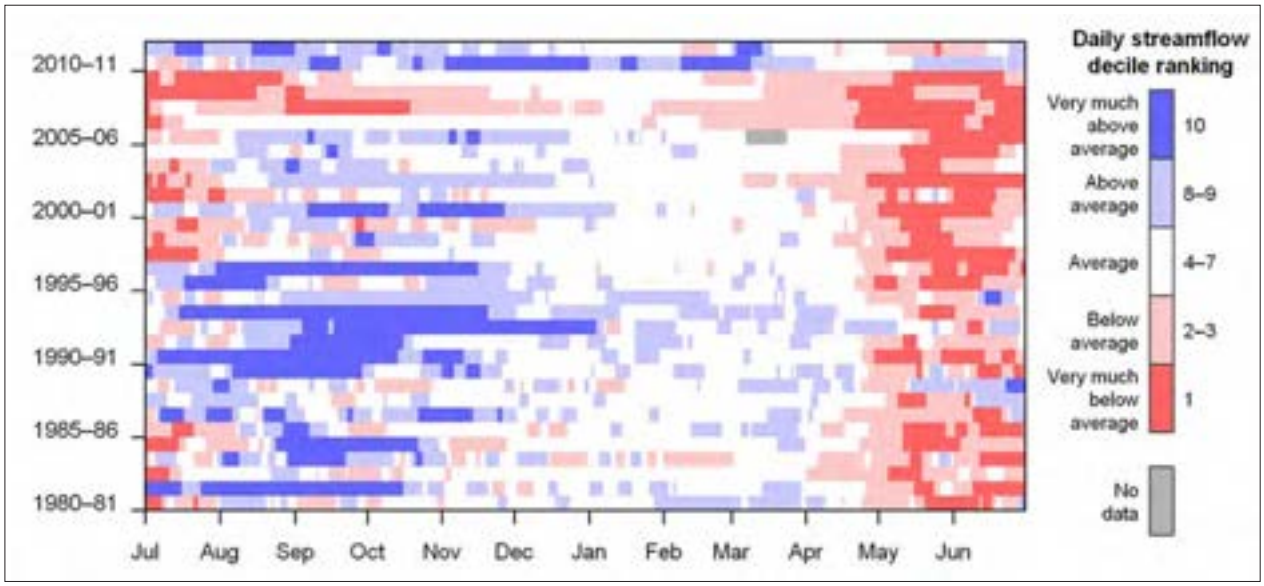


Figure 7.38 Daily flows of the River Murray at Tocumwal between 1980 and 2012, ranked in decile classes

Figure 7.38 presents an overview of the distribution of daily streamflow decile rankings. In the period between 2001 and 2009 environmental flow releases from Hume Dam were undertaken to prevent large parts of the forest from drying out. In particular, between 2007 and 2009 below average flows occurred after which the usually very much above average flows of spring returned.

Figure 7.39 compares monthly flows from 2011–12 with the flow statistics from 1980 onwards. The normally highest September flows were average; however the high July, August and March flows to some extent contributed to inflows to the wetlands.

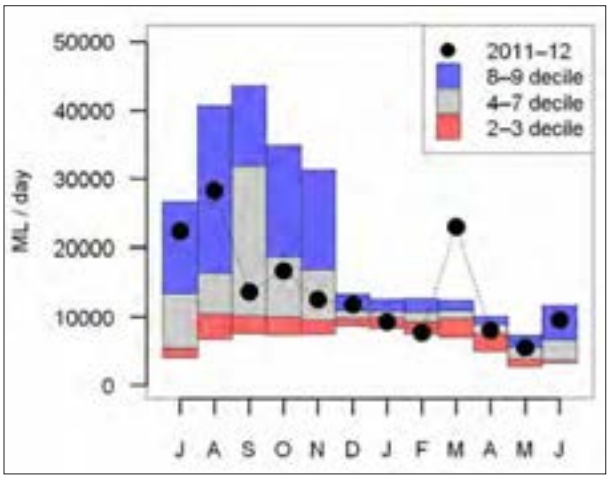


Figure 7.39 Monthly flows at the River Murray monitoring site at Tocumwal from 2011–12 compared with its 1980–2012 decile rankings

7.5.7 Hydrogeology

As shown in the figure below (Figure 7.40), the Murray–Darling Basin region is divided into three broad hydrogeological subdivisions (Murray–Darling Basin Commission 2008), namely:

- the basinal aquifers in sedimentary deposits (Murray Basin and Great Artesian Basin) within the flatter landscapes;
- the fractured rock aquifers in areas where the basement rock outcrops (for example, Palaeozoic and pre-Cambrian Fractured Rock Aquifer); and
- valley-fill alluvium (including the Mid-Murrumbidgee and Upper Namoi) in the highlands bordering the region.

The Great Artesian Basin is the largest groundwater basin in Australia and underlies the northern portion of the region. It consists of a complex, multi-layered system of water-bearing sandstones separated by mostly shale and mudstone confining beds (Murray–Darling Basin Commission 2008). It underlies the sand and clay sequences of the Murray–Darling Basin region that were laid down over the last 50 million years. The Great Artesian Basin provides vital water resources for domestic and town water supply, for stock use by the pastoral industry, and water supplies for the operations of the mining and petroleum industries and associated communities.

The sedimentary aquifers within the region cover the main depositional areas of the Murray Geological Basin and the Darling River basin, including upstream reaches of other major rivers such as the Murrumbidgee and Lachlan rivers. The major aquifers within or at the margins of the Murray geological basin include the Shepparton, Calivil, Parilla-Loxton Sands, Murray Limestone and Renmark Group aquifers, and the upland alluvium of the Cowra and Lachlan formations. The important alluvial sediments of the Darling River basin include the Gunnedah and Narrabri aquifers.

Fractured rock aquifers occur in the highland areas around the margins of the region. In fractured rock aquifers, groundwater is stored in the fractures, joints, bedding planes and cavities of the rock mass. Although fractured rock aquifers are found over a large area, they hold a much lower groundwater volume than sedimentary aquifers. Due to the difficulty of obtaining high yields from fractured rock, the volume of groundwater extracted from any one bore and in a given area is relatively low.

7.5.8 Watertable salinity

Figure 7.41 shows the salinity of the watertable aquifer in the Murray–Darling Basin region as fresh, where (total dissolved solids [TDS] < 3,000 mg/L), or saline, where (TDS ≥ 3,000 mg/L). Generally, the shallow groundwater in the flatter alluvial plain in the region is saline, most likely due to high evapotranspiration and low rainfall recharge. In contrast, fresh groundwater resources occur at the higher elevation where rainfall recharge is higher.

Groundwater in the deeper aquifers is typically fresher than that of the watertable; often the majority of this groundwater is derived from a past wetter climatic period.

Watertable aquifer salinity levels have risen significantly since European settlement, largely due to the clearing of native vegetation, irrigation development and the consequent increase in recharge to groundwater systems (Barnett et al. 2004).

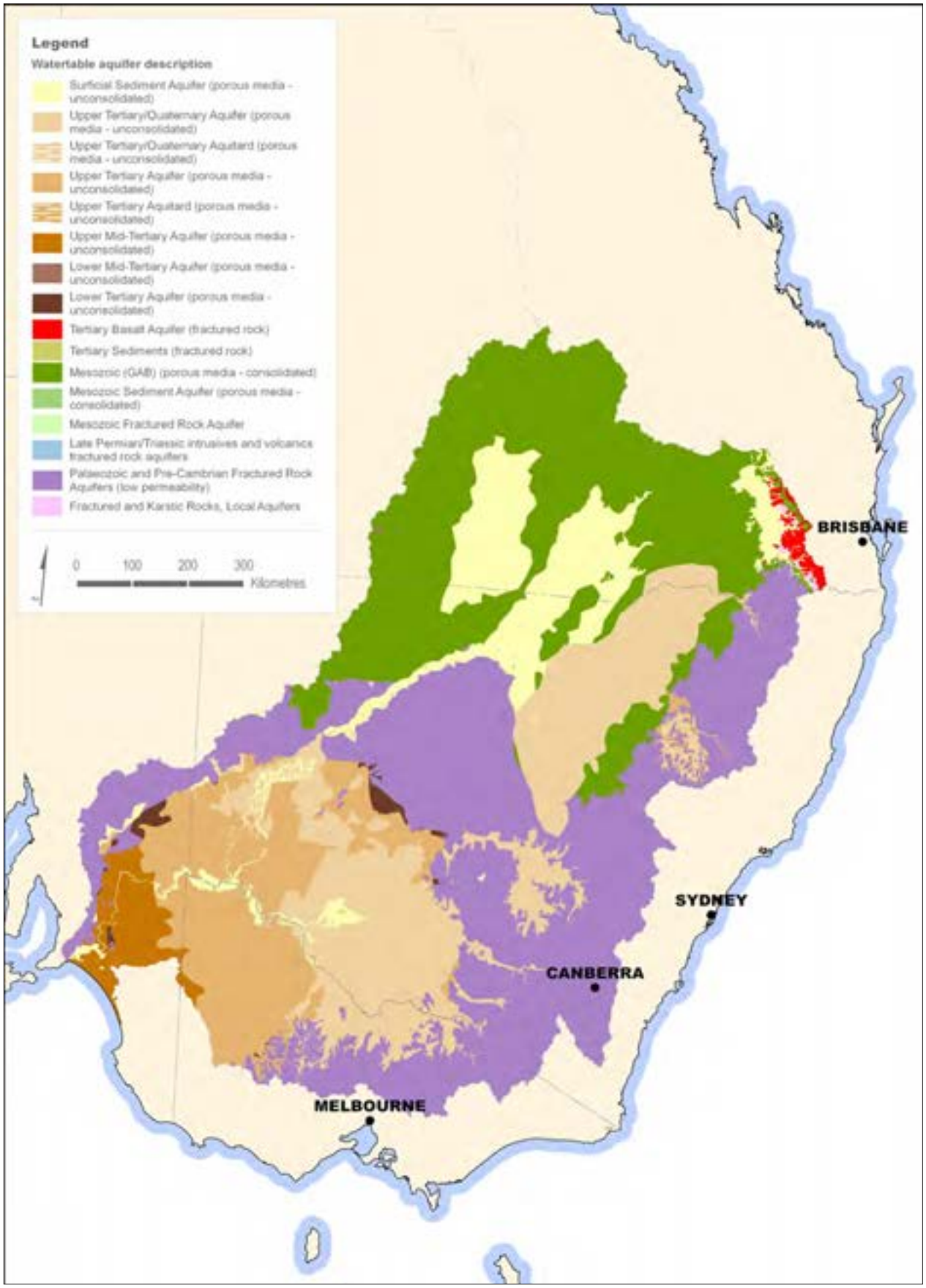


Figure 7.40 Watertable aquifers in the Murray–Darling Basin region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

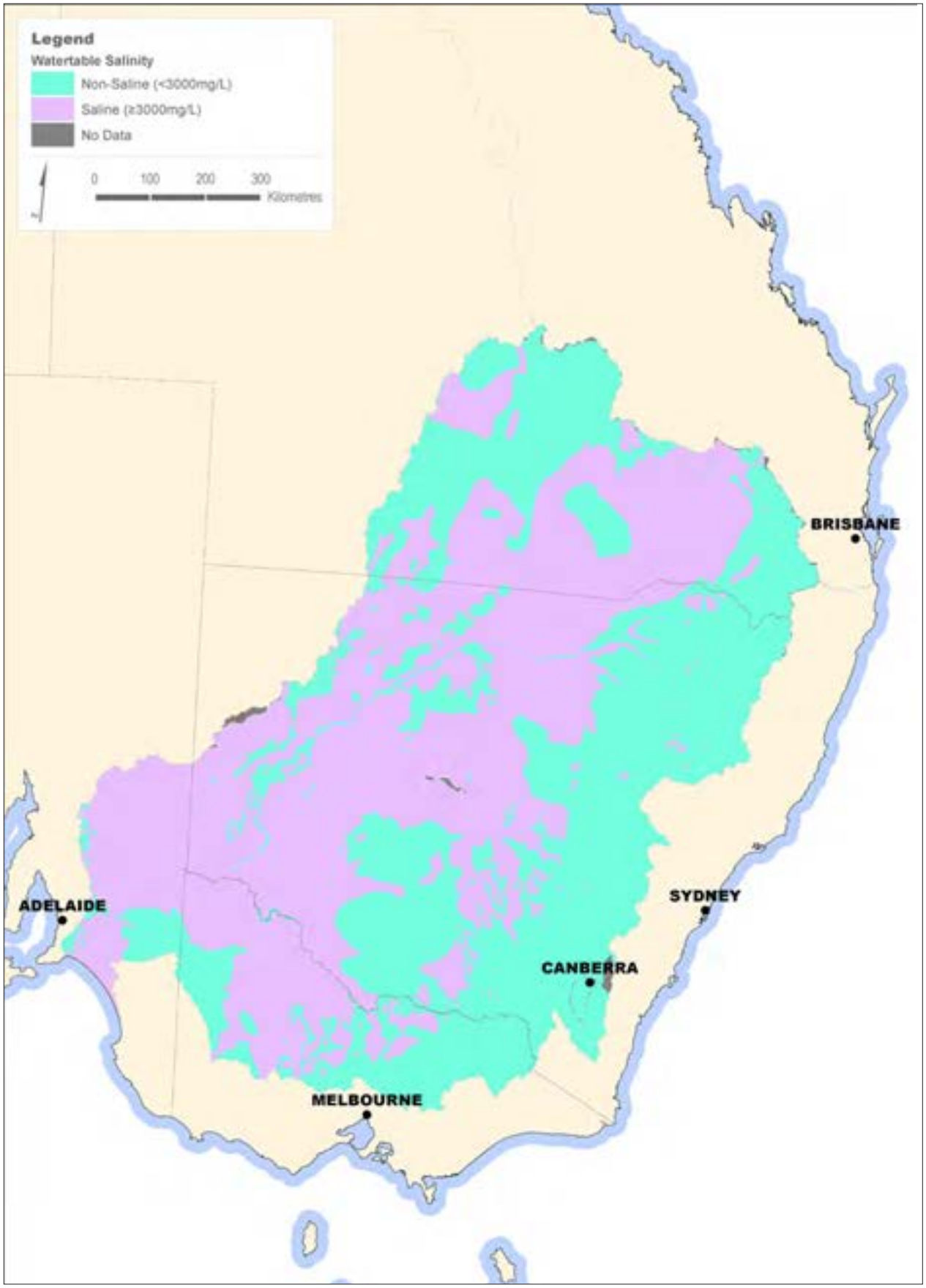


Figure 7.41 Watertable salinity classes in the Murray–Darling Basin region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

7.5.9 Groundwater management units

Total groundwater use in 2010–11 was 511 GL, which was 8% of the surface water diversion in the region decreasing from 24% in 2009–10 (Murray–Darling Basin Authority 2012b). Since 1999–2000, when groundwater reporting started, groundwater use has been steadily rising, but there was a decline in the 2010–11 reporting year. This was linked to high rainfall and wide spread floods which led to good surface water availability.

The Murray–Darling Basin Authority established long-term average sustainable diversion limits (SDL), which will come into effect in 2019, along with a range of other measures that will improve the management of water in the region. The SDL are limits on the volumes of water that can be taken for human uses (including domestic, urban, industrial and agricultural use) from both surface water and groundwater systems across the region.

The groundwater resources in the Murray–Darling Basin region have been split into 22 groundwater water resource plan (WRP) areas, which are further divided into a total of 87 SDL resource units, as shown in Figure 7.42 and Figure 7.43 (Murray–Darling Basin Authority 2012a). These include seven groundwater SDL resource units for deep groundwater that lie beneath the other 80 groundwater SDL resource units (Figure 7.43).

SDL resource unit boundaries, shown in Figure 7.42, were determined according to the types of aquifers present and the management boundaries used by the state jurisdictions. There is a volume allocated to each SDL resource unit in the draft Murray–Darling Basin plan. In some areas, there are SDL resource units that overlap one another. This occurs where SDL units have been set for discrete aquifers that overlie one another under the same area of land (Murray–Darling Basin Authority 2012a).

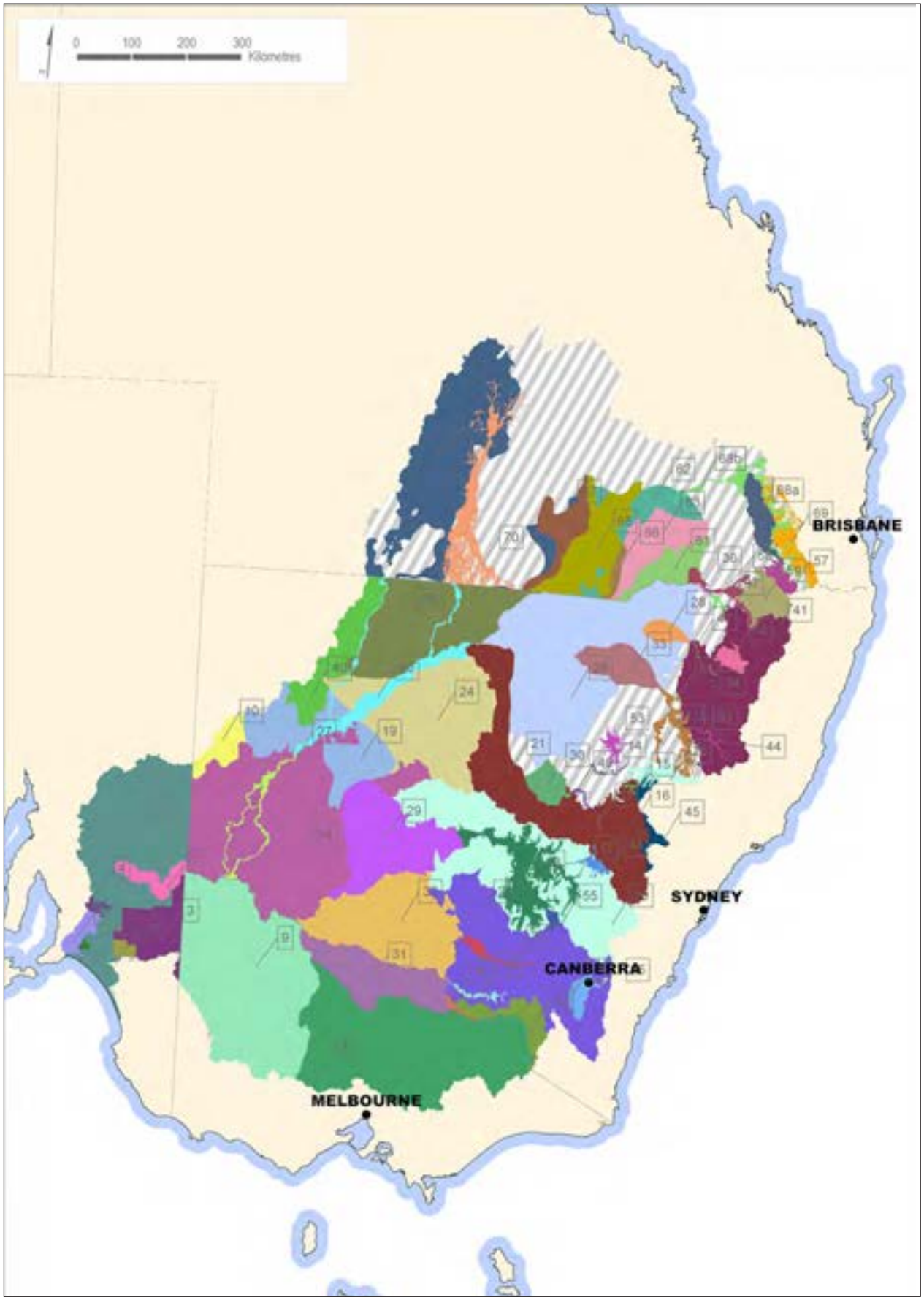


Figure 7.42 Groundwater SDL resource units as at 31 August 2012 (Murray-Darling Basin Authority 2012a)

Legend of Figure 7.42 Groundwater SDL resource units as at 31 August 2012 (Murray–Darling Basin Authority 2012a)

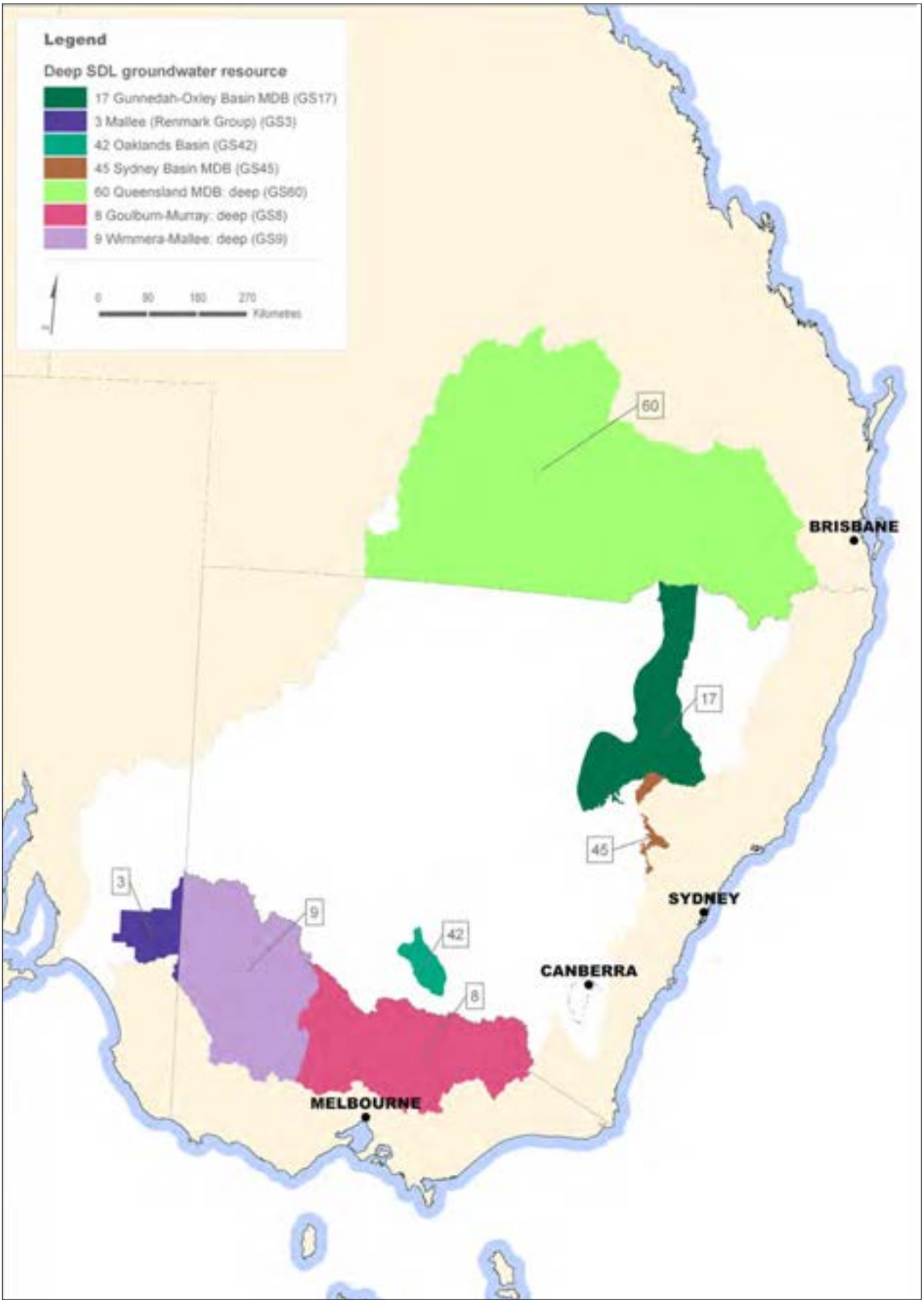


Figure 7.43 Groundwater SDL resource units legend as at 31 August 2012 (Murray–Darling Basin Authority 2012)

7.5.10 Status of selected aquifers

The status of groundwater levels is analysed at each bore throughout the Murray–Darling Basin region. This assessment evaluates trends in groundwater levels over the five-year period 2007–08 to 2011–12.

The trends in groundwater levels over the last five years are investigated using a 20 km x 20 km grid across data rich areas usually associated with the major sedimentary aquifers. This scale reflects the regional flow system of the aquifers in the region.

The linear trend in groundwater levels for each grid cell is assessed as:

- decreasing (where more than 60% of the bores have a negative trend in levels lower than –0.1 m/year); stable (where the trend is lower than 0.1 m/year; and higher than – 0.1 m/year for more than 60% of the bores);
- stable (where more than 60% of the bores have a trend lower than 0.1 m/year and higher than –0.1 m/year);
- increasing (where more than 60% of the bores have a positive trend in levels higher than 0.1 m/year); and
- variable (where there is no dominant trend in groundwater levels amongst the bores within a grid cell).

Example bore hydrographs are presented for each aquifer type over the entire record length and trends are discussed with a focus on the 2007–08 to 2011–12 period. The selected hydrographs are at key bores that have been chosen to assist in the analysis and reporting of groundwater trends. Where possible, the bore hydrographs presented are for the same bores used in the *Groundwater Status Report 2000* (Murray–Darling Basin Commission 2004).

Condamine alluvium aquifer

The map in Figure 7.44 illustrates the spatial and temporal trends in groundwater levels in the Condamine alluvium aquifer from 2007–08 to 2011–12. Many of the grid cells show an increasing trend in groundwater levels. In other cells, groundwater levels are variable or stable. The cells showing a variable trend indicate that, within a grid cell, no clear majority of bores has a specific trend.

For both the alluvial and basalt aquifers the increased rainfall in the last couple of years is associated with an increase in recharge in conjunction with a probable decrease in groundwater abstraction, due to surface water availability, and is the major driver of increasing groundwater levels.

The hydrographs of selected bores 1 and 2 show a clear decline in groundwater levels after 1990 and a noticeable recovery in groundwater levels after 2010; the reasons for this decline are explained in the above paragraph. Bore 3 shows an upward trend in water level for the entire period of record. This bore is located in the upper tributary of the Condamine River away from the main alluvial plain and away from major extraction bores. The long-term increasing trend is probably associated with anthropogenic factors such as land clearing.

Condamine basalt aquifer

The map in Figure 7.45 illustrates the spatial and temporal trends in groundwater levels in the Condamine basalt aquifer from 2007–08 to 2011–12. All of the grid cells show a rising trend in groundwater levels over the past five years.

Selected bores 4 to 6 all show an increasing trend in groundwater levels. The hydrographs all have an increasing trend over the last five years. This reflects the local groundwater use and high rainfall in the past couple of years. The fluctuations in water level observed in Bore 5 are likely to be caused by seasonal groundwater extraction from nearby production bores.

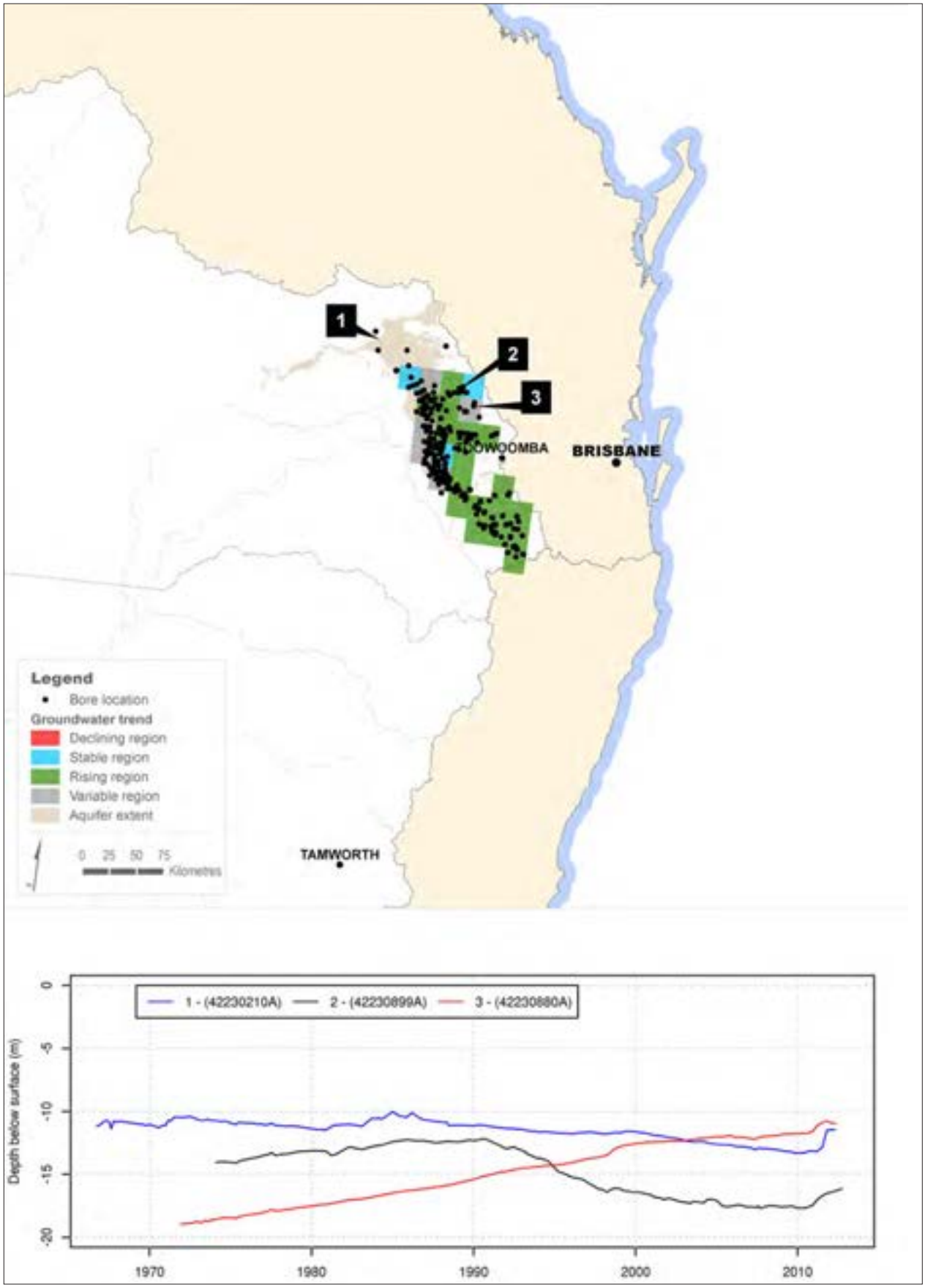


Figure 7.44 Spatial distribution of trends in groundwater levels for the Condamine alluvium aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

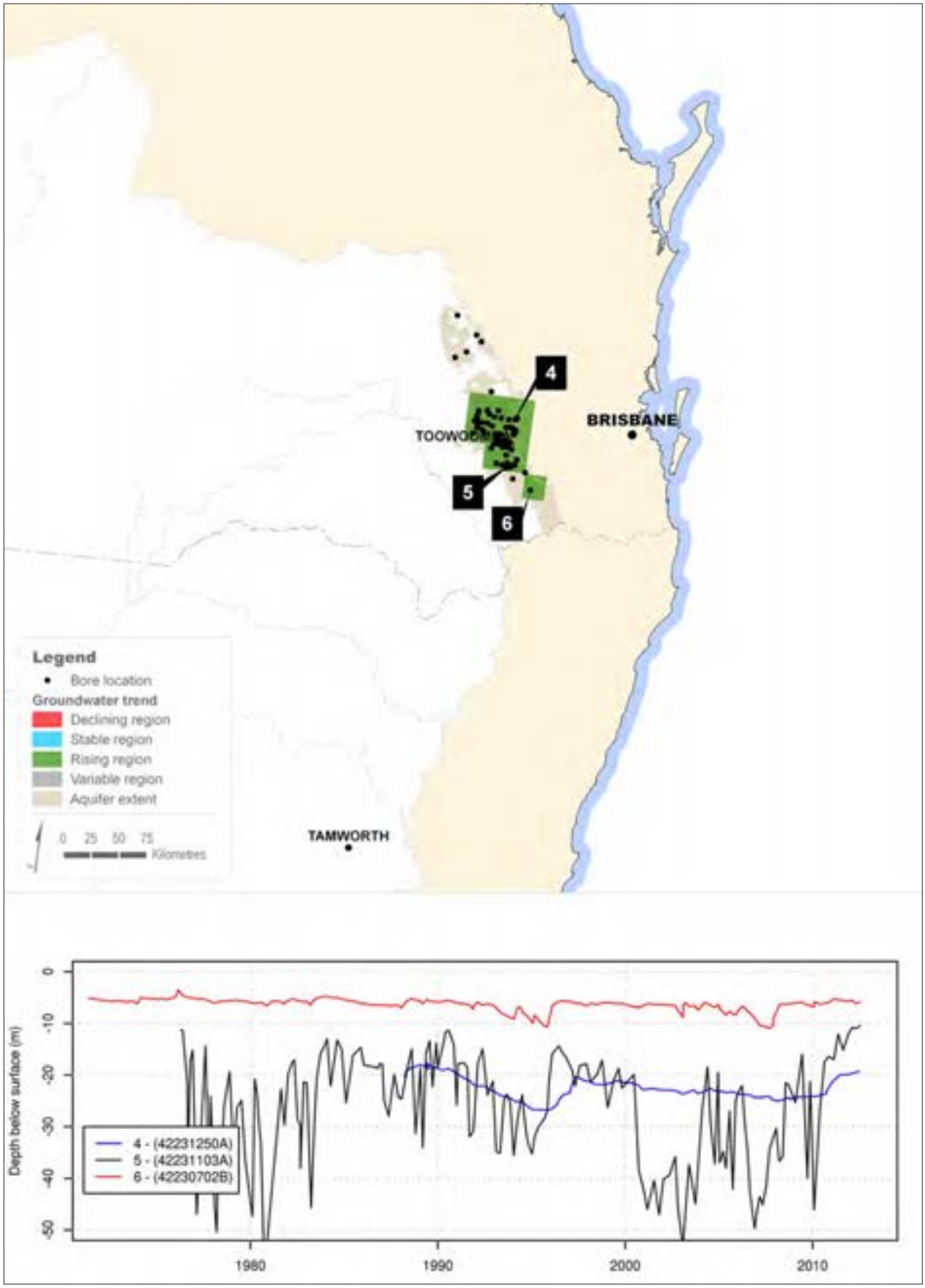


Figure 7.45 Spatial distribution of trends in groundwater levels for the Condamine basalt aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

Narrabri and Gunnedah aquifers

Figure 7.46 and Figure 7.47 illustrate the spatial and temporal trends in the Narrabri aquifer and the associated underlying Gunnedah aquifer respectively.

The water levels in bores within the Narrabri aquifer are generally increasing or stable, with some areas showing a variable trend within the 20 km x 20 km grid cells for the 2007–2012 period. Similarly, groundwater levels in the more permeable Gunnedah aquifer indicate an increasing or stable trend overall. There are a small number of cells that show variable or declining trends in water levels.

Bore 7 is located in the lower reaches of the Gwydir system. The hydrograph indicates an overall stable trend in groundwater level and no annual fluctuations in the groundwater level. Bore 8 is located in the lower Namoi SDL. The hydrograph shows that water levels in 2007–2012 are continuing the gradual long-term decline. Bore 9 is located in the Coxs Creek region of the upper Namoi SDL. The groundwater levels show a minor recovery after 2010 with little annual fluctuation. These two bores, which report groundwater levels for the Narrabri aquifer, are most likely to be remote from the influence of groundwater abstraction or seasonal rainfall recharge.

Bore 10 is located in the Gwydir catchment and shows a very stable water level over the entire measurement period. Similarly, Bore 11 located at the western margin of the lower Namoi groundwater management unit shows stable groundwater levels for the entire record length. These three bores, which report groundwater levels for the underlying Gunnedah aquifer, are remote from the influence of groundwater abstraction or seasonal rainfall recharge.

Bore 12 is located in the lower Namoi groundwater management unit and shows a marked seasonal fluctuation in groundwater levels indicating the influence of seasonal cycles of abstraction and recovery of groundwater levels. This bore also shows a clear recovery in groundwater levels in 2012.

Cowra and Lachlan aquifers

Figure 7.48 and Figure 7.49 illustrate the spatial and temporal trends in the Cowra and the underlying Lachlan aquifers respectively.

Generally the Cowra and Lachlan aquifers show increasing trends in groundwater levels within the grid cells for 2007–2012. This is in contrast to the 2010 assessment where most of the grid cells presented decreasing trends in groundwater levels for the 2005–2010 period. The change in groundwater levels trends is driven by the increased rainfall and widespread floods which occurred since 2010 that have increased groundwater recharge and decreased dependence on groundwater abstraction.

Bores 13, 14 and 15 represent groundwater levels in the Cowra Subsystem while bores 16, 17 and 18 represent groundwater levels in the Lachlan Subsystem. Bores 13 and 17, and also 15 and 18, are nested showing groundwater levels for the upper and lower aquifer at the same location. Groundwater fluctuation for these nested bores indicates a strong hydraulic connection between the Lachlan and overlying Cowra aquifers. Annual variations in groundwater level in these two aquifers are most likely due to the effects of cycles of groundwater abstraction and recovery of groundwater levels. All bores show a varying degree of declining trend in groundwater levels from 2000–2010 and a subsequent recovery in groundwater levels after 2010. This is consistent with the recent widespread flooding in the last couple of years with the break of the millennium drought.

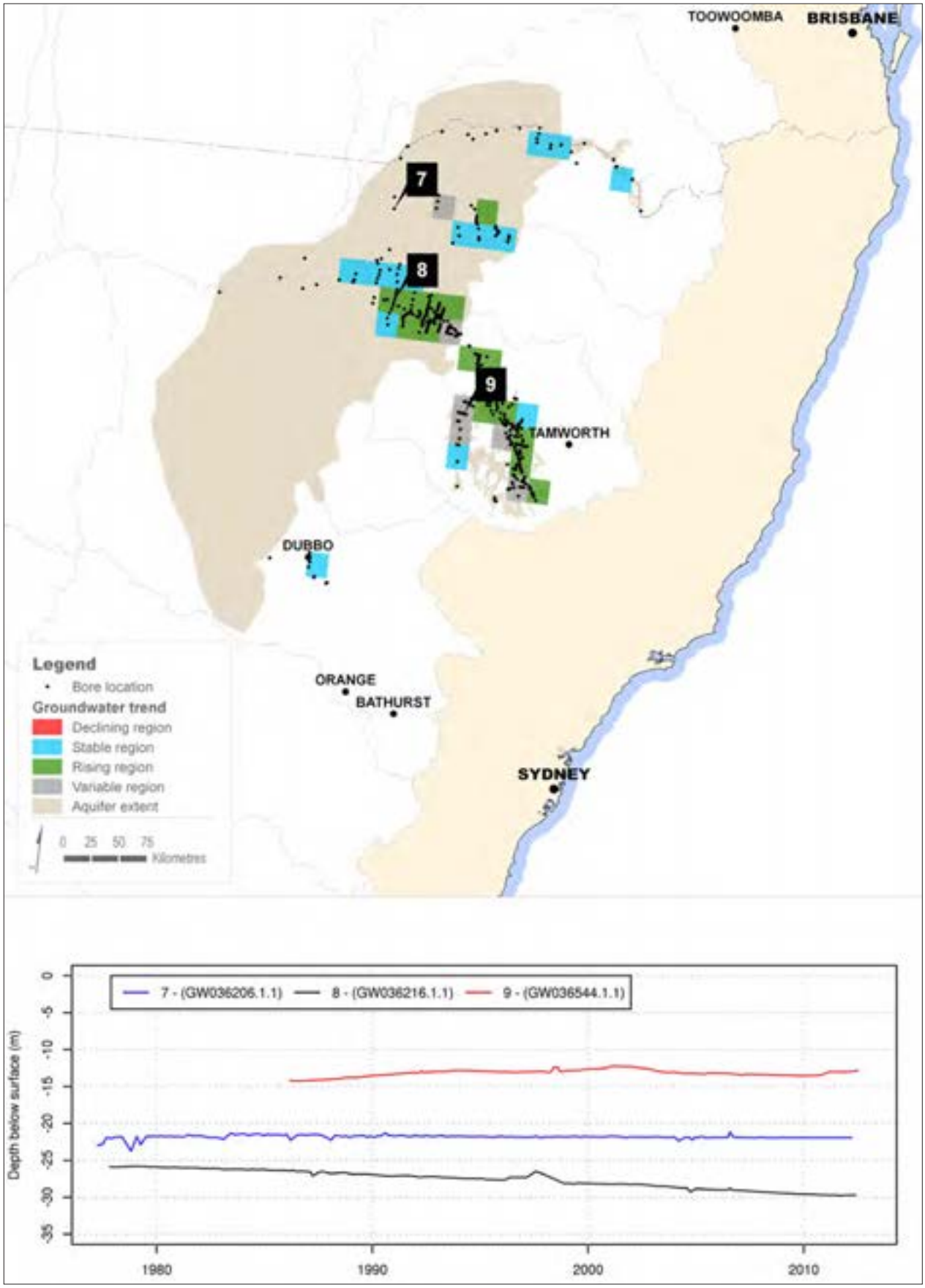


Figure 7.46 Spatial distribution of trends in groundwater levels for the Narrabri aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

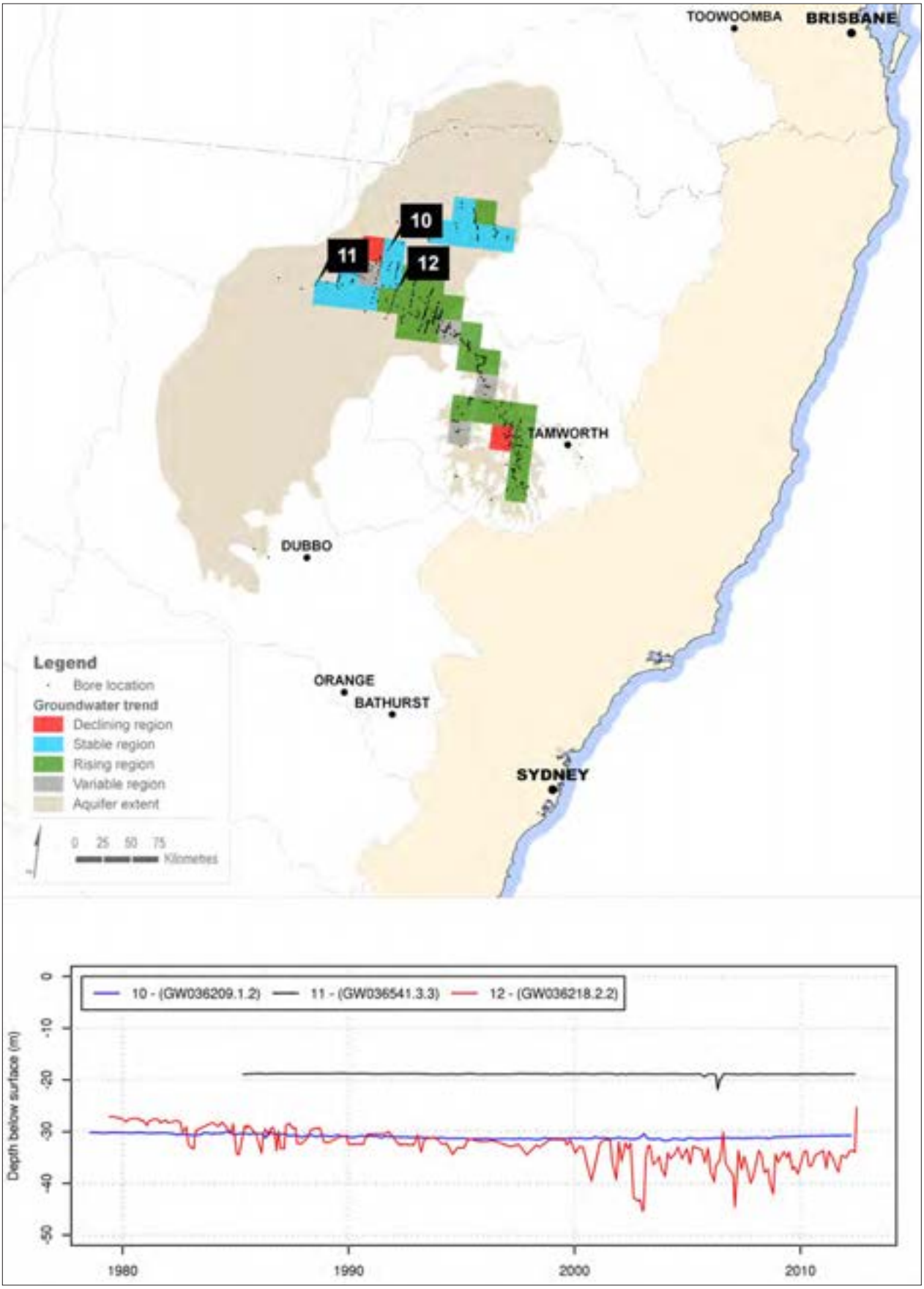


Figure 7.47 Spatial distribution of trends in groundwater levels for the Gunnedah aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

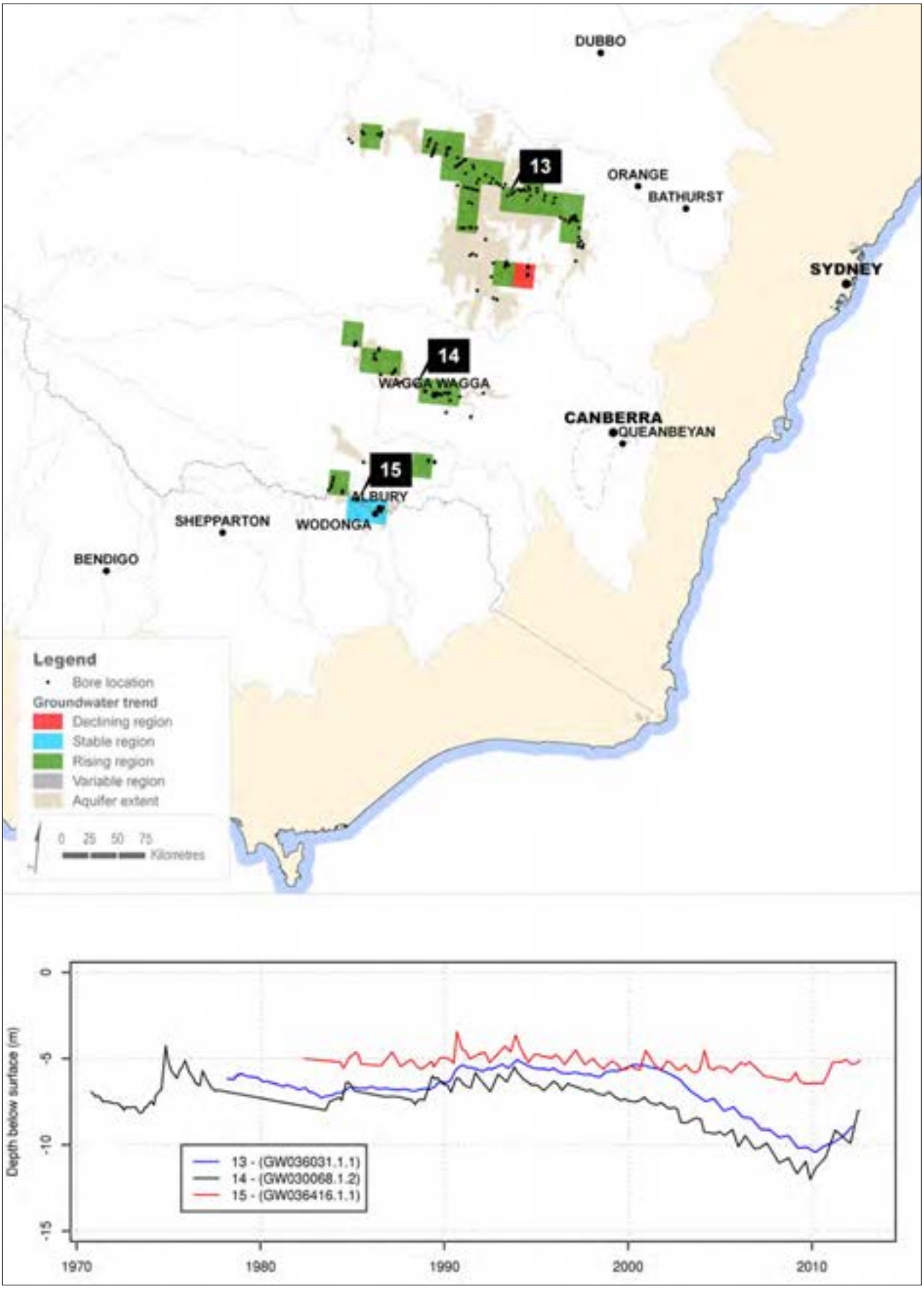


Figure 7.48 Spatial distribution of trends in groundwater levels for the Cowra aquifer for 2007–2012, with selected hydrographs showing groundwater levels

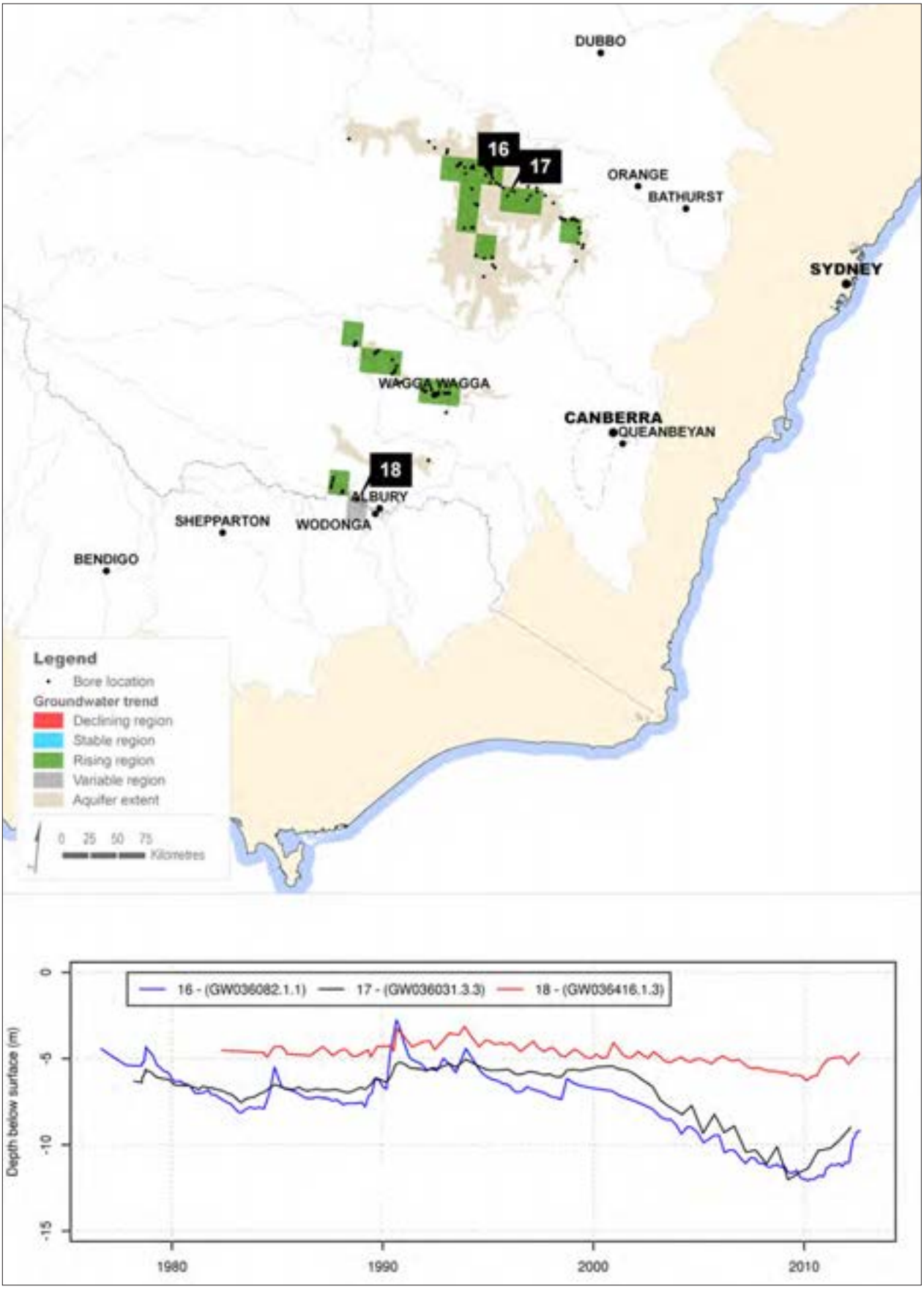


Figure 7.49 Spatial distribution of trends in groundwater levels for the Lachlan aquifer for 2007–2012, with selected hydrographs showing groundwater levels

Shepparton aquifer

Figure 7.50 illustrates that groundwater levels for the Shepparton aquifer for the 2007–08 to 2011–12 period have overall an increasing trend in the southwest of the aquifer and no majority of grid cells with a distinct trend in the southeast. Bore levels most likely respond to groundwater abstraction in the main groundwater management units as well as to the recent high rainfall and floods.

Hydrographs of three bores located within the Shepparton aquifers are presented in Figure 7.50. Bore 19 is located in the Lower Murray SDL in New South Wales. The hydrograph indicates a steady increasing groundwater level overall. Bore 20 is located in the Goulburn Murray SDL in Victoria; the hydrograph indicates a stable trend in groundwater level, with a slight decline in levels since the mid 2000s and a pulse of groundwater recharge producing a marked recovery in groundwater levels after 2010. The hydrographs also illustrate that the recharge event is already starting to disperse. The hydrographs indicate that these bores are not influenced by seasonal cycles of groundwater abstraction and then recovery of levels by seasonal rainfall recharge.

Bore 21 is also located in the Goulburn Murray SDL in Victoria, close to the River Murray and major irrigation areas where groundwater abstraction is high. The hydrograph shows an annual fluctuation of water level of up to 5 m. The high amplitude of water level fluctuation is due to the effects of seasonal groundwater abstraction. There is also a decline in levels since the mid 1990s–2010 followed by a recovery in groundwater levels. This recovery is linked to recent flooding and high rainfall.

Calivil aquifer

The trend analysis illustrated in Figure 7.51 indicates that the density of bores in the Calivil aquifer with up to date groundwater level data is very poor — there are very few grid cells with a trend calculated; however, the grid cells present indicate decreasing groundwater levels in the north and no majority of grid cells with a distinct trend in the south. The decline is likely to be the result of groundwater extraction as well as the fact that recharge due to recent rainfall and floods may not have fully reached the Calivil aquifer yet.

Hydrographs of groundwater levels in three bores located near the southern and western margins in New South Wales are presented in Figure 7.51. Bore 22 is located at the western (downstream) end of the lower Murrumbidgee SDL. The hydrograph shows stable groundwater levels since 1990. Bore 23 is located near the River Murray at the western end of the lower Murray SDL in New South Wales. The water level trends over 2006–07 to 2009–10 indicate a decline, followed by a minor recovery in groundwater levels after 2010. The decline is consistent with a response to pumping further to the east in the lower Murray groundwater SDL and the low rainfall in that period; the increase in groundwater levels is consistent with recent high rainfall.

Bore 24 is located near Deniliquin in the lower Murray SDL in New South Wales. The hydrograph shows considerable fluctuation in groundwater levels due to drawdown associated with groundwater extraction during the irrigation season and subsequent recovery when the extraction ceases in winter. There is a falling trend in groundwater level from the mid-1990s followed by a recovery in groundwater levels after 2010 in response to recent high rainfall.

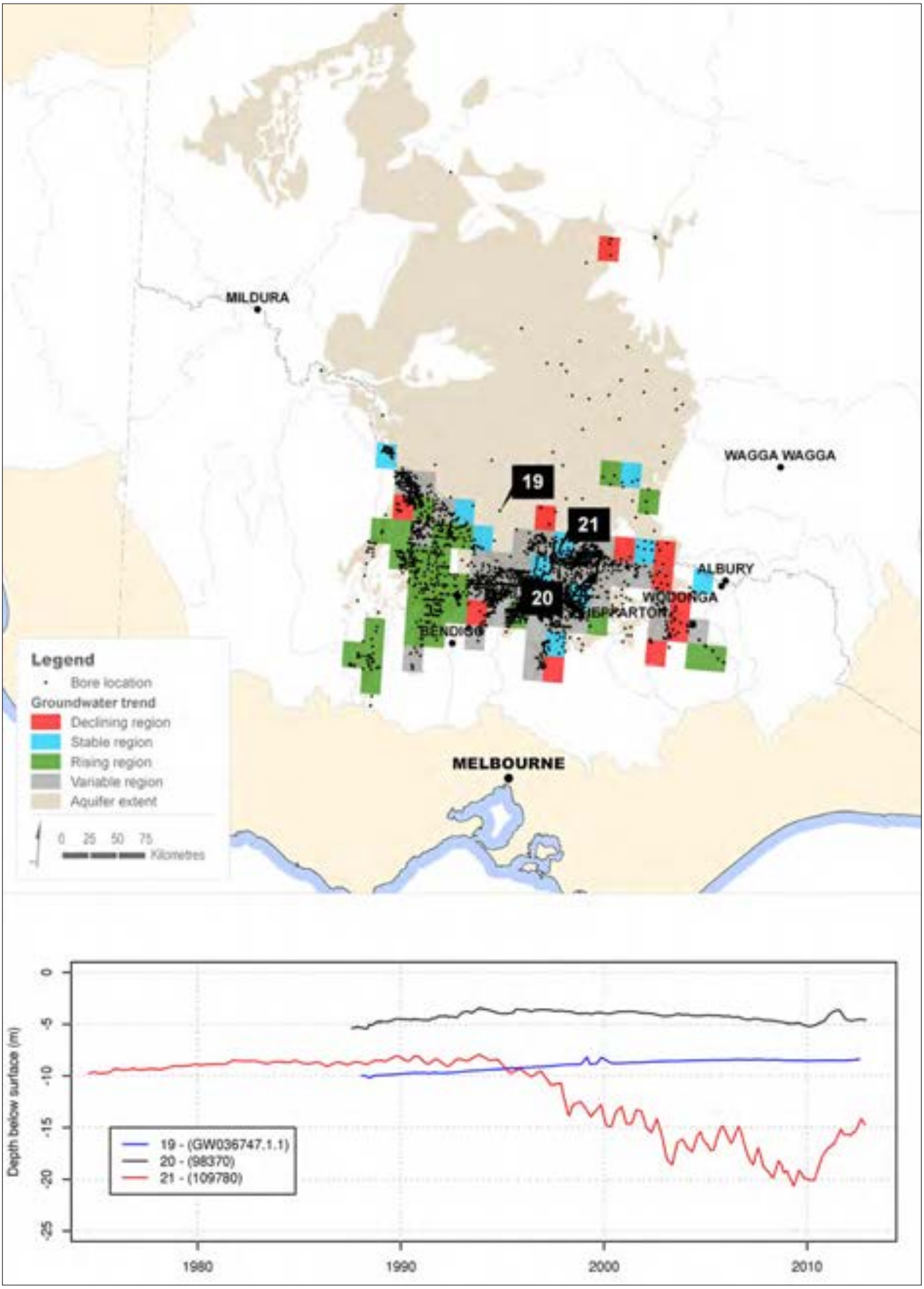


Figure 7.50 Spatial distribution of trends in groundwater levels for the Shepparton aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

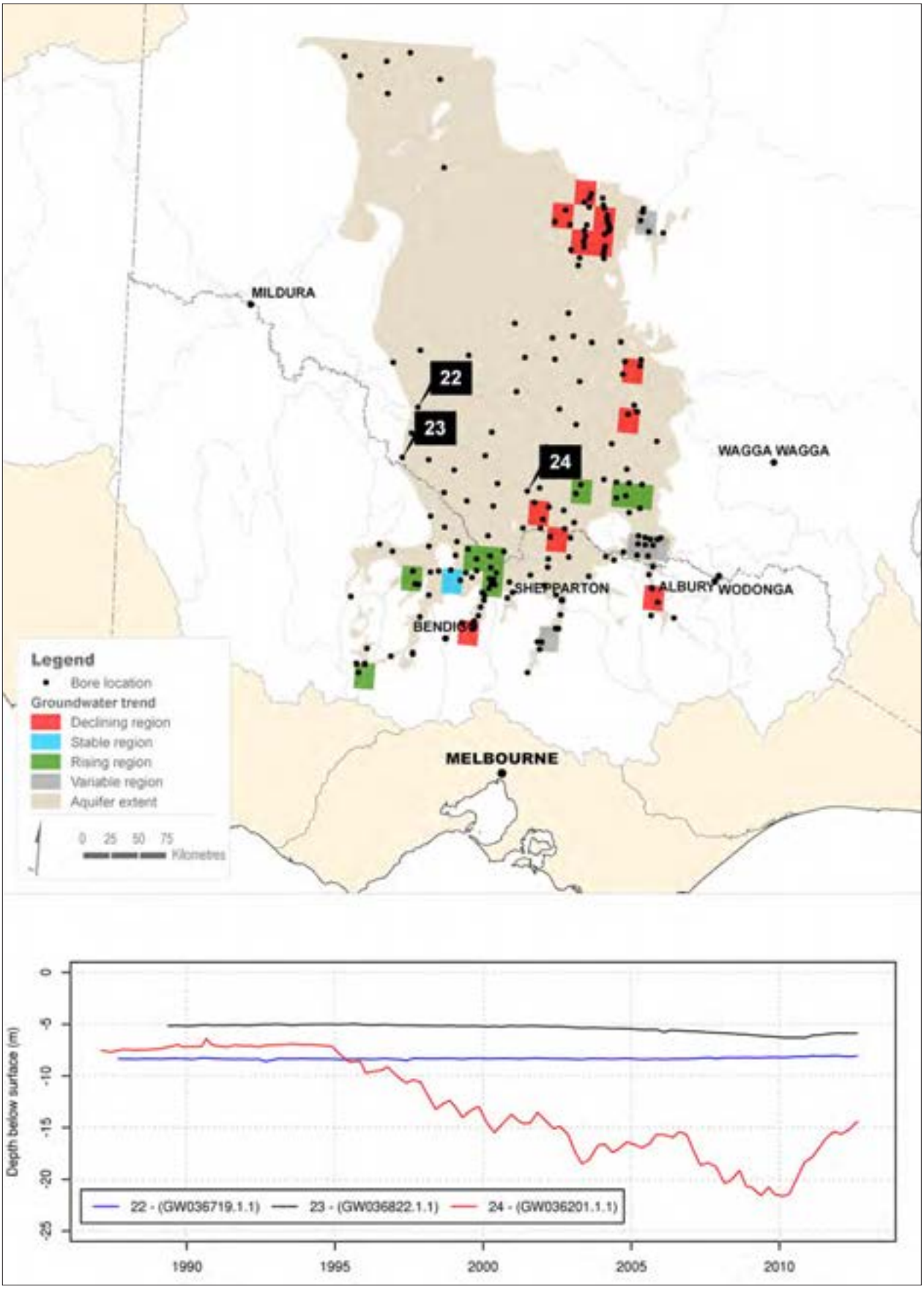


Figure 7.51 Spatial distribution of trends in groundwater levels for the Calivil aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

Murray Group aquifer

Figure 7.52 illustrates the spatial and temporal trends in the Murray Group aquifer. Note that many of the groundwater bores in the Murray Group in South Australia lie outside the Murray–Darling Basin region.

Generally the Murray Group aquifer shows stable or rising trends for the period from 2007–08 to 2011–12, showing a change from the largely decreasing trends observed for 2005–06 to 2009–10 (2010 Assessment).

Bore 25 in the Murray Group shows an annual fluctuation in the water levels, probably due to pumping at nearby wells, and has a slightly rising groundwater level since 2010. Bores 26 and 27 present a very stable groundwater level over a long period of time (Figure 7.52).

Renmark aquifer

Figure 7.53 illustrates the spatial and temporal trends in the underlying Renmark aquifer.

The Renmark aquifer is present at depth, and groundwater observation bores are widely spaced over the large area of the aquifer. Trends generally indicate a fall in Renmark groundwater levels in the west as observed in the 2010 Assessment; the effects of increased rainfall and flooding since 2010 do not yet seem to be affecting the deep Renmark aquifer in most areas.

The hydrograph of bores 28 and 30 show a long term declining trend in groundwater levels with a recovery in levels since 2010. Annual fluctuations of water level of up to 10 m are visible in the hydrograph for Bore 28. The high amplitude of water level fluctuation is due to the effects of seasonal groundwater abstraction.

Bore 29 shows a very stable groundwater level over a long period (Figure 7.53).

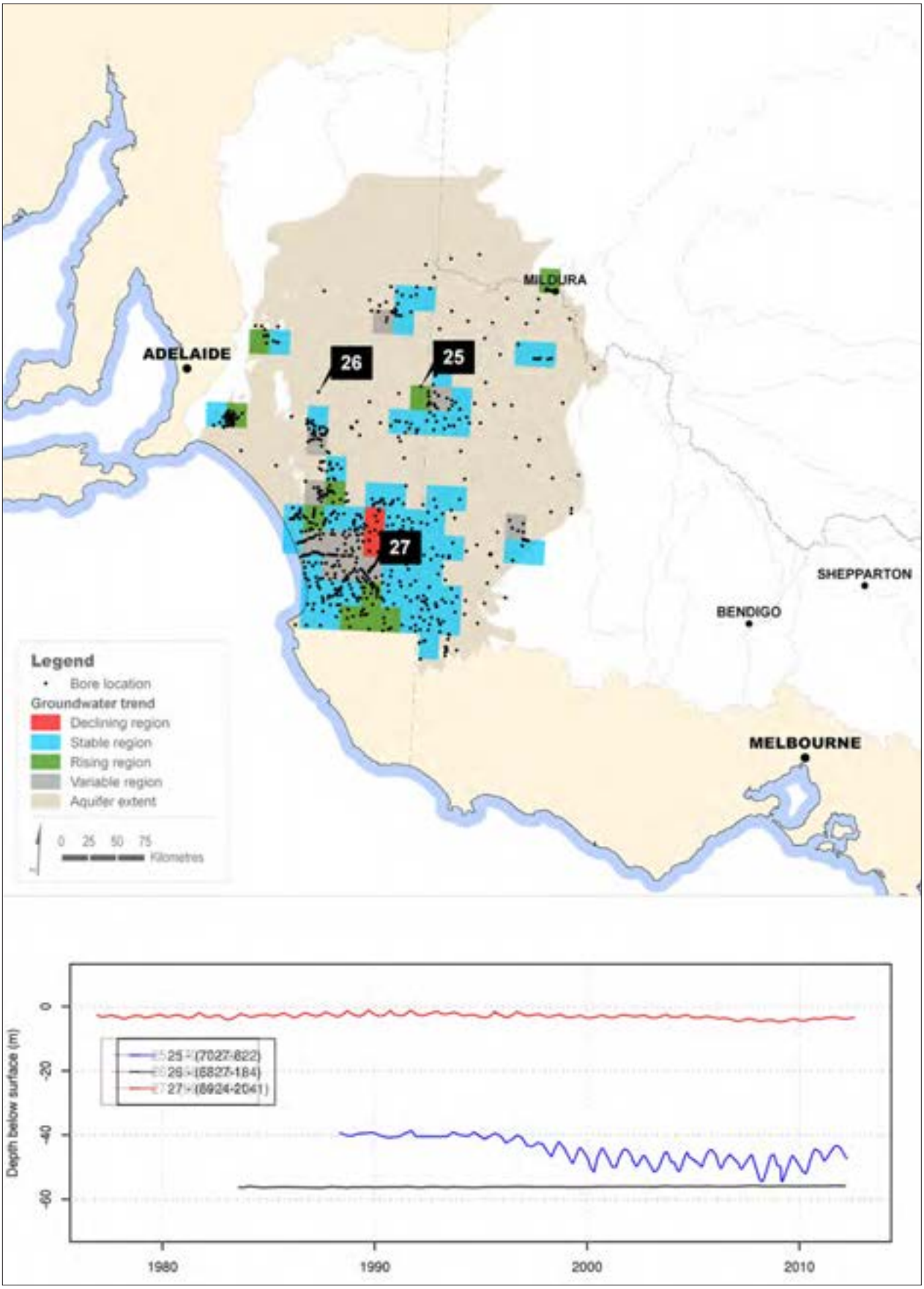


Figure 7.52 Spatial distribution of trends in groundwater levels for the Murray Group aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater level

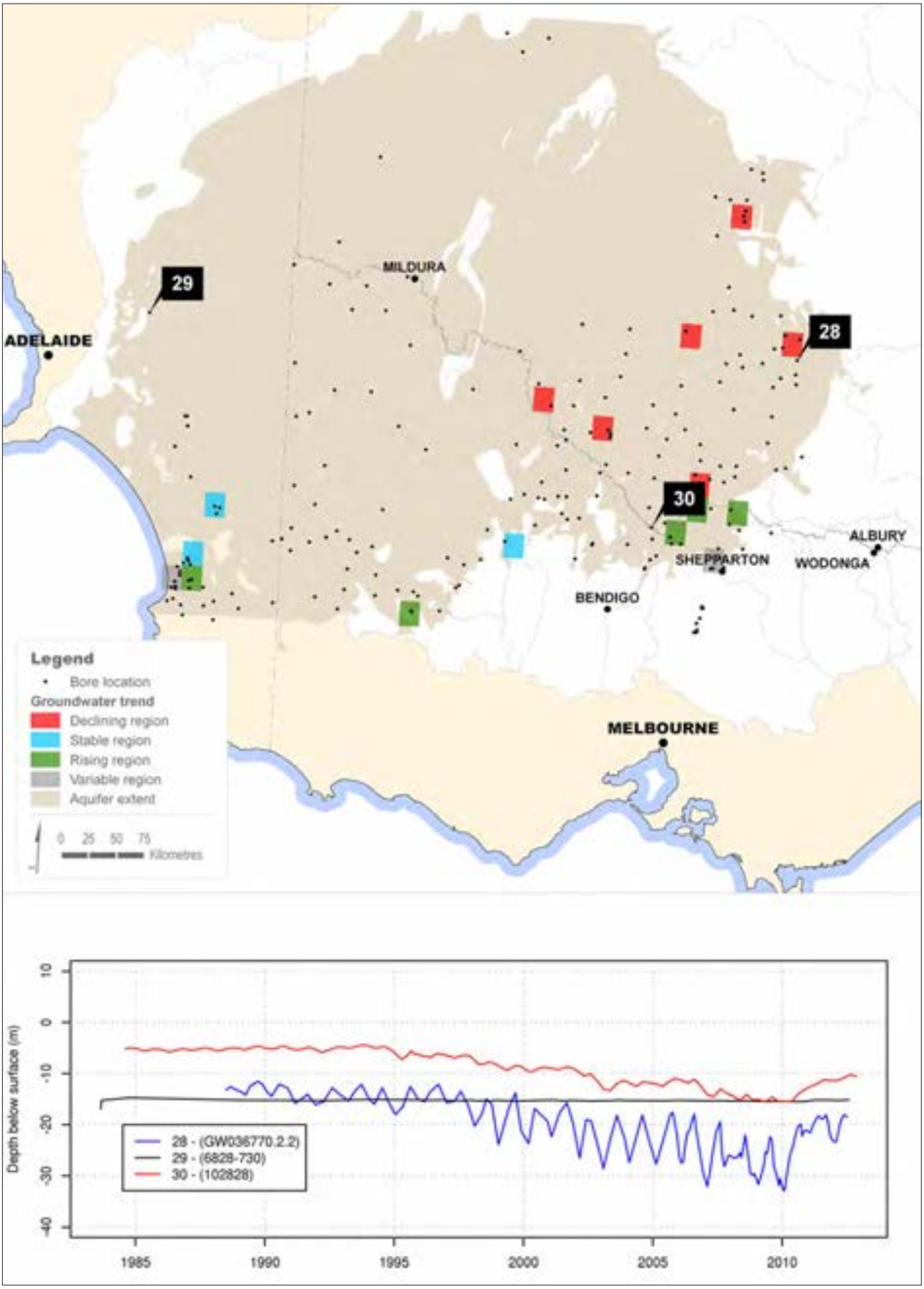


Figure 7.53 Spatial distribution of trends in groundwater levels for the Renmark aquifer for 2007–08 to 2011–12, with selected hydrographs showing groundwater level

7.6 Water for cities and towns

This section examines the urban water supply situation in the Murray–Darling Basin region in 2011–12. The large urban centres in the basin, their water supply systems, and their storage situations are briefly described. The main urbanised areas, Canberra and Queanbeyan, are addressed in more detail and the history of water restrictions over recent years is discussed. A breakdown is provided for water obtained for and delivered to Canberra and Queanbeyan.

7.6.1 Urban centres

Located in the Murrumbidgee River basin in the Australian Capital Territory, Canberra, is the largest city in the region; however, with a population of 356,000 people it ranks only seventh in terms of Australia's major cities.

The major urban centres of the region (those with populations over 25,000 people) are summarised in Table 7.4. This table provides information on the population, surrounding river basin and significant water sources for each of the major urban centres in the region.

The region, often referred to as 'Australia's food bowl', supports a significant percentage of the country's food and fibre production. As such it is home to a number of Australia largest inland centres and cities, including Tamworth, Dubbo, Wagga Wagga and Albury in New South Wales and Mildura, Bendigo and Shepparton in Victoria. These cities, along with Canberra, are shown in Figure 7.54 together with their population ranges.

Table 7.4 Urban centres and their water supply sources

City/town	Population[1]	River basin	Major supply sources
Canberra	356,000	Murrumbidgee	Cotter, Bendora, Googong and Corin storages and Murrumbidgee River
Toowoomba	94,000	Condamine–Culgoa	Cooby Creek, Cressbrook and Perseverance storages
Bendigo	83,000	Loddon	Lake Eppalock and Malmsbury and upper Coliban storages
Albury–Wodonga	77,000	Murray–Riverina and Kiewa	River Murray
Wagga Wagga	47,000	Murrumbidgee	Murrumbidgee River and groundwater
Shepparton–Mooroopna	43,000	Goulburn–Broken	Goulburn and Broken rivers
Queanbeyan	36,000	Murrumbidgee	Cotter, Bendora, Googong and Corin storages and Murrumbidgee River
Tamworth	36,000	Namoi	Chaffey storage
Orange	35,000	Macquarie–Bogan	Suma Park and Spring Creek storages
Dubbo	32,000	Macquarie–Bogan	Macquarie River and groundwater
Mildura–Buronga	33,400	Macquarie–Bogan	Chifley and Winburndale storages
Bathurst	31,000	Macquarie–Bogan	Chifley and Winburndale storages

[1] Australian Bureau of Statistics (2011b)

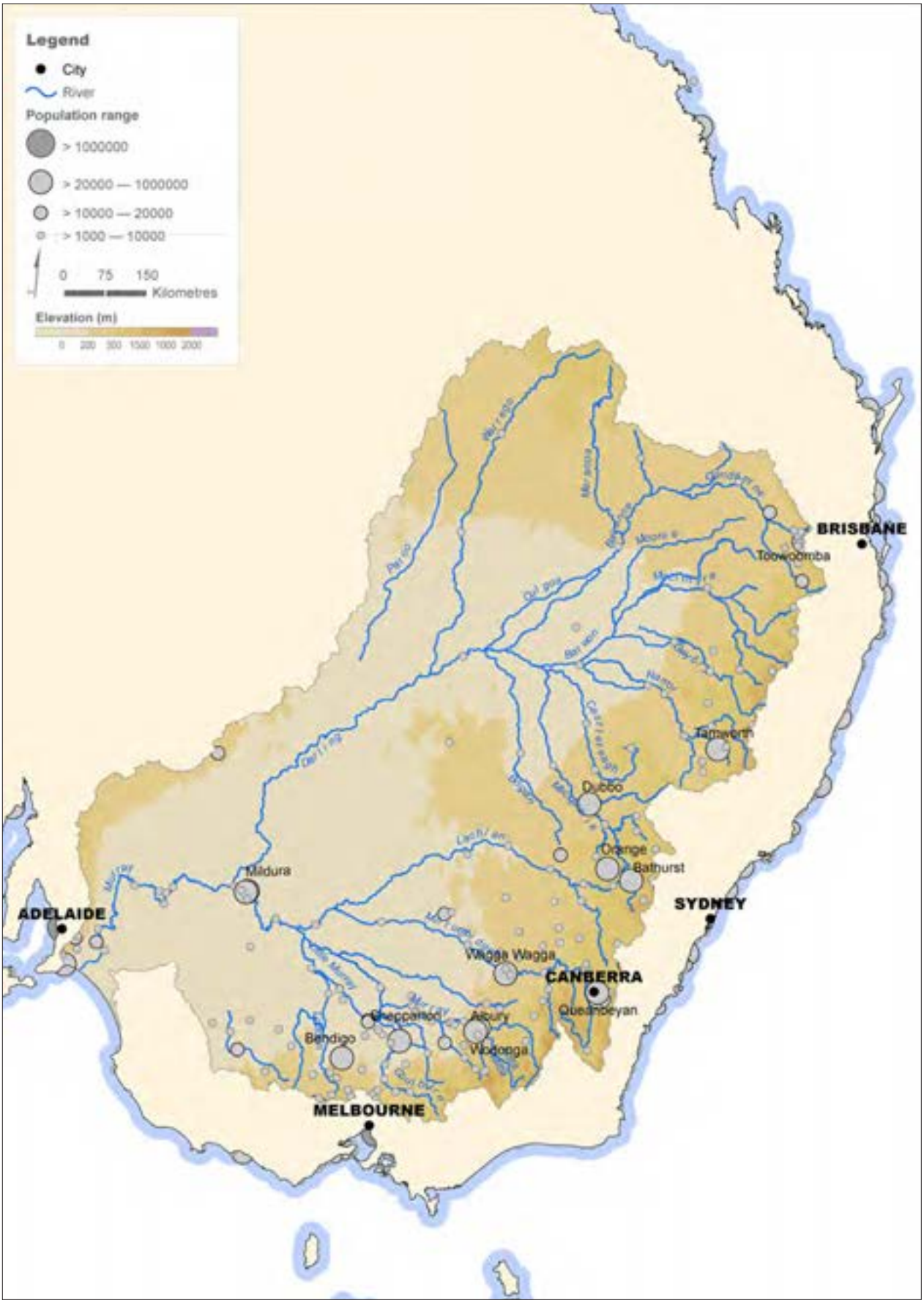


Figure 7.54 Population range for urban centres in the Murray–Darling Basin region

7.6.2 Sources of water supply

The urban cities and towns of the region draw heavily on surface water to meet their water supply needs. This is drawn from the storages located throughout the region (see Figure 7.55). In some cases water supplies are taken by direct river extractions fed from upstream storage releases.

The region has in excess of 70 major public surface water storages, representing over 25% of the nation's total surface water storage capacity. While much of the water stored is used for agriculture and hydroelectricity generation, it is also used to meet the demands of urban consumption.

Significantly, water stored within the region not only meets urban demands of the cities and towns located within it but also of cities and towns in the South Australian Gulf and South East Coast (Victoria) regions.

Dartmouth, Lake Eildon and Hume are, by volume, the three largest surface water storages in the region. However, in terms of urban supply the Cotter, Corin, Bendora and Googong storages play a more significant role, supplying Canberra and the neighbouring town of Queanbeyan.

Groundwater is an important source of water in the urban centres and towns not located near one of the major rivers. Also the supply of water via long pipelines has become essential for some towns, in particular Broken Hill. Recycled water continues to grow as an important source of water supply in the region.

7.6.3 Canberra and Queanbeyan

Canberra and Queanbeyan are located 150 km inland from Australia's southeast coast and lie to the east of the Brindabella Ranges.

The water supply area is serviced by a bulk water supply and sewerage authority, ACTEW Corporation (operating as ACTEW Water), a retail utility ACTEW AGL and a local government (Queanbeyan City Council).

ACTEW Corporation is the Australian Capital Territory (ACT) Government-owned statutory body that owns and manages the Canberra water supply system. It controls surface water diversions, operates water treatment plants, maintains Canberra's reticulation system and delivers water to Queanbeyan where water supply infrastructure is managed and maintained by Queanbeyan City Council.

In conjunction with the Australian Gaslight Company (AGL) the ACTEW Water operates the retail energy and water utility ACTEW AGL which supplies urban demands and collects sewage throughout the ACT.

Supply system

Figure 7.56 illustrates the major components of the Canberra and Queanbeyan urban water supply system. The key components of the system are four water storages, two water treatment plants and five wastewater treatment plants. Water is sourced from three catchments: the Cotter River catchment, the Murrumbidgee River catchment and the Queanbeyan River catchment.

Of the four major surface water storages operated by ACTEW Water, three are located on the Cotter River (Corin, Bendora and Cotter) and a forth on the Queanbeyan River (Googong). These storages provide a total accessible capacity of just over 200 GL. At nearly 120 GL, Googong presently provides over half of the area's total storage capacity.

In addition to its surface water storages, ACTEW extracts water from the Murrumbidgee River. The Murrumbidgee pump station facilitates the transfer extraction of up to 100 ML per day.

Figure 7.55 Storages used for urban water supply in the Murray–Darling Basin region

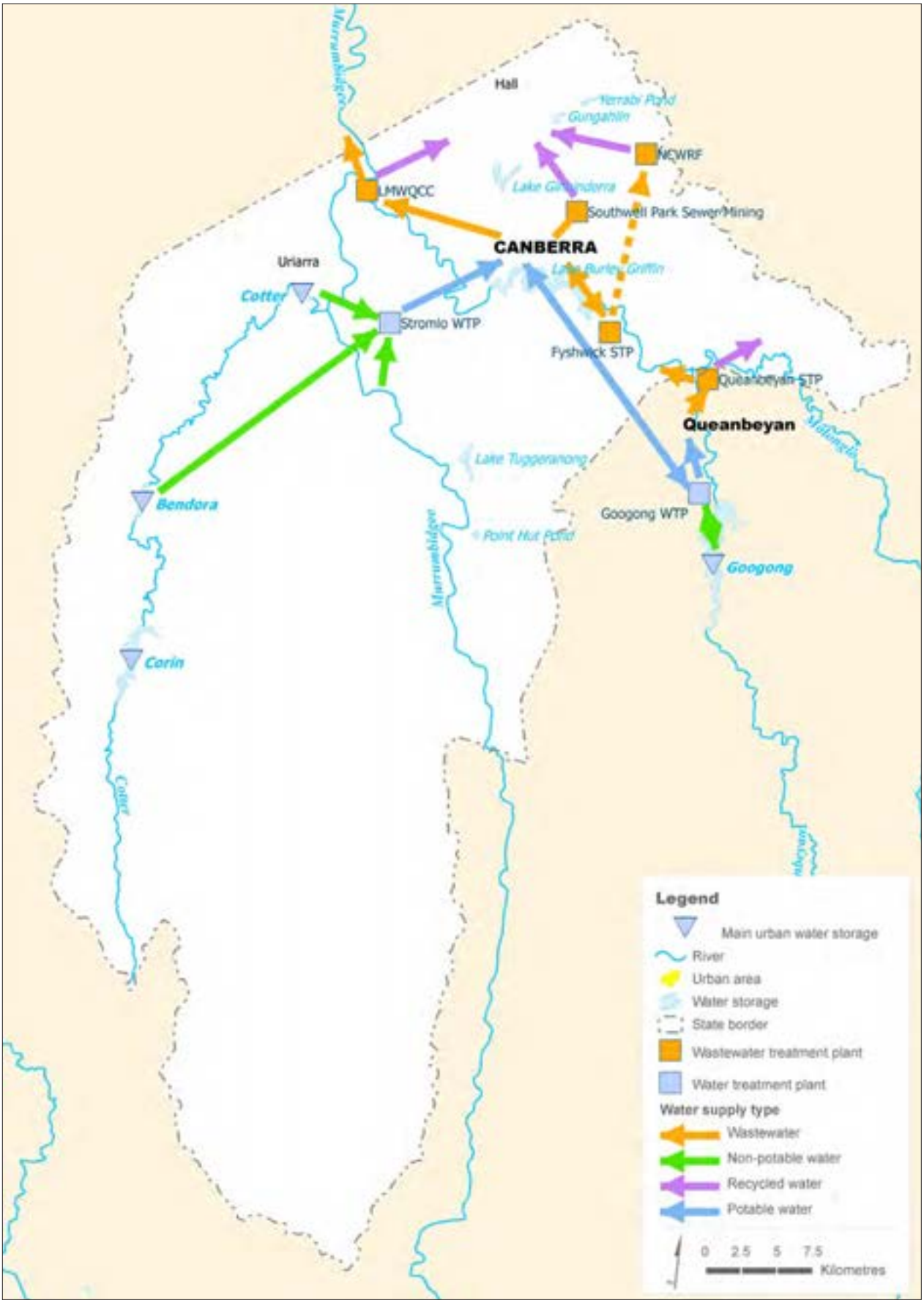


Figure 7.56 Water supply schematic for Canberra and Queanbeyan

Storage volumes

Figure 7.57 presents the total accessible volume held in Corin and Googong storages over the past 32 years (July 1980 to June 2012) and clearly illustrates the impacts of the millennium drought with storages levels, particularly in Corin, reaching critically low levels in 2007–08.

A significant drawdown of Googong can be observed in late 2003–04 and is in part explained by a need to compensate for the decreased inflows and declining storages volumes in the Cotter River system.

A shift in climatic conditions in 2009 and a series of wetter years (including Australia's wettest two-year period on record, 2010–2011) saw the storage levels recover from their historic lows. Continued good rainfall in the region's catchments has seen storage levels maintained at or near capacity throughout 2011–12.

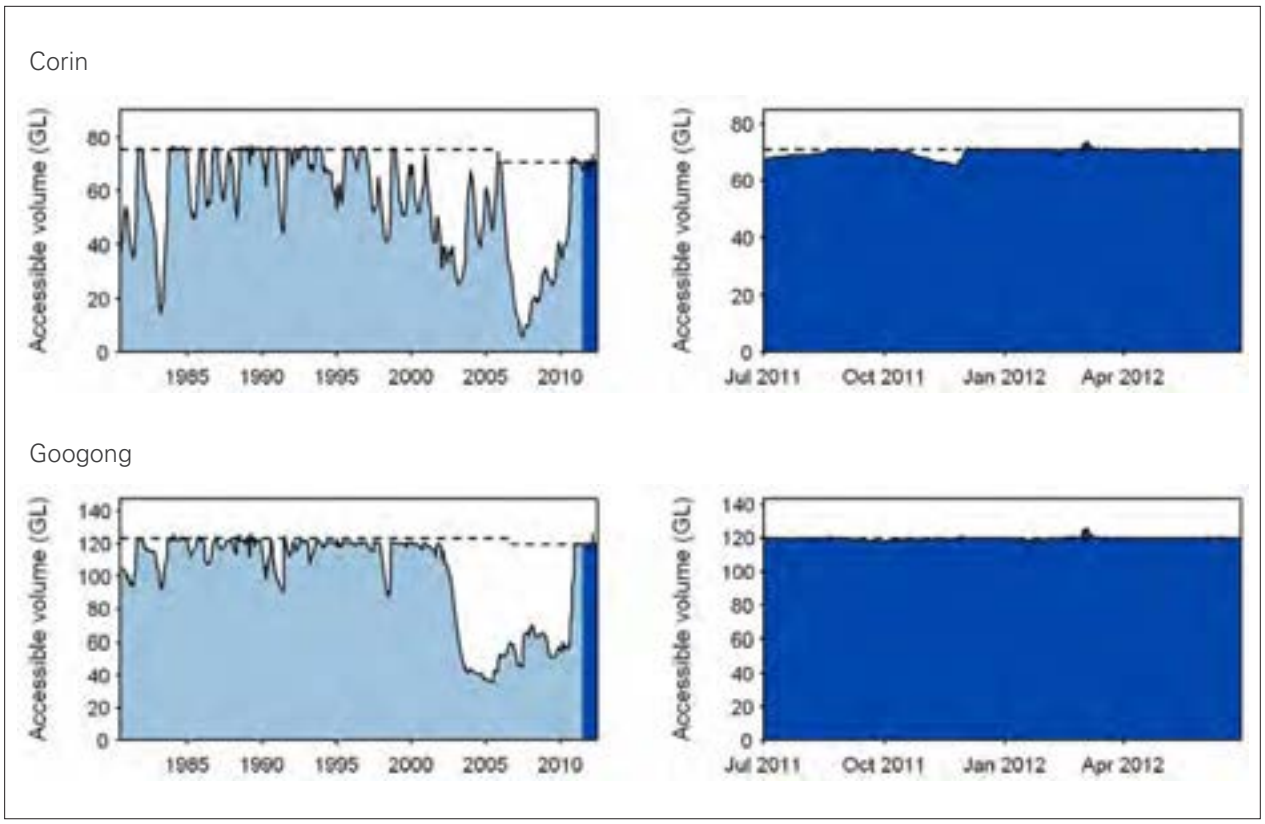


Figure 7.57 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Corin and Googong storages, as well as total accessible storage capacity (dashed line)

Water restrictions

ACTEW Water manages decisions about water restrictions for Canberra with Queanbeyan City Council applying the same decisions for Queanbeyan residents. Restrictions imposed in Canberra and Queanbeyan from 1999–2012 are shown against combined storage levels in Figure 7.58. The different stages of the restrictions are defined in the Utilities (Water Conservation) Regulation 2006 under the *Utilities Act 2000* (ACT).

Until November 2002, Canberra had not experienced water restrictions since 1969. Voluntary Stage 1 water restrictions were introduced in November 2002 but were quickly replaced by mandatory Stage 1 water restrictions when storage levels dropped below 55% accessible capacity.

Stage 3 water restrictions ware introduced in October 2003 and Permanent Water Conservation Measures were introduced in March 2006.

Stage 2 water restrictions were introduced in November 2006 due to very low storage inflows. They were quickly moved to Stage 3 restrictions in December 2006 as warm and dry weather conditions persisted. Stage 3 water restrictions continued until August 2010 and were in Stage 2 until October 2010. Due to higher water levels in dams, permanent water conservation measures were introduced in November 2010 and have continued since then.

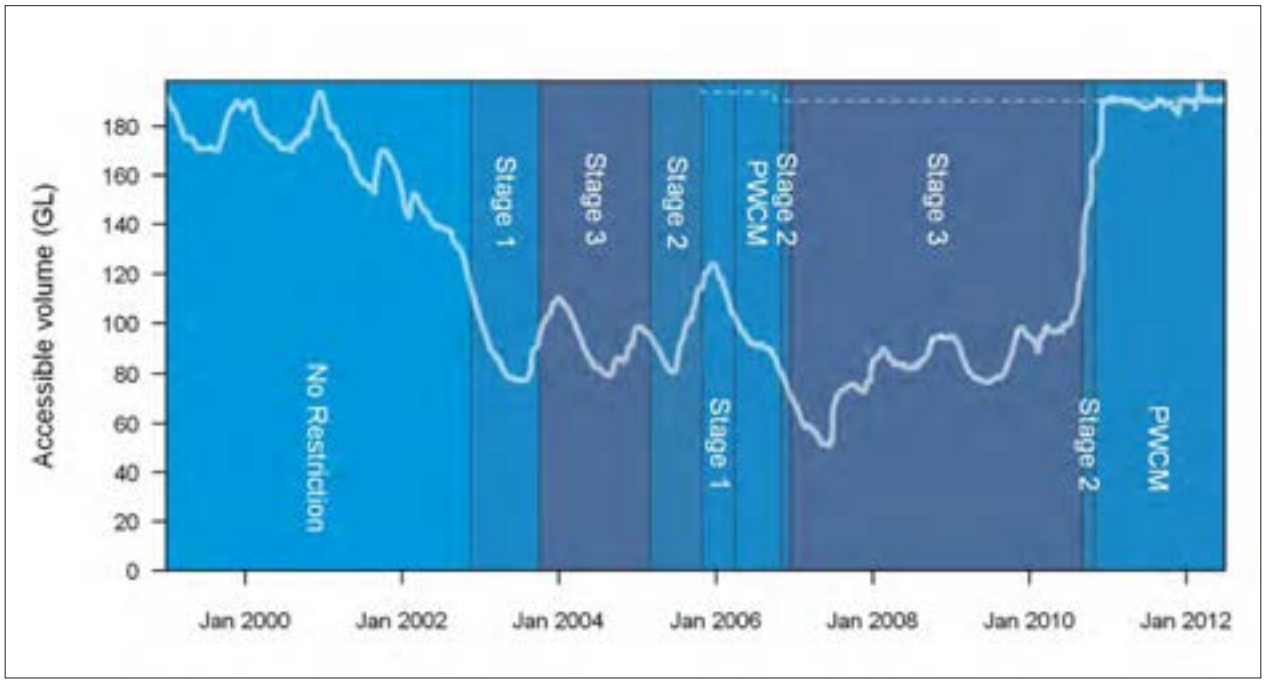


Figure 7.58 Urban water restriction levels for Canberra and Queanbeyan since 1999 shown against the combined accessible water volume of Googong and Corin storages

Sources of water obtained

Water supplied to Canberra and Queanbeyan comes from surface water and recycled water. Figure 7.59 shows the total water supplied from both sources from 2005–06 to 2011–12. During this period, the maximum volume sourced for Canberra and Queanbeyan was in 2005–06. During that year, Stage 2 water restrictions were replaced with permanent water conservation measures.

During 2006–07 and 2007–08, the volume of water supplied decreased as a result of Stage 2 and Stage 3 water restrictions being introduced. Then, during the next two years, water supplied increased slightly and again dropped in following two years.

The use of recycled water increased over the period shown in Figure 7.59, being supplied primarily for commercial, municipal and industrial uses. Recycled water use was more than doubled from 2.1 GL in 2005–06 to 4.6 GL in 2011–12.

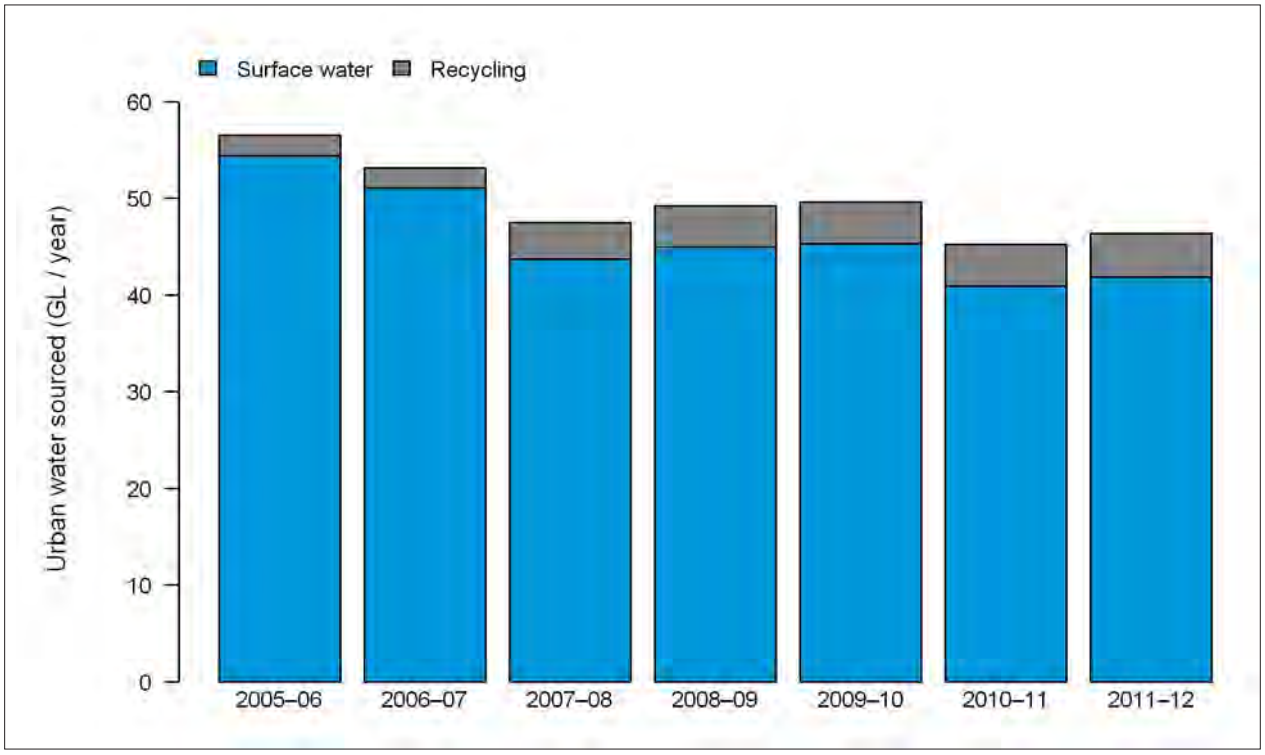


Figure 7.59 Total urban water sourced for Canberra and Queanbeyan from 2005–06 to 2011–12

Categories of water delivered

Figure 7.60 shows the total volume of water delivered between 2005–06 and 2011–12 to residential, commercial, municipal, industrial and other customers in Canberra and Queanbeyan areas. The figure shows that water consumption dropped over the seven-year period, despite a steady population growth.

The consumption pattern is a response to the water restrictions outlined above. When restrictions were eased and replaced by Permanent Water Conservation Measures in 2005–06, the consumption increased to 57 GL, but returned to 52 GL during 2006–07, when Stage 2 followed by Stage 3 water restrictions were introduced. During the next five-year period, the consumption was up and down due to various restriction levels and a likely change in water use habits. Residential water consumption was approximately 66%; commercial, municipal and industrial sector use was approximately 26%; and the remaining water was supplied for other uses.

Canberra and Queanbeyan's per capita residential water use fluctuated between 202 litres/person/day (L/p/d) and 276 L/p/d during this period.

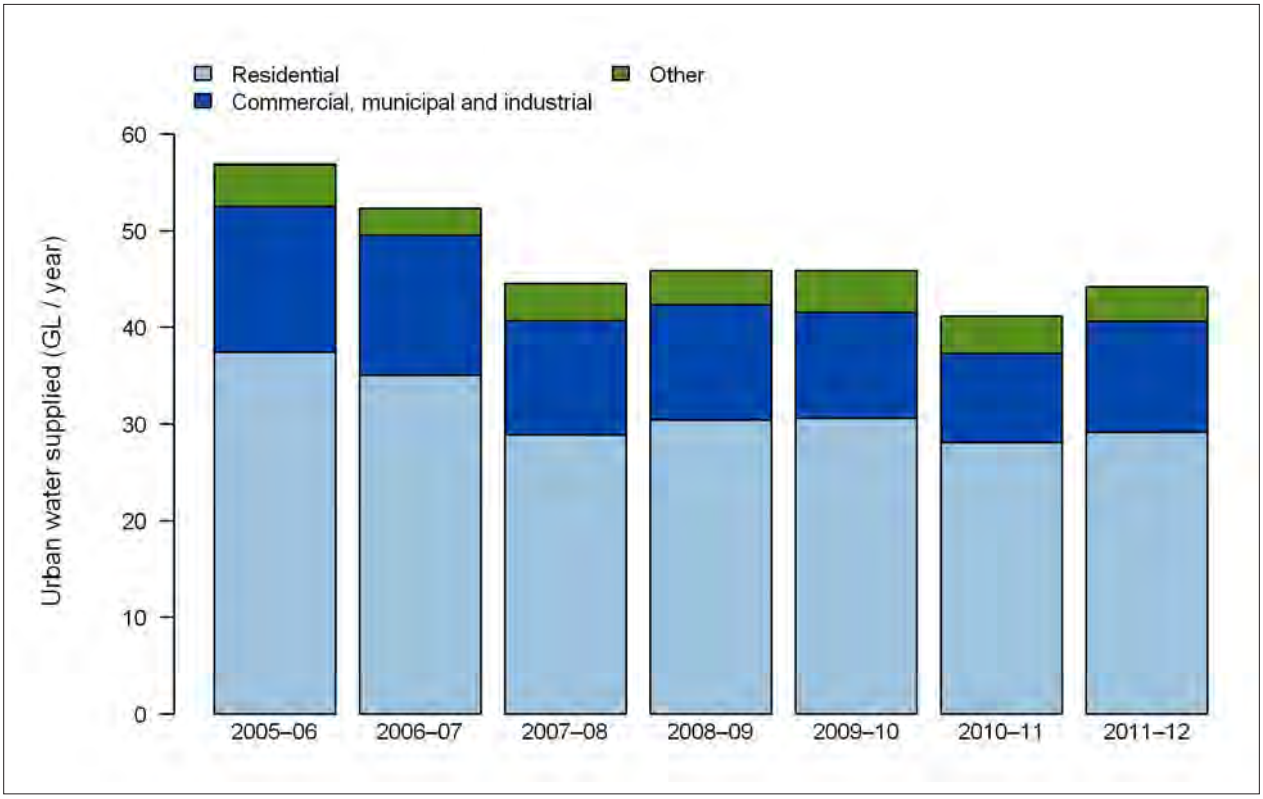


Figure 7.60 Total urban water supplied to Canberra and Queanbeyan from 2005–06 to 2011–12

7.7 Water for agriculture

This section describes the water situation for agriculture in the Murray–Darling Basin region in 2011–12. Soil moisture conditions are presented and important irrigation areas are identified. The Murrumbidgee, Coleambally and Murray irrigation areas are described in more detail and information is provided regarding surface water storage and groundwater.

7.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 km x 5 km grid cell, they are not suitable to compare with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to those of the 1911–2012 period, expressed in decile rankings.

Soil moisture for the majority of the Murray–Darling Basin region was above or very much above average during 2011–12 (Figure 7.61). This is explained by the high rainfall that occurred in the region that was above the 90th percentile for five consecutive months of the year.

This, combined with wet antecedent moisture conditions in the soil, resulted in very much above average soil moisture throughout the year, shown by monthly decile ranking in Figure 7.62. The prevalent wet conditions in the soil provided favourable farming opportunities in the region and reduced the requirement for irrigation.

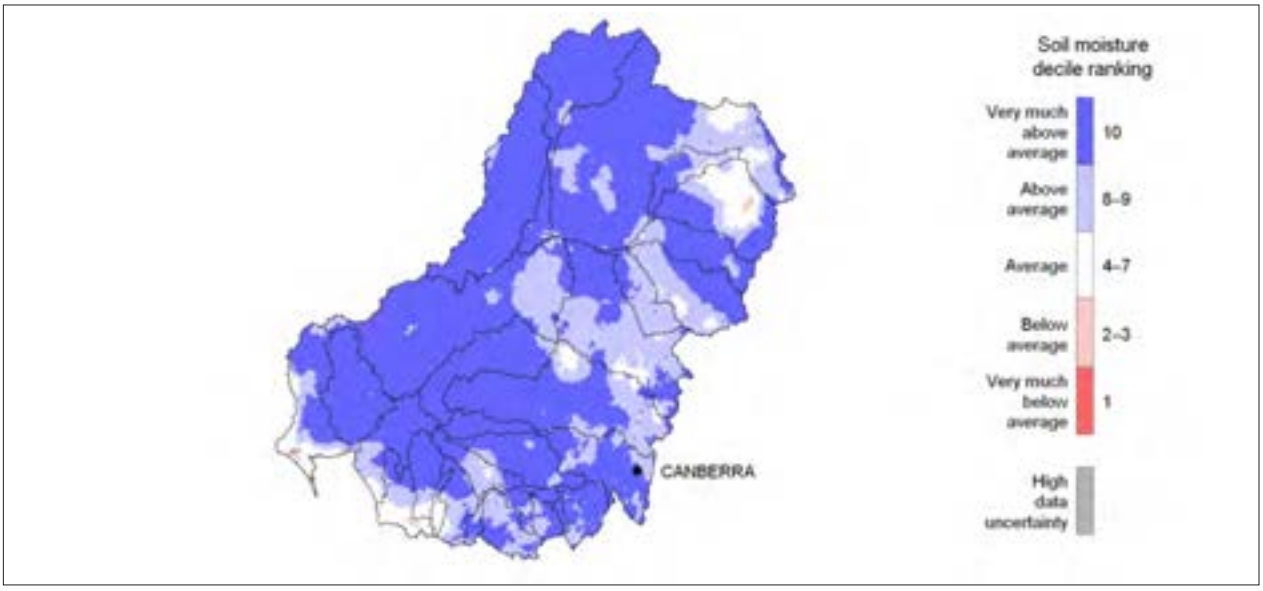


Figure 7.61 Deciles rankings of annual average soil moisture for 2011–12 with respect to the 1911–2012 period for the Murray–Darling Basin region

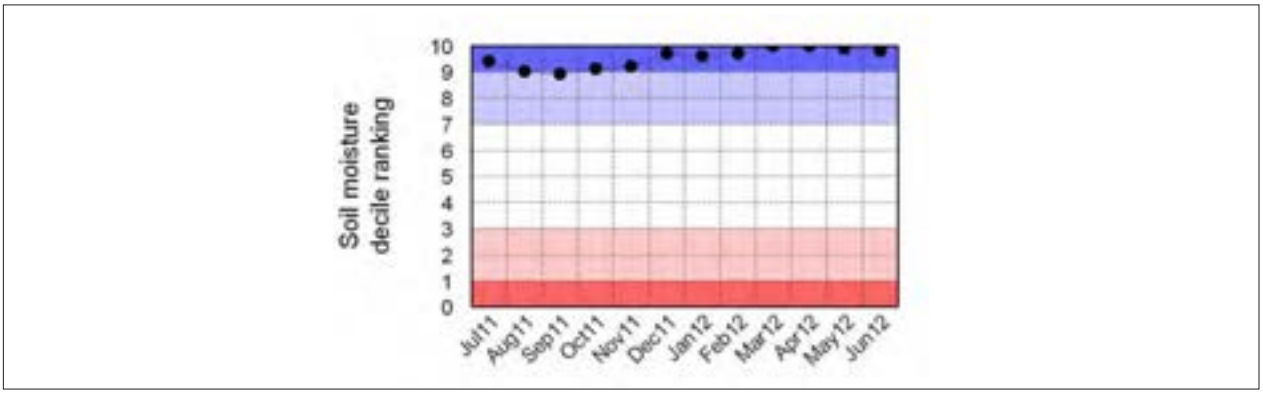


Figure 7.62 Decile ranking of the monthly soil moisture conditions during the 2011–12 period with respect to the 1911–2012 period in the Murray–Darling Basin region

7.7.2 Irrigation water

A comparison of annual irrigation water use in various natural resource management areas across the Murray–Darling Basin region from 2005–06 to 2010–11 and for 2011–12 only, is shown in Figure 7.63 and Figure 7.64, respectively. The graphs indicate that the water use for 2005–06 to 2010–11 was highest in the Murrumbidgee River basin.

Water resource conditions and use in the Coleambally and Murrumbidgee irrigation areas in the Murrumbidgee River basin are considered in more detail in the following sections

7.7.3 Irrigation areas

Pasture, for dryland sheep and cattle production, accounts for 75% of the land area of the Murray–Darling Basin region. The region produces one-third of Australian food supply. About 65% of all irrigated agriculture takes place in the region. This contributes $4.4 billion (or about 38%) to the total gross value of irrigated agricultural production in Australia (ABS 2011a). Prolonged periods of drought and expansion of irrigated agriculture in the region have resulted in the increase in groundwater use.

The largest irrigation areas in the region are located in the Murrumbidgee, Murray, Lachlan, Goulburn, Broken, Loddon and Lower Murray river basins in the south of the region, and the Condamine, Border, Gwydir, Namoi and Macquarie river basins to the north of the region (Figure 7.65).

The Murrumbidgee, Coleambally and Murray irrigation areas are described in more detail in subsections 7.7.5–7.7.7.

7.7.4 Murray Irrigation Area

The Murray Irrigation Area extends from Lake Mulwala in the east to Swan Hill in the west and is composed of Berriquin, Denimein, Deniboota and Wakool districts with a total area of 750,000 ha (Figure 7.65).

Two off-takes from the Murray flow network supply water to the 2,400 landholdings of the area. These are the Mulwala Canal off-take at Lake Mulwala and Wakool Canal off-take upstream of Stevens Weir on Edward River. The Mulwala Canal extends westward and has a capacity of up to 10 GL/day (Figure 7.65).

Water is returned back to the river system through five escapes at various points: the Edward River, Perricoota, Finley, Wakool River and Yallakool Creek escapes.

Water is provided to Murray Irrigation Limited which has a bulk water entitlement of about 1,500 GL. The typical annual water use is about 850 GL.

In 2011–12, 902 GL of water was delivered to irrigators. This was more than double the amount delivered in 2010–11 and more than five times greater than that in 2009–10. The company has reported delivery losses of 176 GL (Murray Irrigation Ltd 2012). The irrigators in the area also used 470 GL of carry-over water. Rice-cropping was the major water user in the area.

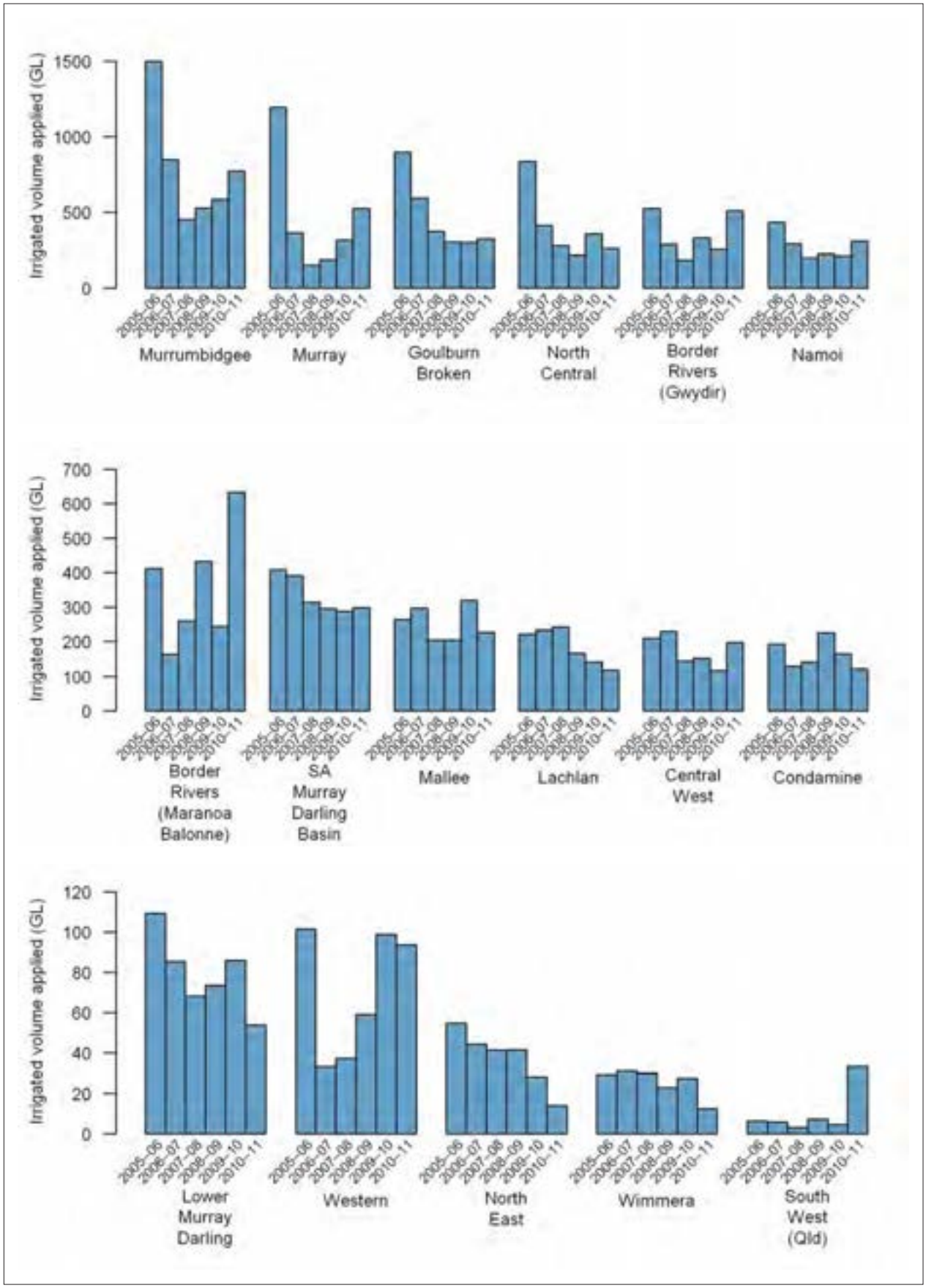


Figure 7.63 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the Murray–Darling Basin region (ABS: 2006–2010; 2011a)

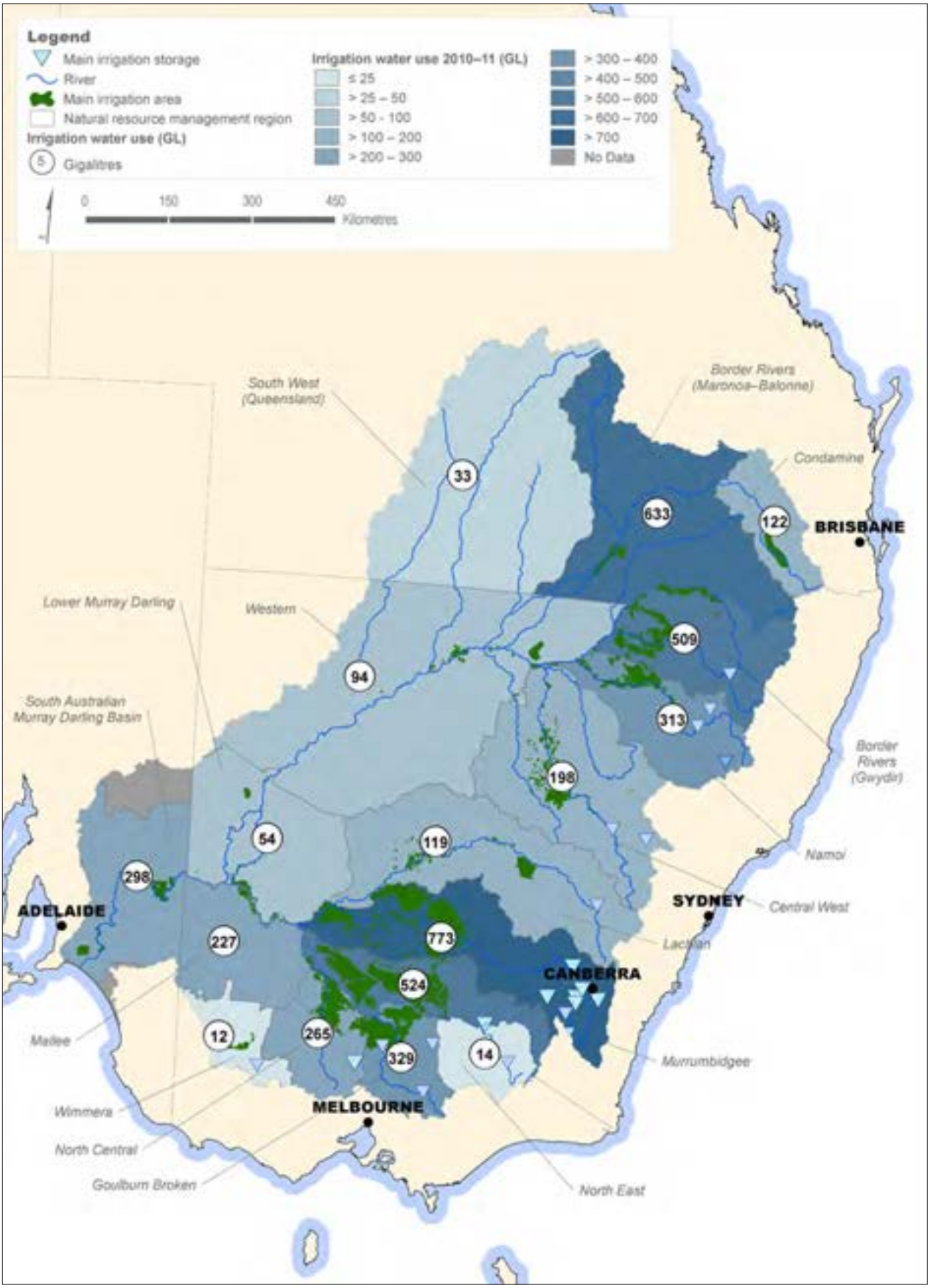


Figure 7.64 Annual irrigation water use per natural resource management region for 2010–11 (ABS 2011a)

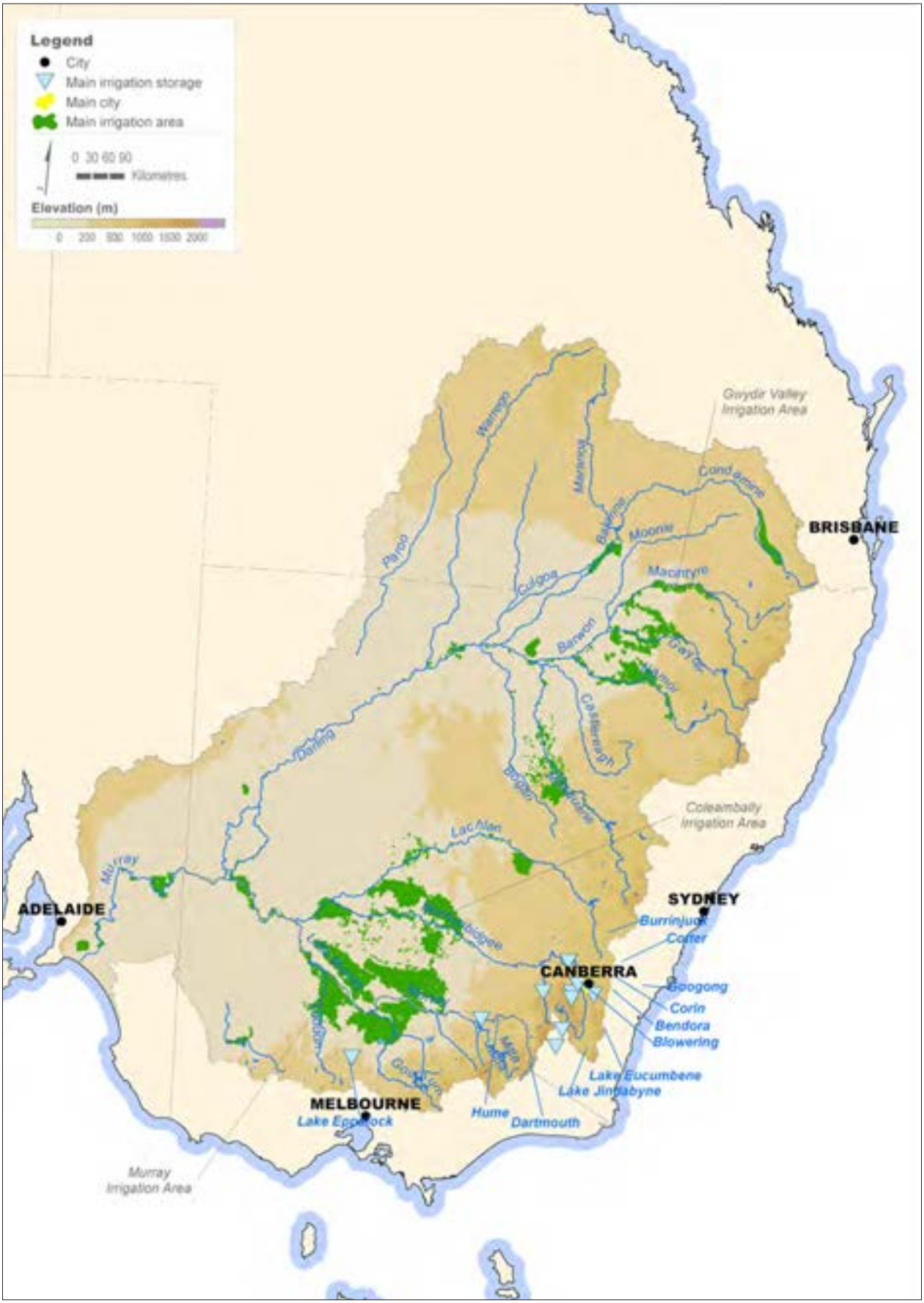


Figure 7.65 Irrigation areas in the Murray–Darling Basin region

7.7.5 Murrumbidgee River basin

The Murrumbidgee River basin is an 84,000 km^2 area in the Murray–Darling Basin region with a diverse climate and distinct physical characteristics. About 17% of the area is covered by native vegetation. Land use varies from sheep and cattle grazing, conservation reserves and residential areas in the upper catchment to irrigated agriculture, horticulture, dryland cropping, grazing and forestry in the mid to lower areas of the catchment.

The Murrumbidgee River basin uses over 22% of the total surface water diverted for irrigation and urban use in the region. Over 24% of the groundwater use in the region occurs in the Murrumbidgee River basin (Murrumbidgee Catchment Management Authority 2010).

Water sharing plans define water-sharing arrangements between the environment and water users in the regulated Murrumbidgee River basin. There are a number of categories of water licences that are assigned different priorities based on the intended use of water (New South Wales Office of Water 2011). The majority of the water entitlements held within the Murrumbidgee River basin are general security entitlements. Priority is given to high security entitlements primarily used for horticultural and grape production.

An 'Available Water Determination' is set at the start of each financial year in terms of megalitres per share. The total number of shares held by a licence holder multiplied by the ML/share announced gives the volume of water credited to that licensee's account, in addition to carry-over provisions.

Burrinjuck Dam is on the Murrumbidgee River and has a storage capacity of 1,000 GL. The Yass and Goodradigbee rivers flow into this dam. It is the headwater storage for the Murrumbidgee irrigation area. Built in 1928, the dam has undergone several remedial and upgrades, the last one being after the 1974 floods.

Blowering Dam on the Tumut River, which was completed in 1969, has a storage capacity of 1,600 GL. It is used for hydroelectric power generation in addition to the water being used for irrigation in the Murrumbidgee and Coleambally irrigation areas.

7.7.6 Murrumbidgee Irrigation Area

The Murrumbidgee Irrigation Area is located north of the Murrumbidgee River, between Leeton and Griffith (Figure 7.66). It occupies an area of approximately 660,000 ha (Murrumbidgee Irrigation Ltd 2011). It covers around 120,000 ha of intensive irrigation and 3,300 landholdings. The region contributes over $2.5 billion annually to the Australian economy.

Water is sourced from the Murrumbidgee River which is regulated from Burrinjuck and Blowering dams. The area is fed by two canals, the Main Canal and the Sturt Canal, diverting water from the Murrumbidgee River. The Main Canal receives water diverted at Berembed Weir to serve the Yanco, Leeton and Griffith areas and can accommodate flows of up to 6.5 GL/day. The Sturt Canal receives water diverted at Gogeldrie Weir to supply the Whitton and Benerembah areas and can accommodate flows of up to 1.7 GL/day.

There are also four drains returning water to the Murrumbidgee River on the lower eastern part of the districts, but the majority of water is being used and recirculated within the irrigation districts.

Most of the irrigation is carried out on the eastern side of the irrigation area through interconnection with the Mirrool Creek, which runs through the centre of the area. The excess water is stored in the Barren Box Swamp.

In 2011–12, a total of 855 GL was diverted for irrigation in the Murrumbidgee irrigation area, of which 753 GL was delivered to the irrigators. The area under irrigation increased by 12% compared with 2010–11 year. The water diversion and delivery also increased by 50% (Murrumbidgee Irrigation Ltd 2012).

Surface water storage inflows

Persistent rainfall during November 2011–March 2012 led to high streamflow generation, which is shown by the average to very much above above average flow in the rivers in the region (Figure 7.23). Major floods occurred in Tumut and Murrumbidgee rivers during March 2012 and the river monitoring sites upstream of Blowering and Burrinjuck registered flows which were very much above average (Figure 7.67).

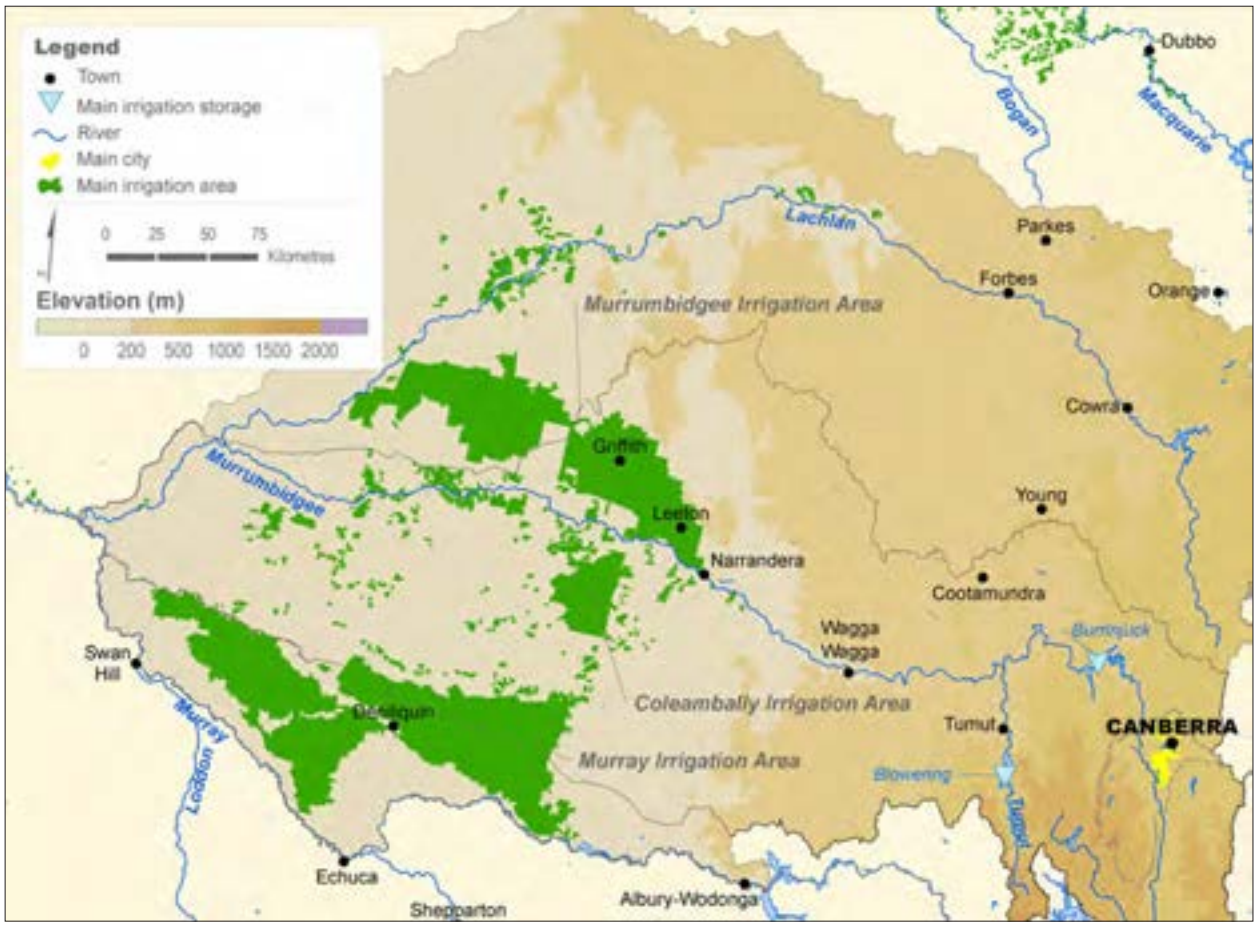


Figure 7.66 Murray, Coleambally and Murrumbidgee irrigation areas

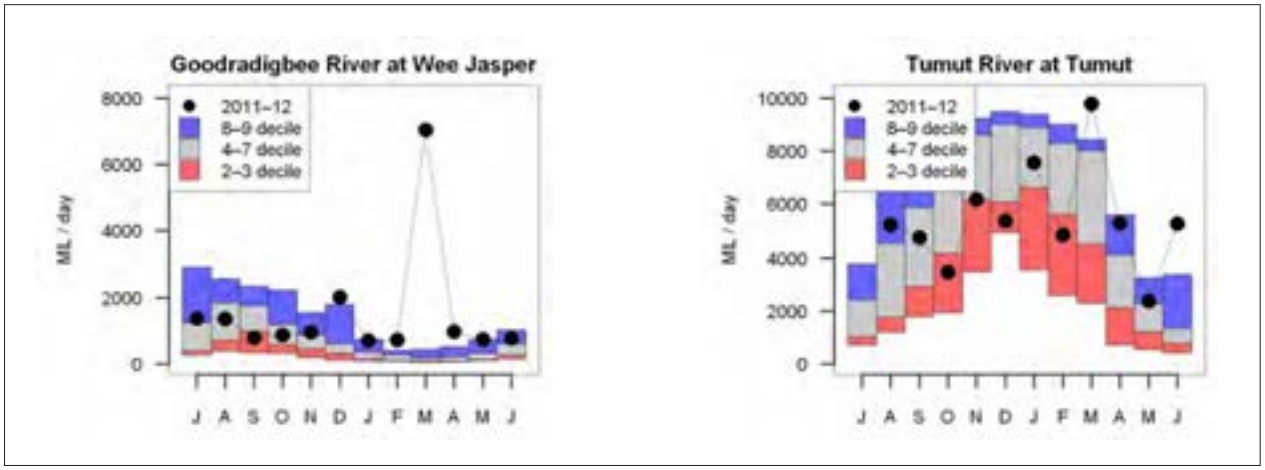


Figure 7.67 Monthly flows of 2012 compared with its 1980–2012 deciles rankings at monitoring sites representative for inflows to the Blowering (Tumut River) and Burrinjuck (Goodradigbee River) storages

Surface water storage volumes

After a long drought period, water levels in the Blowering and Burrinjuck storages started to rise gradually during 2010, and maintained a close to full capacity afterwards. There was a gradual decline in the water levels at the beginning of 2012. In March 2012, increased flows to the storages, as a result of major floods in the area, caused the water volumes to rise to almost full capacity again (Figure 7.68).

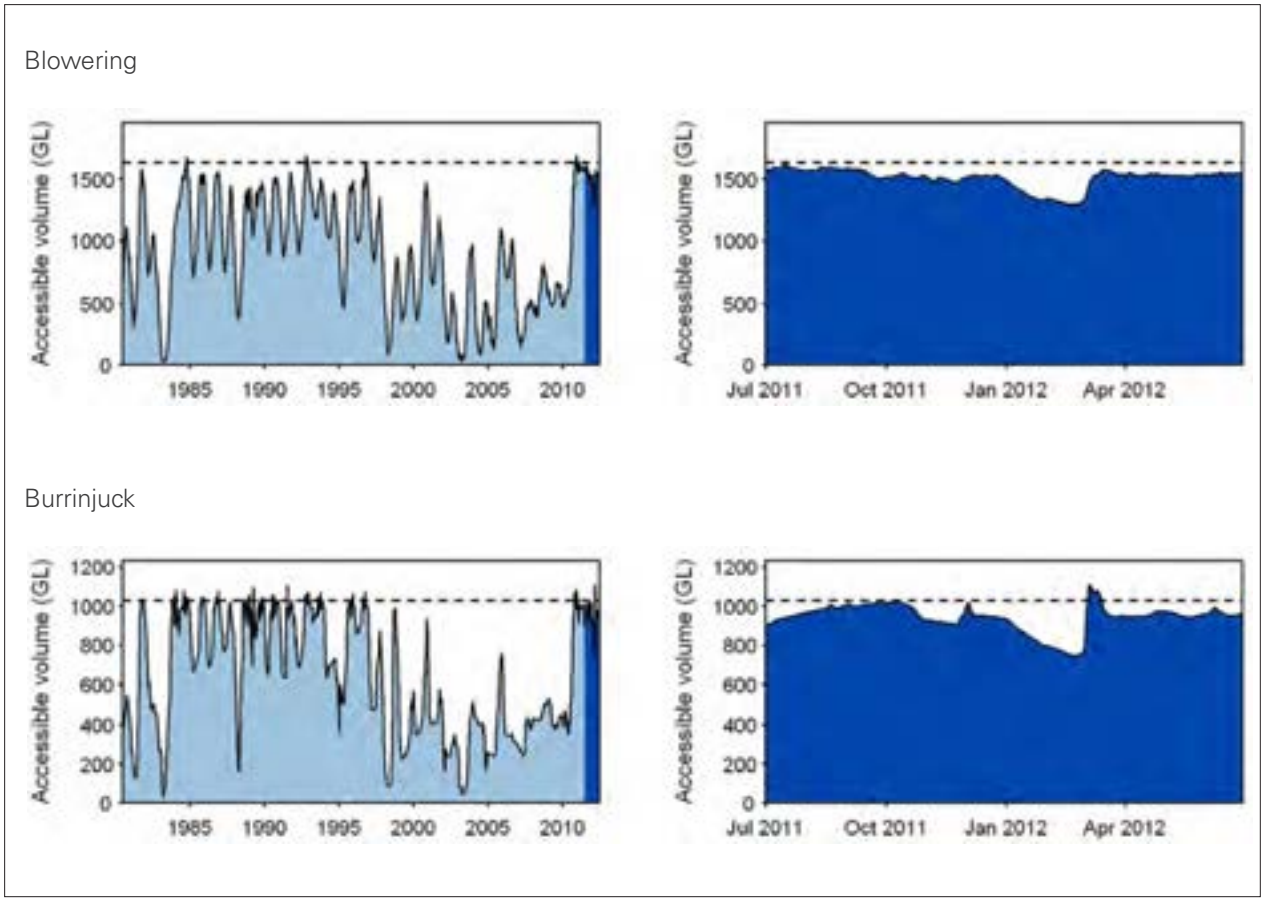


Figure 7.68 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Blowering and Burrinjuck storages, as well as total accessible storage capacity (dashed line)

7.7.7 Coleambally Irrigation Area

Coleambally Irrigation Area is located in the Riverina between Darlington Point and Jerilderie and covers more than 470,000 ha of which 79,000 ha is under intensive irrigation, 42,000 ha irrigation/dry farms and the remainder receive stock and opportunistic irrigation water.

Coleambally Irrigation Limited delivers water supply to 473 farms owned by 364 business units. It also provides town supplies to the Murrumbidgee and Jerilderie Shires. They treat and supply water to the northern and southern districts of the Coleambally Irrigation Area.

Coleambally irrigation water supply is also sourced from the Murrumbidgee River. The off-take is upstream of Gogeldrie Weir. The supply system is gravity fed through a main canal at the eastern side of the irrigation area. Flow is measured through 500 regulators at 1 km intervals in a 500 km network of supply canals. Another 700 km of channels collect the drainage water from the network and are connected to three main outfalls where environmental flow is also supplied to the River Murray.

In October 2011 Burrinjuck exceeded its storage capacity (Figure 7.68) and water was released to balance inflows. This, accompanied by heavy rainfall in the area (739 mm), maximised water allocations for 2011–12 and favoured the increase in summer crop yields, which reached the highest levels in the past five years.

In 2011–12, total water diversion into the Coleambally Irrigation Area was 427 GL out of which 39 GL was channel losses and 388 GL was delivered to irrigators. Groundwater use was 37 GL. The total irrigated crop area was 68,700 ha, of which 16,700 ha was allocated to rice production (Coleambally Irrigation Co-operative Ltd 2012).

Local hydrogeology

The Coleambally Irrigation Area provides an example of groundwater use in the Murray–Darling Basin region (Figure 7.69). In 2011–12, about 10% of the total registered water used for irrigation in the Coleambally Irrigation Area was groundwater.

The Coleambally Irrigation Area is located in the eastern part of the Murray Geological Basin and overlies the lower Murrumbidgee alluvial aquifer system that starts downstream of Narrandera and consists of unconsolidated alluvial deposits of sands, silts, clays and peat. The alluvial system is comprised of three main units: the unconfined shallow Shepparton aquifer, and the confined intermediate Calivil and deep Renmark aquifers. These last two aquifers are often in hydraulic continuity.

The lowermost Renmark aquifer consists of fluvial clays, silts and gravels overlying the basaltic bedrock. In the eastern part of the Murrumbidgee catchment, the Renmark aquifer has an average thickness of about 280 m (Lawson and Webb 1998).

Overlying the Renmark aquifer are the sands of the Calivil aquifer. They were deposited by and are thickest in the ancestral drainage channels of modern-day rivers. The Calivil aquifer varies in thickness from about 50–70 m and can extend to depths greater than 150 m. Of the three regional aquifer systems, the Calivil is the most productive.

The uppermost unit is the Shepparton aquifer, which is typically 20–60 m thick. The Shepparton aquifer comprises a series of fluvio–lacustrine clays, sands and silts. These sediments are laterally discontinuous and form a highly heterogeneous unconfined aquifer system. In the Coleambally Irrigation Area, the Shepparton aquifer can be clearly divided into two parts, the Upper (0–12 m deep) and Lower Shepparton (12–60 m deep).

Recharge and discharge to and from the shallow Shepparton aquifer occurs across the area and its heterogeneity and low overall hydraulic conductivity can inhibit lateral flow. Water movement through the deep aquifers is generally from east to west; however, groundwater flow near the production bores around Darlington Point can be quite complicated. Movement occurs under gentle gradients and is therefore very slow with estimated rates of around 7–10 m/yr (Lawson and Webb 1998). Recharge to deep aquifers occurs mainly from the Murrumbidgee River downstream of Narrandera and from vertical leakage from the Shepparton aquifer.

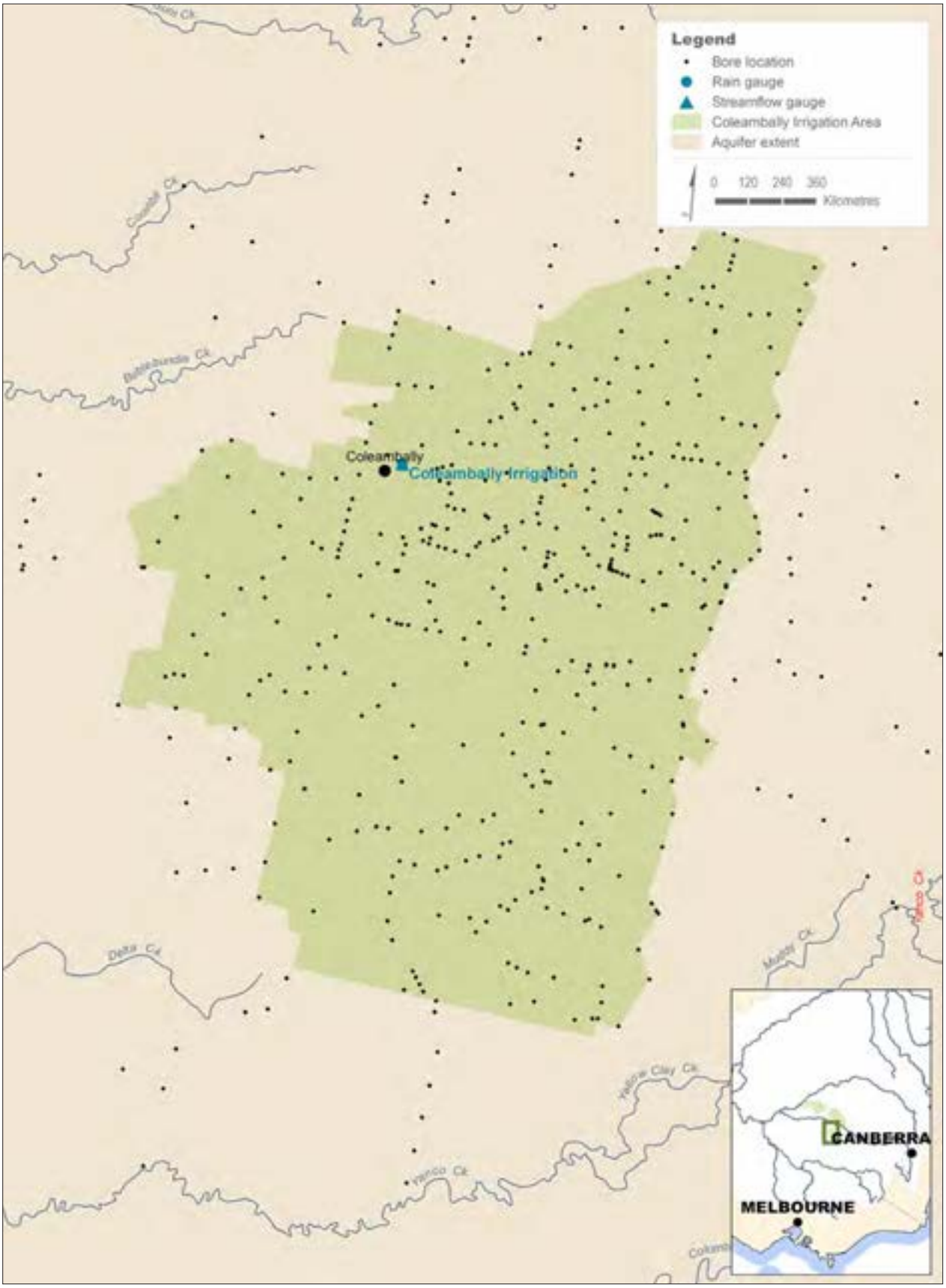


Figure 7.69 The Coleambally Irrigation Area with groundwater bore sites

Influences on shallow groundwater

Prior to irrigation, watertable levels were at depths of 15–20 m; however, due to recharge to the groundwater from inefficient irrigation practices, leaky channels and recharge from rainfall, a significant proportion of the area had watertable levels within two metres of the soil surface by the late 1990s (Coleambally Irrigation Co-operative Limited 2004). These levels have since subsided due to below average rainfall and reduced surface water allocations occurring in the last ten years; however, the recent high rainfall and widespread floods have caused a minor rise in groundwater levels.

Fluctuations in groundwater levels in the Upper Shepparton aquifer are shown in Figure 7.70. No seasonal fluctuations are visible due to the fact that only one measurement per year, in September, has been plotted for consistency with recent measurement frequency. Groundwater levels are averaged between different subregions of the Coleambally Irrigation Area: Argon, Boona, Coly and Yamma.

To investigate the drivers of the shallow groundwater level trends, fluctuations in groundwater levels are compared to the monthly cumulative rainfall residual at Coleambally Irrigation Station and to the monthly discharge of the Murrumbidgee River at Darlington Point (Figure 7.70). The locations are shown in Figure 7.69.

Periods in which the cumulative rainfall residual curve rises indicate wetter than average conditions. Periods with a falling trend indicate drier than average conditions. As shown, river discharge near the off-take for irrigation and rainfall are correlated with the observed trends in groundwater levels. Some peaks in surface water discharge and in the cumulative rainfall residual mass curve correspond to peaks in groundwater.

The most striking feature is the decline in groundwater levels from 2002 to 2010 driven by reduced irrigation and drier than average conditions corresponding to the falling trend in the rainfall cumulative residual curve (and hence less recharge). Groundwater levels have recovered since 2010 consistently with the raising trend in the rainfall cumulative residual curve. The recovery is still well below the levels pre-2002.

Groundwater level

Groundwater level measurements are an important source of information about hydrological and anthropological influences on groundwater in an area, including recharge. Figure 7.71 shows groundwater levels recorded at two regional nested sites within the Coleambally Irrigation Area reaching all three aquifers.

Groundwater level fluctuations at Bore 36040 are similar in the Calivil and Renmark aquifers, indicating that the two are hydraulically connected. Fluctuation in groundwater levels show the effect of pumping during the irrigation season and the subsequent recovery during the winter months when pumping ceased. No recent data is available for the Calivil aquifer but groundwater levels for the Renmark aquifer indicate recovery of groundwater levels since 2010. The Shepparton aquifer at this location (Bore 36040.1) seems disconnected from the deeper aquifers. No major recovery in groundwater levels for the Shepparton aquifer is visible at this location. Hydraulic gradient, and therefore groundwater flow, is downward. This may pose a risk to fresh groundwater at depth if the shallow groundwater is saline.

Groundwater levels at Bore 36372 show that the lower Shepparton aquifer is hydraulically connected to the Calivil aquifer and both are influenced by seasonal cycles of pumping and recovery. Groundwater levels in these two aquifers show a certain degree of recovery since 2010. The underlying Renmark aquifer shows strong effects of pumping for a short period at the end of 2009 and beginning of 2010 (Figure 7.71). Groundwater levels post-2010 have not yet recovered to pre-2010 levels and no further effects of pumping are visible. It appears that there is no hydraulic connection between the Remark and Calivil aquifers at this location. The hydraulic gradient between the Shepparton and Calivil aquifers is downward but the gradient decreases post 2010 as a result of increased recharge to groundwater in recent years.

Figures 7.72–7.75 show ranges of groundwater depth in Upper Shepparton, Lower Shepparton, Calivil and Renmark aquifers in the Coleambally Irrigation Area, and the ranking of 2011–12 median groundwater levels compared to annual median groundwater levels since 1990. The bores used are part of a network of bores that are monitored approximately annually by Coleambally Irrigation Co-operative Limited and regional bores seasonally monitored by the New South Wales Office of Water.

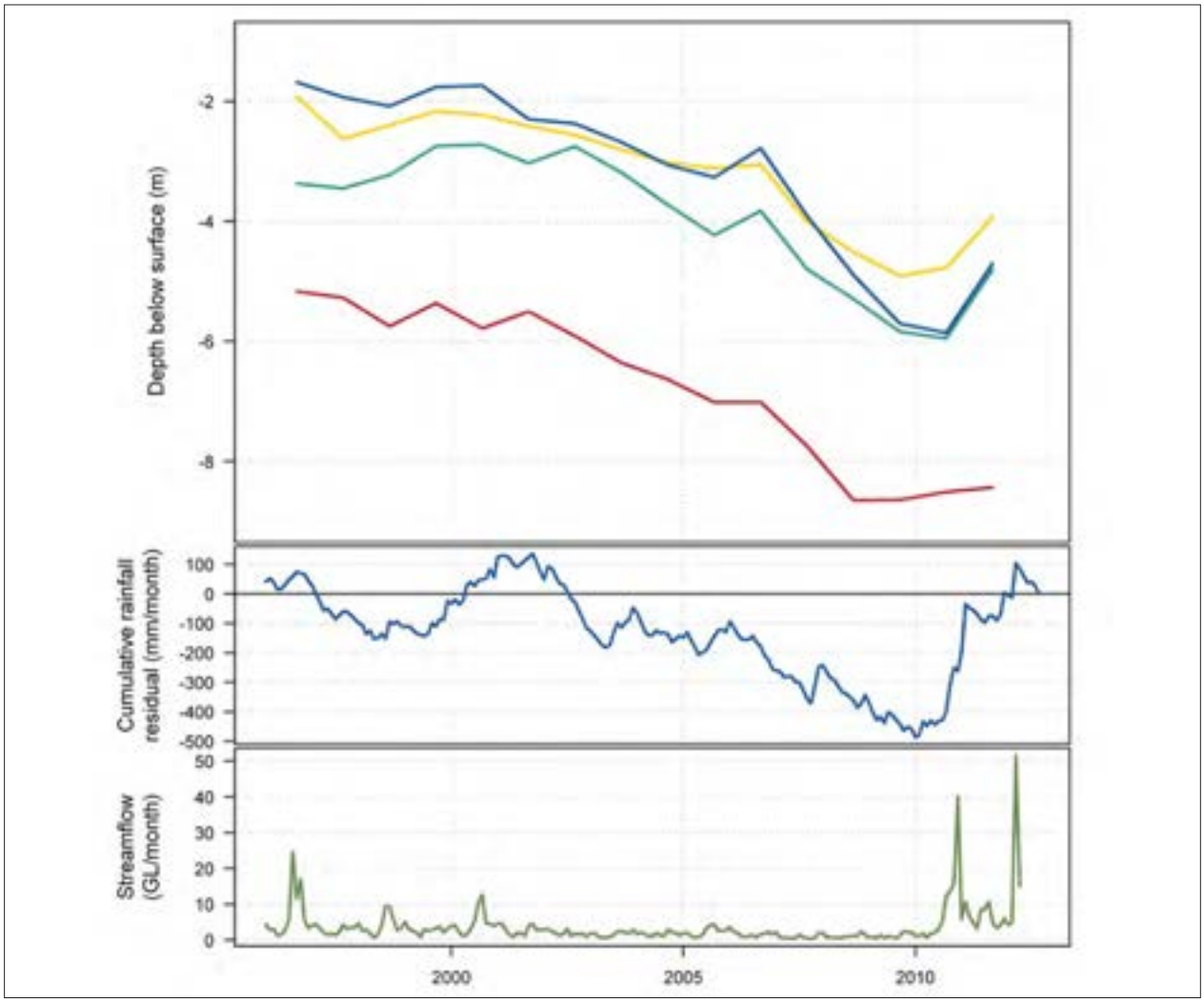


Figure 7.70 Comparison of shallow groundwater levels recorded at nested bore sites with rainfall and streamflow in Coleambally irrigation sub-areas (Coleambally Irrigation Co-operative Limited 2004, top panel: Argon (yellow), Boona (red), Coly (blue) and Yamma (green) sub-areas, middle panel: cumulative rainfall residual mass at Coleambally Irrigation Station 74249, lower panel: streamflow in Murrumbidgee River at Darlington Point)

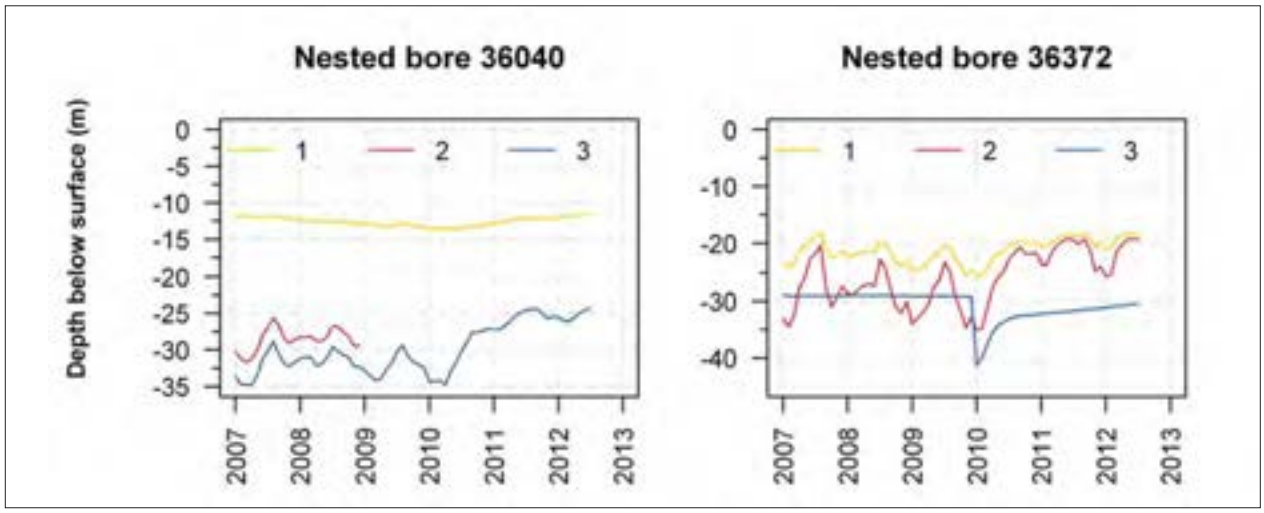


Figure 7.71 Groundwater levels between 2007 and 2012 recorded at selected nested bore sites, reaching all three aquifers: (1) Shepparton, (2) Calivil, and (3) Renmark

Groundwater levels in the Upper Shepparton and Lower Shepparton aquifers vary from deeper than 10 m in the northeast and at the margin of the irrigation area to less than 2.5 m in the southeast of the irrigation area (Figure 7.72 and Figure 7.73). Importantly, groundwater levels are mostly deeper than 2.5 m. This indicates that the risk of groundwater salinisation of the shallow watertable is low.

The figures also show that median groundwater depths in 2011–12 are mostly below the average of recorded levels since 1990 within the irrigation area. This shows that even though wetter than average conditions occurred since 2010, recovery of groundwater levels has been small and groundwater levels are on average the deepest they have been in the past 21 years.

The sparse groundwater level data available for the regional Calivil and Renmark aquifers show that levels are all deeper than 10 m and median groundwater depths in 2011–12 are mostly at the average of recorded levels since 1990 (Figure 7.74 and Figure 7.75)

Groundwater quality overview

During the 1960s, irrigation began in the Coleambally Irrigation Area with water diverted from the Murrumbidgee River upstream of Gogeldrie Weir near Darlington Point. Irrigated agriculture often leads to recharge of regional groundwater systems at rates greater than those the systems can absorb, resulting in the development of shallow watertable and causing salinity and waterlogging.

Salinity in the Calivil and Renmark aquifers is relatively low and generally increases from east near Narrandera to west around Hay along the Murrumbidgee River. In contrast, the shallow Shepparton aquifer is often very saline, especially under irrigation areas.

Irrigation induced salinity is a well known problem in many mature irrigation areas across Australia and internationally. The consequences of salinity in irrigation areas include production losses, increased production costs and damage to environmental and infrastructure assets in the region. The Coleambally Irrigation Area is experiencing such salinity problems; however, no time-series data on groundwater salinity are currently available for further analysis.

A groundwater site in the West Wimmera area, Victoria | Kate Morrison

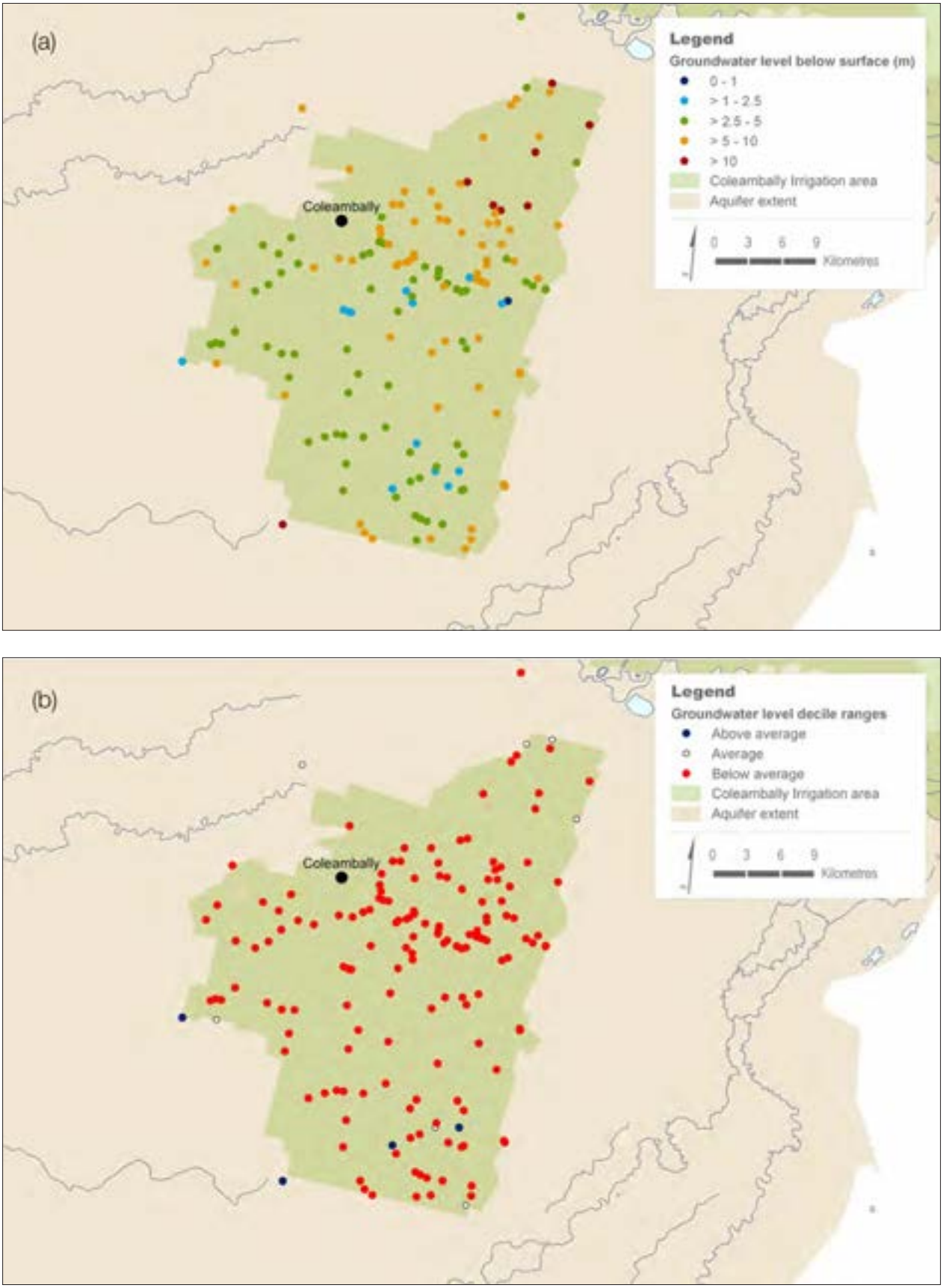


Figure 7.72 Median groundwater depth for the upper Shepparton aquifer, (a) in the Coleambally Irrigation Area in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2011 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

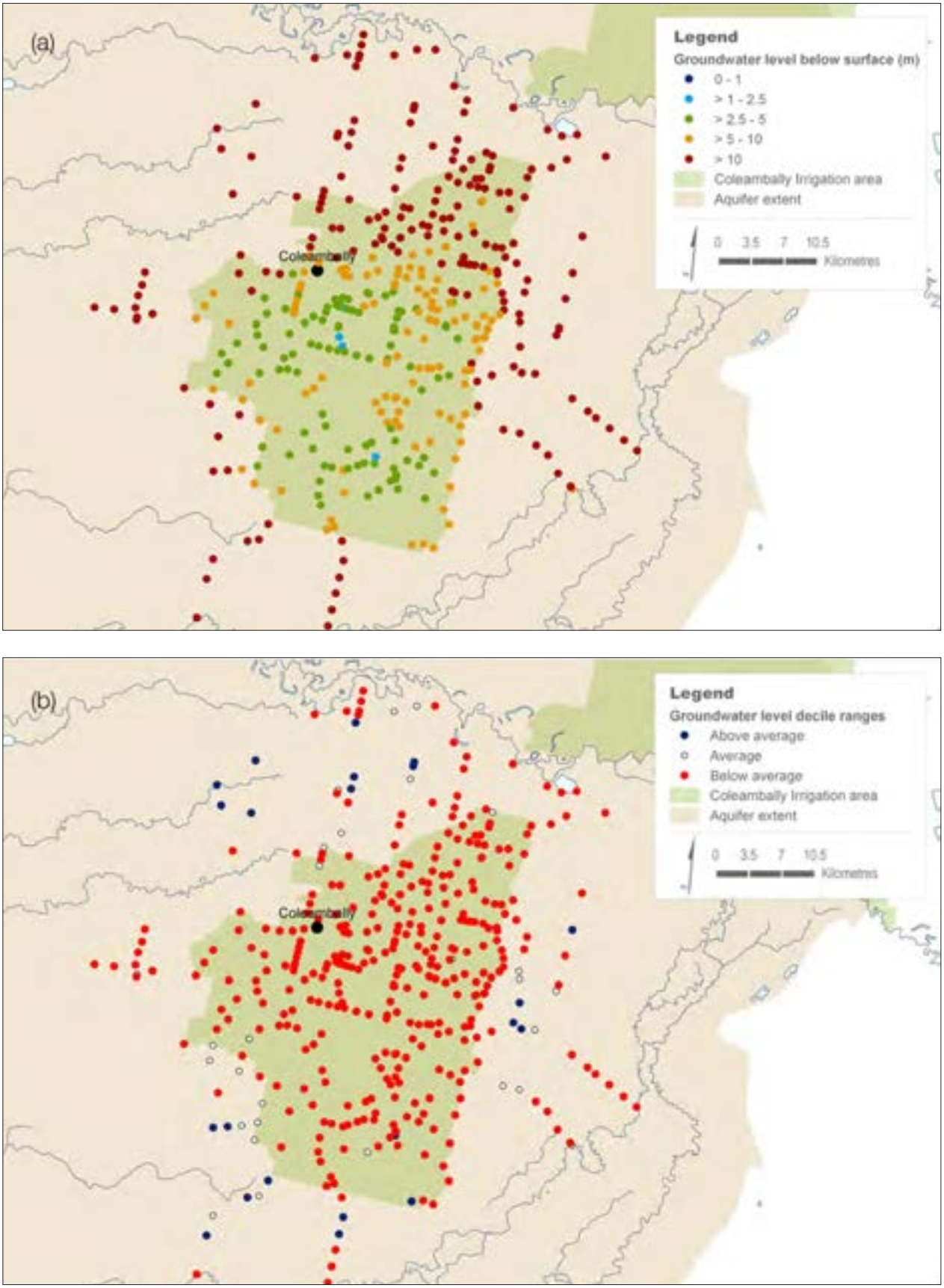


Figure 7.73 Median groundwater depth for the lower Shepparton aquifer (a) in the Coleambally Irrigation Area in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2011 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

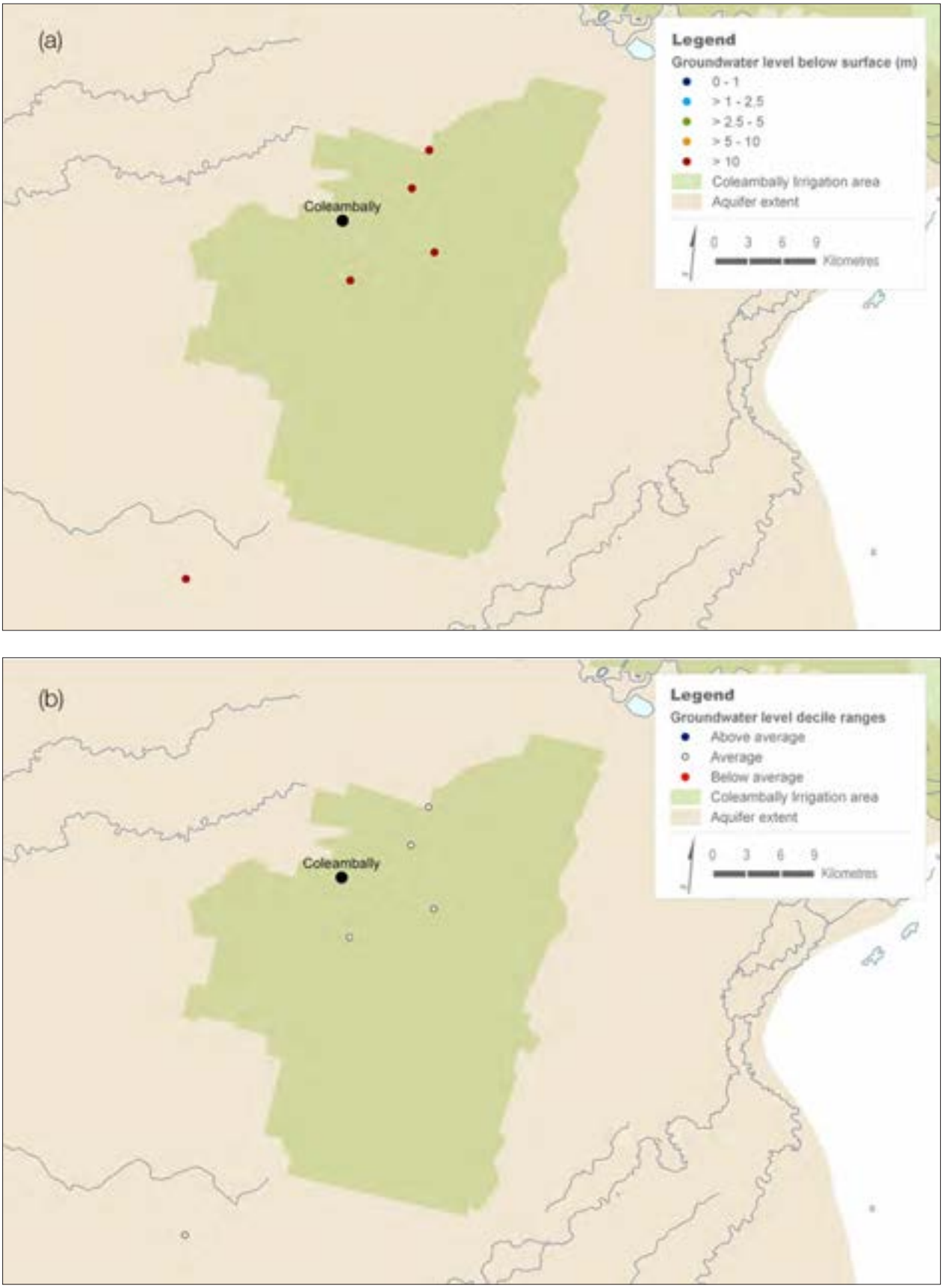


Figure 7.74 Median groundwater depth for Calivil aquifer in the (a) Coleambally Irrigation Area in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2011 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

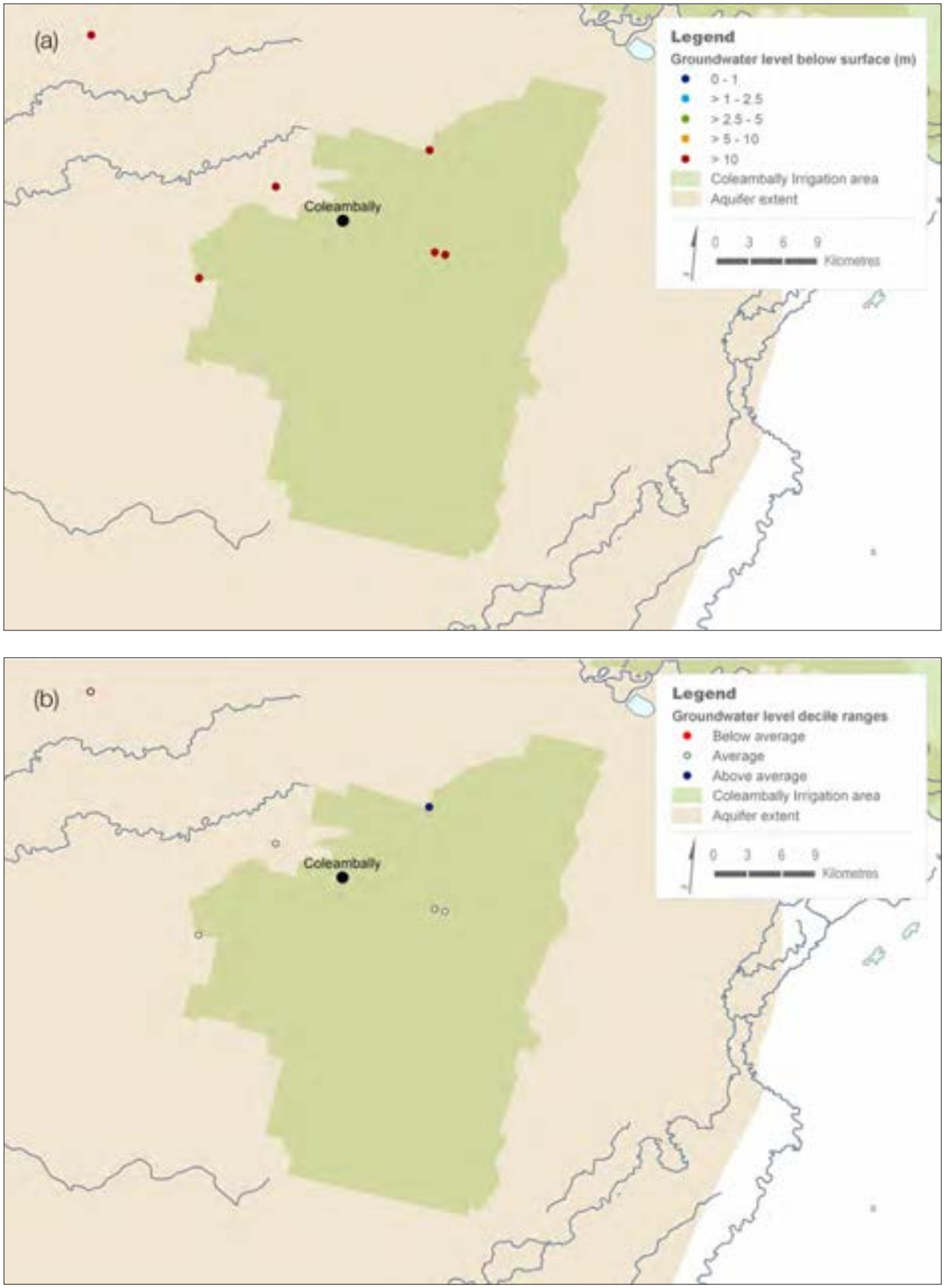


Figure 7.75 Median groundwater depth for Renmark aquifer, (a) in the Coleambally Irrigation Area in 2011–12, and (b) decile ranks of depth in 2011–12 compared to the 1990–2011 period. Deciles 1–3 are shown as below average (greater depth below surface), deciles 4–7 as average and deciles 8–10 as above average

South Australian Gulf

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8 South Australian Gulf

8.1 Introduction

This chapter examines water resources in the South Australian Gulf region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

8.2 Key information

Table 8.1 gives an overview of the key components of the data and information in this chapter.

Table 8.1 Key information on water flows, stores and use in the South Australian Gulf region

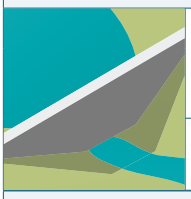
Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	331 mm	+10%	8th—above average
Evapo-transpiration	306 mm	+7%	8th—above average
Landscape water yield	9 mm	–10%	6th—average

Streamflow (at selected gauges)

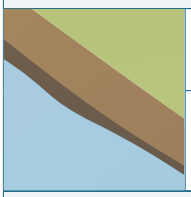
Annual total flow:	Highly variable pattern of high and low flow in the river gauges in the south eastern rivers
Salinity:	Annual median electrical conductivity predominantly above 1,000 µS/cm in gauges in the south eastern rivers and on Kangaroo Island
Flooding:	No major flooding in the monitoring gauges surrounding Adelaide

Surface water storage (comprising about 74% of the region's total capacity of all major storages)



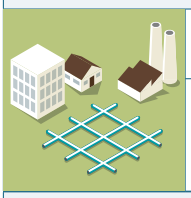
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
197 GL	96 GL	49%	135 GL	69%	–39 GL	–20%

Groundwater (in selected aquifers)



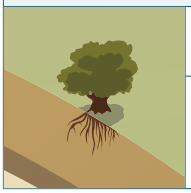
Levels:	Variable trends in the different aquifers, predominantly falling in middle aquifers and rising in deeper aquifers
Salinity:	Saline groundwater (≥3,000 mg/L) throughout most of the region with non-saline (<3,000 mg/L) areas around Adelaide and in the Flinders Ranges

Urban water use (Adelaide)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
138 GL	125 GL	+13 GL (+10%)	Water Wise Measures

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly average annual mean soil moisture and very much above average soil moisture in the far north
Temporal patterns in regional average:	Average to above average soil moisture throughout the year

8.3 Description of the region

The South Australian Gulf region extends over 117,700 km^2 of South Australia, surrounding the Gulf of St Vincent and Spencer Gulf, and stretching inland 300 km to the north of Spencer Gulf. To the east (at the border of the Murray–Darling Basin) the region is bounded by the western slopes of the Mount Lofty and Flinders Ranges; to the north, it is bounded by the Lake Eyre Basin; and to the west by the South Western Plateau region. The south of the region includes Kangaroo Island.

Except for the Flinders Ranges (with a highest peak of 932 m) and the Mount Lofty Ranges, the region has moderately flat terrain. Subsections 8.3.1–8.3.4 give more detail on the physical characteristics of the region.

The South Australian Gulf region has a population in excess of 1.4 million, or just over 6% of the country's total population (Australian Bureau of Statistics [ABS] 2011b). Major population centres in the region include Adelaide, Victor Harbour, Port Pirie, Port Augusta, Whyalla and Port Lincoln (Figure 8.1). Further discussion of the region's population distribution and urban centres can be found in subsection 8.3.6 and section 8.6 respectively.

Dryland pasture and cropping are major land uses in the region. Grazing is concentrated in the northern arid river basins such as Lake Torrens, Willochra Creek and Mambray Coast (south of Lake Torrens), and the Broughton River basin. Several river basins (Wakefield, Gawler and Broughton) have 50% or more of their area occupied by dryland agriculture. More than half of the land area devoted to nature conservation is a single reserve covering the Lake Torrens salt lake (Figure 8.1).

Other significant areas of nature conservation occur on Eyre Peninsula, Kangaroo Island, and through the Mount Lofty and Flinders Ranges. Irrigated agriculture is mostly for viticulture and wine production, the most important of which is concentrated in the Onkaparinga catchment. Section 8.7 has more information on agricultural activities in the region.

The region has a Mediterranean climate in the southeast, and a semi-arid climate inland and to the north. Rainfall mainly occurs in winter. Spring and summer rainfall can be substantial although highly variable. Subsections 8.3.7 and 8.3.8 provide more information on the rainfall patterns and deficits across the region.

There are no major permanent freshwater lakes in the South Australian Gulf region. A number of large endorheic salt lakes exist in the north, including Lake Torrens, Island Lagoon, Pernatty Lagoon, Lake Hart, Lake Gilles and Lake MacFarlane (Figure 8.1). In the south, short rivers drain into the ocean. The region has some important coastal and marine ecosystems.

The hydrogeology of the region can be partitioned into areas of surficial and underlying sediments, and areas of outcropping fractured rock. Significant groundwater resources are found in surficial sediments and the Quaternary and Tertiary aquifers that underlie them. Typically fractured rock systems offer restricted low volume groundwater resources; however, there are some parts of this region with a greater density of fractures and more substantial groundwater resource availability. A more detailed description of the rivers and groundwater status is given in section 8.5.

A view of rural Southern Australia looking north towards Flinders Range | Malcolm Watson

Figure 8.1 Major rivers and urban centres in the South Australian Gulf region

8.3.1 Physiographic characteristics

The physiographic map in Figure 8.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes. The South Australian Gulf region has two physiographic provinces, namely Eyre Peninsula and Gulfs Ranges.

The Eyre Peninsula province occupies 43% of the region and has alluvial plains and salt lakes with some dunes in the north. Moving south, this changes to rounded ranges of acid volcanic rocks and hills of metamorphic rocks followed by stable northwest–southeast oriented longitudinal dunes, locally broken by granite hills, ridges of metamorphic rocks and plains extending as headlands and inlets along the southern coast.

The Gulfs Ranges province occupies 57% of the region and has a complex fold belt of prominent ranges in the north, chiefly quartzite with vales on weaker rocks, and in the southeast stepped fault blocks and islands, mainly of weathered metamorphic rocks with ferruginous cappings. In the northwest, there are dissected sandstone plateaus, salt lakes, alluvial and littoral plains and stabilised longitudinal dunes. In the southwest are undulating lowlands of folded crystalline and metamorphic rocks covered by calcrete and stabilised northwest–southeast longitudinal dunes.

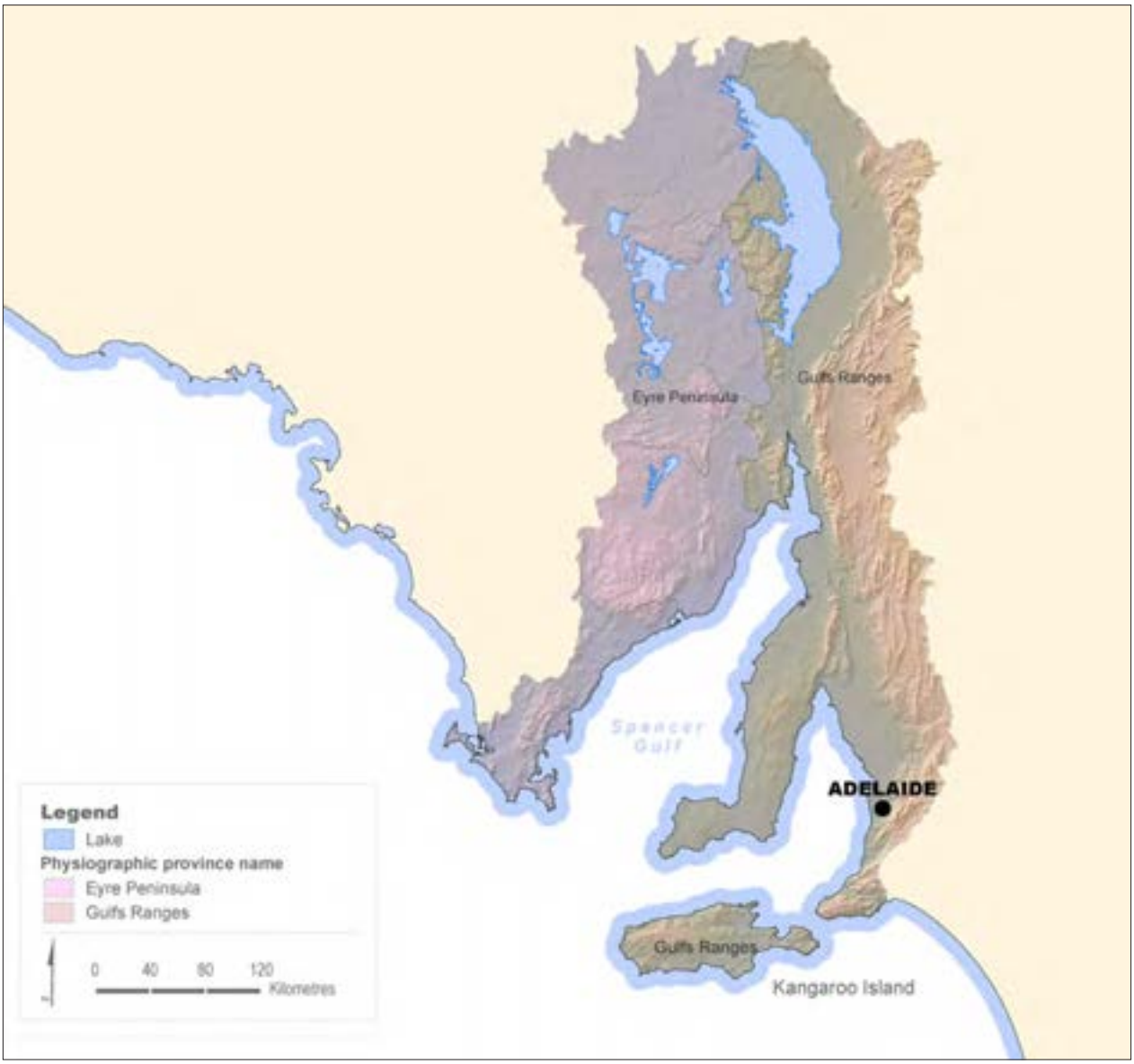


Figure 8.2 Physiographic provinces in the South Australian Gulf region

8.3.2 Elevation

Figure 8.3 presents ground surface elevations in the South Australian Gulf region. Information was obtained from the Geoscience website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The region is clearly defined by the crest of the Mount Lofty Ranges in the south and the eastern ridges of the Flinders Ranges in the north. The highest point in this area is 932 m with most of the borderline on altitudes exceeding 400 m. To the north and the west of the region, the effective water divide is less obvious.

The major mountains in the west are the Minbrie Range on Eyre Peninsula, which reach altitudes of over 400 m above sea level. The western areas contain many closed drainage areas which do not drain towards the sea. This includes the large Lake Torrens basin, which covers the majority of the north of the region.

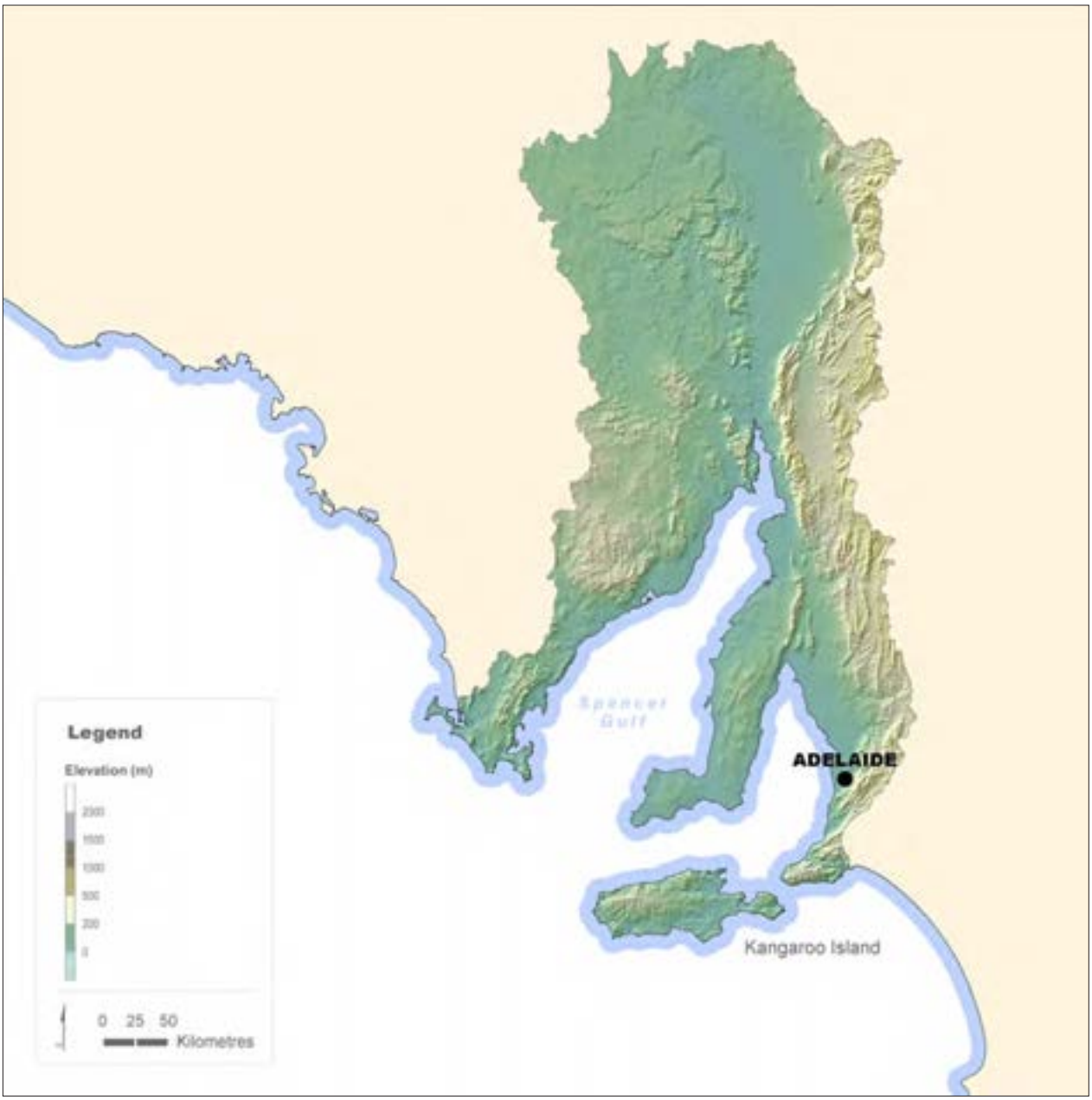


Figure 8.3 Ground surface elevations in the South Australian Gulf region

8.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The South Australian Gulf region has only some areas with steep slopes. Most of the area is rather flat (Table 8.2). The steep slopes in the map of Figure 8.4, in particular, highlight the Flinders Ranges in the east.

Table 8.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	31.4	19.8	39.8	9.0

Significant slopes also exist southeast of Adelaide. The slopes were derived from the elevation information used in the previous section.

The region has a number of flat coastal plains, which, in combination with the climate and the appropriate soil conditions, have formed ideal solar salt production sites.

The flat plains in the north are mostly salt lakes, which collect the sparse run-off from their surrounding ranges. The large flat plain in the centre-north is Lake Torrens, which has only filled once in the last 150 years, as generally it is a large salty flatland.

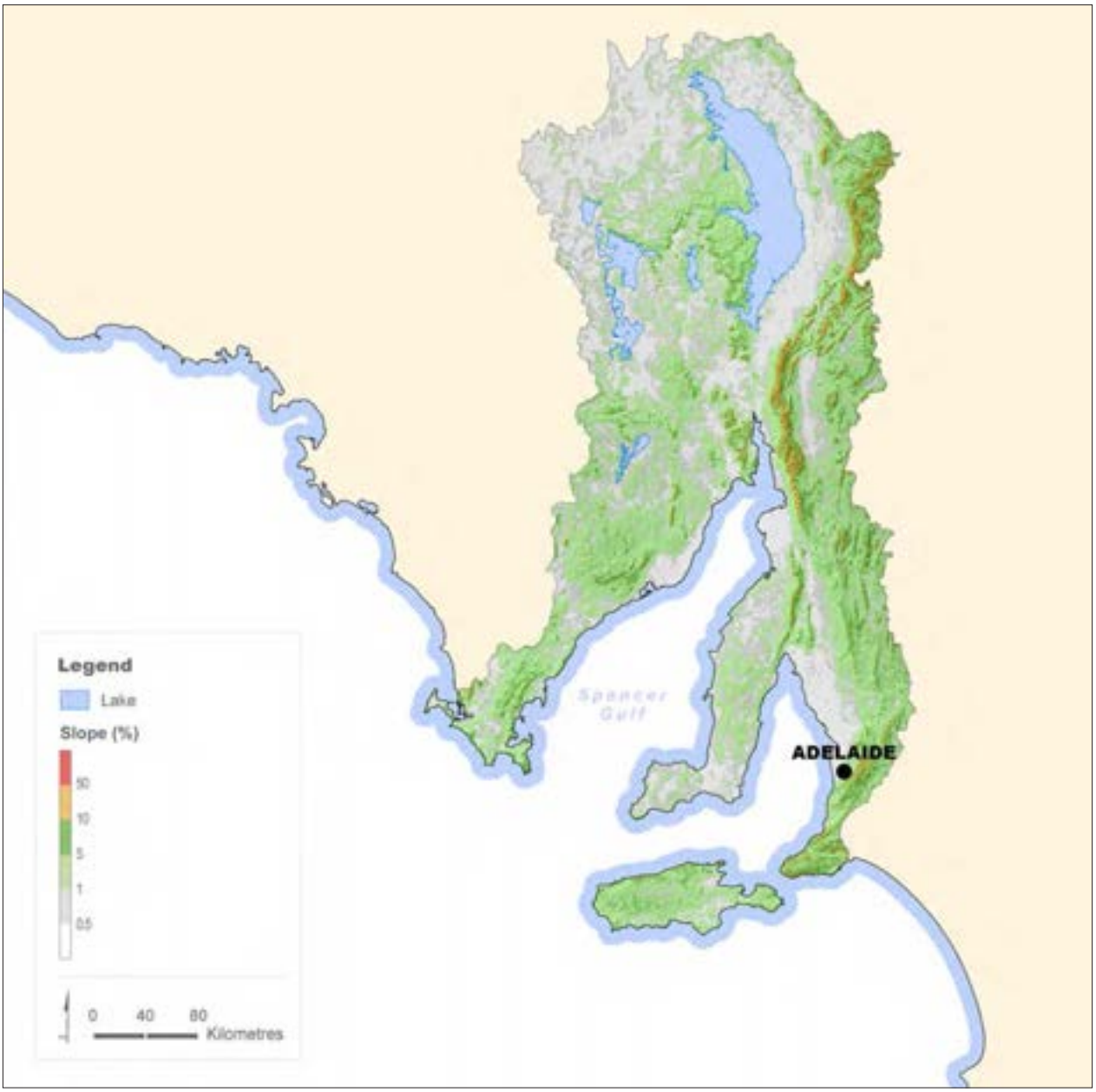


Figure 8.4 Surface slopes in the South Australian Gulf region

8.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contribute to groundwater recharge. The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 88% of the South Australian Gulf region consists of four soil types, namely calcarosols, sodosols, chromosols and tenosols (Figure 8.5 and Figure 8.6).

Calcarosols are widely distributed across the region and cover about 45% of the total area. They are mainly present in areas used for pastures and to some extent for dryland agriculture. Calcarosols are characterised by a high content of calcium carbonate which occurs as soft or hard white fragments or as solid layers. These soils are often shallow and have a low water-holding capacity. They have a low to moderate agricultural potential, and salinity, alkalinity and boron toxicity may often cause problems.

Sodosols are common soils in the north and southwest and are scattered around in the southeast of the region. These soils have a strongly contrasting texture, with impermeable sodic subsoils arising from elevated sodium concentrations and clay. They are susceptible to dryland salinity as well as erosion if vegetation is removed.

Chromosols also have strongly contrasting texture, but have permeable subsoils which are not strongly acidic. They are dominant in the southeast of the region as well as on Kangaroo Island and are mostly present in pastures and areas used for dryland agriculture.

Tenosols are soils with minimal development throughout the profile. They show little or no change in texture and colour. They are often shallow or stony. These soils are low in chemical fertility and water-holding capacity and thus their agricultural potential is low. Tenosols are scattered in the central-west and in the south of the region and are mostly present in pastures and areas used for nature conservation.

The other soil types that have minimal representation in the South Australian Gulf region are rudosols, dermosol, ferrosols, hydrosols, kurosols and podosols (1–6% of the total area).

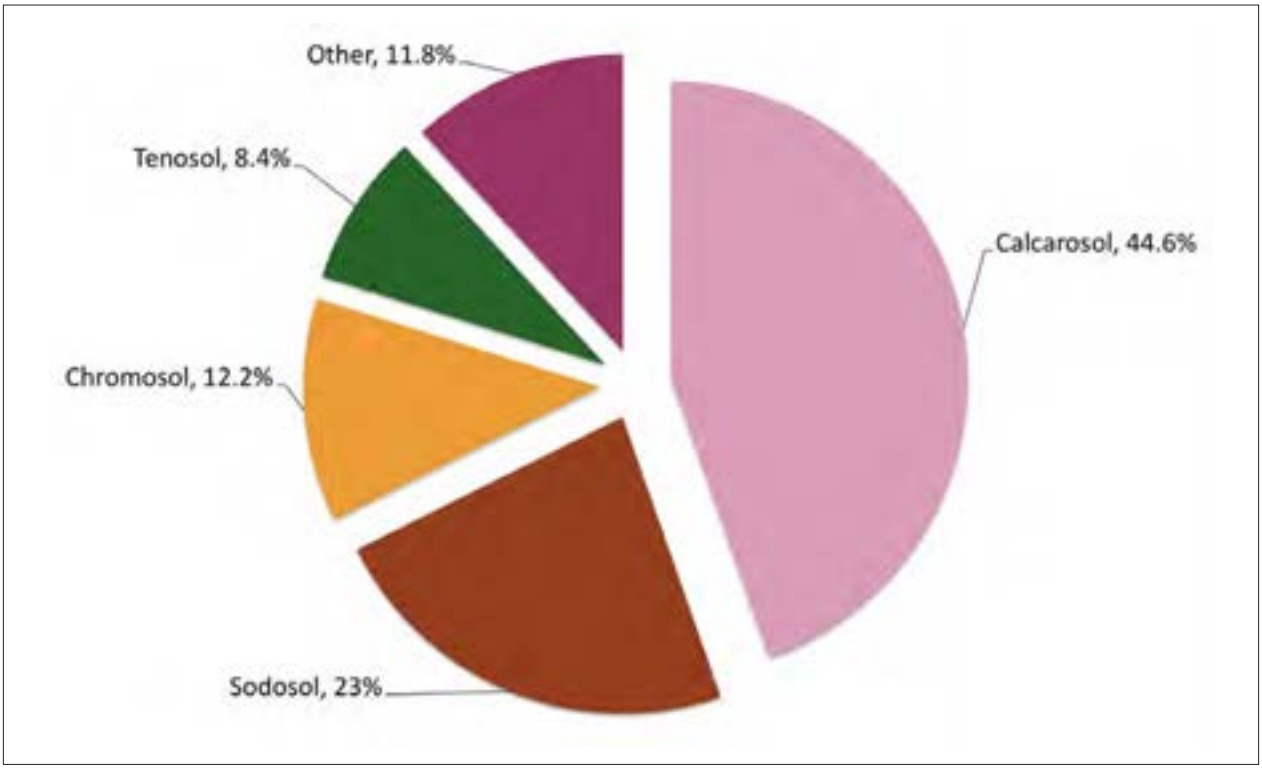


Figure 8.5 Soil types in the South Australian Gulf region

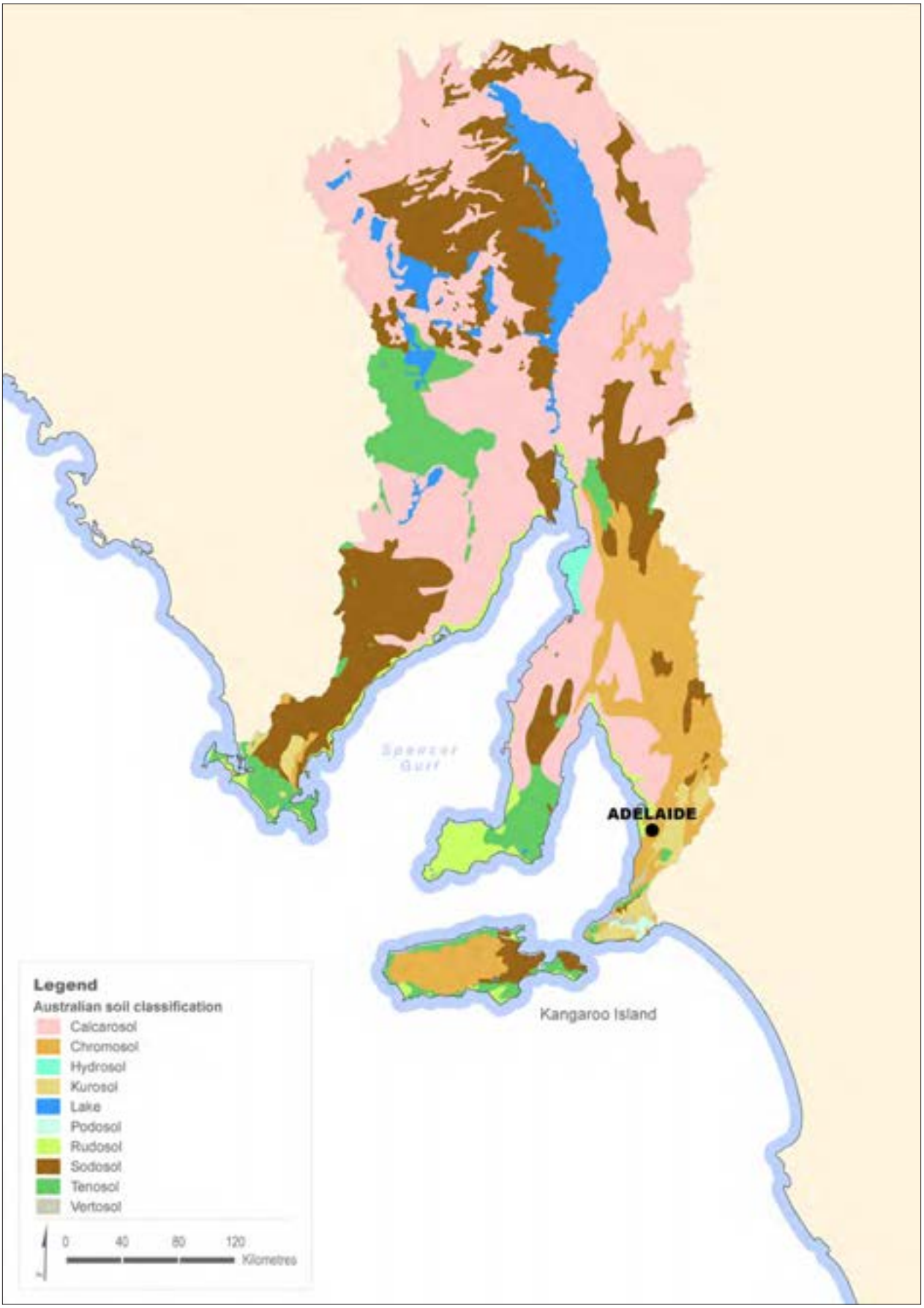


Figure 8.6 Soil type distribution in the South Australian Gulf region

8.3.5 Land use

Dryland pasture and cropping are major land uses in the region (Figure 8.7), being often combined to varying degrees in farming operations across the region (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Grazing predominates in the northern arid river basins such as Lake Torrens, Willochra Creek and Mambray Coast (south of Lake Torrens), and the northern parts of the Broughton River basin. Several river basins (Wakefield, Gawler and Broughton) have 50% or more of their area occupied by dryland agriculture (Figure 8.7).

More than half of the land area devoted to nature conservation is a single reserve covering the Lake Torrens salt lake. Other significant areas of nature conservation occur on Eyre Peninsula, Kangaroo Island and in the Broughton River basin (Figure 8.8), and through the Mount Lofty and Flinders Ranges.

Irrigated agriculture is mostly for viticulture and wine production, the most important of which is concentrated in the Onkaparinga catchment.

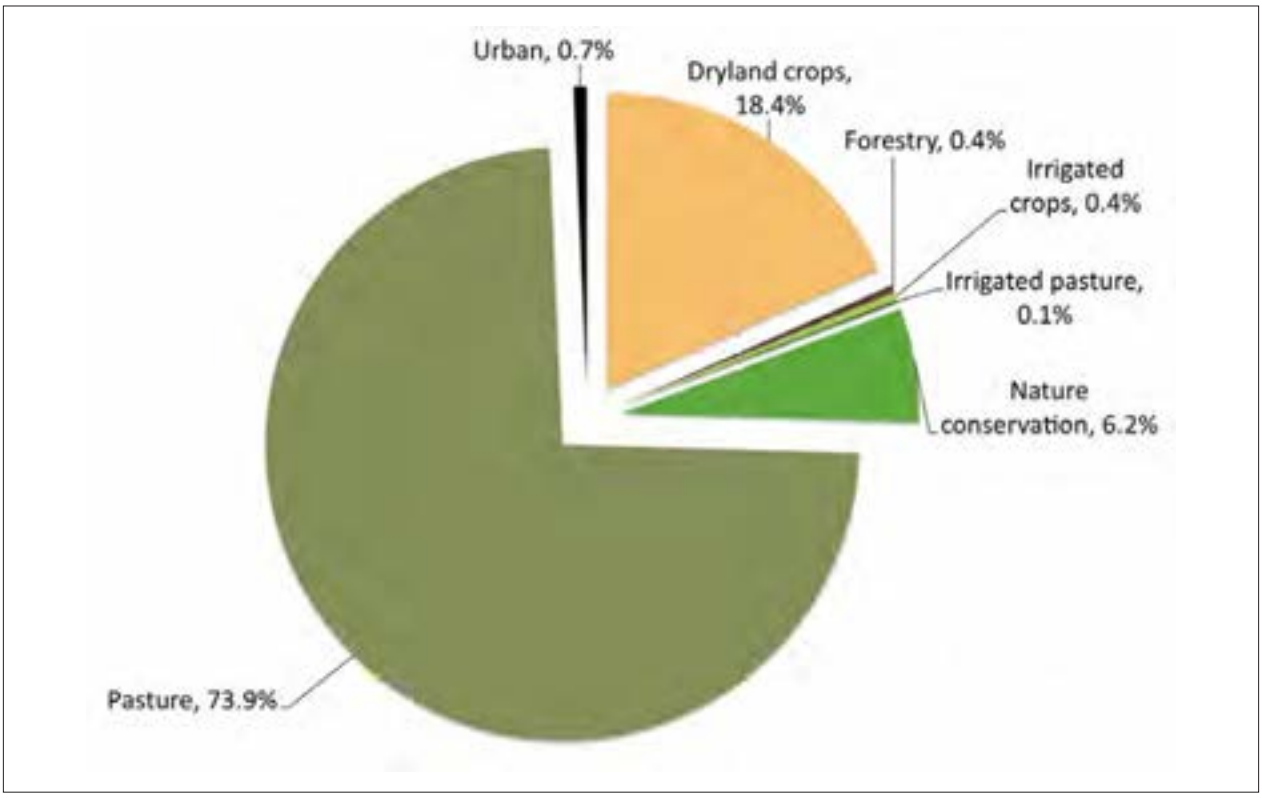


Figure 8.7 Land use in the South Australia Gulf region

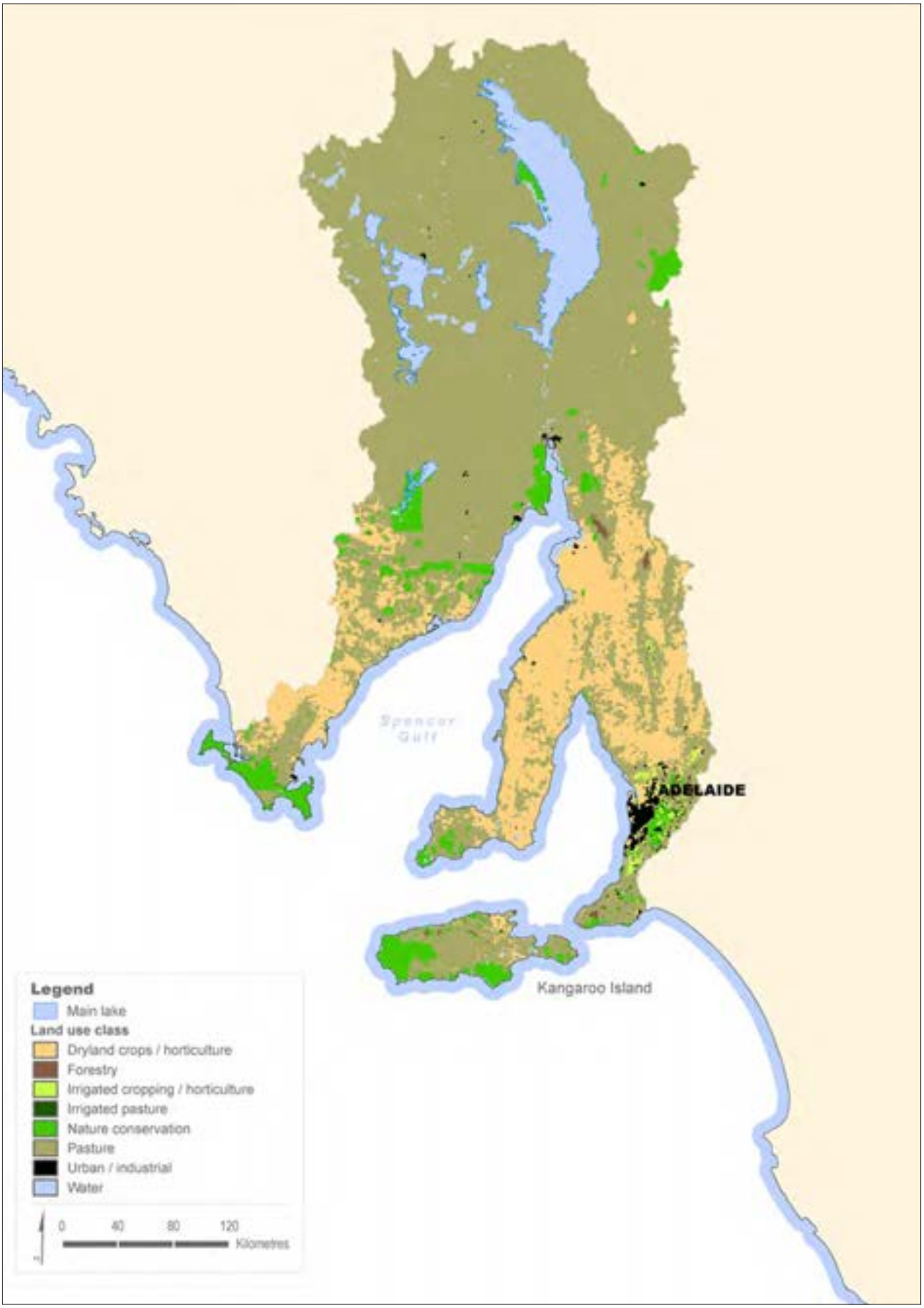


Figure 8.8 Land use distribution in the South Australian Gulf region

8.3.6 Population distribution

The South Australian Gulf region has a population of greater than 1.4 million. Approximately 88% of the population is concentrated in greater Adelaide which occupies the coastal plains along the eastern edge of the Gulf of St Vincent and extends up into the Adelaide Hills (Figure 8.9).

A number of smaller coastal cities and towns are distributed along the edge of the Spencer Gulf and are driven by mining, agriculture and fisheries.

Beyond these smaller centres the remaining population is sparsely distributed throughout the western and northern parts of the region. A number of remote Indigenous communities can be found scatted throughout these parts.

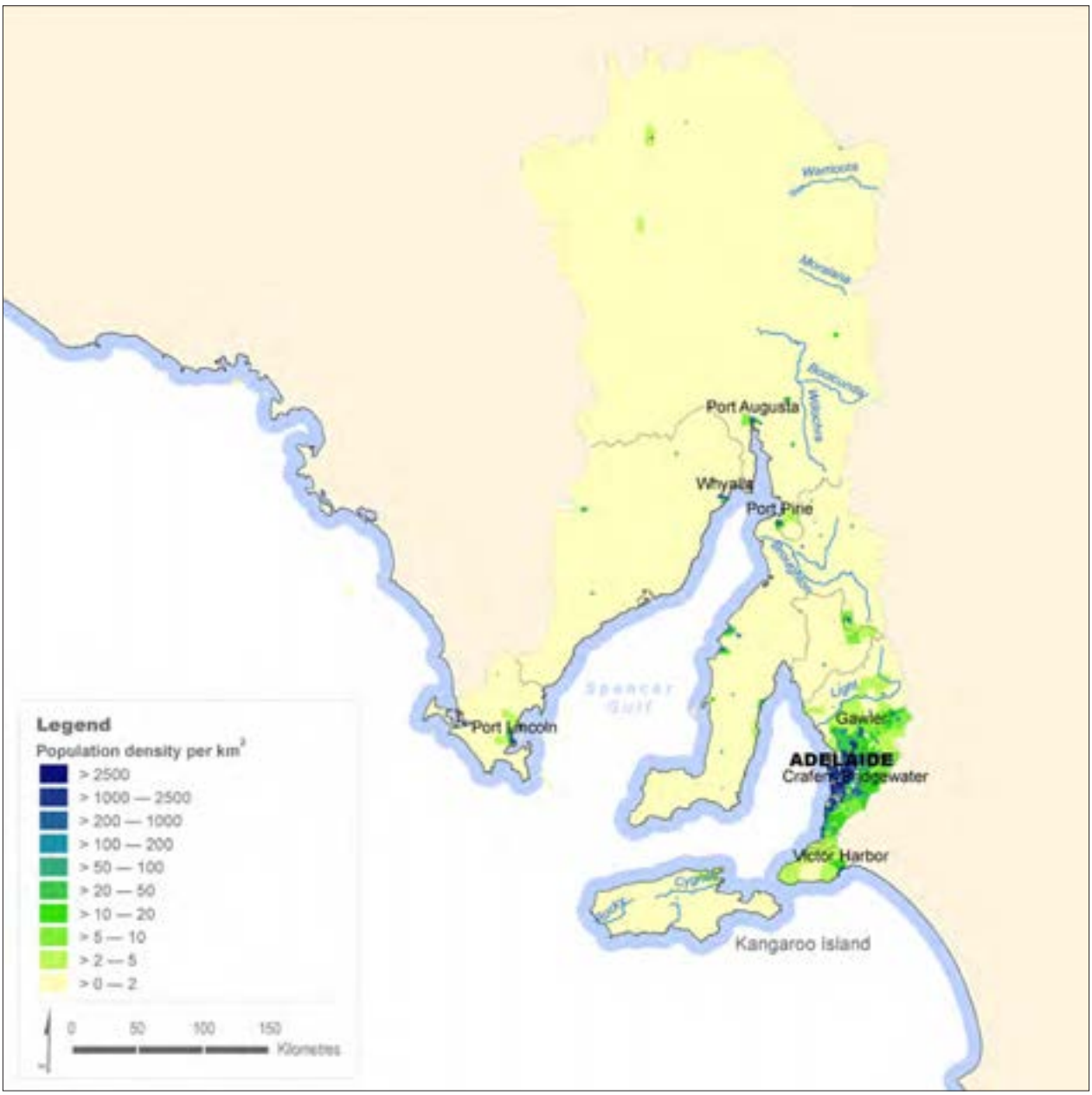


Figure 8.9 Population density and distribution in the South Australian Gulf region

8.3.7 Rainfall zones

The region has a Mediterranean climate in the southeast and a semi-arid climate to the north. Rainfall mainly occurs in winter, though highly variable contributor to rainfall in spring through to early autumn. Median rainfall varies strongly across the region, not exceeding 800 mm throughout (Figure 8.10).

In the most northern part of the region average annual rainfall is limited to less than 200 mm.

Moving south, the annual rainfall totals increase up to levels reaching over 600 mm in the southern tip of Eyre Peninsula and Kangaroo Island.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

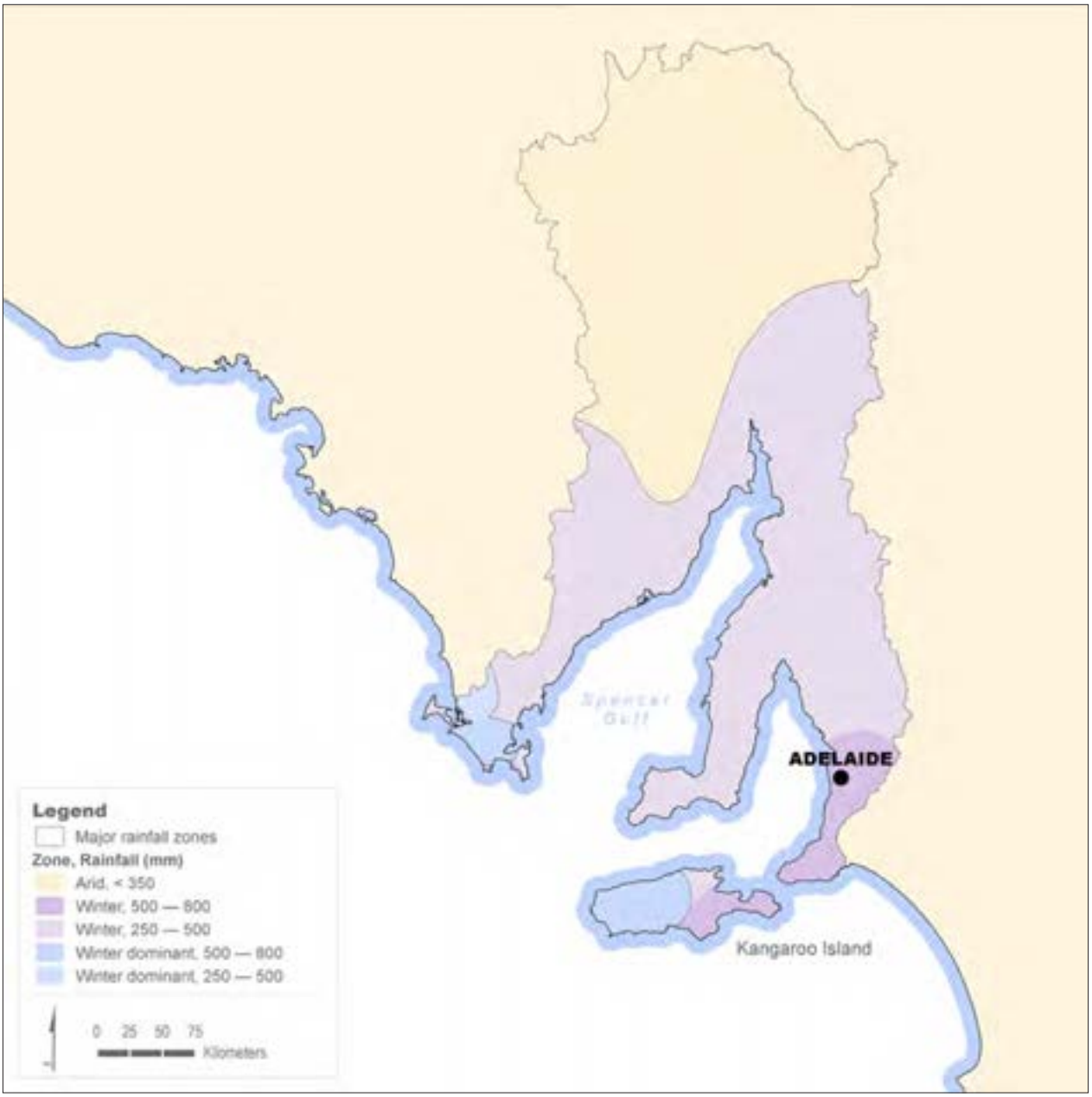


Figure 8.10 Rainfall zones in the South Australian Gulf region

8.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The South Australian Gulf region has a general pattern of substantial deficits in relation to this indicator (Figure 8.11).

High deficits can be expected in large parts of the northern inland areas, which include a number of ephemeral lakes. These are lakes which only get filled after major rainfall. No land cover other than grasses and shrubs is present, resulting in low density stock farming.

In the south of the region, dryland cropping and pasture for livestock are major forms of land use. The farms strongly rely on April–October rainfall for their growing season.

The city of Adelaide has some surface water storages to support the supply of water, but the general deficit in this area means the city relies on water transferred from the River Murray, particularly in summer, and since October 2011 from desalinated water.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

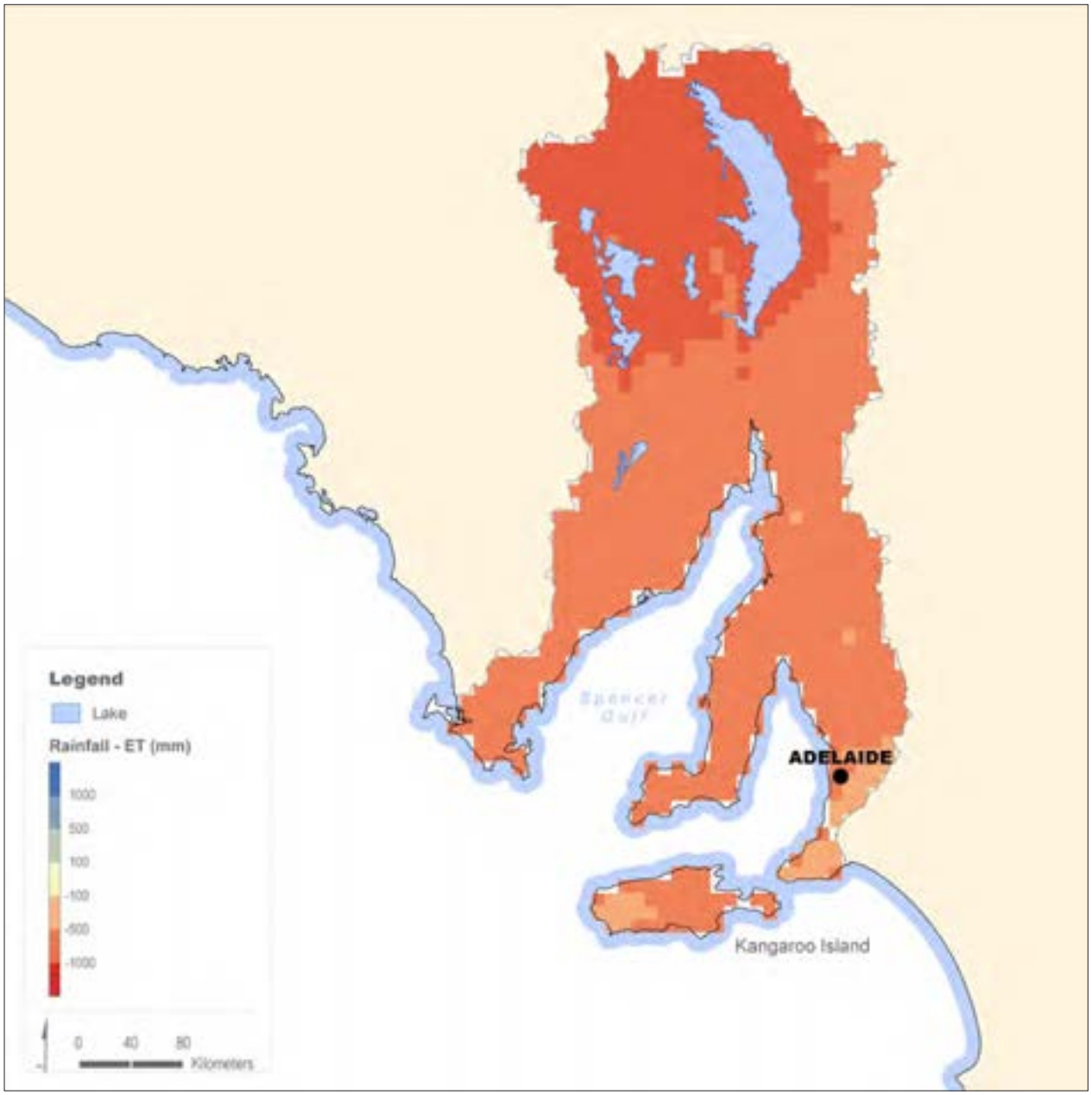


Figure 8.11 Rainfall deficit distribution in the South Australian Gulf region

8.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the South Australian Gulf region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 8.12 shows that the region has a seasonal rainfall pattern with a predominantly wetter winter and drier summer period. Evapotranspiration generally exceeds rainfall from spring up to early summer, extracting the excess water from the soils. The soils refill again in the wetter May–July period. The monthly landscape water yield history for the region shows a stable pattern of very low yield throughout the year.

The 2011–12 year was a relatively average year. Rainfall only exceeded the 90th percentile in the normally driest month of March, albeit only marginally.

Similar to rainfall, evapotranspiration was the highest in March. The rainfall of February and March contributed to higher than usual soil moisture, which in turn was available again for evapotranspiration. Evapotranspiration for March was third highest on record for the 1911–2012 period.

The landscape water yield for 2011–12 followed the very narrow bounds of the historic pattern. A marginally higher landscape water yield was found for March, although with no excessive volumes in absolute terms.

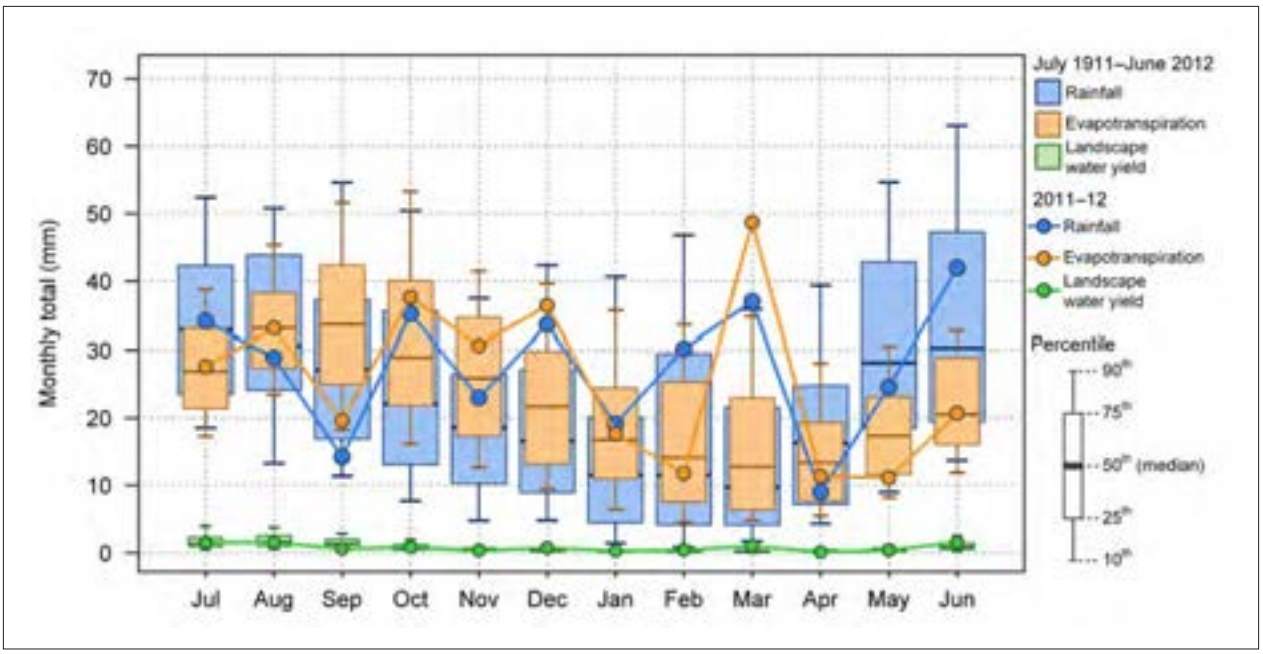


Figure 8.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the South Australian Gulf region

8.4.1 Rainfall

Rainfall for the South Australian Gulf region for 2011–12 is estimated to be 331 mm. This is 10% above the region's long-term average (July 1911–June 2012) of 300 mm. Figure 8.13a shows that the highest rainfall occurred along the southern coastal areas with annual totals locally exceeding 600 mm for 2011–12. The majority of the north had rainfall not exceeding 300 mm, except for the slopes of the Flinders Ranges in the east.

Rainfall deciles for 2011–12 indicate average to above average rainfall for the entire region over the course of the year (Figure 8.13b). The wetter south of the region experienced predominantly average rainfall with the exception of the far southern corner of Eyre Peninsula. In the centre and far north of the region, large areas of above average rainfall are present. As these areas are generally identified as arid, the above average areas experienced no substantially higher absolute total annual rainfall.

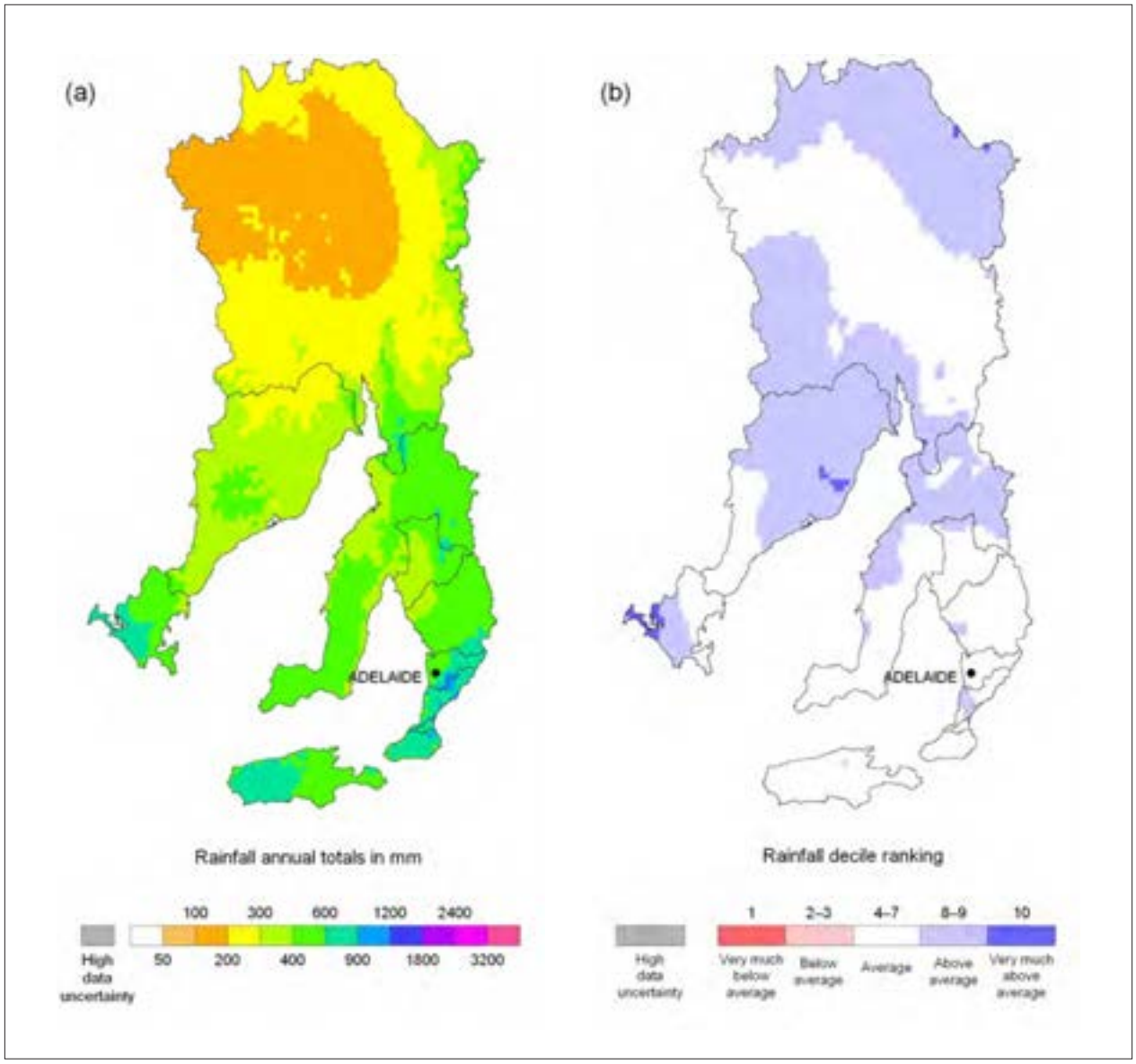


Figure 8.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South Australian Gulf region

Rainfall variability in the recent past

Figure 8.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 305 mm, varying from 187 mm (1982–83) to 477 mm (1992–93). Temporal variability and seasonal patterns since 1980 are presented in Figure 8.14b.

The graphs show a pattern of moderately high variability for the region, which is linked to the highly variable rainfall pattern in the arid north of the region. In Figure 8.14b, a pattern of decreasing rainfall in the winter period and increasing rainfall in the summer period is found in the most recent years. Before this, rainfall was noticeably higher in the winter period compared to the summer period.

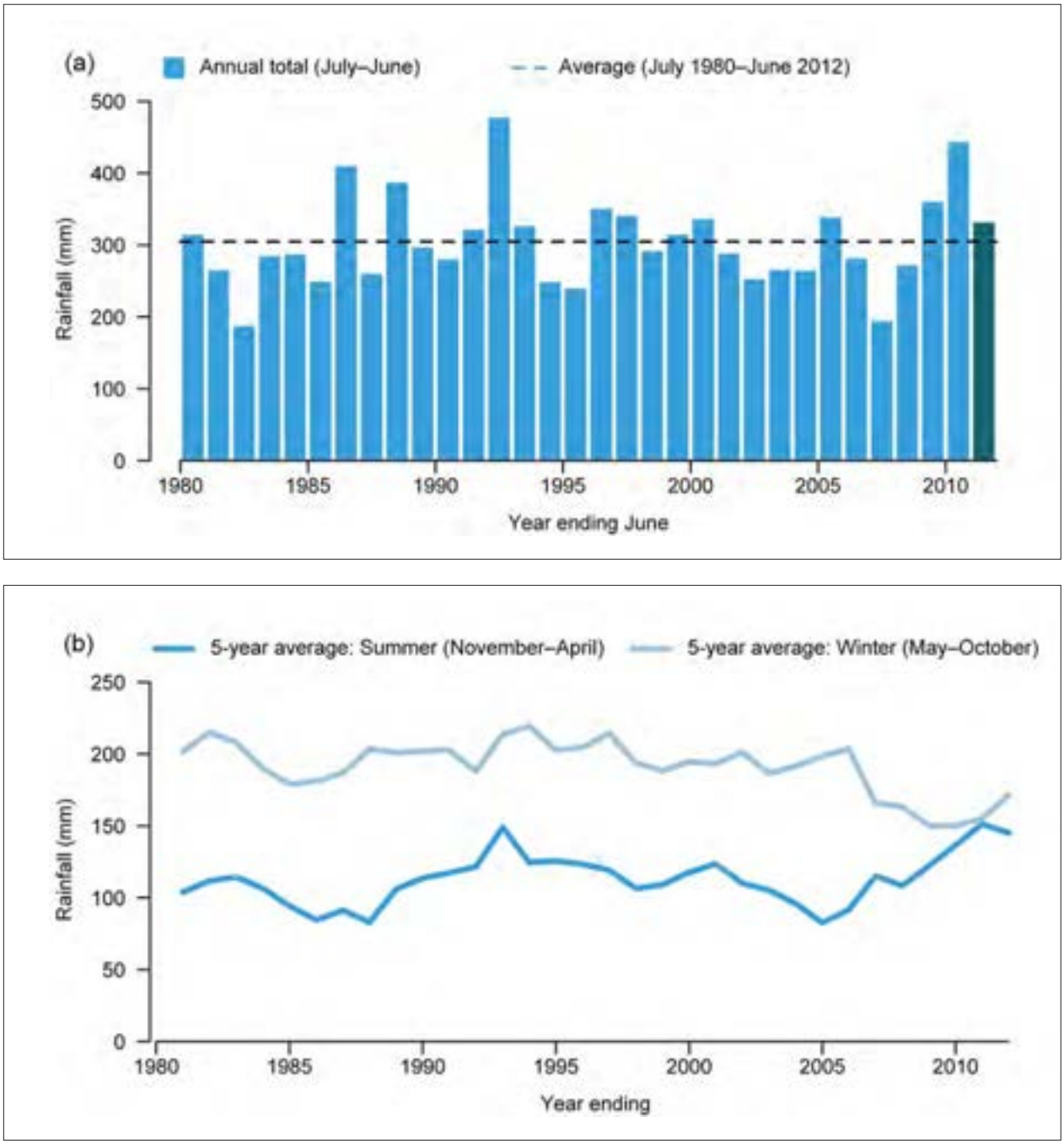


Figure 8.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Australian Gulf region

Recent trends in rainfall

Figure 8.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 8.15b.

Figure 8.15a shows that trends are mostly rising, but to an extent that is marginal. The significance map of Figure 8.15b confirms that the trends are of no statistical importance.

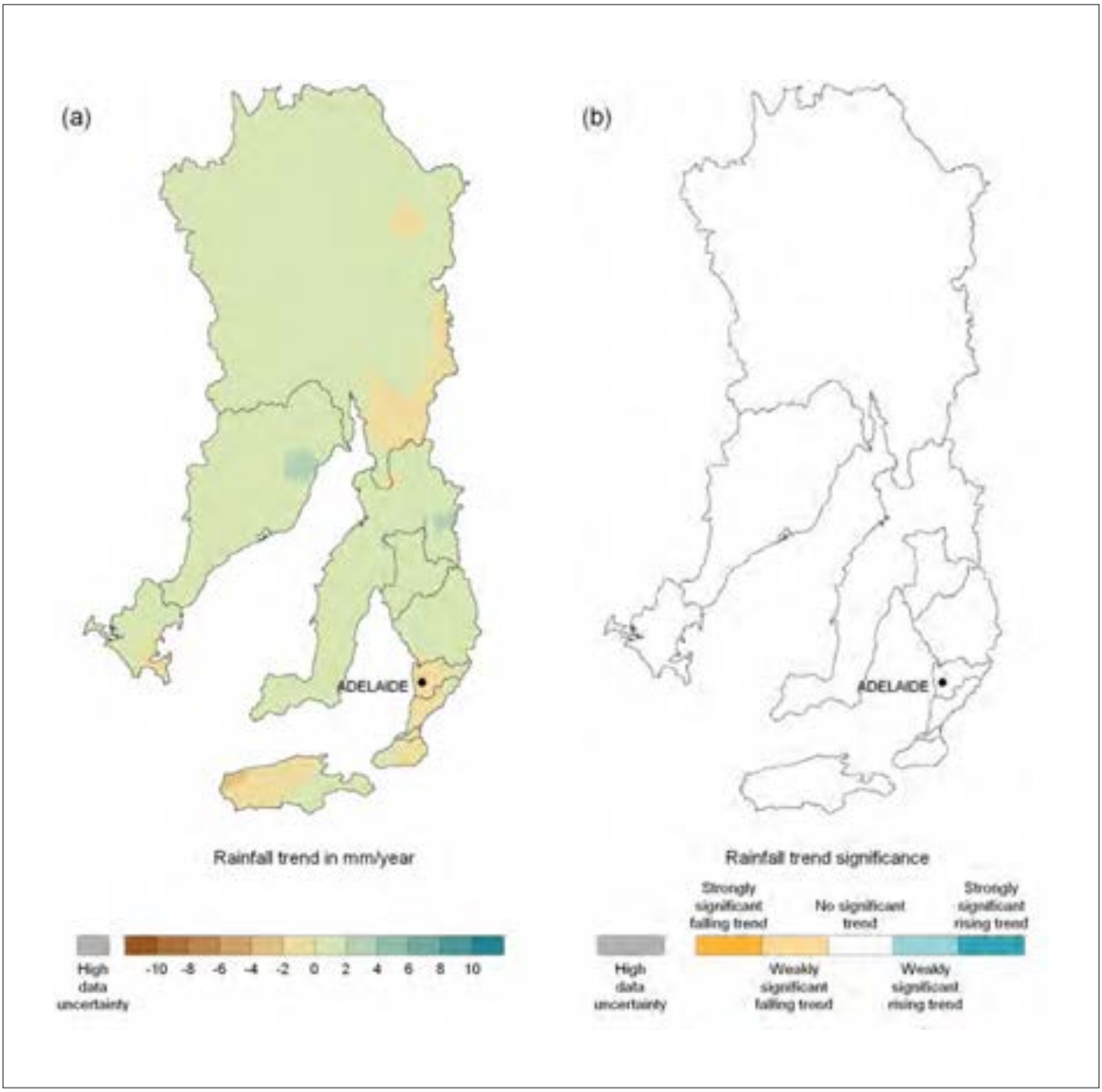


Figure 8.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Australian Gulf region

8.4.2 Evapotranspiration

Modelled annual evapotranspiration for the South Australian Gulf region for 2011–12 is estimated to be 306 mm. This is 7% above the region's long-term (July 1911–June 2012) average of 286 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 8.16a) is almost identical to that of rainfall (Figure 8.13a). In this region, evapotranspiration is mostly limited to the availability of water.

Evapotranspiration deciles for 2011–12 indicate average or above average totals across most of the region (Figure 8.16b). The pattern again reflects that of rainfall (Figure 8.13b), albeit with some minor differences.

Essentially, those areas that had above average rainfall also had above average evapotranspiration. Hence, most water was returned back to the atmosphere within a short period of time.

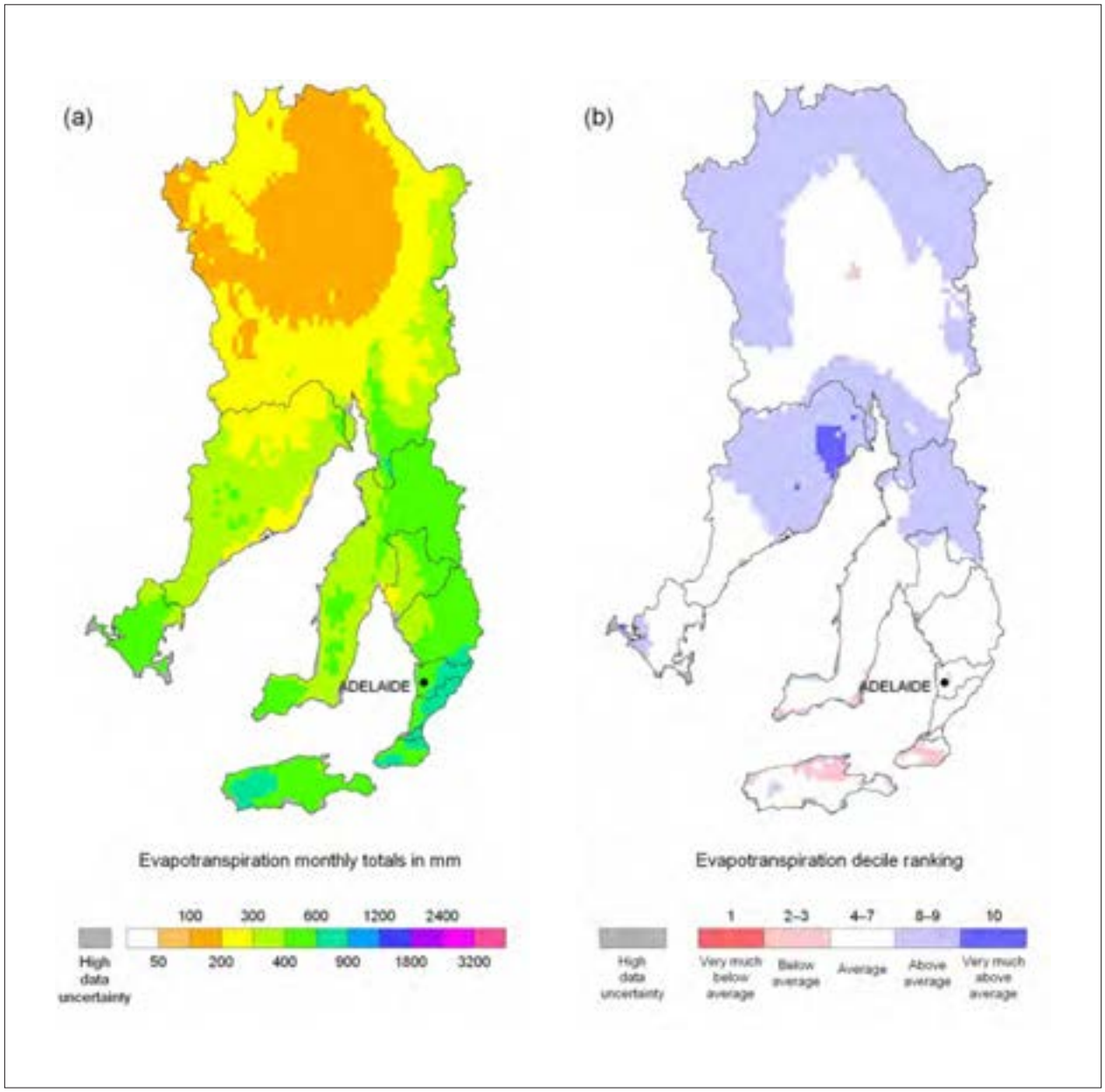


Figure 8.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South Australian Gulf region

Evapotranspiration variability in the recent past

Figure 8.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 292 mm, varying from 191 mm (1982–83) to 447 mm (1992–93). Figure 8.17b presents temporal variability and seasonal patterns since 1980.

The similarity between the rainfall data of Figure 8.14 and the evapotranspiration data of Figure 8.17 is high. Evapotranspiration also shows a narrowing of the difference between the summer and winter periods over the last few years.

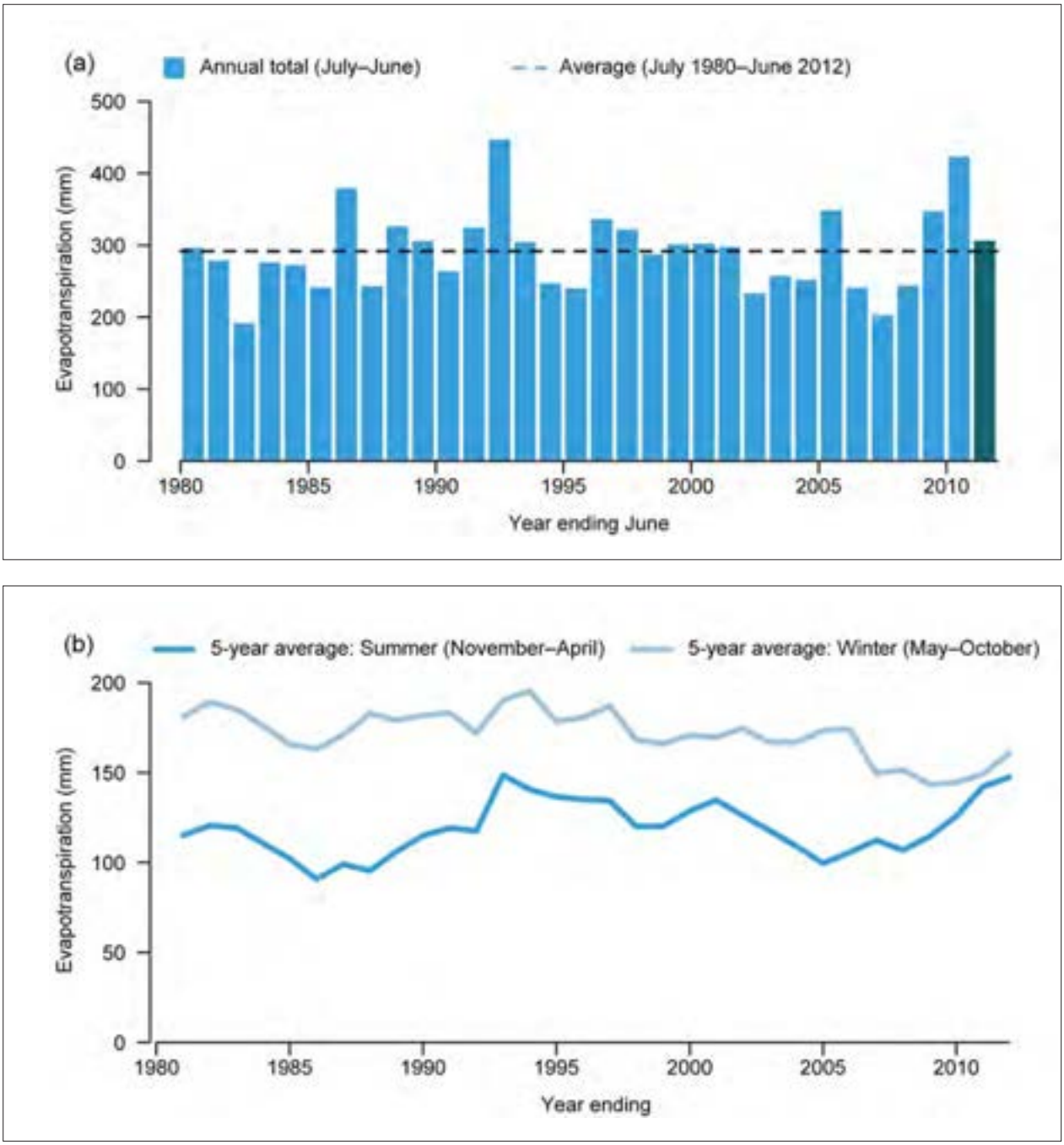


Figure 8.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Australian Gulf region

Recent trends in evapotranspiration

Figure 8.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. Figure 8.18b provides the statistical significance of the trends.

Figure 8.18a shows that since 1980 trends throughout the region are within the –2 to 2 mm/year range.

As shown in Figure 8.18b, the trends are non-significant throughout the region. A major reason for this is that unlike in many other regions, the last two years were not the highest on record for the 32-year period.

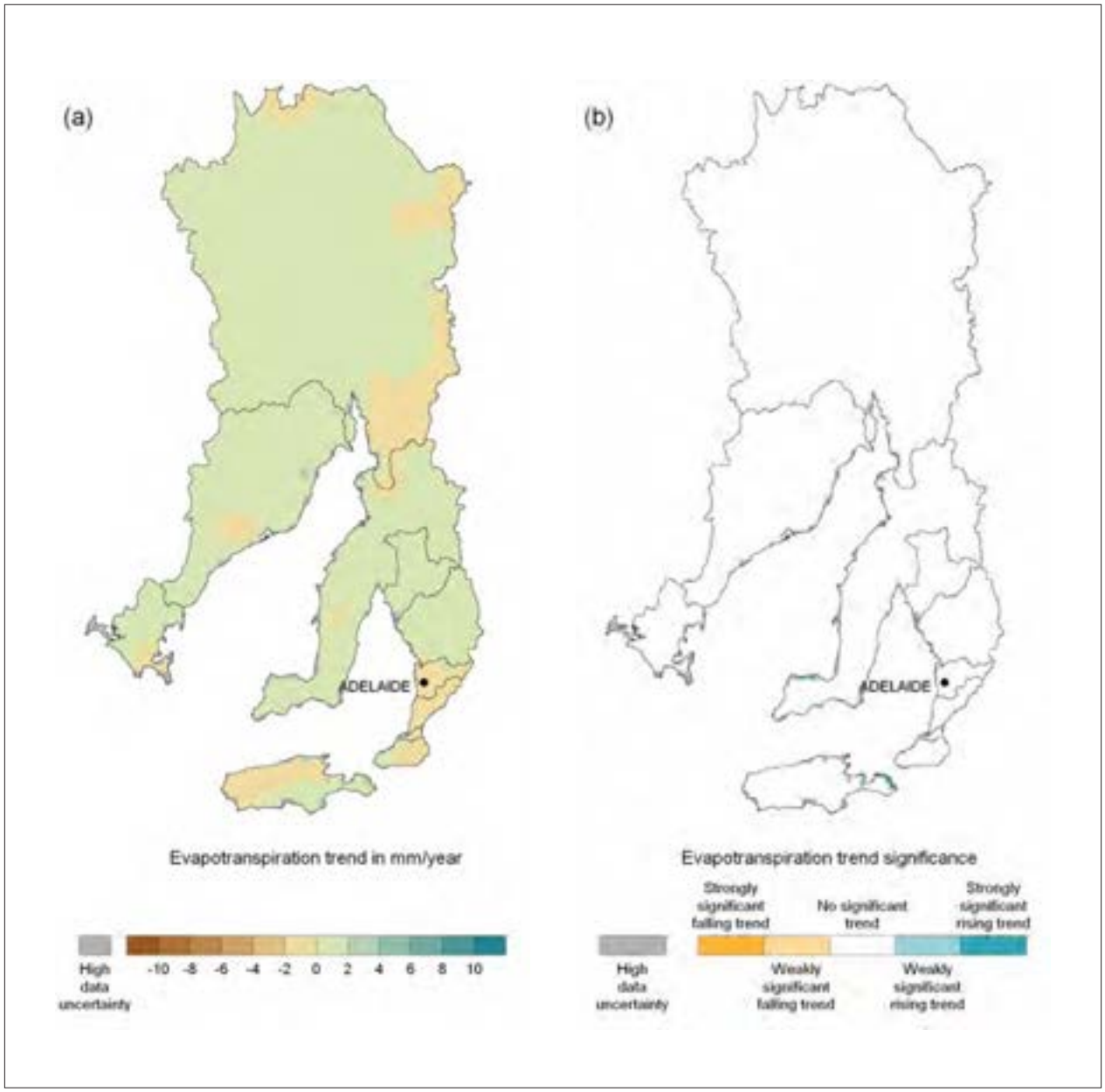


Figure 8.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Australian Gulf region

8.4.3 Landscape water yield

Modelled landscape water yield for the South Australian Gulf region for 2011–12 is estimated to be 9 mm. This is 10% below the region's long-term (July 1911–June 2012) average of 10 mm. Figure 8.19a shows the spatial distribution of landscape water yield for 2011–12. Only in the far southeast and on Kangaroo Island did some areas have landscape water yields exceeding 50 mm.

The decile ranking map for 2011–12 (Figure 8.19b) shows very much above average landscape water yield for the far north of the region. In absolute terms, however, these areas still had very low landscape water yield. In the far south some coastal areas are highlighted as very much below average landscape water yield; however, this is likely an artefact of the model calculations, which has yet to be further investigated.

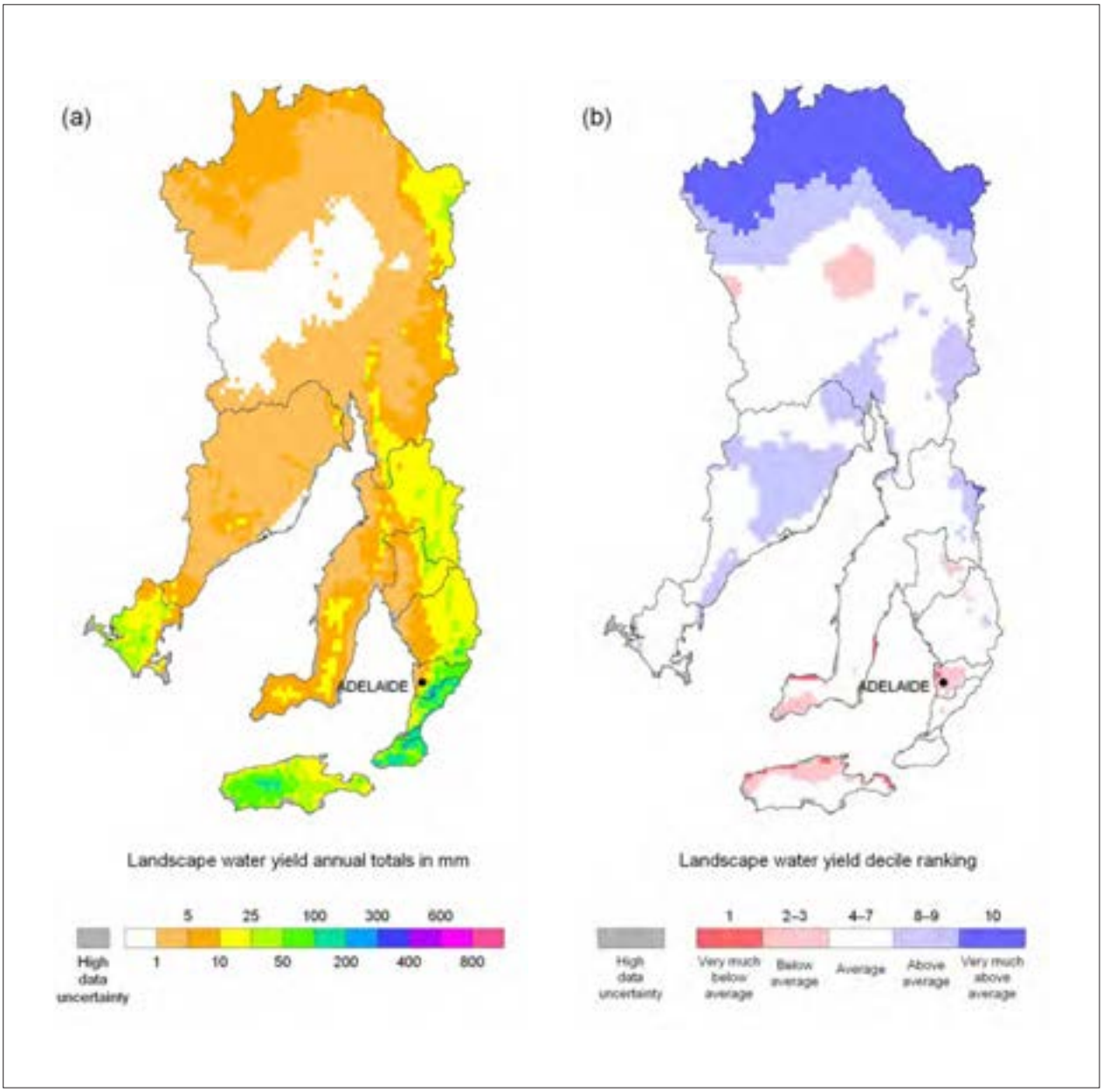


Figure 8.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South Australian Gulf region

Landscape water yield variability in the recent past

Figure 8.20a shows annual landscape water yield for the South Australian Gulf region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 10 mm, varying from 4 mm (1982–83) to 23 mm (1992–93). Temporal variability and seasonal patterns since 1980 are presented in Figure 8.20b.

The graphs show a weak pattern of cyclic behaviour in the annual as well as summer and winter periods landscape water yield. Figure 8.20a shows that landscape water yields for some years were around 5 mm or lower, which generally means that in the arid north of the region landscape water yield was close to zero for those years.

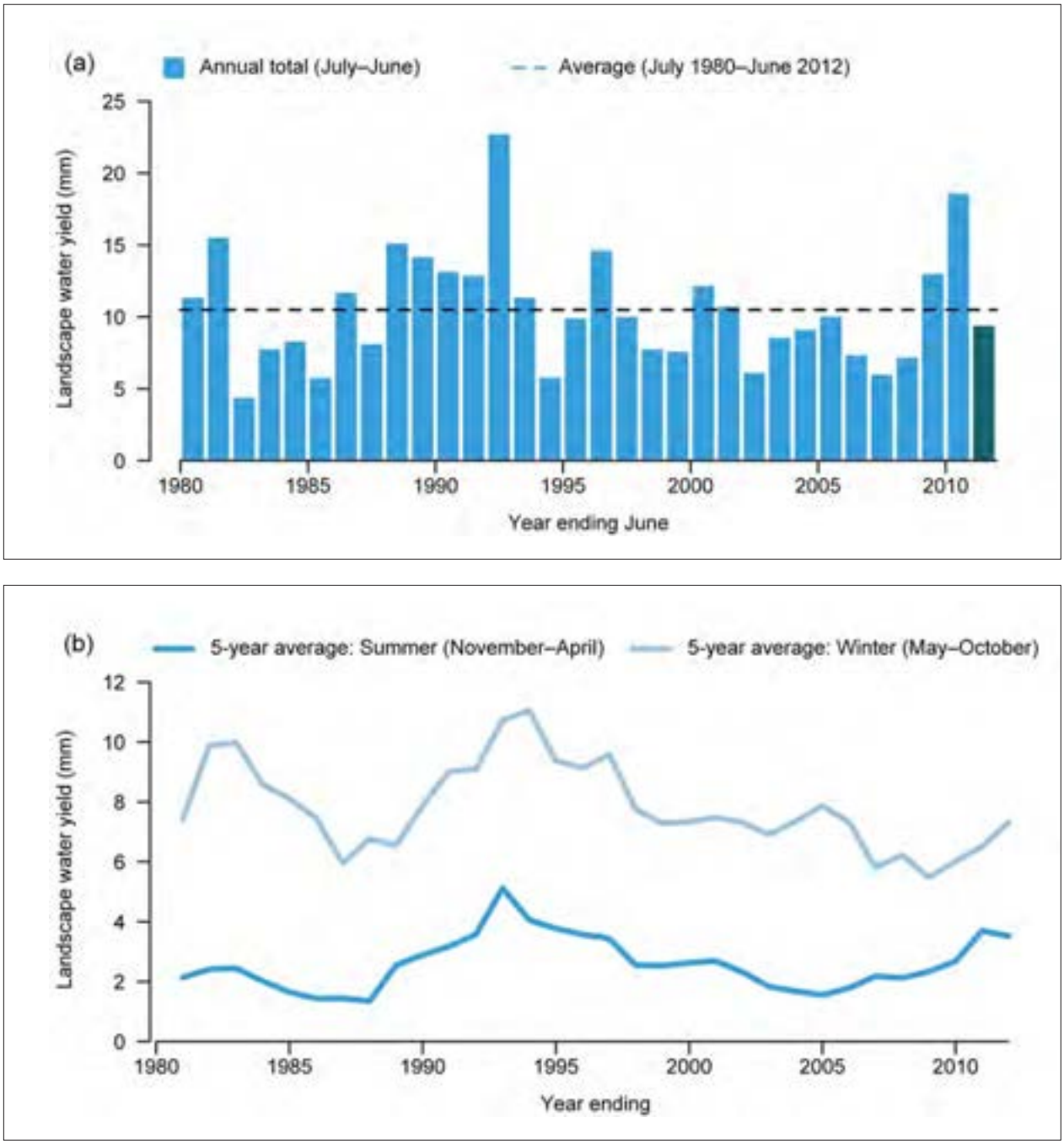


Figure 8.20 Time-series of (a) annual landscape water yield and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Australian Gulf region

Recent trends in landscape water yield

Figure 8.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 8.21b.

Similar to rainfall and evapotranspiration, Figure 8.21a shows that since 1980 trends were within the –2 and 2 mm/year margins. With such low total annual landscape water yields involved, this is not surprising.

Figure 8.21b, however, shows some strongly significant rising trends occurring mainly in the central west of the region and in the southern part of Yorke Peninsula. In absolute terms, though, the trends do not exceed 0.2 mm/year in the central western area and 0.5 mm/year on Yorke Peninsula. The strongly significant falling trends on Kangaroo Island do not exceed –1 mm/year.

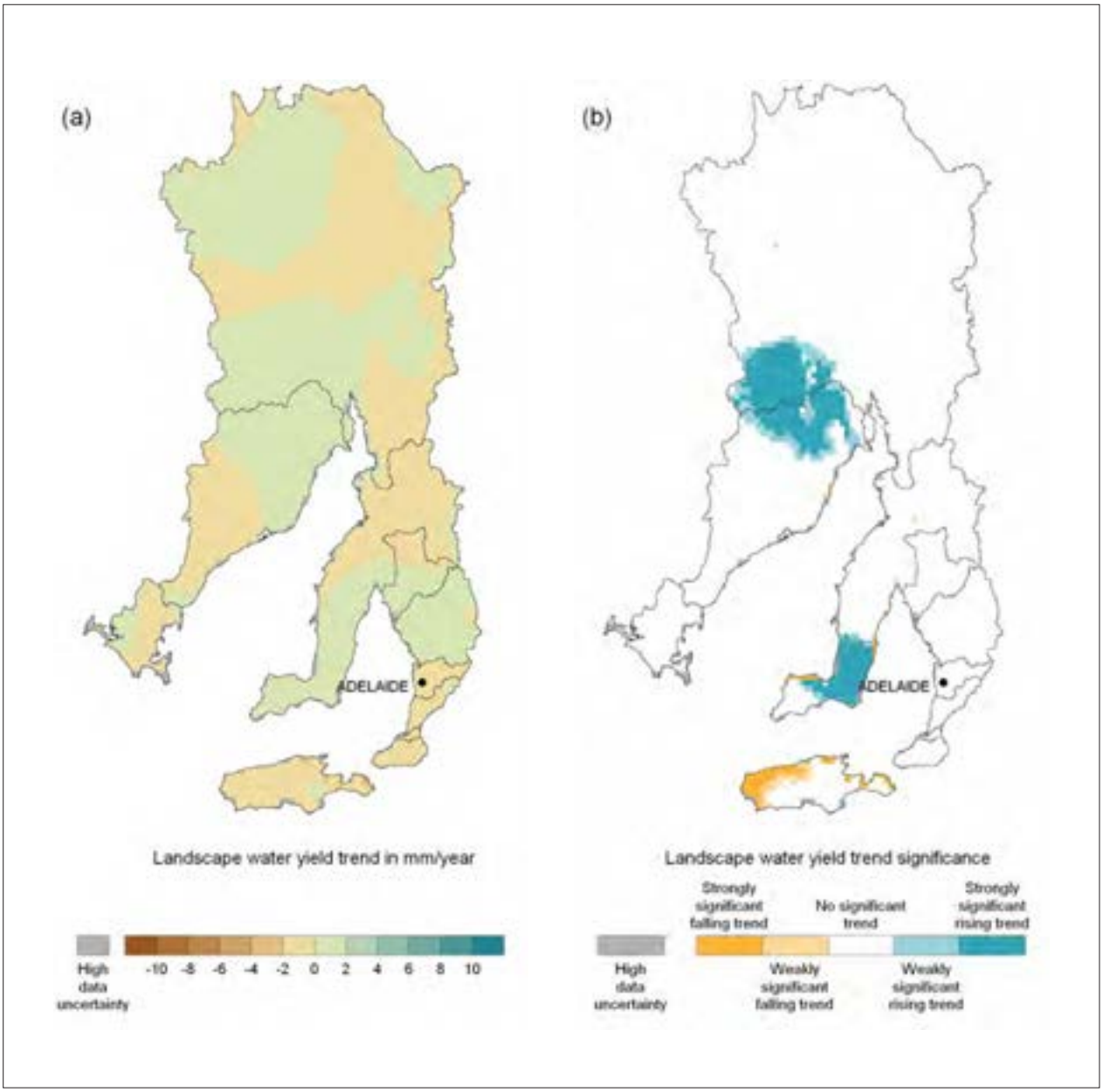


Figure 8.21 Spatial distribution of (a) trends in annual landscape water yield from 1980 to 2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Australian Gulf region

8.5 Surface water and groundwater

This section examines surface water and groundwater resources in the South Australian Gulf region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described and the groundwater status is illustrated by showing changes in groundwater levels at selected sites.

8.5.1 Rivers

There are 11 river basins in the South Australian Gulf region, varying in size from 154–67,000 km^2 (Figure 8.22).

In the west and north, rivers are ephemeral and in the south east corner a few are perennial. There are only minor ephemeral streams in the northern half of the region.

To the southeast of the region, short rivers drain into the ocean. The perennial rivers flow off the slopes of the Mount Lofty Ranges into the Spencer Gulf. In the west, watercourses like the ephemeral Driver River flow from various low hills parallel to the coast on Eyre Peninsula. In the north, the Flinders Ranges supply most of the run-off from the east into Lake Torrens. Undulating land that averages less than 200 m above sea level, including the Andamooka Ranges, supplies the salt lake from the west.

Torrens River, Adelaide | Deqiang Pan, Dreamstime

Figure 8.22 Rivers and catchments in the South Australian Gulf region

8.5.2 Streamflow volumes

Figure 8.23 presents an analysis of flows at 14 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across six geographically representative rivers were selected (see the Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows are mostly average to above average and with some rivers showing very much below average annual flow for 2011–12.

Very much above average flows were observed at two sites located on the South Para River in the southeast and the Hindmarsh River in the far southeast of the South Australian Gulf region. Of the 15 monitoring sites, only one recorded above average flows. This site was on the Hill River near Andrews in the Broughton River basin in the central southeast of the region.

Average flows occurred at seven monitoring sites in the region. These are located on rivers in the southeast and on the Rocky River on Kangaroo Island.

There was only one site where below average flows were recorded. This was on the Myponga River in the far southeast of the region. Very much below average flows were observed at three sites, which are located on the rivers in the central-southeast and on the Onkaparinga River in the southeast.

Flow deciles for the summer period (November 2011–April 2012) are similar to total annual flows for 2011–12 as shown in Figure 8.23. There are a few differences, such as the relatively higher flows observed in the summer period on the Onkaparinga River in the east of the region.

8.5.3 Streamflow salinity

Figure 8.24 presents an analysis of streamflow salinity for 2011–12 at 14 monitoring sites throughout the South Australian Gulf region. Monitoring sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC, µS/cm at 25 °C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation, are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

The median EC values for two monitoring sites in the main rivers fall in the range 0–1,000 µS/cm (suitable for most irrigation uses). Most of the region's rivers and creeks fall outside this range (Figure 8.24).

Of the 14 monitoring sites, two had median EC values between 500–1,000 µS/cm and a further two had values between 1,000–1,500 µS/cm. These are located on the rivers in the far southeast of the region. Of the 14 sites, 71% had median EC values above 2000 µS/cm. These are located on the rivers in the southeast, central southeast and at three sites on Kangaroo Island. The high salinity found in some rivers is a reflection of natural conditions which are influenced by the dry climate, natural salt stores in the landscape and naturally high saline groundwater intrusion which is suitable for most irrigation uses (State of the Environment 2011).

The CV is relatively low for the most of the monitoring sites in the region except for Tanunda Creek. The CV in EC is typically related to the variability in annual flow at the monitoring site. Of the 14 monitoring sites, 21% of them had a CV below 20%, and 71% of the sites had a CV between 20% and 60%. These were located on the rivers in the southeast, central south and on Kangaroo Island. The CV was above 60% in Tanunda Creek in the southeast of the region.

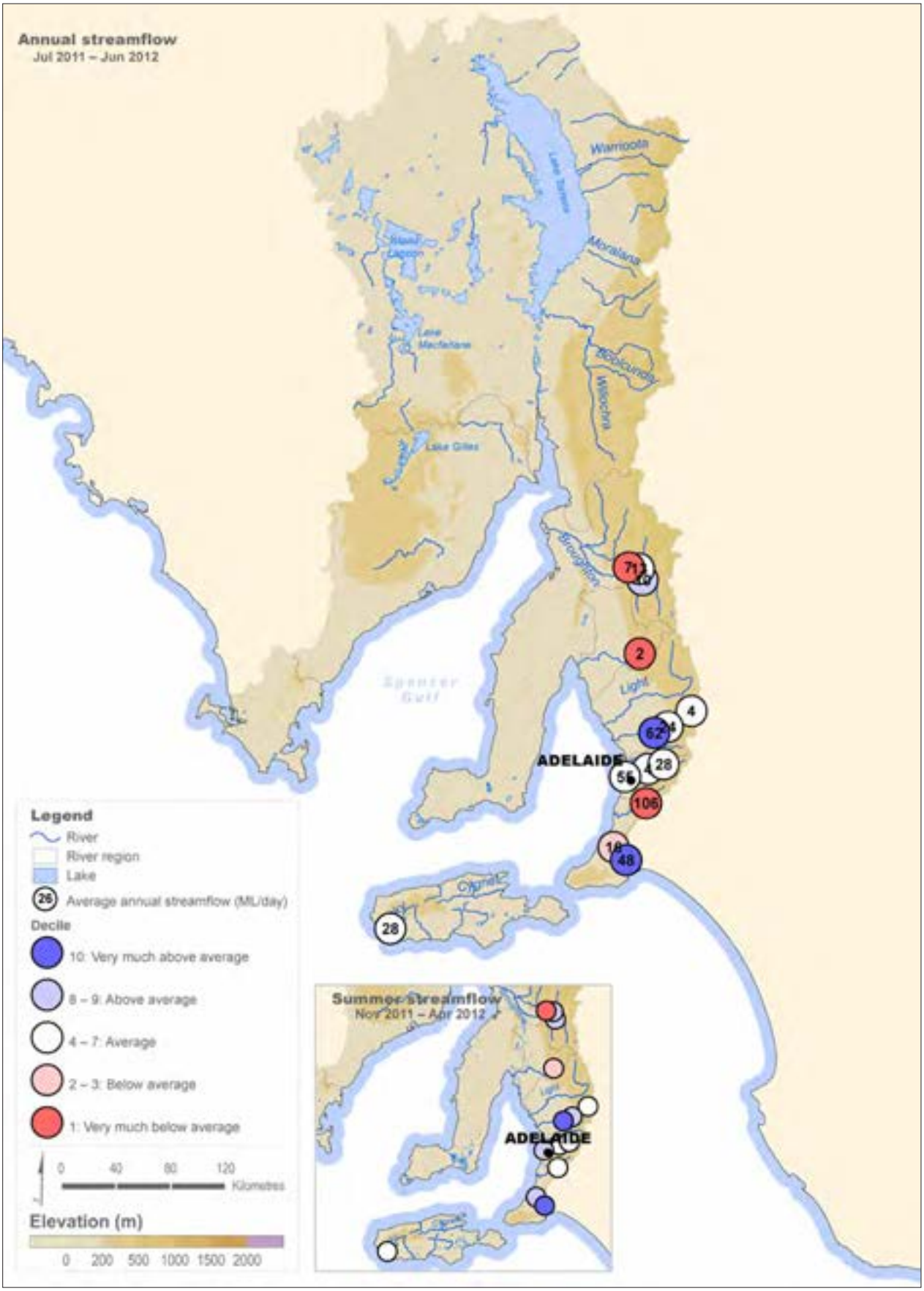


Figure 8.23 Average annual and summer period flow volumes of selected sites for 2011–12 and their decile rankings over the 1980–2012 period in the South Australian Gulf region

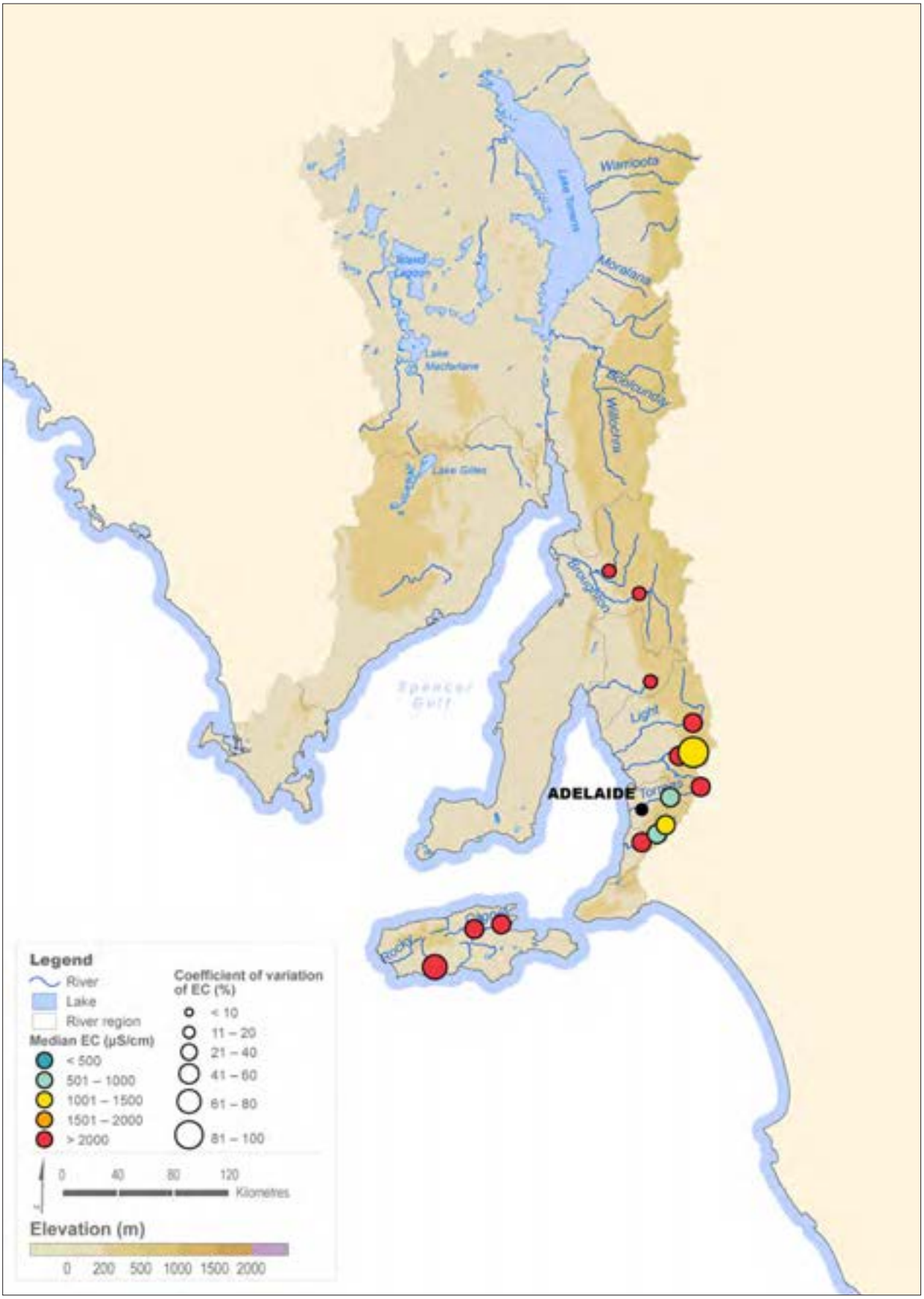


Figure 8.24 Salinity as electrical conductivity and its associated coefficient of variation for 2011–12 in the South Australian Gulf region

8.5.4 Flooding

There were no major floods recorded for the South Australian Gulf region during the reporting year. Minor flooding occurred only in local creeks in July and September 2011 and in March 2012 (Figure 8.25).

8.5.5 Storage systems

There are approximately 16 major publicly owned storages in the South Australian Gulf region with a total capacity in excess of 268 GL. The Bureau's water storage website includes information on approximately 74% of the region's publicly owned storage capacities (as at August 2012)

All of the storages in the Bureau's water storage information for this region supply the city of Adelaide, adding up to a total accessible capacity of 197 GL. At the end of 2010–11, storage levels were at 135 GL (69% of total accessible capacity), but by the end of 2011–12 this had dropped to 96 GL (49% of total accessible capacity). The location of all the systems and associated storages are shown in Figure 8.26.

The city of Adelaide is not fully dependent on storage water supply only. A large portion of the city's water supply originates from transfers out of the River Murray, which has recently been complemented by desalinated water; however, the decrease in storage levels by 20% is not a favourable situation. This is reflected in stricter water conservation rules.

More detailed information on the Adelaide water supply system is given in subsection 8.6, Water for cities and towns. Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

8.5.6 Wetlands

There are no Ramsar-listed, internationally important wetlands in the South Australian Gulf region; however, there are a number of wetlands of national importance mentioned in the *Directory of Important Wetlands in Australia* (www.environment.gov.au/water/topics/wetlands/database/diwa.html). The wetlands vary from coastal tidal flats to inland ephemeral lakes and large salt lakes (Figure 8.27). No detailed assessment on the inflows of selected wetlands has been performed for this region.

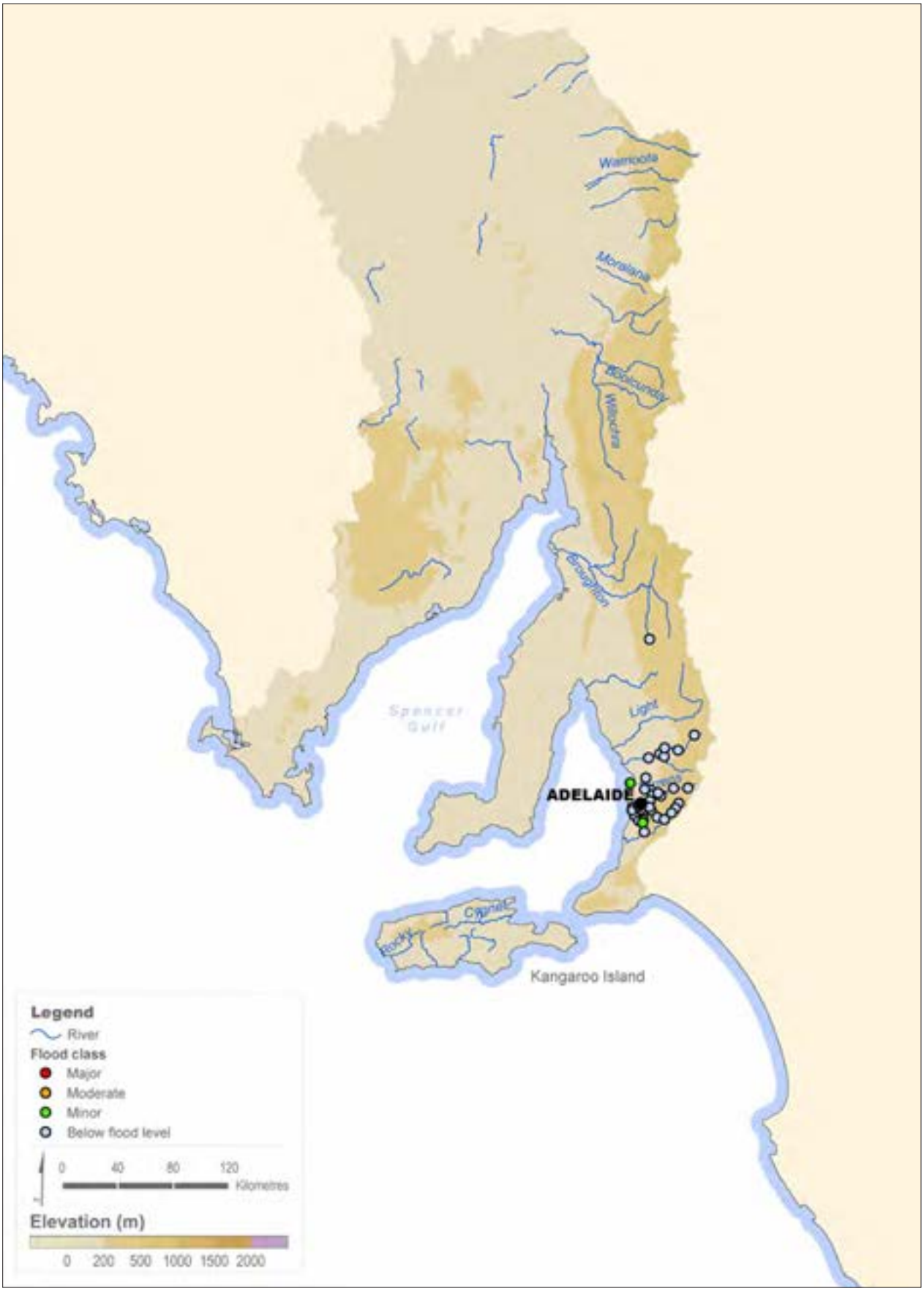


Figure 8.25 Flood occurrence in 2011–12 for the South Australian Gulf region, with each dot representing a river level monitoring station and the colour of the dot representing the highest flood class measured

Figure 8.26 Storage systems in the South Australian Gulf region (information extracted from the Bureau's water information website in August 2012)

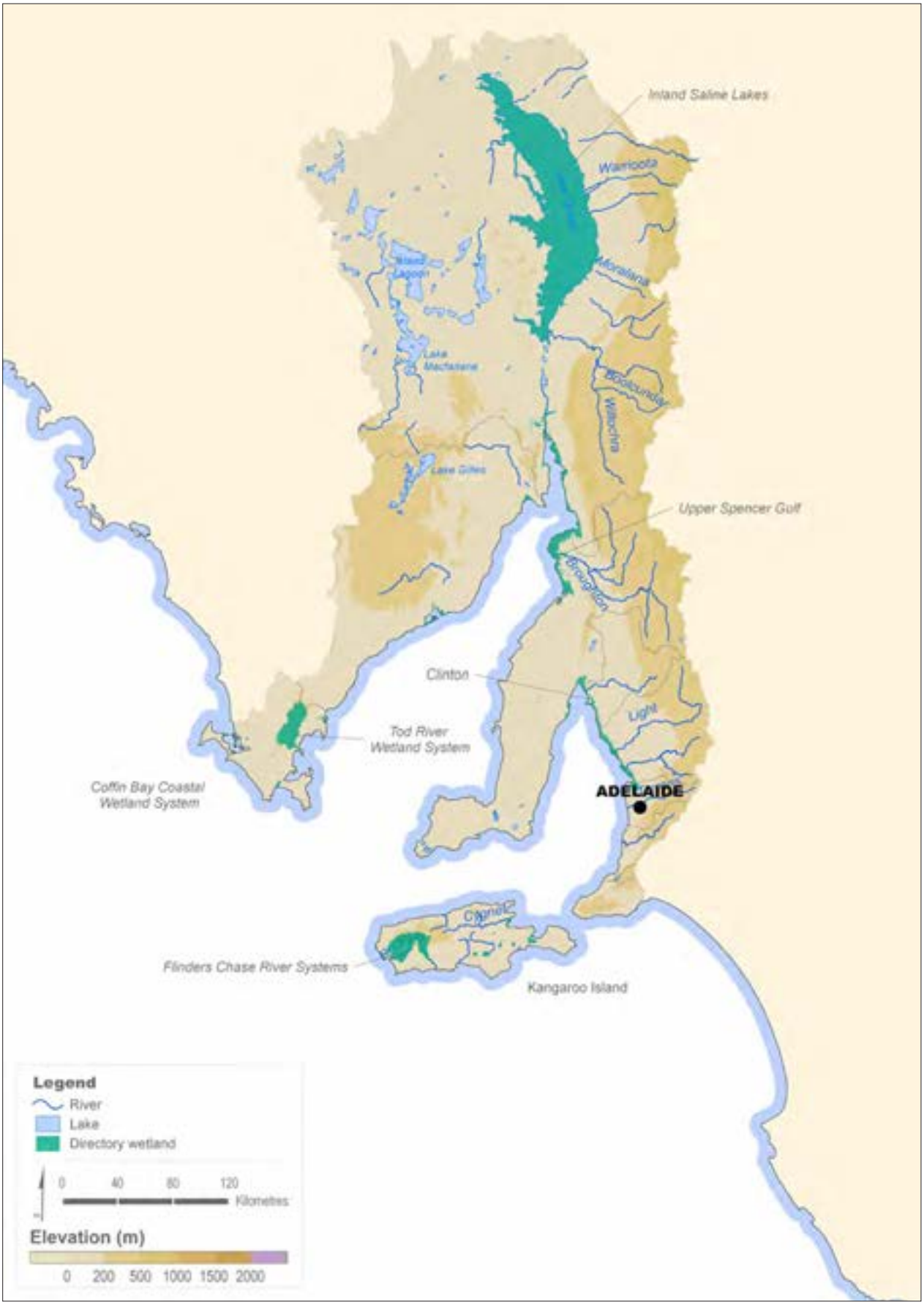


Figure 8.27 Location of important wetlands in the South Australian Gulf region

8.5.7 Hydrogeology

The hydrogeology of the South Australian Gulf region can be partitioned into areas of surficial and underlying sediments, and areas of outcropping fractured rock.

Groundwater use in the region is largest in areas with surficial sediments and underlying aquifers. Figure 8.28 shows major aquifer groups present at the watertable. Aquifer groups that provide potential for groundwater extraction (as labelled in Figure 8.2) are:

- lower mid-Tertiary aquifer ; (porous media— unconsolidated)
- upper Tertiary aquifer (porous media— unconsolidated); and
- upper Tertiary/Quaternary aquifer (porous media—unconsolidated).

The sediments of the Great Artesian Basin are present along the northern boundary of the region but are not dominant for water provision.

8.5.8 Water table salinity

Figure 8.29 shows the classification of watertable aquifers as fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L). As shown, most parts of the region are considered to have saline groundwater that is usually not suitable for irrigation. Non-saline groundwater occurs in the east of the region and in particular around the Adelaide area.

8.5.9 Groundwater management units

The groundwater management units within the region (Figure 8.30) are administrative boundaries that are used to manage the extraction of groundwater through planning mechanisms. These areas are usually created to identify a significant groundwater resource and to provide a boundary within which resource management effort can be focused. Prescription is the legal mechanism for implementing a water resource management regime in South Australia. A prescribed water resource is managed through an allocation and licensing system where the emphasis is on groundwater. These areas are known as water resources prescribed areas and prescribed wells areas within South Australia.

Groundwater management units are found in areas with significant fresh groundwater resources. These are the surficial sediments and the underlying Quaternary and Tertiary aquifers. The fractured rock systems typically offer restricted low volume groundwater resources; however, there are some parts of this region with a greater density of fractures and more substantial groundwater resources. Typically, groundwater use is high in prescribed wells areas such as McLaren Vale, the northern and central Adelaide Plains, and the southern basins.

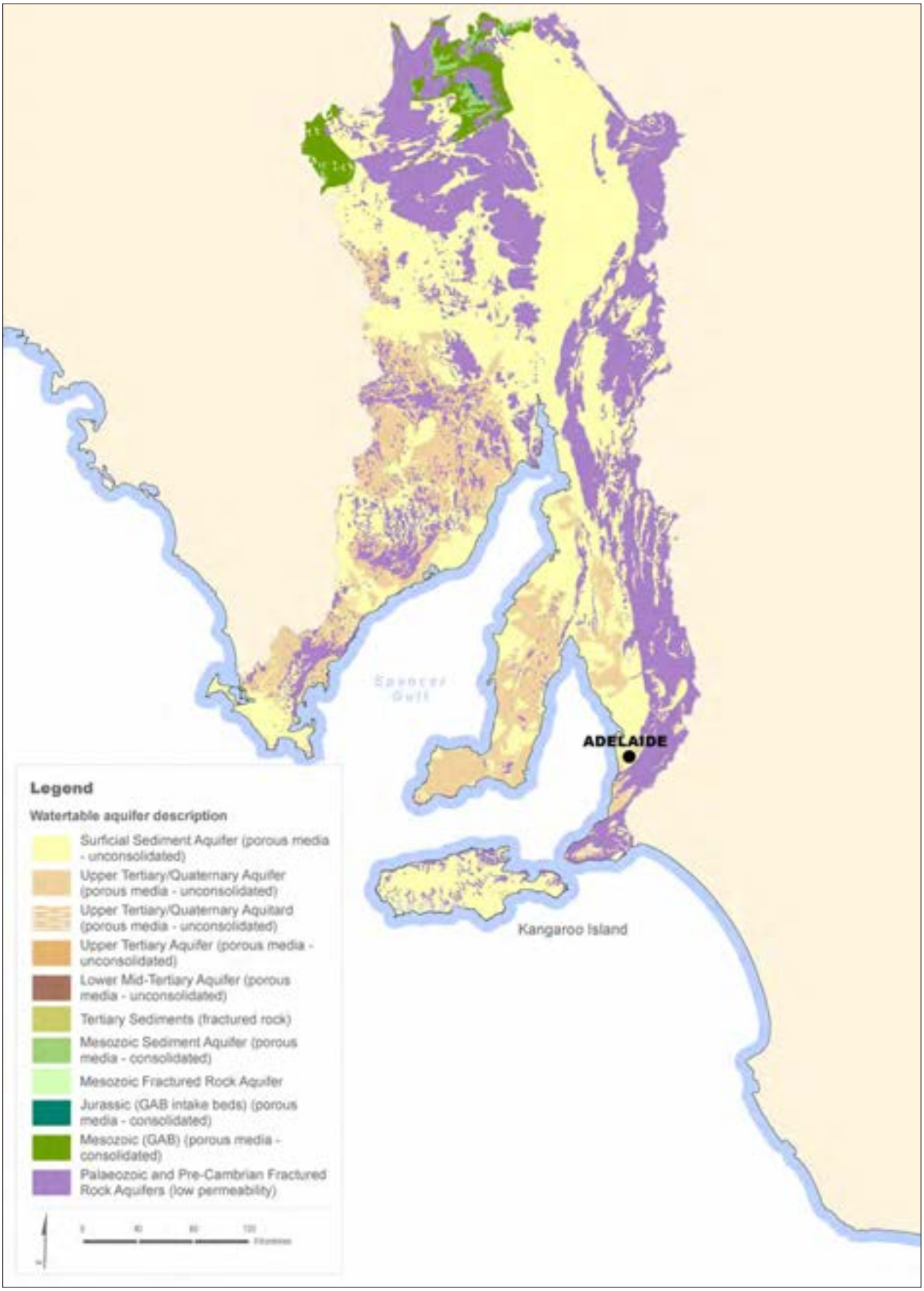


Figure 8.28 Watertable aquifer groups in the South Australian Gulf region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

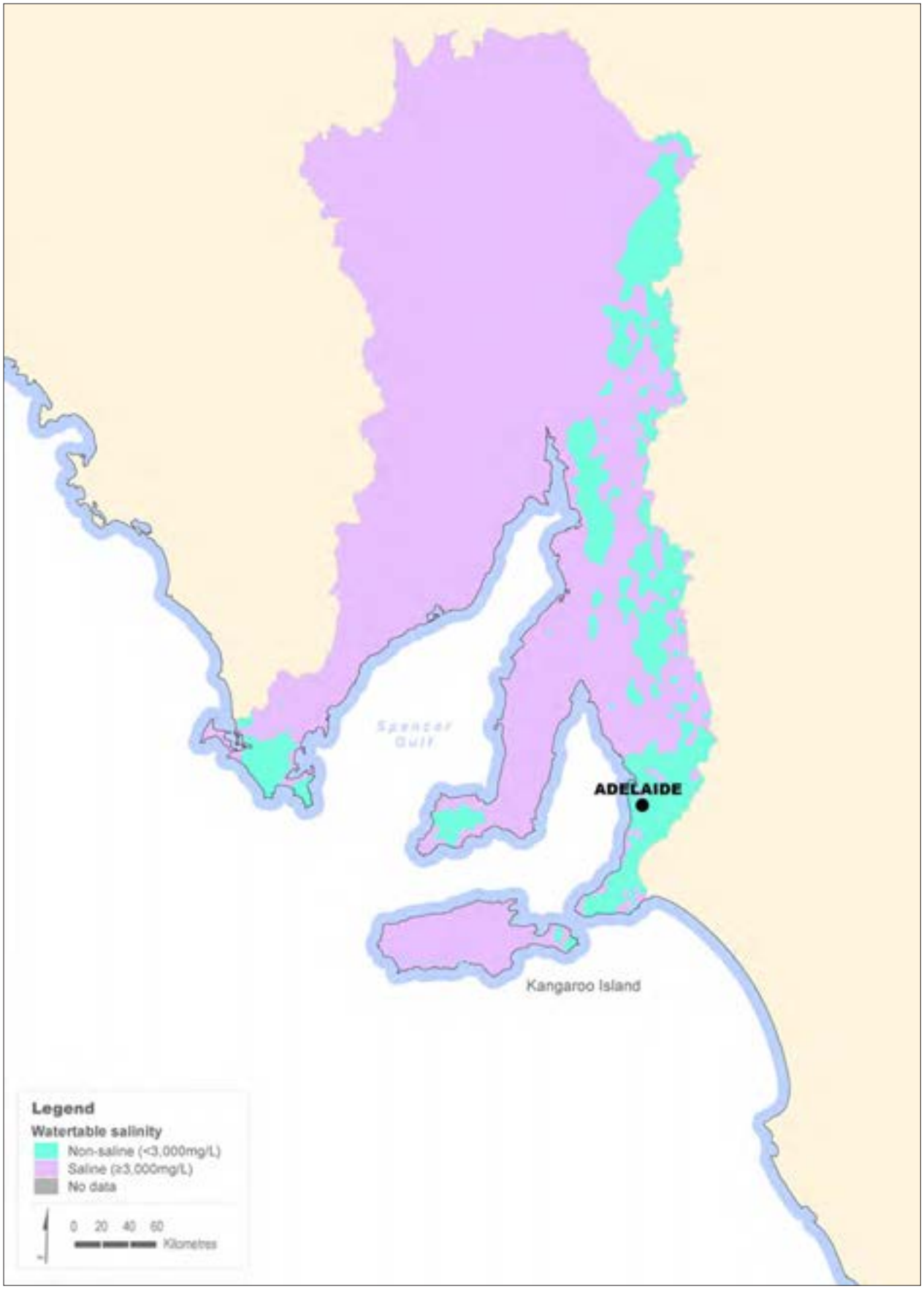


Figure 8.29 Watertable salinity classes in the South Australian Gulf region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2013)

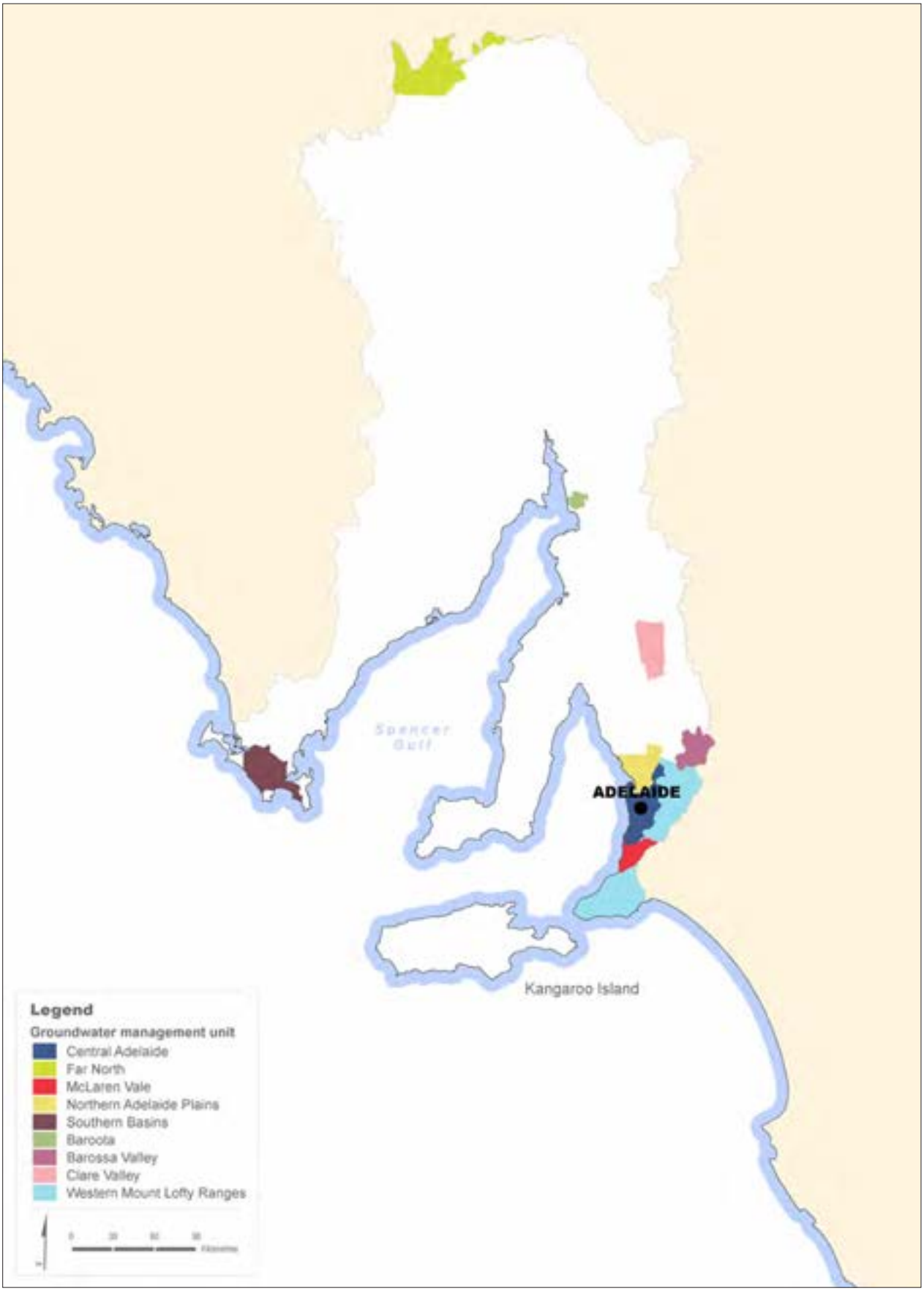


Figure 8.30 Groundwater management units in the South Australian Gulf region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

8.5.10 Status of selected aquifers

The status of groundwater levels is assessed for the Adelaide Plains and McLaren Vale aquifers which are major groundwater resources for the region. These aquifers are associated with three of the most important groundwater management units (prescribed well areas) shown in Figure 8.30. The assessment of groundwater levels evaluates trends in groundwater levels over the 2007–08 to 2011–12 period.

The trends in groundwater levels are investigated using a 5 km x 5 km grid cell across data rich areas. This scale reflects the size of the selected aquifers in the region. The linear trend in groundwater levels for a grid cell is assessed as:

- decreasing (where more than 60% of the bores have a negative trend in levels lower than –0.1 m/year);
- stable (where the trend is lower than 0.1 m/year and higher than –0.1 m/year for more than 60% of the bores);
- increasing (where more than 60% of the bores have a positive trend in levels higher than 0.1 m/year); and
- variable (where there is no dominant trend in groundwater levels amongst the bores within a grid cell).

Example bore hydrographs are presented for each aquifer over the entire record length and trends are discussed with a focus on the 2007–08 to 2011–12 period. The selected bore hydrographs represent mostly bores with high data density that were used in the 2010 Assessment. Aquifers considered:

- Adelaide Plains watertable
- Adelaide Plains Tertiary aquifer 1 (T1)
- Adelaide Plains Tertiary aquifer 2 (T2)
- McLaren Vale watertable
- Willunga
- Maslin.

Adelaide Plain aquifers

Figure 8.31 illustrates the spatial and temporal grid analyses of trends in groundwater levels of the Adelaide watertable over the period 2007–08 to 2011–12. Trends in groundwater levels were analysed in data-rich areas only. As shown in Figure 8.31, in the north of the aquifer groundwater levels are mostly rising. This reflects the increased groundwater recharge due to the recent high rainfall.

Selected bores 1 and 2 show variability in groundwater levels but no significant trend over the period. Peaks in water levels in these two bores represent groundwater response to infrequent recharge events. In contrast, Bore 3 shows stable levels until 2010. All bores show an increase in groundwater level after 2010 indicating recharge to groundwater during the recent high rainfall period.

Figure 8.32 illustrates the spatial and temporal grid analyses of trends in groundwater levels for the Tertiary aquifer T1 over the period 2007–08 to 2011–12. The trend analysis for the south of the aquifer indicates that groundwater levels for the past five years are either declining or variable. This is most likely in response to groundwater extraction in the southern area.

The selected hydrographs 4–6 indicate that variability in levels within a year is much larger than the inter-annual trend in levels. This illustrates the seasonal cycles of pumping and recovery of groundwater levels at the end of pumping season. All selected bores show a declining trend for the period 2007–08 to 2009–10 period and various degrees of recovery of groundwater levels, and therefore recharge, associated with higher rainfall since 2010.

Figure 8.33 illustrates the spatial and temporal grid analyses of trends in groundwater levels for the Tertiary aquifer T2 over the period 2007–08 to 2011–12. The analysis for T2 aquifer is focused in the north of the aquifer, and shows that groundwater levels for the past five years are either increasing or variable, similary to the watertable aquifer. All selected bores show declining trends for the period 2007–08 to 2009–10 and some degree of recovery thereafter.

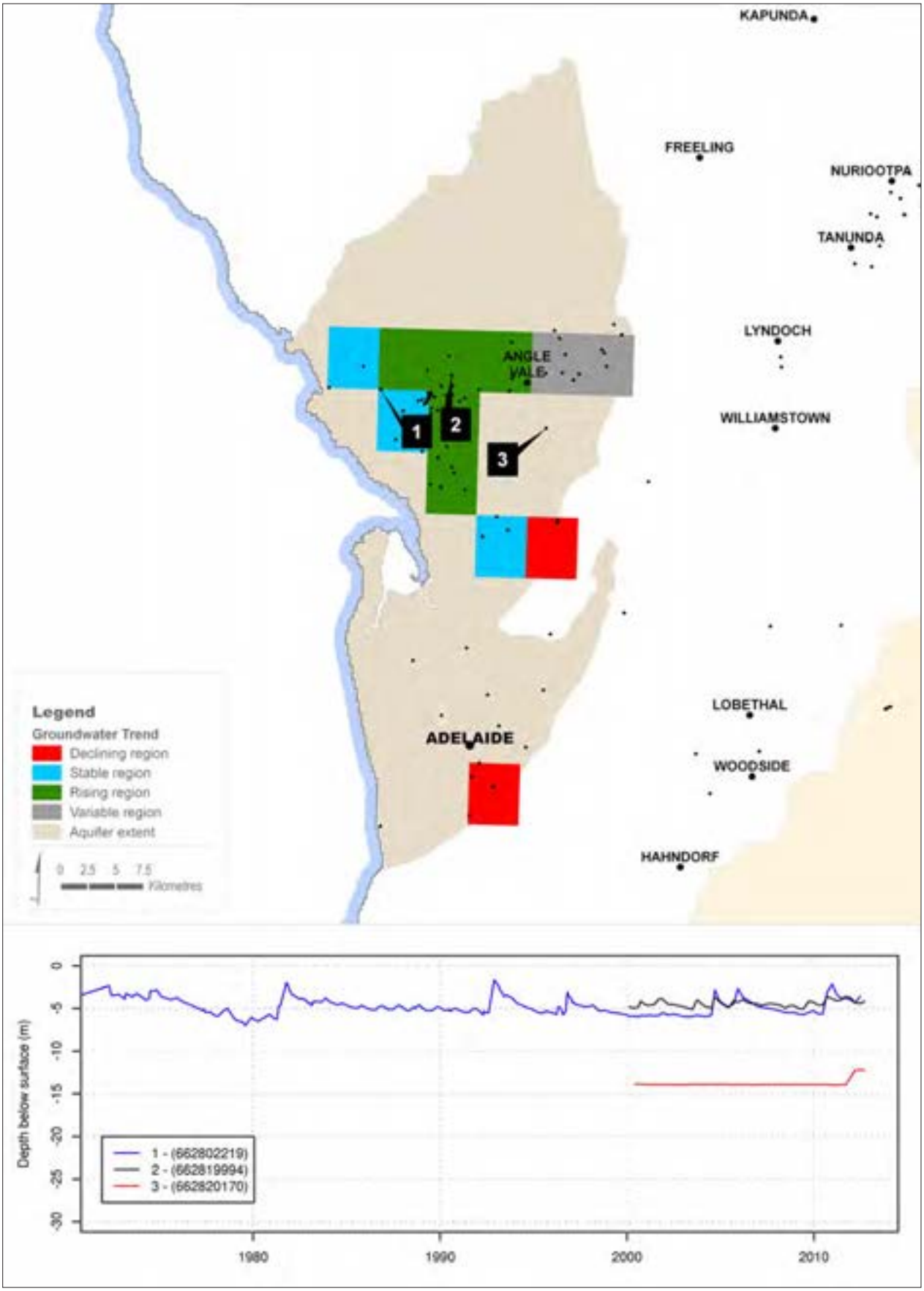


Figure 8.31 Spatial distribution of trends in groundwater levels for the Adelaide Plains watertable in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

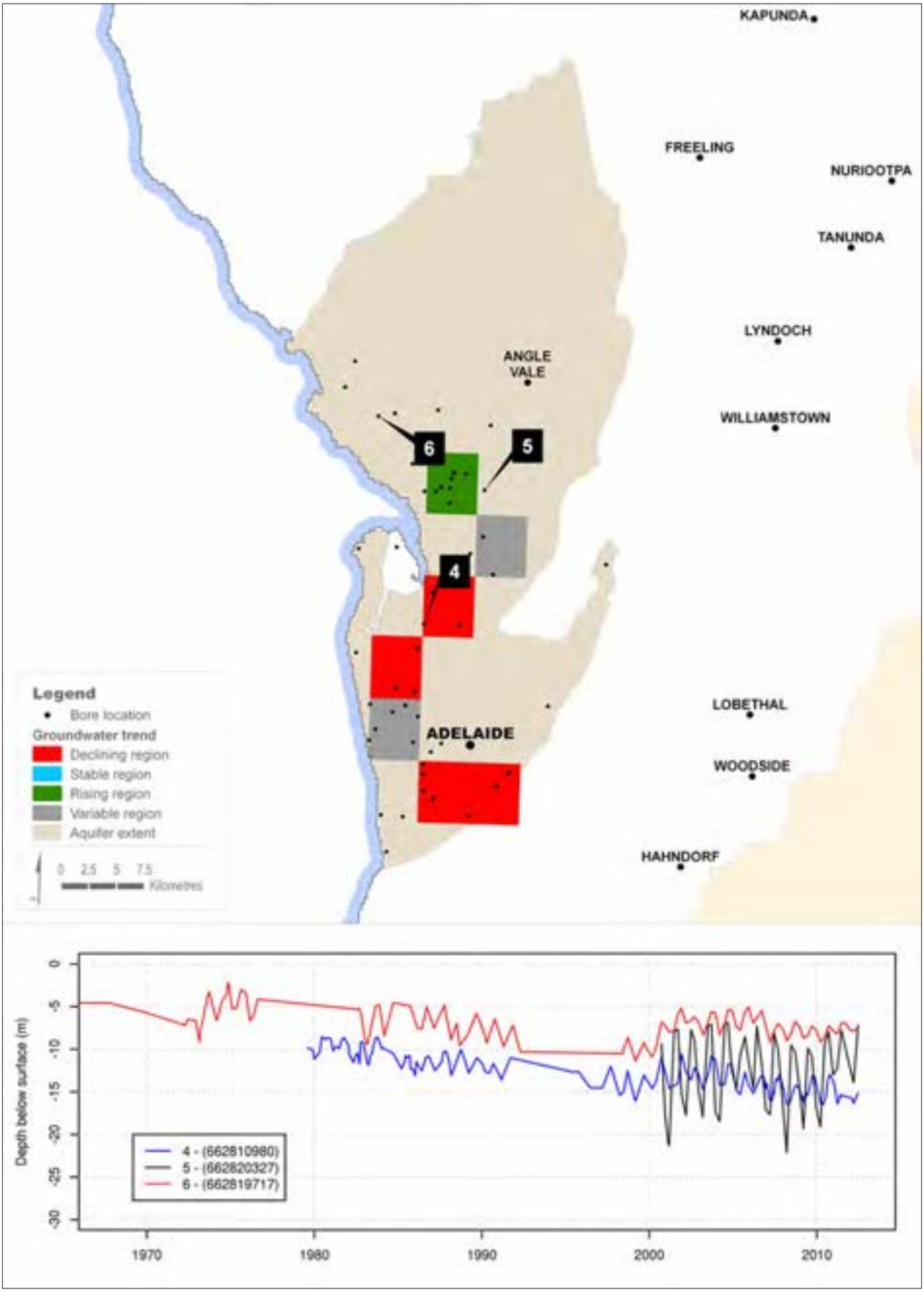


Figure 8.32 Spatial distribution of trends in groundwater levels for the Adelaide Plains T1 aquifer in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

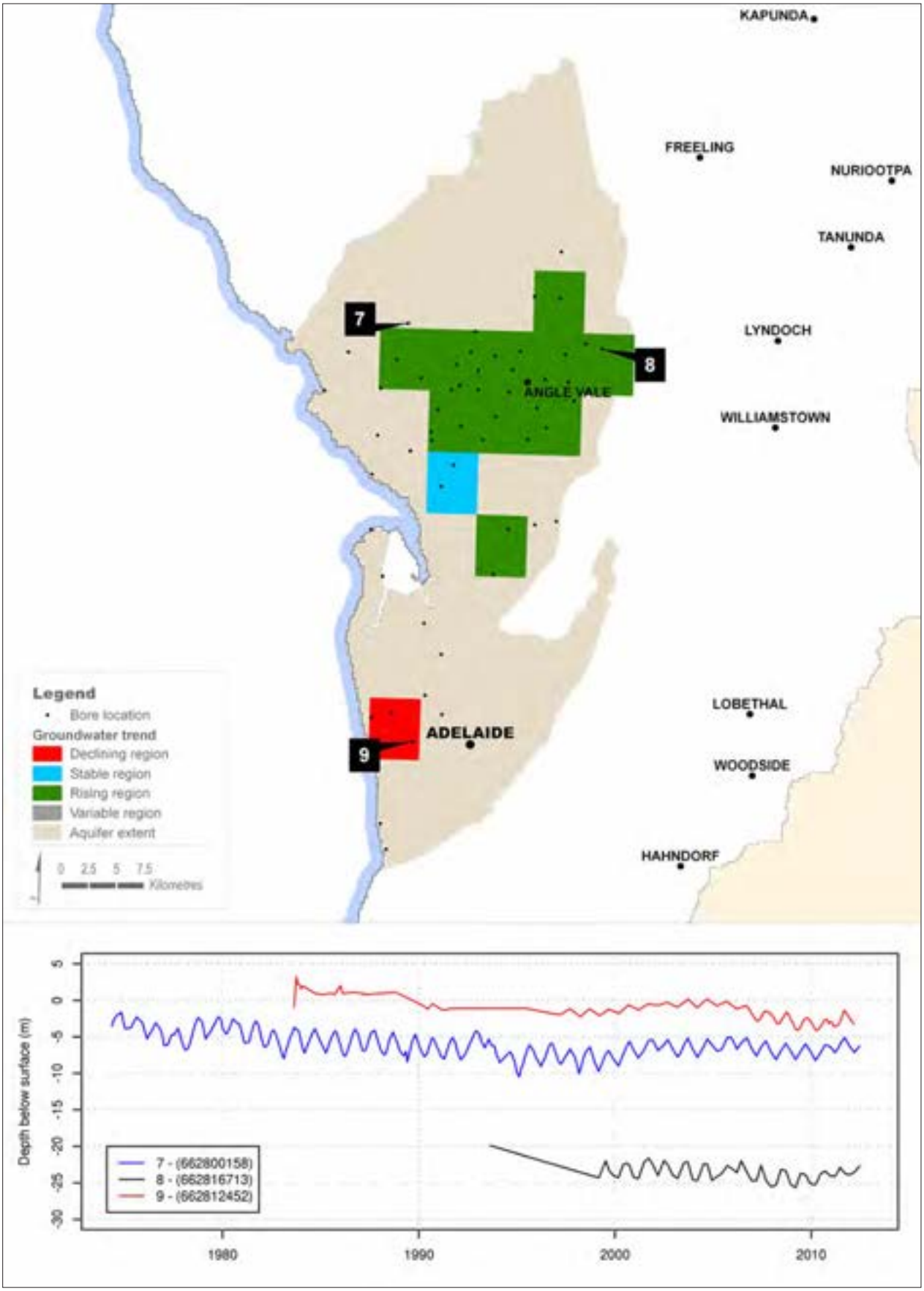


Figure 8.33 Spatial distribution of trends in groundwater levels for the Adelaide Plains T2 aquifer in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

McLaren Vale aquifers

Figure 8.34 illustrates the spatial and temporal trends in groundwater levels of the McLaren Vale watertable over the period 2007–08 to 2011–12. Grid analyses of trends in groundwater levels were carried out in data-rich areas only where three or more bores were present in a grid cell. As shown in Figure 8.34, groundwater levels are consistently stable.

The selected bores 10–12 have annual fluctuations in water levels that are most likely caused by seasonal groundwater recharge to the watertable. Hydrographs for these bores illustrate long- term relatively stable trends in water levels and, in particular, no major recharge event since 2010.

Figure 8.35 shows the grid analyses of trends in groundwater levels within the underlying Willunga aquifer, illustrating stable or declining levels for the period 2007–08 to 2011–12.This is a highly utilised aquifer and therefore the declining trends are most likely driven by groundwater extraction.

The selected bores 13–15 show continuously declining levels since the start of the records, with annual fluctuations in groundwater levels that correspond to seasonal cycles of pumping and recovery.

Figure 8.36 shows the grid analyses of trends in groundwater levels within the Maslin aquifer, indicating no prevalent trend over the period 2007–08 to 2011–12; however, no grid cells with an overall declining trend are present. This aquifer becomes unconfined in the northeast; therefore the groundwater level trends are likely to reflect the recent groundwater recharge episodes due to high rainfall.

Bores 16, 17 and 18 located at the eastern and southern ends of the Maslin Sands aquifer have stable water levels for the period 2007–08 to 2011–12 with no major recharge episode post 2010. Bore 17, located at the western end of the aquifer, shows annual fluctuations in water level that may be due to pumping from a nearby bore.

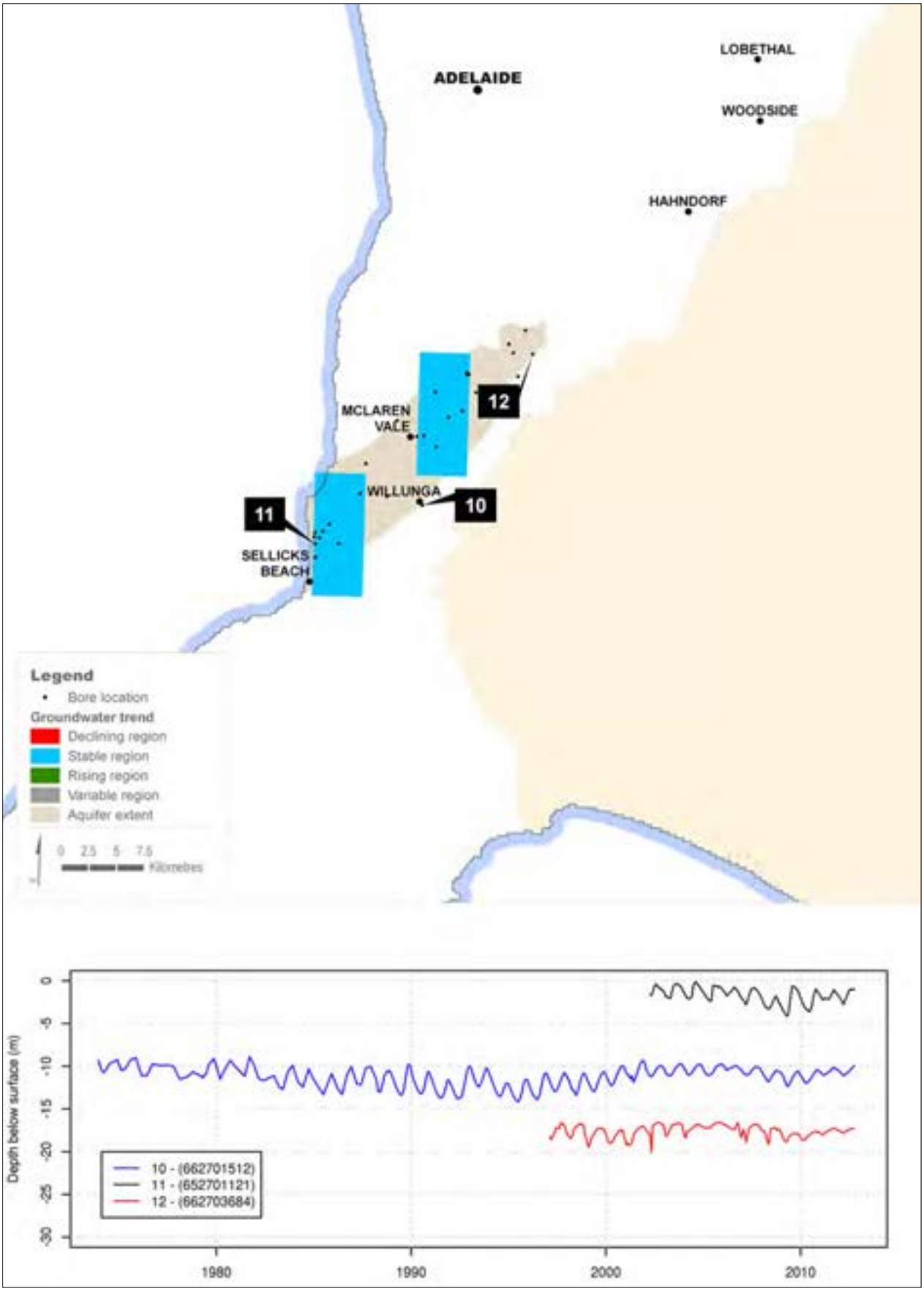


Figure 8.34 Spatial distribution of trends in groundwater levels for the McLaren Vale watertable in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

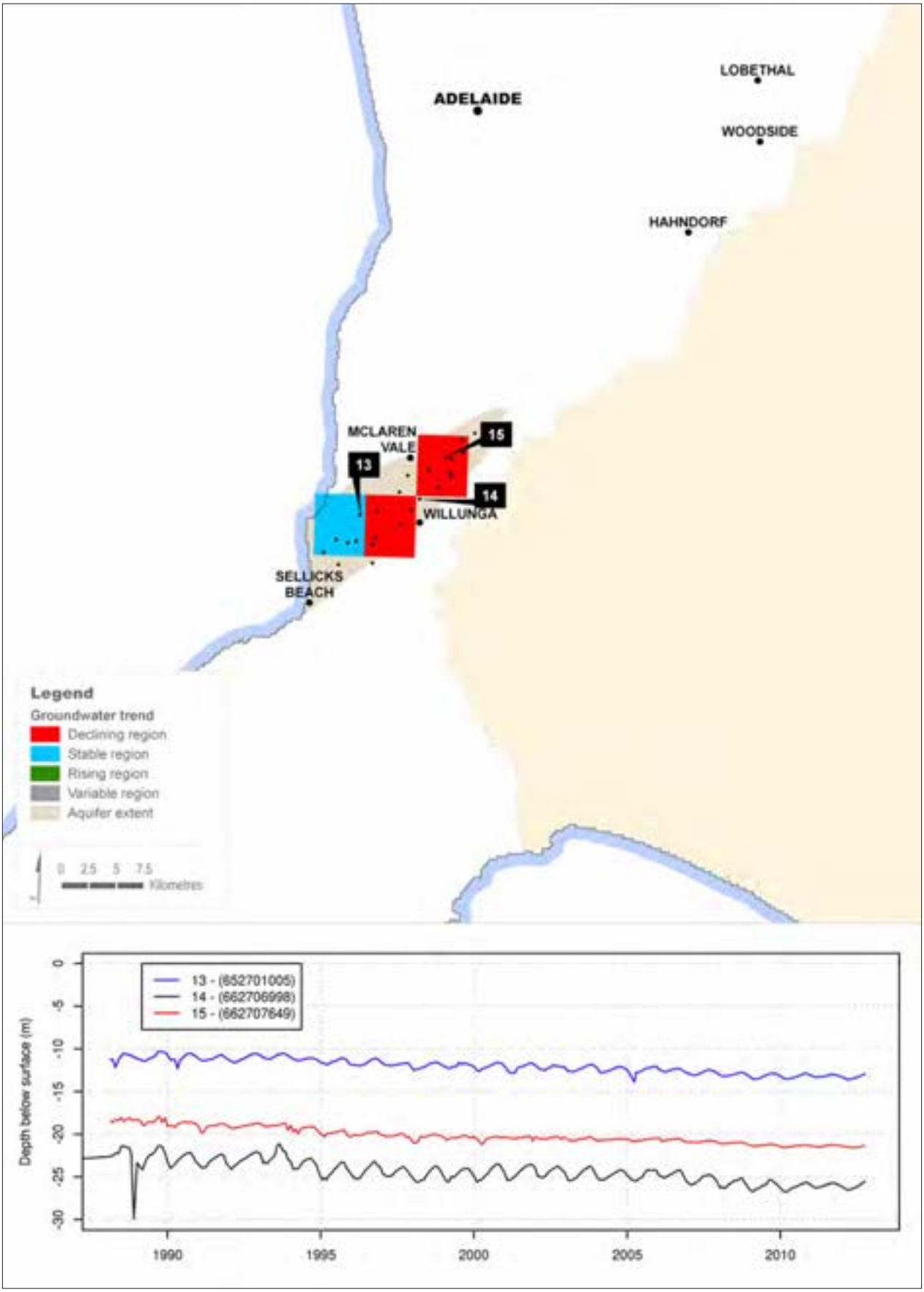


Figure 8.35 Spatial distribution of trends in groundwater levels for the Port Willunga aquifer in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

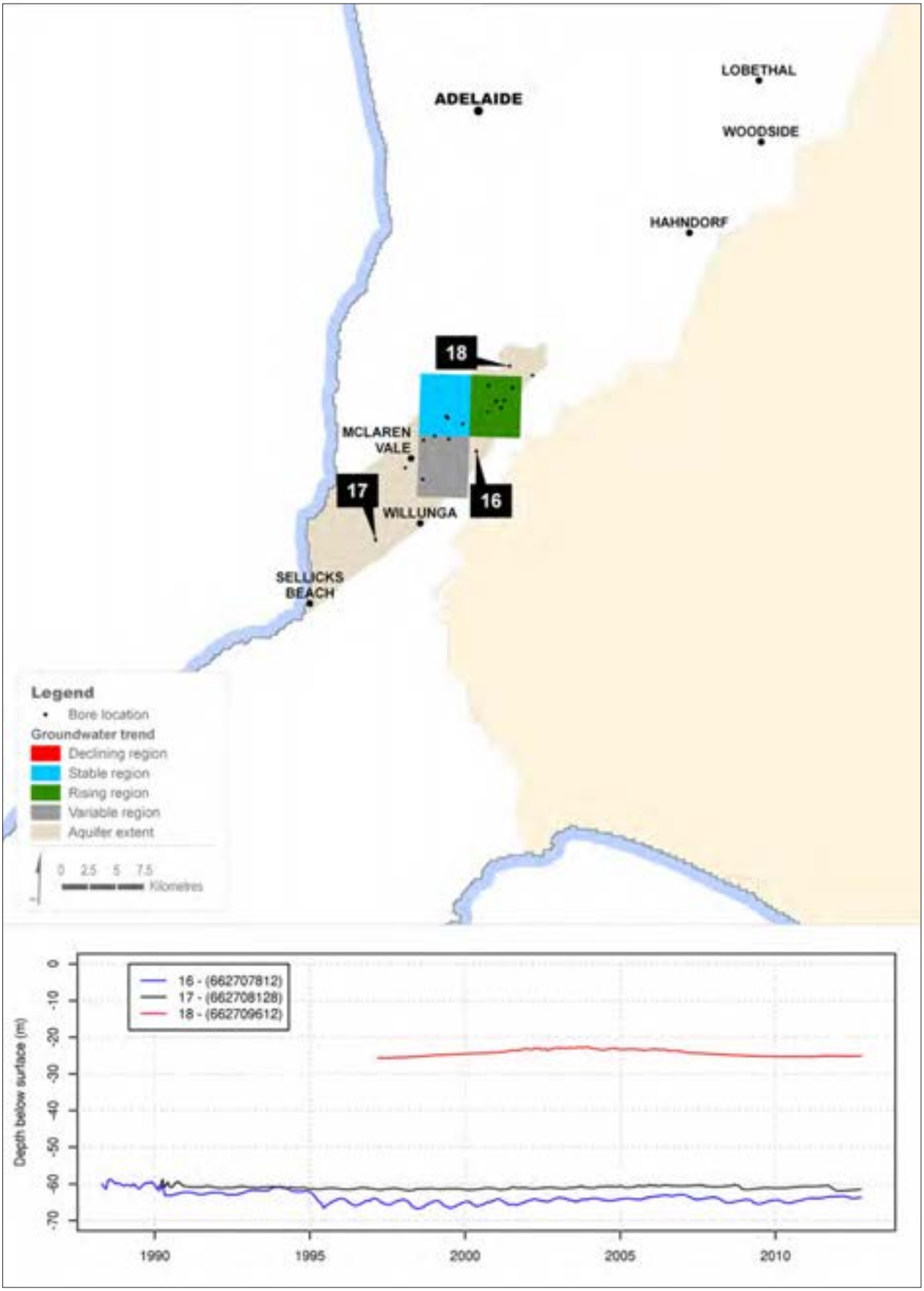


Figure 8.36 Spatial distribution of trends in groundwater levels for the Maslin Sands aquifer in the South Australian Gulf region for 2007–08 to 2011–12, with selected hydrographs showing groundwater levels

8.6 Water for cities and towns

This section examines the urban water situation in the South Australian Gulf region in 2011–12. The large urban centres in the region, their water supply systems and storage situations are briefly described. The main urbanised area, Adelaide, is discussed in more detail in subsection 8.6.3, including the history of water restrictions over recent years.

8.6.1 Urban centres

Adelaide is the largest city in the South Australian Gulf region and has more than 1.1 million residents. It is located north of the Fleurieu Peninsula, on the Adelaide Plains between the Gulf of St Vincent and the low-lying Mount Lofty Ranges which surround the city. Adelaide stretches 20 km from the coast to the foothills, and 90 km from Gawler at its northern extent to Sellicks Beach in the south.

Beyond Adelaide the region has four major population centres: Whyalla, Port Lincoln, Port Augusta and Port Pirie. These urban centres, along with Adelaide and other regional towns in conjunction with their population ranges, are shown in Figure 8.37.

The major urban centres of the region (populations over 10,000 people) are also summarised in Table 8.3. This table provides information on the population, surrounding river basins and significant water storages for each of the major centres.

Whyalla, with a population of just under 22,000, is the region's second most populous city. It is a seaport located on the northeast coast of the Eyre Peninsula. The town is strongly influenced by the mining industry.

Port Lincoln is the third major town in the South Australia Gulf region and has a population of just over 14,000. It is a seaside town on Boston Bay at the southern extremity of the Eyre Peninsula. It is the largest town in the west of the region, and is located approximately 650 km from Adelaide.

Port Augusta has a population of just fewer than 14,000 and is the region's fifth most populous town. It is a seaport and railway junction at the northern tip of the Spencer Gulf.

The population of Port Pirie is 13,800. It is also a seaport on the east coast of the Spencer Gulf, about 225 km north of Adelaide.

Table 8.3 Cities and their water supply sources in the South Australian Gulf region

City	Population[1]	River basin	Major supply sources
Adelaide	1,104,000	Gawler, Torrens, Onkaparinga, Myponga and Fleurieu Peninsula	Myponga, Barossa, Little Para, Kangaroo Creek, Mount Bold, Happy Valley, Hope Valley, Warren, Millbrook and South Para storages
Whyalla	21,700	Spencer Gulf	River Murray (Morgan–Whyalla pipeline)
Port Lincoln	14,100	Eyre Peninsula	Groundwater (Southern Basins) River Murray (Morgan–Whyalla pipeline)
Port Pirie	13,800	Mambray Coast and Broughton River	Baroota storage, River Murray (Morgan–Whyalla pipeline)
Port Augusta	13,500	Mambray Coast	River Murray (Morgan–Whyalla pipeline)

[1] Australian Bureau of Statistics (2011b)

Figure 8.37 Population range of urban centres in the South Australian Gulf region

8.6.2 Sources of water supply

While the regions's surface water storages play an important role in the provision of its water supplies, its relatively low rainfall and long, dry summers have seen a growth in its dependence on diversions from the River Murray to meet its demands. South Australia holds an 1,850 GL-per-year entitlement to flows in the River Murray and during good rainfall years is entitled to extract an additional 3 GL per day as dilution flows.

Flows extracted from the Murray are distributed throughout the region by five bulk water transfer pipelines totalling over 650 km in length.

The Mannum–Adelaide and the Murray Bridge–Onkaparinga pipelines supply the city of Adelaide while the Swan Reach–Stockwell pipeline supplies water to townships (and farms) north of Adelaide and along its route.

The Morgan–Whyalla pipeline supplies many of the regions northern population centres and rural communities, including those of Whyalla, and Port Augusta to Woomera. At a length of 379 km, it is the longest of the five major pipelines in the region. Communities in the upper southeast of the region are supplied via the Tailem Bend–Keith pipeline. Figure 8.38 shows the major pipelines and storages in use for urban water supply.

In addition to imported and surface water storages, the region relies heavily on groundwater, recycled water and harvested storm and rainwater to supply its urban demands. In particular, South Australia has been a national leader in the use of recycled and stormwater.

8.6.3 Adelaide

The South Australia Water Corporation (SA Water) is the South Australian Government-owned statutory body that owns and manages Adelaide's water supply systems, recycled water systems and wastewater services. SA Water controls surface water diversions, operates water treatment plants and maintains Adelaide's reticulation system.

It supplies customers in the greater Adelaide area which includes the city of Adelaide as well as the surrounding suburbs, stretching over the Gawler, Torrens, Onkaparinga and Myponga river basins.

Water supply system

Historically, the provision of a reliable and secure water supply to Adelaide has been a challenge because of its highly variable rainfall; however, the construction of a series of major pipelines supplying water from the River Murray and construction of a desalination plant have served to further ensure a reliable water supply for Adelaide.

Key components of the Adelaide water supply system include the Mannum–Adelaide and Murray Bridge–Onkaparinga pipelines, ten major storages totalling 197 GL in capacity, seven water treatment plants and twelve wastewater treatment plants. In addition, a number of privately operated bore fields supply groundwater primarily for agricultural uses. Some treated water is exported to adjacent regions for urban consumption.

The Mannum–Adelaide pipeline was the first of the pipelines built to deliver River Murray water to Adelaide. It supplies water to the Anstey Hill water treatment plant and to a number of storages.

The Murray Bridge–Onkaparinga pipeline was completed in 1973 and supplies water to the Summit Storage water treatment plant as well as releasing water into the Onkaparinga River for collection and treatment downstream.

Development of the Port Stanvac desalination plant was staged by constructing two 50 GL per year capacity plants. The first plant started production in October 2011 and the second during late 2012. Water from the desalination plant is mixed with treated surface water from the Happy Valley water treatment plant and discharged directly into Adelaide's distribution system.

SA Water operates a number of recycled water and stormwater harvesting schemes. It also strongly promotes individual use of rainwater across the region. A number of recycled water schemes that supply treated effluent for agricultural and municipal irrigation and residential use operate within the greater Adelaide area. Several community or privately operated recycling schemes supply to viticulture and municipal applications.

Figure 8.38 Water supply systems in the South Australian Gulf region

Storage volumes

The Mount Bold, South Para, Kangaroo Creek and Myponga storages constitute 69% of the total Adelaide system storage. South Para serves the Northern Adelaide Plains. Kangaroo Creek is used to supply water to the northern Adelaide suburbs from Port Adelaide to the Torrens River while Mount Bold serves the southern Adelaide suburbs from the Torrens River to the Onkaparinga River. Water from Myponga is distributed along the coast from the Onkaparinga River to Normanville. The accessible volumes of these major storages are shown individually in Figure 8.39.

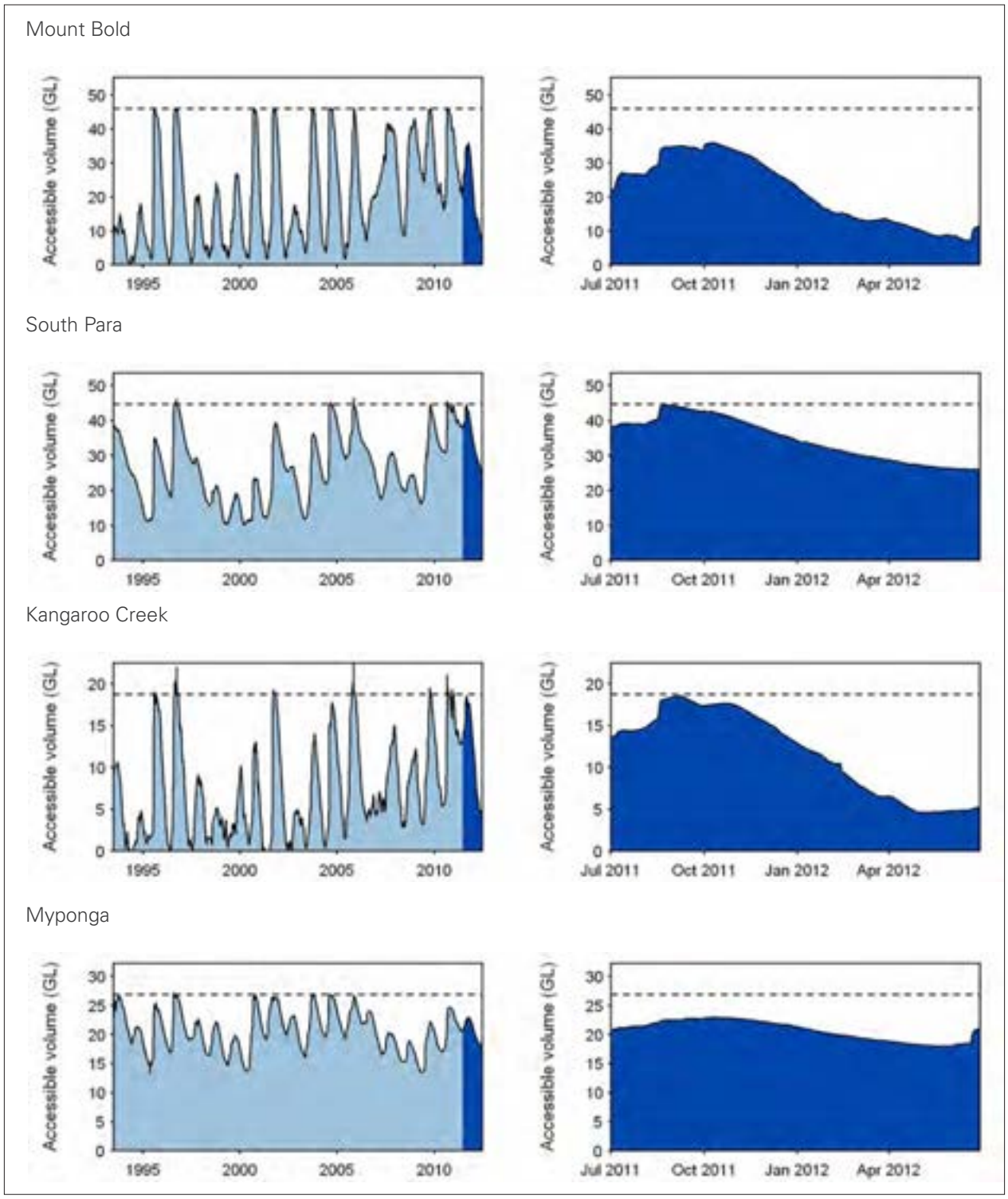


Figure 8.39 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for Mount Bold, South Para, Kangaroo Creek and Myponga storages, as well as total accessible storage capacity (dashed line)

Mount Bold is the largest storage, with a capacity of 46 GL, and it contributes approximately 20% of the total storage capacity.

The large annual fluctuation of the accessible storage shown in these figures illustrates the highly variable nature of Adelaide's surface water resources. The figures highlight the general trend of filling during July–October and their drawdown across the drier summer period.

Extractions from the River Murray are highly dependent on the inflows to storages from their surrounding catchments. Extractions can range from 40% of the total water sourced in high rainfall years to 90% in years of very low rainfall.

Water restrictions

Water restriction in Adelaide and in most of the region are set by the State Government and enforced by SA Water. Restriction triggers are not solely based on the total available water in storage. Water restrictions in Adelaide are instead dependent on flows from the Mount Lofty Ranges and also on conditions in the Murray–Darling Basin, including volumes in the Hume and Dartmouth storages.

Restrictions applied to Adelaide outdoor water consumption are shown against combined storage volumes of Mount Bold, South Para, Kangaroo Creek and Myponga in Figure 8.40.

In the early 2000s, local storages, catchments and the River Murray were stressed as a result of drought conditions within the region and the Murray–Darling Basin. This saw Level 2 water restrictions introduced in July 2003 for four months. Permanent water conservation measures (PWCM) were introduced in October 2003, promoting long-term water conservation.

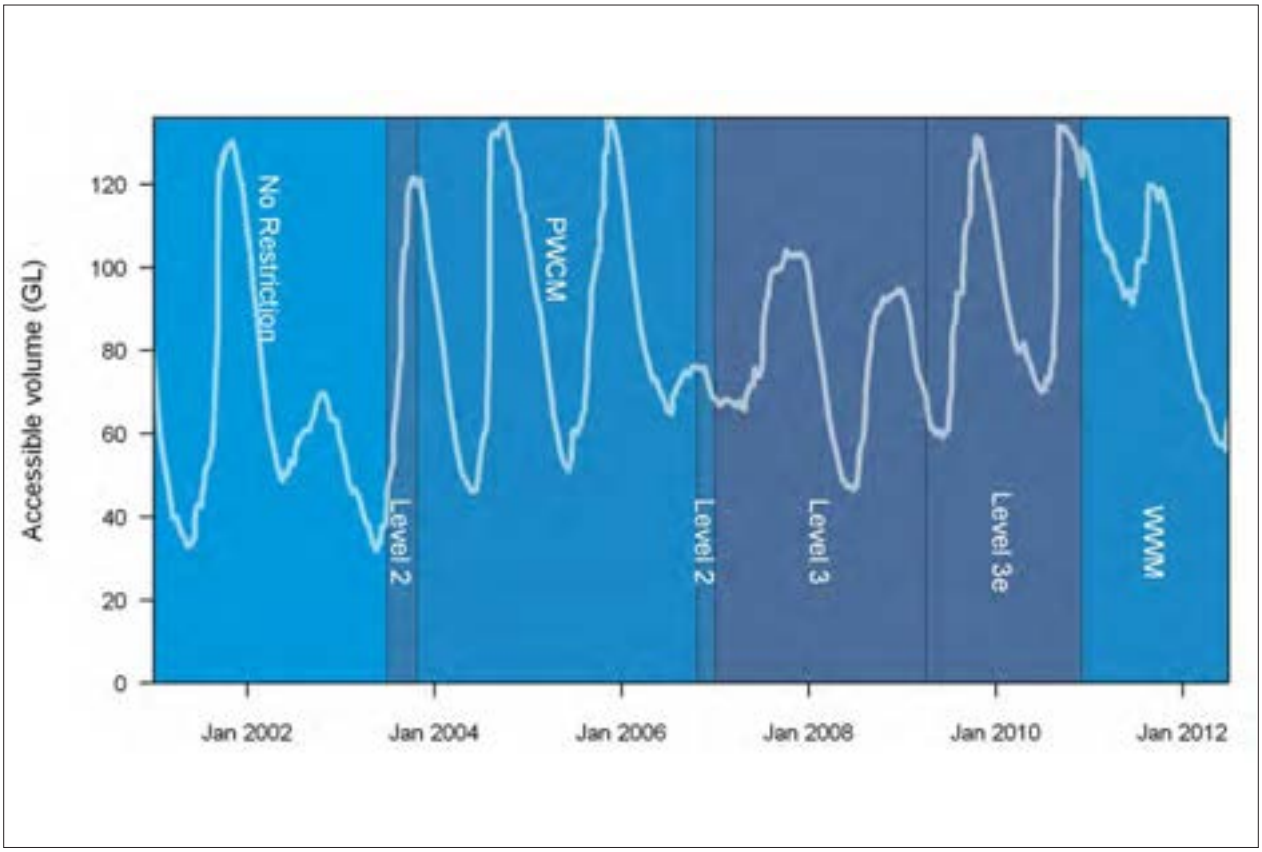


Figure 8.40 Urban water restriction levels across Adelaide since 2001 shown against the combined accessible water volume of Mount Bold, South Para, Kangaroo Creek and Myponga storages

Enhanced level 2 restrictions were introduced in October 2006, after a record dry winter and record low inflows into the River Murray. They were quickly replaced in January 2007 by Level 3 restrictions and average annual residential water use decreased from 235 to 180 kL/property in 2006–07 to 2010–11 respectively.

An easing in water restriction levels in 2011–12 has been in part attributed to a rise in the average annual domestic water consumption of Adelaide, increasing to 195 kL/property (National Water Commission 2012).The South Australian Government imposed a temporary cessation on all outdoor watering in July 2007 which was extended through to August and September due to low winter flows. In October 2007, Adelaide residents were permitted to water for three hours per week; this was increased to five hours and then seven hours in April and May 2010 respectively.

Permanent water wise measures (WWM) were introduced on 1 December 2010 to cement water conservation across the region and to include measures to manage domestic and commercial water use.

Sources of water obtained

Figure 8.41 shows the total volume of water sourced from surface water, recycled and desalination water for supply to Adelaide (National Water Commission 2012). Demand management and water conservation measures have seen a continuing decline in the total water sourced by SA Water.

Between 2006–07 and 2011–12, the highest volume of total water sourced was 181 GL in 2006–07, which was a very dry and hot year. Over the following three years, the volume of water sourced was lower and constant as a result of demand management through water restrictions.

In 2011–12, recycled water comprised 3% of the total water sourced for Adelaide. A further 3% was sourced from desalinated water. For the remaining years shown in Figure 8.41, approximately 15% of the total water sourced was recycled water.

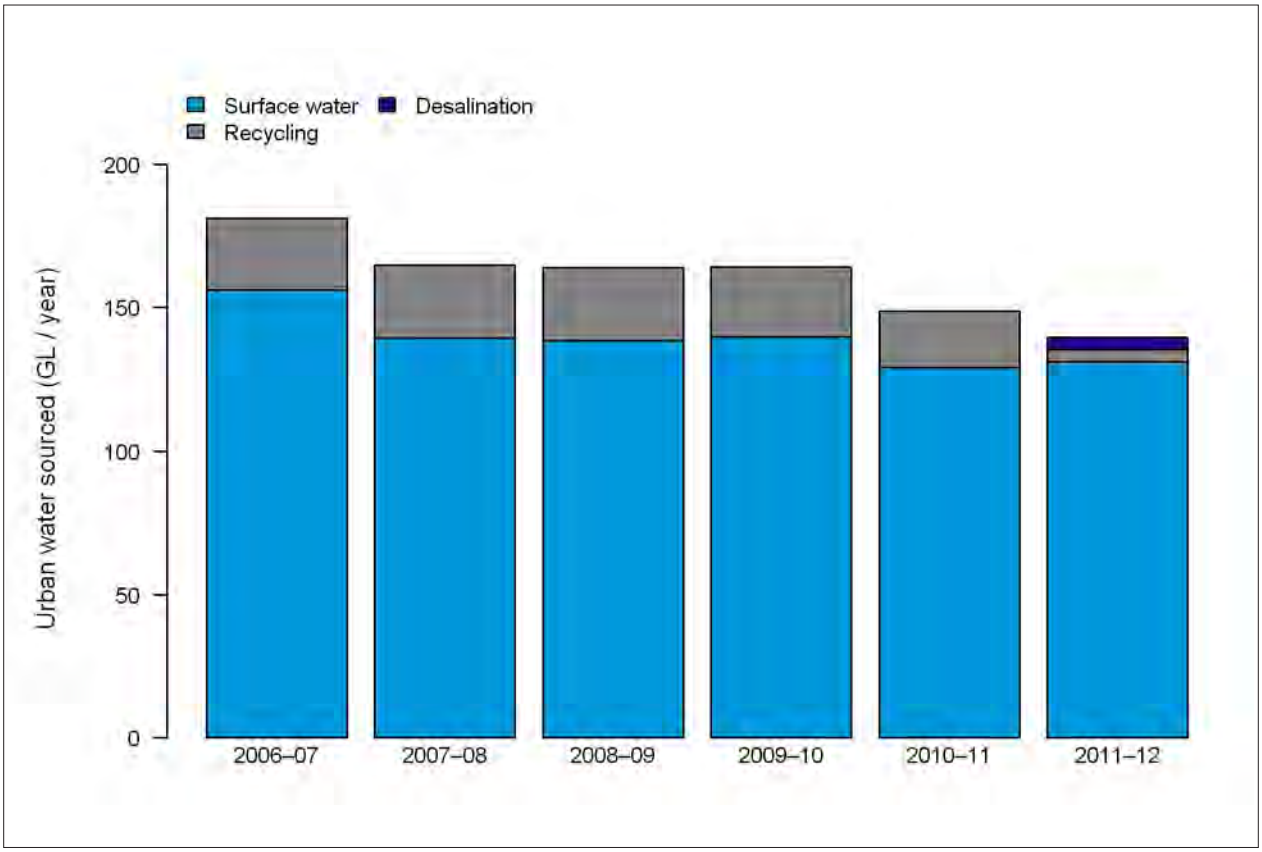


Figure 8.41 Total urban water sourced for Adelaide from 2006–07 to 2011–12

Categories of water delivered

Figure 8.42 shows the total volume of water delivered to residential, commercial, municipal, industrial and other consumers in Adelaide from 2006–07 to 2011–12. Water supply data of the last six years has been obtained from the National Water Commission's National Performance Reports (National Water Commission 2013).

Water supply has steadily decreased from 2006–07 to 2010–11. The consumption of water increased in 2011–12 due to the lower water restrictions and above average rainfall in the region. Residential water use constitutes between 66% and 75% of Adelaide's total water consumption. The maximum residential water use in Adelaide was during the year 2006–07 when more than 115 GL were supplied for residential use. As discussed above, water restrictions and conservation measures subsequently had a marked influence on residential water use.

The Level 2 and Level 3 restrictions introduced in 2006–07 reduced annual residential consumption to an average of 93 GL over the period 2007–08 to 2010–11. The average commercial, municipal and industrial water consumption in Adelaide during 2006–07 to 2011–12 was about 28 GL, with a maximum of more than 35 GL in 2006–07. By 2011–12, consumption by the commercial, municipal and industrial sectors fell to 26 GL with the lowest at 16 GL in 2009–10, almost half of the 2006–07 consumption.

Based on the data obtained from the National Performance Reports, the average water supply per property for residential use in Adelaide from 2006–07 to 2011–12 was estimated to be 195 kL. The maximum annual residential water use per property was 235 kL in 2006–07 and the minimum was 180 kL in 2010–11.

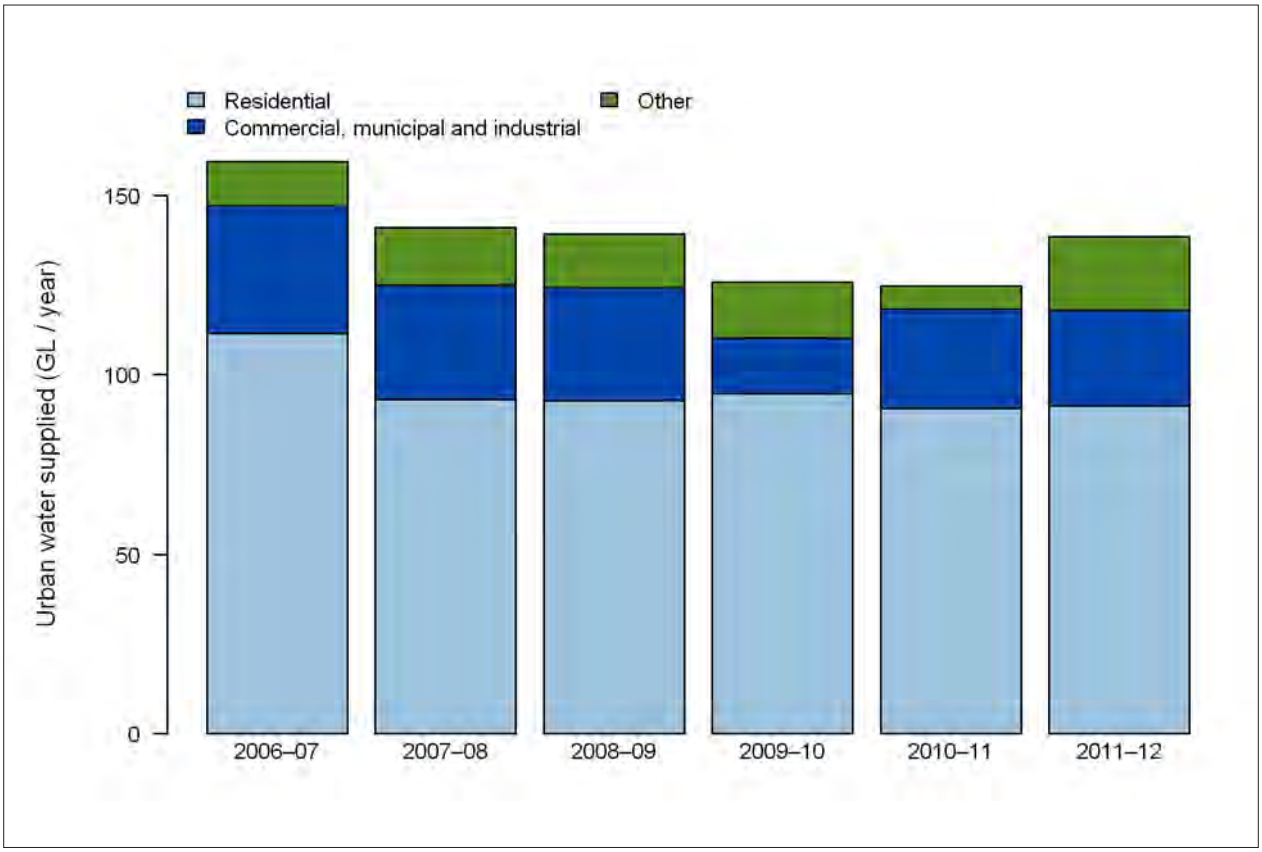


Figure 8.42 Categories of water delivered to Adelaide from 2006–07 to 2011–12

8.7 Water for agriculture

This section describes the water situation for agriculture in the South Australian Gulf region during the 2011–12 year compared with the past. Modelled soil moisture conditions are presented and important irrigation areas are identified. The McLaren Vale Irrigation Area is described in more detail.

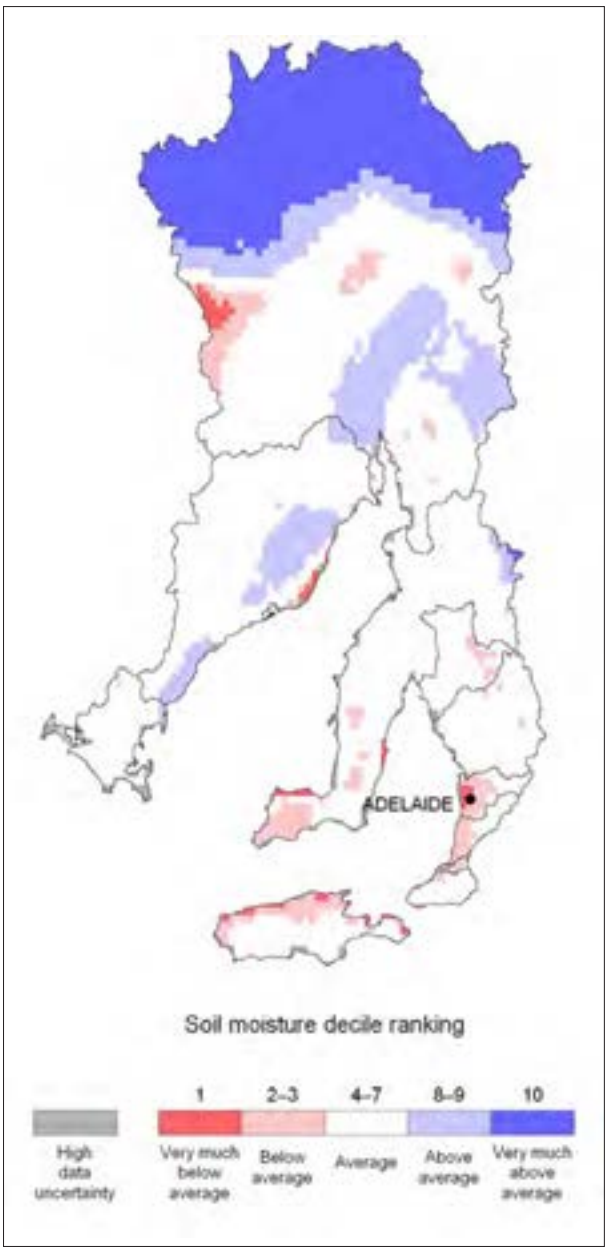


Figure 8.43 Deciles rankings of annual average soil moisture for 2011–12 with respect to the 1911–2012 period for the South Australian Gulf region

8.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 km x 5 km grid cell, they are not suitable for comparison with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

Except for a narrow strip in the northern pastoral lands which had high above average soil moisture conditions, the South Australian Gulf region experienced average conditions (Figure 8.43). This follows the rainfall decile ranking during 2011–12 in the region. The similarity is more distinct for the northern and southern parts of the region.

Some irrigated lands of the southern region experienced below to very much below average soil moisture conditions (Figure 8.43).

Decile ranking of the changes in soil moisture averaged over the whole region during 2011–12 year indicates marginally above average conditions that rose in March due to historically high rainfall events, and continued during the autumn period (Figure 8.44).

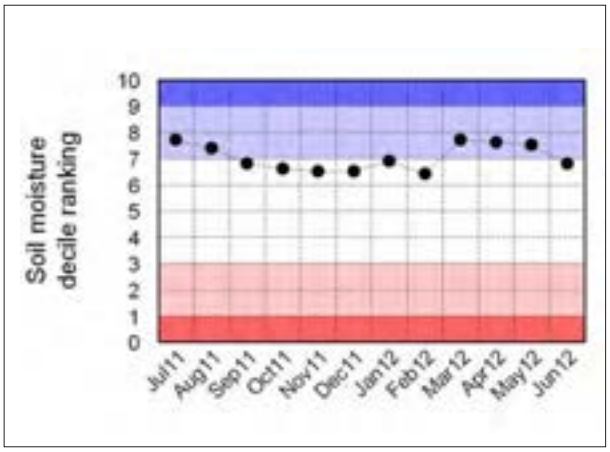


Figure 8.44 Decile ranking of the monthly soil moisture conditions during the 2011–12 period in the South Australia Gulf region

8.7.2 Irrigation water

A comparison of annual irrigation water use in parts of the region for the period between 2005–06 and 2010–11 is shown by natural resource management (NRM) regions in Figure 8.45. Figure 8.46 shows the variation in annual water use between the two NRM regions in the South Australian Gulf region during 2010–11 year.

Data for the 2011–12 year was not available at the time of preparation of this report.

The McLaren Vale prescribed wells area in the Onkaparinga catchment is described in the following section as an example of irrigated agriculture water use in the region.

8.7.3 Irrigation areas

Dryland agriculture is the main agricultural activity in the South Australian Gulf region apart from grazing pasture. Viticulture and wine grape production is the main irrigated agriculture mostly in the Onkaparinga catchment (Figure 8.47). Water for these enterprises is sourced from the Mount Lofty Ranges and River Murray diversions. Mount Bold on the Onkaparinga River is the largest storage in the region with an accessible storage capacity of 46 GL.

In most years, inflows to storage are supplemented by water pumped from the River Murray via a pipeline from Murray Bridge. The majority of irrigated water use occurs in the south-eastern areas where viticulture is concentrated.

The McLaren Vale prescribed wells area is described in more detail in section 8.7.4 below.

8.7.4 McLaren Vale prescribed wells area

The McLaren Vale prescribed wells area is located within the Onkaparinga catchment, 35 km south of Adelaide within the boundaries of the Western Mount Lofty Ranges prescribed area, and covers an area of 320 km^2.

By regulation in 1998, all existing and future wells within the area were declared to be prescribed wells. Prescription is the legal mechanism for implementing a water resource management regime in South Australia. A prescribed water resource is managed through an allocation and licensing system.

The area was formed after amalgamating the Willunga Basin prescribed wells area and the Upper Willunga catchment moratorium area in 2000. The climate of the area is Mediterranean, with cool, wet winters and hot, dry summers. Annual rainfall varies from around 400 mm to around 900 mm. Irrigated viticulture accounts for more than 85% of the irrigation in the region. Orchards and other irrigated crops account for the remainder.

There are no large surface water inflows or storages in the McLaren Vale prescribed wells area. Around 75% of water used for irrigation in the McLaren Vale prescribed wells area is sourced from groundwater. Groundwater occurs in four major aquifers: the Quaternary aquifer, Port Willunga Formation aquifer, Maslin Sands aquifer and Fractured Rock aquifer.

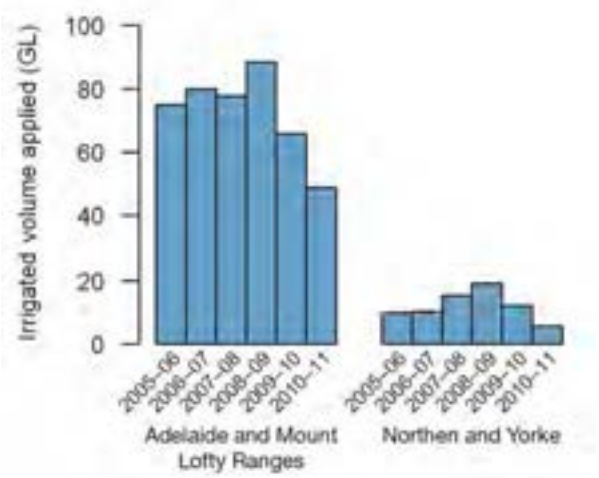


Figure 8.45 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the South Australian Gulf region (ABS 2006–2010; 2011a)

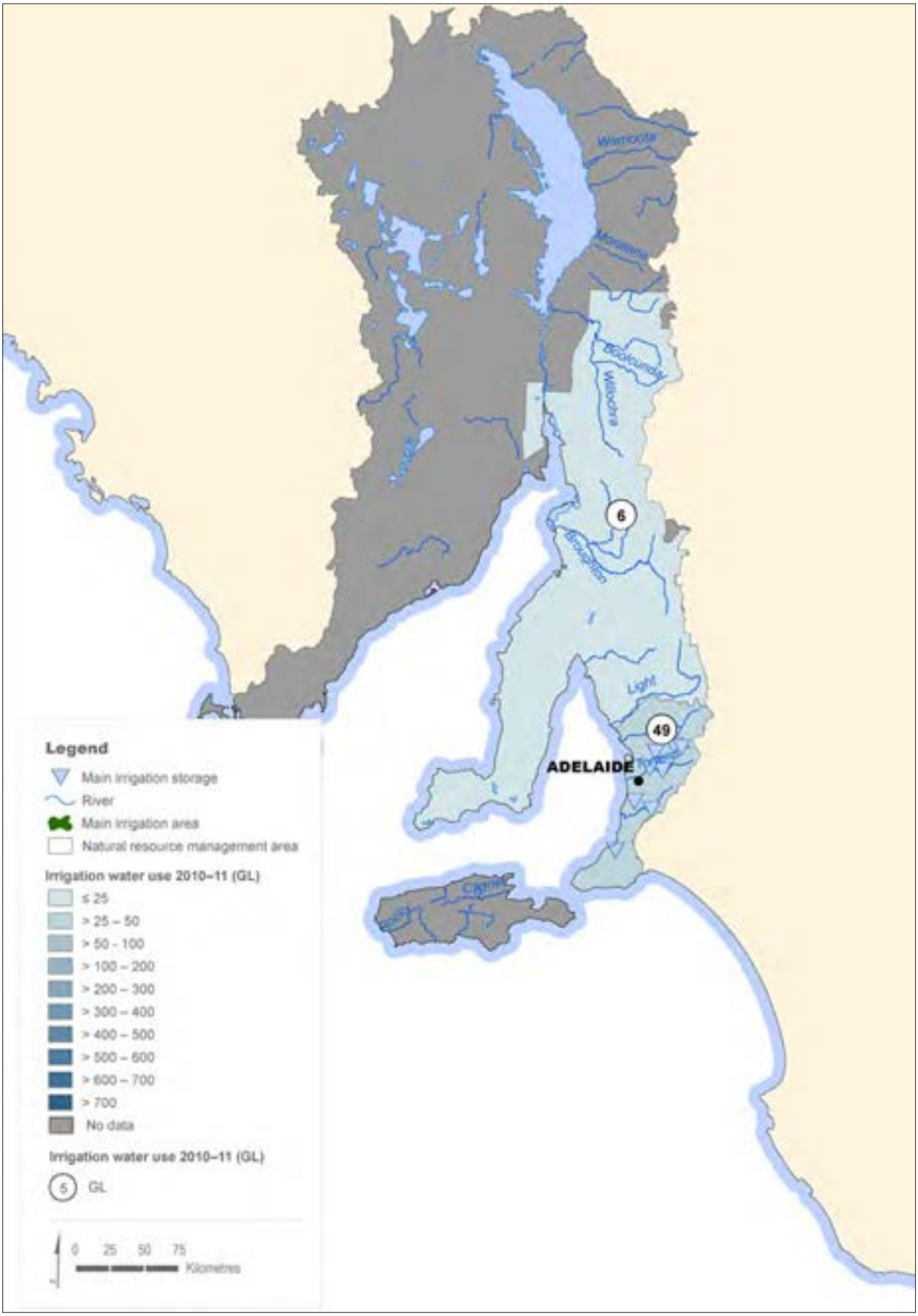


Figure 8.46 Annual irrigation water use per natural resource management region for 2010–11 (ABS 2011a)

Figure 8.47 Irrigation areas in the South Australian Gulf region

The high cost of groundwater has encouraged the development of alternative water sources such as mains water and secondary treated water from the Christies Beach wastewater treatment plant (Government of South Australia 2000).

There is an extraction limit of 6,600 ML from groundwater. Most of the water is extracted from the Port Willunga Formation aquifer. Average allocation in McLaren Vale is 1.5 ML/ha for vines and 2.8 ML/ha for other crops.

Metered groundwater extractions in the McLaren Vale prescribed wells area for 2010–11 totalled 2,529 ML, 27% less than the previous year mostly because of above average rainfall in the region near Mount Bold (Department for Water 2011). Data for the 2011–12 year was not available at the time of preparation of this report.

Local hydrogeology

For the purpose of this report, the McLaren Vale Irrigation Area was selected as an example for the discussion of groundwater use in an irrigation area in the South Australian Gulf region.

The aquifer system in the McLaren Vale prescribed wells area (Figure 8.48) is complex but can be grouped into four aquifers listed from top to bottom: the Quaternary sediments, Willunga Formation, Maslin Sands and fractured basement rock. These aquifers are interconnected and as such, withdrawals from one aquifer will impact other aquifers. Furthermore, the aquifers are not all present at all locations in McLaren Vale.

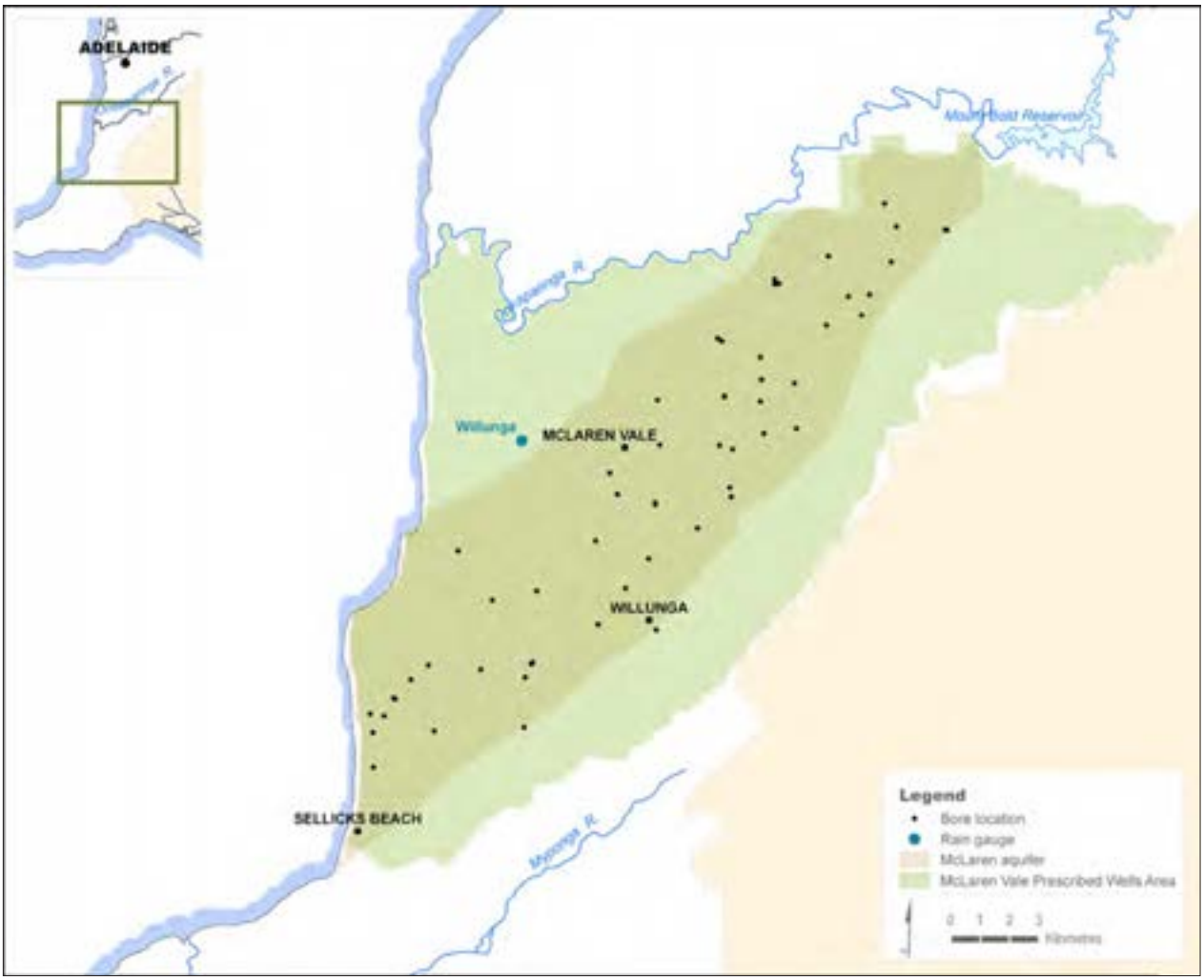


Figure 8.48 The McLaren Vale Prescribed Wells Area showing the location of groundwater bore sites and rain gauge

The Willunga aquifer supplies 64% of groundwater extracted for irrigation, with the Maslin Sands and fractured basement rock aquifers supplying 20% and 16% respectively (Australian Bureau of Agricultural and Resource Economics and Sciences 2003).

The Quaternary aquifer is generally shallow and of poor quality; however, it plays an important role in supporting groundwater-dependent ecosystems such as Aldinga Scrub and by providing base flow to creeks and streams (Department of Water, Land and Biodiversity Conservation 2007).The Willunga aquifer is the most utilised groundwater resource in McLaren Vale prescribed wells area and is comprised of sand and limestone units. The Maslin Sands aquifer overlies the Fractured Rock aquifer. The aquifer is unconfined in the northeast of the area. Like the Willunga aquifer, recharge occurs via direct rainfall infiltration in unconfined areas as well as from streams and inflow from surrounding fractured rocks.

In the McLaren Vale prescribed wells area, localised cones of depression in the groundwater level due to groundwater pumping have been identified as a potential problem, particularly for saline seawater intrusion (Martin 1998; Martin and Hodgkin 2005). Stewart (2006) reported higher salinities between McLaren Vale and Blewitt Springs than in the remainder of the aquifer. This area coincides with a deflection in the potentiometric surface for the aquifer.

Groundwater quality overview

Groundwater salinity increases towards the coast in the Port Willunga formation aquifer. This increase of salinity down the hydraulic gradient suggests that recharge to this aquifer is limited along the groundwater flow path. The salinity of the Maslin Sands aquifer is similar to that of the Port Willunga Formation aquifer. The salinity in the Fractured Rock aquifer is variable, but generally fresh.

Influences on shallow groundwater

There is often a very strong relationship observed in shallow aquifer systems between changes in groundwater levels and rainfall, which occur as a result of rapid recharge to these systems from rainfall (Department of Water, Land and Biodiversity Conservation 2007). Therefore, years of above average rainfall will result in rising groundwater levels, while years of below average rainfall will result in declining groundwater levels.

Fluctuations in the shallow groundwater levels were evaluated for the watertable aquifer at five selected sites using data between 1990 and 2012 (Figure 8.49). In Figure 8.49 fluctuation in groundwater levels are compared to the local monthly rainfall trend (location of rain gauge shown in Figure 8.48). Periods in which the cumulative rainfall residual mass curve rises indicate wetter than average conditions. Periods with a falling trend indicate drier than average conditions. Panel b in Figure 8.49 shows a wetter than average period up to 1994, followed by average rainfall conditions until 2006, then by a drier than average period up to 2009, and thereafter by average rainfall.

The figure illustrates that overall the groundwater response to trends in rainfall is prominent. It also shows that groundwater recharge in the watertable is driven by seasonal cycles in rainfall. All wells, except for one, show a decline in water level after 2006 and a minor recovery post 2009. This was as a result of below average rainfall conditions in the region from 2006 to 2009 followed by averaged rainfall (panel b in Figure 8.49). The pattern and magnitude of change in groundwater level is also influenced by the change in the pattern of extraction across the area.

Groundwater level

Figure 8.50 shows ranges of groundwater depth from bores located in the three aquifers in the McLaren Vale Irrigation Area, and the ranking of 2011–12 median groundwater levels compared to annual median groundwater levels in the last 21 years (1990–2011).

As shown in Figure 8.50, typically groundwater levels in the watertable aquifer vary from very shallow 0–1 m from the surface to greater than 10 m from the surface. Median groundwater depths in 2011–12 are typically below the long-term average east of McLaren Vale town and are generally above the long-term average elsewhere.

Groundwater levels in the Willunga aquifer in 2011–12 are over all deeper than 10 m below the surface (Figure 8.51). The recorded groundwater levels are mostly below the long-term average of the past 21 years.

In the Maslin Sands (Figure 8.52), groundwater levels in 2011–12 were also generally deep (>5 m below the surface). Overall, groundwater levels in the area increased concurrent with the expansion of irrigated land. Towards the coast, groundwater levels are below the average for the last 21 years.

Groundwater salinity

At the time of writing, suitable quality controlled and assured time-series data on groundwater salinity were not available from the Australian Water Resources Information System (Bureau of Meteorology 2011a). Therefore, groundwater salinity status of the McLaren Vale Irrigation Area has not been analysed.

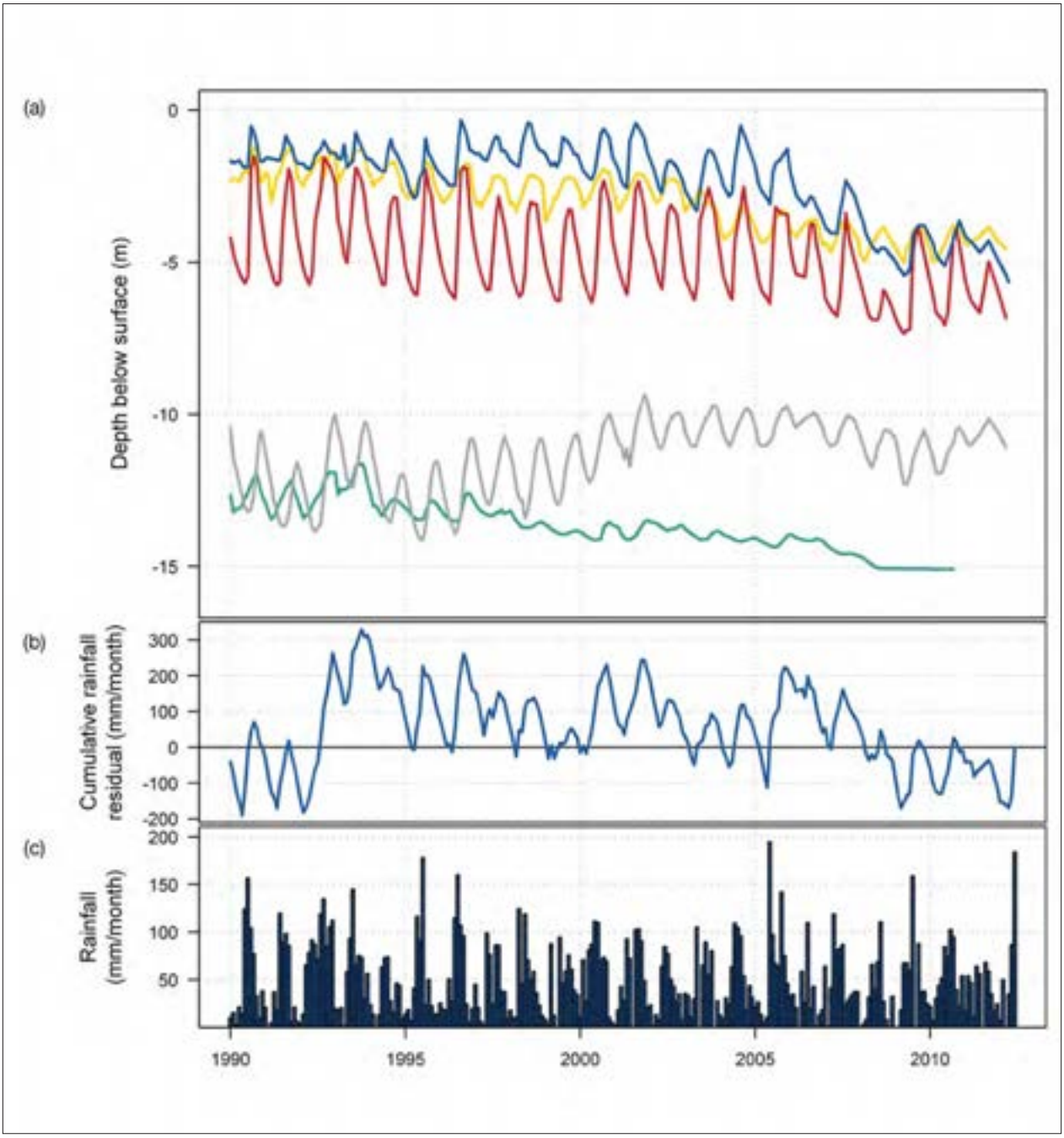


Figure 8.49 (a) Groundwater levels between 1990 and 2012 of the watertable aquifer at five bore sites in the McLaren Vale Irrigation Area, compared with (b) rainfall residuals, and (c) daily rainfall at Willunga

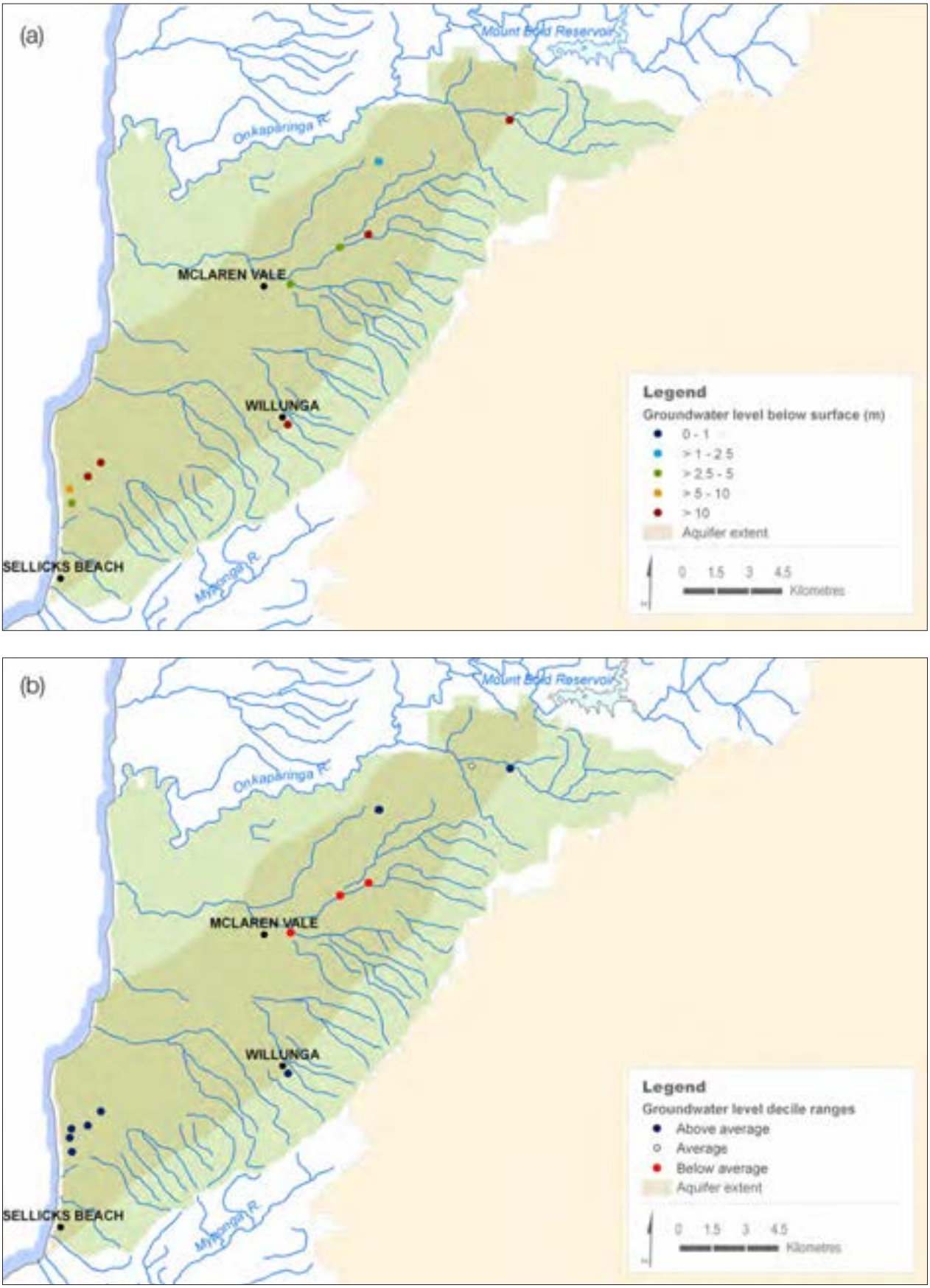


Figure 8.50 (a) Median groundwater depth below surface, and (b) groundwater level deciles in 2011–12 compared to the 1990–2012 reference period for the McLaren Vale watertable aquifer

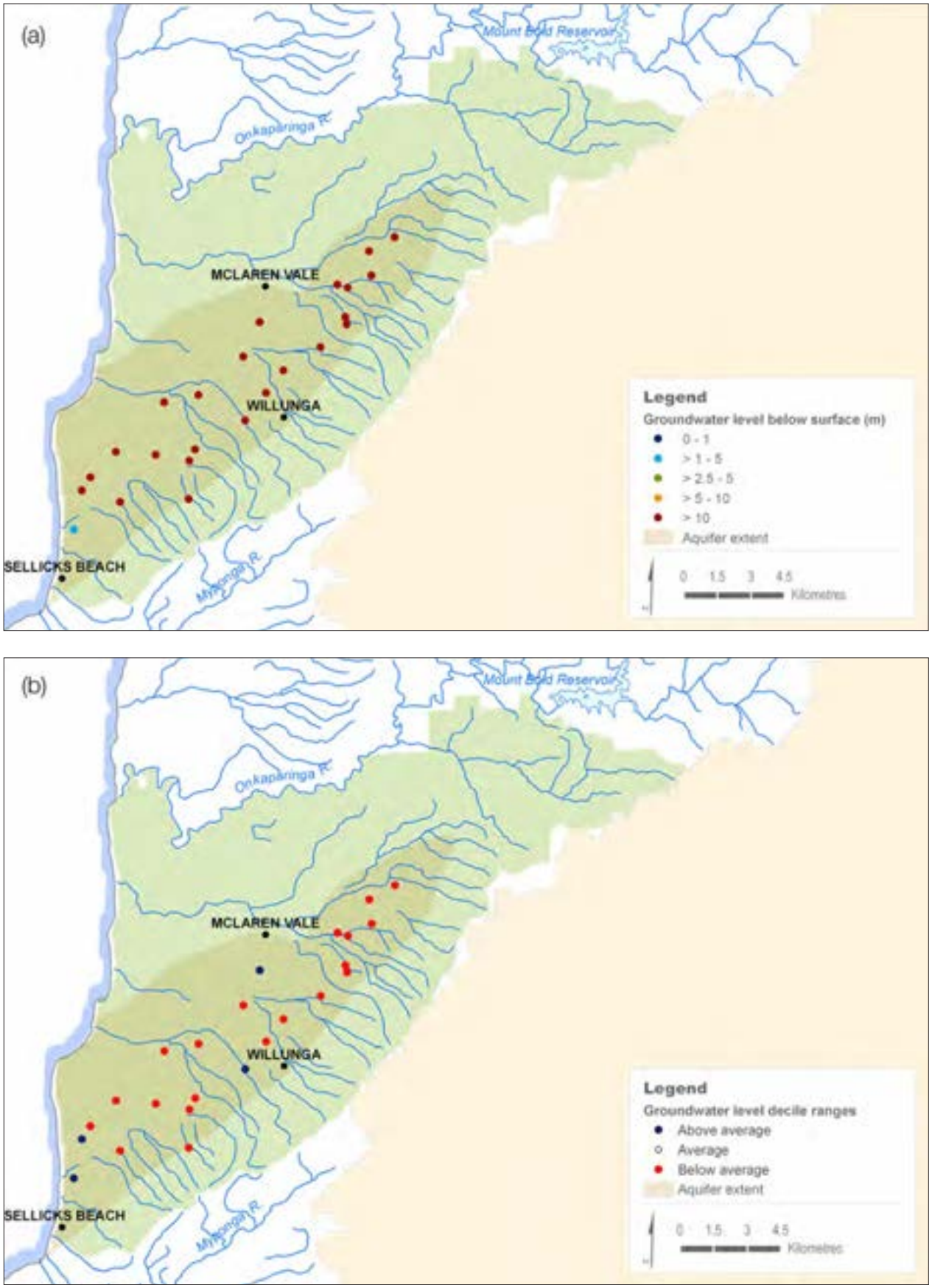


Figure 8.51 (a) Median groundwater depth below surface, and (b) groundwater levels deciles in 2011–12 compared to the 1990–2012 reference period for the Willunga aquifer

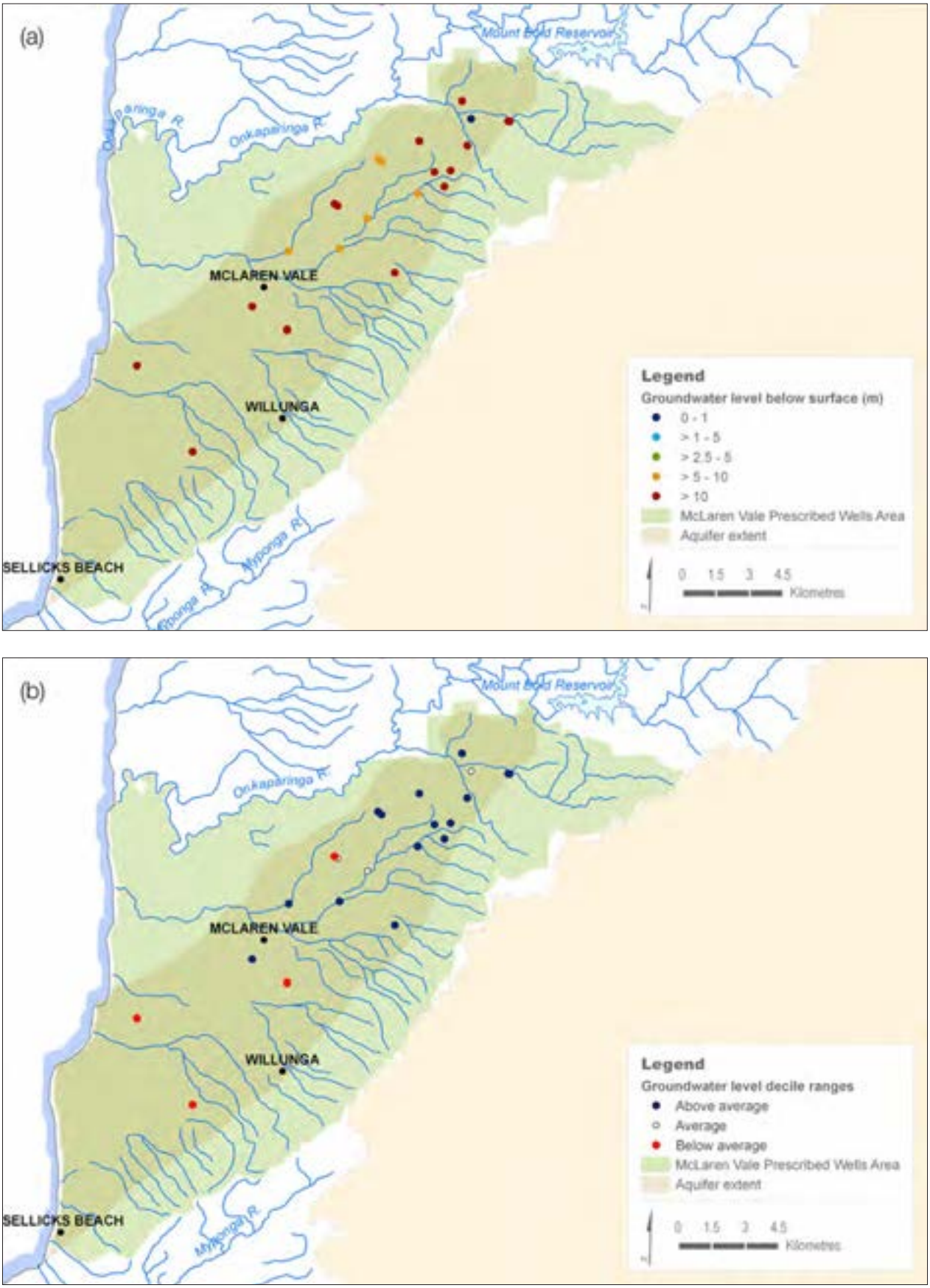


Figure 8.52 (a) Median groundwater depth below surface, and (b) groundwater levels deciles in 2011–12 compared to the 1990–2012 reference period for the Maslin Sands aquifer

South Western Plateau

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9. South Western Plateau

9.1 Introduction

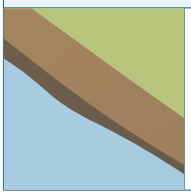
This chapter examines water resources in the South Western Plateau region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, land use, population and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

9.2 Key information

Table 9.1 gives an overview of the key components of the data and information in this chapter.

Table 9.1 Key information on landscape water flows and groundwater quality in the South Western Plateau region

Landscape water flows			
	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	256 mm	+45%	9th—above average
Evapo-transpiration	268 mm	+55%	10th—very much above average
Landscape water yield	6 mm	+100%	10th—very much above average
Groundwater (in selected aquifers)			
	Salinity:	Saline groundwater (≥3000 mg/L) in the south of the region and scattered areas of saline groundwater mainly surrounding (dry) river beds and lakes in the north	

9.3 Description of the region

The South Western Plateau region covers 1,093,000 km^2 of mostly sandy or stony desert within Western Australia, South Australia and the Northern Territory. The region borders the South Australian Gulf region to the east, Lake Eyre Basin region to the northeast, Tanami – Timor Sea Coast and North Western Plateau regions to the north, and the Pilbara–Gascoyne and South West Coast regions to the west. The Southern Ocean is the southern boundary of the region.

The region includes the Nullarbor Plain in the south and a major part of the Great Victorian Desert in the north. Vegetation is sparse with trees largely non-existent. The region is predominantly flat with some hills along the edges of the Nullarbor Plain. Subsections 9.3.1– 9.3.4 give more detail on physical characteristics of the region.

The South Western Plateau region has a population of 72,400 people that accounts for just over 0.3% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b).

Major population centres in the region include Kalgoorlie–Boulder, Esperance, Ceduna, Coolgardie, Kambalda West and Streaky Bay (Figure 9.1).

Further discussion of the region's population distribution and urban centres can be found in Section 9.3.6.

Most of the region comprises nature conservation (Figure 9.1), including much of the Nullarbor Plain and the Great Victorian Desert. To the west and east, large areas of pasture are present, with some areas of dryland agriculture on the Eyre Peninsula (southeast) and north of Esperance (southwest).

Except for the western and eastern parts of the region, the vast area of the region is arid. Subsections 9.3.7 and 9.3.8 provide more information on the rainfall patterns and deficits across the region.

A substantial number of predominantly dry lakes are present in the west and east of the region as well as more sporadically in the north. Some small rivers discharge into the Southern Ocean surrounding Esperance in Western Australia and Ceduna in South Australia.

The hydrogeology of the region is dominated by a outcropping fractured basement rock with limited groundwater resources. There are significant groundwater resources in localised sedimentary aquifers.

The Nullabor Plain | Heidi Kaldahl

Figure 9.1 Major rivers and urban centres in the South Western Plateau region

9.3.1 Physiographic characteristics

The physiographic map in Figure 9.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes.

The South Western Plateau region has four such dominant physiographic provinces, namely:

- Sandland (41%): west-east longitudinal dunes, broken by low tablelands and ridges in the northwest with ferruginous plains in the north;
- Yilgarn Plateau (24%): flat to undulating plain with salt lakes;
- Nullarbor (21%): karst plain of flat-lying limestone and calcrete; and
- Eyre Peninsula (10%): alluvial plains and salt lakes with some dunes and hills of volcanic and metamorphic rocks in the south.

The remaining three provinces occupy only 4% of the region. These are:

- Central Australian Ranges: dissected sandstone, granitic and volcanic ranges with prominent escarpments; separated by sandplains with dunes of hardpan;
- Central Lowlands: silcrete capped low tablelands; and
- Pilbara: mainly alluvial lowland with hardpan and sand plains.

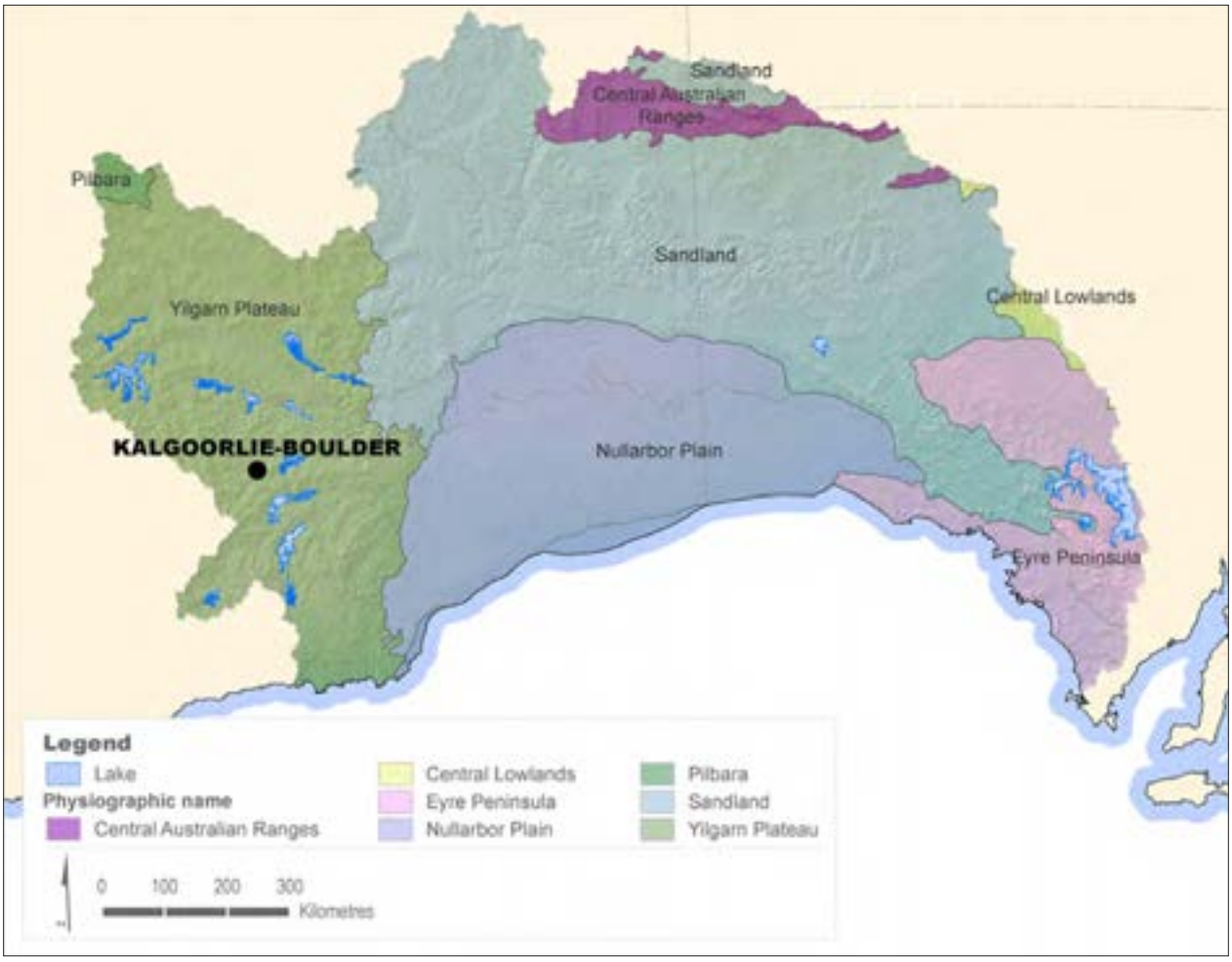


Figure 9.2 Physiographic provinces of the South Western Plateau region

9.3.2 Elevation

The South Western Plateau region includes the Nullarbor Plain in the south and a major part of the Great Victorian Desert in the north. As seen in Figure 9.3, the region is predominantly flat with some hills along the edges of the Nullarbor Plain. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).

The north and west of the region is part of the Western Plateau, which extends north and west to the Indian Ocean.

The highest points in the region exceed 1,200 m and are located in the northeastern Musgrave Ranges. The lowest area is the Roe Plains, a long coastal stretch of a low-lying limestone plateau.

The most eastern part of the region has no major hills and altitudes do not exceed 500 m above sea level in the Gawler Ranges. To the west, the area consists of many closed basins in between the ridges, with many dry lakes and salt plains. Altitudes in this area exceed 600 m above sea level.

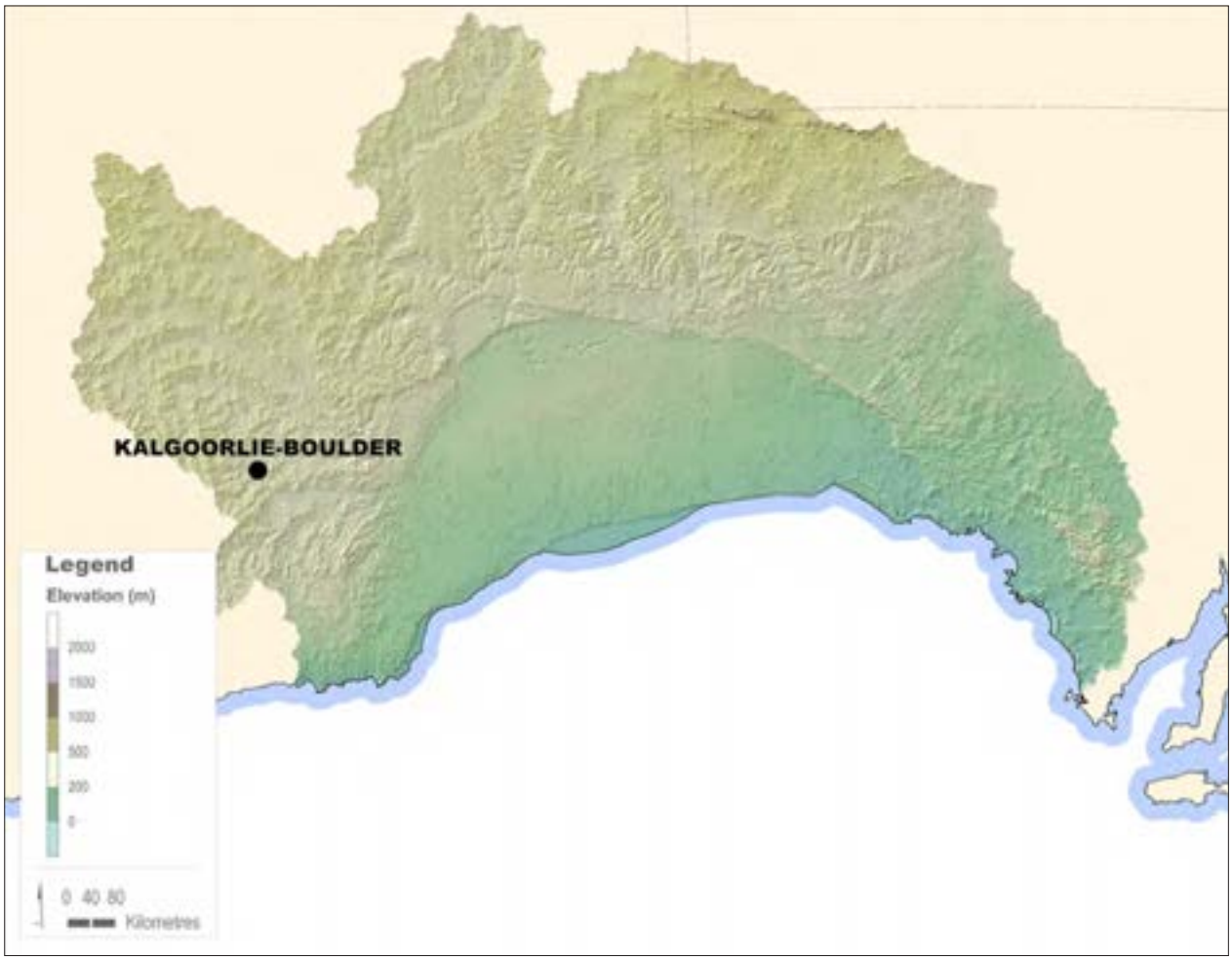


Figure 9.3 Ground surface elevations in the South Western Plateau region

9.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The South Western Plateau region is generally flat, with hardly any steep slopes. Figure 9.4 shows the spatial distribution of surface slopes in the region while Table 9.2 summarises the extent of the slope ranges.

Table 9.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	52.4	26.8	20.0	0.8

The steep slopes in Figure 9.4 in particular highlight the Musgrave Ranges in the north. The large Nullarbor Plain in the south is very distinctive in its flatness. Water flow is practically non-existent in this area.

The slope map also clearly shows the escarpment of the western plateau in the north and the separation between the Nullarbor Plain and the Roe Plains in the south. The slopes were derived from the elevation information used in the previous section.

The ridges to the west are particularly distinctive as well, with many flat areas in between depicting the large dry lakes and salt plains.

Figure 9.4 Surface slopes in the South Western Plateau region

9.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge. The nature of these hydrological pathways and the suitability of the soilds for agricultural purposes are influenced by the soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 97% of the South Western Plateau region is covered by four soil types, namely tenosols, calcarosols, rudosols and kandosols (Figure 9.5 and Figure 9.6). They are mostly present in areas used for grazing or nature conservation. Among these soils tenosols and calcarosols each cover more than 30% of the region.

Tenosols, rudosols and kandosols are soils with weak and minimal development, either throughout the profile (tenosols, rudosols) or in the upper soil profile (kandosols). They show no or little change in texture and colour and are often shallow in depth. These soils are low in chemical fertility and in water-holding capacity and thus their agricultural potential is low.

Tenosols are dominant in the north of the region and here they are found with kandosols. Tenosols are also scattered in the southeast of the region. In the east of the region, rudosols are more common Calcarosols are characterised by a high of calcium carbonate content which occurs as soft or hard white fragments or as solid layers. These soils are found along the coastline and in the eastern part of the region. The soils are often shallow and have a low water-holding capacity. They have low to moderate agricultural potential, and high salinity levels, alkalinity and boron toxicity may often cause problems.

The other soil types that have minimal representation in the South Western Plateau region include sodosols and hydrosols (0.6–3% of the total area).

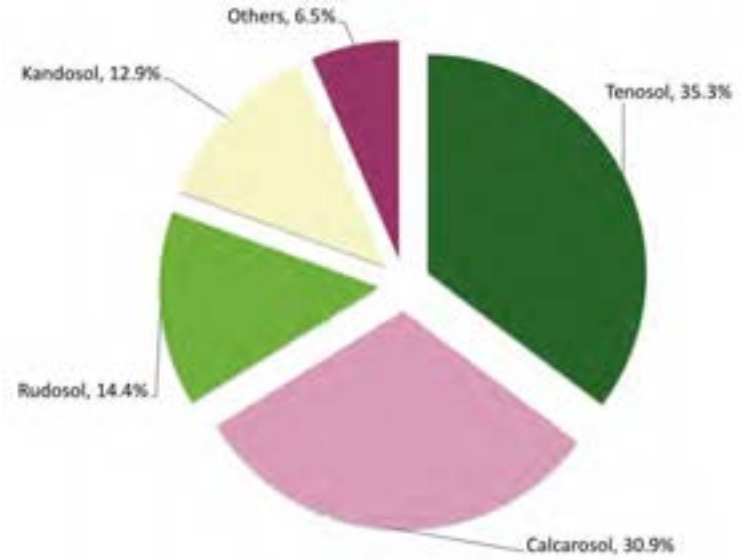


Figure 9.5 Soil types in the South Western Plateau region

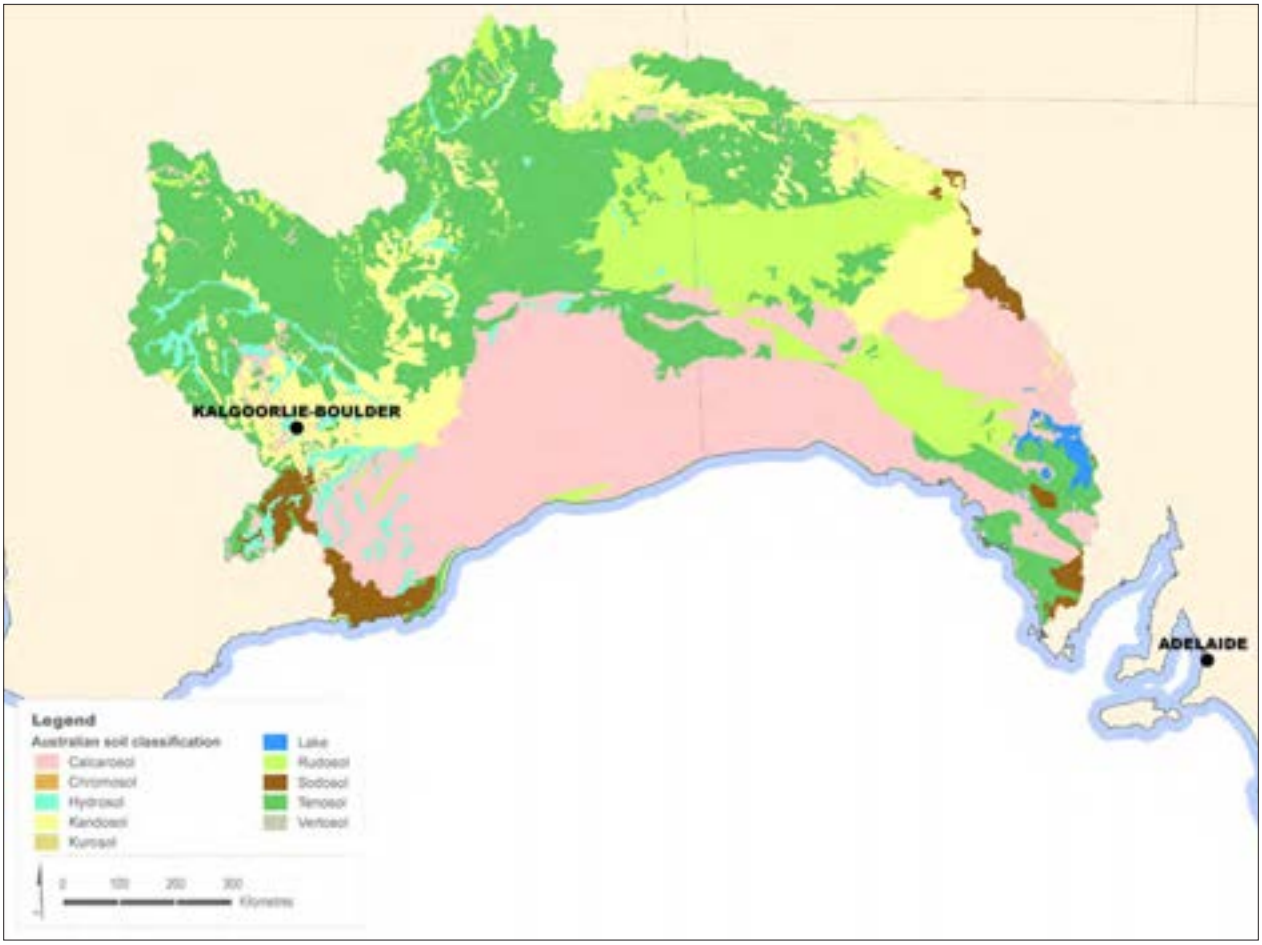


Figure 9.6 Soil type distribution in the South Western Plateau region

9.3.5 Land use

As presented in Figure 9.7 and Figure 9.8, most of the region comprises nature conservation, including much of the Nullarbor Plain and the Great Victorian Desert (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). To the west and east, large areas of pasture are present with some areas of dryland agriculture on the Eyre Peninsula (southeast) and north of Esperance (southwest).

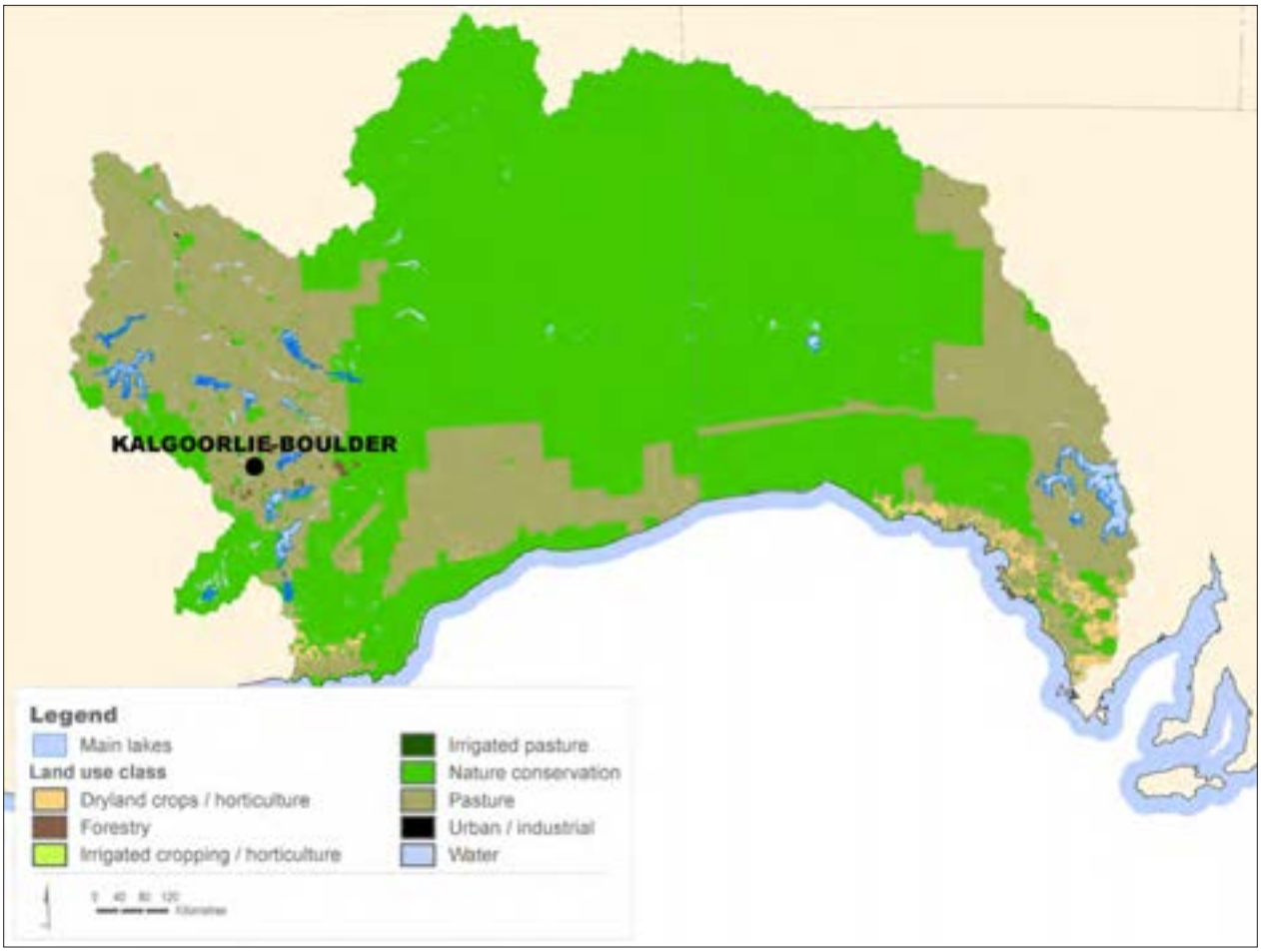


Figure 9.7 Land use distribution in the South Western Plateau region

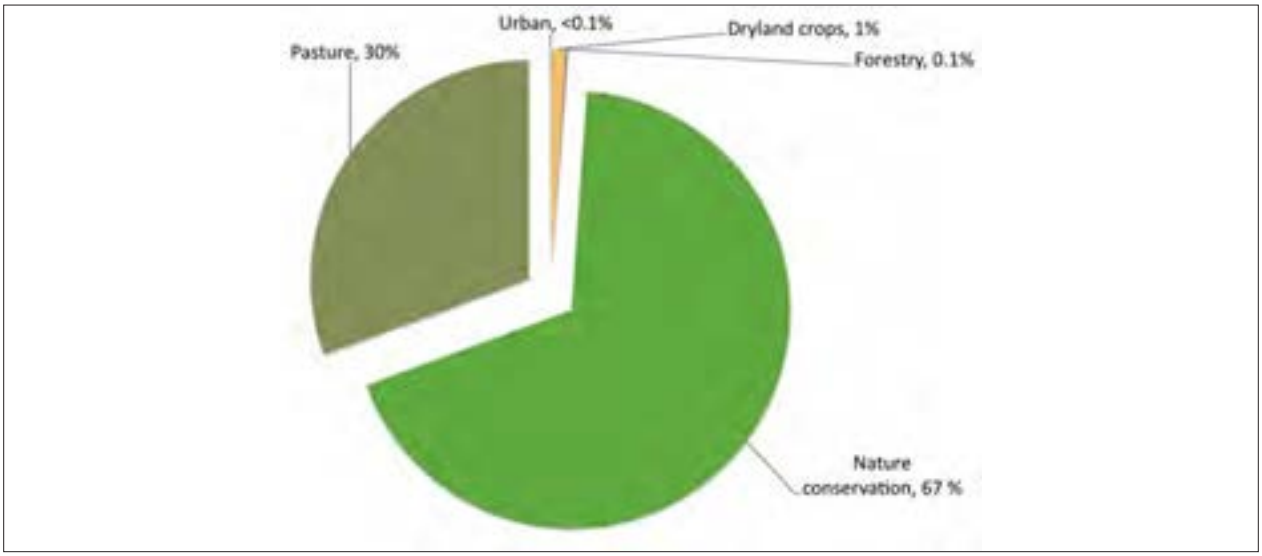


Figure 9.8 Land use in the South Western Plateau region

9.3.6 Population distribution

Figure 9.9 illustrates the sparse nature of the population in the region (ABS 2011b).

The majority of the population is located near the eastern and western extremities of the region. The region is home to a number of remote Indigenous communities. Mining is the primary occupation for the majority of the region's sparsely distributed but permanent population centres. The mining city of Kalgoorlie–Boulder is the largest and most densely populated centre within the region and is situated in the central west, within the Western Australian State boundary. In addition to Kalgoorlie, the coastal centre of Esperance is located in the southwest of the region.

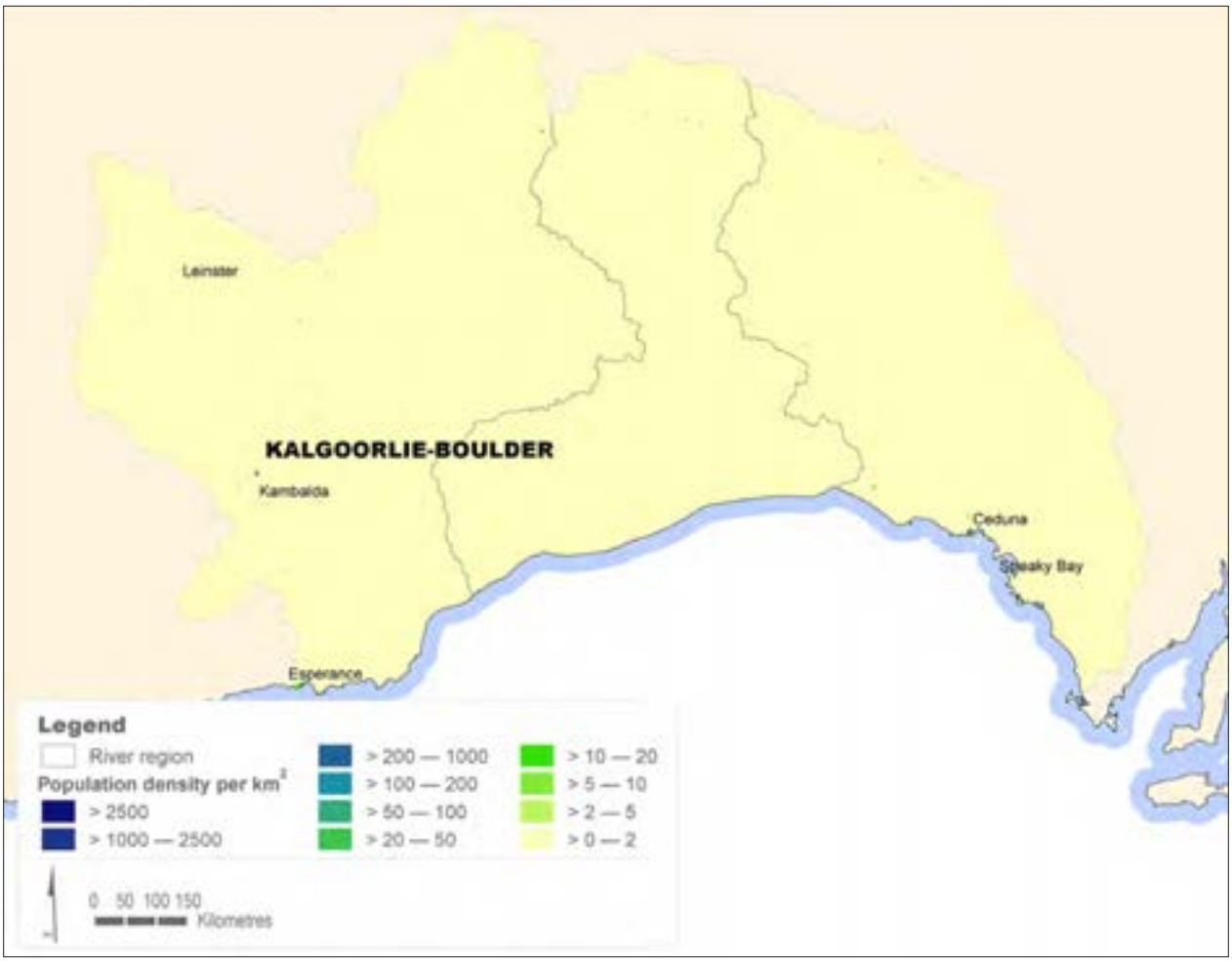


Figure 9.9 Population density and distribution in the South Western Plateau region

9.3.7 Rainfall zones

The South Western Plateau region is the driest region in Australia. Except for the southwest and southeast of the region, which are semi-arid, the vast area in the centre is arid. With the exception of the far western coastline, median rainfall does not exceed 500 mm per year (Figure 9.10).

A large portion of the region has the lowest average annual rainfall of the continent, not exceeding 200 mm.

The winter (dominant) rainfall areas in the west and east have annual average rainfall totals of about 300 mm. In the far southeast, some consistency in winter rainfall is present, although annual average rainfall does not exceed 500 mm.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

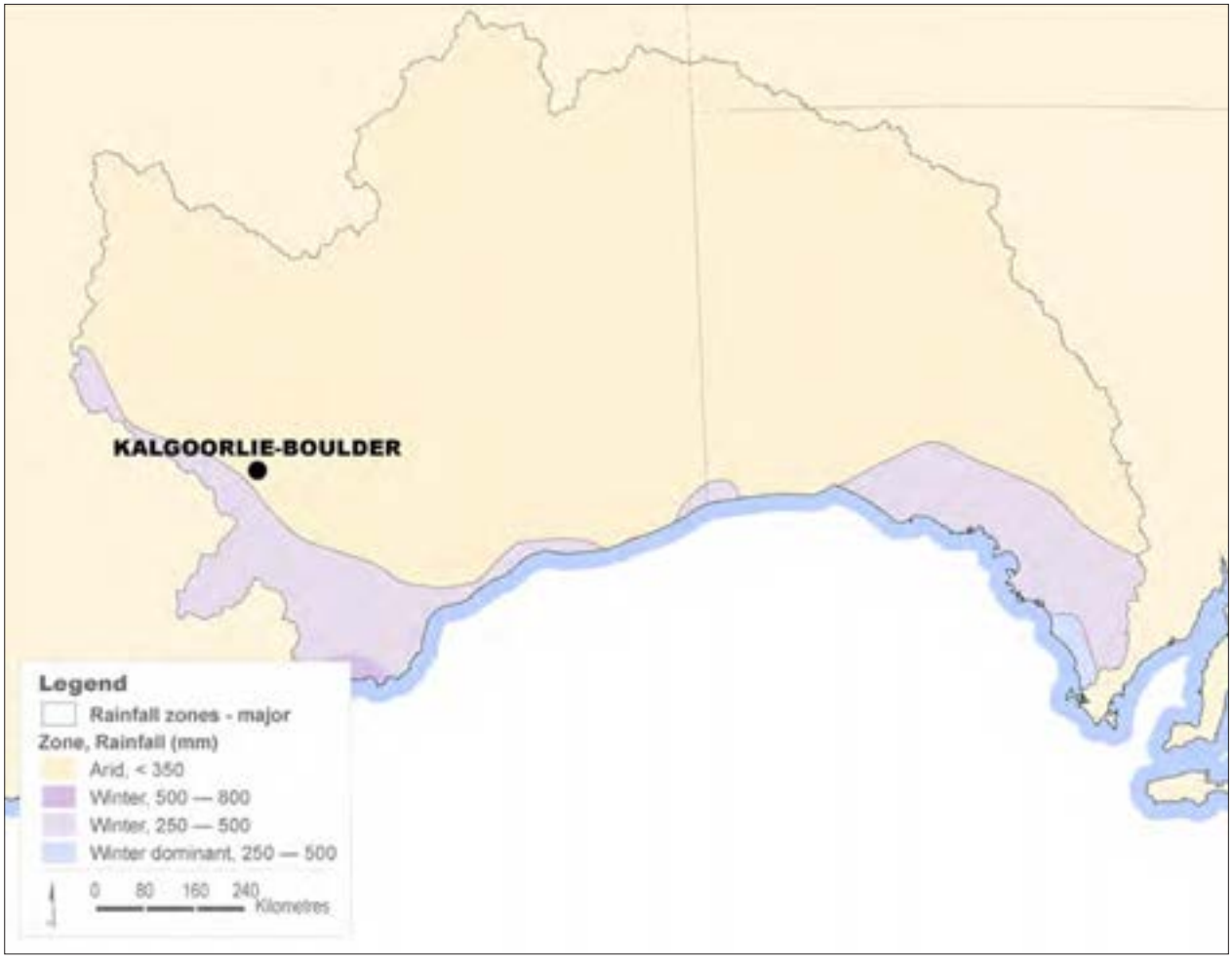


Figure 9.10 Rainfall zones in the South Western Plateau region

9.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The South Western Plateau region is highly prone to water shortages in relation to this indicator.

High deficits can be expected in large parts of the inland areas where desert vegetation prevails (Figure 9.11). For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

Figure 9.11 Rainfall deficit distribution in the South Western Plateau region

9.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the South Western Plateau region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in Introduction and addressed in more detail in the Technical Supplement.

Figure 9.12 show that the region has a highly variable historic rainfall pattern. No clear seasonality in the rainfall can be identified in the boxes of Figure 9.12. This also counts for the historic annual totals of evapotranspiration and landscape water yield. The historic pattern of evapotranspiration closely follows that of rainfall. Landscape water yield is generally close to zero for each month of the year.

It should be noted that the area has low rain gauge density, particularly in the north, and data uncertainty for the spatially interpolated rainfall data is high. Nonetheless, Figure 9.12 shows that the 2011–12 year was a relatively wet year, especially between October 2011 and January 2012. Above average sea surface temperatures were evident in the Indian Ocean during spring 2011, which generated a large number of thunderstorms over the whole of Western Australia.

Evapotranspiration closely followed the temporal pattern of rainfall. A month's delay is noticeable in the October and November evapotranspiration in relation to rainfall, as evapotranspiration is limited to a maximum potential amount per day, based on available energy levels. Since most of the October rainfall was stored in the soil, it was directly available for evapotranspiration in November.

Throughout most of the year, landscape water yield for 2011–12 was higher than the historic monthly averages. Most of this landscape water yield occurred locally, mainly in the western part of the region.

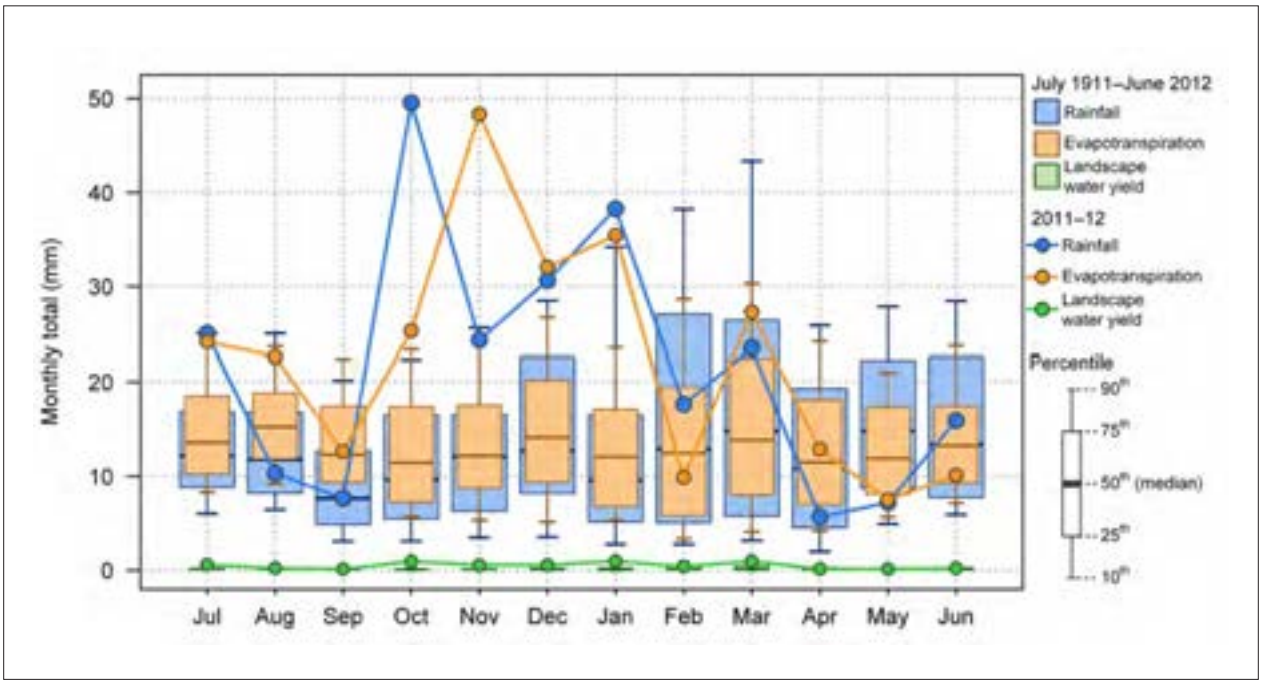


Figure 9.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the South Western Plateau region

9.4.1 Rainfall

Rainfall for the South Western Plateau region for 2011–12 is estimated to be 256 mm. This is 45% above the region's long-term average (July 1911–June 2012) of 176 mm. Figure 9.13a shows that the highest rainfall occurred largely along the western borders, with annual totals exceeding 400 mm in many areas for 2011–12.

The high data uncertainty in the map indicates those areas where rain gauge density is too low to accurately capture localised rainfall, particularly in the form of thunderstorms.

Rainfall deciles for 2011–12 indicate average to above average rainfall for the entire region over the course of the year (Figure 9.13b). The pasture fields in the northwest of the region locally had very much above average rainfall.

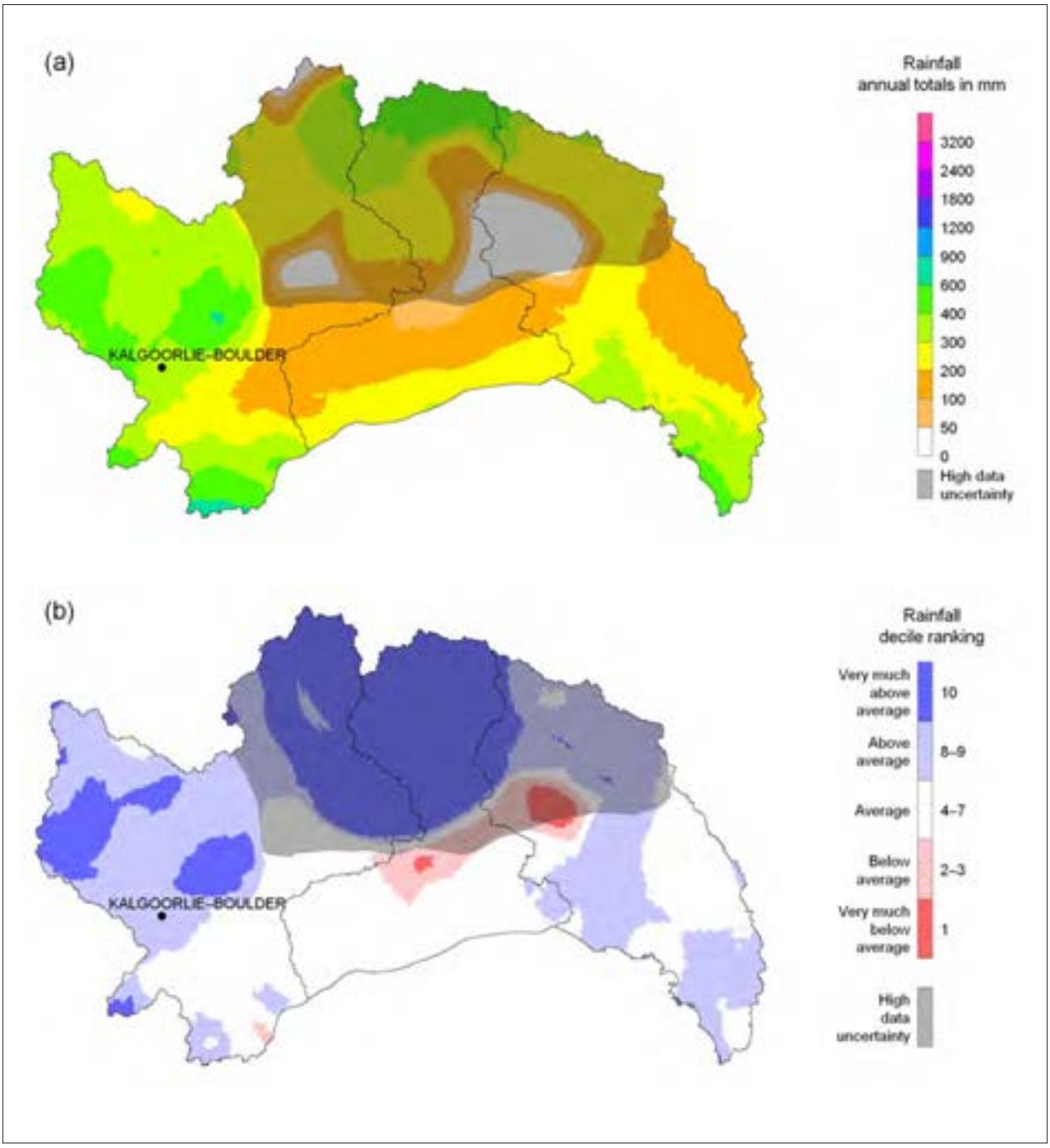
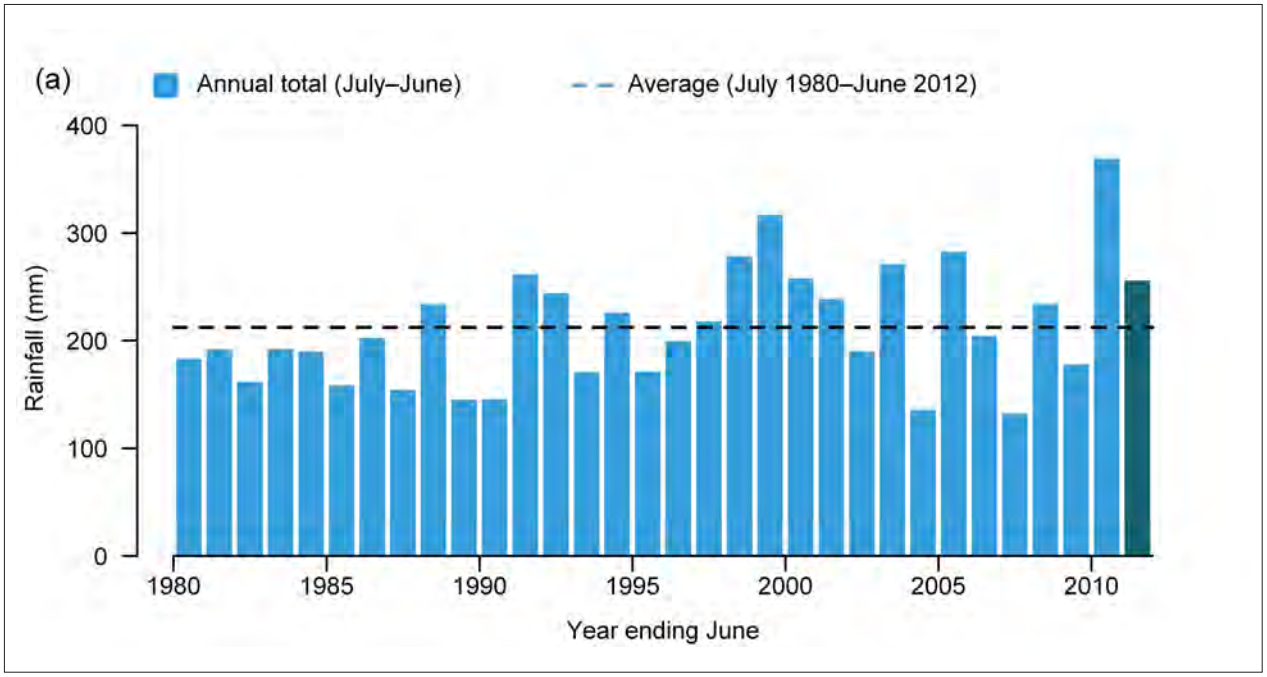


Figure 9.13 Spatial distribution of (a) annual rainfall in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South Western Plateau region

Rainfall variability in the recent past

Figure 9.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 212 mm, varying from 132 mm (2007–08) to 369 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 9.14b.

The graphs indicate a substantial increase in rainfall from 1997 onwards, especially for the summer period. Where rainfall was equally distributed between the summer and winter period in the first half of the 32-year period, summer rainfall suddenly increased to higher totals in the second half of the period.



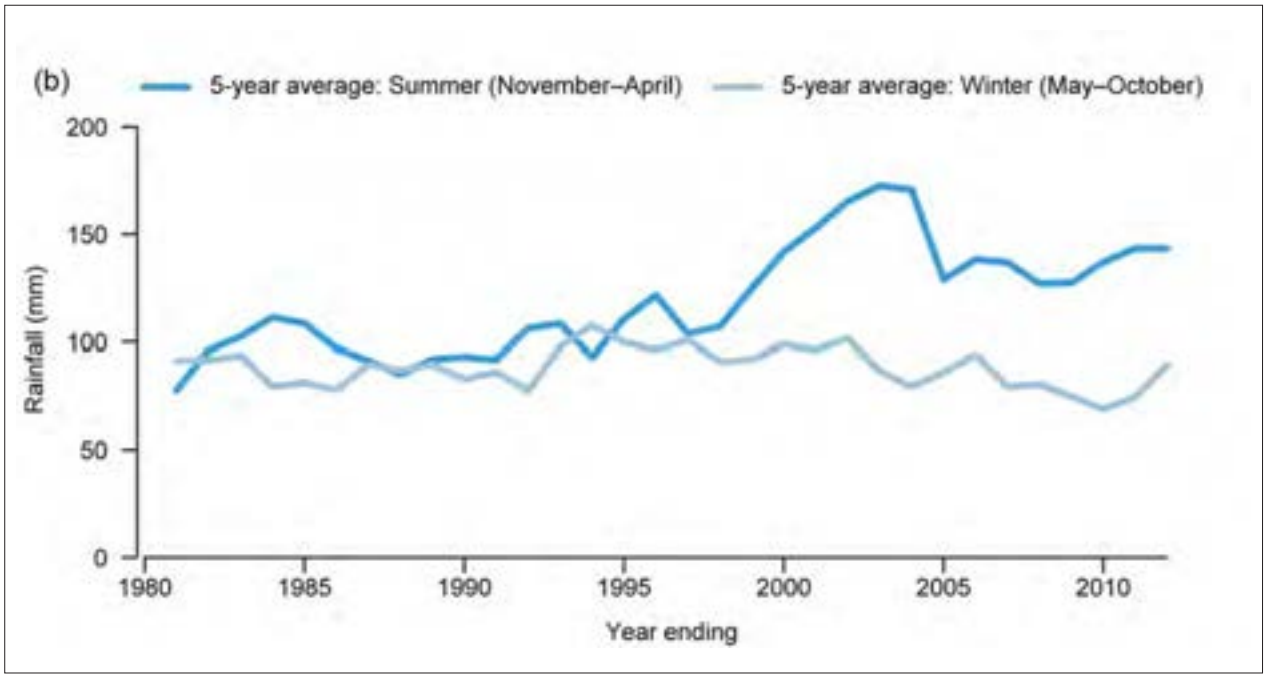


Figure 9.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Western Plateau region

Recent trends in rainfall

Figure 9.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 9.15b.

Figure 9.15a shows that since 1980 an increase in rainfall has occurred in most of the region, particularly in the data sparse north. Some areas with a significant rising trend are present on the Nullarbor in the centre of the region. The more cultivated southwest and southeast of the region had no change in annual rainfall since 1980.

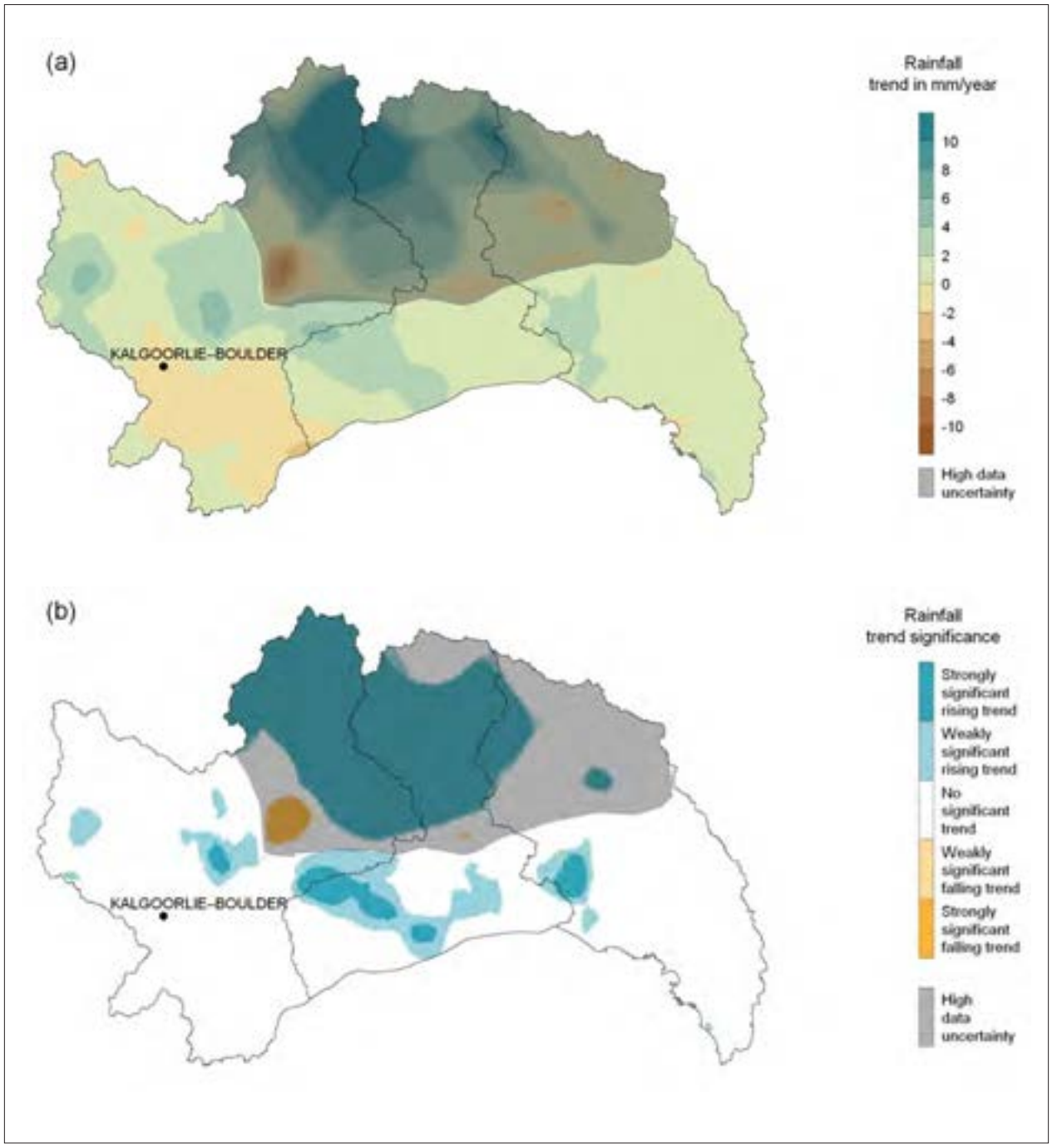


Figure 9.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Western Plateau region

9.4.2 Evapotranspiration

Modelled annual evapotranspiration for the South Western Plateau region for 2011–12 is estimated to be 268 mm. This is 55% above the region's long-term (July 1911–June 2012) average of 173 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 9.16a) is closely related to that of rainfall (Figure 9.13a).

Evapotranspiration deciles for 2011–12 indicate very much above average totals across most of the north of the region (Figure 9.16b). In the south, where the water supply through rainfall was largely average, evapotranspiration was also not able to exceed average levels.

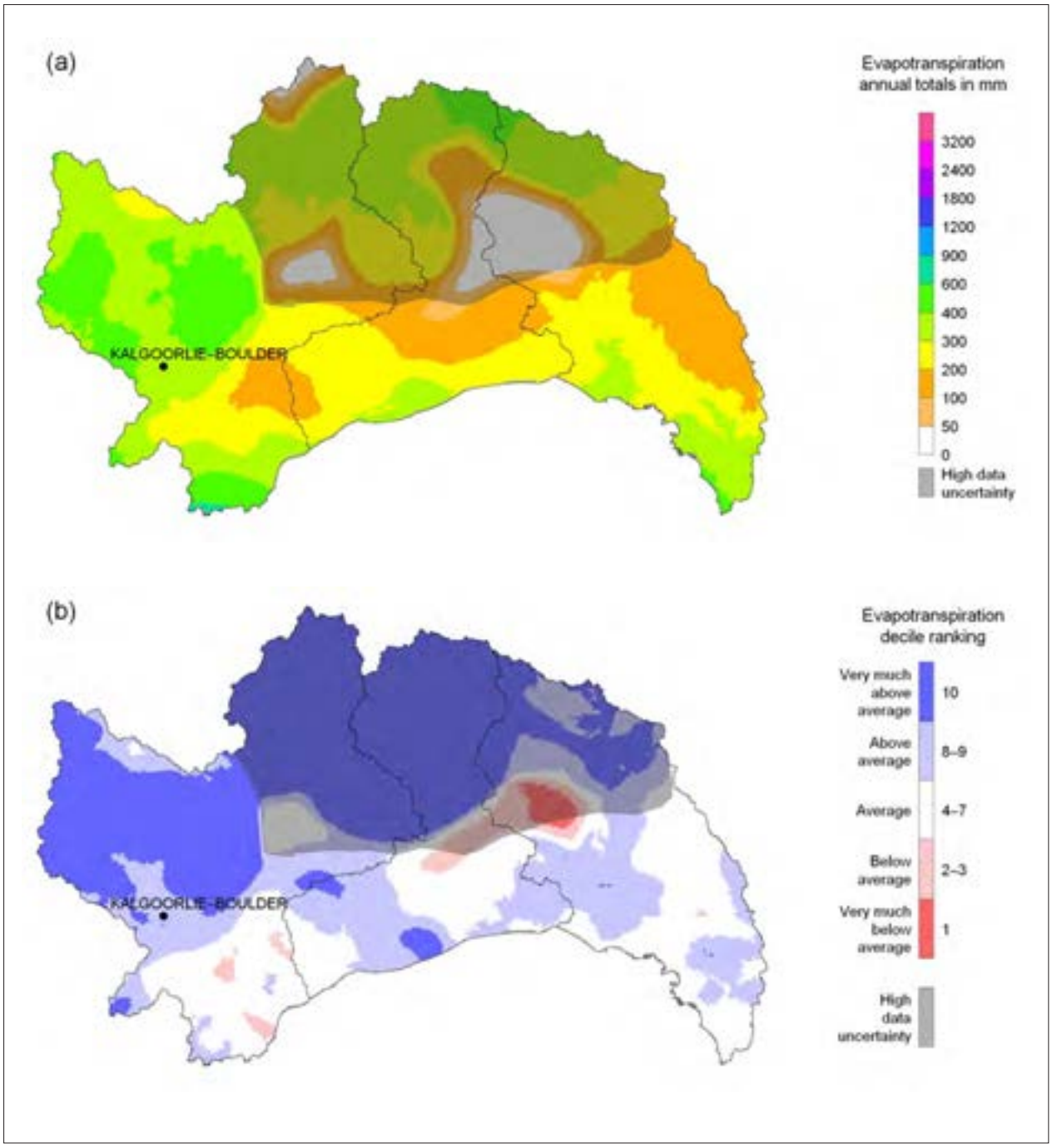
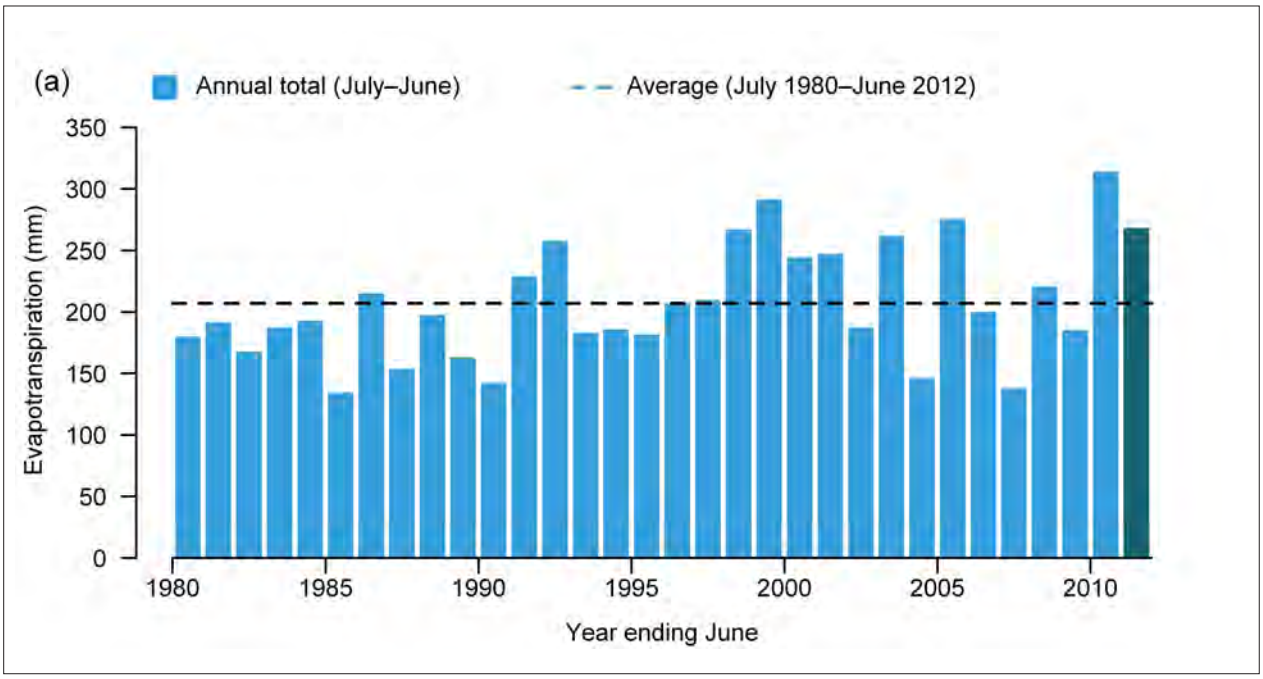


Figure 9.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South Western Plateau region

Evapotranspiration variability in the recent past

Figure 9.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 207 mm, varying from 134 mm (1985–86) to 314 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 9.17b.

Similar to the temporal pattern of rainfall, evapotranspiration shows an increase in annual totals after 1997, mainly occurring in the summer period. Water availability, provided by rainfall, is the only limitation to evapotranspiration in this arid region.



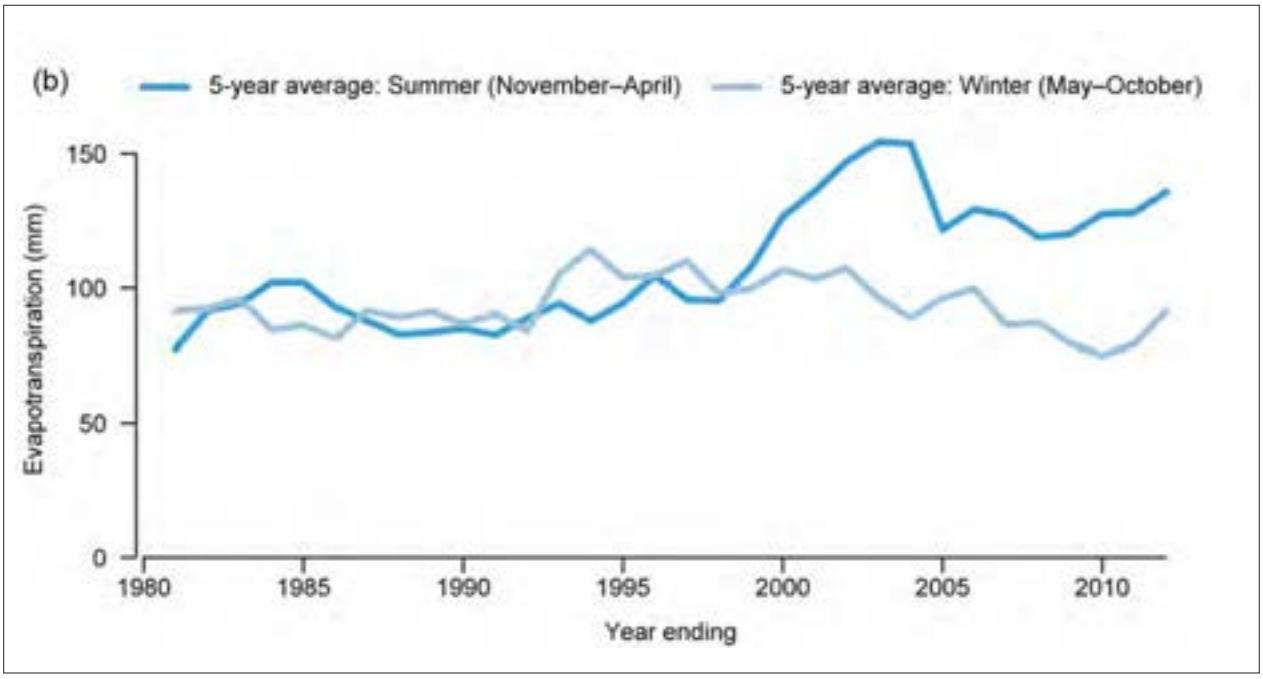


Figure 9.17 Time-series of (a) annual evapotranspiration and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Western Plateau region

Recent trends in evapotranspiration

Figure 9.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 9.18b.

Figure 9.18a shows that, since 1980, trends are mostly positive in the central northern part of the region. In the south, the trends are mostly neutral.

As shown in Figure 9.18b, some statistically significant rising trends in annual evapotranspiration are present in the data sparse north and in large areas in the centre of the region. As evapotranspiration is driven by the availability of moisture, these spatial patterns are again linked to the rainfall trends of Figure 9.15.

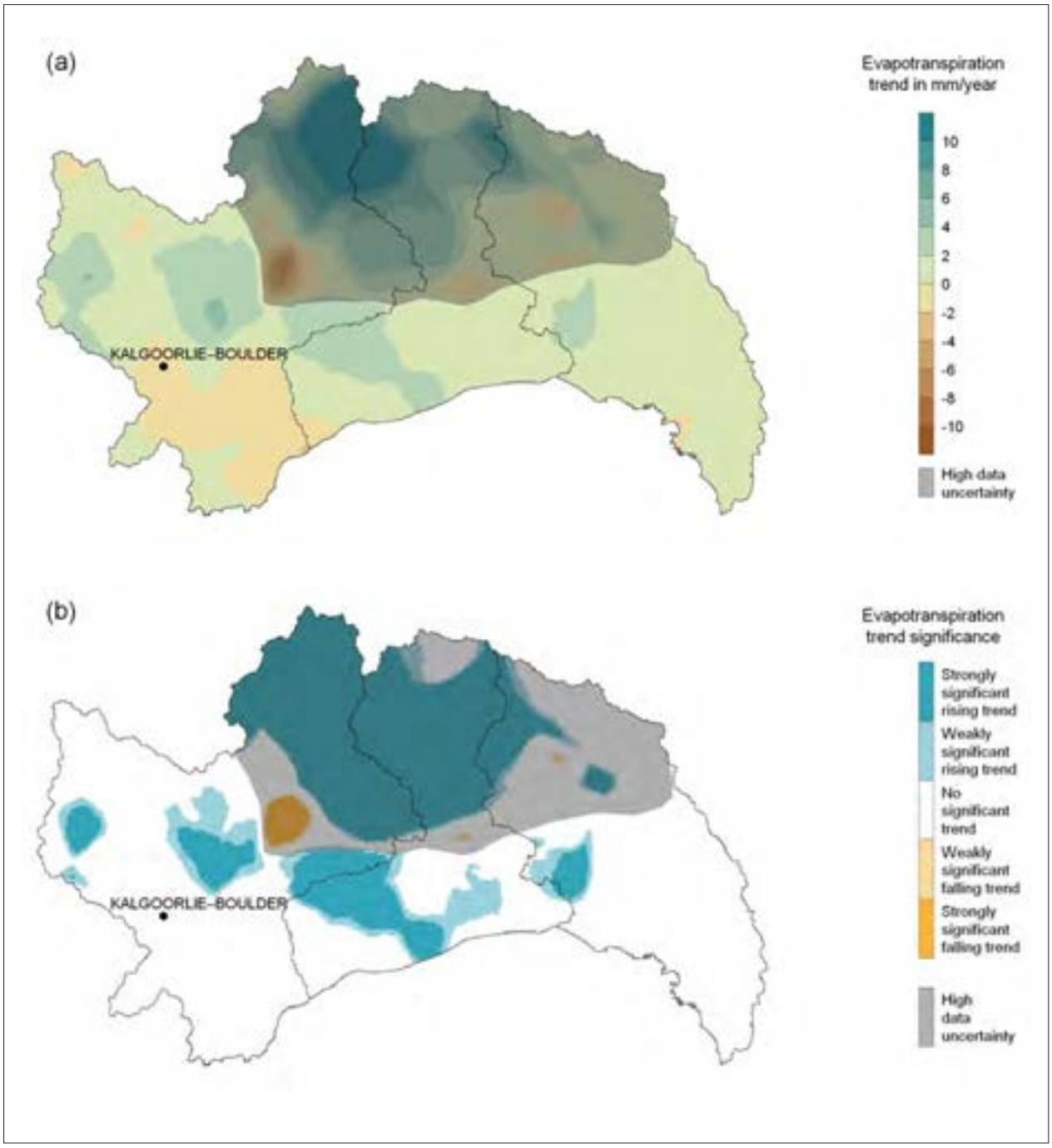


Figure 9.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Western Plateau region

9.4.3 Landscape water yield

Modelled landscape water yield for the South Western Plateau region for 2011–12 is estimated to be 6 mm. This is 100% above the region's long-term (July 1911–June 2012) average of 3 mm. Figure 9.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 9.13a; note the difference in the scale of the two figures).

The decile ranking map for 2011–12 (Figure 9.19b) shows above average to very much above average landscape water yields in most parts of the region. Some below average landscape water yield occurred in the southwest of the region. Throughout the area the model estimates landscape water yields which vary marginally. Only minor differences from the mean could cause areas to appear as above or below average.

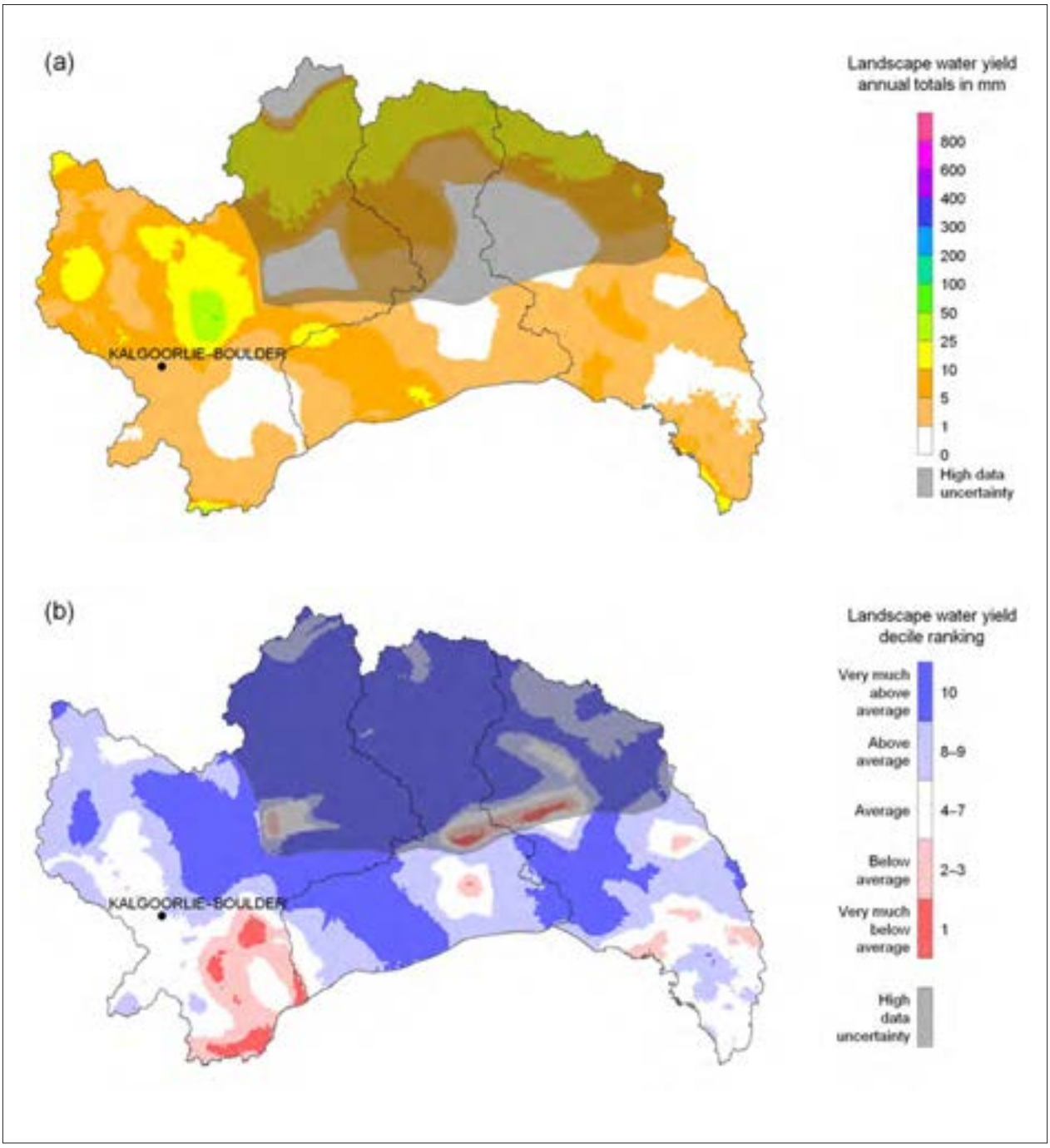


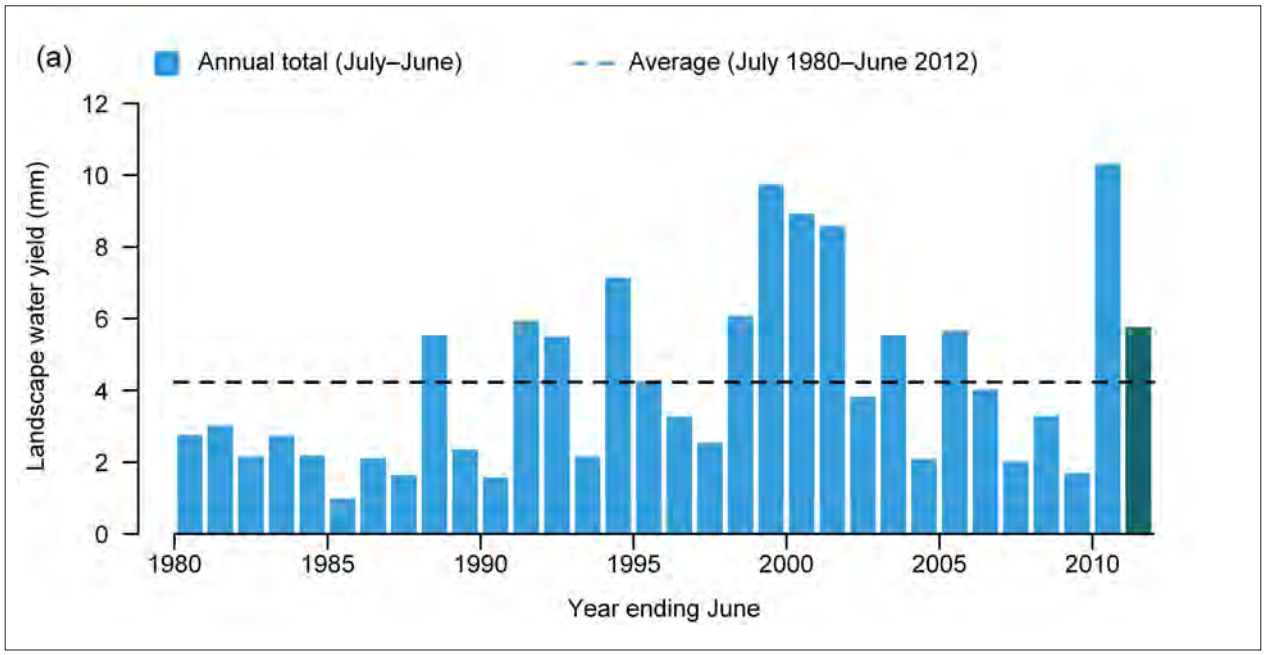
Figure 9.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South Western Plateau region

Landscape water yield variability in the recent past

Figure 9.20a shows annual landscape water yield for the South Western Plateau region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 4 mm, varying from 1 mm (1985–86) to 10 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 9.20b.

The high variability in annual landscape water yield is normal for arid areas. These areas experience only a small number of rainfall events, of which only the high intensity events have the potential to generate landscape water yield.

Landscape water yield is consistently higher during the summer period compared to the winter period, with, however, an increase in the gap between the two seasons since 1997. This again corresponds with the temporal patterns in rainfall of Figure 9.14b.



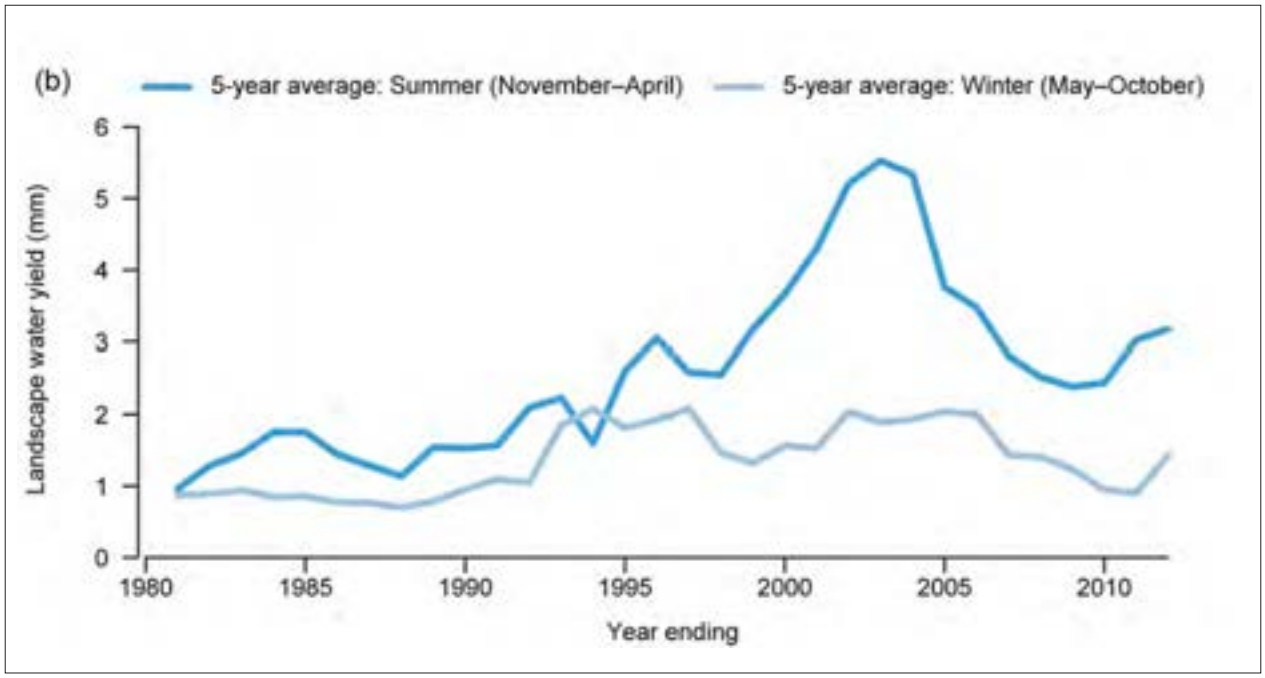


Figure 9.20 Time-series of (a) annual landscape water yield and, (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South Western Plateau region

Recent trends in landscape water yield

Figure 9.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980– 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 9.21b.

Figure 9.21a shows that, since 1980, trends are marginal, which can be expected when applying linear regression to time-series of particularly low values.

On the other hand, Figure 9.21b shows strongly significant rising trends in landscape water yield in large parts of the region, especially in the centre. The magnitudes of the trends in these areas do not exceed 1 mm/year with most of these areas even having trends below 0.2 mm/year.

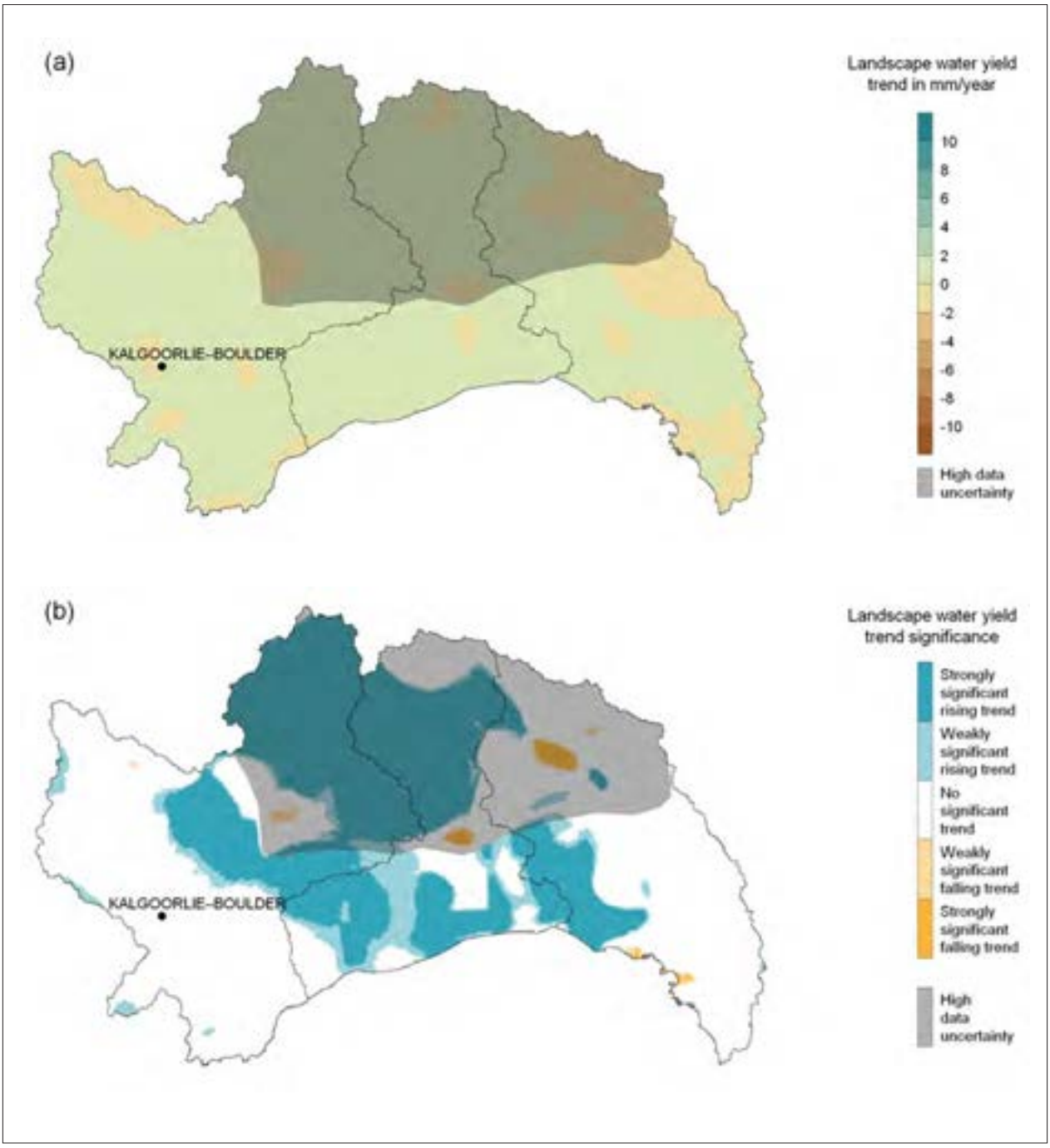


Figure 9.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012 and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South Western Plateau region

9.5 Surface water and groundwater

This section examines surface water and groundwater resources in the South Western Plateau region. Rivers and wetlands are discussed to illustrate the region's surface water resources.

The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

Due to the absence of suitable data on river flows in this region, no analysis is performed on streamflow characteristics and wetland inflows.

There are no major public storages present in the region.

9.5.1 Rivers

There are three river basins in the South Western Plateau region, varying in size from 278,000–496,000 km^2. These river basins are Gairdner, Nullarbor and Salt Lake (Figure 9.22).

A substantial number of predominantly dry lakes are present in the west and east of the region as well as more sporadically in the north.

Some small rivers, near Esperance in Western Australia and Ceduna in South Australia, discharge to the Southern Ocean. All streams flow only after heavy rains, which may be two or three or even ten years apart.

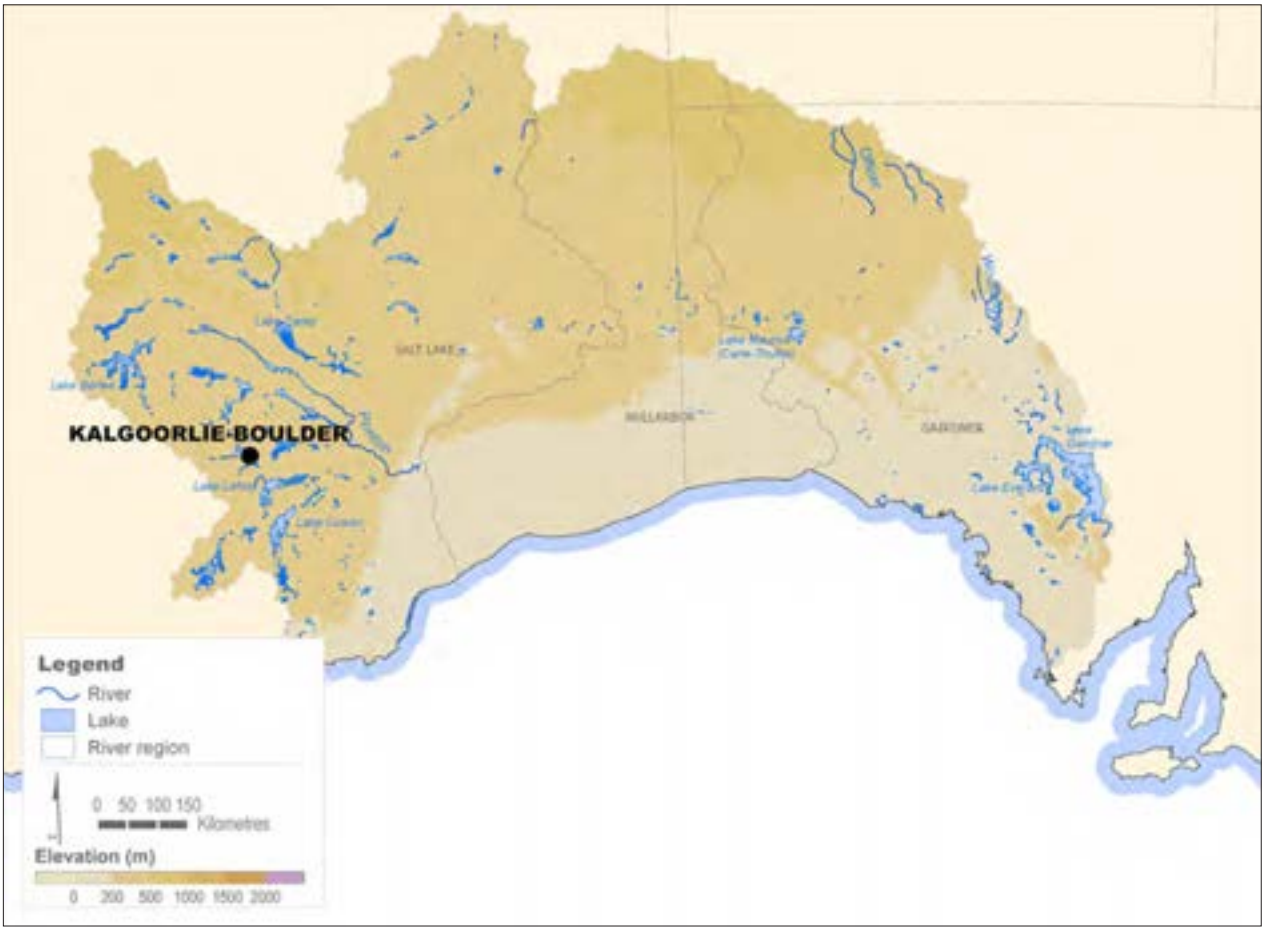


Figure 9.22 Rivers and catchments in the South Western Plateau region

9.5.2 Flooding

No major, moderate or minor floods were recorded at the two available Bureau flood monitoring sites near Esperance.

9.5.3 Wetlands

The wetlands vary from coastal floodplains and tidal flats to inland ephemeral lakes and large salt lakes. There is one Ramsar-listed, internationally important wetland present in the South Western Plateau region and a number of national important wetlands as shown in Figure 9.23.

The wetlands vary from coastal floodplains and tidal flats to inland ephemeral lakes and large salt lakes.

The Ramsar-listed Lake Warden system near Esperance consists of saline lakes and marsh areas separated from the ocean by sand dunes. It is an important habitat for water birds. More information about the region's wetlands is available from the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html).

No detailed assessment on the inflows of selected wetlands has been performed for this region.

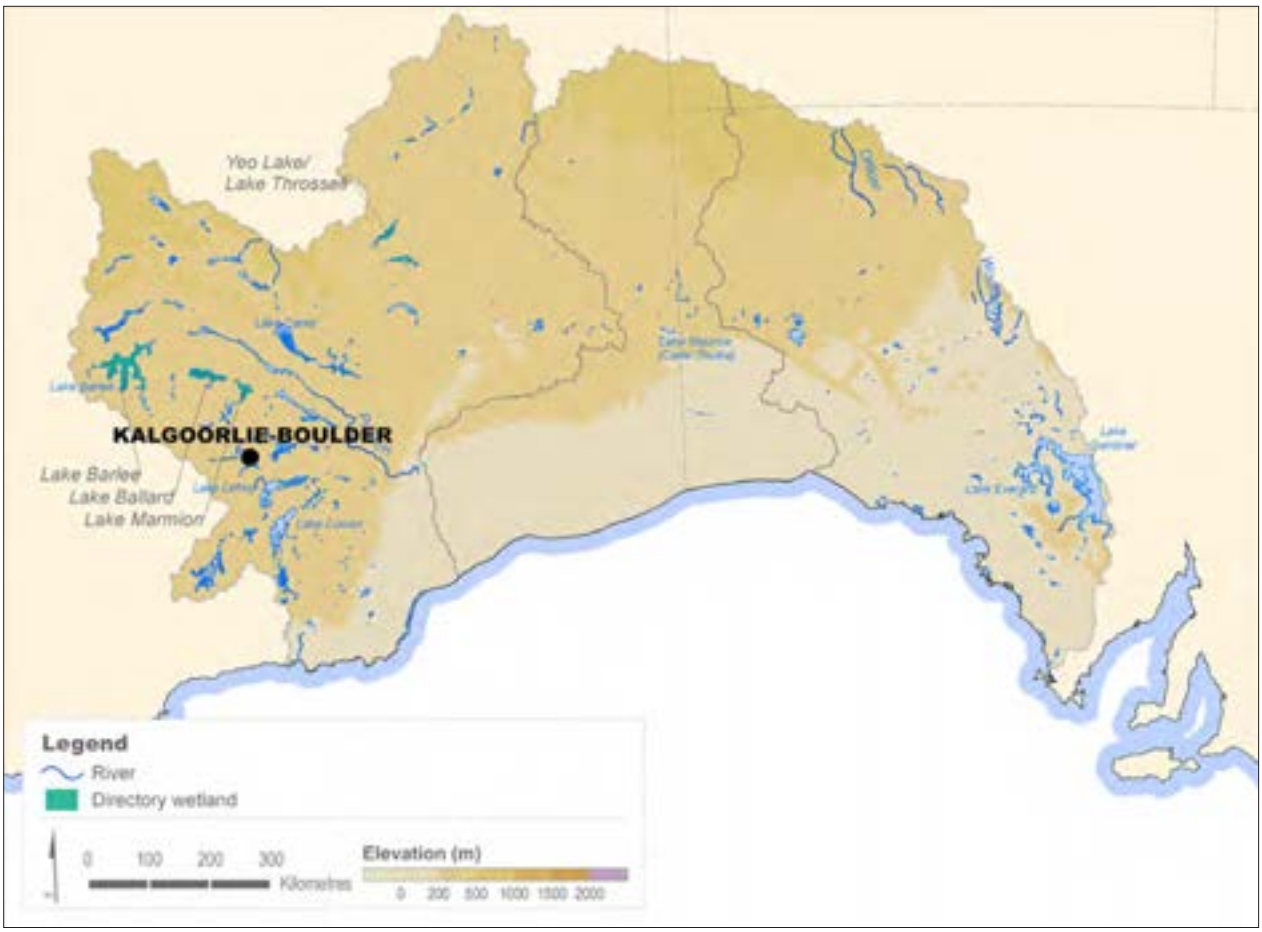


Figure 9.23 Location of important wetlands in the South Western Plateau region

9.5.4 Hydrogeology

The hydrogeology of the South Western Plateau region is dominated by a large area of outcropping fractured basement rock (Figure 9.24).

The groundwater systems in fractured rock typically offer restricted low volume groundwater resources. In contrast, there are significant groundwater resources in localised sedimentary aquifers.

Figure 9.24 shows a discontinuity in aquifers across the State border, which is the result of two different State-based aquifer classification systems.

Groundwater systems that provide potential for extraction are labelled as:

- Surficial sediment aquifer (porous media—unconsolidated); and
- Upper mid-Tertiary aquifer (porous media—unconsolidated).

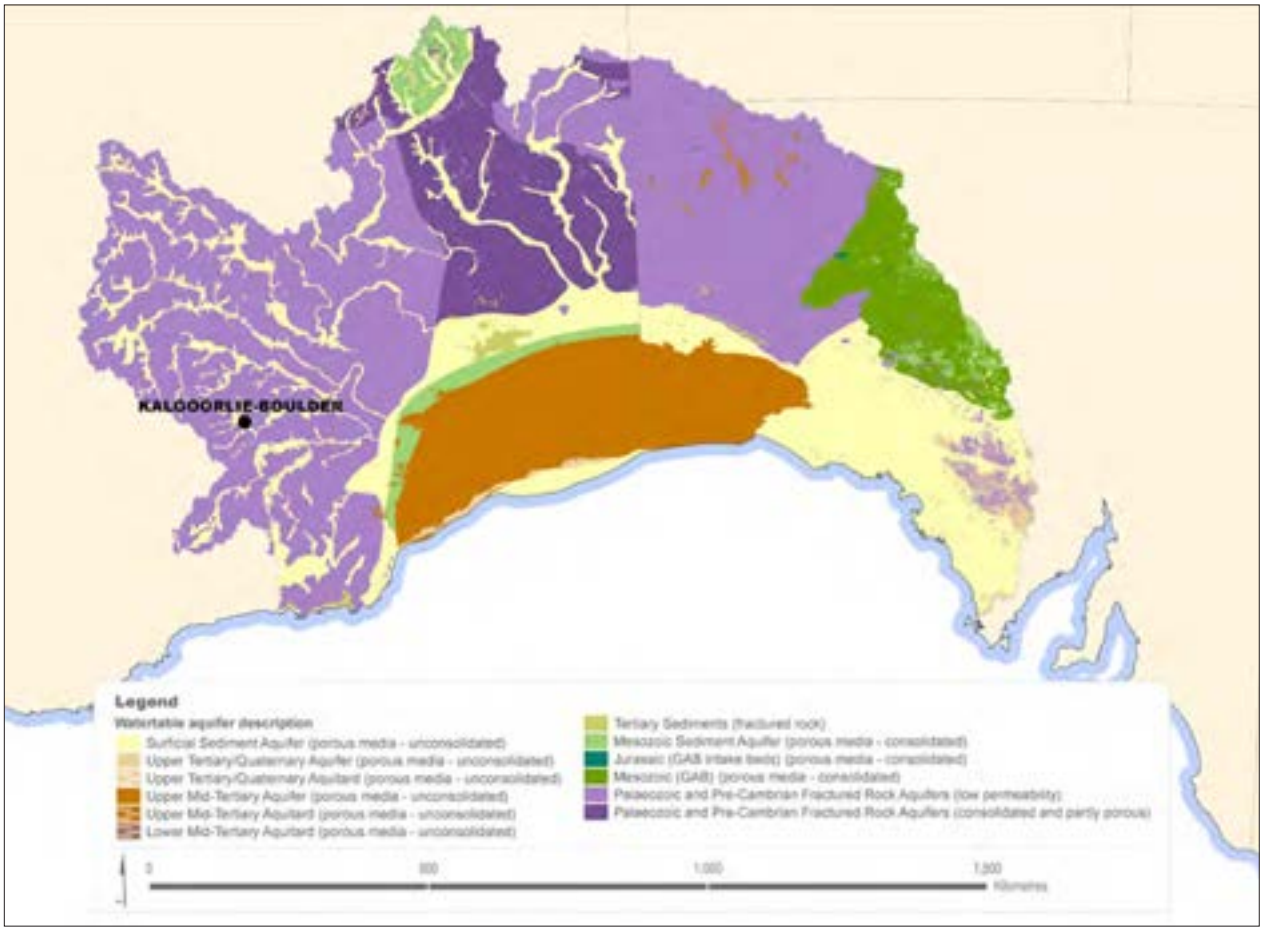


Figure 9.24 Watertable aquifers of the South Western Plateau region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

9.5.5 Watertable salinity

Figure 9.25 shows the classification of watertable aquifers as fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) water according to watertable salinity. The discontinuity in aquifers across the State border in Figure 9.25 is the result of two different State-based aquifer salinity classification systems.

Shallow groundwater has been classified mainly as saline within South Australia and around half fresh and half saline in Western Australia; however, a clear pattern of high groundwater salinity is present in the low-lying areas, in particular in those aquifers that are mentioned as having high extraction potential.

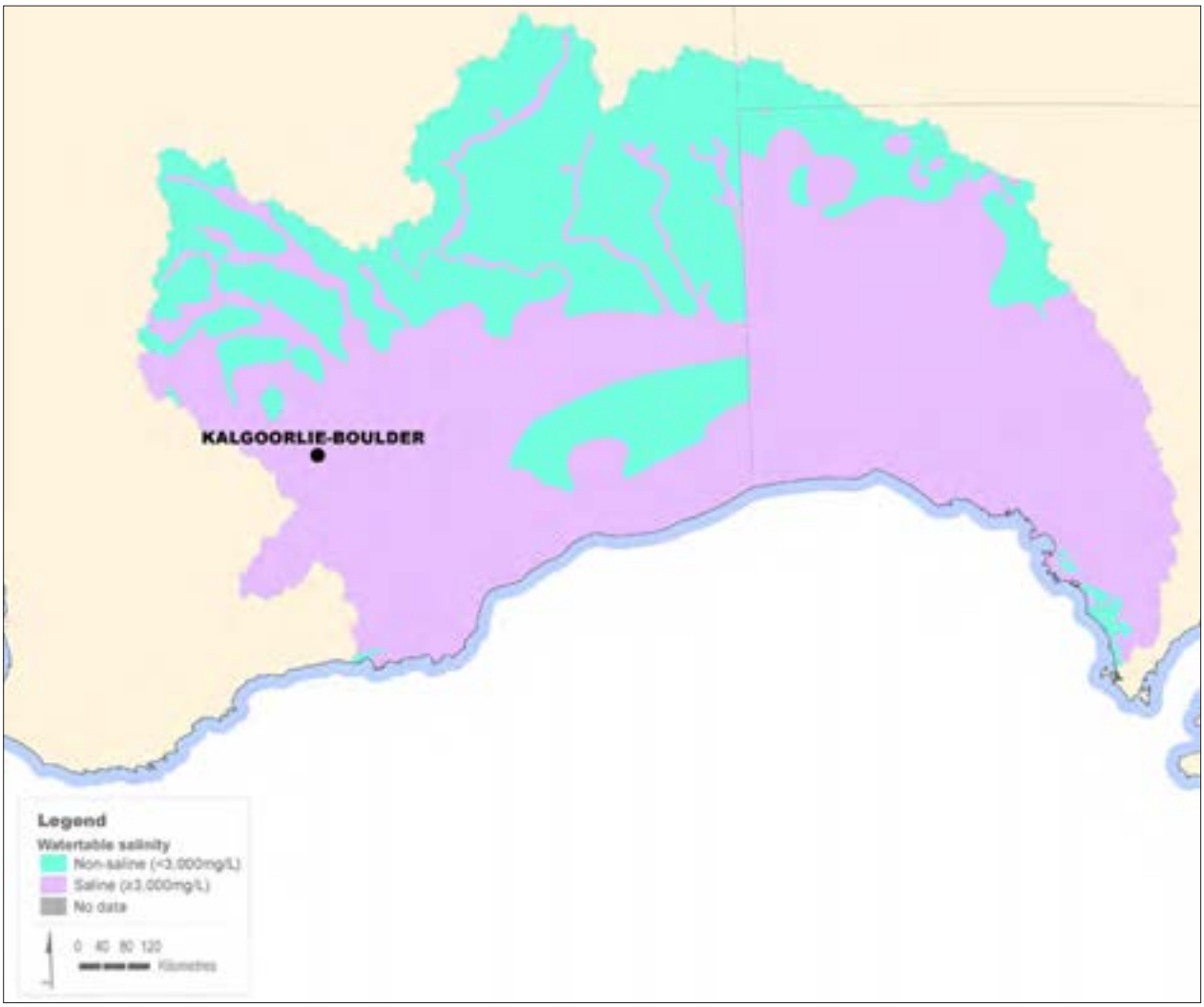


Figure 9.25 Watertable salinity classes of the South Western Plateau region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

9.5.6 Groundwater management units

The groundwater management units within the South Western Plateau region are key features that control the extraction of groundwater through planning mechanisms.

The groundwater management units within the region are presented in Figure 9.26. This dataset is extracted from the National Groundwater Information System (2013) which contains a collection of groundwater management units from all States.

The major management units with significant groundwater use include Goldfield, East Murchison, Nullarbor in Western Australia and Musgrave in South Australia.

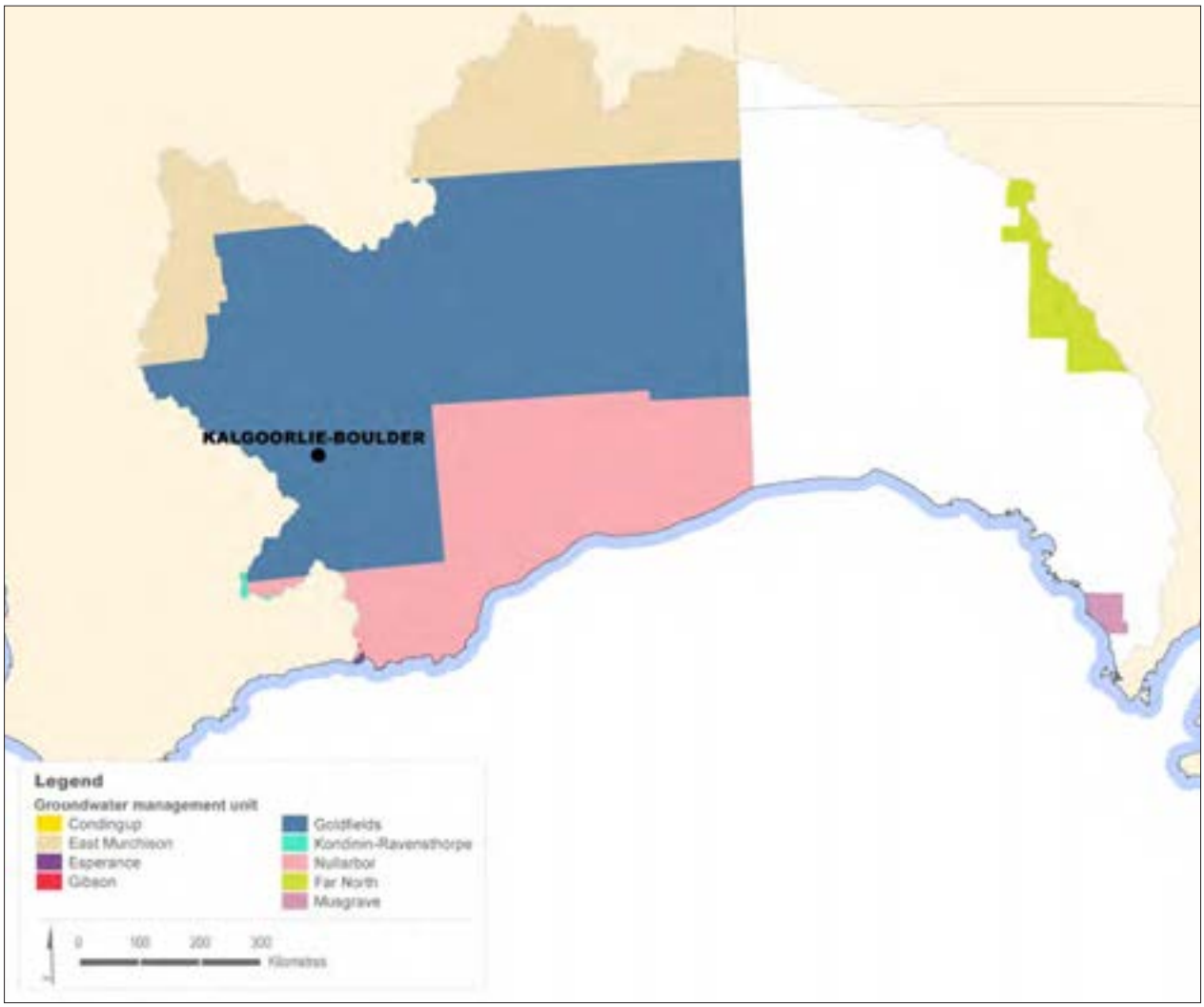


Figure 9.26 Groundwater management units in the South Western Plateau region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

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10 South West Coast

10.1 Introduction

This chapter examines water resources in the South West Coast region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

10.2 Key information

Table 10.1 gives an overview of the key components of the data and information in this chapter.

Table 10.1 Key information on water flows, stores and use in the South West Coast region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	499 mm	+14%	8th—above average
Evapo-transpiration	455 mm	+15%	10th—very much above average
Landscape water yield	28 mm	-24%	4th—average

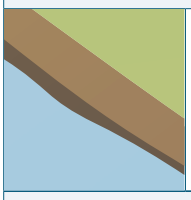
Streamflow (at selected gauges)

Annual total flow:	Between average and very much below average flow throughout the region
Salinity:	Annual median electrical conductivity predominantly above 2,000 µS/cm inland and less saline in the coastal rivers in the west
Flooding:	Sporadic minor and moderate flooding in the southwest river basins

Surface water storage (comprising about 92% of the region's total capacity of all major storages)

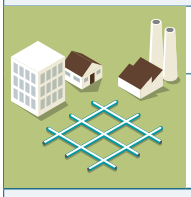
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
951 GL	309 GL	32%	210 GL	22%	+99 GL	+10%

Groundwater (in selected aquifers)



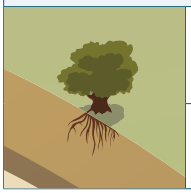
Salinity:	Non-saline groundwater (<3000 mg/L) only along the southwest coastline and in scattered areas in the north

Urban water use (Perth)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
248 GL	247 GL	+1 GL	Eased to Stage 5 in September, back to Stage 7 in June

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly average to below average annual mean soil moisture with large areas of very much below average soil moisture to the east and in the southwest
Temporal patterns in regional average:	Below average soil moisture throughout the year, only reaching average levels in summer

10.3 Description of the region

The South West Coast region covers approximately 326,000 km² of land. It is bounded to the west by the Indian Ocean and to the south by the Great Australian Bight. The northern boundary is the Pilbara–Gascoyne region and the eastern boundary is the South Western Plateau region.

The landscape of the region is generally flat and sandy in inland areas. Higher altitude topographic features include the Darling Scarp that forms an ancient geological boundary to the 30-km wide Swan Coastal Plain along the west coast and the Stirling Range near Albany. The Swan Coastal Plain consists of relatively infertile sandy soils and coastal dunes; a number of estuaries and wetlands are separated from the sea by these dunes. Subsections 10.3.1–10.3.4 give more detail on physical characteristics of the region.

The region has a population just over 2 million people, which accounts for just over 9% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b). Figure 10.1 highlights the major population centres in the region that includes Perth, Mandurah, Bunbury and Albany. Further discussion of the region's population distribution and urban centres can be found in subsection 10.3.6 and section 10.6 respectively.

The north of the region is dominated by pasture, becoming a more complex pattern of pasture and dryland crops towards the central and southern parts of the region. Forestry is important in the wetter higher altitude western slopes, with extensive conservation reserve areas in this part of the region. Conservation shrubland and heathland reserves are well represented in the more arid east (Figure 10.1).

Dryland and irrigated agriculture account for a very small proportion of the land use in the area. Intensive land uses such as urban areas also account for small proportions of the region. The largest areas of irrigated agriculture are located in the Peel–Harvey irrigation district, with a considerable proportion of the water used to irrigate pasture for dairy and for vegetable and fruit crops. Section 10.7 has more information on agricultural activities in the region.

The region has a temperate climate with warm dry summers and cool winters. Most rainfall occurs in the west with reduced rainfall further inland. The Stirling Range receives occasional snowfall. Subsections 10.3.7 and 10.3.8 provide more information on the rainfall types and deficits across the region.

The longest rivers are located in the southwest, with the Avon and Blackwood rivers having the largest catchment areas. Due to the raised topography and orientation of the Darling Scarp, most of the major rivers drain towards the Indian Ocean but the high soil permeability results in generally low surface flows.

The hydrogeology of the region is dominated by a large area of outcropping fractured basement rock. The groundwater systems in fractured rock typically offer a restricted low volume groundwater resource. Significant groundwater resources are, however, available on parts of the coastal plain. Approximately 35–50% of the water supplied to the city of Perth is sourced from groundwater. A more detailed description of the rivers and groundwater status in the region is given in section 10.5.

Figure 10.1 Major rivers and urban centres in the South West Coast region

10.3.1 Physiographic characteristics

The physiographic map in Figure 10.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes. The South West Coast region has two physiographic provinces, namely the Western Coastlands and Yilgarn Plateau provinces.

The Western Coastlands province stretches along the western side of the region, occupying 9% of the area. In the north it has dissected ferruginous plateaus and hills on sedimentary rocks with areas of extensive coastal dune systems. The central portion of the region has dune ridges (on limestone along the coast) and inner alluvial plains. In the southeast there are low moderately dissected ferruginous plateaus on down faulted sedimentary rocks and a swampy south coastal plain. In the southwest there is a narrow granitic ridge with calcareous dunes and dissected ferruginous plateaus.

The Yilgarn Plateau province covers 91% of the area and is largely flat to undulating, with salt lakes and occasional low hills of igneous and metamorphic rock. Some areas have ferruginous breakaways and dunes.

Figure 10.2 Physiographic provinces of the South West Coast region

10.3.2 Elevation

Figure 10.3 presents ground surface elevations in the South West Coast region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The landscape of the region is generally flat in inland areas. Higher altitude topographic features include the Darling Range, reaching altitudes exceeding 400 m above sea level, and the Stirling Range, with its highest peaks reaching just over 1,000 m above sea level (Figure 10.3).

The Darling Range forms an ancient geological boundary to the 30-km wide Swan Coastal Plain along the west coast.

The Swan Coastal Plain consists of relatively infertile sandy soils and coastal dunes. A number of estuaries and wetlands are separated from the sea by these dunes.

Moving from the west to the east into the vast inland area, altitudes gradually rise from around 200 m above sea level in the west to altitudes exceeding 400 m above sea level at the eastern border of the region.

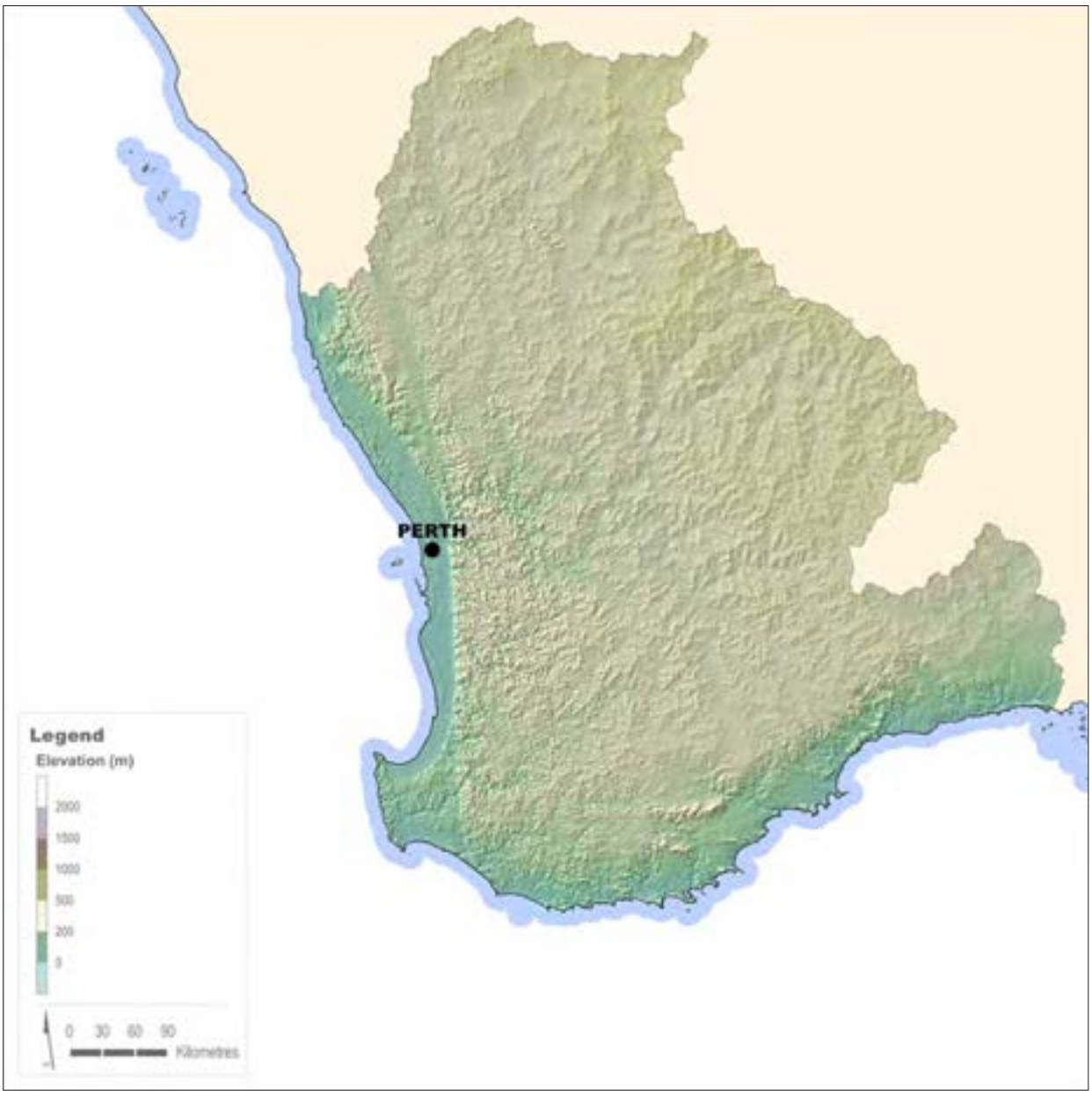


Figure 10.3 Ground surface elevations in the South West Coast region

10.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The South Australian Gulf region has hardly any areas with steep slopes. Most of the area is rather flat (Table 10.2 and Figure 10.4).The slopes were derived from the elevation information used in the previous section.

Table 10.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	20.6	28.0	48.0	3.4

The steep slopes in Figure 10.4 in particular highlight the Stirling Range in the south and some deeper valleys in the Darling Range which have been cut out by rivers. The western coastal plains run along the coast for about 400 km, although the northern part is separated from the sea by a high and wide ridge of sand dunes.

The inland of the region is not as flat as other inland parts of Australia. The gentle slopes there do not interfere with advanced commercial use of land, such as dryland agriculture. On the steeper slopes of the Darling Range, however, forestry is a dominant land use.

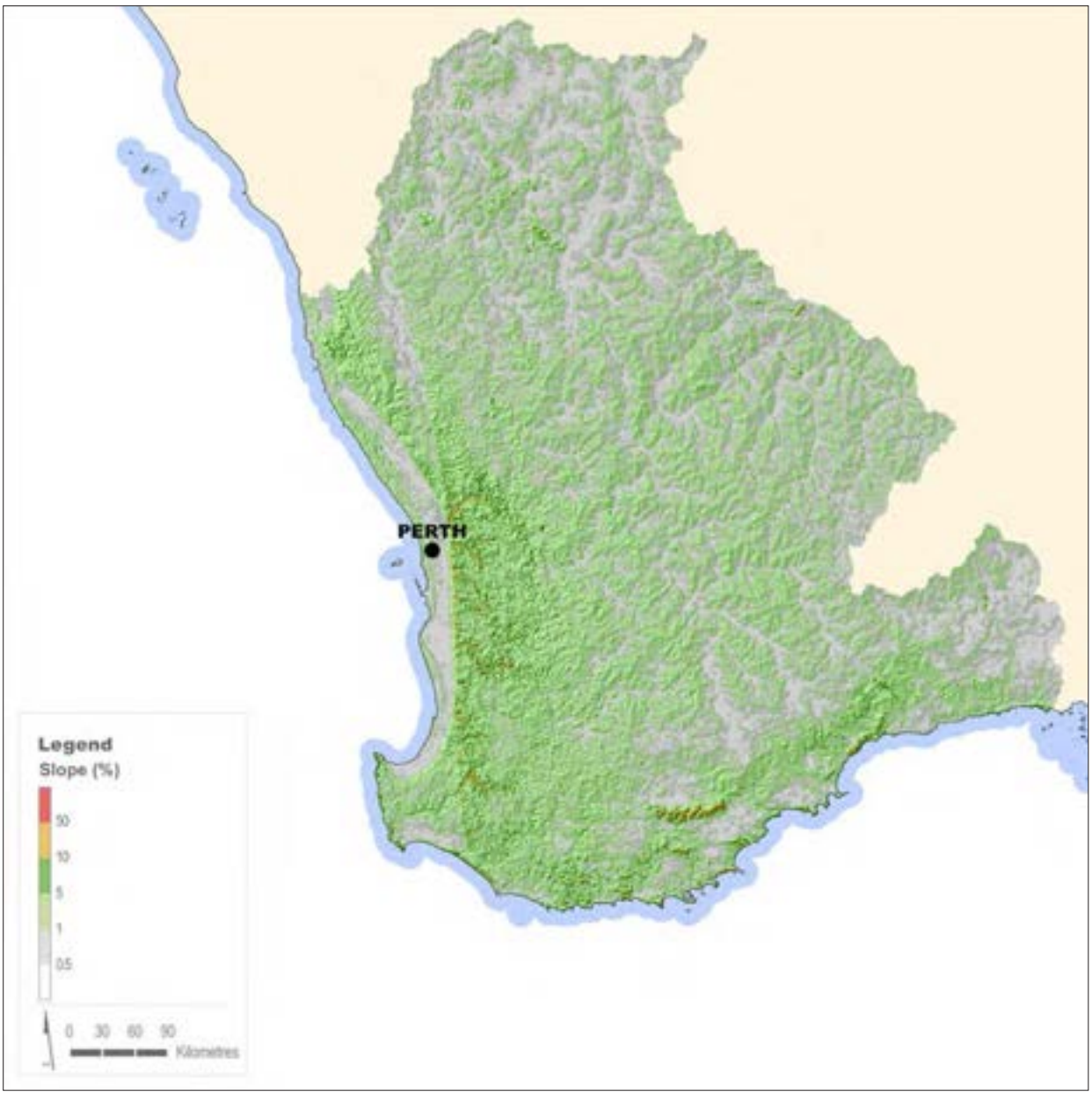


Figure 10.4 Surface slopes in the South West Coast region

10.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 86% of the South West Coast region is covered by four soil types, namely sodosols, tenosols, kandosols and chromosols (Figure 10.5 and Figure 10.6).

Sodosols are the most common soils in this region. They are dominant in the central-south to southeast of the region. These soils have a strongly contrasting texture, with impermeable sodic subsoils arising from elevated sodium concentrations and clay. They are susceptible to dryland salinity as well as erosion, if vegetation is removed. Sodosols are usually low in nutrient status but, in this region, are present in areas used for dryland crops and pastures.

Similarly chromosols have a strongly contrasting texture, but have permeable subsoils which are not high in sodium. They have moderate chemical fertility, water-holding capacity and agricultural potential. Soil acidification and soil structural decline may also occur. They are common in the western part of the region and are mostly present in pastures and areas used for forestry or nature conservation (Figure 10.6).

Tenosols and kandosols are soils with weak and minimal development throughout the profile (tenosols) and are less structured (kandosols). These soils are low in fertility and water-holding capacity, having a weak profile development. They are often shallow or stony. Tenosols are common in the northern as well as in the western part of the region and are scattered in the western part. Kandosols are scattered all over the region. These soils are used for forestry, pastures and nature conservation.

The other soil types that have minimal representation in the South West Coast region are hydrosols, calcarosols, podosols, kurosols and rudosols (1–5% of the total area).

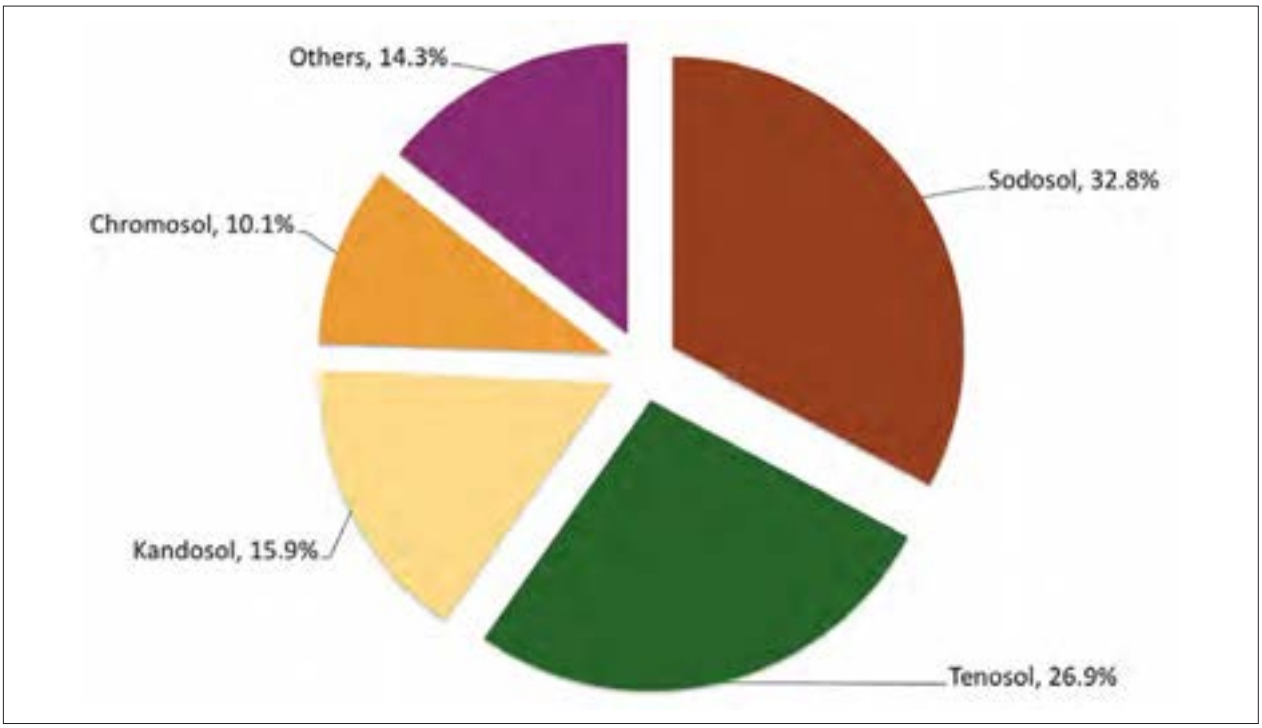


Figure 10.5 Soil types in the South West Coast region

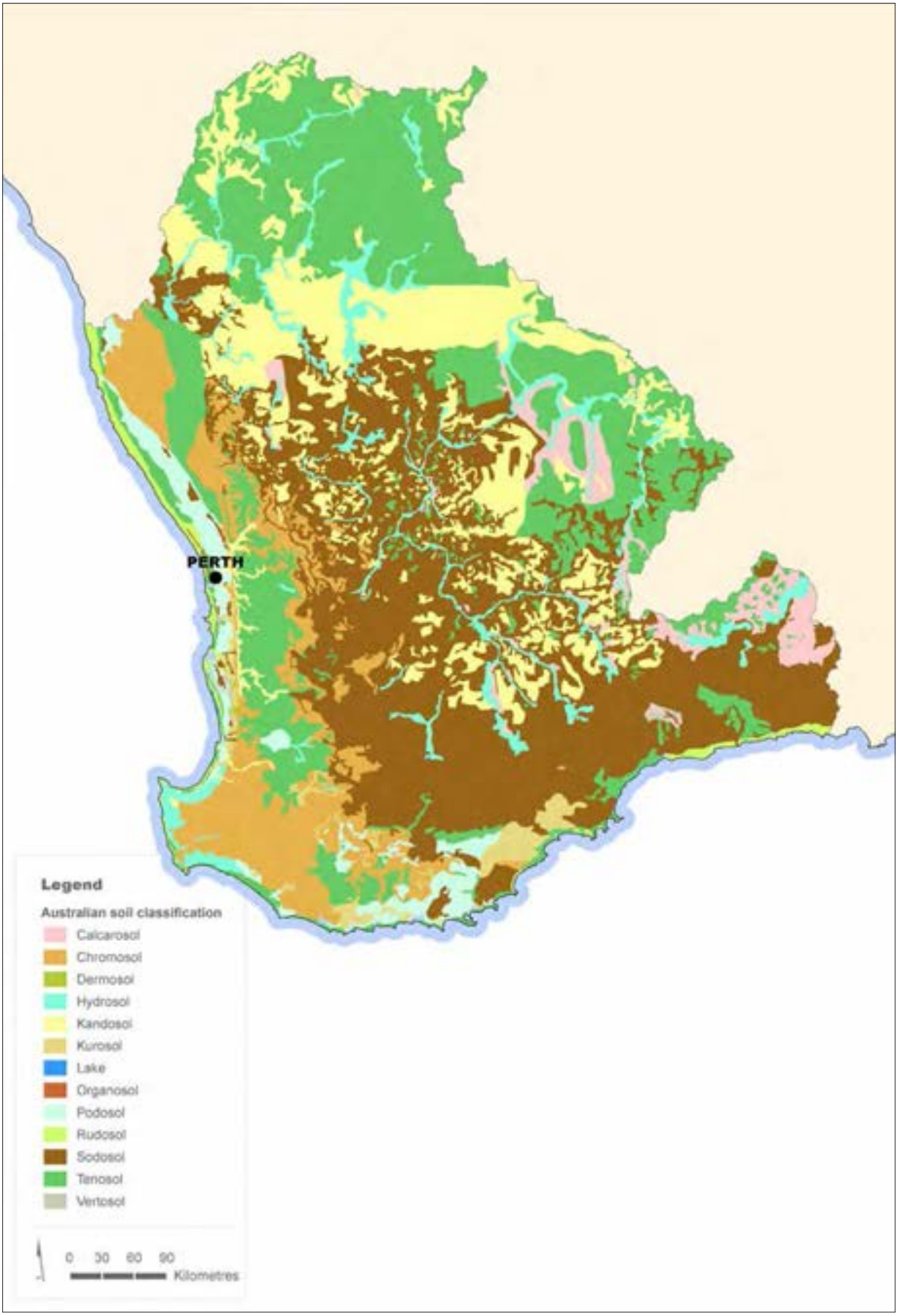


Figure 10.6 Soil type distribution in the South West Coast region

10.3.5 Land use

Figure 10.7 presents land use in the South West Coast region (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Much of the region's north is dominated by pasture, becoming a mix of pasture and dryland crops towards the central and southern parts of the region (Figure 10.8).

Forestry is a major land cover in the wetter, higher altitude southwestern slopes, with extensive conservation reserve areas in this part of the region.

Conservation shrublands and heathland reserves occupy most of the arid east of the region. Irrigated agriculture accounts for a very small proportion of the land use of the area. Intensive land uses such as urban areas also account for small proportions of the region.

The largest areas of irrigated agriculture in the region are located in the Peel–Harvey irrigation district, with a considerable proportion of the water used to irrigate pasture for dairy and for vegetable and fruit crops.

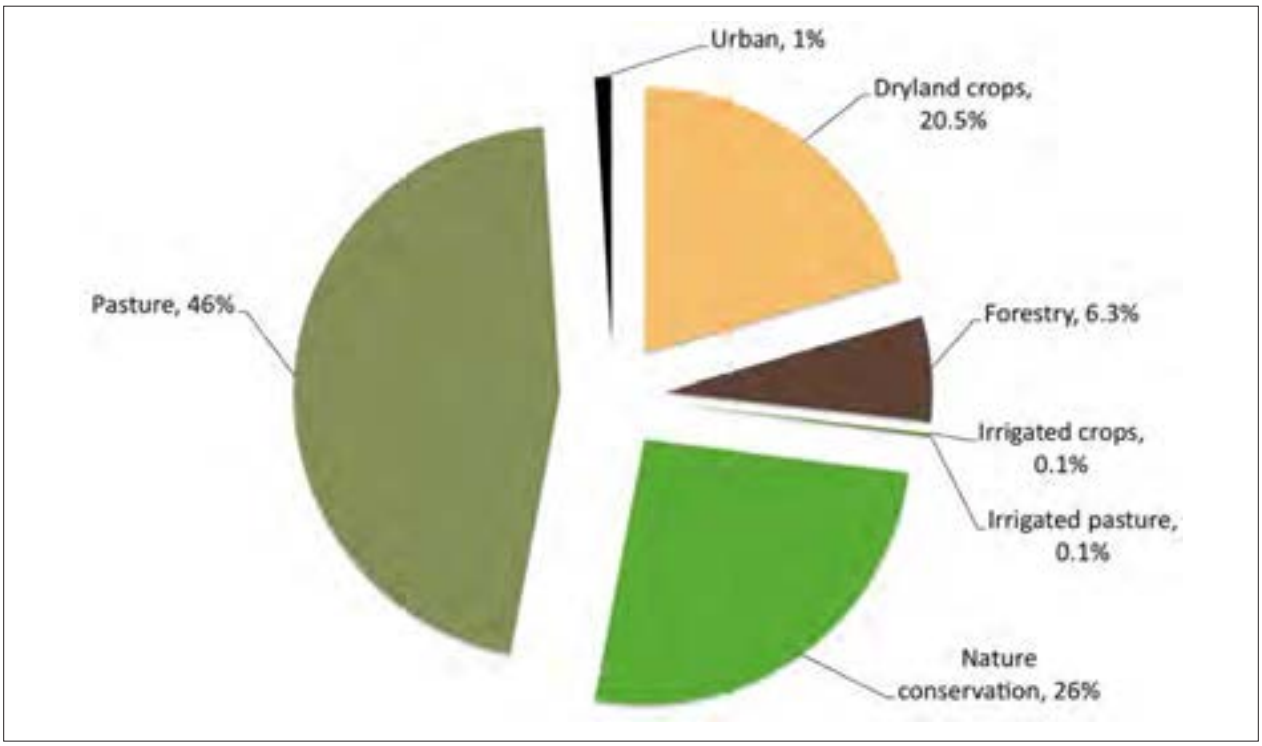


Figure 10.7 Land use in the South West Coast region

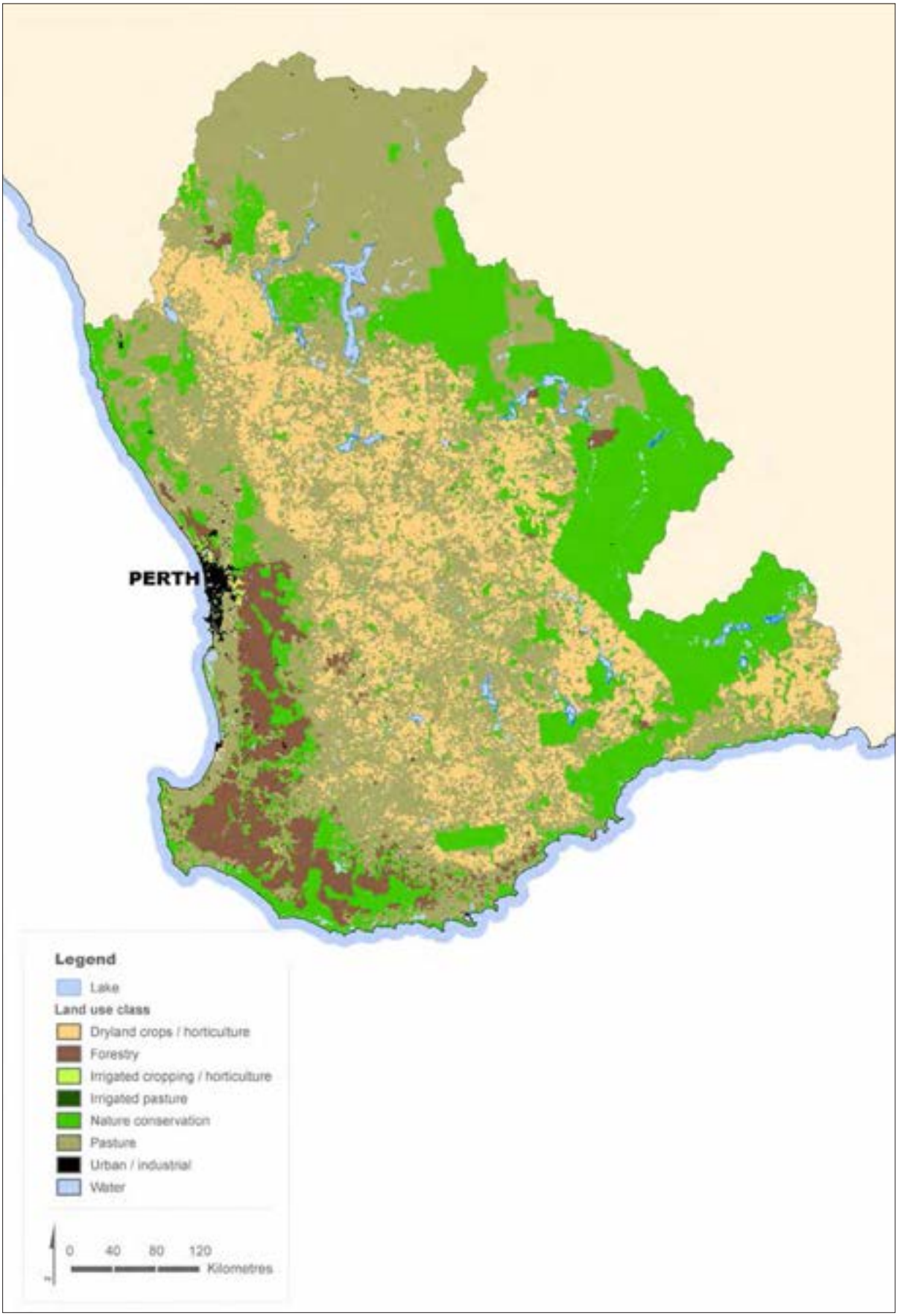


Figure 10.8 Land use distribution in the South West Coast region

10.3.6 Population distribution

While the South West Coast region occupies the more populous southwestern corner of Western Australia, its population density, in contrast to the North East Coast and South East Coast regions, is relatively low.

With the majority of the population residing in Perth, the region's population centre is located on its western coastal fringe. The populations of Perth and surrounding districts have been bolstered in recent years while providing supporting services to the renewed and increased mining activities in the State.

Outside of Perth, agriculture, mining and forestry have played important roles in the distribution of the region's remaining major population centres. Many of these centres are located in the southwestern coastal districts of the region and include the urban centres of Bunbury and Albany. The eastern extents of the region encompass much of the wheatbelt district, where farming activities play a major role in the existence of many towns.

Figure 10.9 shows the spatial distribution of population density for the region and is based on data from the ABS (2011b).

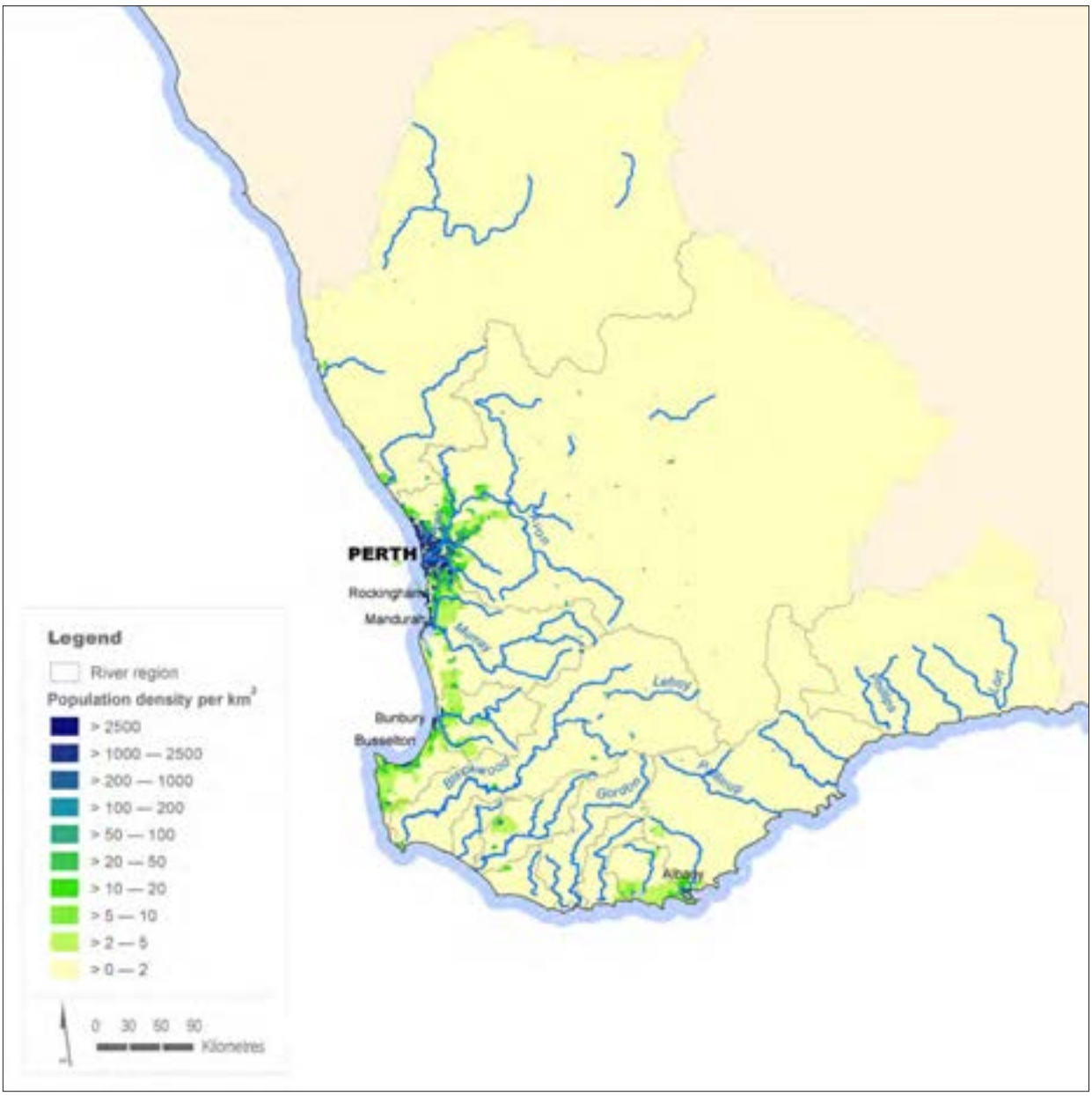


Figure 10.9 Population density and distribution of the South West Coast region

10.3.7 Rainfall zones

The South West Coast region has a temperate climate. Most rainfall occurs in the southwest during winter with reduced rainfall further inland. Median rainfall is rather variable throughout the region.

Figure 10.10 shows that the northeastern inland part of the region is semi-arid to arid and median annual rainfall totals do not exceed 500 mm.

Moving to the southwest, the rainfall becomes more winter dominant and median annual totals increase to levels exceeding 800 mm. Especially in the most southern areas, annual rainfall totals often exceed 1,200 mm.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

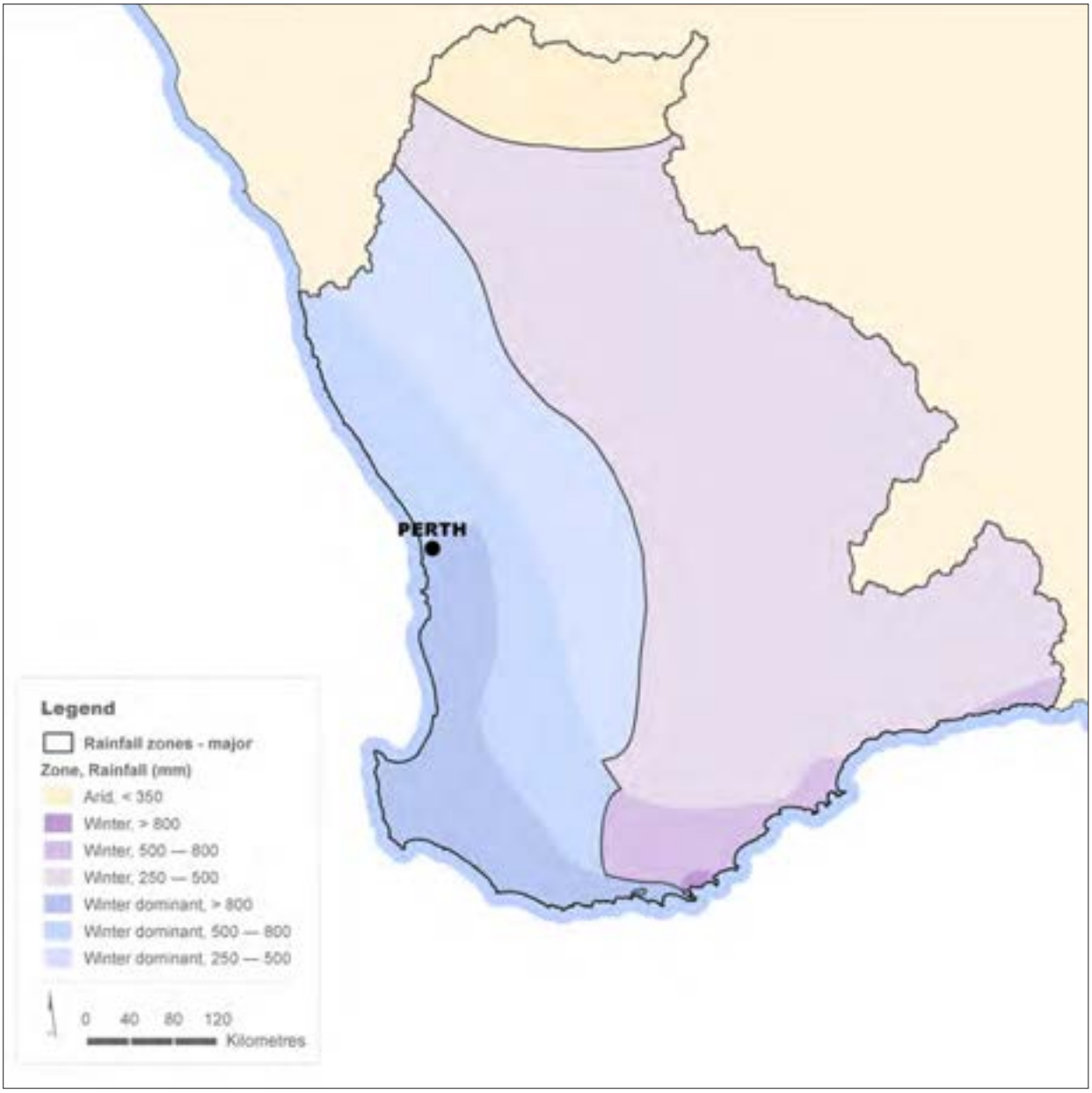


Figure 10.10 Rainfall zones in the South West Coast region

10.3.8 Rainfall deficit

The rainfall minus potential evapotranspiration indicator gives a general impression about where in the region moisture deficits are likely to occur over the period of a year. The South West Coast region has a rather uniform pattern of substantial potential deficits over the entire region (Figure 10.11).

Serious deficits can be expected in inland areas. Due to the seasonality of the rainfall, this area is still well suited for dryland agriculture, which occurs at an extensive scale.

Along the southwest coast, where the deficit is marginal, forestry is a major land use component. The far southwest has some areas of moisture abundance which are predominantly in use for nature conservation, containing some of the tallest trees in Australia, including the Karri forests.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

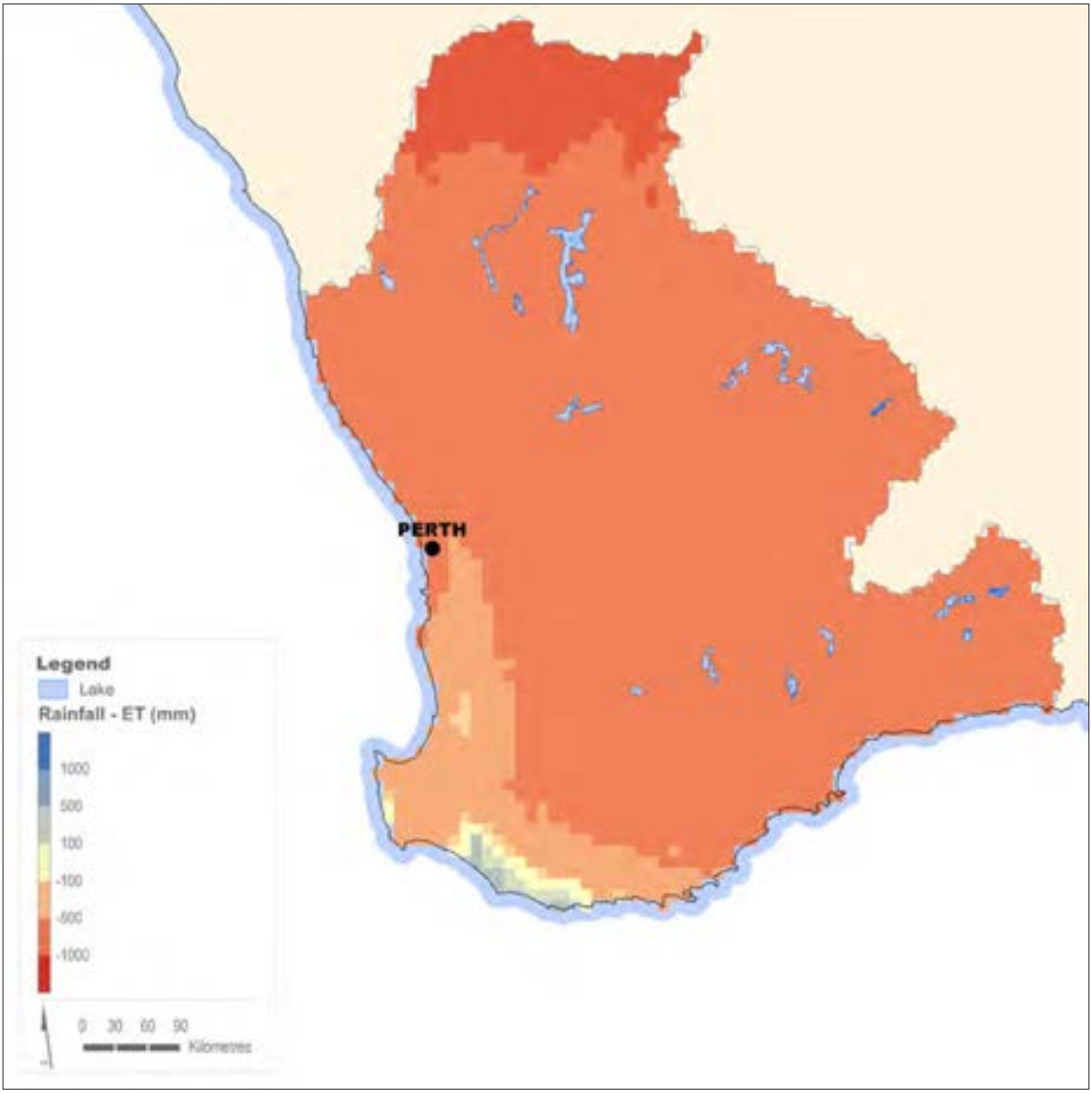


Figure 10.11 Rainfall deficits in the South West Coast region

10.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the South West Coast region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 10.12 shows that the region has a highly seasonal rainfall pattern with a wet winter and a dry summer period. Evapotranspiration follows this pattern, albeit with about a month delay, thereby generally exceeding rainfall during spring and summer. The monthly landscape water yield history for the region shows a stable pattern of very low yield in the dry period. It marginally increases during winter months.

The 2011–12 year was a relatively wet year, with some high rainfall between October and December. The December rainfall was the highest on record over the 1911–2012 period. On the other hand, some below average rainfall occurred during April and May 2012.

With above average soil moisture conditions, due to above average rainfall during the October–December period, evapotranspiration was also relatively high for this period. December 2011 had the highest evapotranspiration on record, whereas November had the second highest evapotranspiration on record.

The landscape water yield for 2011–12 showed some distinct patterns, with December having the second highest landscape water yield on record. On the other hand, the April–May period had the fifth lowest landscape water yield on record; however, with very low absolute landscape water yield occurring in these periods, the absolute difference from the mean is not high.

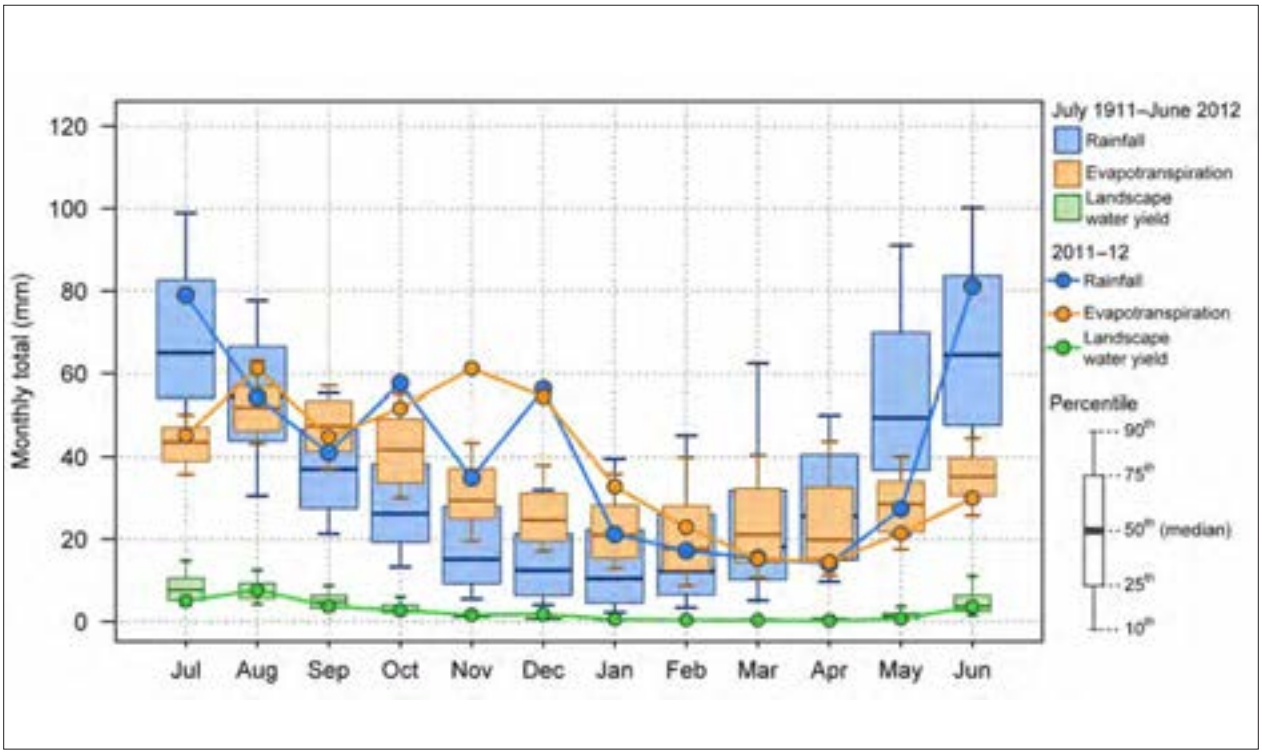


Figure 10.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the South West Coast region

10.4.1 Rainfall

Rainfall for the South West Coast region for 2011–12 is estimated to be 499 mm. This is 14% above the region's long-term average (July 1911–June 2012) of 438 mm. Figure 10.13a shows that the highest rainfall occurred along the southern coastal areas with annual totals locally exceeding 900 mm. The rest of the region mostly had rainfall ranging between 300 and 600 mm for 2011–12.

Rainfall deciles for 2011–12 indicate above average rainfall for most of the region over the course of the year (Figure 10.13b). Most of the inland parts of the region received above average rainfall with some parts in the east receiving very much above average rainfall. The western coastal area south of Perth locally had below average rainfall.

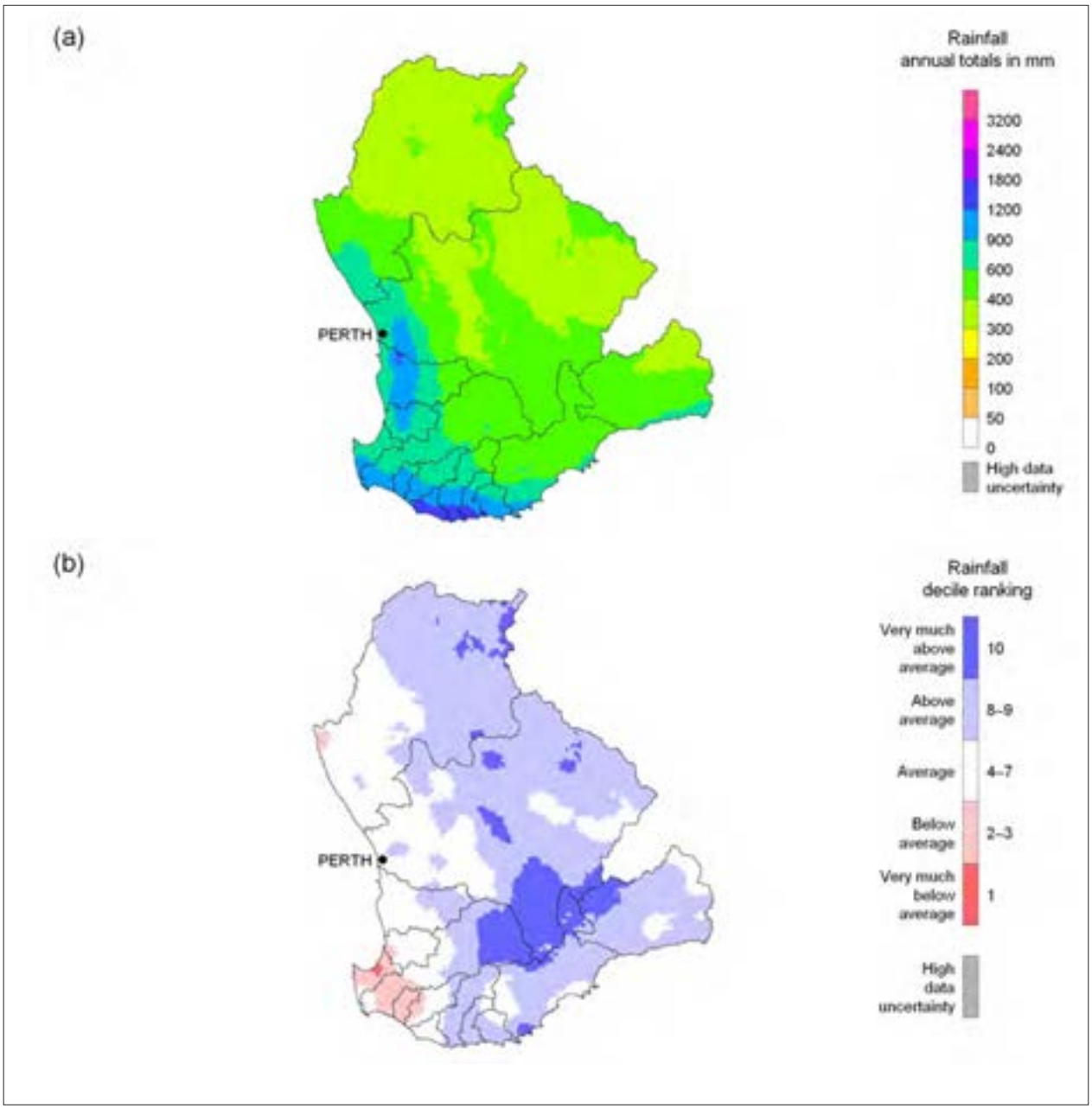
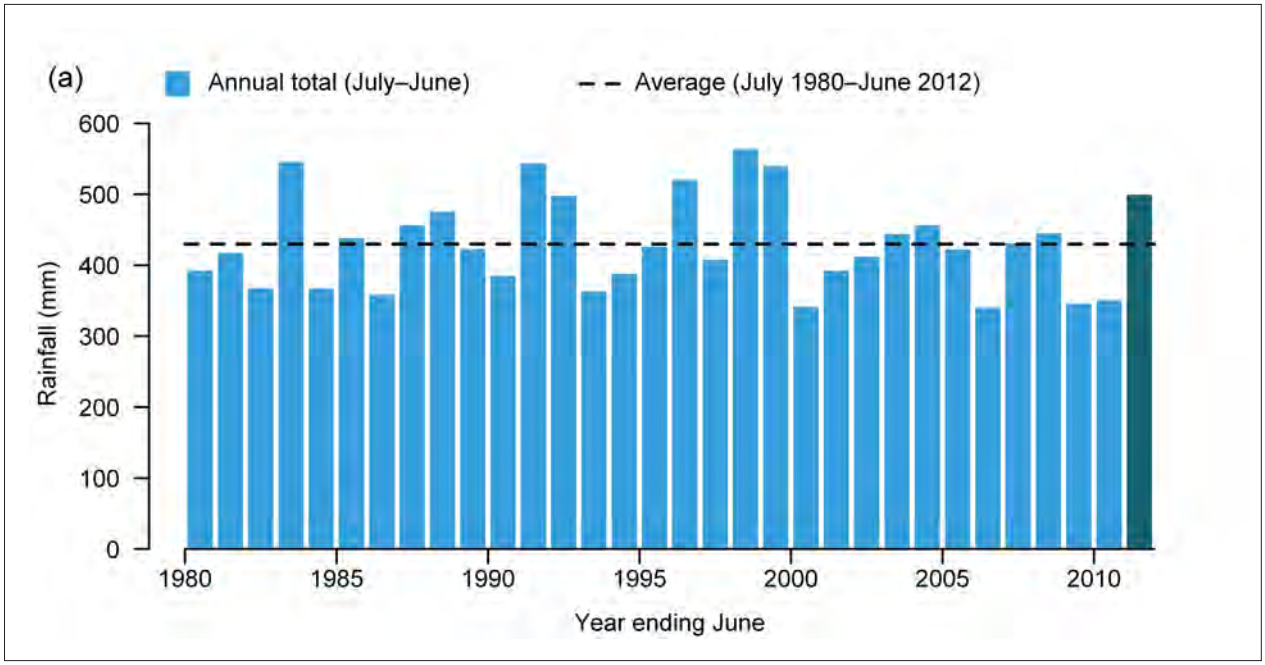


Figure 10.13 Spatial distribution of (a) annual rainfall in 2011–12 and (b) their decile rankings over the 1911–2012 period for the South West Coast region

Rainfall variability in the recent past

Figure 10.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 430 mm, varying from 340 mm (2006–07) to 563 mm (1998–99). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 10.14b.

The graphs show a particularly stable pattern of annual rainfall in comparison to other regions. Rainfall in the winter period is consistently higher than in the summer period, although a decrease in winter period rainfall has occurred after 2001. Since then, only the last year of this period reached an annual rainfall total that was substantially higher than the 32-year period average.



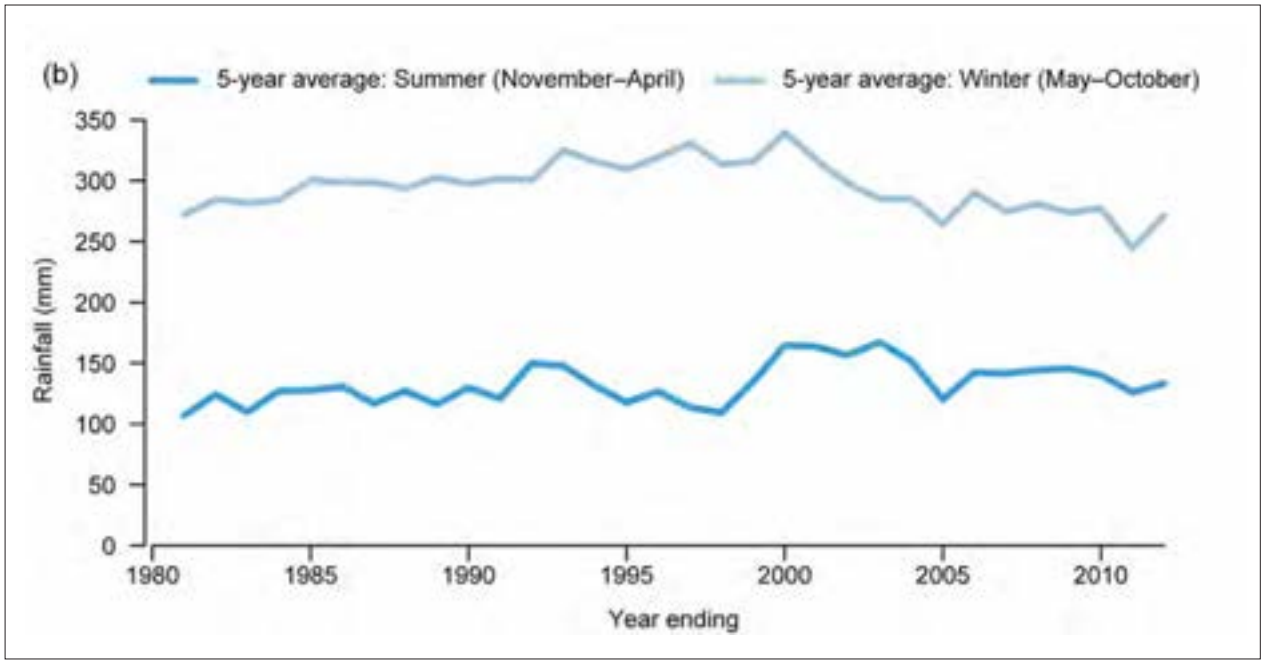


Figure 10.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South West Coast region

Recent trends in rainfall

Figure 10.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 10.15b.

Figure 10.15a shows that since 1980 a strong decrease in rainfall has occurred generally over the whole of the western coastal zone.

The falling trends are strongly significant in large parts of this area (Figure 10.15b), with the peak decrease around Perth. This has seriously impacted the surface water supply for Perth and surroundings (see section 10.6 for more information on urban water supply in the region).

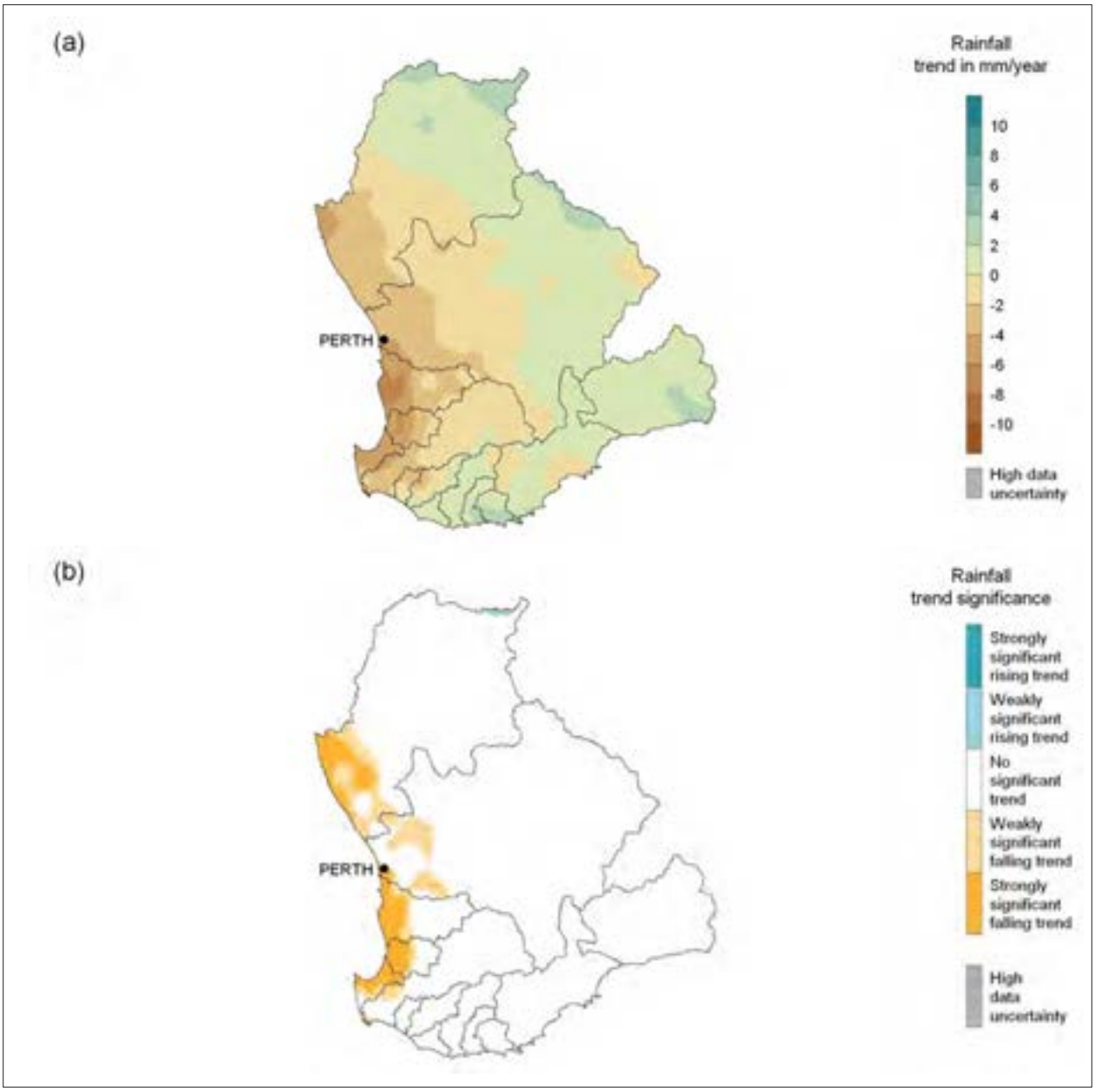


Figure 10.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South West Coast region

10.4.2 Evapotranspiration

Modelled annual evapotranspiration for the South West Coast region for 2011–12 is estimated to be 455 mm. This is 15% above the region's long-term (July 1911–June 2012) average of 397 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 10.16a) is similar to that of rainfall (Figure 10.13a). In absolute terms, evapotranspiration was practically equal to rainfall in the major inland part of the region.

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 10.16b). This coincides with the spatial pattern of rainfall deciles in Figure 10.13b. With limited water availability in the southwest, due to below average rainfall, evapotranspiration also remained below average in this area.

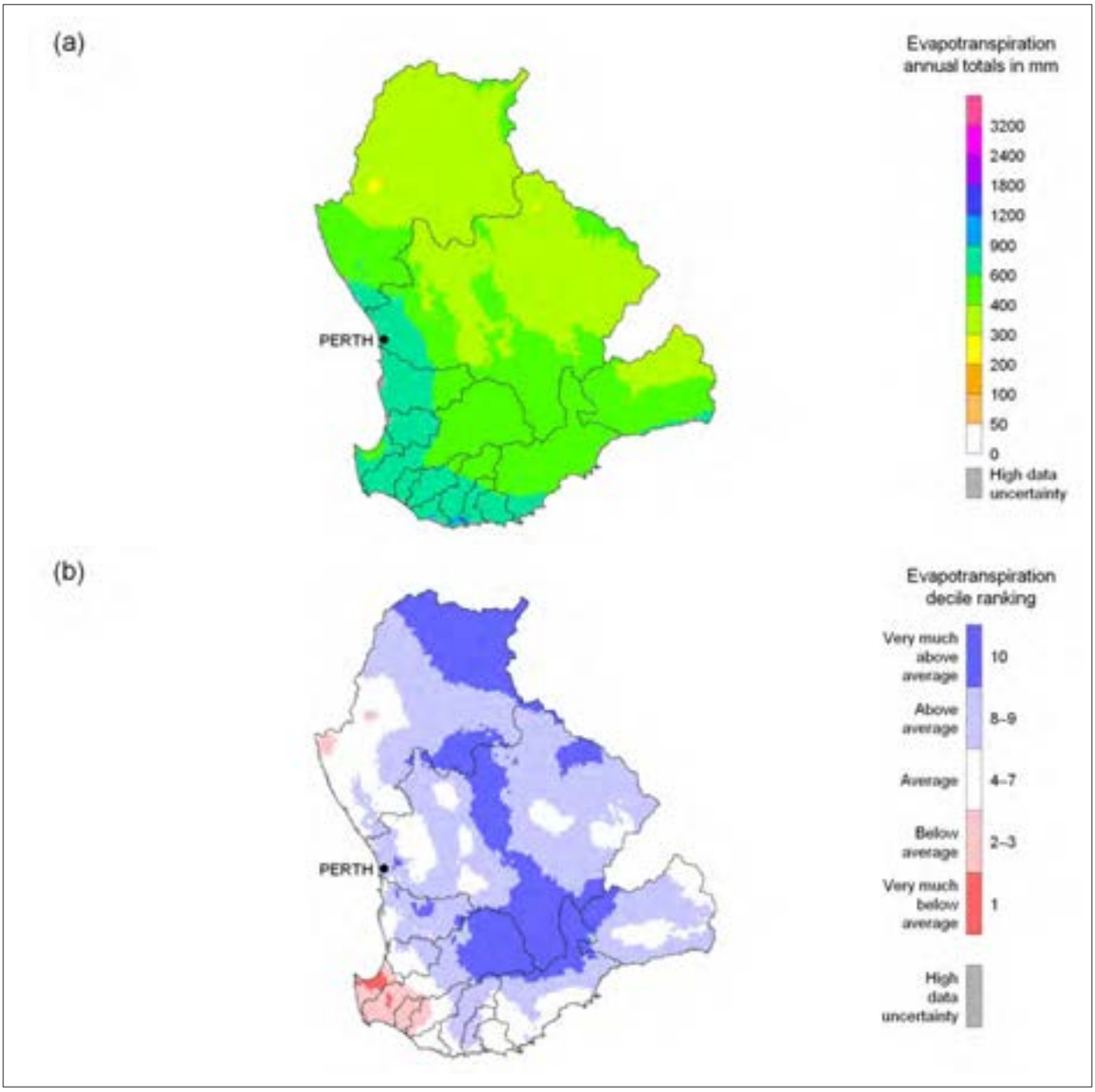


Figure 10.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South West Coast region

Evapotranspiration variability in the recent past

Figure 10.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 395 mm, varying from 317 mm (2010–11) to 535 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 10.17b.

Despite the lower temperatures in the winter period, evapotranspiration is consistently higher than in the summer period, due to lower water availability during the summer period. Compared with the seasonal rainfall (Figure 10.14b), the temporal patterns of evapotranspiration are highly similar and also display the minor decrease in evapotranspiration in the winter period since 2001 (Figure 10.17b).

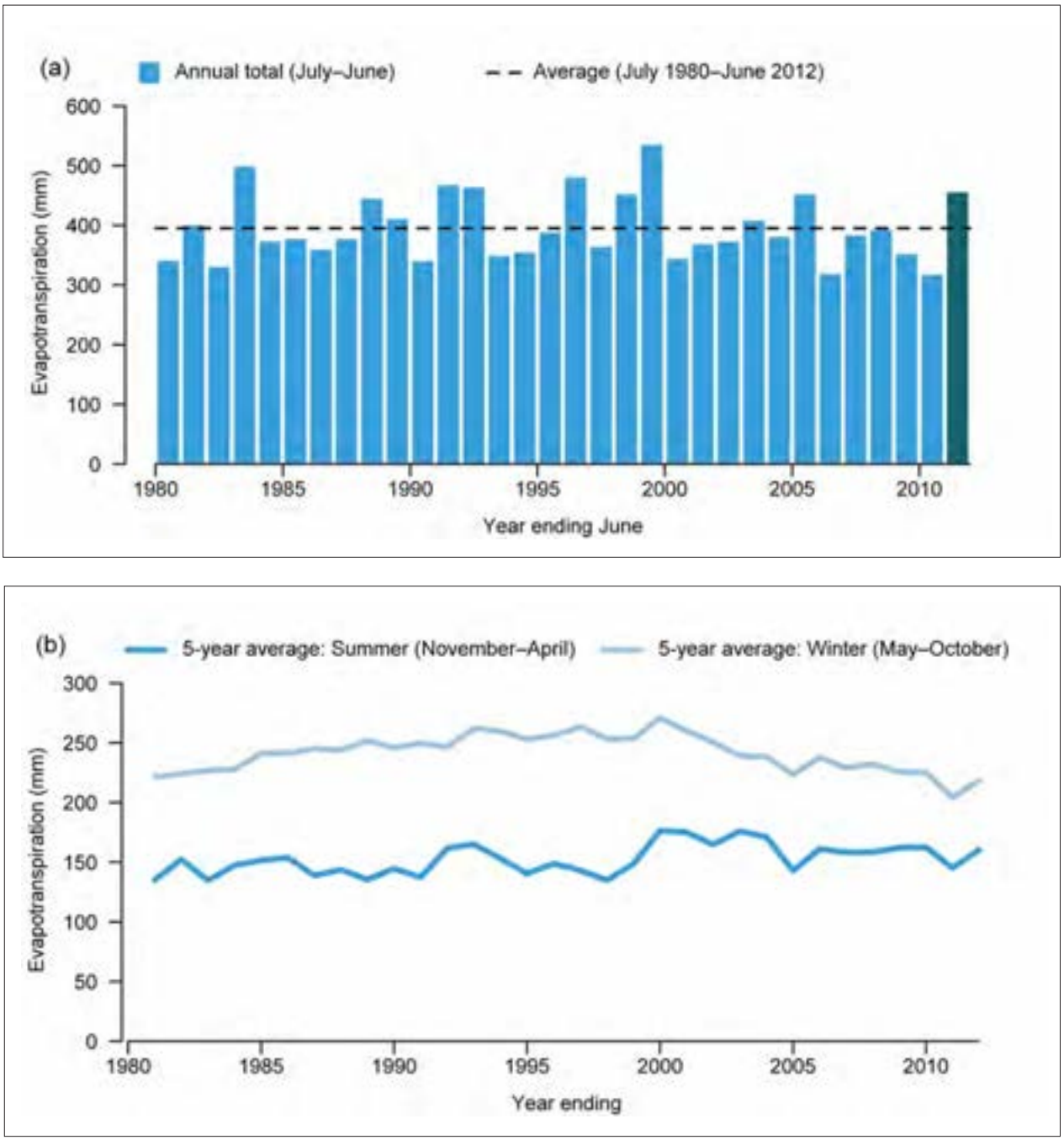


Figure 10.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South West Coast region

Recent trends in evapotranspiration

Figure 10.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 10.18b.

Figure 10.18a shows that, since 1980, falling trends are identified in the western coastal zone. In the east, largely marginally rising trends are calculated.

As shown in Figure 10.18b, the trends are generally only statistically significant in those coastal areas where the trend exceeds –2 mm/year. The spatial distribution of the trends is similar to that of rainfall. As evapotranspiration is driven by the availability of moisture coming from rainfall, the spatial distribution of the trends and the trend significance are similar to rainfall, as shown in Figure 10.15.

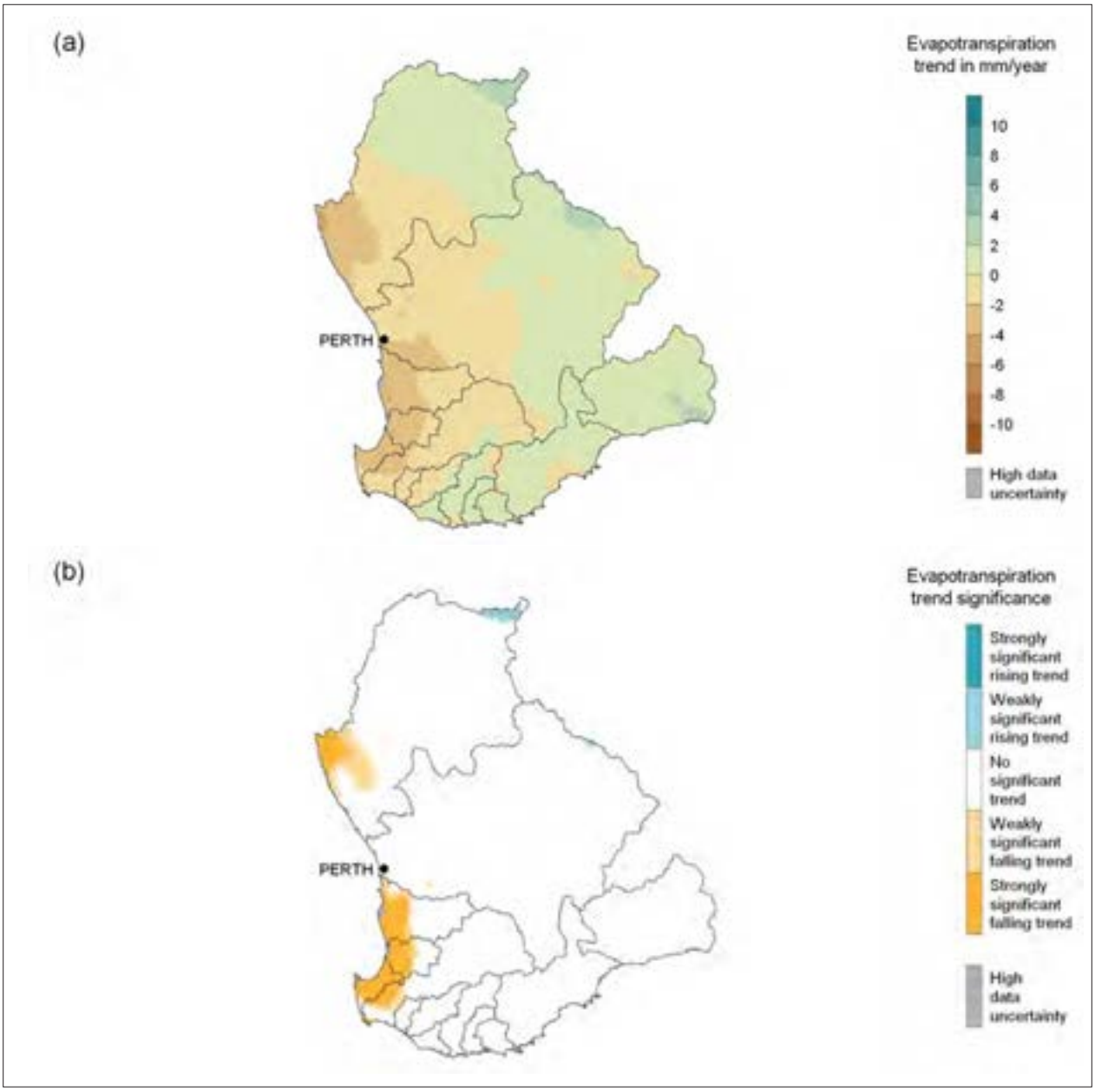


Figure 10.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South West Coast region

10.4.3 Landscape water yield

Modelled landscape water yield for the South West Coast region for 2011–12 is estimated to be 28 mm. This is 24% below the region's long-term (July 1911–June 2012) average of 37 mm. Figure 10.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 10.13a; note the difference in the scales between the two figures).

The decile-ranking map of Figure 10.19b, however, shows a spatial pattern that is dissimilar to those patterns in rainfall of Figure 10.13b. The map shows mostly average to below average landscape water yields for much larger areas along the coast as well as further inland. It has to be acknowledged that model verification assessments for this region identified more questionable performances than in other regions and results should be interpreted with care.

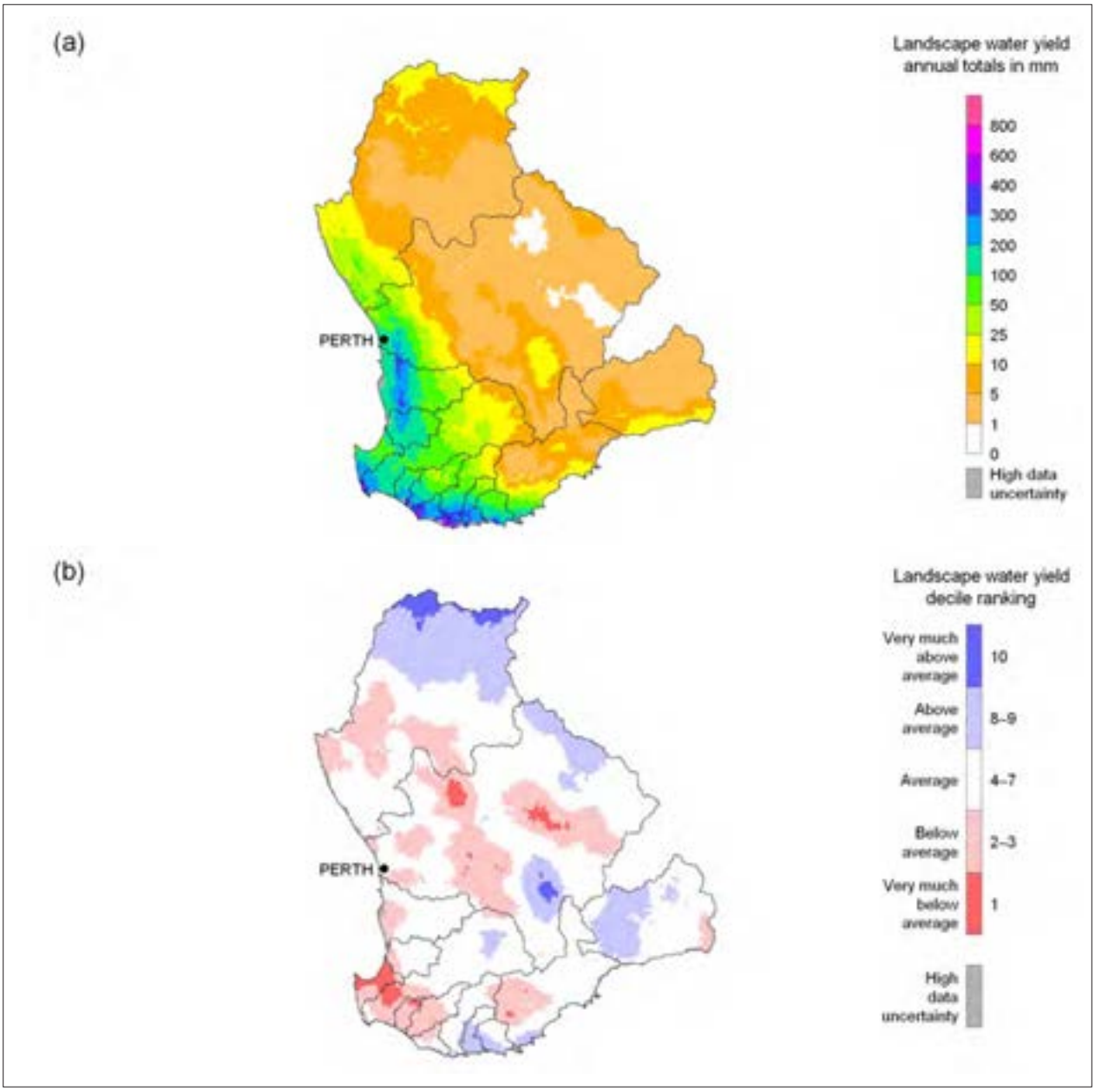


Figure 10.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the South West Coast region

Landscape water yield variability in the recent past

Figure 10.20a shows annual landscape water yield for the South West Coast region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 30 mm, varying from 11 mm (2010–11) to 52 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 10.20b.

Landscape water yield is consistently higher during the winter period and particularly low during the summer period. The falling trend in landscape water yield since 2001 for the winter period is consistent with that of rainfall and evapotranspiration.

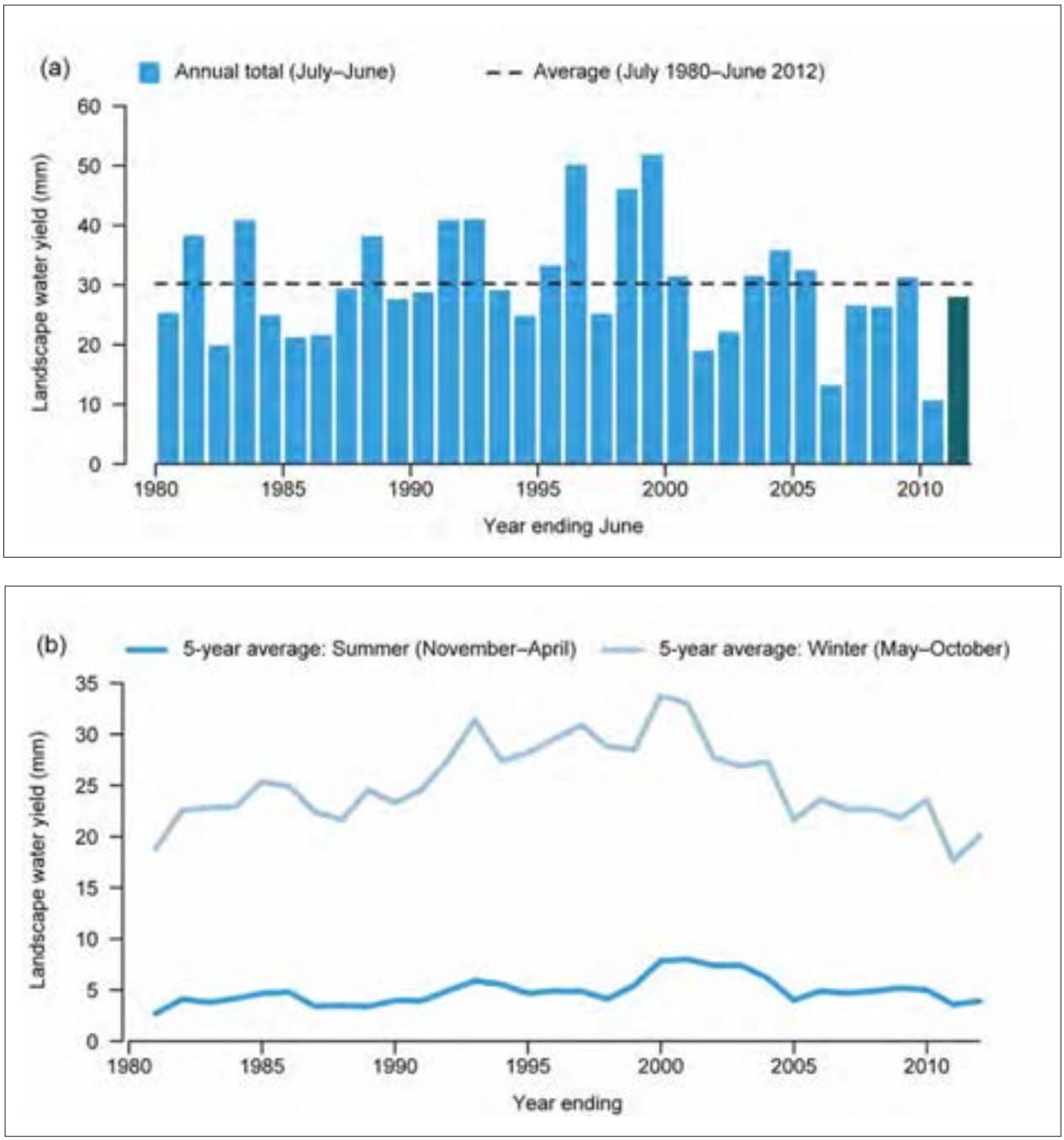


Figure 10.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the South West Coast region

Recent trends in landscape water yield

Figure 10.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 10.21b.

As shown in Figure 10.21a, trends are negative in the coastal zone and over a band covering a large part of the south of the region. In this band, trends are locally statistically significant, reaching values of −0.5 mm/year. The far north and far west have some areas of significant rising trends, with trend line slopes up to 0.5 mm/year.

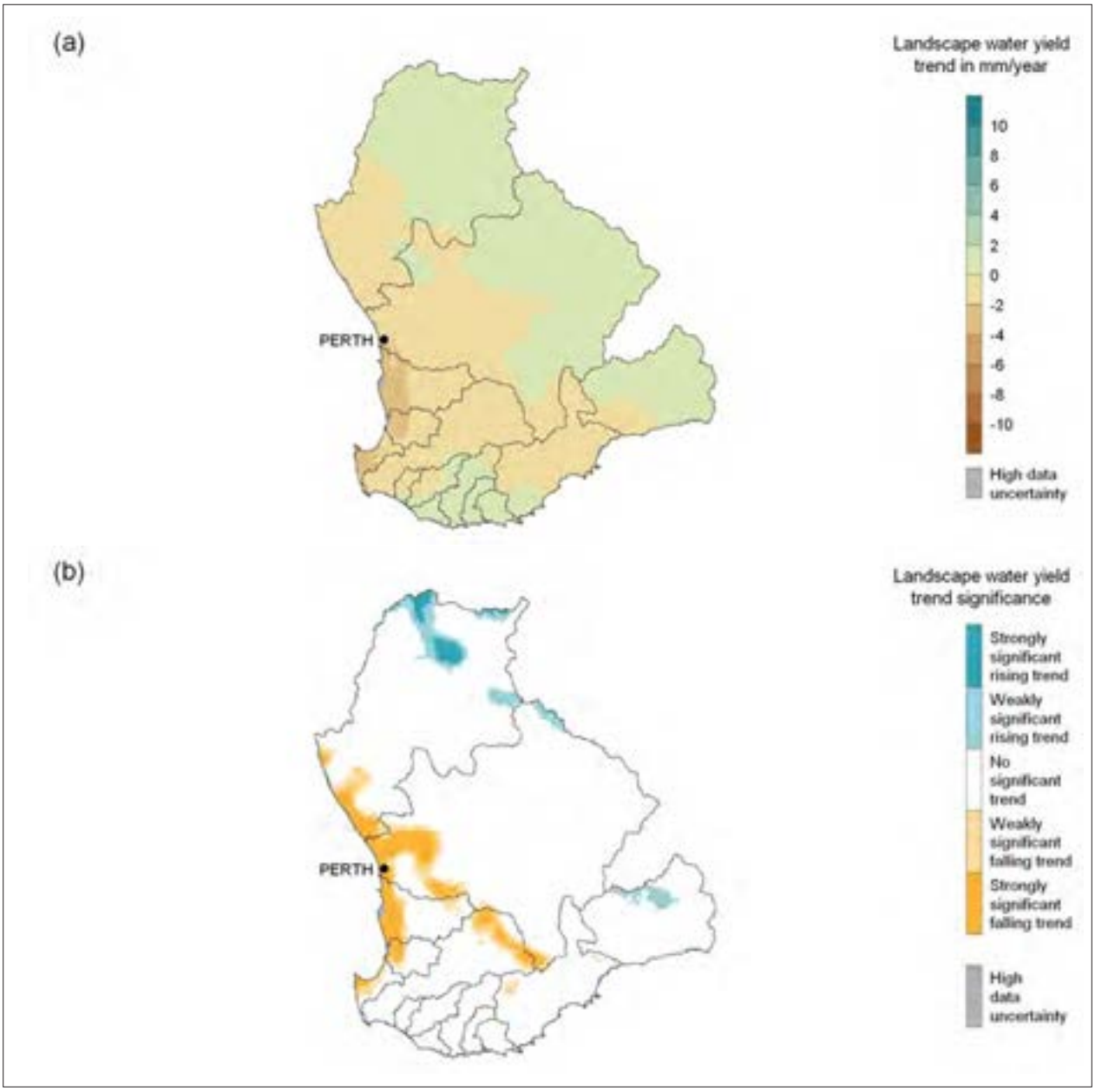


Figure 10.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the South West Coast region

10.5 Surface water and groundwater

This section examines surface water and groundwater resources in the South West Coast region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

10.5.1 Rivers

There are 14 river basins in the South West Coast region, varying in size from about 1,700–121,000 km^2 (Figure 10.22).

Due to the elevated topography and orientation of the Darling Scarp, most of the major rivers drain towards the Indian Ocean; however, the high soil permeability in the Swan Coastal Plain results in substantial losses of surface water to groundwater. The north–south coastal dune pattern causes many watercourses to turn abruptly and flow either in a south or a north direction along the extensive dune swales, often joining with other watercourses before discharging to the sea. There are also inland endorheic river basins to the east of the Darling Scarp.

The longest rivers are located in the southwest, with the Avon and Blackwood rivers having the largest catchments areas. The Swan River becomes the Avon River at the Darling Scarp. Most of the rivers are perennial, but in the north and west many are ephemeral.

Swan River bank, Perth | BockyTandiono (iStockphoto)

Figure 10.22 Rivers and catchments in the South West Coast region

10.5.2 Streamflow volumes

Figure 10.23 presents an analysis of flows at 30 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across 16 geographically representative rivers were selected (see Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows generally reflect the mostly average to below average modelled landscape water yield results shown in Figure 10.19b. Above average annual flows were observed at two sites located on the Arthur and Blackwood rivers in the central southwest of the South West Coast region. Average total annual flows were observed at 12 monitoring sites, mainly located on the rivers in the central south, central west, the Lockhart River in the centre and the Moore River in the north of Perth.

Below average flows occurred at 11 sites in the region which were located on the rivers in the west of the region, especially surrounding Perth, and in the Deep and Kalgan rivers in the central south of the region. Of the 30 monitoring sites, there were only five sites across the region which recorded very much below average flows recorded across the in 2011–12. These five monitoring sites were mainly located on the rivers in the far southwest and in the Harvey River in the central west.

Flow deciles for the summer period (November 2011–April 2012) are different to those for total annual flows as shown in Figure 10.23. The difference is that relatively higher flows occurred throughout the region in the summer period.

10.5.3 Streamflow salinity

Figure 10.24 presents an analysis of streamflow salinity for 2011–12 at 28 monitoring sites throughout the South West Coast region. Monitoring sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC, µS/cm at 25 °C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

The median EC values for five of the monitoring sites in the main rivers fall in the range 0–1,000 µS/cm, suitable for most irrigation uses. Most of the selected monitoring sites in the rivers and creeks of the region have median EC values outside this range (see Figure 10.24). This is unsuitable for most irrigation uses and for many aquatic ecosystems. Of the 28 monitoring sites, 14% had median EC values below 500 µS/cm and at one site (4%) the median fell in the range 500–1,000 µS/cm. For the remainder of the sites (82%), EC values were above 1,500 µS/cm. Median salinities values are generally higher to the west of the region.

Streamflow salinity was above 2,000 µS/cm at 21 of the 28 monitoring sites. These are located on the rivers in the southwest, centre and some sites in the central west of the region. High salinity in the monitoring sites in this area may be influenced by extensive land clearing, large natural stores of salt in the landscape, poor irrigation practices, saline base flow and evaporation during low flow. Naturally occurring saline soils are also a key factor influencing in-stream salinity in the region and are associated with lacustrine sediments of salt lake systems (McArthur 1991).

The CV is the expected variability of a measurement of EC value, relative to the annual mean of EC. The CV is high at some sites in the central west of the region whereas variability is relatively low for the rivers in the southwest of the region. The CV in EC is highly related to the variability in annual flow at the monitoring sites. Of the 28 monitoring sites, 7% of them had a CV below 20%; 57% of the sites had a CV between 20% and 60%; and 36% were above 60%. These were mainly located on the rivers in the central west and southwest of the region. The CV was above 80% at five of the 28 monitoring sites. These were located on the rivers in the central west and at Mobrup Creek in the central southwest of the region.

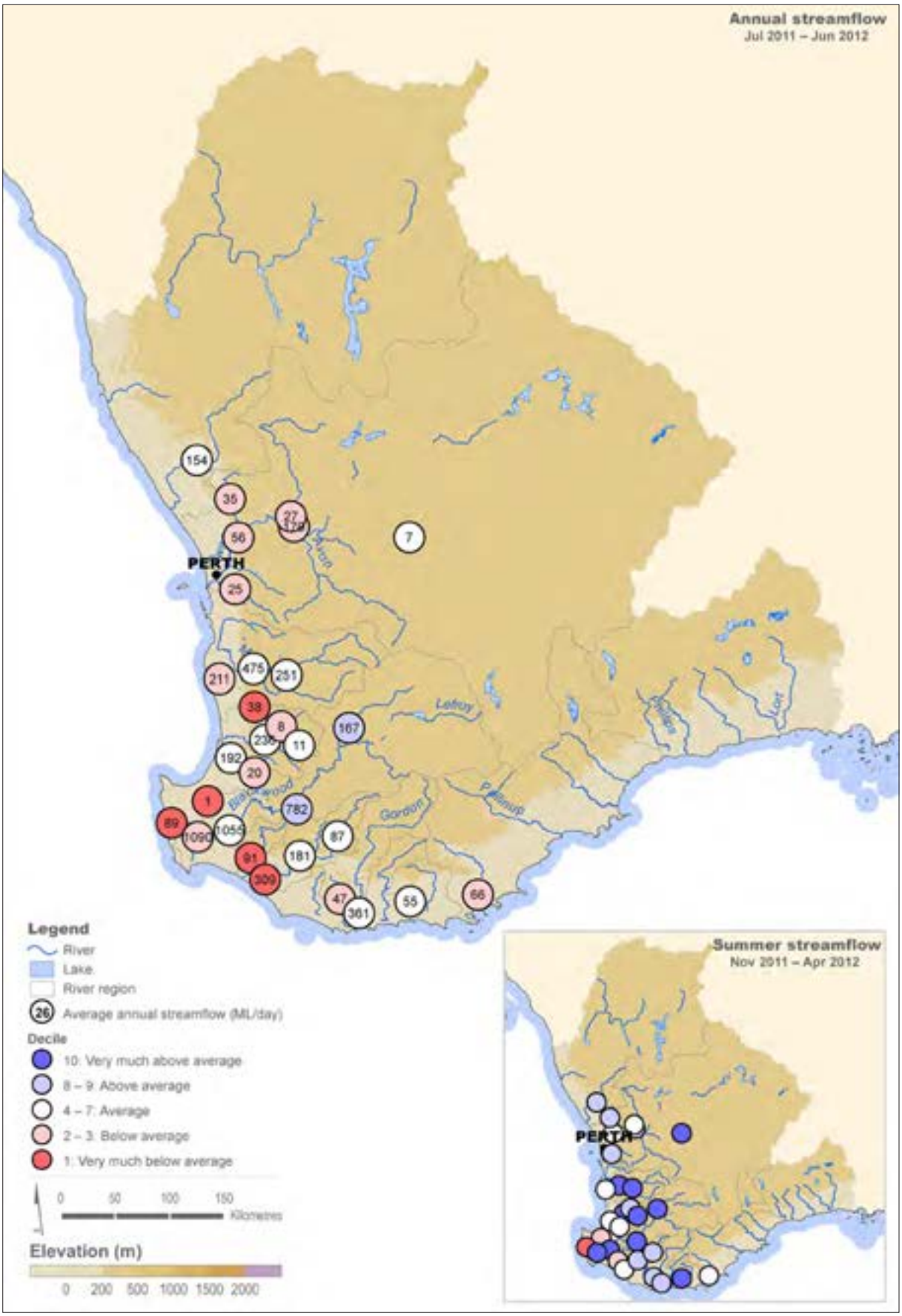


Figure 10.23 Average annual and summer period flow volumes of selected sites for 2011–12 and their decile rankings over the 1980–2012 period in the South West Coast region

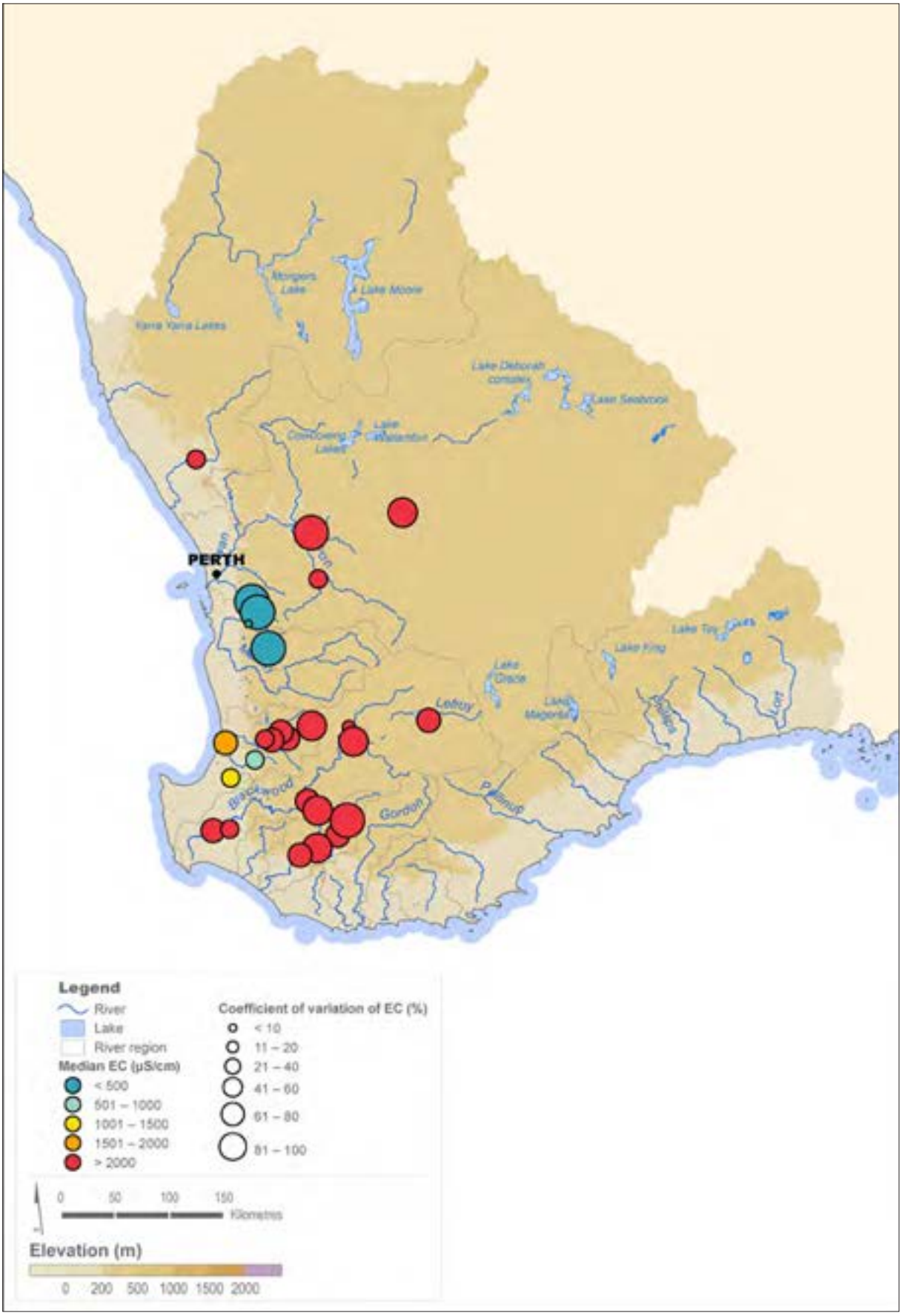


Figure 10.24 Salinity as electrical conductivity (µS/cm) and its associated coefficient of variation for 2011–12 in the South West Coast region

10.5.4 Flooding

There were no major floods in the South West Coast region during the 2011–12 year. The locations of minor and moderate floods are shown in Figure 10.25.

10.5.5 Storage systems

There are 21 major publicly owned storages in the South West Coast region, with a total storage capacity in excess of 1,000 GL. The Bureau's water storage website includes information on approximately 95% of the region's publicly owned storage capacities (as at August 2012). Most storages in the region supply two major systems; the Harvey Irrigation Area and the Integrated Water Supply Scheme which supplies water to the Perth urban area.

Table 10.3 gives a summary of the major storage systems in the region together with an overview of the storage levels at the end of 2010–11 and 2011–12. The location of all the systems and associated storages are shown in Figure 10.26.

The storages in the region currently have particularly low volumes, especially in relation to the storages in the eastern part of Australia. The lower rainfall totals during the winter period (as found in Figure 10.14b) have resulted in the catchment upstream of the dams to be in a very dry state.

New rainfall coming in has to partly fill up these soils first before run-off is generated. With the average to above average rainfall of 2011–12 in the rivers upstream of the storages, this has partly been achieved. Together with the commissioning of a second desalination plant, which reduced the demands on the storage supply, water levels were able to rise by 10% of accessible capacity.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage

10.5.6 Wetlands

There are a number of Ramsar-listed, internationally important wetlands in the South West Coast region as well as a number of wetlands of national importance mentioned in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html). The wetlands vary from coastal tidal flats to inland ephemeral lakes and large salt lakes (Figure 10.27).

No detailed assessment on the inflows of selected wetlands has been performed for this region.

Table 10.3 Major public storage systems in the region as identified in the Bureau's water storage website (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Perth	urban	593 GL	107 GL—18%	139 GL—23%
Harvey	rural	279 GL	72 GL—26%	135 GL—48%
Non-allocated	—	79 GL	30 GL—38%	35 GL—44%
Total		951 GL	210 GL—22%	309 GL—32%

Figure 10.25 Flood occurrence in 2011–12 for the South West Coast region, with each dot representing one gauging station and the colour of the dot representing the highest flood class measured

Figure 10.26 Storage systems in the South West Coast region (information extracted from the Bureau's water information website in August 2012)

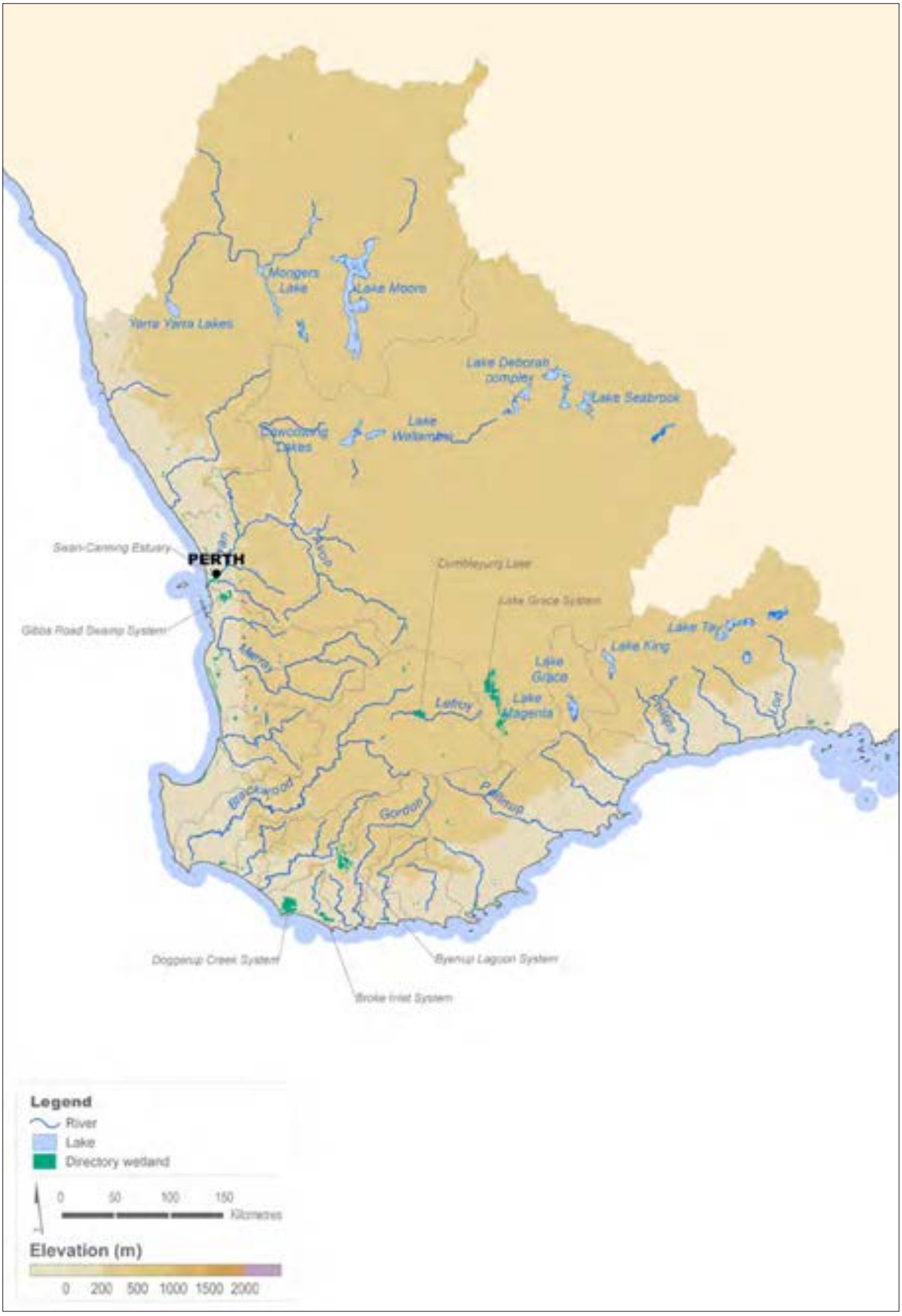


Figure 10.27 Location of important wetlands in the South West Coast region

10.5.7 Hydrogeology

Figure 10.28 shows the major aquifer groups present at the watertable. The region is dominated by fractured rock groundwater systems that may provide a low volume groundwater resource. Groundwater systems that provide more potential for extraction are labelled as:

- Surficial sediment aquifer (porous media—unconsolidated);
- Mesozoic sediment aquifer (porous media — consolidated); and
- Upper tertiary/quaternary aquifer (porous media—unconsolidated).

Confined aquifer systems, underlying some of the watertable aquifers shown in the figure, provide an important resource for the region. Most notable are the Leederville and Yarragadee aquifers beneath the Swan Coastal Plain.

10.5.8 Watertable salinity

Figure 10.29 shows the classification of watertable aquifers as fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) water according to watertable salinity. Most parts of the region are considered to have saline groundwater. The coastal regions with usable groundwater resources are those identified as non-saline.

10.5.9 Groundwater management units

The hydrogeology of the region is dominated by a large area of outcropping fractured basement rock which typically offers a restricted low volume groundwater resource. Significant groundwater resources are, however, available on parts of the coastal plain. Approximately 35% to 50% of the water supplied to the city of Perth is sourced from groundwater.

The groundwater management units within the region are presented in Figure 10.30. Most of the smaller units are located near the western boundary of the region, while the larger units are located in the east and south. The size is inversely correlated to the yield and quality of groundwater resources, that is, large units typically have low volume and low quality. In fact, the major aquifers within the region include surficial aquifers of the Gnangara Mound and the underlying confined Leederville and Yarragadee aquifers.

Figure 10.28 Watertable aquifers of the South West Coast region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 10.29 Watertable salinity classes of the South West Coast region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

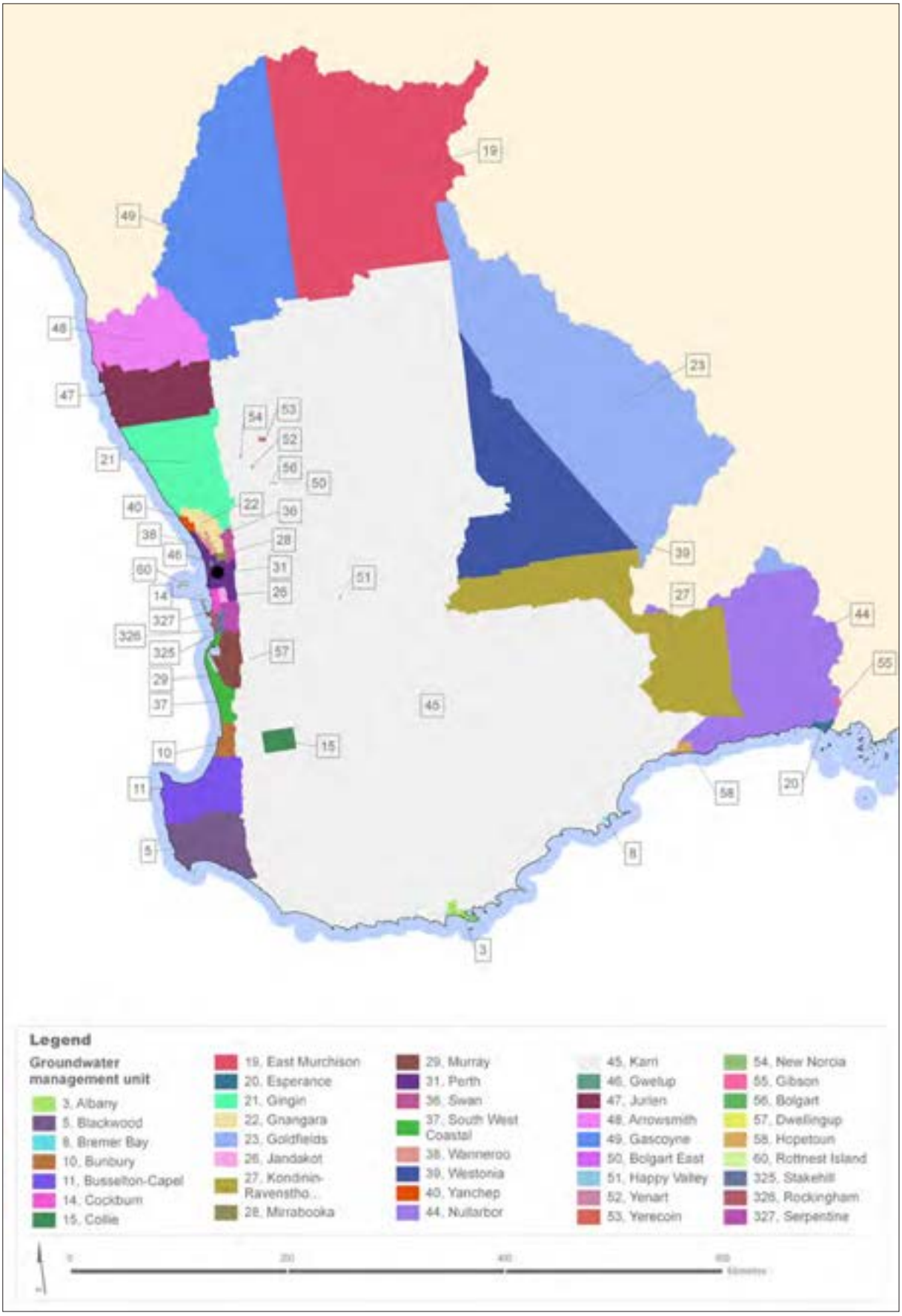


Figure 10.30 Groundwater management units in the South West Coast region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

10.6 Water for cities and towns

This chapter examines urban water supply in the South West Coast region in 2011–12 and over recent decades. The main urban centres in the region are discussed briefly. The main urbanised portion, the Perth water supply area, is presented in detail including their water supply systems, storage position, historical and current water restrictions, water sources and supply information. The main source of data for this section is the National Performance Report (National Water Commission [NWC] 2013).

10.6.1 Urban centres

Perth is the largest urban centre in the South West Coast region with a population of more than 1.6 million people. It includes the suburban centres of Joondalup in the north, Armadale in the southeast and Fremantle, Rockingham and Mandurah along the south coast. About 80% of the region's population lives in Perth.

Outside of Perth the region has two major urban centres (populations over 25,000 people). These are Bunbury and Albany. Table 10.4 provides a summary of their population, surrounding river basin and significant water storages.

Bunbury, situated 175 kilometres south of Perth, has a population of about 64,000. It is a port city, servicing the farming, mining and timber industries of the southwest.

The population of Albany, located about 400 km southeast of Perth, is just under 27,000 and it is also a port city. The main industries of Albany consist of tourism, fishing and agriculture.

In addition to its major urban centres the region has a number of small towns, in particular through its southwest. Figure 10.31 shows these regions cities and towns along with their population ranges.

Table 10.4 Cities and their water supply sources in the South West Coast region

City	Population[1]	River basin	Major supply source
Perth	1,630,000	Swan Coastal	Groundwater Canning, Serpentine and South Dandalup storages, desalination
Bunbury	64,000	Preston River	Groundwater
Albany	26,500	Kalgan River	Groundwater

[1] Australian Bureau of Statistics (2011b)

Figure 10.31. Population range of urban centres in the South West Coast region

10.6.2 Sources of water supply

Unlike much of Australia the region as a whole relies heavily on groundwater for the provision of its urban water supply. While surface water storages are an important component of supply systems, the region's highly variable rainfall and shifting climatic patterns have seen a need to augment supplies with water from additional sources. As a result desalination has become an important source of water for Perth.

In the more remote towns to the north and east of the region, groundwater is often a major source of water supply. The Western Australian Water Corporation has also connected many towns to their pipeline supply network, particularly in the southeast.

Recycled water and harvested storm and rainwater sources are also used to supply the urban water demands throughout the region.

10.6.3 Perth

The water supply system of Perth is controlled by the Water Corporation of Western Australia. It is the principal supplier of water, wastewater and drainage services to homes and businesses in the Perth water supply area, as well as providing bulk water to farms for irrigation. The Water Corporation manages Perth's Integrated Water Supply Scheme (IWSS).

The Water Corporation also recycles water, mainly for supply to sporting ovals and golf courses, but also for industry and agriculture. Various trials for topping up groundwater supplies with recycled wastewater are also being conducted, including the Beenyup Replenishment Trial.

With growing urban water demand, sources of water, in particular the groundwater systems, are being subject to significant stress. To manage groundwater abstraction sustainably, ecological water requirements and environmental water provisions are determined as part of water allocation processes (Water Corporation 2008).

Environmental water provisions are determined by the Western Australian Department of Water in accordance with the principles and processes set out in its Environmental Water Provision Policy (2000).

The environmental water provisions are the water regimes provided as a result of the water allocation decision-making processes. This is a comprehensive assessment that takes into account ecological, social and economic impacts.

Supply system

Perth obtains its water supply from a combination of groundwater, surface water, desalination and recycled water. Together these sources form the IWSS. A schematic of this scheme is provided in Figure 10.32.

Up until two decades ago surface water was the major source of water for Perth. However, consistently below average rainfall in the last three decades has seen groundwater become the major source of water supply for urban use.

With its reliance on the groundwater, drawn from the Gnangara and Jandakot mounds, and decreased recharge a result of changing climatic conditions, Perth's water supply aquifer levels have declined. In response to this, the State Government has begun construction of desalination plants to provide reliable and climate-independent water supply to the Perth region.

The first desalination plant, in Kwinana, was completed in 2006 with the capacity to produce 45 GL per year. The second desalination plant, in Binningup, became operational in September 2011. Together these desalination sources provide about half of the water needed for the Perth metropolitan area.

Surface water supplies for Perth are drawn from ten major water storages located in the catchments to the east of Perth. These storages are shown in Figure 10.33. Together they have a combined total accessible storage capacity of 580 GL.

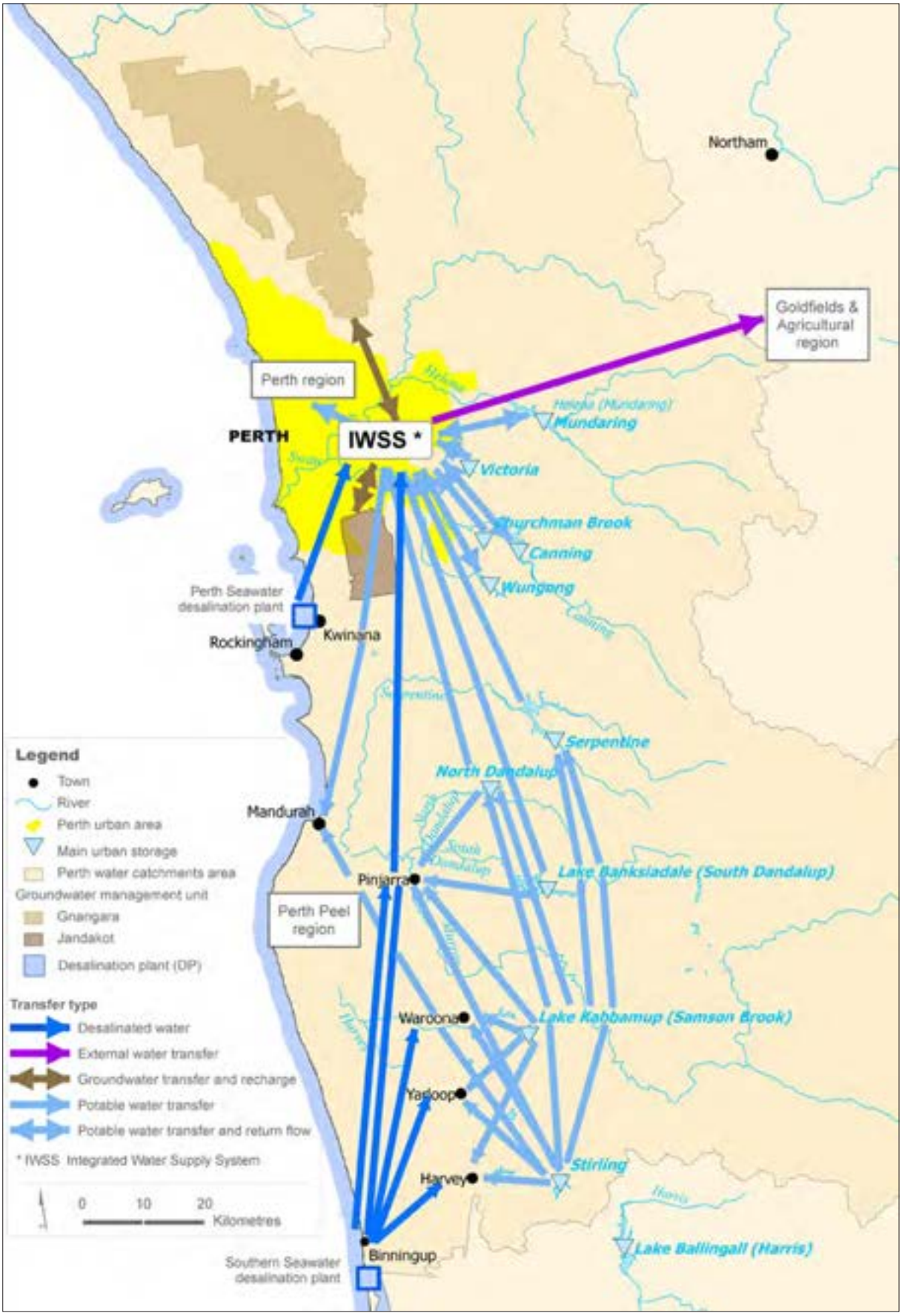


Figure 10.32 Water supply schematic for Perth and surrounds

Figure 10.33 Urban supply storages in the South West Coast region

Storage volumes

The historical time series of the accessible volume of Perth's three major storages (Serpentine, Canning and South Dandalup) are shown in Figure 10.34. Together these storages comprise almost 60% of Perth's total surface water storage capacity.

The significant decline in storage volumes that has resulted from shifting climatic patterns and the resulting decrease in surface water run-off can be clearly observed across all storages. In particular, reduced winter rainfalls and drying catchments have played an important role in the decline of these storages.

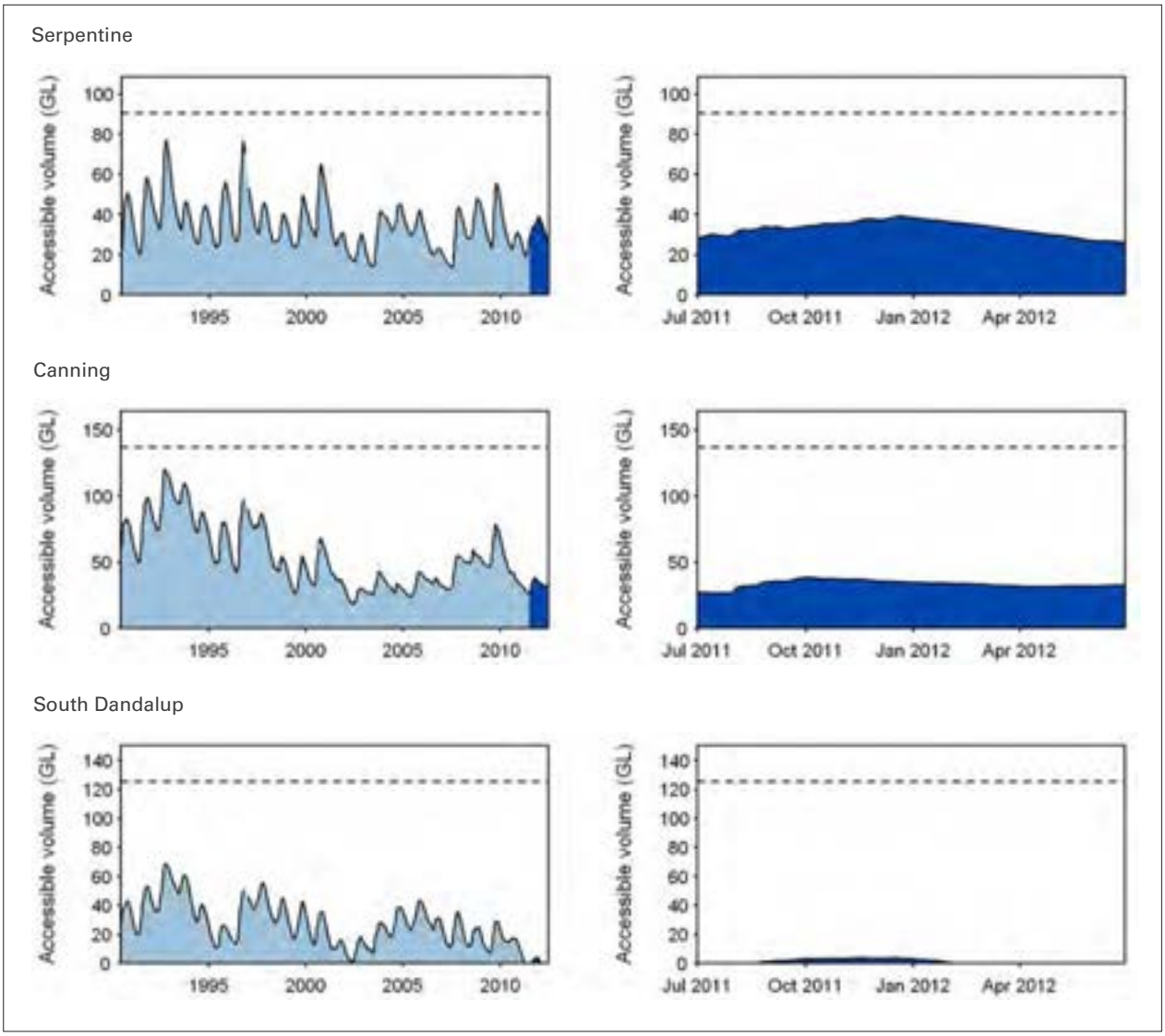


Figure 10.34 Variation in the amount of water held in storage for the combined area over recent years (light blue) and over 2011–12 (dark blue), as well as total accessible storage capacity (dashed line)

Water restrictions

Water restrictions in Perth are set by the State Government and enforced by the Water Corporation. Water restriction policy, including restriction levels, is enacted through Water Agencies (Water Use) by-laws and legislated under the Western Australian *Water Agencies (Powers) Act 1984*.

A historical time series of water restrictions for Perth is presented in Figure 10.35. The figure highlights the decline in surface water resources and the significant role water restrictions have played in the lives of Perth residents as well as its commercial and industrial sectors over the last decade.

In September 2011, following an increase in winter rainfall and the commissioning of Perth's second desalination plant, an easing of restrictions to Stage 5 was allowed. However, in June 2012 restriction levels were back to Stage 7.

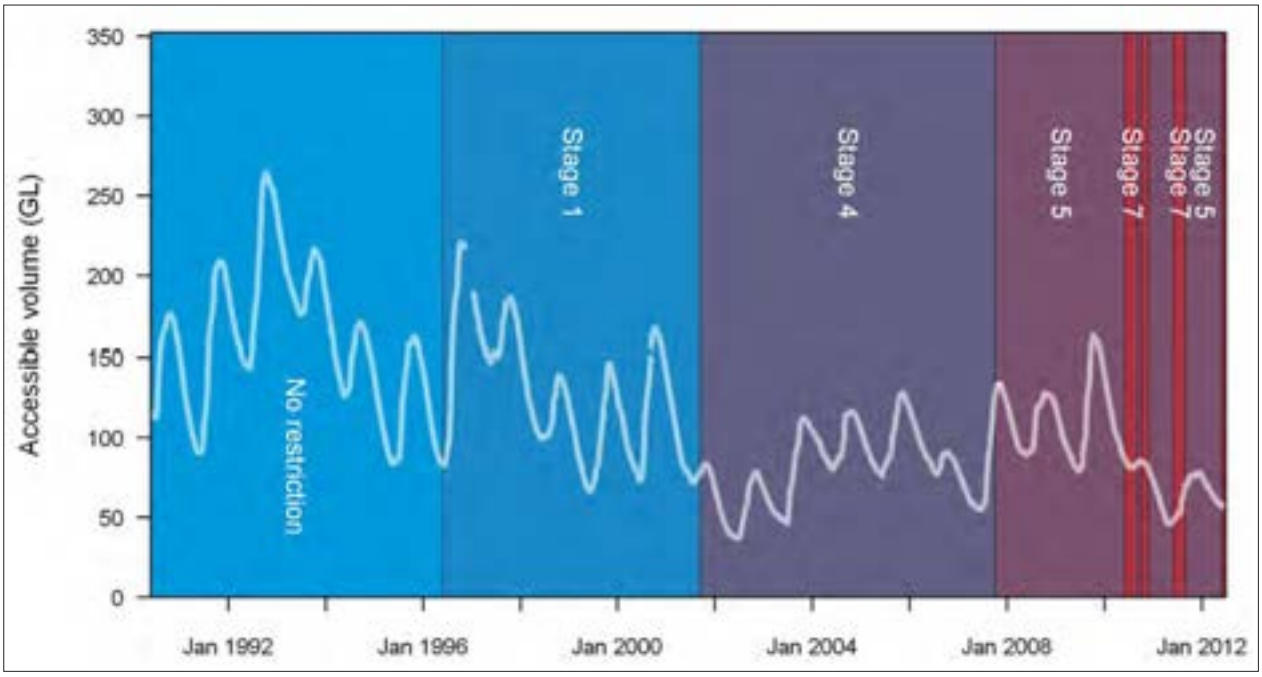


Figure 10.35 Urban water restriction levels for Perth since 1990 shown against the combined accessible water volume of Serpentine, Canning and South Dandalup storages

Sources of water obtained

Groundwater continues to be the main source of water supplied to Perth; however, in the future this may not be the case due to the low recharge of groundwater aquifers. Figure 10.36 illustrates that, on average, more than 50% of the bulk water sourced by the Water Corporation is from groundwater (National Water Commission 2011a).

An increase in desalination capacity, as a result of the Binningup desalination plant becoming operational in 2011, has seen water supplied from this source grow from 18 GL in 2006–07 to just over 50 GL in 2011–12.

Recycled water continues to play a comparatively minor role in Perth's urban water supply. Water supplied from this source has exhibited modest growth, reaching 6 GL in 2011–12, up from 4 GL in 2006–07.

Despite record growth, the total water sourced for Perth water supply has remained relatively consistent over the analysis period. This is directly attributable to demand management and water conservation measures implemented throughout Perth as well as the broader area.

On average, about 5 GL of water has been sourced from recycling on an annual basis since 2006–07. This water is supplied to consumers for a range of activities including the irrigation of agriculture, vineyards and market gardens.

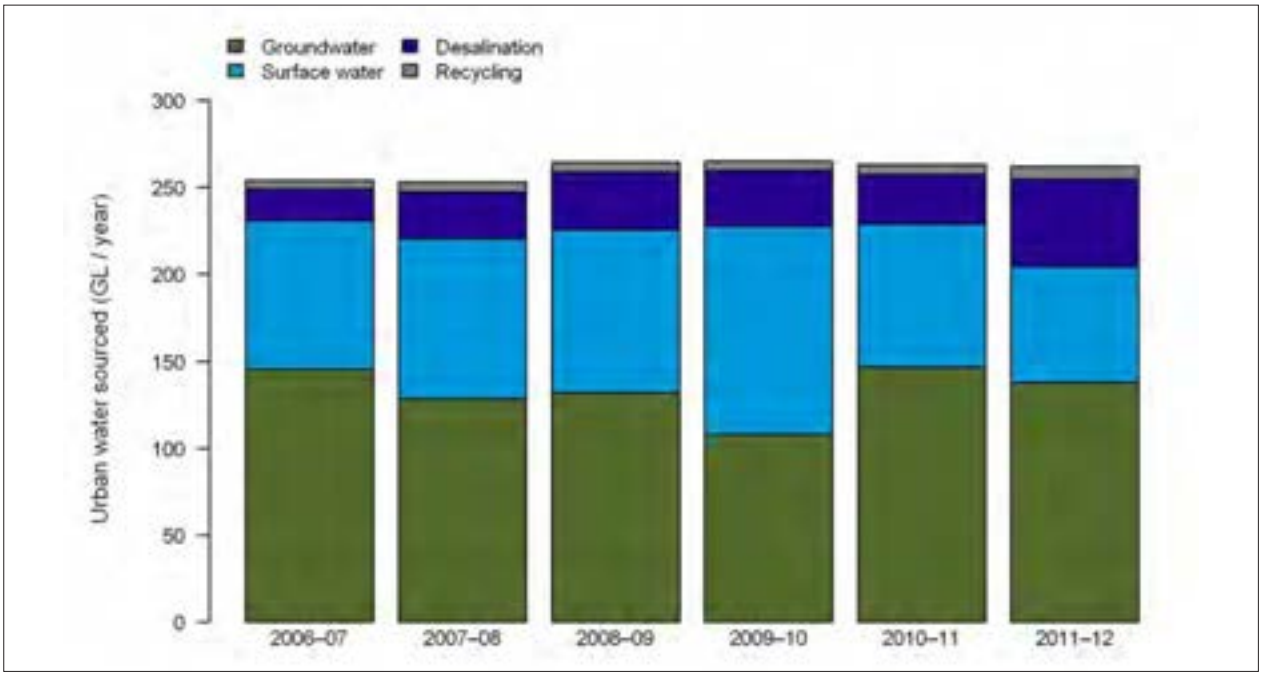


Figure 10.36 Total urban water sourced for the Perth water supply area from 2006–07 to 2011–12

Categories of water delivered

Figure 10.37 shows the total volume of water delivered to residential, commercial, municipal and industrial consumers in the Perth water supply area between 2006–07 and 2011–12 (NWC 2013). The total water supplied increased by 8 GL over this period from 240–48 GL due to an increasing population.

On average about 70% of the water supplied each year was used for residential purposes.

Commercial, municipal and industrial water use comprised around 20% of the water supplied with the remainder accounted for by other water uses.

The average water supplied by the Water Corporation per property for residential use between 2006–07 and 2011–12 was estimated to be 269 kL. The maximum residential water use per property was 281 kL in 2006–07 and the minimum was 250 kL in 2011–12.

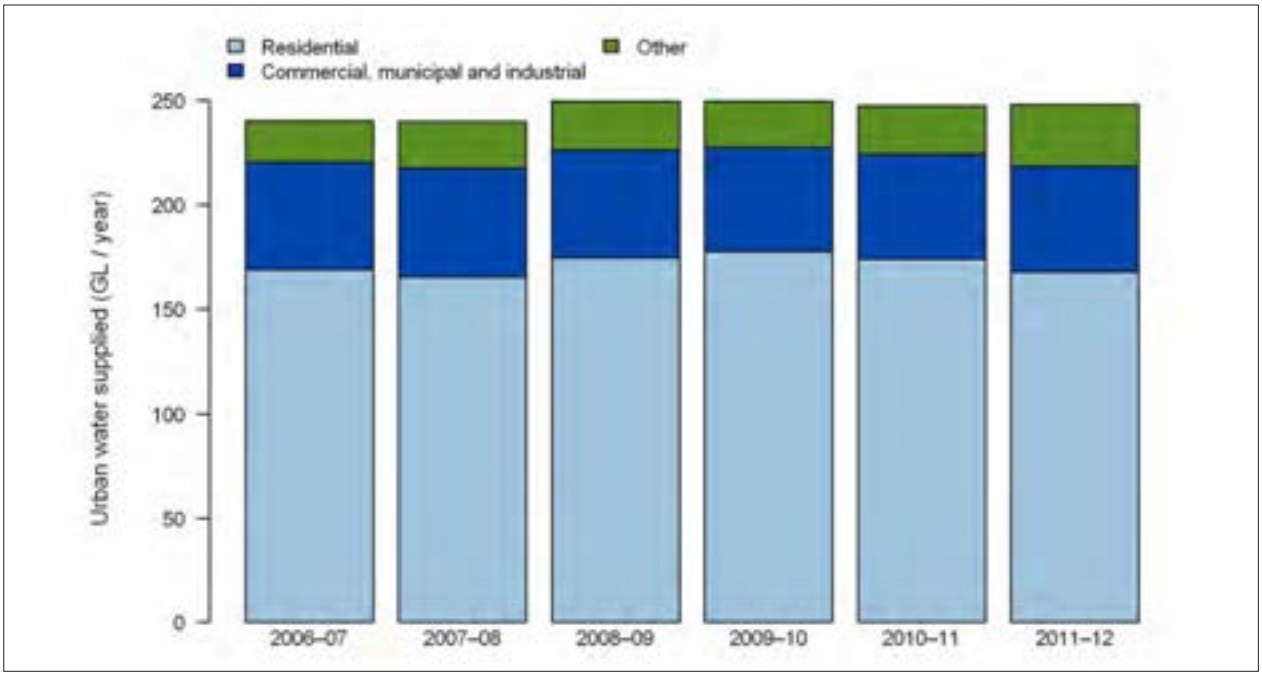


Figure 10.37 Total urban water supplied to Perth from 2006–07 to 2011–12

10.7 Water for agriculture

This section describes the water situation for agriculture in the South West Coast region in 2011–12. Soil moisture conditions are presented and important irrigation areas are identified. The Harvey Irrigation Area is described in more detail and information is provided regarding surface storage and groundwater.

10.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 km x 5 km grid cell, they are not suitable for comparison with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

Soil moisture distribution deciles for the region indicate very dry conditions during the year for a great portion of the region, as shown by the below average to very much below average soil conditions (Figure 10.38). Although the amount of rainfall in the southwest was higher than average during spring and early summer, evapotranspiration that was above or very much above the historic average in the region exceeded the rainfall inputs (see recent patterns in landscape water flows section, Figure 10.12).

The decile ranking of changes in soil moisture during the 2011–12 shows that the region experienced below average conditions throughout the whole year. A marginal rise was observed due to high rainfall periods in spring and early summer (Figure 10.39).

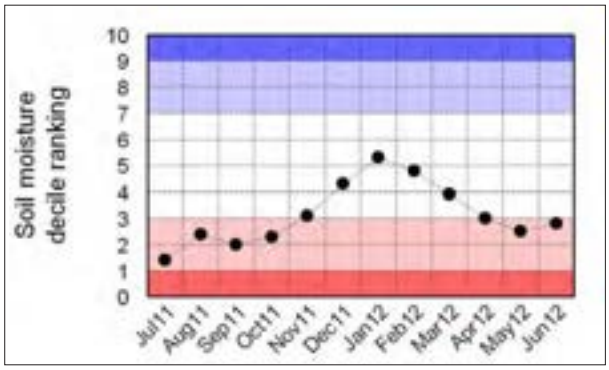


Figure 10.39 Decile ranking of the monthly soil moisture conditions during the 2011–12 period in the South West Coast region

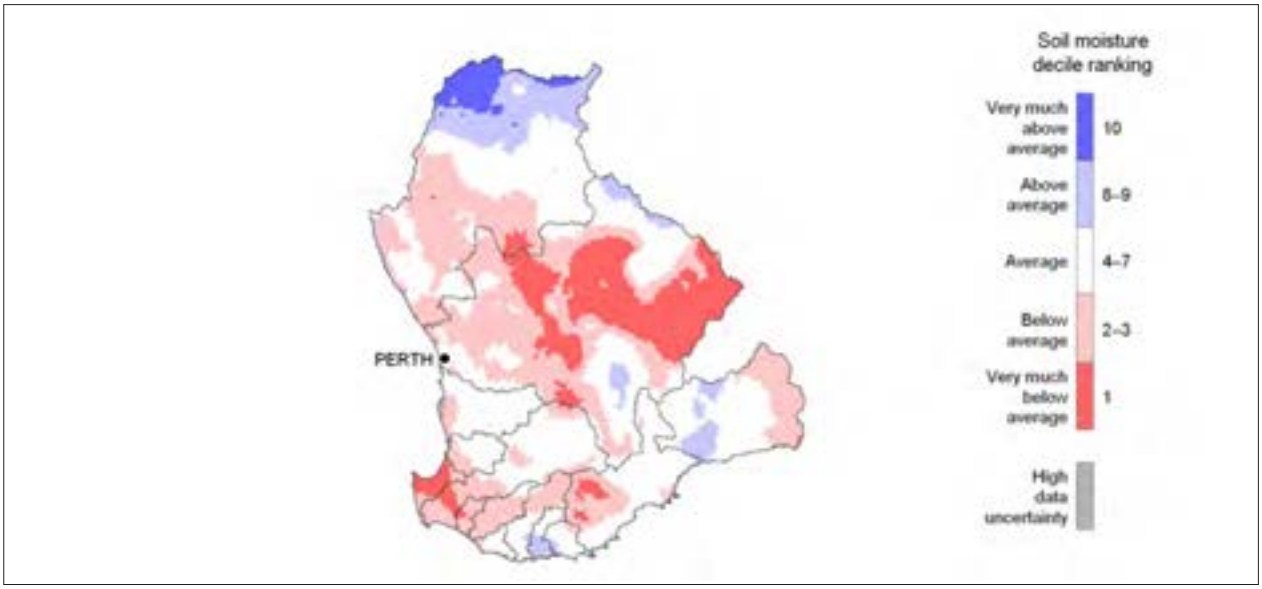


Figure 10.38 Deciles ranking of annual average soil moisture for 2011–12 with respect to the 1911–2012 period for the South West Coast region

10.7.2 Irrigation water

Comparison of annual irrigation water use between 2005–06 and 2010–11 across the South West Coast region by natural resource management regions (NRM) is shown in Figure 10.40. Figure 10.41 shows the map of annual water use of the same NRM regions in 2010–11.

Data for the 2011–12 year period was not available at the time of preparation of this report.

The Harvey Water Irrigation Area is described in subsection 10.7.4 as an example of water use by irrigated agriculture in the South West Coast region.

10.7.3 Irrigation areas

Much of the South West Coast region is cleared for grazing and dryland cropping. Principal land uses include annual dryland cropping (mainly wheat) and grazing (mainly sheep).

The region has a temperate climate with cool, wet winters and hot, dry summers. Rainfall declines rapidly further inland. The region's streamflow and groundwater recharge are generated mostly from rainfall during the cooler, wetter months of May–October.

Irrigated agriculture is carried out in the metropolitan area and parts of the southwest of the region. High salinity levels limit the suitability of water resources for agricultural production.

The main irrigation scheme providing water to irrigation areas in the metropolitan and southwestern parts of the region is the Harvey Water Irrigation Area (Figure 10.42) which is one of the main irrigation schemes in Western Australia after the Ord Irrigation Scheme, both constituting more than 60% of water allocations in the State. Irrigation in the Harvey Water Irrigation Area is mostly for pasture, followed by vegetables and horticulture.

The Preston Valley Irrigation Co-operative is another scheme and is operational in the Donnybrook Shire near Bunbury.

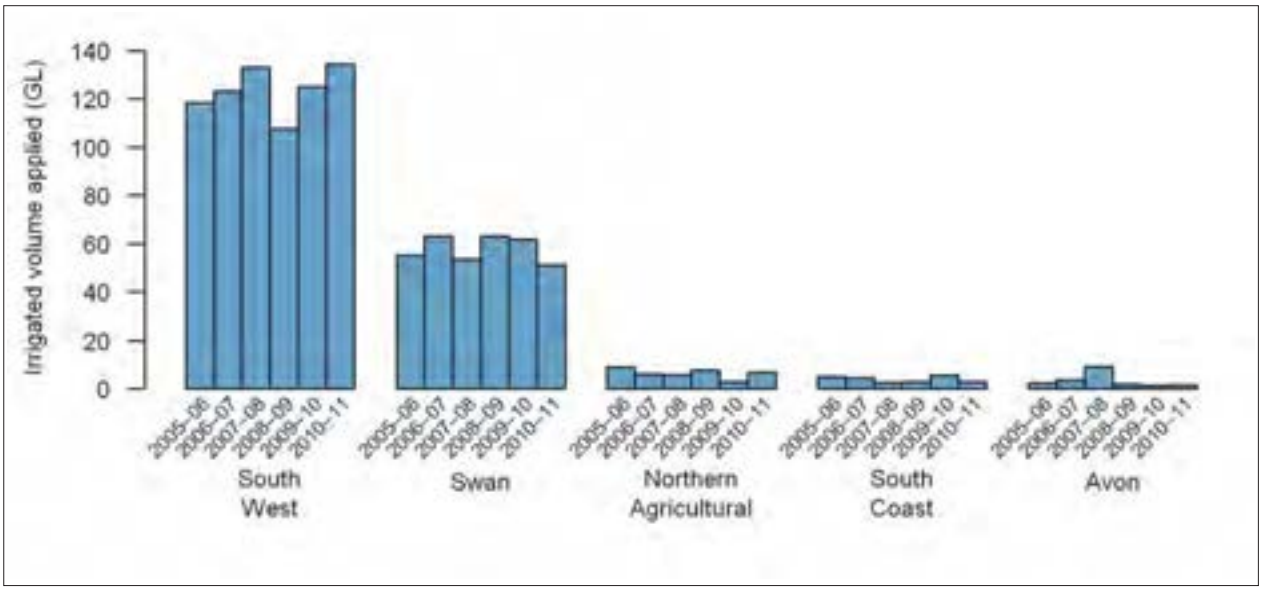


Figure 10.40 Total annual irrigation water use for 2005–06 to 2010–11 for natural resource management regions in the South West Coast region (ABS 2006–2010; 2011a)

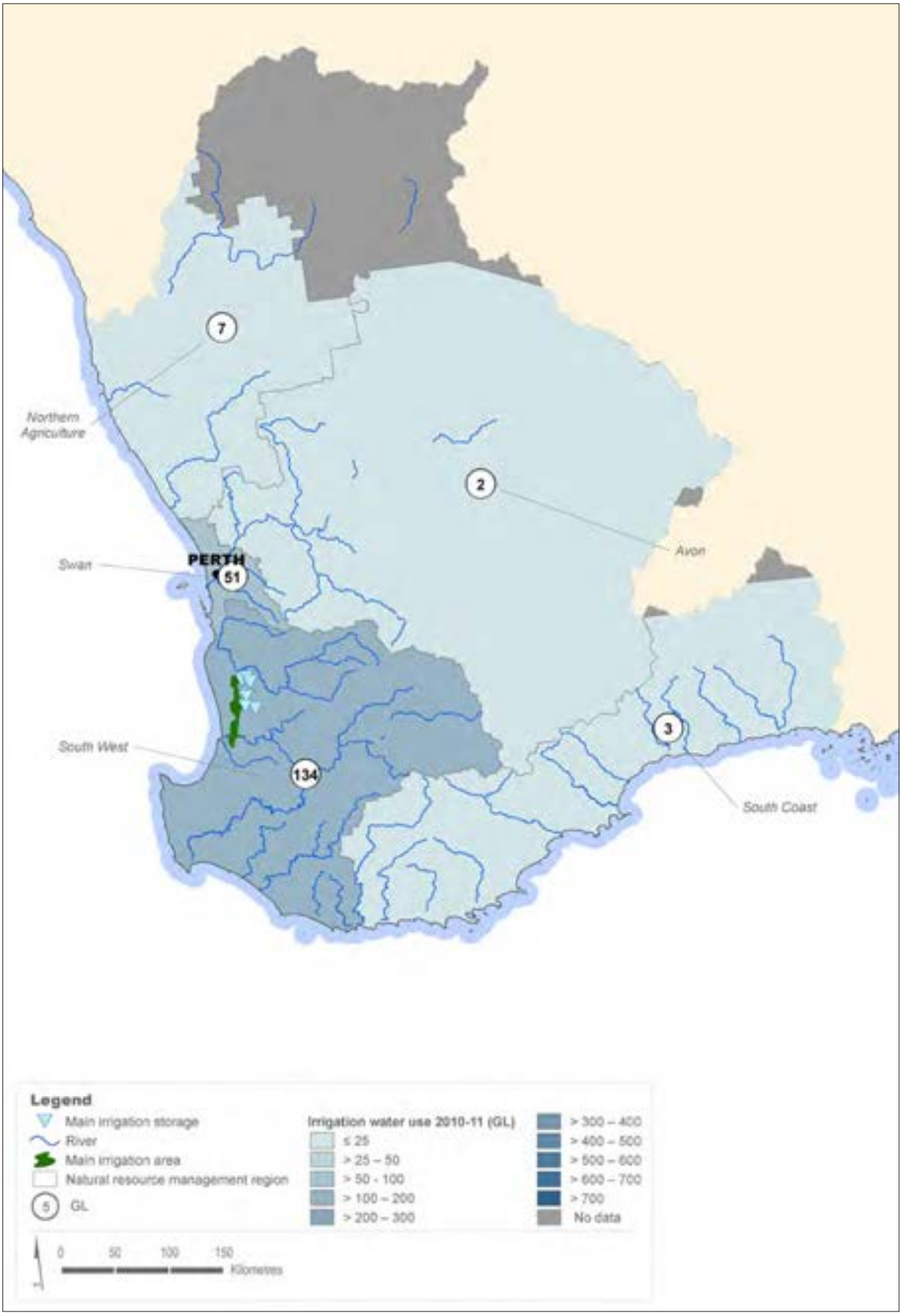


Figure 10.41 Annual irrigation water use (GL) per natural resource management region for 2010–11 in the South West Coast region (ABS 2011a)

Figure 10.42 Irrigation areas in the South West Coast region

10.7.4 Harvey Water Irrigation Area

The Harvey Water Irrigation Area is located to the west of the Darling Scarp on the Swan Coastal Plain (Figure 10.43). It lies within the Peel–Harvey catchment that includes the Harvey, Collie and Preston river basins covering an area of 3,000 km^2.

The Harvey Water Irrigation Area covers an area of 1,000 km^2 in three irrigation zones: Harvey, Waroona and Collie. The majority of land is used for dairy farming and beef production. Currently around 100 km^2 of land is under permanent irrigation for dairy farming, beef grazing and horticulture, with a total irrigable area of approximately 300 km^2 (Harvey Water 2011). It is Western Australia's prime irrigated dairy area, supplying Perth and the southwest with more than 40% of its milk.

Harvey Water is responsible for the water delivery infrastructure and is licensed to draw water from Drakes Brook (Lake Moyanup), Harvey, Logue Brook (Lake Brockman), Samson Brook (Lake Kabbamup), Stirling, Waroona (Lake Navarino) and Wellington storages. Water is supplied by gravity flow from storages to farms via a network of open channels and pipes. The transfer system is progressively being made more efficient by the use of high density piping.

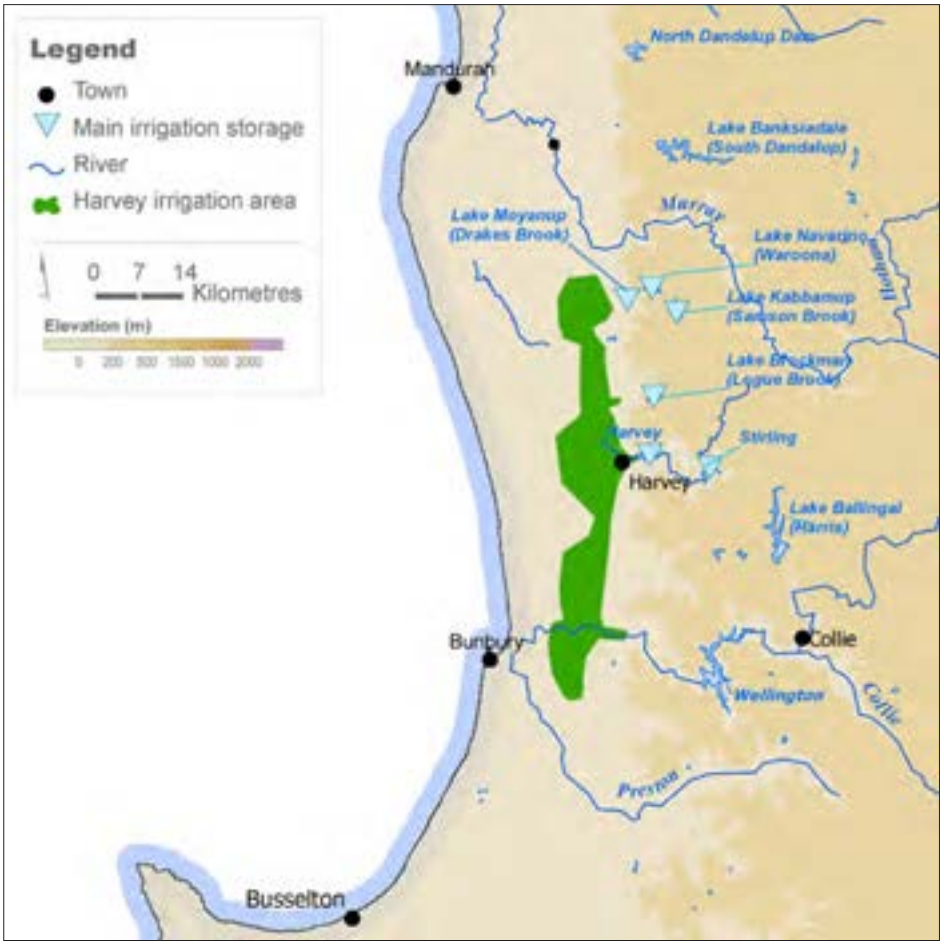


Figure 10.43 Harvey Water Irrigation Area

Surface water storage volumes

Total volume for the seven water storages in the irrigation area between 1990 and 2012 are shown in Figure 10.44. The total storage volume was drawn down to low levels, approximately 20% of capacity, during the 2002–03 drought. The data indicate storage total volume during 2011–12 period recovered from similarly low levels in spring 2011 to be in excess of 200 GL in summer 2011–12. This recovery did not extend into the following autumn due to reduced inflow to the storages.

The irrigation water use in the three districts of Collie, Harvey and Waroona in the Harvey irrigation area has dropped from an average of 70 GL per year since 1996 to just 48 GL per year between 2010 and 2012 (Figure 10.45). The reduction in water use in recent years has been related to deterioration of water quality and reduction in demand.

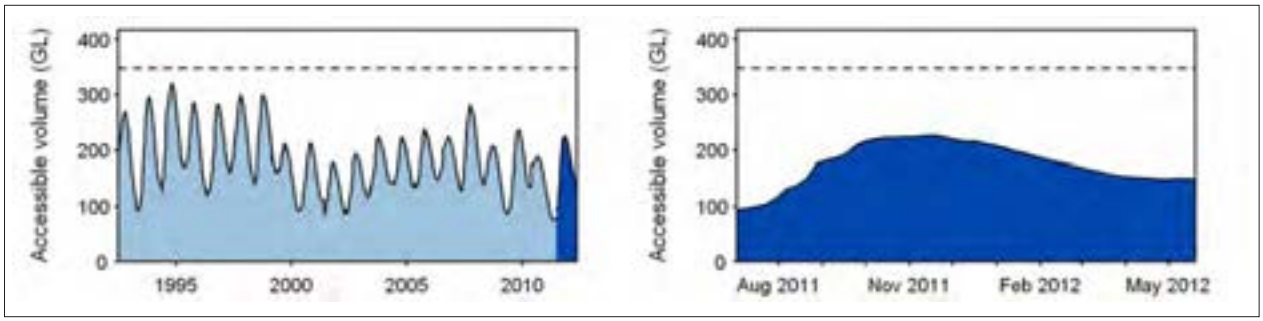


Figure 10.44 Variation in the amount of water held in seven storages supplying the Harvey Water Irrigation Area over recent years (light blue) and over 2011–12 (dark blue), as well as total accessible storage capacity (dashed line)

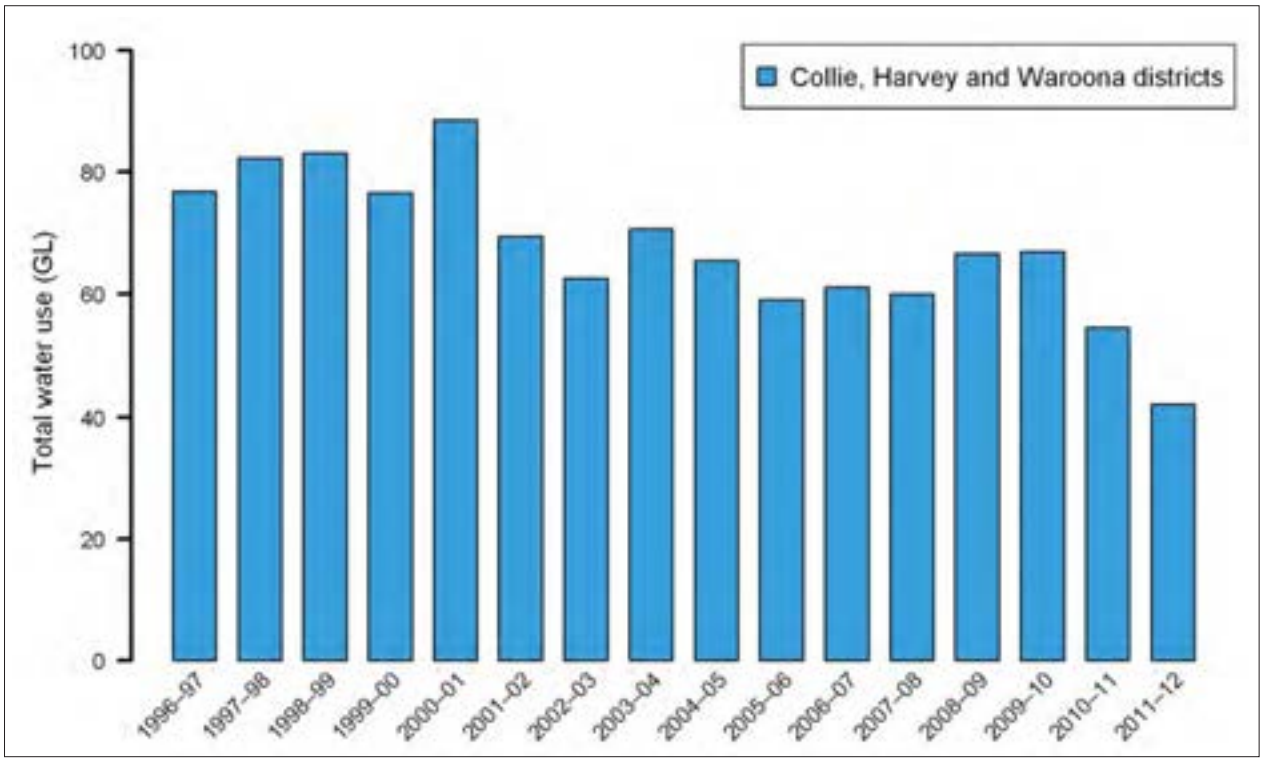


Figure 10.45 Water use in the three irrigation districts of the South West Coast region between 1996 and 2012

Pilbara–Gascoyne

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11 Pilbara–Gascoyne

11.1 Introduction

This chapter examines water resources in the Pilbara–Gascoyne region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

11.2 Key information

Table 11.1 gives an overview of the key components of the data and information in this chapter.

Table 11.1 Key information on water flows, stores and use in the Pilbara–Gascoyne region

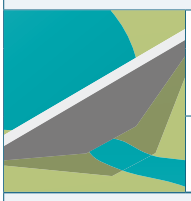
Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	338 mm	+29%	9th—above average
Evapo-transpiration	341 mm	+36%	9th—above average
Landscape water yield	19 mm	+73%	10th—very much above average

Streamflow (at selected gauges)

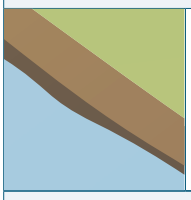
Flooding:	Minor flooding limited to two gauges in the far northern rivers in single gauges in the midstream part of the Gascoyne and Ashburton rivers

Surface water storage (comprising all of the region's major surface water storages)



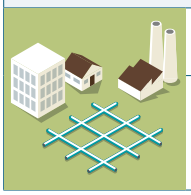
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
63 GL	36 GL	57%	62 GL	98%	-26 GL	-41%

Groundwater (in selected aquifers)



Salinity:	Large areas of saline groundwater (≥3000 mg/L) along the coast and in alluvial aquifers surrounding major river beds

Urban water use (Geraldton)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
7.8 GL	8.1 GL	–0.3 GL (-4%)	Permanent Water Conservation Measures

11.3 Description of the region

The Pilbara–Gascoyne region is the central western corner of Western Australia. It covers a long coastal section and a dry inland section bordered by the North Western Plateau and South Western Plateau regions in the east, and the South West Coast region in the south. The region covers about 478,000 km² of land area. River basin areas vary in size from 18,000 km² to 91,000 km².

The area encompasses two major plateaus: the Pilbara plateau in the north and the Gascoyne plateau in the southeast. The western part of the region includes coastal and inland dunes and alluvial floodplains, with some low hills in the southwest. Seasonal or persistent aridity has resulted in low vegetation cover and intermittent river systems. Subsections 11.3.1–11.3.4 give more detail on the physical characteristics of the region.

The Pilbara–Gascoyne region has a population of approximately 117,000 people, which is 0.5% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b).

Major population centres are shown in Figure 11.1 and include the city of Geraldton as well as the regional centres of Karratha, Port Hedland (including South Hedland) and Carnarvon. Further discussion of the region's population distribution and regional urban centres can be found in subsection 11.3.6 and section 11.6 respectively.

Most of the region is in a relatively natural state, much of which is used for grazing (See Figure 11.1).

Dryland agriculture accounts for approximately 3% of the land use in the region. Irrigation is limited and intensive land uses such as urban areas account for 0.03%. Section 11.7 has more information on agricultural activities in the region.

The region has an arid subtropical climate, with a temperate Mediterranean climate predominantly occurring in the south. Rainfall is generally low and variable. Irregular monsoonal rain occurs in the north. Subsections 11.3.7 and 11.3.8 provide more information on the rainfall patterns and deficits across the region.

The generally flat landscapes ensure high rainfall infiltration rates. Rivers are sparse and drain internally or towards the Indian Ocean. The major rivers only generate substantial amounts of flow during and after high rainfall periods.

The hydrogeology of the region is dominated by the large area of outcropping Palaeozoic fractured basement rock of low permeability. The groundwater systems in this rock typically offer restricted low volume groundwater resources. A more detailed description of the rivers and groundwater status in the region is given in section 11.5.

Python Pool, Millstream–Chichester National Park, Western Australia | Tourism Australia

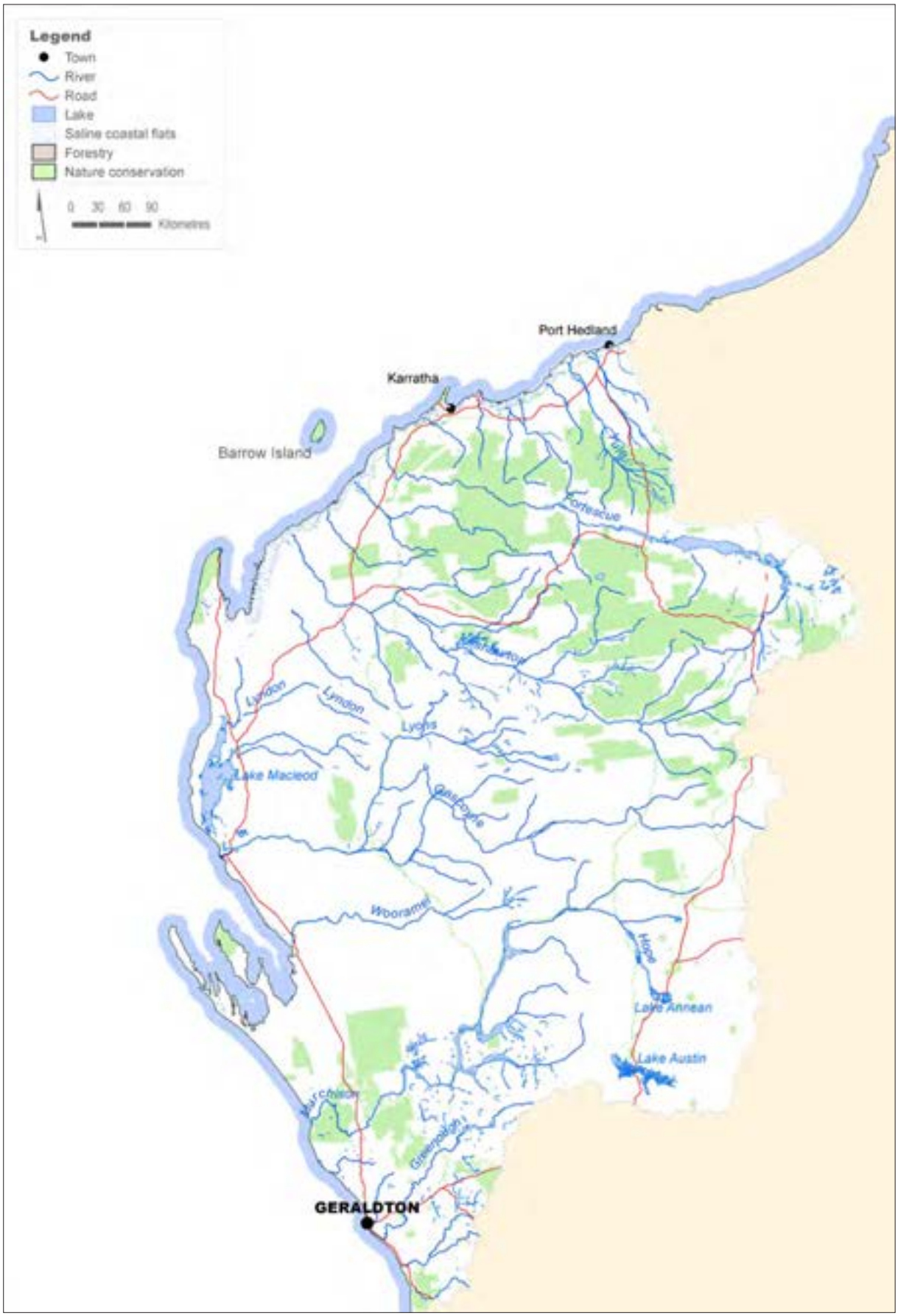


Figure 11.1 Major rivers and urban centers in the Pilbara–Gascoyne region

11.3.1 Physiographic characteristics

The physiographic map in Figure 11.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes. The Pilbara–Gascoyne region has three physiographic provinces, namely the Pilbara, Western Coastlands and the Yilgarn Plateau.

The Pilbara province occupies 50% of the region. In the north along the coast are flood and deltaic plains with tidal flats and some metamorphic, volcanic and granitic hills. Inland from this are dissected flat-topped hills of igneous and metamorphic rocks interspersed by stony plains on granite. Further south are dissected plateaus and ranges of sandstone, quartzite and volcanic rocks. There are also some alluvial lowlands with sand, stony and hardpan plains.

The Western Coastlands province occupies 29% of the region and comprises mainly plains of sand, stone and calcrete with dunes, some low ridges, plateaus and hills of sandstone and shale.

The Yilgarn Plateau province occupies 21% of the region and comprises sand and hardpan plains with outgoing drainage and salt lakes, broken by ridges of metamorphic rocks and granite.

Figure 11.2 Physiographic provinces of the Pilbara–Gascoyne region

11.3.2 Elevation

Figure 11.3 presents ground surface elevations in the Pilbara–Gascoyne region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).The region encompasses two major plateaus: the Pilbara plateau in the north and the Gascoyne plateau in the southeast. The western part of the region includes coastal and inland dunes and alluvial floodplains, with some low hills in the southwest.

In the north of the region, the Hamersley Range form a dominant landscape feature. Peaks exceed 1,200 m above sea level, the highest in Western Australia.

The low-lying coastal zone covers a large part of the region and is only intercepted by the Cape Range. It contains limestone plateaus exceeding 300 m in altitude.

The eastern border of the region is not an obvious water divide in a topographical sense. Many smaller and larger internally draining basins exist on both sides of the border.

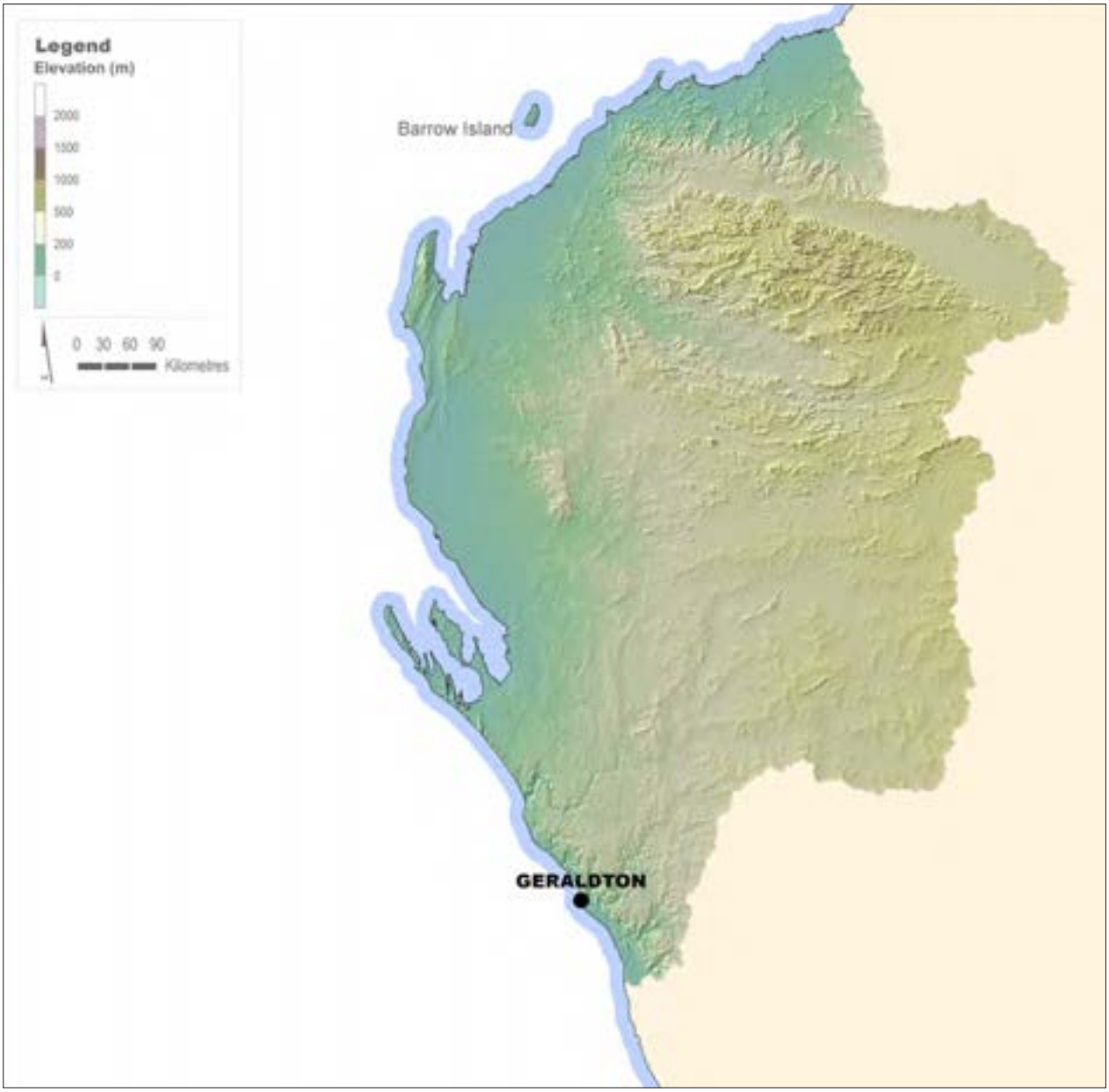


Figure 11.3 Ground surface elevations in the Pilbara–Gascoyne region

11.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The Pilbara–Gascoyne region has few areas with steep slopes. Most of the area is rather flat (Table 11.2). The slopes were derived from the elevation information used in the previous section.

Table 11 2. Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	44.0	21.6	28.3	6.1

Steep slopes are particularly concentrated in the Hamersley Range in the north (Figure 11.4).

The flat stretch to the north of the ranges is the Fortescue River and includes the Fortescue Marsh wetland.

The Gascoyne plateau is located in the centre of the region. Most of it is drained by the Gascoyne River. Slopes have a minor impact on flooding in this region. It was the rainfall intensity and duration only that created a major flood in December 2010.

The coastal plains are flat and contain many lakes that are separated from the sea by dunes. The most dominant lake is Lake MacLeod. The extent of Lake MacLeod varies over time depending on the occasional inflows. It is identified as an important wetland, but is also a salt-harvesting site.

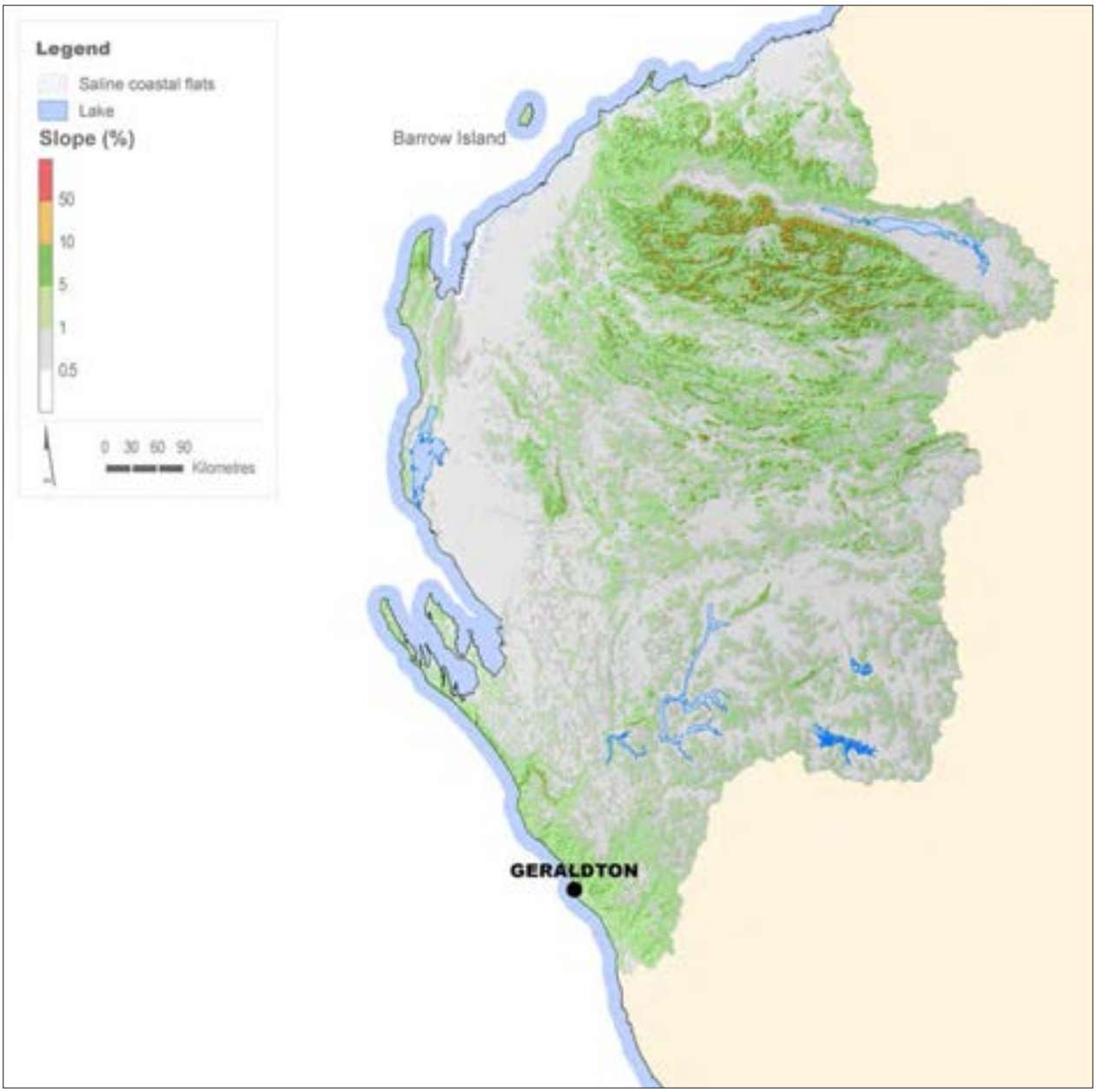


Figure 11.4 Surface slopes in the Pilbara–Gascoyne region

11.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About almost 90% of the Pilbara–Gascoyne region is covered by three soil types, namely tenosols, sodosols and kandosols (see Figure 11.5 and Figure 11.6). Among those more than 40% of the area is covered by tenosols. They are scattered throughout the entire region and are mixed with mostly sodosols in the north and with kandosols in the south of the region. These soils are mostly used for pastoral agriculture and to some extent for nature conservation in the region.

Tenosols are typically sandy and are often shallow in depth. These soils have low fertility and water-holding capacity and thus are of low agricultural potential. Sodosols have clear textural contrast, with impermeable, sodic subsoils arising from elevated sodium concentrations and clay.

They are susceptible to dryland salinity as well as erosion if vegetation is removed. Sodosols are usually low in nutrient status.

Kandosols are structureless soils which are often very deep (up to 3 m or more), but they do not have a strongly contrasting texture and they do not contain carbonate throughout their profile. They are low in chemical fertility and are well-drained. With only moderate water-holding capacity compared with other soil types, they only have low to moderate agricultural potential.

The other soil types that have minimal representation in the Pilbara–Gascoyne region are calcarosols, rudosols, vertosols, chromosols and hydrosols (1–4%).

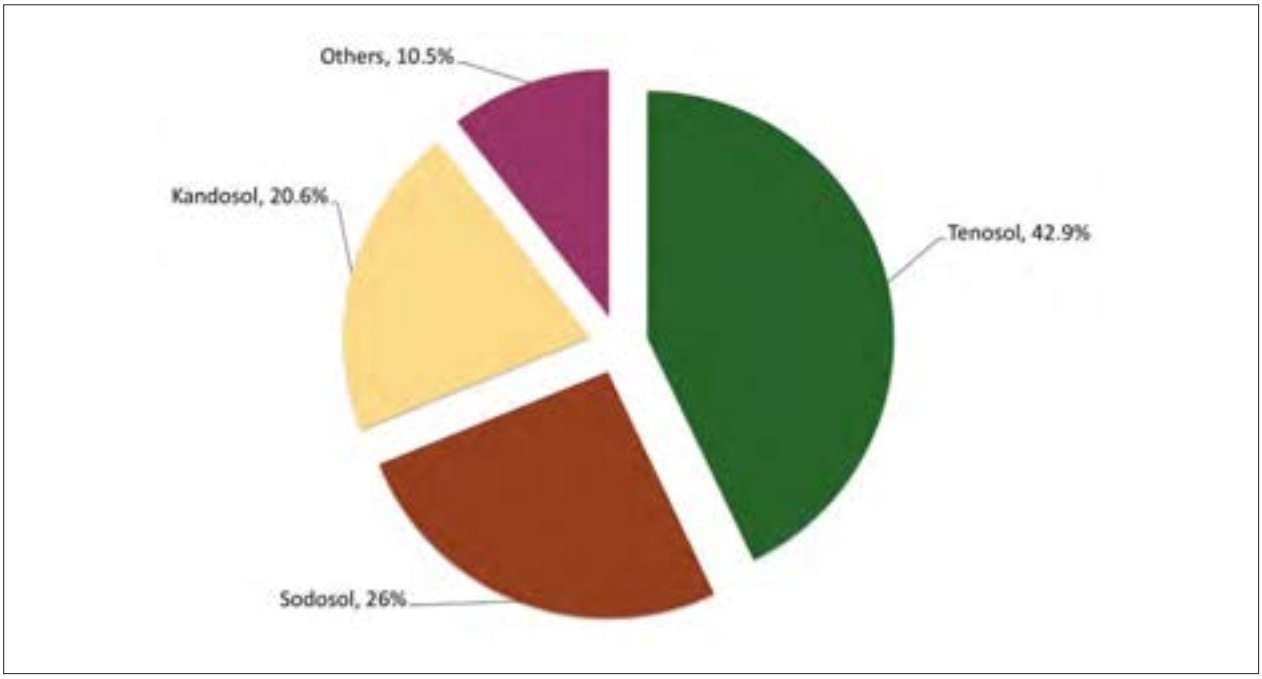


Figure 11.5 Soil types in the Pilbara–Gascoyne region

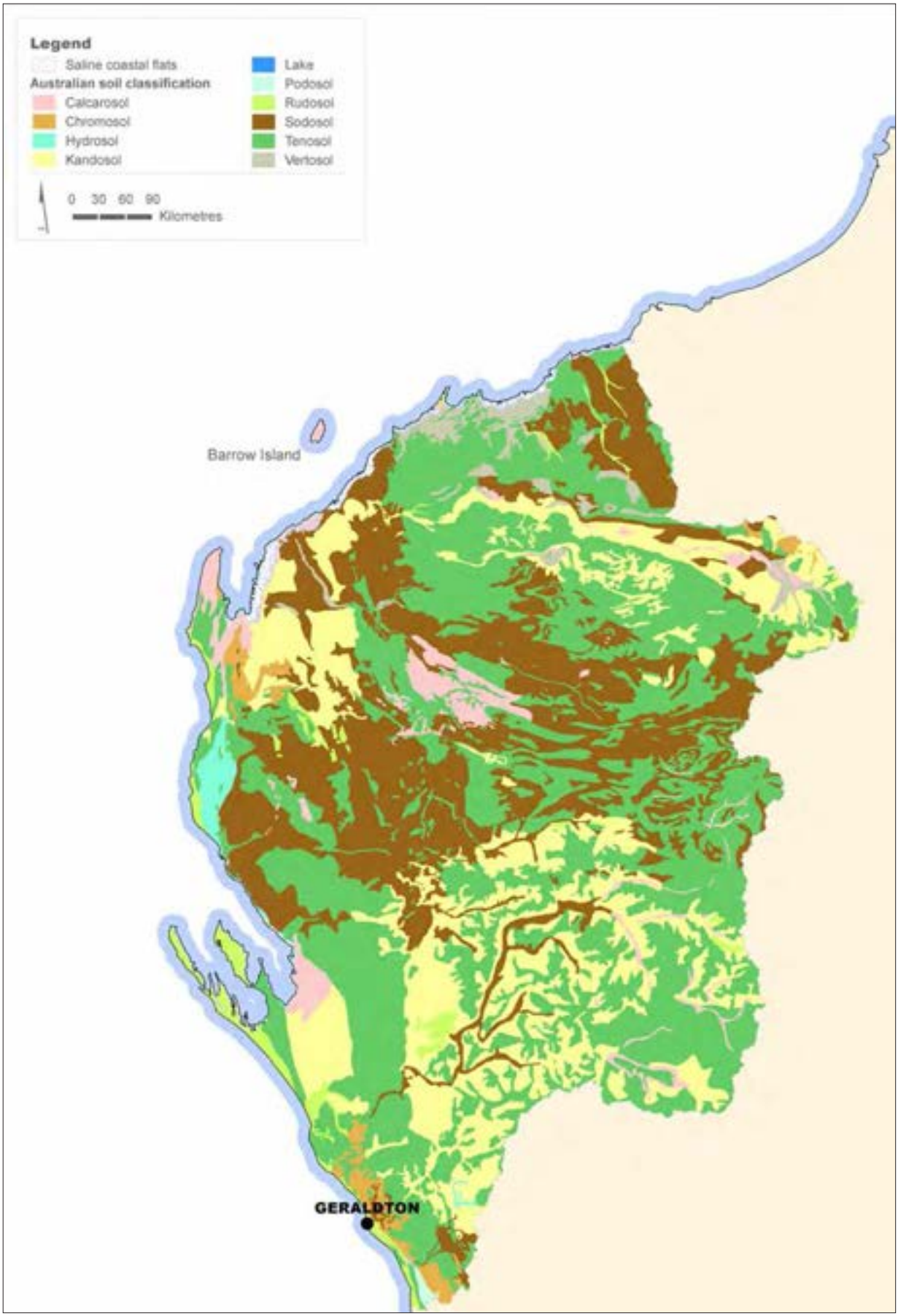


Figure 11.6 Soil type distribution in the Pilbara–Gascoyne region

11.3.5 Land use

Most of the Pilbara–Gascoyne region is in a relatively natural state, much of which is used for grazing (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Aridity has resulted in low vegetation cover in the inland section. Dryland agriculture accounts for approximately 3% of the region's land use.

Irrigation is limited to the southern coastal part of the region. The Carnarvon horticultural district close to the Gascoyne River is one of the most productive areas in Western Australia for horticulture, producing a wide variety of fruit and vegetable crops, particularly over the winter months. Although the Gascoyne River is mostly dry, underground aquifers provide irrigation water to the crops.

Intensive land uses such as urban areas account for 0.03% of the region (Figure 11.7 and Figure 11.8).

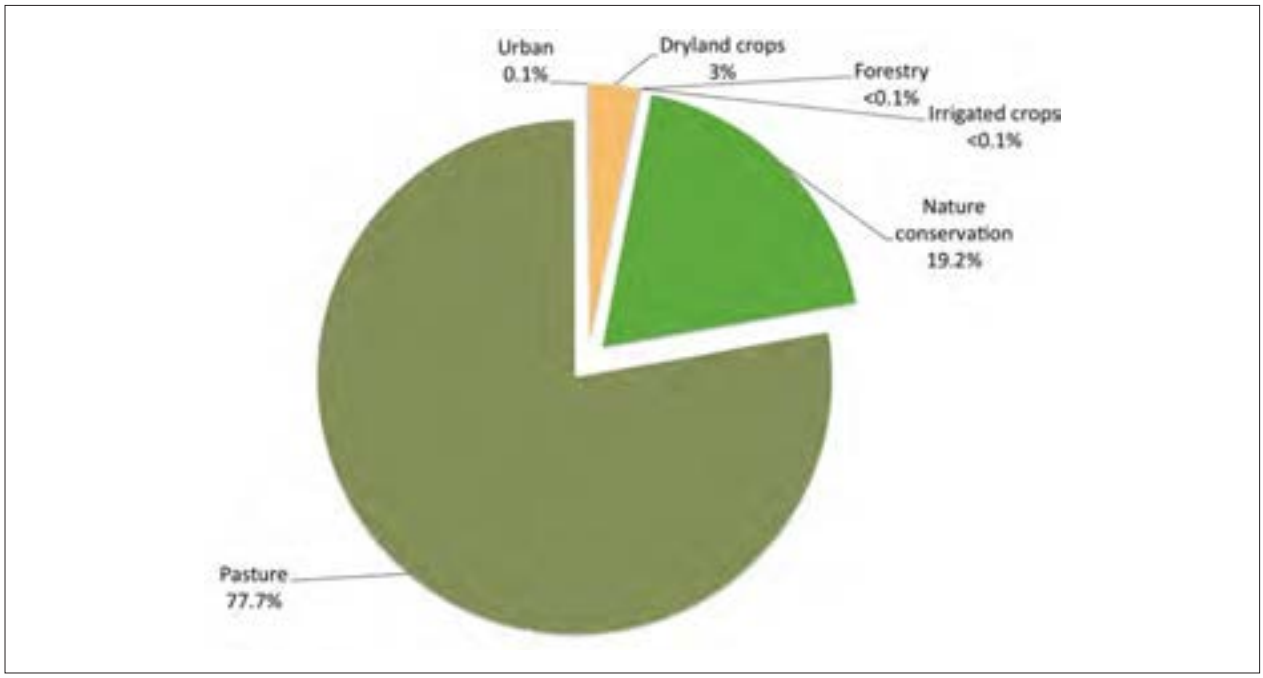


Figure 11.7 Land use in the Pilbara–Gascoyne region

Basil growing at one of the many plantations near Carnarvon, Western Australia | Gascoyne Development Commission

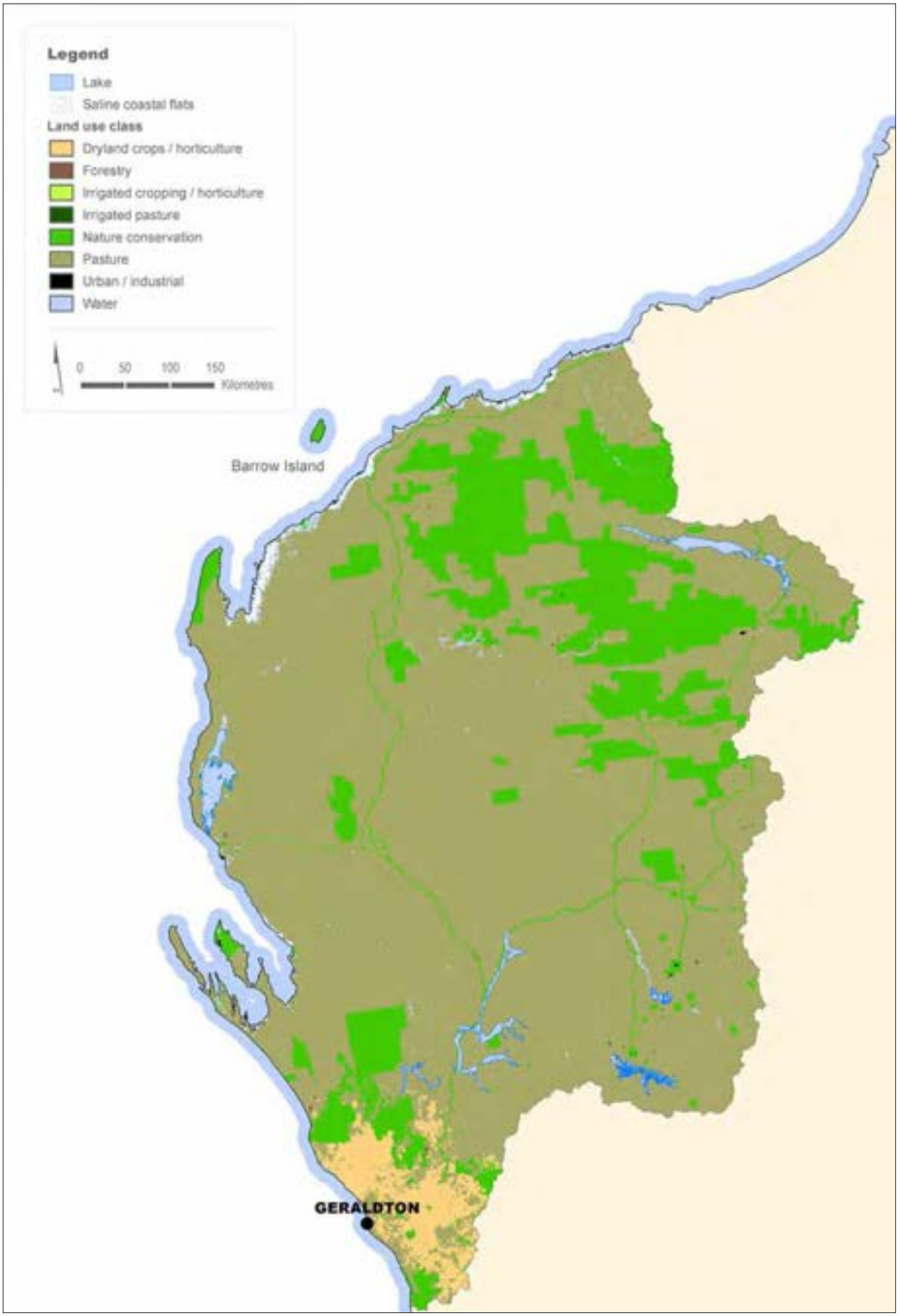


Figure 11.8 Land use distribution in the Pilbara–Gascoyne region

11.3.6 Population distribution

With a population representing just over 0.5% of the nation's total and a land area of 478,000 km² (Figure 11.9), Pilbara–Gascoyne is one of the most sparsely populated regions (ABS 2011b).

The region is home to a number of remote Indigenous communities, and mining is the most significant driver for the region's population distribution. Permanent settlements have developed around the many mining leases across the region; however, the coastal port cities and towns provide the focal point for the population. The city of Geraldton, in the southwest, is the largest population centre in the region. The northern coastal centres of Karratha, Dampier and Port Hedland (including South Hedland) are centres with growing mining activities.

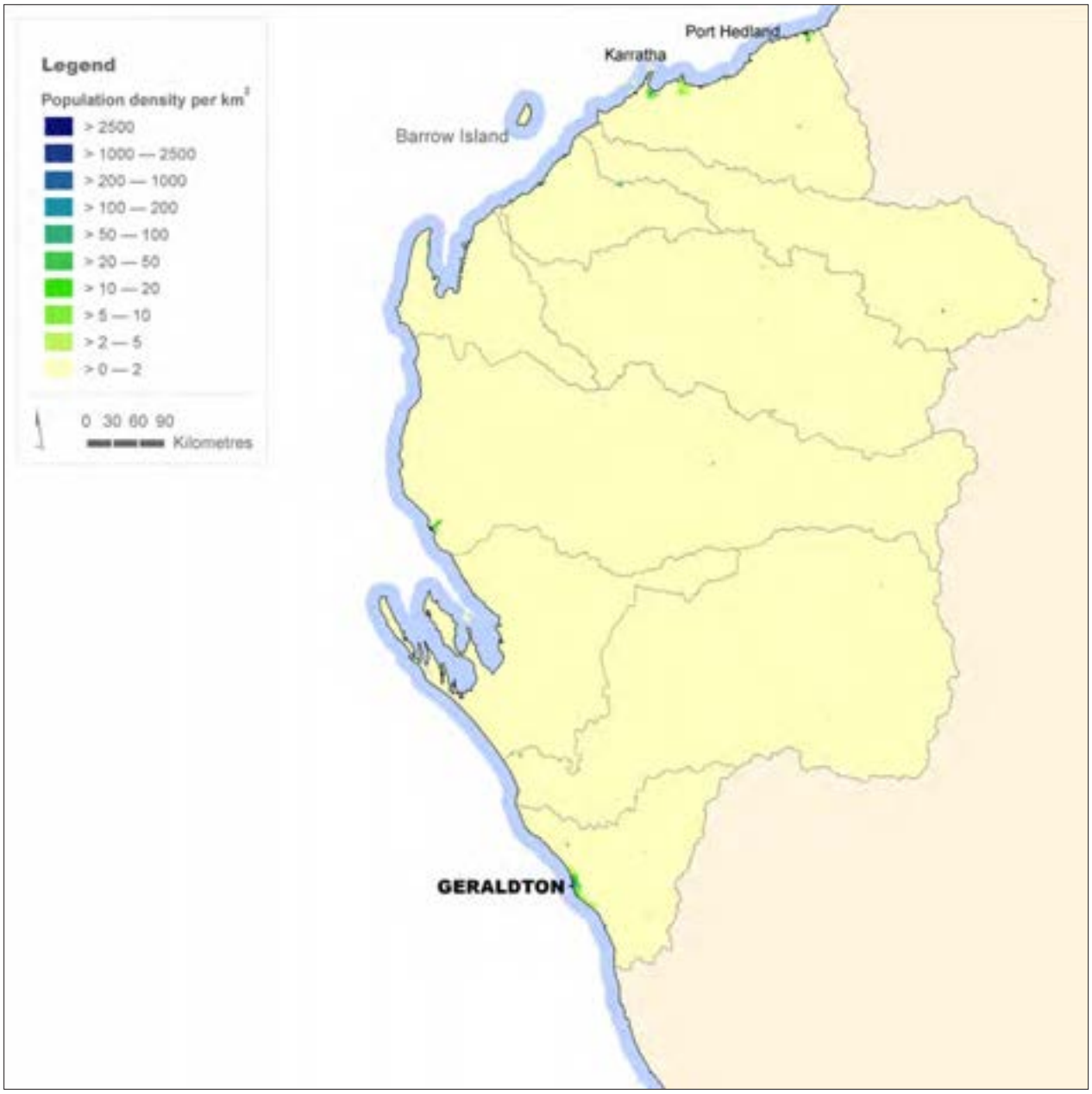


Figure 11.9 Population density and distribution in the Pilbara–Gascoyne region

11.3.7 Rainfall zones

The region has an arid subtropical climate, with a temperate Mediterranean climate predominantly occurring in the south. Rainfall in the north is highly variable and dependent on the passage of tropical cyclones and monsoon activity. Elsewhere, rainfall is typically low.

Median rainfall does not exceed 500 mm and is generally highly variable (Figure 11.10).

Most of the region is classified as arid but, especially in the north, monsoons supply enough rain to cause average annual rainfall totals in some of these areas to exceed 400 mm.

Together with the Nullarbor coast, the Pilbara coast experiences the lowest average annual rainfall totals for coastal areas in Australia. Even along the Gascoyne coast the winter dominant rainfall does not exceed average annual totals of 500 mm.

For more information on this and other climate classifications, visit the Bureau's climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

Figure 11.10 Rainfall zones in the Pilbara–Gascoyne region

11.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration indicator gives a general impression about which part of the region moisture deficits are likely to occur over the period of a year. The Pilbara–Gascoyne region has a rather uniform pattern of serious potential deficits over the whole region (Figure 11.11).

Due to the seasonality of the rainfall along the south coast, this area is still well-suited for dryland agriculture, which occurs at an extensive scale.

The rest of the region is covered by either pasture, sparsely in use for stock farming. The north is covered by many national park and conservation lands. A fair amount of mining occurs in the region. The rainfall deficits form serious challenges to supply the mine workers with fresh drinking water from natural resources.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

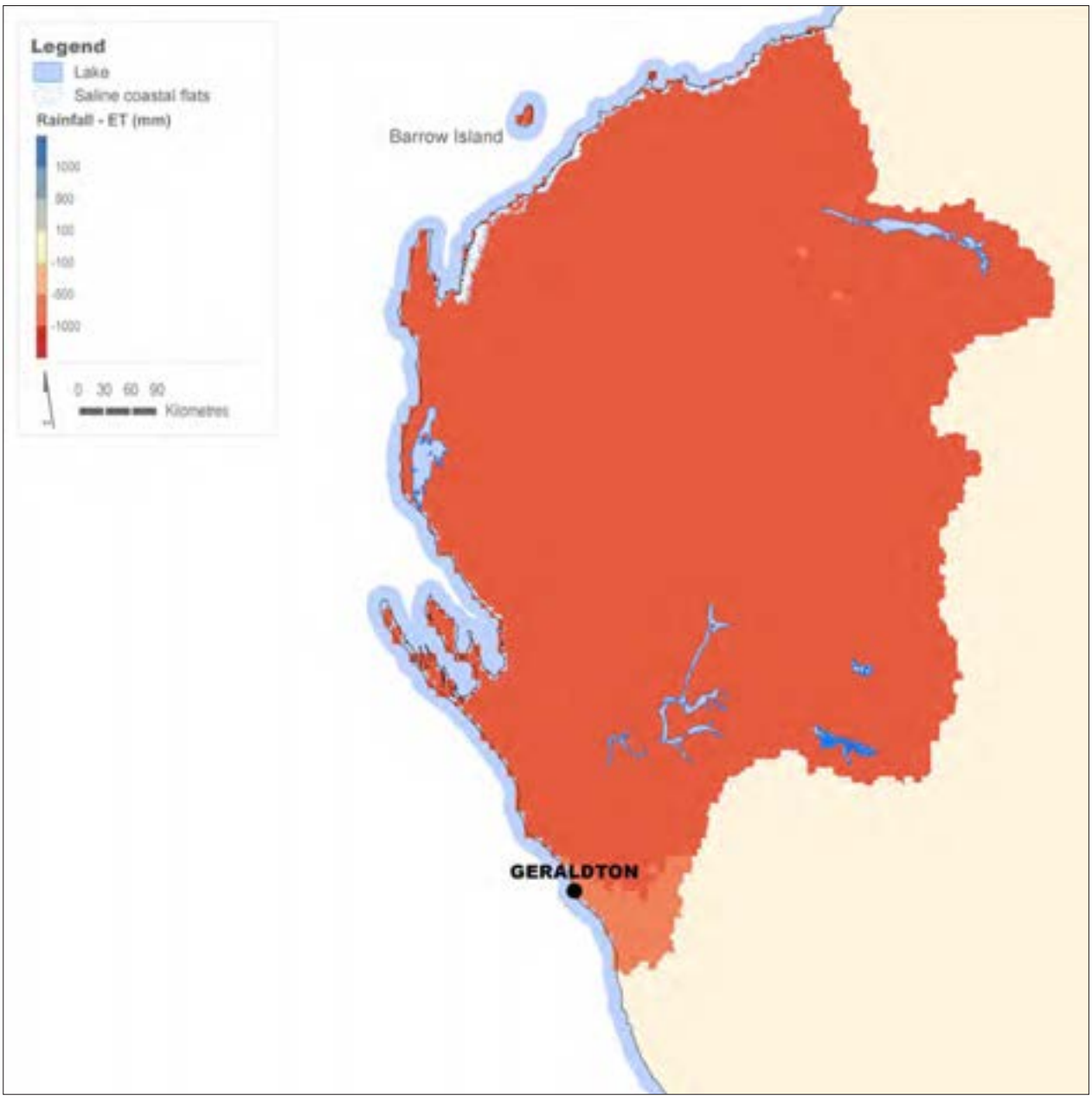


Figure 11.11 Rainfall deficit distribution for the Pilbara–Gascoyne region

11.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Pilbara–Gascoyne region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 11.12 shows that the region has a seasonal rainfall pattern of a predominantly wet January–July period and a dry August–December period. Evapotranspiration in the dry period generally exceeds rainfall. After the wet period the soils normally contain plenty of moisture that is available for evapotranspiration.

The monthly landscape water yield history for the region shows a stable pattern of very low yield throughout the year.

The 2011–12 year was a relatively wet year. The month of January recorded the second highest regional rainfall total over the 1911–2012 period. Two tropical cyclones hit the region in this month. The first (*Heidi*) made landfall in the north of the region. The second (*Iggy*) also affected the region in the north.

With wet soil conditions present at the start of the year, evapotranspiration rates were higher than rainfall for the first six months of 2011–12. With the exception of January, March and June 2012, evapotranspiration rates remained above rainfall for the rest of the year as a result of high water availability after the January rainfall.

Following the high January rainfall, landscape water yield was highest on record for this month. The other months also saw some high landscape water yields, but these were not really significant in absolute terms.

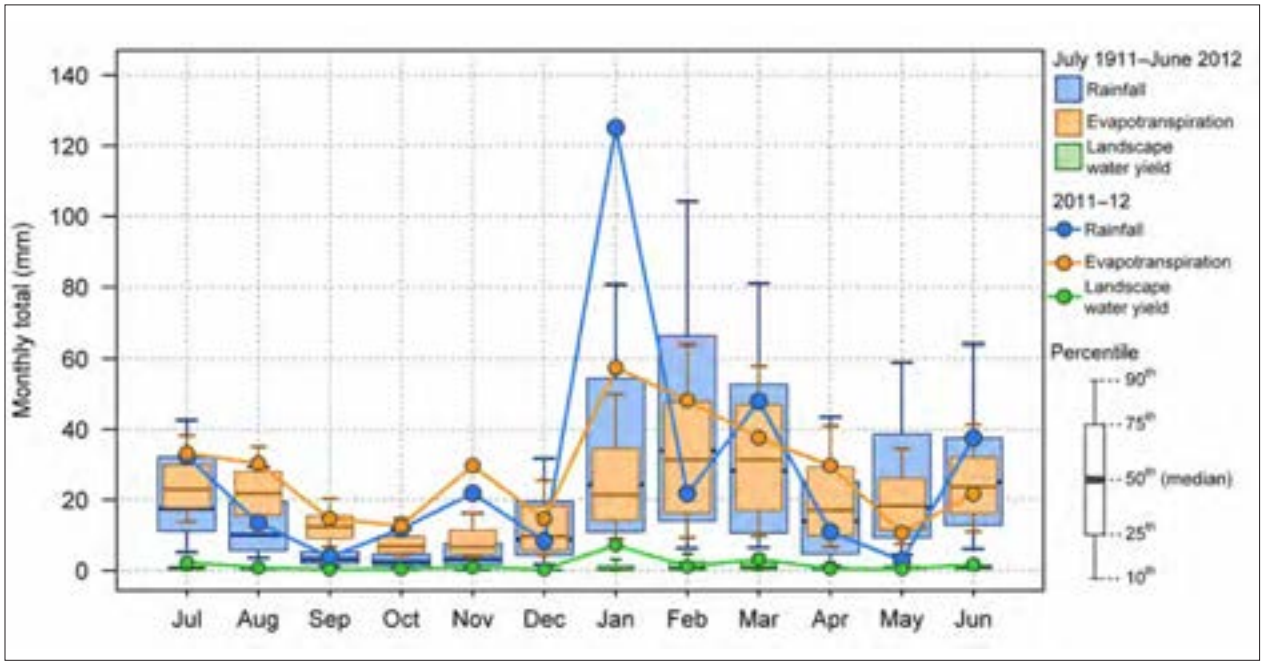


Figure 11.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911– June 2012) for the Pilbara–Gascoyne region

11.4.1 Rainfall

Rainfall for the Pilbara–Gascoyne region for 2011–12 is estimated to be 338 mm. This is 29% above the region's long-term average (July 1911–June 2012) of 263 mm. Figure 11.13a shows that the highest rainfall for 2011–12 occurred in the Pilbara district along the northeast and in the far south around Geraldton. Most of the coastal zone had rainfall not exceeding 300 mm, whereas in the northeast rainfall exceeded 400 mm throughout.

Rainfall deciles for 2011–12 indicate a gradient of below average rainfall in the northwest, increasing to very much above average in the central east of the region (Figure 11.13b). Most of the inland parts of the region received above average rainfall and along the coast average rainfall generally occurred. The very much above average rainfall in the central west was caused almost entirely by tropical cyclone *Heidi*.

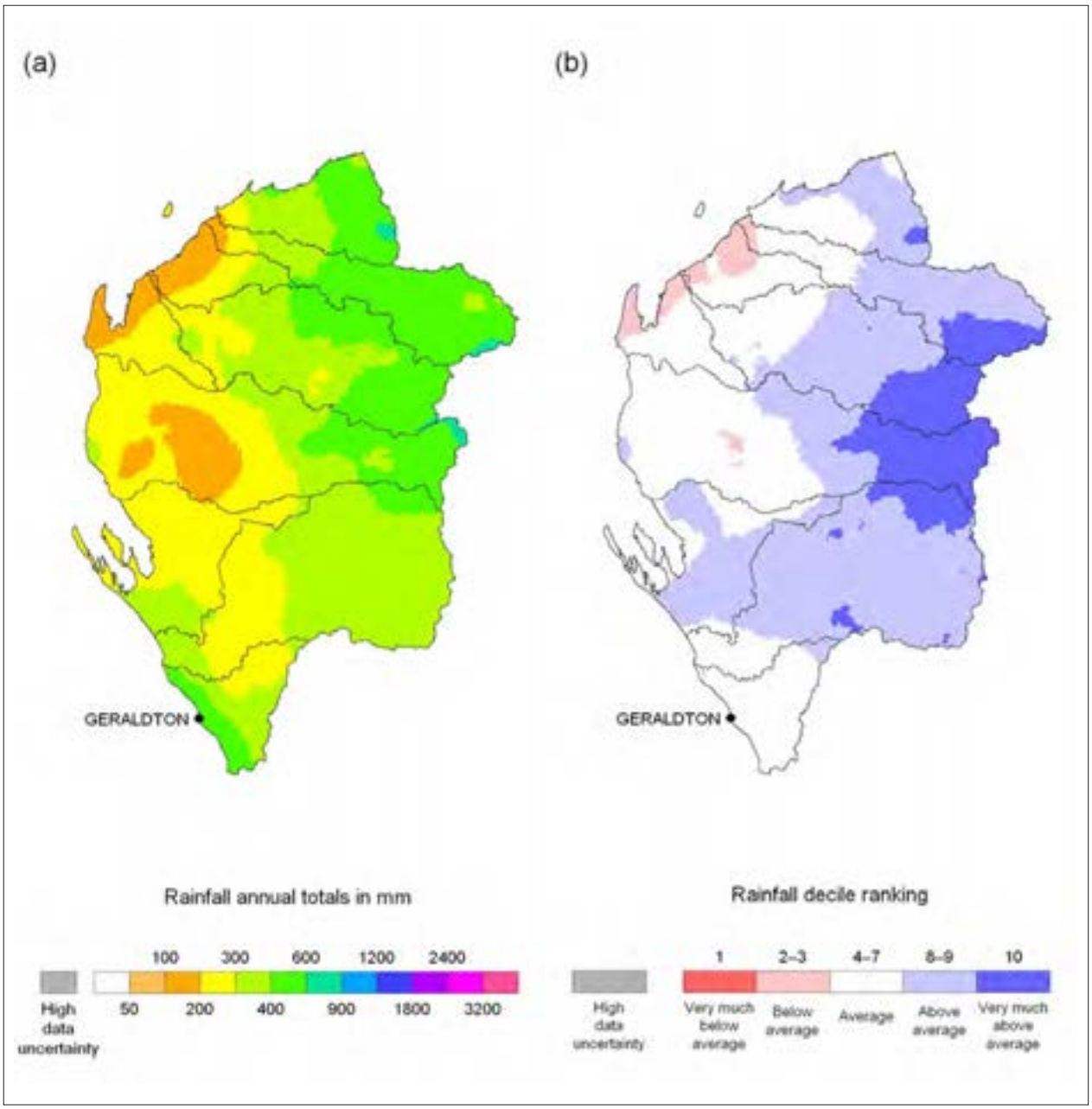
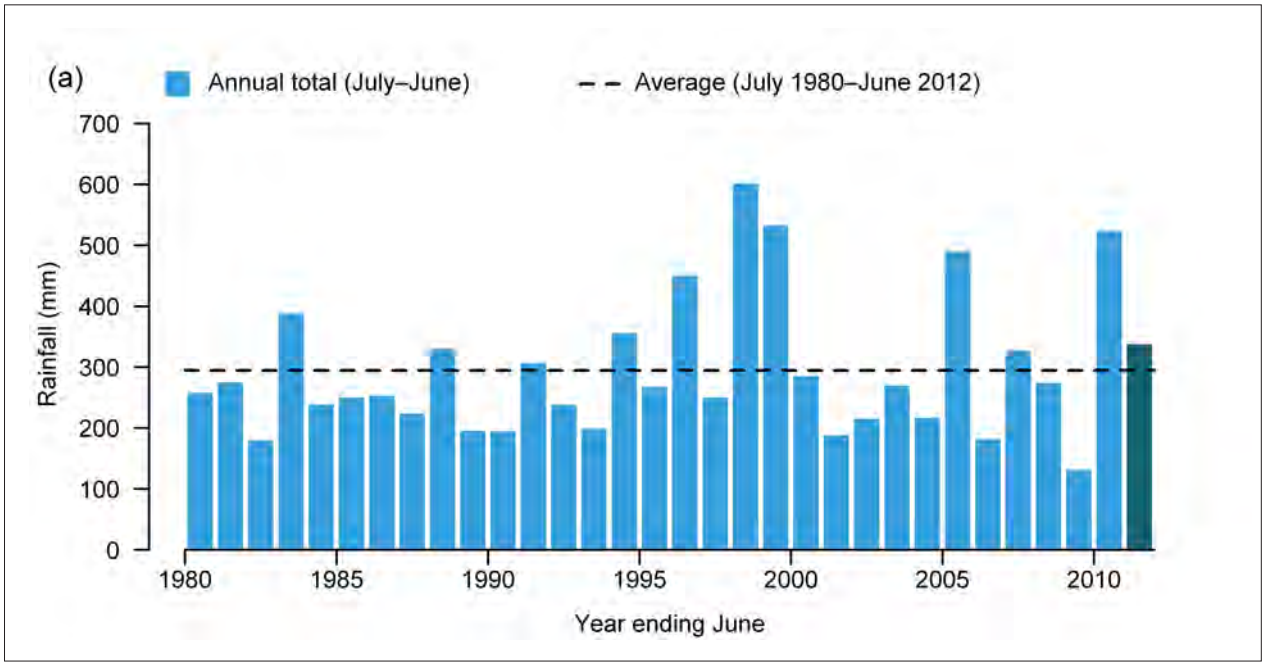


Figure 11.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Pilbara–Gascoyne region

Rainfall variability in the recent past

Figure 11.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 295 mm, varying from 131 mm (2009–10) to 601 mm (1998–99). Temporal variability and seasonal patterns since 1980 are presented in Figure 11.14b.

The graphs indicate a highly variable pattern of annual rainfall totals over the last 32 years. In fact, the Pilbara–Gascoyne region has the highest coefficient of variation (standard deviation divided by the mean) in annual rainfall of all regions. This means that rainfall is highly unpredictable. It normally depends on the occurrence of large monsoonal or tropical storms.



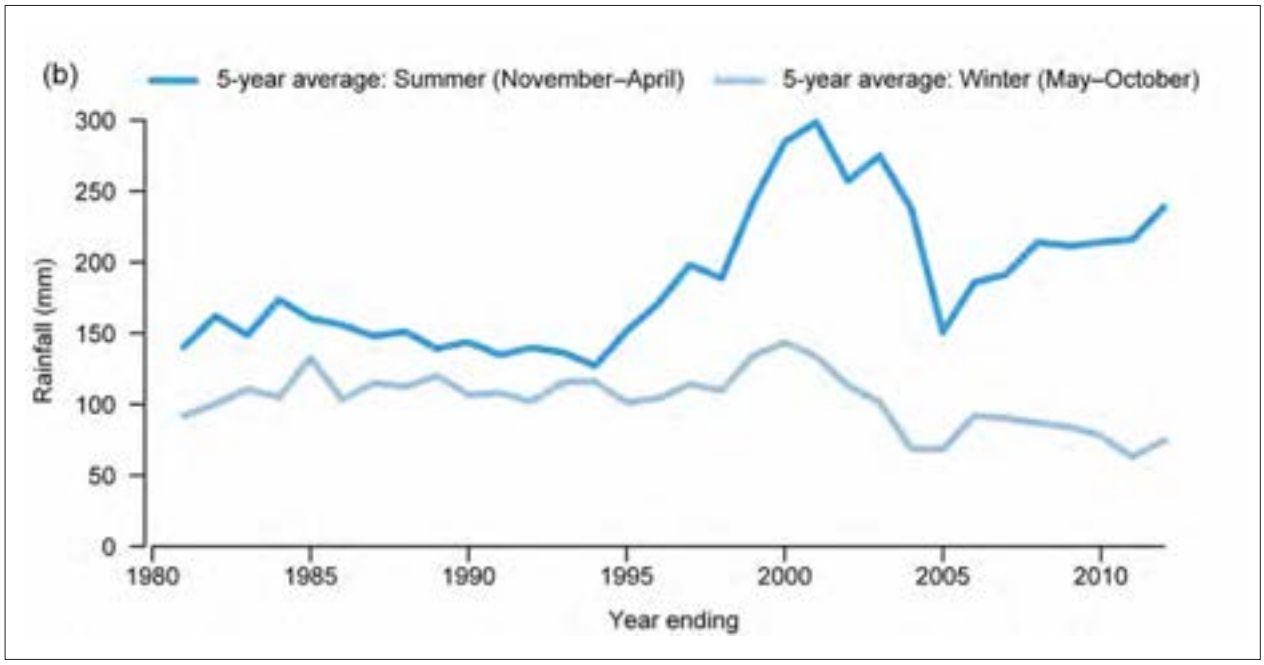


Figure 11.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Pilbara–Gascoyne region

Recent trends in rainfall

Figure 11.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 11.15b. This analysis indicates that the region experienced a general increase in rainfall since 1980, with the exception of the far south coast where the trend is falling.

However, the rising trends are strongly significant in 4% of the region only (Figure 11.15b). In the south, only some small areas recorded a significant falling trend in rainfall since 1980.

Because of the high variability in rainfall, these trends are highly dependent on the reference period chosen. Since most of the high rainfall years happened in the second half of the reference period (see Figure 11.14), a rising trend is to be expected; however, the driest year occurred in 2009–10 which shows that the trend analysis is not very relevant in the context of highly variable time-series.

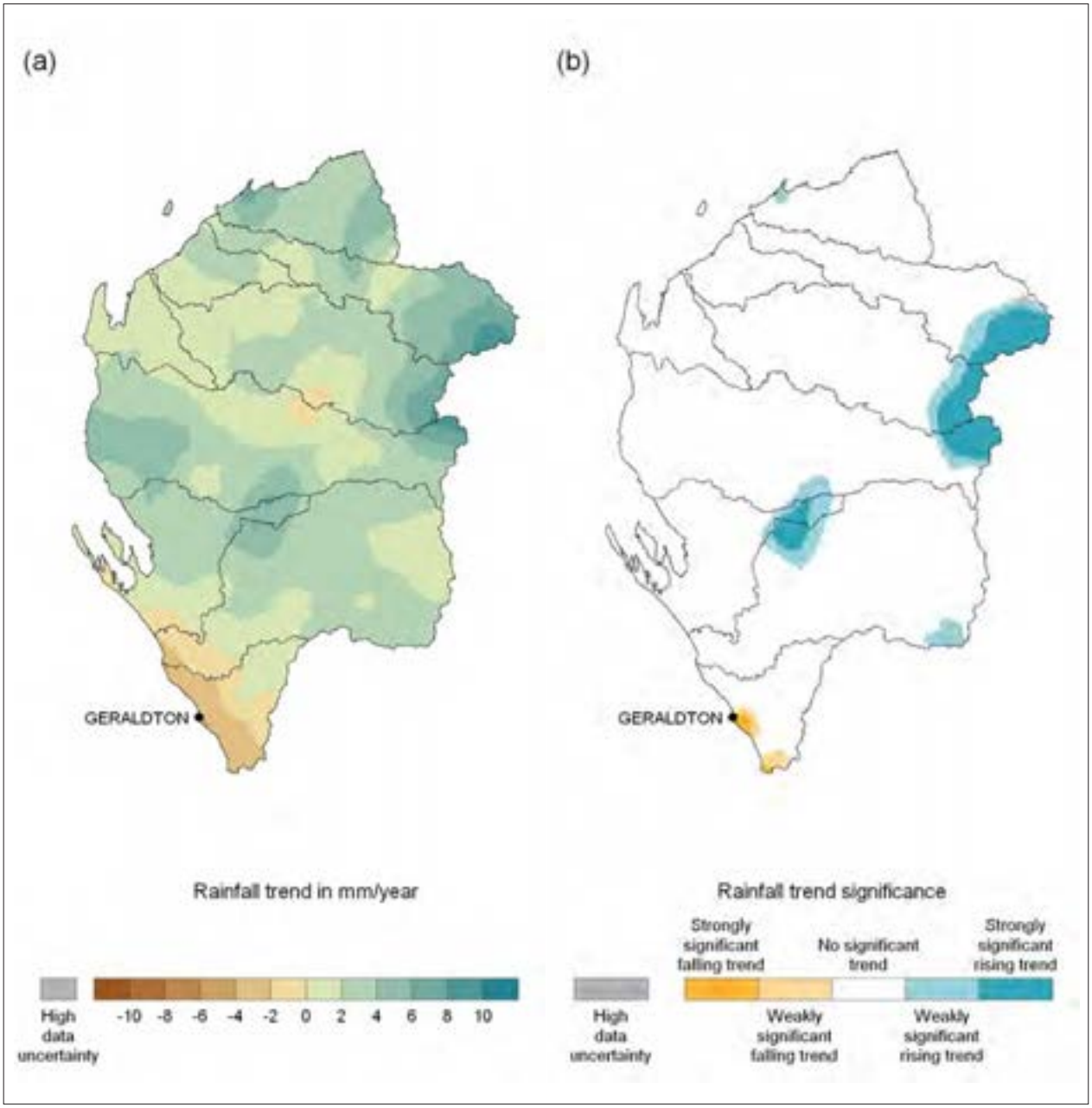


Figure 11.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Pilbara–Gascoyne region

11.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Pilbara–Gascoyne region for 2011–12 is estimated to be 341 mm. This is 36% above the region's long-term (July 1911–June 2012) average of 251 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 11.16a) was similar to that of rainfall (Figure 11.13a).

Relatively high soil moisture volumes at the start of the year allowed the annual total evapotranspiration to exceed annual total rainfall in large areas along the northwest coast.

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 11.16b). The decile levels of total annual evapotranspiration throughout the region are a little higher than rainfall (Figure 11.13b), again caused by the relatively high soil moisture availability at the start of the year. Most coastal areas are estimated to have average evapotranspiration, with some areas having above average annual evapotranspiration.

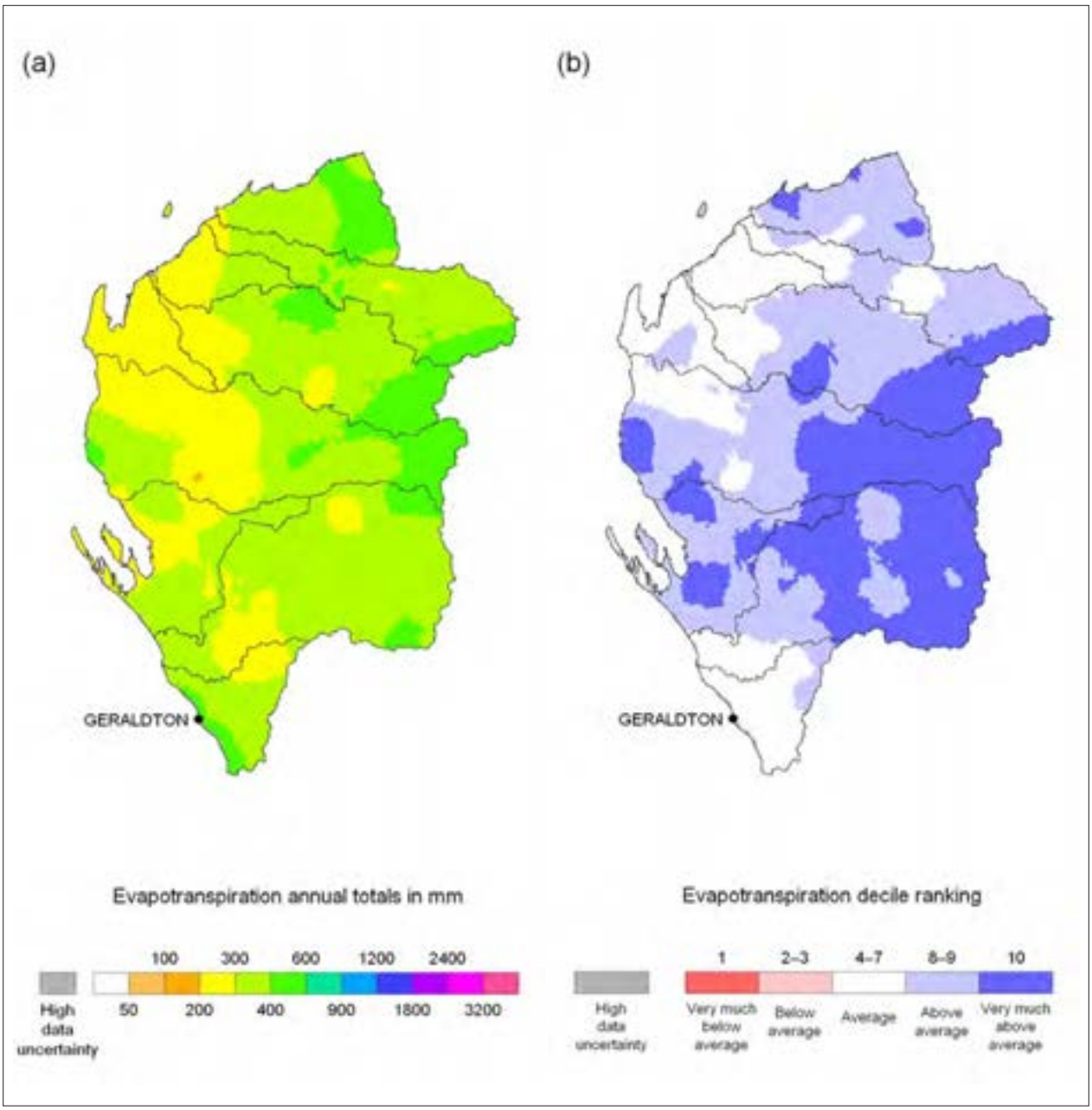
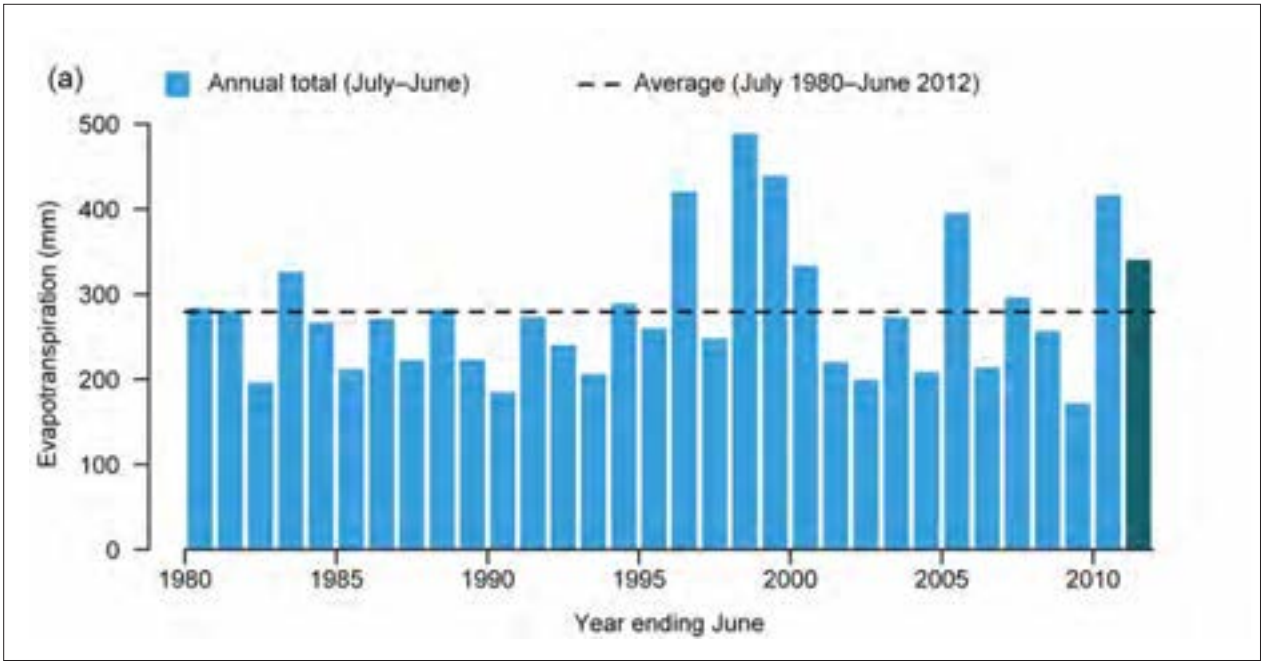


Figure 11.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Pilbara–Gascoyne region

Evapotranspiration variability in the recent past

Figure 11.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 279 mm, varying from 172 mm (2009–10) to 489 mm (1998–99). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 11.17b.

The summer period showed a sudden increase in evapotranspiration since 1996, following a similar trend in rainfall (Figure 11.14b). Due to the higher water availability in the summer period, evapotranspiration was higher than the winter period evapotranspiration on a five-year average basis.



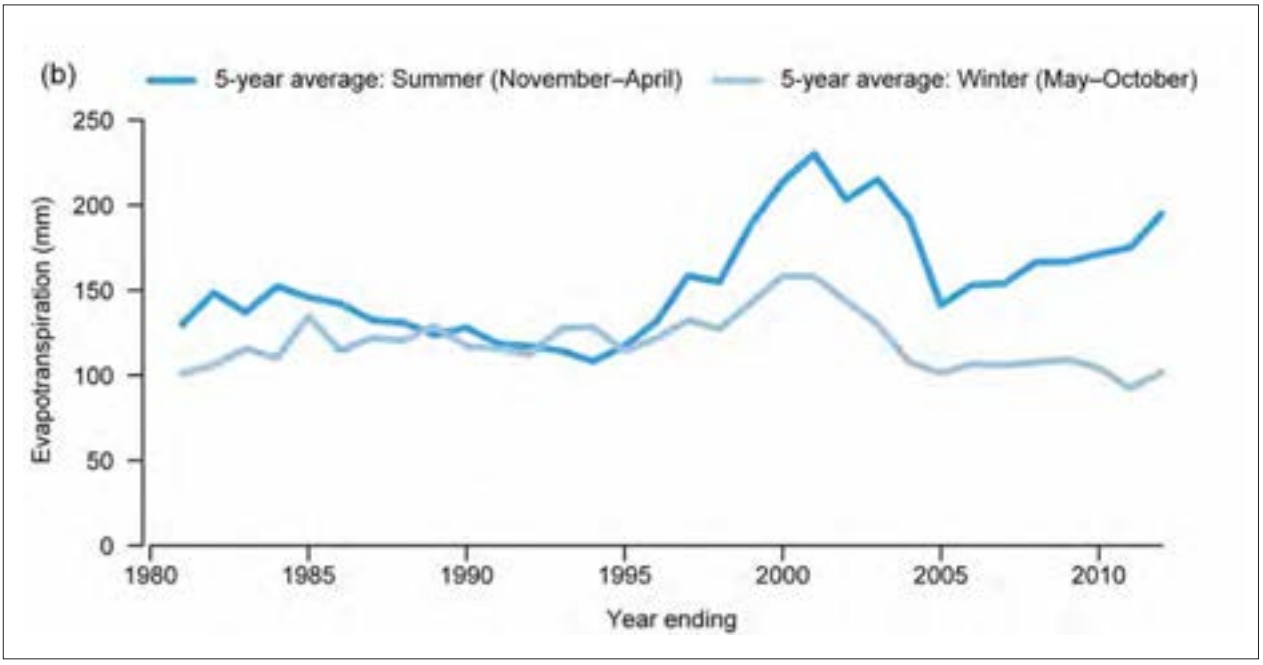


Figure 11.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Pilbara–Gascoyne region

Recent trends in evapotranspiration

Figure 11.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 11.18b.

Figure 11.18a shows that trends in evapotranspiration are almost identical to those of rainfall (Figure 11.15a).

As shown in Figure 11.18b, the trends are generally only statistically significant in some inland parts of the region as well as around Karratha and Dampier on the north coast; however, the total area indicated as having a strongly significant trend of rising evapotranspiration covers only 6% of the region.

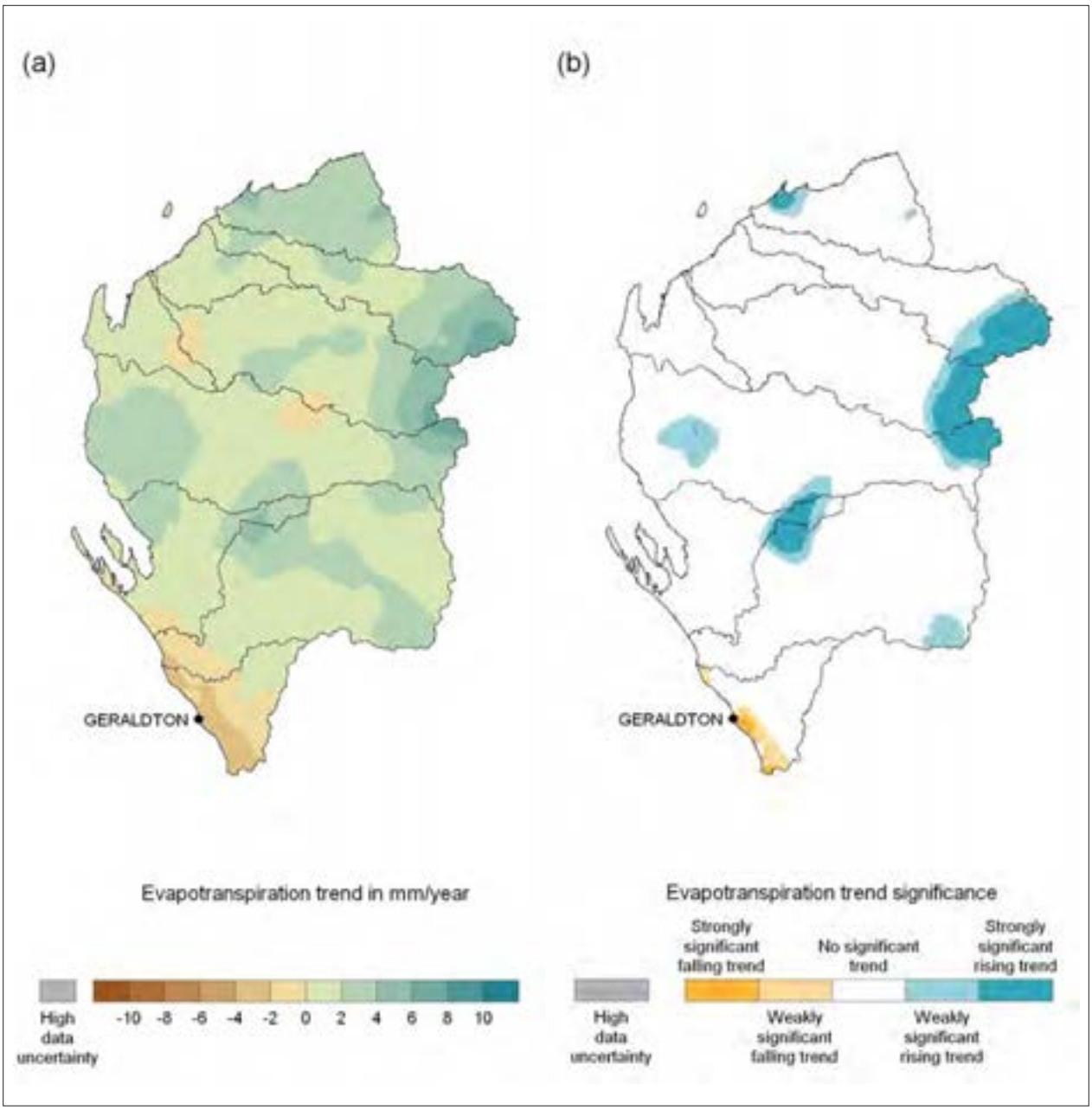


Figure 11.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Pilbara–Gascoyne region

11.4.3 Landscape water yield

Modelled landscape water yield for the Pilbara–Gascoyne region for 2011–12 is estimated to be 19 mm. This is 73% above the region's long-term (July 1911–June 2012) average of 11 mm. Figure 11.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 11.13a, note the difference in the scale of the two figures).

The highest landscape water yields in 2011–12 are observed in the northeast of the region where tropical cyclone *Heidi* made landfall in January 2012.

The decile-ranking map for 2011–12 (Figure 11.19b) shows average to above average landscape water yields. Very much above average water yields are found across much of the Gascoyne area. Below average landscape water yields are found only in some areas around Exmouth in the northwest and Geraldton in the south.

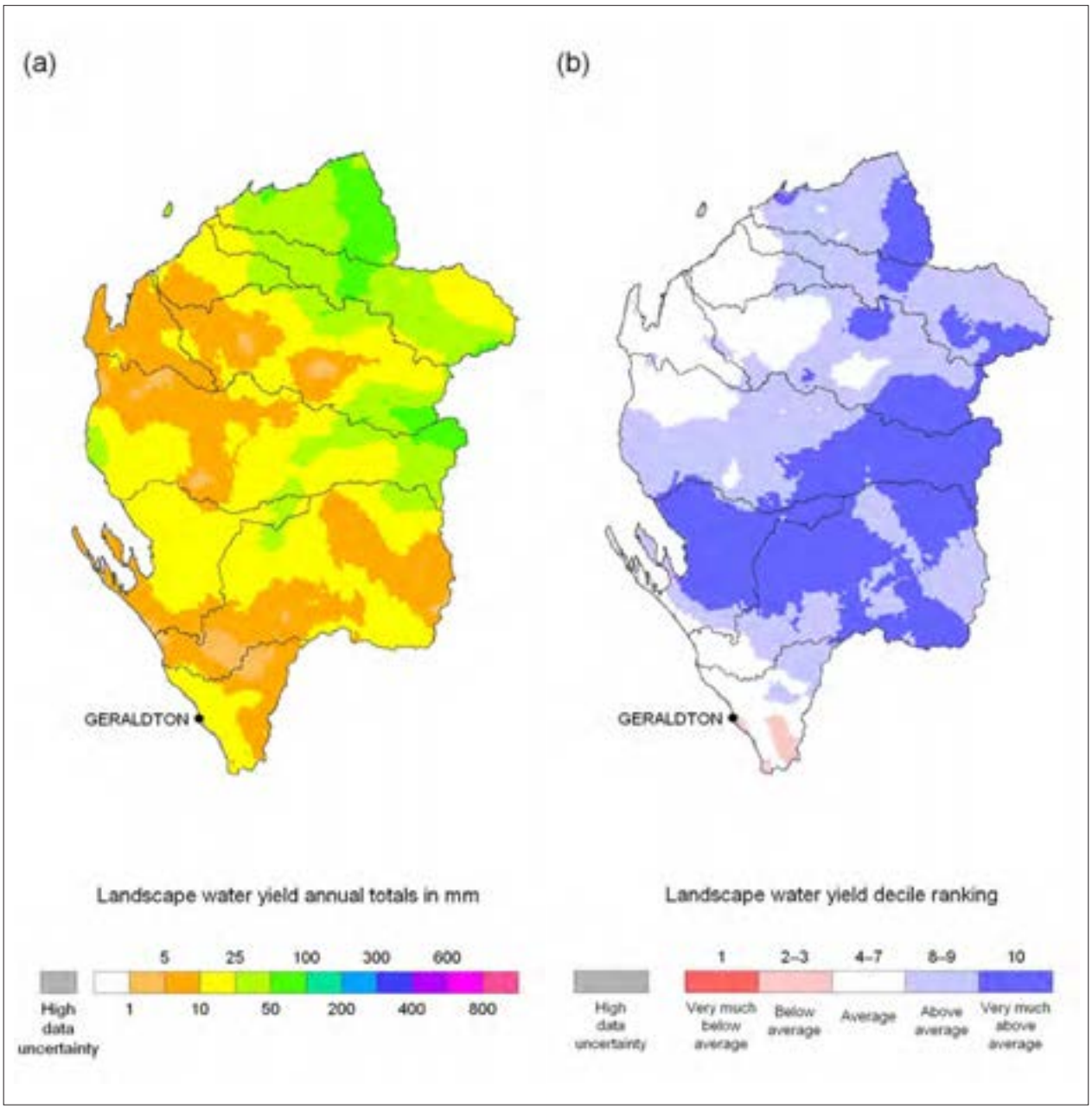
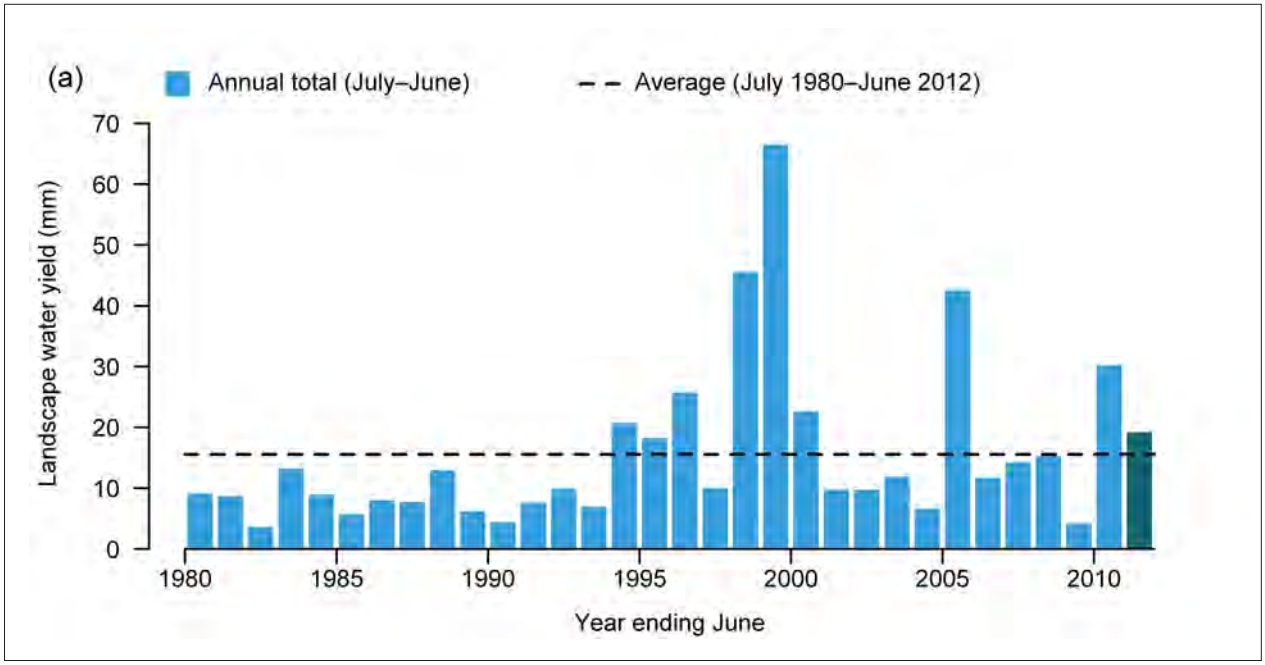


Figure 11.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Pilbara–Gascoyne region

Landscape water yield variability in the recent past

Figure 11.20a shows annual landscape water yield for the Pilbara–Gascoyne region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 16 mm, varying from 4 mm (1982–83) to 67 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 11.20b.

The sudden increase in rainfall in the summer period since 1997 has had a major impact on landscape water yield for the region. Landscape water yield increased fivefold for the five-year retrospective moving average for the years 2000–2004 , and remained significantly higher for the rest of the period.



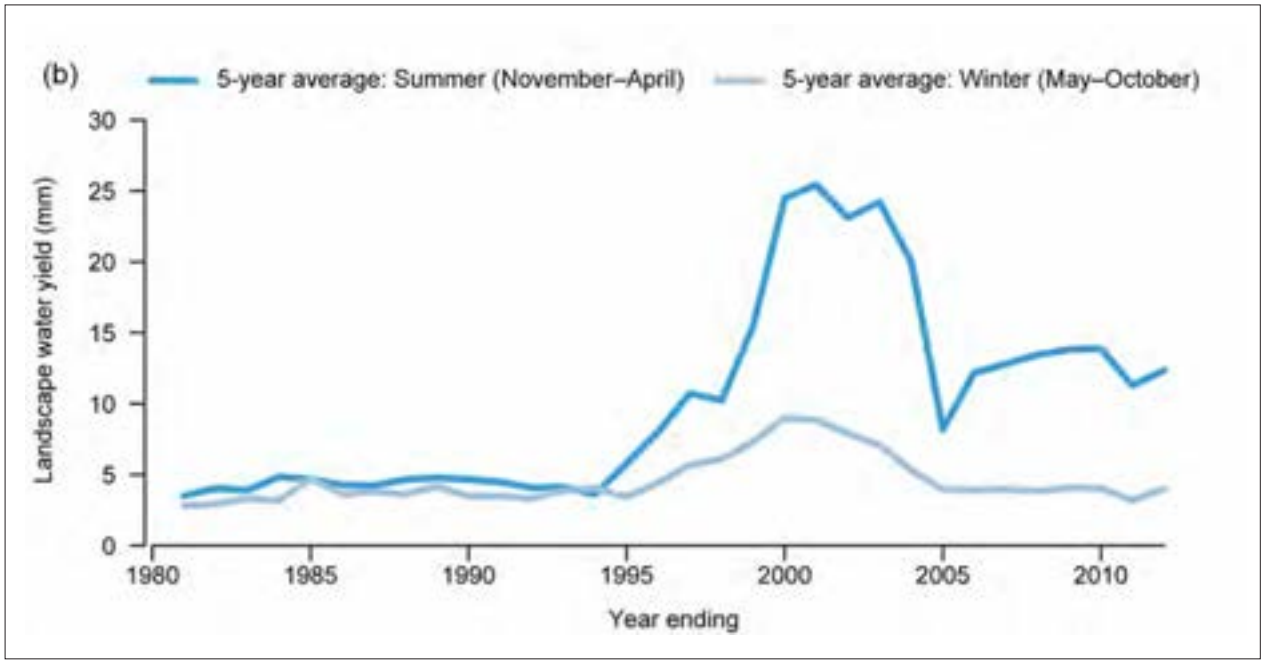


Figure 11.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Pilbara–Gascoyne region

Recent trends in landscape water yield

Figure 11.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 11.21b.

Figure 11.21a shows that since 1980 trends are marginal in comparison to the rainfall trends. This can be expected when applying linear regression to time-series of particularly low annual totals.

However, Figure 11.21b shows strongly significant trends occur over a large area in the centre of the region. The magnitudes of the trends associated with this area are mostly limited to 0.5 mm/year in the east and 1 mm/year in the west. The area with a strongly significant rising trend in the north has a trend of 2 mm/year. The area with a falling trend in the south does not appear to have any statistical significance.

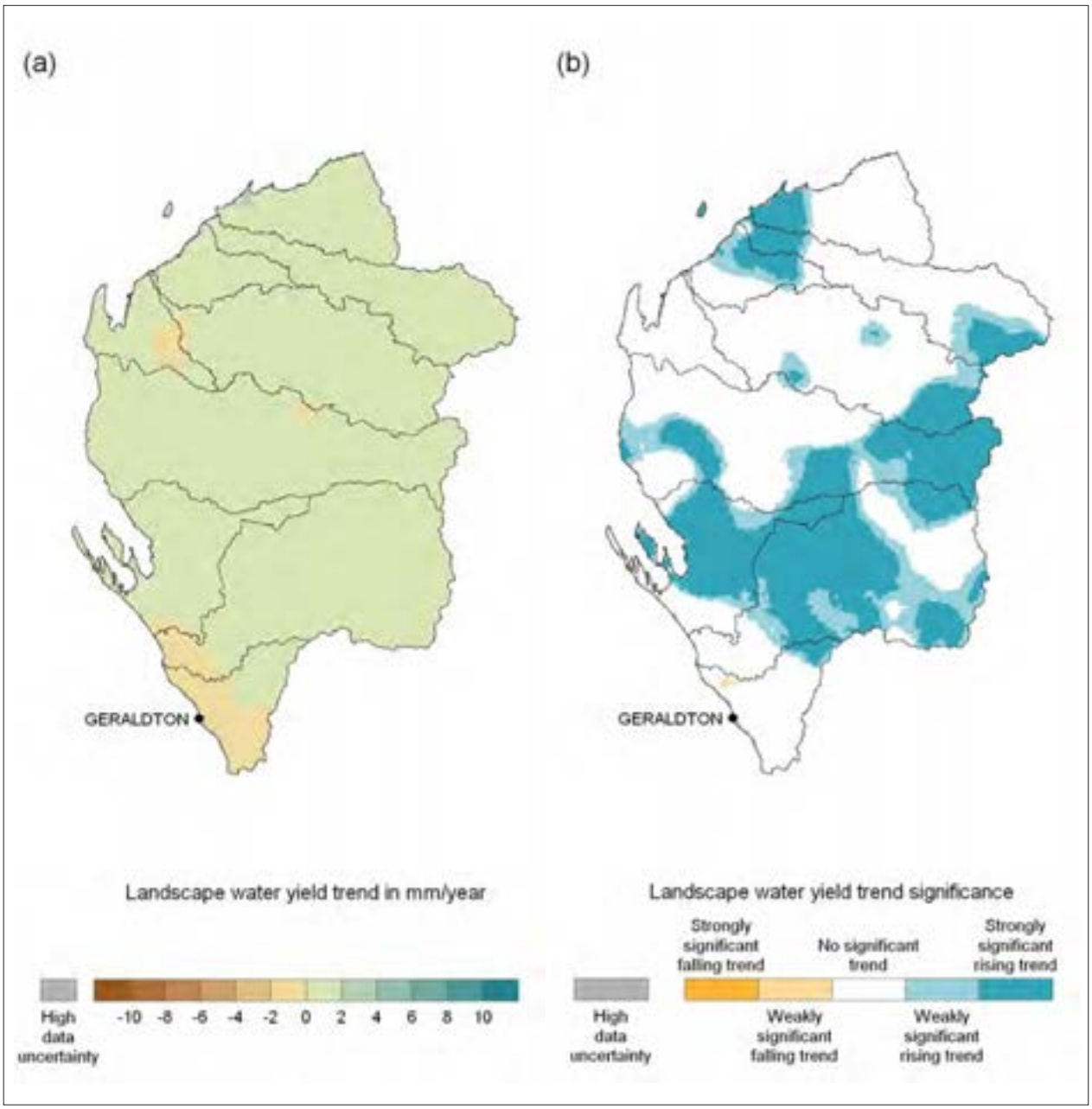


Figure 11.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Pilbara–Gascoyne region

11.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Pilbara–Gascoyne region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

11.5.1 Rivers

There are nine river basins in the Pilbara–Gascoyne region, varying in size from 18,400 to 108,000 km^2. The major basins are the Gascoyne, Murchison and Ashburton river basins (Figure 11.22). The watersheds are a maze of mountains covering almost the entire region from which the rivers flow in all directions.

Rivers are sparse, large, and drain internally or towards the Indian Ocean. They are relatively flat and streamflows tend to quickly recharge alluvial aquifers through the riverbeds. Rivers are all seasonal, flowing only during and after heavy rains. The major rivers generate substantial amounts of flow at high rainfall periods. The Murchison River is about 700 km long, originating in the Robinson Range 450 km from the coast. It merges with the Hope, Roderick and Sandford rivers, which are all seasonal like the Murchison, and flows across the coastal lowlands into the Murchison Gorge.

Analysis of streamflow volumes and salinity was not possible for this region due to unavailability of data.

11.5.2 Flooding

There were no major floods on the gauged rivers in the Pilbara–Gascoyne region during 2011–12 (Figure 11.23). Rainfall was mainly above average in the inland parts of the region due to tropical cyclone *Heidi*, where it did cause some minor flooding.

11.5.3 Storage systems

There is only one major storage located in the Pilbara–Gascoyne region, being Harding. This storage provides industrial and domestic water to the towns of Dampier, Karratha, Wickham, Roebourne, Point Samson and Cape Lambert. The location of this storage is 20 km south of Roebourne on the Harding River. The storage has an accessible capacity of 63 GL.

At the beginning of 2011–12 Harding's storage volume was just short of 100% at 62 GL, but over the year this volume dropped, reaching 36 GL by the end of June 2012. The absence of a large inflow event, as had happened previous years, and the continued use of the water in combination with the normally high evaporation levels, caused this 41% decrease in storage volume.

11.5.4 Wetlands

There are no Ramsar-listed, internationally important wetlands in the Pilbara–Gascoyne region; however, there are a number of wetlands of national importance mentioned in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html). The wetlands vary from coastal floodplains, lakes and tidal flats to inland ephemeral lakes and river floodplain systems (Figure 11.24).

No detailed assessment on the inflows of selected wetlands has been performed for this region.

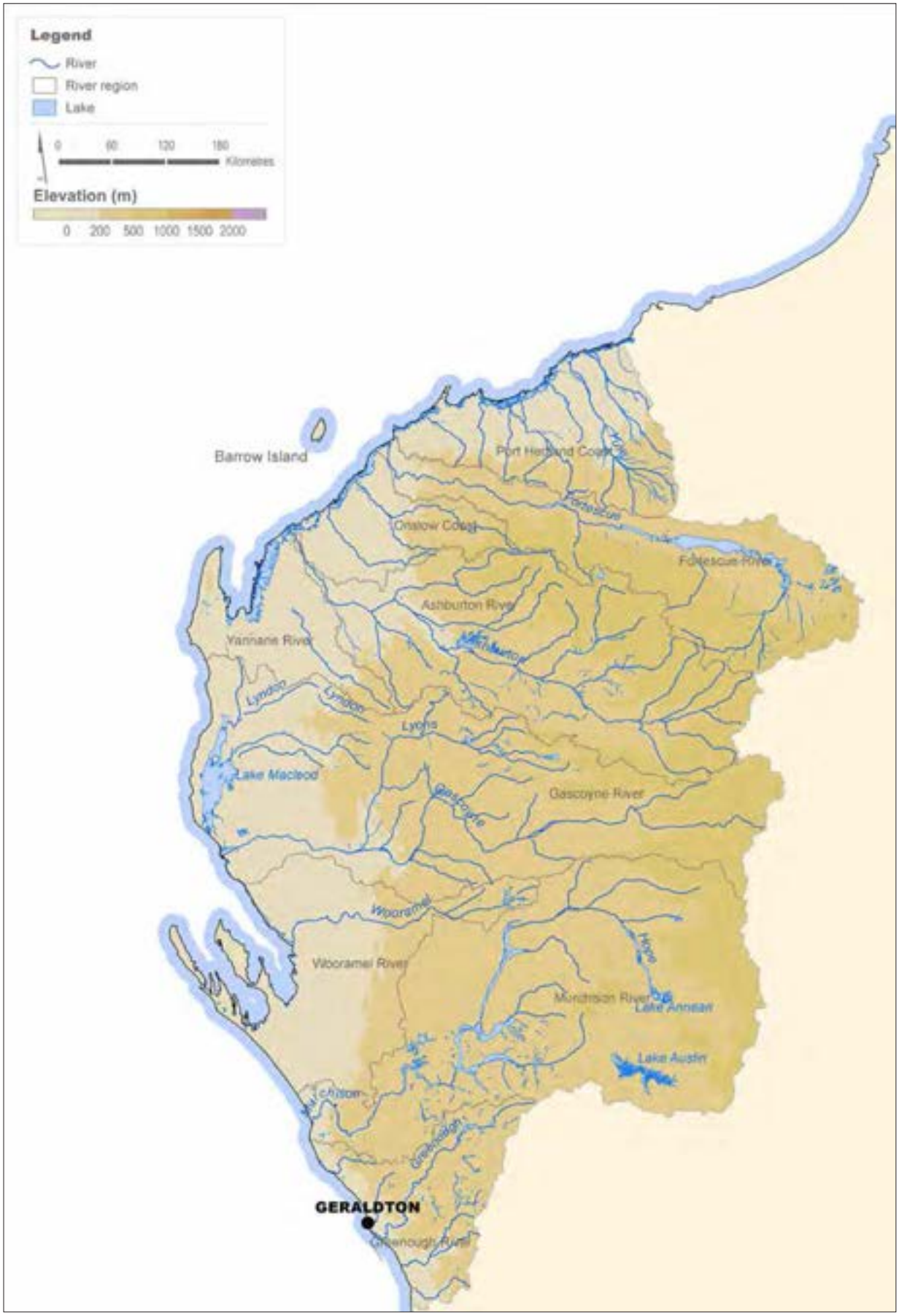


Figure 11.22 Rivers and catchments in the Pilbara–Gascoyne region

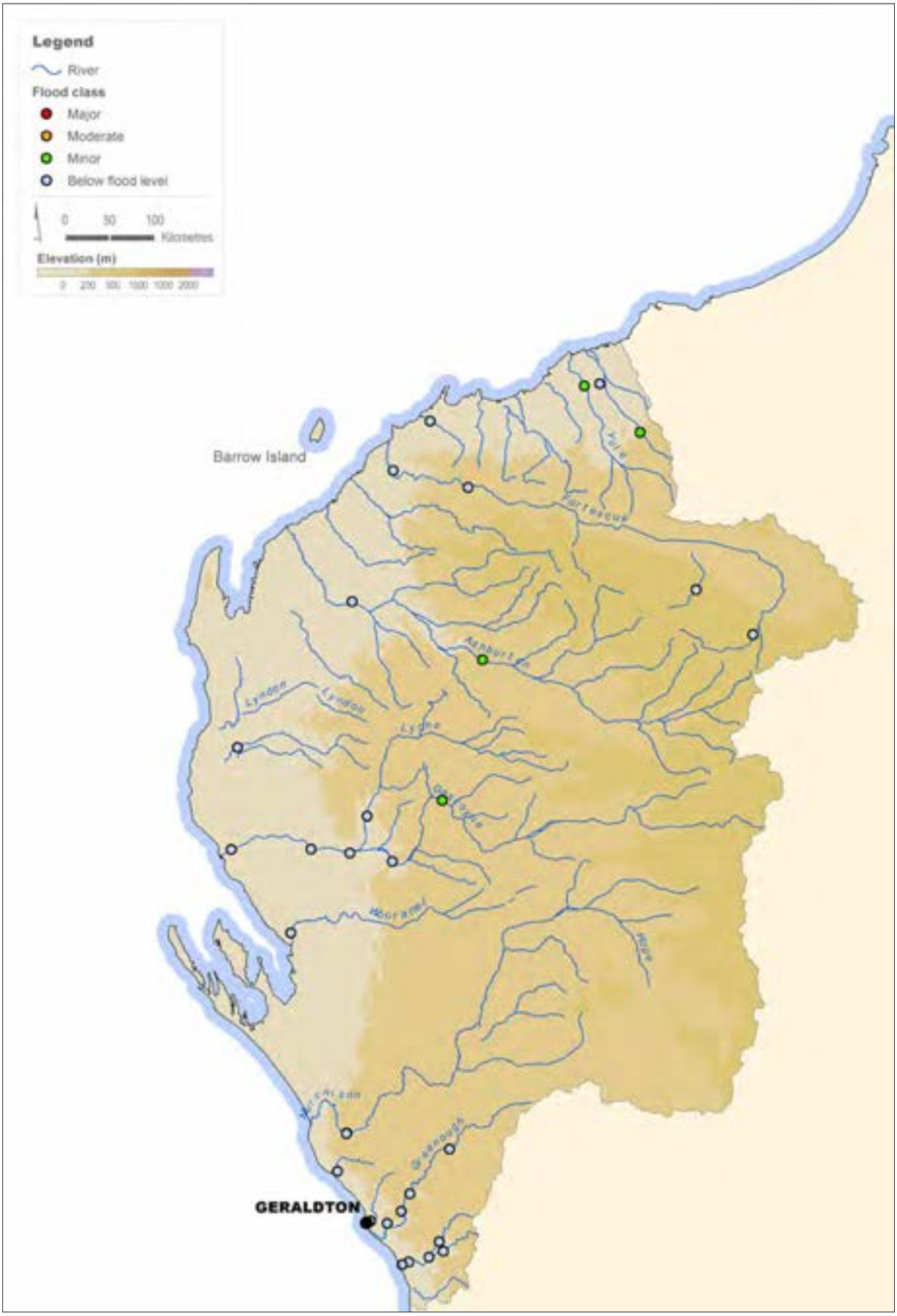


Figure 11.23 Flood occurrence in 2011–12 for the Pilbara–Gascoyne region

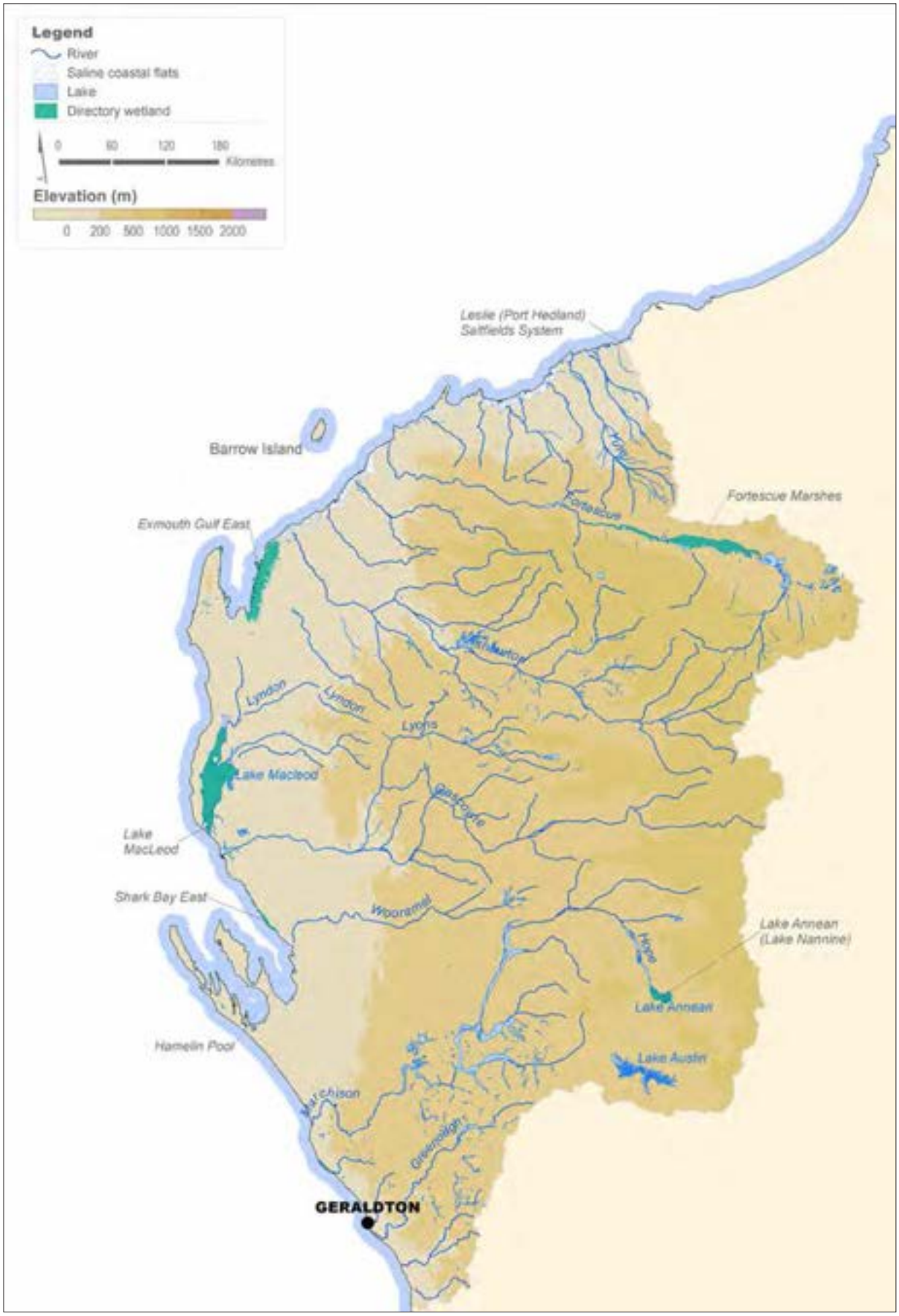


Figure 11.24 Location of important wetlands in the Pilbara–Gascoyne region

11.5.5 Hydrogeology

The watertable aquifers present in the region are given in Figure 11.25. The hydrogeology of the region is dominated by the large area of outcropping Palaeozoic fractured basement rock of low permeability. The main groundwater resources in the region are contained in the Mesozoic fractured rock aquifer which corresponds to the Carnarvon artesian basin and a small part of the Leederville and Yarragadee aquifers beneath the Swan Coastal Plain.

The Carnarvon artesian basin contains the Birdrong sandstone aquifer, Western Australia's most geographically extensive artesian aquifer. Artesian groundwater from the Birdrong has historically been used by the pastoral industry but is under increasing demand from new development proposals. While the resources of the Birdrong aquifer are significant, recharge is limited.

11.5.6 Water table salinity

Figure 11.26 shows the classification of the groundwater in the watertable aquifer as fresh (total dissolved solids (TDS) < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L). As shown in the figure, the Palaeozoic fractured basement is shown to have fresh water, while the Mesozoic fractured rock aquifer which corresponds to the Carnarvon artesian basin along the coastal region is identified as having mainly saline groundwater water.

However, the Carnarvon artesian basin contains six overlapping main hydrogeological formations with the principal aquifer being the Birdrong, a portion of which contains significant fresh groundwater resources.

11.5.7 Groundwater management units

The groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 11.27 shows that major groundwater management units within the region include Gascoyne, East Murchison and Pilbara. Of these only Gascoyne and Carnarvon are proclaimed.

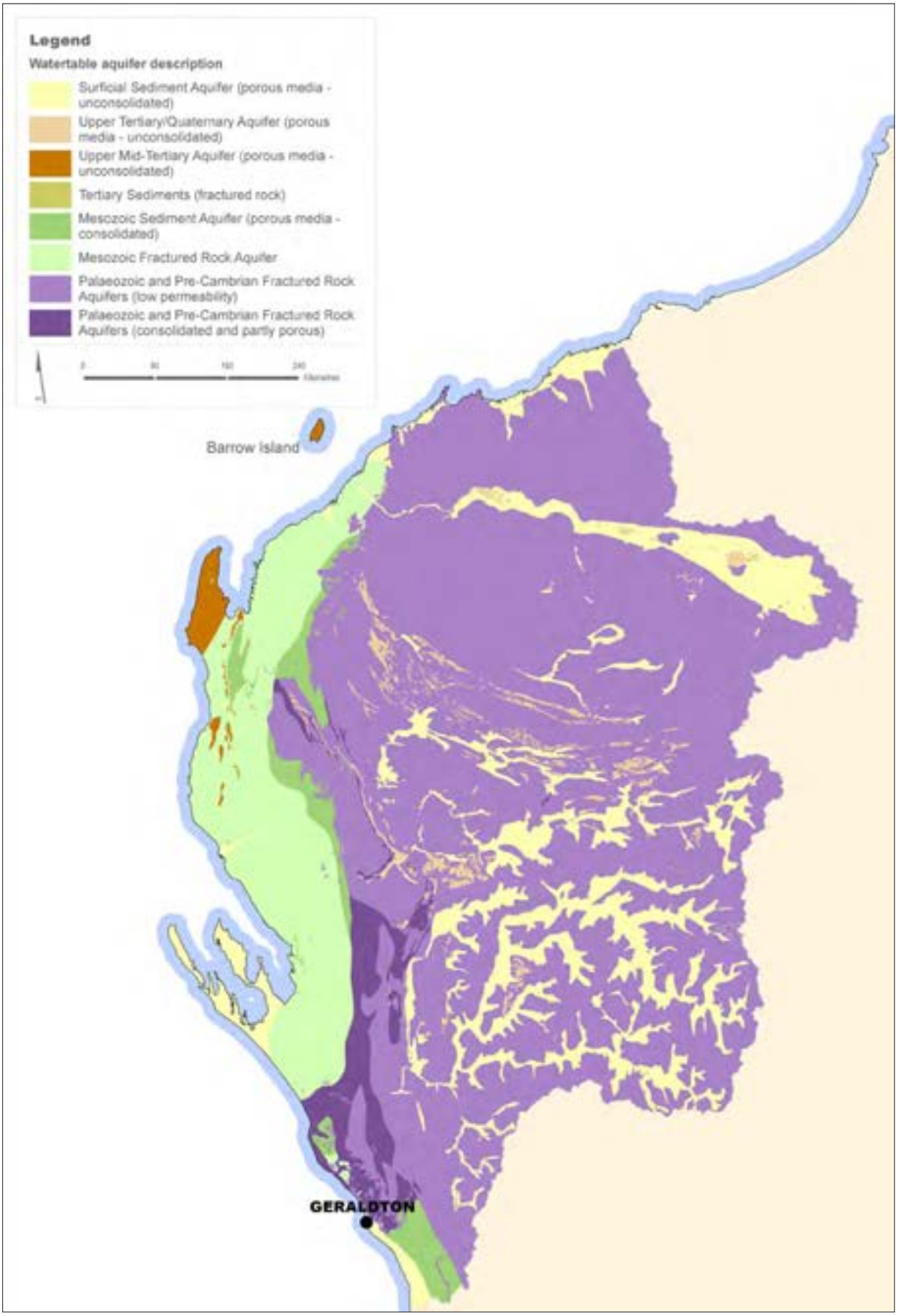


Figure 11.25 Watertable aquifers of the Pilbara–Gascoyne region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 11.26 Water table salinity classes of the Pilbara–Gascoyne region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 11.27 Groundwater management units in the Pilbara–Gascoyne region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

11.6 Water for cities and towns

This section examines the urban water situation in the Pilbara–Gascoyne region in 2011–12. The large urban centres in the region, their water supply systems and storage situations are briefly described. The main townships, Geraldton, Karratha and Port Hedland, are addressed in brief. A breakdown is provided for water obtained for and delivered to Geraldton, which is the largest town in the region.

11.6.1 Urban centres

Geraldton, Karratha and Port Hedland are the three major urban centres in the Pilbara–Gascoyne region with a combined population of more than 60,000 people. Figure 11.28 shows the population range for the region.

Geraldton is the largest centre with a population of about 31,500 people. Geraldton is a port in the mid-west area of Western Australia, located about 425 km north of Perth. The town is an important service centre for regional mining, fishing, wheat, sheep and tourism industries.

Karratha is the second largest urban centre in the region with a population of just under 16,500 people and adjoins the port of Dampier. It was developed in the late 1960s to accommodate the processing and exportation workload of the Hamersley Iron mining company. Further development of the town occurred in the 1980s to support the petroleum and liquefied natural gas operations of the North West Shelf Venture.

Port Hedland is the third major town, with a population of just under 14,000, including the satellite town of South Hedland. Port Hedland is a natural deep anchorage port which, as well as being the main fuel and container receival point for the region, serves for shipment of the iron ore being mined in the ranges located inland from the town. Other major resource activities supported include the offshore natural gas fields, salt, manganese, and livestock.

11.6.2 Sources of water supply

The Water Corporation of Western Australia manages the urban water supply in the Pilbara–Gascoyne region for all the major urban centres.

Domestic water supplied to Geraldton is sourced from groundwater. The aquifer that supplies Geraldton forms part of the Yarragadee formation, a vast store of groundwater that stretches from Allanooka, just south of Geraldton in the north, to Augusta in the south. Since 1967, Geraldton has been supplied from the Allanooka and Mt Hill borefields situated 55 km southeast of Geraldton. There are 19 production bores of various capacities supplying Geraldton, 13 of these being in the Allanooka borefield with the remainder at Mt Hill. The bores are between 50 and 150 metres deep. Mt Hill bores are only used to help meet summer peak demand.

The major source of water for Karratha is groundwater from the Millstream wellfield, located approximately 100 km south of Karratha. This wellfield is a reliable source of water, augmented by storage water from Harding. These two sources of water are used by the Water Corporation to supply water to the West Pilbara water supply scheme. This scheme supplies water to Karratha, Dampier, Roebourne, Wickham, Point Samson, Cape Lambert and the Burrup Peninsula.

Port Hedland and South Hedland are supplied with drinking water via the East Pilbara Water Supply Scheme. The system has two independent groundwater sources, the Yule River and the De Grey River borefields. The licensed allocation from the sources is 13.5 GL per year. While the current demand on the scheme is less than the licensed allocation, commitments to industry and domestic growth will fully utilise the capacity of the scheme when they are taken up.

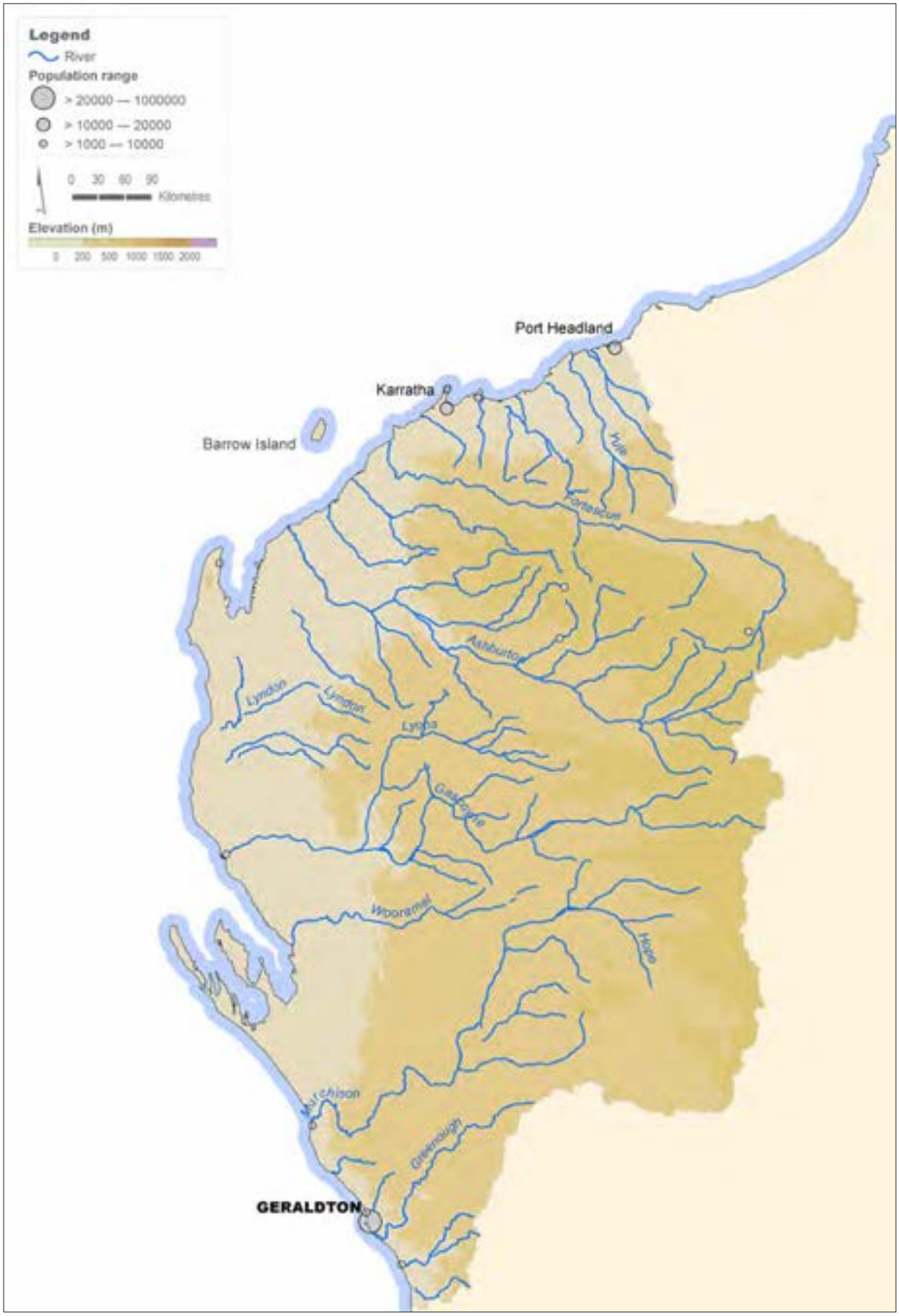


Figure 11.28 Population range of major urban centres in the Pilbara–Gascoyne

11.6.3 Geraldton

Sources of water obtained

Figure 11.29 illustrates the different sources of water for Geraldton from 2006–07 to 2011–12. Data were obtained from the National Performance Report for 2011–12 (National Water Commission 2013). On average about 97% of water is sourced from groundwater. The use of recycled water is limited to less than 3%.

The use of groundwater ranged from about 9.4–7.8 GL between 2006–07 and 2011–12. Due to water restrictions being in place, there was less water used in 2011–12 compared to 2006–07 which may be due to increased community awareness of the need to conserve water.

Recycled water use ranged between 290 and 220 ML in 2006–07 to 2011–12. Figure 11.29 reveals a decreasing trend of water use.

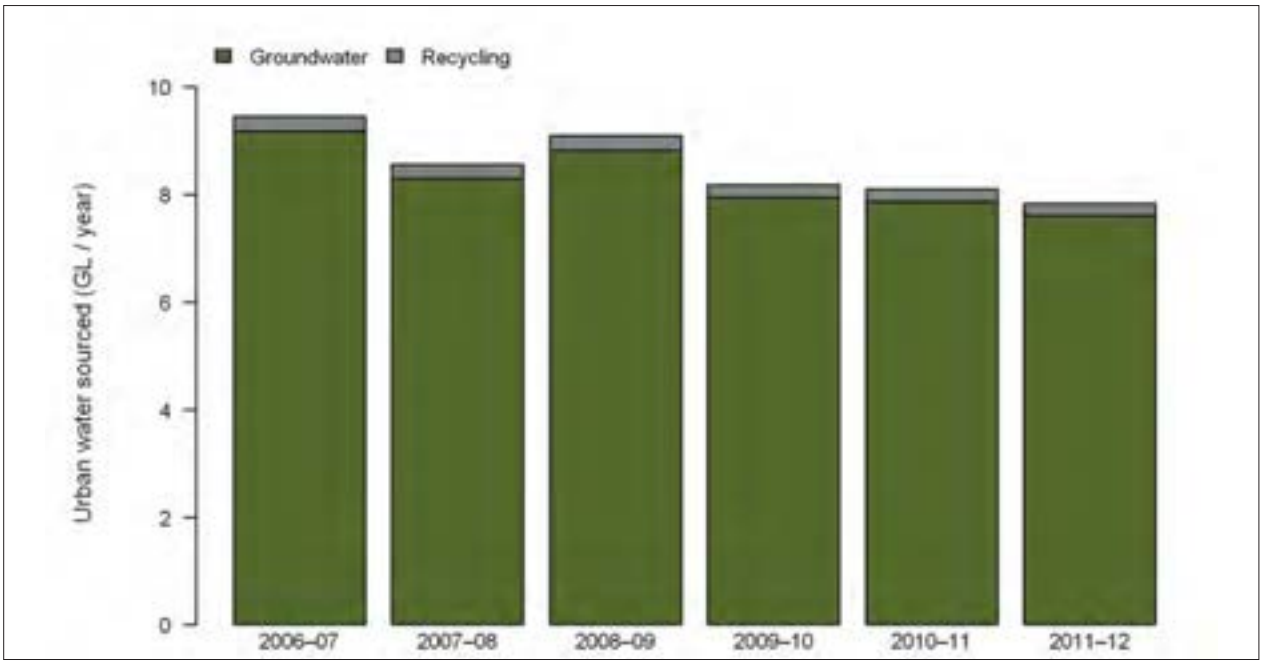


Figure 11.29 Total urban water sourced for Geraldton from 2006–07 to 2011–12

Categories of water delivered

Figure 11.30 shows the total volume of water delivered to residential, commercial, municipal and industrial consumers in Geraldton (National Water Commission 2013) from 2006–07 to 2011–12. Between 62% and 72% of the water was supplied for residential use and between 23% and 30% was for commercial, municipal and industrial use. The total water use decreased slowly from 8.2 GL to 7.8 GL between 2006–07 and 2011–12 largely as a result of water restrictions. The water used for other purposes also decreased from 1.25 GL to 0.8 GL from 2009–10 to 2011–12.

Based on the data from the National Performance Reports (National Water Commission 2013), the average residential water supplied to each property was estimated to be 387 kL from 2006–07 to 2011–12. The maximum residential water use per property was 457 kL in 2006–07 and the minimum was 343 kL in 2011–12.

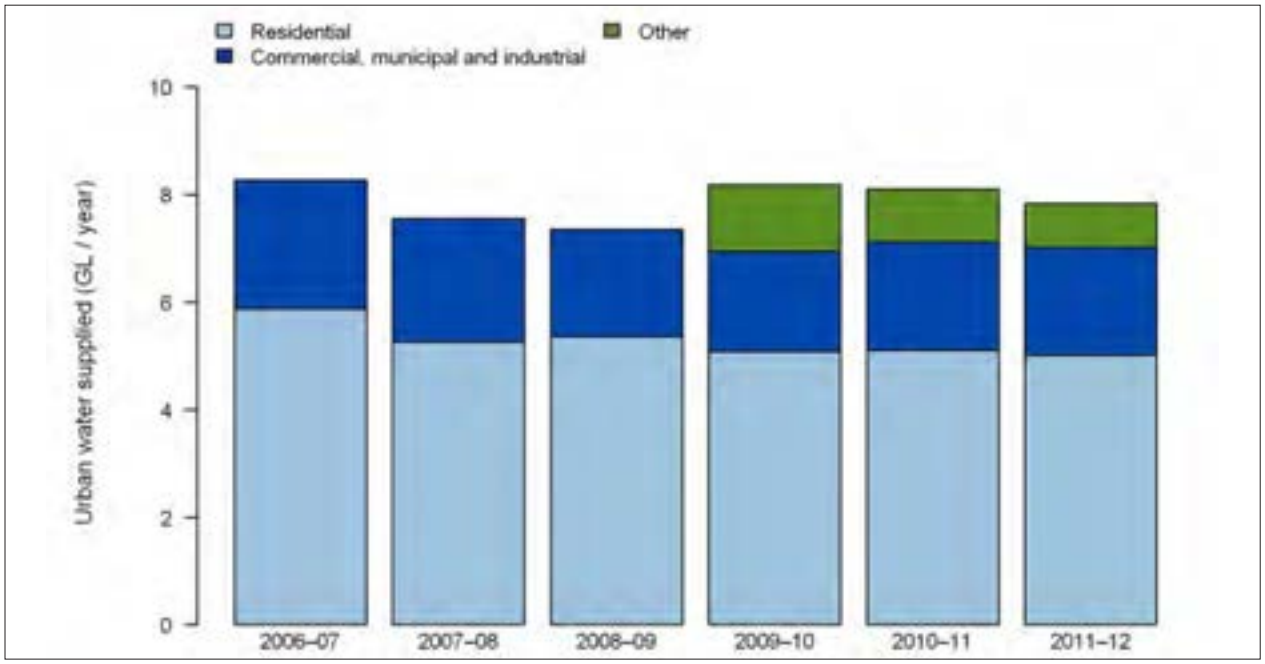


Figure 11.30 Total urban water supplied to Geraldton from 2006–07 to 2011–12

North Western Plateau

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12 North Western Plateau

12.1 Introduction

This chapter examines water resources in the North Western Plateau region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources to finish the chapter. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

12.2 Key information

Table 12.1 gives an overview of the key components of the data and information in this chapter.

Table 12.1 Key information on landscape water flows, floods and groundwater quality in the North Western Plateau region

Landscape water flows			
	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	319 mm	+65%	10th—very much above average
Evapo-transpiration	291 mm	+61%	10th—very much above average
Landscape water yield	26 mm	+136%	10th—very much above average
Streamflow (at selected gauges)			
	Flooding:	Major flooding in the De Grey River basin	
Groundwater (in selected aquifers)			
	Salinity:	Scattered areas of saline groundwater (≥3000 mg/L) mainly surrounding (dry) riverbeds and lakes	

12.3 Description of the region

The North Western Plateau region is located in northwest Australia and includes major parts of the Great Sandy and Gibson deserts. The region covers 716,000 km² of land area and only has some limited surface water resources present in the northern and eastern parts of the region (see Figure 12.1).

The coastline consists of tide-dominated plains and tidal creeks. Dry lakes are scattered across the region, but aeolian landforms including dunes and sand plains dominate the landscape. Subsections 12.3.1–12.3.4 provide more information on the physical characteristics of the region.

With a population of 13,100 people, the North Western Plateau is home to less than 0.1% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b).

Figure 12.1 shows the only major town of the region, Marble Bar. Subsection 12.3.6 provides some additional information on the population and distribution across the region.

The area is important for mineral resources and there are several mining operations in the region.

Most of the region is in a relatively natural state and 77% is associated with nature conservation.

A further 22% of the region is used for grazing, particularly along the western and northern boundaries (Figure 12.1). Irrigated agriculture and urban areas account for less than 0.01% of the region's area.

The climate is arid and is affected by erratic monsoonal rainfall, particularly in the north. Subsections 12.3.7 and 12.3.8 provide more information on the rainfall patterns and deficits across the region.

All the rivers in the region are ephemeral and only flow after a heavy rainfall.

The hydrogeology is dominated by a large area of outcropping fractured basement rock in the west and east of the region. The associated groundwater systems typically offer limited low volume water resources. Other important hydrogeological groups are the Mesozoic sediments through the centre of the region and the surficial sediments in-filling paleovalleys. These groups are likely to offer more reliable groundwater resources. Given the irregular nature of surface flows, water is generally supplied by groundwater.

A more detailed description of the rivers and groundwater status in the region is given in subsection 12.5.

Gibson Desert, Western Australia | Airspeed (iStockphoto)

Figure 12.1 Major rivers and urban centres in the North Western Plateau region

12.3.1 Physiographic characteristics

The physiographic map in Figure 12.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes, and have distinct physical characteristics that can influence hydrological processes.

The North Western Plateau region is dominated by the Sandland physiographic province which occupies 73% of its area. This province comprises mainly east-west longitudinal dunes with minor salt lakes. There are some sandy or stony ferruginous plains and low sandstone hills. The remaining five provinces occur along the region's southwest and northeast borders.

These provinces are:

- Pilbara (14%): largely dissected flat-topped hills of granitic, volcanic and metamorphic rocks interspersed by stony plains on granite;
- Barkly–Tanami Plains (7%): mainly sand plains with scattered low ranges and tablelands with occasional granite and sedimentary hills;
- Yilgarn Plateau (3.5%): sand, gravel and hardpan-wash plains with salt lakes, broken by ridges of metamorphic rocks and granite and mesas;
- Central Australian Ranges (2%): dunefields and sandplains with sandstone, granitic and volcanic ranges, salt lakes and calcrete plains; and
- Kimberley (0.5%): scattered tablelands, ranges of sedimentary rocks and plains with east-west longitudinal dunes.

Figure 12.2 Physiographic provinces of the North Western Plateau region

12.3.2 Elevation

As presented in Figure 12.3, aeolian landforms, including dunes and sand plains, dominate the landscape of the North Western Plateau. The region has no significant mountain ranges within its border. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).

The southwest of the region has some higher altitudes with plateaus exceeding 600 m in altitude.

The region has some of the largest paleodrainage systems in Australia. They currently incorporate a number of aligned lakes. The topography clearly depicts the valleys these rivers have formed in the past.

Apart from the De Grey River in the far west, the region has no surface water flow to the Indian Ocean. Under heavy rainfall, the many closed river basins fill up the lakes that have formed over time; however, rainfall is very unreliable and lakes are normally dry.

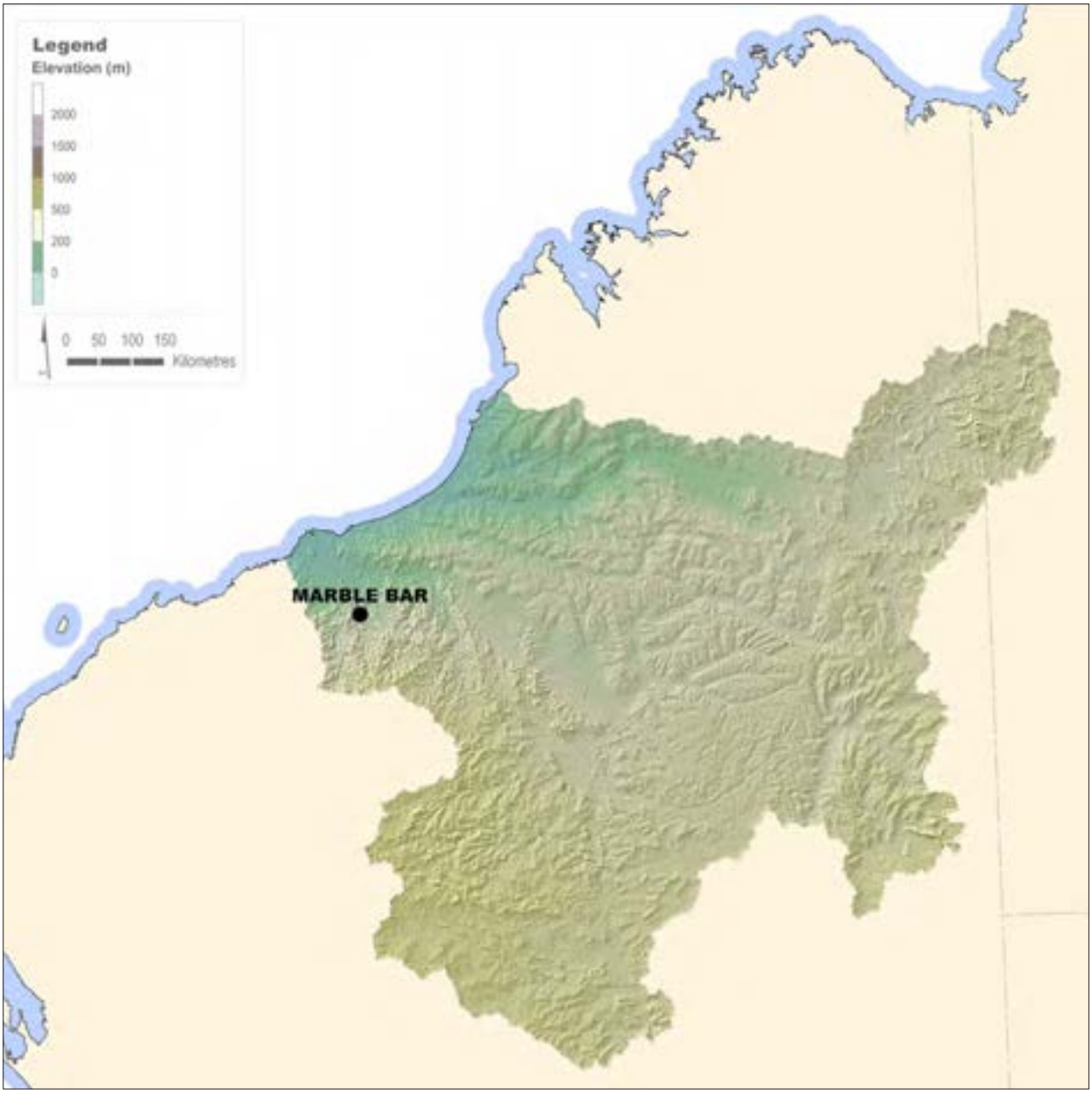


Figure 12.3 Ground surface elevations in the North Western Plateau region

12.3.3 Slopes

Areas with steep slopes provide higher runoff generating potential than flat areas which are more favourable for vertical infiltration. The North Western Plateau region has generally a flat topography, without any distinct slopes (Table 12.2 and Figure 12.4).

Table 12 2. Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	50.6	31.7	16.9	0.8

The slightly steeper slopes particularly around Marble Bar in the west provide some gradient for streamflow to be generated (Figure 12.4). These headland streams occasionally reach the De Grey River, which flows into the Indian Ocean. The slopes were derived from the elevation information used in the previous section.

The absence of slopes and reliable rainfall makes this region highly receptive for aeolian influences. Former hills have been levelled out by wind erosion and plains are vast and covered with sand dunes.

Apart from the northern part, the border of the region is not a natural topographic water divide. Many small and large internally draining river basins exist on both sides of the border of the inland region.

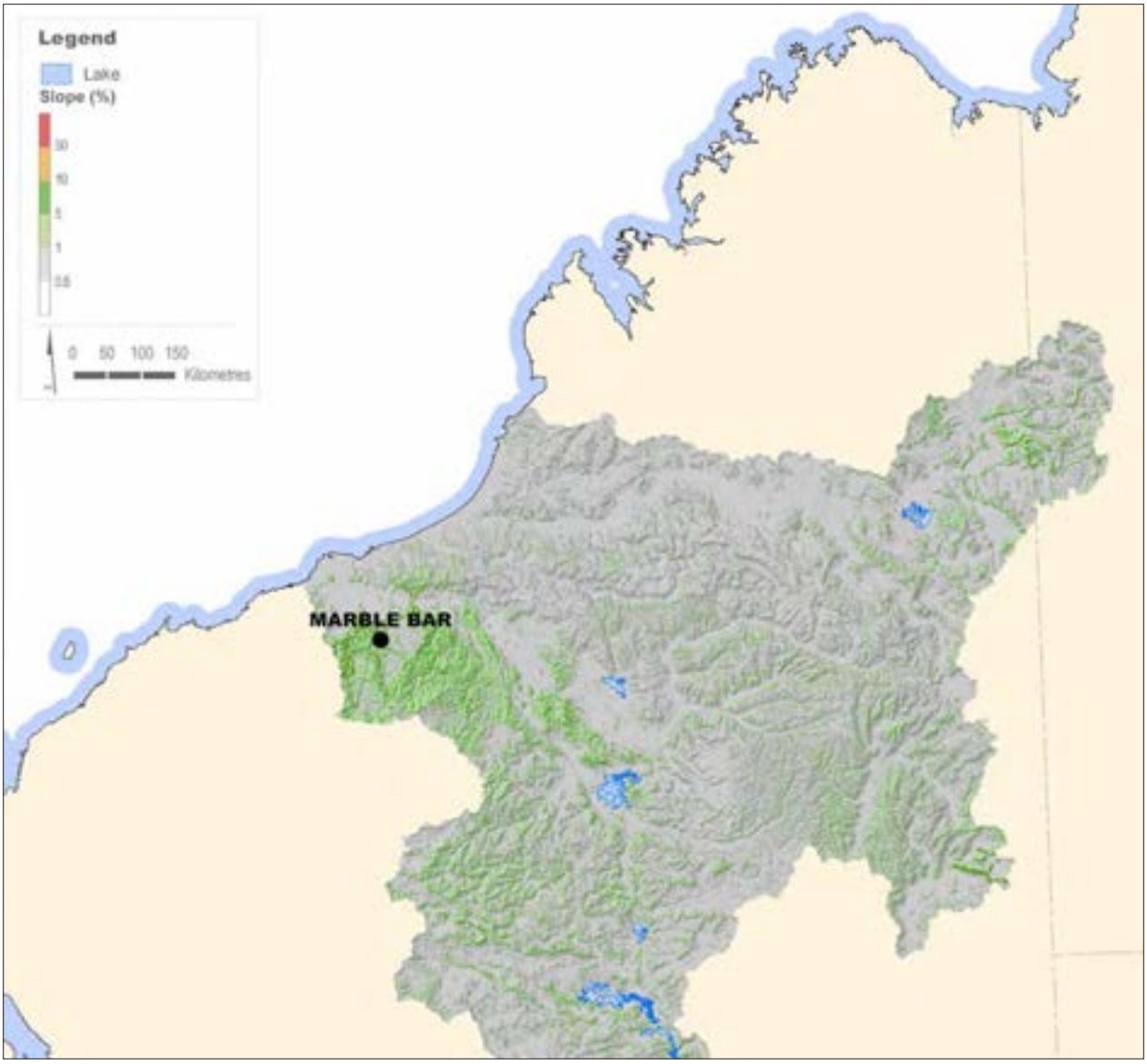


Figure 12.4 Surface slopes in the North Western Plateau region

12.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as runoff or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 90% of the North Western Plateau area is covered by three soil types, namely tenosols, rudosols and kandosols (Figure 12.5 and Figure 12.6).

Tenosols and rudosols are typically sandy, and show little change in texture and colour through the profile and are often shallow in depth. Tenosols and rudosols have low chemical fertility and have a low water-holding capacity, thus their agricultural potential is low. Both soil types are mostly present in areas used for nature conservation rather than agriculture.

Tenosols cover more than 50% of the total area of this region. They are dominant in all parts of the region, except for the northeast to southeast where rudosols are dominant.

Kandosols are structureless soils which are often very deep (up to three metres or more), but they do not have a strongly contrasting texture and they do not contain carbonate throughout their profile. They are low in chemical fertility and are well-drained, with only moderate water-holding capacity compared with other soil types; thus they only have low to moderate agricultural potential. They are mostly used for grazing in this region.

The other soil types that have minimal representation in the North Western Plateau region are sodosols, calcarosols, hydrosols, vertosols and chromosols (0.8–3%).

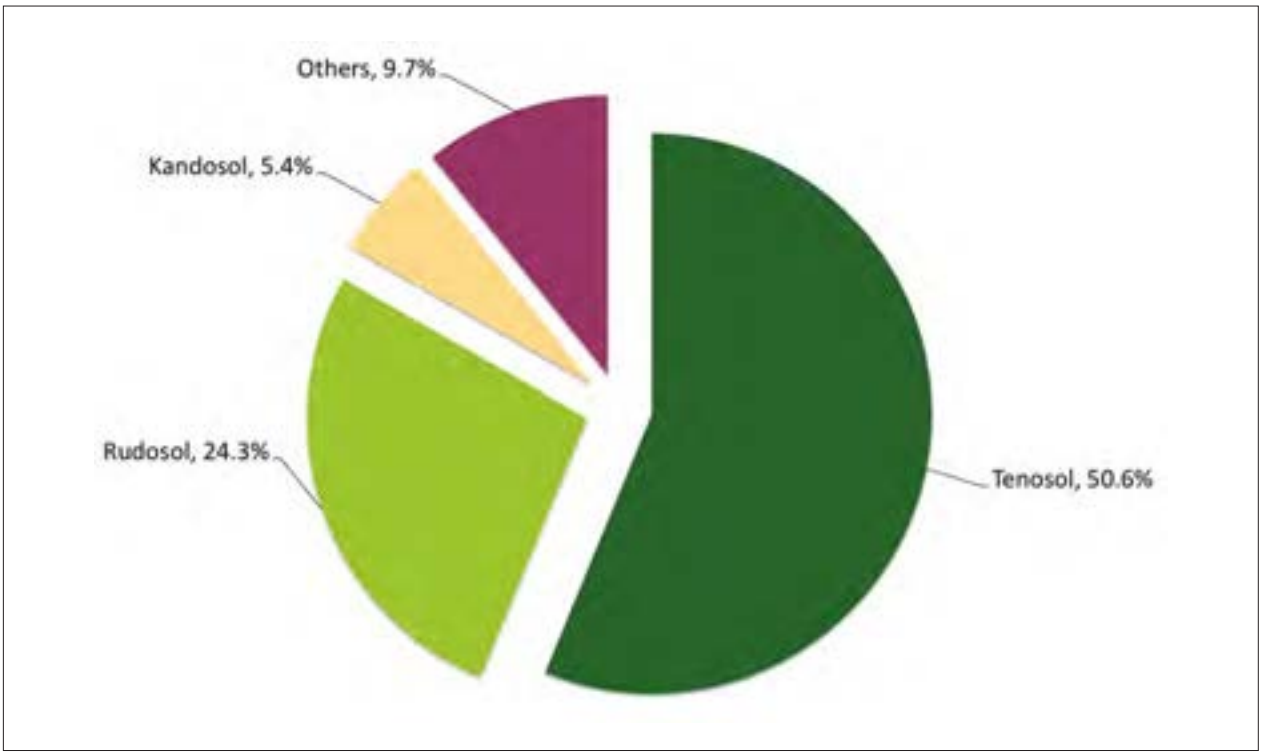


Figure 12.5 Soil types in the North Western Plateau region

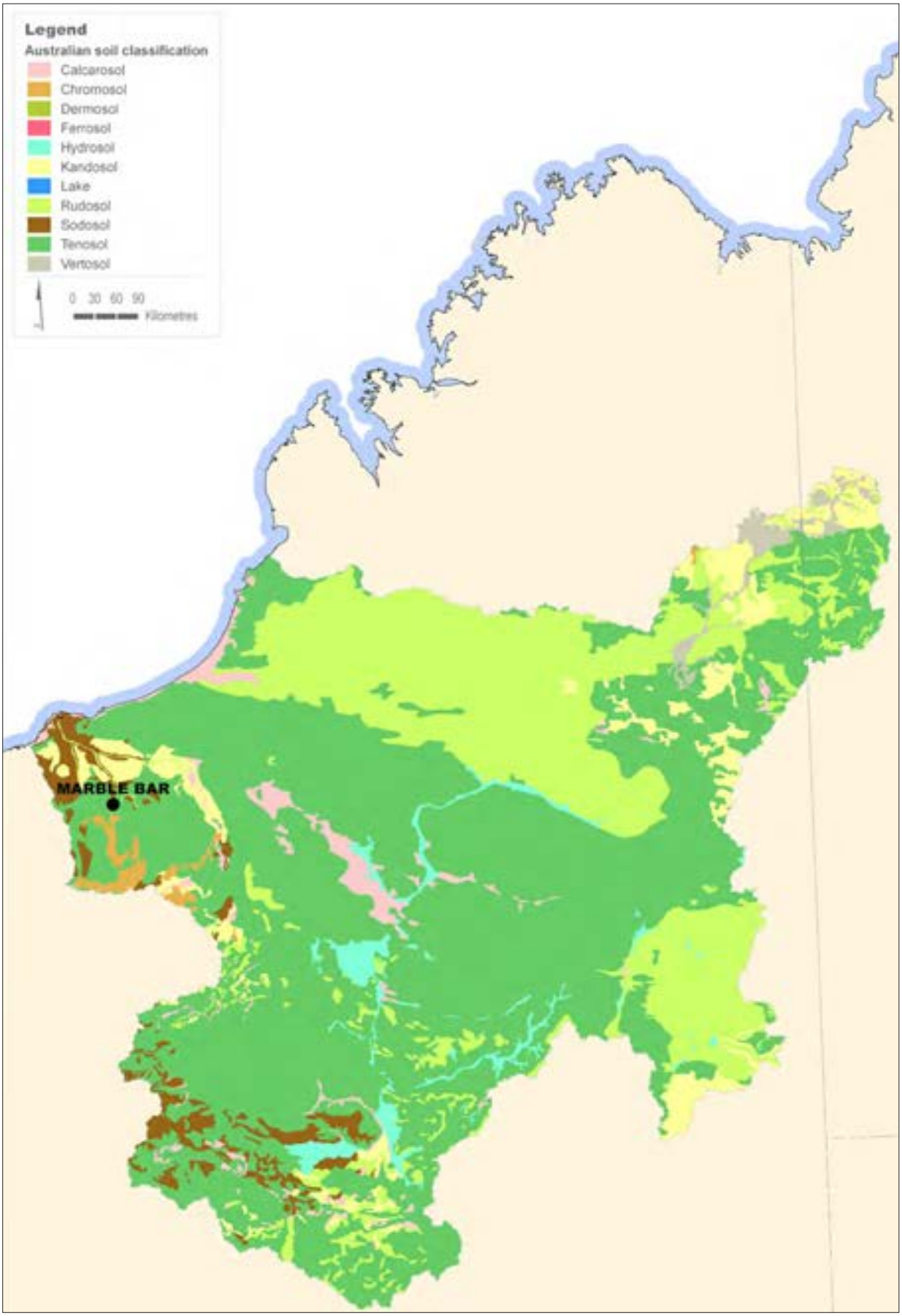


Figure 12.6 Soil type distribution in the North Western Plateau region

12.3.5 Land use

As presented in Figure 12.7 and Figure 12.8, most of the region is in a relatively natural state with 77% associated with nature conservation. A further 22% of the region is used for grazing along the western and northern boundaries. Irrigated agriculture and urban areas account for less than 0.01% of the area (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml).

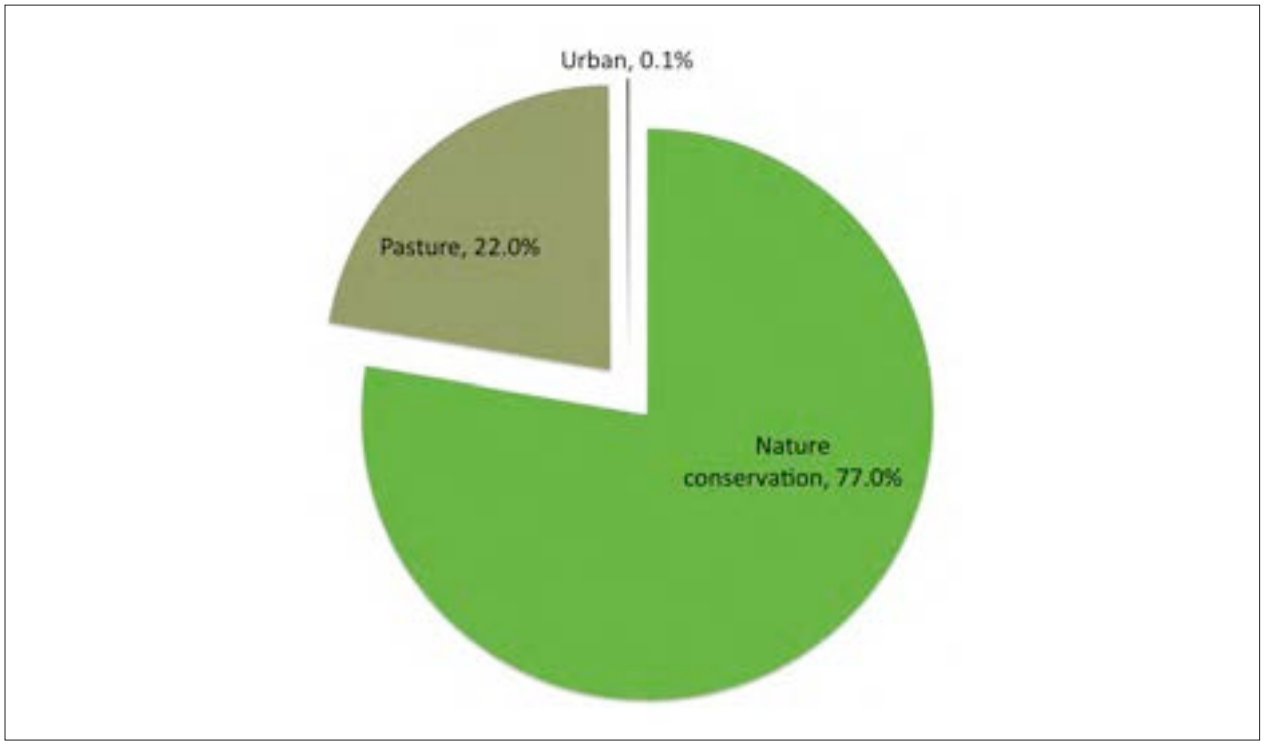


Figure 12.7 Land use in the North Western Plateau region

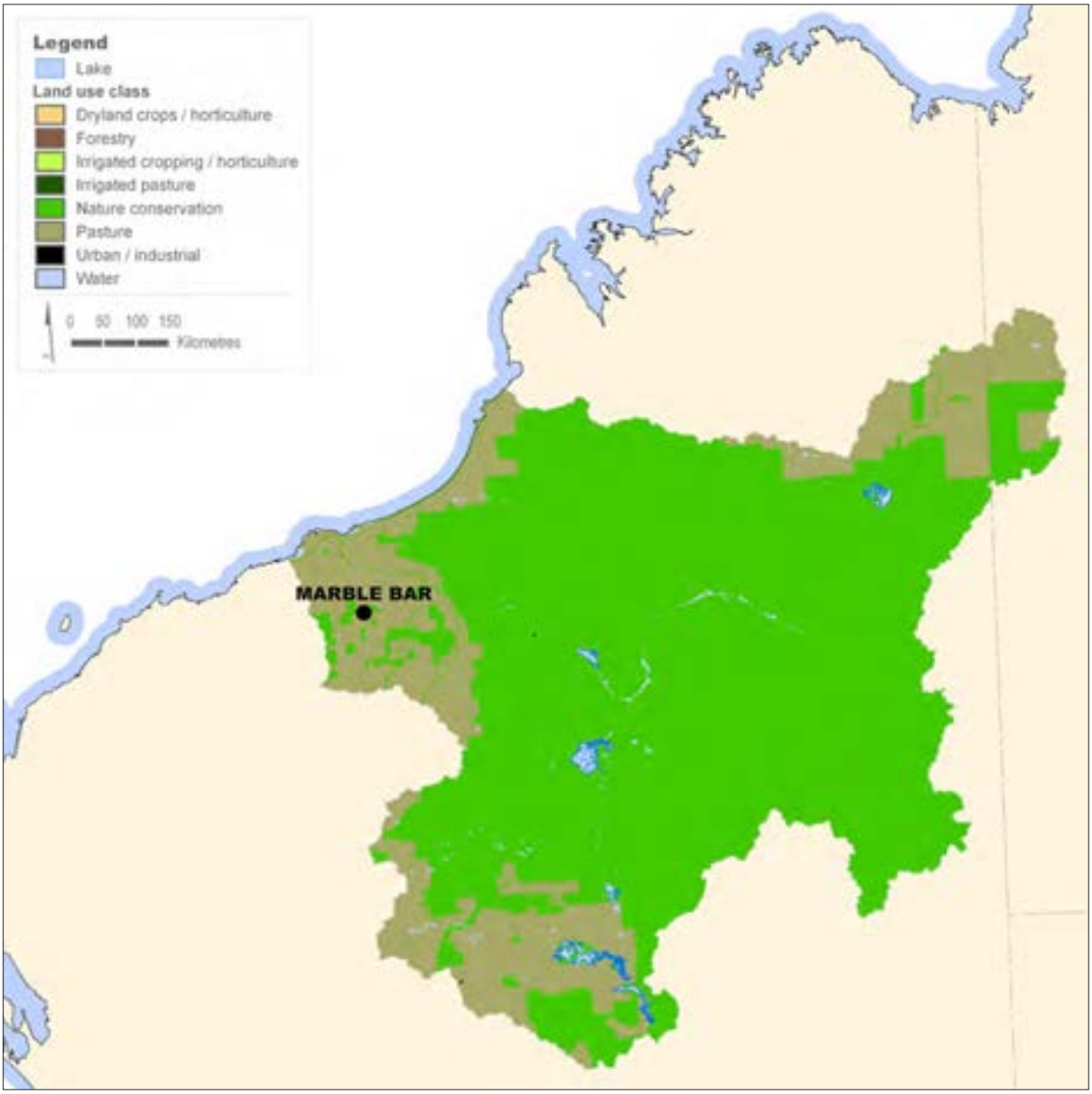


Figure 12.8 Land use distribution in the North Western Plateau region

12.3.6 Population distribution

With a population density in much of the region being zero, the North Western Plateau region is the least populated of the regions. The scarcity of the population is clearly illustrated in Figure 12.9 (ABS 2011b).

The largest of the permanent population centres is Marble Bar, located 200 km southwest of Port Hedland. Mining leases, remote Indigenous communities and a number of small settlements located adjacent to major roads in the region (including the Great Northern Highway and Marble Bar Road) account for the remaining population.

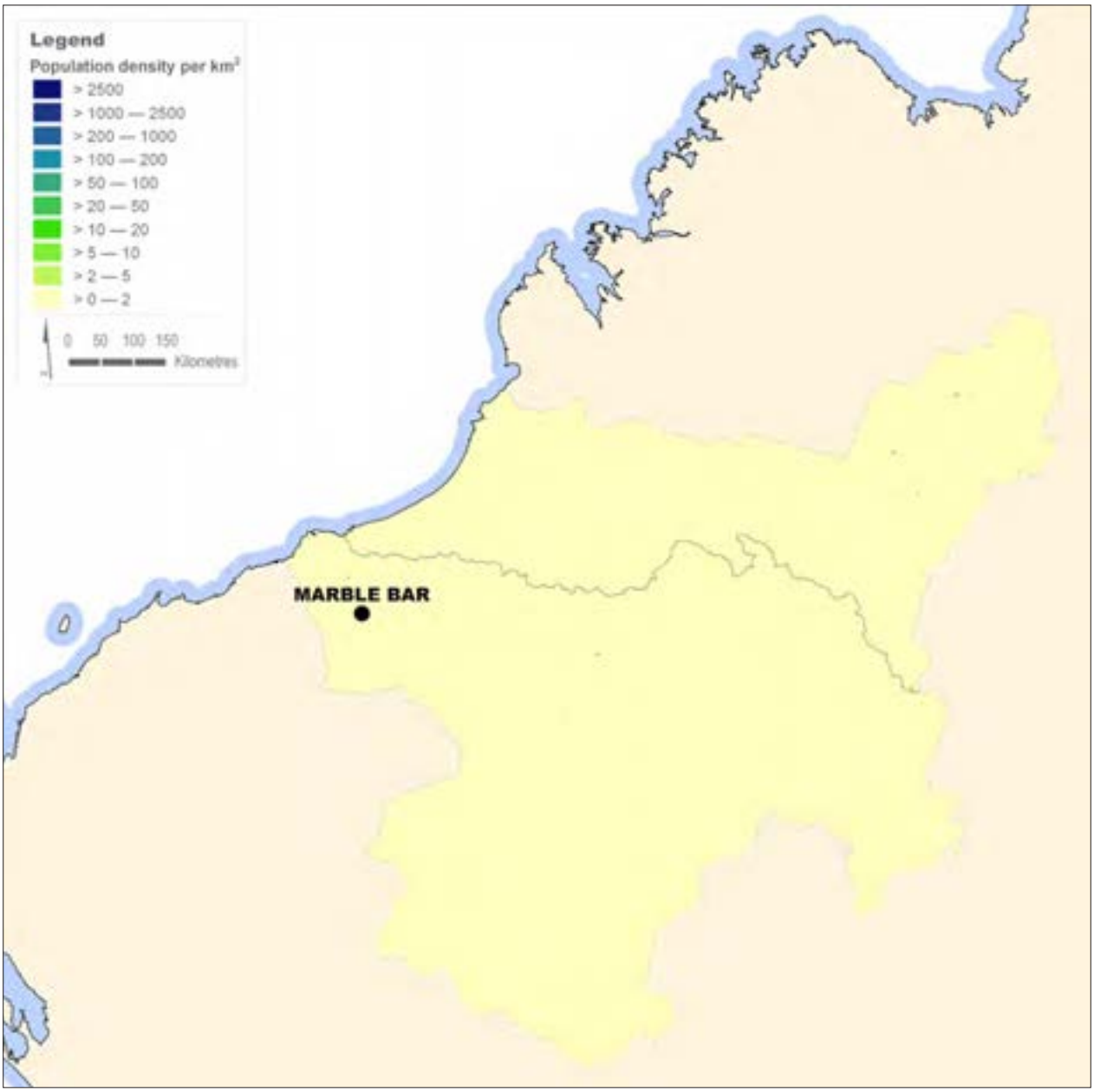


Figure 12.9 Population density and distribution in the North Western Plateau region

12.3.7 Rainfall zones

The region's climate is semi-arid to arid. The northern part is affected by occasional monsoonal rainfall in summer. Median rainfall does not exceed 650 mm per annum (Figure 12.10).

In the northern part of the region, rainfall is very irregular. Relatively low rainfall amounts can occur over the wet season, due to the limited extent of the monsoon and tropical depressions, and storms often bypass the region.

The arid south receives average annual rainfall totals generally not exceeding 300 mm. As with many arid zones, rainfall is very unreliable and highly variable between years.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website (www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp).

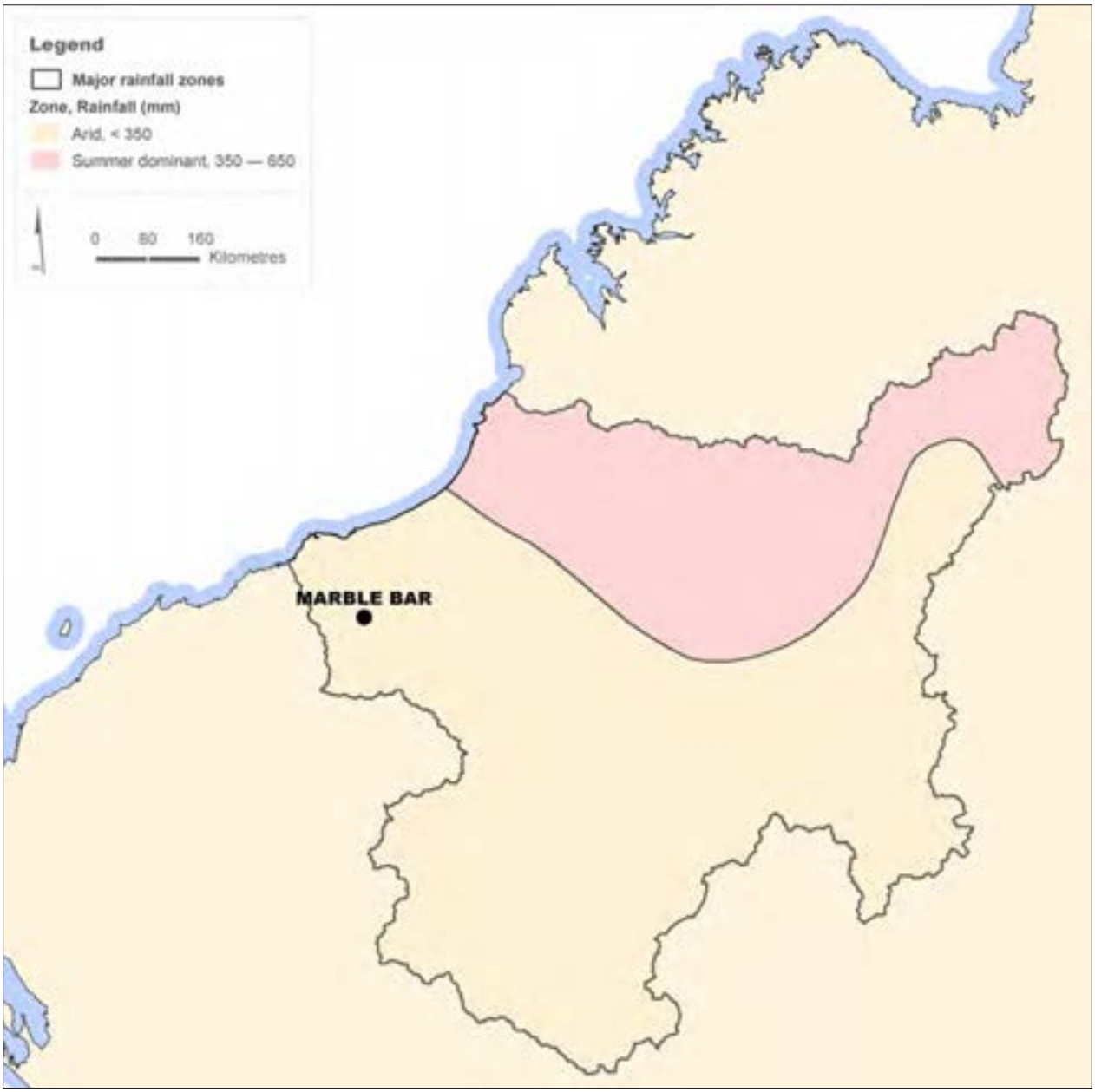


Figure 12.10 Rainfall zones in the North Western Plateau region

12.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression of which parts of the region are likely to experience moisture deficits over the period of a year. The North Western Plateau region has a uniform pattern of serious potential deficits (Figure 12.11).

Most of the region consists of desert land with some ephemeral streams and lakes. The moisture deficits in this area allow sand dunes and plains to dominate the landscape.

In the north, the unreliable supply of rainfall and the long dry season create a harsh environment. Marble Bar has the world's longest record (161 consecutive days) of above 37.8 °C. The majority of the region is declared as nature conservation land, containing some unique flora and fauna.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions (www.bom.gov.au/climate/averages/maps.shtml).

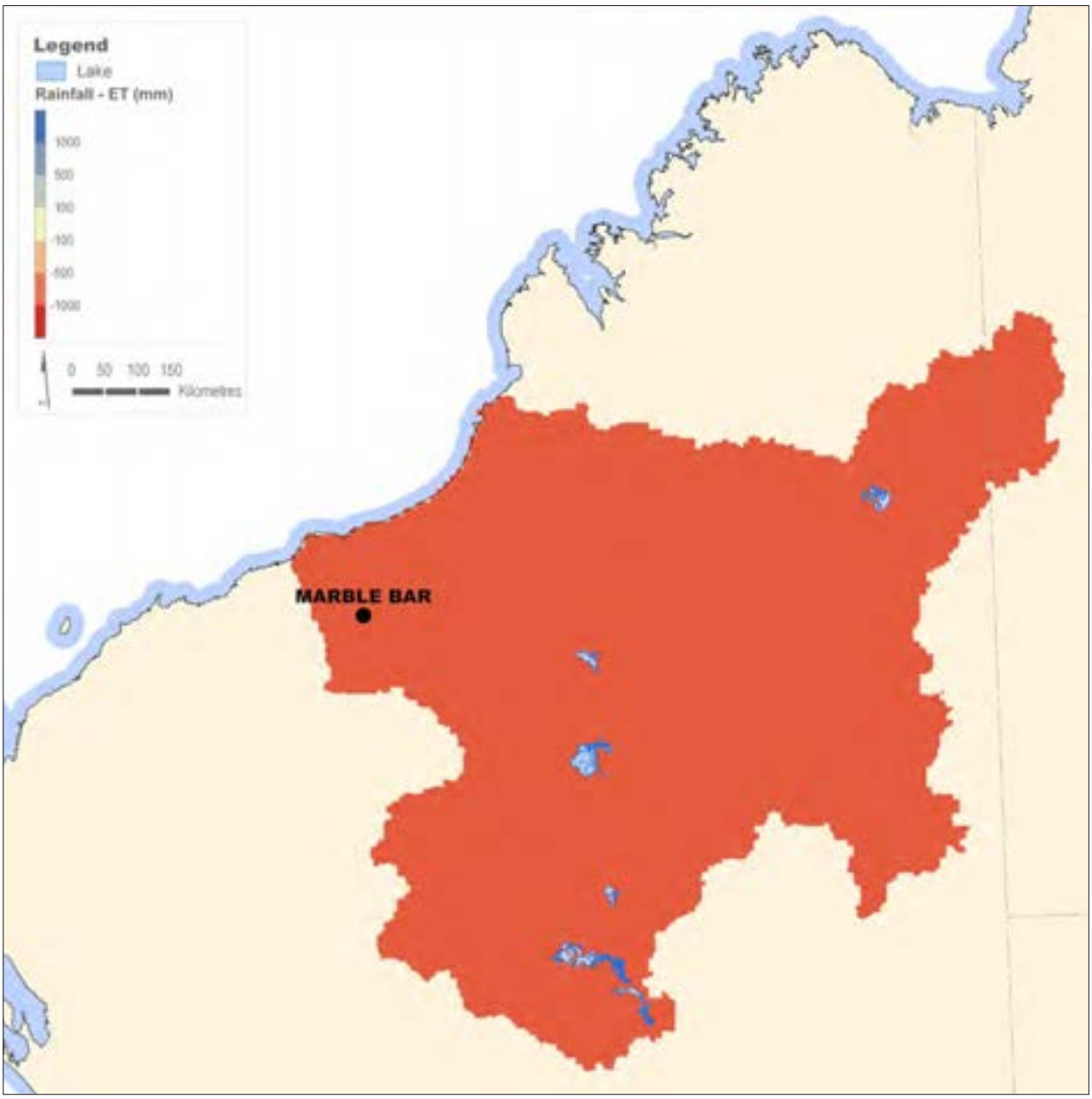


Figure 12.11 Rainfall deficit distribution in the North Western Plateau region

12.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the North Western Plateau region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 12.12 shows that the region has a highly seasonal rainfall pattern with a relatively wet summer and a dry winter period. Evapotranspiration in the dry winter period generally exceeds rainfall. After the wet period the soils normally contain an above average water volume that is available for evapotranspiration. The monthly landscape water yield history for the region shows a stable pattern of very low yield in the dry period. It only increases marginally during the summer period (November to April).

The 2011–12 year was a relatively wet year, particularly between October 2011 and March 2012, when rainfall was much higher than the historic median. In 2011, the region recorded the highest November rainfall on record (1911–2012). In fact, the period between October 2011 and January 2012 was the wettest on record for this four-month period. In March the passage of tropical cyclone *Lua* also caused heavy falls and flooding.

With wet conditions present at the start of the year and the excess of rainfall in November and January, evapotranspiration was particularly high throughout the year. Evapotranspiration was highest on record for the November month, and second-highest on record in the October–January period.

Landscape water yield for 2011–12 started to increase in January. March had the highest monthly landscape water yield for the year.

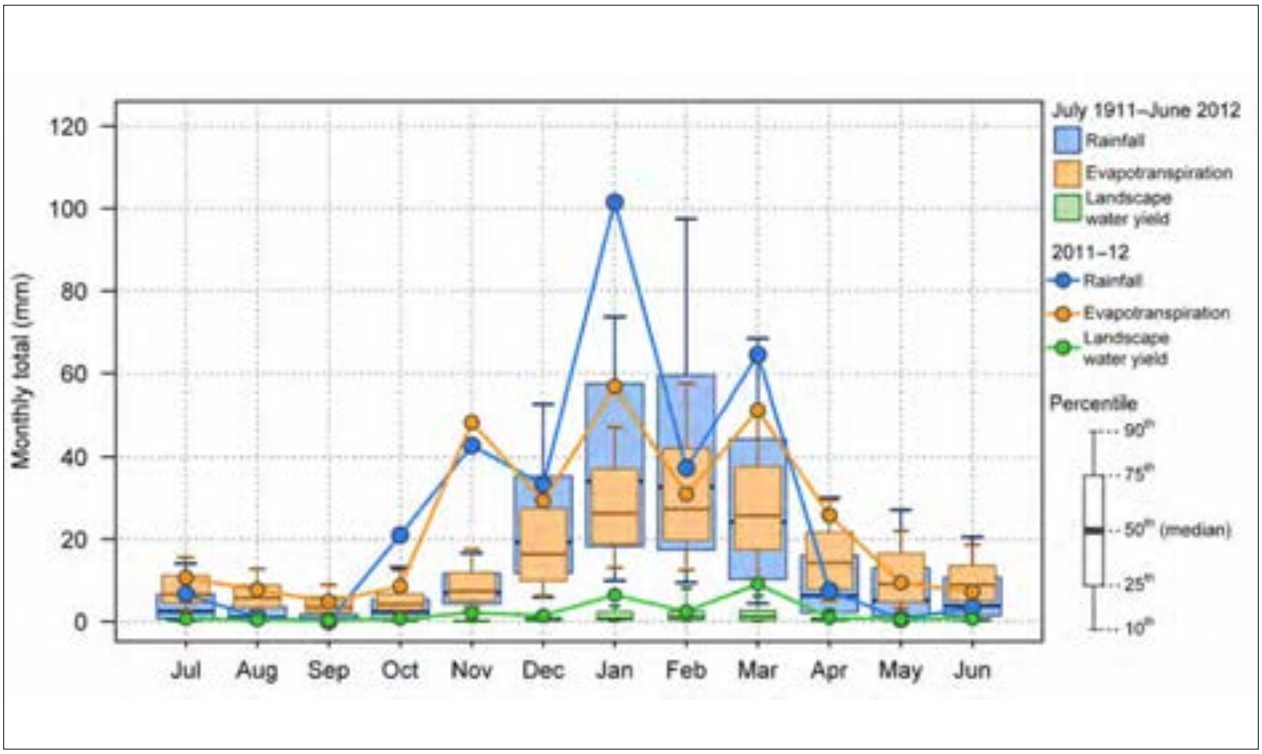


Figure 12.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the North Western Plateau region

12.4.1 Rainfall

Rainfall for the North Western Plateau region for 2011–12 is estimated to be 319 mm. This is 65% above the region's long-term average (July 1911–June 2012) of 193 mm. Figure 12.13a shows a large proportion of uncertainty of rainfall data in the region. This is due to a low rain gauge density and explains the low rainfall in the centre of the region. For consistency reasons, however, this area included for calculating totals and statistics.

Rainfall in 2011–12 marginally exceeded 600 mm per year, generally in the areas that show very much above average rainfall in Figure 12.13b. For the remainder of the region with reasonable data reliability, rainfall deciles for 2011–12 indicate predominantly above average rainfall.

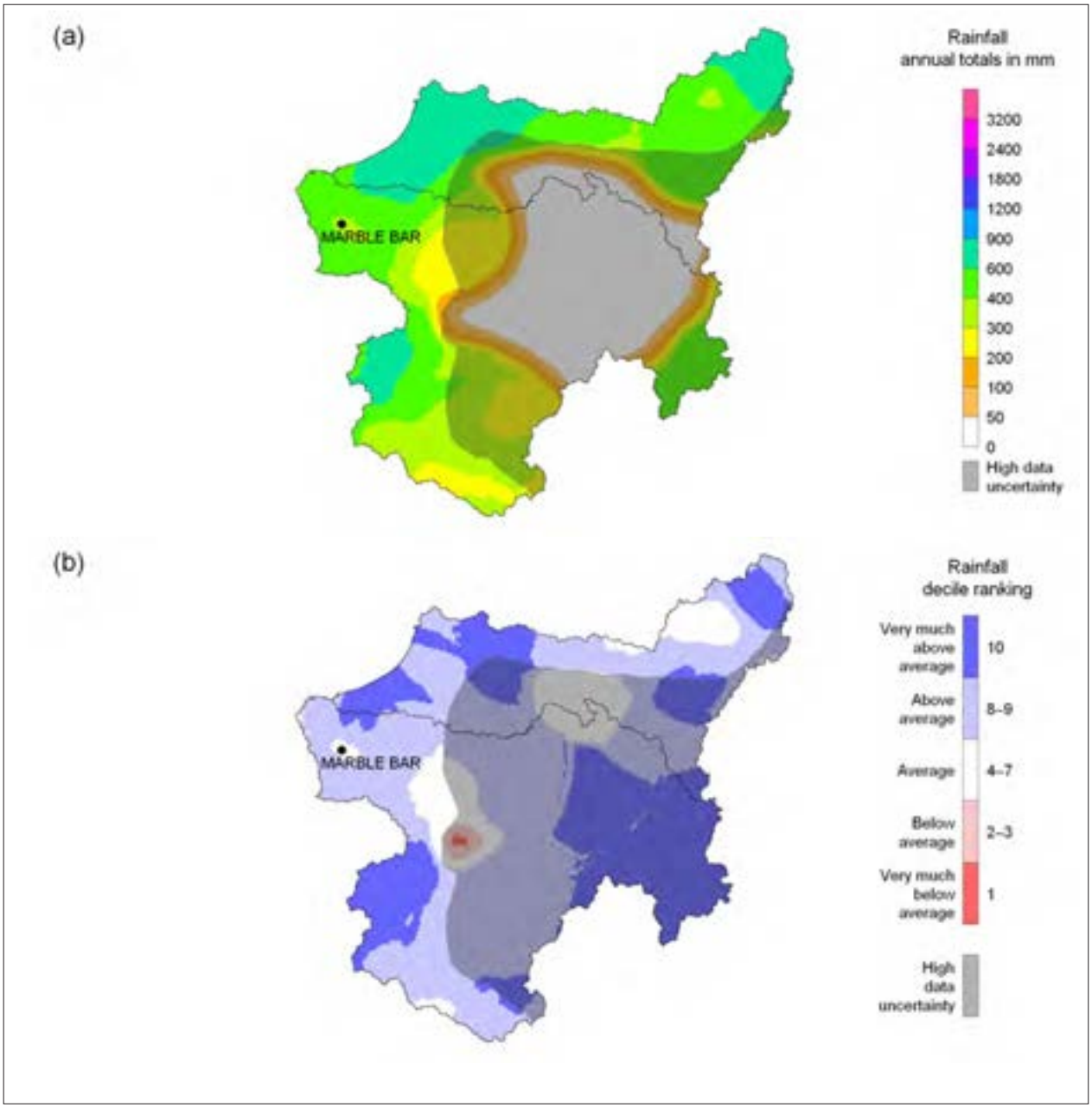
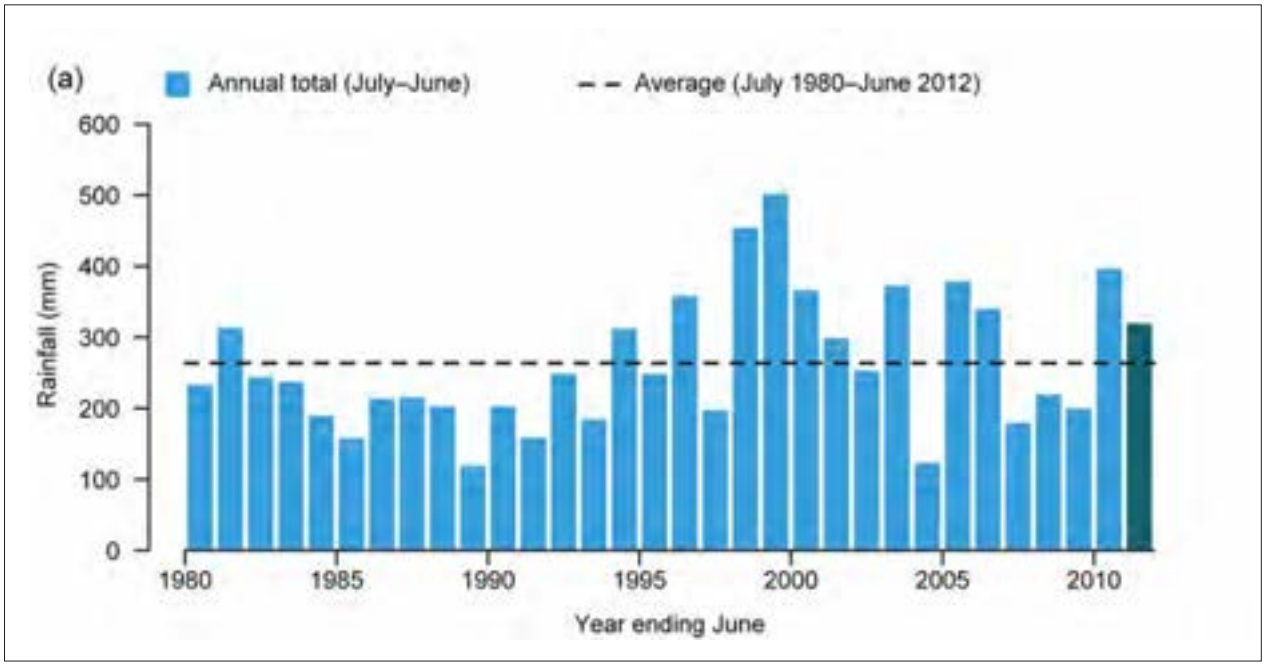


Figure 12.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North Western Plateau region

Rainfall variability in the recent past

Figure 12.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 264 mm, varying from 119 mm (1989–90) to 502 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 12.14b.

The graphs indicate the dependency of annual rainfall on the amount of rainfall occurring in the summer period. Rainfall in the winter period is generally low and relatively stable between years whilst rainfall in the summer period is highly variable. Consequently annual rainfall is highly variable as well (Figure 12.14a). In fact, the North Western Plateau has the second highest coefficient of variation (standard deviation divided by the mean) for annual rainfall compared to other reporting regions of Australia, only behind its neighbour, the Pilbara–Gascoyne region.



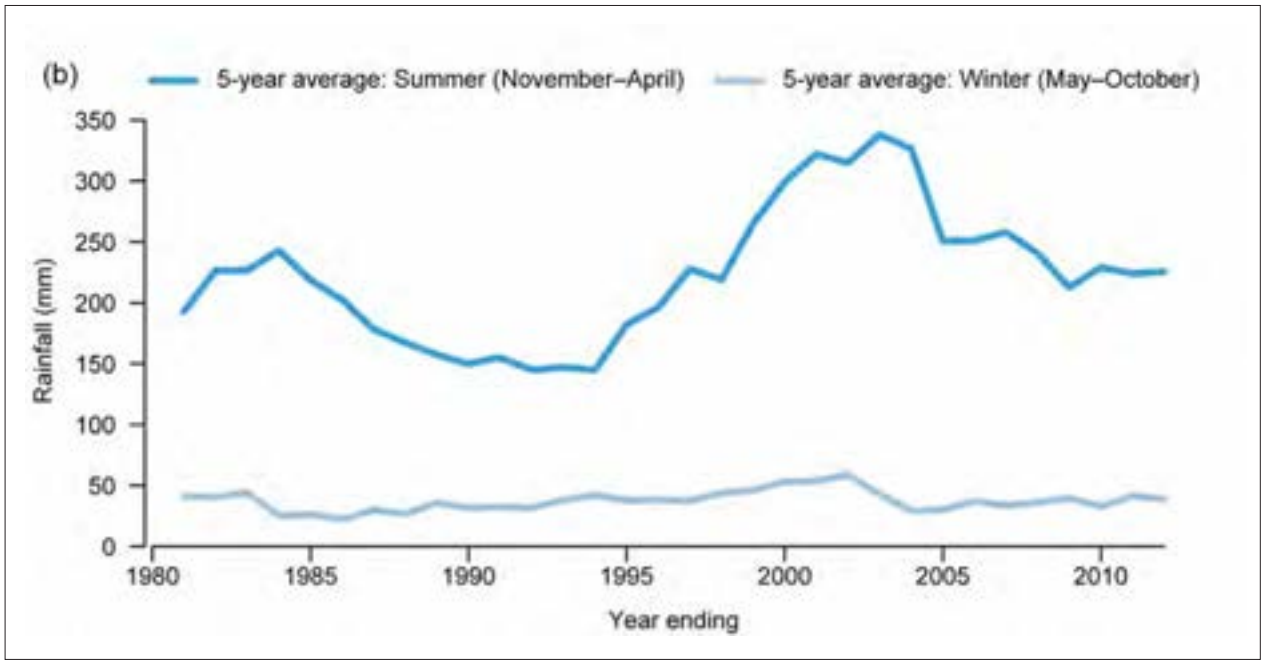


Figure 12.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North Western Plateau region

Recent trends in rainfall

Figure 12.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 12.15b.

Figure 12.15a shows that since 1980 an increase in rainfall has occurred in large parts of the region. The significance of the trends is particularly strong in the south of the region.

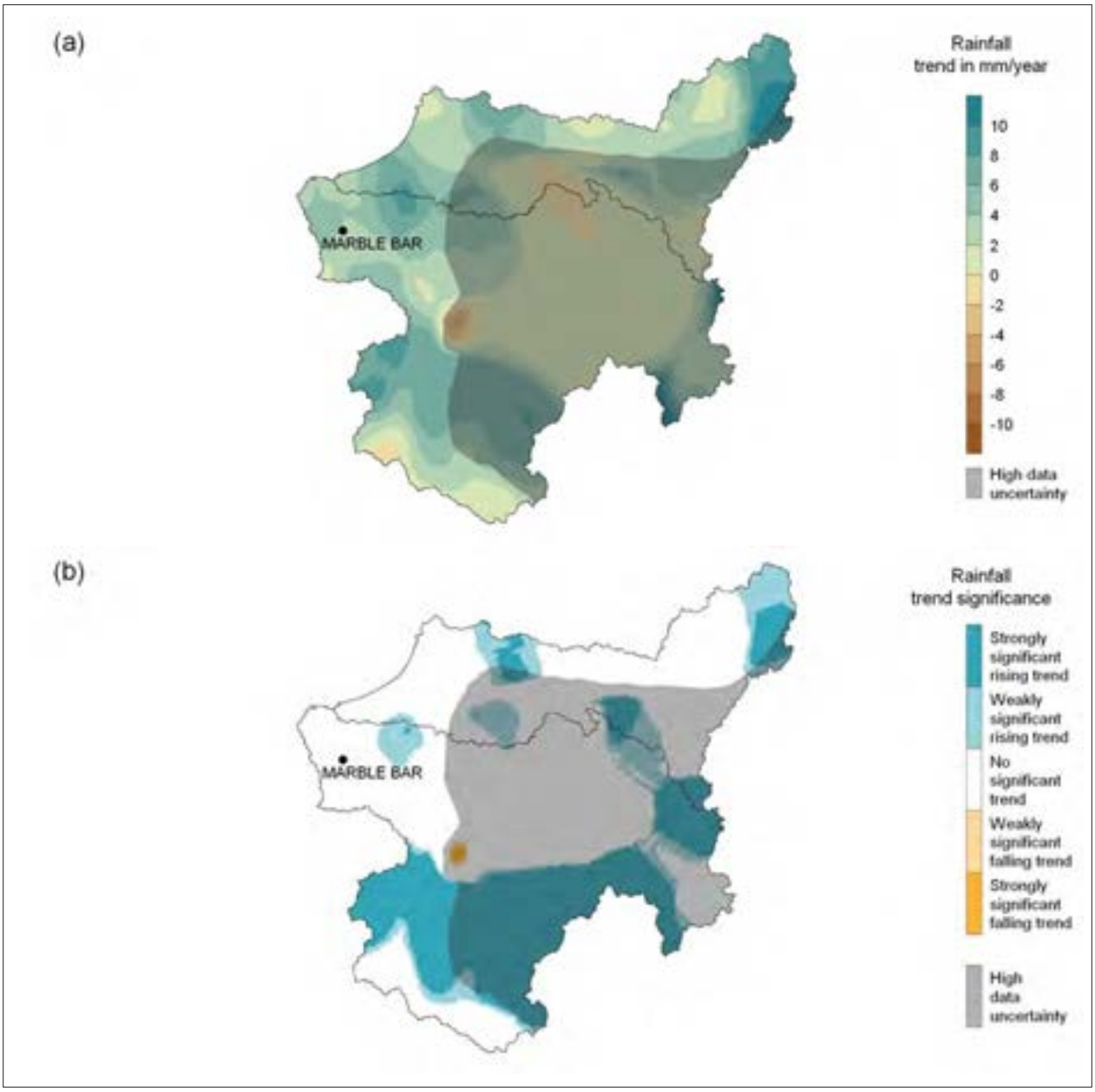


Figure 12.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North Western Plateau region

12.4.2 Evapotranspiration

Modelled annual evapotranspiration for the North Western Plateau region for 2011–12 is estimated to be 291 mm. This is 61% above the region's long-term (July 1911– June 2012) average of 181 mm. The spatial distribution and magnitude of annual of evapotranspiration in 2011–12 (Figure 12.16a) is similar to that of rainfall (Figure 12.13a).

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 12.16b). It also resembles the rainfall patterns of Figure 12.13b rather closely, which indicates that water availability, through rainfall, limits the amount of evapotranspiration occurring.

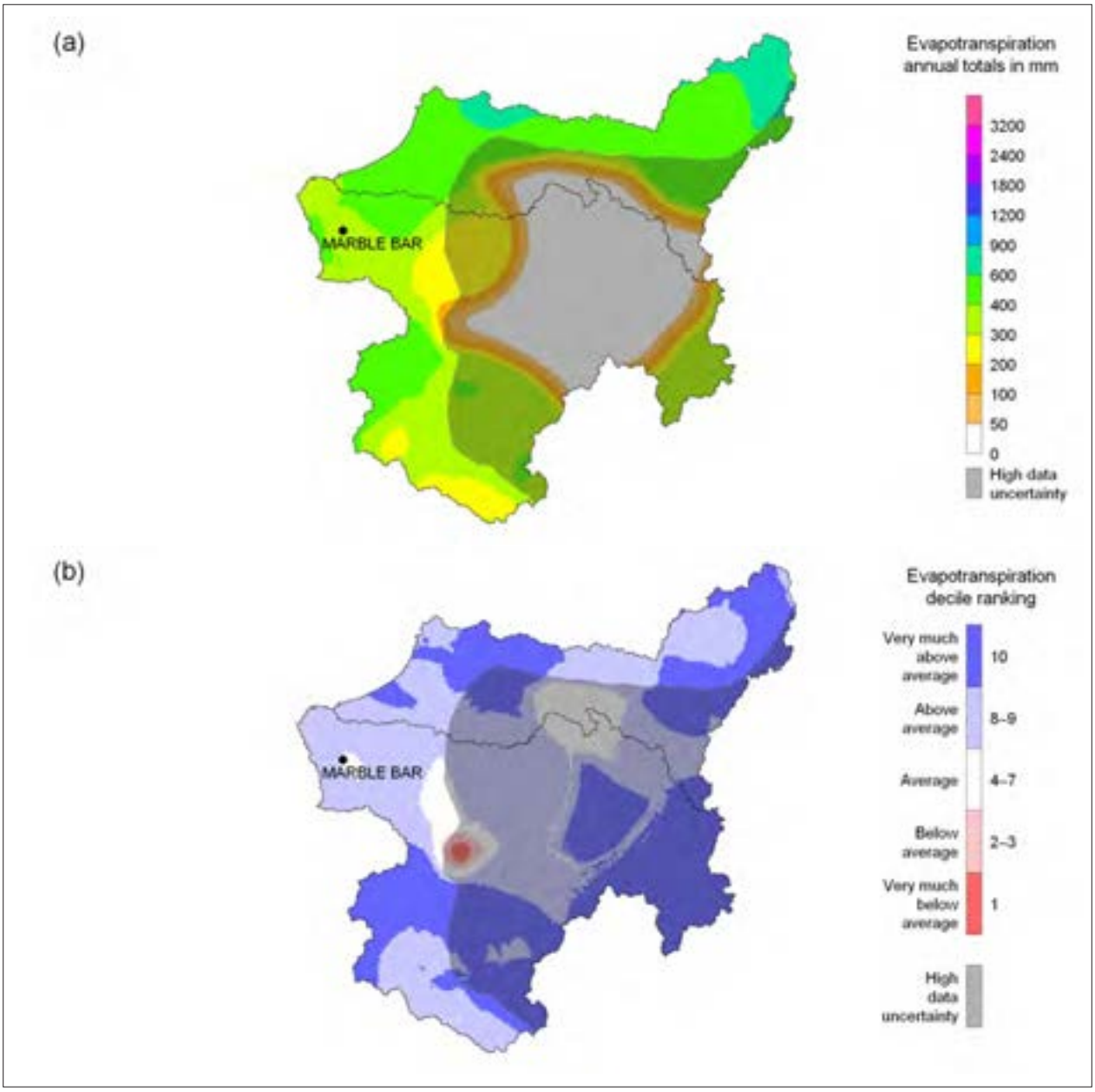
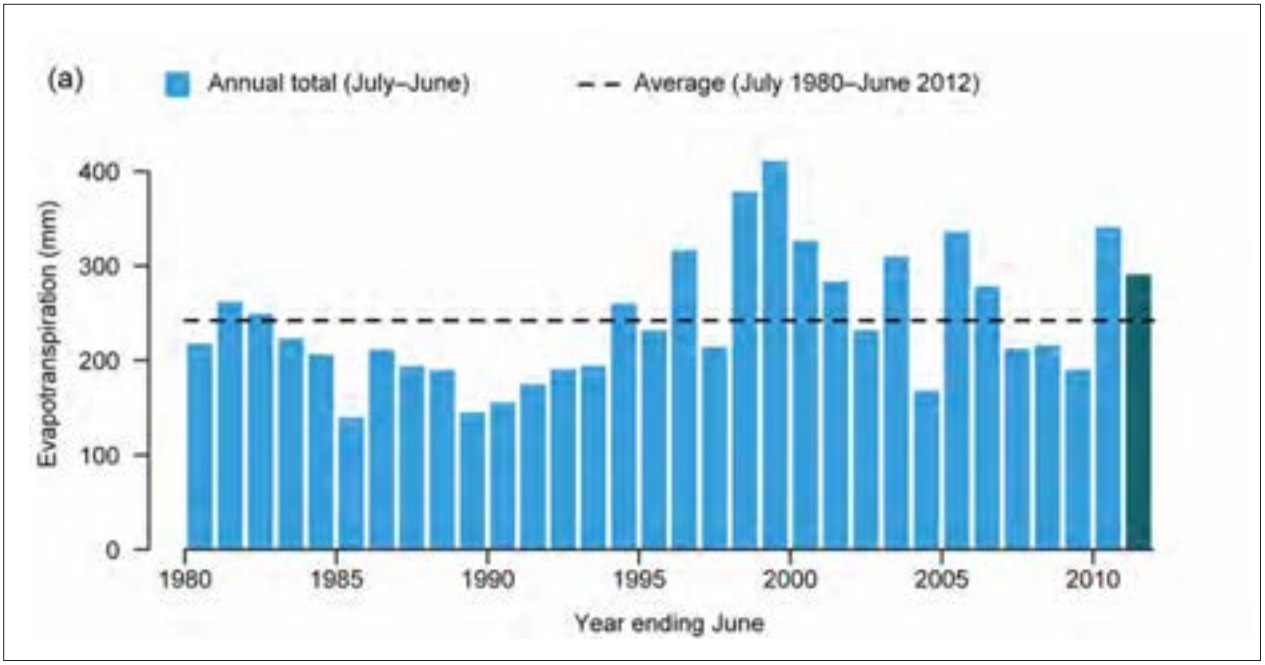


Figure 12.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North Western Plateau region

Evapotranspiration variability in the recent past

Figure 12.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 242 mm, varying from 140 mm (1985–86) to 411 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 12.17b.

Summer periods show consistently higher evapotranspiration than the winter period. The higher temperatures and the higher rainfall amounts during these periods are the main contributing factors. Compared with seasonal rainfall (Figure 12.14b), evapotranspiration exceeds the input of rain during the winter period. This is due to the higher availability of soil moisture after the relatively wet summer period.



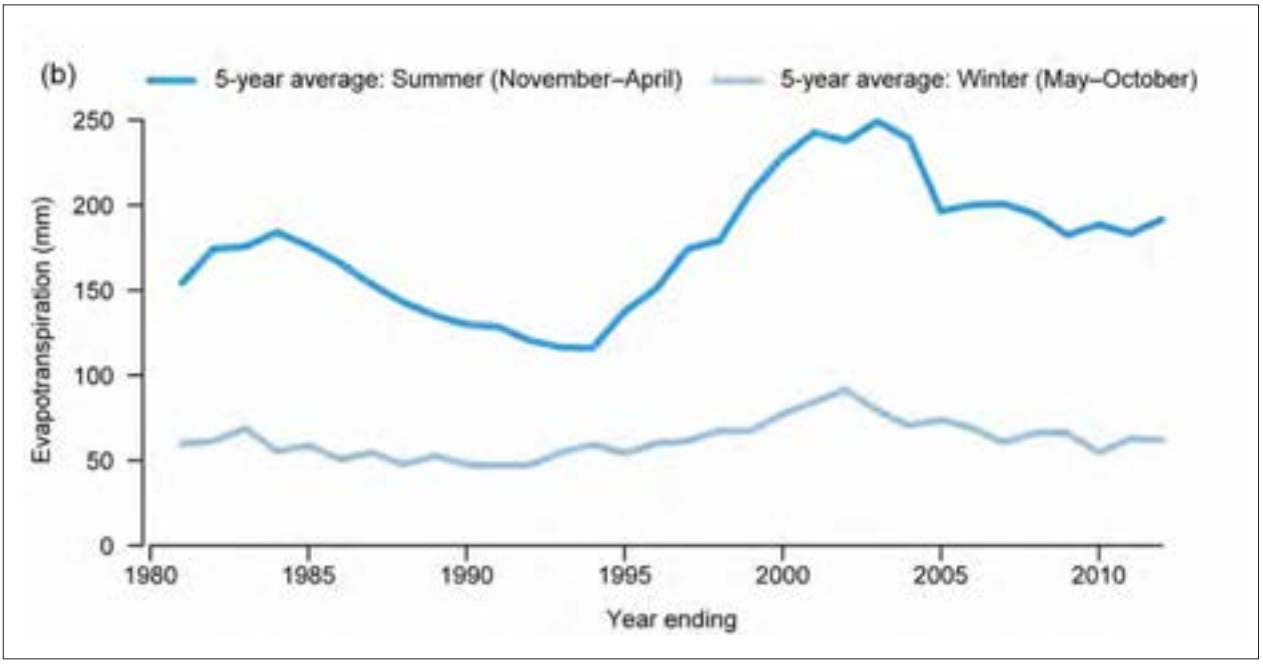


Figure 12.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North Western Plateau region

Recent trends in evapotranspiration

Figure 12.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 12.18b.

Figure 12.18a shows that since 1980, trends are mostly positive throughout the region. Similar areas of statistical significance (Figure 12.18b) are identified as compared to the rainfall trend significance in Figure 12.15b, though the areas of statistically significant evapotranspiration increase are somewhat larger.

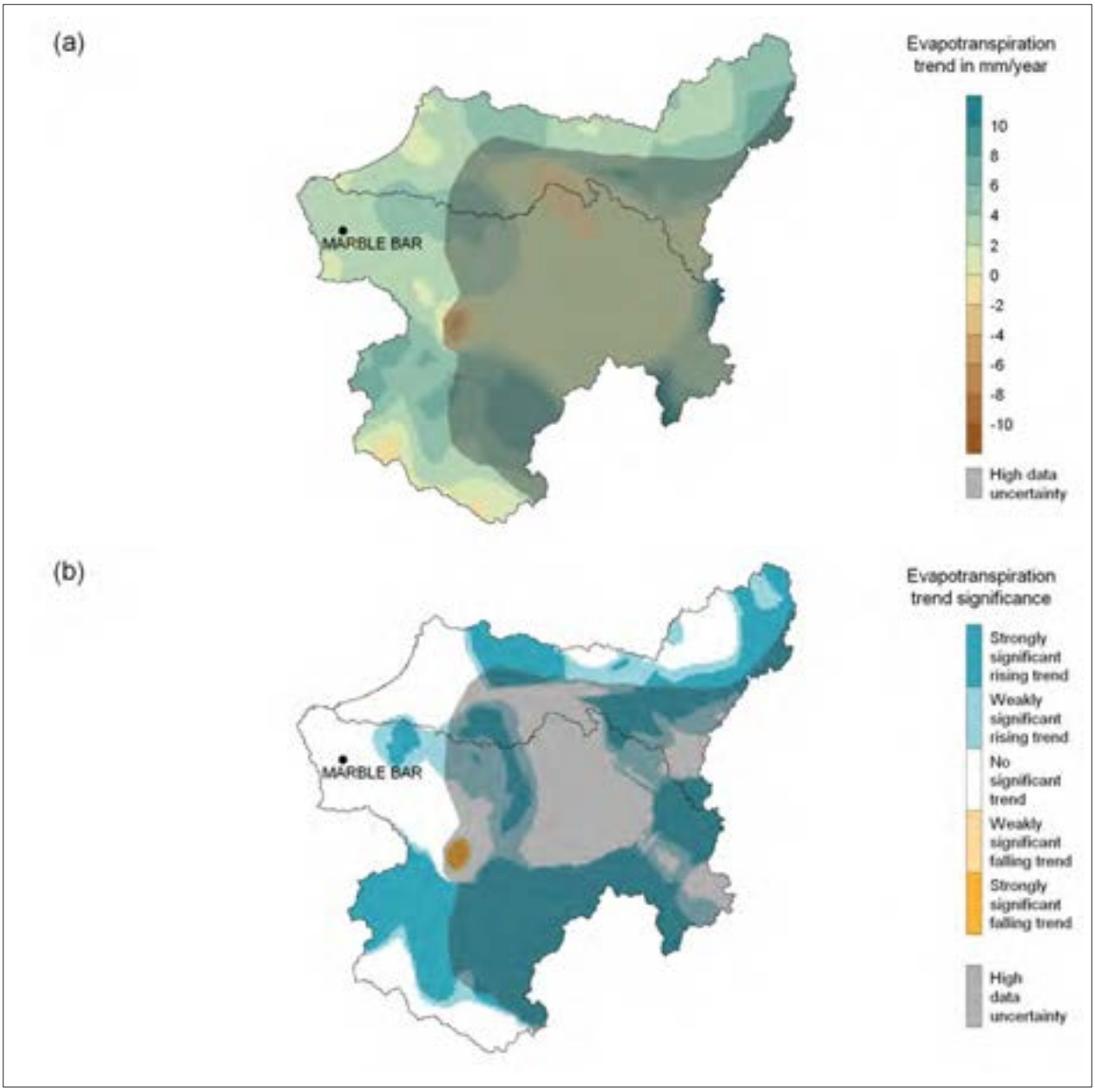


Figure 12.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North Western Plateau region

12.4.3 Landscape water yield

Modelled landscape water yield for the North Western Plateau region for 2011–12 is estimated to be 26 mm. This is 136% above the region's long-term (July 1911–June 2012) average of 11 mm. Figure 12.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 12.13a, note the difference in the scale of the legend).

The decile-ranking map for 2011–12 (Figure 12.19b) shows above average to very much above average landscape water yields, similar to what can be seen in the rainfall patterns of Figure 12.13b. Very much above average water yields are found across much of the data-sparse southeast, but these results should be used with caution as they are model results generated with highly uncertain rainfall data.

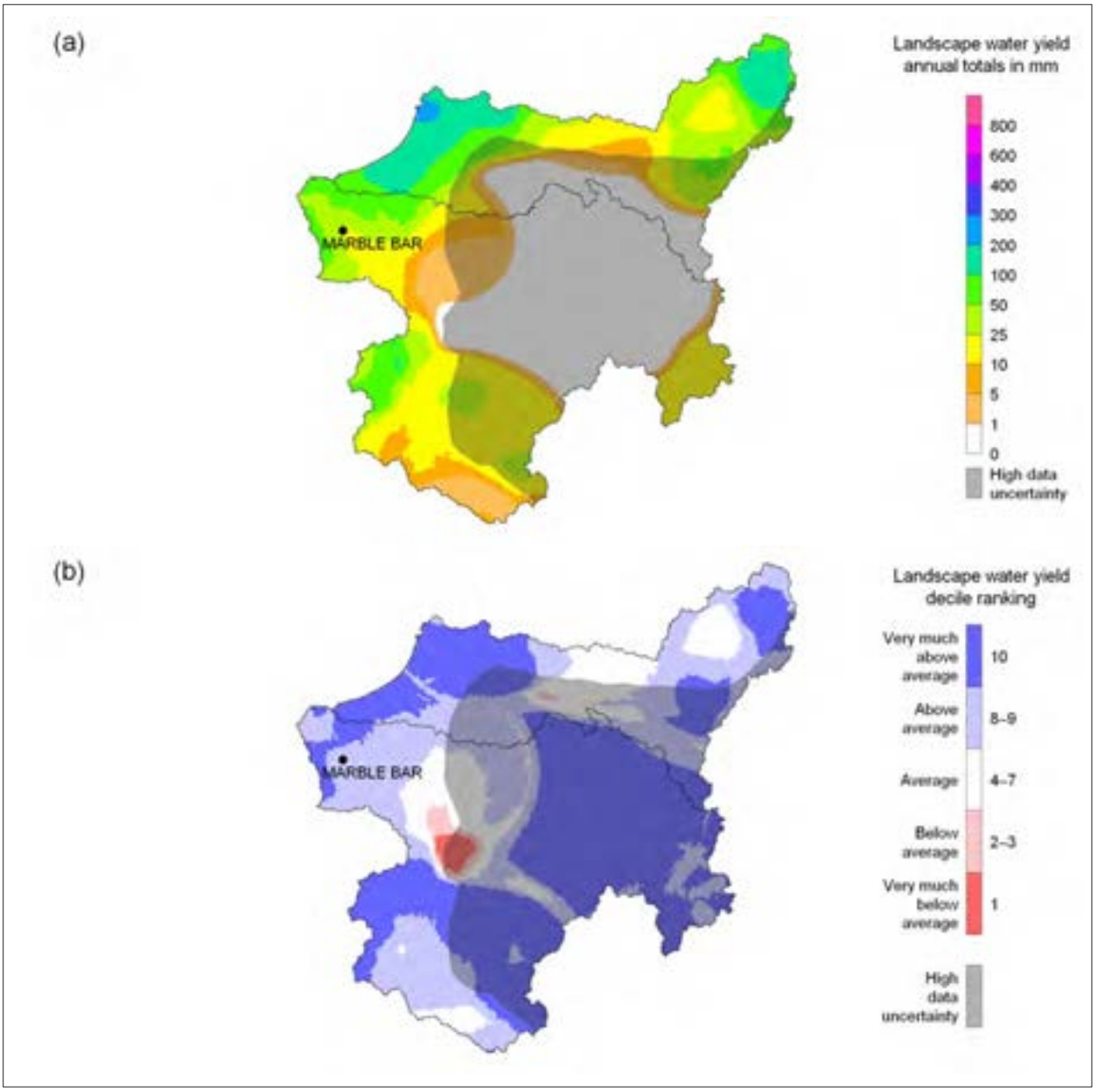
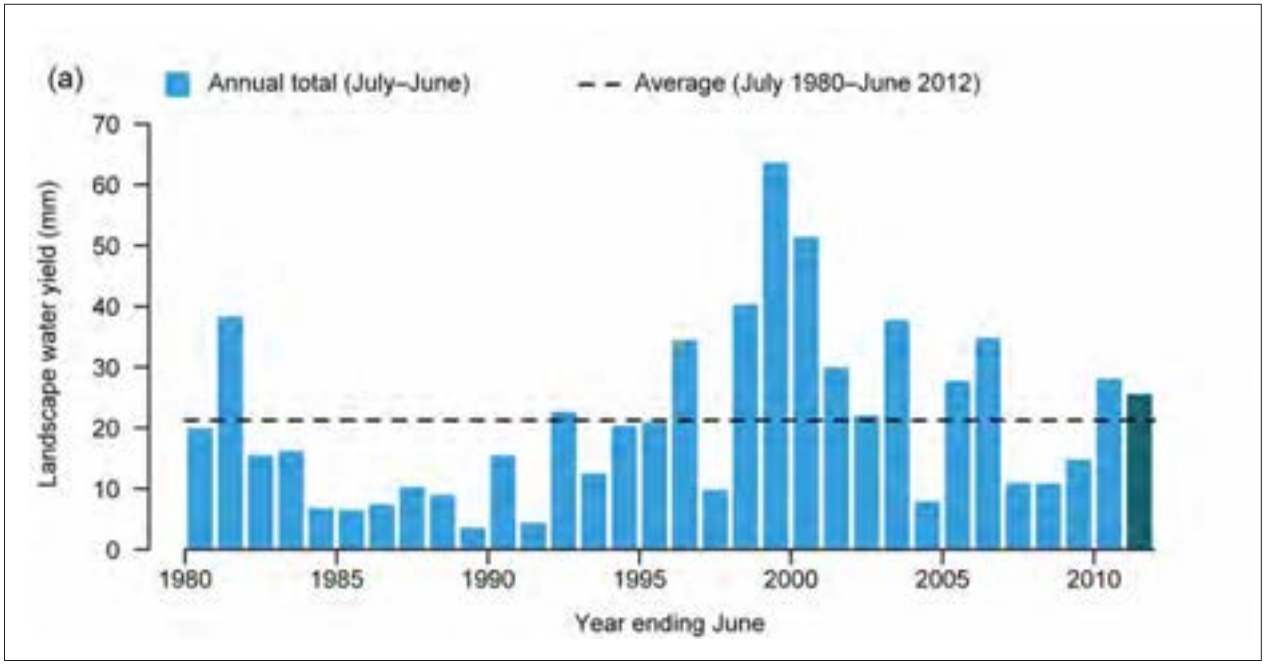


Figure 12.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the North Western Plateau region

Landscape water yield variability in the recent past

Figure 12.20a shows annual landscape water yield for the North Western Plateau region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 21 mm, varying from 4 mm (1989–90) to 64 mm (1999–2000). Temporal variability and seasonal patterns (over the summer and winter periods) since 1980 are presented in Figure 12.20b.

Landscape water yield is consistently higher during the summer period compared to the winter period. Rainfall obviously is the major force behind landscape water yield and the temporal variability closely resembles the variability in rainfall. Again, the coefficient of variation (standard deviation divided by the mean) of the annual data is high compared to most other regions.



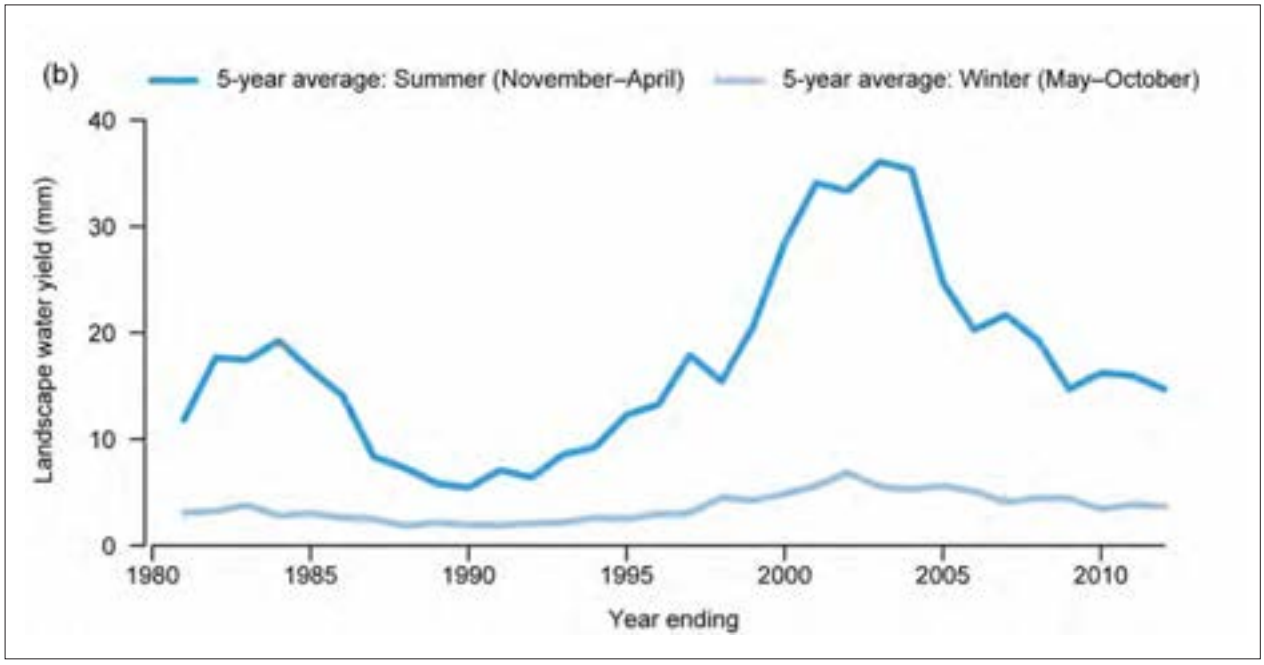


Figure 12.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the North Western Plateau region

Recent trends in landscape water yield

Figure 12.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 12.21b.

Figure 12.21a shows that there is no obvious trend in most of the region with the exception of the far northeast where landscape water yield increases towards the eastern border of the region. Figure 12.21b confirms the significance of these trends and shows some strong signals mainly in the southwest of the region; however, trends here only just reach 1 mm/year.

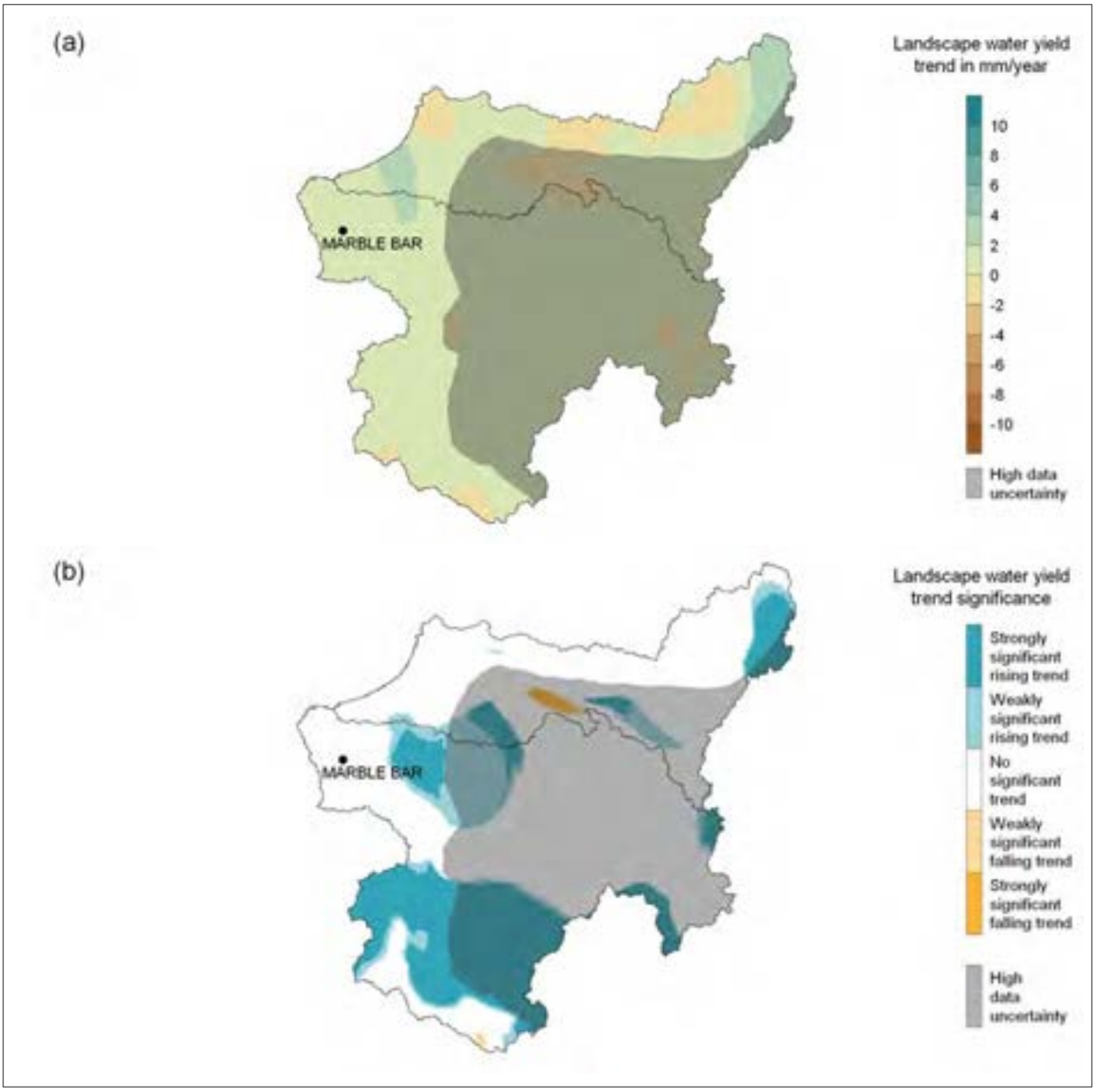


Figure 12.21 Spatial distribution of (a) trends in annual landscape water yield from 1980– 2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the North Western Plateau region

12.5 Surface water and groundwater

This section examines surface water and groundwater resources in the North Western Plateau region in 2011–12. Rivers and wetlands are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

There are no major storages located in the region.

12.5.1 Rivers

There are two river basins in the North Western Plateau region. The De Grey River basin covers an area of 477,000 km^2 and the Sandy Desert basin is 239,000 km^2 in size.

The region has some limited surface water resources present in the western part of the region (Figure 12.22). The coastline consists of tide-dominated strand plains and tidal creeks. Some dry lakes are scattered over the region, but aeolian landforms including dunes and sand plains dominate the landscape.

Almost all rivers are ephemeral, ending up in desert country or salt lakes, except for the De Grey River basin. All streams flow only after heavy rains, which occur infrequently.

12.5.2 Flooding

Heavy rainfall in January associated with an active monsoon brought tropical cyclones *Heidi* and *Iggy* to the region. These tropical cyclones caused moderate to major flooding particularly in the Shaw and Coongan rivers. Major floods affected the Nallagine and De Grey rivers in March with the passage of tropical cyclone *Lua* (Figure 12.23).

12.5.3 Wetlands

There is one Ramsar-listed, internationally important wetland in the North Western Plateau region and there are a number of wetlands of national importance in the region mentioned in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html). The wetlands vary from coastal floodplains, lakes and tidal flats to inland ephemeral lakes and river floodplain systems (Figure 12.24).

The Eighty Mile Beach Ramsar site mainly consists of tidal flats, which sometimes extend up to 5 km in width. It is a highly important retreat for many species of (migrating) shorebirds.

No detailed assessment on the inflows of selected wetlands has been performed for this region.

Birdlife on the Eighty Mile Beach, Western Australia | Gayle Partridge

Figure 12.22 Rivers and catchments in the North Western Plateau region

Figure 12.23 Flood occurrence in 2011–12 for the North Western Plateau region

Figure 12.24 Location of important wetlands in the North Western Plateau region

12.5.4 Hydrogeology

The hydrogeology is dominated by a large area of outcropping fractured basement rock in the west and east of the region. The associated groundwater systems typically offer restricted low volume water resources. Other important hydrogeological groups are the Mesozoic sediments through the centre of the region and the surficial sediments in-filling palaeovalleys. These groups are likely to offer more reliable groundwater resources (Figure 12.25).

The watertable aquifers present in the region are given in Figure 12.25 below. Groundwater systems that provide more potential for extraction are labelled as:

- Mesozoic sediment aquifer (porous media — consolidated); and
- surficial sediment aquifer (porous media — unconsolidated).

12.5.5 Watertable salinity

Figure 12.26 shows the classification of watertable aquifers as fresh (total dissolved solids (TDS) < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) according to watertable salinity. As shown, most parts of the region are considered to have fresh goundwater. Saline groundwater occurs in localised areas along the major drainage lines in the alluvial sediments.

12.5.6 Groundwater management units

The groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 12.27 shows that the groundwater management units within the region include Canning–Kimberley, East Murchison, Goldfields and Pilbara.

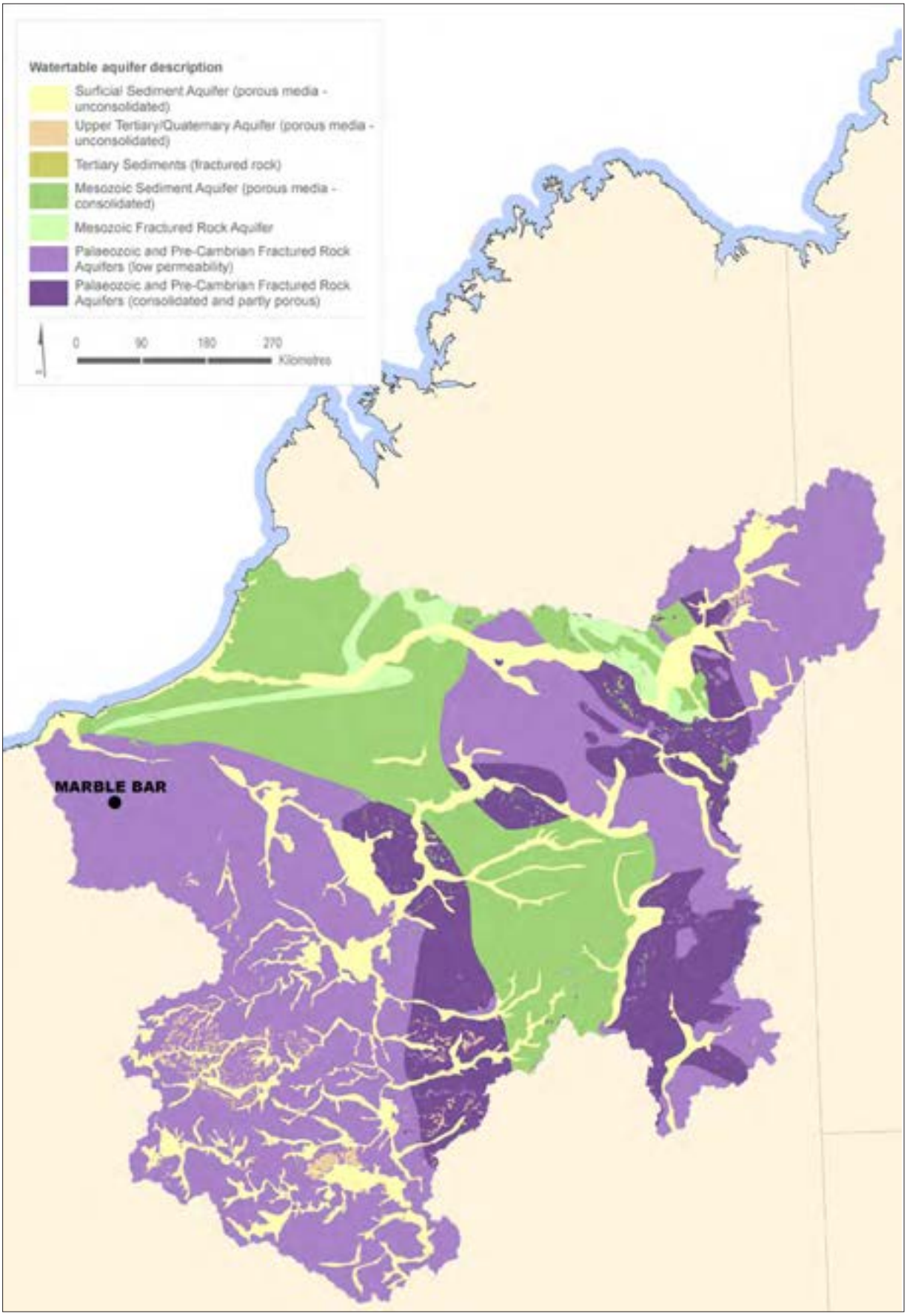


Figure 12.25 Watertable aquifers of the North Western Plateau region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 12.26 Watertable salinity classes of the North Western Plateau region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 12.27 Groundwater management units in the North Western Plateau region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

Tanami – Timor Sea Coast

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13 Tanami – Timor Sea Coast

13.1 Introduction

This chapter examines water resources in the Tanami – Timor Sea Coast region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The chapter concludes with a review of the water situation for urban centres and irrigation areas. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

13.2 Key information

Table 13.1 gives an overview of the key components of the data and information in this chapter.

Table 13.1 Key information on water flows, stores and use in the Tanami – Timor Sea Coast region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	754 mm	+35%	9th—above average
Evapo-transpiration	646 mm	+40%	10th—very much above average
Landscape water yield	142 mm	+53%	9th—above average

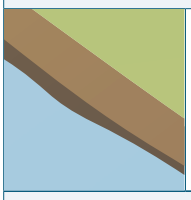
Streamflow (at selected gauges)

Annual total flow:	Predominantly average to above average flow in river basins in the central north
Flooding:	Localised minor to moderate flooding in the northern half of the region

Surface water storage (comprising about 96% of the region's total capacity of all major storages)

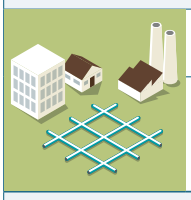
Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
10,733 GL	10,549 GL	98%	10,710 GL	100%	-161 GL	-2%

Groundwater (in selected aquifers)



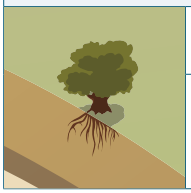
Salinity:	Non-saline groundwater (<3000 mg/L) throughout the region

Urban water use (Darwin)



Total sourced in 2011–12	Total sourced in 2010–11	Change	Restrictions
35.5 GL	32.3 GL	+3.2 GL (+10%)	No restrictions

Annual mean soil moisture (model estimates)



Spatial patterns:	Predominantly above average to very much above average annual mean soil moisture
Temporal patterns in regional average:	Very much above average soil moisture throughout most of the year, above average in the wet season

13.3 Description of the region

The Tanami – Timor Sea Coast region extends over a large area of northern Australia covering much of the Northern Territory and the north of Western Australia. The region is approximately 1,162,000 km² and includes the Ord, Darwin, Daly, Victoria and Fitzroy river basins (Figure 13.1).

The region is dominated by two major drainage systems with a dense network of northern rivers that drain to the Timor Sea, and drier rivers generally draining south to inland ephemeral lake systems. Subsections 13.3.1–13.3.4 provide more information on the topography and soil types.

With a population of 201,500 the region is home to 0.9% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b).

Major population centres in the region are shown in Figure 13.1 and include Darwin, Palmerston, Broome, Katherine and Kununurra. Further discussion of the region's population distribution and urban centres can be found in subsection 13.3.6 and section 13.6 respectively.

Land use in the region mainly consists of pasture and nature conservation reserves (see subsection 13.3.5). Some of the most well-known natural landscape features and conservation reserves in Australia are located in this region, including the Kimberley, Kakadu National Park and Uluru–Kata Tjuta National Park.

The Ord Irrigation Scheme, located in the Ord River catchment in the far northeastern part of Western Australia, is the largest area of irrigated agriculture in the region. Subsection 13.3.5 provides more information on the region's agricultural activities.

The region extends across distinct climatic zones and is characterised by a humid tropical climate to the north and a very dry arid climate to the south. Subsections 13.3.7 and 13.3.8 provide more information on the rainfall patterns and deficits across the region.

River flows in the tropical northern climate zone experience distinct seasonal patterns, with approximately 90% of the average annual flow occurring in the wet season from November–April.

The hydrogeology of the region is dominated by the Kimberley hard rock plateau and Canning basin sedimentary rocks. In the hard rock plateau, groundwater occurs in low but valuable quantities in fractured rocks and surficial river alluvium. Substantial quantities of confined and unconfined groundwater of varying quality occur in the sedimentary basins. The extensive groundwater resources associated with the widespread fractured and cavernous limestone of the Daly basin are important for the region. Shallow groundwater is often of good, low salinity quality, reflecting the annual fill-and-spill cycle, and can provide good supplies of potable water. A more detailed description of the rivers and groundwater status in the region is given in section 13.5.

Kata Tjuta (the Olgas) | stefaniaandreetto (iStockphoto)

Figure 13.1 Major rivers and urban centres in the Tanami – Timor Sea Coast region

13.3.1 Physiographic characteristics

The physiographic map in Figure 13.2 shows areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that influence hydrological processes. The Tanami – Timor Sea Coast region has four such dominant physiographic provinces, namely:

- Barkly–Tanami Plains (38%): black clay, sand and limestone plains and sandstone rises and plateaus, some with ferruginous mantles and occasional granitic and sedimentary hills;
- North Australian Plateaus (23%): dissected basaltic, quartzite and sandstone plateaus (some with laterite-capping), rounded ridges of folded metamorphic rocks, lowlands of limestone and weak sedimentary rocks including alluvial plains;
- Kimberley (21%): granitic, volcanic and sedimentary ranges, plateaus and hills with some partially laterised tableland and undulating plains; and
- Central Australian Ranges (13%): ranges and hills of igneous rock, sandstone and quartzite amongst sand, stone and hardpan plains with some dune fields and salt lakes.

The remaining two provinces occupy only 5% of the region. These are:

- Sandland (4.7%): east-west longitudinal dunes and minor salt lakes with some narrow sandstone ranges; and
- Carpentaria Fall (0.3%): dissected coastal fall, tabular ridges giving way seawards to sloping plains and low hills.

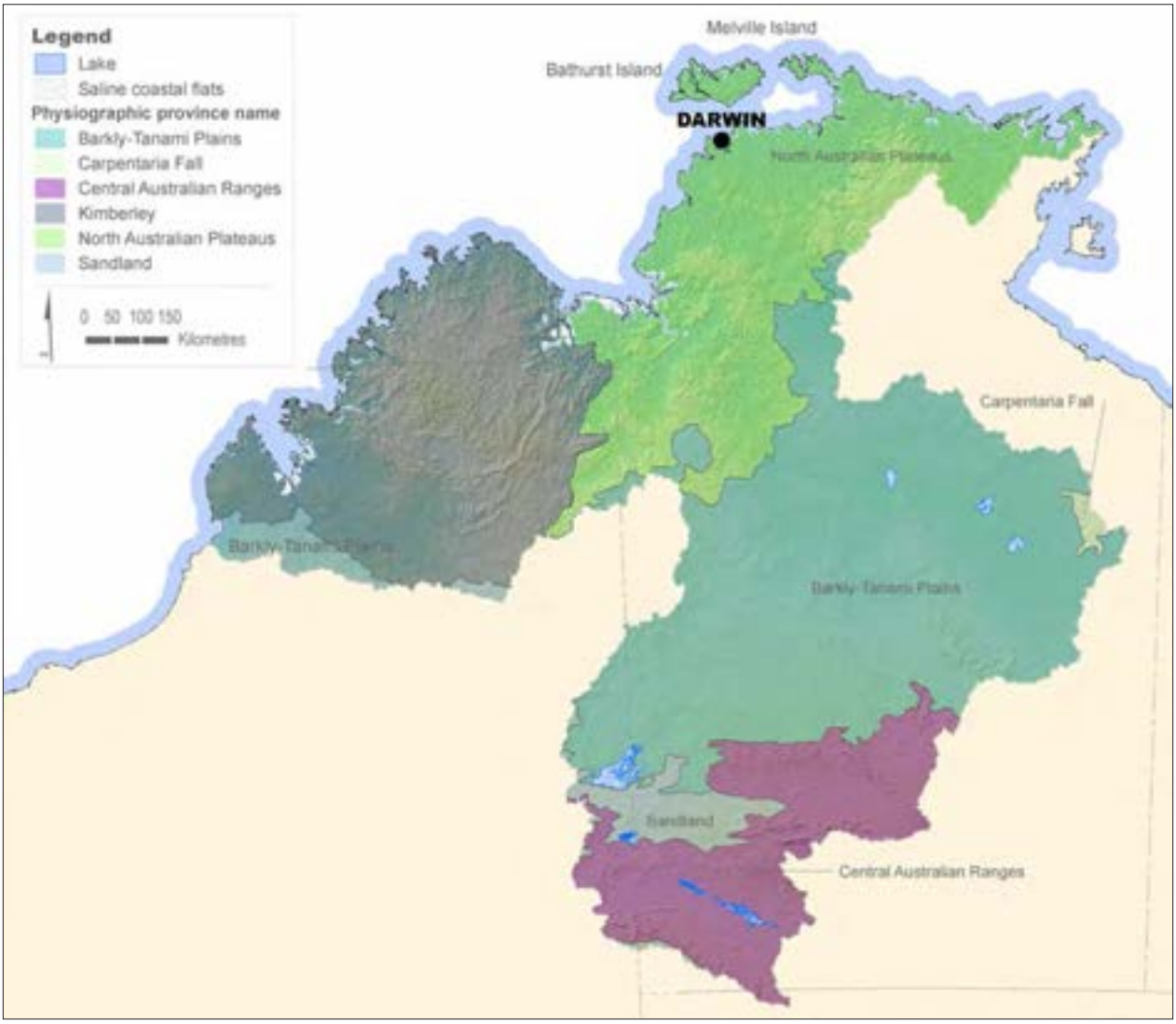


Figure 13.2 Physiographic provinces of the Tanami – Timor Sea Coast region

13.3.2 Elevation

Figure 13.3 presents ground surface elevations in the Tanami – Timor region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The topography of the region has generated two major drainage systems with the floodplains of northern rivers draining to the Timor Sea and the arid zone rivers of the Tanami Desert draining south, terminating in ephemeral lakes (Figure 13.3).

In the west of the region most rivers originate from the Kimberley Plateau, which has peaks exceeding 600 m above sea level. The rivers to the west and east of the plateau pass through extensive floodplains, draining to the sea.

The rivers in the northeast of the region have their headwaters in the many mountain ranges and plateaus of this area, including the Arnhem Land escarpment. Peaks in these mountainous areas occasionally reach 300 m above sea level.

More mountainous ranges are present in the Tanami Desert and the far south of the region including the MacDonnell Ranges just west of Alice Springs. Some peaks in the area exceed 1,000 m above sea level.

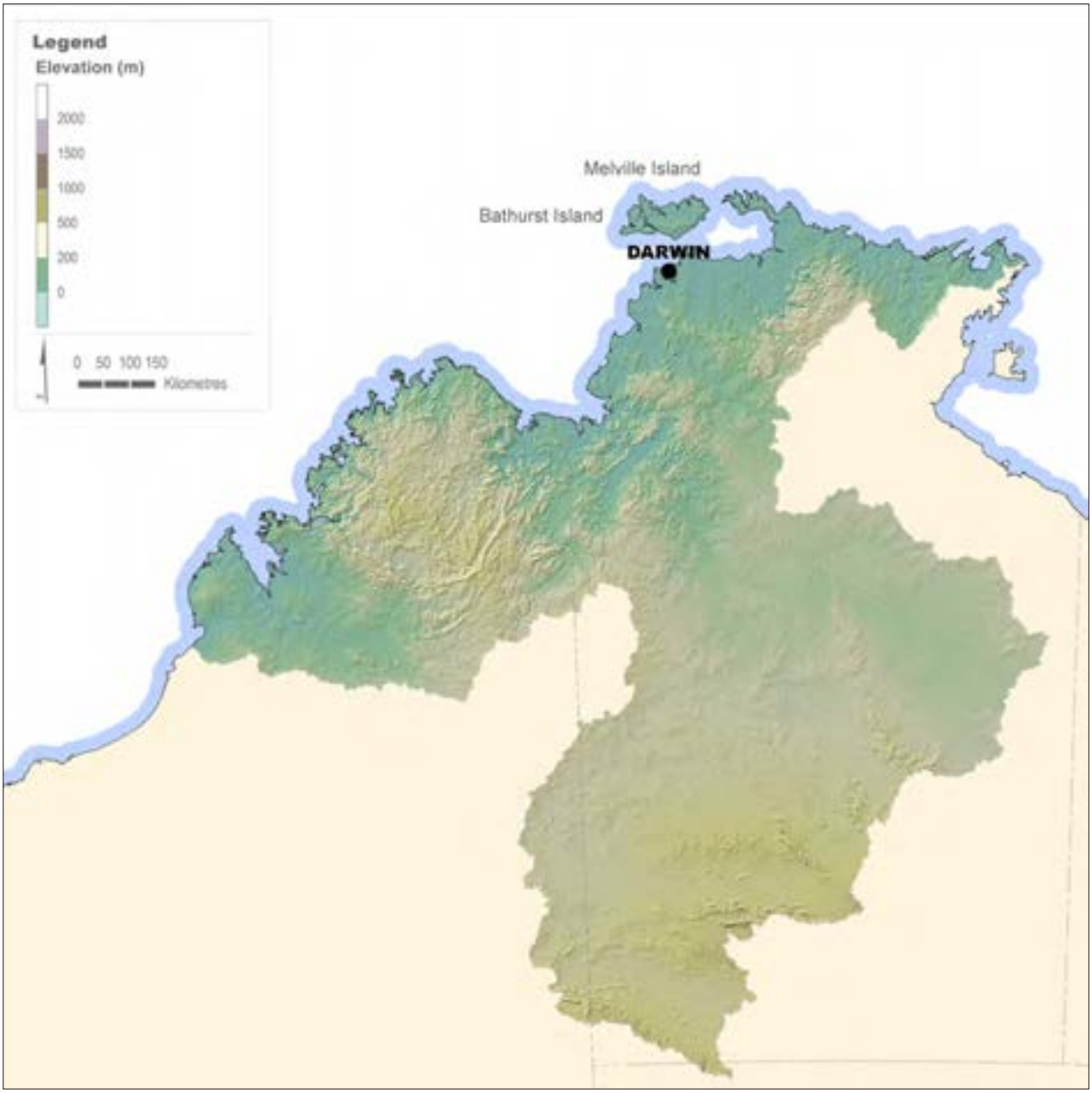


Figure 13.3 Ground surface elevations in the Tanami – Timor Sea Coast region

13.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The Tanami – Timor Sea Coast region has very few areas with steep slopes (see Table 13.2) and the inland area is particularly flat (Figure 13 4). The slopes were derived from the elevation information used in the previous section.

Table 13 2. Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	48.1	18.4	26.1	7.4

The ranges surrounding the Kimberley Plateau in the northwest have the steepest slopes in this part of the region. Some quite steep slopes can also be found on the escarpment of the Arnhem Land Plateau.

Due to the low topography of the arid inland parts of the region, rivers need to receive large quantities of water before starting to flow. When the arid zone rivers do flow in large volumes, they terminate in and occasionally fill the ephemeral lakes in the area.

The Fitzroy River crosses the plains to the southwest of the Kimberley Plateau. In this part of the region the Fitzroy River has a complex arid floodplain system of meandering flow paths with an average width of around 10 km.

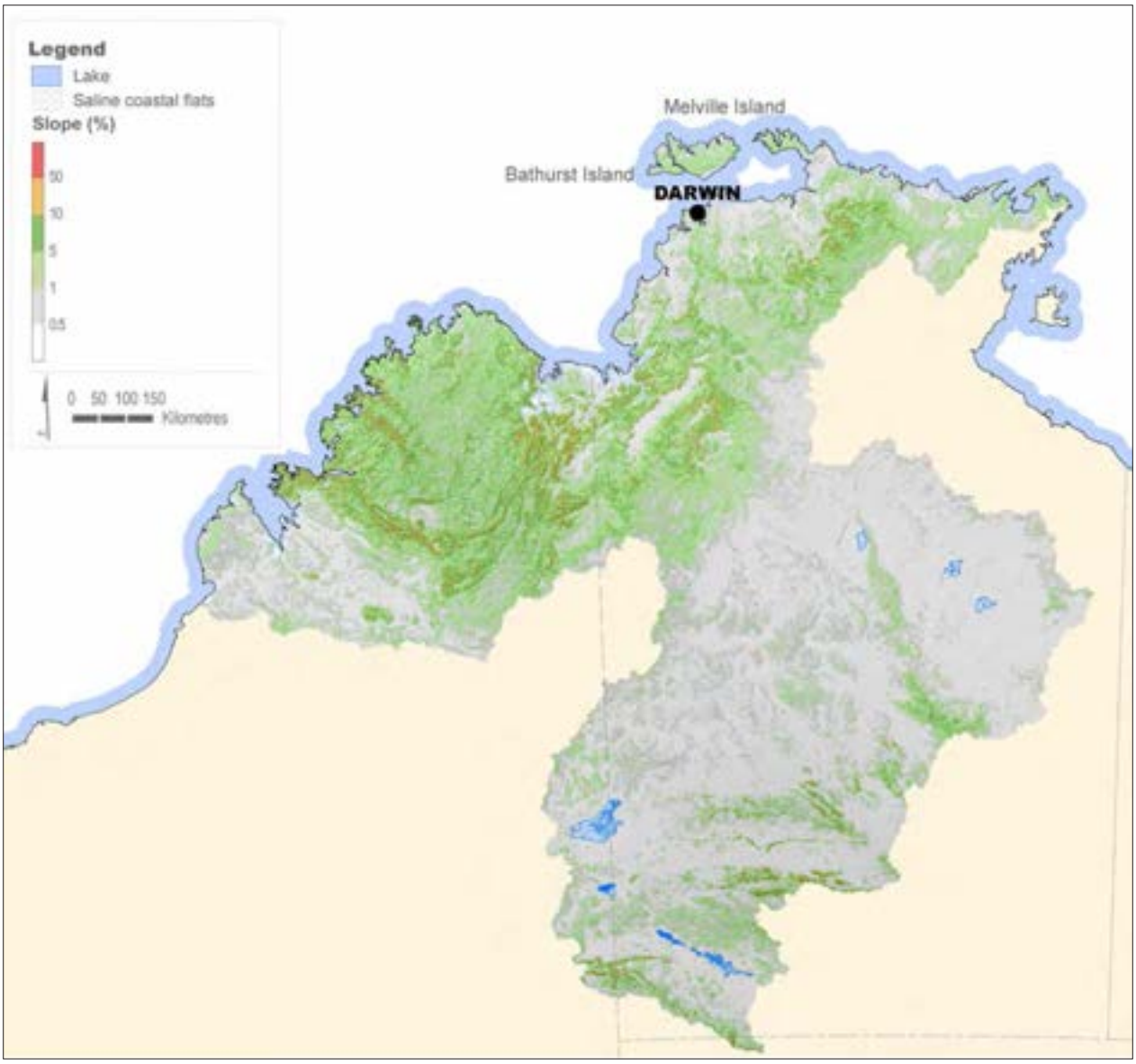


Figure 13.4 Surface slopes in the Tanami – Timor Sea Coast region

13.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 90% of the total Tanami – Timor Sea Coast region consists of four soil types, namely tenosols, rudosols, kandosols and vertosols (Figure 13.5 and Figure 13.6). These soils are usually widely distributed across the region and are mostly used for grazing and nature conservation.

Tenosols and rudosols are characterised by having a weak and minimal development. They show no or little change in texture and colour and are often shallow in depth. They also have low chemical fertility and have a low water-holding capacity, thus their agricultural potential is low. Both soil types are mostly present in areas used for nature conservation rather than for agriculture.

Kandosols are structureless soils which are often very deep, that is, up to 3 m or more. They do not have a strongly contrasting texture and they do not contain carbonate throughout their profile. They are low in chemical fertility and are well-drained with only moderate water holding capacity compared with other soil types; thus they only have low to moderate agricultural potential

Vertosols are mostly distributed between the northwest and northeast of the Tanami – Timor Sea Coast region. Vertosols are clay-rich soils which tend to crack when dry and swell during wetting. They are highly fertile and have a large water-holding capacity; however they must hold a significant amount of water before it becomes available to plants. In this region they are mostly used for grazing.

The other soil types that have minimal representation in the Tanami – Timor Sea Coast region are hydrosols, ferrosols, sodosols, chromosols, calcarosols and dermosols (0.8–3% of the total area).

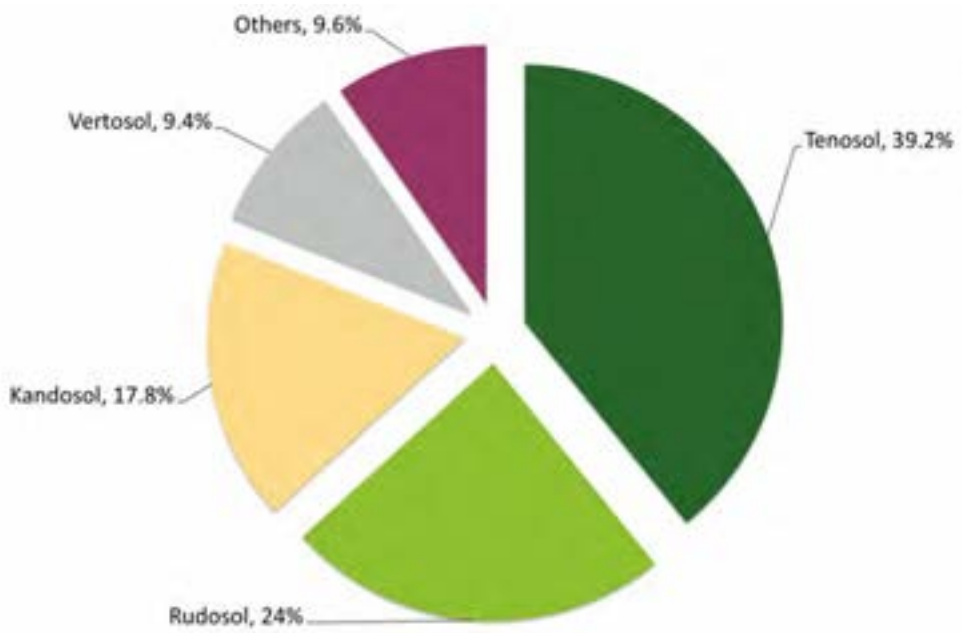


Figure 13.5 Soil types in the Tanami – Timor Sea Coast region

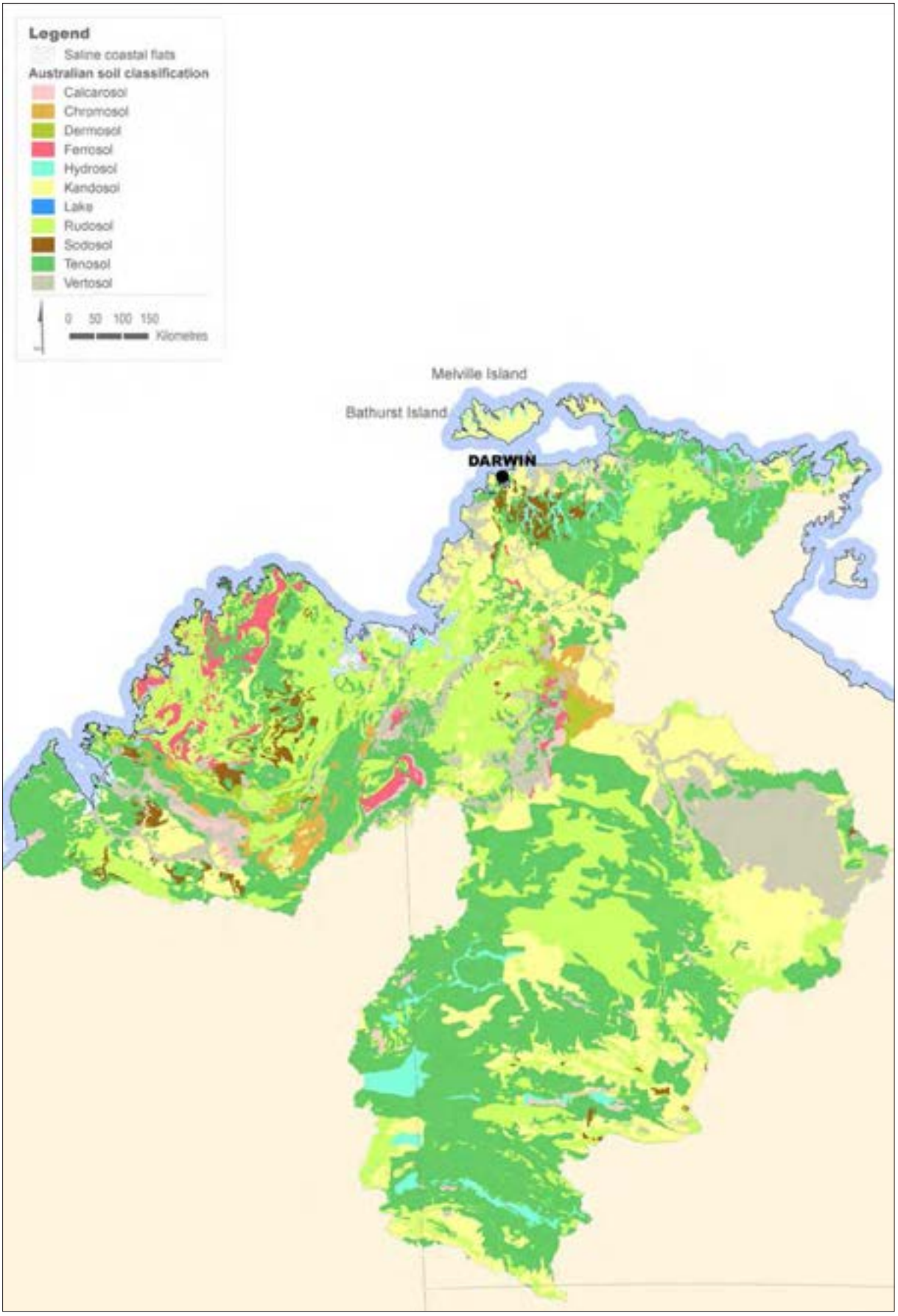


Figure 13.6 Soil type distribution in the Tanami – Timor Sea Coast region

13.3.5 Land use

Land use in the region consists mainly (more than 95%) of pasture and natural conservation (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml). Some of the most famous natural attractions in Australia are located in this region including the Kimberley and Kakadu National Park. Irrigated agriculture makes up less than 1% of the land use in the region, much of which is concentrated in the Ord River basin (Figure 13.7 and Figure 13.8). The main industries within the Ord River basin are agriculture, horticulture, tourism and mining.

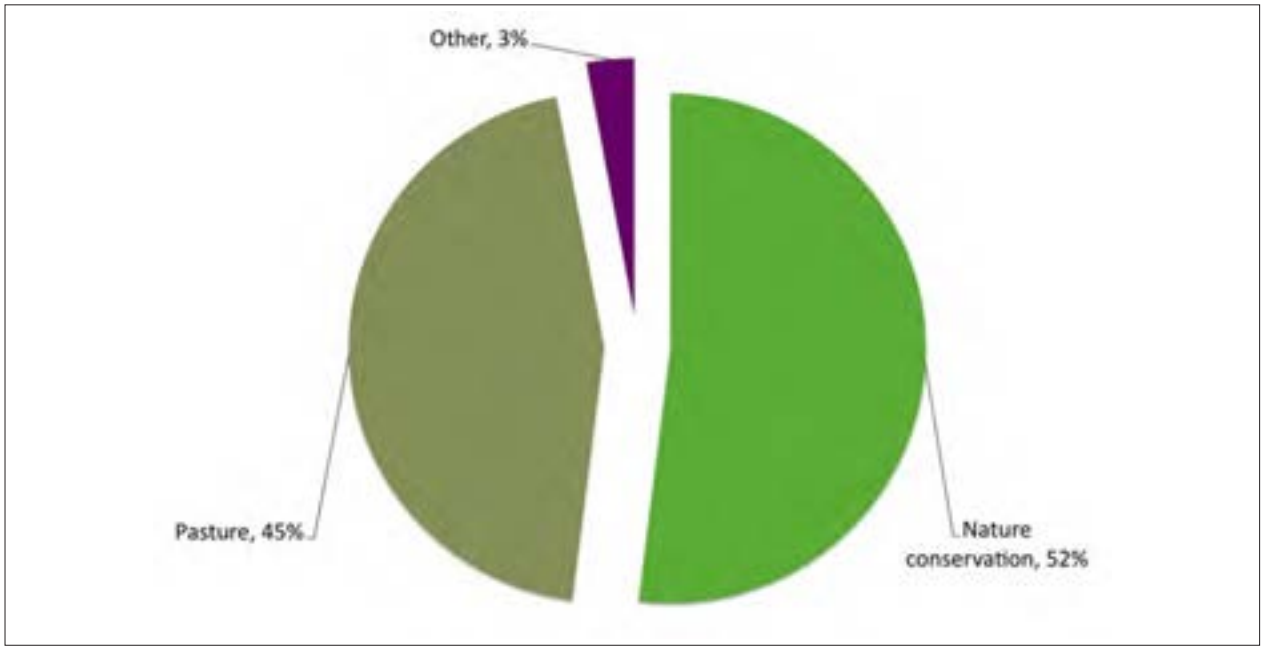


Figure 13.7 Land use in the Tanami – Timor Sea Coast region

Ord River valley | Simon Krzic (Dreamstime)

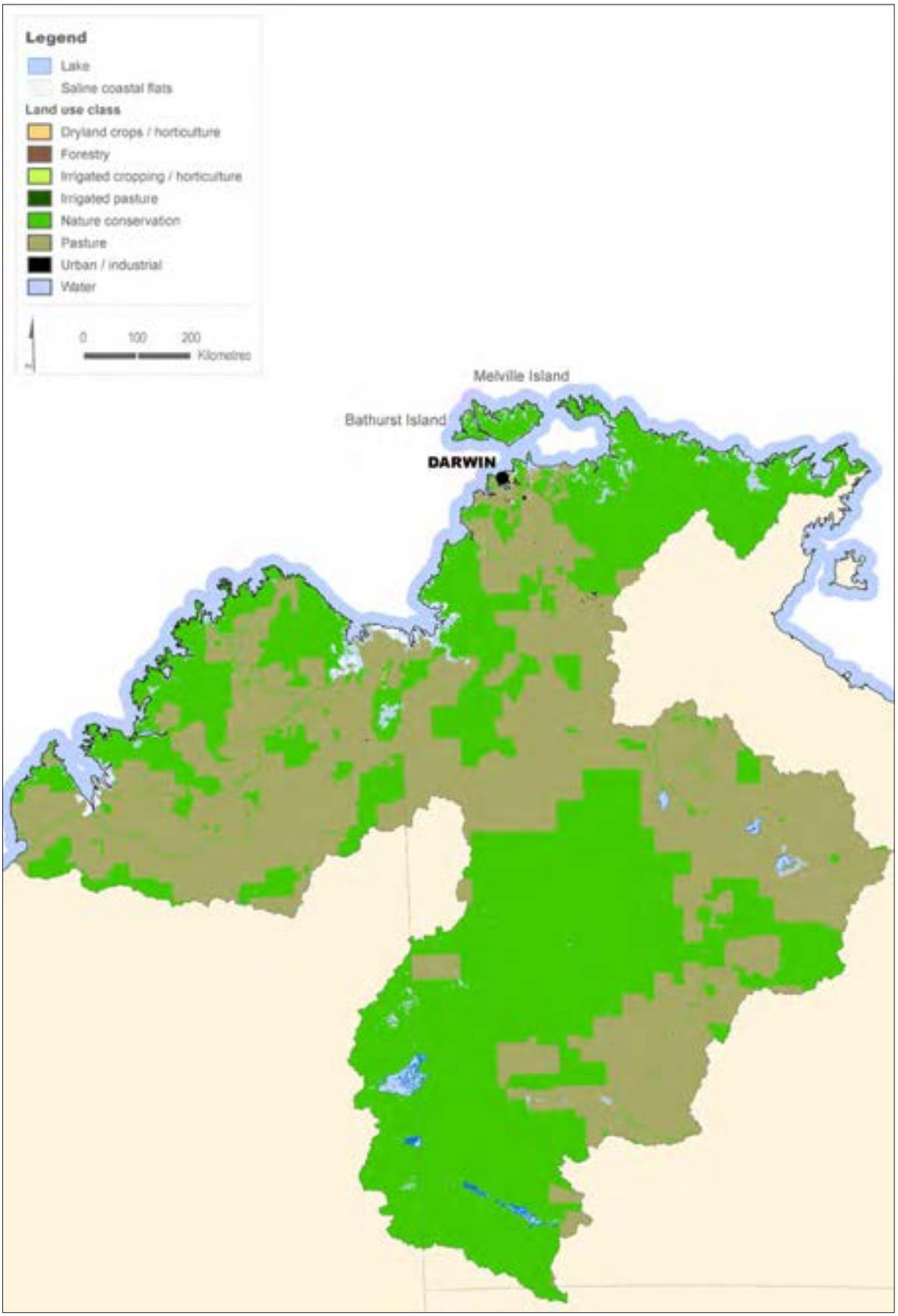


Figure 13.8 Land use distribution in the Tanami – Timor Sea Coast region

13.3.6 Population distribution

The Tanami – Timor Sea Coast region is one of the most sparsely populated in Australia. This is despite some populated centres on its coastline (Figure 13.9), and a number of smaller irrigation and mining centres (ABS 2011b).

Darwin, located in the far north, is the largest city in the region, followed by Broome, which is situated on its coastal western tip.

Outside of the major regional urban centres, mining leases, Indigenous communities and a number of small towns and settlements located adjacent to major roads in the region (including the Stuart, Kakadu and Arnhem highways) account for much of the remaining population.

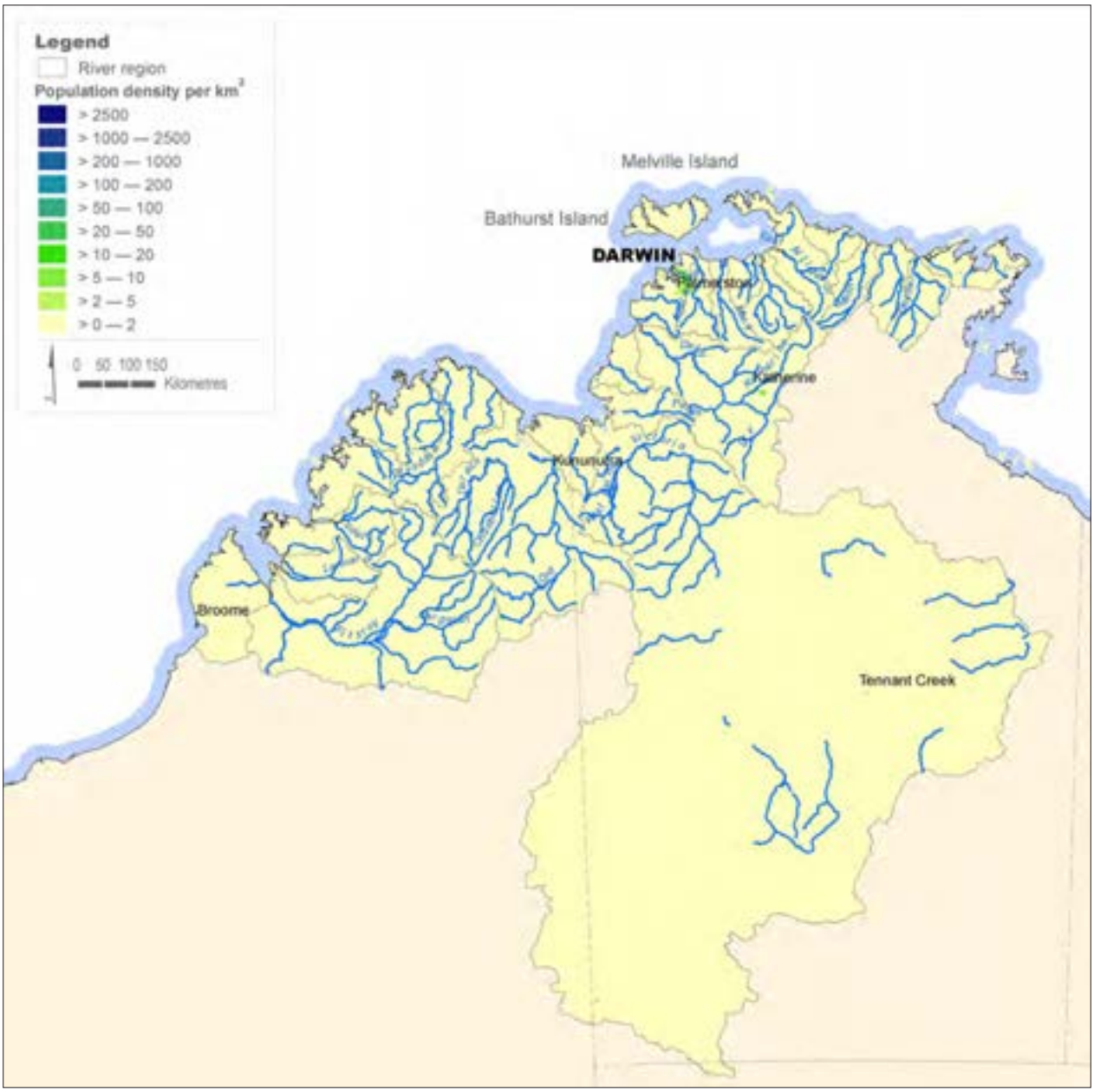


Figure 13.9 Population density and distribution in the Tanami – Timor Sea Coast region

13.3.7 Rainfall zone

The region extends across distinct climatic zones and is dominated by a humid tropical climate to the north and a very dry arid climate to the south. Median rainfall is variable throughout the region (Figure 13.10).

Rainfall in the north of the region is summer dominant. Monsoonal rain and tropical cyclones and depressions contribute to average annual rainfall totals exceeding 1,500 mm in the far north of the region. Moving inland from the coast, average annual rainfall totals gradually reduce.

In the south, the region includes a large component of the Australian dry inland area where average annual rainfall does not exceed 400 mm.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

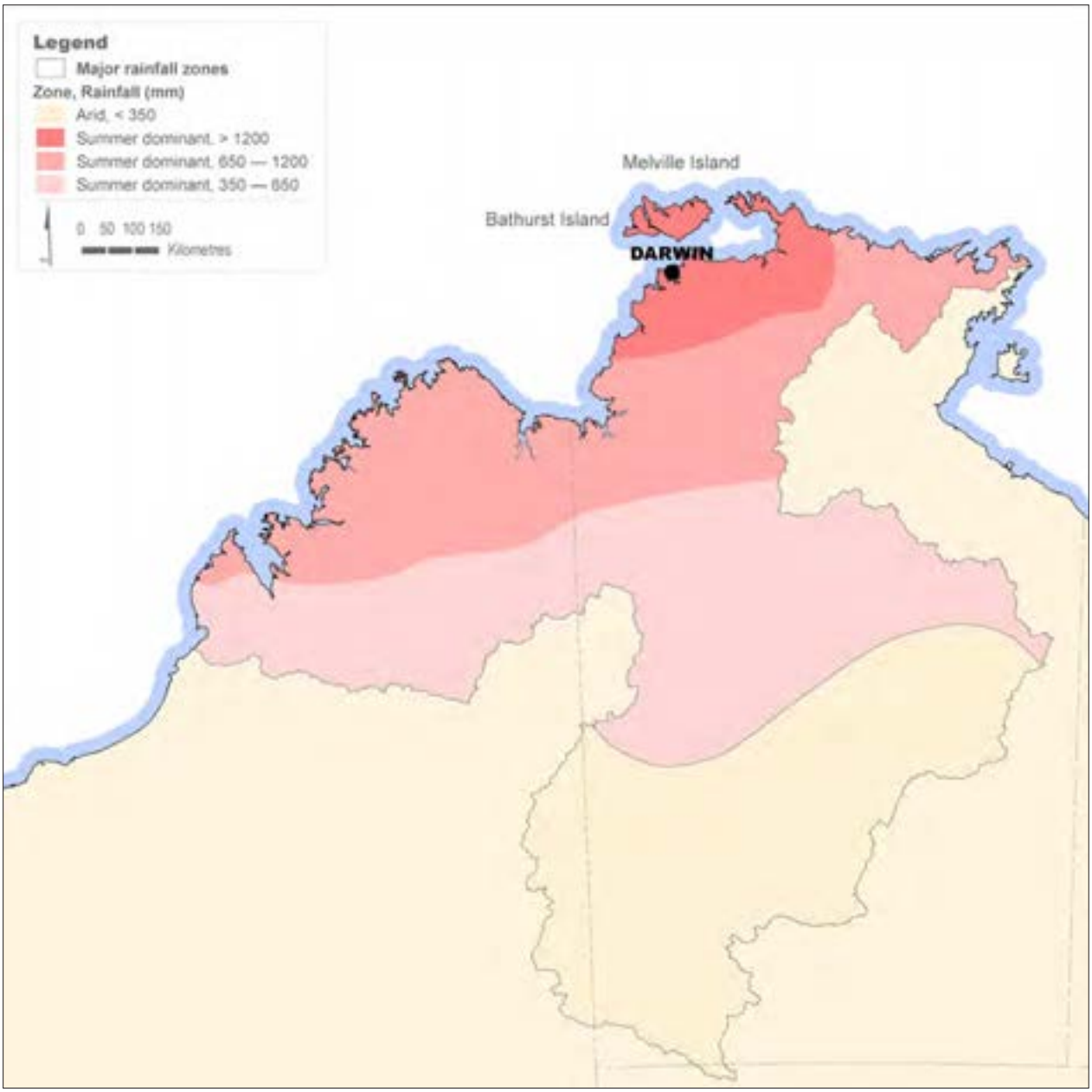


Figure 13.10 Rainfall zones in the Tanami – Timor Sea Coast region

13.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The Tanami – Timor Sea Coast region has a rather uniform pattern of high potential deficits over the whole region (Figure 13.11).

Due to the seasonality of rainfall in the north, with humid wet summers and dry, warm winters, there is a clear pattern of moisture deficits in the dry winter season and moisture recharge in the wet summer season; however, on an annual average basis, the potential evapotranspiration exceeds rainfall.

In the southern arid part of the region, rainfall deficits are high and, as a consequence, vegetation density is low. Most of the southern part of the region is covered by pasture, sparsely used for stock farming and nature conservation.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

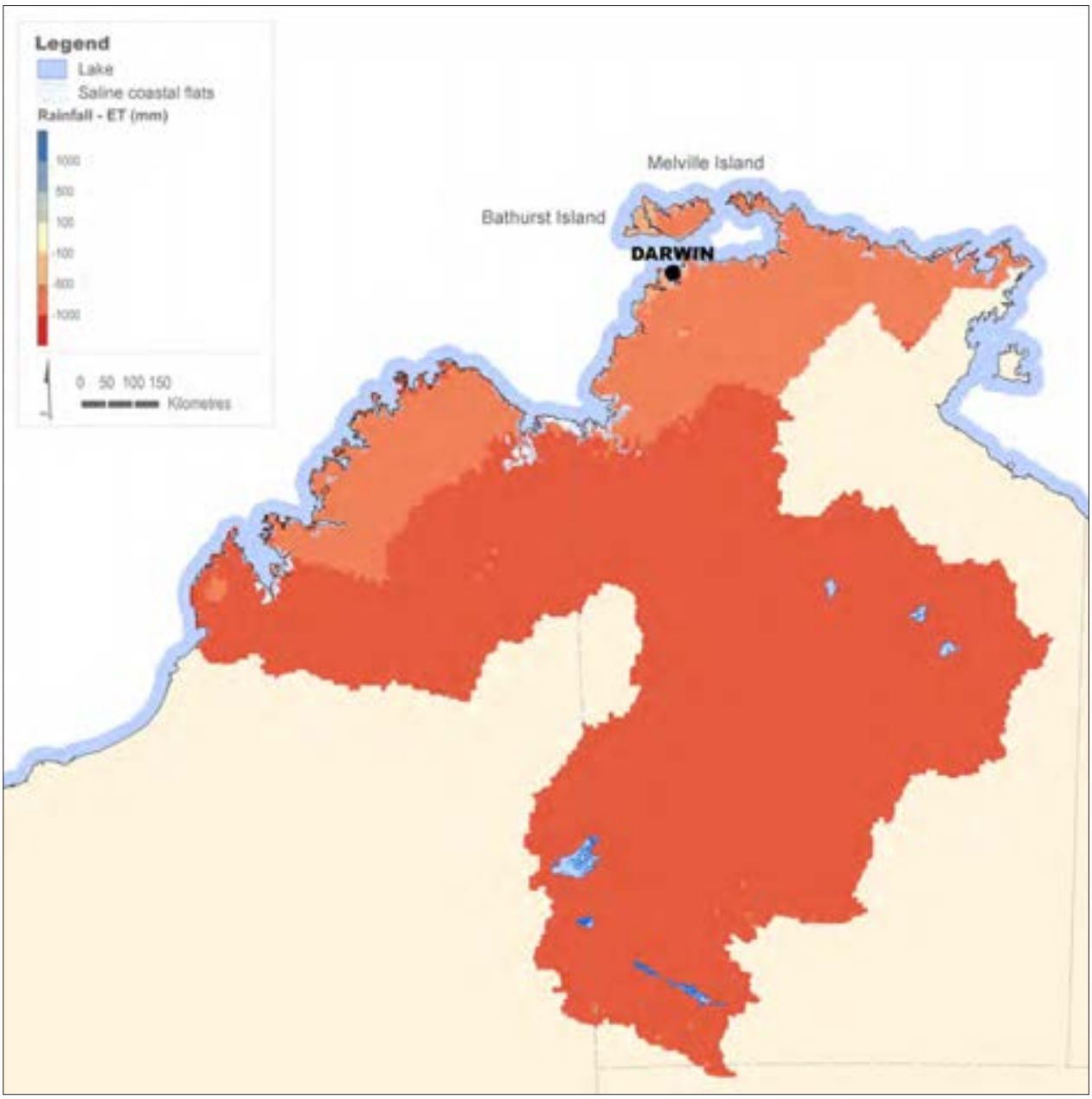


Figure 13.11 Rainfall deficit distribution for the Tanami – Timor Sea Coast region

13.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Tanami – Timor Sea Coast region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 13.12 shows that the region has a highly seasonal rainfall pattern with a wet summer period (November–April) and a dry winter period (May–October). Evapotranspiration in the dry season generally exceeds rainfall. After the wet season the soils normally contain a lot of moisture that is available for evapotranspiration.

The monthly landscape water yield history for the region shows a stable pattern of very low yield in the dry season. It gradually increases during December through to February and subsides in March and April.

The 2011–12 year was a relatively wet year, with the wet season starting particularly early. An active monsoon in the region's north contributed to particularly high rainfall totals for the month of March.

With wet soil conditions present in July 2011 and above average rain in October and November, evapotranspiration was above average for the first six months of 2011–12. After the March rainfall, evapotranspiration again remained above the 75th percentile until June 2012.

The landscape water yield for 2011–12 closely followed the monthly rainfall pattern. Landscape water yield in March was the fourth highest on record (1911–2012), following the seventh highest, as a consequence of the seventh highest rainfall on record for that month.

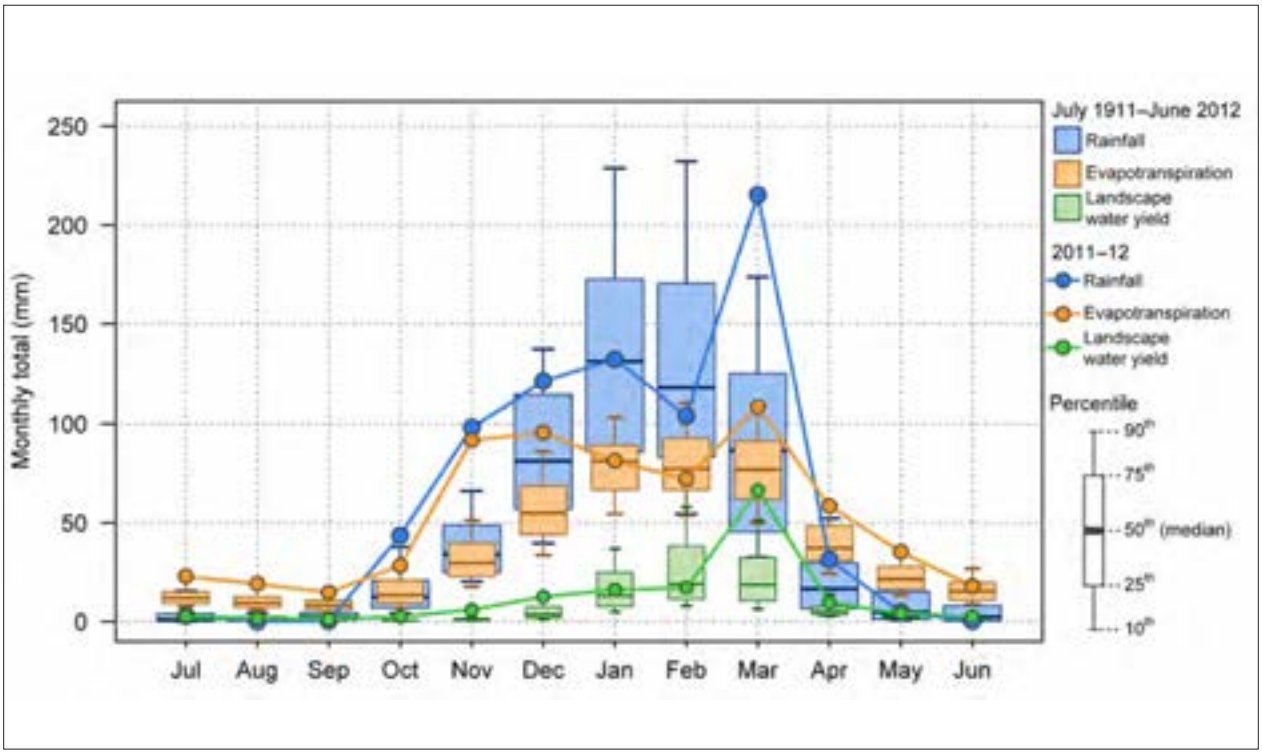


Figure 13.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the Tanami – Timor Sea Coast region

13.4.1 Rainfall

Rainfall for the Tanami – Timor Sea Coast region for 2011–12 is estimated to be 754 mm. This is 35% above the region's long-term average (July 1911–June 2012) of 559 mm. Figure 13.13a shows that the highest rainfall occurred in the tropical north with annual totals exceeding 1,200 mm in many areas for 2011–12. The Tanami district in the south had rainfall not exceeding 600 mm.

The high data uncertainty areas in the map indicate those areas where rain gauge density is too low to accurately capture localised rainfall, often in the form of localised thunderstorms.

Rainfall deciles for 2011–12 indicate average to above average rainfall for the entire region over the course of the year (Figure 13.13b). Scattered throughout the region are areas with very much above average rainfall.

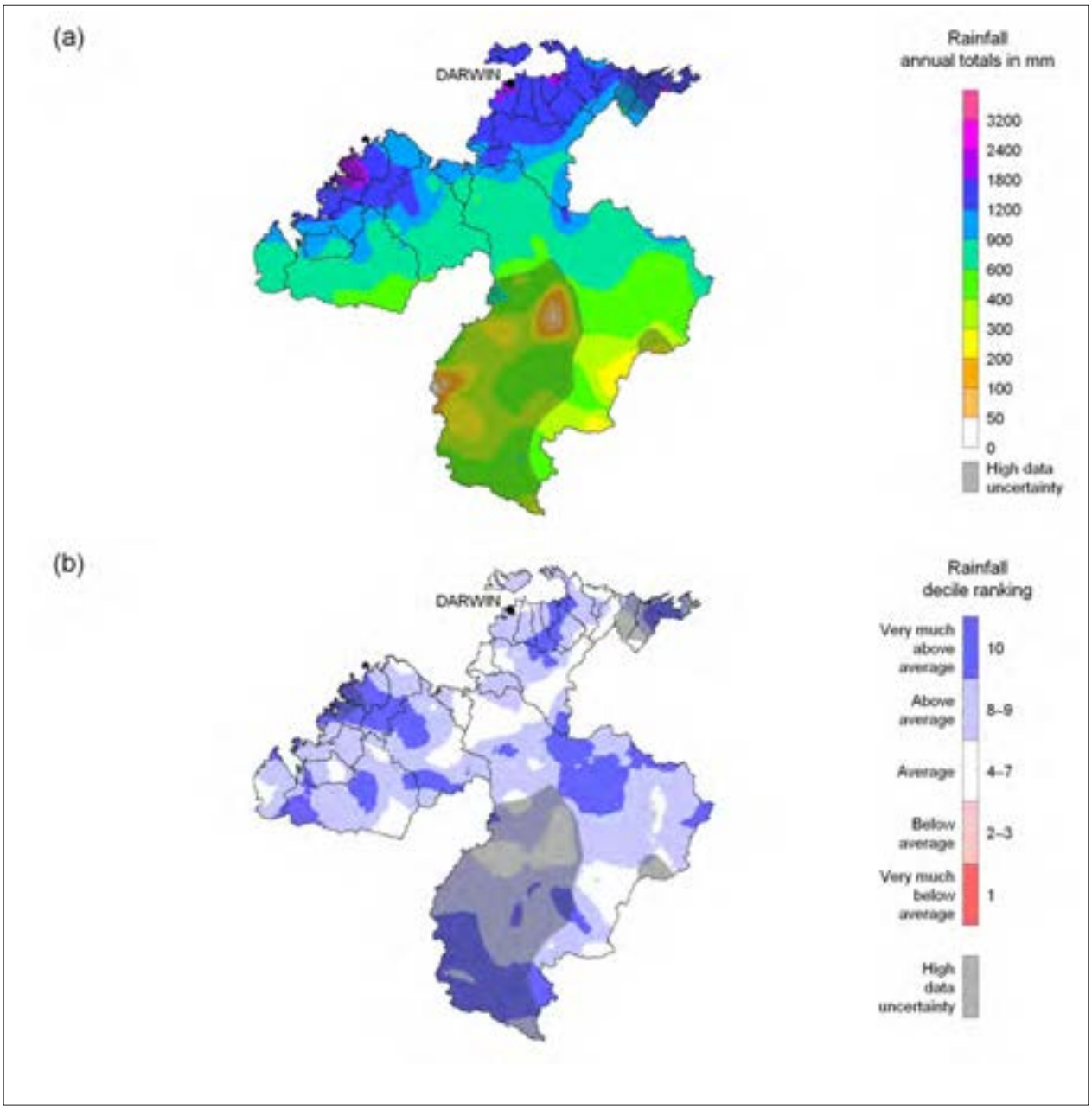
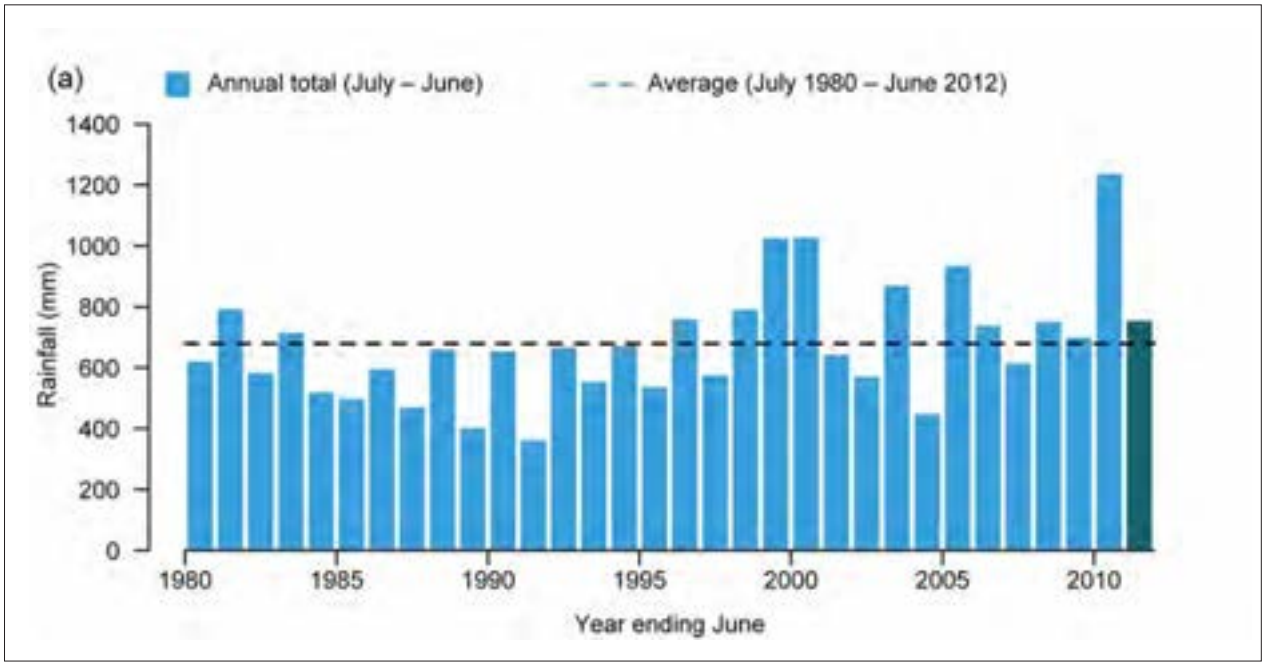


Figure 13.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Tanami – Timor Sea Coast region

Rainfall variability in the recent past

Figure 13.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 679 mm, varying from 362 mm (1991–92) to 1,236 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 13.14b.

The graphs indicate the presence of a rising trend in average rainfall over the region from 1990 onwards; however, the last six years had close to average rainfall in the region with only 2010–11 having exceptionally high rainfall.



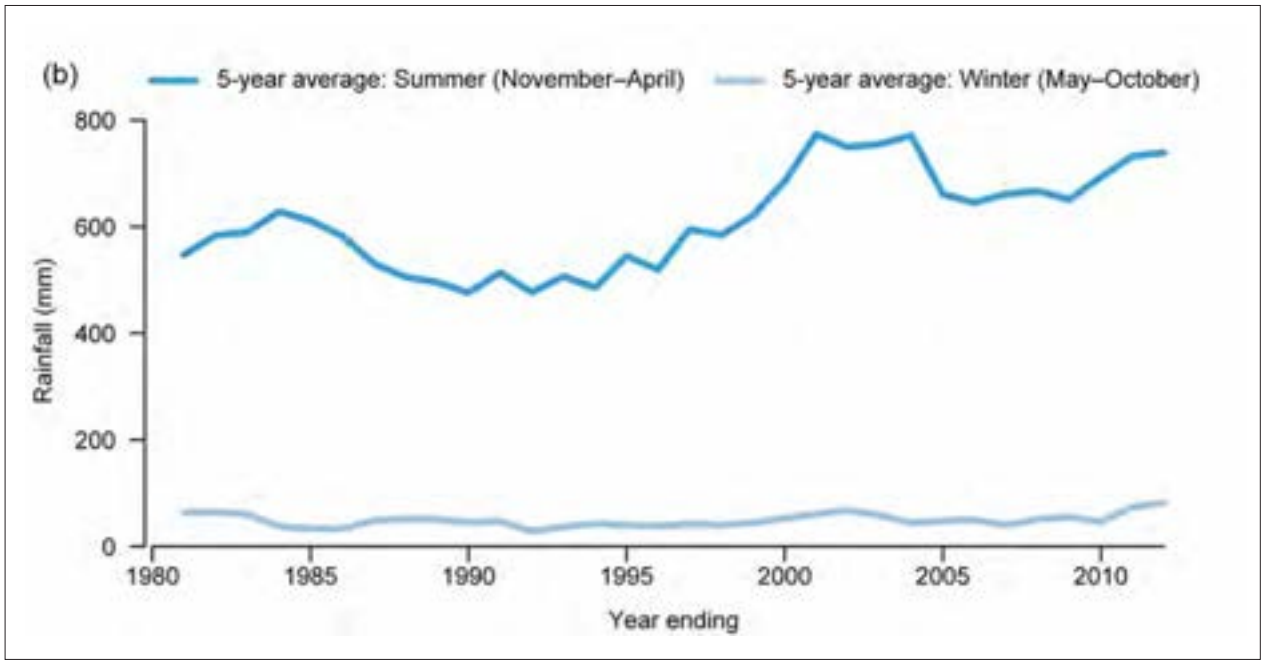


Figure 13.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) periods for the Tanami – Timor Sea Coast region

Recent trends in rainfall

Figure 13.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell.

The statistical significance of the trends is provided in Figure 13.15b.

Figure 13.15a shows that since 1980 a strong increase in rainfall has occurred in large parts of the region, particularly towards the north. Some areas reached trends of up to 20 mm/year. The trends are strongly significant in most of these areas (Figure 13.15b).

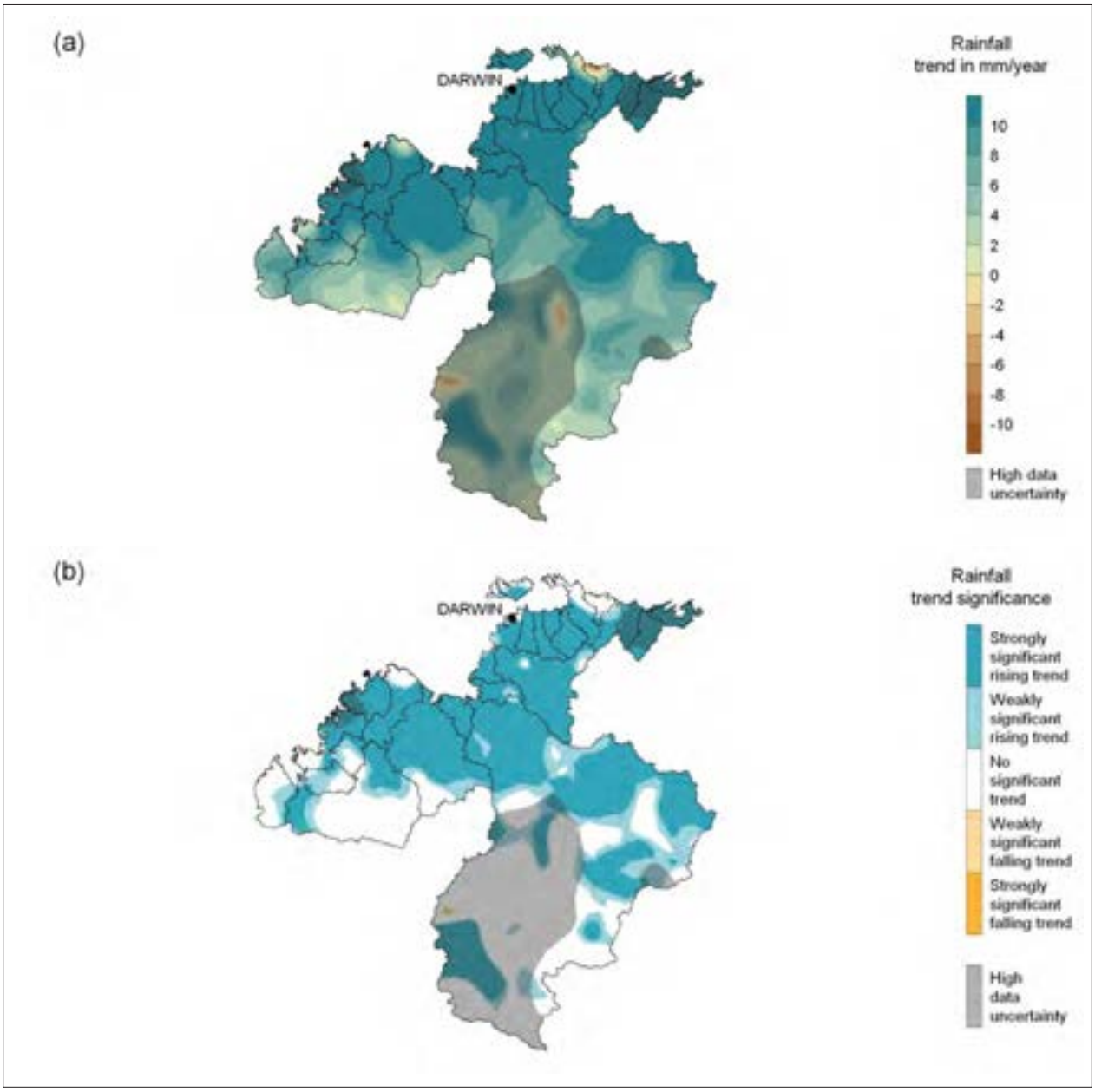


Figure 13.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tanami – Timor Sea Coast region

13.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Tanami – Timor Sea Coast region for 2011–12 is estimated to be 646 mm. This is 40% above the region's long-term (July 1911–June 2012) average of 461 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 13.16a) is similar to that of rainfall (Figure 13.14a), but with lower annual totals in the north of the region.

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 13.16b). The larger areas of very much above average evapotranspiration in comparison to rainfall was made possible by the high soil moisture levels at the start of the year, due to record high rainfall the previous year, which allowed evapotranspiration to be higher than average in the dry months of July– September 2011 (see Figure 13.12).

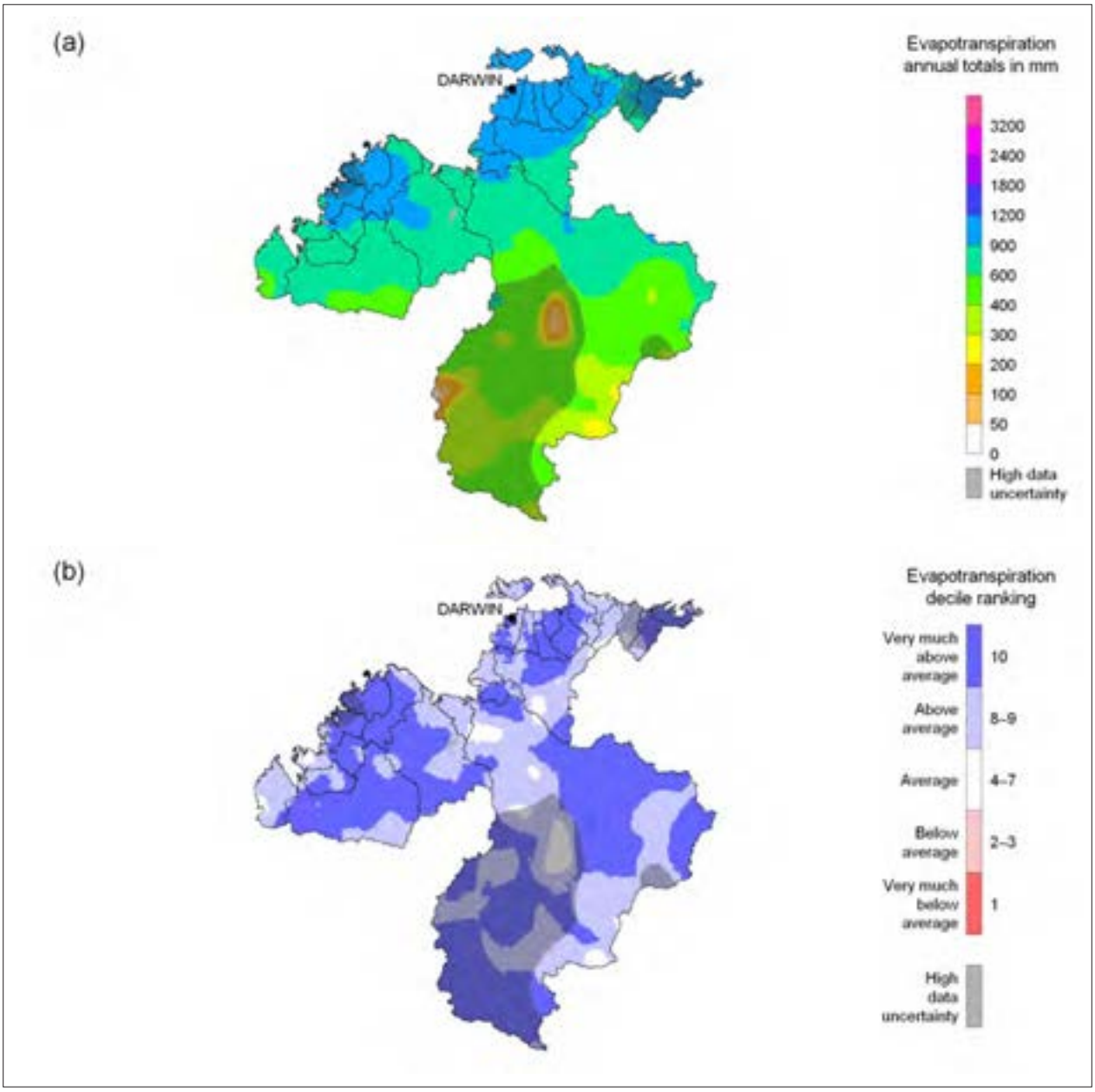


Figure 13.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Tanami – Timor Sea Coast region

Evapotranspiration variability in the recent past

Figure 13.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 541 mm, varying from 379 mm (1991–92) to 807 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 13.17b.

The wet period (November–April) shows consistently higher evapotranspiration than the dry period. Evapotranspiration in the dry period is substantially higher than rainfall in this period (Figure 13.14b), whereas evapotranspiration in the wet period is substantially lower than rainfall in this period.

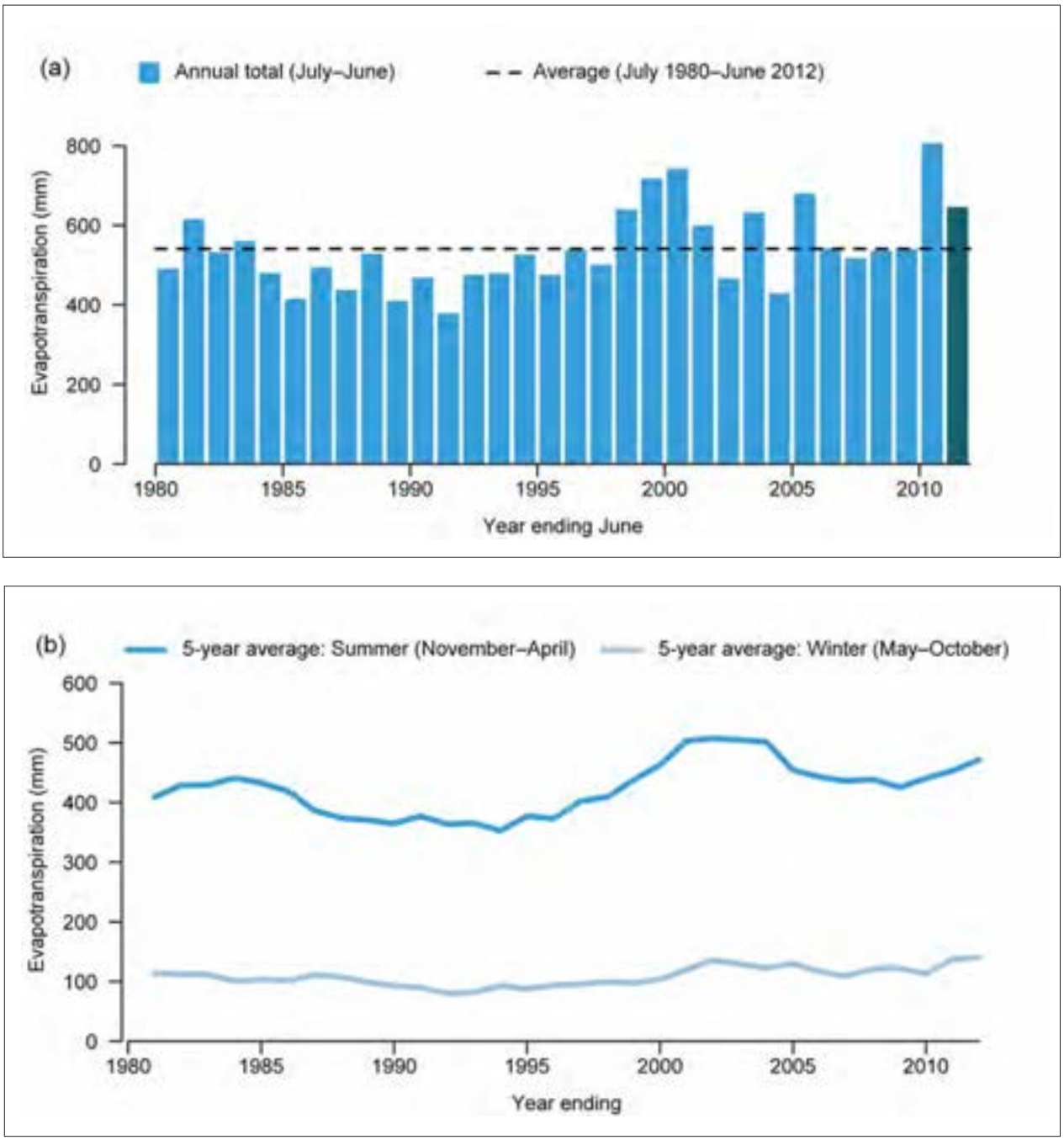


Figure 13.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) periods for the Tanami – Timor Sea Coast region

Recent trends in evapotranspiration

Figure 13.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 13.18b.

The trends in evapotranspiration are rising throughout the region with some local exceptions along the northern coastline. As shown in Figure 13.18b, the trends are statistically significant in most parts of the region, particularly in those areas where the rising trends are high.

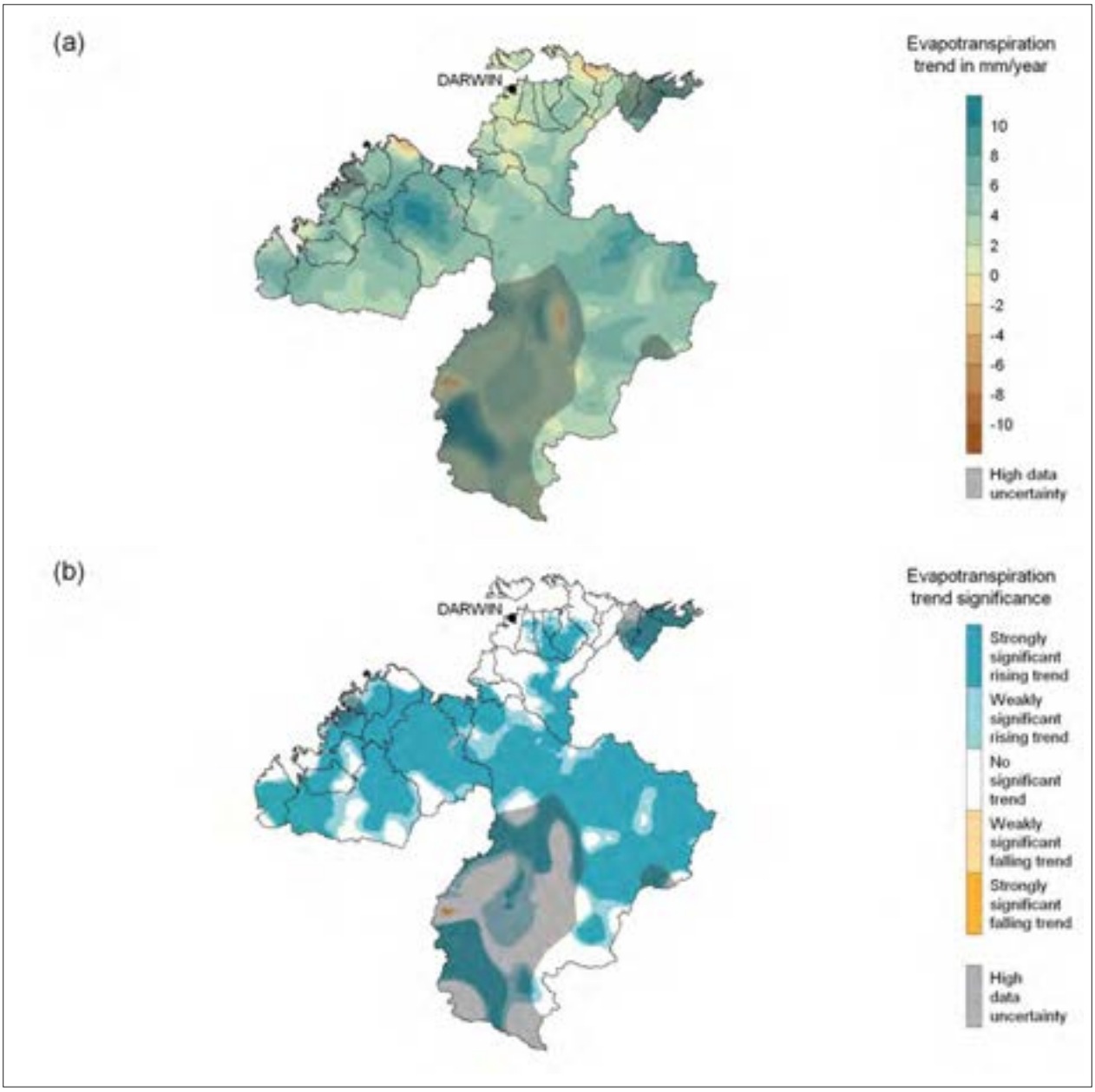


Figure 13.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tanami – Timor Sea Coast region

13.4.3 Landscape water yield

Modelled landscape water yield for the Tanami – Timor Sea Coast region for 2011–12 is estimated to be 142 mm. This is 53% above the region's long-term (July 1911– June 2012) average of 93 mm. Figure 13.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 13.13a).

The highest landscape water yields in 2011–12 are observed in some areas along the coast, locally exceeding 600 mm. In the southern Tanami district landscape water yield did not exceed 50 mm.

The decile-ranking map for 2011–12 (Figure 13.19b) shows average to above average landscape water yields, which again shows high similarity with the rainfall decile map of Figure 13.13b.

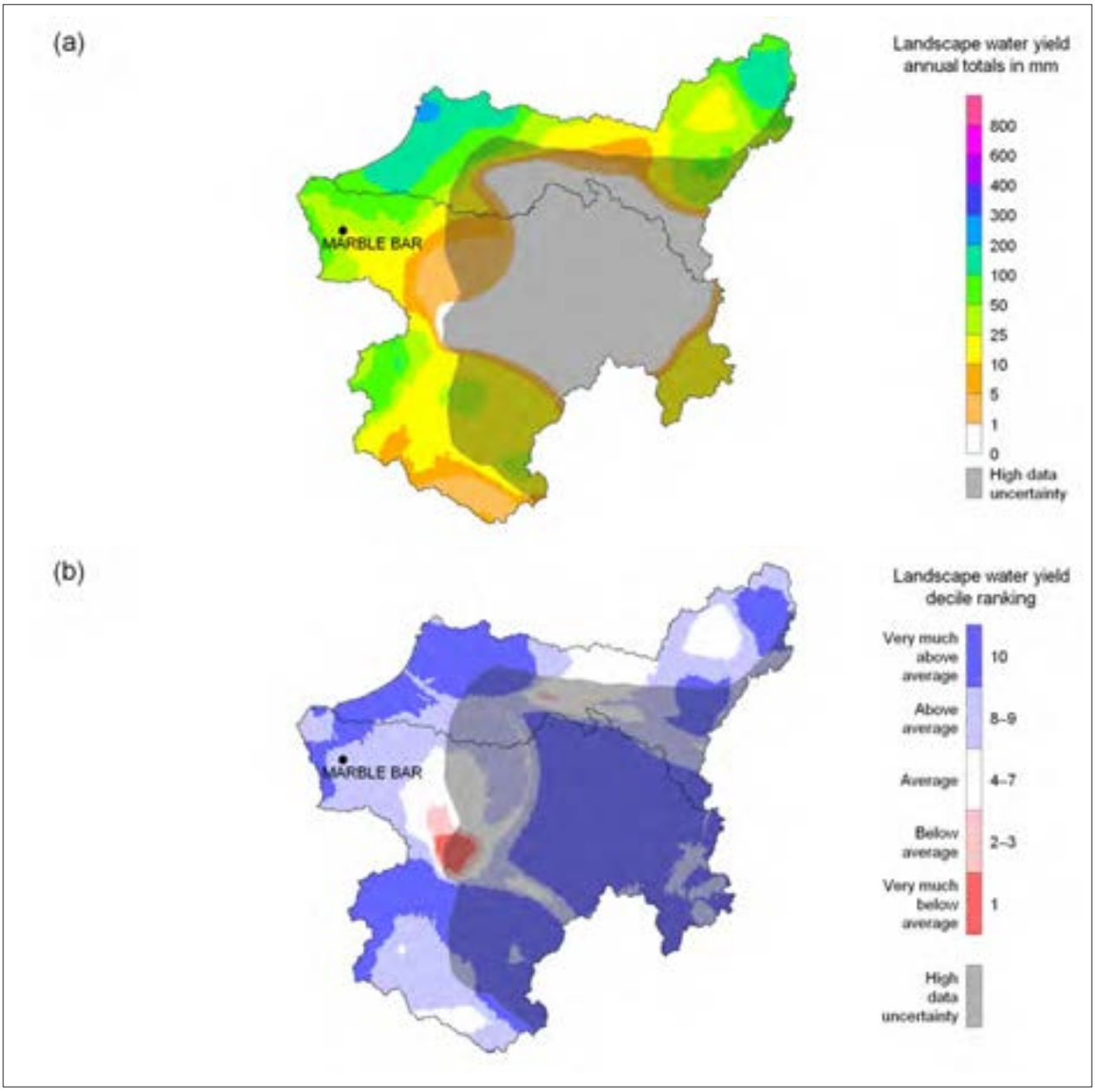


Figure 13.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Tanami – Timor Sea Coast region

Landscape water yield variability in the recent past

Figure 13.20a shows annual landscape water yield for the Tanami – Timor Sea Coast region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 132 mm, varying from 30 mm (1989–90) to 377 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 13.20b.

Landscape water yield in 2010–11 was very much above average, but even without this exceptional year the general trend in regional average annual landscape water yield shows a rising trend since 1990. This can be totally allocated to increased rainfall in the wet period. In the first half of the reference period, only three years reached total annual landscape water yields that were above the periods average, albeit only marginally.

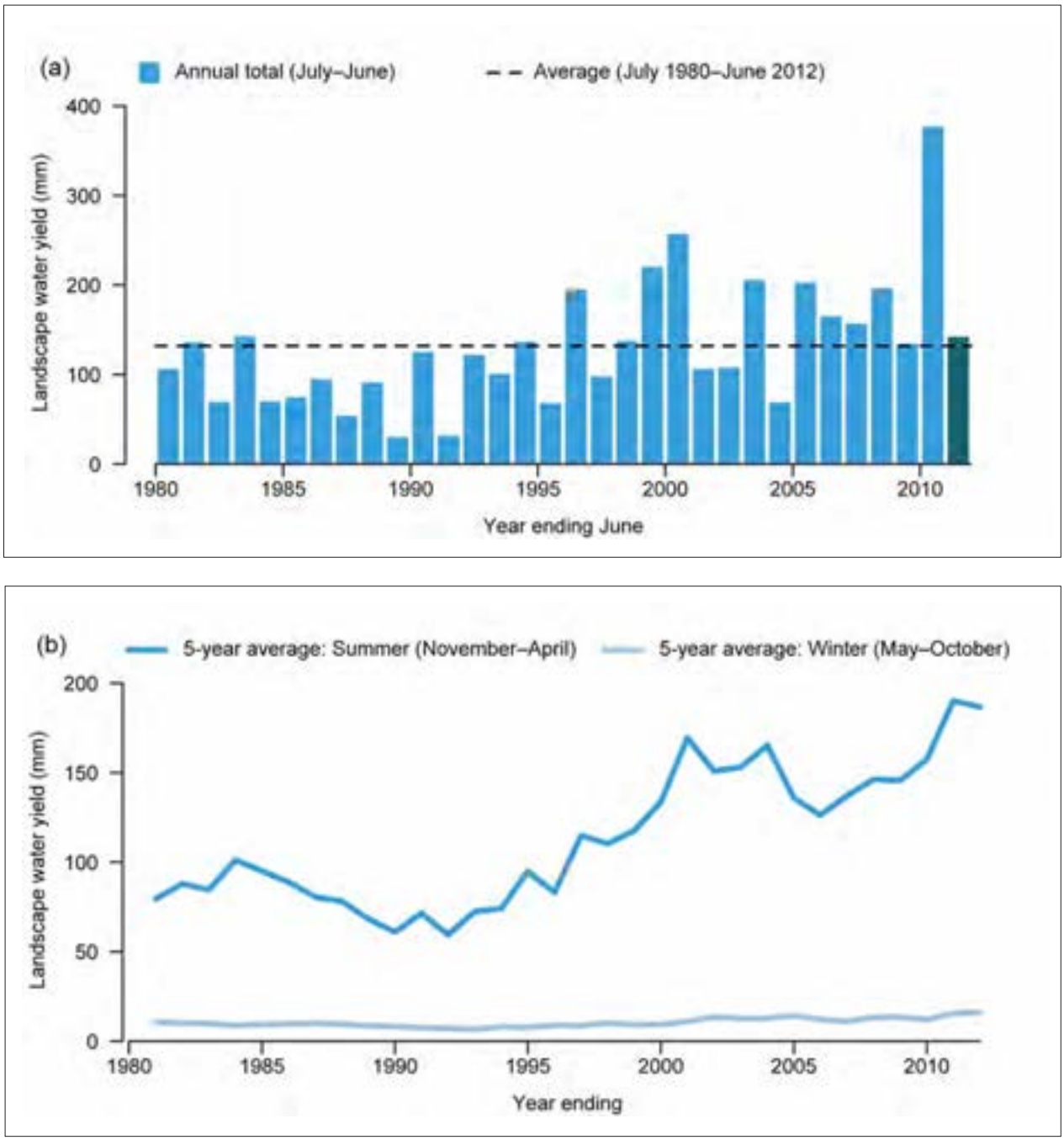


Figure 13.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) periods for the Tanami – Timor Sea Coast region

Recent trends in landscape water yield

Figure 13.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 13.21b. Figure 13.21a shows strong rising trends occur in the north of the region. In some areas these trends exceed 16 mm/year.

As well as the trends being statistically significant in the north, a large area of strongly significant rising trends is also present in the central east of the region. With much lower landscape water yield in this part of the region, the small rise in annual totals is still statistically significant.

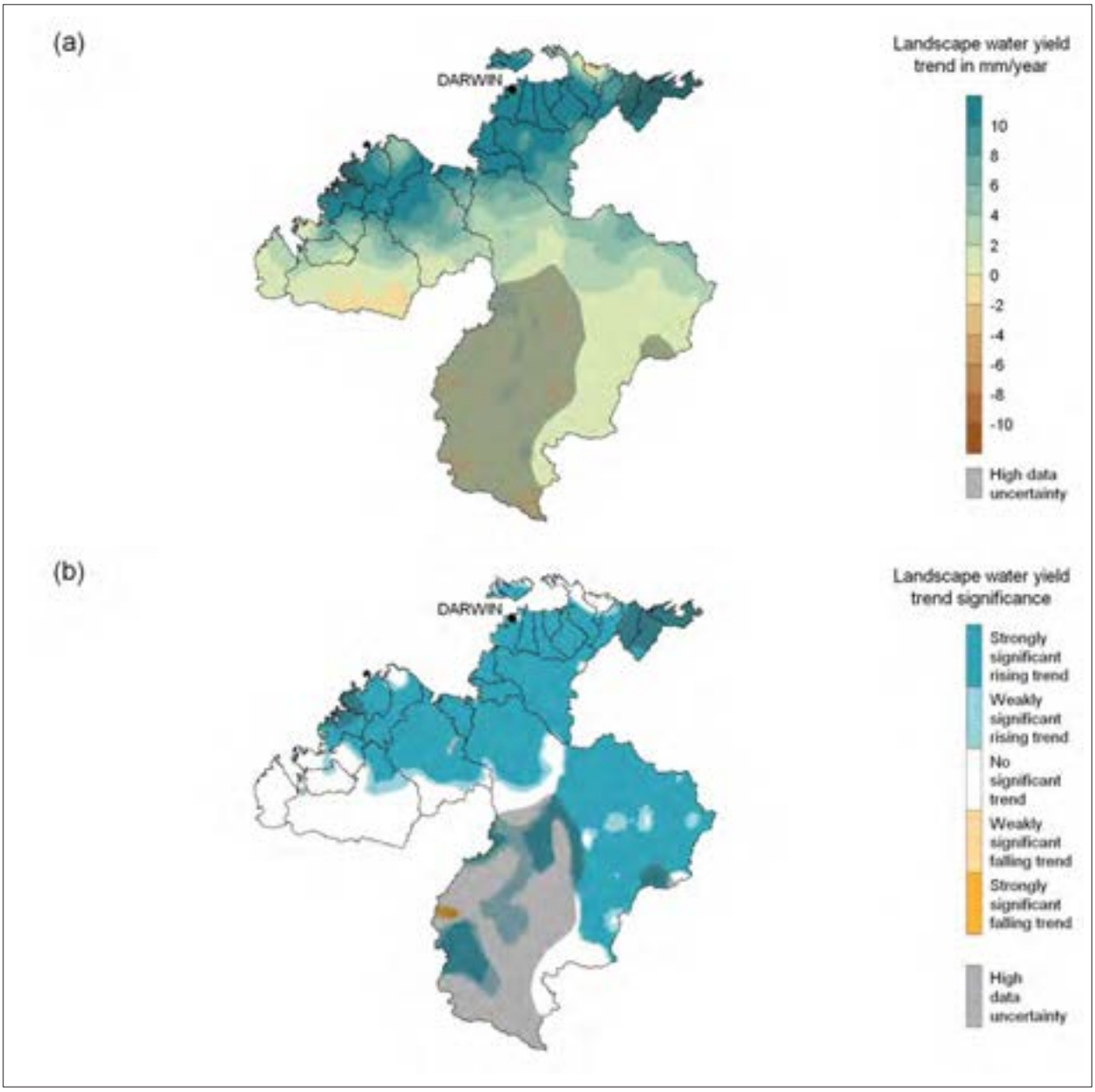


Figure 13.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Tanami – Timor Sea Coast region

13.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Tanami – Timor Sea Coast region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

13.5.1 Rivers

There are 25 river basins in the Tanami – Timor Sea Coast region, varying in size from 4,800 to 670,000 km^2 (Figure 13.22).

Major river basins of the region are the Ord, Daly, Fitzroy, Victoria and Finniss. The topography of the region generates two dominant drainage patterns.

There is a complex network of floodplain rivers that flow north to the Timor Sea. The inland Victoria River–Wiso catchment, however, covers the Tanami Desert, with several ephemeral rivers draining southwards to temporarily fill inland ephemeral lakes, depending on the scale and intensity of rainfall and run-off.

River flows in the tropical northern parts of the region experience distinct seasonal patterns with approximately 90% of the average annual discharge occurring in the four-month wet season from December–March. One of the largest rivers, the Ord River with an approximate length of 650 km, has its headwaters in the Dixon Range near Hill's Creek. The flow at the headwaters is seasonal, but has become perennial below Lake Argyle. This is due to agricultural developments in this area and flow modifications for irrigation supply.The lower section of the Ord River is a large tidal estuary.

Katherine Gorge | photosbyash (iStockphoto)

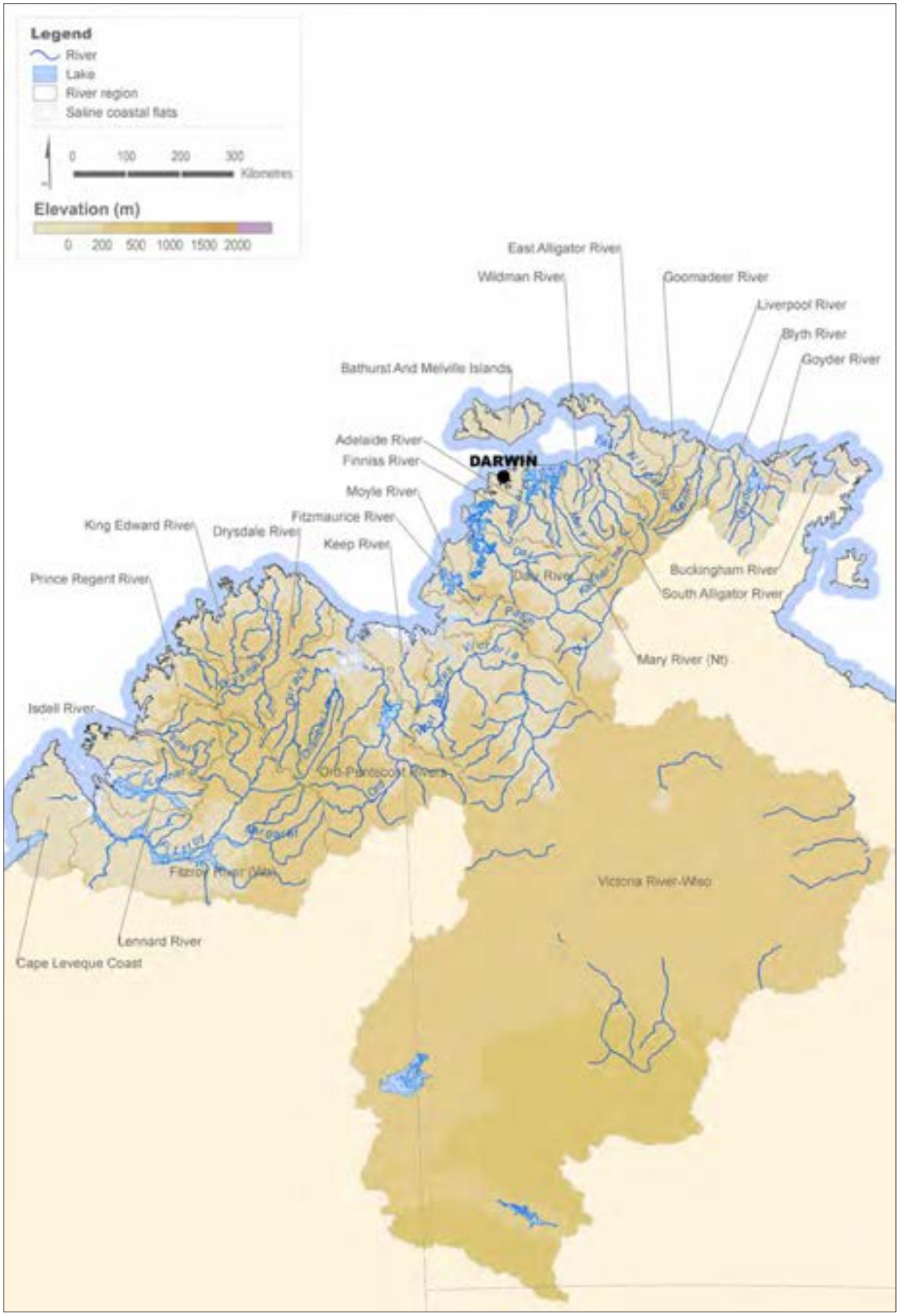


Figure 13.22 Rivers and catchments in the Tanami – Timor Sea Coast region

13.5.2 Streamflow volumes

River monitoring gauges are relatively sparsely distributed in the Tanami – Timor Sea Coast region due to the low population. Figure 13.23 presents an analysis of flows at 13 monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring gauges with relatively long records across five geographically representative rivers were selected (see Technical Supplement for details). The annual flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows generally reflect the mostly average to above average modelled landscape water yield results shown in Figure 13.19b.

Very much above average flows were observed at one monitoring site located on the Douglas River in the central north of the Tanami – Timor Sea Coast region. Above average total flows were recorded at three monitoring sites. These were mainly located on the rivers in the north of the region.

Average flows occurred at eight sites in the region which were located on the rivers in the region's central north. Of the 13 monitoring sites, there was only one below average flow recorded across the region in 2011–12. This one monitoring site was on Rapid Creek, a flash flood system in the far north.

Flow deciles in the wet season (November 2011–April 2012) were similar to total annual flows for 2011–12 as shown in Figure 13.23. Wet season high river levels are the typical pattern for flows in this part of Australia, especially in the region's north. There were a few monitoring sites that did not show this general pattern of high wet season flows. Lower flows during this period were recorded for the Katherine and the Douglas rivers in the central north of the region.

Suitable salinity data were not available during this period. Therefore, streamflow salinity analysis is not included in the chapter.

13.5.3 Flooding

Figure 13.24 shows that some moderate flooding occurred at the monitored river gauge sites, associated with heavy rainfalls in January and March. The most significant flood occurred in the Daly River south of Darwin.

Other rivers had a minor flood level measured during 2011–12, but most rivers remained below flood levels.

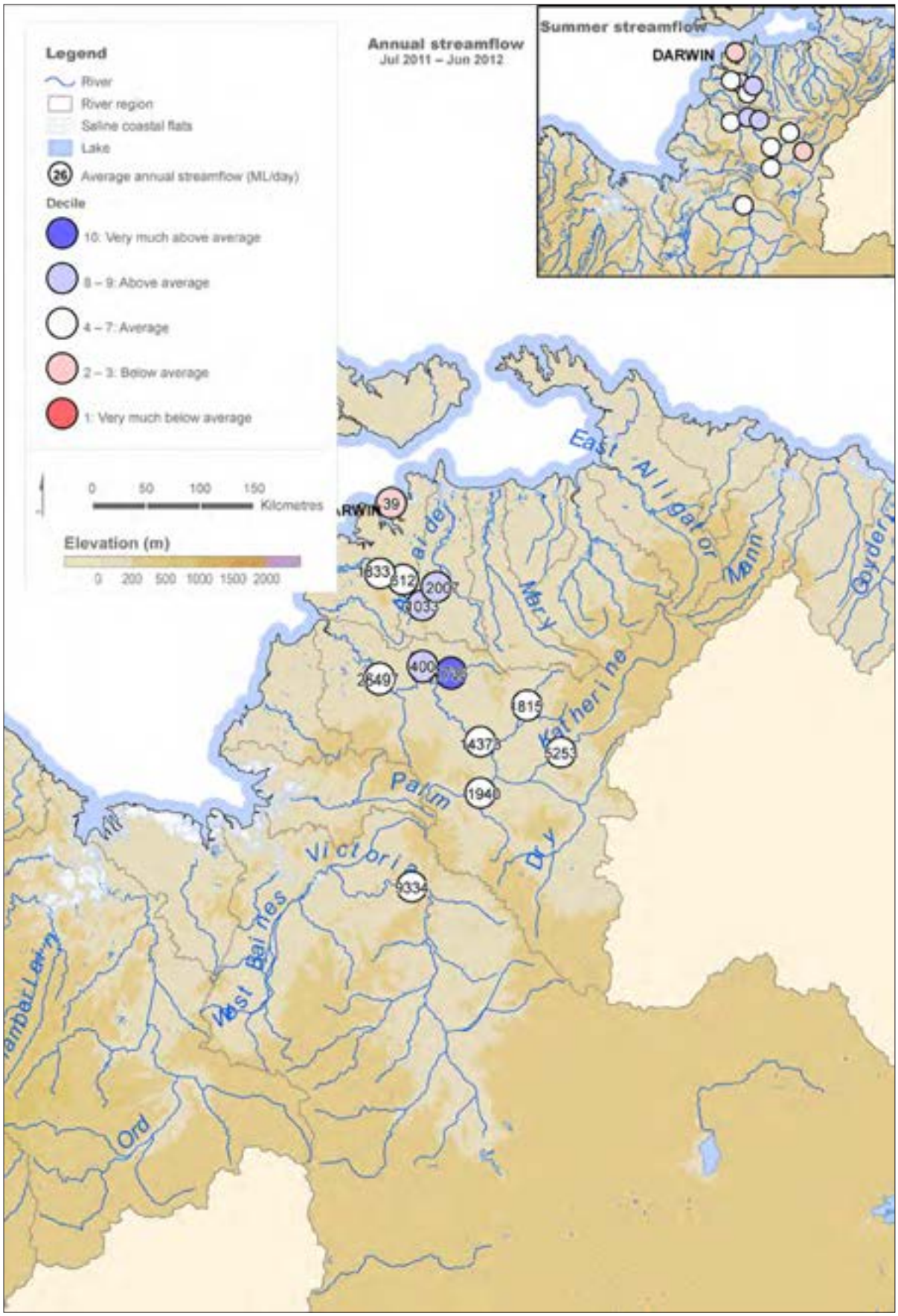


Figure 13.23 Average annual and wet season (November 2011–April 2012) flow volumes at monitoring sites for 2011–12 and their decile rankings over the 1980–2012 period in the Tanami – Timor Sea Coast region

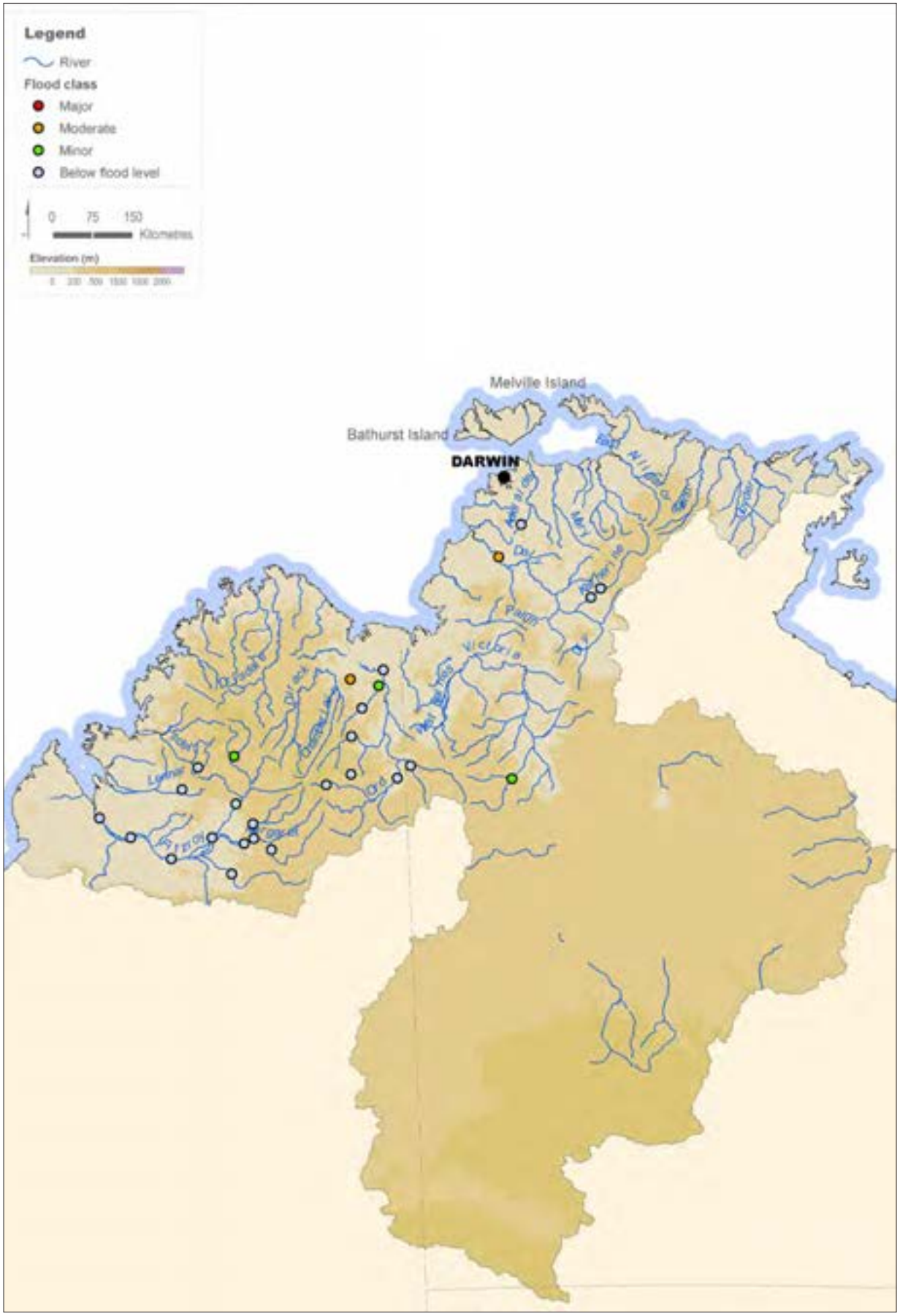


Figure 13.24 Flood occurrence in 2011–12 for the Tanami – Timor Sea Coast region

13.5.4 Storage systems

There are ten major, publicly owned, storages in the Tanami – Timor Sea Coast region with a total storage capacity in excess of 11,200 GL. The Bureau's water storage website includes information on approximately 96% of the region's publicly owned storages (as at August 2012).

The major storages in the region supply the Ord irrigation scheme and the city of Darwin. Table 13.3 gives a summary of the region's major storage systems together with an overview of the storage levels at the end of 2010–11 and 2011–12. Storage volumes reflect the situation in the middle of the dry season. The location of all the systems and associated storages are shown in Figure 13.25.

Lake Argyle, the major storage in the Ord irrigation scheme with an accessible capacity of 10,400 GL, is the second largest storage of Australia, after Lake Gordon in Tasmania, and is the result of a major plan to increase the generally abundant water resources in the north of the country. During 2011–12, the storage volumes were much above full supply level and spilling, with the exception of February 2012 and the end of June 2012.

The Darwin River storage also has no water shortage and hence the city of Darwin has no water conservation rules in place. The storage was filled up to full supply level during the wet season.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website (http://water.bom.gov.au/waterstorage/awris/).

13.5.5 Wetlands

There are five Ramsar-listed, internationally important wetlands in the Tanami – Timor Sea Coast region as well as a number of wetlands of national importance mentioned in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html).

The wetlands mainly consist of river floodplains and estuaries as well as inland ephemeral lakes (Figure 13.26). The artificial lakes Argyle and Kununurra are listed under the Ramsar convention.

No detailed assessment on the inflows of selected wetlands has been performed for this region.

Table 13.3 Storage systems in the region as identified in the Bureau's water storage information (August 2012), with 'non-allocated' accounting for the storages not allocated to a particular system

System name	System type	System capacity	Accessible volume at 30 June 2011	Accessible volume at 30 June 2012
Ord	rural	10,446 GL	10,440 GL—100%	10,286 GL—98%
Darwin	urban	285 GL	268 GL—94%	262 GL—92%
Non-allocated	—	1.8 GL	1.7 GL—94%	1.7 GL—94%
Total		10,733 GL	10,710 GL—100%	10,549 GL—98%

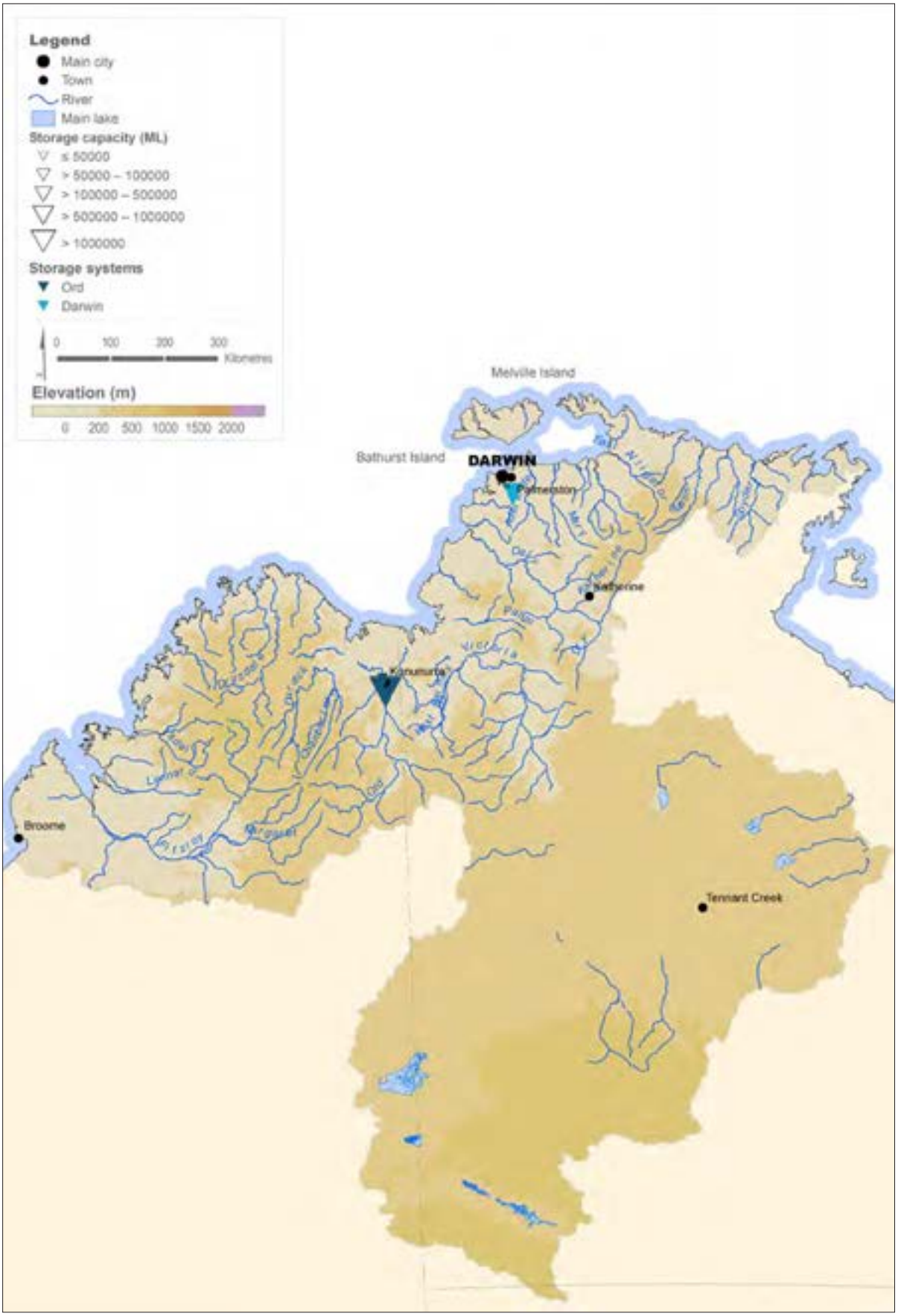


Figure 13.25 Storage systems in the Tanami – Timor Sea Coast region (information extracted from the Bureau of Meteorology's water storage website in August 2012)

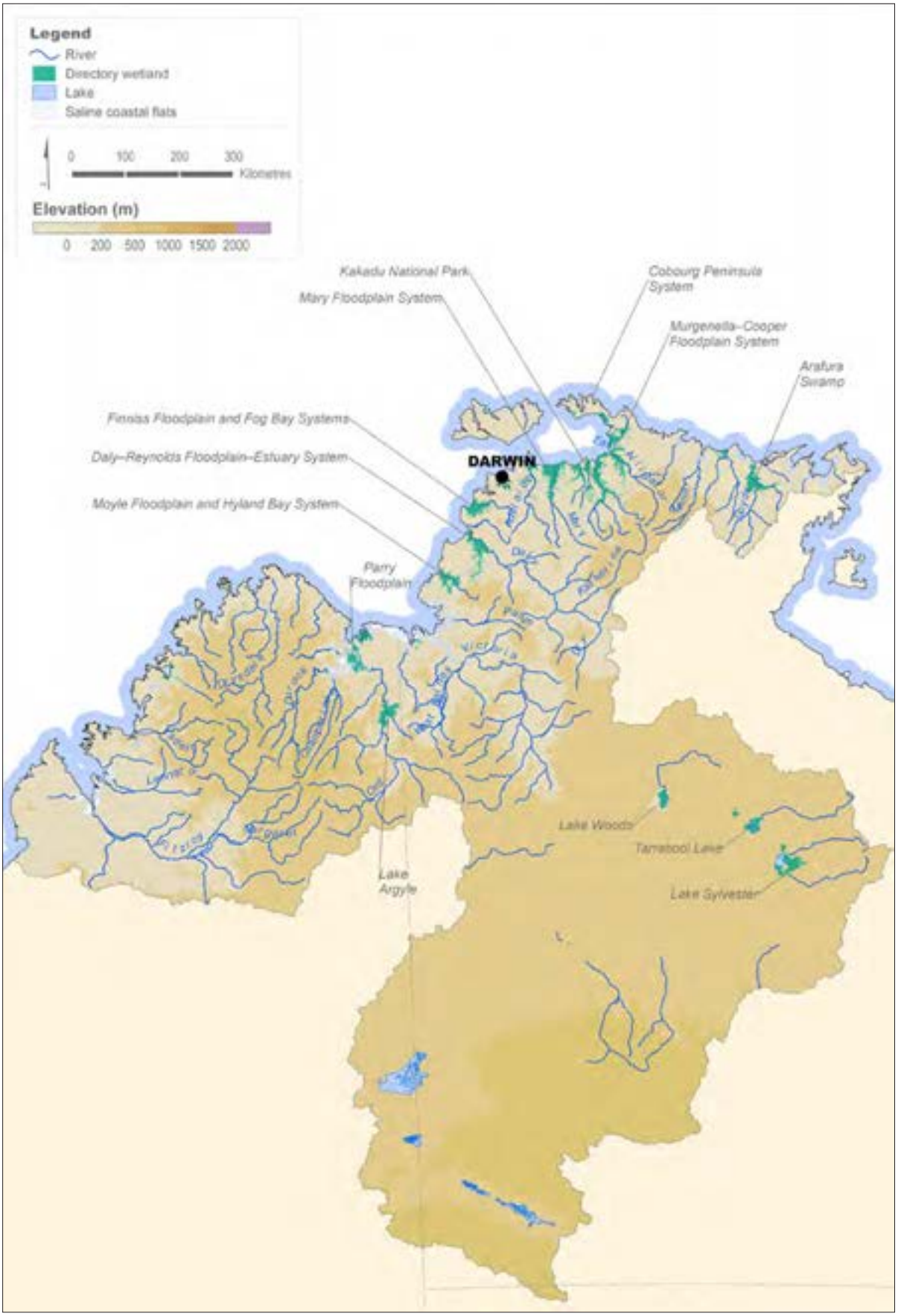


Figure 13.26 Location of important wetlands in the Tanami – Timor Sea Coast region

13.5.6 Hydrogeology

The watertable aquifers present in the region are given in Figure 13.27 below. The hydrogeology of the region is dominated by the Kimberley hard rock plateau and Canning basin sedimentary rocks and by the extensive regional karstic system in the central-east part of the region. In the hard rock plateau, groundwater occurs in lesser but valuable quantities in fractured rocks and surficial river alluvium.

Substantial quantities of confined and unconfined groundwater of varying quality occur in the sedimentary basins. The extensive groundwater resources associated with the widespread fractured and cavernous limestone of the Daly basin are very important for the region.

Groundwater systems that provide great potential for extraction are labelled as:

- Fractured and Karstic rocks, regional scale and local scale aquifers; and
- Mesozoic sediment aquifer (porous media — consolidated).

13.5.7 Watertable salinity

Figure 13.28 shows the classification of watertable aquifers as fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) water according to watertable salinity. Shallow groundwater generally has good quality throughout the region, reflecting the annual fill-and-spill cycle, and can be a good source of local supply of potable water.

In the northern part of the region, watertables in shallow aquifers respond dramatically to the seasonal rains, often rising and falling several metres each year. Many shallow aquifers fill to capacity and drain slowly to the rivers and the coast during the dry season.

The extensive regional aquifers of the Tindall limestone and Oolloo dolostone (in the Daly River basin) are often the primary sources of water that keep local streams flowing year-round (CSIRO 2009).

The areas with high salinity values are relatively small.

13.5.8 Groundwater management units

The groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 13.29 shows that most of the major groundwater management units within the Northern Territory are located within the fractured and karstic rocks aquifers. In Western Australia the major groundwater management unit is the Canning–Kimberley.

Most of the population in the region is concentrated in Darwin, Broome, Katherine and Kununurra. Increasingly surface water, a major source of water for Darwin and Katherine, is supplemented by groundwater while smaller communities usually rely mostly on groundwater. In rural areas, domestic production bores are the main sources of water. The pastoral industry across the region also uses groundwater. Irrigated agriculture occurs predominantly along the Ord River and, at a smaller scale, near Darwin and Katherine.

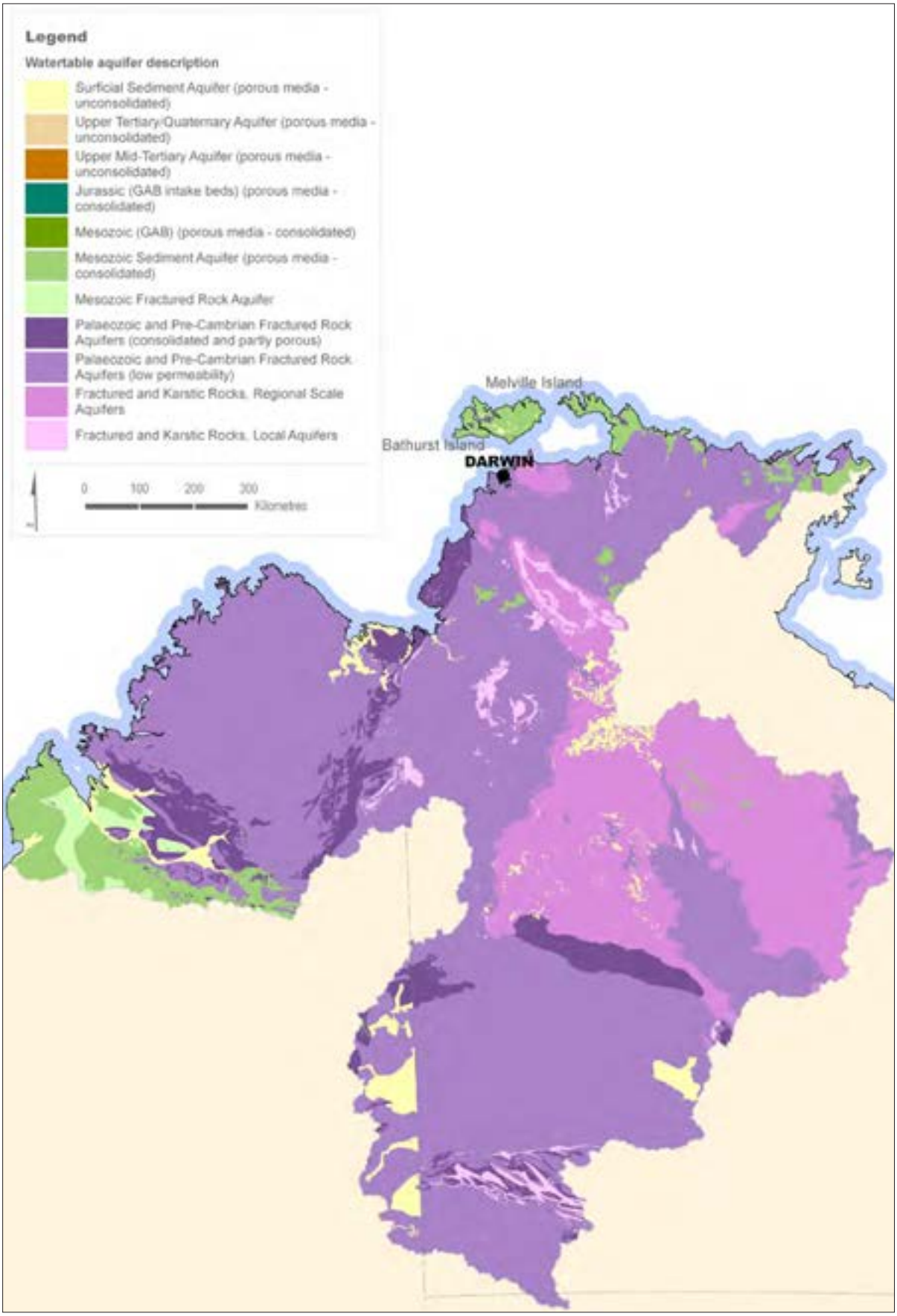


Figure 13.27 Watertable aquifers of the Tanami – Timor Sea Coast region, data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

Figure 13.28 Watertable salinity classes in the Tanami – Timor Sea Coast region, data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

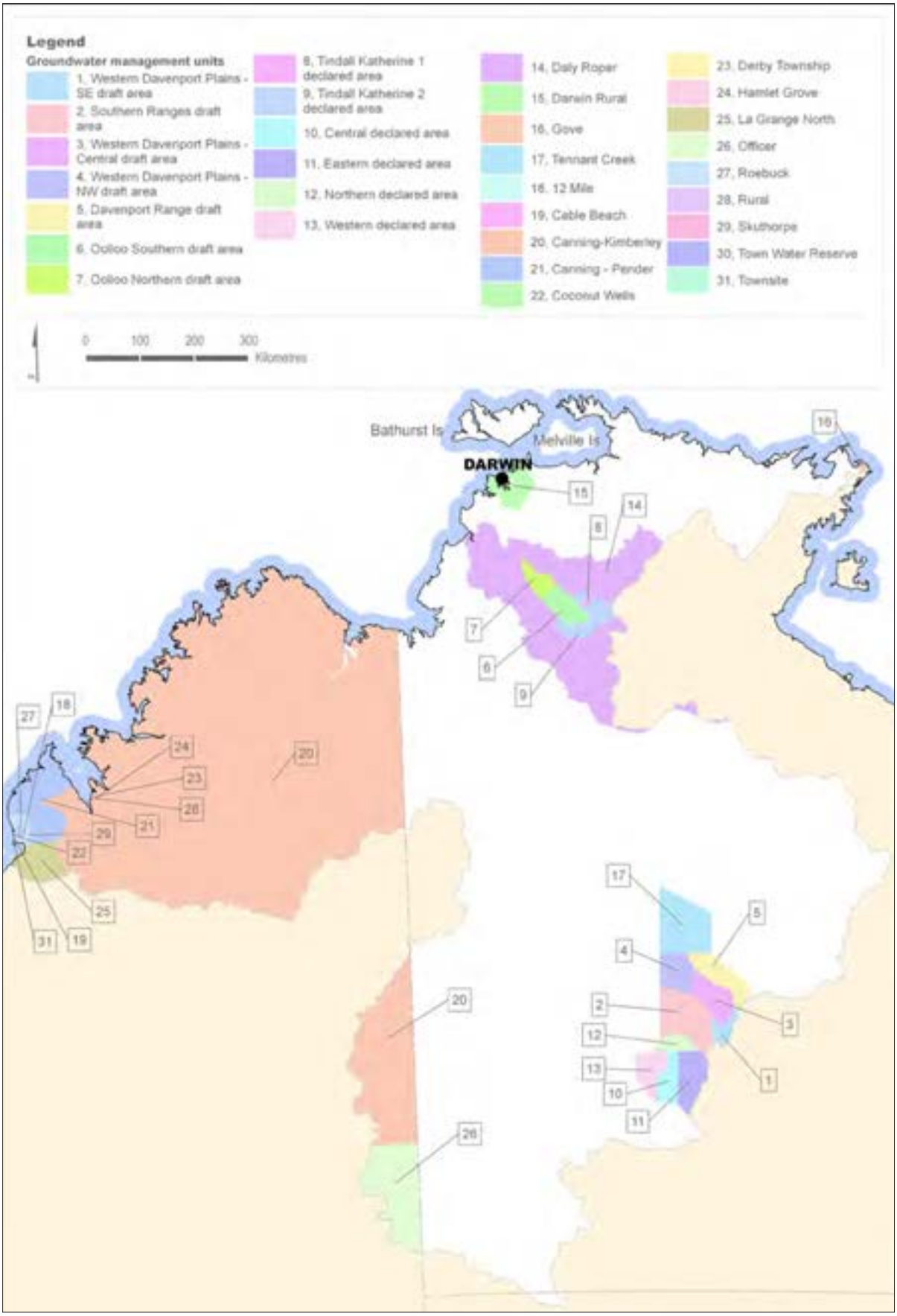


Figure 13.29 Groundwater management units in the Tanami – Timor Sea Coast region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

13.6 Water for cities and towns

This section examines the urban water situation in the Tanami – Timor Sea Coast region in 2011–12. The large urban centres in the region, their water supply systems and storage situations are briefly described. The main urbanised area, Darwin, is addressed in more detail and a breakdown is provided for water obtained for and delivered to this city.

13.6.1 Urban centres

Darwin, Palmerston, Broome, Katherine and Kununurra are the major urban centres in the Tanami – Timor Sea Coast region and are shown in Figure 13.30 in conjunction with their population ranges.

Darwin is the capital city of the Northern Territory and has a population of 103,000 people, making it by far the largest and most populated city in the sparsely populated region. It is the smallest of the Australian capital cities.

The second largest town in the region is Palmerston, a planned satellite city close to Darwin. Palmerston is situated near Darwin Harbour and has a population of 27,700 people. Palmerston briefly held in the past the title of the fastest growing city in Australia.

The third largest town in the region is Broome with a population of 12,800 people. It was built on an industry of pearl harvesting, but nowadays residents are supported by a large tourism industry.

Katherine and Kununurra both have populations below 7,000 and have much less relative growth than Darwin and Palmerston.

13.6.2 Sources of water supply

Surface and groundwater are both significant sources of urban water supplied in the region. Many of the region's small, and in some cases isolated communities rely predominantly on groundwater supplies.

The region's only major surface water storage, the Darwin River storage, is shown in Figure 13.31. It supplies surface water to the residents of Darwin and Palmerston.

Groundwater is used throughout the region and in addition to augmenting the supply of the Darwin and Palmerston areas it is the major source for water supplied to the population centres of Broome, Katherine and Kununurra.

Management of groundwater and surface water resources is the responsibility of the Northern Territory's Department of Land Resource Management.

Recycled water plays a minor role in the region and is used to meet the irrigation needs of a number of sporting facilities and playing fields across Darwin.

13.6.3 Darwin–Palmerston

The Power and Water Corporation is owned by the Northern Territory Government and supplies water, sewerage and power services in the Northern Territory, including the Darwin and Palmerston areas. With respect to water supply it operates as both a bulk water supplier and retail utility.

Darwin has a tropical climate with distinct wet and dry seasons which impacts greatly on the availability of surface water in the storages and recharge to the groundwater. Most of the annual rainfall is experienced from December–April. The timing of the onset of regular evening storms, together with the presence or absence of dry season rainfall, significantly influences water consumption.

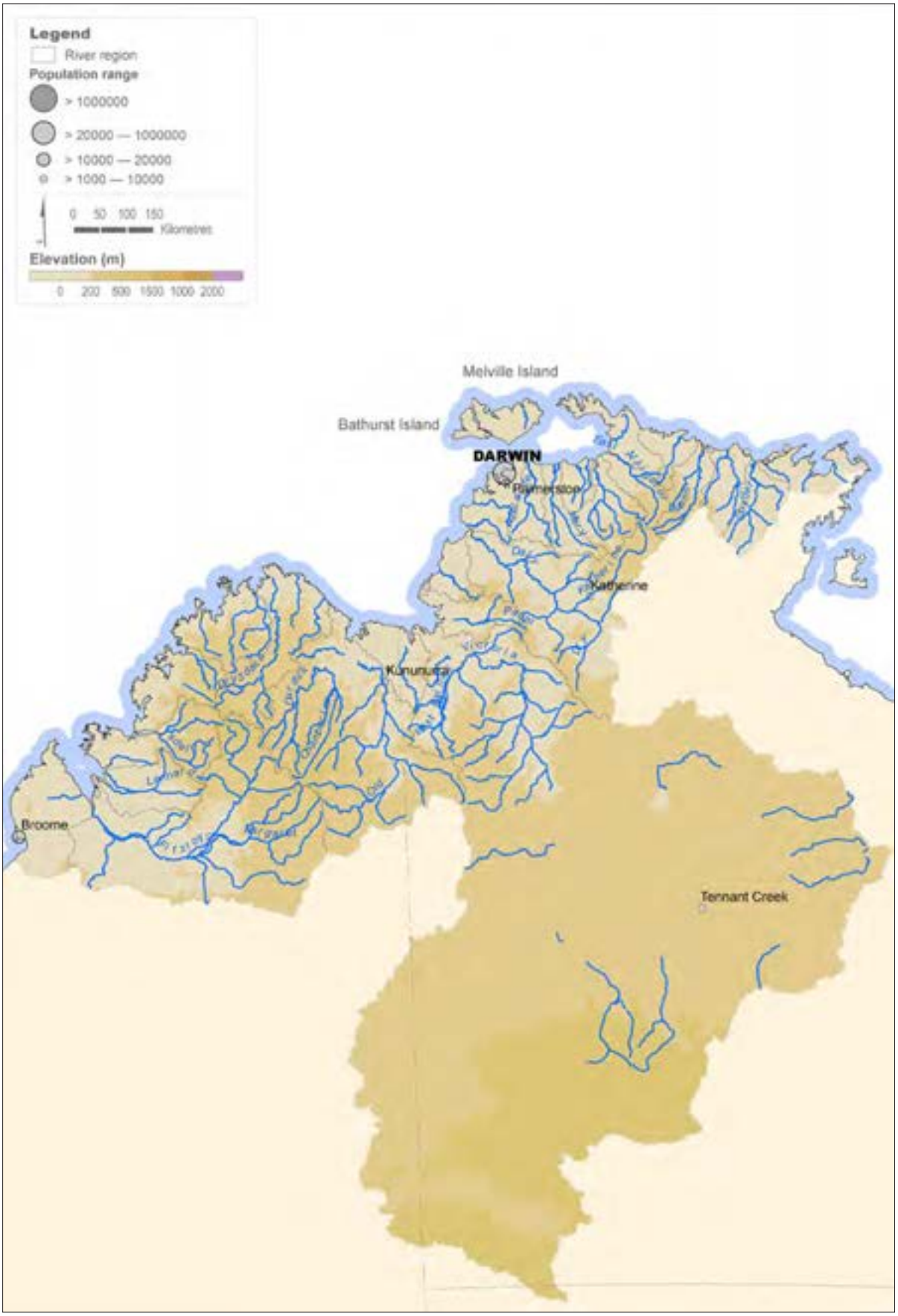


Figure 13.30 Urban population range in the Tanami – Timor Sea Coast region

Figure 13.31 Urban supply storages in the Tanami – Timor Sea Coast region

Supply system

Water is supplied from a combination of surface water and groundwater sources. Most of this water is sourced from the Darwin River storage and is supplemented from the Howard East and McMinns bore fields.

In 1972, the Darwin River Dam was built to address growing water needs arising from the increasing population in the supply area. With the raising of the dam spillway height in January 2011 by 1.3 m, the total accessible storage capacity of the Darwin River storage is now 259 GL.

Sources of water obtained

Figure 13.32 presents the volumes and sources of water sourced to meet Darwin–Palmerston's urban demand (National Water Commission 2013). The data clearly illustrates the region's reliance on surface water, which typically comprises over 80% of the total supply source.

Groundwater as a secondary source has exhibited some growth over this period; however, its extraction is correlated with the available surface water volume and hence is relied upon more significantly in dry years. Recycled water has grown in the recent years, up by almost 25%; however, this growth has been from a very low base, and on a volumetric basis remains less than 1% of the total water sourced to supply the region.

A series of wetter years, including Australia's wettest two-year period on record (2010–2011), saw an improvement in surface water storage levels and a commensurate rise not only in the volume sourced from surface water but also in the total volume extracted for urban use.

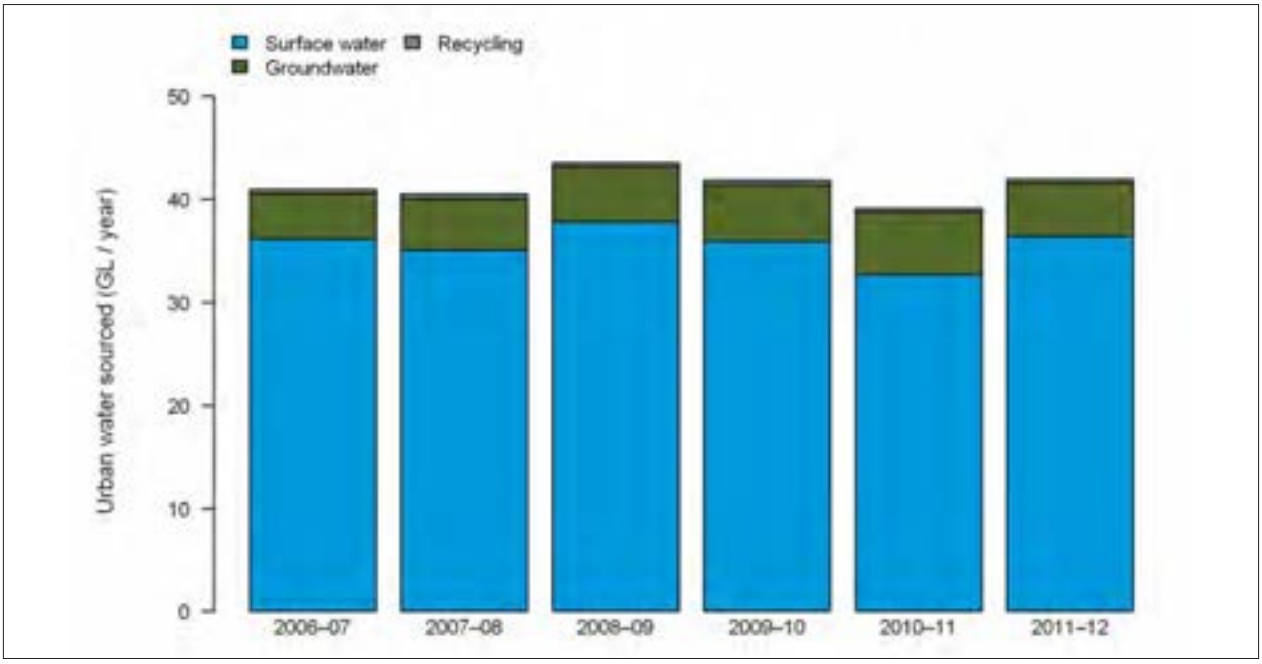


Figure 13.32 Total urban water sourced for Darwin from 2006–07 to 2011–12

Categories of water delivered

Figure 13.33 shows the total volume of water delivered to residential, commercial, municipal and industrial consumers by the Power and Water Corporation (National Water Commission 2013).

After an across-the-board reduction in water consumption levels during 2010–11, above average rainfall and improving storage levels saw residential consumption return to the previous highs. Based on data obtained from the National Performance Reports (National Water Commission 2013), the average water supplied by the Power and Water Corporation for residential use over the analysis period was 507 kL per property per year, making Darwin residents some of the highest residential water users in the country.

After exhibiting a downward trend between 2008–09 and 2010–11, water use was up in 2011–12 along with water supplied to users classified as 'other'. This trend is again, in part, explained by the improving water resources outlook resulting from above average rainfalls in 2010 and 2011 and improving water storage levels in the Darwin River storage.

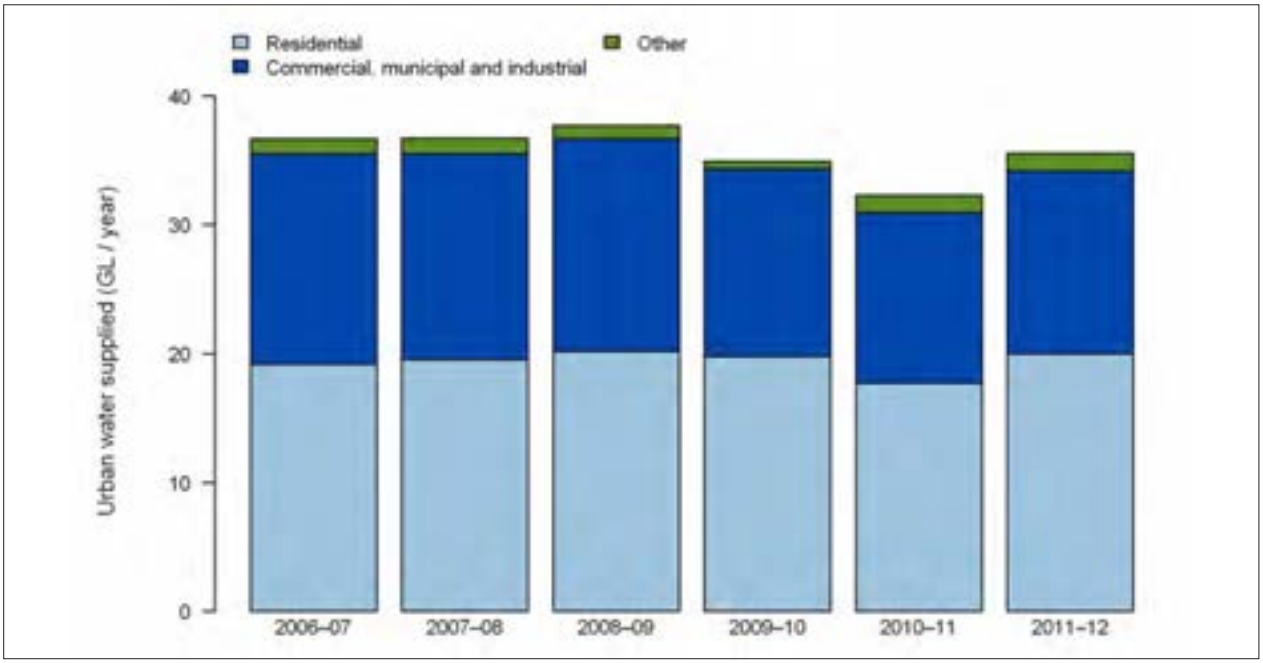


Figure 13.33 Total urban water supplied to Darwin from 2006–07 to 2011–12

13.7 Water for agriculture

This section describes the water situation for agriculture in the Tanami – Timor Sea Coast region in 2011–12. Soil moisture conditions are presented and important irrigation areas are identified. The Ord River irrigation area is described in more detail and information is provided regarding surface storage and groundwater.

13.7.1 Soil moisture

Since model estimates of soil moisture storage volumes are based on a simple conceptual representation of soil water storage and transfer processes averaged over a 5 km x 5 km grid cell, they are not suitable for comparison with locally measured soil moisture volumes. This analysis therefore presents a relative comparison only, identifying how modelled soil moisture volumes of 2011–12 relate to modelled soil moisture volumes of the 1911–2012 period, expressed in decile rankings.

Soil moisture conditions during the 2011–12 year were above average in many parts of the landscape (Figure 13.34) due to above average rainfall from October through to December 2011.

Only in the mid to late summer months did the soil moisture in the region drop to average and below average, but returned to above average conditions as a result of very high rainfalls in March 2012 in the region (Figure 13.35).

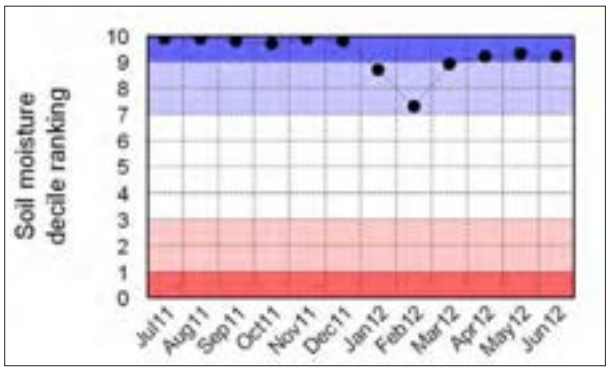


Figure 13.35 Decile ranking of the monthly soil moisture conditions during the 2011–12 period in the Tanami – Timor Sea Coast region

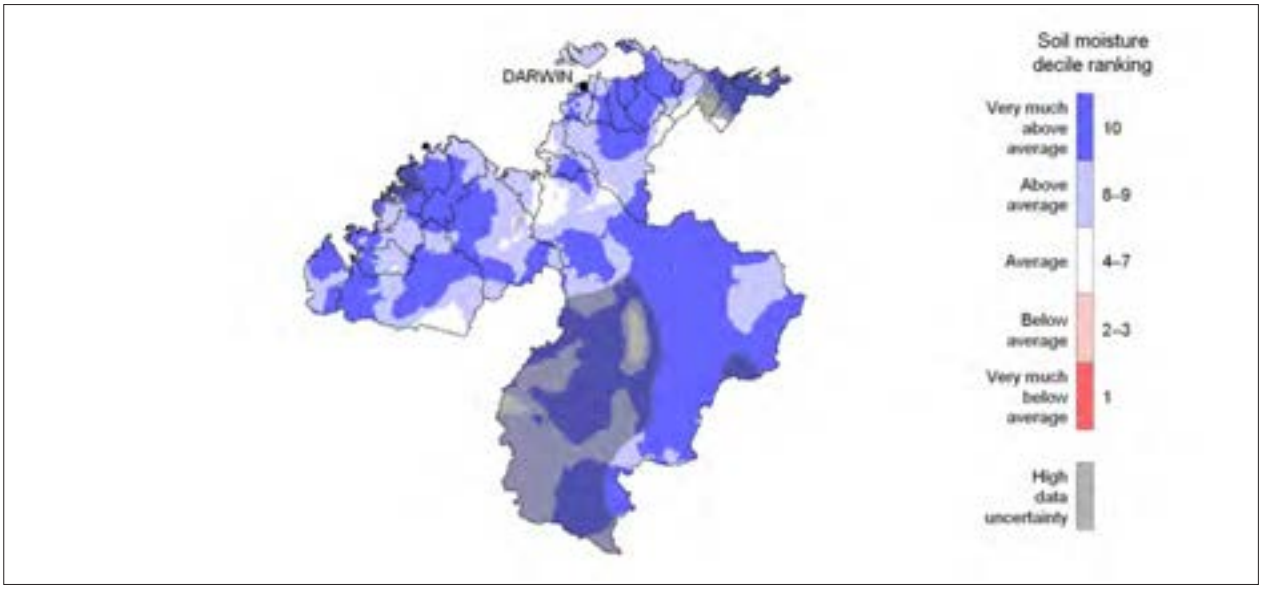


Figure 13.34 Deciles rankings of average soil moisture over 2011–12 with respect to the 1911–2012 period in the Tanami – Timor Sea Coast region

13.7.1 Irrigation areas

The Tanami – Timor Sea Coast region extends across a range of climatic zones including a humid tropical climate to the north and arid conditions across the southern inland areas. In addition to nature conservation, much of the region is pastoral lands. Irrigated agriculture is concentrated in the Ord River basin (Figure 13.37).

13.7.2 Ord River Irrigation Area

The Ord River basin is located in the east of northern Western Australia. The Ord River, 650 km long, is one of the major rivers of the State (Figure 13.38). The main tributaries of the Ord River include the Negri, Wilson and Bow rivers (upstream of Lake Argyle), and the Dunham River, which joins the Ord River downstream of the Kununurra Diversion Dam.

The Ord River irrigation area was developed in 1962 with the construction of the Kununurra Diversion Dam which led to the formation of Lake Kununurra. It comprises approximately 13,000 ha of irrigable soils. In 1973 the Ord Dam was built that created Lake Argyle. This supplied water for an irrigation project of more than 50,000 ha. In 1996, the spillway wall was raised by 6 m, which doubled the dam's capacity.

The main industries within the Ord River basin are agriculture, horticulture, tourism and mining. Mean annual rainfall in the Ord River basin ranges from 780 mm in the north to 450 mm in the south.

Lake Argyle, the storage behind the Ord River Dam with an accessible capacity of 10,700 GL, is the largest irrigation storage in Australia. The Kununurra Diversion Dam, downstream of Lake Argyle, diverts water to irrigation areas near Kununurra (Government of Western Australia Department of Water 2010a).

Water is released from Lake Argyle through hydro-power outlets and a series of controlled release valves at the base of the dam. Additional flow is released through a spillway plug. These combined releases provide inflow into Lake Kununurra from where it is diverted to the Ivanhoe Plains systems and the Packsaddle pumping stations (Ord Irrigation 2011). The Ord Irrigation Cooperative provides water and drainage services to the farms within the Ord River Irrigation Area.

Prolonged dry periods could have a major impact on water supply reliability of Lake Argyle (Government of Western Australia Department of Water 2010b); however, the large storage capacity of Lake Argyle buffers the system against isolated drier years. Evaporation from the surface accounts for a large component of loss from the lake.

Surface water storage volumes

Despite the large storage capacity of Lake Argyle, prolonged dry periods have a major impact on water supply reliability (Government of Western Australia Department of Water 2010b). Open water evaporation also accounts for a large component of loss from the lake.

The historic data (Figure 13.36) shows that the volume of water in the lake regularly exceeded its total storage capacity. This was also the case in 2011–12, where the water level in the storage for two consecutive years was at or above its capacity for the most part of the year.

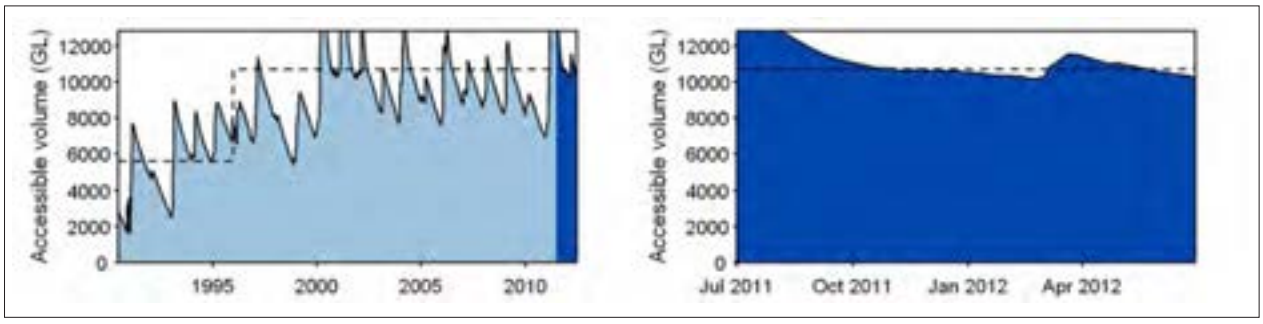


Figure 13.36 Variation in the amount of water held in storage over recent years (light blue) and over 2011–12 (dark blue) for the Lake Argyle storage, as well as total accessible storage capacity (dashed line)

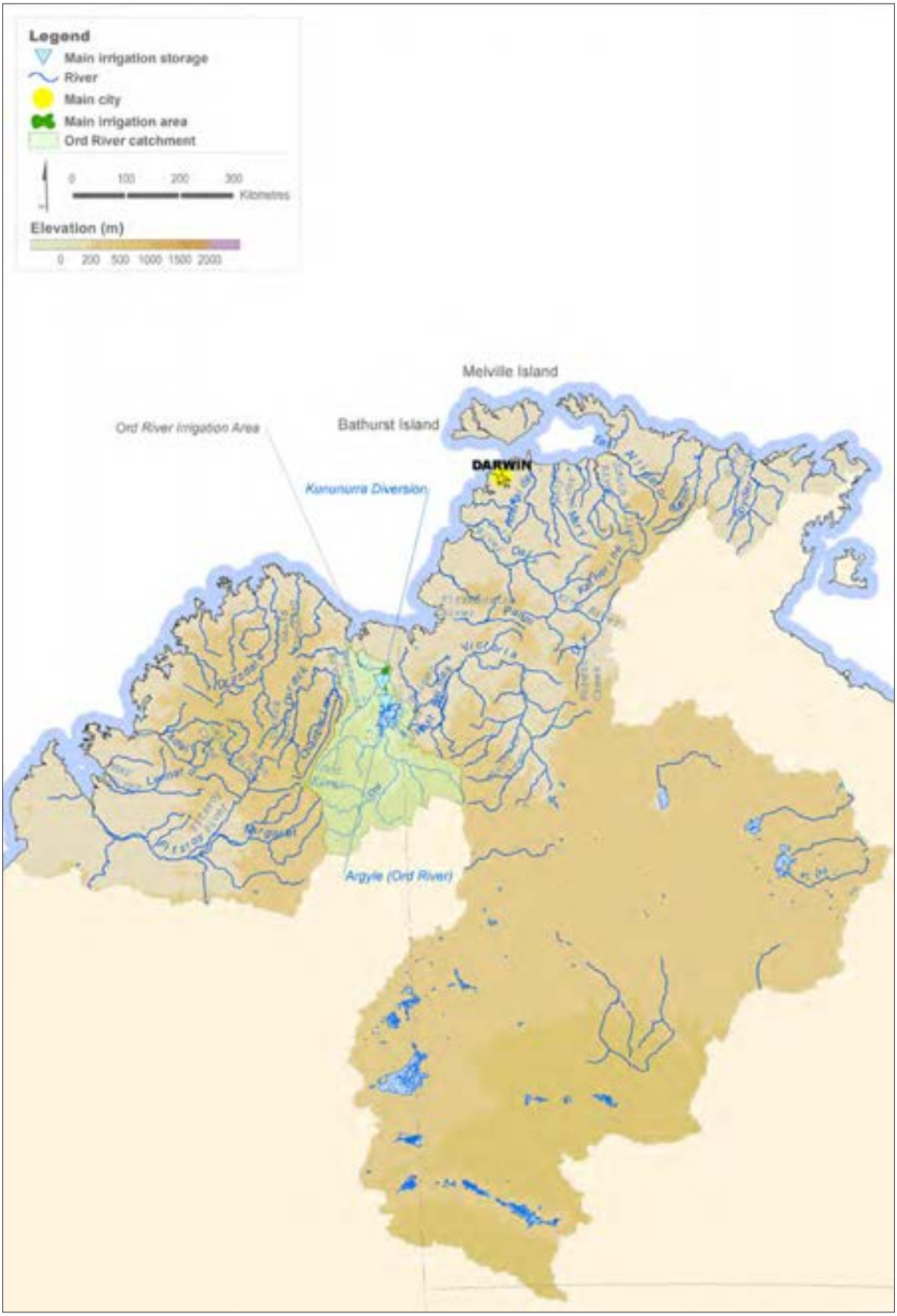


Figure 13.37 Irrigation areas in the Tanami – Timor Sea Coast region

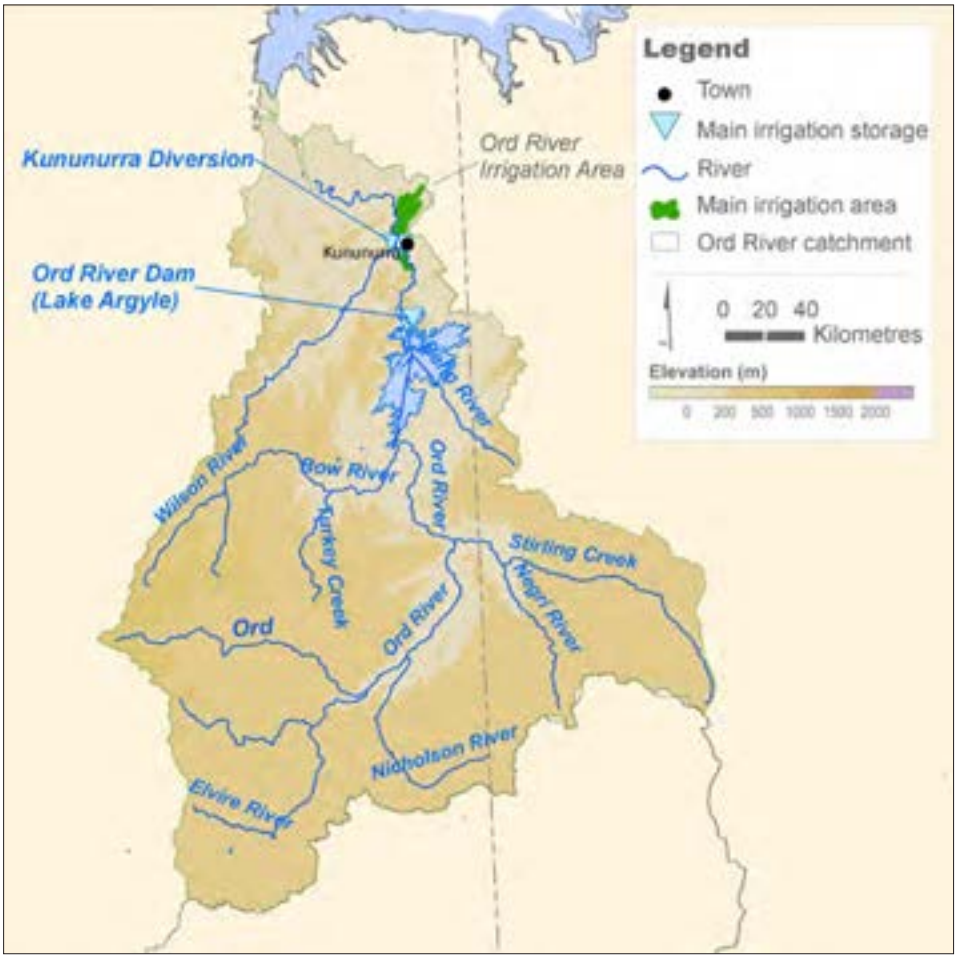


Figure 13.38 The Ord River irrigation area

Lake Eyre Basin

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14 Lake Eyre Basin

14.1 Introduction

This chapter examines water resources in the Lake Eyre Basin region in 2011–12 and over recent decades. It starts with summary information on the status of water flows and stores. This is followed by descriptive information for the region including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented as well as an examination of the surface and groundwater resources. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

14.2 Key information

Table 14.1 gives an overview of the key components of the data and information in this chapter.

Table 14.1 Key information on water flows and groundwater quality in the Lake Eyre Basin region

Landscape water flows			
	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911–2012 record
Rainfall	337 mm	+42%	9th—above average
Evapo-transpiration	327 mm	+45%	10th—very much above average
Landscape water yield	25 mm	+150%	10th—very much above average

Streamflow (at selected gauges)		
	Annual total flow:	Above average flow in three gauges in the east. Average flows on one of the gauges in the centre
	Flooding:	Major floods in the upstream part of the Cooper Creek basin, decreasing in severity downstream and some flooding in the Diamantina and Bulloo rivers

Groundwater (in selected aquifers)		
	Salinity:	Mostly non-saline (<3000 mg/L) groundwater in the north and saline (≥3000 mg/L) in the south

14.3 Description of the region

The Lake Eyre Basin region covers approximately 1.2 million km² of arid and semi-arid Central Australia. It represents 17% of the continent and stretches, north to south, from just below Mount Isa in Queensland to Marree in South Australia. From west to east, it extends from Alice Springs in the Northern Territory to Tambo and Blackall in central Queensland.

Landforms in the region mainly consist of plains, inland dunes, sand plains, floodplains, and low relief hills and plateaus. Highly variable and on average low rainfall has resulted in sparse vegetation cover and intermittent river systems. Subsections 14.3.1–14.3.4 provide more information on the topography and soils cover.

With a population of approximately 59,000, the Lake Eyre Basin accounts for less than 0.25% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b).

Alice Springs is the major population centre along with a number of remote and regional centres (Figure 14.1) including Coober Pedy, Birdsville, Winton, Longreach and Peterbourough. Further discussion of the region's population distribution can be found in subsection 14.3.6.

Most of the land use within the region is for grazing and nature conservation. There are numerous dry lakes that form a substantial part of the region. Only a small patch in the far south includes some dryland agriculture.

The region's climate is generally quite arid, with rainfall much below potential evaporation. The region is driest in the northeast, but this area does receive some monsoonal rain and, although being highly variable, it can supply large amounts of water, in particular into the upper reaches of the Diamantina and Georgina rivers.

The region is divided into several major river basins. The major rivers are the Georgina, Diamantina, Thomson and Barcoo rivers and Cooper Creek, which flow from central and western Queensland into South Australia, as well as the Finke, Todd and Hugh rivers in Central Australia. These waterways all drain into Lake Eyre. The rivers and creeks are characterised by high variability and unpredictability in their flow, and high transmission losses and very low gradients.

The hydrogeology of the region is dominated by the sediments of the Great Artesian Basin with porous sandstone aquifers. This groundwater basin underlies the region from the northeast. It is one of Australia's most significant groundwater basins. There is notable extraction of groundwater for stock and domestic purposes.

Lake Eyre salt lake | iTobi (iStockphoto)

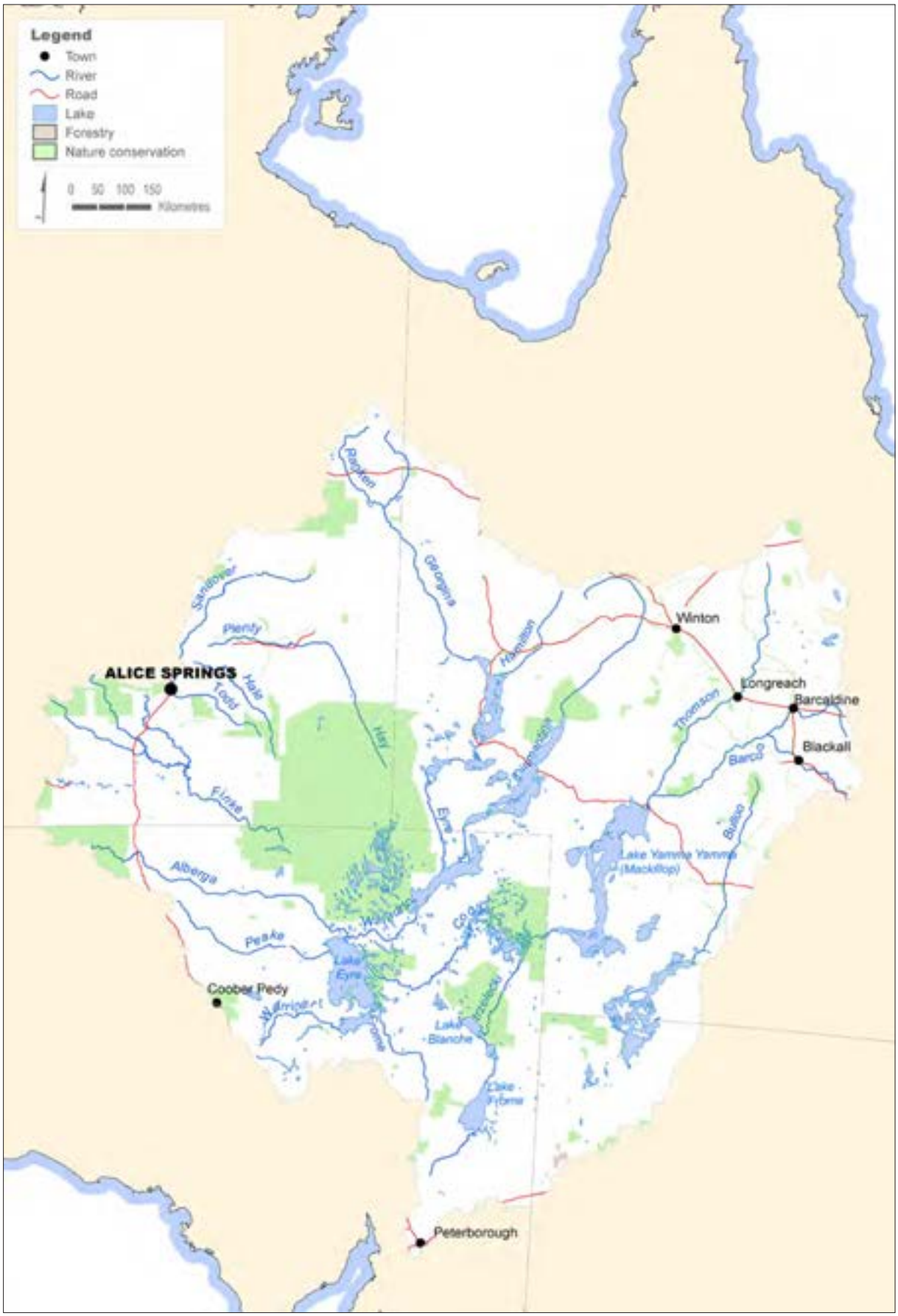


Figure 14.1 Major rivers and urban centres in the Lake Eyre Basin region

14.3.1 Physiographic characteristics

The physiographic map in Figure 14.2 indicates areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes.

The Lake Eyre Basin region has three such dominant physiographic provinces, namely:

- Central Lowlands (72%): undulating clay plains, sand plains with low sandstone, shale and silcrete hills;
- Central Australian Ranges (11%): ranges and hills of igneous rock, sandstone and quartzite surrounded by hardpan wash plains and some dune fields, sand and stony plains and salt lakes; and
- Barkly–Tanami Plains (10%): black clay, sand and limestone plains and sandstone rises and plateaus some with ferruginous mantles.

The remaining six provinces (see Figure 14.2) occupy only 7% of the region and contain a variety of physiographic features from plains to prominent ranges.

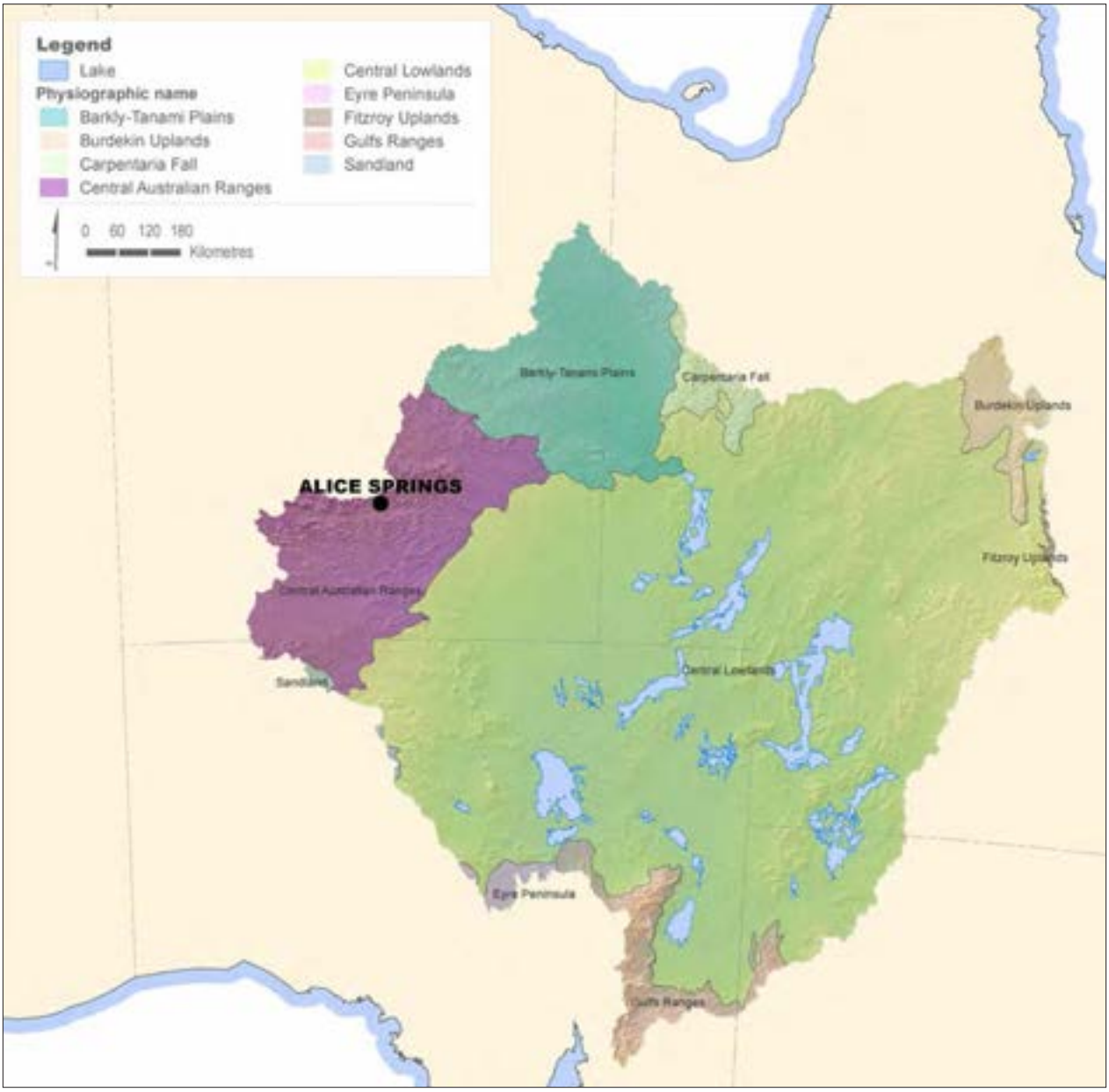


Figure 14.2 Physiographic provinces of the Lake Eyre Basin region

14.3.2 Elevation

Figure 14.3 presents ground surface elevations in the Lake Eyre Basin. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html). The region consists of enclosed river basins as the rivers do not flow to the sea. Most of the region drains into Lake Eyre, provided enough water is available to reach the lake. The lake itself is the lowest point in Australia. The bottom of the lake is 15 m below sea level and the shores are 9 m below sea level.

The major rivers that fill Lake Eyre are the Diamantina and Georgina rivers, which receive most of their (monsoonal) water on the northern mountain ranges.

The water travels through Channel Country, where the landforms are typical of desert conditions. The area mainly consists of plains, inland dunes, sandplains, floodplains, and low relief hills and plateaus.

The highest mountains in the region are located around Alice Springs, with peaks exceeding 1,000 m above sea level. The northern tip of the Flinders Ranges in the south also has some high peaks close to 1,000 m above sea level (Figure 14.3).

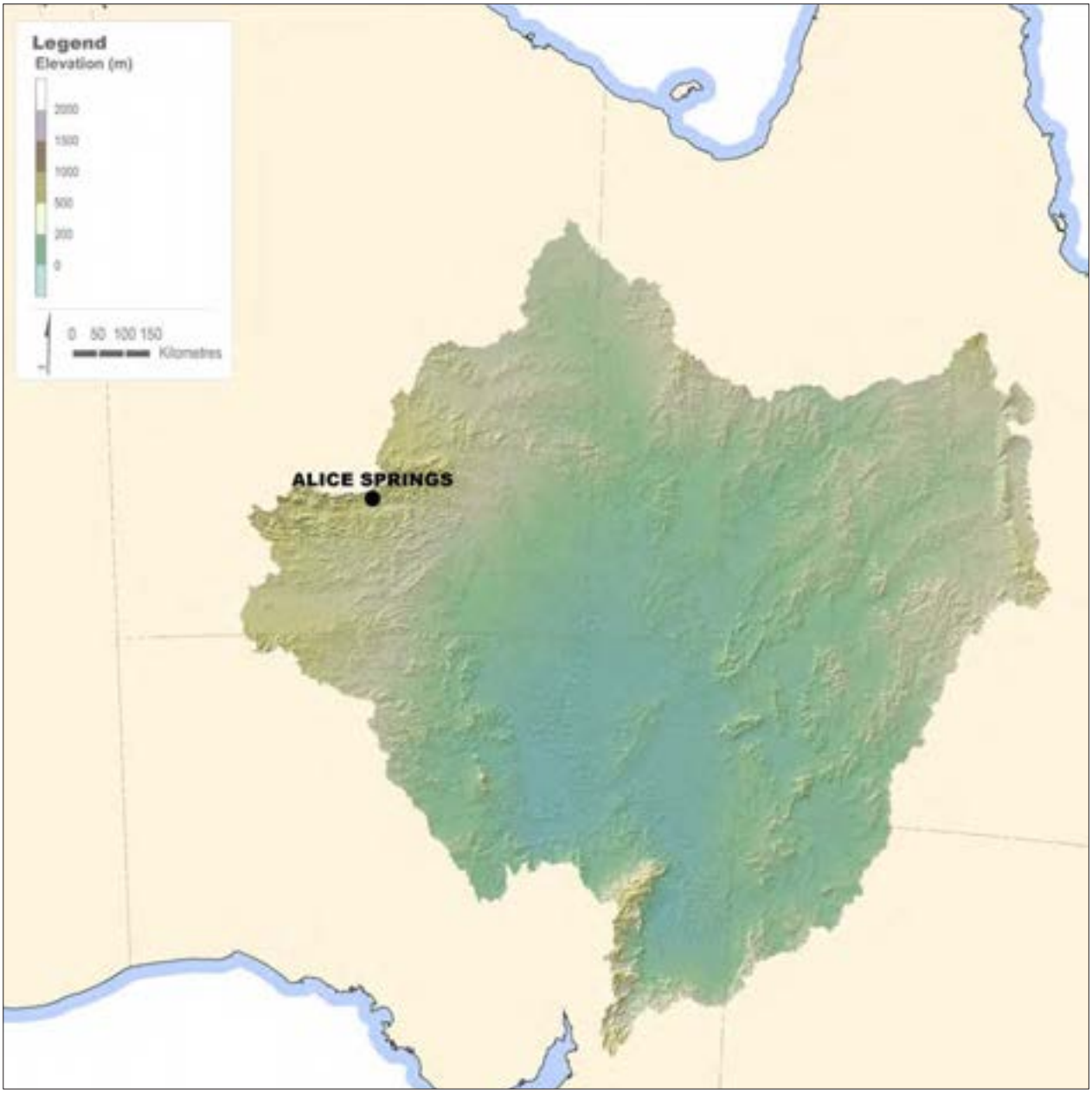


Figure 14.3 Ground surface elevations in the Lake Eyre Basin region

14.3.3 Slopes

Areas with steep slopes provide higher run-off generating potential than flat areas. The Lake Eyre basin region is generally flat, with some minor areas with steep hills (Table 14.2 and Figure 14.4). The slopes were derived from the elevation information used in the previous section.

Table 14.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	61.2	20.1	16.8	1.9

The steep slopes in the map in particular highlight the Flinders Ranges in the south and the MacDonnell Ranges in the west.

The large areas of minor slopes in the centre of the region are the sand dunes of the Simpson Desert.

As can be noted in Figure 14.4, the rivers in the region run through vast areas with hardly any gradient, which means that large amounts of water are needed to make the rivers flow.

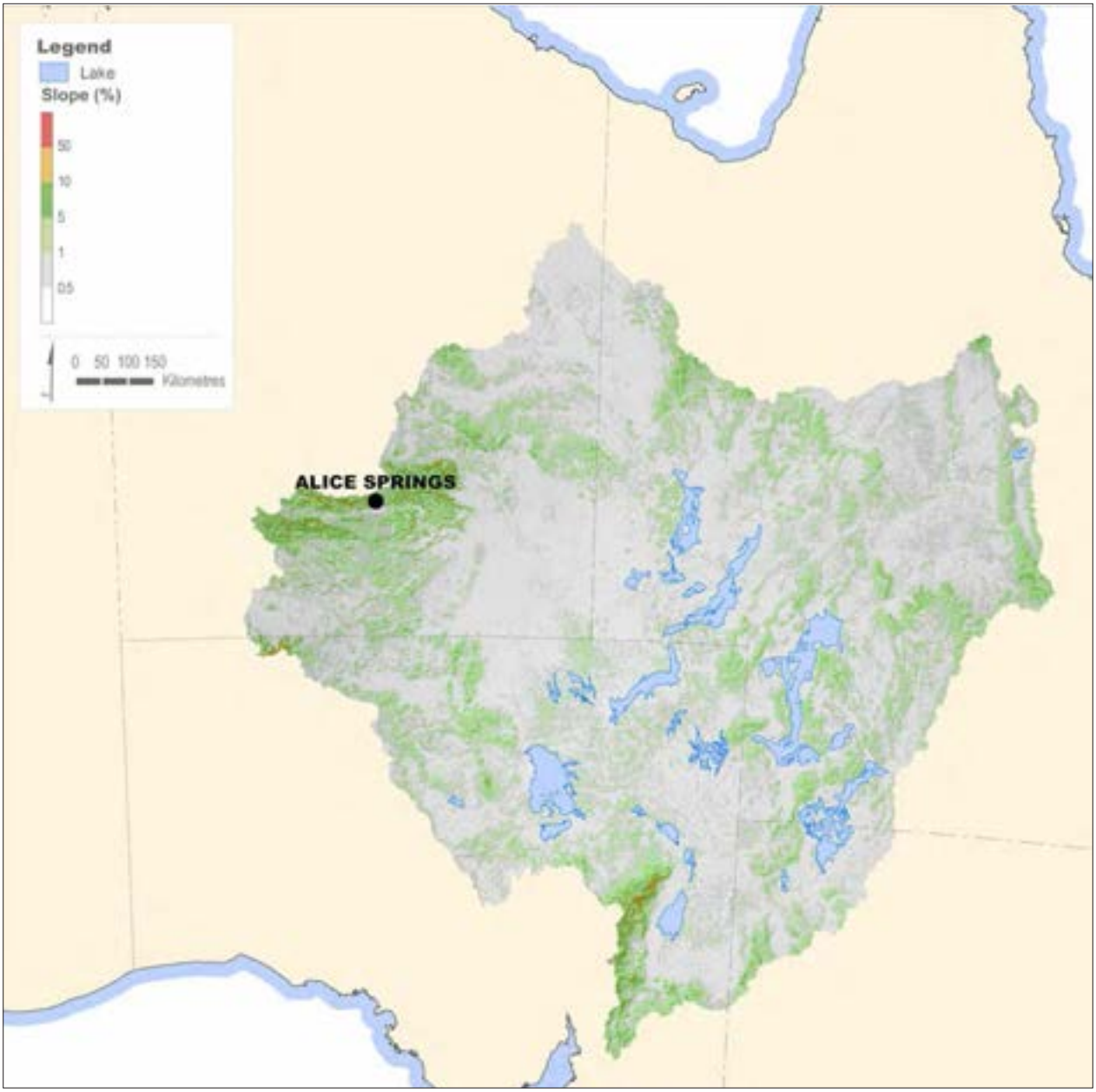


Figure 14.4 Surface slopes in the Lake Eyre Basin region

14.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 90% of the Lake Eyre Basin region is covered by five types of soil, namely vertosols, rudosols, kandosols, sodosols and tenosols (Figure 14.5 and Figure 14.6). The soils are common in areas used for grazing and nature conservation in this region.

Vertosols are mostly distributed in the eastern half of this region. They are clay rich soils which have a tendency to crack when dry and swell while wetting. They are highly fertile and have a large water-holding capacity. They do, however, absorb a significant amount of water before any becomes available to plants.

Rudosols are most common in the western half of the region. Rudosols as well as tenosols, which are scattered in the northwest and east of the region, are characterised by having a weak and minimal development. They show no or little change in texture and colour and are often shallow in depth. Tenosols and rudosols are low in chemical fertility and in water-holding capacity and thus their agricultural potential is low.

Kandosols are structureless soils which are often very deep (up to three metres or more), but they do not have a strongly contrasting texture and they do not contain carbonate throughout their profile. They are low in chemical fertility and are well-drained; with only moderate water-holding capacity compared with other soil types, thus they only have low to moderate agricultural potential. Kandosols are scattered across the region, except in the central part.

Sodosols are dominant in the central-west and scattered in small patches across other parts of the region. These soils have a clear texture contrast, with an impermeable sodic subsoil due to elevated sodium concentrations as well as increasing clay contents. They are susceptible to dryland salinity as well as erosion, if vegetation is removed. Sodosols are usually low in nutrient status.

The other soil types that have minimal representation in the Lake Eyre Basin region include dermosols and chromosols (1–6% of the total area).

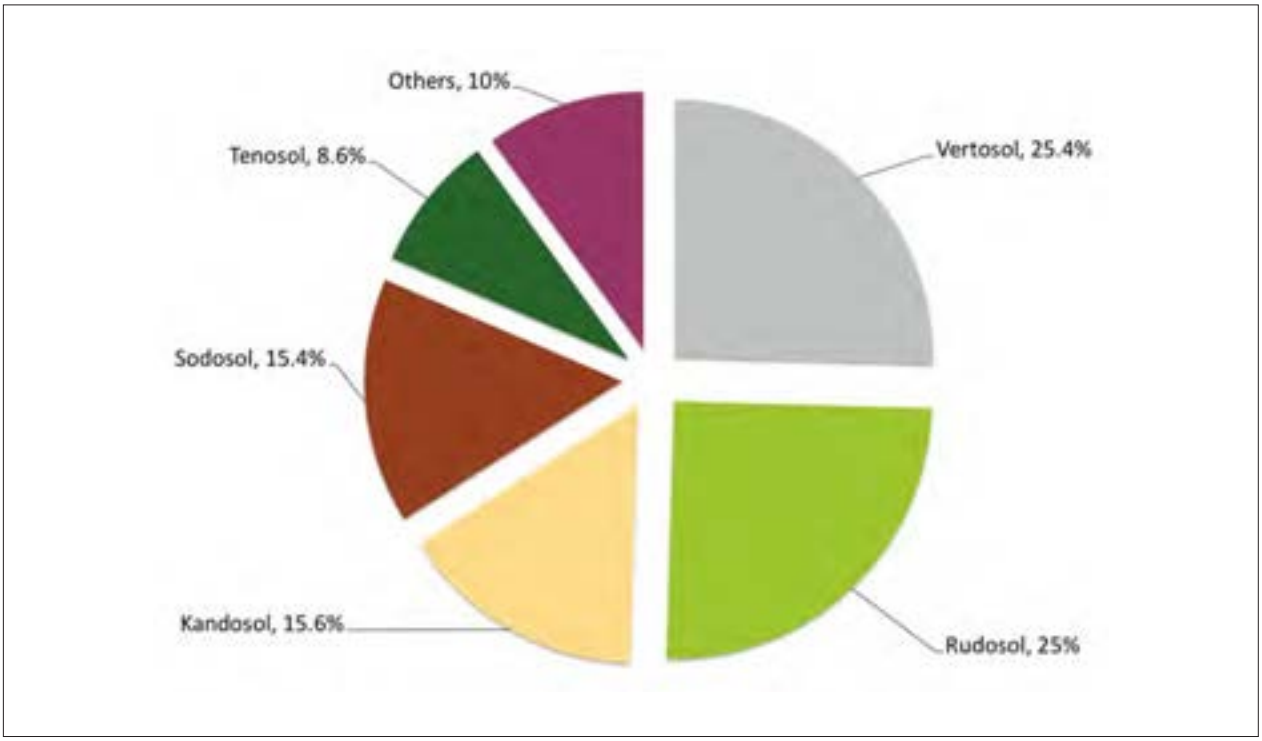


Figure 14.5 Soil type in the Lake Eyre Basin region

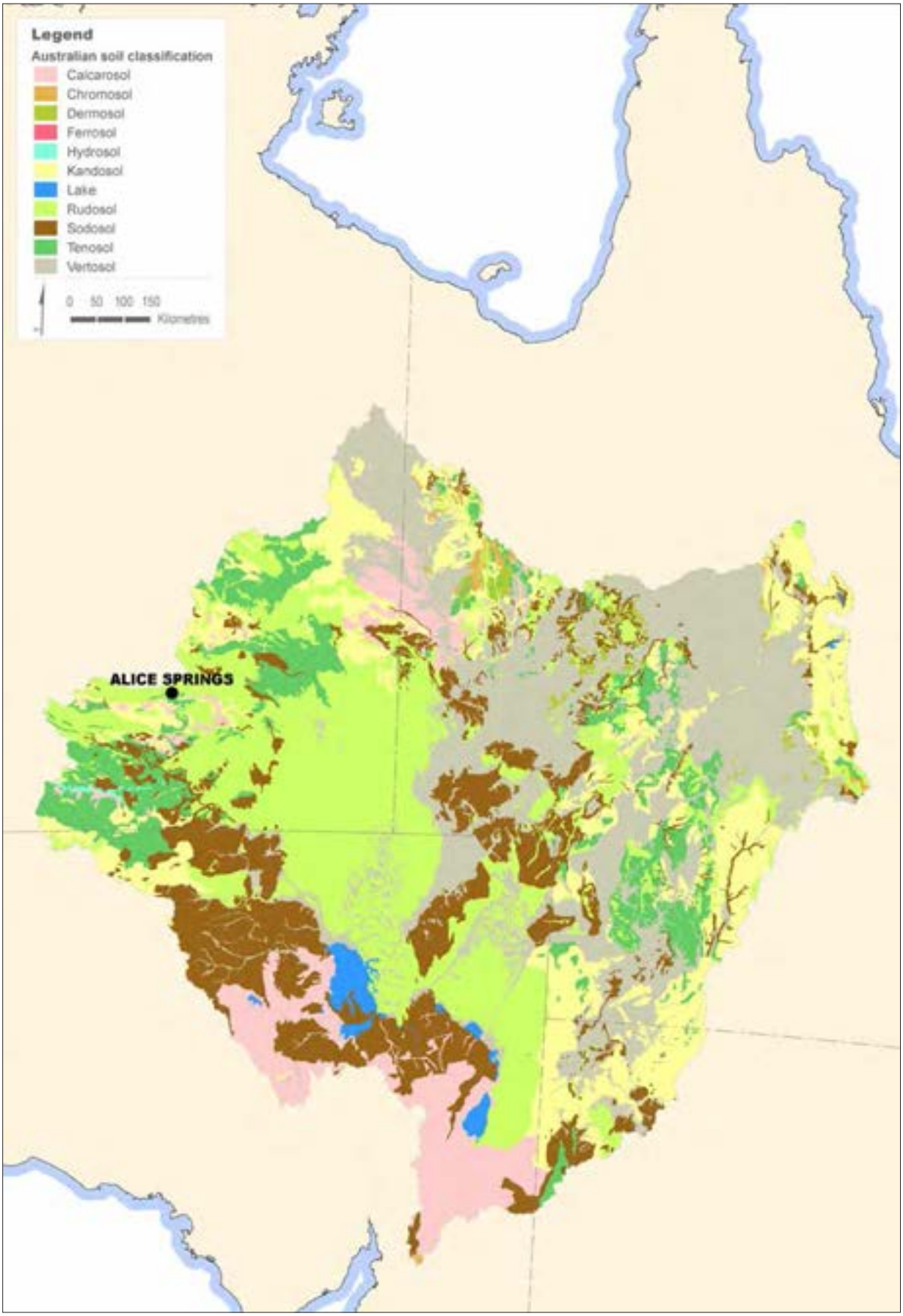


Figure 14.6 Soil type distribution in the Lake Eyre Basin region

14.3.5 Land use

Figure 14.7 presents land use in the Lake Eyre Basin region. Most of the land is used for grazing and nature conservation (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml).

There are numerous dry lakes which form a substantial part of the region. Only a small patch in the far south includes some dryland agriculture (Figure 14.8).

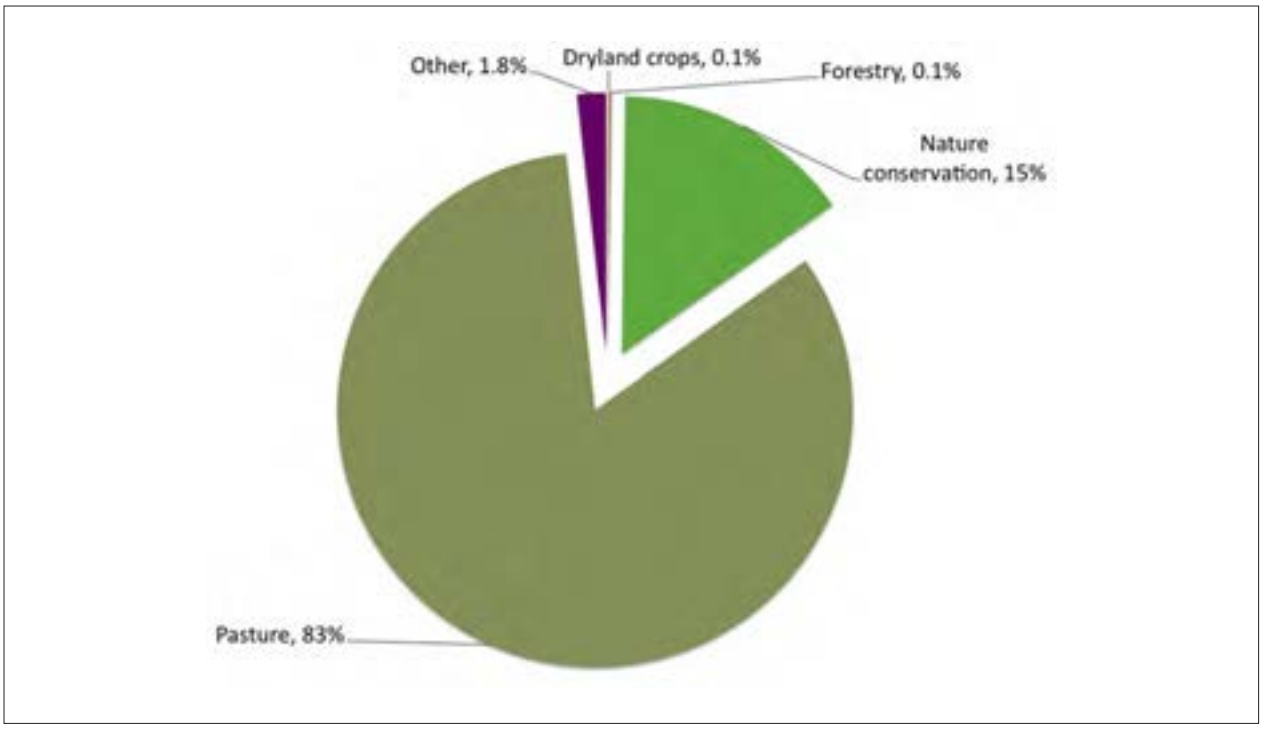


Figure 14.7 Land use in the Lake Eyre Basin region

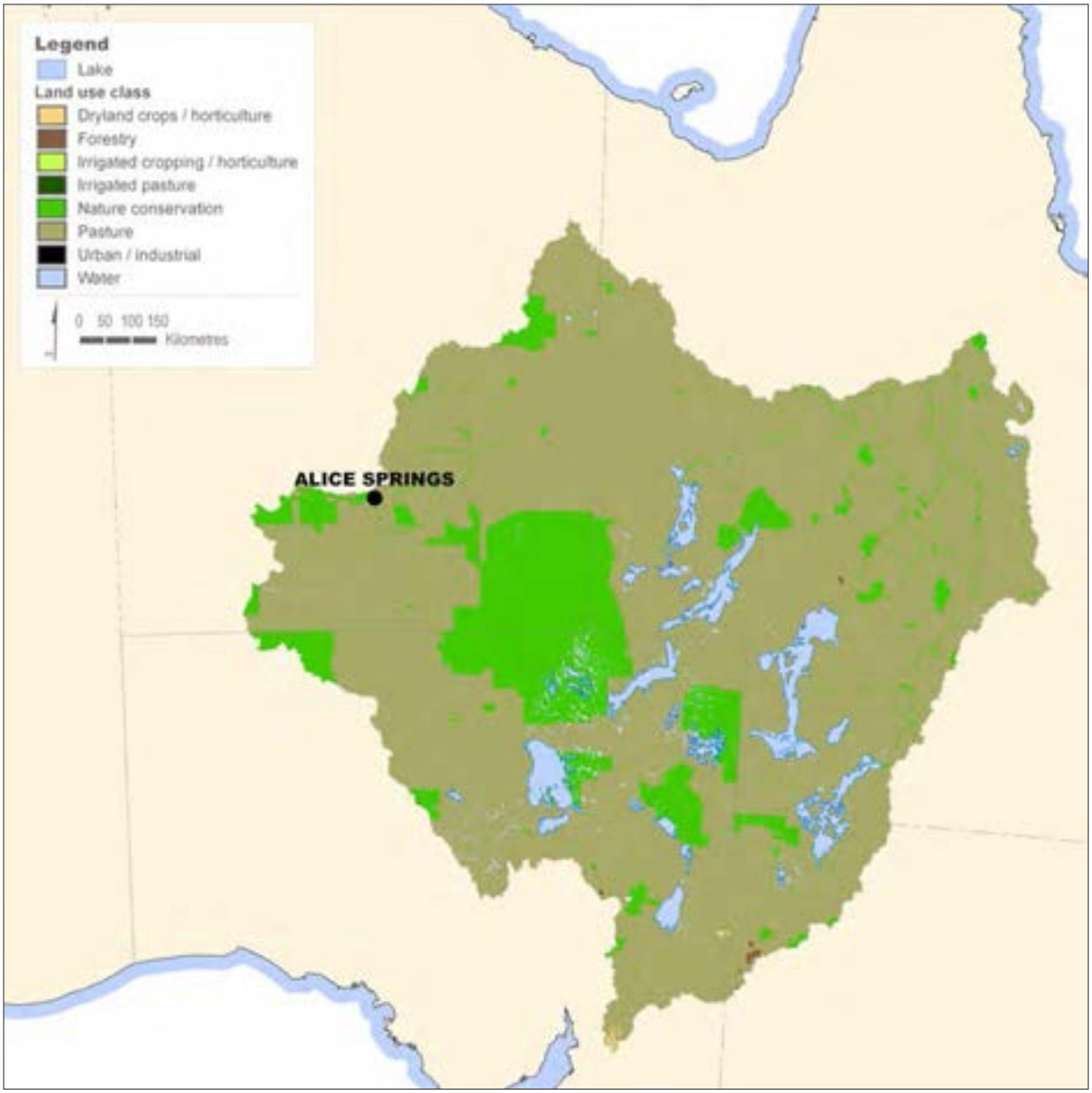


Figure 14.8 Land use distribution in the Lake Eyre Basin region

14.3.6 Population distribution

Lake Eyre Basin region is amongst the least populous areas in Australia. Figure 14.9 shows the population densities for the region and illustrates the sparse nature of its population (ABS 2011b).

Its major population centre of Alice Springs is located near its boundary in the northwest. Other remote communities are located on or near the region's borders in the south and west.

Outside of the major urban centres, mining leases, Indigenous communities and a number of small towns and settlements located adjacent to major roads account for much of its remaining population.

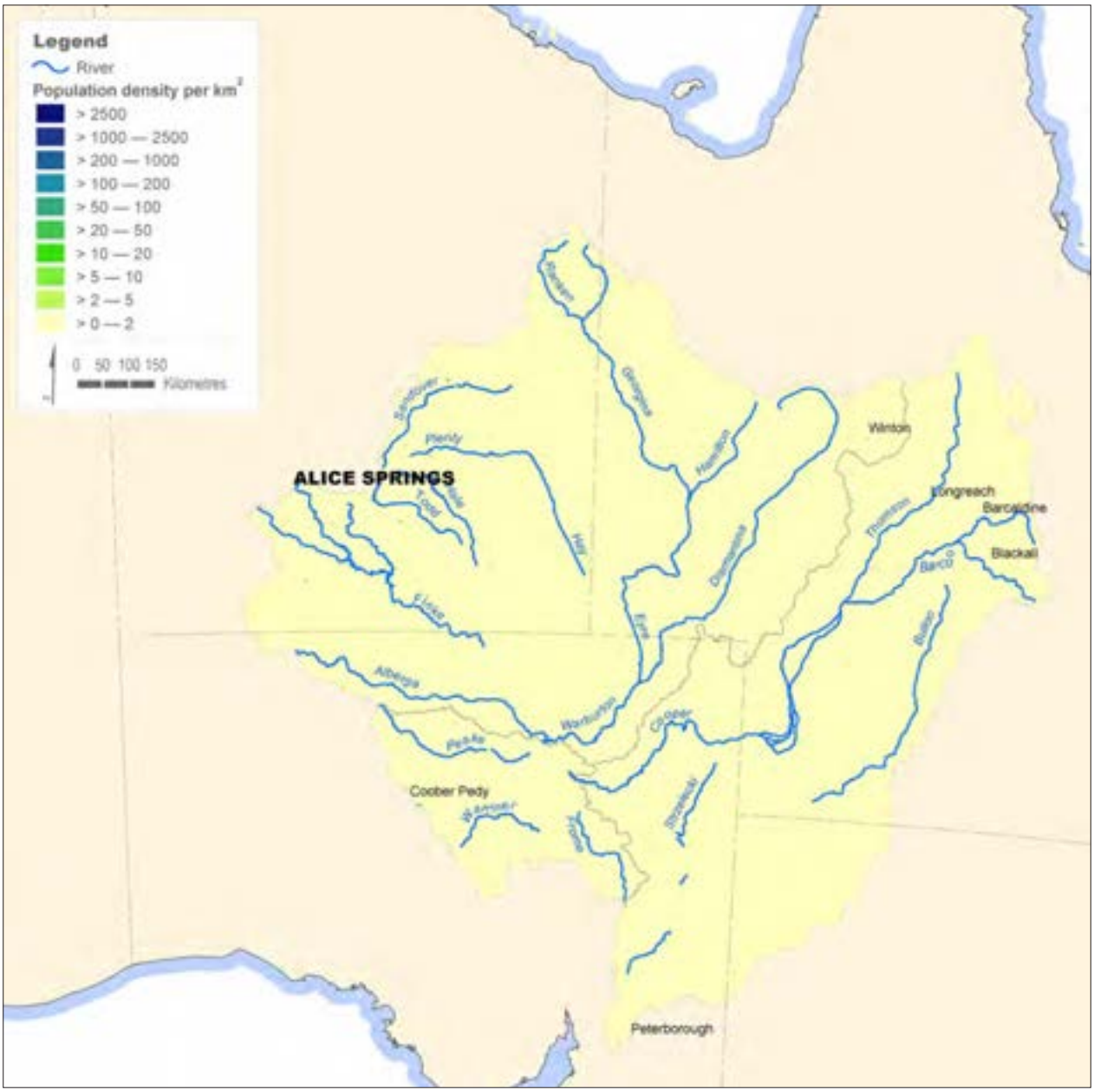


Figure 14.9 Population density and distribution in the Lake Eyre Basin region

14.3.7 Rainfall zones

The Lake Eyre Basin region's climate is arid throughout. The region receives monsoonal rain across the basin, in particular in the upper reaches of the Diamantina and Georgina rivers. Median rainfall does not exceed 650 mm per year anywhere in the region (Figure 14.10).

The region consists of one of the driest parts of the continent, with large areas in the centre not exceeding 200 mm of rainfall on average.

The far northeast has a pronounced wet season, with annual averages of about 400 mm. In the far south, some consistency in winter rainfall is present, although annual median rainfall does not exceed 500 mm.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

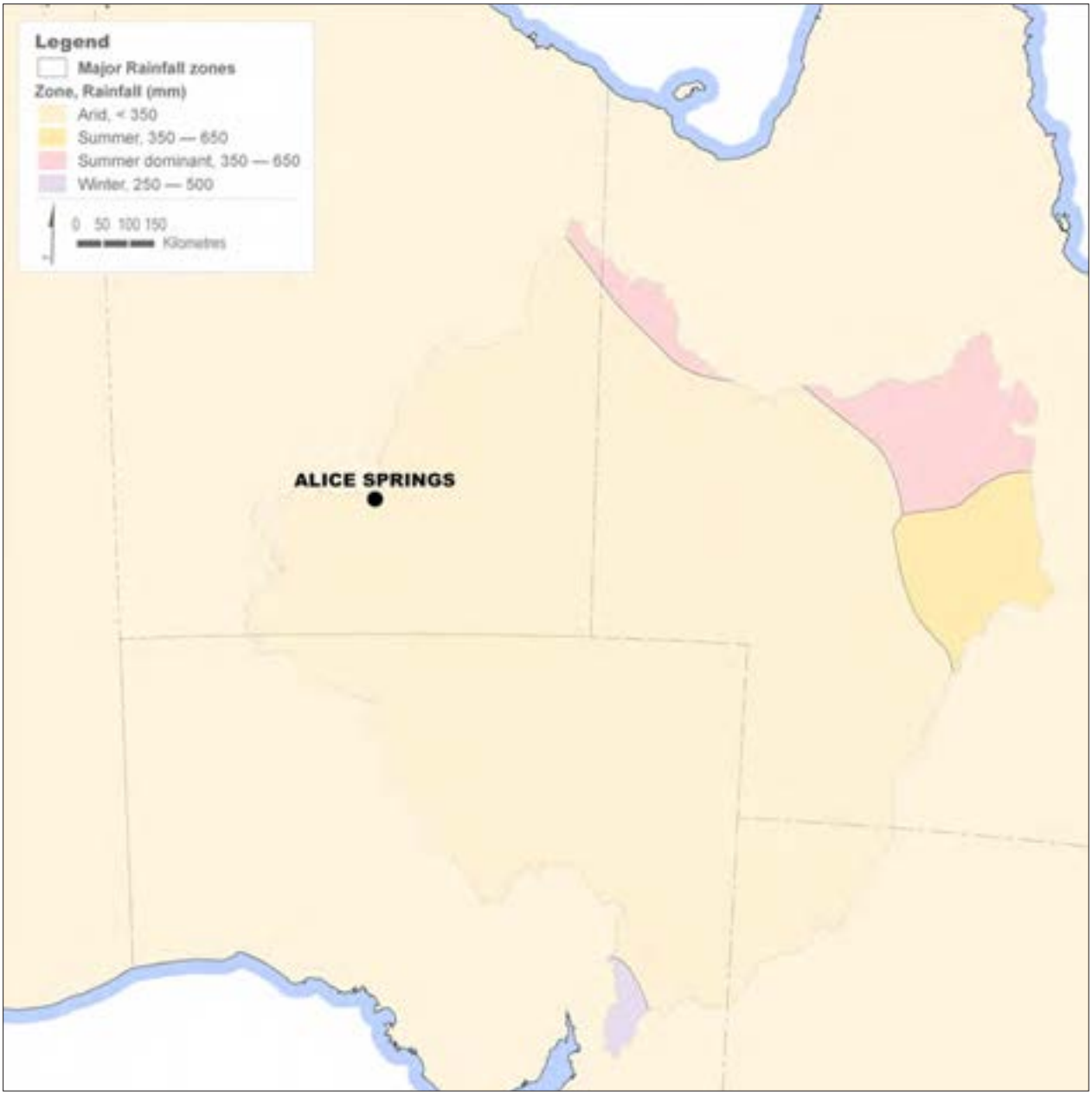


Figure 14.10 Rainfall zones in the Lake Eyre Basin region

14.3.8 Rainfall deficit

The rainfall deficit indicator, that is, rainfall minus potential evapotranspiration, gives a general impression about which parts of the region are likely to experience moisture deficits over the period of a year. The Lake Eyre Basin region has a uniform pattern of very high potential deficits over the whole region (Figure 14.11), although rainfall is highly variable from year to year.

Most of the region consists of desert land and ephemeral lakes, including Lake Eyre itself. Streamflow, often coming from the northeast as a result of monsoonal rainfall and tropical storms, occasionally feeds these lakes and forms large floodplains.

Other than grasses and some shrubs used for sparsely stocked farming, no real land use occurs in this dry landscape.

The moisture deficit does, however, provide many areas with a unique flora and fauna, mostly preserved in the many nature conservation areas in the region.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

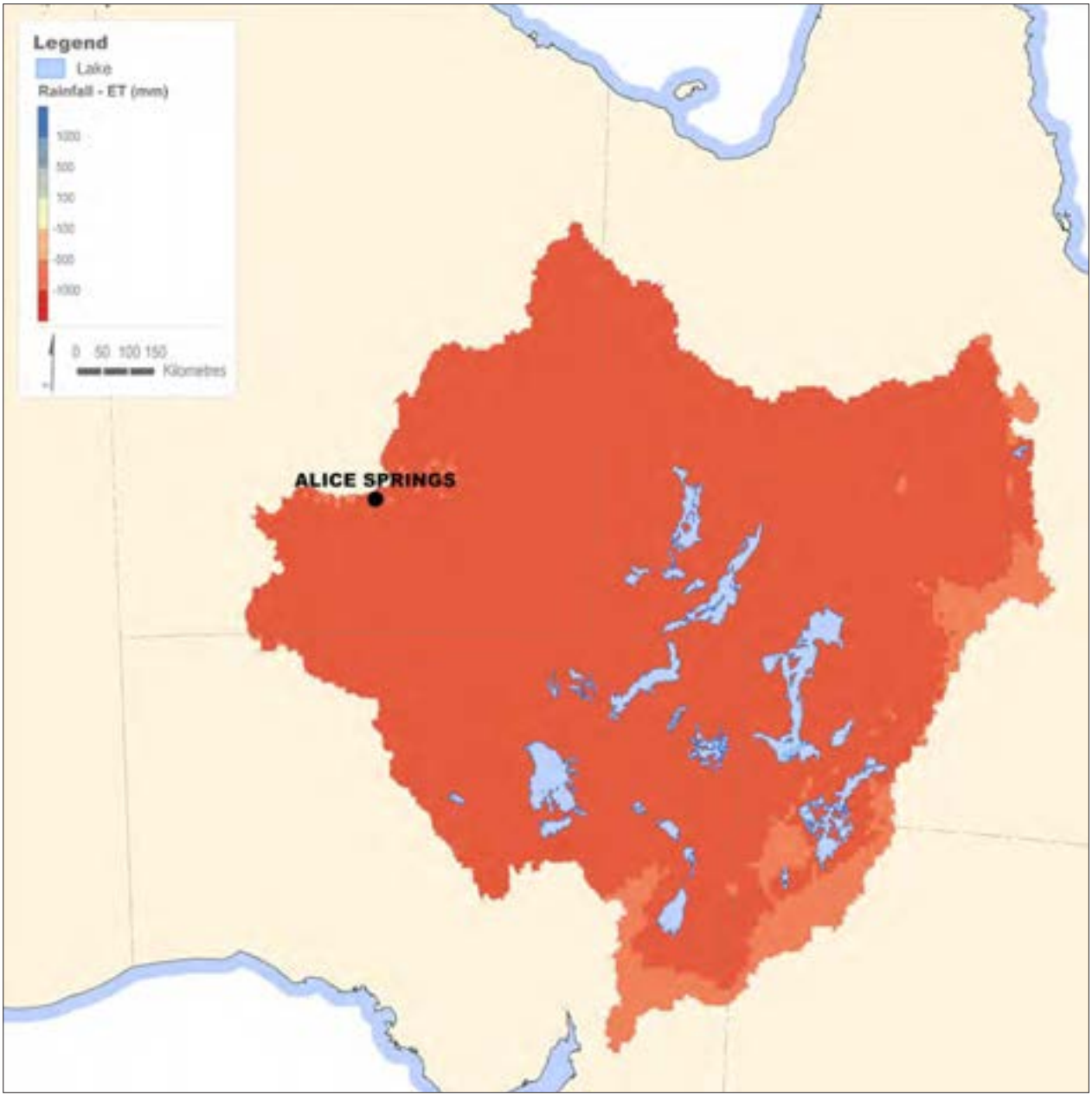


Figure 14.11 Rainfall deficit distribution in the Lake Eyre Basin region

14.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Lake Eyre Basin region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 14.12 shows that the Lake Eyre Basin region has a seasonal rainfall pattern with a wetter spring to early autumn and a largely dry winter period. Evapotranspiration in the dry winter period generally exceeds rainfall. After the wet period the soils normally contain plenty of moisture that is available for evapotranspiration. The monthly landscape water yield history for the region shows a stable pattern of very low yield throughout the year, although it marginally increases between January and March.

The 2011–12 year was a relatively wet year, with the months of November and March receiving very much above average rainfall. An active monsoon in the north of the region and La Niña and wetter Indian Ocean influences contributed to high rainfall totals, particularly for the month of March.

Evapotranspiration was particularly high in November, December and March. In March, evapotranspiration was the second highest on record for the 1911–2012 time-series.

The landscape water yield for 2011–12 was fifth highest on record in November and third highest on record in March.

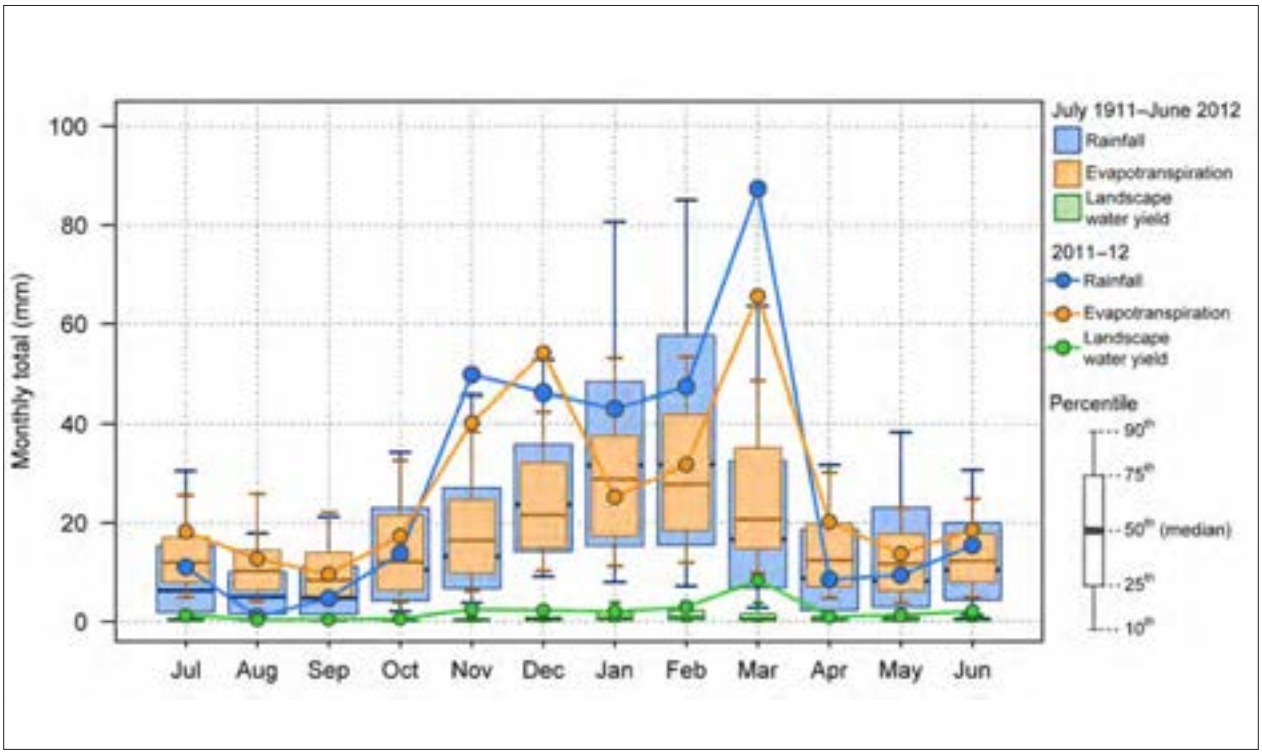


Figure 14.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the Lake Eyre Basin region

14.4.1 Rainfall

Rainfall for the Lake Eyre Basin region for 2011–12 is estimated to be 337 mm. This is 42% above the region's long-term average (July 1911–June 2012) of 237 mm. Figure 14.13a shows that the highest rainfall occurred in the northeast with annual totals exceeding 600 mm in 2011–12. Rainfall in the centre of the region did not exceed 200 mm over large areas.

Rainfall deciles for 2011–12 indicate average to above average rainfall for the entire region over the course of the year (Figure 14.13b). The southeast of the region received very much above average rainfall. The Diamantina–Georgina river basins in the northwest of the region received predominantly average rainfall only.

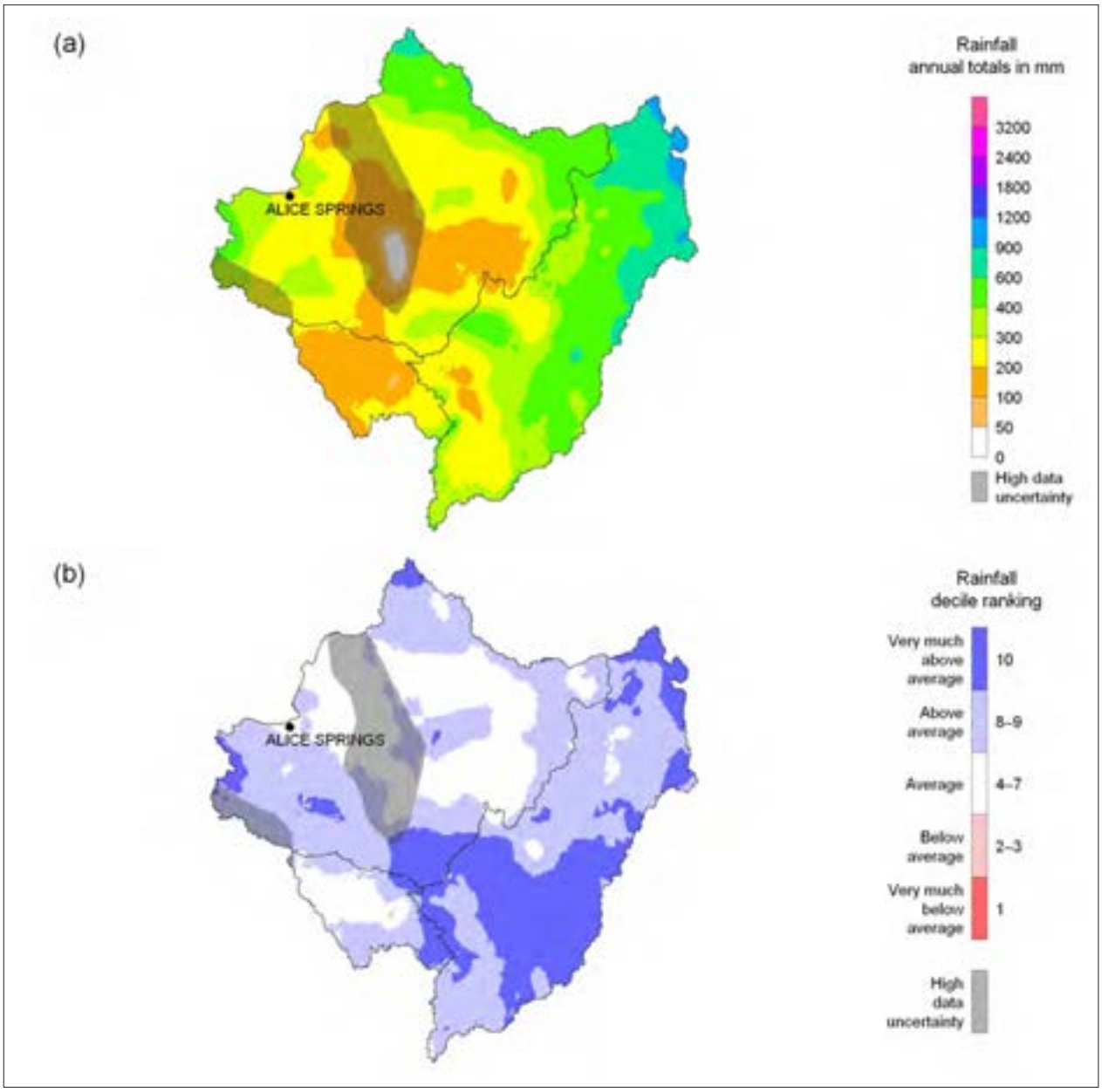
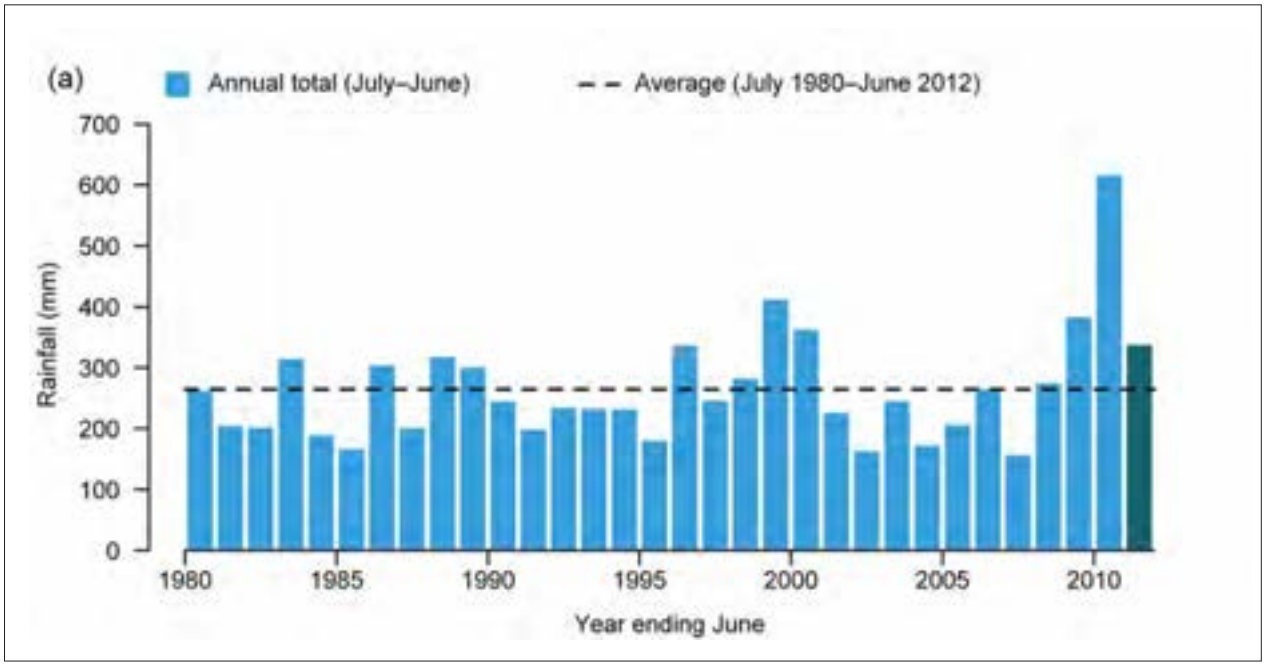


Figure 14.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Lake Eyre Basin region

Rainfall variability in the recent past

Figure 14.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 264 mm, varying from 156 mm (2007–08) to 616 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 14.14b.

The graphs indicate the presence of cyclical patterns typical in the region's annual rainfall, which are particularly noticeable in the summer period. This pattern is closely linked to the Southern Oscillation Index and the occurrence of El Niño and La Niña periods (see the National Overview chapter). A strong La Niña period typically delivers above average rainfall, particularly to the northeast of the region, clearly seen in the recent very strong 2010–11 La Niña event.



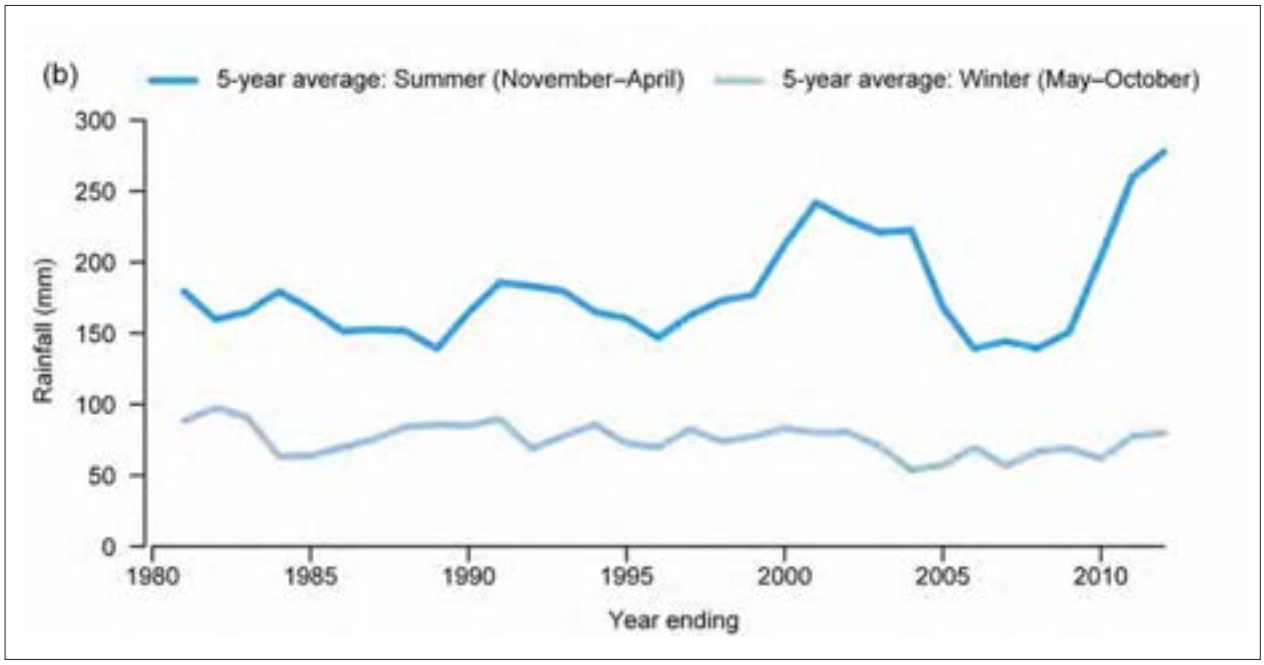


Figure 14.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Lake Eyre Basin region

Recent trends in rainfall

Figure 14.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 14.15b.

Figure 14.15b shows that since 1980 an increase in rainfall has occurred in large parts of the region, particularly towards the north; however, the trends are only strongly statistically significant in 6% of the region. The trends are largely a result of the multi-annual cyclic rainfall pattern shown in Figure 14.14 and the particularly high rainfall of 2011–12.

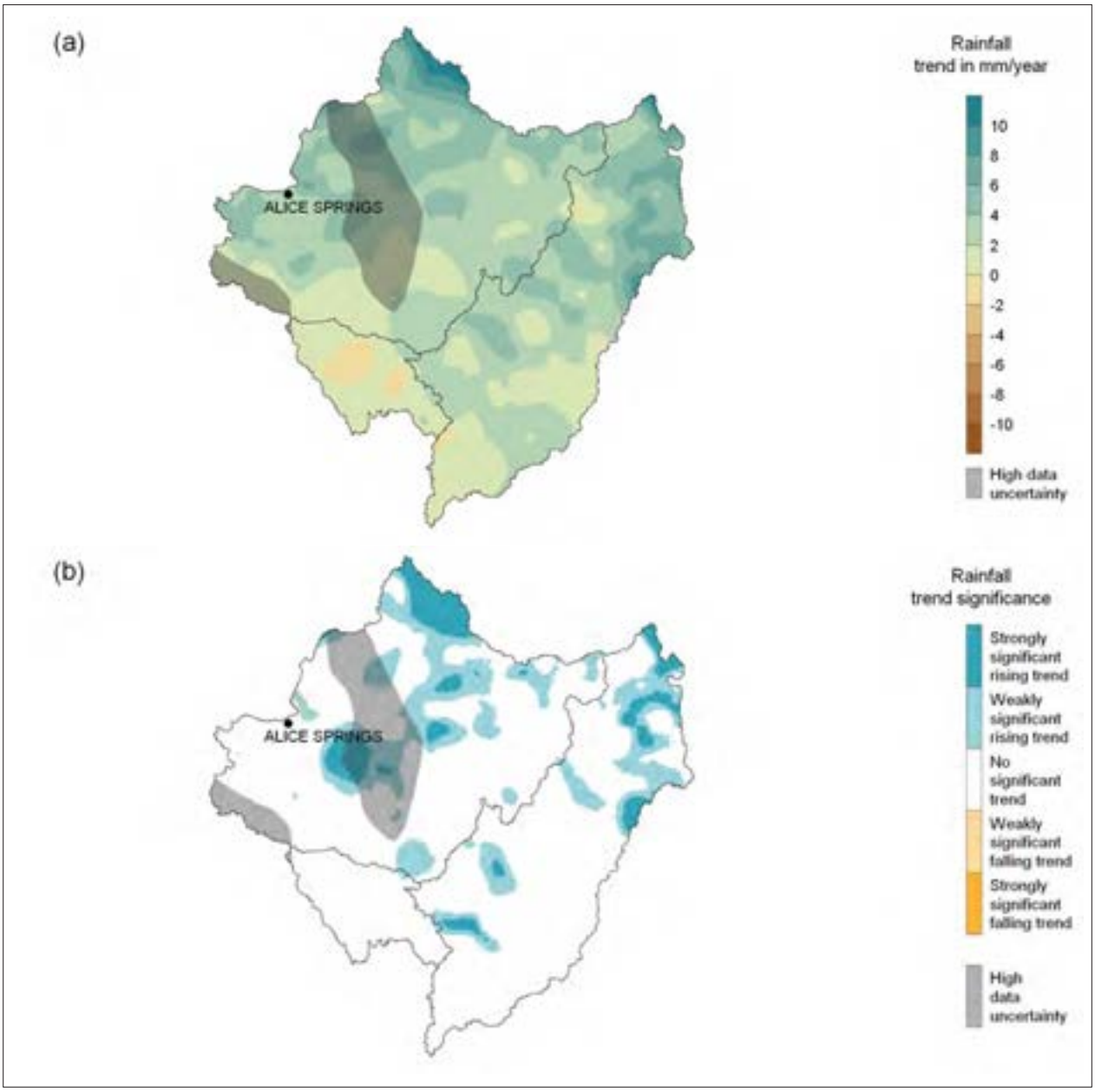


Figure 14.15 Spatial distribution of (a) trends in annual rainfall from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Lake Eyre Basin region

14.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Lake Eyre Basin region for 2011–12 is estimated to be 327 mm. This is 45% above the region's long-term (July 1911–June 2012) average of 226 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 14.16a) is similar to that of rainfall (Figure 14.13a).

Evapotranspiration deciles for 2011–12 indicate above average totals across most of the region (Figure 14.16b). Around 23% of the region even recorded very much above average evapotranspiration, scattered throughout. The Lake Eyre district in the southwest is the exception, where generally average evapotranspiration is estimated.

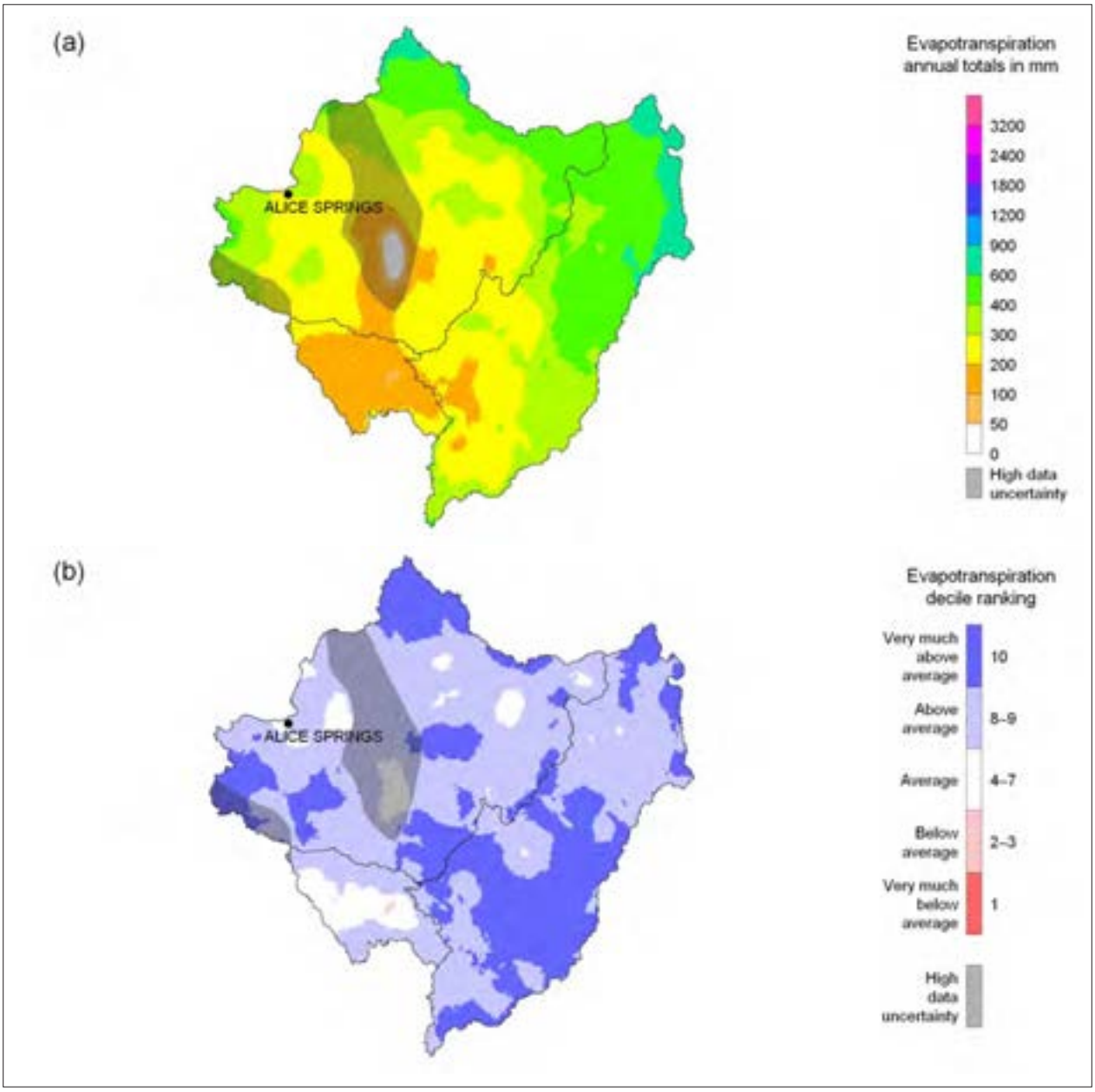


Figure 14.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Lake Eyre Basin region

Evapotranspiration variability in the recent past

Figure 14.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 250 mm, varying from 153 mm (2004–05) to 543 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 14.17b.

Summer periods showed consistently higher evapotranspiration than the winter period due to the higher temperatures and the higher rainfall in the north of the area. Also the annual variability is mainly caused during the summer period, which again follows the pattern of rainfall (Figure 14.14b).

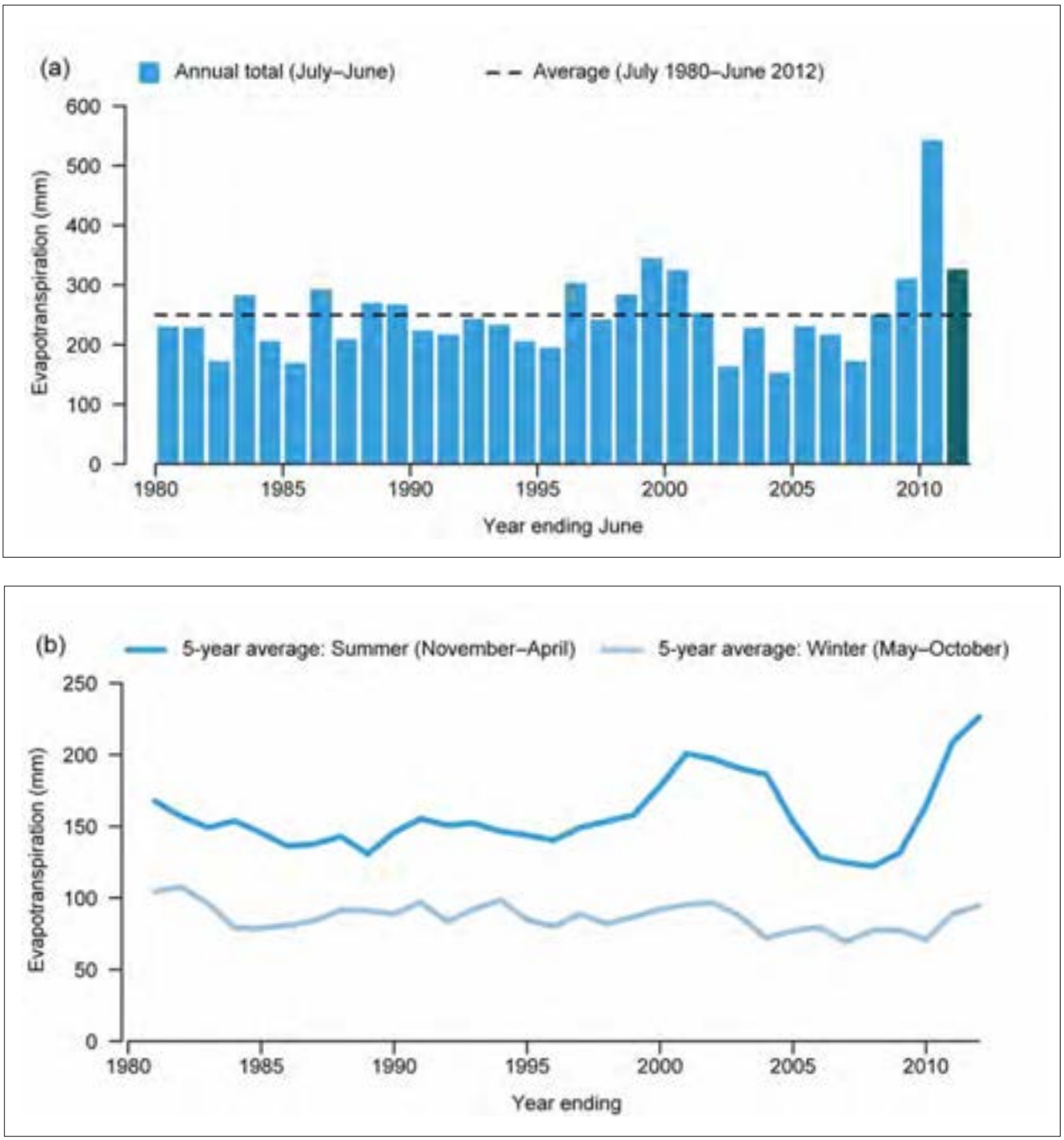


Figure 14.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Lake Eyre Basin region

Recent trends in evapotranspiration

Figure 14.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980– 2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 14.18b.

Figure 14.18a shows that since 1980 trends are mostly rising with a stronger signal in the north of the region. Figure 14.18b confirms that these stronger northern trends are statistically more significant.

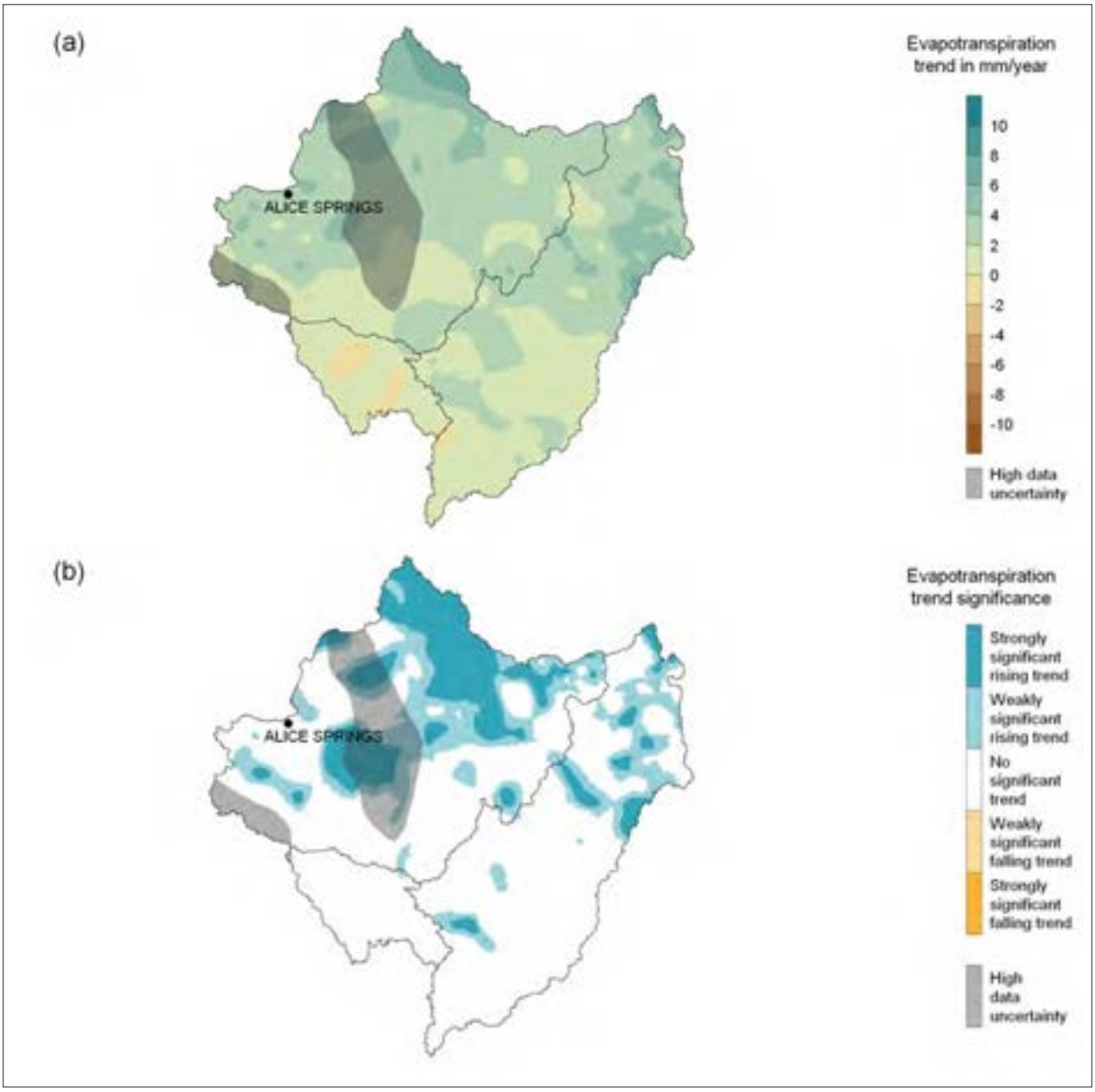


Figure 14.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Lake Eyre Basin region

14.4.3 Landscape water yield

Modelled landscape water yield for the Lake Eyre Basin region for 2011–12 is estimated to be 25 mm. This is 150% above the region's long-term (July 1911–June 2012) average of 10 mm. Figure 14.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 14.13a, note the difference in the scales between the two figures).

The decile-ranking map for 2011–12 (Figure 14.19b) shows above average to very much above average landscape water yields. The decile rankings of landscape water yield are substantially higher than those of rainfall due to the higher initial soil moisture levels, caused by the strong wet season in 2010–11.

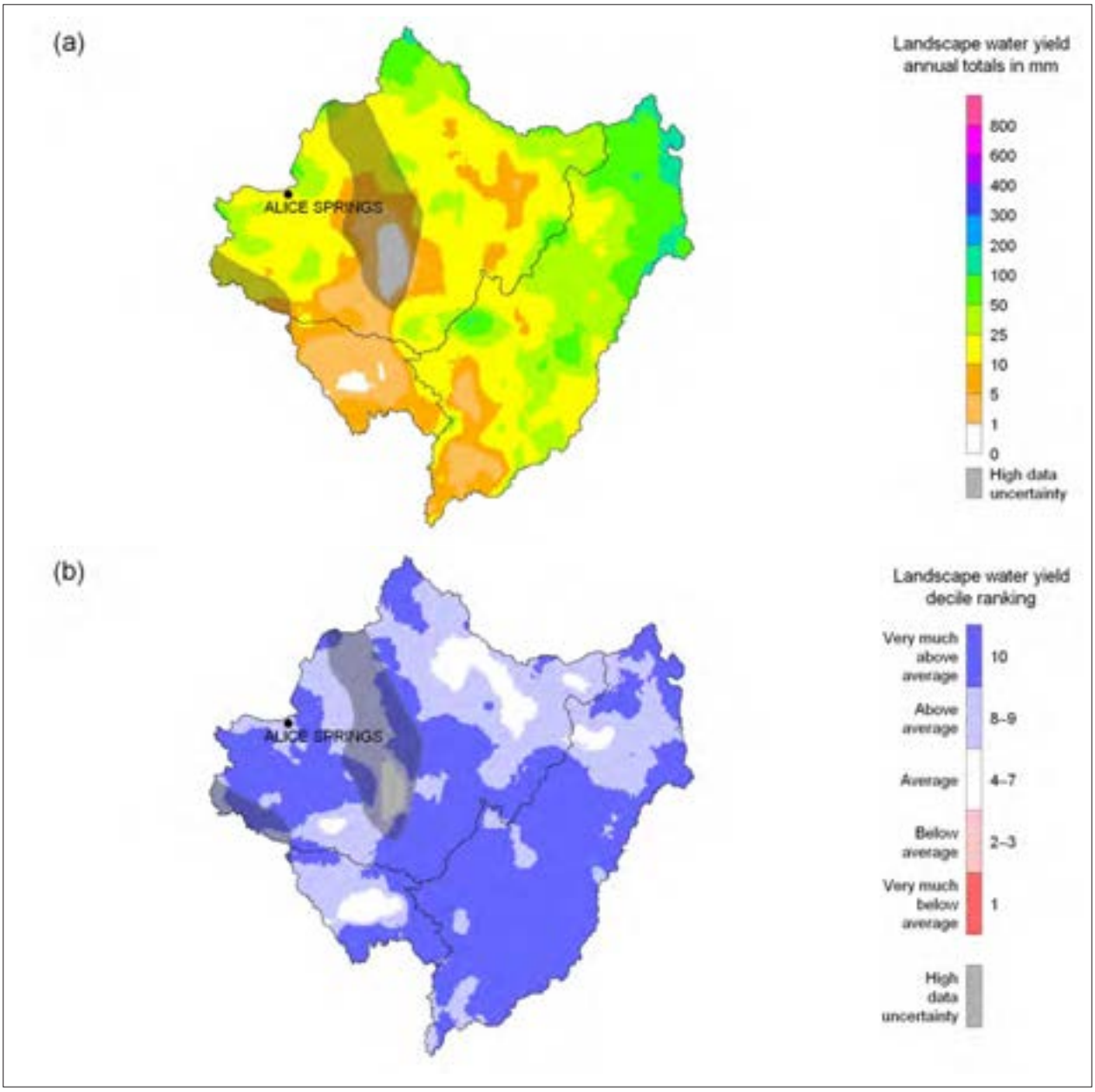


Figure 14.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Lake Eyre Basin region

Landscape water yield variability in the recent past

Figure 14.20a shows annual landscape water yield for the Lake Eyre Basin region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 13 mm, varying from 4 mm (1985–86) to 51 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 14.20b.

Landscape water yield is highly variable in the Lake Eyre Basin region with the second highest coefficient of variation (standard deviation divided by mean) of all regions, behind the Pilbara–Gascoyne region. The variability in landscape water yield in the annual totals as well as the landscape water yield of the summer period is directly related to rainfall.

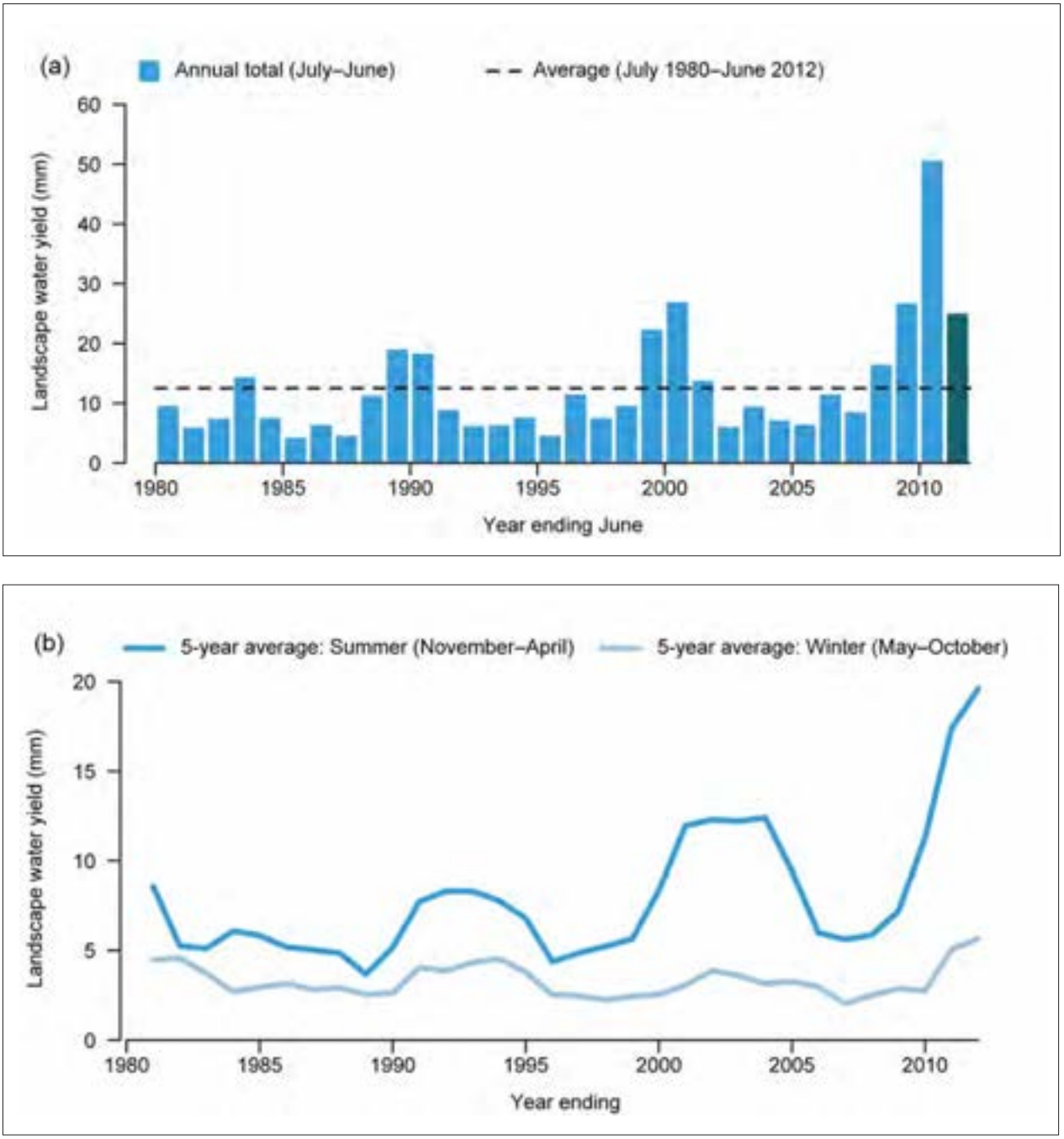


Figure 14.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the summer (November–April) and winter (May–October) periods for the Lake Eyre Basin region

Recent trends in landscape water yield

Figure 14.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 14.21b.

The pattern in Figure 14.20a and the particularly high peak of 2010–11 makes the landscape water yield trends stand out as rising throughout the region, with the exception of the very low landscape water yield area in the Lake Eyre district in the southwest. Figure 14.21b shows that in large parts of the region trends are statistically significant.

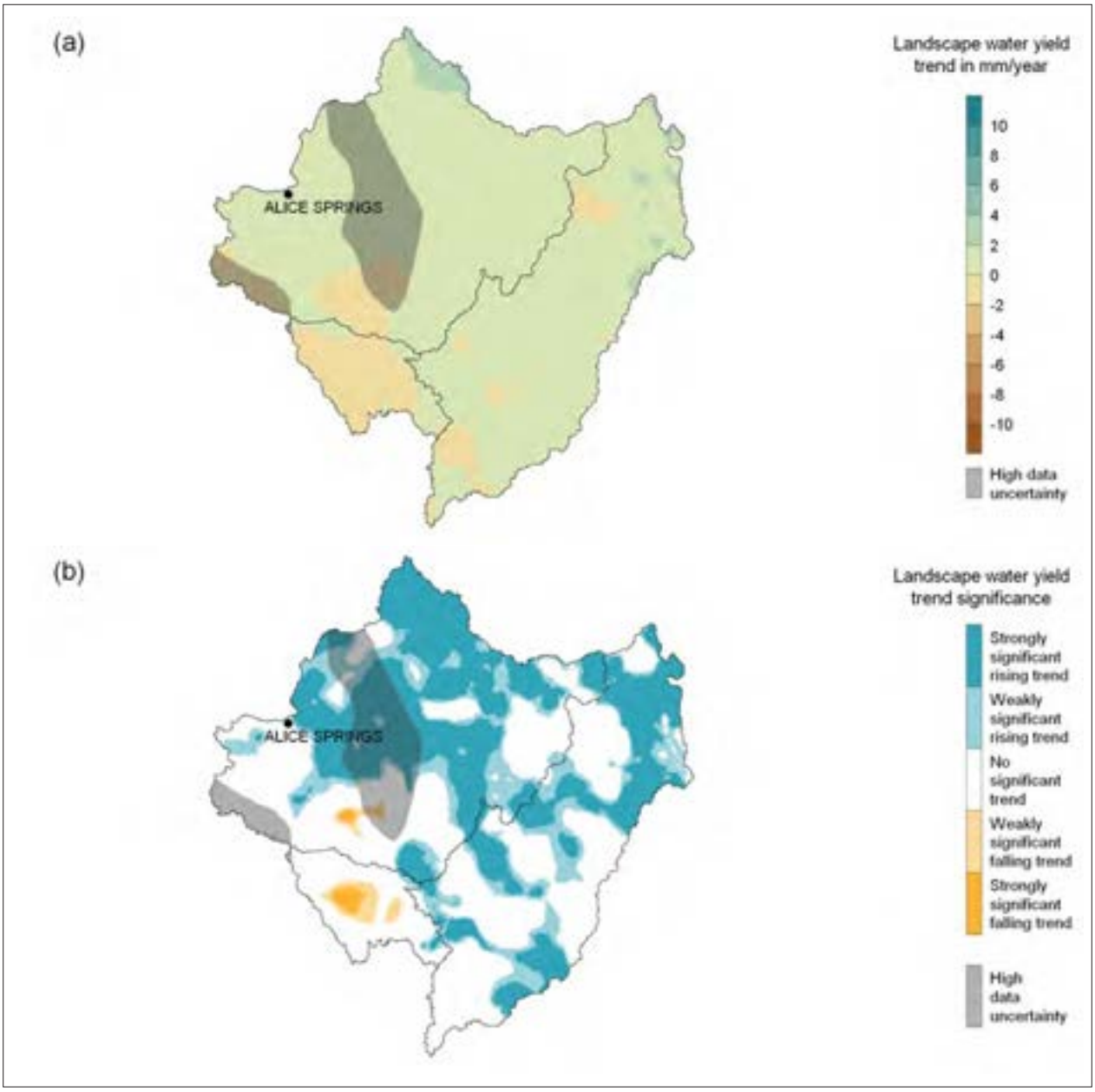


Figure 14.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Lake Eyre Basin region

14.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Lake Eyre Basin region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

Data was not available for streamflow salinity in the Lake Eyre Basin.

There are no storage systems in the Lake Eyre Basin.

14.5.1 Rivers

The region is the world's largest internally draining system and Lake Eyre is the fifth largest terminal lake in the world. There are three river basins in the region, varying in size from 106,000 to 699,000 km^2 (Figure 14.22).

The major rivers in the region flow from central and western Queensland in the northeast into South Australia in the south. The southwest corner of the region (Lake Eyre) is up to 15 m below sea level and it is the final receiving area for all major watercourses in the basin if the flood extent is large enough.

The rivers and creeks are characterised by high variability and unpredictability in their flow with high transmission losses and very low gradients. All creeks and rivers of the basin are ephemeral with relatively short periods of flow following rain, and often long periods with no flow.

14.5.2 Streamflow volumes

Figure 14.23 presents an analysis of flows at five monitoring sites during 2011–12 relative to annual flows for the period from July 1980–July 2012. Monitoring sites with relatively long records across four geographically representative rivers were selected (see Technical Supplement). The annual river flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows generally reflect the mostly average to above average modelled landscape water yield results shown in Figure 14.19b. Only the monitored flows in the Darr River present a slightly different pattern of below average flows (red dot in Figure 14.23).

Above average flows were observed at three sites in the region which were located on rivers in the east of the Lake Eyre Basin region. Average total flows were recorded at one monitoring site. This was on the Diamantina River in the centre of the region.

Flow deciles in the summer (November 2011–April 2012) were very similar to total annual flows for 2011–12 as shown in Figure 14.23. This is to be expected given the bulk of flows in the region, particularly in the northeast, occurred over the summer period. It is also the consequence of the summer-dominated rainfall in that part of the region.

Figure 14.22 Rivers and catchments in the Lake Eyre Basin region

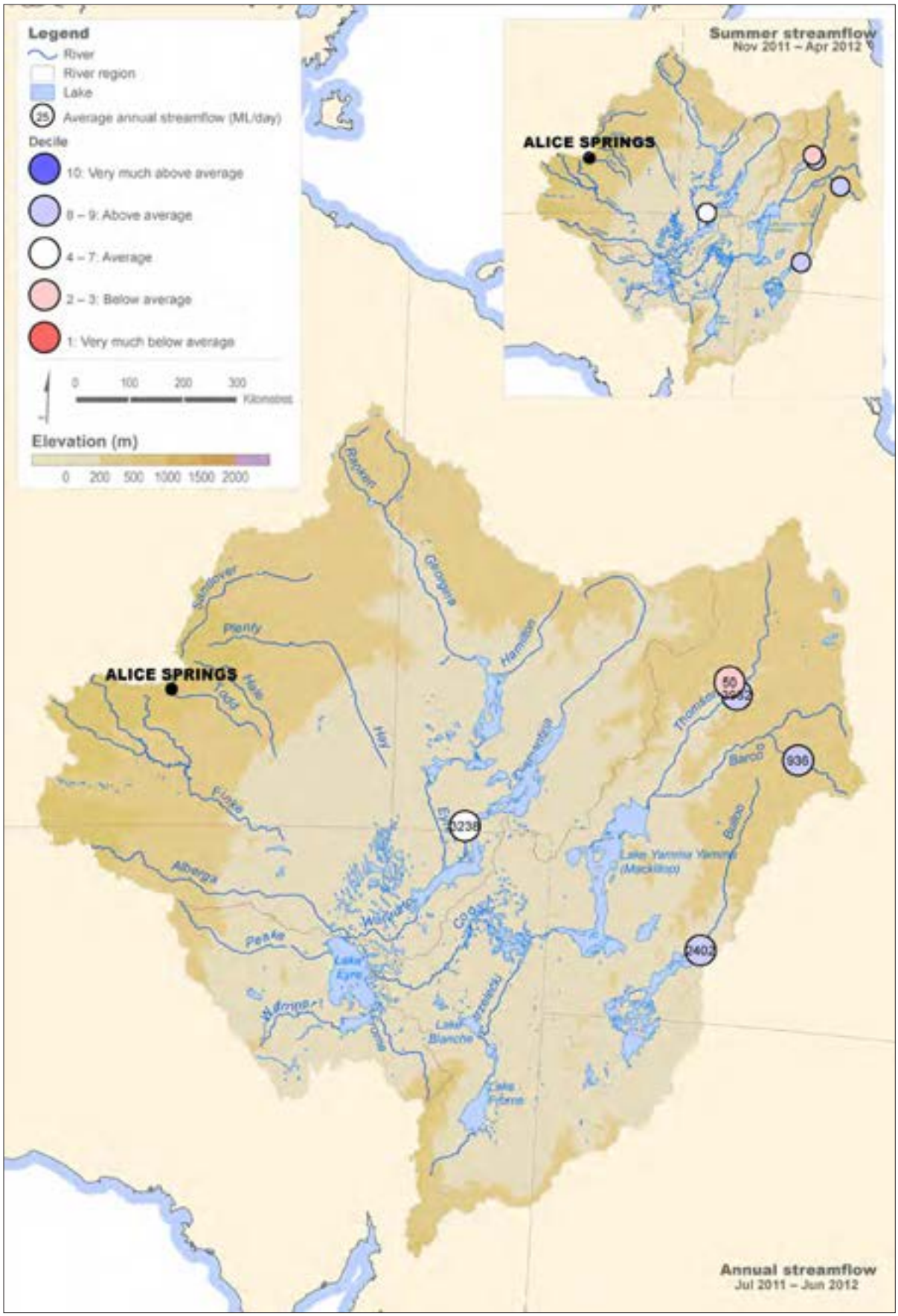


Figure 14.23 Average annual and summer period flow volumes of selected gauges for 2011–12 and their decile rankings over the 1980–2012 period in the Lake Eyre Basin region

14.5.3 Flooding

Figure 14.24 gives an overview of the locations where the Bureau is monitoring flood levels in the Lake Eyre Basin region through the Northern Territory Government. These levels are further specified in the Technical Supplement.

A sequence of wet and dry spells has been observed in the lake over years, which is very much related to the El Niño—Southern Oscillation Index. Major events of filling the Lake Eyre are associated with rare cases of annual rainfall in excess of 500 mm. Several of the tributaries to the lake were flooded during the months between January and March 2012. In early 2012, major floods occurred in the Bulloo River.

Later in February, the main tributary to Lake Eyre, the Diamantina River, was flooded; this was concurrent with major floods in several segments of the Barcoo River. Some moderate floods were also registered in the Thomson and Bulloo rivers during February.

In March 2012 and following heavy rainfalls in the catchment all tributaries of the lake were flooded, the most significant of which was the Diamantina River which had major floods. Moderate floods occurred in other tributaries of the lake. In April, the floods gradually subsided and were limited to some moderate and minor floods in the Diamantina and Thomson rivers, respectively.

14.5.4 Wetlands

There are two Ramsar-listed, internationally important wetlands in the Lake Eyre Basin region as well as a number of wetlands of national importance mentioned in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html)

The wetlands mainly consist of ephemeral river floodplains and lakes (Figure 14.25). They play important roles in the survival of many rare species of plants and animals. They also attract large numbers of common water birds when the lakes and floodplains are flooded.

No detailed assessment on the inflows of selected wetlands has been performed for this region.

Coongie Lakes wetlands | Paul Wainwright

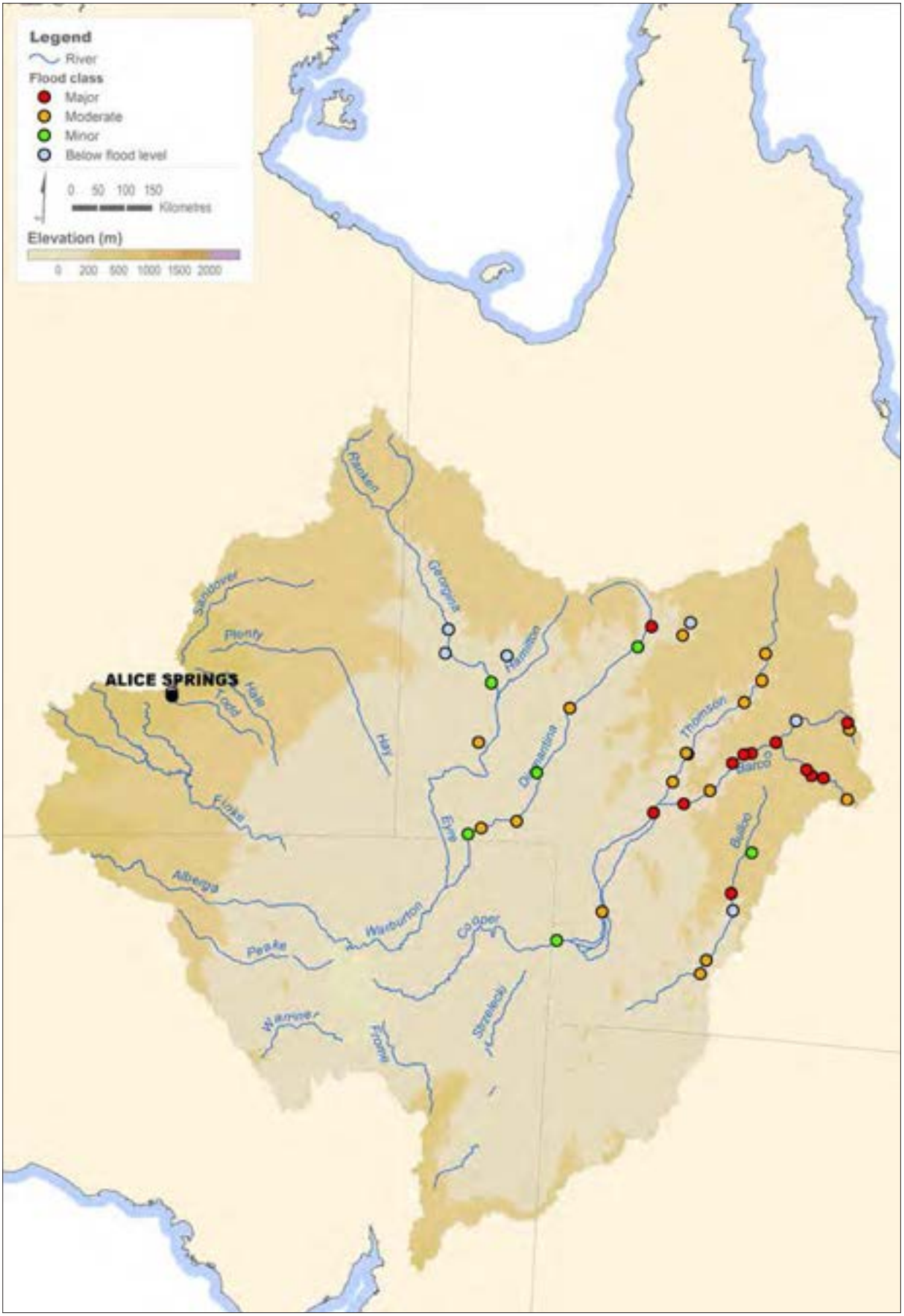


Figure 14.24 Flood occurrences in the Lake Eyre Basin region

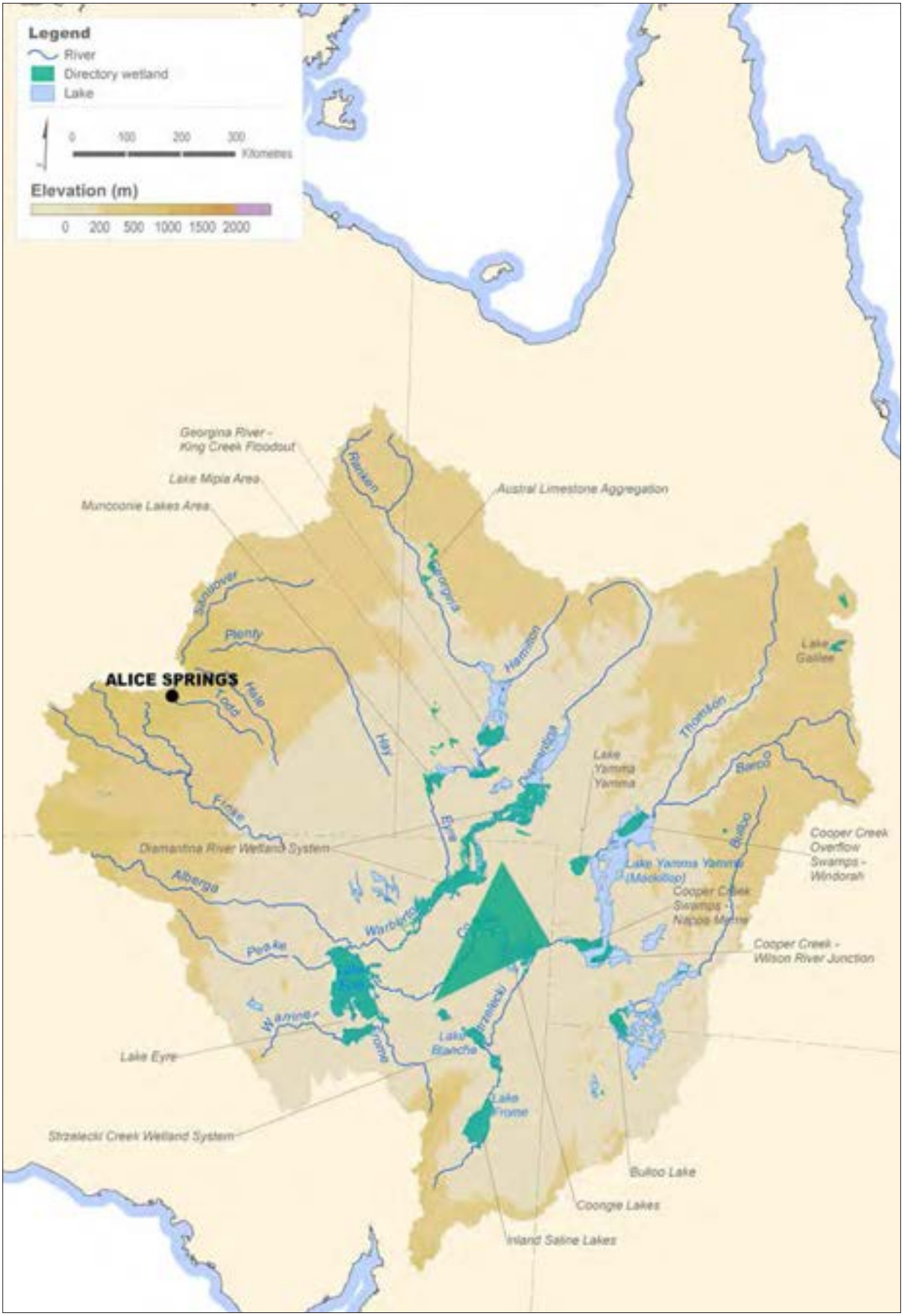


Figure 14.25 Location of important wetlands in the Lake Eyre Basin region

14.5.5 Hydrogeology

The hydrogeology of the region is dominated by the sediments of the Great Artesian Basin with porous sandstone aquifers. Figure 14.26 shows that the Great Artesian Basin underlies the region from the northeast, where the boundaries of both basins closely approximate each other, and extends through to the central and southwest margins. This basin is one of Australia's most significant groundwater basins. The areas identified as Palaeozoic fractured rock (low permeability) in the northwest of this region typically offer restricted low volume groundwater resources.

In contrast, the areas identified as fractured and karstic and Palaeozoic fractured rock (consolidated and partly porous) provide a usable groundwater resource in some parts. These units provide 95% of the town water supply for Alice Springs.

Groundwater systems that provide more potential for extraction are labelled as:

- Fractured and Karstic Rocks (regional) and (local); and
- Mesozoic GAB (porous media—consolidated).

14.5.6 Watertable salinity

Figure 14.27 below shows the classification of watertable aquifers as fresh (total dissolved solids <3,000 mg/L) or saline (TDS ≥3,000 mg/L) water according to water table salinity. There are small areas of no data represented in grey. In general, groundwater has been classified as mainly fresh along the borders of the Northern Territory and New South Wales, and mainly saline in the South Australian border area.

14.5.7 Groundwater management units

The groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 14.28 shows the major groundwater management units that are superimposed on the Great Artesian Basin, that is, Northern Territory, Great Artesian Basin Water Control District; South Australia: Far North Prescribed Wells Area; Queensland: Great Artesian Basin; New South Wales: Great Artesian Basin Cap Rock, and the Karstic and Fractured Rocks resources, that is, Northern Territory: Alice Springs and Queensland: Mount Isa.

Aerial view, Lake Eyre with water | Edstock (iStockphoto)

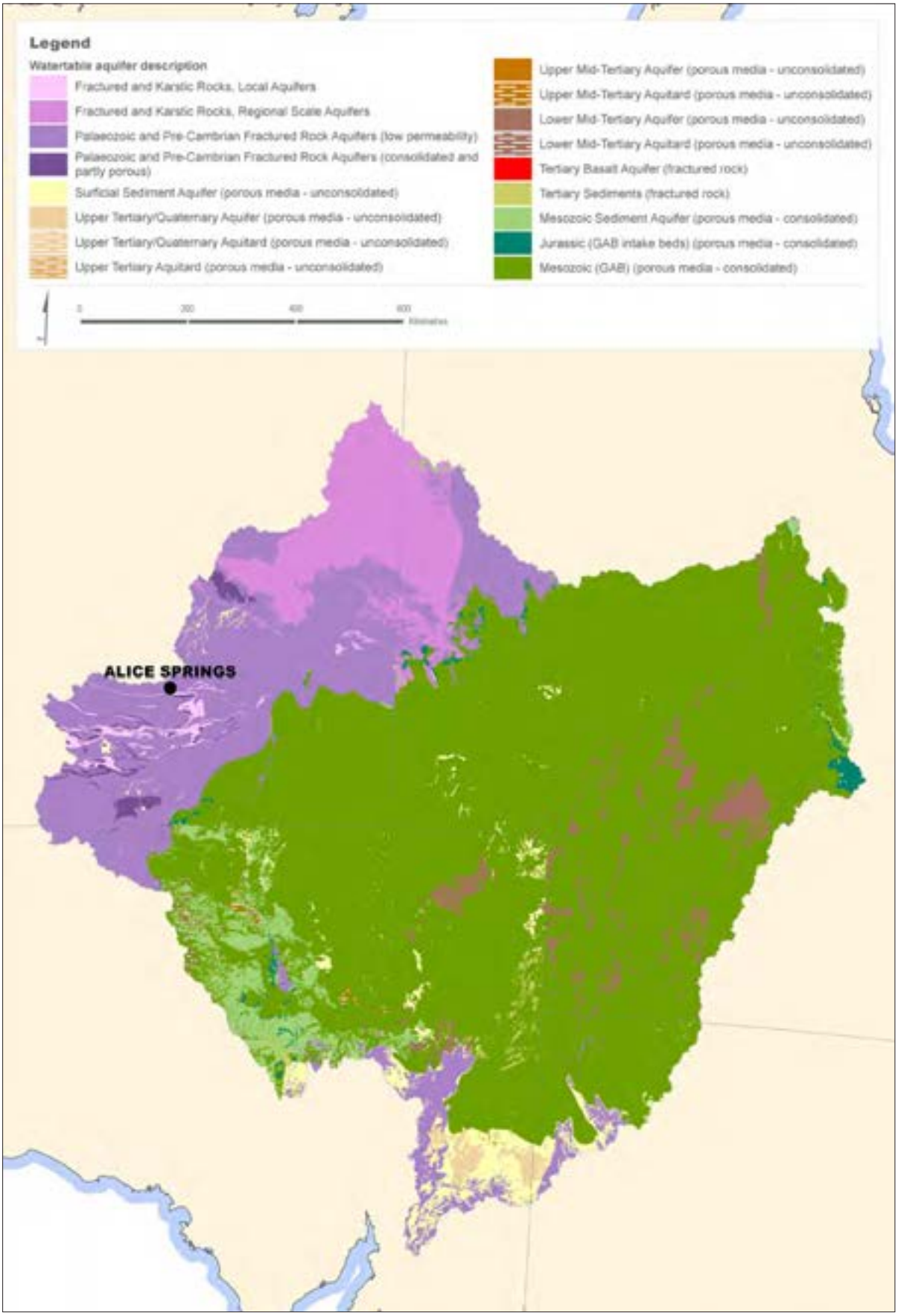


Figure 14.26 Watertable aquifers of the Lake Eyre Basin region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

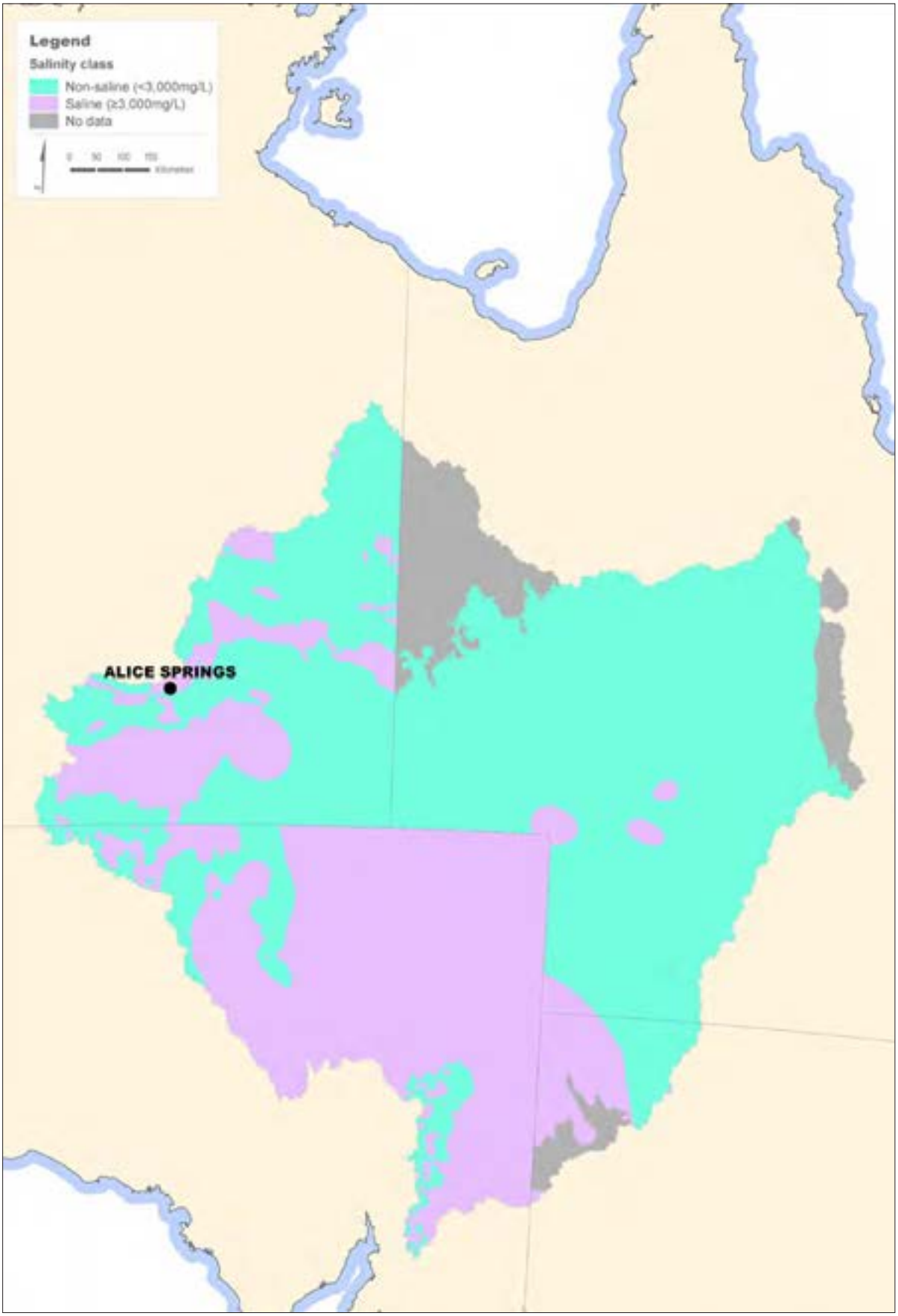


Figure 14.27 Water table salinity classes in the Lake Eyre Basin region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

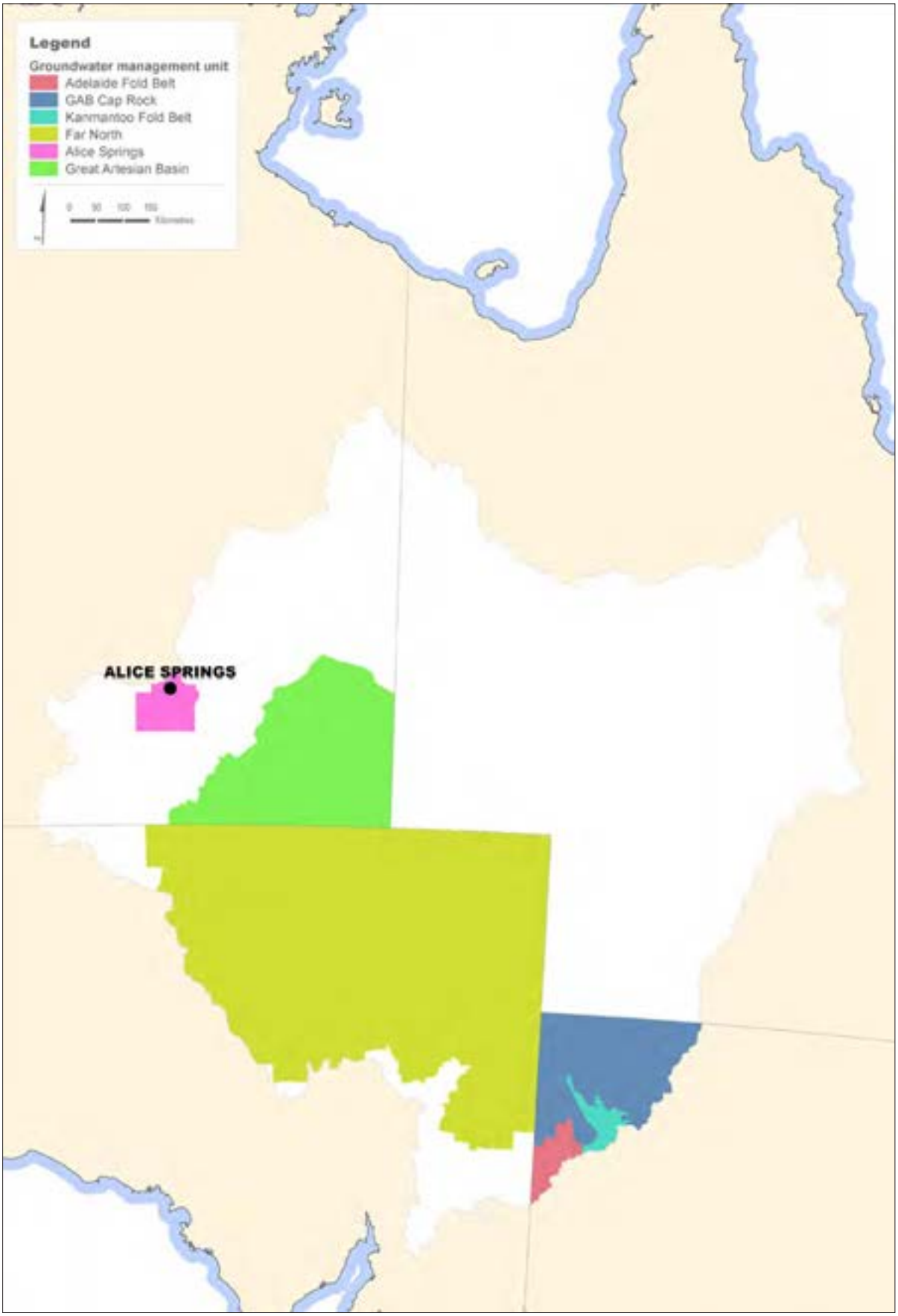


Figure 14.28 Groundwater management units in the Lake Eyre Basin region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

Carpentaria Coast

15 Carpentaria Coast 2
15.1 Introduction 2
15.2 Key information 3
15.3 Description of the region 4
15.3.1 Physiographic characteristics 6
15.3.2 Elevation 7
15.3.3 Slopes 8
15.3.4 Soil types 9
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15 Carpentaria Coast

15.1 Introduction

This chapter examines water resources in the Carpentaria Coast region in 2011–12 and over recent decades. It starts with summary information on the status of water flows, stores and use. This is followed by descriptive information for the region, including the physiographic characteristics, soil types, population, land use and climate.

Spatial and temporal patterns in landscape water flows are presented, followed by an examination of the surface water and groundwater resources to finish the chapter. The data sources and methods used in developing the diagrams and maps are listed in the Technical Supplement.

15.2 Key information

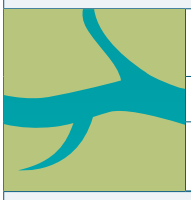
Table 15.1 gives an overview of the key components of the data and information in this chapter.

Table 15.1 Key information on water flows and stores in the Carpentaria Coast region

Landscape water flows

	Region average	Difference from 1911–2012 long-term annual mean	Decile ranking with respect to the 1911—2012 record
Rainfall	992 mm	+31%	9th— above average
Evapo-transpiration	775 mm	+30%	10th—very much above average
Landscape water yield	237 mm	+54%	9th—above average

Streamflow (at selected gauges)

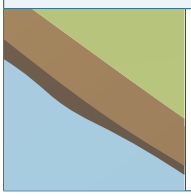


Annual total flow:	Predominantly average flow, above average flow in some headwater rivers
Salinity:	Annual median electrical conductivity below 1,000 µS/cm
Flooding:	Minor to moderate floods in most gauges, major floods in some gauges in the southern and western rivers

Surface water storage (comprising about 24% of the region's total capacity of all major storages)

Total accessible capacity	30 June 2012		30 June 2011		Change	
	accessible volume	% of total capacity	accessible volume	% of total capacity	accessible volume	% of total capacity
99 GL	92 GL	93%	93 GL	94%	-1 GL	-1%

Groundwater (in selected aquifers)



Salinity:	Non-saline groundwater (<3000 mg/L) throughout the region with some coastal areas of saline groundwater (≥3000 mg/L), due to seawater intrusion

15.3 Description of the region

The Carpentaria Coast region covers approximately 647,000 km^2. To the west is Arnhem Land and Groote Eylandt, the largest island in the Gulf of Carpentaria. To the east is the Cape York Peninsula.

The landscape is generally flat and low-lying, comprised of floodplains, much of which drain into the gulf. Subsections 15.3.1–15.3.4 provide more information on the topography and soils cover.

Approximately 66,500 people permanently reside in the Carpentaria Coast region. This accounts for less than 0.29% of the nation's total population (Australian Bureau of Statistics [ABS] 2011b). Over one quarter of the region's population is Indigenous.

In addition to its major population centre of Mount Isa, the region has a number of remote and regional towns that are shown in Figure 15.1. These include the regional centres of Cloncurry, Normanton, Doomadgee and Kowanyama. Further discussion of the region's population distribution can be found in subsection 15.3.6.

Grazing is the dominant land use. There are large areas of nature conservation, Indigenous land use and some forestry. Irrigated agriculture only exists on a very local scale, supported by water from two major storages. There is extensive mining activity in the region.

The climate is hot and humid mostly in the wet season. The dry season runs from about May–October and the monsoonal wet season from November–April. Subsections 15.3.7 and 15.3.8 provide more information on the rainfall patterns and deficits across the region.

The rivers are very large by Australian standards and carry approximately a quarter of the continent's total yearly streamflow. Most rivers, however, flow mainly during the wet season. Therefore, perennial rivers and perennial springs in the region are important sources of water.

The hydrogeology of the region is dominated by the sediments of the Great Artesian Basin, fractured and karstic rock in some areas, and some outcropping basement rock. A more detailed description of the rivers and groundwater status in the region is given in section 15.5.

River delta on the Gulf of Carpentaria between Weipa and Pormpuraaw, Queensland | Dr Linda Sands

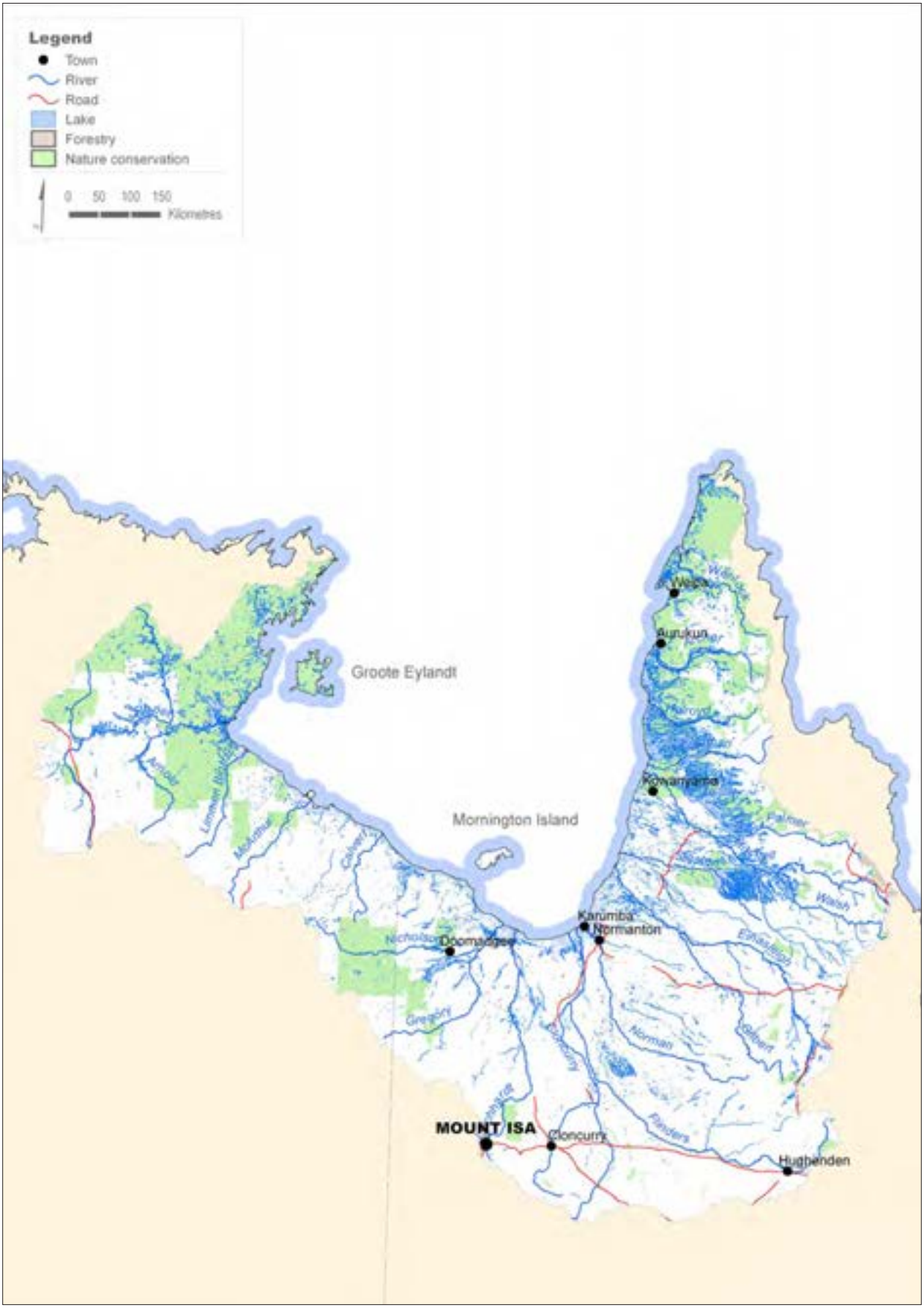


Figure 15.1 Major rivers and urban centres in the Carpentaria Coast region

15.3.1 Physiographic characteristics

The physiographic map in Figure 15.2 indicates areas with similar landform evolutionary histories (Pain et al. 2011). These can be related back to similar geology and climatic impacts which define the extent of erosion processes. The areas have distinct physical characteristics that can influence hydrological processes.

The Carpentaria Coast region has three such dominant physiographic provinces, namely:

- Carpentaria Fall (26%): ridges and hills with plains along much of the coast; ranges and lowlands on folded metamorphic rocks and granites in the east;
- Carpentaria Lowlands (37%): clay and sandy plains and plateaus of sandstone or bauxite in some areas; and
- Peninsular Uplands (13%): sandstone plateaus and hilly country on acid igneous and metamorphic rocks.

The remaining four provinces occupy 24% of the region.

- Barkly–Tanami Plains (7%): alluvial valleys;
- Central Lowlands (7%): undulating clay plains;
- North Australian Plateaus (6%): ranges of folded metamorphic rocks; and
- Burdekin Uplands (4%): partly sandstone plateau and some young basaltic plateaus; ranges predominantly of granite and metamorphic rocks.

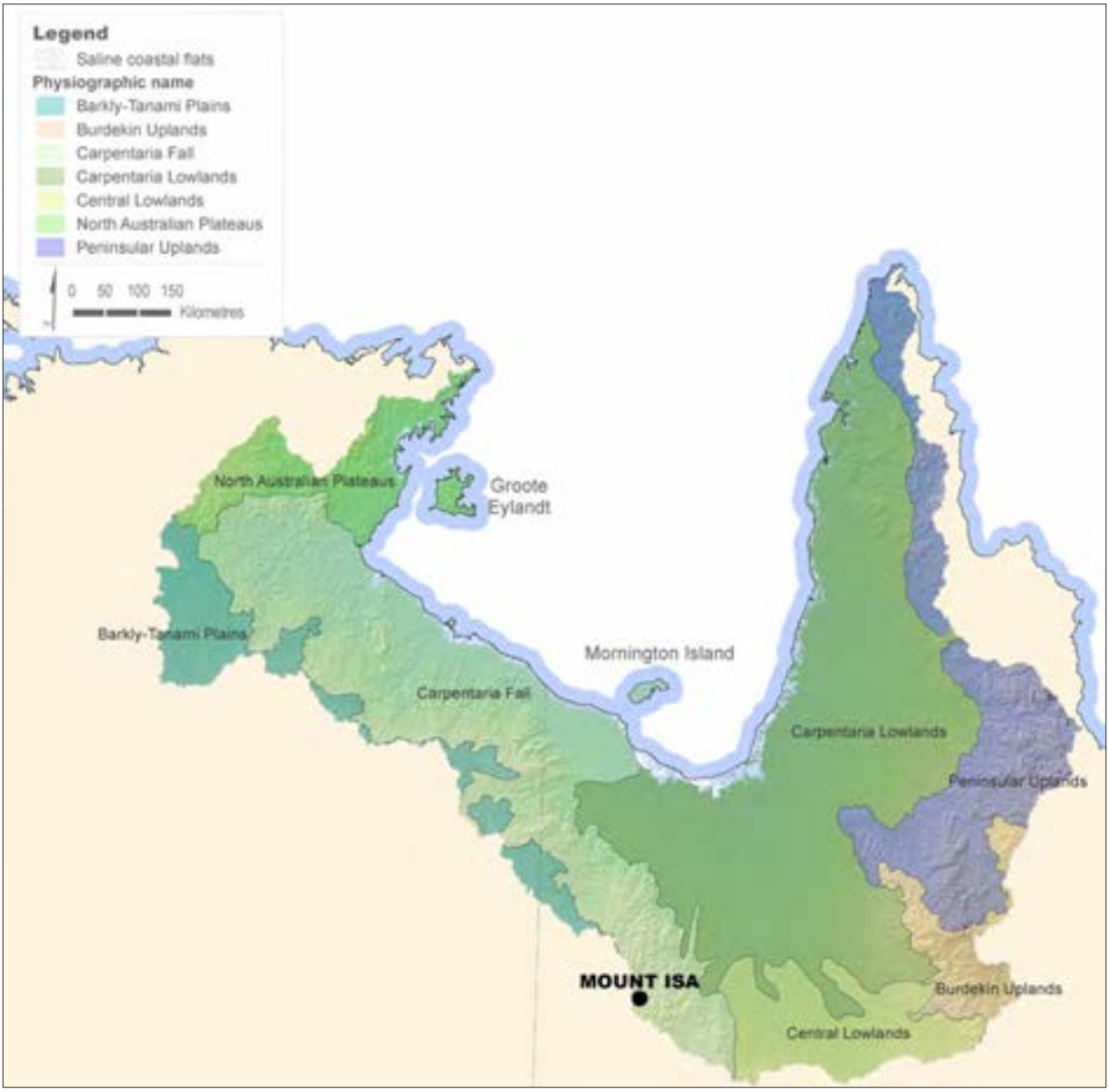


Figure 15.2 Physiographic provinces of the Carpentaria Coast region

15.3.2 Elevation

Figure 15.3 presents ground surface elevations in the Carprentaria Coast region. Information was obtained from the Geoscience Australia website (www.ga.gov.au/topographic-mapping/digital-elevation-data.html).

The eastern border of the region is formed by the crest of the northern part of the Great Dividing Range. The highest peaks in the area exceed 1,200 m above sea level. They are located where the region's border almost reaches the Coral Sea (Figure 15.3).

In the western part of the region, rivers originate from the mainland plateau and from the Arnhem Land Plateau in the north.

The central low-lying area (Gulf Plains) is crossed by the Flinders River and its tributaries. The Flinders River originates in the southeast of the region and is the longest river in Queensland.

Besides the Gulf Plains, the Gulf of Carpentaria coastline is a wide band of low-lying plains. The rivers in this area often form large floodplains in the wet season.

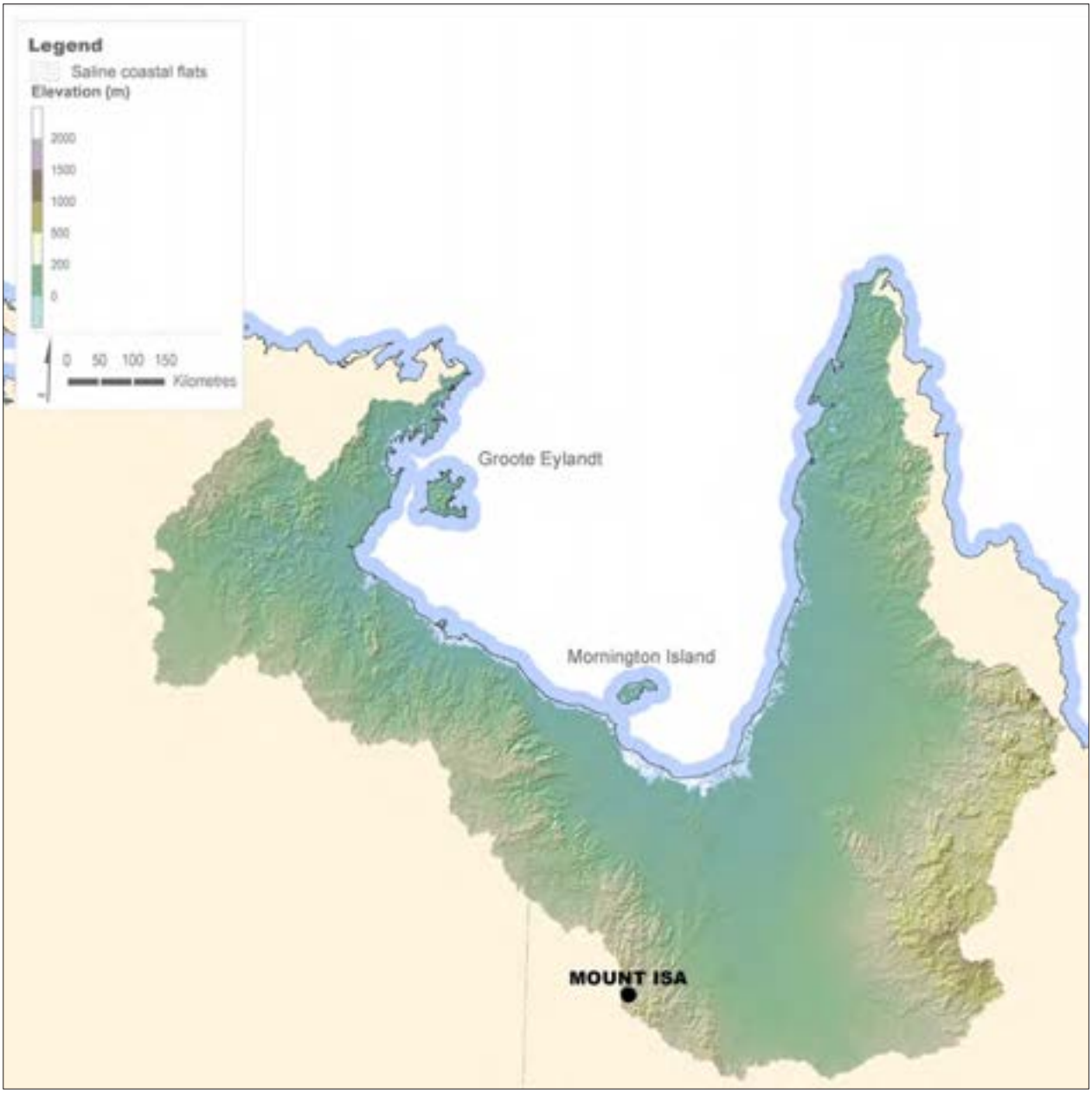


Figure 15.3 Land surface elevations in the Carpentaria Coast region

15.3.3 Slopes

Table 15.2 summarises the proportions of slope classes for the region while Figure 15.4 shows the spatial distribution of the surface slopes. Areas with steep slopes provide higher run-off generating potential than flat areas. The Carpentaria Coast region has few areas with steep slopes. The slopes were derived from the elevation information used in the previous section.

Table 15.2 Proportions of slope classes for the region

Slope class (%)	0–0.5	0.5–1	1–5	> 5
Proportion of region (%)	49.5	16.5	28.1	5.9

The steep slopes in Figure 15.4 particularly highlight the ranges and tableland escarpments west of Cairns. These are areas of high rainfall, and run-off generated in this area makes the Mitchell River one of the highest discharging rivers in Australia. Due to the high variation in rainfall during the year, the river has a seasonal flow pattern.

Due to the flatness of the central plain in the region (Gulf Plains), the rivers that cross it meander over vast areas. The streambeds of the Fitzroy River and its tributaries cover large areas.

In the hills north of Mount Isa, the valleys with their steep slopes have made it suitable for dam construction. Two major dams have been constructed here, forming Lake Moondarra and Lake Julius. These storages provide water for the local irrigation areas and fresh water for the town of Mount Isa.

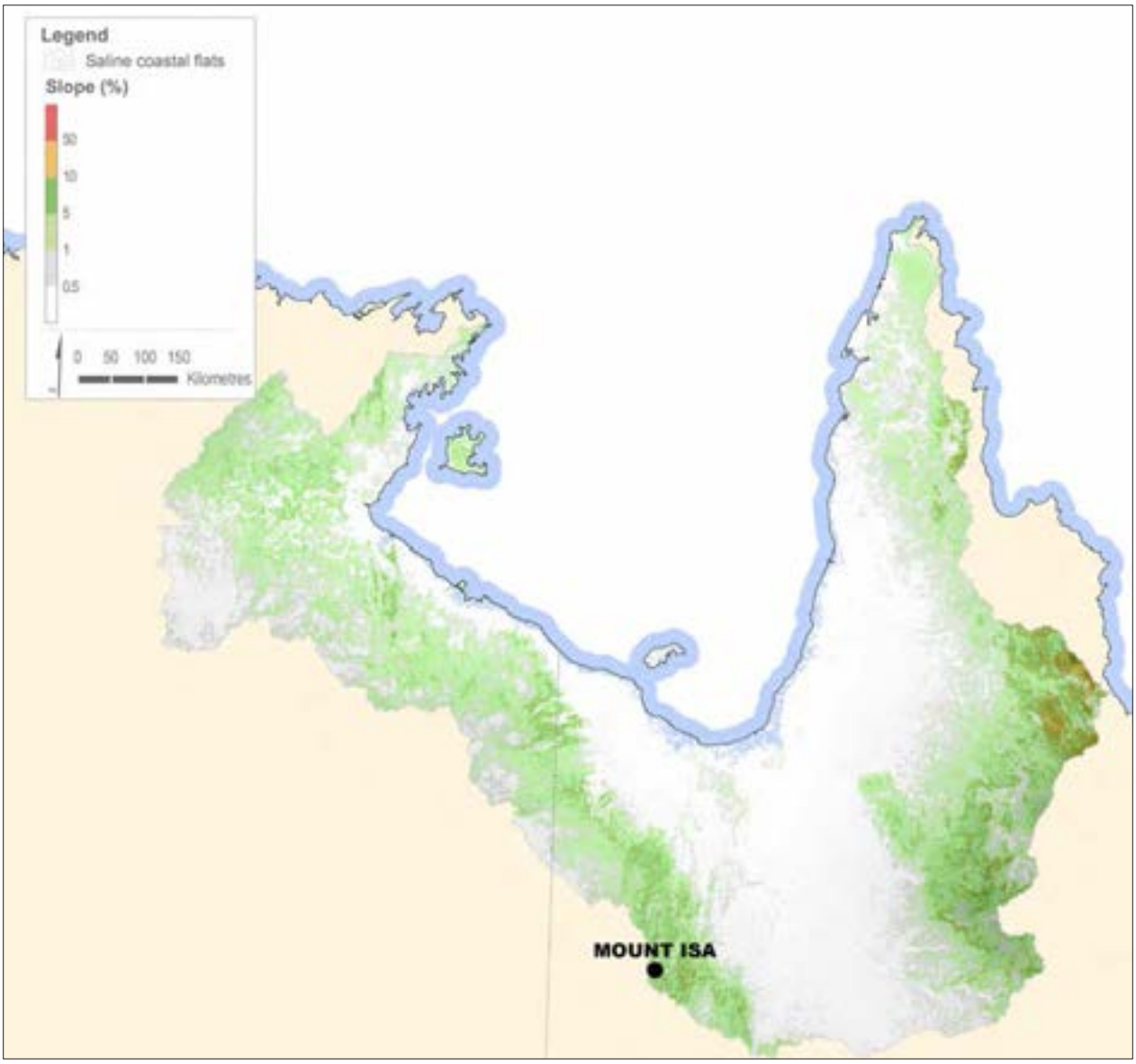


Figure 15.4 Surface slopes in the Carpentaria Coast region

15.3.4 Soil types

Soils play an important role in the hydrological cycle by distributing water that reaches the ground. Water can be transported to rivers and lakes via the soil surface as run-off or enter the soil and provide water for plant growth as well as contributing to groundwater recharge.

The nature of these hydrological pathways and the suitability of the soils for agricultural purposes are influenced by soil types and their characteristics. Soil type information was obtained from the Australian Soil Resource Information System website (www.asris.csiro.au).

About 89% of the Carpentaria Coast region consists of five soil types, namely tenosols, kandosols, vertosols, rudosols and hydrosols (Figure 15.5 and Figure 15.6). The majority of these soils are used for pastures and to some extent for nature conservation.

Tenosols as well as kandosols are widely spread across the region. Rudosols are more common in the western half of the region. Rudosols as well as tenosols are characterised by having weak and minimal development. They show no or little change in texture and colour and are often shallow in depth. Tenosols and rudosols are low in chemical fertility and in water-holding capacity and thus their agricultural potential is low.

Kandosols are structureless soils which are often very deep, up to three metres or more, but have neither a strong texture contrast nor carbonate throughout their profile. They have a low to moderate agricultural potential with moderate water-holding capacity, are mostly well drained and have moderate chemical fertility.

Vertosols are dominant in the central part of this region. They are clay rich soils with tendencies for soil cracks when dry, and swelling during wetting. They are highly fertile and have a large water-holding capacity. They, however, require a large amount of water before becoming available to plants.

Hydrosols are most common along the narrow coastal plains of the region, and to a greater extent along the east coast. These soils are seasonally wet due to high seasonal rainfall, and are thus saturated for two to three months and can also be influenced by tidal changes.

Other soil types with small area coverage in the region are chromosols, sodosols, ferrosols and dermosols (1–4%).

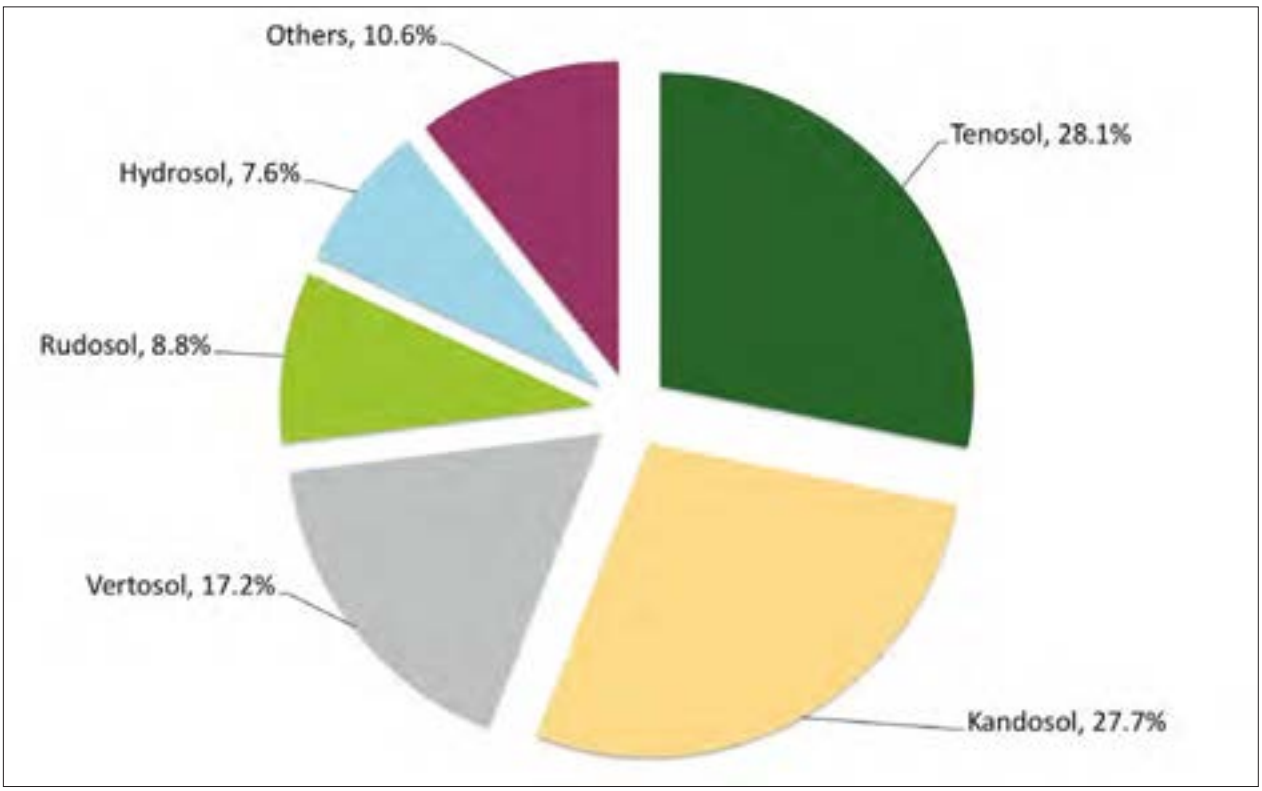


Figure 15.5 Soil types in the Carpentaria Coast region

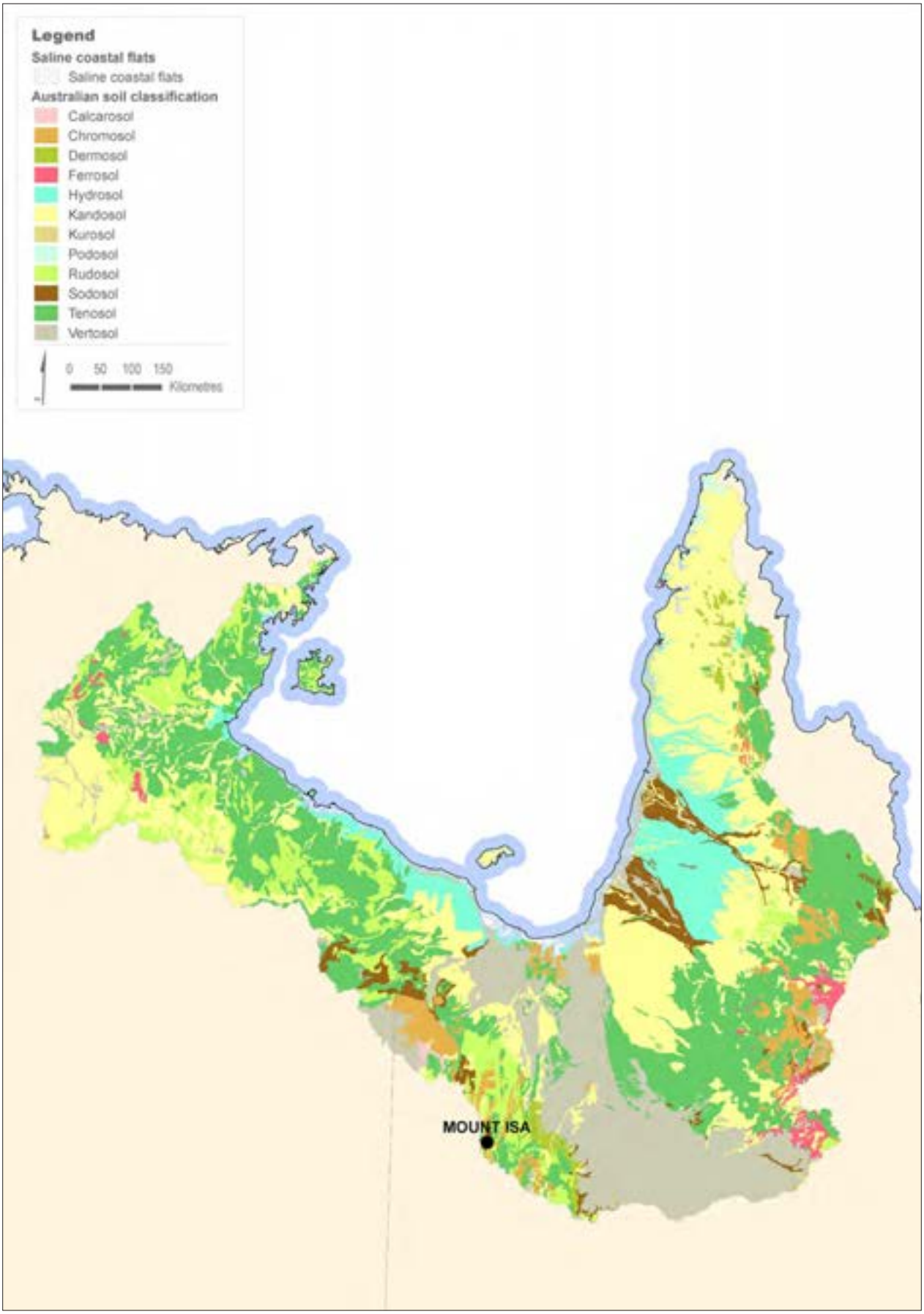


Figure 15.6 Soil type distribution in the Carpentaria Coast region

15.3.5 Land use

Figure 15.7 and Figure 15.8 present land use information in the Carpentaria Coast region (data from data.daff.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml).

The region is predominantly covered by pasture with large areas also designated for nature conservation Cropping, either irrigated or dryland, occupies a very small portion of the region. Most income is generated by mining. Irrigated agriculture around Mount Isa only exists on a very local scale, supported by water from the storages of the Julius and Moondarra dams.

The Mareeba–Dimbulah Irrigation Area on the Atherton Tableland in the far east of the region is the region's only main irrigation area. Irrigation of sugarcane and horticultural crops occurs with water taken from Lake Tinaroo on the Barron River in the North East Coast region.

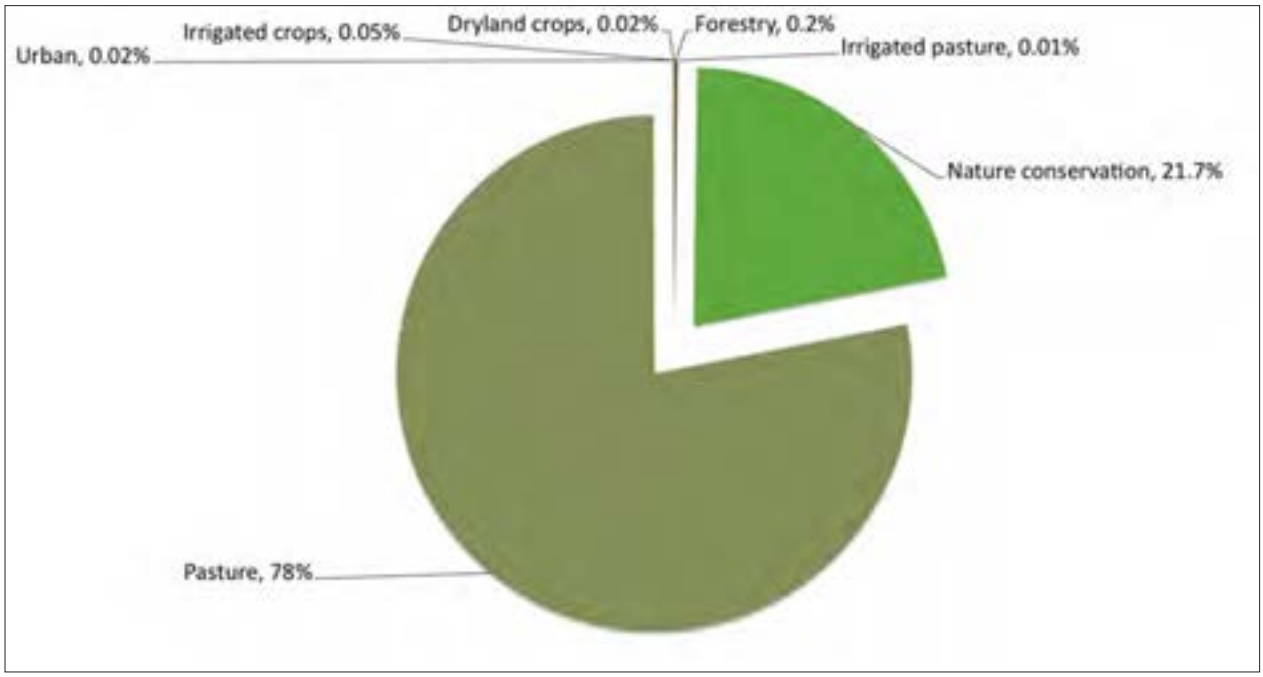


Figure 15.7 Land use in the Carpentaria Coast region

Julius Dam, Leichhardt River | Bureau of Meteorology

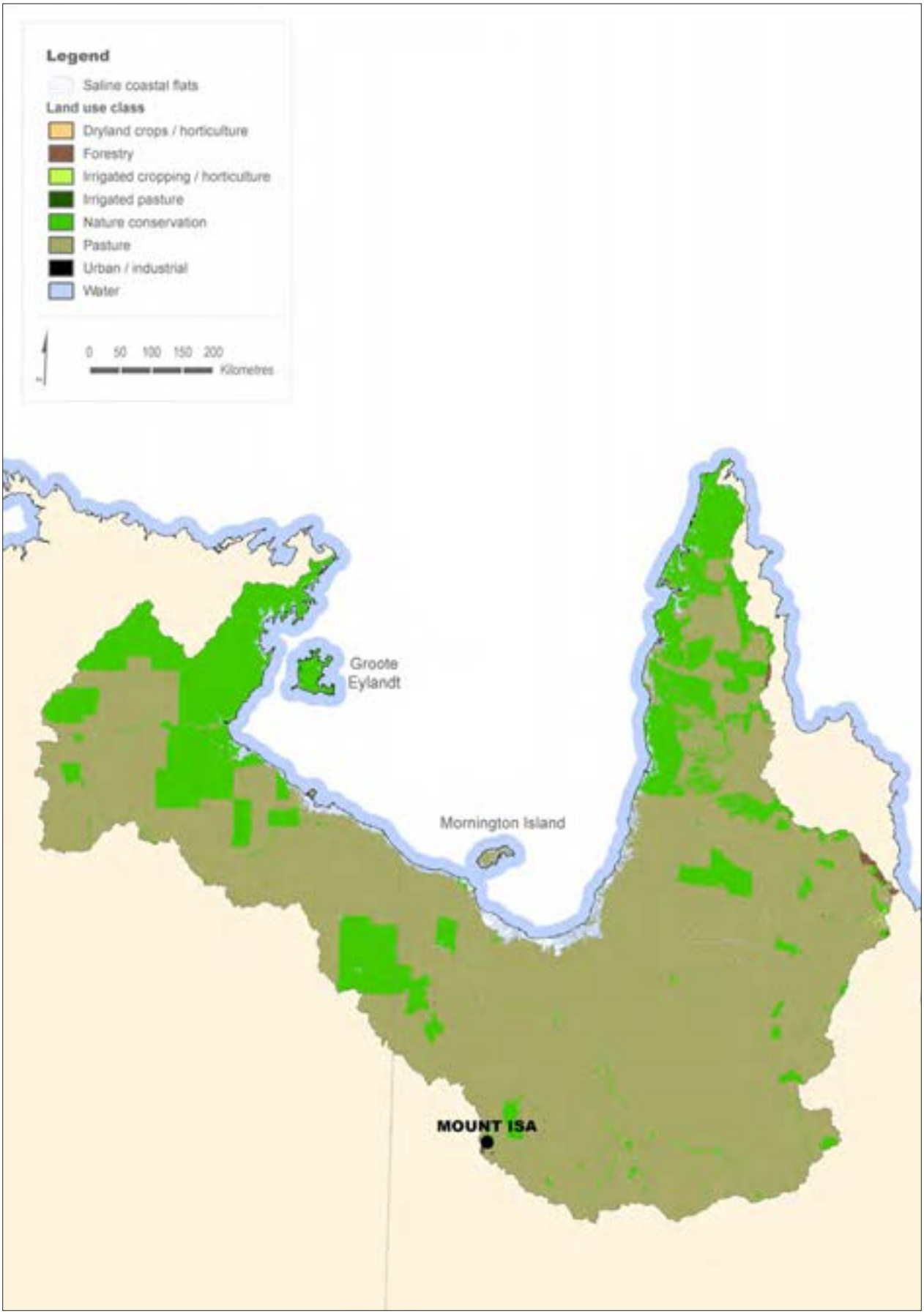


Figure 15.8 Land use distribution in the Carpentaria Coast region

15.3.6 Population distribution

Given its size and the number of people permanently residing in the Carpentaria Coast region, the population densities are very low and in many parts approach zero. This is clearly illustrated in Figure 15.9 (ABS 2011b).

The mining town of Mount Isa, in the central south of the region, is the major population centre and accounts for just under half of the region's population.

Whilst Mount Isa is located inland, the majority of regional communities are scattered along the coastal fringe of the Gulf of Carpentaria and include a number of remote Indigenous communities.

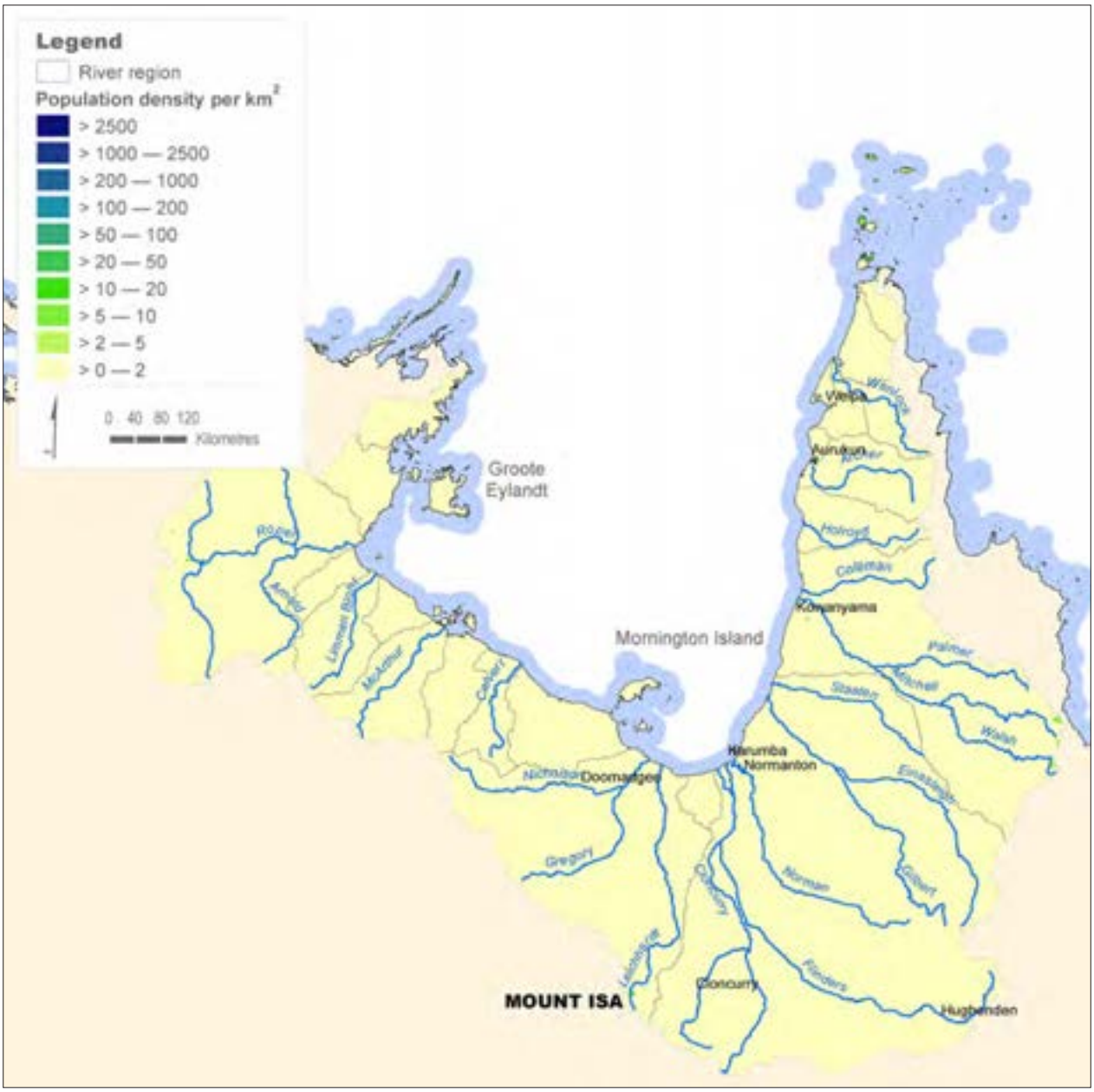


Figure 15.9 Population density and distribution in the Carpentaria Coast

15.3.7 Rainfall zones

The climate is hot and humid with two distinct seasons per year. The dry season runs from about May–September and the monsoonal wet season from October–April. The majority of rainfall occurs in a three-month period. Median rainfall exceeds 350 mm throughout (Figure 15.10).

The tropical northeast of the region, Cape York, receives most rainfall, with median rainfall exceeding 1,200 mm per annum.

Along the Gulf of Carpentaria coast the median rainfall normally reaches levels between 650 and 1,200 mm.

The southern part of the region has a much drier rainfall pattern gradually reaching median values lower than 350 mm in the far south of the region.

For more information on this and other climate classifications, visit the Bureau of Meteorology's (the Bureau's) climate website: www.bom.gov.au/jsp/ncc/climate_averages/climate-classifications/index.jsp

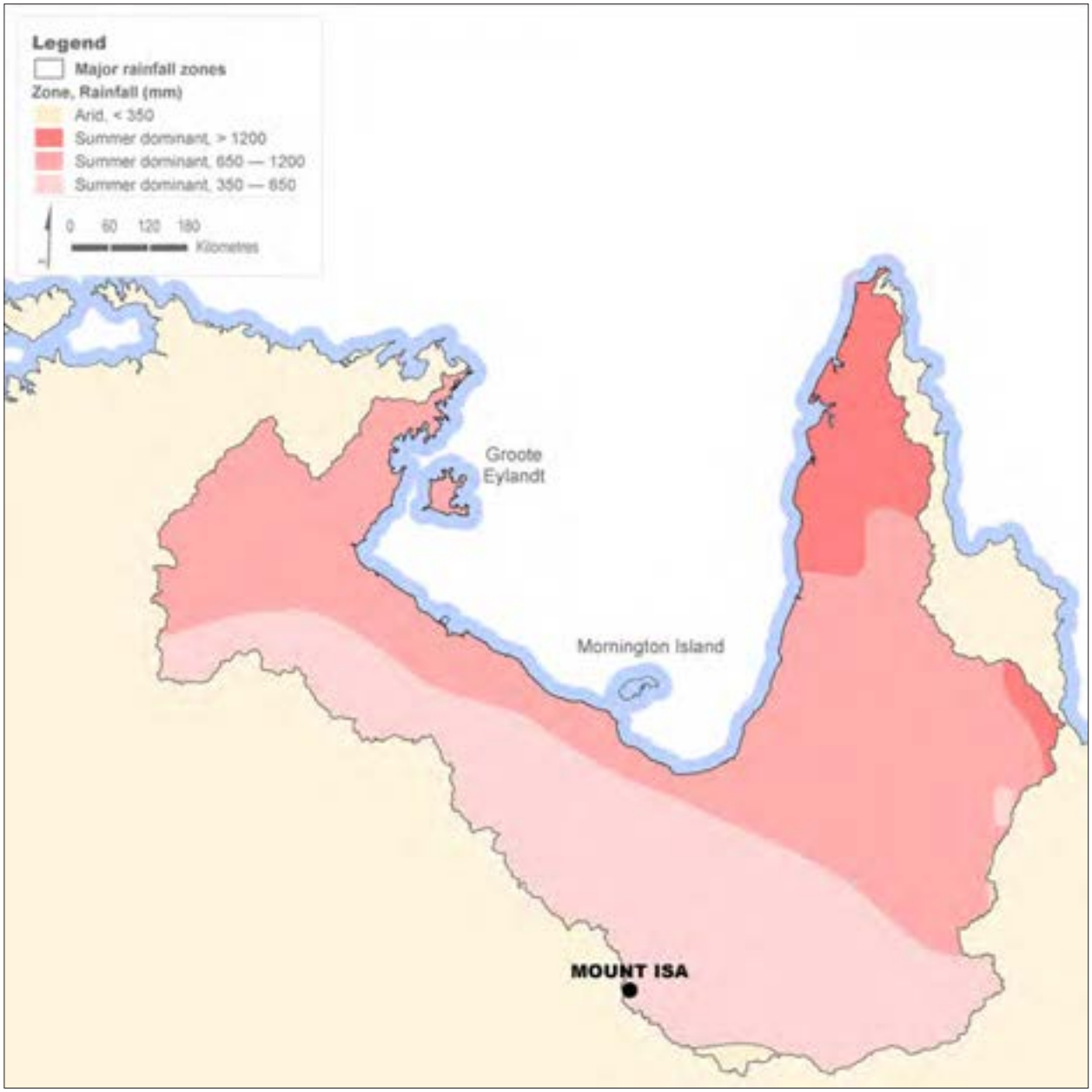


Figure 15.10 Rainfall zones in the Carpentaria Coast region

15.3.8 Rainfall deficit

The rainfall minus potential evapotranspiration indicator gives a general impression of which parts of the region moisture deficits are likely to occur over the period of a year. The Carpentaria Coast region is one of extremes in relation to this indicator (Figure 15.11).

Large deficits can be expected in most parts of the inland areas.

Along the coast, some areas experience less distinct deficits. The abundance of water in the headlands of the Mitchell River in the far east of the region is only of minor importance to streamflow in this river.

For more information on the rainfall and evapotranspiration data, see the Bureau's maps of average conditions: www.bom.gov.au/climate/averages/maps.shtml

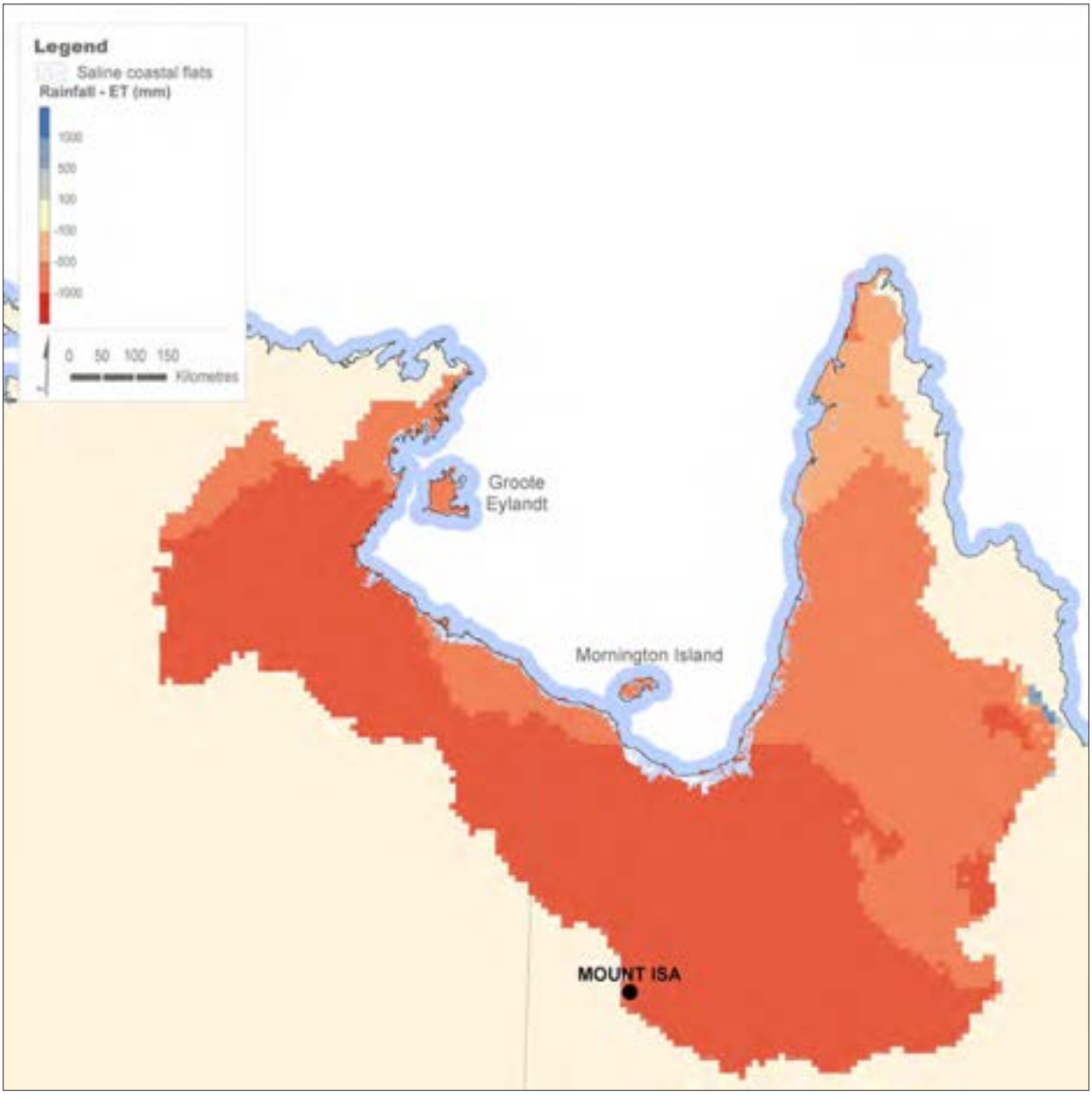


Figure 15.11 Rainfall deficit distribution for the Carpentaria Coast region

15.4 Landscape water flows

This section presents analyses of the spatial and temporal variation of landscape water flows (rainfall, evapotranspiration and landscape water yield) across the Carpentaria Coast region in 2011–12. National rainfall grids were generated using data from a network of persistent, high-quality rainfall stations managed by the Bureau. Evapotranspiration and landscape water yields were derived using the landscape water balance component of the Australian Water Resources Assessment System (Van Dijk 2010). These methods and associated output uncertainties are discussed in the Introduction and addressed in more detail in the Technical Supplement.

Figure 15.12 shows that the region has a highly seasonal rainfall pattern with distinct wet and dry seasons. Evapotranspiration in the dry season always exceeds rainfall. After the wet season, the soils normally contain plenty of moisture that is available for evapotranspiration. The monthly landscape water yield history for the region shows a stable pattern of very low yield in the dry season.

It gradually increases during the wet season and subsides afterwards.

The 2011–12 year was a relatively wet year, especially during November–December 2011, when rainfall was consistently higher than the historic median. Additionally, an active monsoon in the north of the region contributed to particularly high rainfall totals for the month of March 2012.

With wet soil conditions present at the start of the year, evapotranspiration was high for the first six months of 2011–12. With the exception of January and February 2012, evapotranspiration rates remained above the 75th percentile for the rest of the year. Evapotranspiration in June 2012 was the second highest on record (1911–2012) for this month.

The landscape water yield for 2011–12 closely followed the rainfall pattern, with the March landscape water yield being fourth highest on record. The only exception is the month of February, when rainfall was below average, but high soil moisture levels, due to the wet spring, maintained a relatively high landscape water yield.

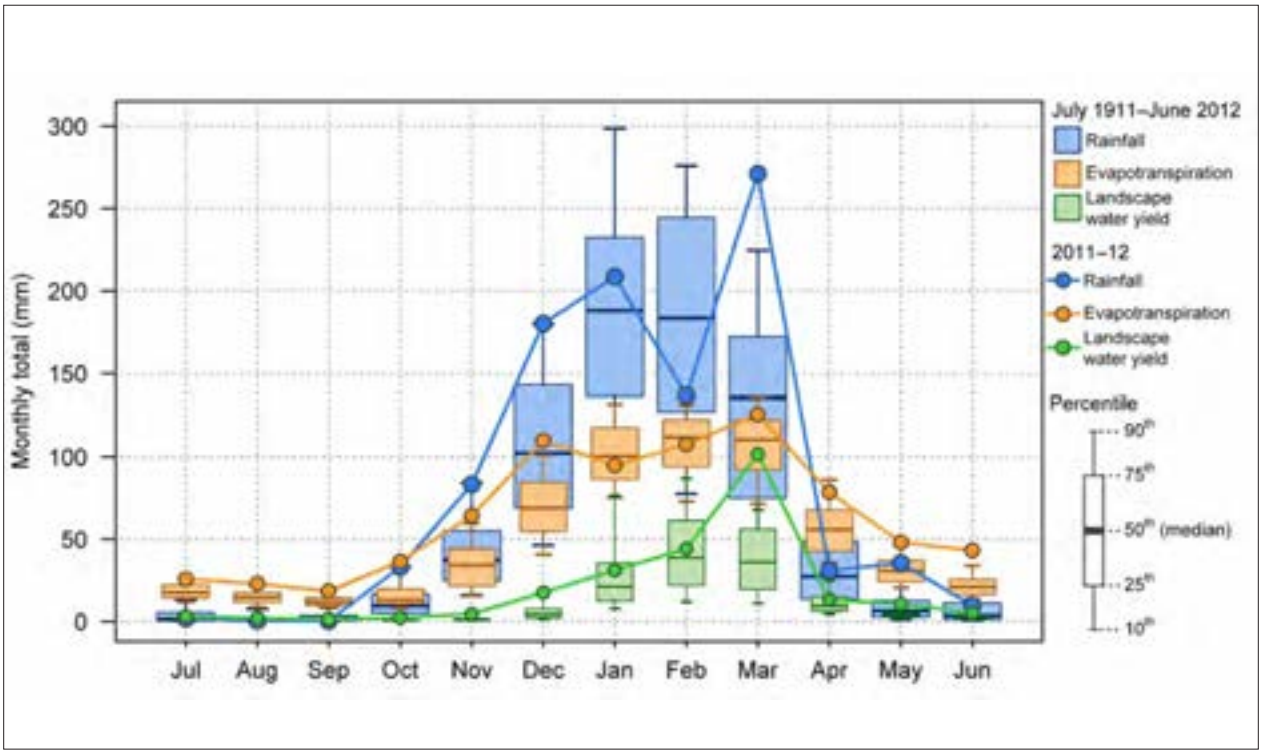


Figure 15.12 Landscape water flows in 2011–12 compared with the long-term record (July 1911–June 2012) for the Carpentaria Coast region

15.4.1 Rainfall

Rainfall for the Carpentaria Coast region for 2011–12 is estimated to be 992 mm. This is 31% above the region's long-term average (July 1911–June 2012) of 755 mm. Figure 15.13a shows that the highest rainfall occurred along the eastern coastal areas of the Gulf of Carpentaria with annual totals exceeding 1,800 mm in 2011–12. The western and southern parts of the region had rainfall mostly ranging between 600 and 900 mm.

Rainfall deciles for 2011–12 show average to very much above average rainfall (Figure 15.13b). The high rainfall in the Cape York area only resulted in a very much above average decile ranking in parts of the area. The southern part of the region was also relatively wet. In the far northwest and the far east, rainfall was average. In the Mitchell River basin, rainfall was below historic average.

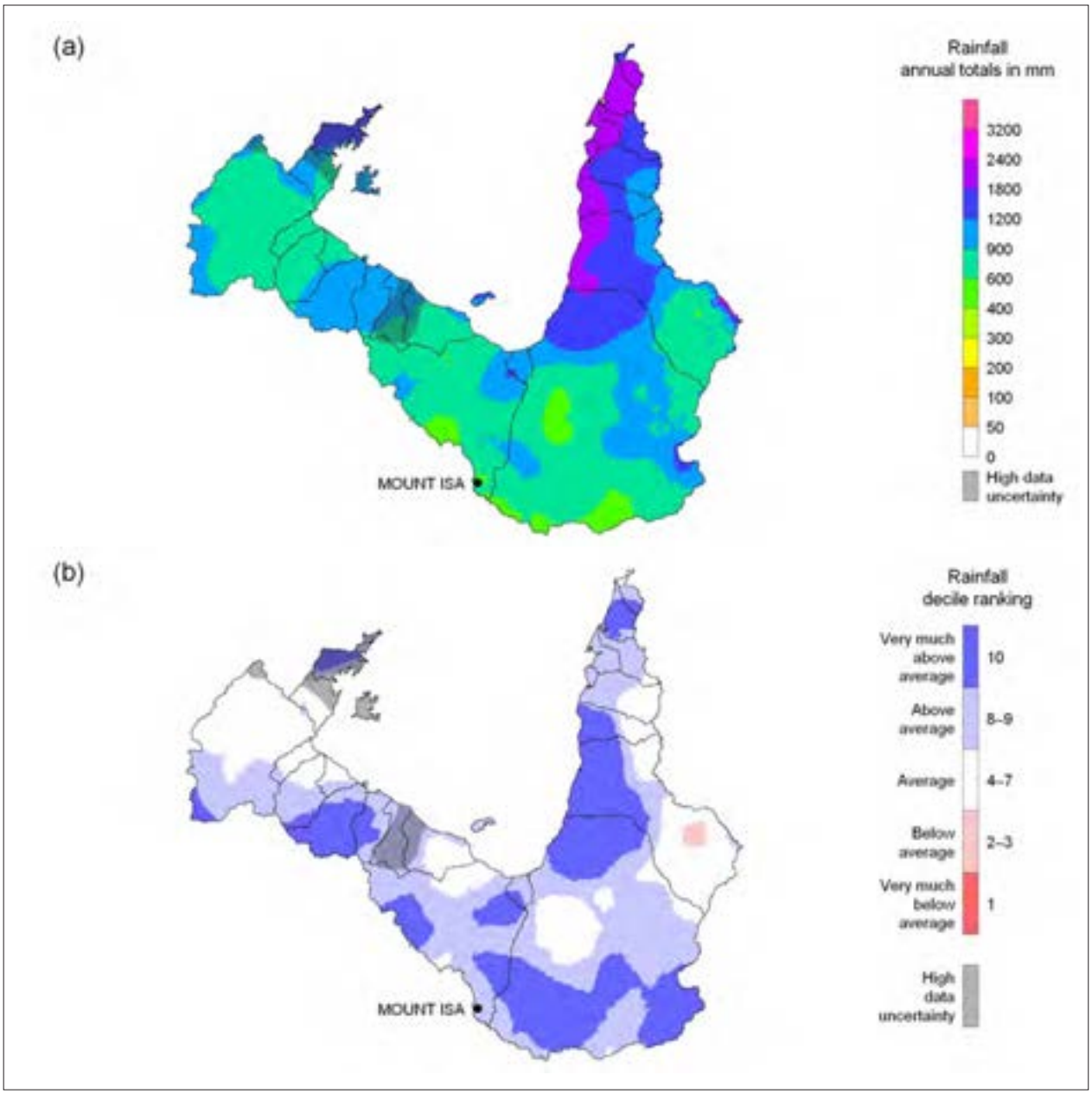
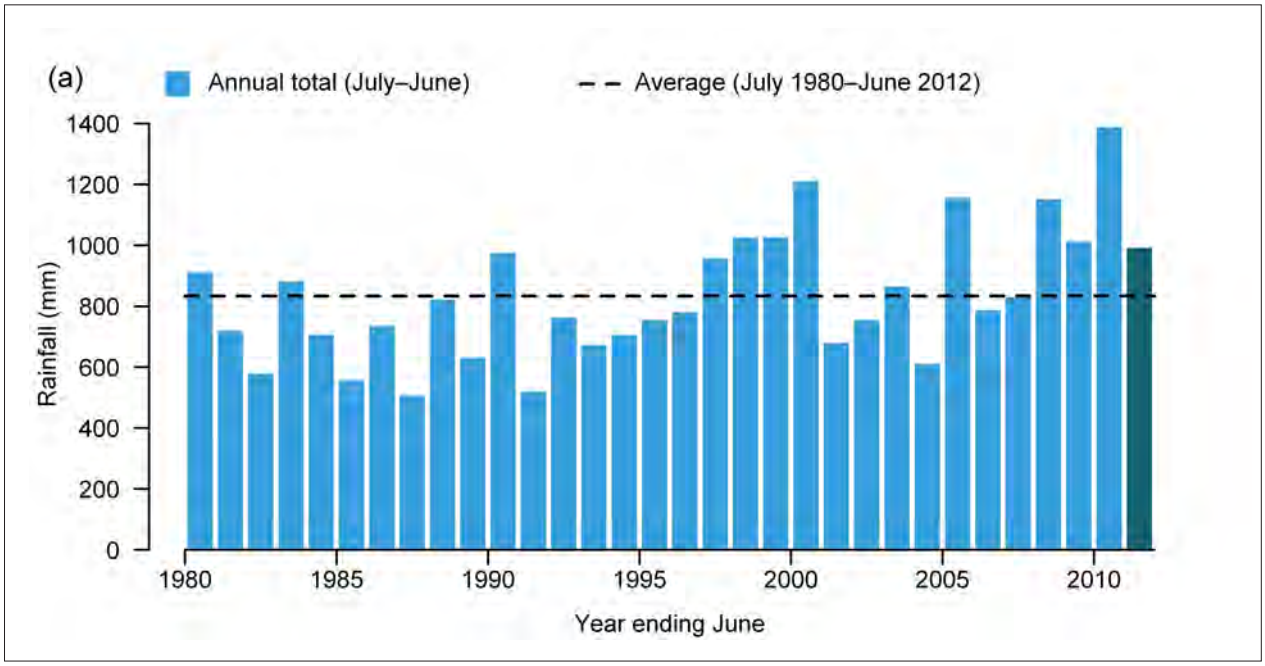


Figure 15.13 Spatial distribution of (a) annual rainfall in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Carpentaria Coast region

Rainfall variability in the recent past

Figure 15.14a shows annual rainfall for the region from July 1980 onwards. Over this 32-year period the annual average was 833 mm, varying from 506 mm (1987–88) to 1,388 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 15.14b.

The graphs indicate that the annual variation in rainfall is based on the variation in rainfall in the wet season (November–April) only. The difference between rainfall in the winter and summer periods, as in Figure 15.14b, is indicative for a region that is completely dependent on the annually returning monsoon to deliver rainfall.



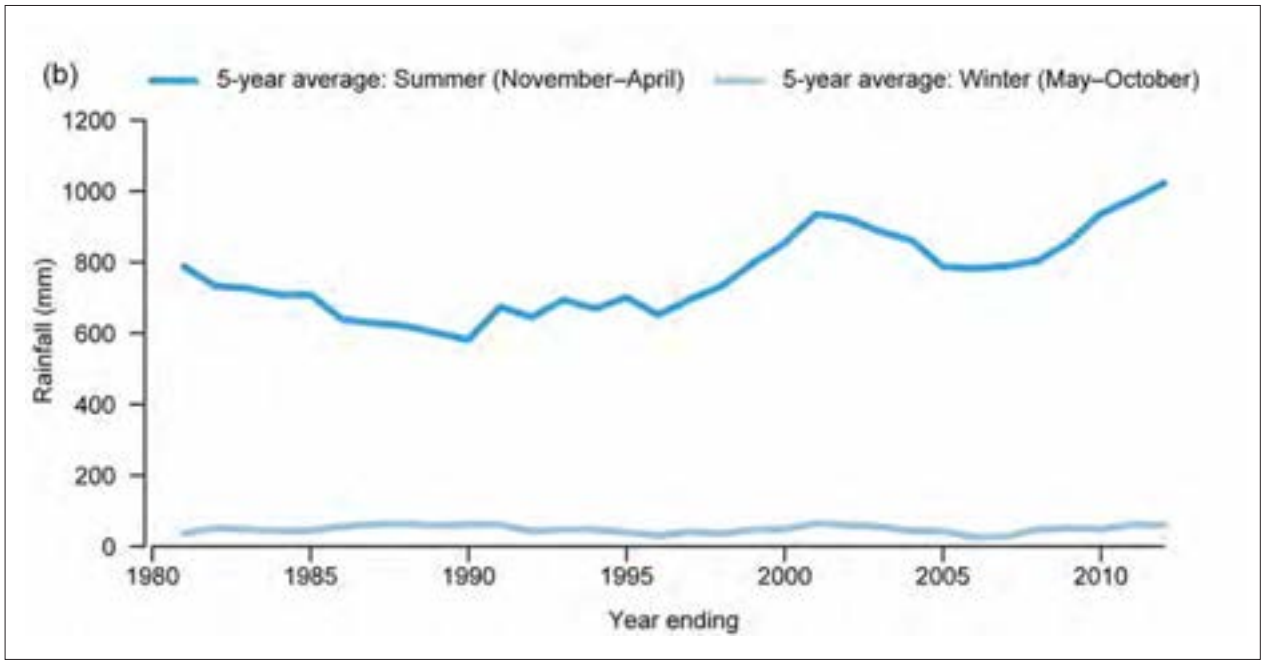


Figure 15.14 Time-series of (a) annual rainfall, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) periods for the Carpentaria Coast region

Recent trends in rainfall

Figure 15.15a presents the spatial distribution of the trends in annual rainfall for July 1980–June 2012. These are derived from linear regression analyses on the time-series of each model grid cell.

The statistical significance of the trends is provided in Figure 15.15b.

Figure 15.15a shows that since 1980 a strong increase in rainfall has occurred in large parts of the region. These trends are strongly significant in most of the region (Figure 15.15b). The local area of decreasing rainfall in the northeast is remarkable, but not statistically significant.

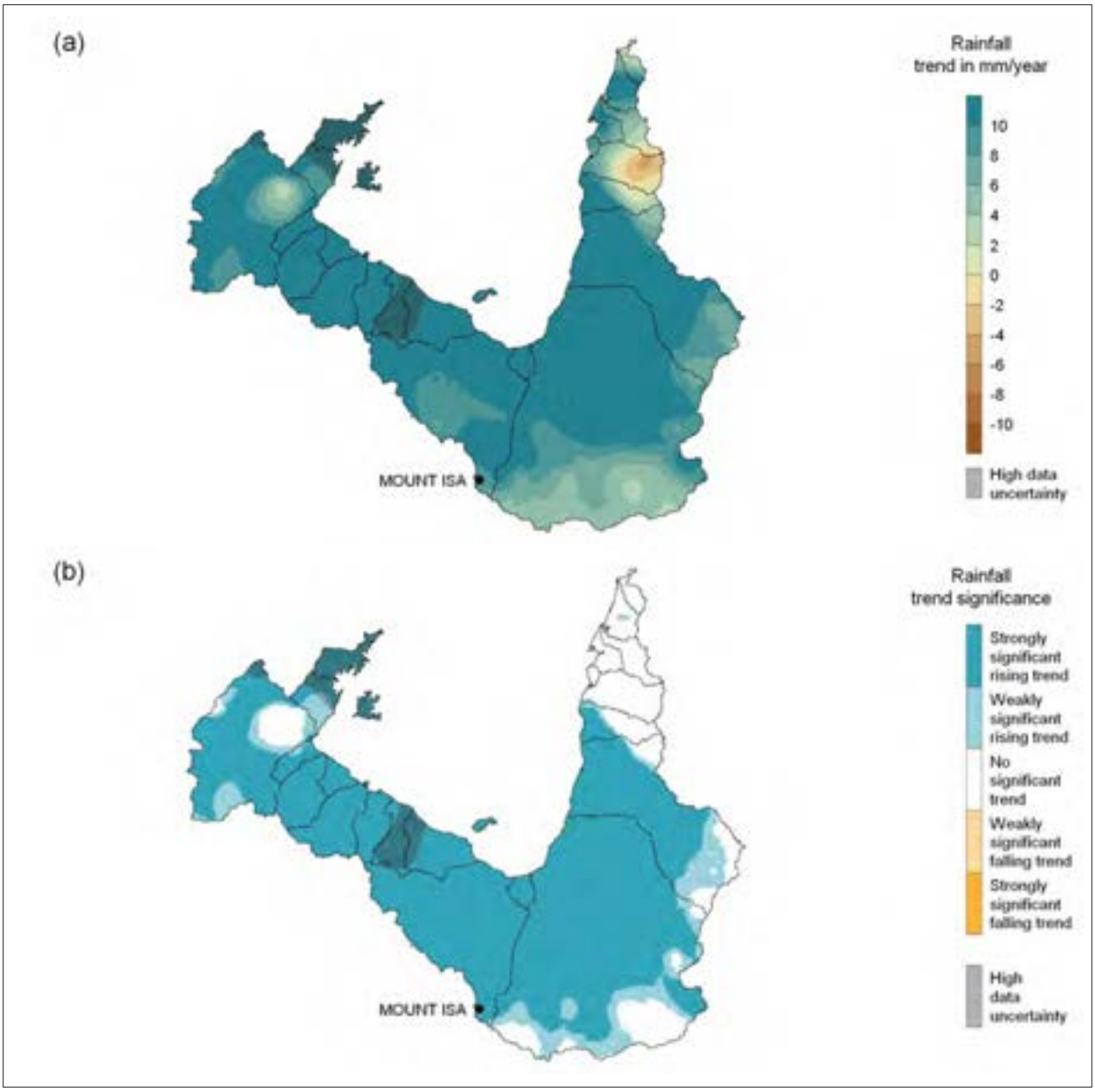


Figure 15.15 Spatial distribution of (a) trends in annual rainfall from 1980– 2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Carpentaria Coast region

15.4.2 Evapotranspiration

Modelled annual evapotranspiration for the Carpentaria Coast region for 2011–12 is estimated to be 775 mm. This is 30% above the region's long-term (July 1911–June 2012) average of 598 mm. The spatial distribution of annual evapotranspiration in 2011–12 (Figure 15.16a) is similar to that of rainfall (Figure 15.13a), but lower in magnitude.

Evapotranspiration deciles for 2011–12 indicate above average or very much above average totals across most of the region (Figure 15.16b). The exceptions are the northern part of Cape York and in the upstream part of the Mitchell River basin. The very much above average evapotranspiration along much of the southwest is largely the result of the high soil moisture availability starting in the previous wet year 2010–11.

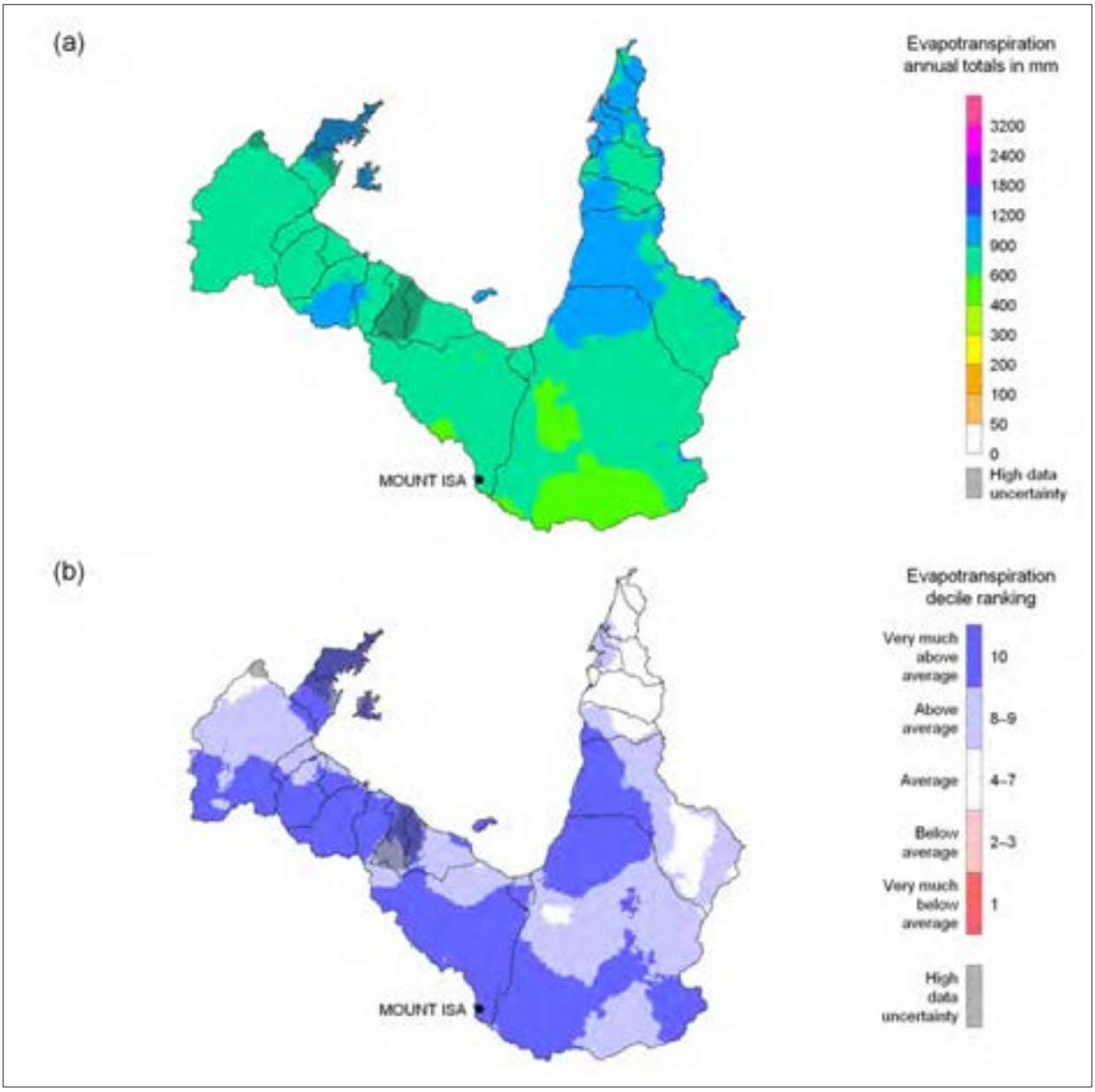


Figure 15.16 Spatial distribution of (a) modelled annual evapotranspiration in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Carpentaria Coast region

Evapotranspiration variability in the recent past

Figure 15.17a shows annual evapotranspiration for the region from July 1980 onwards. Over this 32-year period the annual evapotranspiration average was 634 mm, varying from 479 mm (1987–88) to 935 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 15.17b.

Evapotranspiration in the wet season is much higher than in the dry season. This is due to the higher rainfall amounts and therefore water availability during the wet season. During the dry season, evapotranspiration is substantially higher than the rainfall for this season (Figure 15.14b).

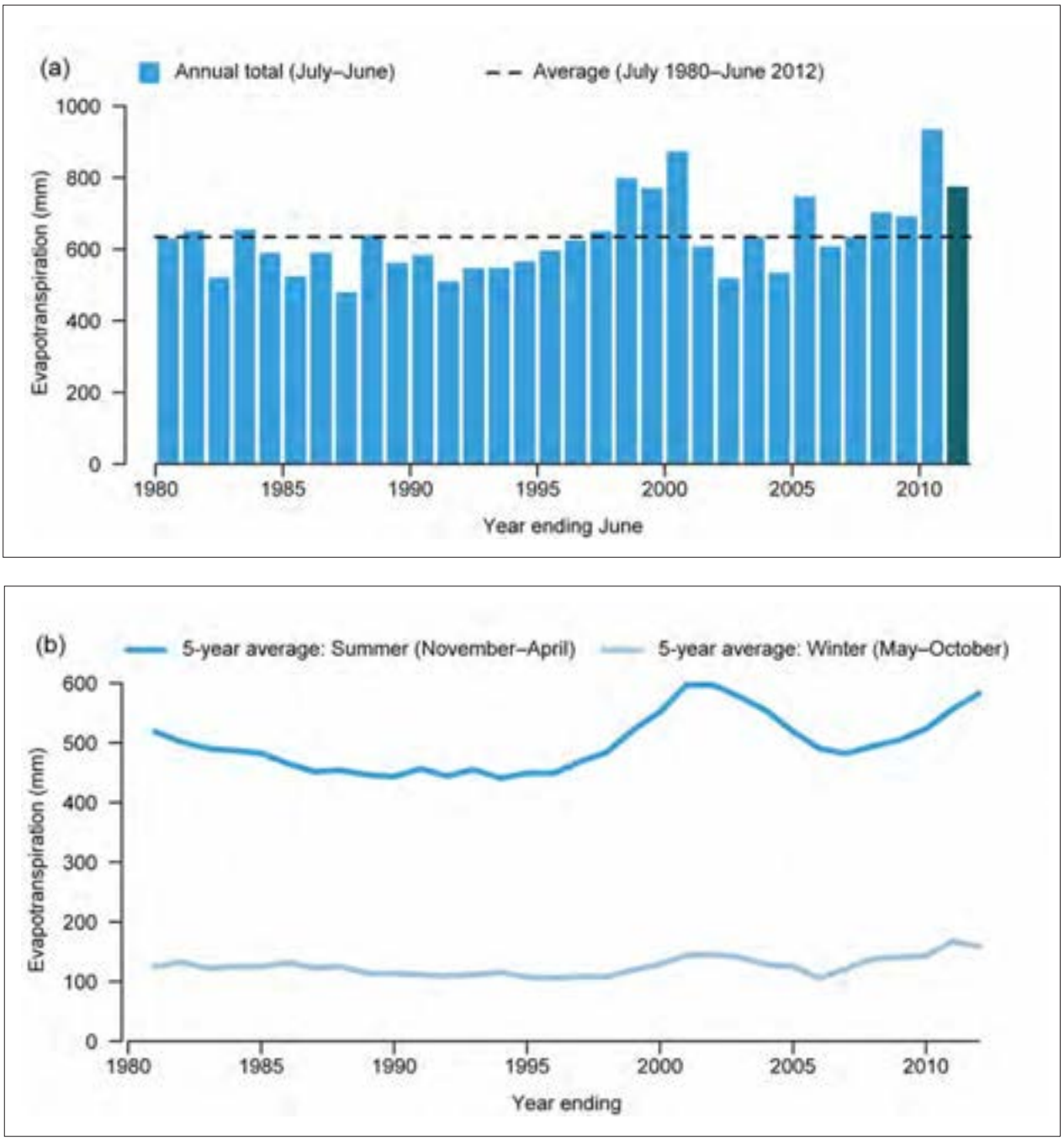


Figure 15.17 Time-series of (a) annual evapotranspiration, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) period for the Carpentaria Coast region

Recent trends in evapotranspiration

Figure 15.18a presents the spatial distribution of the trends in modelled annual evapotranspiration for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 15.18b.

Figure 15.18a shows that since 1980 trends are rising in the most of the region except for the far northern part of Cape York.

As shown in Figure 15.18b, the trends are generally statistically significant throughout most of the region. The marginal and negative trends in the north are not statistically significant.

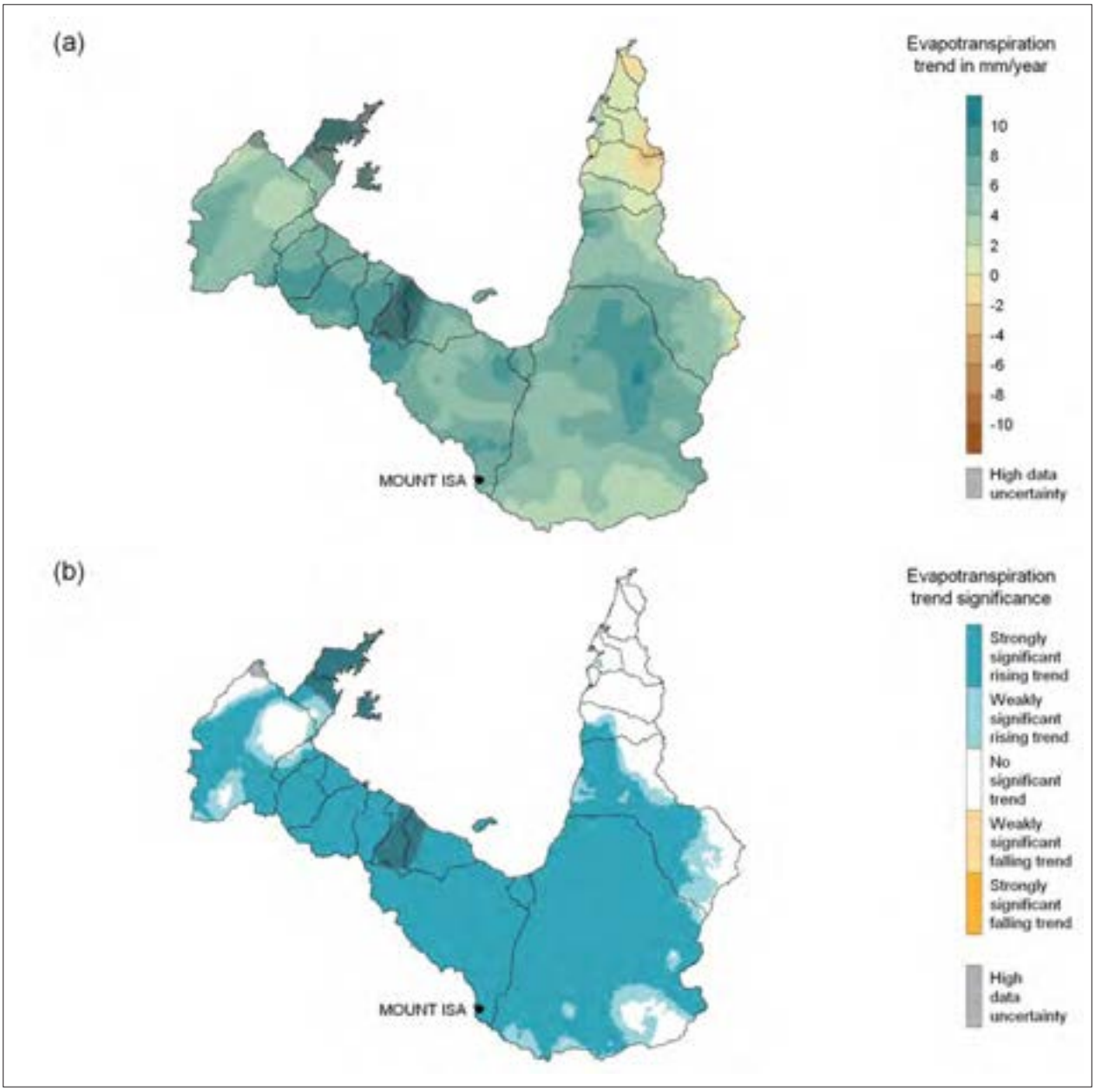


Figure 15.18 Spatial distribution of (a) trends in annual evapotranspiration from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Carpentaria Coast region

15.4.3 Landscape water yield

Modelled landscape water yield for the Carpentaria Coast region for 2011–12 is estimated to be 237 mm. This is 54% above the region's long-term (July 1911–June 2012) average of 154 mm. Figure 15.19a shows the spatial distribution of landscape water yield for 2011–12, which is similar to the annual rainfall distribution (Figure 15.13a).

The highest landscape water yields in 2011–12 occurred in the northeast, locally exceeding 900 mm. For the south and west of the region, the landscape water yield generally did not exceed 200 mm over the year.

The decile-ranking map for 2011–12 (Figure 15.19b) shows that landscape water yield closely followed the patterns of rainfall deciles in Figure 15.13b.

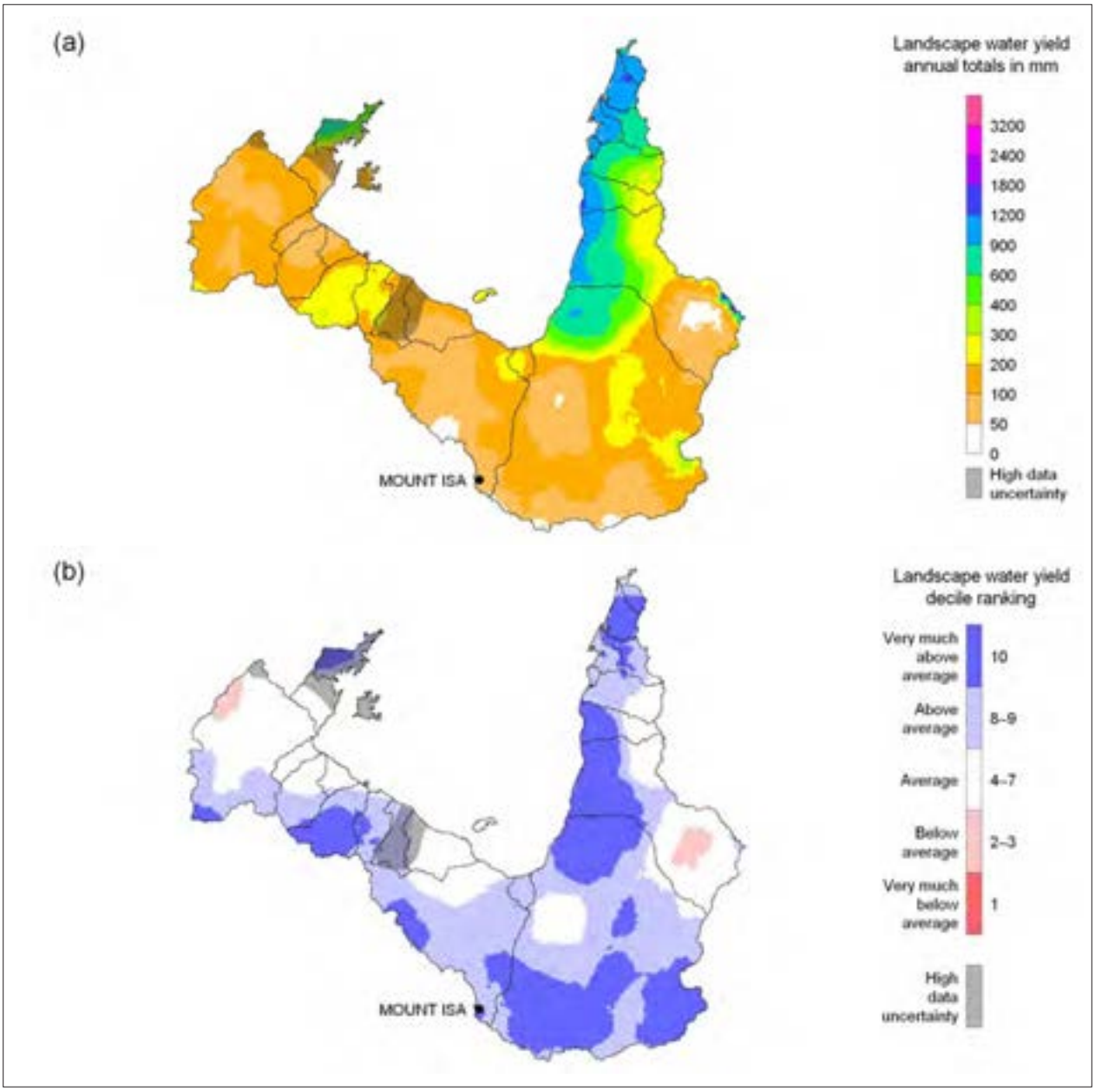


Figure 15.19 Spatial distribution of (a) modelled annual landscape water yield in 2011–12, and (b) their decile rankings over the 1911–2012 period for the Carpentaria Coast region

Landscape water yield variability in the recent past

Figure 15.20a shows annual landscape water yield for the Carpentaria Coast region from July 1980 onwards. Over this 32-year period, annual landscape water yield was 194 mm, varying from 50 mm (1982–83) to 437 mm (2010–11). Temporal variability and seasonal patterns since 1980 are presented in Figure 15.20b.

Landscape water yields clearly shows a rising trend in annual and wet season totals. In particular the last five years have seen consistently high landscape water yields.

Dry season landscape water yield is particularly low and has had minimal contribution to the annual total landscape water yield.

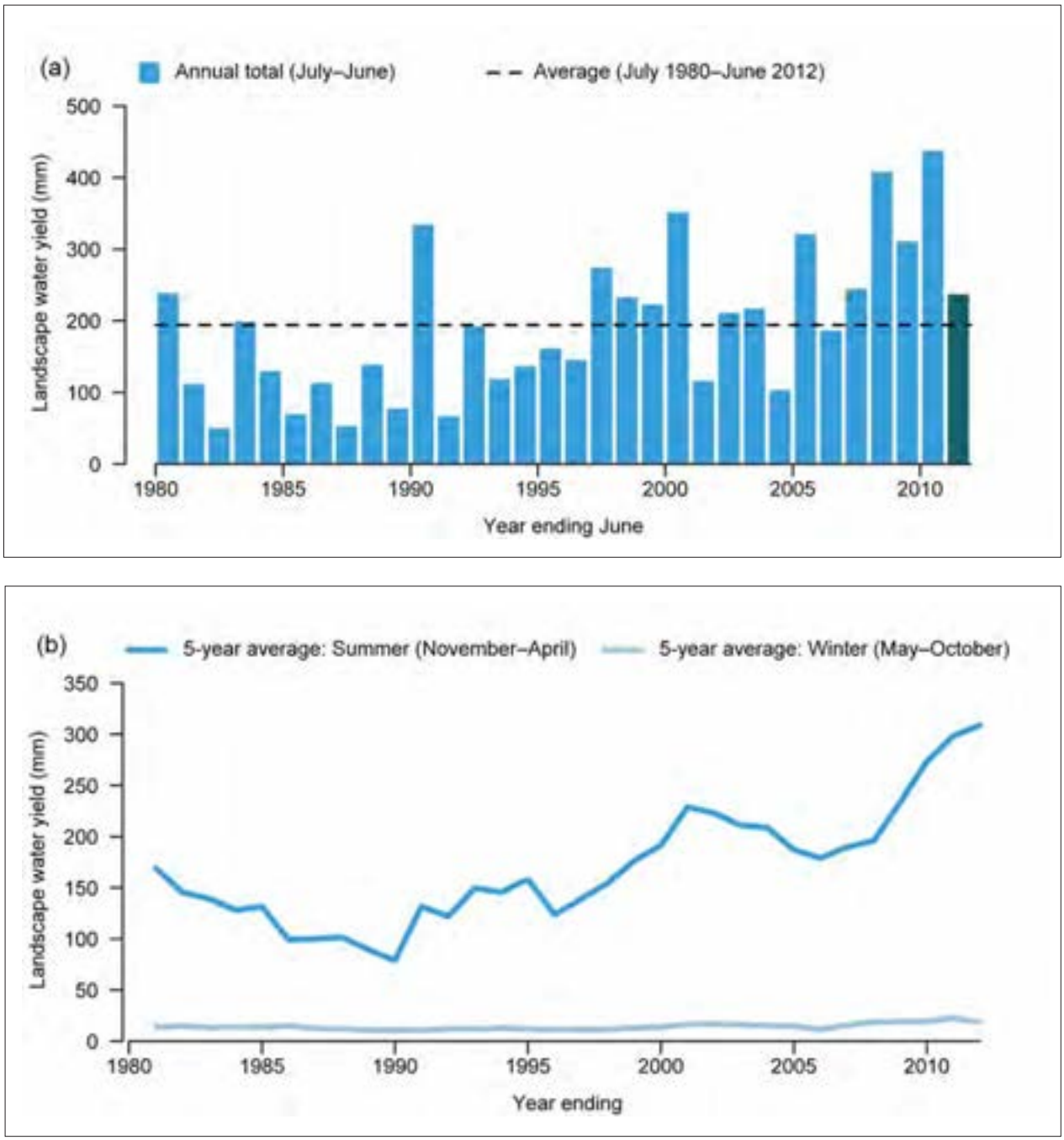


Figure 15.20 Time-series of (a) annual landscape water yield, and (b) five-year retrospective moving averages for the wet summer (November–April) and dry winter (May–October) periods for the Carpentaria Coast region

Recent trends in landscape water yield

Figure 15.21a shows the spatial distribution of the trends in modelled annual landscape water yield for 1980–2012. These are derived from linear regression analyses on the time-series of each model grid cell. The statistical significance of the trends is provided in Figure 15.21b.

Figure 15.21a shows that since 1980 strong rising trends occur along the coastline of the Gulf of Carpentaria. Locally these trends exceed 14 mm/year.

Figure 15.21b shows that most of the rising trends are confirmed to be statistically significant. As already noted in the graphs of Figure 15.20, the trends are very obvious, especially with the period of very high landscape water yield for the last five years.

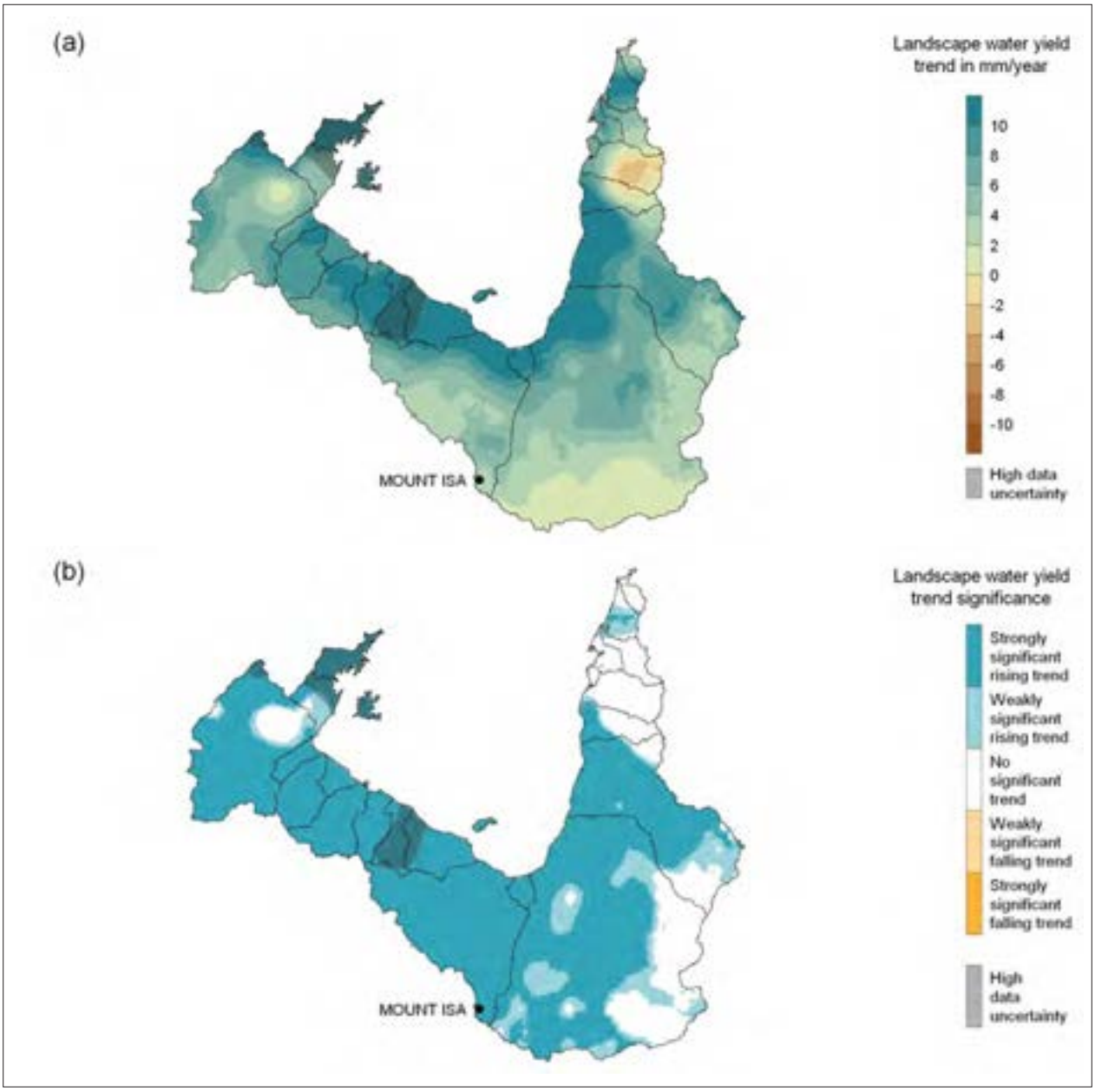


Figure 15.21 Spatial distribution of (a) trends in annual landscape water yield from 1980–2012, and (b) their statistical significance at 90% (weak) and 95% (strong) confidence levels for the Carpentaria Coast region

15.5 Surface water and groundwater

This section examines surface water and groundwater resources in the Carpentaria Coast region in 2011–12. Rivers, wetlands and storages are discussed to illustrate the state of the region's surface water resources. The region's watertable aquifers and salinity are described. No data was available at the Bureau in a suitable format for a detailed analysis on individual aquifers.

15.5.1 Rivers

There are 23 river basins in the Carpentaria coast region, varying in size from 1,000 to 231,000 km^2 (Figure 15.22). The four major basins in the region are the Flinders–Norman, Roper, Nicholson–Leichhardt, and Mitchell–Coleman. Much of the Carpentaria Coast region drains into the Gulf of Carpentaria and comprises floodplains.

The rivers, however, are very large by Australian standards and carry approximately a quarter of the continent's total yearly streamflow.

The main rivers flowing north to the Gulf of Carpentaria are the Mitchell, Flinders, Gilbert, Roper and Leichhardt. These rivers are generally braided and seasonally intermittent. A few exceptions like the Roper and the Gregory are perennial. The Gilbert, Mitchell, Flinders and Leichhardt rivers are typical of seasonal rivers and their discharge can vary greatly depending on the intensity of the monsoon. The Leichhardt River flows north from the Mount Isa district towards the Gulf of Carpentaria, east of Burketown, and the Flinders River rises in the Great Dividing Range, 110 km northeast of Hughenden and flows into the gulf west of Karumba. Most rivers, however, flow only during the wet season. Therefore, all perennial rivers and perennial springs are important sources of water.

Boodjamulla (Lawn Hill) National Park | Wilderness Challenge Pty Ltd

Figure 15.22 Rivers and catchments in the Carpentaria Coast region

15.5.2 Streamflow volumes

Figure 15.23 presents an analysis of river flows at 16 monitoring sites in the Carpentaria Coast region during 2011–12 relative to annual flows for the July 1980–July 2012 period. Sites with relatively long records across seven geographically representative rivers were selected (see Technical Supplement). The annual river flows for 2011–12 are colour-coded according to the decile rank at each site over the 1980–2012 period.

The flows generally reflect the mostly average to above average modelled landscape water yield results shown in Figure 15.19b.

Above average flows were observed at five sites located on rivers in the southeast and McArthur River in the southwest of the region. Five further sites, mainly located on the rivers in the central east, the Roper River in the west and the Gregory River in the southwest, recorded average flows.

Of the 16 monitoring sites across the region there were only two locations where below average flows were recorded. These were located on the Waterhouse River in the west and Walsh River in the central east of the region.

Flow deciles in the wet season (November 2011–April 2012) were very similar to total annual flows for 2011–12 as shown in Figure 15.23. There are few monitoring sites that did not show this pattern, such as on the Roper River in the west of the region which had relatively low flows in the wet season.

15.5.3 Streamflow salinity

Figure 15.24 presents an analysis of streamflow salinity for 2011–12 at seven monitoring sites throughout the Carpentaria Coast region. The monitoring sites with at least a five-year data record were selected for analysis. The results are presented as electrical conductivity (EC, µS/cm at 25 °C). This is a commonly used surrogate for the measurement of water salinity in Australia. Standard EC levels for different applications, such as for drinking water or types of irrigation, are provided in the Technical Supplement. The median annual EC values are shown as coloured circles. The size of the circle depicts the variability in annual EC, shown as the coefficient of variation (CV), being the standard deviation divided by the mean.

The median EC values for most of the monitoring sites in the main rivers fall in the range 0–1,000 µS/cm, which is suitable for most irrigation uses. Of the seven monitoring sites, 43% had median EC values below 500 µS/cm and 57% were between 500–1,000 µS/cm. A little higher salinity occurs in the river basins in the south of the region.

The salinity CV is the expected variability of a measurement of EC, relative to the mean EC. The CV in EC is typically related to the variability of the flow at the monitoring sites. The CV is relatively low for the most of the monitoring sites in the region except Dugald River in the south of the region. Of the seven monitoring sites, 43% had a CV below 20%; 43% of the sites had a CV between 20% and 60%; and the CV was above 60% at one of the seven monitoring sites. This was on the Dugald River in the south of the region.

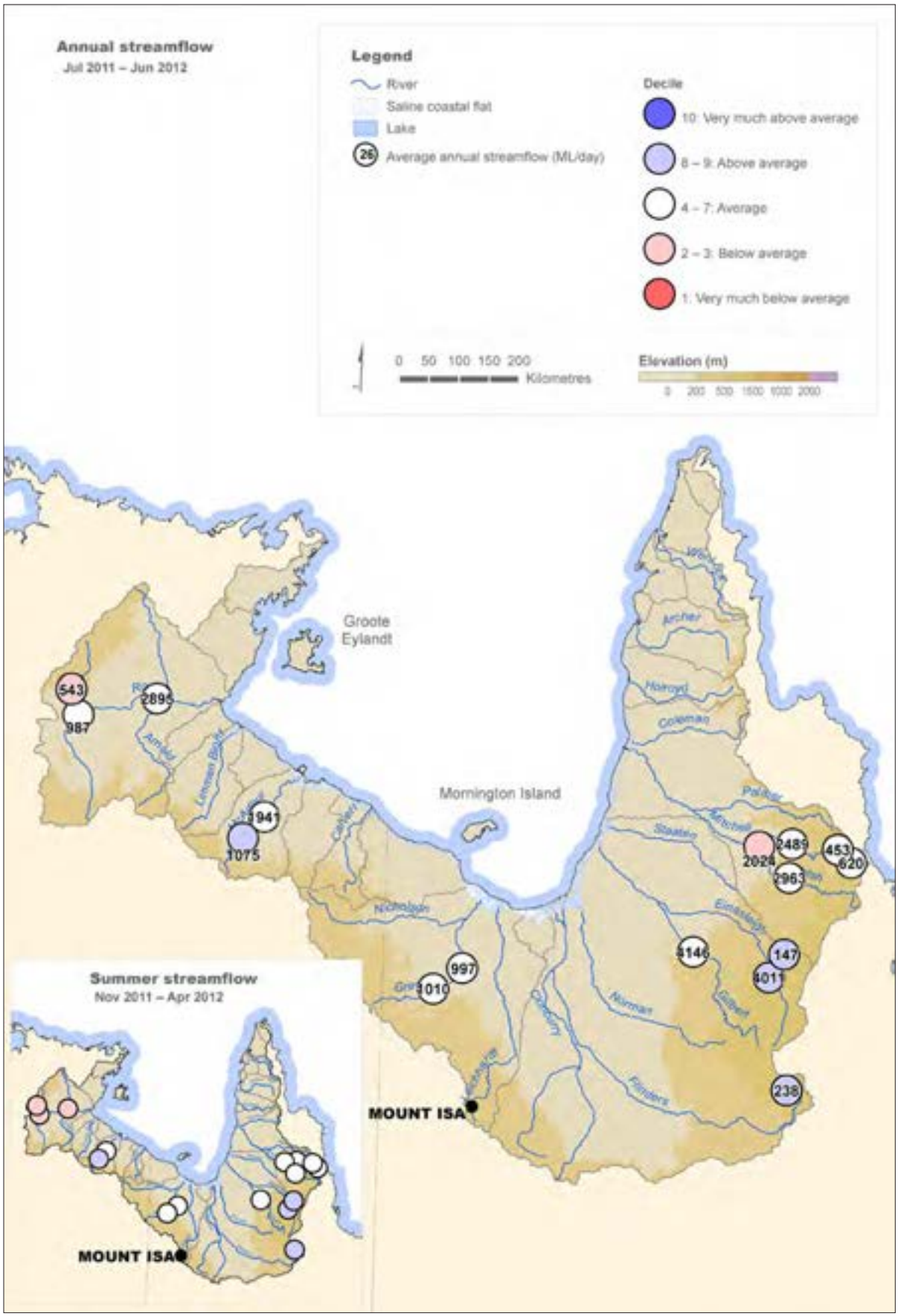


Figure 15.23 Average annual and wet season (November 2011–April 2012) flow volumes of selected monitoring sites for 2011–12 and their decile rankings over the 1980–2012 period in the Carpentaria Coast region

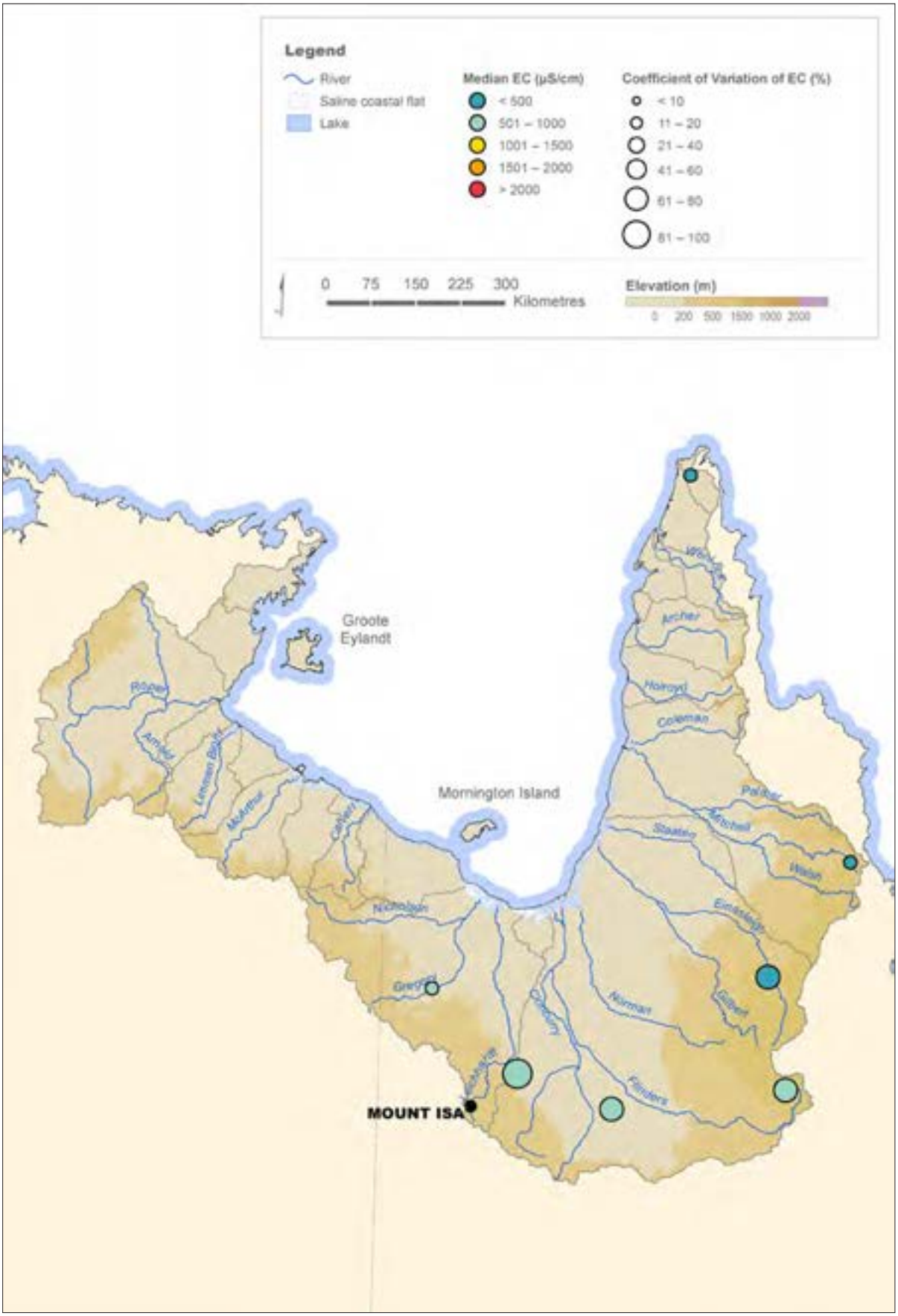


Figure 15.24 Salinity as electrical conductivity and its associated coefficient of variation for 2011–12 in the Carpentaria Coast region

15.5.4 Flooding

Figure 15.25 gives an overview of the locations where the Bureau is assesses flood levels in the Carpentaria Coast region through the Northern Territory Government as part of its flood forecasting service. These levels are further specified in the Technical Supplement.

There were major floods in the region, mostly during the January–March 2012 period, that were associated with an active monsoon over northern Australia and the Gulf of Carpentaria.

In the last week of December 2011 the monsoon was very active over the eastern half of Northern Australia. In late January 2012 a low formed over western Cape York Peninsula and moved into the southeast Gulf of Carpentaria. Major floods occurred in the Cloncurry River with other moderate floods in the Leichhardt River and minor floods further west in the Gregory River.

In mid to late February 2012 a low pressure system produced heavy rainfalls across most of the Gulf Country and resulted in major floods over vast part of the region from the Einasleigh River in the east to the Gregory River in the west.

In early March 2012 moderate to heavy rainfall affected the north tropical coast and central coast and major floods occurred in northeast rivers such as Mitchell with minor flooding in other eastern rivers such as the Gilbert and Einasleigh.

One major flood occurred during April 2012 in upper Flinders. The heavy rainfalls subsided in the region and no flooding occurred afterwards.

15.5.5 Storage systems

One storage, Lake Julius, is reported in the Carpentaria Coast region by the Bureau's water storage information. The Bureau's water storage website includes information on approximately 24% of the region's publicly owned storage capacity (as at August 2012). Storages not reported include Lake Moondarra and Lake Mitchell. Lake Julius provides water to Mount Isa and surrounding mines.

The location of Lake Julius is shown in Figure 15.26. The storage normally fills up over the wet season and slowly drops in level over the dry season. In June 2012, Lake Julius was filled to 93% of its storage capacity. The lowest storage level was 80% of its storage capacity.

Further information on the past and present volumes of the storage systems and the individual storages can be found on the Bureau's water storage website: water.bom.gov.au/waterstorage/awris/

15.5.6 Wetlands

There are no Ramsar-listed internationally important wetlands in the Carpentaria Coast region, but there are a large number of wetlands of national importance mentioned (Figure 15.27). More information about the wetlands in the region can be found in the *Australian Directory of Important Wetlands* (www.environment.gov.au/water/topics/wetlands/database/diwa.html).

The wetlands consist mainly of widespread tidal flats in the estuaries of most rivers. These estuaries are flooded with fresh water during the wet season peak flows, and provide large habitats for water birds to feed and breed.

No detailed assessment on the inflows of selected wetlands has been performed for this region.

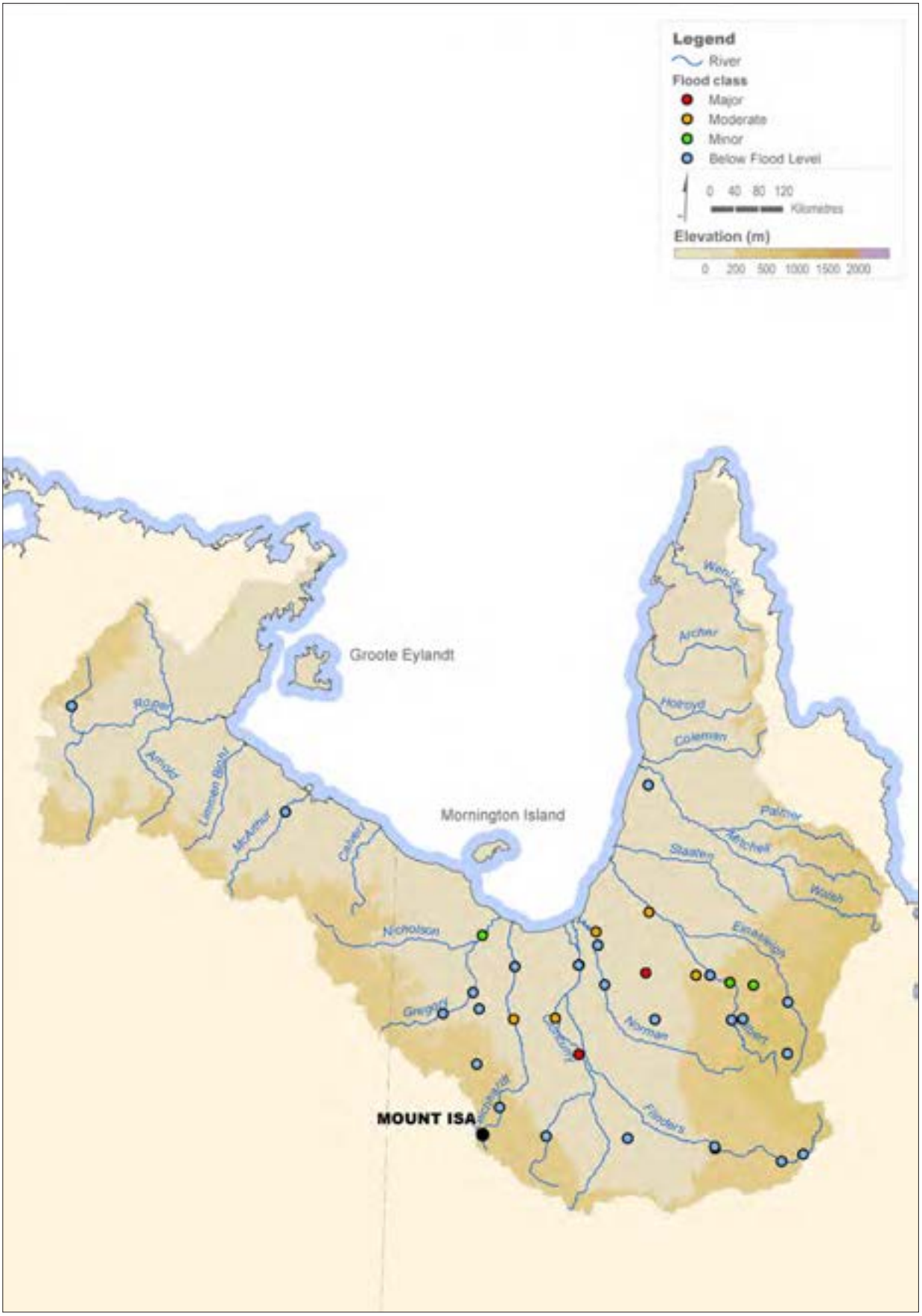


Figure 15.25 Flood occurrence in 2011–12 for the Carpentaria Coast region

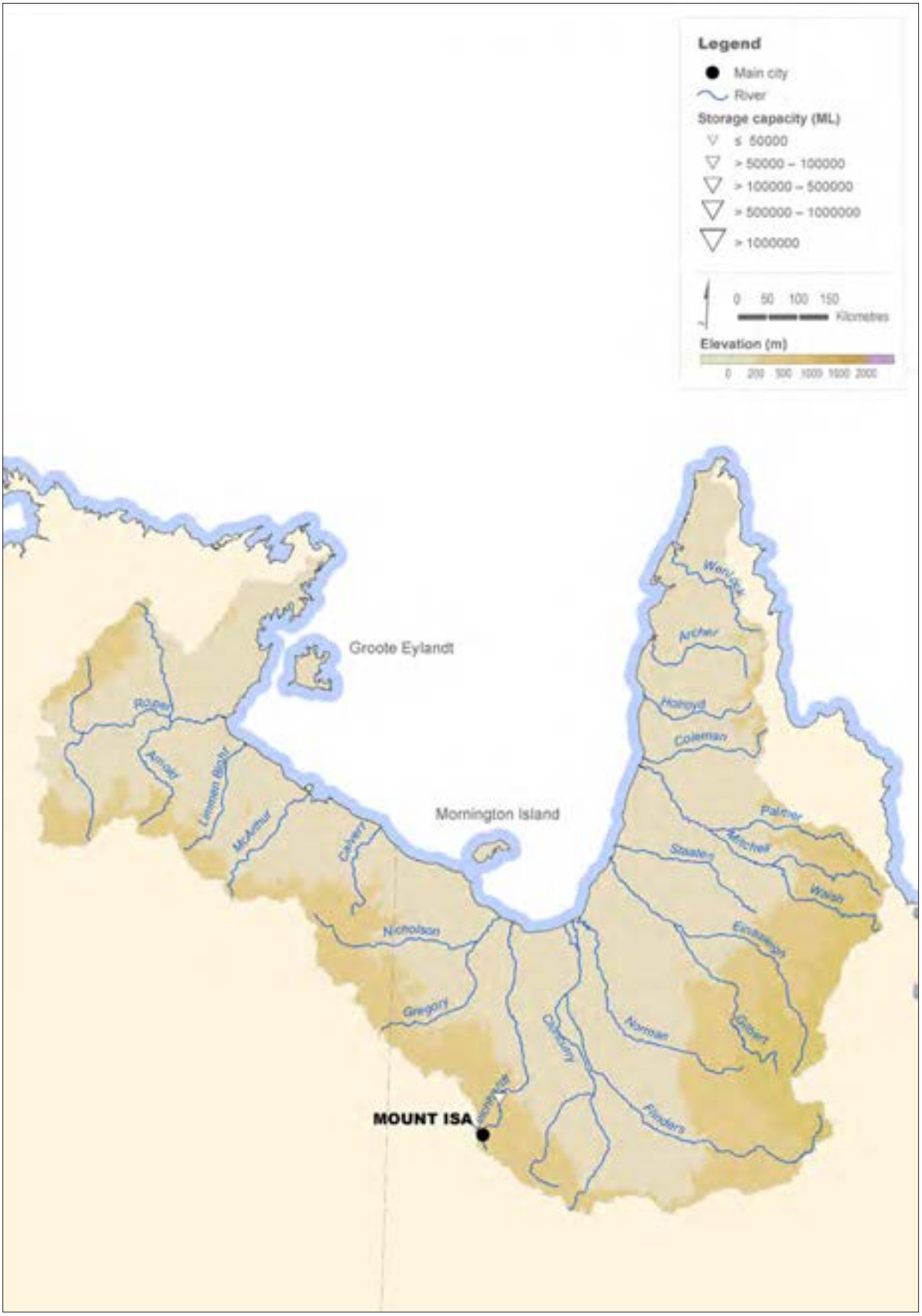


Figure 15.26 Storage systems in the Carpentaria Coast region (information extracted from the Bureau's water storage website in August 2012)

Figure 15.27 Location of important wetlands in the Carpentaria Coast region

15.5.7 Hydrogeology

The hydrogeology of the region is dominated by the sediments of the Great Artesian Basin, fractured and karstic rock in some areas, and some outcropping basement rock (Figure 15.28).

Groundwater systems that provide more potential for extraction are labelled as:

- Fractured and Karstic Rocks; and
- Mesozoic GAB (porous media—consolidated).

The Great Artesian Basin is one of Australia's largest and most significant groundwater basins with porous sandstone aquifers from the Triassic, Jurassic and Cretaceous periods. There is a substantial amount of extraction of groundwater from this large resource for stock and domestic purposes.

Fractured and karstic rock occurs in the Roper catchment (in the region's west) and the Mount Isa area in the south. In the hard rock of the basement, substantial groundwater flow only occurs in rock fractures and this type of groundwater system typically offers restricted low volume groundwater resources.

15.5.8 Water table salinity

Figure 15.29 shows the classification of watertable aquifers as fresh (total dissolved solids [TDS] < 3,000 mg/L) or saline (TDS ≥ 3,000 mg/L) water according to watertable salinity. As shown in this figure there is a large area of no data represented in grey; however, where the data exists groundwater is mainly fresh.

Although the water quality of shallow aquifers is generally good, the seasonal variability of rainfall, and consequently the level of the watertable, reduces the reliability of the yield.

15.5.9 Groundwater management units

The groundwater management units within the region are key features that control the extraction of groundwater through planning mechanisms. Figure 15.30 shows that the major groundwater management unit within the Northern Territory contains the fractured and karstic rocks aquifers of the Daly Roper area. In Queensland the major groundwater management units are the Great Artesian Basin, the Cook, and the Mount Isa.

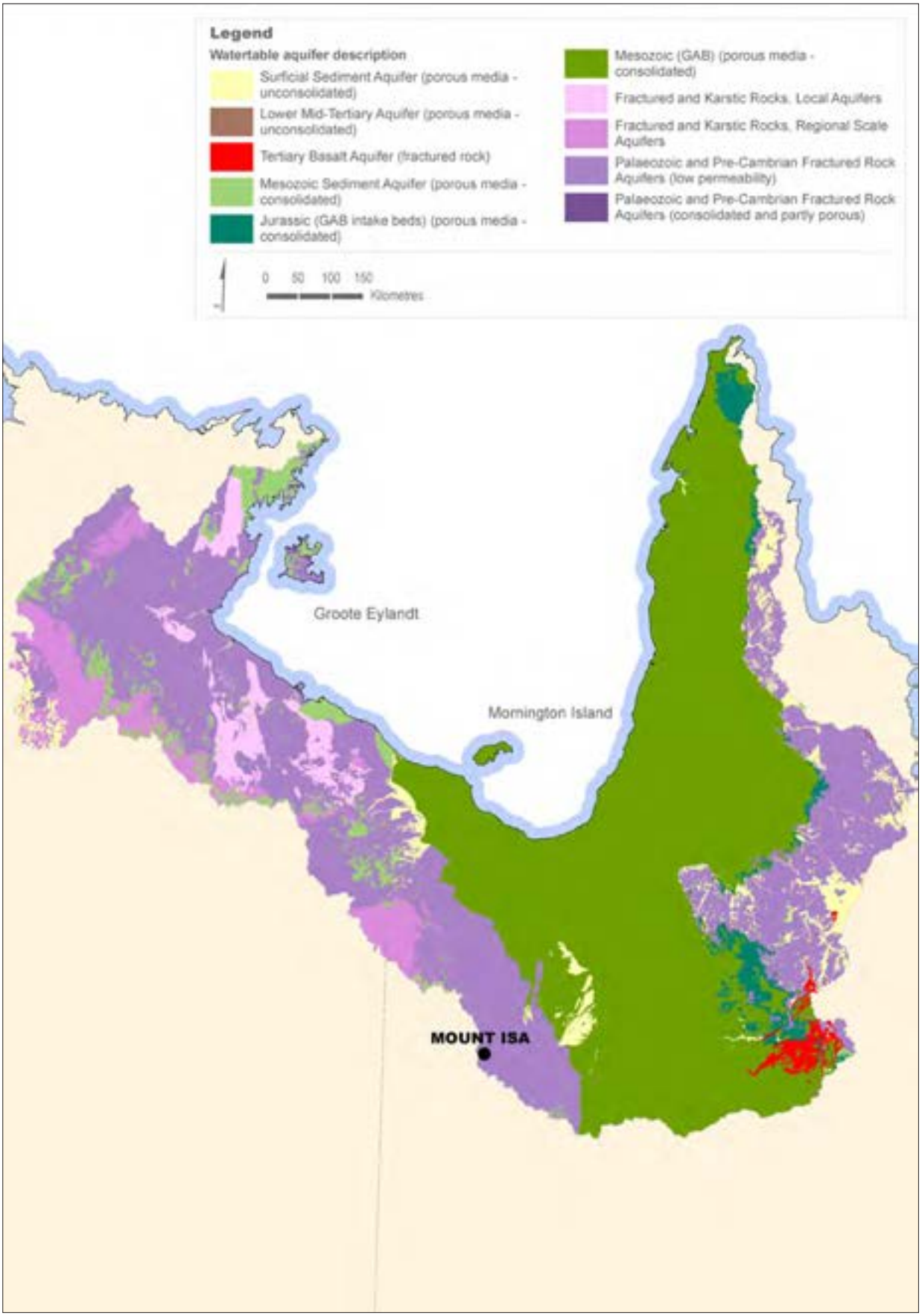


Figure 15.28 Watertable aquifers in the Carpentaria Coast region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

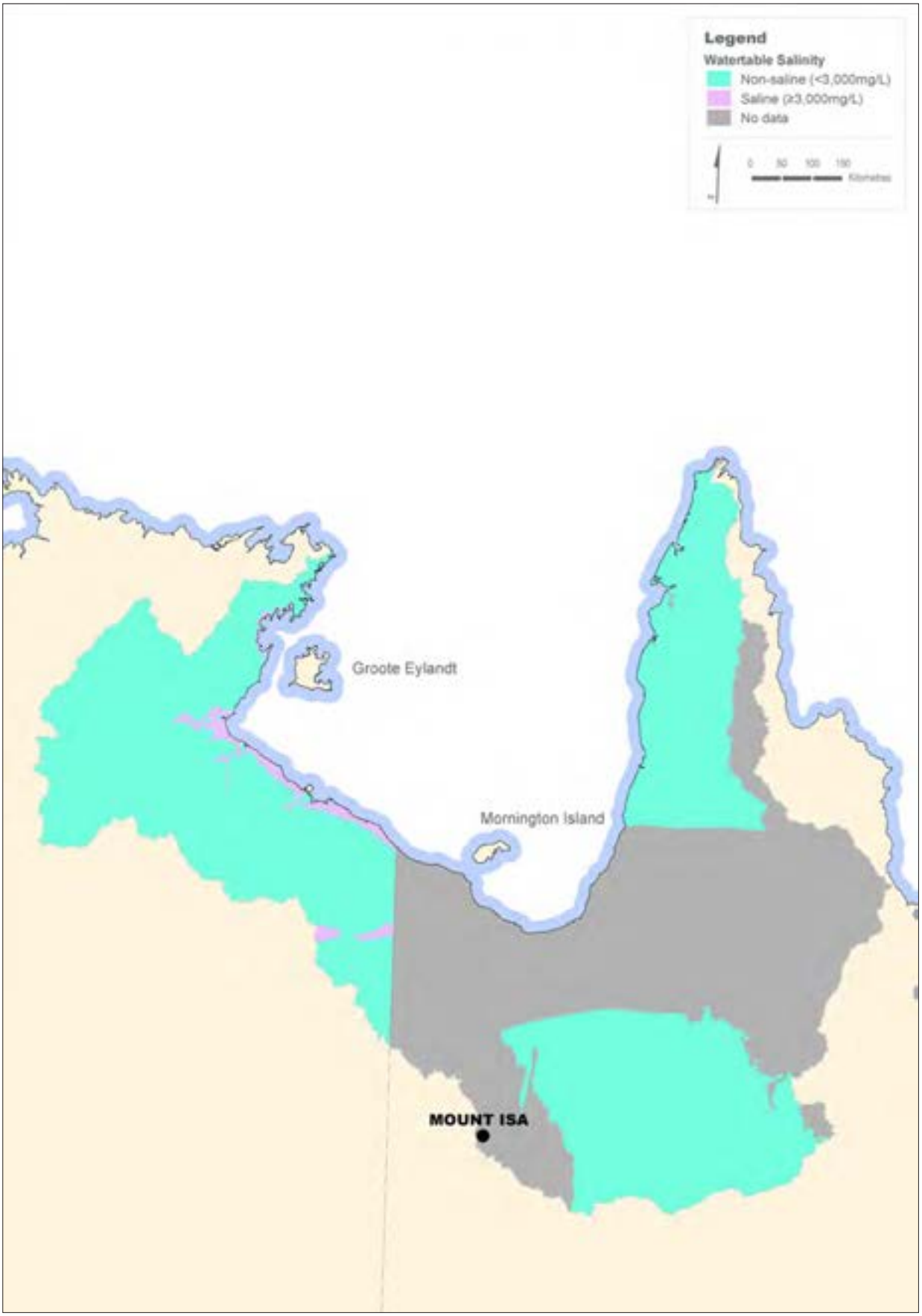


Figure 15.29 Watertable salinity classes in the Carpentaria Coast region; data extracted from the Groundwater Cartography of the Australian Hydrological Geospatial Fabric (Bureau of Meteorology 2012)

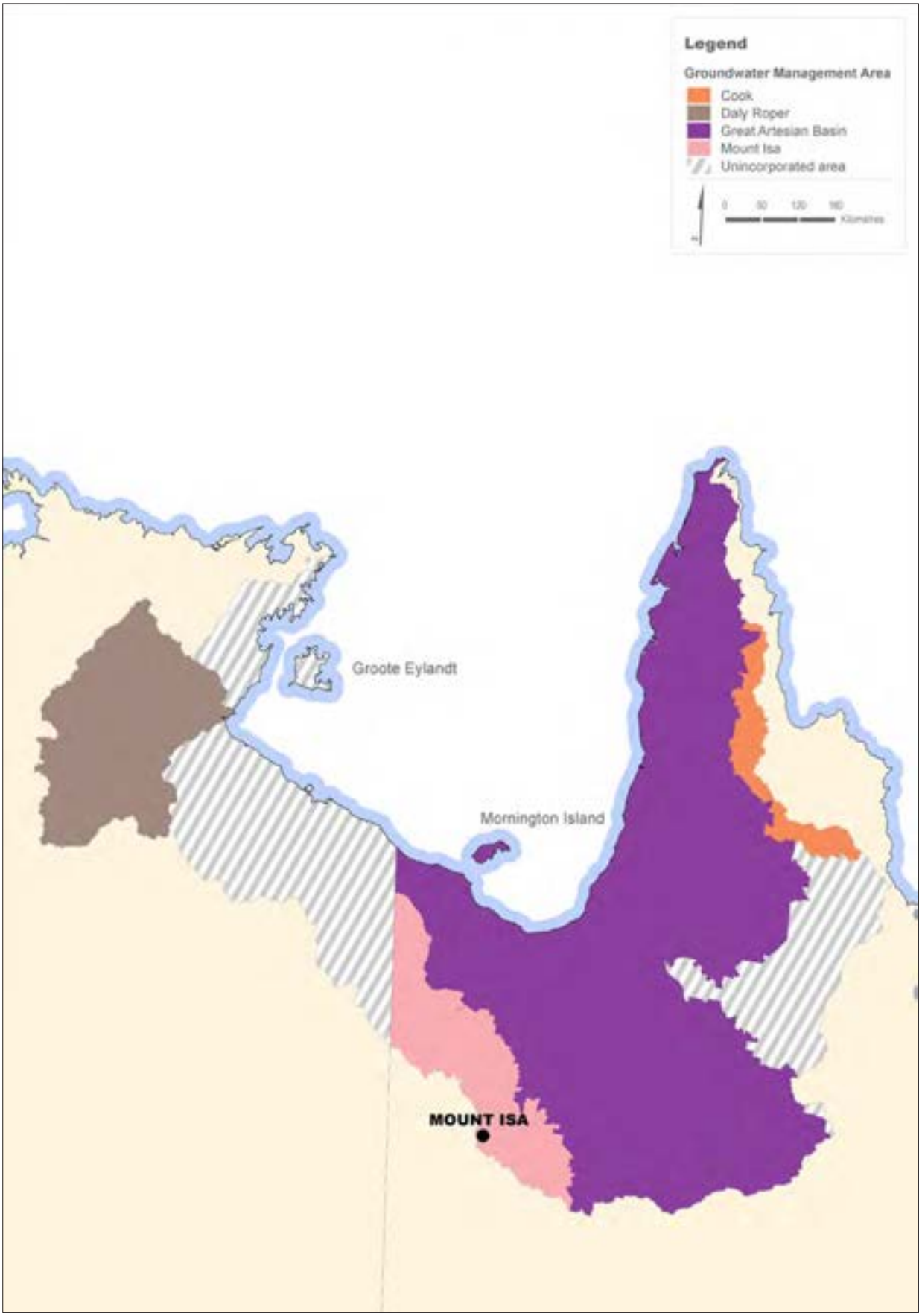


Figure 15.30 Groundwater management units in the Carpentaria Coast region; data extracted from the National Groundwater Information System (Bureau of Meteorology 2013)

Technical supplement

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1 Introduction

The *Australian Water Resources Assessment 2012* (the 2012 Assessment) is the second in a series of reports produced by the Bureau of Meteorology (the Bureau). The report presents assessments of Australia's climate and water resources in 2011–12 (July 2011– June 2012) and discusses regional variability and trends in water resources and patterns of water use over recent years and decades, based on the currently accessible data.

This Technical Supplement provides supporting information for the 2012 Assessment and includes:

- Region boundaries
- Landscape water balance framework
- Methods summaries
- Data sources and analyses
- Data available with the report.

2 Region boundaries

Similar to the 2010 Assessment, the 2012 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 natural 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 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); 12 drainage divisions were defined at the highest level of the hierarchy and were used as the basis for the reporting regions in the 2012 Assessment. This work builds on and approximates the drainage boundaries developed by Geoscience Australia (1997) that were the result of a joint State, Territory and Australian Commonwealth Government project to create a national spatial database of major hydrological basins.

One of the drainage divisions developed by Geoscience Australia, 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 (Victoria), creating the 'South East Coast (NSW)' and 'South East Coast (Vic)' regions.

The differences between the original Geoscience Australia boundaries and those used in the 2012 Assessment are illustrated in Figure 1.

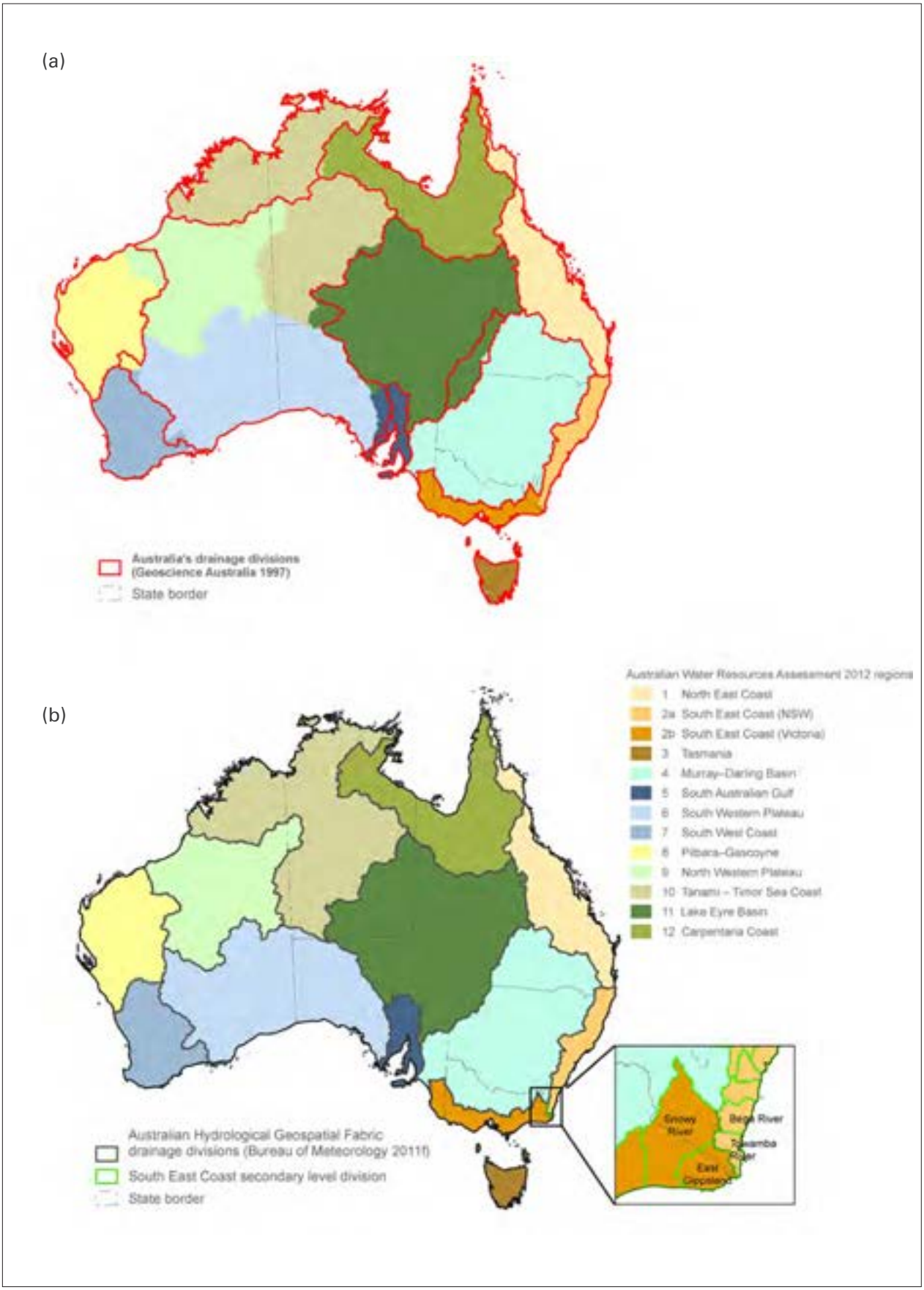


Figure 1 (a) Comparison of drainage division boundaries of Geoscience Australia (1997) and the 2012 Assessment regions, and (b) the subdivision of the South-East Coast drainage division into two reporting regions

3 Landscape water balance framework

3.1 Background

The estimation of the dominant landscape water flows and stores on a national scale is a major part of the 2012 Assessment. This includes information on precipitation, actual evapotranspiration, soil moisture and landscape water yield (comprising run-off and groundwater discharge). These components are not measured directly. To generate this information across all parts of Australia, modelling simulations and spatial interpolation techniques were used.

This chapter explains the reasoning for the choice of the methods to estimate the spatial and temporal variability of these non-measured water balance components.

Considerations for choice of the 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 major information products are being produced. These are the Australian Water Resources Assessment (www.bom.gov.au/water/awra) 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. Initial investigations identified the need for a framework, according to which the spatially and temporally distributed information was to be presented. This conceptual water balance framework (Barratt 2008) is illustrated in Figure 2. As observations are not available for all of these stores and flows at sufficient frequency and resolution across the continent, as required by the water balance reporting terms, models or/estimation methods are required.

The methods for estimating components of the water balance for the Australian Water Resources Assessment and the National Water Account are 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; and
- **Robustness:** the methods are demonstrably robust compared with other available methods.

The National Water Account presents a detailed annual water balance for the components as shown in Figure 2, focusing on water use and manageable storage from the surface water and groundwater stores. The Australian Water Resources Assessment only captures the major landscape water flow processes, that is, rainfall, actual evapotranspiration, landscape water yield and soil moisture storage, focusing on water availability and the landscape water flows. The choice of methods for estimating these landscape water flows are discussed, in turn, below.

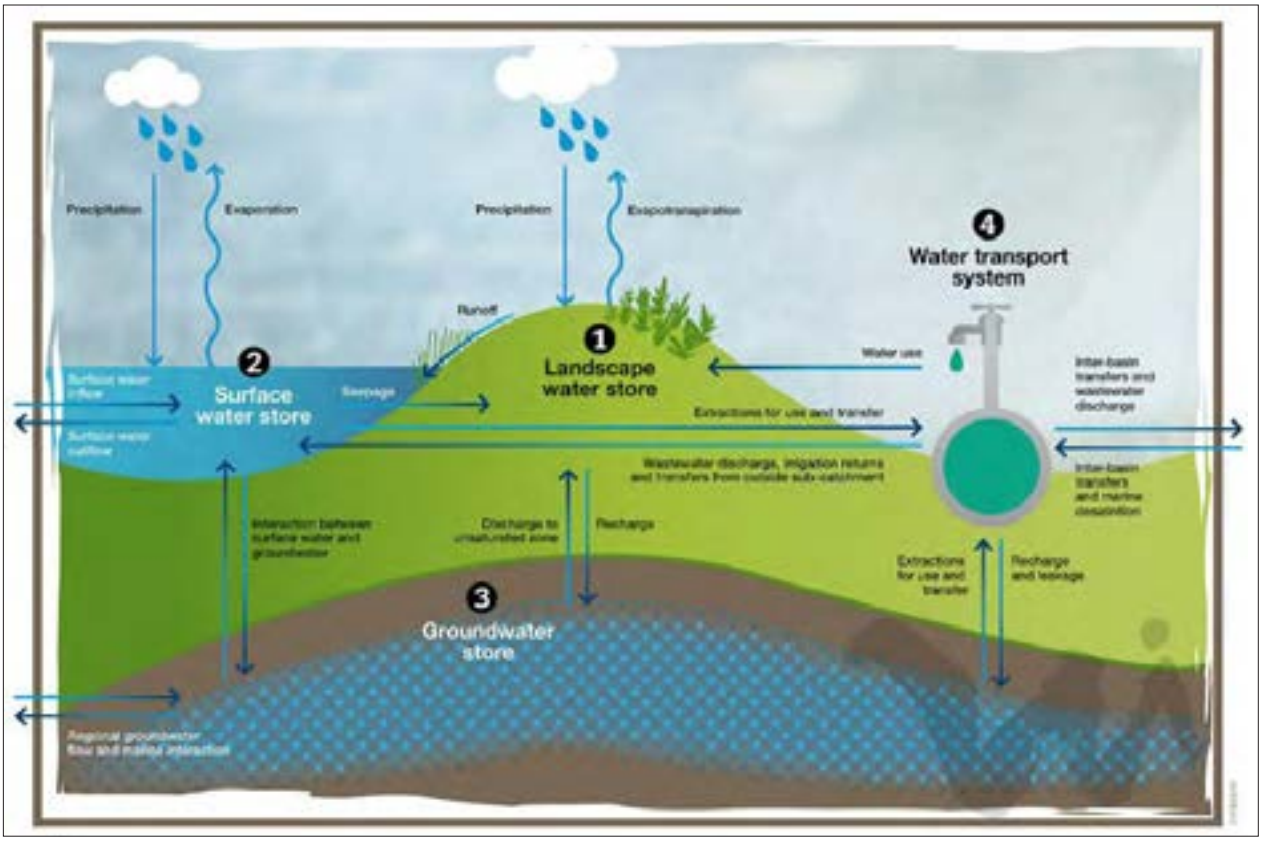


Figure 2 Water flows and stores in the conceptual water balance framework (Barratt 2008)

3.2 Measured water balance and climatic data

Rainfall measurements are required for estimation of the spatial distribution of rainfall across Australia and for input into the water balance model. Gridded rainfall estimates produced by the Bureau (Jones et al. 2009) were used. The dataset was derived from spatial interpolation of available daily rainfall readings collected by the Bureau.

Solar radiation and temperature also serve as input into water balance model. Daily gridded estimates provided under the Australian Water Availability Project (AWAP) were used (see www.bom.gov.au/jsp/awap/).

3.3 Modelled landscape water balance estimates

The 2010 Assessment included estimates of actual evapotranspiration, landscape water yield (run-off and groundwater discharge) and soil moisture storage from a combination of two conceptually similar models: WaterDyn and AWRA-L. The 2012 Assessment has moved away from that approach to continue with an updated version of the AWRA-L model only. The AWRA-L model version 2.0 (the 2010 Assessment used AWRA-L version 0.5) has been used to produce estimates of the major landscape water flow processes of actual evapotranspiration, landscape water yield and soil moisture storage. Figure 3 shows a diagram of the conceptual processes contained in this model.

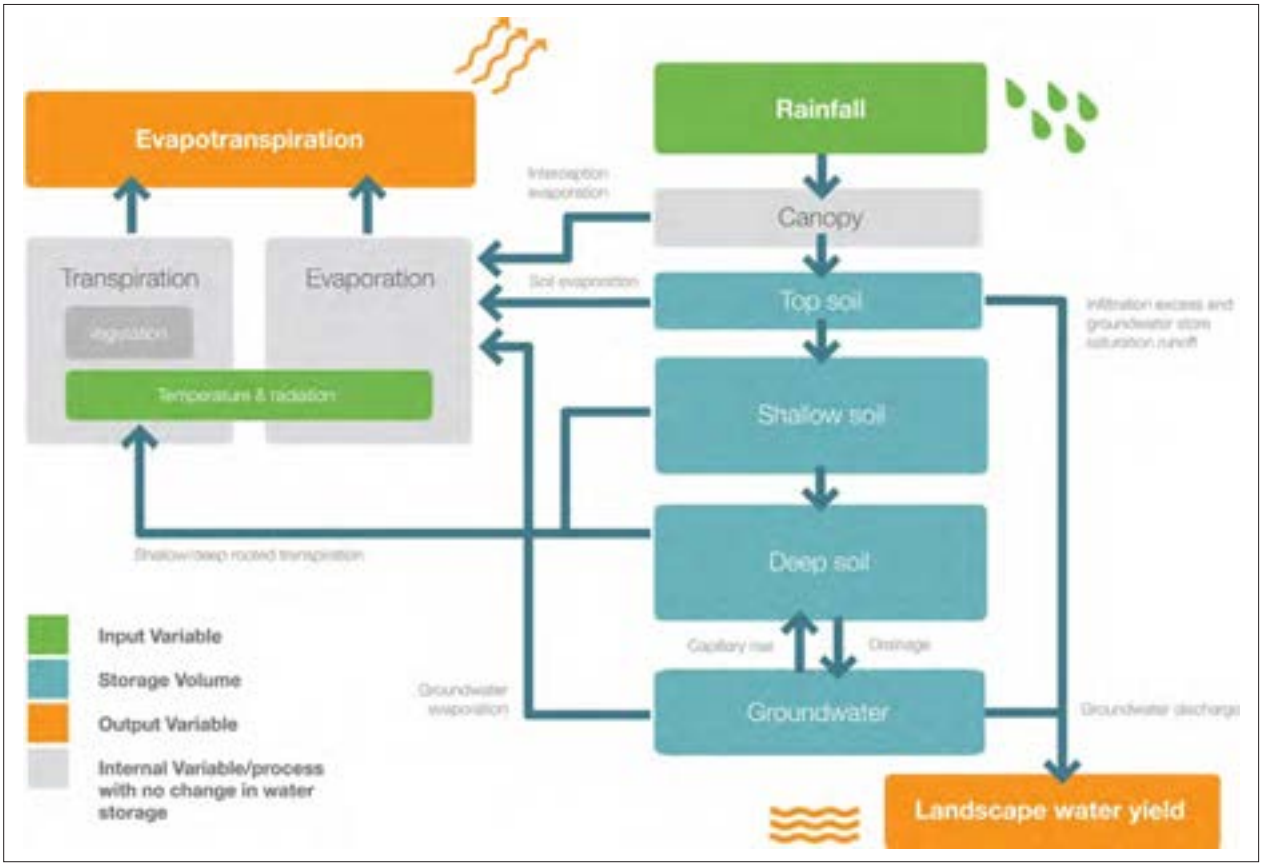


Figure 3 Conceptual diagram of AWRA-L model processes

The choice is based on the fact that the Bureau, in collaboration with CSIRO, is in the process of implementing a holistic water balance model and data assimilation system (named as the AWRA System) which consists of the AWRA-L landscape model, complemented in the future by river and groundwater model components (Figure 4). Already at this stage, but even more so in the future, this system will provide a consistent water balance estimation system, which will be the cornerstone of the Australian Water Resources Assessment and National Water Account products.

The AWRA modelling system will eventually include the following components:

- A holistic **water balance** model (AWRA-LRG)
- 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 (for example, 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 (for example, 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.

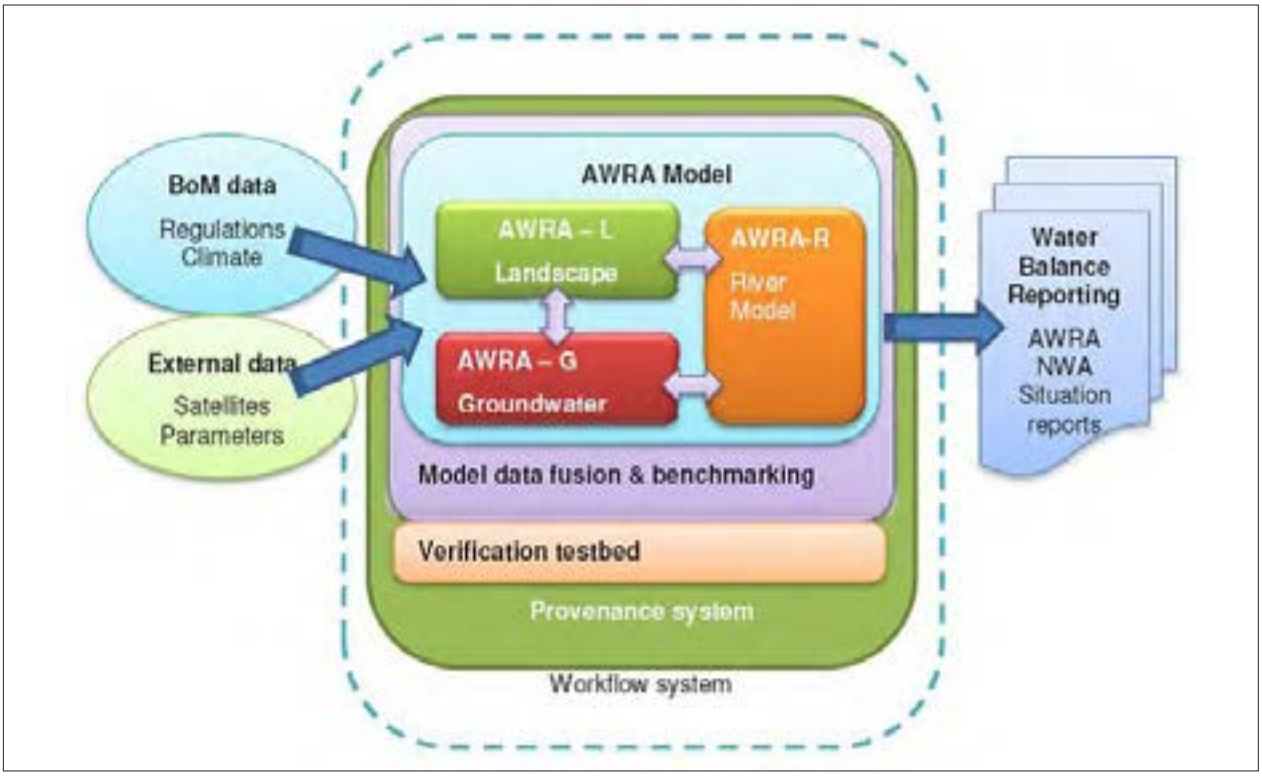


Figure 4 Australian Water Resources Assessment modelling system conceptual diagram

3.4 Model performance

The introduction of a sophisticated calibration and verification structure in the last year have enhanced the reliability of the AWRA-L model outcome using AWRA-L v2.0 compared to the combination of models that was used in the 2010 Assessment (that is, average of AWRA-L v0.5 and WaterDyn).

The model calibration and validation structure optimises the reprodution of streamflow and Leaf Area Index (LAI). LAI is a measure of leaf growth and is estimated using satellite imagery. The LAI is included in the objective function of the calibration procedure to improve the model's capacity to reflect vegetation growth. Vegetation growth plays an important role in the generation of transpiration, which in turn forms a large part of the actual evapotranspiration that is reported on in the 2012 Assessment.

The calibration of model parameters to optimise streamflow reproduction is done to improve the model's estimates on landscape water yield. In the calibration procedure, the landscape water yield totals of all grid cells in the catchment are combined to form streamflow at the gauging point of a catchment.

Figure 5 indicates model performances in estimating streamflow throughout Australia with a single parameter set. The results of the model are compared with previous versions of the model as well as the previously used (single parameter set) WaterDyn model. To indicate achievable model performances a purpose specific rainfall run-off model (CWYET_GR4J) is also included in this comparison.

Nash–Sutcliffe model efficiency coefficient (NSE) and the relative bias are used as measures of the predictive strength of these models (Figure 5). The higher the NSE and the lower the bias, the better the match between the model results and the observations.

The CWYET_GR4J model results given in Figure 5 are estimated on the basis of using calibrated parameter sets of neighbouring catchments. The AWRA-L model on the other hand uses one parameter set for the whole country.

The introduction of the advanced calibration tool (in AWRA-L v1.0) particularly helped improving the AWRA-L model results. Since then, minor improvements have been achieved mainly through the introduction of additional information, in particular on vegetation, from remotely sensed products and small conceptual changes in some components of the model.

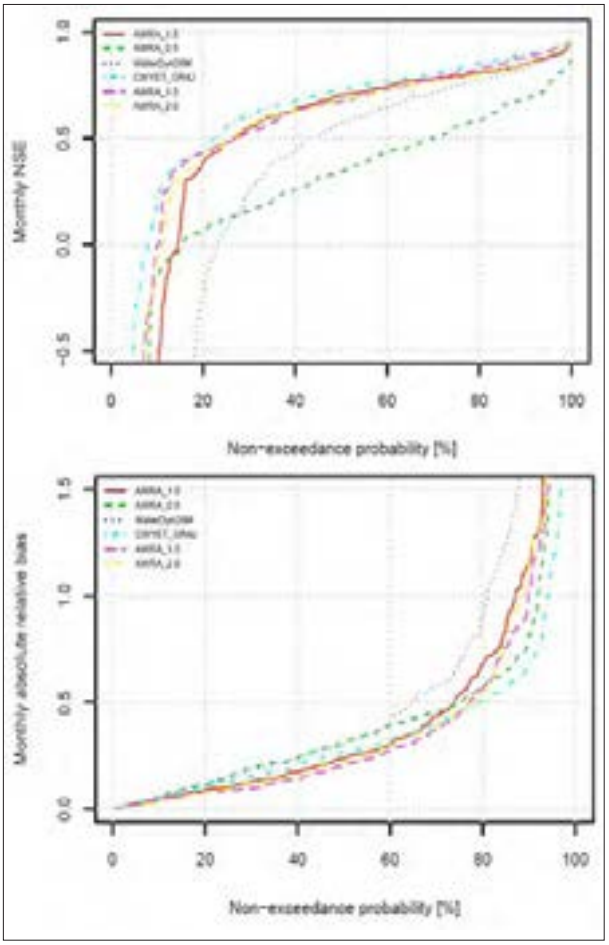


Figure 5 Distribution of the Nash-Suthcliff Efficiency (NSE) scores and relative bias for monthly streamflow reproduction of 289 catchments

4 Methods summaries

The 2012 Assessment includes many different analysis methods, most of them specifically focusing on particular components of the water resources (that is, groundwater, reservoirs or streamflow). These methods were carefully selected based on a sound investigation of similar assessments previously performed in Australia and overseas.

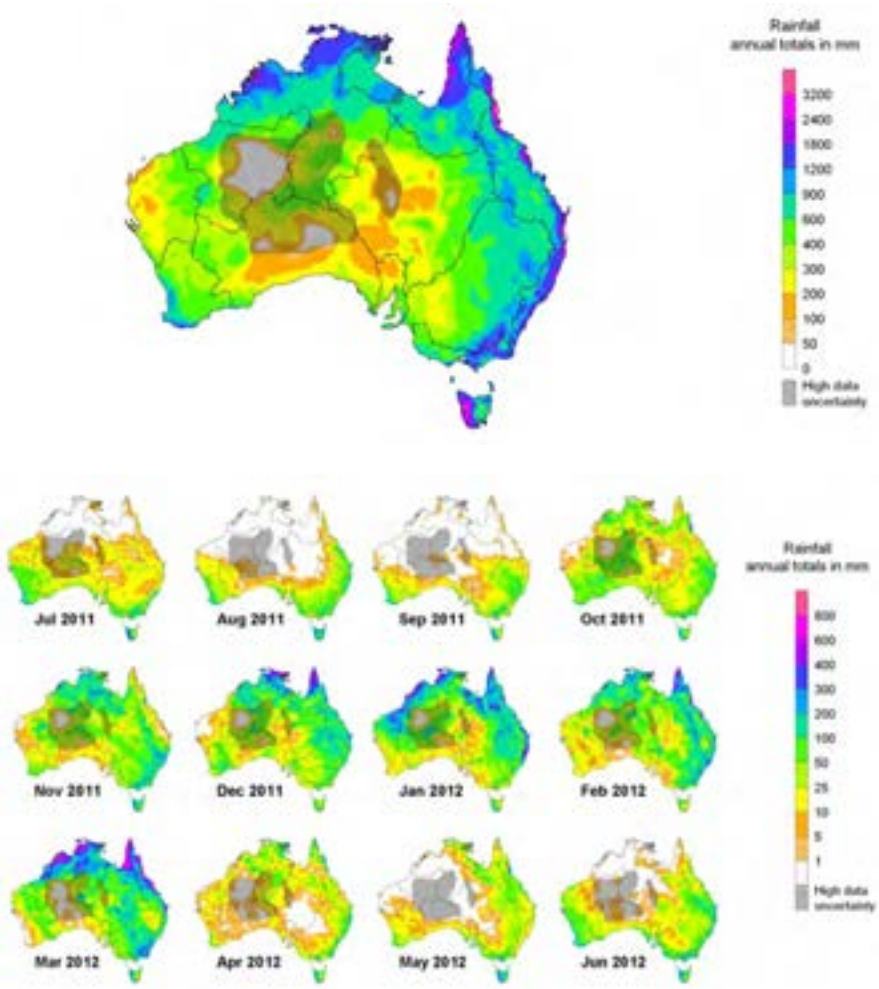
The tables that follow provide a list of references and peer reviews of each of the methods used, so as to demonstrate their validity. For each method the following information is provided:

- 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; and
- an example illustration of the output.

In addition to this, 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 website: www.bom.gov.au/water/awra/

2012 Assessment analysis	Data	Method	Reference / peer review
Annual and monthly national rainfall surfaces Landscape water flows in 2011–12, National Overview, s. 2.3	**Description** 5 km x 5 km original 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. Resolution of output Temporal: annual / monthly Spatial: 5 km x 5 km grid (national coverage)	Bureau of Meteorology 2012, *Annual Climate Summary 2011*, www.bom.gov.au/climate/annual_sum/2011/index.shtml Jones, DA, Wang, W, Fawcett, R 2009, 'High-quality spatial climate data-sets for Australia', *Australian Meteorological and Oceanographic Journal, vol. 58*, pp. 233–48

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Annual and monthly national modelled actual evapotranspiration surfaces Landscape water flows in 2011–12, National Overview, s. 2.3	**Description** 5 km x 5 km actual evapotranspiration grid data, based on the Priestly–Taylor equation. **Source** AWRA-L 2.0	**Description** Bureau standard spatial climate data presentation method. Monthly and annual total modelled actual evapotranspiration grids (July–June) presented. **Resolution of output** Temporal: annual / monthly Spatial: 5 km x 5 km grid (national coverage)	Van Djik A 2010, The Australian Water Resources Assessment system, Technical report 3, Landscape model, version 0.5, *Water for Healthy Country*, CSIRO National Research Flagship, www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-aus-water-resources-assessment-system.pdf

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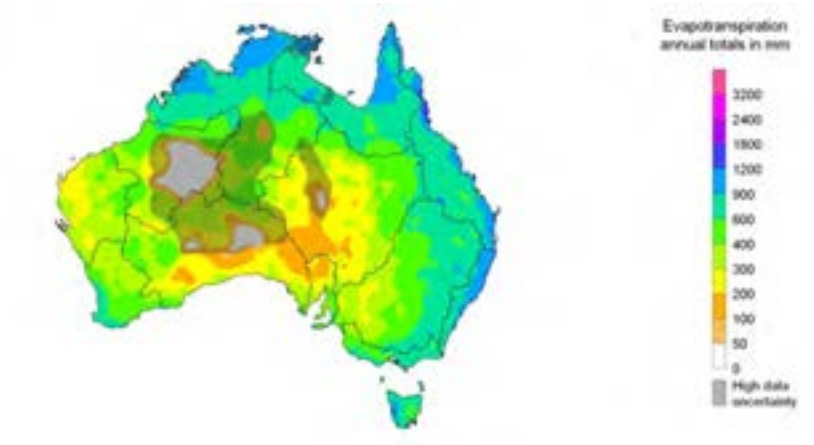

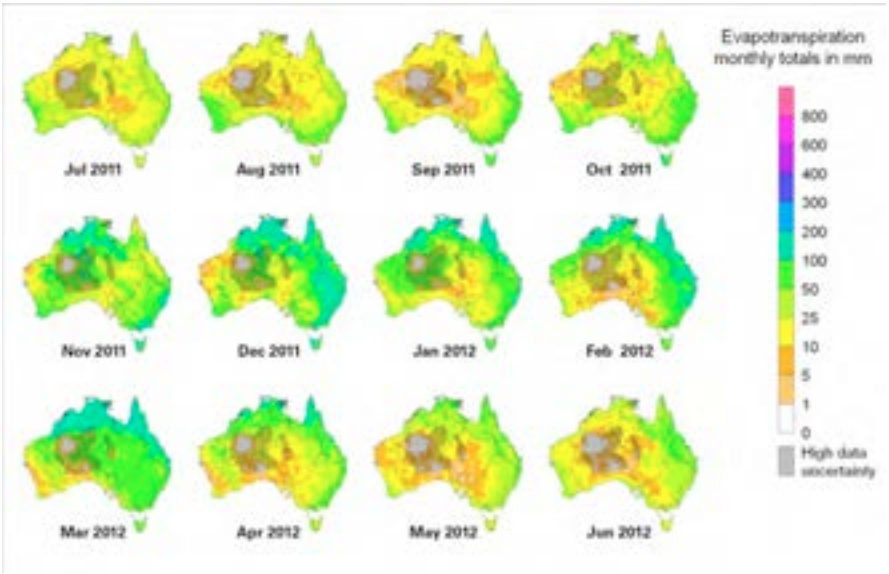

2012 Assessment analysis	Data	Method	Reference / peer review
Annual and monthly national modelled landscape water yield surfaces Landscape water flows in 2011–12, National Overview, s. 2.3	**Description** 5km x 5 km modelled landscape water yield grid data. **Source** AWRA-L 2.0	**Description** Bureau standard spatial climate data presentation method. Monthly and annual total modelled landscape water yield grids (July–June) presented. **Resolution of output** Temporal: annual / monthly Spatial: 5km x 5 km grid (national coverage)	Van Djik A 2010, The Australian Water Resources Assessment system, Technical report 3, Landscape model, version 0.5, *Water for Healthy Country*, CSIRO National Research Flagship, www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-aus-water-resources-assessment-system.pdf Viney, NR 2010, 'A comparison of modelling approaches for continental stream flow prediction', Water for Healthy Country, CSIRO National Research Flagship, CSIRO, Canberra.

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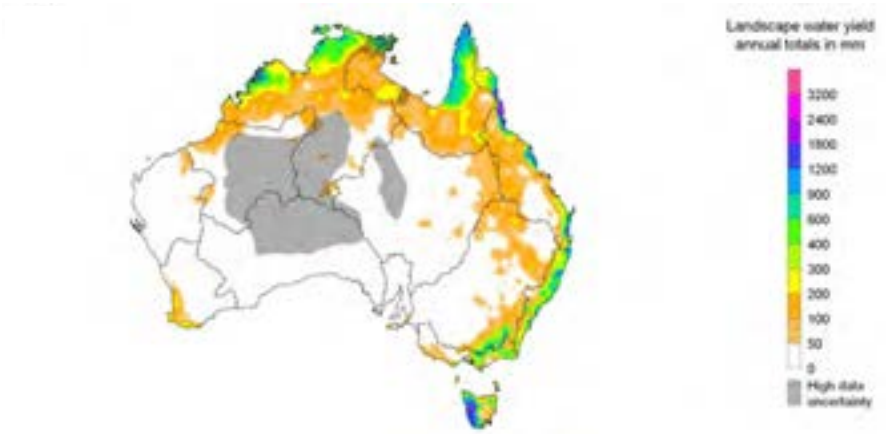

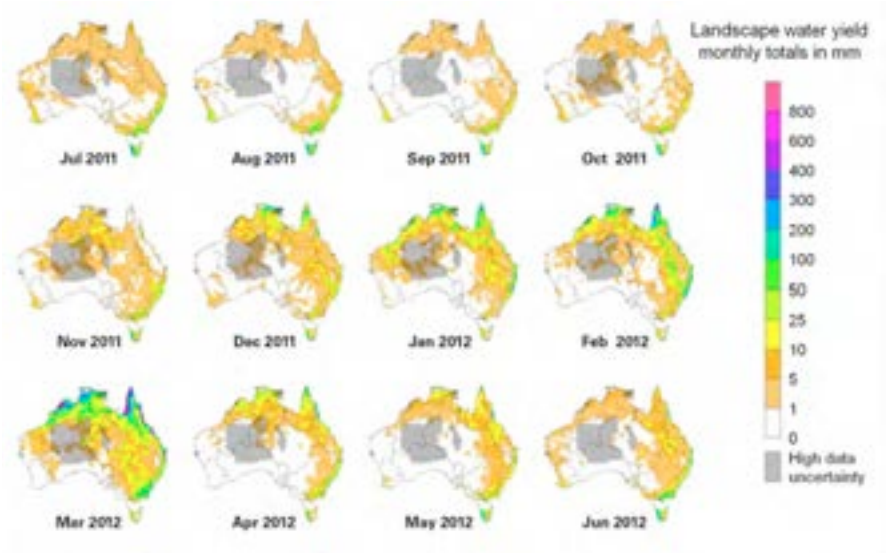

2012 Assessment analysis	Data	Method	Reference / peer review
Annual and monthly national deciles (rainfall, evapotranspiration and landscape water yield) Landscape water flows in 2011–12, National Overview, s. 2.3	**Description** 5 km x 5 km annual and monthly deciles grid data generated for each of the landscape water flows. Deciles calculated from long-term gridded data (July 1911–June 2012). **Source** Bureau (National Climate Centre) and AWRA-L 2.0	**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–June 2012). **Resolution of output** Temporal: annual / monthly Spatial: 5 km x 5 km grid (national coverage)	Bureau of Meteorology 2012, *Annual Climate Summary 2011*, www.bom.gov.au/climate/annual_sum/2011/ Bureau of Meteorology 2013, Special climate statements, www.bom.gov.au/climate/current/special-statements.shtml Centre for Australian Weather and Climate Research 2013, www.cawcr.gov.au/publications/researchletters.php

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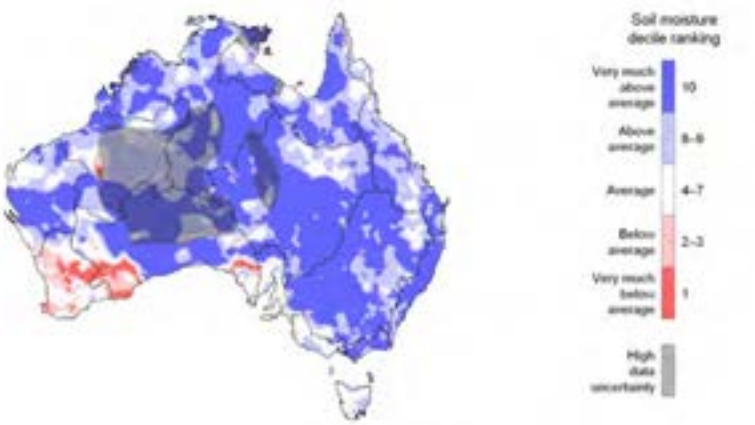

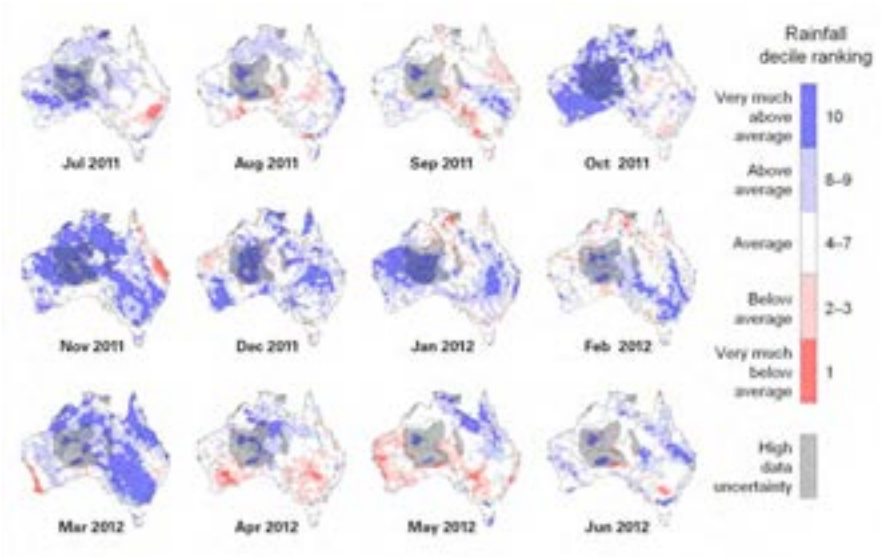

2012 Assessment analysis	Data	Method	Reference / peer review
Annual variation in national soil moisture surfaces Soil Moisture in 2011–12, National Overview, s. 2.4	**Description** 5 km x 5 km gridded annual soil moisture volume data. Deciles calculated from long-term gridded data (July 1911–June 2012). **Source** AWRA-L 2.0	**Description** Modelled annual average soil moisture deciles for 2011–12 with respect to the 1911–2012 record **Resolution of output** Temporal: annual Spatial: 5 km x 5 km grid (national coverage)	Van Djik A 2010, The Australian Water Resources Assessment system, Technical report 3, Landscape model, version 0.5, *Water for Healthy Country*, CSIRO National Research Flagship, www.clw.csiro.au/publications/waterforahealthycountry/2010/wfhc-aus-water-resources-assessment-system.pdf

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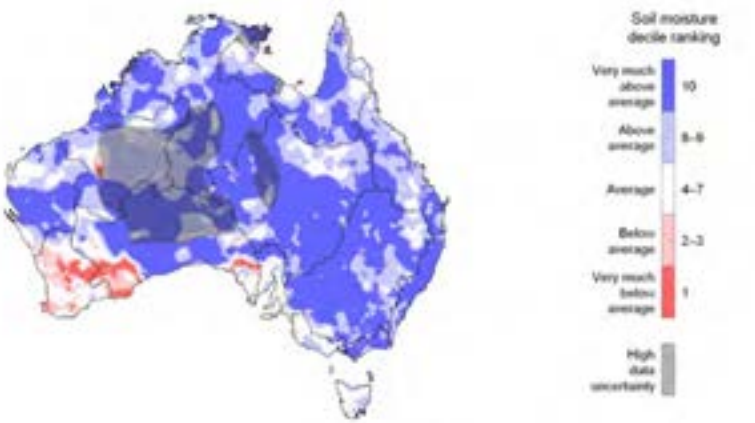
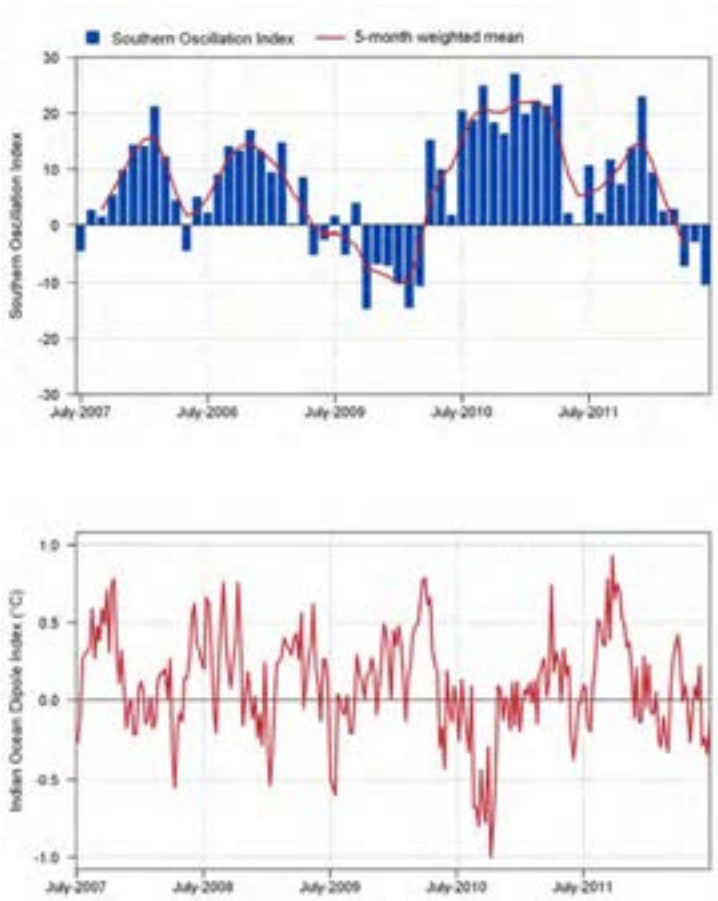


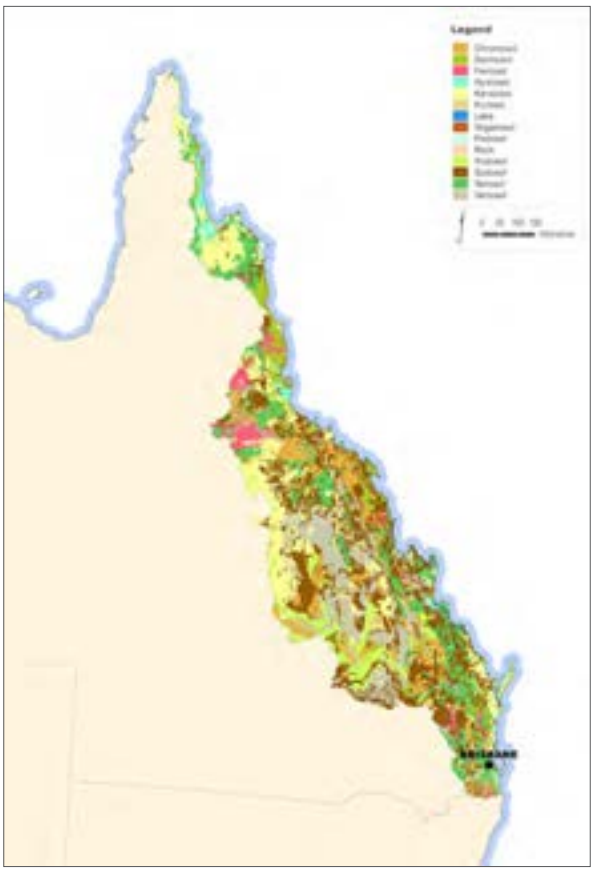
2012 Assessment analysis	Data	Method	Reference / peer review
Southern Oscillation Index (SOI) and Indian Ocean Dipole (IOD) time-series Drivers of the Australian climatic condition in 2011–12, National Overview, s. 2.9	**Description** Monthly Southern Oscillation Index (SOI) time-series data (July 2007– July 2012). Weekly Indian Ocean Dipole (IOD) time-series data (July 2007–July 2012). **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 = (SOIx-2 + 4SOIx-1 + 6SOIx + 4SOIx+1 + SOIx+2)/16 IOD Index data presented at weekly resolution. **Resolution of output** Temporal: monthly (SOI) and weekly (IOD)	Bureau of Meteorology 2012, 'El Niño / La Niño', ENSO Wrap-Up, www.bom.gov.au/climate/enso/ Bureau of Meteorology 2012, SOI and IOD time-series, www.bom.gov.au/climate/current/soi2.shtml, and www.bom.gov.au/climate/enso/indices.shtml Troup, A 1965, 'The southern oscillation', *Quarterly journal of Royal Meteorological Society*, vol. 91, pp. 490–506. Saji, NH et al. 'A dipole mode in the tropical Indian Ocean', Nature, vol. 401, pp. 360–63.

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Soil types Description of the region, s. 3 of the regional chapters	**Description** The map shows the distribution of soil types as classified per Australian soil order classification system.	**Description** The soil type map was produced by linking digital soil mapping units of the *Atlas Australian Soil Classification* (Northcote et al.1960–1968) to the Australian Soil Classification soil order as developed by Ashton and McKenzie (2001). *The Atlas of Australian Soils* was produced between 1960 and 1968 (Northcote et al. 1960–1968). A digital version of the atlas was created by the Bureau of Rural Science in 1991. The data was accessed through the ASRIS website (ASRIS 2011) The digital soil mapping units are accessible at a scale of 1:2,000,000, but the original compilation was at scales from 1:250,000 to 1:500,000.	Ashton, LJ, McKenzie, NJ 2001, 'Conversion of the Atlas of Australian Soils to the Australian Soil Classification', CSIRO Land and Water (unpublished) CSIRO, Australian Soil Resource Information System 2012, retrieved 7 November 2012, www.asris.csiro.au Northcote, KH et al. 1960–1968, *Atlas of Australian Soils*, sheets 1 –10 (includes explanatory data), CSIRO Australia and Melbourne University Press, Melbourne

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Monthly box plots of regional landscape water balance model flows Landscape water flows, s. 4 of the regional chapters	**Description** Regionally averaged monthly landscape water flow data. Data presented are rainfall, evapotranspiration and landscape water yield. **Source** Bureau (National Climate Centre) and AWRA-L 2.0	**Description** Monthly data for the current year (2011–12) are presented relative to long-term record. Monthly distributions (box and whiskers) are calculated from long-term model run data (July 1911–June 2012). Landscape water flow variables presented are: • rainfall; • actual evapotranspiration; and • landscape water yield. **Resolution of output** Temporal: monthly Spatial: 2012 Assessment reporting region (spatially averaged)	Bureau of Meteorology 2013, '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

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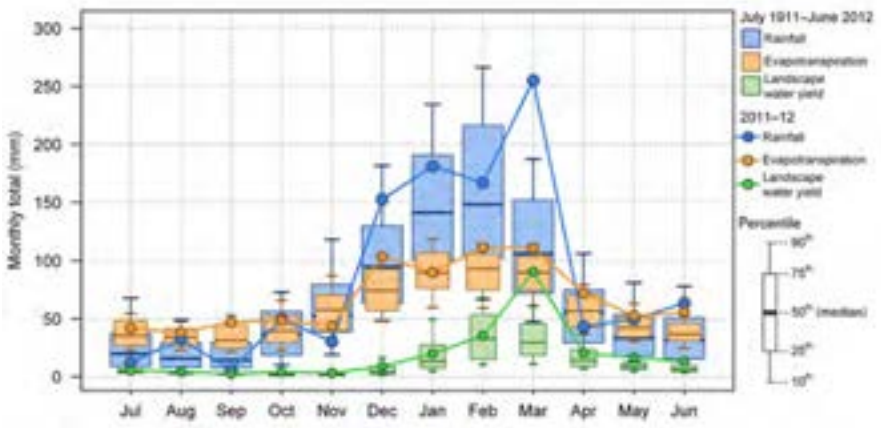

2012 Assessment analysis	Data	Method	Reference / peer review
Regional summary of annual landscape water flows (mapped annual totals and deciles) Landscape water flows, s. 4 of the regional chapters	**Description** 5 km x 5 km gridded annual landscape water flows data (July–June). Deciles calculated from long-term gridded data (July 1911– June 2012) The underlying data are the same as presented for the national overview landscape water flow surfaces in s. 2.3. **Source** Bureau (National Climate Centre) and AWRA-L 2.0	**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–June 2012). Landscape water flow variables presented are: • rainfall; • actual evapotranspiration; and • landscape water yield **Resolution of output** Temporal: annual Spatial: 5 km x 5 km grid for each 2012 Assessment reporting region	Bureau of Meteorology 2012, *Annual Climate Summary 2011*, www.bom.gov.au/climate/annual_sum/2011/

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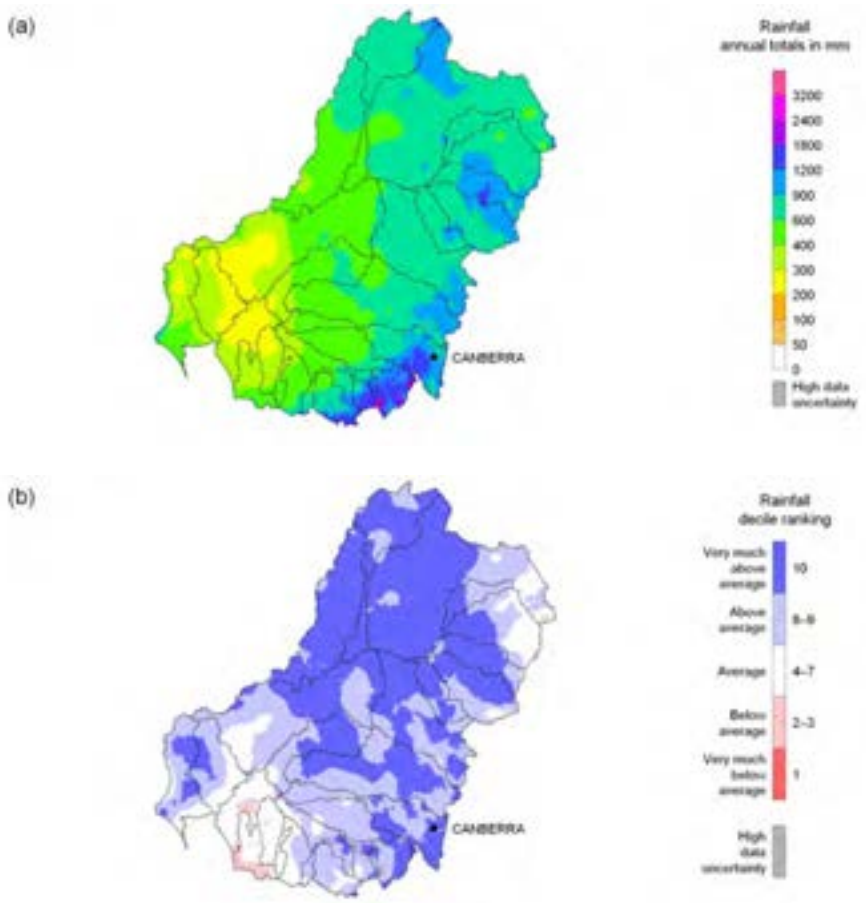

2012 Assessment analysis	Data	Method	Reference / peer review
Time-series of landscape water flows over the past 32 years (annual and seasonal) Landscape water flows, s. 4 of the regional chapters	**Description** Spatially averaged monthly and annual landscape water flow data (July–June). Summer (November–April) and winter (May–October) season totals calculated from monthly model output data. **Source** Bureau (National Climate Centre) and AWRA-L 2.0	**Description** Time-series plot of annual data presented for last 32 years (July 1980– June 2012). Time-series plot of seasonal five-year moving averages (backward looking) data presented for last 32 years (November 1980–October 2012). Landscape water flow variables presented are: • rainfall; • actual evapotranspiration; and • landscape water yield. **Resolution of output** Temporal: annual (July–June) and six-month seasons (November–April and May–October) Spatial: 2012 Assessment reporting region (spatially averaged)	Bureau of Meterology 2013, 'Example of the Bureau's climate variability and change time series: Annual plot', Australian climate variability and change—Time series graphs, www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=aus&season=0112&ave_yr=A Bureau of Meteorology 2013, 'Example of the Bureau's climate variability and change time series: Seasonal plot', Australian climate variability and change—Time series graphs, www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi?graph=rain&area=aus&season=0411&ave_yr=5 Jones, DA, Wang, W, Fawcett, R 2009, 'High-quality spatial climate data-sets for Australia', *Australian Meteorological and Oceanographic Journal,* vol. 58, pp. 233–48.

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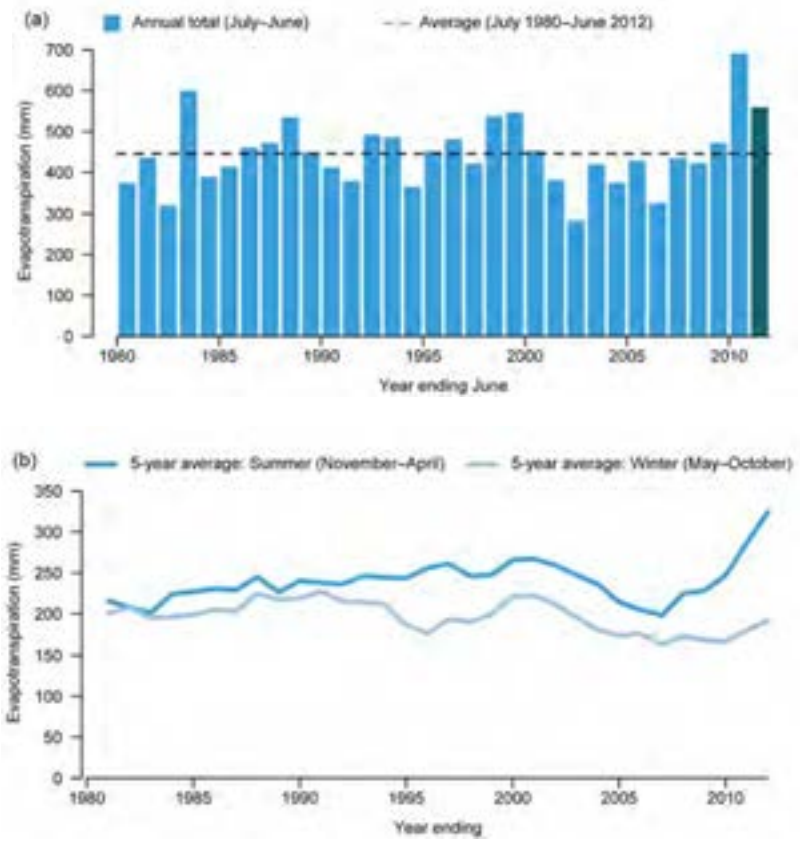

2012 Assessment analysis	Data	Method	Reference / peer review
Regional maps trends in annual landscape water flows over the past 32 years (seasonal) Landscape water flows, s. 4 of the regional chapters	**Description** 5 km x 5 km gridded landscape water flow data. Trend analysis applied to annual totals for the past 32 years (1980–2012). **Source** Bureau (National Climate Centre) and AWRA-L 2.0	**Description** Linear regression trend calculated for annual totals at each 5 km x 5 km grid cell over the last 32 years (July 1980–June 2012). Slope of linear regression line (mm/year) reflects the strength and direction of potential trends. The significance test (t-test) for the slopes of the regression lines at 5% (strongly significant) and 10% (weakly significant) was calculated. **Resolution of output** Temporal: annual Spatial: 5 km x 5 km grid for each 2012 Assessment reporting region	Bureau of Meterology 2013, '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, Robson, AJ 2004, 'Change detection in hydrological records — a review of the methodology', *Hydrological Sciences Journal/Journal des Sciences Hydrologiques*, vol. 49, no. 1, pp. 7-19

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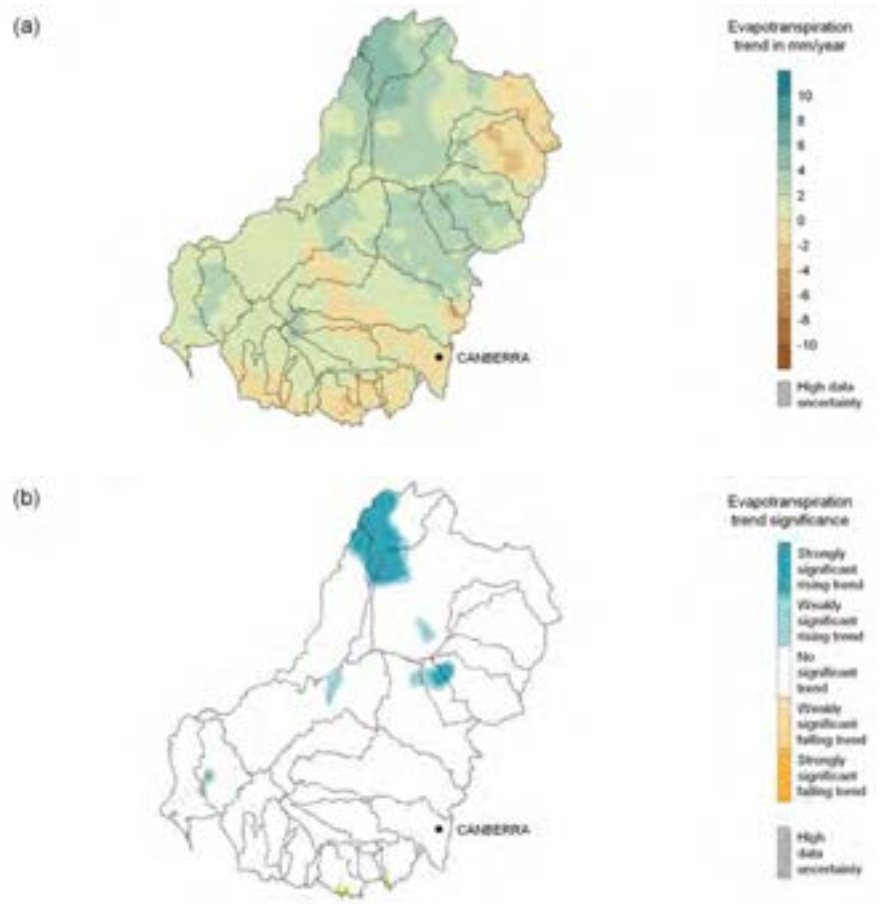

2012 Assessment analysis	Data	Method	Reference / peer review
Site-based seasonal streamflow anomaly analyses Regional water resources assessments and surface water and groundwater, s. 5 of some regional chapters	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational selected streamflow gauges with records available for at least the past 32 years (July 1980–June 2012). **Source** Bureau	**Description** Annual discharge and decile ranking of annual discharge for the reporting year (July 2011–June 2012) compared to long-term (July 1980–June 2012) annual time series. Decile ranking of summer discharge for the reporting year (November 2011– April 2012) compared to long-term (November 1980– April 2012) seasonal time series. **Resolution of output** Temporal: annual / summer season (November–April) Spatial: sites within relevant 2012 Assessment reporting region	Marsh, T, Sanderson, F 2009, *UK Hydrological Review 2008*, NERC/ Centre for Ecology and Hydrology, United Kingdom, www.ceh.ac.uk/data/nrfa/nhmp/annual_review/pdf/Hydrological_Review_2008.pdf

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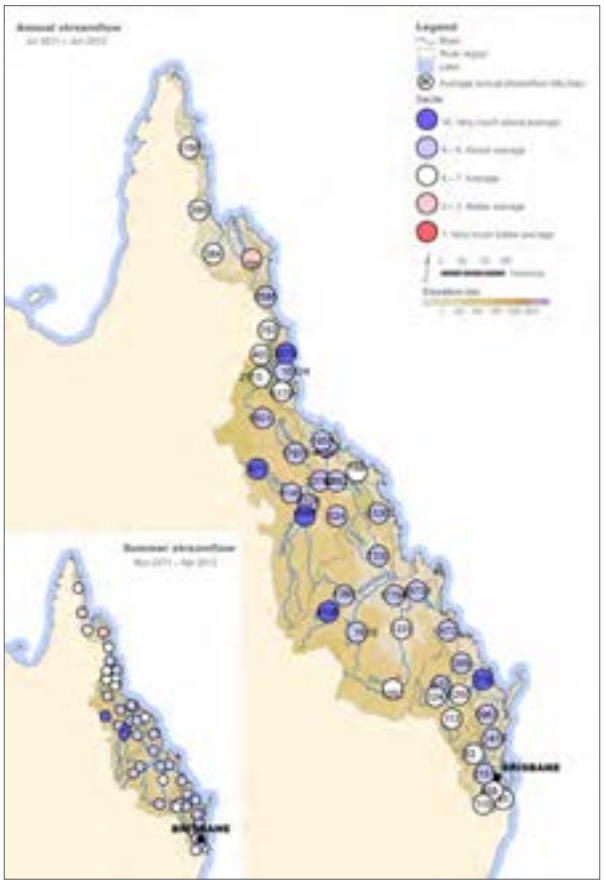
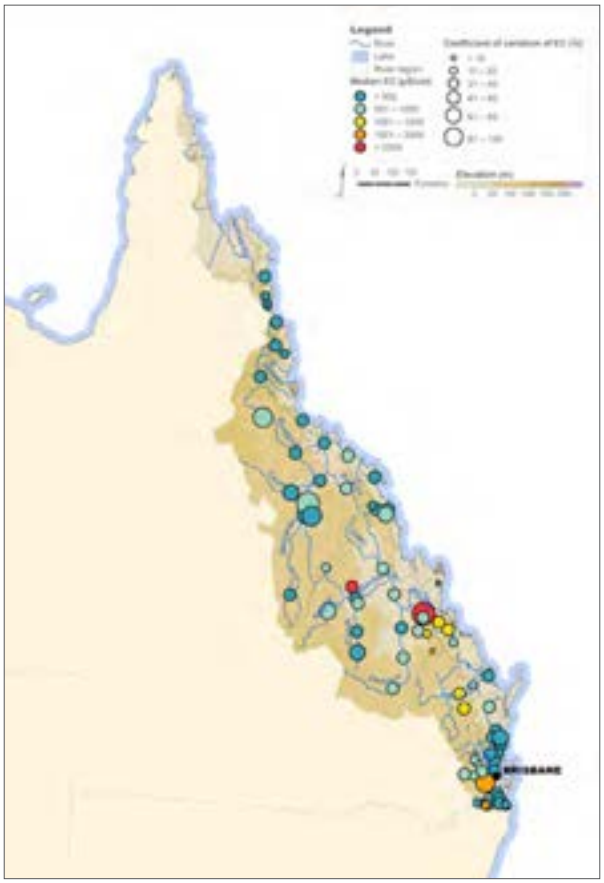


2012 Assessment analysis	Data	Method	Reference / peer review
Site-based annual median with variation of streamflow salinity analyses. Surface water and groundwater, s. 5 of some regional chapters	**Description** Measured electrical conductivity of streamflow (µS/cm at 25 °C). Data collated for currently operational selected streamflow salinity gauges with records available for at least the past five years (July 2007 –June 2012). **Source** Bureau	**Description** Median of annual streamflow salinity for the reporting year (July 2011–June 2012) are coloured-coded relative to the classification of electrical conductivity (EC) i.e., < 500, 501–1000, 1001–1500, 1501–2000 and > 2000. Coefficients of variation (standard deviation divided by the mean) of annual streamflow EC for the reporting year are different sizes relative to the CV of EC ranges i.e., < 10, 11–20, 21–40, 41–60, 61–80 and 81–100. **Resolution of output** Temporal: annual Spatial: sites within relevant 2012 Assessment reporting region.	Standard analysis and presentation of hydrological information

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Decile rankings of daily streamflow Inflows to wetlands, s. 5 of some regional chapters	**Description** Daily streamflow since 1980 **Source** Bureau	**Description** Data ranked in their respective decile categories and given in colours of occurrence **Resolution of output** Temporal: daily	Koehler, R 2004, *Raster Based Analysis and Visualization of Hydrologic Time Series*, Ph.D. dissertation, University of Arizona, USA, p. 189 Strandhagen, E, Marcus, WA, Meacham, JE 2006. 'Views of the rivers: representing streamflow of the greater Yellowstone ecosystem', *Cartographic Perspectives*, no. 55, Fall 2006

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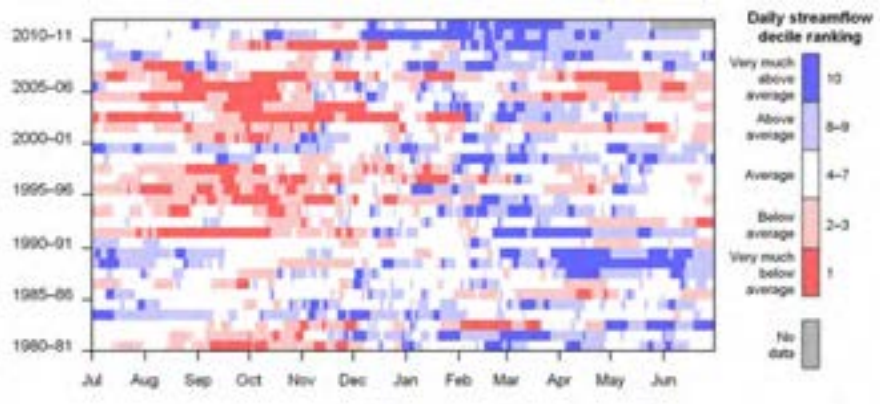
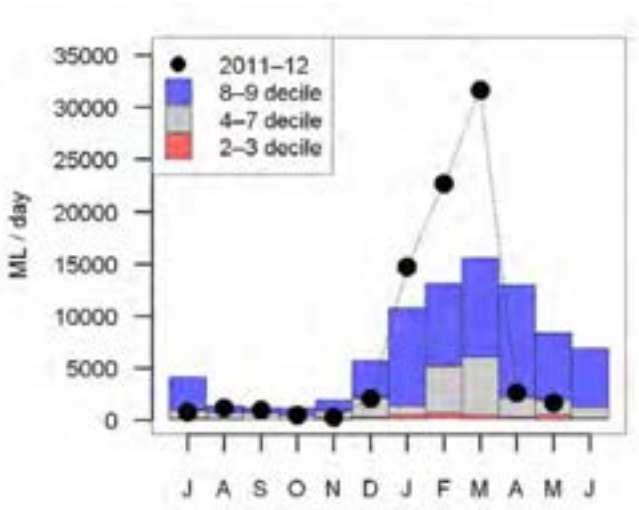


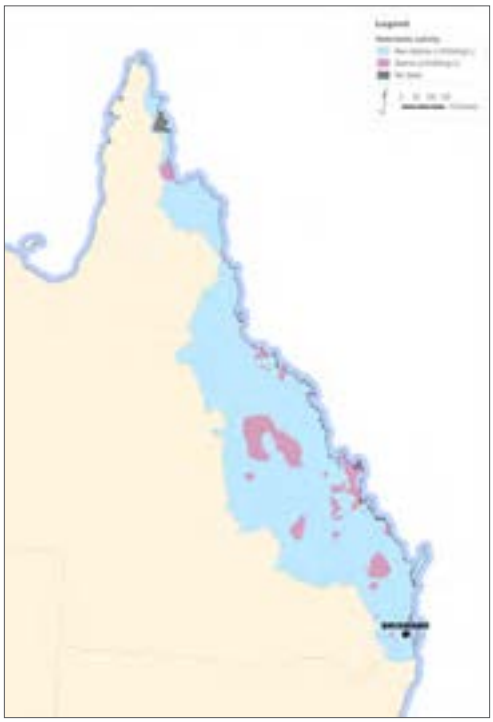
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based time series of monthly flows into wetlands and into selected storages (urban / irrigation) Surface water and groundwater, s. 5 of some regional chapters Water for cities and towns, s. 6 of some regional chapters Water for agriculture, s. 7 of some regional chapters	**Description** Measured streamflow discharge (ML/day). Data collated for currently operational selected streamflow gauges with records available for at least the past 32 years (July 1980–June 2012). **Source** Bureau	**Description** Graphical presentation of measured monthly streamflow for 2011–12 plotted against derived monthly percentile classes (10–30, 30–70 and 70–90). Percentiles calculated from 32-year (July 1980– June 2012) record. **Resolution of output** Temporal: monthly Spatial: sites within relevant 2012 Assessment reporting region	Standard graphical presentation of hydrological information

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Regional map of groundwater salinity class Regional water resources assessments and surface water and groundwater, s. 5 of all regional chapters	**Description** Salinity class of water table aquifer based on electrical conductivity of ground water. Data collated for bores less than 40 m deep for the past 22 years (July 1990–June 2012). **Source** Bureau (Groundwater database)	**Description** Interpolated salinity map using Inverse Distance Weighting, calculated from average electrical conductivity measurements in bores over the 22-year period (July 1990–June 2012) presented in classes of less than 3000 mg/L (fresh) and more than 3000 mg/L (saline). The bores were all less than 40 m deep. 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 of output** Temporal: long -term average (22 years) Spatial: sites within relevant 2012 Assessment reporting region	Peer reviewed by senior hydrogeologist from Queensland Government Department of Natural Resources and Mines Department of Primary Industry 2011, *Victoria's groundwater resource*, Victorian Resources Online

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Regional map and site-based time-series of groundwater level status Regional water resources assessments / Surface water and groundwater (s. 3.5)	**Description** Trends in groundwater levels for major aquifers for the past five years (2007–2012). Selected bore hydrographs reporting groundwater levels fluctuations for the entire period of records **Source** Bureau (Groundwater database)	**Description** Linear trend (negative, stable, positive) in groundwater is calculated based on a 0.1 m/yr change as the criteria. The period of calculation is the last 5 years. This is represented at a 5- or 20-km grid resolution as: decreasing, stable, increasing, and variable based on a 60% majority of the bores in each grid square (at minimum data from three bores). Graphical presentation of variations and changes in groundwater level for selected bores over the 22-year period (July 1990–June 2012) **Resolution of output** Temporal: 5-year trend (2007–2012) for the maps and length of records for hydrographs) Spatial: sites within relevant 2012 Assessment reporting region	Murray–Darling Basin Commission 2004, *Groundwater status: 1990–2000 summary report*, MDB, Commission, Canberra. Murray–Darling Basin Commission (2008), *Groundwater status: 2000–2005 technical report*, MDB Commission, Canberra. Department of Primary Industry 2011, *Victoria's groundwater resource*, Victorian Resources Online Department of Environment and Primary Industries 2013, Ground water levels www.water.vic.gov.au/monitoring/monthly/groundwater_levels#groundwatermaps

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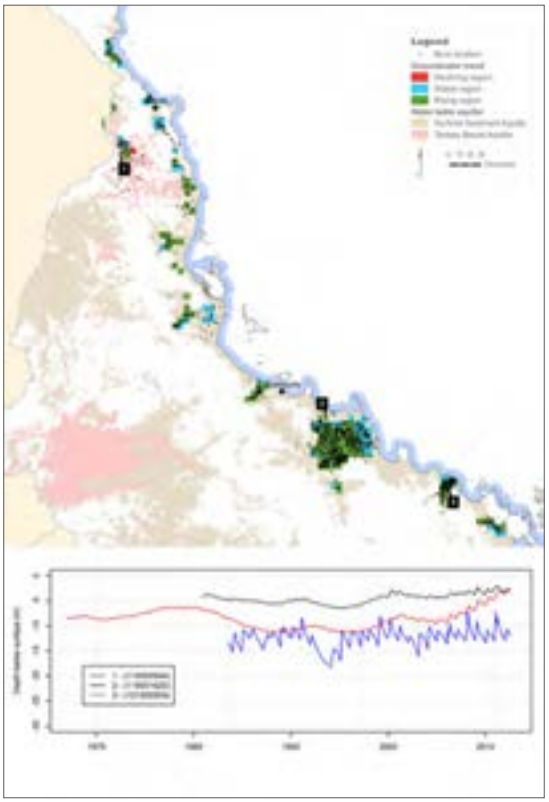
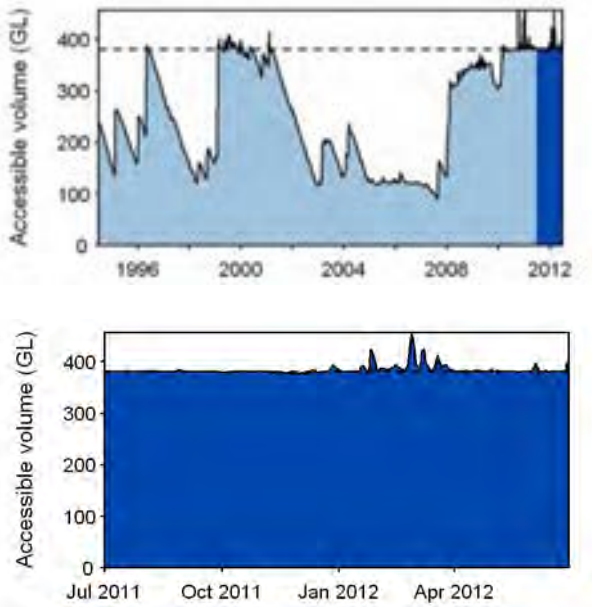


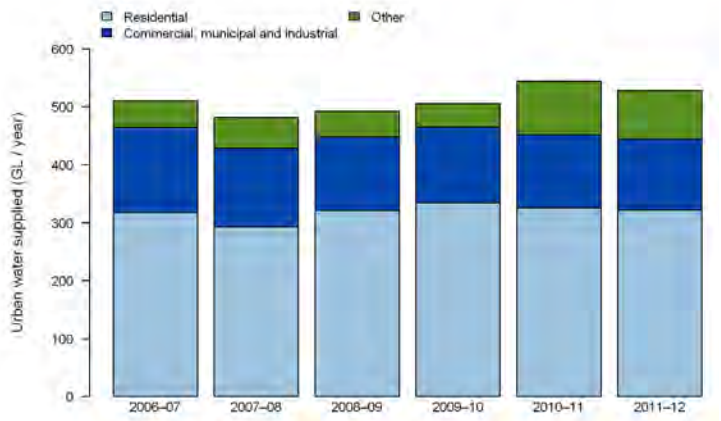
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based time-series of changes in surface water storage (urban / irrigation) Regional water resources assessments and Water for cities and towns, s. 6 of some regional chapters Regional water resources assessments and Water for agriculture, s. 7 of some regional chapters	**Description** Volume of water held in a major storage. **Source** Bureau's Australian Water Resources Information System (AWRIS)	**Description** Graphical presentation of observed long-term and reporting year storage data (2011–12). Graphical axes represent data as both storage level and per cent full (per cent of maximum capacity). **Resolution of output** Temporal: daily Spatial: sites within relevant 2012 Assessment reporting region	Standard presentation of water storage information water.bom.gov.au/waterstorage/awris www.bom.gov.au/water/about/publications/document/factsheet_waterstorage.pdf

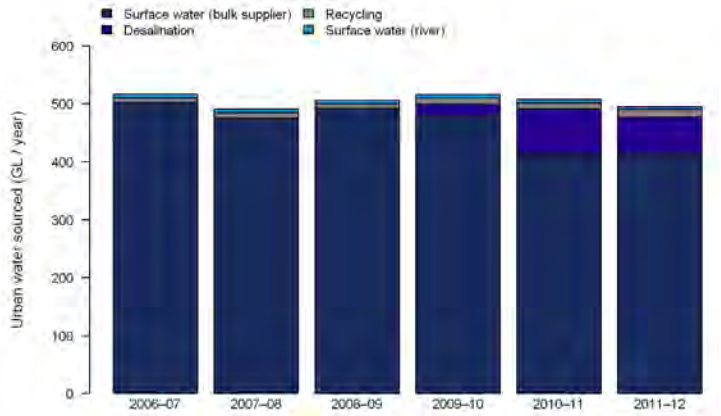
Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Time-series of annual urban water supply by source Water for cities and towns, s. 6 of most regional chapters	**Description** Information about urban water management. **Source** National Performance Report 2009–10: Urban water utilities, archive, archive.nwc.gov.au/library/topic/npr/npr-2009-10-urban	**Description** Plot of total annual water sourced from surface water, groundwater, recycled and desalination water for urban consumption. **Resolution of output** Temporal: annual (July–June) Spatial: urban water supply area within relevant 2012 Assessment reporting region	Standard graphical presentation of hydrological information

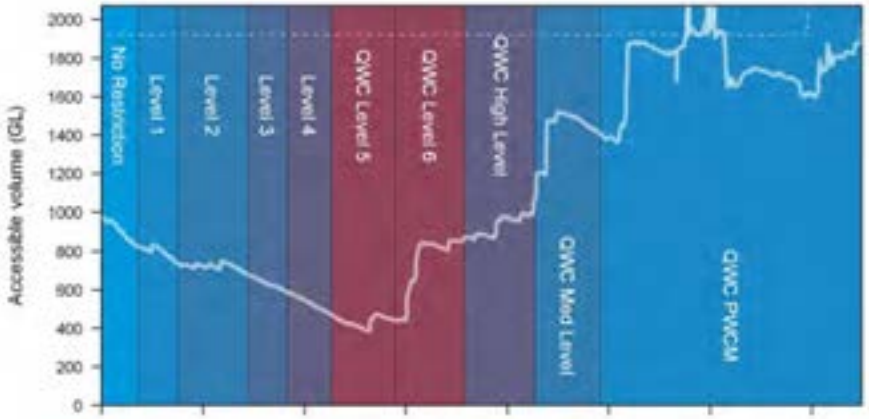
Example figures





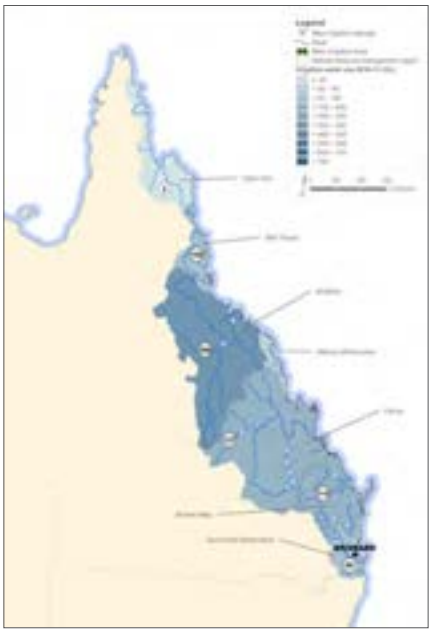
2012 Assessment analysis	Data	Method	Reference / peer review
Changes in urban water restrictions over time Regional water resources assessments and Water for cities and towns, s. 6 of some regional chapters	**Description** Water use restriction announcements indicating level, commencement and termination dates, a description of water restriction levels and where they apply. **Source** Bureau's water information database	**Description** Graphical representation of water restriction levels over time plotted against a relevant measure of water availability, that is, water storage. Only applied where restrictions may be defined relative to a defined storage level or other resource availability variable. **Resolution of output** Temporal: variable—dependent on announcements of changes to restriction levels Spatial: water supply area within relevant 2012 Assessment reporting region	Standard graphical presentation of hydrological information

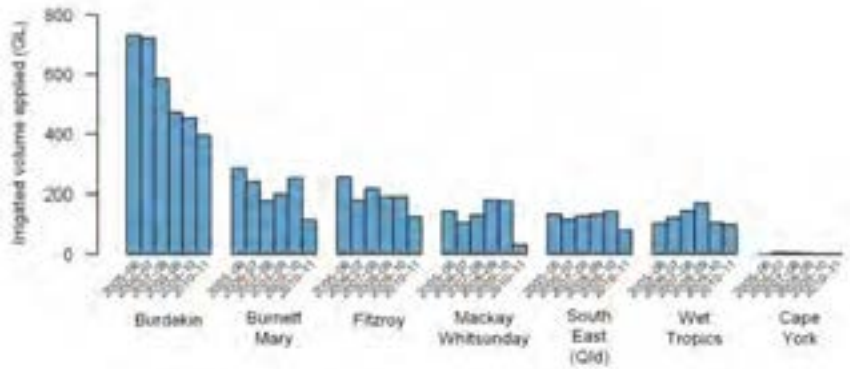
Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Patterns in annual irrigation water use Water for agriculture, s. 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 an NRM level for the four years between 2005–06 and 2010–11. Data for the 2011–12 year were not available at the time of publication. **Source** Australian Bureau of Statistics	**Description** Mapped and graphical representation of annual irrigation water use for each natural resource management region within the reporting region. **Resolution of output** Temporal: annual Spatial: natural resource management regions within relevant 2012 Assessment reporting region	Australian Bureau of Statistics (ABS) 2012, *Water Use on Australian Farms 2010–11*, ABS, Canberra, www.abs.gov.au/ausstats/abs@.nsf/mf/4618.0

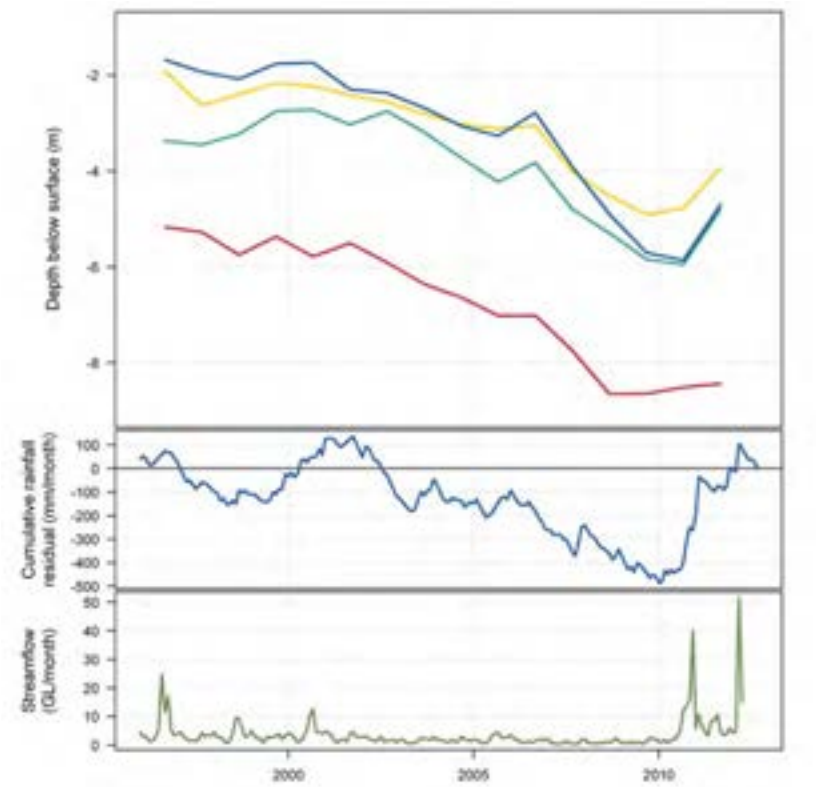
Example figures





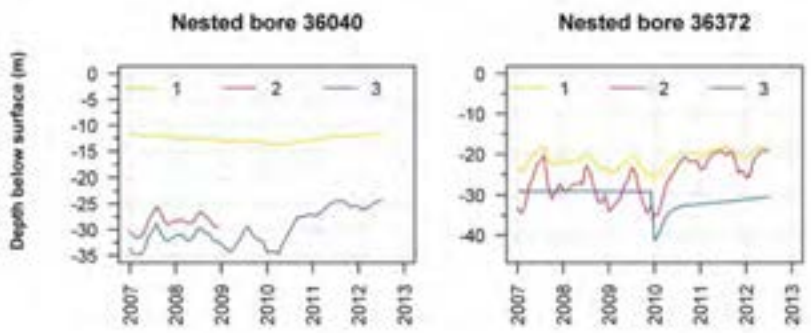
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based time-series of variations in shallow groundwater levels, residual rainfall, streamflow and reservoir level Regional water resources assessments and Water for agriculture, s. 7 of some regional chapters	**Description** Groundwater level of a bore (relative to datum) and measured streamflow discharge (GL/month) and reservoir monthly level (m). Data collated for currently operational monitoring bores for the past 22 years (July 1990–June 2012). **Source** Bureau's water information database	**Description** Graphical presentation of the relationship between monthly variations in shallow groundwater levels (m), local residual rainfall (mm/month), measured streamflow (GL/month) and monthly reservoir levels (m). The rainfall residual mass curve is based on the following equation. 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 of output** Temporal: monthly Spatial: sites within relevant 2012 Assessment reporting region	Murray–Darling Basin Commission 2008, *Groundwater Status Report 2000–2005*, Technical Report, ed. Murray–Darling Basin Commission, Canberra. Southern Rural Water 2012, *Gippsland Groundwater Atlas*, Southern Rural Water www.srw.com.au/Page/Page.asp?Page_Id=689&h=-1

Example figures



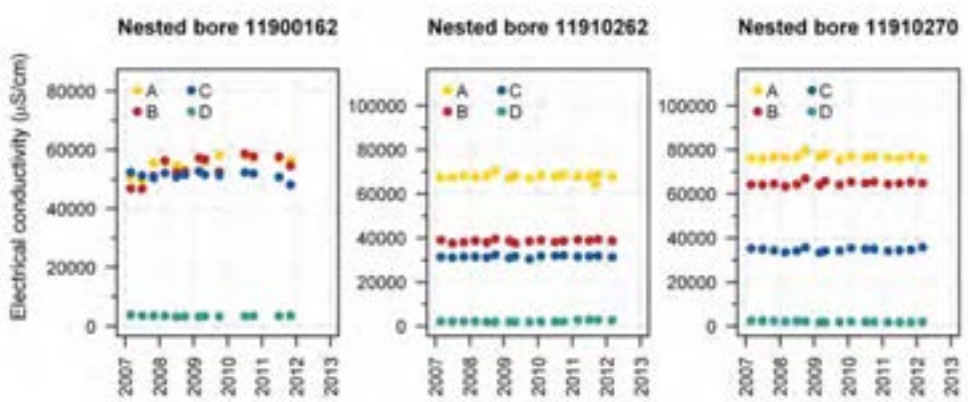
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based time-series of variations in groundwater levels at nested sites Regional water resources assessments and Water for agriculture, s. 7 of some regional chapters	**Description** Groundwater level of a bore (relative to datum) Data collated for currently operational monitoring bores for the past five years (July 2007–June 2012). **Source** Bureau (Groundwater database)	**Description** Graphical presentation of the relationship between variations in shallow groundwater levels (m) for bores screened in different aquifers at the same location **Resolution of output** Temporal: groundwater—sub-annual depending on the frequency of observation from 2007–12 Spatial: selected nested bores	Standard analysis and presentation of groundwater level information

Example figures



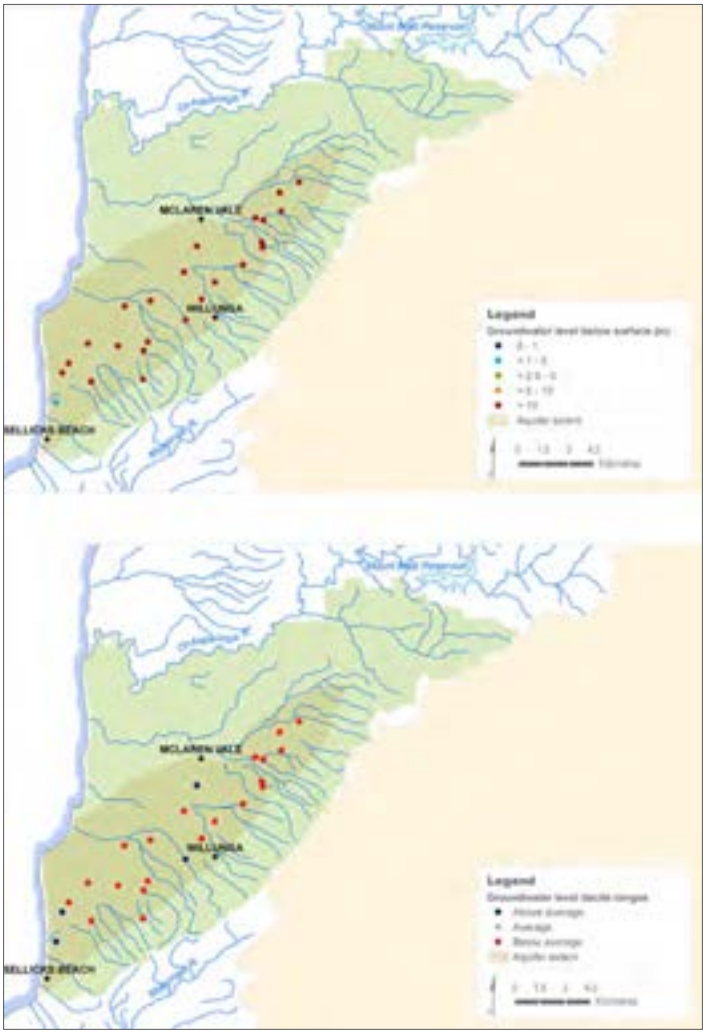
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based time-series of variations in groundwater salinity at nested sites Regional water resources assessments and Water for agriculture, s. 7 of some regional chapters	**Description** Groundwater salinity of a bore as electrical conductivity. Data collated for currently operational monitoring bores for the past five years (July 2007–June 2012). **Source** Bureau (Groundwater database)	**Description** Graphical presentation of the relationship between variations in shallow groundwater salinity as electrical conductivity (µS/cm) for bores screened in different aquifers at the same location **Resolution of output** Temporal: groundwater: sub-annual depending on the frequency of observation from 2007–2012 Spatial: selected nested bores	Standard analysis and presentation of groundwater salinity information

Example figures



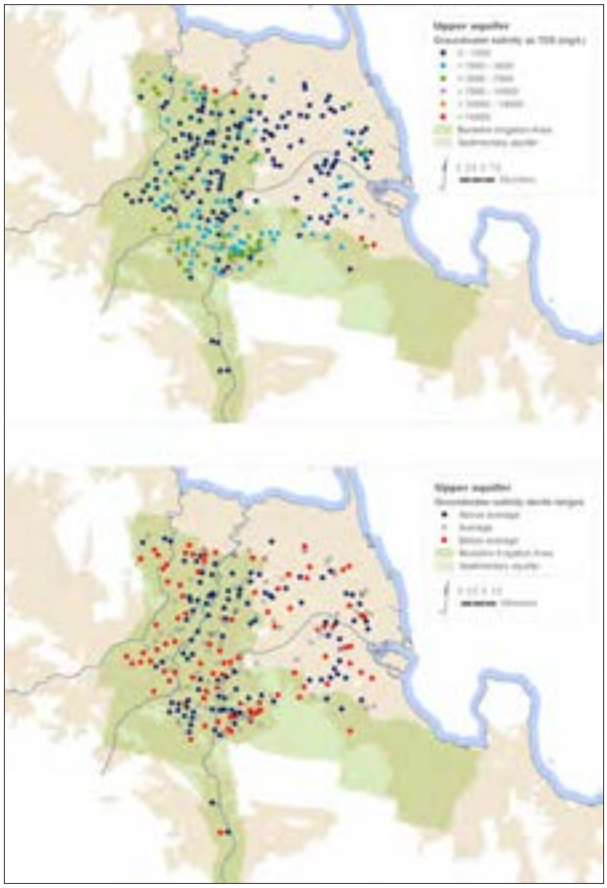
2012 Assessment analysis	Data	Method	Reference / peer review
Site-based analysis of groundwater depth Regional water resources assessments and Water for agriculture, s. 7 of some of the regional chapters	**Description** Groundwater level of a bore (relative to datum). Data collated for currently operational monitoring bores for the past 20 years (July 1990–June 2012). **Source** Bureau (Groundwater database)	**Description** Standard map presentation of calculated median depth to groundwater (m) for the reporting year (July 2011–June 2012). Decile ranking of median depth to groundwater (m) for the reporting year (July 2011–June 2012) compared to long-term (July 1980–June 2012) levels. **Resolution of output** Temporal: annual (median level and decile rank) Spatial: sites within relevant 2012 Assessment reporting region	Peer review from groundwater expert within the Bureau

Example figures



2012 Assessment analysis	Data	Method	Reference / peer review
Site-based analysis of groundwater salinity Regional water resources assessments and Water for agriculture, s. 7 of some regional chapters	**Description** Groundwater salinity of a bore based on electrical conductivity of ground water and reported as total dissolved solids (TDS) (mg/L). Data collated for currently operational monitoring bores for the past 22 years (July 1990–June 2012). **Source** Bureau (Groundwater database)	**Description** Standard map presentation of calculated median groundwater salinity to (mg/L) for the reporting year (July 2011–June 2012). Empirical equation (below) used to convert units of electrical conductivity (EC) (µS/cm) to TDS (mg/L). TDS (mg/L) = EC(µS/cm at 25 °C) x 0.6 Decile ranking of median groundwater salinity (m) for the reporting year (July 2011–June 2012) compared to long-term (July 1990–June 2012) levels. **Resolution of output** Temporal: annual (median level and decile rank) Spatial: sites within relevant 2012 Assessment reporting region	Peer review from groundwater expert within the Bureau

Example figures



5 Data sources and analyses

This section gives background information on data sources, selection procedures and the methods applied to produce the figures in the 2012 Assessment. The data available for download from the website is also discussed.

5.1 Data sources and selection procedures

A number of different selection procedures were employed to identify suitable data for the 2012 Assessment. Sources included the Australian Water Resources Information System (AWRIS) (Bureau 2011a), the related web pages and direct contact with data custodians. To the extent that data was available, careful consideration was given to maintain consistency in presenting information across various study regions. The procedures adopted for each data type are discussed below.

5.1.1 Estimated flows – high data uncertainty 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 datasets for the calculation of potential and actual evapotranspiration. These are maximum and minimum temperature, humidity and incoming solar radiation.

As the analysis and interpretation of the model results are based on the model runs for a 101-year period (July 1911– June 2012), an understanding of the reliability and quality of model input data is necessary. This is particularly important for rainfall data that exhibit high levels of spatial variability.

Jones et al. (2009) investigated the reliability of the interpolated rainfall surfaces to identify areas of poor quality data following the expansion of the rain-gauge network between 1990 and 2006. They reported interpolation failures are generated as a result of sparse gauge networks that are particularly prominent in the central and western deserts of Australia. Their analysis produced surfaces of rainfall interpolation reliability ranging from 100% unreliable (data show consistent interpolation failure) to zero per cent unreliable, where data are reliable throughout the record as defined by the interpolation technique used in their work.

In the 2012 Assessment, the areas that were more than 20% unreliable (or less than 80% reliable) were identified in the maps of the landscape water balance modelling results. The majority of these areas, which are shown in Figure 6, are located in the central west portions of the continent where the amount of precipitation is minimal and thus they are hydrologically less active compared to the rest of the landscape.

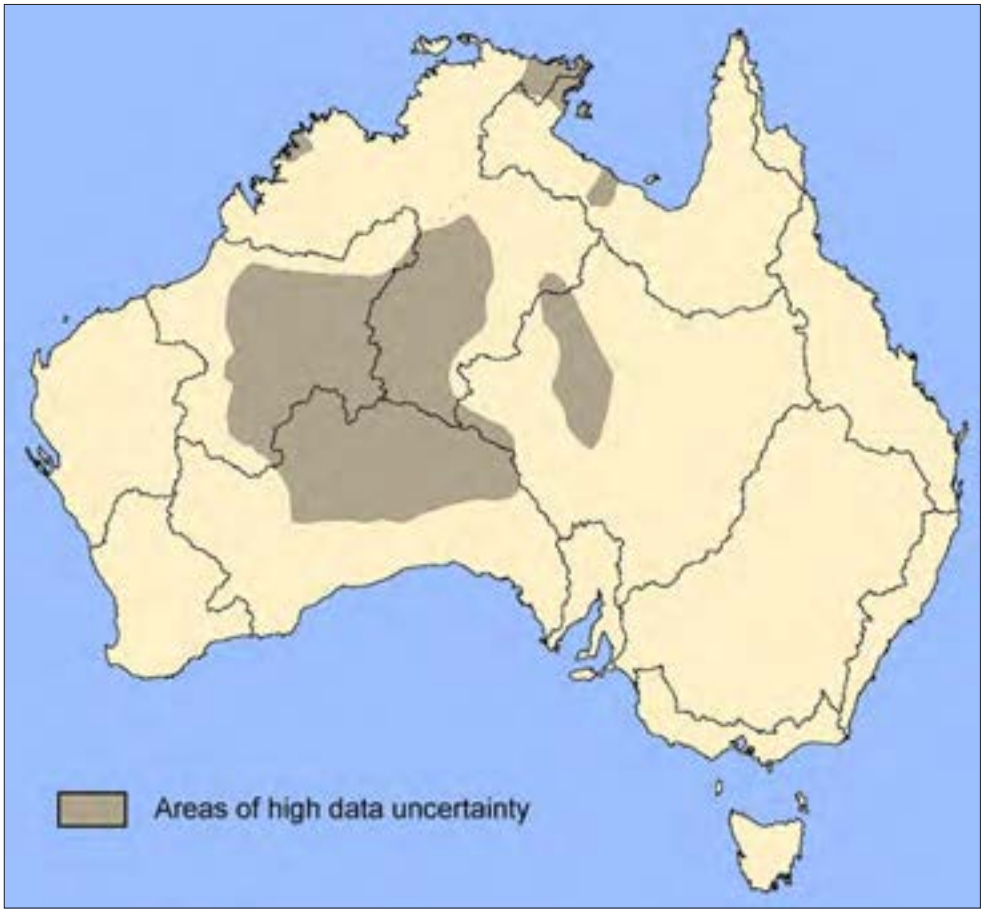


Figure 6 Map of high data uncertain areas which were included in the 2012 Assessment landscape water balance modelling but were highlighted in the maps generated from the modelling results

5.1.2 Streamflow and salinity gauge selection

Gauges were selected for all relevant river basins to represent the lower reaches of each basin (that is, 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 data for selected gauges are provided in the data files accompanying the report chapters.

Gauges were selected which:

- were in on-going operation in 2011–12 year;
- possessed greater than or equal to 30 years of data record; and
- have data records available within the Bureau's data archives.

Stream salinity gauges were selected in terms of availability and quality of data for river basins, creeks and tributaries to represent the region. A number of factors have been taken into consideration for the site selection of streamflow salinity analysis.

These include whether:

- gauges are in ongoing operation and have a history of at least five years to allow statistical analysis;
- sites located where the water in the river is mixed and away from the direct influence of point source pollution such as drains and outlets;
- records are of good quality data (that is, there are limited data gaps and an appropriate measurement frequency); and
- data records are available within the Bureau's data archives.

Summaries of all streamflow and salinity gauges are provided in the data section. The following table provides the standard values of electrical conductivity for different purposes of use (ANZECC and ARMCANZ 200b).

Table 1 Standard value of electrical conductivity (ANZECC/ARMCANZ 2000b)

Purpose	Typical value of EC (µS/cm)
Irrigation water—very low salinity rating *	<650
Irrigation water—low salinity rating*	650–1,300
Irrigation water—medium salinity rating*	1,300–2,900
Irrigation water—high salinity rating*	2,900–5,200
Irrigation water—extremely high salinity rating*	>5,500
Drinking water—cattle	<6,000
Drinking water—sheep	<7,500
Drinking water—human	800

*This is a general guide, as the impact of saline irrigation water on crops varies greatly due to the wide range of crop tolerances to salinity, irrigation method, soil properties and growth stage of the plant.

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. These included the outliers and erroneous data and where long gaps existed in the data. It was recognised that some distinct patterns were caused by human actions (for example, construction of new weirs/dams or deviation of river beds) and therefore not all unusual patterns were the result of data errors.

5.1.3 Flood classification sites

Sites for the flood classification maps were selected from the Bureau's Australian Integrated Forecast System database. The selection was based on the condition that a quantitative flood forecast classification is present (these sites usually correspond with populated centres and better quality data). It means that for the chosen sites, river water levels are identified, which relate to a minor, moderate or major flood level. The data was quality checked for data errors and inconsistencies. The maps display a flood class for each site, which represents the highest occurring class during the year.

5.1.4 Selection of water storages in urban and agricultural context

Water storages were selected based on their representation of the total system storage and system behaviour, and upon suitable data availability for 2011–12.

5.1.5 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 New South Wales Office of Water and the Department of 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 the State of New South Wales and within the Murray–Darling Basin were identified based on the Geographical Information System data connected with the Groundwater Status Report 2000–05 (Murray–Darling Basin Commission 2008a). The aquifer information for bores located within the States of Queensland and South Australia were obtained either from the relevant databases or reports.

5.1.6 Natural Resource Management regions and irrigation water use

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

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 2012 Assessment 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 2012 Assessment regions. The areas used are shown in Figure 7 against a backdrop of the situation in the Australian Water Resources Assessments reporting regions. The Wimmera natural resource management region, for example, spans both the South East Coast (Victoria) and Murray–Darling Basin reporting regions. In this publication, the irrigation water use has been reported where majority of the natural resource management region has been inside the reporting regions and no partitioning was attempted in that regard.

5.2 Data analysis procedures

5.2.1 Guide to landscape flows trend analysis results

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 that is not sufficiently long, but this cannot be interpreted as a demonstration of the absence of change.

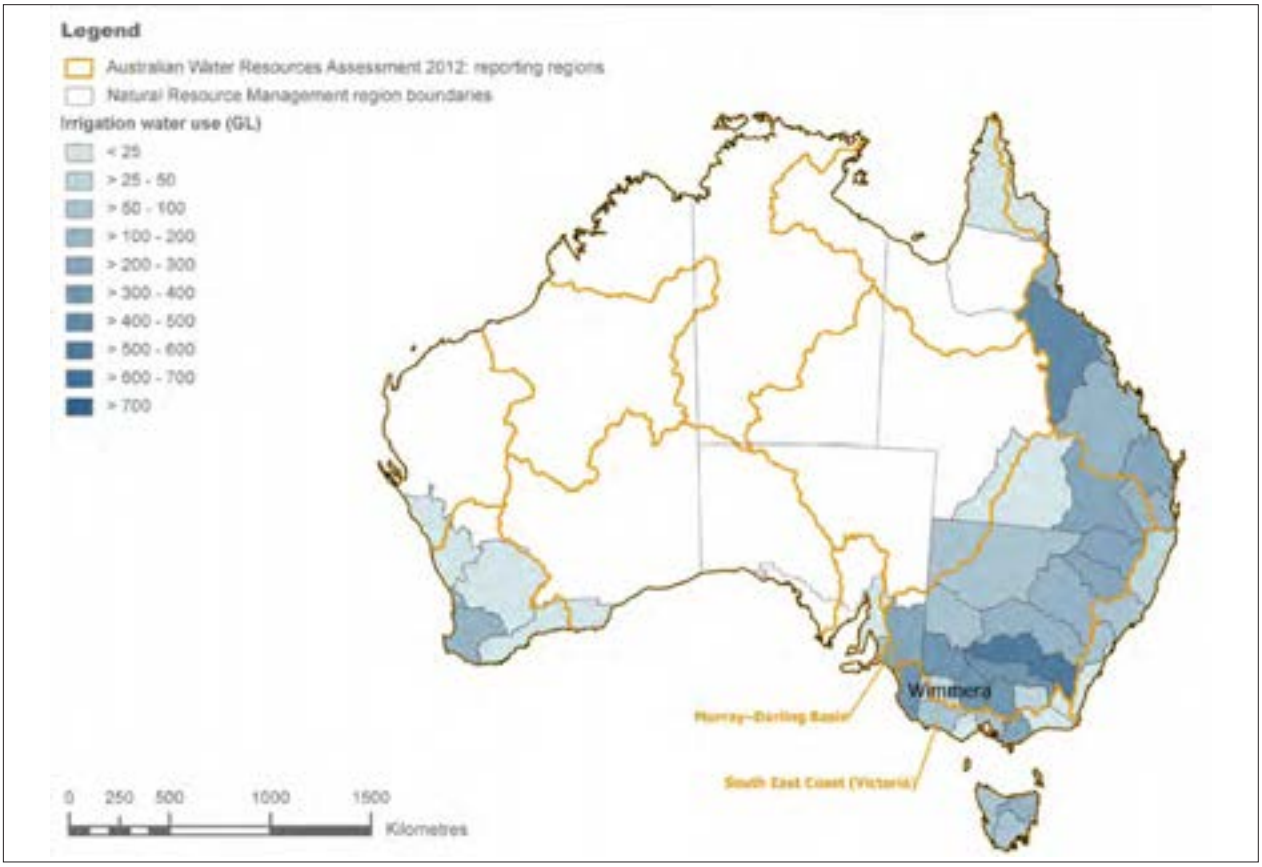


Figure 7 The Australian Water Resources Assessment 2012 reporting region and natural resource management region boundaries

The test statistic for linear regression was used to estimate trends across Australia applying the ordinary least squares estimator to fit a straight line between the points in the time-series. The analysis provides an estimate of whether water flow variables increased or decreased over the defined time period (32 years in the 2012 Assessment) by calculating the gradient of the best-fit regression line.

Data

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

- rainfall;
- modelled evapotranspiration; and
- modelled landscape water yield.

These data represent modelled inputs or outputs associated with the landscape water balance model applied for each 5 x 5 km model grid cell, giving full coverage of Australia.

Linear regression

Linear regression fits a straight line through the set of points in such a way that minimises the sum of square of residuals. The residuals are the differences between the 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.

$$Y = B_0 + B_1 X$$

Where B_0 is a constant, B_1 is the slope (also called the regression coefficient), X is the value of the independent variable (in this case the years), and Y is the value of the dependent variable (annual total landscape water flow variable). The slope coefficient (B_1) was calculated at each grid cell for all three flow variables.

Significance of estimated regression trend

An assessment of the significance of annual trends was also carried out as part of the statistical trend analysis process and the results of the significance tests were included in the regional chapters. The trend analysis was carried out to determine whether these changes are statistically significant. A linear regression t-test was applied to determine whether the slope of the regression line differs significantly from zero. Significance levels of five per cent and ten per cent were chosen for the presentation of results, which are widely used in statistics.

Length of reference period

To identify the impact of the chosen reference period on the trends and their significance, a comparison has been conducted between the period from 1911–2012 (101 years) and from 1980–2012 (32 years). National maps of the calculated linear regression slopes (in mm/year) and statistical significance are presented for rainfall, evapotranspiration and landscape water yield in figures 8-10.

As can be noted from the figures, a clear difference in the magnitude and significance of the trends for the 101-year and 32-year reference periods exists. Where the magnitudes of the trends are larger for the shorter reference period, the actual significance of these trends is less. In short this means that the reliability of the 32-year trend analysis is less than the 101-year trend analysis; however, there are further assumptions and limitations of the linear regression analysis that need to be taken into consideration.

Assumptions and limitations

The trends 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 32 years. In addition, the significance of these trends should be taken to be indicative as a consequence of the nature of the statistical test and the inherent variability, spatially and temporally, of the underlying data.

Some of the relevant assumptions and limitations of the statistical analysis are identified below.

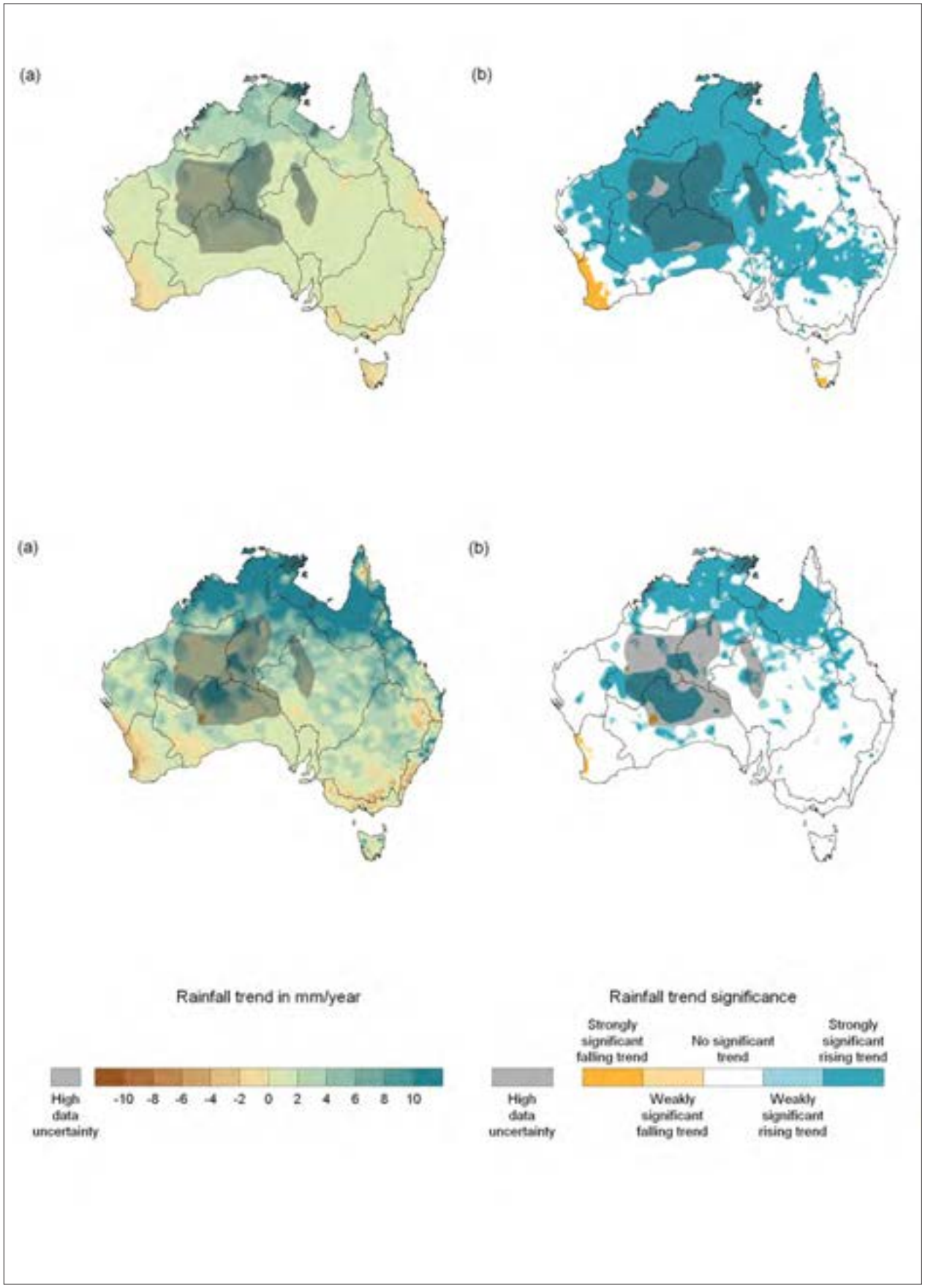


Figure 8 Magnitude and significance of linear regression trends for the period of (a) 1911–2012, and (b) 1980–2012 for rainfall in Australia

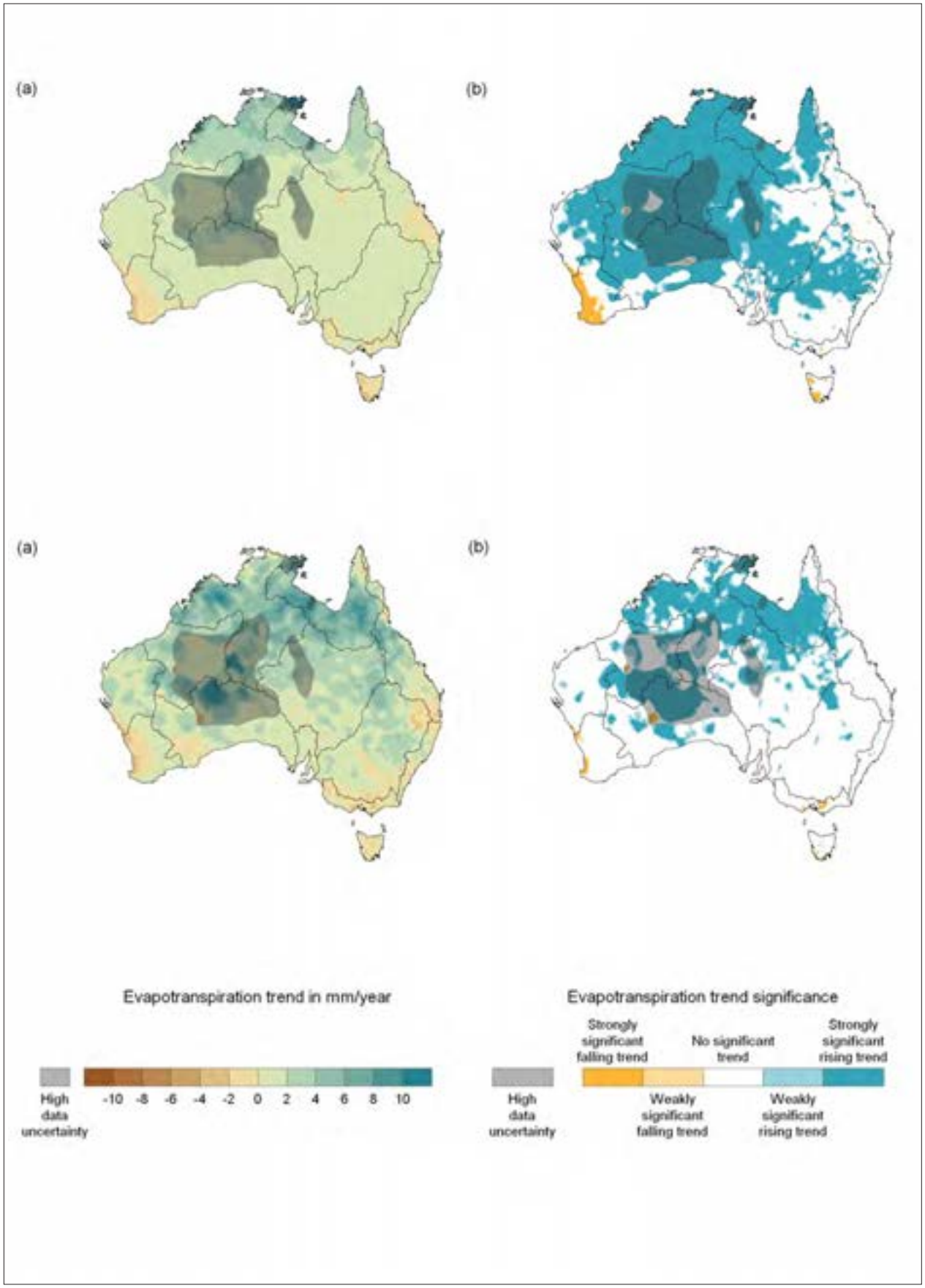


Figure 9 Magnitude and significance of linear regression trends for the period of (a) 1911–2012, and (b) 1980–2012 for evapotranspiration in Australia

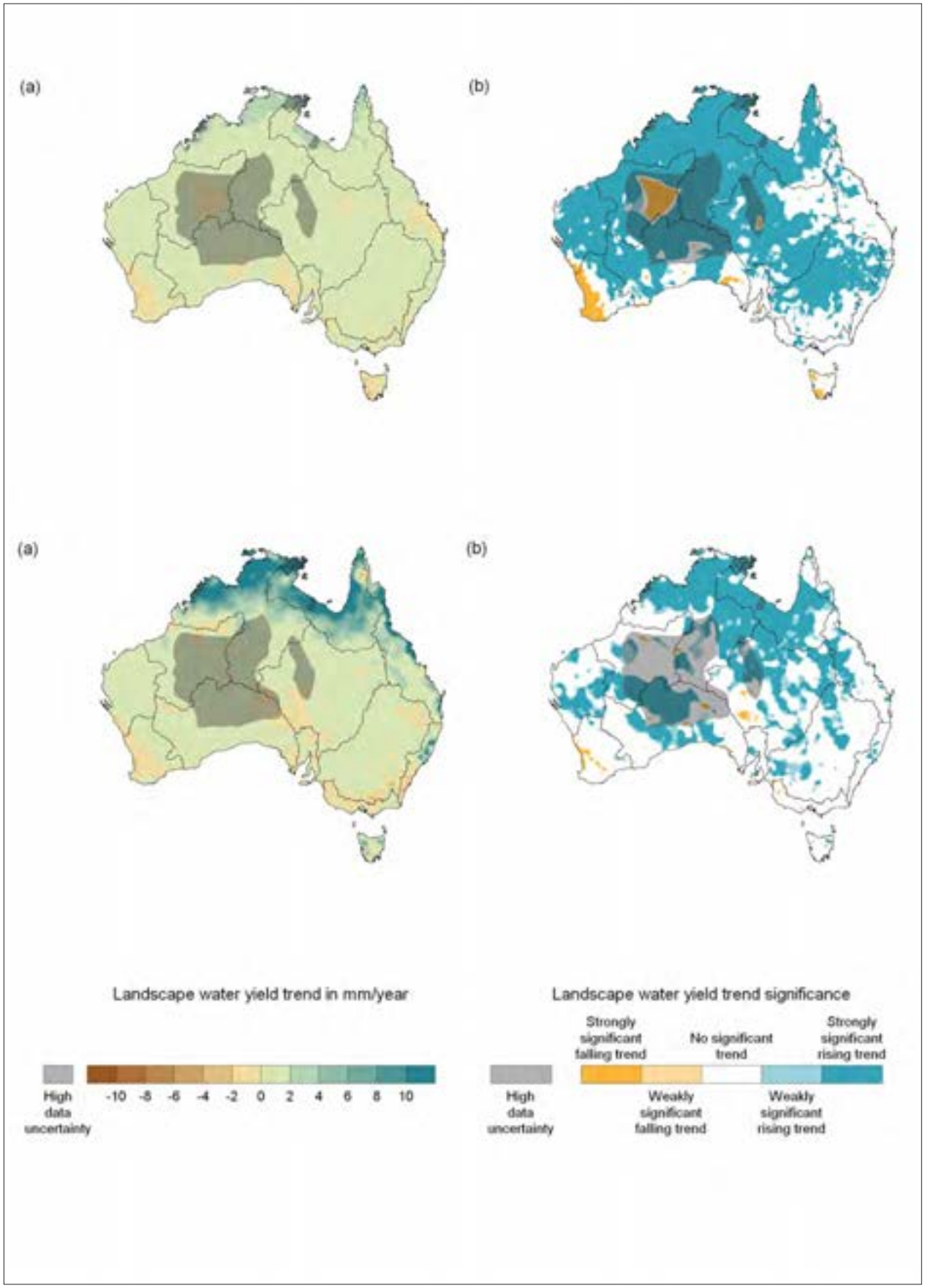


Figure 10 Magnitude and significance of linear regression trends for the period of (a) 1911–2012, and (b) 1980–2012 for landscape water yield in Australia

Assumptions

- Trends in seasonal and annual rainfall, modelled evapotranspiration and landscape water yield are assumed to be linear over the past 32 years.
- The data points are assumed to be independent with no serial correlation, that is, no short-term correlation between samples.
- The measurement and calculation of the data is assumed to be consistent over space and time, that is, the method used for the generation of landscape water flow surfaces is the same over the 32-year period.
- The data are assumed to be normally distributed. Data transformations to compensate for undesirable data properties, that is, 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 linear regression test does not 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 32-year reference period was assumed to be sufficient for the analysis of statistical trends. The analysis of much longer records, that is, up to 101 years, may provide a more statistically robust result, but is mainly diluted by the assumption of homogeneity in the time-series. This is not the case, as over time, the density of the rainfall and temperature stations has changed. Also, the data inputs of solar radiation were only introduced as a measurement for the last 40 years. As a result, the trend assessments in the regional chapters contain the trend map as well as the trend significance map (weak trend = 10% significance, strong trend = 5% significance) to illustrate the magnitude of recent trends (32-years) together with an indicative measure of uncertainty about the statistical significance of the trends.

5.2.2 Guide to surface water storage information

This section provides information relating to the water storage figures presented in the 2012 Assessment. This is general information regarding terminology, understanding storage graphs and data, copyright and data supply and general data processing. 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 11.

- **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% 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 used to report on the capacity of all storages. The sum of this capacity is used to report on storage systems.
- **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.

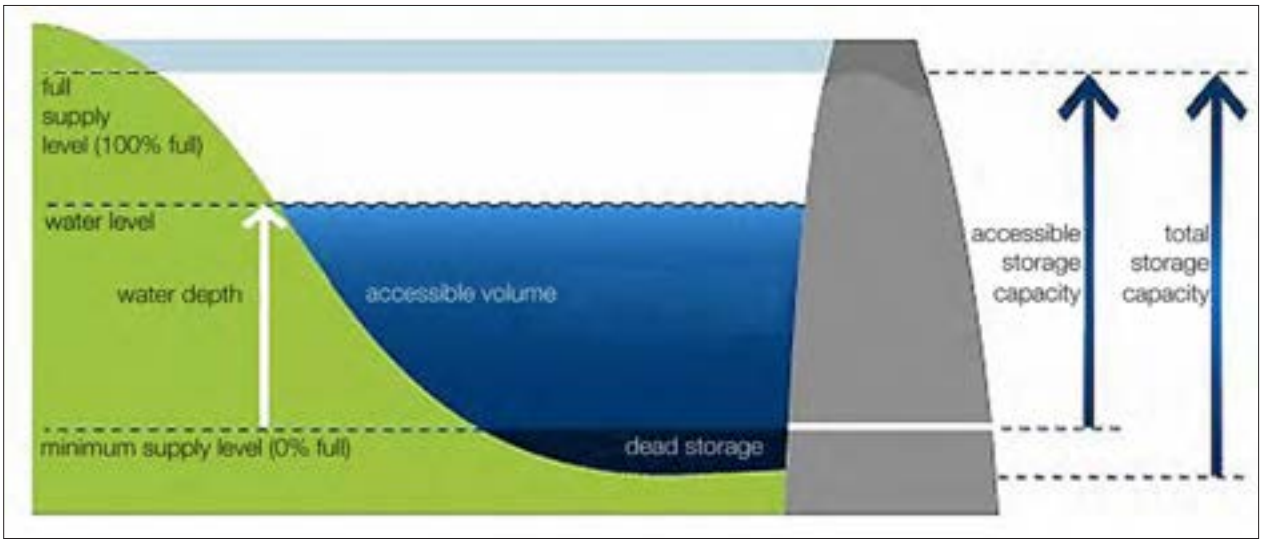


Figure 11 Conceptual representation of a water storage

Storage data graphs in the 2012 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 from one or more storages are unavailable. There are no gaps in the blue shading as data were linearly interpolated over the gaps. See, for example, sources of water supply in the South East Coast (NSW) region.

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

Percentages are calculated based on the accessible capacity of the storage as of 30 June 2012. Therefore, the storage volume in previous years may also exceed 100% 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.

6 Data available with the report

6.5 Introduction

Data files are available for download for most of the figures contained in the report from the Bureau's website: www.bom.gov.au/water/awra/2012/metadata.shtml

Readily available background information (particularly for the maps) is referenced only, as are a few datasets 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.

6.6 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.

6.7 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.

7 Appendix

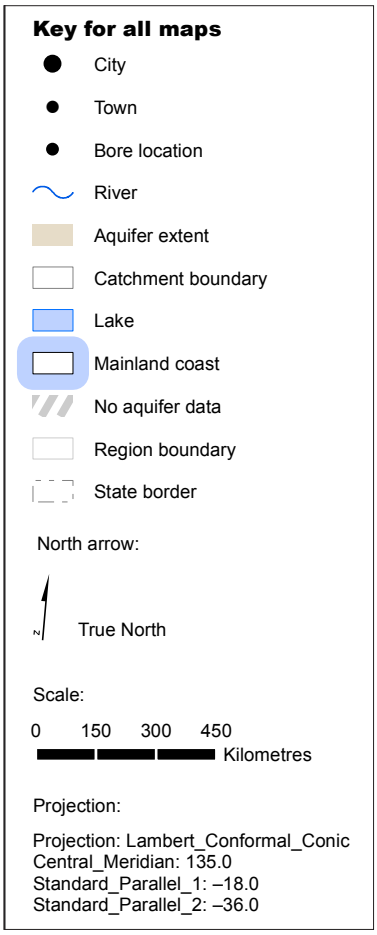
The data sources used in developing the 2012 Assessment maps are listed in the following table.

Type of map	Data source
Overview	**Rivers, catchments:** Bureau of Meteorology www.bom.gov.au/water/geofabric/index.shtml Surface network, hydrology reporting catchments **Cities and towns:** Geoscience Australia www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68695 Habitation: built-up areas, place names, populated places **Roads:** Geoscience Australia www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68695* Transport: Roads **Land use:** Department of Agriculture Fisheries and Forestry http://adl.brs.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml *(*reclassified for forestry and nature conservation)*
Physiographic provinces	CSIRO www.asris.csiro.au/themes/PhysioRegions.html
Elevation	Geoscience Australia www.ga.gov.au/topographic-mapping/digital-elevation-data.html
Slope	Derived from Geoscience Australia www.ga.gov.au/topographic-mapping/digital-elevation-data.html
Soil types**	CSIRO www.asris.csiro.au/index_ie.html *(**map and soil type pie chart)*
Land use***	Department of Agriculture Fisheries and Forestry http://adl.brs.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml (***map and land use type pie chart)
Population density	Australian Bureau of Statistics www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3218.02011?OpenDocument
Rainfall zone	Bureau of Meteorology www.bom.gov.au/climate/environ/other/seas_all.shtml
Rainfall deficit	Rainfall deficit calculated in the GIS ArcMap. Long-term average rainfall minus potential evapotranspiration (1961–1999) **Rainfall** www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp **Arial evapotranspiration:** www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp?maptype=3&period=an#maps
Rivers and catchments	Bureau of Meteorology www.bom.gov.au/water/geofabric/index.shtml Surface network, hydrology reporting catchments

Type of map	Data source
Annual and summer streamflow	See list of data providers at www.bom.gov.au/water/awra/2012/copyright.shtml and also: **State of Victoria** www.vicwaterdata.net/vicwaterdata/data_warehouse_content.aspx?option=4 **State of Tasmania** wrt.tas.gov.au/wist/ui
Electrical conductivity	See list of data providers at: www.bom.gov.au/water/awra/2012/copyright.shtml and also: **State of Victoria** www.vicwaterdata.net/vicwaterdata/data_warehouse_content.aspx?option=4
Flood	Unpublished data produced by the Bureau as described at: www.bom.gov.au/water/floods/index.shtml
Storage systems	**Bureau of Meteorology** www.bom.gov.au/water/geofabric/documentation.shtml **Surface cartography** See list of data providers at: www.bom.gov.au/water/awra/2012/copyright.shtml and also: **State of Tasmania** www.hydro.com.au **State of South Australia** www.environment.sa.gov.au
Wetlands	**Department of Sustainability, Environment, Water, Population and Communities** www.environment.gov.au/water/topics/wetlands/database/index.html
Watertable aquifers	**Bureau of Meteorology** www.bom.gov.au/water/geofabric/index.shtml Groundwater cartography
Salinity	**Bureau of Meteorology** www.bom.gov.au/water/geofabric/index.shtml Groundwater cartography
Groundwater management units	**Bureau of Meteorology** National Groundwater Information System, Groundwater Management Units V2 (unpublished data)
Trends of bore locations	Data as provided to the Bureau through the water regulations **State of New South Wales** New South Wales Office of Water: www.water.nsw.gov.au/ **State of South Australia** Department of Water: www.waterconnect.sa.gov.au/Pages/Home.aspx **State of Victoria** Department of Sustainability and Environment: Groundwater Management System www.vvg.org.au/cb_pages/gms.php **State of Queensland** Department of Natural Resources and Mines www.nrm.qld.gov.au/water
Population range	Australian Bureau of Statistics: www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3218.02011?OpenDocument

Type of map	Data source
Urban supply storage	See list of data providers at: www.bom.gov.au/water/awra/2012/copyright.shtml as well as: **State of Tasmania** www.hydro.com.au **State of South Australia** Urban storage www.environment.sa.gov.au **Geoscience Australia** www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68695 Utility: Pipelines
www	**Brisbane water supply schematic** www.seqwgm.qld.gov.au/seq-water-grid-operations/about-the-water-grid/connected-assets as well as: www.previous.seqwater.com.au/public/news-publications/annual-reports **Sydney water supply schematic:** www.sydneywater.com.au/SW/water-the-environment/how-we-manage-sydney-s-water/water-network/index.htm **Canberra water supply schematic** www.actew.com.au/Water and Sewerage Systems/ACT Water Supply System/ACT Water Supply Map.aspx **Adelaide water supply schematic** www.sawater.com.au/NR/rdonlyres/D929607D-8E12-45F2-9AC9-67698E7446EF/0/ar03comp.pdf%5d **Melbourne water supply schematic** www.melbournewater.com.au www.westernwater.com.au/aboutus/Pages/AboutUs.aspx www.sewl.com.au/Pages/Home.aspx www.yvw.com.au/home www.citywestwater.com.au **Perth water supply schematic** www.water.gov.au/RegionalWaterResourcesAssessments/SpecificGeographicRegion/TabbedReports.aspx?PID=WA_SW_614x
Irrigation areas****	**Department of Agriculture, Fisheries and Forestry:** adl.brs.gov.au/anrdl/metadata_files/pa_luav4g9abl07811a00.xml *(****Reclassified for irrigation areas)*
Average annual water use	**Australian Bureau of Statistics** www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/4618.02010-11?OpenDocument

Type of map	Data source
Irrigation areas with trends in groundwater bores	Data as provided to the Bureau through the regulations **State New of South Wales** New South Wales Office of Water www.water.nsw.gov.au Coleambally irrigation district CICL pdf report C new.colyirr.com.au/?TabId=69 **State of South Australia** Department of Water www.waterconnect.sa.gov.au/Pages/Home.aspx **State of Victoria** Department of Sustainability and Environment: Groundwater Management System www.vvg.org.au/cb_pages/gms.php **State of Queensland** Department of Natural Resources and Mines www.nrm.qld.gov.au/water



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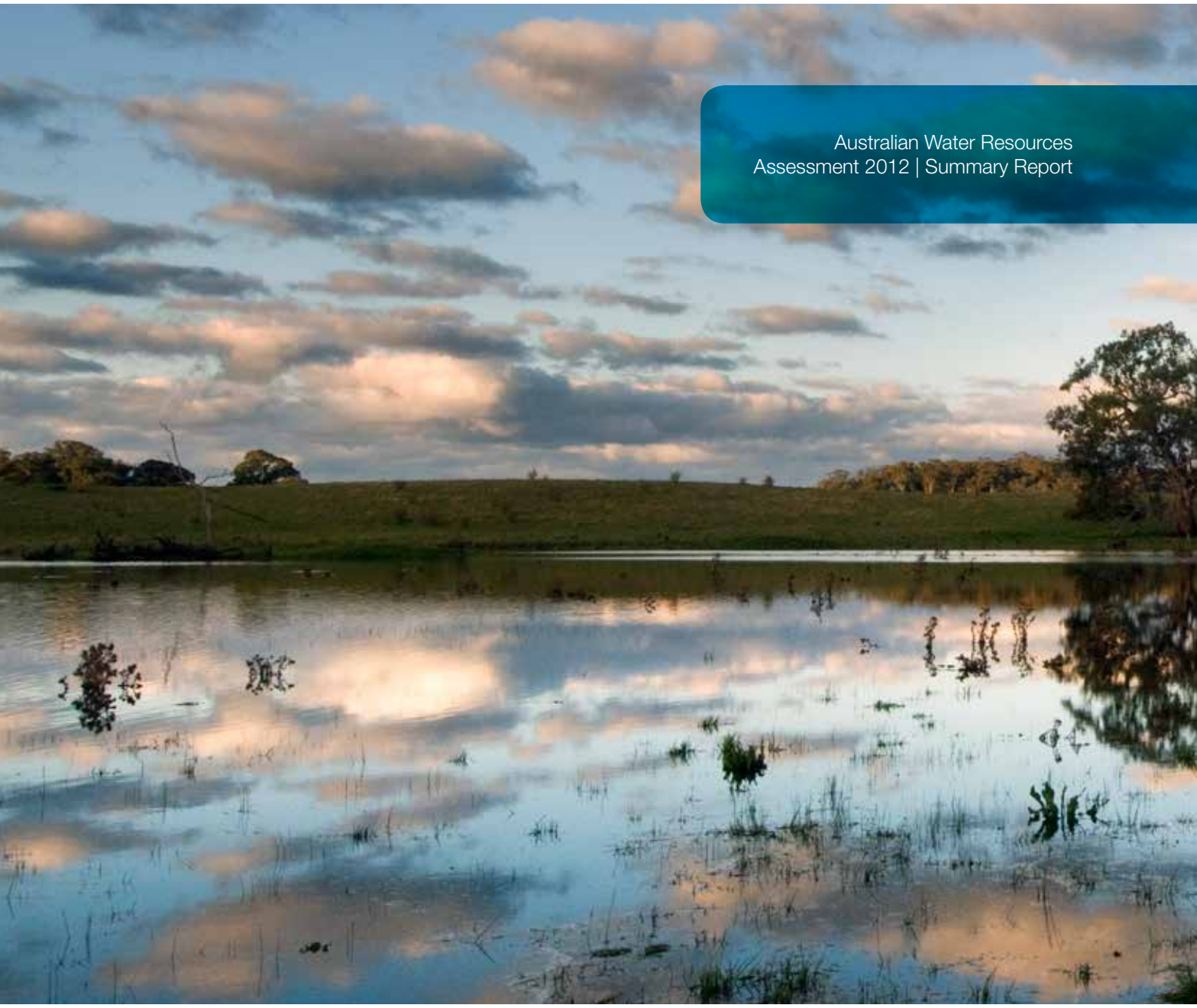

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