Australian Government

BIOREGIONAL ASSESSMENTS

PROVIDING SCIENTIFIC WATER RESOURCE INFORMATION ASSOCIATED WITH COAL SEAM GAS AND LARGE COAL MINES

# Context statement for the Galilee subregion

## Product 1.1 from the Lake Eyre Basin Bioregional Assessment

29 May 2014

A scientific collaboration between the Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia

## The Bioregional Assessment Programme

The Bioregional Assessment Programme is a transparent and accessible programme of baseline assessments that increase the available science for decision making associated with coal seam gas and large coal mines. A bioregional assessment is a scientific analysis of the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of coal seam gas and large coal mining development on water resources. This Programme draws on the best available scientific information and knowledge from many sources, including government, industry and regional communities, to produce bioregional assessments that are independent, scientifically robust, and relevant and meaningful at a regional scale.

The Programme is funded by the Australian Government Department of the Environment. The Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit <www.bioregionalassessments.gov.au>.

## Department of the Environment

The Office of Water Science, within the Australian Government Department of the Environment, is strengthening the regulation of coal seam gas and large coal mining development by ensuring that future decisions are informed by substantially improved science and independent expert advice about the potential water related impacts of those developments. For more information, visit <www.environment.gov.au/coal-seam-gas-mining/>.

## Bureau of Meteorology

The Bureau of Meteorology is Australia's national weather, climate and water agency. Under the *Water Act 2007*, the Bureau is responsible for compiling and disseminating Australia's water information. The Bureau is committed to increasing access to water information to support informed decision making about the management of water resources. For more information, visit <www.bom.gov.au/water/>.

## CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation. For more information, visit <www.csiro.au>.

## Geoscience Australia

Geoscience Australia is Australia's national geoscience agency and exists to apply geoscience to Australia's most important challenges. Geoscience Australia provides geoscientific advice and information to the Australian Government to support current priorities. These include contributing to responsible resource development; cleaner and low emission energy technologies; community safety; and improving marine planning and protection. The outcome of Geoscience Australia's work is an enhanced potential for the Australian community to obtain economic, social and environmental benefits through the application of first class research and information. For more information, visit <www.ga.gov.au>.

**ISBN-PDF 978-1-4863-0257-4, ISBN-Word 978-1-4863-0270-3**

## Citation

Evans T, Tan KP, Magee J, Karim F, Sparrow A, Lewis S, Marshall S, Kellett J and Galinec V (2014) Context statement for the Galilee subregion. Product 1.1 from the Lake Eyre Basin Bioregional Assessment. Department of the Environment, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Authorship is listed in relative order of contribution.

## Copyright

## Disclaimer

## Cover photograph

Artesian Spring Wetland at Doongmabulla Nature Refuge, QLD, 2013.

Credit: Jeremy Drimer, University of Queensland.

Australian Government
Department of the Environment
Bureau of Meteorology
Geoscience Australia

# Contents

# Figures

# Tables

# Contributors to the Technical Programme

The following individuals have contributed to the Technical Programme, the part of the Bioregional Assessment Programme that undertakes bioregional assessments. Discipline Leaders are underlined.

| | |
|---|---|
| First Assistant Secretary | Department of the Environment: Suzy Nethercott-Watson |
| Programme Director | Department of the Environment: Edwina Johnson |
| Technical Programme Director | Bureau of Meteorology: Bronwyn Ray |
| Projects Director | CSIRO: David Post |
| Principal Science Advisor | Department of the Environment: Peter Baker |
| Science Directors | CSIRO: Brent Henderson |
| | Geoscience Australia: Trevor Dhu |
| Programme management | Department of the Environment: Ebony Coote, Anisa Coric, Geraldine Cusack, James Hill, Broni McMaster, Craig Watson |
| | Bureau of Meteorology: Graham Hawke, Louise Minty |
| | CSIRO: Damien Barrett, Carol Couch, Scott Keyworth, Warwick McDonald |
| | Geoscience Australia: Bruce Kilgour, Stuart Minchin |
| Project Leaders | CSIRO: Tim McVicar, David Rassam, Wendy Welsh |
| | Geoscience Australia: Kriton Glenn |
| Assets | Bureau of Meteorology: Brendan Moran |
| | Department of the Environment: Dave Holt, Brad Moore, David Robertson, Jin Wang |
| Bioregional Assessment Information Platform | Bureau of Meteorology: Bronwyn Ray |
| | CSIRO: David Lemon |
| | Geoscience Australia: Brian Cannell, Neal Evans |
| Communications | Department of the Environment: Crystal Bradley, Amanda Cox |
| | Bureau of Meteorology: Mel Martin |
| | CSIRO: Tsuey Cham, Leane Regan |
| | Geoscience Australia: David Beard, Chris Thompson |
| Ecology | CSIRO: Tanya Doody, Brendan Ebner, Alexander Herr, Kate Holland, Craig MacFarlane, Tracey May, Heather McGinness, Patrick Mitchell, Justine Murray, Anthony O'Grady, Chris Pavey, Jodie Pritchard, Nat Raisbeck-Brown, Ashley Sparrow, Georg Wiehl |

| | |
|---|---|
| Geology | CSIRO: Deepak Adhikary, Luke Connell, Emanuelle Frery, Cedric Griffiths, Jane Hodgkinson, Rob Jeffrey, Dane Kasperczyk, James Kear, Laurent Langhi, Zhejun Pan, Kaydy Pinetown, Matthias Raiber, Hayley Rohead-O'Brien, Regina Sander, Peter Schaubs, Garth Warren, Paul Wilkes, Andrew Wilkins, Yanhua Zhang<br>Geoscience Australia: Jon Clarke, Tim Evans, Steven Lewis, John Magee, Bruce Radke, Martin Smith |
| Geography | Bureau of Meteorology: Natasha Herron |
| Geographic information systems | CSIRO: Phil Davies, Malcolm Hodgen, Steve Marvanek<br>Geoscience Australia: Joseph Bell, Luke Caruana, Katherine Fontaine, Gerard Stewart |
| Groundwater modelling | CSIRO: Olga Barron, Russell Crosbie, Tao Cui, Warrick Dawes, Lei Gao, Sreekanth Janardhanan, Catherine Moore, Luk Peeters, Praveen Kumar Rachakonda, Wolfgang Schmid, Chris Turnadge, Binzhong Zhou |
| Hydrogeology | CSIRO: Konrad Miotlinski<br>Geoscience Australia: Hashim Carey, Rebecca Cassel, Scott Cook, Laura Gow, Wenping Jiang, Jim Kellett, Sarah Marshall, Rebecca Norman, Jessica Northey, Tim Ransley, Gerhard Schoning, Emily Slatter, Martin Smith, Peter Somerville, Ross Spulak, Baskaran Sundaram, KokPiang Tan, Luke Wallace, Gabrielle Yates |
| Information management | Department of the Environment: David Holt<br>Bureau of Meteorology: Jill McNamara, Brendan Moran<br>CSIRO: Nick Car, Andrew Freebairn, Mick Hartcher, Geoff Hodgson, Brad Lane, Trevor Pickett, Tim Smith, Matt Stenson, Garry Swan<br>Geoscience Australia: Luke Caruana, Penny Kilgour, Matti Peljo, Gail Ransom |
| Products | CSIRO: Maryam Ahmad, Daniel Aramini, Heinz Buettikofer, Will Francis, Simon Gallant, Karin Hosking, Frances Marston, Becky Schmidt, Sally Tetreault-Campbell, Catherine Ticehurst, Audrey Wallbrink<br>Geoscience Australia: Veronika Galinec, Penny Kilgour, Daniel Rawson |
| Risk and uncertainty | CSIRO: Simon Barry, Susan Cuddy, Jeffery Dambacher, Jess Ford, Keith Hayes, Geoff Hosack, Dan Pagendam, Carmel Pollino |
| Support | Bureau of Meteorology: John Timermanis, Sarah van Rooyen<br>CSIRO: Rose Geus<br>Geoscience Australia: Michael Langdon, Tenai Luttrell |
| Surface water hydrology | CSIRO: Santosh Aryal, Jie Chen, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Tom Van Niel, Neil Viney, Bill Wang, Ang Yang, Yongqiang Zhang<br>Geoscience Australia: Wenping Jiang |

# Acknowledgements

This technical product was reviewed by several groups:

- Discipline Leaders: Steven Lewis (geology, Geoscience Australia), Tim Ransley (hydrogeology, Geoscience Australia), Jim Kellett (hydrogeology, Geoscience Australia), Neil Viney (surface water hydrology, CSIRO), Alexander Herr (ecology, CSIRO), Becky Schmidt (products, CSIRO)
- Senior Science Leaders: David Post (Projects Director, CSIRO), Brent Henderson (CSIRO), Trevor Dhu (Geoscience Australia)
- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment), this group comprises officials from the New South Wales, Queensland, South Australian and Victorian governments.

# Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the Federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments.

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made publicly available, providing the opportunity for all other interested parties, including community, industry and government regulators, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential direct, indirect and cumulative impacts of CSG and coal mining development on water resources.

The IESC has been involved in the development of *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the BA methodology; Barrett et al., 2013) and has endorsed it. The BA methodology specifies how BAs should be undertaken. Broadly, a BA comprises five components of activity, as illustrated in Figure 1. Each BA will be different, due in part to regional differences, but also in response to the availability of data, information and fit-for-purpose models. Where differences occur, these are recorded, judgments exercised on what can be achieved, and an explicit record is made of the confidence in the scientific advice produced from the BA.

## The Bioregional Assessment Programme

The Bioregional Assessment Programme is a collaboration between the Department of the Environment, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical experts, such as from state governments or universities, are also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions:

- the Galilee, Cooper, Pedirka and Arckaringa subregions, within the Lake Eyre Basin bioregion
- the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions, within the Northern Inland Catchments bioregion
- the Clarence-Moreton bioregion
- the Hunter and Gloucester subregions, within the Northern Sydney Basin bioregion
- the Hawkesbury-Nepean, Georges River and Wollongong Coast subregions, within the Southern Sydney Basin bioregion
- the Gippsland Basin bioregion.

Technical products (described in the following section) will progressively be delivered throughout the Programme.

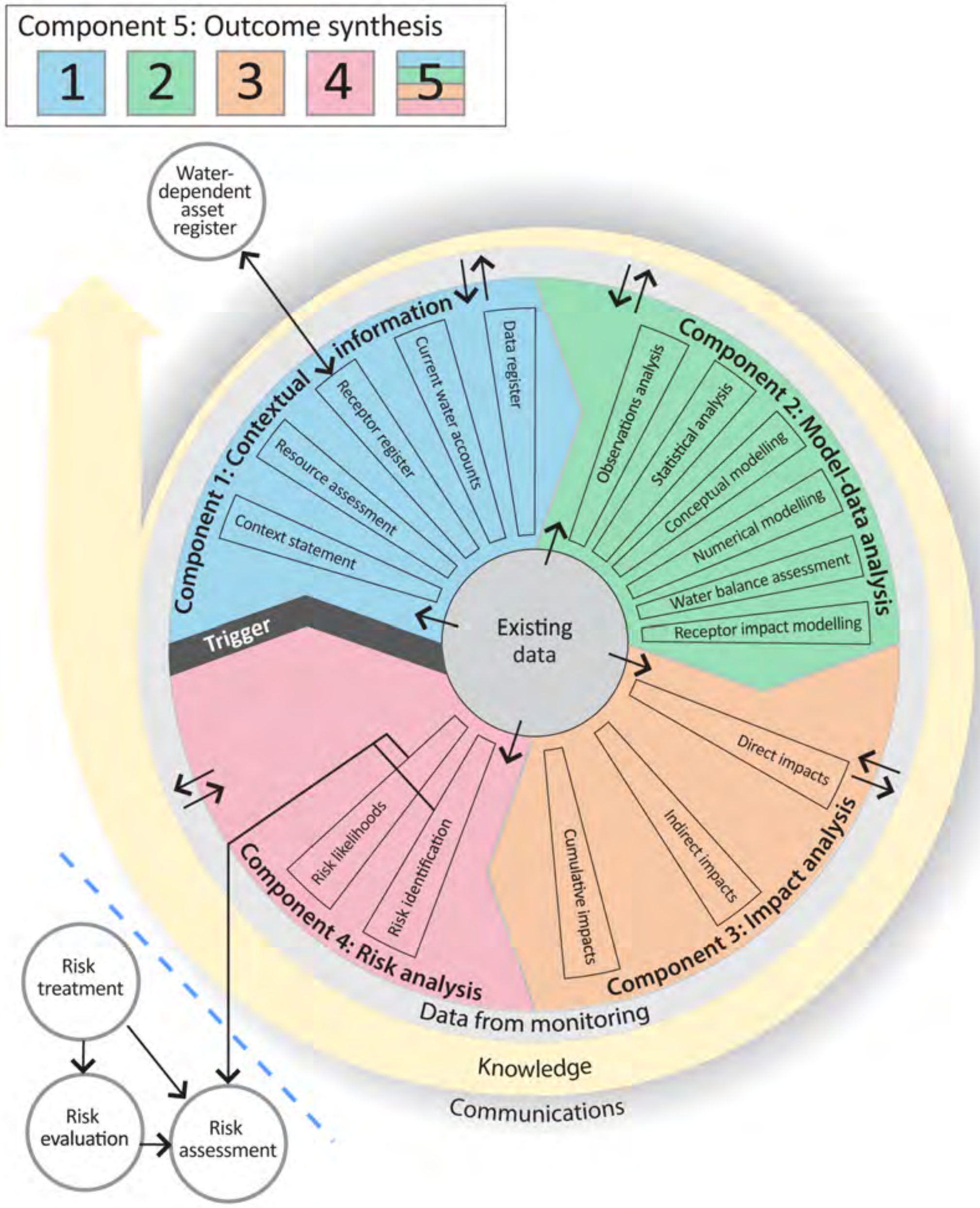


**Figure 1 Schematic diagram of the bioregional assessment methodology**

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The risk identification and risk likelihood components are conducted within a bioregional assessment and may contribute to risk evaluation, risk assessment and risk treatment undertaken externally.

## Technical products

The outputs of the BAs include a suite of technical products variously presenting information about the ecology, hydrology, hydrogeology and geology of a bioregion and the potential direct, indirect and cumulative impacts of CSG and coal mining developments on water resources, both above and below ground. Importantly, these technical products are publicly available, providing the opportunity for all interested parties, including community, industry and government regulators, to draw from a single set of accessible information when considering CSG and large coal mining developments in a particular area.

The information included in the technical products is specified the BA methodology. Figure 2 shows the information flow within a BA. Table 1 lists the content provided in the technical products, with cross-references to the part of the BA methodology that specifies it. The red ovals in both Figure 2 and Table 1 indicate the information presented for this technical product.

This technical product is delivered as a report (PDF). Additional material is also provided, as specified by the BA methodology:

- all unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- the workflow, comprising a record of all decision points along the pathway towards completion of the BA, gaps in data and modelling capability, and provenance of data.

The PDF of this technical product, and the additional material, are available online at the following website: <www.bioregionalassessments.gov.au>.

## About this technical product

The following notes are relevant only for this technical product.

- The context statement is a collation of existing information and thus in some cases figures are reproduced from other sources. These figures were not redrawn for consistency (with respect to 'look and feel' as well as content), and the resolution and quality reflects that found in the source.
- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and two standard parallels of –18.0° and –36.0°.

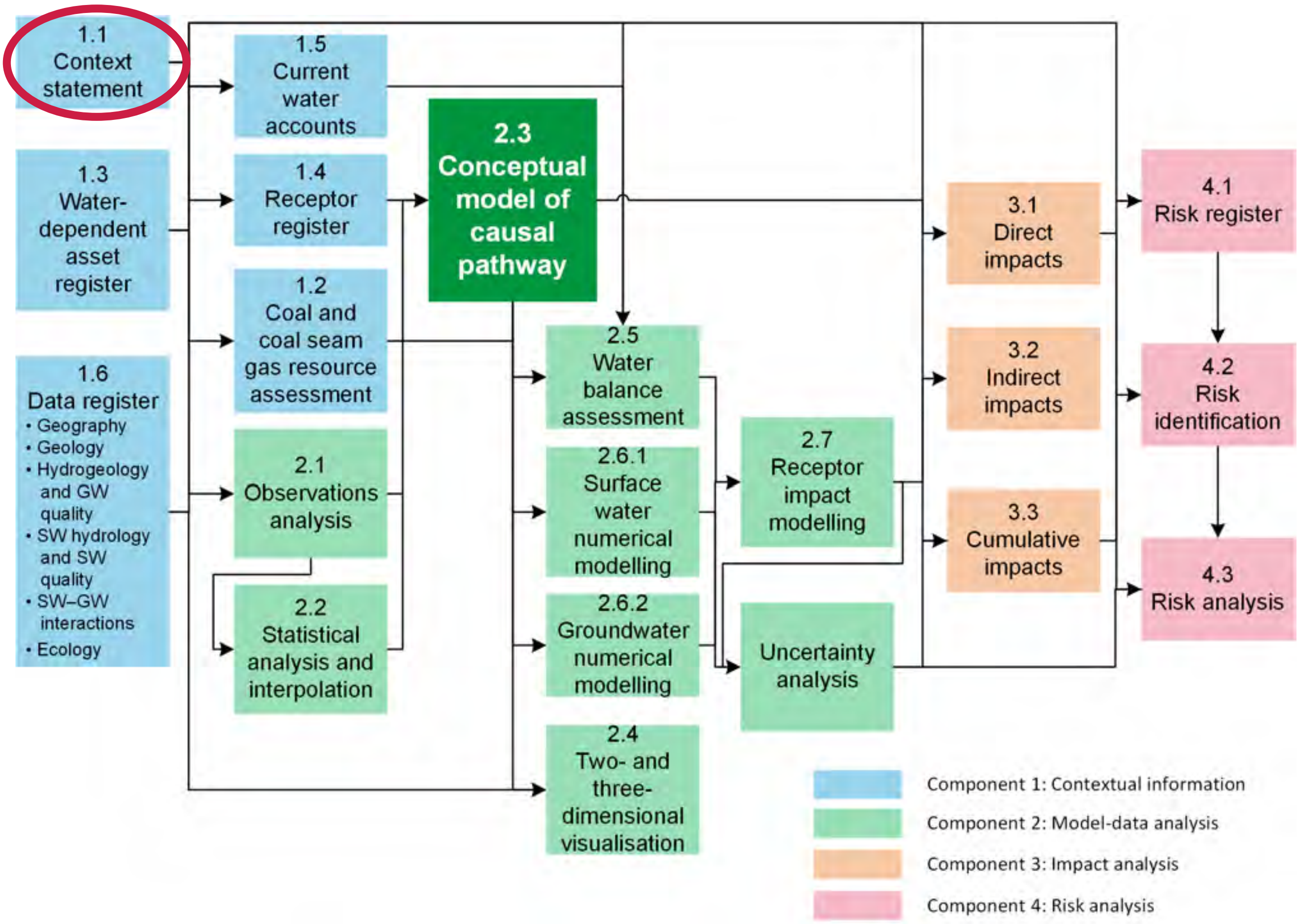


**Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment**

The red oval indicates the information covered in this report.

**Table 1 Technical reports being delivered as part of the Lake Eyre Basin Bioregional Assessment**

For each subregion in the Lake Eyre Basin Bioregional Assessment, technical products will be delivered as data, summaries and reports (PDFs) as indicated by ■ in the last column of Table 1. Merged cells indicate that more than one product is reported in one report. The red oval indicates the information covered in this report. A suite of other technical and communication products – such as maps, registers and factsheets – will also be developed through the bioregional assessments.

| | Product code | Information | Section in the BA methodology[a] | Report |
|---|---|---|---|---|
| **Component 1: Contextual information for the Galilee subregion** | 1.1 | Context statement | 2.5.1.1, 3.2 | ■ |
| | 1.2 | Coal and coal seam gas resource assessment | 2.5.1.2, 3.3 | ■ |
| | 1.3 | Description of the water-dependent asset register | 2.5.1.3, 3.4 | ■ |
| | 1.4 | Description of the receptor register | 2.5.1.4, 3.5 | ■ |
| | 1.5 | Current water accounts and water quality | 2.5.1.5 | [b] |
| | 1.6 | Description of the data register | 2.5.1.6 | ■ |
| **Component 2: Model-data analysis for the Galilee subregion** | 2.1 | Observations analysis | 2.5.2.1 | |
| | 2.2 | Statistical analysis and interpolation | 2.5.2.2 | |
| | 2.3 | Conceptual modelling | 2.5.2.3, 4.3 | ■ |
| | 2.4 | Two- and three-dimensional representations | 4.2 | [c] |
| | 2.5 | Water balance assessment | 2.5.2.4 | ■[b] |
| | 2.6.1 | Surface water numerical modelling | 4.4 | ■ |
| | 2.6.2 | Groundwater numerical modelling | 4.4 | ■ |
| | 2.7 | Receptor impact modelling | 2.5.2.6, 4.5 | ■ |
| **Component 3: Impact analysis for the Galilee subregion** | 3.1 | Direct impacts | 5.2.1 | ■ |
| | 3.2 | Indirect impacts | 5.2.2 | |
| | 3.3 | Cumulative impacts of mining | 5.2.3 | |
| | 3.4 | Baseline for other sectors | 5.2.4 | |
| **Component 4: Risk analysis for the Galilee subregion** | 4.1 | Risk register | 2.5.4, 5.3 | ■ |
| | 4.2 | Risk identification | 2.5.4, 5.3 | |
| | 4.3 | Risk analysis | 2.5.4, 5.3 | |
| **Component 5: Outcome synthesis for the Lake Eyre Basin bioregion** | 5.1 | Synthesis of contextual information | 2.5.5 | ■ |
| | 5.2 | Synthesis of model-data analysis | 2.5.5 | |
| | 5.3 | Synthesis of impact analysis | 2.5.5 | |
| | 5.4 | Synthesis of risk analysis | 2.5.5 | |

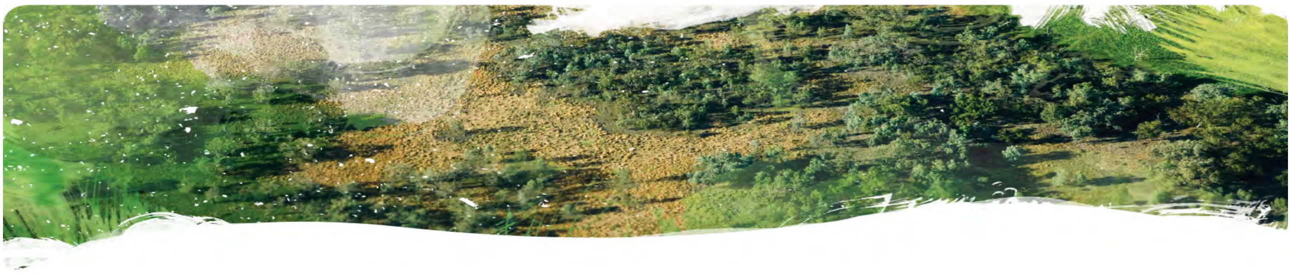
[a] Barrett et al. (2013)

[b] Product 1.5 (Current water accounts and water quality) will be included in the report for product 2.5 (Water balance assessment).

[c] The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

## *References*

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 1 November 2013, <www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.



# 1.1 Context statement for the Galilee subregion

The context statement summarises the current extent of knowledge on the ecology, hydrology, geology and hydrogeology of a bioregion. It provides baseline information relevant to understanding the regional context of water resources within which coal seam gas and coal mining development is occurring. Information is collated to support the interpretation of the impact analysis, risk analysis and outcomes of the bioregional assessment.

The context statement includes materially relevant characteristics of a bioregion that are needed to adequately interpret output from ecological, surface water and groundwater datasets and models, and from this develop improved knowledge of whole-of-system functioning.

No new analysis or modelling is presented in the context statement; it is essentially a literature review of existing information. Thus, some figures are reproduced from other sources and thus may not be consistent with those produced in the Assessment. Likewise, results from different sources may use different methods or inconsistent units.

### 1.1.1 Bioregion

The Galilee subregion is part of the Lake Eyre Basin bioregion (Figure 3). The Lake Eyre Basin bioregion covers an area of approximately 1.31 million km$^2$ of central and north-eastern Australia, including parts of Queensland, NSW, South Australia and the Northern Territory. The Lake Eyre Basin bioregion incorporates the whole of the Lake Eyre surface drainage basin as well as portions of several adjacent surface drainage catchments. The main areas of interest within the Lake Eyre Basin bioregion are principally those underlain by four separate coal-bearing geological basins – the Pedirka and Arckaringa basins in the west, and the Galilee and Cooper basins in the east.

The Galilee, Cooper, Pedirka and Arckaringa basin areas each define subregions within Lake Eyre Basin bioregion. Each of these subregions will be the subject of a bioregional assessment.

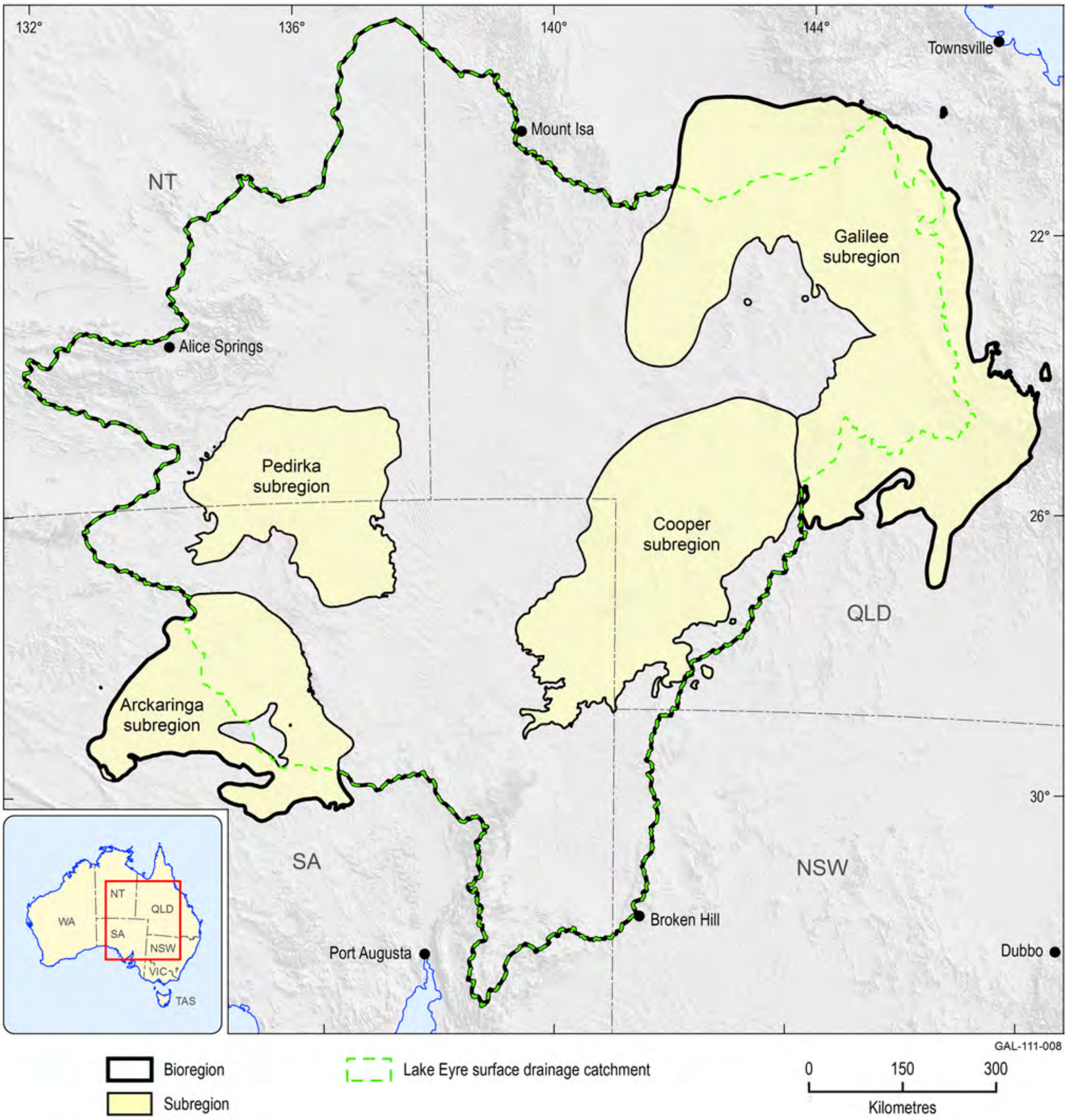


Figure 3 Lake Eyre Basin bioregion and subregions

### 1.1.1.1 *Definitions used*

The Galilee subregion is located entirely in Queensland (Figure 4), and is defined by the extent of the geological Galilee Basin (see Section 1.1.1 for further detail). The subregion spans an area of about 248,000 km$^2$. It also also includes the headwaters of seven major surface drainage catchments (see Section 1.1.5 for further detail). It straddles the Great Dividing Range and extends westwards and northwards well into the Lake Eyre surface drainage catchment and Flinders-Norman rivers catchment.

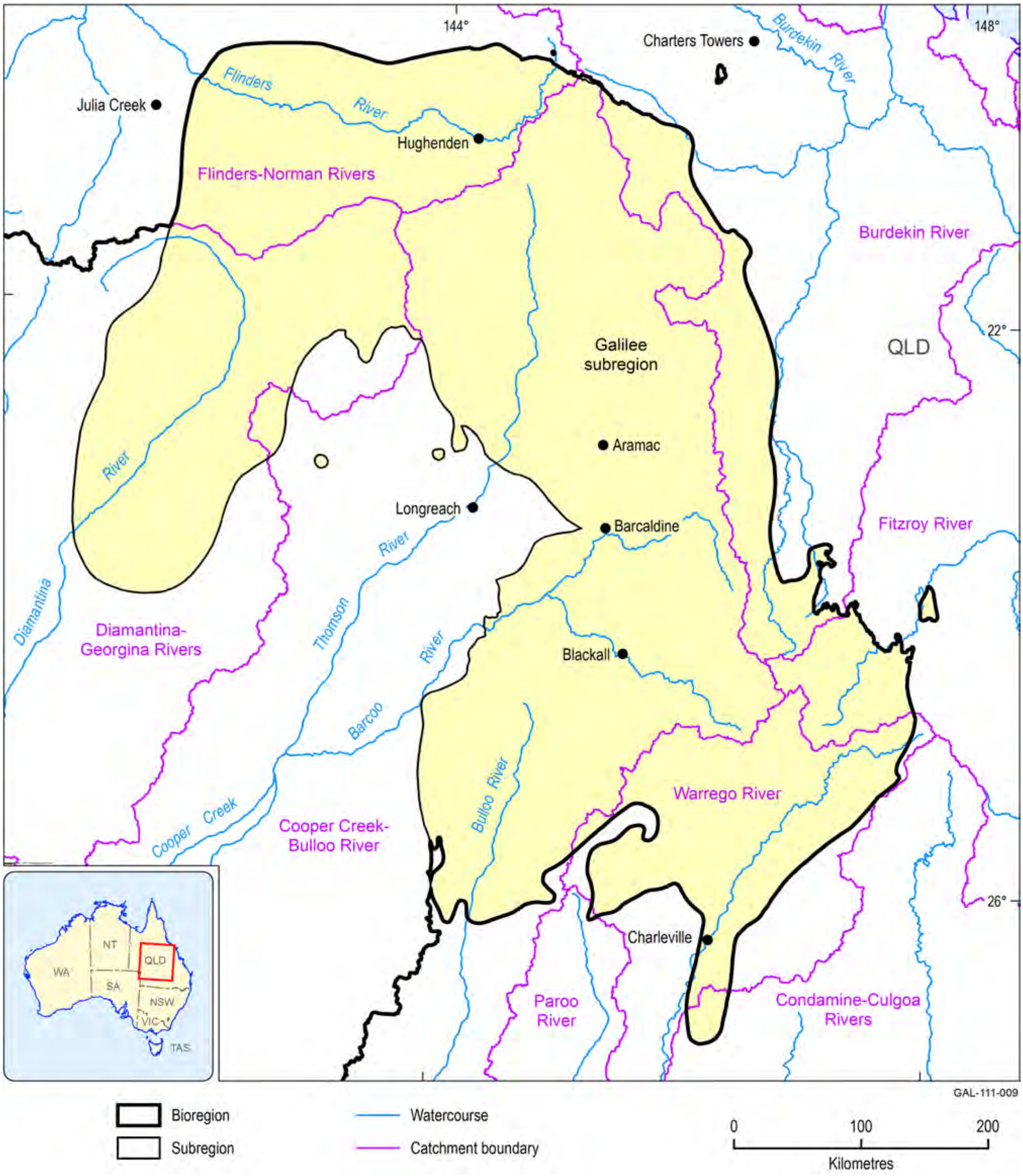


**Figure 4 Galilee subregion showing surface water catchments**

## 1.1.2 Geography

### *Summary*

The Galilee subregion is located entirely in Queensland, and includes the headwaters of seven major river basins. The subregion spans an area of about 248,000 km$^2$, extending from the headwaters of easterly flowing rivers across the eastern highlands and well into the Australian Central Lowlands physiographic province. Elevations vary from a minimum of about 150 m Australian Height Datum (mAHD) in the Diamantina River floodplain near the north-western margin of the Galilee subregion to nearly 1000 mAHD at the north-western end of the Carnarvon Ranges in the south-eastern portion of the subregion. In addition to major river systems, an arcuate intermontane valley in the eastern highlands contains two large playa lakes, Buchanan (117 km$^2$) and Galilee (257 km$^2$), within closed internal drainage basins. Both of these lakes are listed in *A directory of important wetlands in Australia* (Department of the Environment, 2014).

Soils vary across the subregion and typically correlate with physiographic region and land cover or vegetation. The eastern highlands portion of the subregion are topographically and physiographically more complex than the lowlands and have a correspondingly greater complexity of land cover and soil types. Kandosols, which are non-calcareous and low texture-contrast soils with moderate fertility and agricultural potential, are the dominant soil in the eastern highlands portion of the subregion. Also occurring are Vertosols, Tenosols, Sodosols and Rudosols as well as Ferrosols in the north, on the Gilberton and Burdekin plateaux, and Chromosols and Calcarosols in the south-east, on the Nagoa Scarplands and the Maranoa Lowland. Clay-rich Vertosols with shrink-swell features and high agricultural potential dominate much of the grassland lowlands in the central portion of the subregion west of the eastern highlands. The western lowland margins of the subregion have a more complex topographically controlled mixture of Vertosols, Sodosols, Tenosols, Rudosols, Kandosols and Dermosols which form on variable parent materials and have generally low to moderate fertility and agricultural potential.

Though significant areas have soils with moderate to high fertility and agricultural potential, there has been virtually no agricultural development in the form of cropping or pasture improvement. Sheep and cattle grazing on natural pasture is the dominant land use in the subregion. Other than relatively small areas of plantation forestry and minor clearing for pasture improvement, there is very little modification of the natural land cover, which is dominated by hummock and tussock grasses in the lowland west and sparse and scattered trees in the eastern highlands.

The subregion covers 13 local government areas, with none entirely included, and spans parts of nine planning regions and five natural resource management regions. The population is sparse and difficult to estimate accurately, as census divisions do not correspond to the subregion boundary. In the 2011 census there were almost certainly less than 20,000 residents in the subregion, representing a considerable decline (5 to 10%) over the previous decade. Charleville is the largest town in the subregion with a population of 3561 people. Primary production, mainly in the form of rangeland grazing, is the major economic activity of

the subregion and accounted for 32.5% of occupations in the 2011 census. This is followed by government services (19.8%), and retail, construction, education, transport and accommodation (all 5 to 8%). The development of proposed mining and coal seam gas extraction in the subregion may affect population and economic activities in the future.

The climate is generally hot and dry throughout, becoming more extreme towards the west where the altitude is lower and the coast more distant. Rainfall variation across the region ranges from less than 300 mm to more than 700 mm. Rainfall is summer dominant and potential evapotranspiration significantly exceeds rainfall in all months. Climate change projections suggest slightly higher warming for the Galilee subregion than the continental average, with a range of 1.0 to 1.2 °C by 2030 and up to 3 to 4 °C by 2070 under a high greenhouse gas emissions scenario. With high emissions, there is a greater than 90% probability of exceeding 2 °C warming and a 20 to 40% probability of exceeding 4 °C warming by 2070. Projected changes in rainfall have more uncertainty but a slight decline of 1 to 2.5% is projected by 2030 and this increases to 5 to 20% by 2070 under a high-emissions scenario. Most of these rainfall declines are projected to occur in winter and spring.

### *1.1.2.1 Physical geography*

The Galilee subregion is located predominantly in the upper Lake Eyre drainage catchment, including the headwaters of the Diamantina River and the Thompson and Barcoo rivers of the Cooper Creek system. However, the subregion is defined by the extent of the mostly subsurface geological Galilee Basin and extends beyond the Lake Eyre drainage catchment to the headwaters of the Flinders River in the north-west, the Bulloo River in the south, and the Warrego River in the south-east. The subregion also extends across the Great Dividing Range to the east and north-east into the headwaters of the Fitzroy and Burdekin river basins.

The topography (Figure 5) of the subregion reflects this physiographic context and the elevation generally declines to the west from the eastern highlands. Though the subregion does extend east of the Great Dividing Range watershed, most of the headwater reaches of the Fitzroy and Burdekin river basins included in the subregion are incised parts of the eastern highlands and are above 500 mAHD. The eastern highlands within the subregion are quite complex with two broad areas continuously over 500 mAHD in the south and the north linked by two relatively narrow parallel arcuate lines of ranges with crests mostly below 500 mAHD. The eastern line of these ranges forms the Great Dividing Range. Between these ranges lies an elongate intermontane valley that extends for almost 400 km. The western line of range is breached by upper elements of the Thompson and Barcoo river systems incorporating parts of the intermontane valley into the westerly drainage. In two places the valley has closed internal drainage forming the catchments of the playa lakes Buchanan and Galilee. In the southern part of the subregion, in the Warrego, Bulloo and south-eastern Barcoo river basins, the topography declines to the west and south-west of the eastern highlands but maintains an elevation above 200 mAHD. In the northern and north-western parts of the subregion the elevations are generally lower with extensive parts of the major drainage valleys of the Barcoo, Thompson, Diamantina and Flinders rivers lying below 200 mAHD and elongate interfluves between those valleys above 200 mAHD. In the north-west an eastward extension of the Selwyn Range in the Mount Isa area extends into the subregion.

Lakes Buchanan and Galilee are both listed in *A directory of important wetlands in Australia* and are classified as inland wetlands, with Buchanan described as both a seasonal/intermittent saline lake and a seasonal saline marsh and Galilee also as a seasonal/intermittent saline lake and as a seasonal/intermittent freshwater pond and marsh. Both lakes satisfy five of the six listed criteria for inclusion on the listing as agreed to by the Australian and New Zealand Environment and Conservation Council Wetlands Network in 1994 (Department of the Environment, 2014). Only one criterion is required for listing.

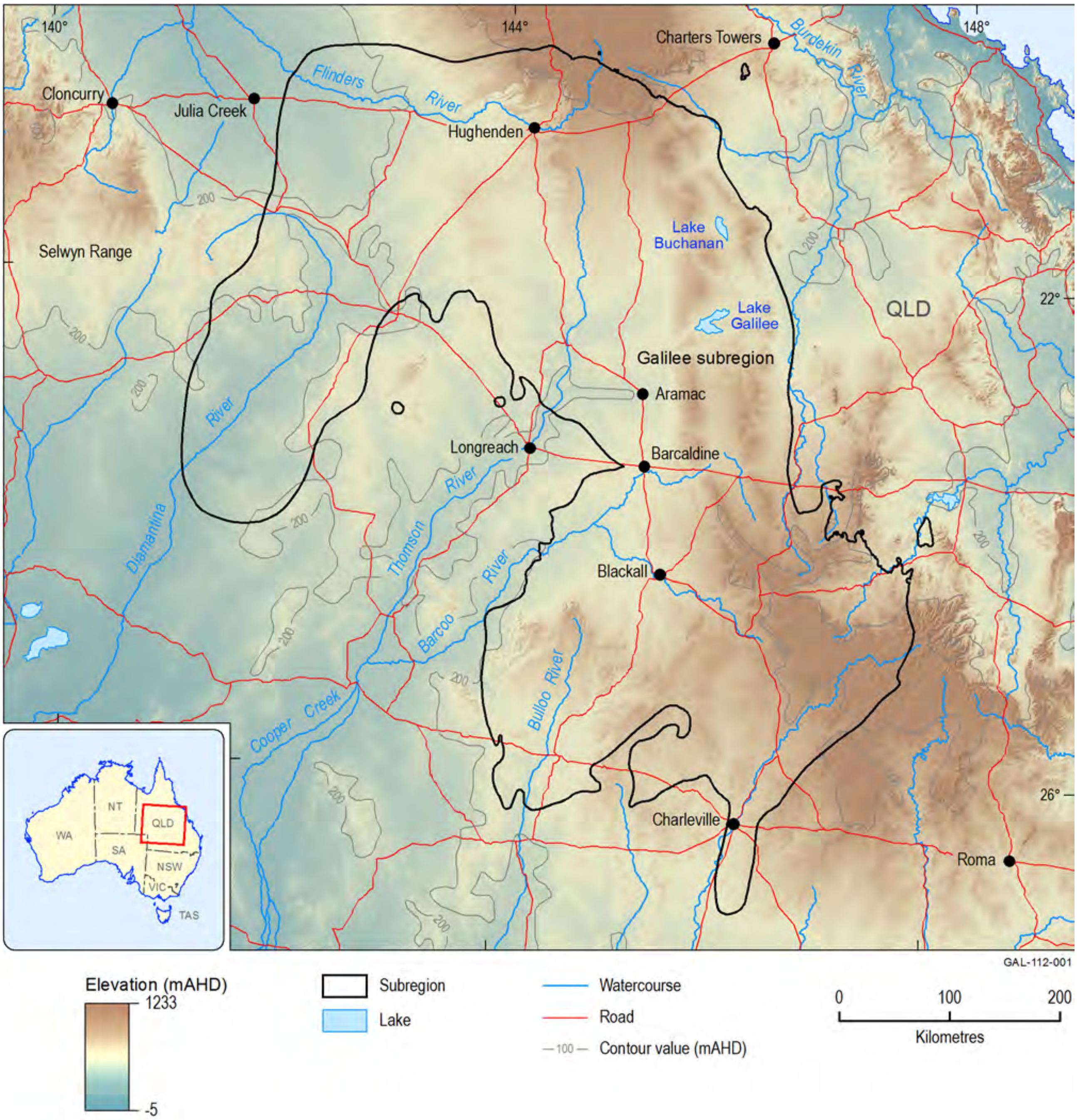


**Figure 5 Topography of the Galilee subregion, generated from the 3-second digital elevation model**

Source data: GA (2011a)

### 1.1.2.1.1 Physiographic regions

A physiographic region is defined as a discrete morphological unit with internal coherence of its landform characteristics (Jennings and Mabbutt, 1977). Physiographic regions are defined and mapped by landform characteristics that reflect uniform landform evolution, underlying geology and contained regolith materials (Pain et al., 2011). Early, largely descriptive, state-based treatments of Australian physiography that included Victoria (Hills, 1940) and Western Australia (Jutson, 1914) progressed to continental-scale physiographic mapping by Jennings and Mabbutt (1977) using improved topographic maps and other data. Physiographic mapping is descriptive and provides a regional-scale classification of landforms and related physical geography as they reflect underlying geological and climatic controls. The most recent national-scale physiographic mapping by Pain et al. (2011) extends the mapping of Jennings and Mabbutt (1977) by utilising the Shuttle Radar Topography Mission (SRTM) digital elevation model and other new data such as national and state soil and land survey data in a GIS mapping system. The classification has three divisions at the broadest level, 23 provinces distinguishing major physiographic changes, and 220 regions forming the basic subdivision of internally consistent landform morphology and inferred origin (Pain et al., 2011).

The Galilee subregion spans elements of the upper Lake Eyre drainage catchment, Bulloo river basin and Murray–Darling Basin and the adjacent eastern highlands. The subregion also extends into the upper coastward Burdekin and Fitzroy river basins to the north-east and east and the Gulf of Carpentaria to the north-west. This geographic complexity ensures that the Galilee subregion spans a number of physiographic regions with a relatively complex pattern in the eastern highlands and headwaters (Figure 6). In terms of the broad-scale physiographic divisions the subregion lies dominantly in the Interior Lowlands division but extends north-east across the boundary to the Eastern Uplands division. At the intermediate scale (physiographic province), the subregion falls dominantly into the Central Lowlands province and extends to the north-east into the south-western margins of the Burdekin Uplands and Fitzroy Uplands provinces. At the north-western subregion margin, small portions of the Carpentaria Lowlands province occur.

Eight physiographic regions have a significant coverage in the Galilee subregion and 11 physiographic regions have a minor presence. Five of the well represented physiographic regions are in the Central Lowlands province with the following characteristics, including region identification number, derived from Pain et al. (2011):

- the Eromanga Lowlands (20209), stony plains with silcrete-capped mesas and minor alluvial and sandy tracts west and south of Longreach
- the Winton-Blackall Downs (20201), undulating clay plains that extend across the whole subregion from north-west to south-east
- the Jericho Plain (20202), a sand plain occurring in the central eastern part of the subregion in the Barcaldine Ridge area
- the Maranoa Lowland (20203), a sand plain with low sandstone hills in the south-eastern part of the subregion
- the Charleville Tableland (20204), a low sandy tableland of weathered sandstone and shale at the western edge of the subregion in its south-eastern corner.

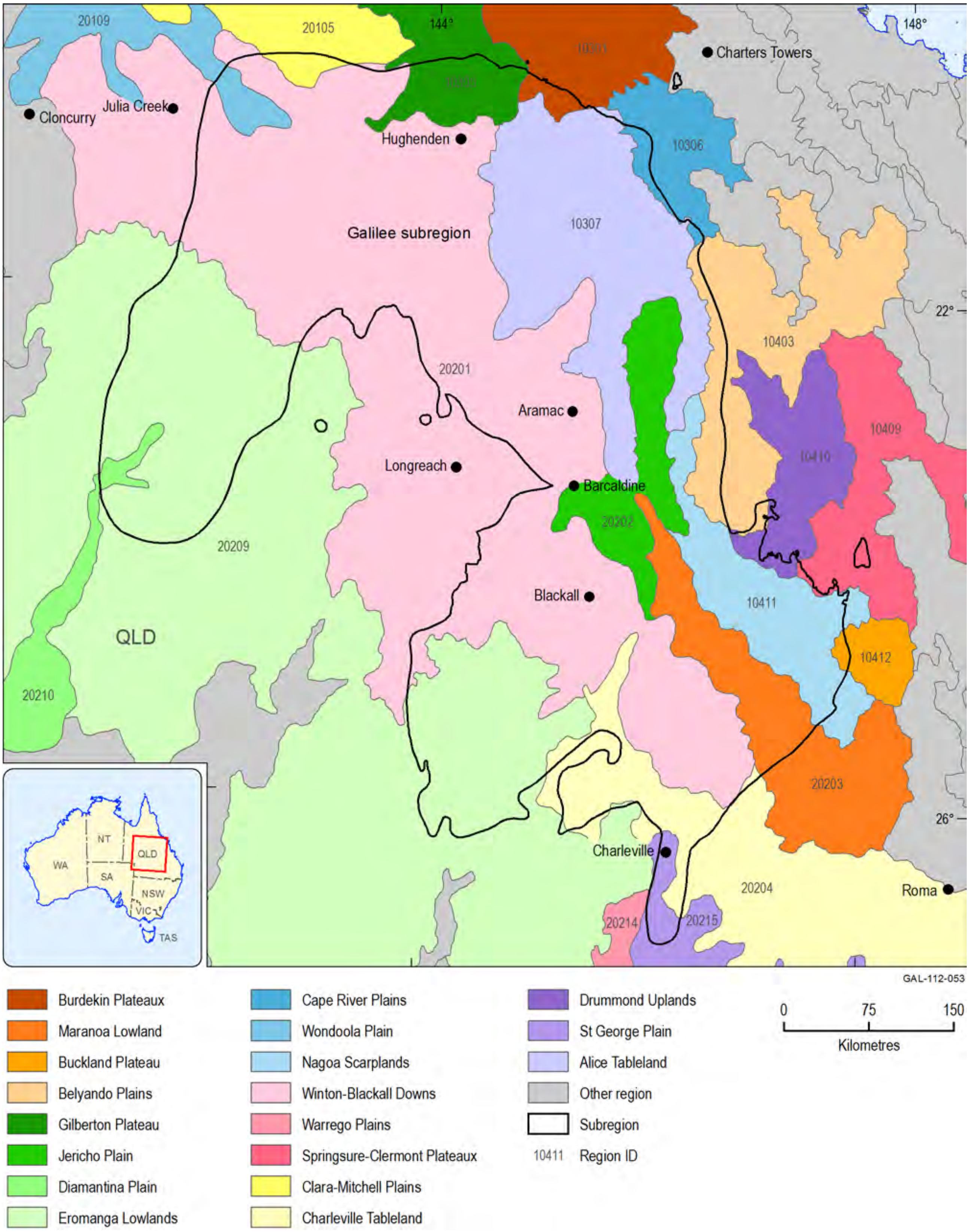


**Figure 6 Physiographic regions (Pain et al., 2011)**

Region identification numbers are as used by Pain et al. (2011).
Source data: Pain et al. 2011

Two of the well represented physiographic regions are in the Burdekin Uplands province and one in the Fitzroy Uplands province with the following characteristics, including region identification number, derived from Pain et al. (2011):

- the Gilberton Plateau (10305), a partly dissected sandstone plateau at the northern margin of the subregion north of Hughenden
- the Alice Tableland (10307), a perched sandy plain with interior drainage and a higher ferruginous-capped rim which lies in the central eastern part of the subregion and includes lakes Buchanan and Galilee
- the Nagoa Scarplands (10411), sandstone strike ridges separated by clay-rich valleys at the eastern edge of the subregion in its south-eastern corner.

Of the 11 sparsely represented physiographic regions, two – the Clara-Mitchell Plains (20105) and the Wondoola Plain (20109) at the north-western subregion boundary – are in the Carpentaria Lowlands province. Two of the sparsely represented physiographic regions – the Burdekin Plateaux (10301) and the Cape River Plains (10306) – are in the Burdekin Uplands province. Four of the sparsely represented physiographic regions – the Belyando Plains (10403), the Drummond Uplands (10410), the Springsure-Clermont Plateaux (10409) and the Buckland Plateau (10412) – are in the Fitzroy Uplands province. Three of the sparsely represented physiographic regions – the Diamantina Plain (20210), the Warrego Plains (20214) and the St George Plains (20215) – are in the Central Lowlands province. Physiographic details of these sparsely represented regions are available in Pain et al. (2011).

#### 1.1.2.1.2 Soils and land capability

Figure 7 shows the subregion soils derived from the Australian Soils Classification (Isbell, 2002), which is a hierarchical classification that particularly features the soil B horizon characteristics and also provides an assessment of the soil agricultural potential. The soil characteristics described in this section are sourced from Isbell (2002). Comparison between Figure 6 and Figure 7 indicates correspondence between physiographic region and soil type. The Winton-Blackall Downs physiographic region (which extends north-west to south-east across the subregion west of the eastern highlands) coincides with a band dominated by Vertosols which, in the north-western part of the subregion, extends to both the north-east and south-west of the Winton-Blackall Downs into adjacent physiographic regions. Vertosols are clay-rich soils characterised by shrink-swell properties that produce both strong cracking when dry and gilgai microrelief at the surface and slickensides and lenticular aggregates at depth. Gilgai microrelief is an irregular generally polygonal pattern of alternating mounds and depressions, at variable scales, produced by physical subsoil movements in alternate shrink-swell cycles due to wetting and drying. Soil properties and profiles of gilgai mounds and depressions can vary. Vertosols have high agricultural potential with high fertility, variable structure depending on wetting state, and good water-holding capacity.

The Eromanga Lowlands west of Longreach in the Galilee subregion are a topographically controlled complex mix of Vertosols, Sodosols, Tenosols, Rudosols and minor Kandosols and Dermosols. Sodosols show strong texture contrast with a highly sodic B horizon and pH greater than 5.5. They generally form on highly to moderately siliceous parent material and generally have low agricultural potential, low to moderate fertility, poor structure, low permeability, high erodibility and soil salinity. Tenosols are a diverse range of weakly developed sandy soils with an A horizon and are generally formed on highly siliceous parent materials. They tend to have low agricultural potential, low fertility, poor structure and low water-holding capacity. Rudosols are young soils with minimal pedogenic organisation and can vary widely in terms of texture, structure and depth. Dermosols have a low texture contrast with low free iron in the B horizon, are formed on a range of parent material from siliceous to intermediate and basic, and have high agricultural potential, moderate to high fertility, good structure and water-holding capacity. Kandosols are non-calcareous soils that lack a strong texture contrast and are developed on highly siliceous to intermediate parent material. They have low to moderate agricultural potential with moderate fertility and water-holding capacity. The Eromanga Lowlands immediately north-west of Charleville are dominated by Kandosols with minor Rudosols, Sodosols and Vertosols.

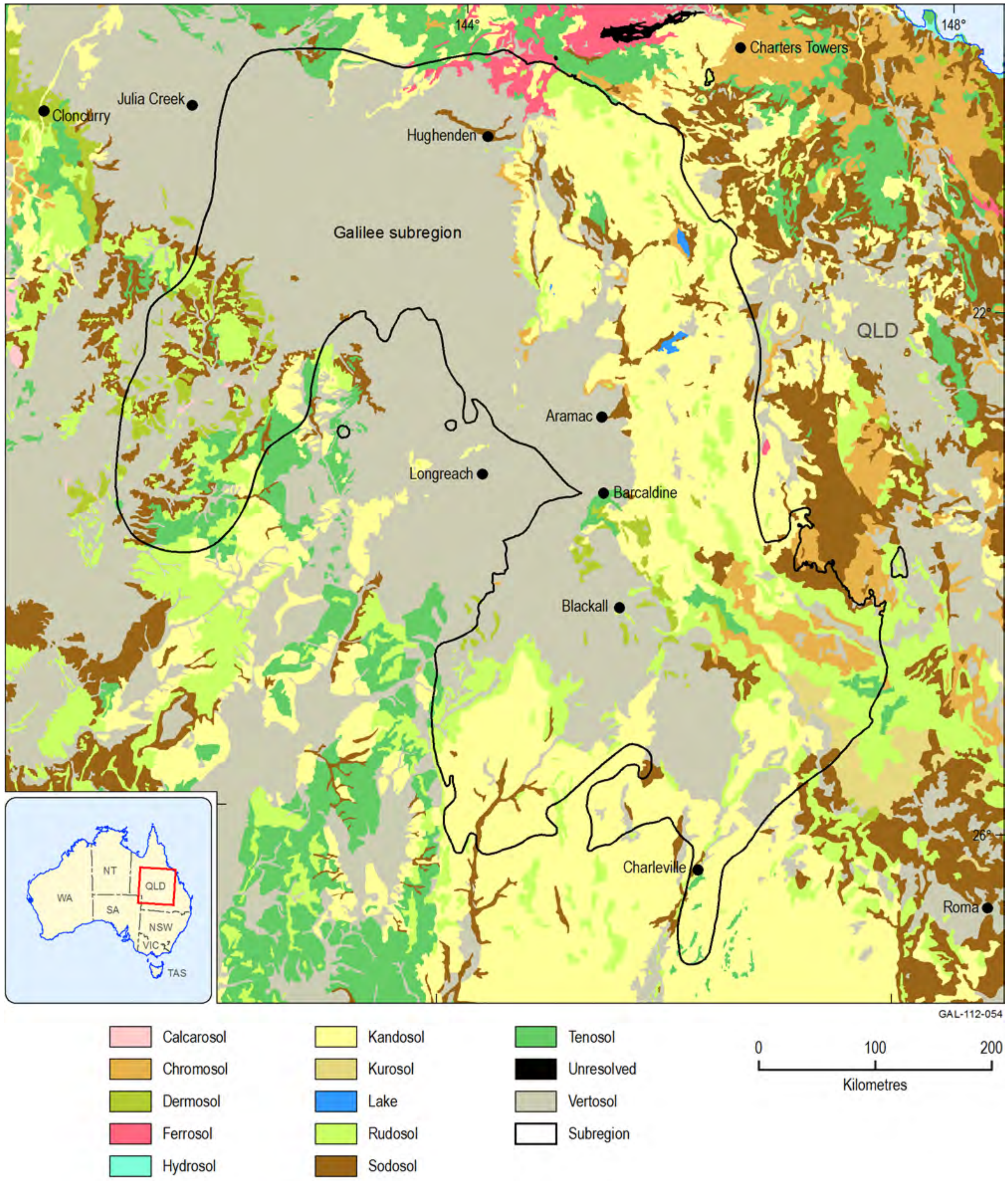


**Figure 7 Soils classified using the Australian Soil Classification (Isbell, 2002)**

Source data: Australian Soil Resource Information System (ASRIS)

The eastern highlands physiographic regions of the Galilee subregion are more complex and have a corresponding complexity of soil types. In the north the Gilberton and Burdekin plateau physiographic regions have Ferrosols in addition to Vertosols, Tenosols and Kandosols. Ferrosols are soils without a strong texture contrast and with high free iron-oxide content in the B horizon. They are developed on intermediate to mafic parent material and have high agricultural potential, high fertility, good structure and water-holding capacity. Further south, the Alice Tableland, Jericho Plains, northern Nagoa Scarpland and Maranoa Lowland physiographic regions are dominated by Kandosols with minor Vertosols, Sodosols, Rudosols, Tenosols Chromosols and Dermosols. Chromosols have strong texture contrast and non-acidic and non-sodic B horizons and are formed on highly siliceous to intermediate parent material. They have moderate agricultural potential, moderate fertility and water-holding capacity. The Nagoa Scarplands and Maranoa Lowland physiographic regions of the south-eastern portion of the subregion have elongate bands of soil types parallel to the north-west trend of the highlands, which probably reflect alternating valley and range physiography. Soil types represented are mainly Chromosols, Rudosols and Calcarosols with more minor Kandosols, Tenosols and Sodosols. Calcarosols are soils characterised by calcium carbonate, especially in the B horizon subsoil, and can develop on a range of highly siliceous to intermediate parent material. They generally have low to moderate agricultural potential, low fertility and water-holding capacity. They may also have high salinity, alkalinity and boron toxicity.

### 1.1.2.1.3 Land cover

Figure 8 shows the dynamic land cover distribution across the Galilee subregion derived from Geoscience Australia remote sensing mapping which uses a time series analysis of 34 structural vegetation classes ranging from cultivated and managed land covers (crops and pastures) to natural land covers (forests and grasslands) (Lymburner et al., 2011). The subregion is characterised by many different land cover classes but the broad distribution pattern of classes clearly reflects the physiographic regions and the soil class distribution as shown in Figure 6 and Figure 7. The Winton-Blackall Downs, which extend north-west to south-east across the subregion, are dominated by sparse tussock grasses with thin corridors of scattered trees along the drainage lines. To the south-west, the Eromanga Lowlands have a more complex pattern of sparse hummock grasses, sparse tussock grasses, scattered grassland and sparse shrubs, reflecting topography. This domination by grasslands reflects the inability of the clay-rich soils to provide sufficient accessible moisture to support trees in this semi-arid seasonal rainfall area. The eastern highlands portion of the subregion is dominated by sparse and scattered trees with small areas of open trees which become dominant in the south-eastern corner. The Gilberton Plateau physiographic region in the north-eastern highland portion of the subregion has open hummock grassland, and significant areas of rain-fed pasture are present in the south-eastern corner of the subregion.

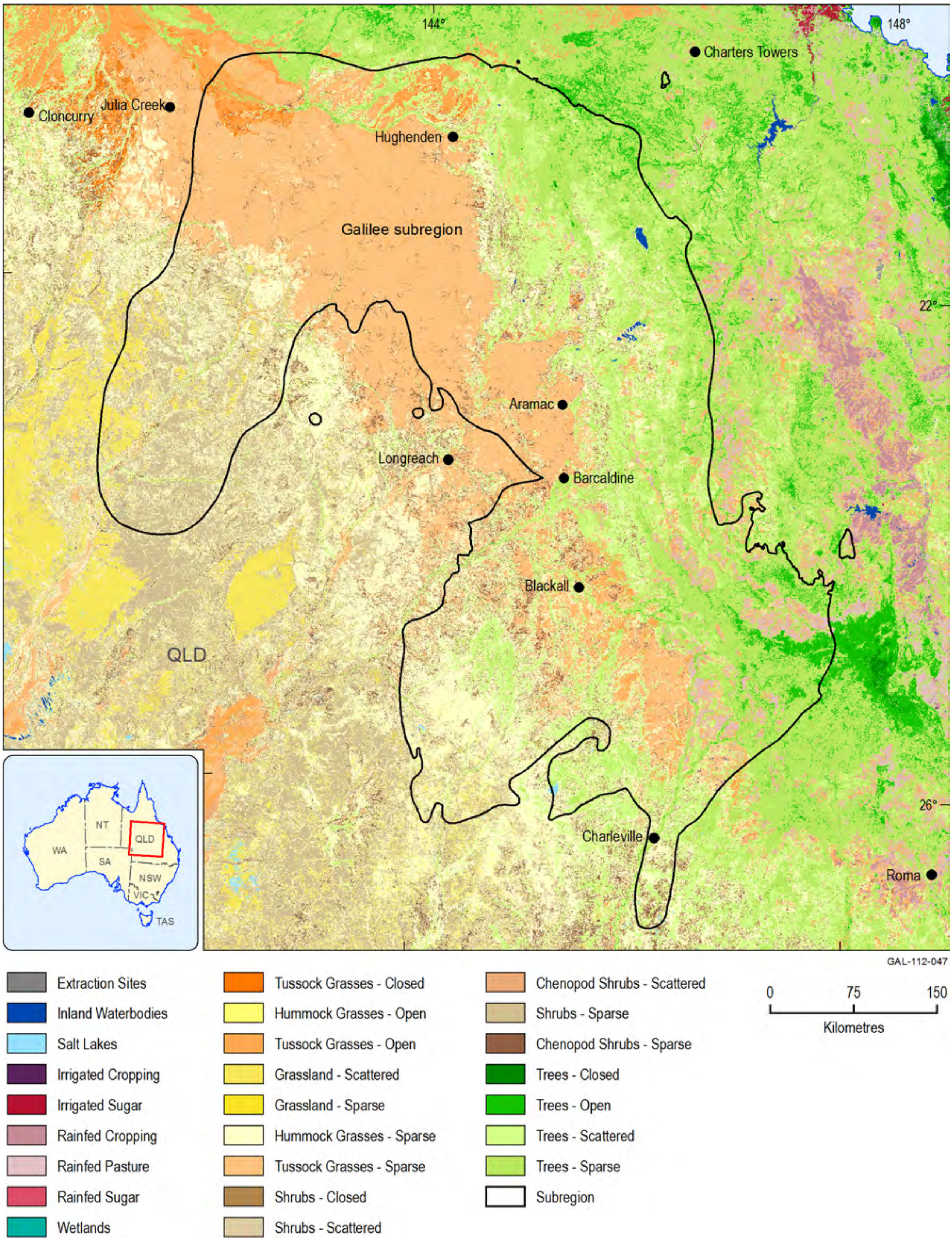


**Figure 8 Land cover**

Source data: GA (2011b)

### *1.1.2.2 Human geography*

#### 1.1.2.2.1 Population

The subregion is sparsely populated, though exact numbers are difficult to determine because population statistics are only available for selected urban areas and other statistical subdivisions which do not coincide with the Galilee subregion boundaries. Three small urban areas with a population greater than 1200 (Barcaldine, Blackall and Charleville) and five smaller localities (Richmond, Hughenden, Aramac, Tambo and Augathella) are included within the subregion. An additional small urban area (Longreach) and four localities (Winton, Quilpie, Alpha and Julia Creek) lie just outside the margins (Figure 9, Table 2). These urban areas have combined populations of 8,775 and 5,496, respectively, for a total urban population of 14,271. There was a significant decline in the urban population over the decade 2002 to 2011, typically in the 5 to 10% range and averaging 7.3% for all centres. However, the decline was considerably higher in some localities such as Augathella (27.4%), Winton (14%) and Julia Creek (24.4%). The decline is consistent with an Australia-wide decline in inland rural population and contrasts markedly with substantial increases in Queensland as a whole and in larger urban centres, especially in coastal zones. Comparison between 2011 and 2012 suggests that the general population decline of the previous decade has halted with many centres showing very small increases and an average increase of 0.3% across all centres (Table 2).

Estimating the non-urban population of the subregion is more difficult with 13 local government areas (LGAs) occurring mostly or partially within the subregion but none of them entirely included (Table 3). The population totals for each LGA, when adjusted by subtracting urban centre numbers, indicate the non-urban rural population of the subregion. However, these numbers include some very small localities (not listed in Table 2) and are an overestimation because portions of most of the LGAs lie outside the subregion. This process results in a total maximal non-urban population of 5,849 (Table 3). The anomalous Central Highlands Regional Council area figures are excluded because only a very small portion of the south-western part of that LGA is included in the subregion and the total population for that LGA is biased by the large urban centres of Emerald and Blackall, which lie well outside the subregion. In summary, all these sources indicate that the subregion has a population of less than 20,000 with more than 75% of those located in urban centres. Charleville, the largest town, has fewer than 3,500 residents. The population change figures for LGAs indicate that all northern and western areas are declining and the three LGAs covering the south-east of the subregion show minimal increases of zero to 1%. The Central Highlands Regional LGA is anomalous, with population growth of greater than 2%.

**Table 2 Population of towns and localities (L) in the Galilee subregion in 2002, 2011 and 2012 and changes from 2002 to 2011 and 2011 to 2012**

Negative figures indicate population declines.

| Town | 2002 Population (number) | 2011 Population (number) | 2012 Population (number) | 2002 to 2011 change (number) | 2002 to 2011 change (%) | 2011 to 2012 change (number) | 2011 to 2012 change (%) |
|---|---|---|---|---|---|---|---|
| **Subregion centres** | | | | | | | |
| Richmond (L) | 569 | 527 | 526 | –42 | –7.4% | –1 | –0.2% |
| Hughenden (L) | 1,316 | 1,180 | 1,172 | –136 | –10.3% | –8 | –0.7% |
| Aramac (L) | 348 | 305 | 307 | –43 | –12.4% | 2 | 0.7% |
| Barcaldine | 1,432 | 1,347 | 1,362 | –85 | –5.9% | 15 | 1.1% |
| Blackall | 1,345 | 1,250 | 1,277 | –95 | –7.1% | 27 | 2.2% |
| Tambo (L) | 339 | 364 | 365 | 25 | 7.4% | 1 | 0.3% |
| Augathella (L) | 464 | 337 | 336 | –127 | –27.4% | –1 | –0.3% |
| Charleville | 3,561 | 3,400 | 3,430 | –161 | –4.5% | 30 | 0.9% |
| **Subtotal** | **9,374** | **8,710** | **8,775** | **–664** | **–7.1%** | **65** | **0.7%** |
| **Marginal centres** | | | | | | | |
| Winton (L) | 1,148 | 987 | 981 | –161 | –14.0% | –6 | –0.6% |
| Longreach | 3,294 | 3,215 | 3,211 | –79 | –2.4% | –4 | –0.1% |
| Quilpie (L) | 647 | 592 | 586 | –55 | –8.5% | –6 | –1.0% |
| Alpha (L) | 398 | 358 | 359 | –40 | –10.1% | 1 | 0.3% |
| Julia Creek (L) | 476 | 360 | 359 | –116 | –24.4% | –1 | 0.3% |
| **Subtotal** | **5,963** | **5,512** | **5,496** | **–451** | **–7.6%** | **–16** | **–0.3%** |
| | | | | | | | |
| **Total** | **15,337** | **14,222** | **14,271** | **–1,115** | **–7.3%** | **49** | **0.3%** |

Source data: Queensland Treasury and Trade (2013)

**Table 3 Population of local government areas in the Galilee subregion**

All = Local government area (LGA) almost entirely in subregion, Most = more than half of LGA in subregion, Small = less than half of LGA in subregion. The non-urban population numbers are derived by subtracting town and locality numbers (Table 2) from the LGA number.

| Local government area | Area | 2012 Population (number) | 2011 to 2012 change (number) | Towns included | Non-urban population (number) |
|---|---|---|---|---|---|
| Flinders Shire | Most | 1,835 | Decline | Hughenden | 663 |
| Richmond Shire | Most | 847 | Decline | Richmond | 321 |
| McKinlay Shire | Small | 1,086 | Decline | Julia Creek | 610 |
| Winton Shire | Most | 1,380 | Decline | Winton | 399 |
| Longreach Regional | Small | 4,298 | Decline | Longreach | 1,004 |
| Barcaldine Regional | Most | 3,305 | 0–1% | Barcaldine, Aramac, Alpha | 1,127 |
| Blackall-Tambo Regional | All | | | Blackall, Tambo | 601 |
| Quilpie Shire | Small | 1,012 | Decline | Quilpie | 365 |
| Murweh Shire | Most | 4,784 | 0–1% | Charleville, Augathella | 759 |
| Central Highlands Regional | Small | 30,545 | >2% | Emerald, Capella, Blackwater, Duaringa, Woorabinda, Springsure | 8,399 |

Source data: ABS (2013a)

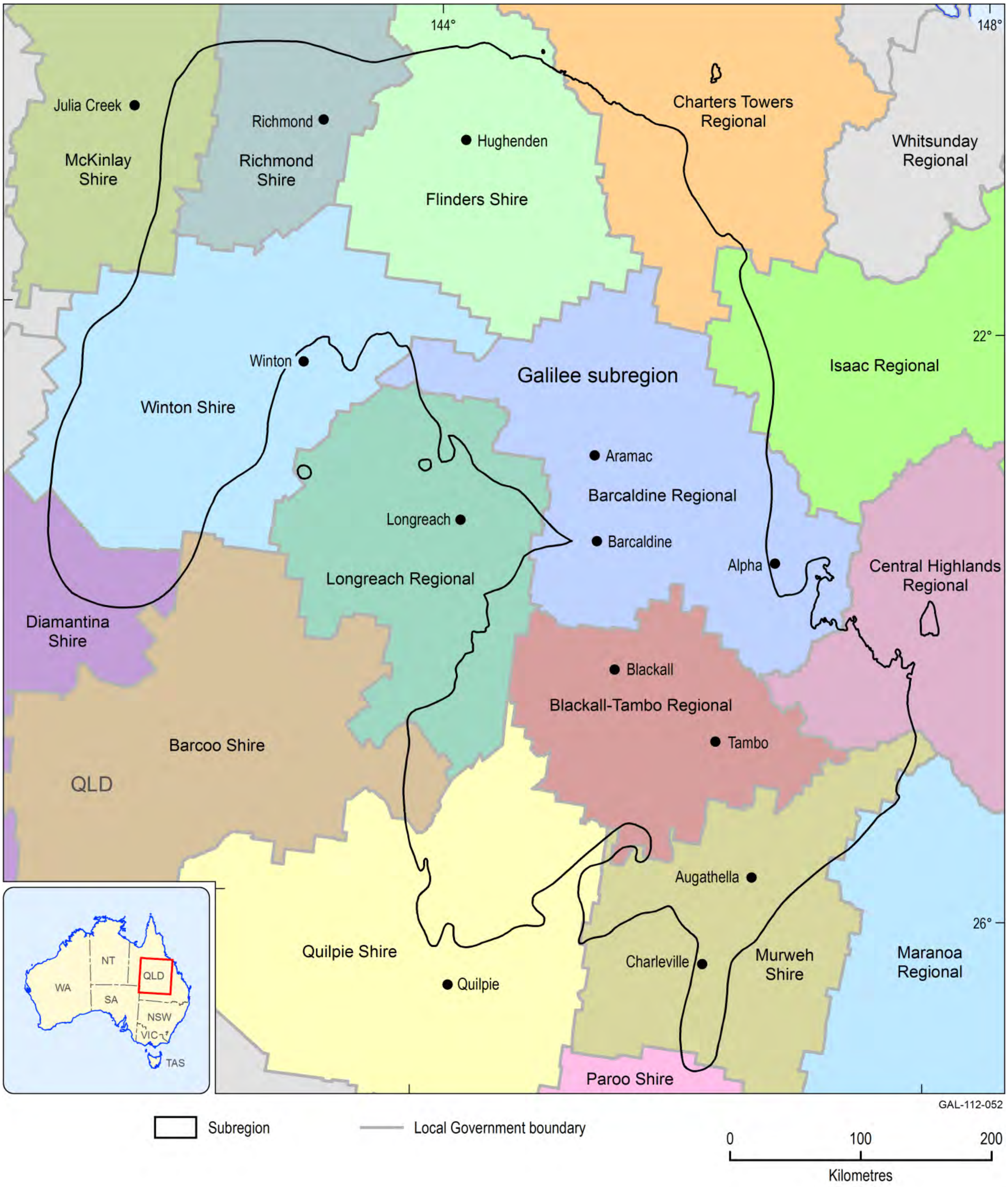


Figure 9 Local government areas, towns and localities

### 1.1.2.2.2 Economic activity

The major economic activities in the Galilee subregion are primary production (mostly rangeland grazing), government services, retail, education and tourist-related activities. The employment statistics from the 2011 census (Table 4)(ABS, 2013b) reflect these characteristics. The census data are provided in various areal categories, none of which exactly coincide with the Galilee subregion. Table 4 contains employment category data from four LGAs (the Winton, Flinders, Barcaldine

Regional and Blackall-Tambo Regional shires), which are all contained mostly within the subregion and together comprise a substantial proportion of the subregion. The summary statistics combined from these four shires are regarded as very likely to be representative of the subregion as a whole. By far the most dominant occupation (32.5%) is in the agriculture, forestry and fishing category. With limited forestry restricted to the south-eastern corner and no coastal connection for fishery, this category is dominated by sheep and beef production. Clearly the second most important category is government services, which includes local government and health and social service care (19.8%). This is followed by five categories including retail trade; construction; education and training (schools mostly); transport, postal and warehousing; and accommodation and food services, which all provide significant employment (5 to 8%) in the subregion. All other categories listed in the census results, including mining, are currently low-level occupations (<2.5%) within the subregion.

Currently mining is a low-level occupation category within the subregion at 1.3% but this may increase during the constructional and/or operational phases of projected coal mining and coal seam gas extraction developments, with possible impacts on other employment categories.

**Table 4 Occupation categories in four local government areas within the Galilee subregion, listed in decreasing order of numbers of participants**

| Occupation | Employment in Flinders Shire (number) | Employment in Winton Shire (number) | Employment in Barcaldine Regional (number) | Employment in Blackall-Tambo Regional (number) | Total (number) and percentage (%) |
|---|---|---|---|---|---|
| Agriculture, forestry and fishing | 308 | 206 | 499 | 302 | **1315 (32.5%)** |
| Public administration and safety | 101 | 93 | 162 | 103 | **459 (11.4%)** |
| Health care and social assistance | 38 | 52 | 145 | 105 | **340 (8.4%)** |
| Retail trade | 61 | 57 | 101 | 109 | **328 (8.1%)** |
| Construction | 58 | 49 | 135 | 52 | **294 (7.3%)** |
| Education and training | 53 | 38 | 92 | 71 | **254 (6.3%)** |
| Transport, postal and warehousing | 97 | 35 | 81 | 34 | **247 (6.1%)** |
| Accommodation and food services | 46 | 46 | 66 | 49 | **207 (5.1%)** |
| Manufacturing | 18 | 11 | 42 | 22 | **93 (2.3%)** |
| Professional, scientific and technical services | 4 | 9 | 50 | 18 | **81 (2.0%)** |
| Wholesale trade | 11 | 12 | 23 | 26 | **72 (1.8%)** |
| Other services | 16 | 9 | 32 | 15 | **72 (1.8%)** |
| Mining | 4 | 12 | 28 | 10 | **54 (1.3%)** |
| Administrative and support services | 15 | 12 | 14 | 8 | **49 (1.2%)** |
| Electricity, gas, water and waste services | 6 | 9 | 21 | 9 | **45 (1.1%)** |
| Inadequately described/Not stated | 8 | 3 | 27 | 6 | **44 (1.1%)** |
| Arts and recreation services | 4 | 4 | 10 | 13 | **31 (0.8%)** |
| Financial and insurance services | 11 | 6 | 3 | 6 | **26 (0.6%)** |
| Rental, hiring and real estate services | 6 | 3 | 5 | 3 | **17 (0.4%)** |
| Information media and telecommunications | 3 | 0 | 9 | 0 | **12 (0.3%)** |
| **Total** | **868** | **666** | **1545** | **961** | **4040** |

Source data: 2011 census (ABS, 2013b)

#### 1.1.2.2.3 Land use

Land use in the Galilee subregion is shown in Figure 10 (ABARES, 2012) and is dominated across most of the area by stock grazing on natural vegetation. Nature conservation areas, chiefly such as national parks, occur in the eastern highlands and in the western portions of the subregion. In the eastern highlands, national parks are scattered throughout but are more common in the north-eastern and south-eastern parts and consist of broader range and tableland areas (such as White Mountains, Salvator Rosa and Ka Ka Mundi national parks) or more restricted elongate areas focused on specific gorges (Porcupine Gorge National Park). In the north-western portions of the subregion, larger national parks such as the Diamantina and Goneaway straddle the boundary while Bladensburg and Astrebla Downs national parks occur just outside the boundaries. Similarly, the Idalia and Hell Hole Gorge national parks in the south-western subregion and the Welford and Mariala national parks occur just outside the boundaries. Some areas of production forestry land also occur in the south-eastern subregion in the vicinity of the western Carnarvon National Park.

Most of the Galilee Basin is within the Desert Channels natural resource management (NRM) region  which corresponds to the Queensland portion of the Lake Eyre drainage catchment. The Desert Channels Natural Resource Management Plan 2010 to 2015 is voluntary and lacks statutory power but was designed to include the monitoring, evaluation, reporting and improvement processes included in the Australian Government’s natural resource management planning frameworks and to support relevant Australian and Queensland government legislation. The management plan and the focus of the Desert Channels Group tends to be on specific on-ground measures to improve land, water and biodiversity assets by addressing factors like soil erosion, stream bank condition and weed and feral animal control. Smaller peripheral portions of the subregion fall within different NRM regions including the Southern Gulf NRM region in the north, the Burdekin NRM region in the east, the Fitzroy NRM region in the south-east and the South West Queensland NRM region in the south. All of these NRM regions have active management committees and plans.

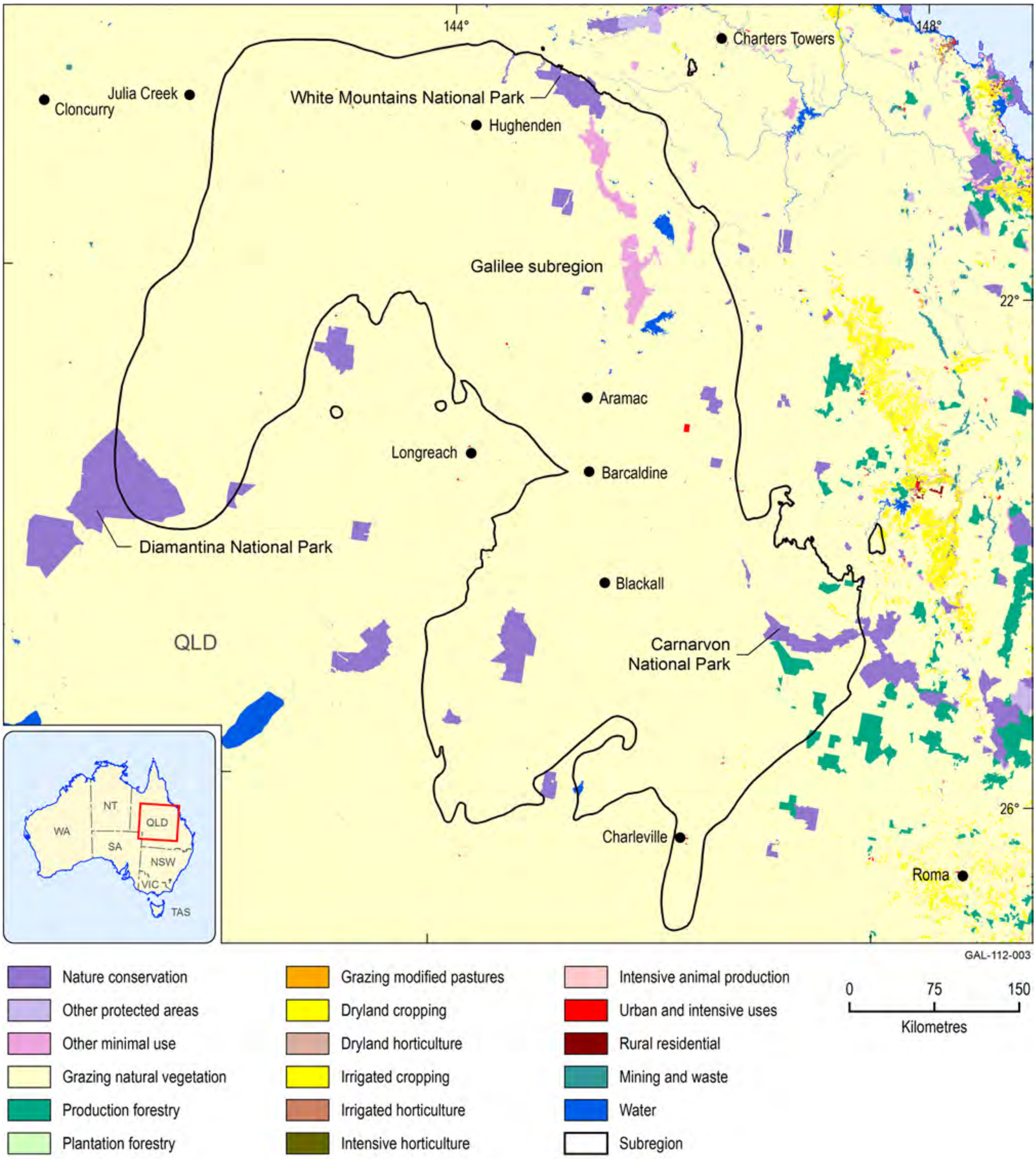


**Figure 10 Land use**

Source data: ABARES (2012)

### 1.1.2.2.4 Indigenous heritage

Indigenous heritage of the Galilee subregion is complex with inclusion of at least 12 Indigenous tribal/language groups in four separate language regions – Eyre, Gulf, Northeast and Riverine (Horton, 1994). There are native title claims covering large portions of the subregion and a number of Indigenous Land Use Agreements (ILUAs) in place. ILUAs are negotiated agreements between native title claimants and others about the use and management of lands and waters and were introduced by 1998 amendments to the Commonwealth's *Native Title Act 1993*. An ILUA can be negotiated and registered separately to a native title determination. ILUAs in the Galilee subregion include (at the time of writing) the Yirendali People in the Hughenden area in the north; the Wangan, Jagalingou and Bidjara peoples which extend into the eastern margins of the subregion; and the Maiawali and Karuwali peoples on Brighton Downs, Muellers Range and Chiltern Hills stations south-west of Winton in the in the north-west of the subregion. An ILUA registered by the Mardigan people in the Quilpie area just extends into the south-western portion of the subregion.

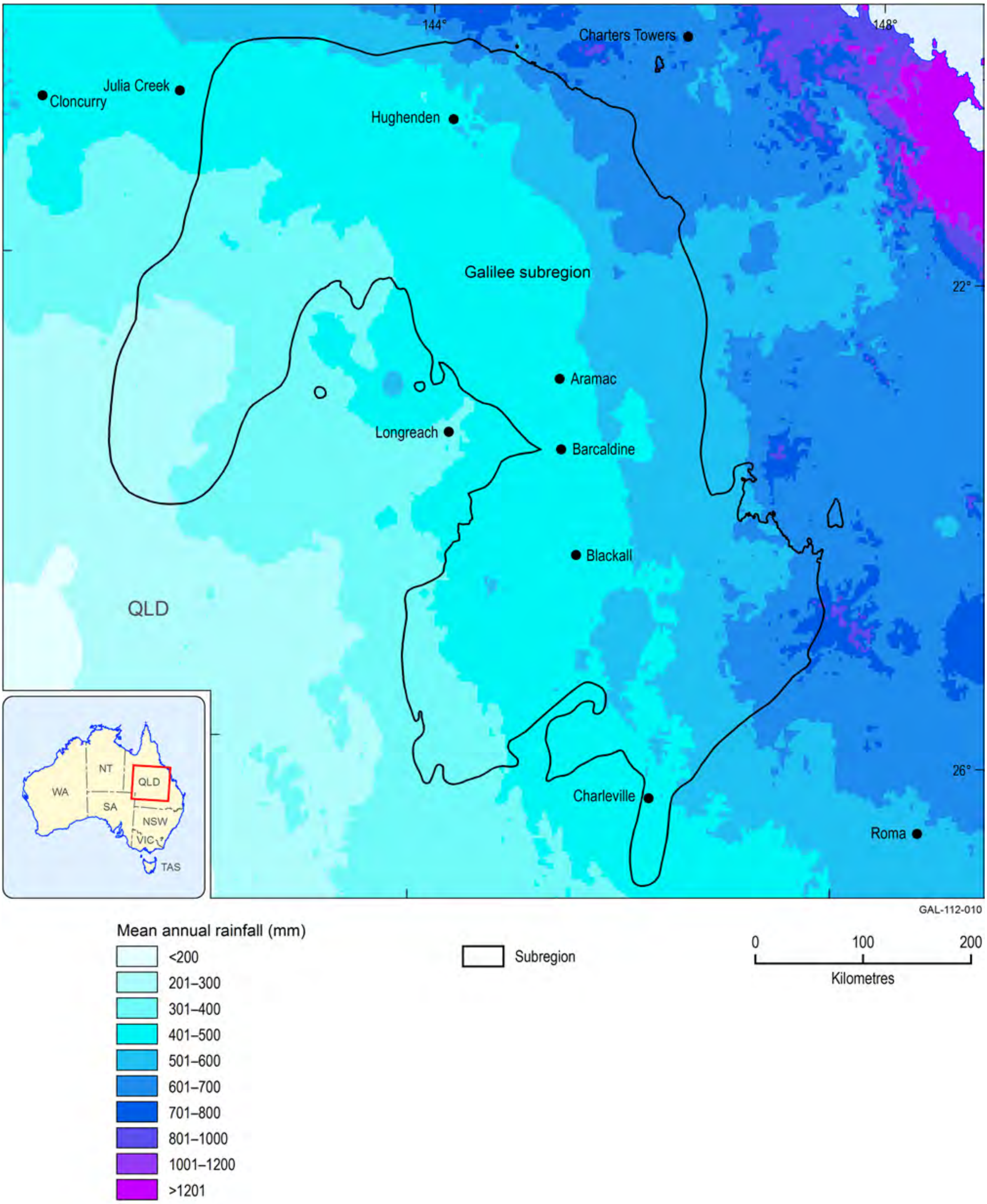


**Figure 11 Mean annual rainfall**

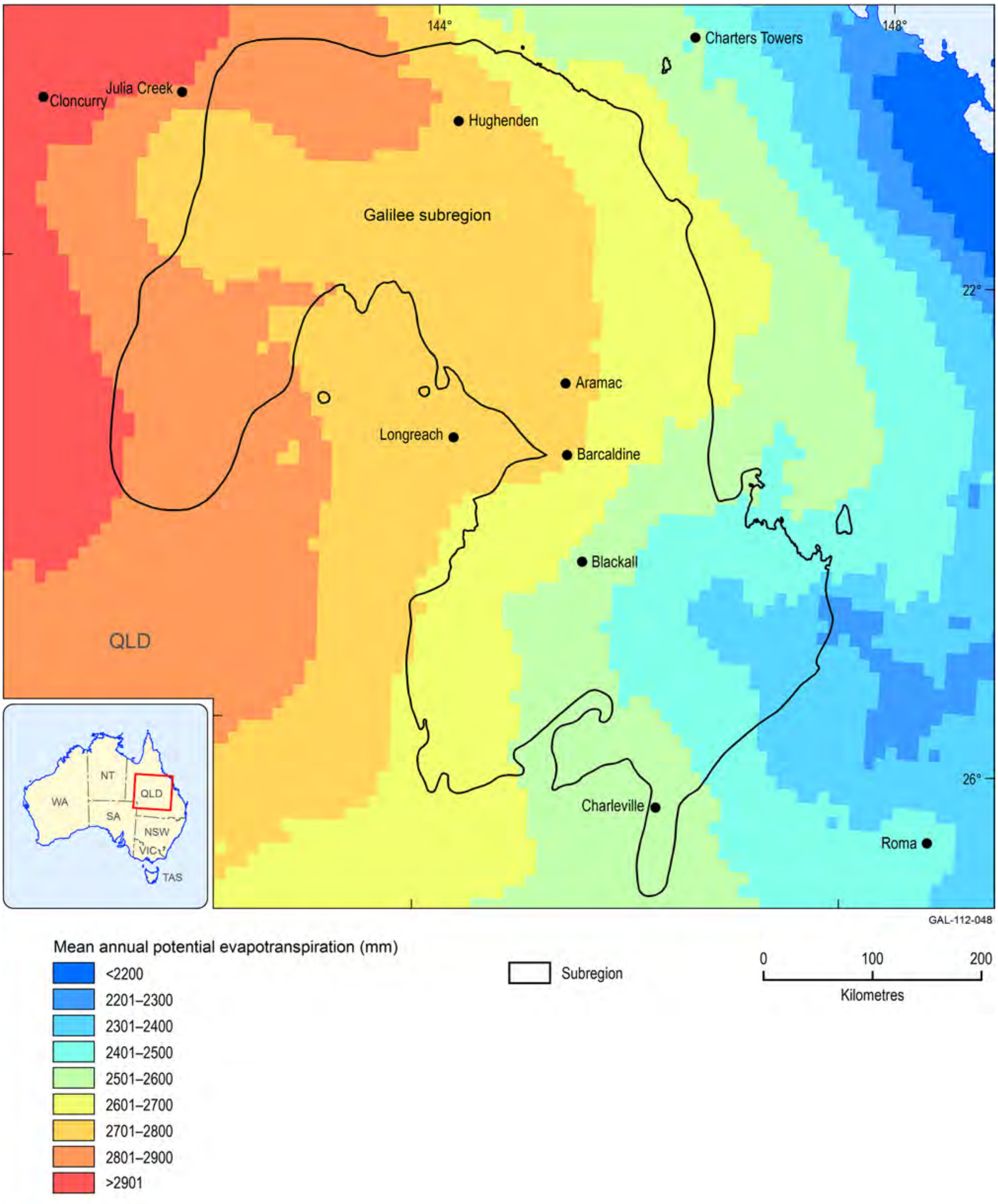


**Figure 12 Mean annual potential evapotranspiration**

### 1.1.2.3 *Climate*

The widely used Köppen-Geiger climate classification scheme to classify world climate is based on the concept that native vegetation forms the best expression of climate. The modified Köppen-Geiger climate classification of Australia adopted by the Bureau of Meteorology (Stern et al., 2000; BoM, 2014) characterises most of the subregion as hot grassland, persistently dry in the south and with dry winters in the north. The north-western part of the subregion is classified as hot desert mostly with dry winters and small patches persistently dry. At the eastern margin are areas classified as subtropical, mostly with moderately dry winters and some small patches of distinctly dry winters. Figure 11 shows mean annual rainfall across the subregion, indicating a strong trend of decreasing values inland from the coast with some added complexity due to elevation of the eastern highlands. Most of the subregion has a mean annual rainfall between 300 and 600 mm but values vary from less than 300 mm in the north-west to more than 700 mm in highland parts of the south-east and north-east. Figure 12 shows the potential evapotranspiration across the subregion with values increasing away from the coast and towards the north and centre of the continent reflecting the high temperatures and low atmospheric moisture of the desert interior. The contrast between Figure 11 and Figure 12 demonstrates the excess of potential evapotranspiration over precipitation across the region. Figure 13 – which shows mean monthly rainfall, potential evapotranspiration, and maximum and minimum temperatures averaged across the subregion – demonstrates that this applies to all months of the year.

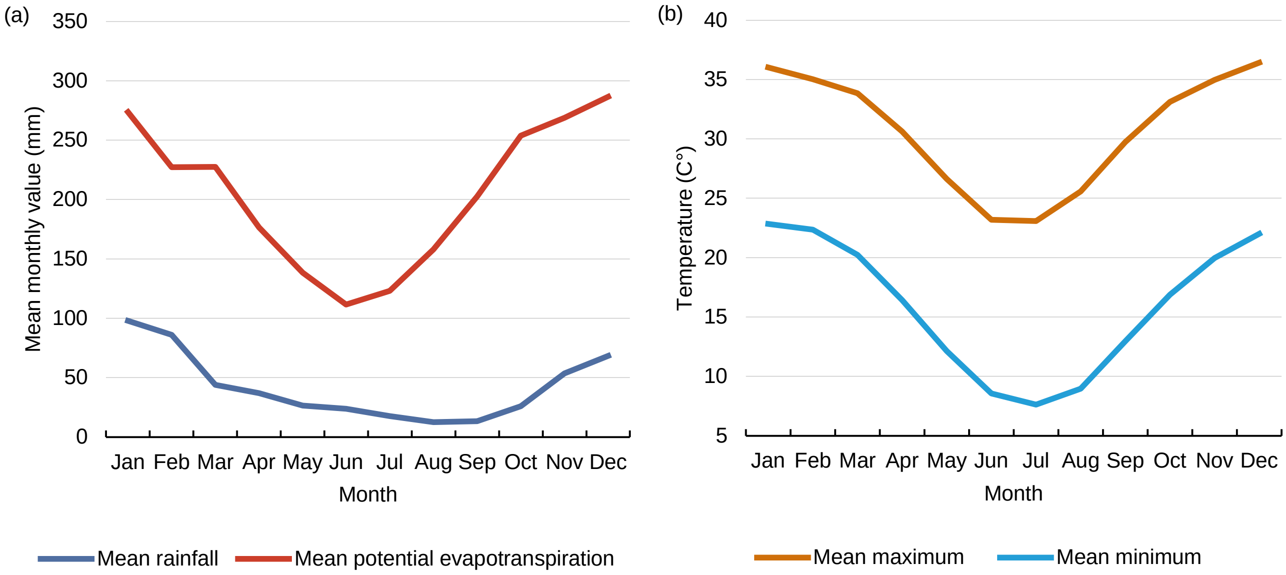


**Figure 13 (a) Mean monthly rainfall and potential evapotranspiration and (b) mean monthly maximum and minimum temperatures averaged over the subregion**

Figure 13 shows that the region experiences hot summers with mean maximum temperatures over 35 °C and minima over 20 °C. Winter maxima are warm (>20 °C) and minima cool (<10 °C) and the relatively large diurnal range throughout the year reflects the continental setting. Precipitation is generally low and shows a distinct summer maximum which is more evident in the northern part of the subregion than the south. Average January precipitation for Hughenden in the north is 114.5 mm compared to 74.4 mm for Charleville in the south. The lowest rainfall occurs in the late winter to early spring period (August to September) and is lower in the north than the south, with Hughenden averaging 7.9 mm and Charleville 19.5 mm for August. Importantly, rainfall is highly variable from year to year across the whole subregion with Hughenden recording the lowest on record to highest on record figures for January of 2.0 mm to 659.7 mm and for August of zero to 119.8 mm. The corresponding figures for Charleville are 4.6 mm to 263.8 mm and zero to 91.5 mm, respectively.

CSIRO and Bureau of Meteorology (2012) is based on historical records and shows a 0.9 °C increase in mean annual temperature between 1910 and 2011. The records show little consistent change between 1910 and 1950 followed by a progressive increase since 1950 , with each decade since 1950 being warmer than the previous decade. This clear warming trend is complicated by a background of natural variability due to factors such as El Niño – Southern Oscillation (ENSO) and regional differences. Overnight minimum temperatures have warmed more than daytime maxima. The records show that the annual average daily mean temperature of the Galilee subregion warmed by 0.4 to 0.8 °C in the north and 0.8 to 1.2°C in the south between 1960 and 2011. Australian rainfall is highly variable but certain trends are evident in some areas, such as reduced winter rainfall in south-western Australia. The Galilee subregion does not lie in a region with a strong rainfall trend but is likely to have had a slight increase over recent decades along with northern monsoon-rainfall areas. Extreme events are rare and it is more difficult to identify statistical trends in their frequency or intensity than it is for average conditions. However, across the continent, hot days and nights, heatwaves, periods of high fire danger and heavy rainfall events have all increased in intensity in recent decades. No significant trend in the frequency of total numbers or high-intensity of tropical cyclones has been apparent in the Australian region. The CSIRO and Bureau of Meteorology (2012) survey concluded that both natural and human influences have affected climate over the past 100 years and that anthropogenic greenhouse gases have caused most of the surface warming, temperature extremes, ocean warming and sea-level rise, which is consistent with global patterns. The reduction in rainfall in the south-west since the 1970s is also most likely to be due to increased anthropogenic greenhouse gases, though other less marked rainfall trends in other regions are more difficult to attribute. Recent droughts, such as the severe ‘millennium drought’ which lasted a decade from the late 1990s, have been exacerbated by higher temperatures that increased water stress.

CSIRO (2007) provides projections of future changes in the Australian climate, under different emissions scenarios, and the application of those projections for impact studies and risk assessments. The study used 23 climate models used by climate research groups around the world with different Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emission scenarios converted to radiative forcing of the climate system. Projections for annual and seasonal mean changes to temperature, rainfall, humidity, solar radiation, wind speed, potential evaporation and sea-surface temperature are provided in probabilistic form but only qualitative assessments were possible for other climate variables. Projections for 2030 showed varying patterns of regional change but minimal impact of different emission scenarios because such shorter-term future projections strongly reflect the impact of greenhouse gases already emitted. Projections for 2050 and 2070 show more variability according to emissions scenario. The median value (50th percentile) is used as the best estimate with the uncertainty range derived from the 10th and 90th percentile values.

According to CSIRO (2007), the best estimate of Australia-wide warming is about 1.0 °C (uncertainty: 0.6 to 1.5 °C) by 2030; about 1.2°C (uncertainty: 0.8 to 1.8 °C) under a low-emissions scenario by 2050; about 2.2 °C (uncertainty: 1.5 to 2.8 °C) under a high-emissions scenario by 2050; about 1.8 °C (uncertainty: 1.0 to 2.5 °C) under a low-emissions scenario by 2070; and about 3.4 °C (uncertainty: 2.2 to 5.0 °C) under a high-emissions scenario by 2070. Warming is higher inland than coastal and northern than southern and lower in winter than other seasons. In the

Galilee subregion the projections of warming are generally higher than the continental average values. According to CSIRO (2007) the 2030 projection is for a mean annual temperature increase in the range of 1.0 to 1.1 °C over most of the subregion, with the western part extending into the 1.1 to 1.2 °C range. The 10th and 90th percentile figures are 0.6 to 0.8 °C and 1.4 to 1.6 °C, respectively. Under the 2050 low-emissions and high-emissions scenarios, projected increases are 1 to 1.5 °C and 2 to 2.5 °C, respectively; the corresponding values for 2070 are 1.5 to 2.0 °C and 3 to 4 °C. Under the low-emissions scenario there is a greater than 90% probability of the subregion exceeding a 1 °C warming by 2070 but less than 10% probability of exceeding 3 °C. Under the high-emissions scenario, there is a greater than 90% probability of exceeding 2 °C and a 20 to 40% probability of exceeding 4 °C.

CSIRO (2007) provides the best current estimate of changes to Australia-wide precipitation. CSIRO (2007) suggests that there will be little change in the far north of Australia and a decrease elsewhere of 2 to 5%, especially in winter and spring and especially in the south-west of Australia. Decadal-scale natural variability is of similar magnitude and may therefore counteract or enhance greenhouse gas emissions forced changes. In the Galilee subregion the best estimate (50th percentile) of projected mean annual rainfall is for a slight decline in the range of 1 to 2.5% with a relatively large uncertainty range from a decrease of 10 to 15% (10th percentile) to an increase on 5 to 10% (90th percentile). However, the minimal annual change contains considerable seasonal variability with summer and autumn precipitation showing minimal increase or decrease, and winter and spring showing stronger decrease from 2.5 to 10%. By 2050 the mean annual precipitation projection ranges from a decrease of 2 to 5% under the low-emissions scenario to 5 to 10% under the high-emissions scenario, with estimates of 2 to 10% and 5 to 20%, respectively, for 2070. By 2070 there is a 30 to 40% probability of a mean annual rainfall decline of at least 10% under the low-emissions scenario and a probability of 50 to 70% under the high-emissions scenario.

Solar radiation, relative humidity and potential evapotranspiration are projected to change little with a very slight increase for the former and a decrease for the latter two in 2030 with slightly greater changes for 2050 and 2070, especially under high-emission scenarios. Drought occurrence is projected to increase with increased effectiveness due to higher temperatures. There is a projected possibility of an increase in more intense tropical cyclones but a decrease in the total number of cyclones. ENSO impact projections suggest that El Niño events will become drier and La Niña events will become wetter.

## *References*

ABARES (2012) Catchment scale land use mapping for Australia update November 2012 (CLUM Update 11/12) dataset. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

ABS (2013a) 3218.0 Regional Population Growth, Australia. Table 3. Estimated Resident Population, Local Government Areas, Queensland. ABS – Regional Population Growth. Viewed 29 May 2014, <http://www.abs.gov.au/ausstats/abs@.nsf/Products/3218.0~2011-12~Main+Features~Queensland>.

ABS (2013b) Census data by location. Australian Bureau of Statistics. ABS – Census data by location. Viewed 29 May 2014, <http://www.abs.gov.au/websitedbs/censushome.nsf/home/map>.

BoM (2014) Bureau of Meteorology climate zones. Viewed 21 March 2014, <http://www.bom.gov.au/iwk/climate_zones/map_2.shtml>.

CSIRO (2007) Climate change in Australia: Technical report 2007. Viewed 29 November 2013, <http://www.climatechangeinaustralia.gov.au/technical_report.php>.

CSIRO and Bureau of Meteorology (2012) State of the climate 2012. Viewed 29 May 2014, <http://www.csiro.au/Portals/Media/2012/State-of-the-Climate-2012.aspx>.

Department of the Environment (2014) A directory of important wetlands in Australia. Department of the Environment, Canberra. Viewed 20 February 2014, <http://www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database/directory-important>.

GA (2011a) 3 Second SRTM Derived Digital Elevation Model (DEM) version 1.0, Geosciences Australia, Canberra

GA (2011b) The National Dynamic Land Cover Dataset, Geosciences Australia, Canberra.

Hills S (1940) The Physiography of Victoria. Whitcomb and Tombs, Melbourne and Sydney, 292 pp.

Horton D (ed) (1994) The Encyclopaedia of Aboriginal Australia. The Australian Institute of Aboriginal and Torres Strait Islander Studies, Aboriginal Studies Press, Canberra, Australia.

Isbell R (2002) The Australian Soil classification. Revised Edition, Australian Soil and Land Survey Handbook Series 4, CSIRO Publishing, 152 pp.

Jennings JN and Mabbutt JA (1977) Physiographic outlines and regions. In: Jeans DN (ed.) Sydney Australia: a Geography. University Press, 38–52.

Jutson JT (1914) An outline of the physiographical geology (physiography) of Western Australia. Second Edition, revised. Western Australia Geological Survey, Bulletin 61, 366 pp.

Lymburner L, Tan P, Mueller N, Thackway R, Lewis A, Thankappan M, Randall L, Islam A and Senarath U (2011) Dynamic Land Cover Dataset Version 1, Geoscience Australia, Record 2011/31, 95 pp.

Pain C, Gregory L, Wilson P and McKenzie N (2011) The Physiographic Regions of Australia: Explanatory notes. Australian Collaborative Land Evaluation Program, 30 pp.

Queensland Treasury and Trade (2013) Estimated resident population (a) by urban centre and locality (b), Queensland, 2002 to 2012r. Queensland Treasury and Trade, Queensland Government. Queensland Treasury and Trade.

Stern H, De Hoedt G and Ernst J (2000) Objective classification of Australian climates. Australian Meteorological Magazine, 49(1): 87–96.

## 1.1.3 Geology

### *Summary*

The principal geological province in the Galilee subregion is the crescent-shaped, intracratonic geological Galilee Basin, which covers about 248,000 km$^2$ of central Queensland. Other geological features of interest for this bioregional assessment subregion include the younger sedimentary sequences of the Eromanga Basin, and the overlying Cenozoic river and lake deposits which have formed over the last 60 million years. These three distinctive packages of sedimentary deposition cover an important period of Australia's geological history, including the major episodes of coal formation in the Permian to Triassic and Jurassic to Cretaceous.

The Galilee Basin is infilled with a mixed assemblage of clastic sedimentary rocks dominated by thick successions of sandstone, mudstone and coal. These rocks were deposited in terrestrial (rivers, lakes and swamps) and marginal marine (deltas and shallow continental slopes) environments from the Late Carboniferous to the Middle Triassic, approximately 323 to 238 million years ago. The maximum stratigraphic thickness in the Galilee Basin is about 2800 metres. The thickest rock sequences occur in structurally controlled depositional centres, such as the Koburra Trough and Lovelle Depression in the northern Galilee Basin and the Powell Depression in the southern Galilee Basin. Underlying the Galilee Basin are several older Paleozoic basins (the Drummond, Belyando and Adavale basins) as well as the basement crystalline rock terranes of the Thompson Orogen and the Mount Isa Inlier.

Surface exposures of Galilee Basin rocks occur only along the eastern margin of the basin, forming an elongated band about 600 km long and up to 80 km wide. West of this outcrop zone the Galilee Basin strata are buried under geologically younger sedimentary deposits such as the Mesozoic rocks of the Eromanga Basin, and the widespread but relatively thin veneer of terrestrial Cenozoic sediments. Deposition within the Eromanga Basin occurred from the Middle Jurassic to the Late Cretaceous, around 175 to 95 million years ago. The Eromanga Basin contains thick sequences of sandstone, mudstone and shale which formed in various depositional settings, such as rivers, lakes, swamps and shallow marine environments.

Multiple stratigraphic units in the Galilee Basin contain significant black coal resources, particularly the Early Permian Aramac Coal Measures and the Late Permian assemblage comprising of the Betts Creek beds, Bandanna Formation and Colinlea Sandstone. Although there are currently no mines in production, existing development plans are proposed for six mines. Some coal resources have also been defined in parts of the upper sequence of the Eromanga Basin (Winton Formation).

The Galilee Basin also has potential for future development of coal seam gas resources. To date, significant greenfield exploration programs have been undertaken in parts of the northern Galilee Basin, with two pilot well fields established in the Aramac Trough.

This geological overview of the Galilee subregion has synthesised the existing geoscientific knowledge of the Galilee Basin and the overlying sedimentary deposits formed in the Mesozoic (Eromanga Basin) and the more recent Cenozoic Era. New outputs herein include an

updated stratigraphic column that integrates (for the first time) the stratigraphic framework for the Galilee and Eromanga basins, as well as the overlying Cenozoic deposits. Additionally, several new maps have been compiled to illustrate key components of the regional surface geology and structural architecture of the Galilee subregion.

## ***1.1.3.1 Geological structural framework***

### 1.1.3.1.1 Introduction

The Galilee subregion encompasses the entire geological Galilee Basin, which is the principal geological feature of interest in the Galilee subregion bioregional assessment. The Galilee Basin encompasses about 248,000 km$^2$ of Central Queensland and is a large, intracratonic, coal-bearing basin. It was an active depositional centre from the Late Carboniferous through to the Middle Triassic (Scott et al., 1995), around 323 to 238 million years ago. Galilee Basin rocks outcrop as an elongated corridor some 600 km long and up to 80 km wide along the eastern margin of the Galilee subregion (Figure 14).

There are three major geological sequences of interest to this bioregional assessment in the Galilee subregion: the Galilee Basin, the Eromanga Basin, and Cenozoic sediments and volcanics. The cross-sections in Figure 15 and Figure 16 demonstrate that rocks in the Galilee Basin are for the most part buried by younger rocks belonging to the Eromanga Basin. Cenozoic sediments and volcanics overlie Eromanga and Galilee basin rocks, but are too thin to be shown on the cross-sections. On the section in Figure 15, the faults that occur near the eastern margin of the Galilee Basin are likely to have a flatter east dip than what is shown.

Crystalline basement rocks underlie the Galilee subregion (Figure 17). The oldest rocks belong to the Proterozoic Mount Isa Inlier, which formed around 1870 to 1500 million years ago (GSQ, 2011) and underlies the north-west Galilee subregion. The rest of the Galilee subregion is underlain by rocks belonging to the Late Proterozoic to Early Paleozoic, Thomson Orogen. It consists of polydeformed, Neoproterozoic to Devonian, volcanic and sedimentary rocks that are intruded by mafic to acidic sills, dykes and plutons (Purdy et al., 2013).

In some parts of the Galilee subregion, the Adavale, Belyando, and Drummond basins overlie the Thomson Orogen basement rocks (Figure 17). The Early to Middle Devonian Adavale Basin sequence includes volcanic rocks, fluvial, marine and evaporative units. The basal unit is the Gumbardo Formation which mainly comprises felsic volcanics and interbedded volcaniclastic sediments. Subsequent tectonic events led to the formation of half-grabens and the deposition of fluvial sediments of the Eastwood beds and Log Creek Formation. Ensuing marine incursion led to the deposition of carbonate and siliciclastic strata of the Lissoy Sandstone and Bury Limestone. A change to arid climate involved the deposition and transformation of carbonate rocks to dolomite, and widespread formation of halite-rich sediments (i.e. Cooladdi Dolomite and Boree Salt formations). Following a hiatus, the Etonvale and Buckabie formations were deposited in fluvial to marginal marine environments (McKillop, 2013).

The Late Devonian to Early Carboniferous Drummond Basin units outcrop to the east of the Galilee subregion, but also underlies the eastern margin of the Galilee Basin. These units consist of sedimentary and volcanic rocks that were deposited in three major depositional cycles (Henderson and Blake, 2013). The stratigraphy of the final cycle, which is in contact with the Galilee Basin, includes the Ducabrook, Natal, Star of Hope and Bulliwallah formations. These units can be up to 1800 m thick and consist primarily of volcaniclastic sandstone, siltstone, mudstone and tuff. Little is known about the Belyando Basin as it has not been drilled, but it predates the Drummond and Galilee basins and is younger than the Thomson Orogen (Draper, 2013).

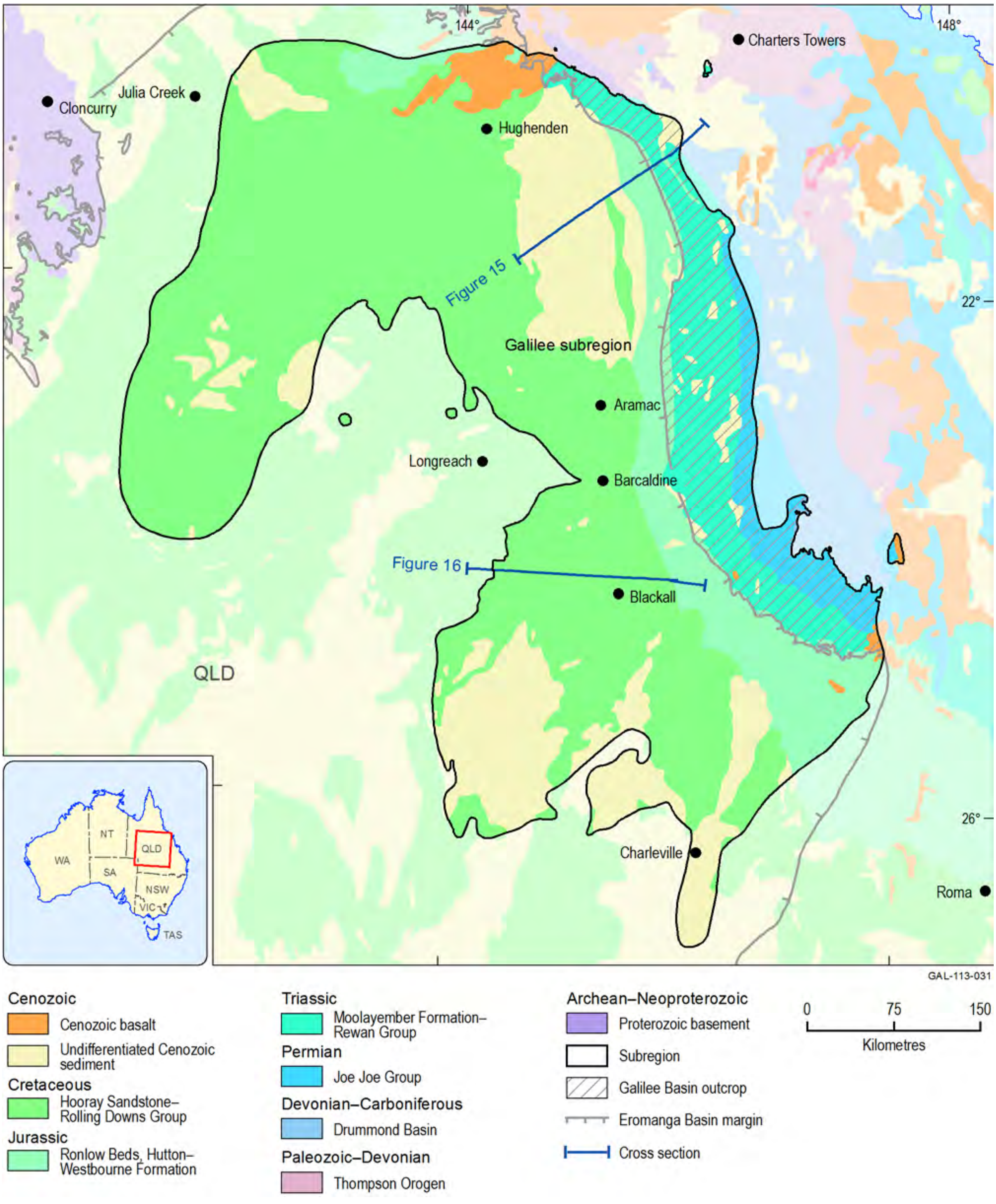


Figure 14 Surface geology of the Galilee subregion and surrounds

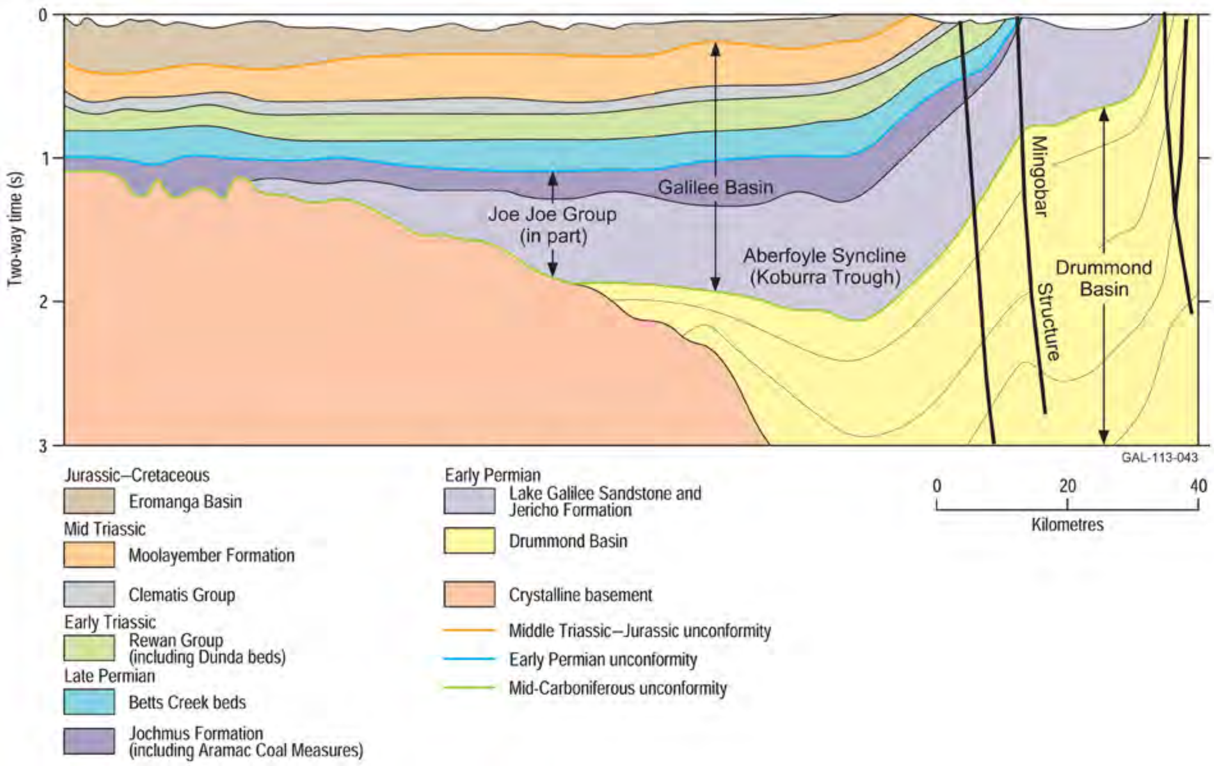


**Figure 15 Cross-section through Koburra Trough and eastern margin of the Galilee Basin**

Source: Figure 3.111 McKellar and Henderson (2013)
TWT equates to Two Way Time. This interpreted geological section is derived from a seismic survey section. Two way time is a measure of the amount of time it takes for sound wave generated by a seismic survey to be reflected off a feature in the earth then return to surface.

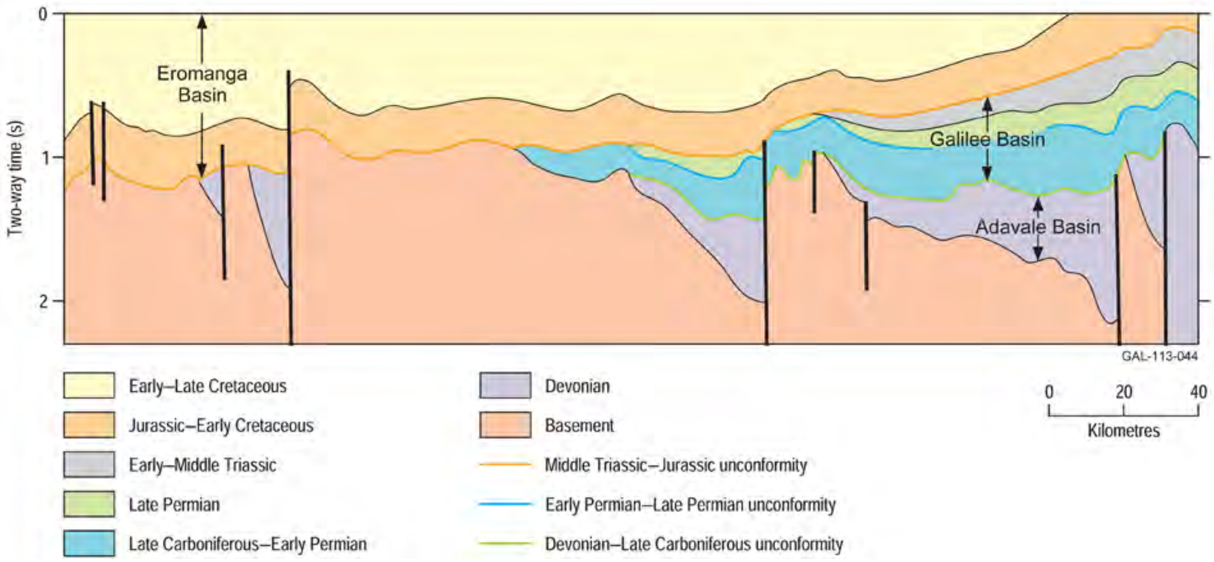


**Figure 16 Cross-section through southern Galilee subregion**

Source: Figure 3.113, McKellar and Henderson (2013)
TWT equates to Two Way Time. This interpreted geological section is derived from a seismic survey section. Two way time is a measure of the amount of time it takes for sound wave generated by a seismic survey to be reflected off a feature in the earth then return to surface.

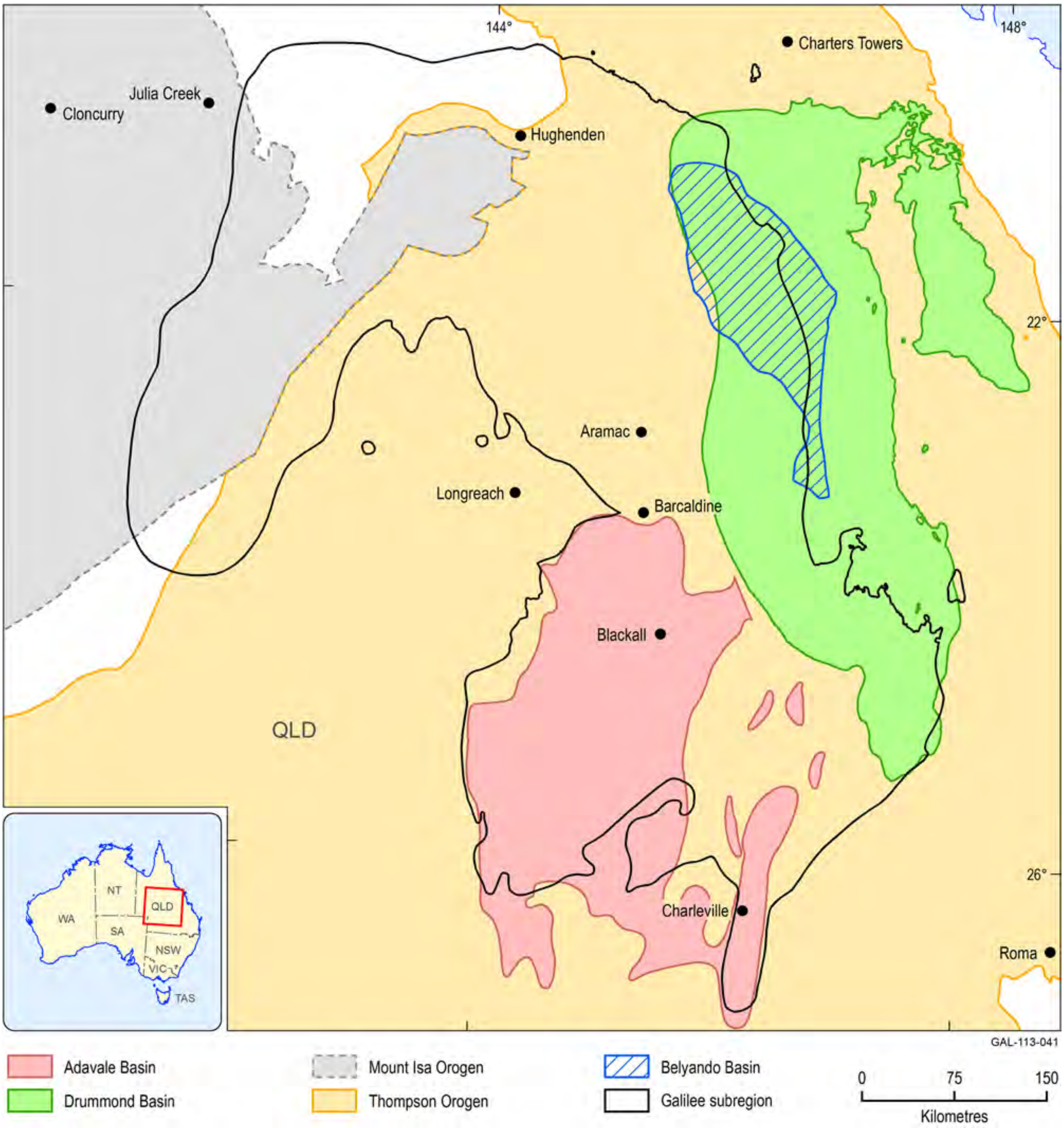


**Figure 17 Geological features underlying the Galilee Basin**

### 1.1.3.1.2 Subregion structure

There are many significant geological structures in the Galilee subregion (Figure 15, Figure 16, and Figure 18). They have played an important role in determining the present day spatial and stratigraphic distribution of rock types (including coal) in the Galilee Basin. Structural fabrics in the Galilee Basin have also influenced the structural architecture in the overlying Eromanga Basin (Cook et al., 2013). The following describes the key architectural elements within the Galilee subregion.

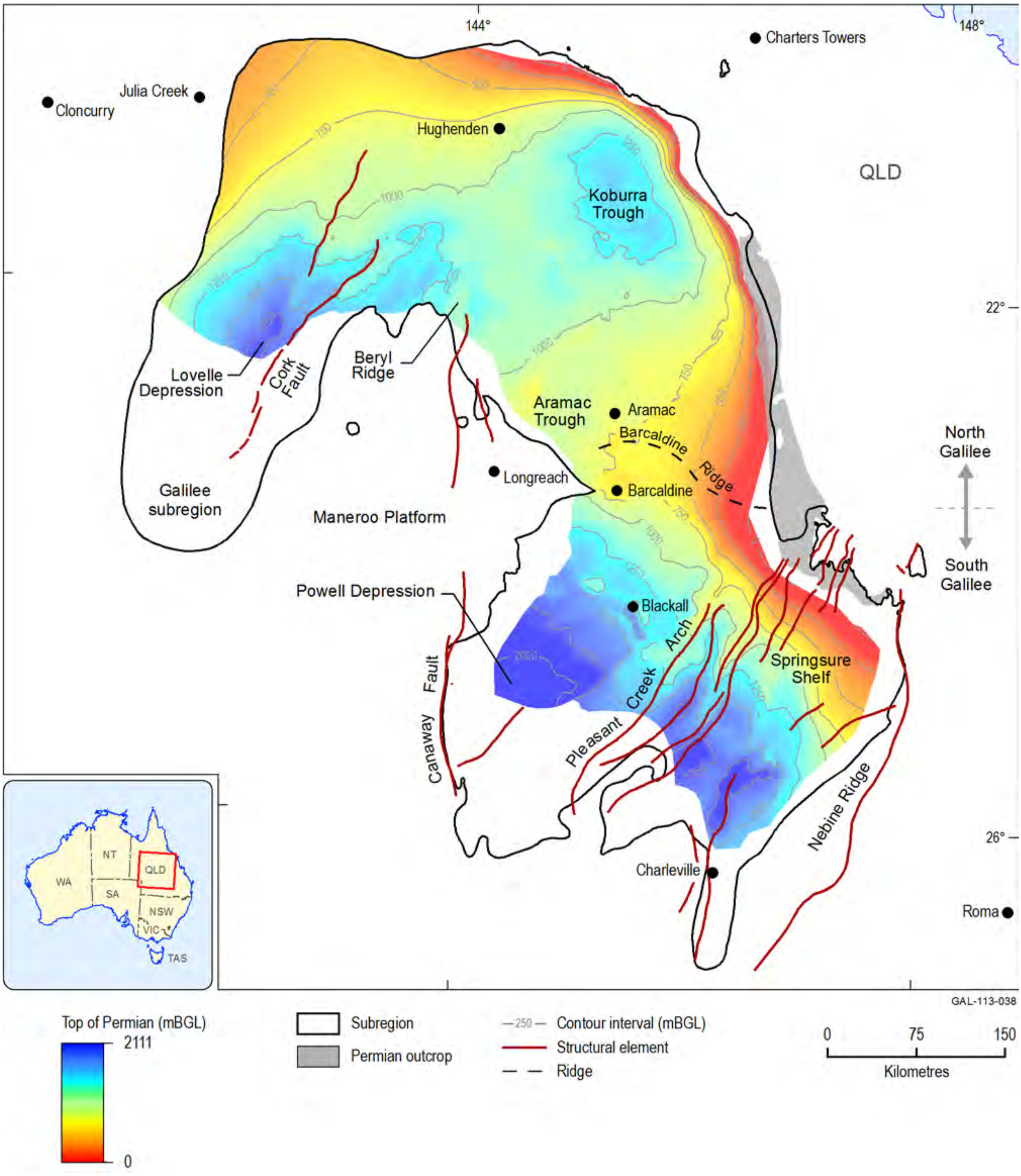


**Figure 18 Structures and depositional centres in the Galilee Basin**

Source data: Top of Permian surface mapping derived from Bradshaw et al. (2009). While Permian exists throughout the basin, not all of it was shown in the mapping presented in Bradshaw et al.(2009).
mBGL – Metres below ground level

**Maneroo Platform**: Broad structural high composed of Paleozoic basement situated between the Powell and Lovelle depressions on the western side of the Galilee Basin. The Maneroo Platform existed as a structural high during the Permian and Triassic. It exerted significant influence on the paleogeography of the Galilee Basin and has also affected structuring in the overlying Eromanga Basin. Monoclinal folds found in the vicinity of the Maneroo Platform margin deform both the Galilee and Eromanga basins.

**Canaway Fault/Canaway Ridge:** North-trending structures that separate the Galilee from the Cooper Basin. The Canaway Fault is a normal fault downthrown to the east (Galilee side), which was active during the Early Permian. Late Permian to Triassic sedimentary rocks can be correlated between the two sedimentary basins, across this major fault. Reactivation during the Paleogene increased displacement across the fault by about 400 m (Ransley et al., 2012).

**Nebine Ridge:** North-trending basement high that forms a boundary between sedimentary sequences in the Bowen Basin – Surat Basin to the east and the Galilee Basin – Central Eromanga Basin to the west.

**Barcaldine Ridge**: A major easterly-trending ridge composed of crystalline basement rocks, situated around 24° South latitude near the town of Barcaldine. It segregates the northern Galilee Basin from the southern Galilee Basin. The Barcaldine Ridge exerted significant influence on the deposition of stratigraphic sequences during the Permian, acting as a partial barrier between the north and south Galilee Basin.

The terms north Galilee Basin and south Galilee Basin are not formalised geological subdivisions. However, they are commonly used terms in the literature and will be adopted for this report. Some major structural features in the northern and southern Galilee Basin are:

***North Galilee Basin***

**Lovelle Depression:** North-east trending depression infilled with up to 700 m of Galilee Basin rocks (Hawkins and Green, 1993). It was also an active depositional centre for the overlying Eromanga Basin.

**Cork Fault:** A basement-intersecting normal fault, downthrown to the west. It occurs along the south-eastern margin of the Lovelle Depression. This fault was active during the development of the Lovelle Depression in the Early Permian (Van Heeswijck, 2010). It was later reactivated in the Paleogene, with a further 420 m of displacement (Ransley et al., 2012).

**Beryl Ridge:** North-trending ridge of crystalline basement that forms an extension from the Maneroo Platform.

**Aramac Trough:** North-easterly trending depression running from the edge of the Maneroo High towards the Koburra Trough.

**Koburra Trough:** Significant north-trending trough near the eastern margin of the Galilee Basin, mainly north of the Barcaldine Ridge. The Koburra Trough is interpreted as one of the earliest features to form in the Galilee Basin and contains up to 2800 m of sedimentary rocks. Part of the eastern margin of the trough is structurally defined by a series of folds and east dipping thrust faults (White Mountains Structure; Mingobar Monocline; Hopkins Thrust; Van Heeswijck, 2010). The Koburra Trough was not an active depositional centre for the Eromanga Basin.

***South Galilee Basin***

**Powell Depression:** North-easterly trending depression adjacent to the Maneroo Platform and west of the Pleasant Creek Arch. This is the main depositional centre for the south Galilee Basin. It was also active as a depositional centre for the Jurassic Eromanga Basin.

**Pleasant Creek Arch:** North-east trending structure between the Springsure Shelf and south-eastern margin of the Powell Depression. It is associated with the Warrego Fault.

**Springsure Shelf:** The area located between the Nebine Ridge and Pleasant Creek Arch near the south-eastern margin of the Galilee Basin. Significant north-east trending fold structures that occur in this region are not evident in the north Galilee Basin (Van Heeswijck, 2006). The folds developed during the Paleogene (around 50 Ma) and have deformed sedimentary sequences in the Galilee Basin and overlying Eromanga Basin.

### *1.1.3.2 Stratigraphy and rock type*

Except where noted and discussed otherwise, the classification followed in this report adopts the current formal stratigraphic nomenclature from the Australian Stratigraphic Unit Database (Geoscience Australia, 2012). Figure 19 is a stratigraphic column for the Galilee subregion. The Galilee Basin stratigraphy is after McKellar and Henderson (2012), and the Eromanga Basin stratigraphy after Ransley et al. (2012).

For Figure 19, the stratigraphy is subdivided into three chronostratigraphic intervals: the Late Carboniferous to Early Triassic (Galilee Basin), Middle Jurassic to Middle Cretaceous (Eromanga Basin) and the Cenozoic. The Galilee Basin stratigraphy is further subdivided into three geographical regions, because of the structural influence on the paleogeography of the basin. The northern section includes units around the northern margin of the Galilee Basin as well as the Lovelle Depression. The eastern section covers the Koburra Trough, Aramac Trough and westwards to the Maneroo Platform. The southern section applies to areas of Galilee Basin south of the Barcaldine Ridge.

#### 1.1.3.2.1 Galilee Basin

The Galilee Basin stratigraphy presented in this report is based on the most recent compilation of McKellar and Henderson (2013). Galilee Basin stratigraphic units for most part unconformably overlie the older geological basement terranes and the Adavale, Belyando and Drummond basins. Conformable stratigraphic relations may exist in places between Late Carboniferous Galilee and Drummond basins (Van Heeswijck, 2010).

Galilee Basin stratigraphy is complicated by local variations in the timing of deposition in different parts of the basin. Broadly there are two major depositional intervals; the Late Carboniferous to Early Permian Joe Joe Group and a Late Permian to Middle Triassic sequence. The Late Permian to Middle Triassic sequence includes the: Betts Creek beds, Rewan Group, Clematis Group and Moolayember Formation. A significant unconformity separates the Lower and Upper Permian sedimentary sequences. Further information on paleogeography and stratigraphy of the Galilee Basin is documented in Scott et al. (1995), Hawkins and Green (1993) and Wells (1989).

### *Joe Joe Group*

**Lake Galilee Sandstone** (Late Carboniferous): fine- to medium-grained quartzose sandstone with minor mudstone. It is the basal unit for the Koburra Trough and outcrops along the eastern margin of the Galilee Basin (McKellar and Henderson 2013; Bradshaw et al., 2009). The maximum stratigraphic thickness is 260 m.

**Jericho Formation** (Late Carboniferous): consists of diamictite, conglomerate, and sandstone with interbedded siltstone. This formation records up to three glacial – interglacial events, with interglacial sediments deposited in lacustrine to fluvial environments (Jones and Fielding, 2008). The Jericho Formation outcrops along the eastern margin of the Galilee Basin, but also occurs in the Koburra Trough and southern Galilee Basin. The Jericho Formation is up to 760 m thick and includes the Oakleigh Siltstone Member. It was recognised as a distinct seismic facies (G1) by Van Heeswijck (2010).

**Jochmus Formation** (Early Permian): volcanic-lithic sandstones with interbedded silty tuff. It includes the Edie Tuff Member. The Boonderoo beds, which outcrop along the north-eastern margin of the Galilee Basin, are an equivalent of the Upper Jericho and Jochmus formations (McKellar and Henderson, 2013). Much of the Jochmus Formation was deposited in fluvial environments with minor glaciogenic influence. It occurs in the Koburra Trough, Aramac Depression, and the Lovelle Depression (Hawkins and Green, 1993) but has a restricted distribution in the southern Galilee Basin (Bradshaw et al., 2009). It has a maximum recorded thickness of around 750 m and was recognised as a distinct seismic facies (G2) by Van Heeswijck (2010).

**Aramac Coal Measures** (Early Permian): Dominated by sandstone with coal and mudstone interbeds. They only occur in the northern Galilee Basin and its extent was defined by drill intersections and seismic surveys. The distribution of the Aramac Coal Measures is restricted to the Aramac Trough, small depressions in the Galilee Basin around the margin of Maneroo Platform, and the Lovelle Depression. It is a lateral equivalent to the Upper Jochmus Formation. Although the Aramac Coal Measures have been significantly truncated by erosion, it can still be up to 250 m thick.

A significant unconformity occurs between the Early and Late Permian sequences. This was a period of non-deposition and erosion.

**Weston beds** (Permian): An informal stratigraphic unit consisting of sandstone that is unconformably bounded between the Aramac Coal Measures and Betts Creek beds. It is restricted to the Lovelle Depression.

**Betts Creek beds** (Late Permian): Interbedded siltstone, mudstone, coal, and sandstone deposited in fluvial and coastal plain environments (Bradshaw et al., 2009). The Betts Creek beds outcrop along the north-east margin of Galilee Basin and also occur in the Koburra Trough, Lovelle Depression and west of Maneroo Platform (Hawkins and Green, 1993). It was recognised as a distinct seismic facies (G3) by Van Heeswijck (2010).

The Betts Creek beds have been correlated with sedimentary rocks in the Bowen Basin. From oldest to youngest, these are the Colinlea Sandstone, Peawaddy Formation, Black Alley Shale and Bandanna Formation. These rock units have also been identified in southern Galilee Basin. Further information on their distribution can be found in Section 1.1.3.4.

Allen and Fielding (2007) identified six transgressive-regressive stratigraphic sequences within the Betts Creek beds, and correlated them with sequences in the Bowen Basin. Sequence 6 in the Betts Creek beds is thought to correlate with the Bandanna Formation. Allen and Fielding (2007) considered the Betts Creek beds to have been deposited at a time when there was little accommodation space available for sediment deposition within the Galilee Basin, suggesting minimal tectonic influence on its depositional architecture.

**Colinlea Sandstone** (Late Permian): medium to coarse-grained sandstone with interbedded siltstone mudstone and coals deposited in fluvial to lacustrine environments.

**Peawaddy Formation and Black Alley Shale** (Late Permian): the Peawaddy Formation is predominantly sandstone with minor siltstone, mudstone and coal deposited in marginal marine to deltaic environments (Hawkins and Green, 1993). The Black Alley Shale consists of dark grey to black shale and siltstone, interbedded with light green-grey tuff and fine-grained sandstone.

The Peabody Formation and Black Alley Shale thin onto the Barcaldine Ridge and are largely restricted in distribution to the southern Galilee Basin (Wells, 1989).

**Bandanna Formation** (Late Permian): interbedded sandstone, siltstone, mudstone and coal deposited in paludal, fluvial and lacustrine environments. Only the Black Alley Shale and Bandanna Formation have been identified in the Powell Depression (Hawkins and Green, 1993).

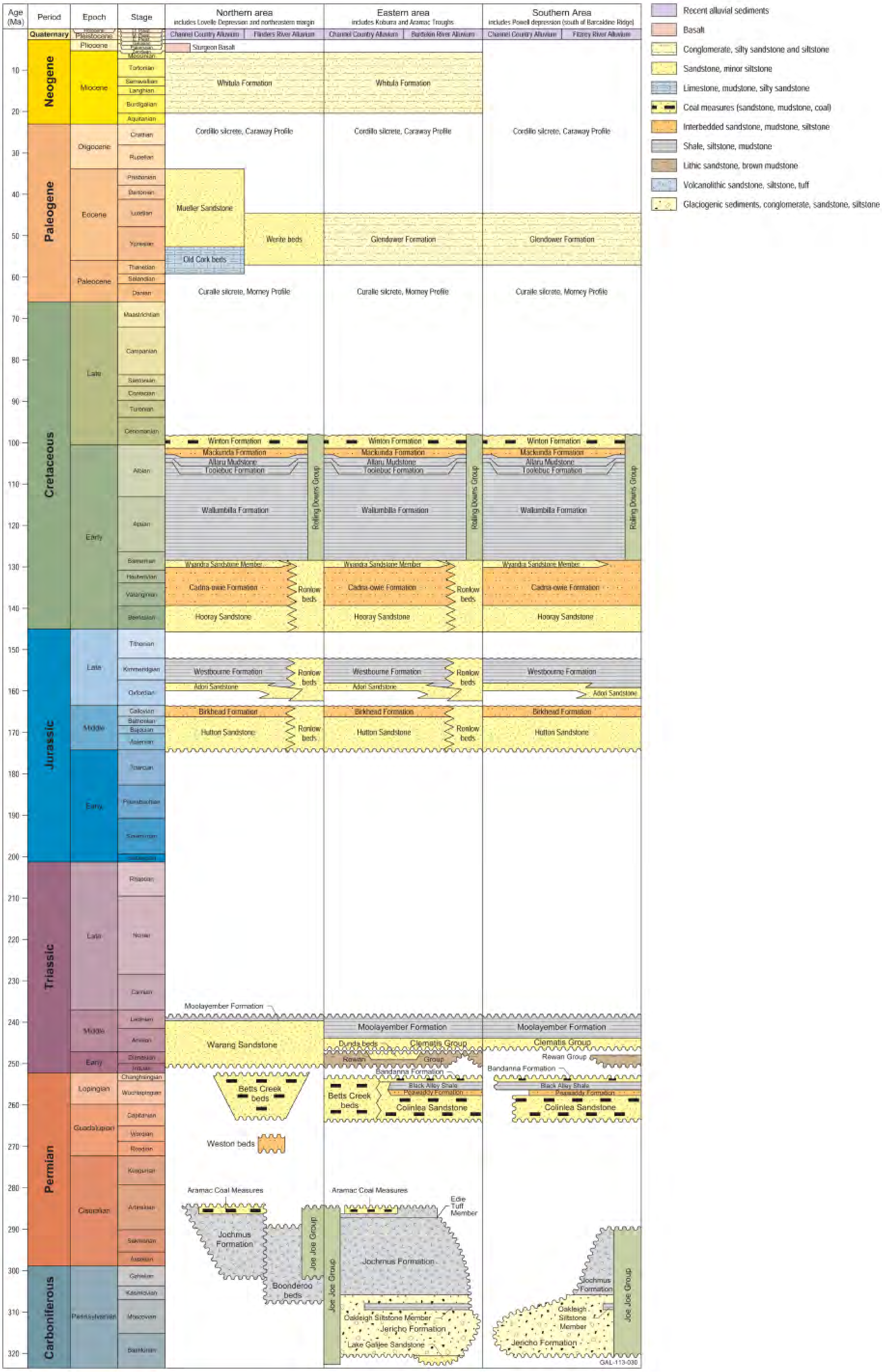


**Figure 19 Stratigraphic column for the Galilee subregion showing coal-bearing units**

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

**Rewan Group and Dunda beds** (Early Triassic): consists of interbedded light grey sandstone and grey-green mudstone (Hawkins and Green, 1993). It was recognised as a distinct seismic facies (G4) by Van Heeswijck (2006).The Dunda beds are a predominantly sandy facies that is conformable with upper sections of the Rewan Group. The Dunda Beds outcrop along the north-eastern margin of the Galilee Basin and occur in the vicinity of the Koburra Trough.

**Clematis Group** (Early – Middle Triassic): unconformably overlies the Rewan Group and consists predominantly of sandstone with minor siltstone, mudstone and conglomerate deposited in braided fluvial environments. This is an equivalent of the Warang Sandstone.

**Warang Sandstone** (Early – Middle Triassic): Up to 700 m thick quartz-rich sandstone with interbedded siltstone and mudstone. It is a basin margin facies prevalent across much of the far northern Galilee Basin and parts of the Lovelle Depression (Hawkins and Green, 1993; Scott et al., 1995). The Warang Sandstone is coeval with the Rewan Group, Clematis Group and the lower Moolayember Formation. The upper Moolayember Formation conformably overlies the Warang Sandstone.

**Moolayember Formation** (Middle Triassic): consists mostly of siltstone and mudstone deposited in lacustrine and fluvial environments. It conformably overlies the Clematis Group and blankets much of the Galilee Basin and Maneroo Platform (Hawkins and Green, 1993) and is the uppermost stratigraphic unit of the Galilee Basin sequence.

### 1.1.3.2.2 Eromanga Basin

The Eromanga Basin constitutes most of the sedimentary cover over the Galilee Basin (Figure 14 to Figure 16). A significant unconformity, representing approximately a 65 million year period of non-deposition, separates rocks of the Galilee and Eromanga basins. This section only focuses on major stratigraphic groups of the Eromanga Basin. Further detail can be found in Ransley et al. (2012). In the Galilee subregion, the Eromanga Basin sequence is at its thickest in the Powell and Lovelle depressions (up to 1800 m), which suggests that these Galilee Basin depositional centres were actively subsiding during deposition of the Jurassic and Cretaceous Eromanga sequences (Wells, 1989). In contrast, subsidence had ceased in the Koburra Trough as the Eromanga Basin sedimentary rocks do not thicken above it.

From oldest to youngest the Eromanga Basin sequences include:

**Ronlow beds** (Middle Jurassic – Early Cretaceous): quartzose sandstone with minor siltstone, mudstone and coal deposited in fluvial to floodplain environments. It overlies parts of the northern Galilee Basin and outcrops along the eastern margin of the Eromanga Basin as far south as Barcaldine.

‘Ronlow beds’ is an informal stratigraphic name (Geoscience Australia, 2012), but the rocks are an equivalent of the Hutton Sandstone-Hooray Sandstone-Cadna-owie Formation, which occur in other parts of the Galilee subregion. Several depositional hiatuses are present in the Late Jurassic to Early Cretaceous section of the Ronlow beds (Cook et al., 2013).

**Hutton Sandstone, Hooray Sandstone Cadna-owie Formation:** (Middle Jurassic – Early Cretaceous): The Hutton Sandstone consists mainly of quartzose sandstone with minor siltstone and mudstone interbeds deposited in braided fluvial environments (Draper, 2002). The Birkhead Formation, Westbourne Formation and the Adori Sandstone, conformably overlie the Hutton Sandstone.

The Birkhead Formation consists of interbedded sandstone and siltstone with minor shale. The Adori Sandstone is mostly sandstone with minor siltstone, and the Westbourne Formation is dominated by siltstone and shale. The Birkhead Formation was deposited in fluvial and lacustrine settings, whereas braided fluvial systems dominated during deposition of the Adori Sandstone. The Westbourne Formation was predominantly deposited in a lacustrine setting (Draper, 2002).

The Hooray Sandstone is predominantly quartzose sandstone deposited in a braided fluvial environment. This unit transitions into the Cadna-owie Formation, which consists of fine-grained sandstone with siltstone and silty mudstone beds. The Cadna-owie Formation was deposited in a shallow marine environment and is conformably overlain by the Rolling Downs Group.

**Rolling Downs Group** (Early Cretaceous to base of Late Cretaceous). The Rolling Downs Group includes the Wallumbilla and Toolebuc formations, Allaru Mudstone, and the Mackunda and Winton Formations. The bulk of Eromanga outcrop in the Galilee subregion is assigned to the Rolling Downs Group.

The Wallumbilla Formation to Allaru Mudstone sequence consists predominantly of shale and mudstone with minor impure limestone and volcanic-lithic sandstone. These units were deposited in shallow to deep marine environments and represent a significant marine transgressive phase across the Eromanga Basin.

The Mackunda Formation consists of interbedded volcanolithic feldspathic sandstone, siltstone, and mudstone with minor limestone. It was deposited in shallow marine to marginal marine environments during the final regression in the Eromanga Basin.

The Winton Formation consists of interbedded volcanolithic feldspathic sandstone, siltstone, mudstone and coal. Deposition of the Winton Formation marks the return to terrestrial environments following the earlier marine transgression. The lower sections were deposited in a series of estuarine, deltaic and fluvial environments, whereas the upper sections were deposited in fluvial to lacustrine environments (McKellar and Draper, 2013). The Winton Formation contains a significant assemblage of dinosaur fossils including the famous Winton dinosaur tracks.

#### 1.1.3.2.3 Cenozoic

In the Galilee subregion, significant erosion and intense weathering occurred during the Late Cretaceous to Early Palaeogene (Early Cenozoic). This resulted in the formation of the Morney weathering profile, which consists of up to 95 m of kaolinised deeply weathered sediments capped by 5 m of silcrete. Sedimentation recommenced in the Late Paleocene with the main stratigraphic units being:

**Glendower Formation** (Late Paleocene – Middle Eocene): comprises up to 70 m of quartz sandstone, pebble conglomerate, sandy conglomerate and subordinate siltstone and mudstone with a well-developed upper silcrete. It occurs as an irregular elongate valley-fill tract that extends across the Galilee subregion from near Hughenden to south-west of Longreach. From Longreach it develops into a sheet-like deposit that covers much of south-western Queensland, as well as the south-western Galilee subregion. The Glendower Formation has been variously correlated with (Grimes, 1980; Draper, 2002), or included in (Senior, 1979) the Eyre Formation (Callen et al., 1995), which is a widespread (commonly lignitic) fluvial deposit in the geological Lake Eyre Basin of South Australia.

**Old Cork beds** (Late Paleocene): the sub-circular Old Cork Basin occurs west of the Cork fault over the Lovelle Depression of the Galilee Basin and contains generally flat-lying sediments with extensive silicification and ferruginisation of the upper part of the sequence. The basal Old Cork beds comprise up to 78 m of freshwater (lacustrine deposited) limestone and mudstone with subordinate silty sandstone, calcareous sandstone and sandy siltstone (Cook, 2013).

**Mueller Sandstone** (Eocene) and **Werite beds**: comprises up to 9 m of coarse-grained fluvial-deposited pebbly sandstone and pebbly conglomerate, which unconformably overlies the Old Cork beds in the Old Cork Basin (Cook, 2013).

Similar Paleogene continental lacustrine, paludal and fluvial sediments occur in the Springvale Basin at the north-western margin of the Galilee subregion. It outcrops as the Werite beds at the eastern margin of the Lovelle Depression (Cook, 2013).

**Whitula Formation** (Miocene): comprises up to 160 m of interbedded fluvial and lacustrine conglomerate, quartzose sandstone, siltstone and mudstone which is partially gypsiferous and lignitic. It unconformably overlies Cretaceous rocks and the Paleocene Glendower Formation. Similar sediments are recognised in the Springvale Basin (Horse Creek Formation) at the north-western margin of the Galilee subregion.

**Sturgeon Basalt** (Pliocene - Pleistocene): overlies the Glendower Formation near Hughenden (Cook, 2013). The Sturgeon Basalt is a part of the Sturgeon basalt province. Geomorphic evidence suggests that Sturgeon basalt province was formed by at least three major episodes of volcanism, each volcanic episode was separated by a period of erosion (Cohen et al., 2013).

### *1.1.3.3 Basin history*

Extensional tectonism in the Late Carboniferous initiated formation of the Koburra Trough, and resulted in the deposition of Lake Galilee Sandstone (Van Heeswijck, 2010). This was followed by deposition of the Jericho Formation in the Koburra Trough and the southern Galilee Basin.

By the Early Permian, sedimentation had become more widespread with deposition of the Jochmus Formation across the northern Galilee Basin and the Lovelle Depression. At the same time the Boonderoo beds were deposited around the north-eastern margin of Galilee Basin. The Aramac Coal Measures were formed west of the Koburra Trough and in the Lovelle Depression during the latter stages of deposition of the Jochmus Formation. Minor uplift and faulting took place along pre-existing structures near the eastern margin of the Galilee Basin, towards the end of Early Permian sedimentation (Van Heeswijck, 2010). A significant erosional-non depositional event occurred across the Galilee Basin during the Early to Late Permian.

Sedimentation recommenced in the Late Permian with the deposition of coal-rich Betts Creek beds and its correlatives to the south, the Colinlea Sandstone - Bandanna Formation sequence. In the Early to Middle Triassic this was followed by deposition of the Rewan and Clematis groups and their lateral equivalent in the north-eastern Galilee Basin, the Warang Sandstone. The Moolayember Formation was the final sedimentary unit deposited in the Galilee Basin.

By the end of the Hunter-Bowen Orogeny in the Middle Triassic, sedimentation in the Galilee Basin ceased. This was accompanied by inversion of eastern Galilee Basin margin with reactivation of pre-existing structures (McKellar and Henderson, 2013). I’Anson (2013) suggests that in the Middle Triassic to Middle Jurassic, the amount of Galilee Basin sedimentary sequence that was eroded away was less than 600 m thick.

In the Galilee subregion, sediment deposition in the Eromanga Basin commenced in the Middle Jurassic. Here, the Ronlow beds and their equivalents, the Hutton Sandstone to Hooray Sandstone, and the Cadna-owie Formation, comprise the basal sequences of the Eromanga Basin. With the exception of the Cadna-owie Formation, these sequences were deposited in fluvial-lacustrine or braided fluvial environments. The Lower Cretaceous Cadna-owie Formation was deposited in marginal marine environments, which marked the onset of a major marine transgression across the Eromanga Basin.

Deep marine environments existed throughout much of the Early Cretaceous until the deposition of the Makunda Formation, which formed in shallow marine settings as sea levels regressed across the Eromanga Basin. The Winton Formation heralds the return of continental fluvial deltaic depositional environments in the Eromanga Basin. Deposition of the Winton Formation ceased in the earliest stages of the Late Cretaceous.

Extensive planation and deep weathering of the Late Cretaceous Eromanga Basin surface continued into the Paleocene with formation of the Morney weathering profile, which can be up to 95 m deep and is characterised by kaolinite, ferricrete, mottling, capped by the Curalle silcrete. I’Anson (2013) suggests that during this time, the thickness of sedimentary sequence that was eroded away varied from 500 to 1900 m across the Galilee Basin region.

At the beginning of the Cenozoic, Queensland was emergent above sea level and in a relatively passive extensional tectonic regime with a low-lying plain west of the Eastern Highlands. This period is characterised by shallow isolated basins produced by mild regional deformation (Jell, 2013). Three broad Cenozoic cycles of uplift, erosion and deposition with intervening landscape stability and deep weathering are recognised west of the Eastern Highlands.

A Late Paleocene to Early Eocene depositional hiatus marks the onset of a new cycle of tectonic activity and the end of an extension regime for eastern Australia and Papua New Guinea. Geological structures in the Eromanga and Galilee basins were reactivated and in places Eromanga Basin rocks were faulted and deformed into a series of folds (McKellar and Draper, 2013). During this time, warping and erosion of the Morney Profile occurred with deposition of fluvial siliciclastic sediments in some isolated depositional centres and as broader sheets of quartz sandstone, pebble conglomerate, sandy conglomerate and subordinate siltstone and mudstone across the Lake Eyre surface drainage catchment.

By the end of the Eocene, tectonic activity waned and planation occurred across the basin which was accompanied by deep weathering and the formation of silcrete and ferricrete. These erosive and deep weathering events resulted in the development of the Featherby Surface and the

Canaway Profile. The Oligocene to Early Miocene Canaway Profile consists of up to a 50 m deep weathering profile capped by the Cordillo silcrete.

In the Late Oligocene, subsidence along the north-eastern continental margin was associated with north-south compression in western Queensland, which modified the small regional Paleogene basins and gently warped their sediments, weathering profiles and duricrusts. During the Miocene, a second succession of sedimentation, in part derived from earlier Paleogene sediments, was initiated and resulted in the deposition of sedimentary sequences such as the Whitula Formation (Jell, 2013).

The Late Miocene conclusion of this second depositional cycle and associated planation and weathering events are not well defined in the region. From the Late Miocene, western Queensland was relatively stable, and well-weathered colluvial and channel and floodplain fluvial sediments were deposited as gentle Pliocene uplift and warping occurred (Cook, 2013). The Sturgeon Basalt erupted near Hughenden in the Pliocene to Pleistocene.

Post-Miocene duricrust stratigraphy is less well understood within the region although some Pliocene silcrete has been described. Gypcretes began to form as the paleoclimate trended towards greater aridity in the Pliocene and Quaternary (Cook, 2013).

The Quaternary has been dominated by the repetitive global glacial-interglacial temperature oscillations, driven by Milankovitch orbital insolation cycles. In western Queensland, far from sites of glaciation, these cycles have seen oscillation from warm, wetter interglacials with enhanced monsoon rainfall, runoff and fluvial and lacustrine deposition to cool dry glacials with reduced monsoon and enhanced aeolian sedimentation (Price, 2013).

Most of the Galilee Basin is covered by the Lake Eyre drainage catchment, which includes channel country river systems of the Diamantina and Cooper. Deposition in these fluvial systems has probably been episodically continuous through the Quaternary. However, a lack of significant subsidence and subsequent accommodation space is likely to have caused horizontal separation of successive fluvial phases, resulting in lateral erosion and reworking of earlier Quaternary fluvial sediments. Fluvial deposits from the most recent (Holocene) interglacial and the two previous interglacials have been extensively studied and dated (Nanson et al., 1992; Maroulis et al., 2007; Nanson et al., 2008). These studies show that discharge during successive interglacial episodes declined markedly, indicating either a progressive waning in monsoon intensity or some other switching of the precipitation moisture source (Nanson et al., 2008). Studies of Late Pleistocene paleo-channels suggest that discharges from the Cooper Creek paleo-stream were up to seven times larger than present day volumes.

The eastern margin of the Galilee Basin is covered by the headwaters of the large coastal catchments of the Fitzroy and Burdekin rivers where they are probably incisional. Sediments of these systems are poorly studied, though initial dating of fluvial sediments down catchment from the Galilee subregion in the Fitzroy surface drainage catchment suggests a similar chronology to the Lake Eyre channel country rivers (Croke et al., 2011). At the southern margin of the Galilee Basin are the upper catchments of the Bulloo River system and the Warrego River of the Murray–Darling Basin, both of which are poorly studied and undated. At the north-western margin of the

Galilee Basin is the upper catchment of the Flinders River, which flows north-westerly to the Gulf of Carpentaria and is also poorly studied and undated.

Lake Buchanan is a playa lake near the eastern margin of the Galilee subregion that lies astride the Eastern Highlands in a closed intermontane depression between the upper catchments of the Cooper Creek and Burdekin River systems (Chivas et al., 1986). A 15 m core from the lake indicates uniform non-laminated sandy clay sediments. There are no occurrences of primary or chemically precipitated gypsum or carbonate. Paleomagnetic reversal dating returned an age of 0.781 Ma (Middle Pleistocene) at 5.0 m and an extrapolated age of between 1.5 and 2 Ma at 15 m depth. A total of 13 dry episodes, as indicated by paleosols, are evident in the core and four major wet phases are recorded in the Middle and Late Pleistocene (Chivas et al., 1986).

### *1.1.3.4 Coal and hydrocarbons*

This section provides a brief summary of available information on coal and hydrocarbons in the Galilee subregion. More specific information will be presented in the forthcoming coal seam gas and coal resource assessment for the Galilee subregion bioregional assessment.

In the Galilee Basin, significant coal-bearing sequences occur in the Early Permian Aramac Coal Measures, the Late Permian Betts Creek beds, the Bandanna Formation and the Colinlea Sandstone (Figure 20). In the Lovelle Depression, the Aramac Coal Measures can be up to 272 m thick with aggregate coal thickness of up to 60 m (Scott et al., 1995). Vitrinite reflectance data suggest that the Aramac Coal Measures have, for the most part, reached thermal maturity for oil generation (Hawkins and Green, 1993).

The Betts Creek beds (and its equivalents) are widespread in the Galilee Basin, and are up to 200 m thick in the Koburra Trough and 120 m thick in the Lovelle Depression (Hawkins and Green, 1993). Areas of maximum coal development within Betts Creek beds (and its equivalents) tend to occur towards the central Lovelle Depression and Koburra Trough, with individual seams and aggregate coal thicknesses up to 20 m and 45 m respectively (Scott et al., 1995). Hawkins and Green (1993) report that Betts Creek beds and equivalents reached thermal maturity for oil generation in deeper sections of Koburra Trough and Lovelle Depression and adjacent to the Maneroo Platform.

The Betts Creek beds, Bandanna Formation and Colinlea Sandstone outcrop along the eastern margin of the Galilee Basin. The coals are classified as high volatile sub-bituminous coals. In the Lovelle Depression, the coal measures are less developed in the southern parts compared to the northern sections (Radke, 2009).

As of December 2013, two development proposals had been approved, and a further four were undergoing the development approval process (Figure 21). The Colinlea Sandstone is the host unit for mineable coal resources at the proposed Alpha coal development (Hancock Prospecting, 2010). At the South Galilee Coal Project the mineable coal resources lie within the Bandanna Formation (AMCI 2012).

Sub-bituminous coals occur in the Winton Formation in the Eromanga Basin. Although these may be considered a secondary target by some exploration companies, very significant tonnages are delineated around Blackall and at the South Blackall deposit.

Exploration for hydrocarbons in the Galilee subregion commenced in the late 1950s with initial focus on conventional oil and gas reservoirs. Overall about 130 wells have been drilled in the Galilee subregion for hydrocarbons, of which about 52 targeted coal seam gas. Most conventional petroleum wells targeted reservoirs in the Powell Depression, the Lovelle Depression, or along the western margin of the Galilee Basin.

Most recent exploration has focused on coal seam gas. To date, almost all coal seam gas drilling has occurred within the northern Galilee Basin, in particular the Aramac Trough, Koburra Trough, and the Lovelle Depression. Two coal seam gas production pilot well fields have been established in the vicinity of the Aramac Trough. The Glenaras production pilot CSG project has recently commenced operations (Galilee Energy, 2013).

To date, the only commercial conventional hydrocarbon discovery in the Galilee subregion is the Gilmore Gas Field in the Lissoy Sandstone reservoir. The Lissoy Sandstone is in the Adavale Basin, which is beneath the Galilee Basin.

Hawkins and Green (1993) provided details on potential conventional petroleum reservoirs and possible source rocks in the Galilee Basin. Reservoirs and traps may be developed in Aramac Coal Measures and Betts Creek beds, and potentially some Triassic sequences. The best source rocks for hydrocarbons in Galilee subregion are coals in the Aramac Coal Measures and Betts Creek beds.

Shale gas and oil in the Toolebuc Formation in the overlying Eromanga Basin is considered to be another potential hydrocarbon target (Galilee Energy, 2013). Conventional hydrocarbons are also targeted in the Eromanga Basin, within the Galilee subregion.

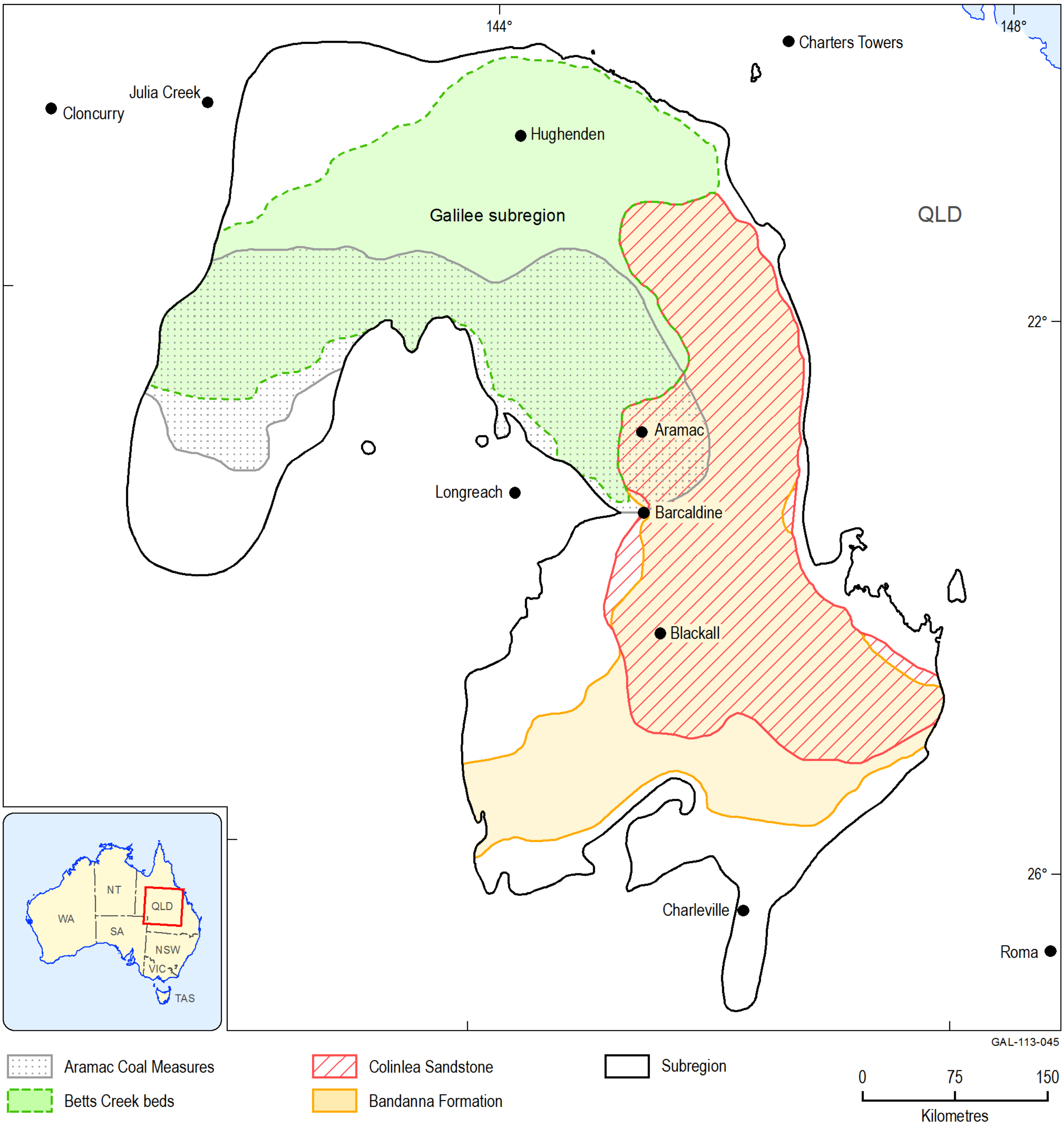


**Figure 20 Distribution of the coal-bearing formations in the Permian Galilee Basin**

Source data: modified from Figures 9, 10, 13 and 14 of Scott et al. (1995)

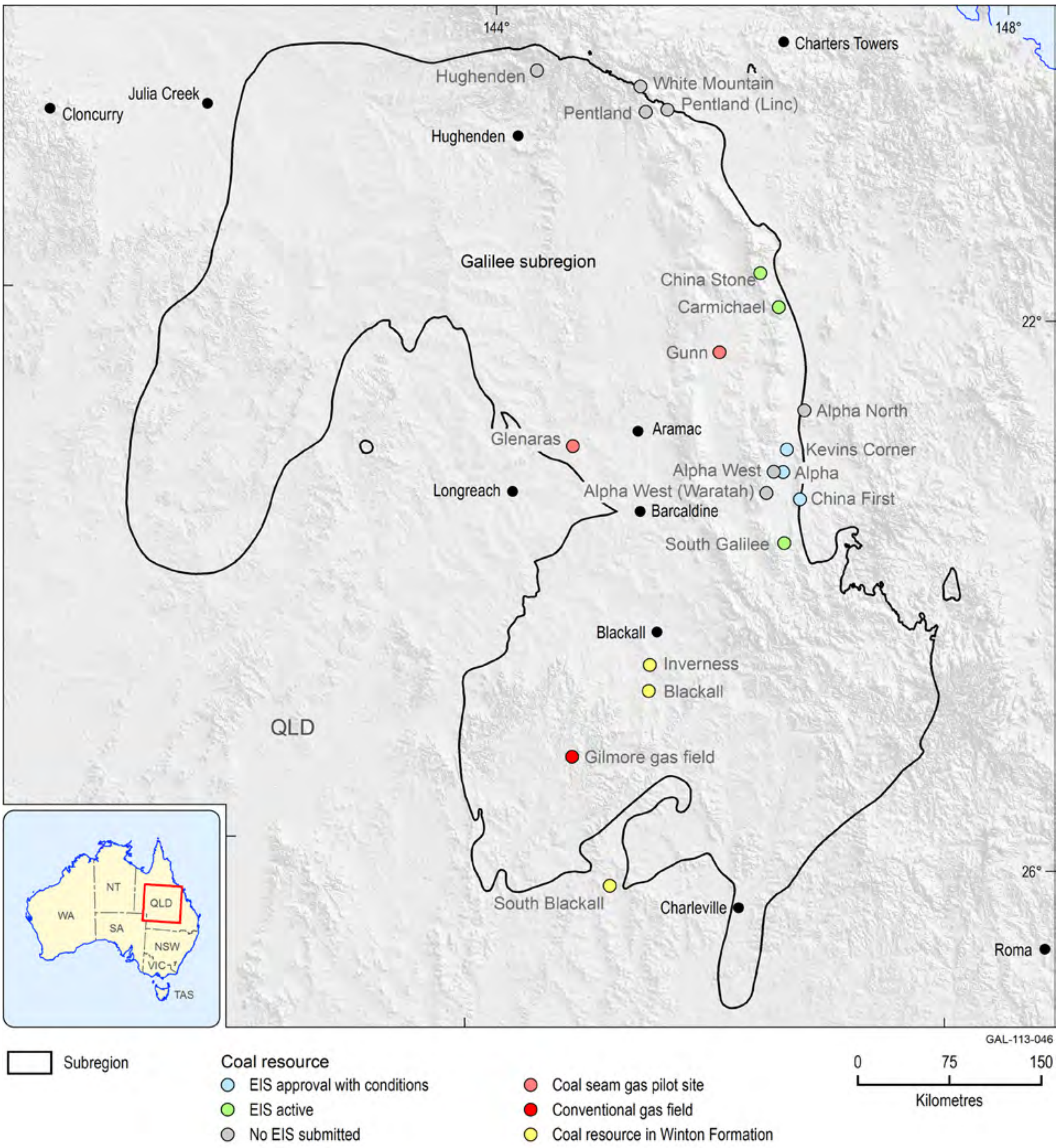


**Figure 21 Significant coal and coal seam gas developments in the Galilee subregion**

EIS is an acronym for environmental impact statement. All coal and coal seam gas developments, unless otherwise specified, occur within the Galilee Basin sedimentary sequence.

### *1.1.3.5 Potential basin connectivities*

There is little information documented in the literature on basin connectivity in the Galilee subregion. The potential for basin connectivity will be further analysed as part of the Galilee subregion bioregional assessment.

Ransley et al. (2012) provided a qualitative assessment of the potential for connectivity between Galilee and Eromanga basins. This will be discussed more fully in the hydrogeology section of the contextual report. Where the Clematis Group (Galilee Basin) is in contact with the Hutton Sandstone (Eromanga Basin) there is good potential for connectivity between the two basins.

Significant reactivation of pre-existing structures, such as the Cork and Canaway Faults, could enhance hydraulic connectivity between different groundwater flow systems, or impede it if the faults are resealed or if relatively impermeable sediments are juxtaposed against sandstone. Naturally occurring geological fracturing associated with anticlinal fold axes could potentially act as preferential pathways for connectivity. For instance, in the southern Galilee subregion, some lines of springs occur in the vicinity of major anticlinal fold axes or other major structures such as the Barcaldine Ridge. Whether this is coincidence, is at the moment unclear.

It may be possible that some connection exists between the Galilee Basin and underlying basins, in particular the Adavale or Drummond basins. Some of the proposed coal mines in the Galilee Basin are located near the Galilee - Drummond Basin margins.

Some potential for connectivity may exist between Cenozoic sediments and underlying Eromanga Basin sediments or Cenozoic sediments and Galilee Basin sediments.

## *References*

Allen JP and Fielding CR (2007) Sequence Architecture within a low accommodation setting: An example from the Permian of Galilee and Bowen basins, Queensland, Australia. AAPG Bulletin 91(11), 1503–1539.

AMCI (2012) Section 4 – Project Description South Galilee Coal Project Environmental Impact Statement. AMCI (Alpha) Pty Ltd

Bradshaw BE, Spencer LK, Lahtinen AC, Khinder K, Ryand DJ, Colwell JB, Chirinos A and Bradshaw J (2009) Queensland Carbon Dioxide Geological Storage Atlas. Department of Employment, Economic Development and Innovation, Queensland Government.

Callen RA, Alley NF and Greenwood DR (1995) Lake Eyre Basin. The Geology of South Australia, Vol 2, The Phanerozoic. JF Drexel and WV Preiss, Geological Survey of South Australia Bulletin, 54, 188–194.

Chivas AR, De Deckker P, Nind M, Thiriet D and Watson G (1986) The Pleistocene palaeoenvironmental record of Lake Buchanan: An atypical Australian playa. Palaeogeography, Palaeoclimatology 54, 131–152.

Cook AG (2013) Palaeogene and Neogene: Sedimentary Basins. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 578–606.

Cook AG, McKellar JL and Draper (2013) Eromanga Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 523-533.

Cohen BE, Withnall IW and Vasconcelos PM (2013). Intraplate magmatism of eastern Queensland. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 629-645.

Croke J, Jansen JJ, Amos K and Pietsch TJ (2011) A 100 ka record of fluvial activity in the Fitzroy River basin, tropical northeastern Australia. Quaternary Science Reviews 30, 1681–1695.

Draper JJ (2002) Cenozoic. In: J. J. Draper (ed) Geology of the Cooper and Eromanga Basins, Queensland. Brisbane, Queensland Department of Natural Resources and Mines. Queensland Minerals and Energy Review Series, 60–62.

Draper JJ (2013) Belyando Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 174-175.

Galilee Energy (2013) ASX/Media Announcement, Galilee Energy: Glenaras gas pilot restarts. Galilee Energy Ltd.

Geological Survey of Queensland (GSQ) (2011) North-West Queensland Mineral and Energy Province Report, DEEDI, 110.

Geoscience Australia. (2012). Australian Stratigraphic Units Database. Viewed 10th September 2013, from < http://www.ga.gov.au/products-services/data-applications/reference-databases/stratigraphic-units.html >.

Grimes GK (1980) The Tertiary geology of north Queensland. The geology and geophysics of northeastern Australia. R. A. Henderson and P. J. Stephenson. Brisbane, Geological Society of Australia, Queensland Division.

Hancock Prospecting (2010) Alpha Coal Project Environmental Impact Statement. Hancock Prospecting Pty Ltd.

Hawkins PJ and Green PM (1993) Exploration results, hydocarbon potential and future strategies for the northern Galilee Basin. APPEA Journal 33(1), 280–296.

Henderson RA and Blake PR (2013) Drummond Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 189-196.

I’ Anson A (2013) Coal seam gas in the Galilee Basin, Queensland. The geological and social contexts of resource exploration. BSc (Hons) School of Geosciences, University of Sydney. p182.

Jell JS (2013) Palaeogene and Neogene: Synthesis. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 645–657.

Jones AT and Fielding CR (2008) Sedimentary facies of a glacially influenced continental succession in the Pennsylvanian Jericho Formation, Galilee Basin, Australia. Sedimentology 55, 531–556.

Maroulis JC, Nanson GC, Price DM and Pietsch TJ (2007) Aeolian-fluvial interaction and climate change: source-bordering dune development over the past 100ka on Cooper Creek, central Australia. Quaternary Science Reviews 26, 386–404.

McKellar JL and Henderson RA (2013) Galilee Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 196-202.

McKillop MD (2013) Adavale Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 175-183.

Nanson GC, Price DM, Jones BG, Maroulis JC, Coleman M, Bowman M, Cohen TJ, Pietsch TJ and Larsen JR (2008) Alluvial evidence for major climate and flow regime changes during the middle and late Quaternary in eastern central Australia. Geomorphology 101, 109–129.

Nanson GC, Price DM and Short SA (1992) Wetting and Drying of Australia over the past 300ka. Geology 20, 791–794.

Price GJ (2013) Quaternary. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 653–685.

Purdy DJ, Carr PA and Brown DD (2013) A review of the geology, mineralisation, and geothermal energy potential of the Thomson Orogen in Queensland. Queensland Geological Record 2013/01: 220.

Radke B (2009) Hydrocarbon & Geothermal Prospectivity of Sedimentary Basins in Central Australia; Warburton, Cooper, Pedirka, Galilee, Simpson & Eromanga Basins, Geoscience Australia.

Ransley TR, Radke BM, Kellett JR (2012) Jurassic-Cretaceous geology. Hydrostratigraphy, hydrogeology and system conceptualisation of the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship. Ransley TR and Smerdon BD (eds). Australia.

Scott SG, Beeston JW, Carr AF (1995) Galilee Basin. In: Ward CR, Harrington HJ, Mallett CW and Beeston JW (eds) Geology of Australian Coal Basins. Geological Society of Australia – Coal Geology Group. 1, 341–353.

Senior BR (1979) Mineralogy and chemistry of weathered and parent sedimentary rocks in southwest Queensland. BMR Journal of Australian Geology and Geophysics 4, 111–124.

Van Heeswijck A (2006) The structure, sedimentology, sequence stratigraphy and tectonics of the northern Drummond and Galilee Basins, central Queensland, Australia. Vol 1. PhD Thesis, James Cook University.

Van Heeswijck A (2010) Late Palaeozoic to Early Mesozoic deformation in the northeastern Galilee Basin, Australia. 57(4), 431–451.

Wells AT (1989) Chapter 10 - Stratigraphy and Permian Coal Measures of the Galilee Basin, Queensland. In Harrington HJ (ed) Permian Coals of Eastern Australia. Bureau of Mineral Resources Bulletin 231. Australian Government Publishing Service, Canberra.

## 1.1.4 Hydrogeology and groundwater quality

### *Summary*

The Galilee subregion consists of seven groundwater systems. These include: the Cenozoic units, the north-eastern part of the Eromanga Basin, the Galilee Basin, Adavale Basin, Belyando Basin, the north-western part of the Drummond Basin, and the underlying Mount Isa Inlier and Thomson Orogen. The groundwater systems most relevant to the Galilee subregion are the Cenozoic, Eromanga and Galilee basins. Very limited hydrogeological information is available for the Adavale, Belyando and Drummond basins, the Thomson Orogen and the Mount Isa Inlier, and this was not included in this contextual report. These basins and geological basement may require assessment in subsequent project components if considered relevant to the impacts of coal seam gas (CSG) and coal mining development. There is also minimal existing information on the hydrogeology of the Cenozoic units and hydrogeology and hydrochemistry data for the Galilee Basin.

The main aquifers of the Galilee Basin are the Triassic Warang and Clematis groups, and the Late Permian Colinlea Sandstone. The Carboniferous Lake Galilee Sandstone is the only aquifer of the Permian – Carboniferous Joe Joe Group, which also consists of partial aquifers such as the Aramac Coal Measures and the Jochmus Formation. The main aquifers of the Eromanga Basin include the Cretaceous Winton, the Mackunda Formation, the Wyandra Sandstone member of the Cadna-owie Formation, the Jurassic – Cretaceous Hooray Sandstone, and the Jurassic Adori and Hutton sandstones. The Mueller Sandstone is the main Cenozoic aquifer of the Lake Eyre Drainage Basin and it occurs in the north-western part of the Galilee subregion.

Based on the Australian Drinking Water Guidelines (NHMRC and NRMMC , 2011), the water qualities of the Wyandra, Hooray and Hutton sandstone aquifers are mostly fresh to poor, with some brackish groundwater. Those of the Winton and Mackunda formations are dominantly brackish, with subordinate fresh water. Groundwater qualities in the Cenozoic aquifers are commonly fresh to poor, with some being brackish and saline. Groundwater quality in all the aquifers varies with depth to a certain extent and both fresh and saline groundwater can coexist in the same location at different depths. The distribution of groundwater quality is three dimensional, with potential compartmentalisation within some aquifers of the basins.

The hydraulic head gradients of the Eromanga Basin aquifers are high in the east and decrease towards the west. Albeit based on limited data, the hydraulic gradient of the Triassic Warang and Clematis group aquifers of the Galilee Basin appear to decrease from the south-east towards the centre of the subregion, which may suggest discharge as baseflow to the Carmichael and Belyando rivers. This will be further examined in subsequent project components.

There are 28 Water Resource Plans across Queensland of which seven are relevant to the Galilee subregion. Only three of these refer to groundwater in addition to surface water. The Water Resource Plans that encompass the Galilee subregion include those for the Burdekin Basin, Cooper Creek, Fitzroy river basin, Georgina and Diamantina, Bulloo and Nebine catchments, Gulf, and the Great Artesian Basin.

The Great Artesian Basin Water Resource Plan provides water reserves for aquifers in the Triassic sequences of the Galilee Basin, as wells as aquifers in the overlying Eromanga Basin. As there is not one management unit that considers the water reserves for the whole Galilee subregion, they must be inferred from seven plans that overlap the basin.

### *1.1.4.1 Groundwater systems*

The Galilee subregion consists of stacked basins that in some places are overlain by Cenozoic sediments. The subregion includes the following geological environments which generally represent individual groundwater systems:

- Cenozoic aquifers
- Cretaceous and Jurassic sedimentary rocks of the Eromanga Basin
- Triassic, Permian and Carboniferous sedimentary rocks of the Galilee Basin
- Devonian sedimentary rocks of the Adavale Basin
- Devonian sedimentary and volcanic rocks of the Drummond and Belyando basins
- Proterozoic – Cambrian – Ordovician metamorphic rocks of the Mount Isa Inlier and Thomson Orogen.

#### 1.1.4.1.1 Underlying basement

The Proterozoic Mount Isa Inlier and Late Proterozoic – Early Paleozoic Thomson Orogen metamorphic and igneous rocks form the hydrogeological basement for the subregion and underlie the Galilee, Drummond, Belyando and Adavale basins. Across the Maneroo Platform, the Eromanga Basin strata directly overlie the Thomson Orogen basement, whereas in other parts of the subregion the Eromanga Basin overlies the older Galilee Basin (See Section 1.1.3.1, Figure 17).

#### 1.1.4.1.2 Adavale Basin

The top of the Adavale Basin is observed at 2200 m below the surface in petroleum wells. McKillop (2013) reports that the rock porosity  can be up to 15%, and horizontal permeability up to 38.7 milli Darcies (mD). The low porosity means that the rocks are likely to be, at best, partial aquifers. These partial aquifers include sandstone or conglomerate facies of the Buckabie, Etonvale, Lissoy Sandstone and Log Creek formations and the Eastwood beds. The Cooladdi Dolomite is the cap rock for gas migration and is a potential aquiclude. The Bury Limestone, apart from massive limestone facies, contains shale and siltstone and is likely to be a partial aquifer at best. The Boree Salt is predominantly comprised of various salts and shale and  is an aquitard. Overall, little information is available on the hydrogeology of the Adavale Basin.

### 1.1.4.1.3 Drummond and Belyando basins

The western part of the Drummond Basin outcrops adjacent to, and underlies, the Galilee subregion. No hydrogeological information is available for portions of the Drummond Basin that underlie the Galilee subregion. Little is known about the Belyando Basin as it has not been drilled (Draper, 2013)

### 1.1.4.1.4 Galilee Basin

Galilee Basin rocks outcrop as an elongated corridor some 600 km in length and up to 80 km wide along the eastern margin of the Galilee subregion on both flanks of the crest of the Great Dividing Range. Information on the sedimentology of the Galilee Basin sediments is available in Section 1.1.3.2.1.

The main regional aquifers include the Clematis Group, Warang Sandstone, Colinlea Sandstone and Lake Galilee Sandstone. The Moolayember Formation, Rewan Group, Jochmus Formation and Jericho Formation can be used as a local source of groundwater where they subcrop or outcrop (RPS, 2012). The Late Carboniferous to Early Permian Joe Joe Group, which includes the Jochmus and Jericho formations and the Lake Galilee Sandstone, comprises diamictite, fluvial and lacustrine sediments deposited under glacial and interglacial events (McKellar and Henderson, 2013), and are considered to be partial aquifers. A Joe Joe Group equivalent, the Boonderoo beds, also consists of glaciogene strata and forms a partial aquifer. The Late Permian Black Alley Shale is a tight aquitard, whereas the Peawaddy Formation comprises mainly sandstone with lesser amounts of siltstone, mudstone and coal and forms a partial aquifer. In the northern part of the Galilee Basin, the Late Permian formations, including the Colinlea Sandstone and Bandanna Formation, become undifferentiated and are grouped as the Betts Creek beds, which is considered to be a partial aquifer. On a regional scale, the Rewan Group forms an aquitard that is leaky in some areas and tight in others. The Dunda beds, which is a part of the Rewan Group is a partial aquifer due to sandstone content. Regionally, the Moolayember Formation forms a leaky aquitard across the Galilee Basin.

Drill core porosity measurements indicate that the aquifers remain relatively porous to a depth of approximately 1400 m, before a significant decrease in porosity with increasing depths (Bradshaw et al., 2009). This suggests that the aquifers in deeper parts of the basin such as the Lovelle Depression or Koburra Trough, or older Permian – Carboniferous sequences which commonly occur at depths greater than 1400 m below ground level, are likely to have reduced groundwater storage capacity.

### 1.1.4.1.5 Eromanga Basin

The Eromanga Basin covers much of the Galilee Basin, west of the Great Dividing Range. The Eromanga Basin deepens towards the south-west and directly overlies the Thomson Fold Belt metamorphic rocks on the Maneroo Platform, where the Triassic – Permian sedimentary rocks of the Galilee Basin pinch out.

The Eromanga Basin is considered as a series of stacked aquifers separated by aquitards in the thicker central depocentre. Elsewhere, the aquitards are thinner and the separate aquifers coalesce. Smerdon and Ransley (2012) proposed a qualitative classification of the hydrogeological units to account for variation in hydraulic properties that may be due to one or a combination of sediment sources, rates of basin subsidence during deposition, and alteration since the time of deposition. Their classification included aquifer, partial aquifer, leaky aquitard, tight aquitard and aquiclude.

Hydrostratigraphic relationships of the Eromanga Basin are shown in Figure 22. The main aquifers of the Eromanga Basin in the subregion are the Wyandra Sandstone member of the Cadna-owie Formation, Hooray Sandstone, Adori Sandstone of the Injune Creek Group and Hutton Sandstone.

Partial aquifers include the Winton and Mackunda formations of the Rolling Downs Group, and the Cadna-owie Formation.

Leaky aquitards include the Wallumbilla Formation of the Rolling Downs Group, and the Westbourne and Birkhead formations of the Injune Creek Group.

Tight aquitards are the Allaru Mudstone and Toolebuc Formation of the Rolling Downs Group.

The Eromanga sequence is up to 1800 m thick. Disruptions to aquifer continuity can occur where displacements across a fault significantly offsets an aquifer system. Significant fault offsets are evident in the Galilee subregion along the Cork and Canaway faults (see Section 1.1.3.1.2).

In the northern half of the Eromanga Basin, the Jurassic to Early Cretaceous sedimentary succession is mostly undifferentiated and collectively referred to as the Ronlow beds. The Ronlow beds are considered to be an aquifer.

### 1.1.4.1.6 Cenozoic

The Cenozoic aquifers in the Cooper Creek and Diamantina drainage catchments (Lake Eyre Drainage Basin) mainly consist of unconfined to semi-confined paleo-channel deposits. In addition, lacustrine deposits are present in some areas and form leaky or tight aquitards. In the north of the subregion the Pliocene Sturgeon Basalt is likely to be a partial aquifer. These Paleocene to Pliocene sediments and volcanics have been subjected to varying degrees of weathering and cementation, forming local kaolinite, ferruginous and silcrete-rich profiles. These profiles could influence hydrogeological properties at a local scale. Further information on Cenozoic stratigraphy is available in Section 1.1.3.2.3.

The Holocene sediments present within the subregion were deposited as part of the surface drainage catchments which includes the Flinders River in the north, Cape River in the north-east, Fitzroy River in the east, the Warrego River in the south, the Cooper Creek-Bulloo rivers in the central area and the Diamantina-Georgina rivers in the west. The alluvial sediments are likely to consist of a mixture of sand and mud and form a partial aquifer. The alluvial sediments would be in part unsaturated as the regional watertable is commonly at, or exceeding, 10 m in depth (Ransley and Smerdon, 2012). The sediments may become saturated or contain a perched watertable during periodic flood events.

### 1.1.4.1.7 Hydrostratigraphic relationships

The hydrostratigraphic units in temporal succession of the Cenozoic, Eromanga and Galilee basins are shown in Figure 22. The members and formations are colour coded to depict aquifers, partial aquifers, leaky aquitards, aquitards and aquicludes, in accordance with the classification of hydrostratigraphic units in the Great Artesian Basin by Ransley and Smerdon (2012). For the Galilee Basin, apart from the Clematis Group and the Colinlea Sandstone which are the main aquifers, the interpretation for the rest of the Triassic to Late Carboniferous succession is uncertain due to lack of hydrogeological information. For the same reason, there is low confidence in the interpretation of Cenozoic aquifers. The Adavale, Belyando and Drummond basins are not considered further in this contextual report due to a lack of hydrogeological data. They may require assessment in subsequent project components, if considered relevant to the impacts of CSG and coal mining development.

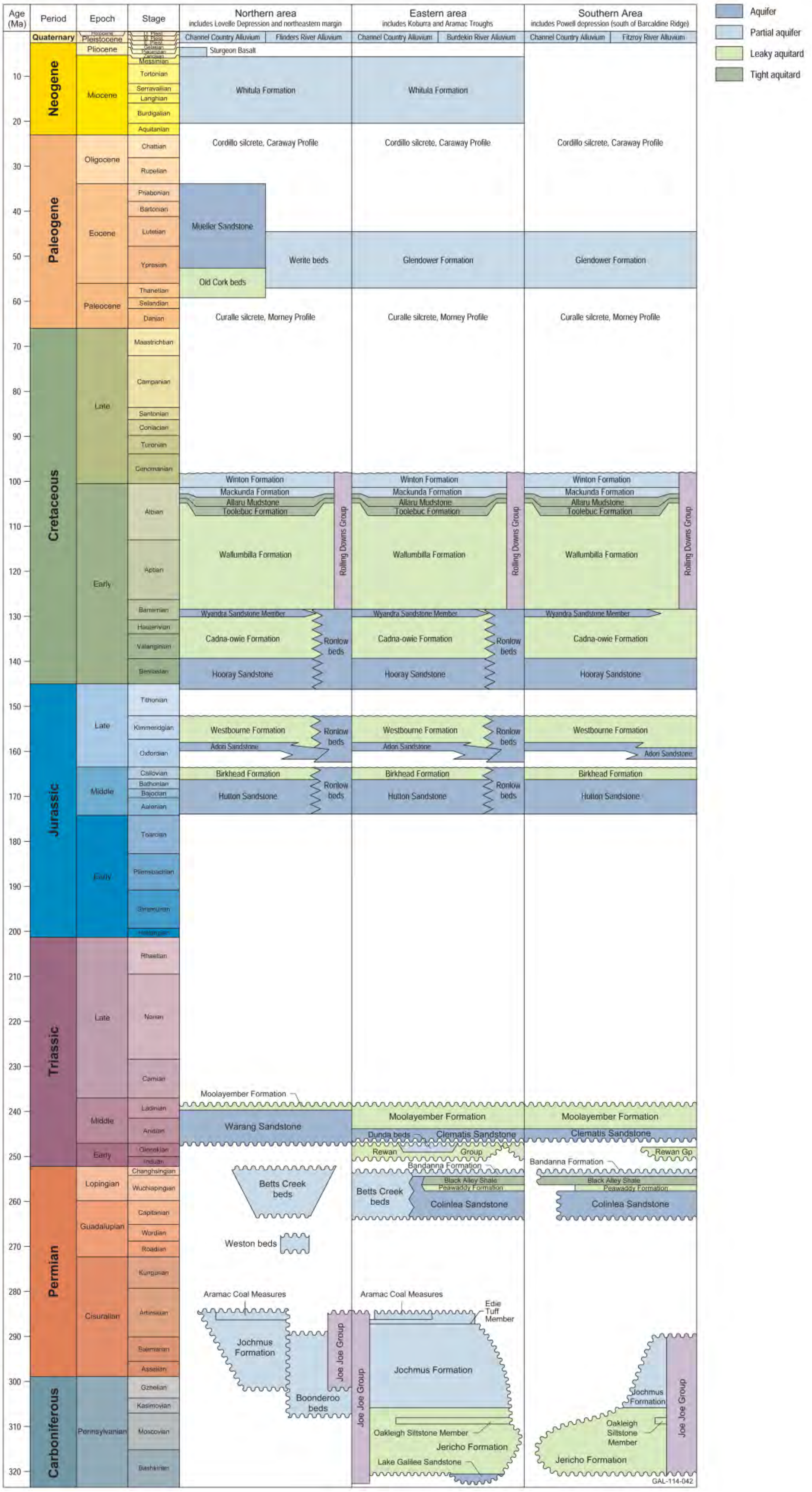


**Figure 22 Hydrostratigraphic sequence for the Cenozoic, the Eromanga Basin and Galilee Basin**

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

### 1.1.4.2 *Groundwater quality*

For this report, groundwater quality information is primarily sourced from data compiled and interpreted by RPS (2012). RPS (2012) datasets were not crosschecked for completeness or accuracy of interpretation for the contextual reporting component of the bioregional assessment. The RPS study sourced groundwater quality information from the Department of Environment and Resource Management (DERM) groundwater and Queensland Petroleum Exploration Data (QPED) databases (extracted December 2010). These are state based bore databases that contain archival information ranging in age from present day to several decades ago.

RPS (2012) tagged groundwater quality data with the name of the formation from which the sample was derived. The depths of the aquifers sampled ranged from 2 to 2999 m below ground. Groundwater salinity for the key aquifers sampled has been grouped into the three main stratigraphic groupings found in the subregion, i.e. Cenozoic, Eromanga Basin and Galilee Basin (Table 5).

| **Table 5 Summary statistics of total dissolved solids (TDS) of groundwater obtained from the main hydrostratigraphic units of the Cenozoic, Eromanga and Galilee basinsTotal dissolved solids (mg/L)** | **Cenozoic**[a] | **Eromanga Basin**[b] | **Galilee Basin**[c] |
|---|---|---|---|
| Minimum | 48 | 19 | 102 |
| Median | 492 | 333 | 619 |
| Mean | 1,057 | 688 | 3,008 |
| Maximum | 13,618 | 17,073 | 24,790 |
| Total number of samples | 78 | 312 | 26 |

Source data: RPS (2012) Appendix E

[a] Includes Quaternary alluvium and other Cenozoic aquifers.
[b] Includes Winton and Mackunda formations, Hooray Sandstone and Hutton Sandstone aquifers only.
[c] Includes Clematis Group and Colinlea Sandstone aquifers only.

#### 1.1.4.2.1 Underlying basins and basement

No groundwater quality information was identified for the Adavale, Belyando or Drummond basins or the Thomson Orogen basement.

#### 1.1.4.2.2 Galilee Basin

While some limited hydrochemistry data are available for Galilee Basin aquifers, there has been little interpretation. Further investigation of available hydrochemistry data from Galilee Basin will be undertaken as part of the Galilee subregion bioregional assessment.

The limited available data for the Permian – Carboniferous Joe Joe Group are located in the central part of the subregion (Figure 23). Groundwater quality ranges from fair to brackish (600–10,000 mg/L Total Dissolved Solids (TDS)) with no apparent spatial segregation. This is partly due to the limited number of bores with data and also partly attributed to the potentially complex three dimensional spatial distribution of water quality within the Joe Joe Group and its formation aquifers.

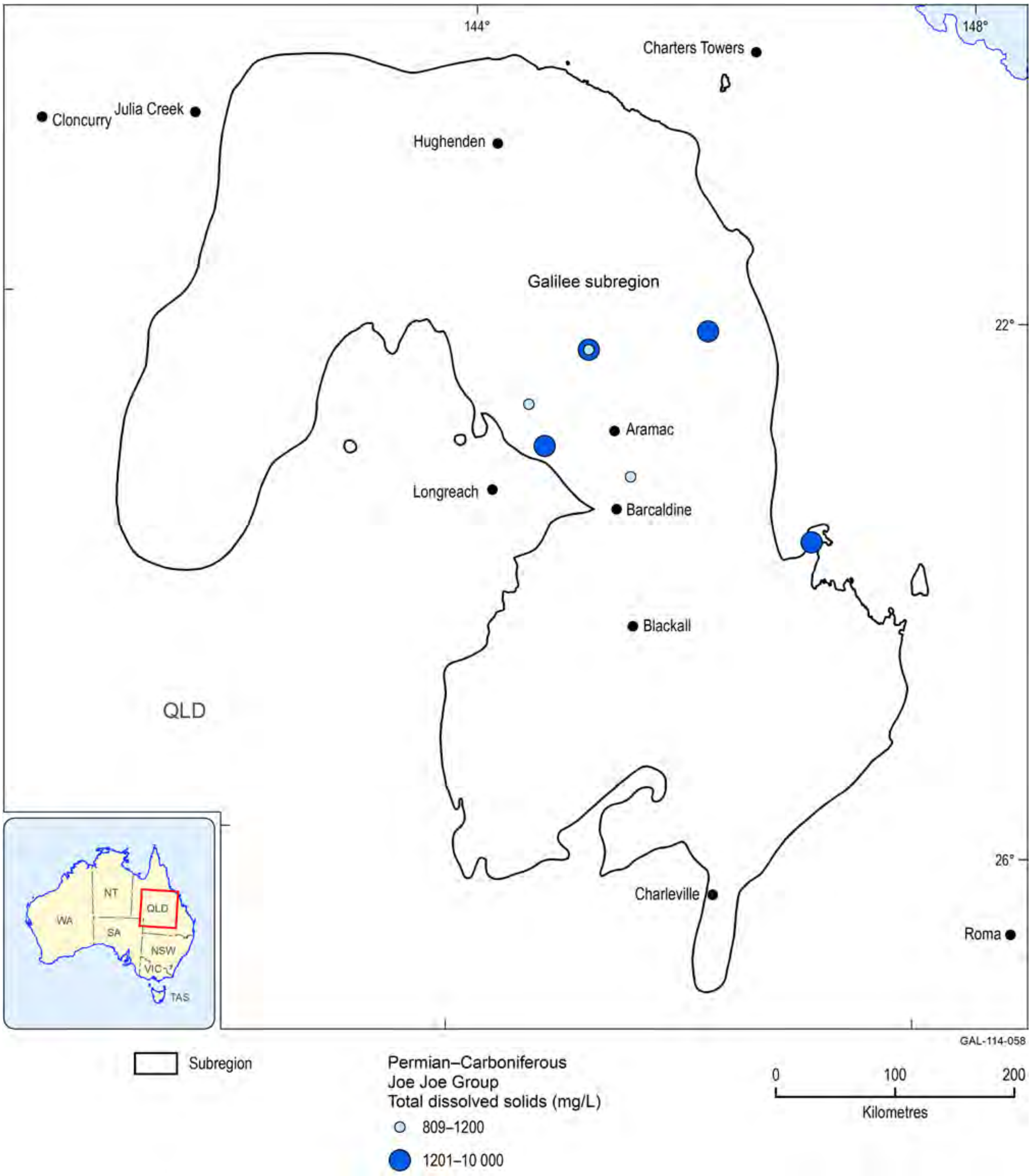


**Figure 23 Groundwater quality of the Permian – Carboniferous aquifers of the Galilee Basin**

Source data: RPS (2012) Appendix E

### 1.1.4.2.3 Eromanga Basin

The main aquifers of the Eromanga Basin include the Cretaceous Winton and Mackunda formations, the Jurassic – Cretaceous Hooray Sandstone, and the Jurassic Hutton Sandstone. The water quality data have been compiled by RPS (2012) using DERM (2012) and QPED databases, and the greatest number of samples with depth information were taken from the Hooray Sandstone (n = 100) and the Hutton Sandstone aquifers (n = 195).

Overall, the water quality of the main aquifers from the Eromanga Basin ranges from fresh (19 mg/L TDS) to saline (17,073 mg/L TDS), with most water being fresh and fair to poor (median and mean of 333 mg/L and 688 mg/L TDS respectively).

The Jurassic Hutton Sandstone aquifer predominantly consists of fresh water to approximately 1000 m depth, with salinity slightly increasing with depth (Figure 24). These bores are well distributed across the north-west, north and central part of the subregion (Figure 27). Fair to poor water (600–1200 mg/L TDS) mainly occurs at depths of 800 to 1200 m (Figure 24) and the bores are mainly located in the central part of the subregion, on or adjacent to the Maneroo Platform. The quality of the groundwater obtained from the same location may vary with depth, as evidenced from the overlapping of different water quality symbols on the spatial map (Figure 27).

Groundwater from the Hooray Sandstone aquifer was sampled from a wide range of depths, from 80 to 1100 m (Figure 25). The salinity generally increases with depth but there appears to be two populations. The first population has fresh water at shallow depth and becomes fair to poor at depths reaching 1000 m. The second population contains fair to poor water and becomes brackish at depths of 1000 m or beyond. Two anomalous samples at shallow depths less than 100 m have brackish to saline water.

Bores tapping the Hooray Sandstone aquifer that provide fresh water lie in the north and central part of the subregion (Figure 27). The majority of the bores with fair to poor water (600–1200 mg/L TDS) lie in the central region of the Galilee subregion. Bores that produce brackish water (1,200–10,000 mg/L TDS) lie on, or adjacent to, the western margin of the Galilee subregion or occur in the vicinity of Hughenden township.

Samples obtained from the Cretaceous Winton and Mackunda formations range in depth from 60 to 840 m (Figure 26), with the majority between 100 to 200 m. The salinity of the groundwater, especially for the Winton Formation, increases rapidly with depth from fair and poor to saline. There is no spatial partitioning of groundwater quality in these aquifers (Figure 28).

The Cretaceous aquifers of the Wallumbilla Formation and the Ronlow beds tend to yield fresh water, with a few bores having fair and poor or brackish groundwater (Figure 28).

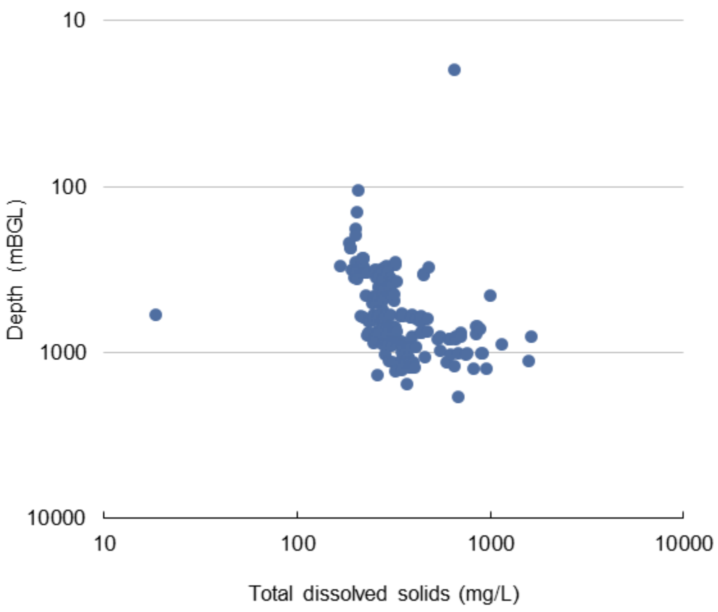


**Figure 24 Graph of depth and water quality of the Jurassic Hutton Sandstone aquifer**

Source data: RPS (2012) Appendix E

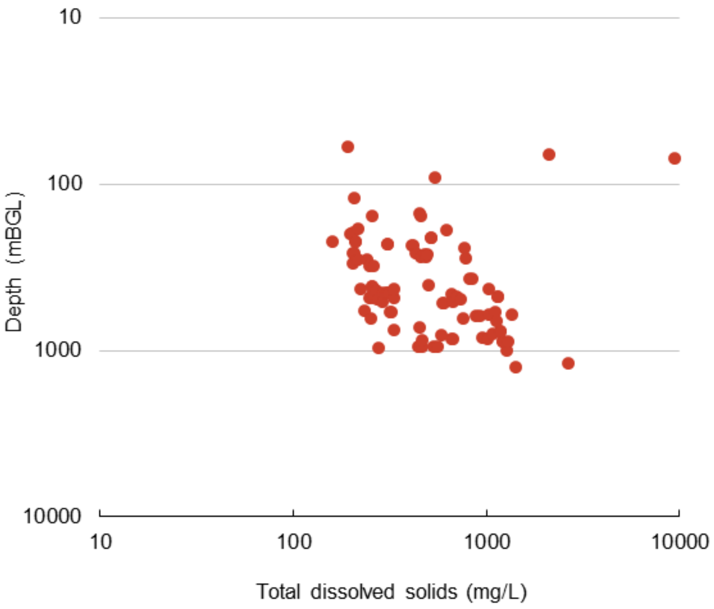


**Figure 25 Graph of depth and groundwater quality of the Cretaceous – Jurassic Hooray Sandstone aquifer**

Source data: RPS (2012) Appendix E

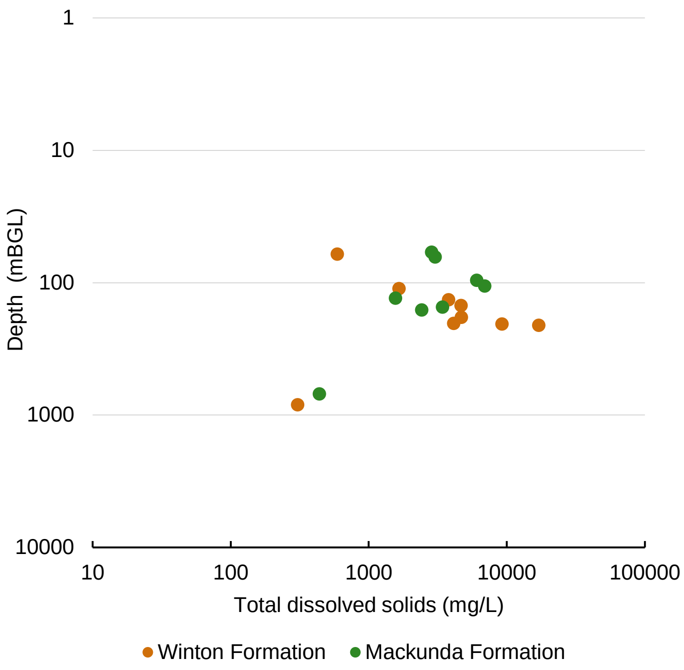


**Figure 26 Graph of depth and groundwater quality of the Winton and Mackunda formations of the Cretaceous Rolling Downs Group**

Source data: RPS (2012) Appendix E

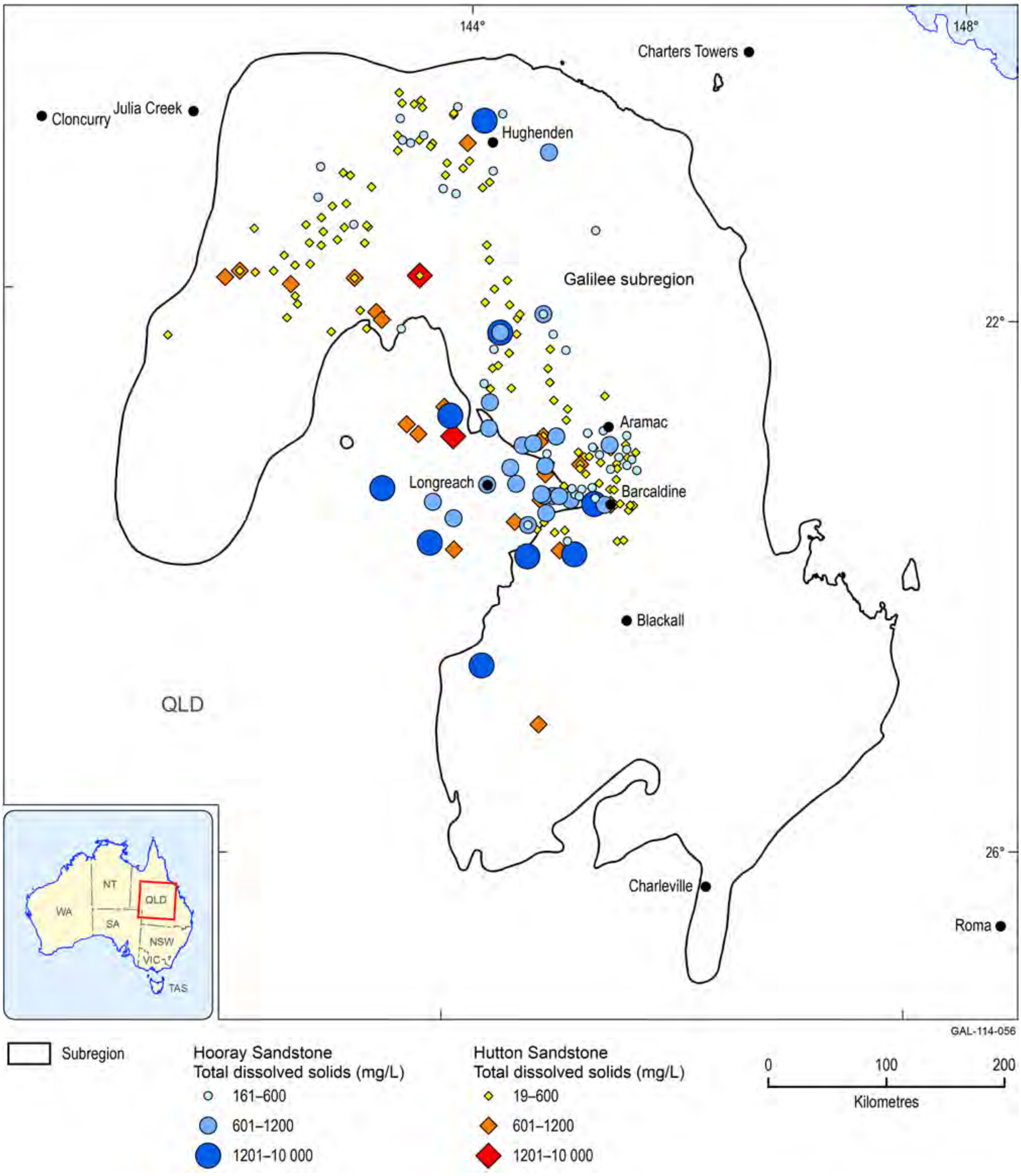


**Figure 27 Groundwater quality of the Jurassic Hooray and Hutton sandstone aquifers of the Eromanga Basin**

Source data: RPS (2012) Appendix E

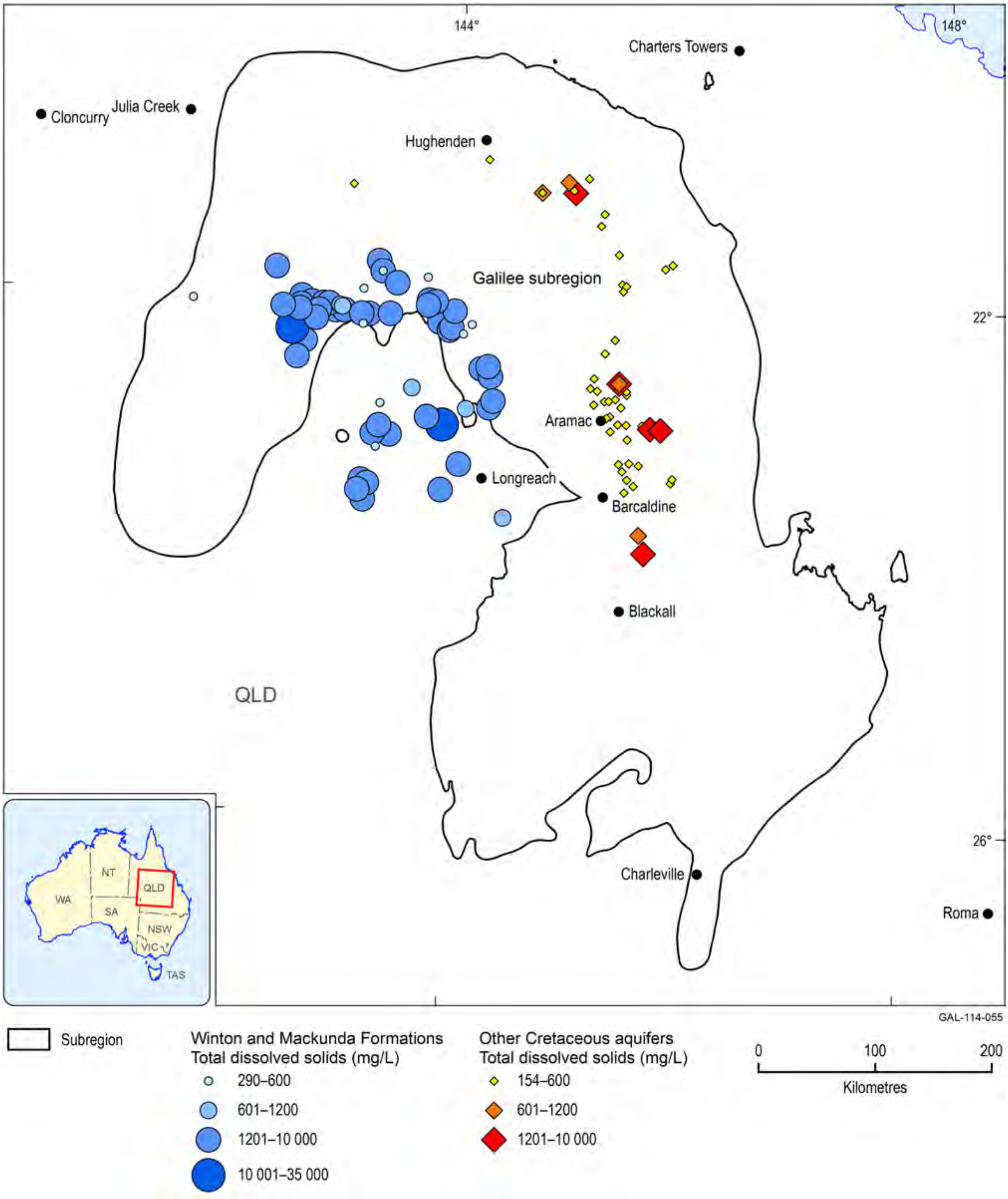


**Figure 28 Groundwater quality of the Winton and Mackunda formation aquifers and other Cretaceous aquifers of the Eromanga Basin**

Source data: RPS (2012) Appendix E

### 1.1.4.2.4 Cenozoic aquifers

The Cenozoic aquifers, which include the Quaternary alluvium and other Cenozoic sediments, are important groundwater resources in the subregion. In the RPS (2012) dataset, the groundwater sample depth ranged from less than 10 m to approximately 150 m (Figure 29), with most Quaternary alluvium sampled at depths of less than 30 m and the other Cenozoic aquifers sampled between 30 and 140 m. RPS (2012) suggested that there are probably at least twice as many bores as those shown in Figure 30 tapping into the Cenozoic aquifers.

The water quality of the Cenozoic alluvial aquifers ranges from fresh to saline (minimum and maximum of 48 to 13,618 mg/L TDS respectively). According to the Australian Drinking Water Guidelines classification (NHMRC and NRMMC, 2011), most groundwater in the Cenozoic aquifers is classed as fresh (<600 mg/L TDS) or fair to poor (600–1,200 mg/L TDS), with a median of 492 mg/L and a mean of 1057 mg/L TDS (Figure 29).

The water quality in the Quaternary alluvium aquifer shows an increase in salinity with depths (Figure 29), from very fresh (<100 mg/L TDS) to brackish (~3000 mg/L TDS). This may represent the chemical evolution of the groundwater as it flows from shallow recharge areas to deeper parts (~30 m depth) of the alluvium. In comparison, the water quality from other Cenozoic aquifers does not exhibit any distinct relation with depth or spatial pattern (Figure 30).

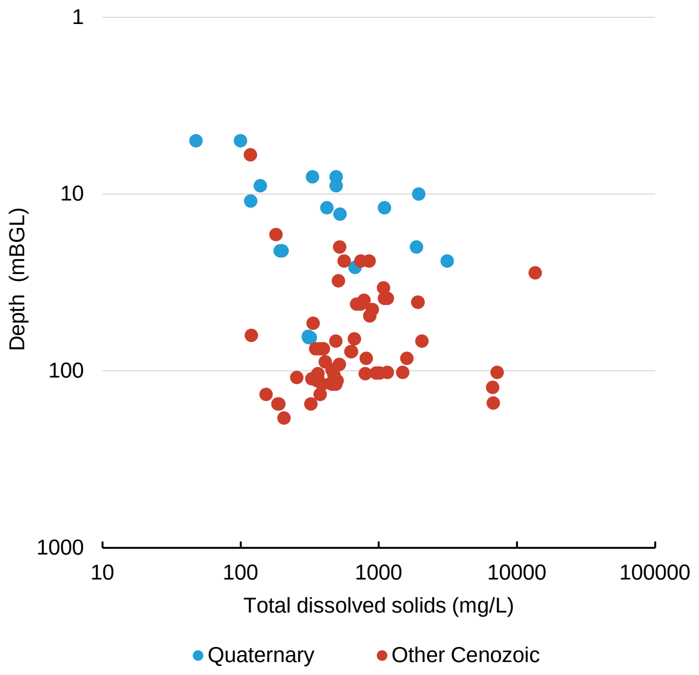


**Figure 29 Graph of depth and groundwater quality for Cenozoic aquifers**

Source data: RPS (2012) Appendix E

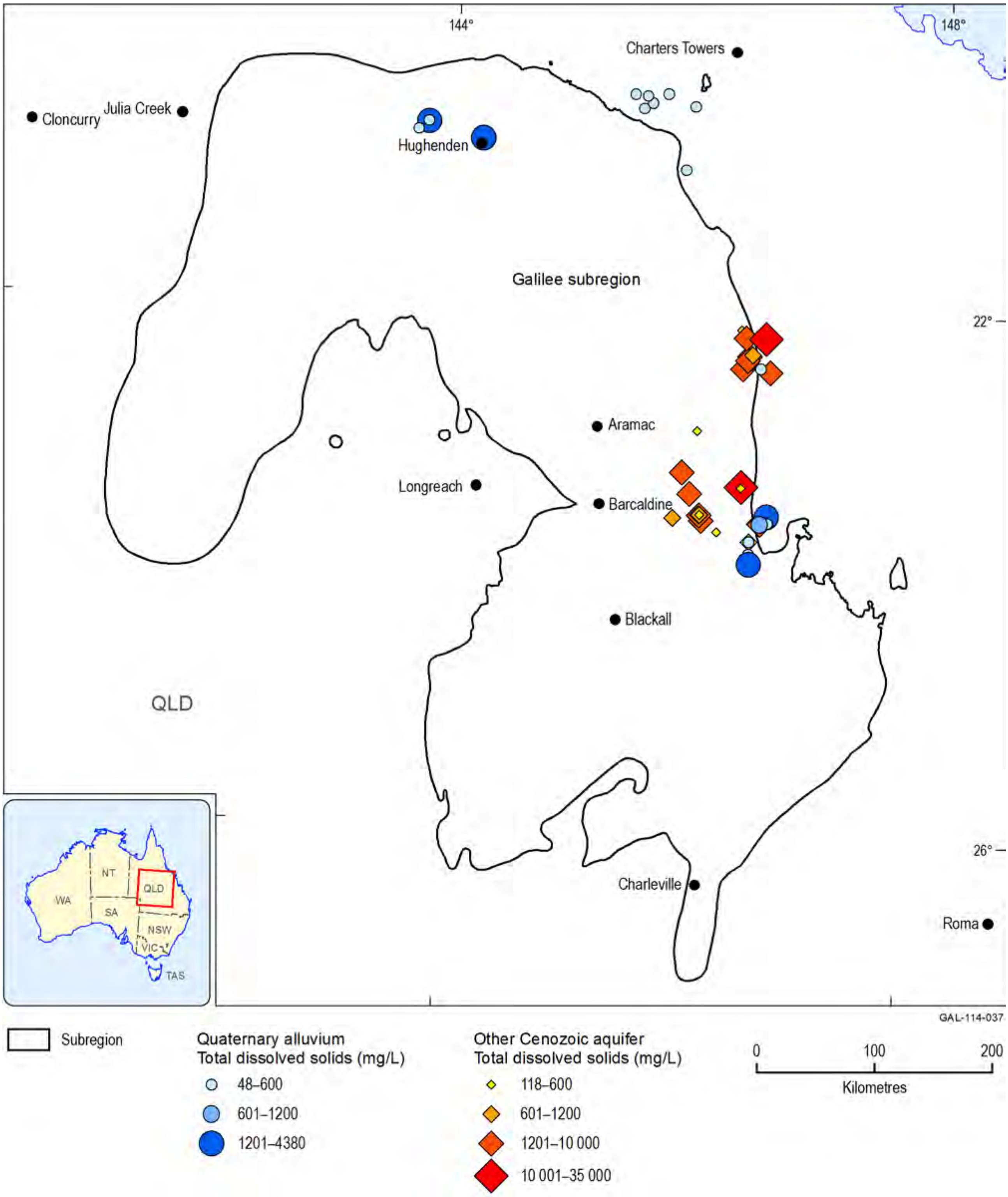


**Figure 30 Groundwater quality for Cenozoic aquifers**

Source data: RPS (2012) Appendix E

### 1.1.4.3 Groundwater flow

To date, much of the work assessing groundwater flows within the subregion has focused on aquifers of the Great Artesian Basin (GAB). The earliest comprehensive GAB-wide potentiometric surface of the Jurassic-Lower Cretaceous combined aquifers was produced by Audibert (1976) for the years 1900 and 1970. In addition, Audibert (1976) produced a watertable map and a potentiometric surface for the first confined aquifer which equates to the Winton and Mackunda formations within the subregion. Subsequently, Habermehl (1980) produced modified potentiometric surfaces for 1880 and 1970 for the Jurassic-Lower Cretaceous aquifers and a regional watertable map, based on the GABHYD simulation model (Seidel, 1978), from which the regional groundwater flow directions in the Jurassic-Lower Cretaceous aquifers were inferred. (Radke et al., 2000) reported regional flow direction within the Cadna-owie – Hooray Aquifer based on the GABMOD steady state model (Welsh, 2000) which differed from that of Habermehl (1980). More recently a regional watertable map for the topmost GAB formations and a 2010 potentiometric surface map of the Cadna-owie – Hooray aquifer was produced as part of the Great Artesian Basin Water Resources Assessment (Ransley and Smerdon, 2012) (Figure 31).

RPS (2012) compiled the Queensland DERM and QPED databases and generated the potentiometric surfaces for Eromanga Basin aquifers within the extents of the Galilee Basin boundary. Due to insufficient data and the bias of bore distribution towards the eastern part of the Galilee Basin, no potentiometric surface was generated for the Galilee Basin aquifers in the RPS (2012) report.

Using the compiled data in the RPS (2012) report, groundwater elevation contour maps for the various aquifer groups have been produced and are shown in Figure 32, Figure 33 and Figure 34.

These groundwater elevation contour maps were constructed using water level data measurements taken at different times. They can be used to elucidate trends in the aquifer system at a semi-regional scale but do not represent a ‘snapshot’ of groundwater levels at a specific time. Few bores in the Galilee subregion have time series groundwater level data.

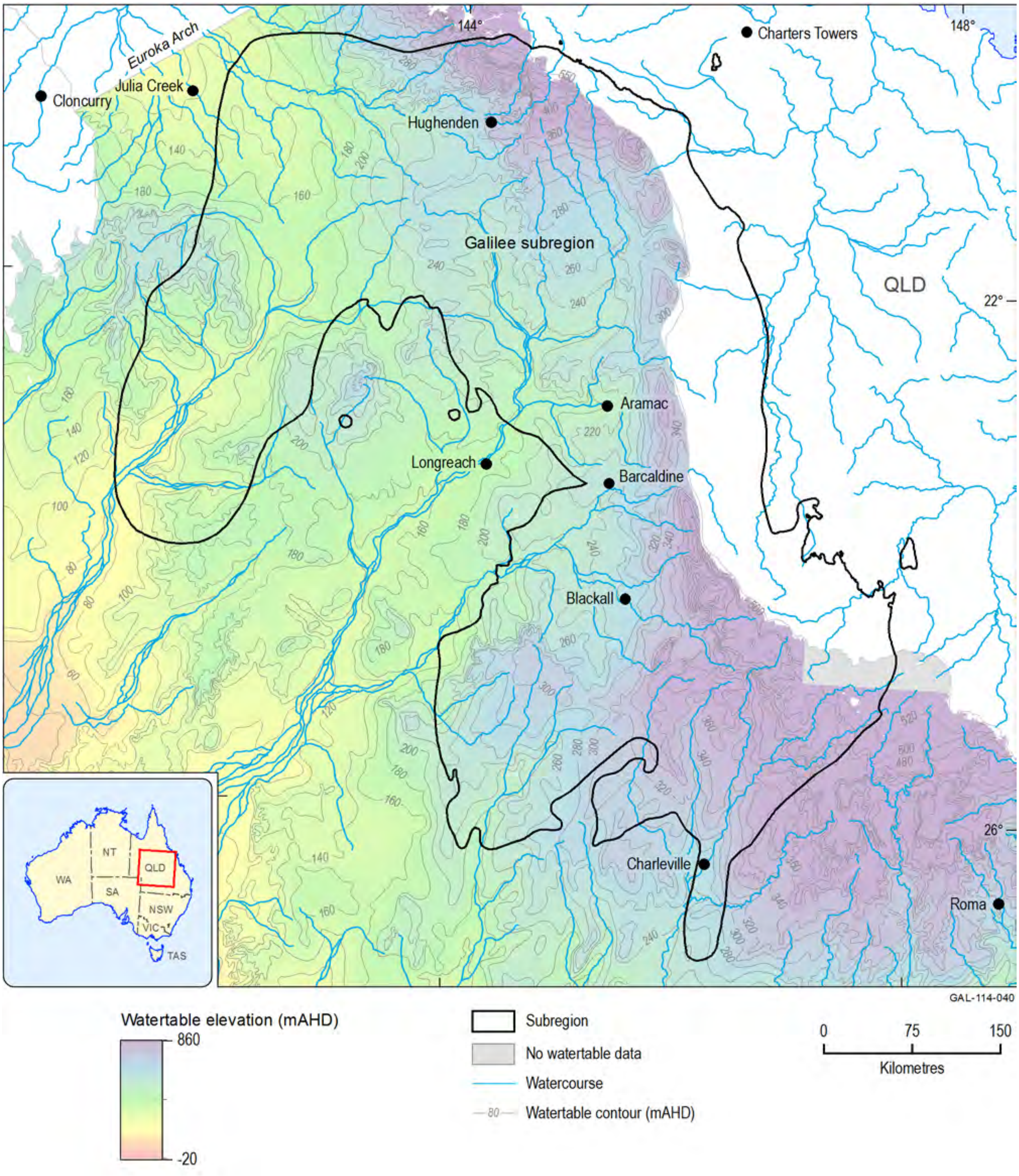


**Figure 31 Regional shallow watertable for the Eromanga Basin**

Source data: after Figure 6.2, Ransley and Smerdon (2012).

### 1.1.4.3.1 Underlying basins and basement

Limited information is available on hydrogeological systems that may operate below the Galilee Basin.

### 1.1.4.3.2 Galilee Basin

Using data available from RPS (2012), a preliminary potentiometric surface was created by contouring the groundwater levels from the Triassic formation aquifers, specifically the Warang Sandstone, the Clematis Group and the Dunda beds (Figure 32). To produce the figure, an assumption was made that there is hydraulic connectivity between the different aquifers. The reason this assumption was made is that no aquitards separate the different aquifer units; therefore these units are likely to be in direct connection. There is no temperature information on static water levels and the hydraulic head has not been corrected for temperature gradient. Potentiometry for these aquifers will be further analysed as part of the Galilee subregion bioregional assessment.

For the Warang Sandstone, Clematis Group and Dunda beds, water levels are slightly higher in the south-east (350–450 mAHD) of the Galilee Basin (Figure 32) than the north-east (250–350 mAHD) and are interpreted as potential recharge areas. There appears to be a general convergence of flow towards the central-eastern part (water levels of 250–300 mAHD) of the basin, in the vicinity of the Carmichael River.

In the northern Galilee Basin, the Rewan Group is likely to cause a degree of hydraulic disconnection between the Late Permian Colinlea Sandstone aquifer and Triassic aquifers – the Clematis Group and the Warang Sandstone. In the southern Galilee Basin, the Rewan Group is largely absent (Scott et al., 1995) but the Black Alley Shale, where present, may still impede hydraulic connectivity. Only a few wells around the eastern margin of the Galilee Basin were identified by RPS (2012) as tapping the Colinlea Sandstone. From the limited available data for the south-eastern edge of the subregion, the static water level of the Colinlea Sandstone is consistent between 300 and 350 mAHD.

Limited information is available on groundwater discharge from the Galilee Basin. Also, a lack of information from far southern parts of the Galilee Basin (the Powell Depression and south of Springsure Shelf) makes it difficult to deduce potential groundwater discharge pathways. The artesian pressures and the near surface sub-artesian groundwater levels for aquifers in the Warang Sandstone, the Clematis Group and the Dunda beds suggest that groundwater in the Galilee Basin has the potential to leak into the overlying Carmichael and Belyando rivers, provided a pathway exists.

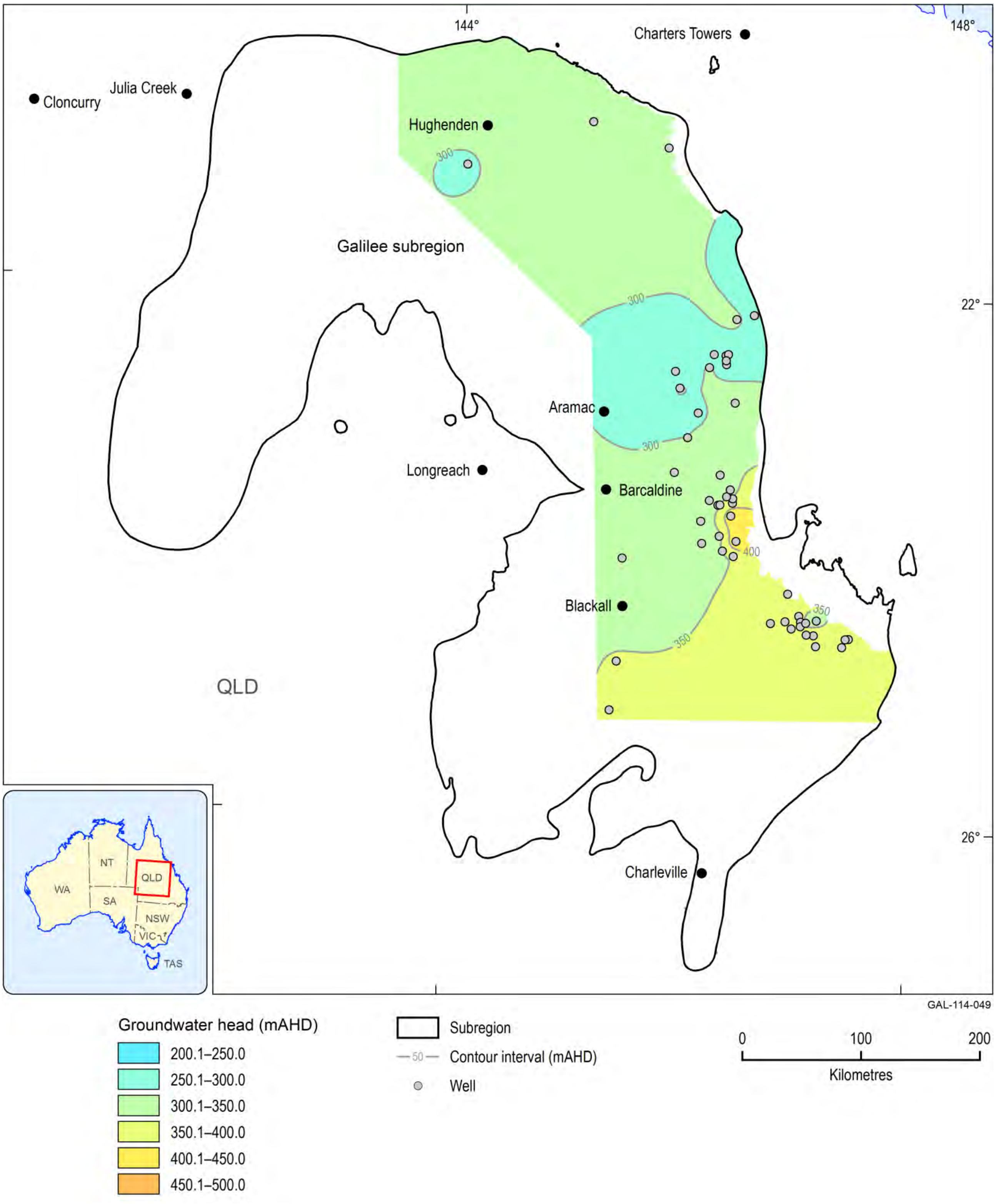


**Figure 32 Potentiometric surface of groundwater head in wells tapping into Warang Sandstone, Clematis Group and Dunda beds aquifers of the Galilee Basin**

Source data: RPS (2012) Appendix D

Well locations where the information was sourced are shown.

### 1.1.4.3.3 Eromanga Basin aquifers

On a regional scale, groundwater in the Eromanga flows from recharge areas along the Great Dividing Range and westwards towards the discharge zones of the western Eromanga Basin. Discharge areas include Lake Eyre and an arcuate band containing lakes Frome, Callabonna, Blanche and Gregory (Smerdon and Ransley, 2012, p. 81). This is in contrast to the groundwater flow potential in parts of the underlying Warang Formation, Clematis Group and Dunda beds aquifers, where it has been proposed in some recent environmental impact statements that groundwater flow is from the south and north towards the Carmichael River. This however is yet to be substantiated.

The watertable (Figure 31) lies in the areas of outcrop of all the GAB aquifers (intake beds) and aquitards along the western slopes of the Great Dividing Range. It then passes into the Rolling Downs Group which abuts the intake beds and dips gently basinward (Smerdon and Ransley, 2012, p. 82). The largest area of occurrence of the watertable – throughout the vast plains of western Queensland – lies in the Early to Late Cretaceous Winton Formation, and less commonly, in the underlying Early Cretaceous Mackunda Formation. Nevertheless, the Winton and Mackunda formations form a hydraulically continuous unit, and thus water levels in the Mackunda Formation can also be regarded as equivalent to the regional watertable (Smerdon and Ransley, 2012, p. 82).

Despite the slight bias in distribution of wells towards the south and the central west of the subregion, the groundwater hydraulic head of the aquifers in the Rolling Downs Group (Figure 35) provides a general depiction of groundwater gradient, possible flow directions and recharge areas within the Galilee subregion. Groundwater elevation is the highest (400–450 mAHD) in the south-eastern part and relatively high in the north. The recharge areas are the north, east and south-east of the subregion. In the south, groundwater flows towards the west and in the north, groundwater flows towards south-west.

Deep regional confined aquifers in the Eromanga Basin include the Hutton Sandstone, the Hooray Sandstone and the Wyandra Sandstone member of the Cadna-owie Formation. The potentiometric surface for the Hutton Sandstone (Figure 33) shows a local high (500–550 mAHD) in the south of the subregion. The aquifers are recharged in the east, along the Great Dividing Range, with groundwater flowing down the hydraulic gradient towards the north-west and west.

The combined groundwater potentiometric surface of the Wyandra Sandstone Member of the Cadna-owie Formation, and Hooray Sandstone aquifers is shown in Figure 34, assuming vertical connectivity between the aquifers. There is no temperature information on the static water levels and the hydraulic head has not been corrected for temperature gradient. The potentiometric surface shows high static water levels (450–500 mAHD) in the southern part of the subregion. This potentiometric surface is even higher than those of the Rolling Downs Group aquifers, suggesting that the aquifers are confined and there is potential for upward flow if pathways exist. The potentiometric surface is also relatively high in the north and the overall gradient and flow is towards the west. Recharge areas for these aquifers are taken to be the outcrops and shallow subcrop at the Great Diving Range in the east. RPS (2012) has identified a northward component of the flow towards the Flinders River system and potentially discharging into the Carpentaria Basin in the north.

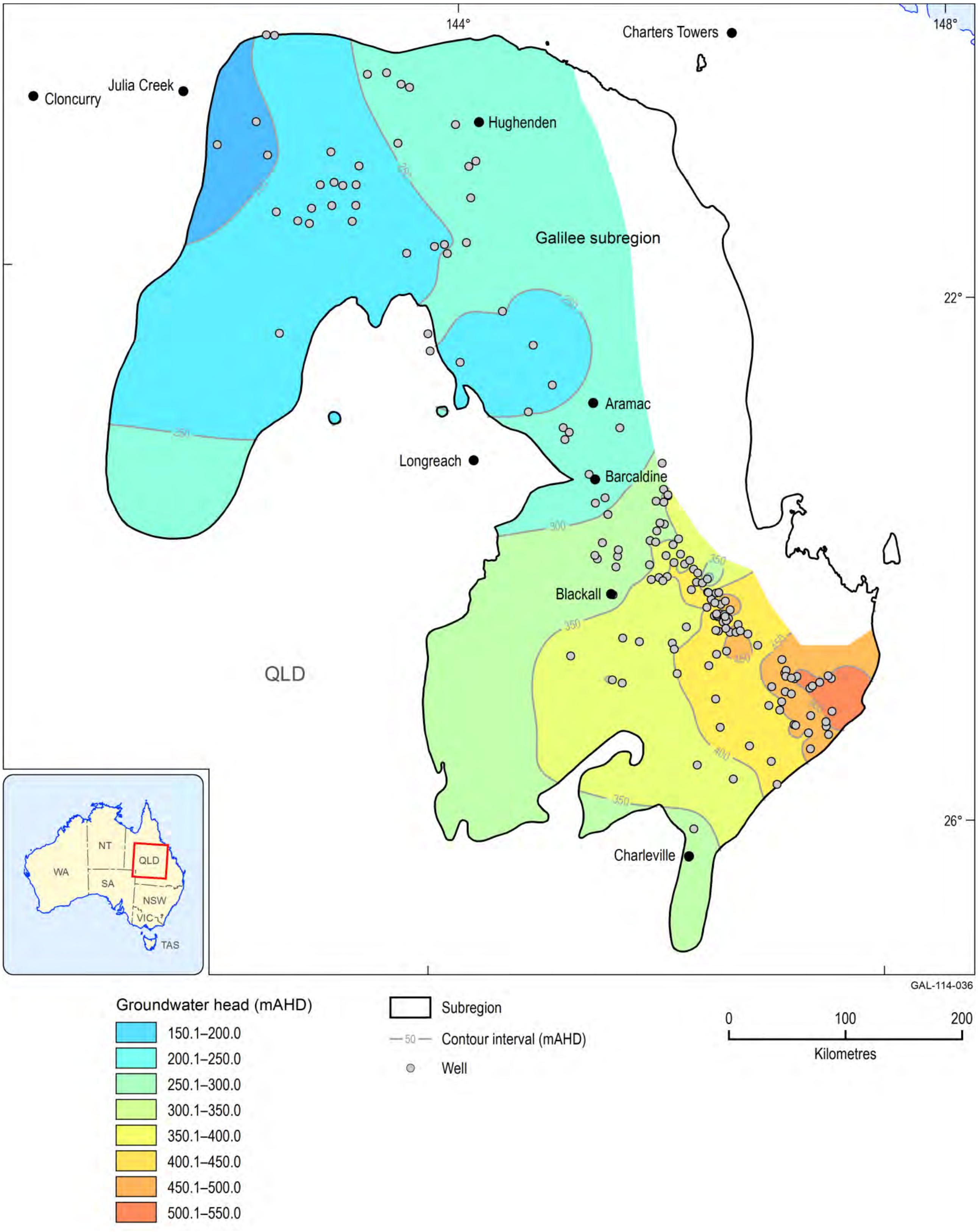


**Figure 33 Potentiometric surface of groundwater head of the Jurassic Hutton Sandstone aquifer**

Source data: RPS (2012) Appendix D

Well locations where the information was sourced are shown.

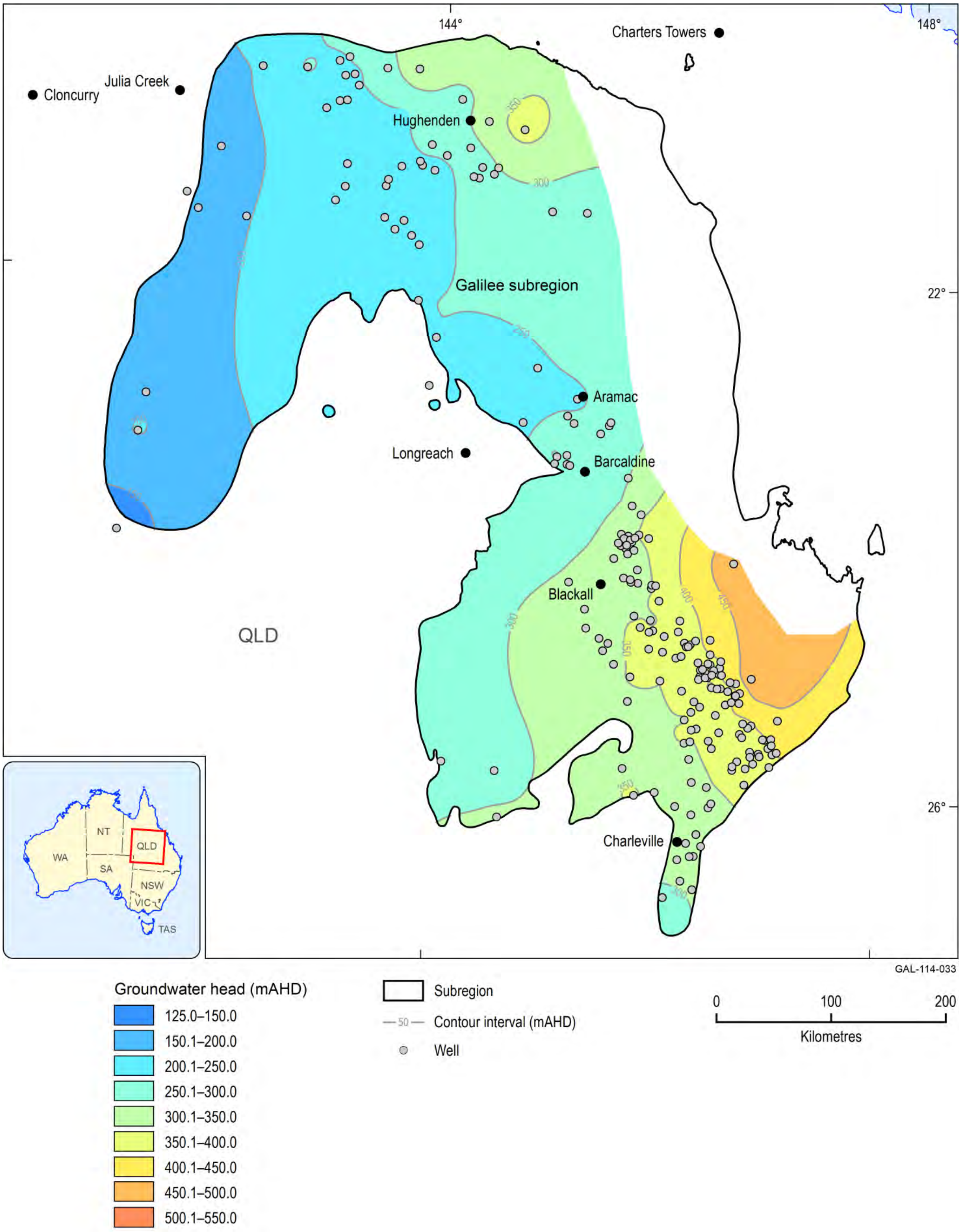


**Figure 34 Potentiometric surface of groundwater head of the Wyandra Sandstone member of the Cadna-owie Formation, and Hooray Sandstone, assuming vertical hydraulic connectivity between aquifers**

Source data: RPS (2012) Appendix D

Well locations where the information was sourced are shown.

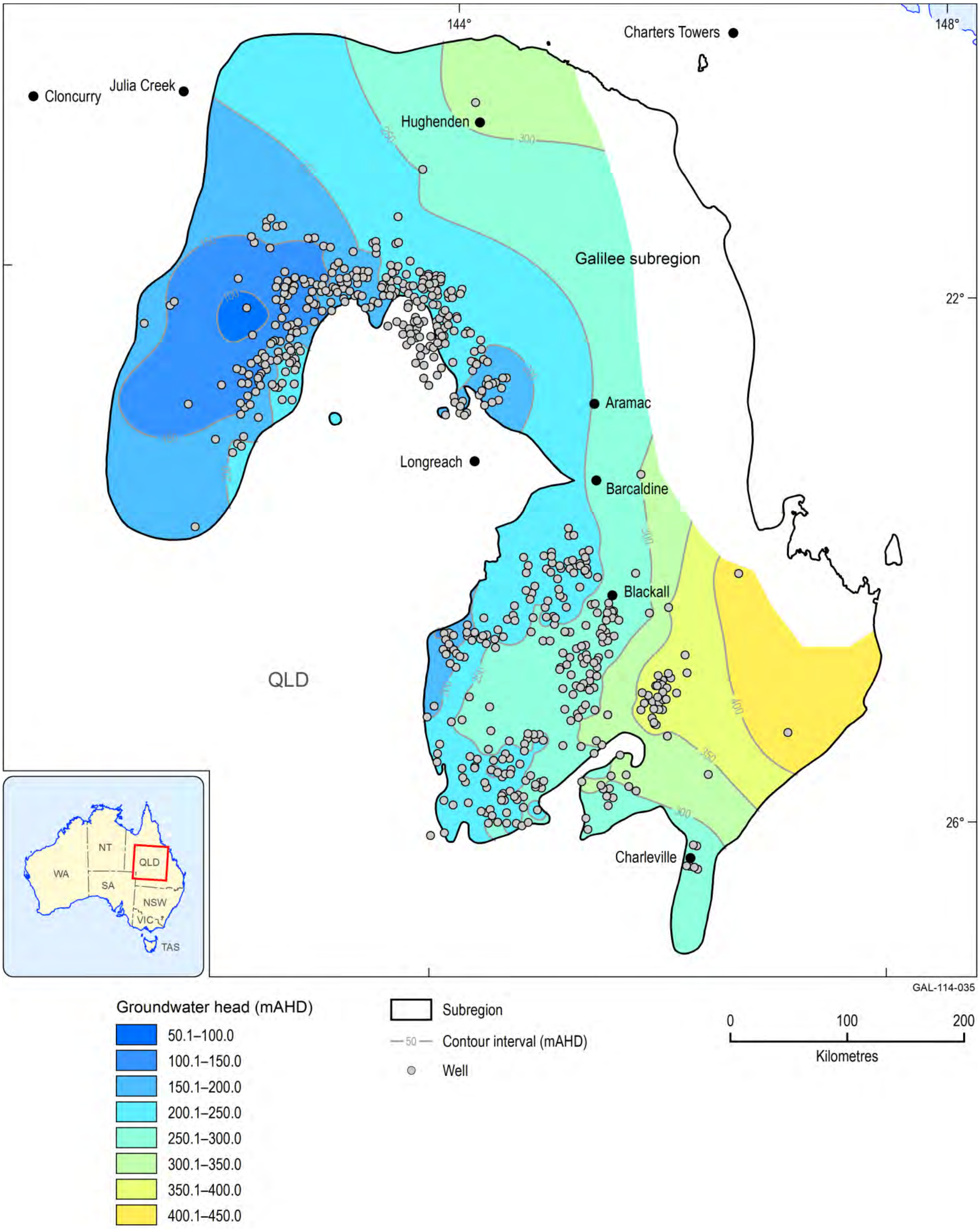


**Figure 35 Regional watertable with groundwater head of the aquifers within the Rolling Downs Group, assuming vertical hydraulic connectivity between aquifers**

Source data: RPS (2012) Appendix D

Well locations where the information was sourced are shown.

### 1.1.4.3.4 Cenozoic

Across the channel country in the semi-arid zone, recharge is low as potential evaporation exceeds precipitation. Periodic high precipitation may result in high river flow or floods and recharge into the Cenozoic aquifers. The extent of diffuse recharge occurring across the channel plains during flood events is unknown.

The regional watertable slopes from the north-east and east to the south-west, sympathetic with the topography (Smerdon and Ransley, 2012, p. 81) (Figure 31). The watertable in Cenozoic sediments generally forms a continuum with the pressure surface of the first water cut in the underlying Eromanga Basin aquifers, most commonly the Winton Formation of the Rolling Downs Group. However, water levels in some alluvial bores within and peripheral to stream channels may temporarily lie above the regional watertable following periods of high river stages when they are recharged (Ransley and Smerdon, 2012). Temporary head differences of 10 to 15 m have been observed. These perched systems are very dynamic compared to the much slower moving and less responsive regional watertable. However, the fluctuations in groundwater levels in the alluvium of the river channels represent an interesting phenomenon and may shed light on locations of point source recharge to the regional GAB aquifers (Ransley and Smerdon, 2012).

### 1.1.4.3.5 Inter-aquifer leakage

Based on a regional hydrostratigraphic classification of GAB units, potential connectivity with underlying basins is offered by the overlap of adjacent aquifers and leaky aquitards above and below the basal unconformity of the Eromanga Basin. In Figure 36, the basal hydrostratigraphic units of the Eromanga Basin are denoted by patterns and the uppermost stratigraphic units of the Galilee and Cooper basins, as well as the Thomson Orogen basement rocks, are depicted by colours.

From the potential hydraulic interconnectivity map (Figure 36), the Galilee Basin area is mostly covered in light blue, which demarcates the presence of the Moolayember Formation leaky aquitard. This formation impedes the hydraulic connectivity between the Eromanga and Galilee basin aquifers. In Figure 36, areas shaded dark to medium blue represent zones where Galilee Basin aquifers underlie and are likely to be directly in contact with the Eromanga Basin aquifers such as the Hutton Sandstone. Where the basal unit for the Eromanga Basin sequence is an aquifer and there is direct contact between it and Galilee Basin aquifers would be areas with good potential connectivity. In the Galilee subregion this configuration occurs near the western margin of the Galilee subregion (in the vicinity of Longreach and Winton), south-west of Blackall in the southern Galilee Basin, and around the north-eastern margin of the GAB in the vicinity of Hughenden.

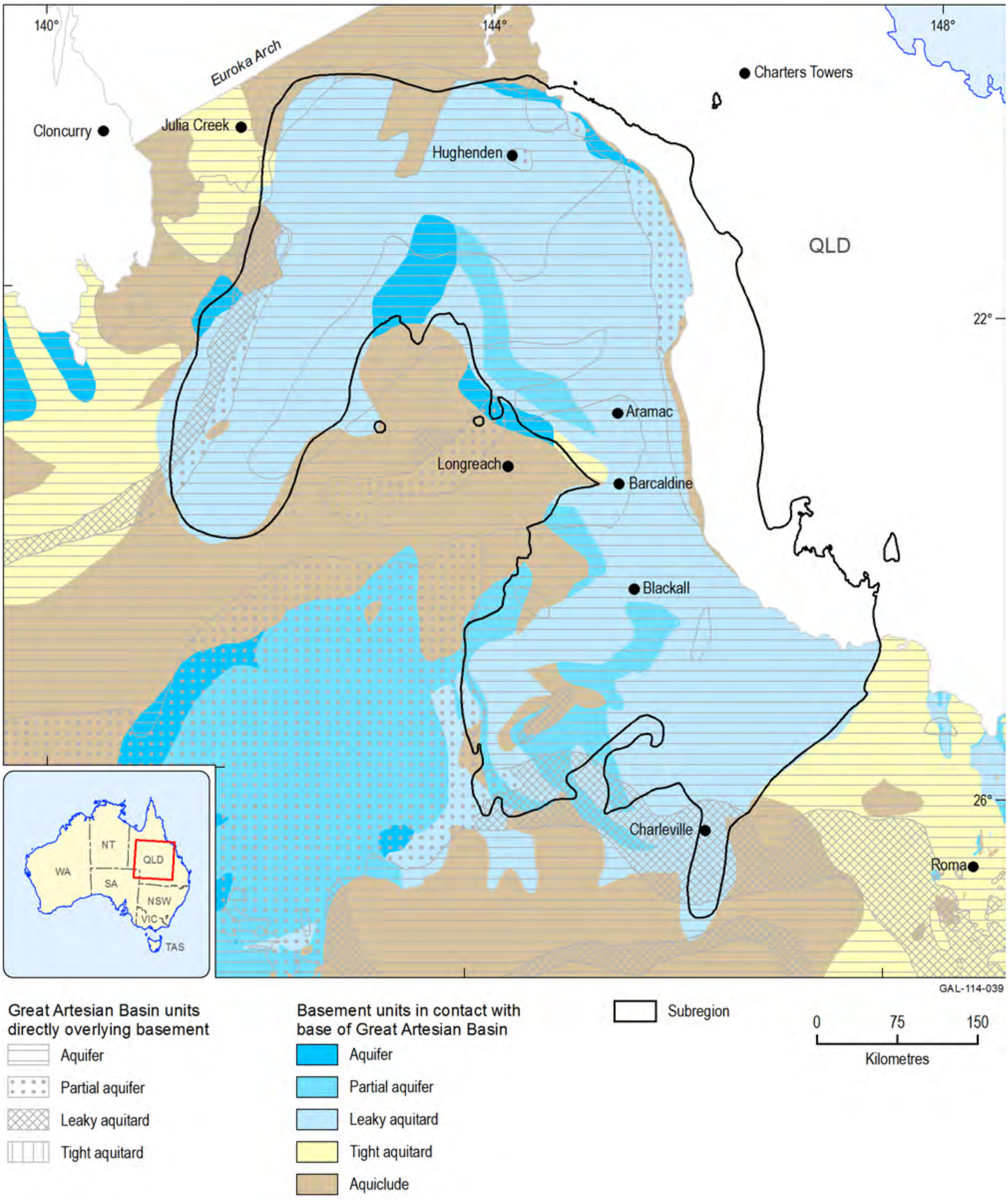


**Figure 36 Areas of potential hydraulic interconnection between the base of the Eromanga Basin and underlying basement units, including the Galilee Basin**

Source data: after Figure 5.8, Smerdon and Ransley (2012).

### 1.1.4.4 Groundwater planning and use

Groundwater in Queensland is managed under the Water Act 2000 through subsequent Water Resource Plans (WRP), Resource Operations Plans (ROPs) that are prepared for proclaimed/declared areas (Queensland Government, 2013a, 2013b, 2013c), or through declared Sub-artesian Areas under the Water Regulation 2002. ROPs provide the operational details to meet the goals of Water Resource Plans, including monitoring and reporting. The applicable water resource plan or sub-artesian area outlines the licence requirements for the take of water as well as the permit requirements to construct bores.

A licence is generally required for:

- extraction of groundwater for purposes other than stock and domestic use within proclaimed/declared areas (Water Resource Plan areas, declared Sub-artesian Areas)

- taking artesian water for any purpose and from any location.

It should be noted that a licence is required for the taking of sub-artesian water hydraulically linked to GAB artesian water for stock purpose in some parts of the Great Artesian Basin WRP.

Metering of groundwater extraction can be required for licensed groundwater access.

Water Resource Plans are generally catchment-based for surface water management, and may include specific groundwater management areas (GMAs) and may also regulate groundwater hydraulically connected to surface water. The Great Artesian Basin Water Resource Plan differs in that it applies to artesian water and connected sub-artesian water in an area that spans parts of several surface water catchments. Groundwater in the Galilee Basin and potentially impacted areas is managed under the Water Resource Plans described in Table 6. Sub-artesian Areas which also regulate groundwater in the Galilee Basin include the Highlands Sub-artesian Area and Great Artesian Basin Sub-artesian Area.

The general reserves for a water management area are shown in Table 6. The Water Resource Plan (Great Artesian Basin) was published in 2006 (Queensland Government, 2013b). The Great Artesian Basin WRP includes aquifers from Galilee Basin, specifically the Clematis Group, Warang Sandstone, and Rewan Group, as well as aquifers found within the overlying Eromanga Basin. The GMAs usually include stratigraphic units from the Eromanga and Galilee Basins. The Western GMA is the only area that is exclusively Eromanga Basin.

As there is not one management unit that considers the general reserves for the Galilee Basin subregion, they must be inferred from seven plans that overlap with the basin. Further analysis is required to understand the percentage of allocation for each Water Resource Plan within the Galilee Basin.

**Table 6 Water Resource Plans and Groundwater Management Areas**

| Water Resource Plans | Relevant groundwater management area/zone | General Reserves for water licences in the management area/zone |
|---|---|---|
| Great Artesian Basin (2006) plan covers artesian water and connected sub-artesian water, while connected springs includes 25 spatial GMAs, each with several stratigraphic GMUs.<br>The Great Artesian Basin Water Resource Plan includes some of the aquifers found in the Galilee Basin (Warang Sandstone, Clematis Group, Dunda beds, Rewan Group) as well as aquifers in the overlying Eromanga Basin. | 7. Flinders GMA – 5 GMUs covering Toolebuc Formation – Clematis Group<br>8. Flinders East GMA – 5 GMUs covering Toolebuc Formation – Warang Sandstone<br>11. Barcaldine West GMA – 5 GMUs covering Toolebuc Formation – Clematis Group<br>12. Barcaldine North GMA - 3 GMUs covering Wallumbilla Formation – Clematis Group<br>13. Barcaldine East GMA - 4 GMUs covering Westbourne Formation – Rewan Group<br>14. Barcaldine South GMA - 6 GMUs covering Toolebuc Formation – Clematis Group<br>15. Western GMA - 2 GMUs covering Toolebuc Formation – Algebuckina Sandstone<br>16. Central GMA - 7 GMUs covering Toolebuc Formation – Rewan Group<br>17. Warrego West GMA - 7 GMUs covering Toolebuc Formation – Rewan Group<br>18. Warrego East GMA – 7 GMUs covering Toolebuc Formation – Rewan Group | 7. Flinders GMA – 2000 ML.<br>8. Flinders East – 100 ML.<br>11. Barcaldine West GMA – 3000 ML.<br>12. Barcaldine North – 500 ML.<br>13. Barcaldine East – 0 ML.<br>14. Barcaldine South – 1500 ML.<br>15. Western – 0 ML.<br>16. Central – 1000 ML.<br>17. Warrego West – 1000 ML.<br>18. Warrego East – 4000 ML. |
| Gulf (2007) plan covers artesian and sub-artesian waters that are not Great Artesian Basin water, and springs not connected to Great Artesian Basin water. Surface water - groundwater under or within 1 km of a watercourse is considered to be within the watercourse.<br>Includes 3 spatial GMAs. | 1. Great Artesian Basin GMA (predominantly defined by the Flinders River Catchment Area) | Volumetric limits are allocated based on catchment and subcatchment areas. Flinders River Catchment Area – 80 000 ML. |
| Burdekin Basin (2007) plan covers recharge springs and surface water. Groundwater designated as ‘watercourse’ water in the Giro Benefited Groundwater Area. | Nil | N/A |
| Fitzroy Basin (2011) plan covers groundwater; recharge springs. Surface water includes 5 spatial GMAs, which may include sub-areas and stratigraphic GMUs. | Carnarvon GMA<br>Highlands GMA – Groundwater Unit 1 (alluvials) and Groundwater Unit 2 (non-alluvials), and Sandy Creek Alluvium groundwater sub-area | Carnarvon – 250 ML.<br>Fitzroy – 500 ML. |
| Warrego, Paroo, Bulloo and Nebine (2003) plan covers recharge springs and surface water. | Nil | N/A |

| Water Resource Plans | Relevant groundwater management area/zone | General Reserves for water licences in the management area/zone |
|---|---|---|
| Cooper Creek (2011) plan covers recharge springs, surface water, and sub-artesian groundwater that is hydraulically linked to surface water (i.e. surface water and hydraulically linked groundwater managed as a single resource). | Nil, but Water Resource Plan refers to protected watercourses, waterholes and lakes, which may have implications for hydraulically connected groundwater | N/A |
| Georgina and Diamantina (2004) plan covers surface water and sub-artesian groundwater that is hydraulically linked to surface water (i.e. surface water and hydraulically linked groundwater managed as a single resource). | Nil | N/A |

Source: Compiled from National Water Commission (2011) and Queensland Government (2013a, 2013b, 2013c).
GMU: Groundwater management unit
GMA: Groundwater management area

## *References*

Audibert M (1976) Progress report of the Great Artesian Basin hydrogeological study, 1972–1974. Record 1976/5. Canberra, Bureau of Mineral Resources, Geology and Geophysics.

Bradshaw BE, Spencer LK, Lahtinen AC, Khinder K, Ryand DJ, Colwell JB, Chirinos A and Bradshaw J (2009) Queensland Carbon Dioxide Geological Storage Atlas. Department of Employment, Economic Development and Innovation, Queensland Government.

Department of Environment and Resource Management, Queensland (DERM) (2010) Groundwater Database.

Draper JJ (2013) Belyando Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 174-175.

Habermehl MA (1980) The Great Artesian Basin, Australia. Bureau of Mineral Resources Journal of Australian Geology and Geophysics 5, 9–38.

McKellar JL and Henderson RA (2013) Galilee Basin. Geology of Queensland. In: Jell PA (ed), Geological Survey of Queensland.

McKillop MD (2013) Adavale Basin. In: Jell PA (ed) Geology of Queensland. Geological Survey of Queensland, 175-183.

National Water Commission (2011) National Water Planning – Report Card 2011.

NHMRC and NRMMC (2011) Australian Drinking Water Guidelines 6. National Water Quality Management Strategy: National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Queensland Government (2013a) Water Resource (Fitzroy Basin) Plan 2011. Viewed 14 October 2013, <https://www.legislation.qld.gov.au/Acts_SLs/Acts_SL_W.htm>.

Queensland Government (2013b) Water Resource (Great Artesian Basin) Plan 2006. Viewed 14 October 2013, <https://www.legislation.qld.gov.au/Acts_SLs/Acts_SL_W.htm>.

Queensland Government (2013c) Water Resource (Gulf) Plan 2007. Viewed 14 October 2013, <https://www.legislation.qld.gov.au/Acts_SLs/Acts_SL_W.htm>.

Radke BM, Ferguson J, Cresswell RG, Ransley TR and Habermehl MA (2000) Hydrochemistry and implied hydrodynamics of the Cadna-owie – Hooray Aquifer, Great Artesian Basin, Australia. Canberra, Bureau of Rural Sciences: xiv, 229 pp.

Ransley TR and Smerdon BD (eds) (2012) Hydrostratigraphy, hydrogeology and system conceptualisation of the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. 285 pp.

RPS (2012) Galilee Basin. Report on the hydrogeological investigations. Brisbane. 387 pp.

Scott SG, Beeston JW and Carr AF (1995) Galilee Basin. Geology of Australian Coal Basins. In: Ward CR, Harrington HJ, Mallett CW and Beeston JW (eds) , Geological Society of Australia – Coal Geology Group 1, 341–353.

Seidel GE (1978) Hydrogeological studies – Great Artesian Basin – GABHYD program expansion, model calibration, sample application, documentation.  Report 208. Australia, Bureau of Mineral Resources Australia, 33–35.

Smerdon BD and Ransley TR (eds) (2012) Water resource assessment for the Central Eromanga region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. 120 pp.

Welsh WD (2000) GABFLOW: A steady state groundwater flow model of the Great Artesian Basin. Canberra, Bureau of Rural Sciences, 75pp.

## 1.1.5 Surface water hydrology and water quality

### *Summary*

The Galilee subregion of the Lake Eyre Basin bioregion is located in the state of Queensland and it intersects several river basins including the Cooper-Bulloo and Diamantina in the west, the Flinders in the north, the Burdekin and Fitzroy in the east and the Warrego in the south. The area of the Galilee subregion is about 247,000 km$^2$ of which 46% is included in the Cooper creek-Bulloo river basin followed by 17% in Diamantina, 14% in Flinders, 12% in Warrego, 8% in Burdekin and 3% in Fitzroy river basins.

Much of the Galilee subregion is part of the Cooper creek-Bulloo river basin. Cooper Creek and the Thomson, Barcoo and Bulloo rivers are the major waterways in this basin. The Thomson and Barcoo rivers originate in the Galilee subregion and join each other at Currareva. The stream below the junction of Thomson and Barcoo rivers is known as Cooper Creek and is characterised by complex anastomosing channels and numerous wetlands and waterholes. Floods occur infrequently on the floodplain of Cooper Creek but can be much more damaging and disruptive due to the flat topography and the large number of braided channels in the floodplain. Water quality information such as total phosphorus (TP), total nitrogen (TN), electrical conductivity (EC) and turbidity is scarce for this basin. Salinity is normally low and stable. Turbidity is high and subject to varying trends as a result of local influences.

The north-western part of the Galilee subregion is part of the Diamantina river basin. The Diamantina River originates in the Galilee subregion and flows through a series of wetlands, lakes and waterholes along its 1000 km length. The Diamantina River is one of the major contributors of surface water to Kati Thanda – Lake Eyre. The flow regimes of the basin are dominated by late summer flow events resulting from highly variable monsoonal rainfall in the upper catchments. The rivers have greatly varying widths of active channel and floodplain. Floods are infrequent but during large events, floodwaters inundate thousands of square kilometres. There are no permanent water quality monitoring sites in the basin. However, data from occasional in situ measurements indicate low salinity and high turbidity in this basin.

The northern part of the Galilee subregion is included in the Flinders river basin. The Flinders River and two of its tributaries originate in the Galilee subregion. The flow regimes of the Flinders river basin are characterised as dry seasonal. The Flinders River carries large volumes of water during wet months. Floods are infrequent and can occur both upstream and downstream of the Flinders River. Water quality in the Flinders region appears to be reasonably good. There is spatial variability in the magnitude and ranges of both salinity and turbidity, and although there are some broad regional trends in salinity, turbidity appears to be dominated by local influences.

A small proportion of the Galilee subregion in the east is part of the Burdekin river basin. The Cape and Belyando rivers are the two major waterways of the Burdekin river basin that originate in the Galilee subregion. These two rivers carry upper catchments runoff to the

Burdekin River above the Burdekin Falls Dam. The flow regime of the basin varies between locations, ranging from perennial to dry seasonal. Floods occur along the major rivers both upstream and downstream of the Burdekin Falls Dam. Although floods in the lower part of the basin can occur from local rainfall, inflows from upstream rivers contribute significantly to flood volume and duration. Availability of water quality data for the areas included in the Galilee subregion is very poor. Overall, salinity is low all across the basin but TN, TP and turbidity concentrations are high at many locations.

Only a small proportion of the Galilee subregion is part of the Fitzroy river basin. The Nogoa and Claude rivers originate in the Galilee subregion and carry catchment runoff to the Fitzroy River. The Fitzroy Basin comprises both perennial and seasonal streams. Inflows from headwater streams including Nogoa contribute greatly to flood volume on floodplain of the Fitzroy River and due to its immense size and fan-like shape the Fitzroy River has produced several large floods in the past. Water quality indicators such as TP, TN and turbidity show higher concentration in all major rivers although salinity is generally low.

The south-eastern part of the Galilee subregion is part of the Warrego river basin. The Warrego River and its three upstream tributaries originate in the Galilee subregion. The river flows through a series of reservoirs including swamps, billabongs, waterholes and dams. The flow regime of the Warrego River is characterised as perennial. Although floods are infrequent several large floods occurred in the past. Water quality indicators are generally good in this basin.

### *1.1.5.1 Surface water systems*

The stream networks in the Galilee subregion are part of six large river basins in Queensland (Figure 37). The following sections describe details of the surface water systems in Galilee and surrounding regions.

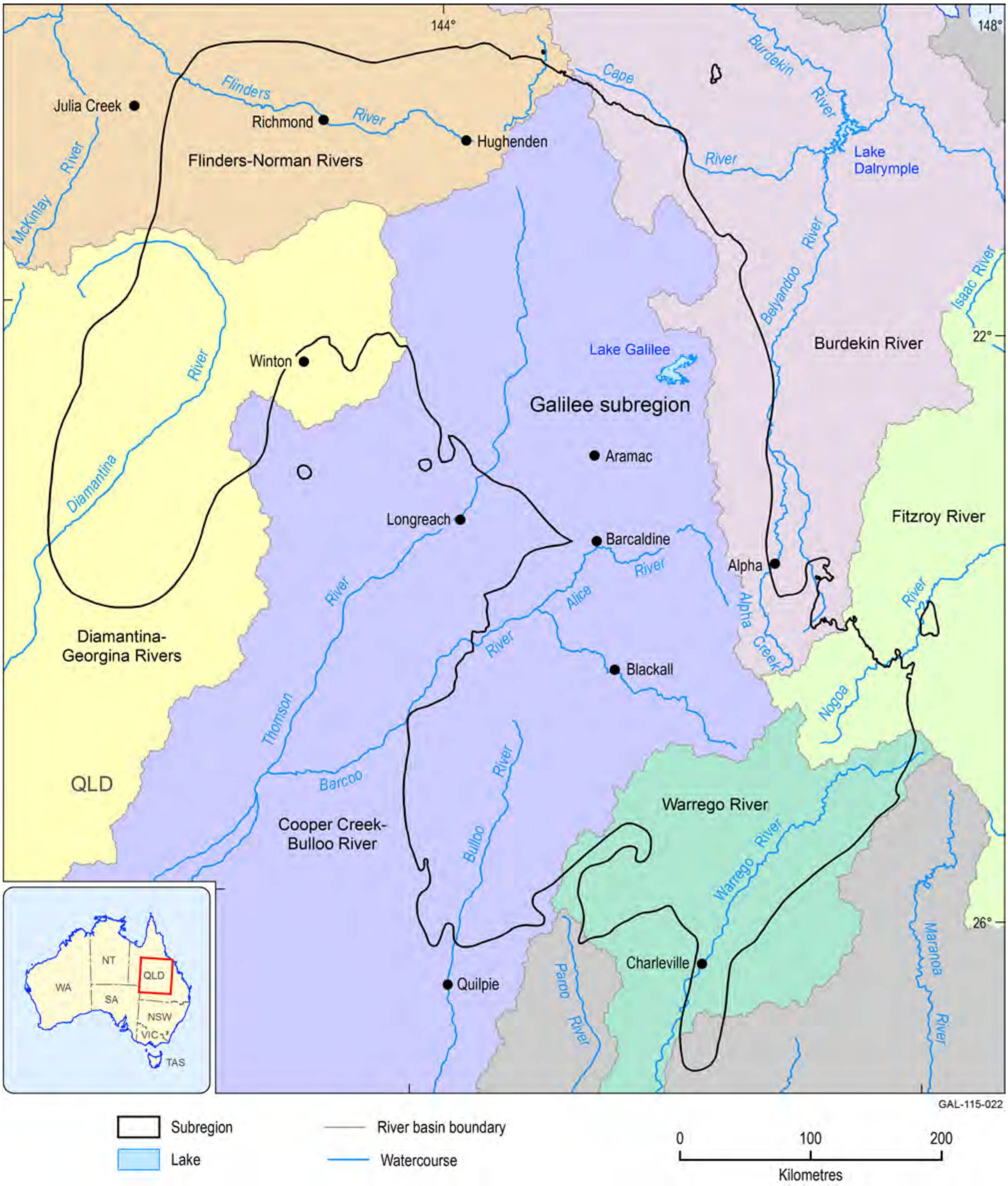


Figure 37 The Galilee subregion and associated nearby river basins

### 1.1.5.1.1 Cooper creek-Bulloo river basin

The Cooper creek-Bulloo river basin is located in the core of the Australian arid region. It has a drainage area of 503,565 km$^2$ and covers parts of Queensland, South Australia and NSW (McMahon et al., 2005). The major surface water systems include Cooper Creek and the Thomson and Barcoo rivers, as well as numerous wetlands and lakes in the Cooper creek basin, and the Bulloo River as well as wetlands and lakes in the Bulloo river basin (Figure 38). A notable feature of the system is the extensive floodplain that dominates the basin south of Windorah and divides into two distinct parts near the Queensland-South Australia border. The Bulloo river basin is an internally draining system located between Kati Thanda – Lake Eyre and the Murray–Darling Basin. About 114,000 km$^2$ (or 46%) of the Galilee subregion is part of the Cooper creek-Bulloo river basin which comprises 23% of the river basin.

The stream below the junction of the Thomson and Barcoo rivers is known as Cooper Creek and is characterised by complex anastomosing channels and numerous wetlands and waterholes. Headwater streams originate in the Galilee subregion from the Great Dividing Range of Queensland and feed Cooper Creek through the Thomson and Barcoo rivers. Cooper Creek flows toward the south-west to its final terminus in Kati Thanda – Lake Eyre after passing more than 1500 km of different geographical features. The area of the Cooper Creek floodplain is approximately 15,300 km$^2$ and the width can exceed 60 km at many locations near Currareva. In the dry season, the channels are restricted to numerous lagoons and claypans but during high flow the actual main channel becomes hard to define. In a big flood, the area becomes a huge inland sea broken only by a few ridges and numerous stunted trees (Knighton and Nanson, 2001). Records of large floods in the area extend back as far as the late 19th century, with the most significant episodes of flooding occurring in 1893, 1906, 1949, 1955, 1963, 1974, 1990 and 2000 (Bureau of Meteorology, 2014).

Flow in Cooper Creek has not yet been affected by diversion of water for irrigated agriculture or major dams or weirs (McMahon et al., 2005). In 1995, a consortium of cotton growers proposed 42 GL of water to irrigate cotton at Currareva (Walker et al., 1997). But the proposal was rejected by the Queensland Government in 1996 considering environmental need of water in this region. In a recent water resource plan for the Cooper Creek the Queensland Government reserved a total of 2 GL of unallocated water (200 ML for general reserve, 1300 ML for strategic reserve and 500 ML for the town and community reserve) to meet future demand (DERM, 2011a). There is no major water storage within the Cooper creek-Bullo river basin.

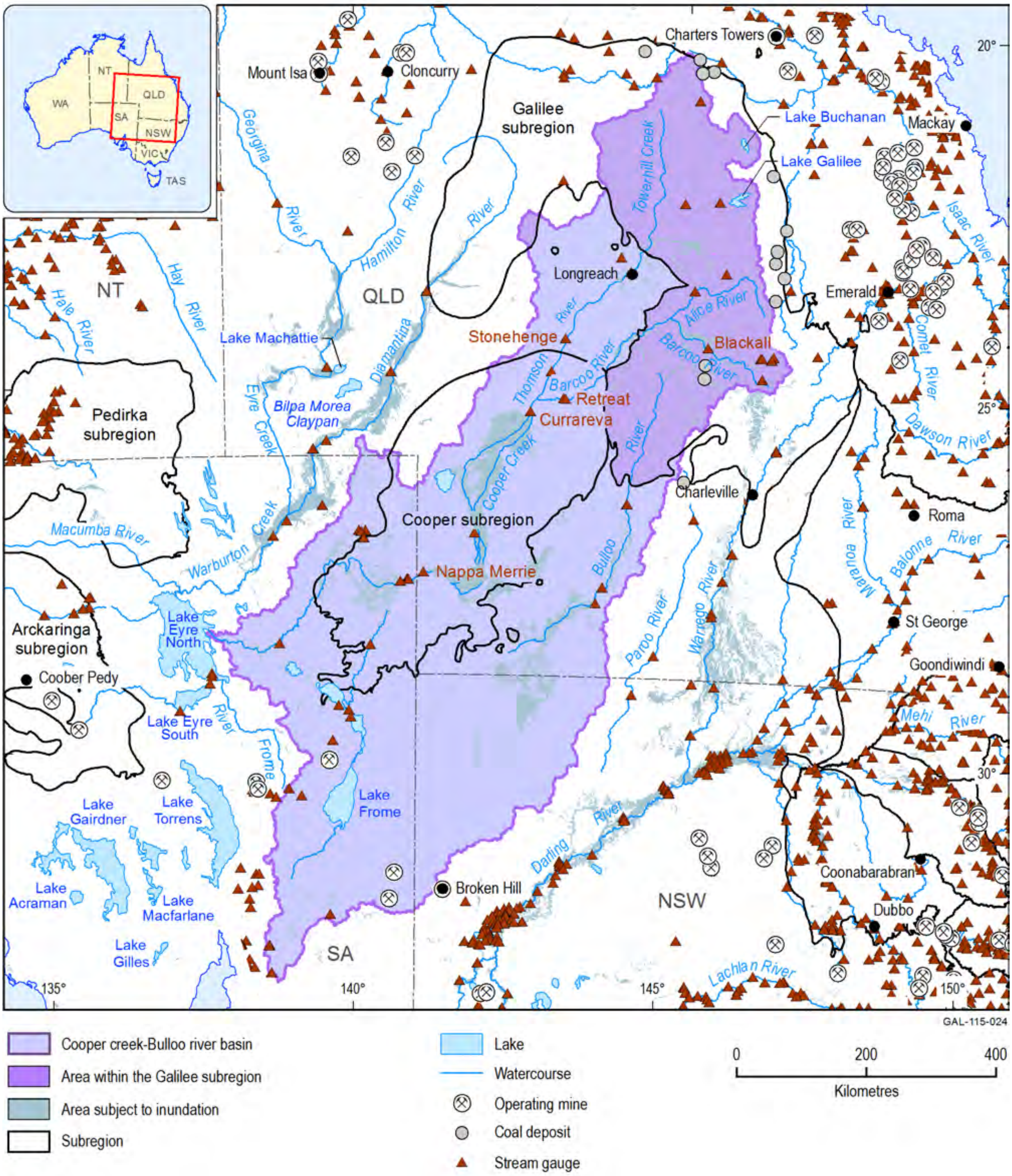


**Figure 38 Cooper creek-Bulloo river basin showing major stream network, water assets and location of mining activities in this subregion**

### 1.1.5.1.2 Diamantina river basin

The Diamantina river basin is located in the central part of Australia and is one of the largest river basins of the Lake Eyre Basin. It has a drainage area of 160,000 $km^2$ which is about one eighth of the Lake Eyre Basin, including areas of Queensland and South Australia (McMahon et al., 2005). The major surface water resources in the basin are Diamantina and Mayne rivers and Farrars Creek as well as numerous wetlands and lakes. Other minor stream channels include Western River and Mill Creek as well as a series of small unnamed tributaries and swamps. A notable feature of the system is the extensive floodplain that dominates the catchment above Birdsville. About 43,000 $km^2$ (or 17%) of the Galilee subregion is part of the Diamantina river basin which comprises 36% of the total basin area.

The headwaters of the Diamantina River occur in the Galilee subregion. The entire river length is 1000 km to its terminus at Kati Thanda – Lake Eyre. The Western and Mayne rivers, which also originate in the Galilee subregion, join the Diamantina River above Diamantina Lakes, and Farrars Creek joins below Monkira (Figure 39). The rivers are characterised by complex anastomosing channels, wide floodplains, and numerous waterholes and wetlands. Overall the Diamantina river basin is very flat and the rivers have greatly varying widths of active channel and floodplain. During large flood events, floodwaters can inundate thousands of square kilometres due to the low relief throughout the area. Floods normally develop in the headwaters of the Diamantina River and its major tributaries, however flooding may result from heavy rainfall falling in the middle to lower reaches around Diamantina Lakes. Since 1965, large floods have occurred in 1974, 1991, 2004 and 2010 (Bureau of Meteorology, 2013).

The Queensland Government protected the water allocation in the Diamantina river basin under the *Queensland Wild Rivers Act 2005*. Currently, there are no significant storages on the Diamantina River and it retains a near-natural flow regime.

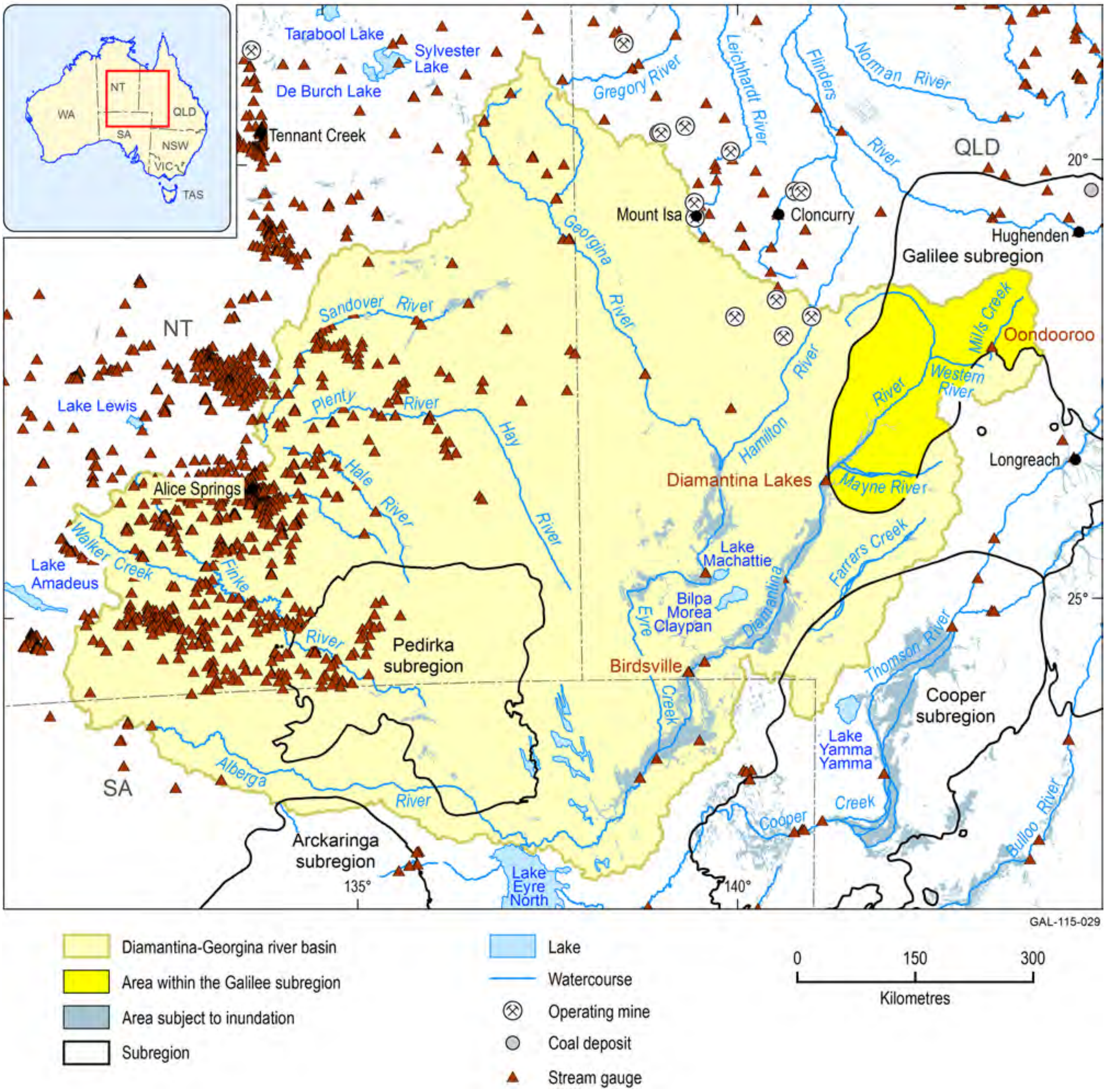


Figure 39 Diamantina river basin showing major stream network, water assets and location of mining activities in this subregion

### 1.1.5.1.3 Flinders river basin

The Flinders river basin is located in north-west Queensland and drains an area of 109,000 km$^2$. The surface water system of the basin includes several large rivers, two dams and numerous wetlands and springs (Figure 40). The Flinders River and two of its tributaries (Dutton and Stawell rivers) originate in the Galilee subregion. A notable feature of the system is its extensive floodplain in the lower part of the basin below Canobie. About 35,000 km$^2$ (or 14%) of the Galilee subregion is part of the Flinders river basin, which comprises 32% of the river basin.

The Flinders River rises in the Great Dividing Range north-east of Hughenden, nearly 1000 km from its entry to the Gulf of Carpentaria. It flows initially in a westerly direction towards Julia Creek, before flowing north to the vast savannah country downstream of Canobie. It traverses through its delta and finally into the Gulf of Carpentaria. The Dutton River joins the Flinders River at Richmond and the Stawell River joins below Richmond. Floods cause widespread inundation of the Flinders floodplain below Canobie and floodwaters of the Flinders and Norman rivers often merge creating a large water body. The region was severely affected by floods in 1974, 2001, 2009 and 2011 (Dutta et al., 2013).

The current surface water availability for the Flinders river basin is about 2023 GL/year and on average about 107 GL/year (or 5%) of this water is allocated for consumptive purposes (CSIRO, 2009). In November 2011, both the Gulf Water Resource Plan and the Resource Operations Plan were amended to establish unallocated water reserves to support Indigenous people in the Flinders areas in achieving their social and economic development aspirations. In May 2013, new water licences were granted from the general unallocated water reserve. A total of 80 GL was granted in the Flinders river basin and 14.2 GL was granted in the Gilbert river basin (DNRM, 2013).

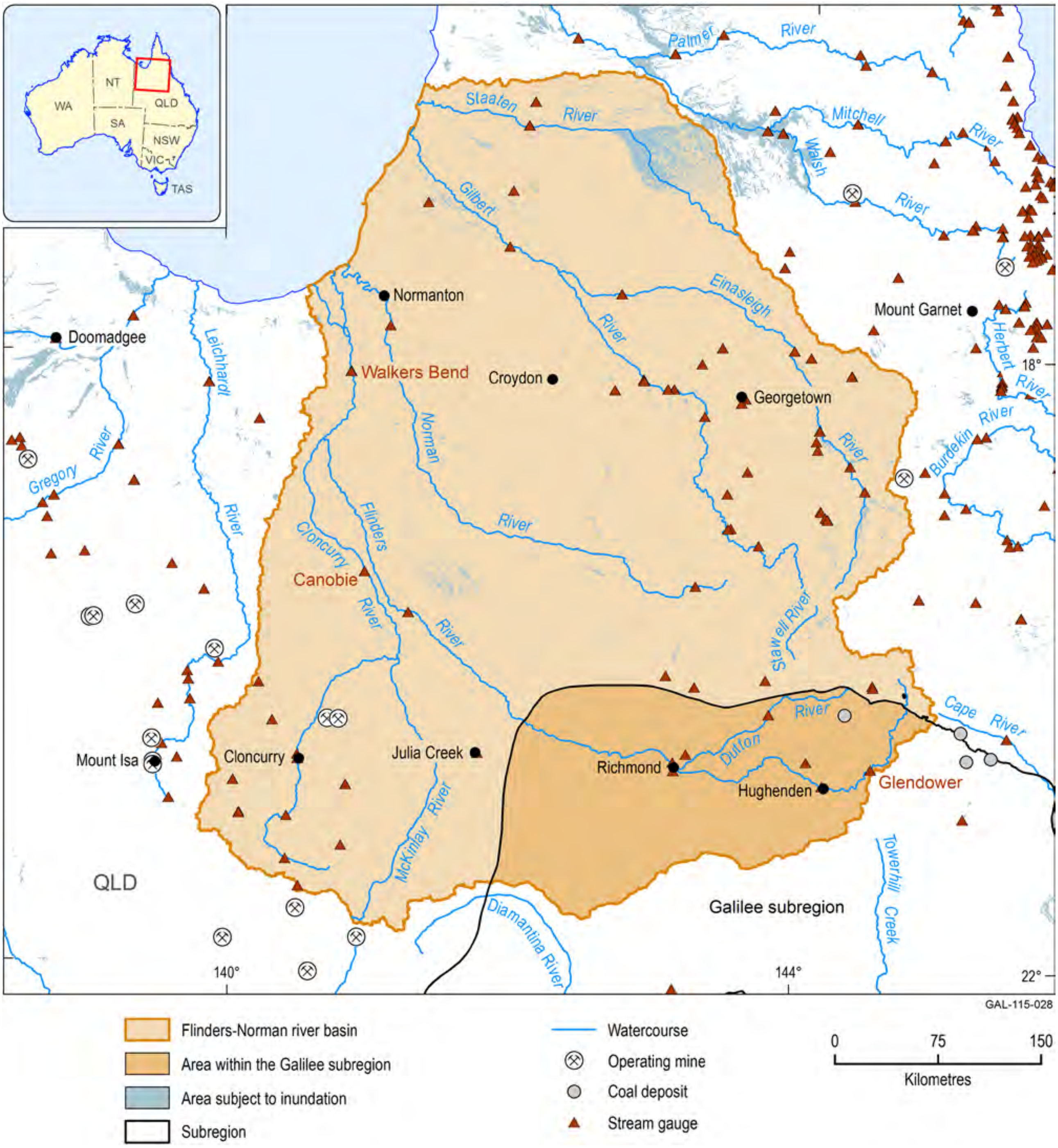


**Figure 40 Flinders river basin showing major stream network, water assets and location of mining activities in this subregion**

### 1.1.5.1.4 Burdekin river basin

The Burdekin river basin is part of northern Queensland and it covers an area of 134,000 $km^2$. It is the second largest river basin that drains into the Great Barrier Reef lagoon. The surface water system of the basin consists of several large rivers (e.g. Burdekin, Belyando, Bowen, Cape, Clarke and Suttor) as well as numerous wetlands, waterholes and dams (Figure 41). The Cape and Belyando rivers originate in the Galilee subregion. These two rivers carry upper catchments runoff and feed the Burdekin River above the Burdekin Falls Dam. About 20,000 $km^2$ (or 8%) in the east of the Galilee subregion is part of the Burdekin river basin which comprises 15% of the total basin area.

The Burdekin River rises on the western slope of the Seaview Range and flows into the Pacific Ocean at Upstart Bay over 200 km to the south-east of the source. Two main tributaries, the Burdekin River flowing from the north and the Belyando River from the south, join at the Burdekin Falls Dam. Downstream of the dam, the Bowen and Bogie rivers join the Burdekin River before it flows into the sea near Ayr. The source of the Belyando River is in central western Queensland and it traverses almost 500 km before it joins the Burdekin River. The Cape River rises in the Great Dividing Range north-east of Hughenden near Mount Richardson and joins the Burdekin River near Mount Elsie. Floodplains of major rivers both upstream and downstream of the Burdekin Falls Dam are susceptible to occasional flooding. Downstream of the dam, floods result from either flood waters travelling down from the upper Burdekin and Belyando river basins or from intense rain in areas below the dam. Several large floods have been recorded in the Burdekin since 1910 including a major flood in 1991.

There are a large number of dams and weirs in the Burdekin river basin located on Burdekin, Haughton and Bowen rivers. The Burdekin Falls Dam, which is the largest dam in Queensland, is the major water storage in this basin and much of its water comes from upper catchments runoff including areas within the Galilee subregion. Water licences are allocated under Burdekin Haughton and Bowen Broken water supply schemes. The amount allocated depends on availability of water. Currently the maximum allocation under the Burdekin Haughton water supply scheme is 204 GL for a high priority group and 1300 GL for a medium priority group (DERM, 2010).

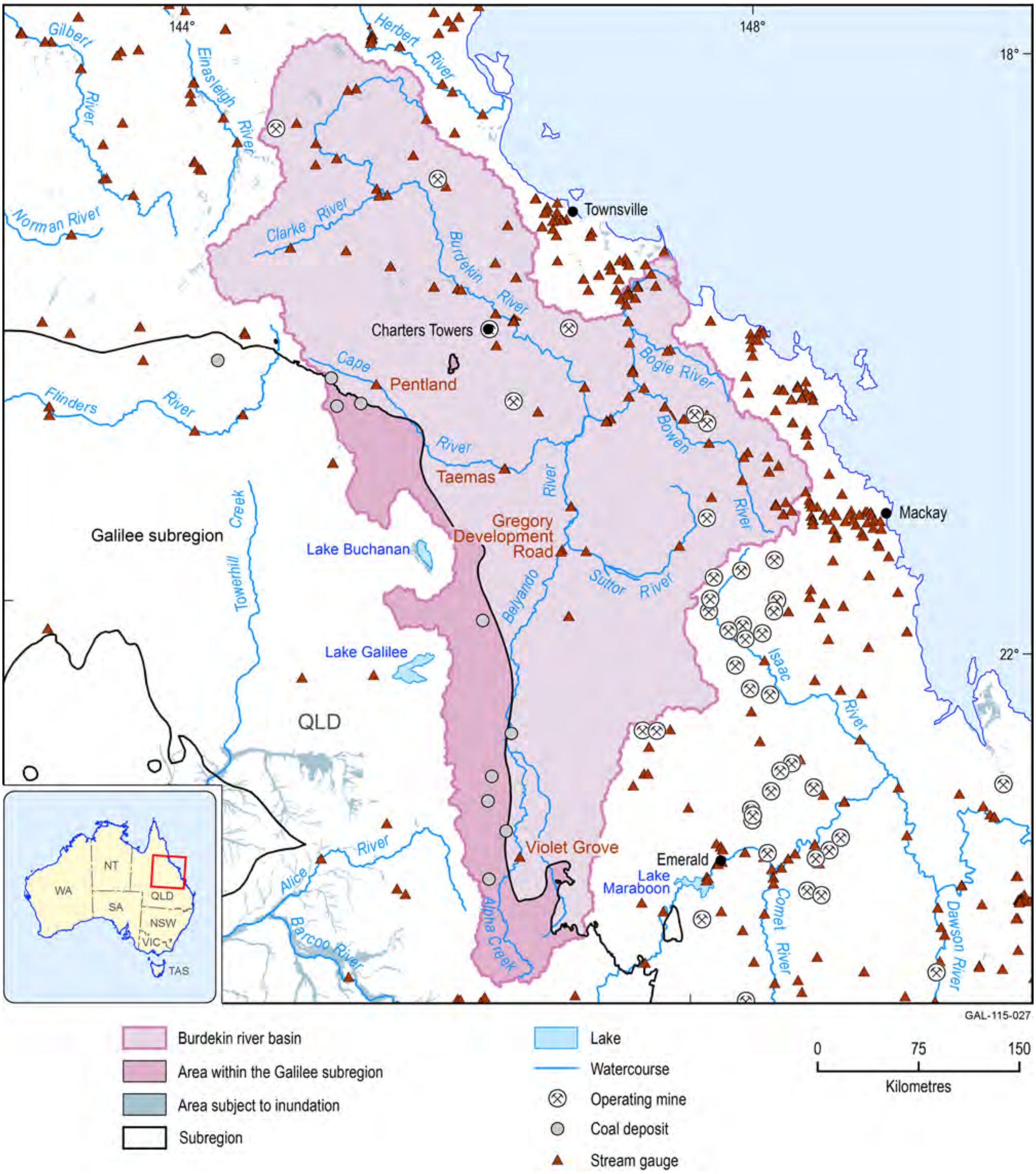


**Figure 41 Burdekin river basin showing major stream network, water assets and location of mining activities in this subregion**

### 1.1.5.1.5 Fitzroy river basin

The Fitzroy river basin is located in central Queensland and is bounded to the north by the Burdekin river basin and to the south by the Burnett river basin and covers an area of 142,665 km$^2$. It is the largest river basin flowing to the Great Barrier Reef lagoon. The surface water system of the basin consists of several large rivers (e.g. Fitzroy, Isaac, Nogoa, Comet, Mackenzie and Dawson) as well as numerous wetlands, lakes, weirs and dams (Figure 42). The Claude and Nogoa rivers originate in the Galilee subregion and carry upper catchments runoff via the Mackenzie River through to the Fitzroy River. The Claude River is relatively short and joins the Nogoa River at Myola, 104 km from its origin. About 8000 km$^2$ (or 3%) in the south-east of the Galilee subregion is part of the Fitzroy river basin, which comprises 5% of the total basin area.

The Nogoa River, which is in the far west of the Fitzroy river basin, starts to flow through Emerald and joins with the Comet River. The stream below the junction of the Nogoa and Comet rivers is named the Mackenzie River. The Connors River, which is situated in the northern part of the basin, joins the Isaac River at Yatton. The Isaac River joins with the Mackenzie River just upstream of Tartrus weir. The Fitzroy River is then formed by the joining of the Mackenzie and Dawson rivers in the Duaringa area and it passes through Rockhampton and into Keppel Bay, a further 60 km downstream (Amir et al., 2013). Flooding in the Fitzroy region typically occurs in summer or early autumn, in association with tropical cyclones or intense monsoonal depression. Due to the size of the basin and each of its major tributaries, the Fitzroy river basin frequently experiences flooding following high rainfall events. Several large floods have been recorded since 1859, including a major flood in 2011. The Nogoa River, which originates in the Galilee subregion, produces floods in the city of Emerald and contributes to downstream floods as well.

There are a large number of water storages in the Fitzroy basin including dams, weirs, barrages and ring tanks. Water licences are allocated under four water supply schemes, the Dawson Valley, Fitzroy Barrage, Lower Fitzroy and Nogoa Mackenzie. The amount allocated depends on availability of water. Currently the maximum allocation under the Nogoa Mackenzie water supply scheme is 56 GL.

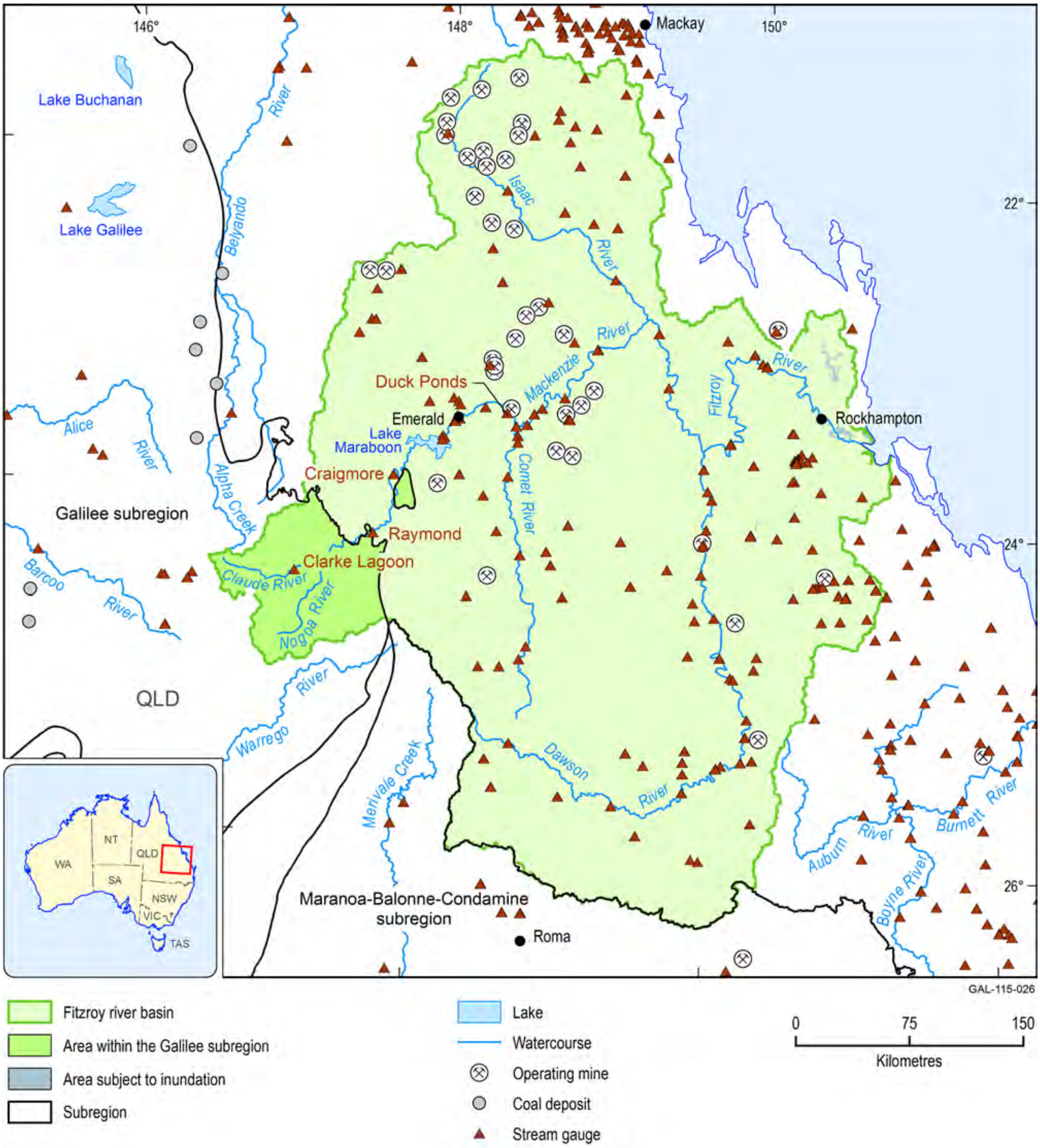


**Figure 42 Fitzroy river basin showing major stream network, water assets and location of mining activities in this subregion**

### 1.1.5.1.6 Warrego river basin

The Warrego river basin is located in south-west Queensland and north-west NSW and covers an area of approximately 65,000 km$^2$. The Warrego River is the only major water channel in this basin and is a tributary of the Darling River. The major surface water resources in the basin are the Warrego, Nive, Ward and Langlo rivers, as well as several wetlands, lakes, weirs and dams (Figure 43). About 29,000 km$^2$ (or 12%) of the Galilee subregion in the south is part of the Warrego basin, comprising 44% of the total basin area.

The Warrego River rises from Mount Ka Ka Mundi in the Carnarvon Range, near Tambo in Queensland, and flows generally south, reaching its confluence with the Darling River downstream from Bourke. It originates in the Galilee subregion and traverses Augathella, Charleville, Wyandra and Cunnamulla over the course of its 1380 km length. Three of its major tributaries (the Nive, Ward and Langlo rivers) also originate in the Galilee subregion and join the Warrego River between Augathella and Charleville. The Warrego is a perennial river and flows through a series of reservoirs, including the Dillalah Waterhole, Ten Mile Waterhole, Lower Lila Dam, Six Mile Dam, Turtle Waterhole and Boera Dam. Although floods are infrequent, the Warrego River produced several large floods in the past including a recent flood in 2011.

Water diversions from the Warrego River are low. Water entitlements in this basin are managed by the Cunnamulla Water Supply Scheme which relies on water from the upper Warrego river basin that is part of the Galilee subregion. There are no high priority water allocations in the scheme. About 2.6 GL of water is currently allocated as medium priority for the purpose of irrigation.

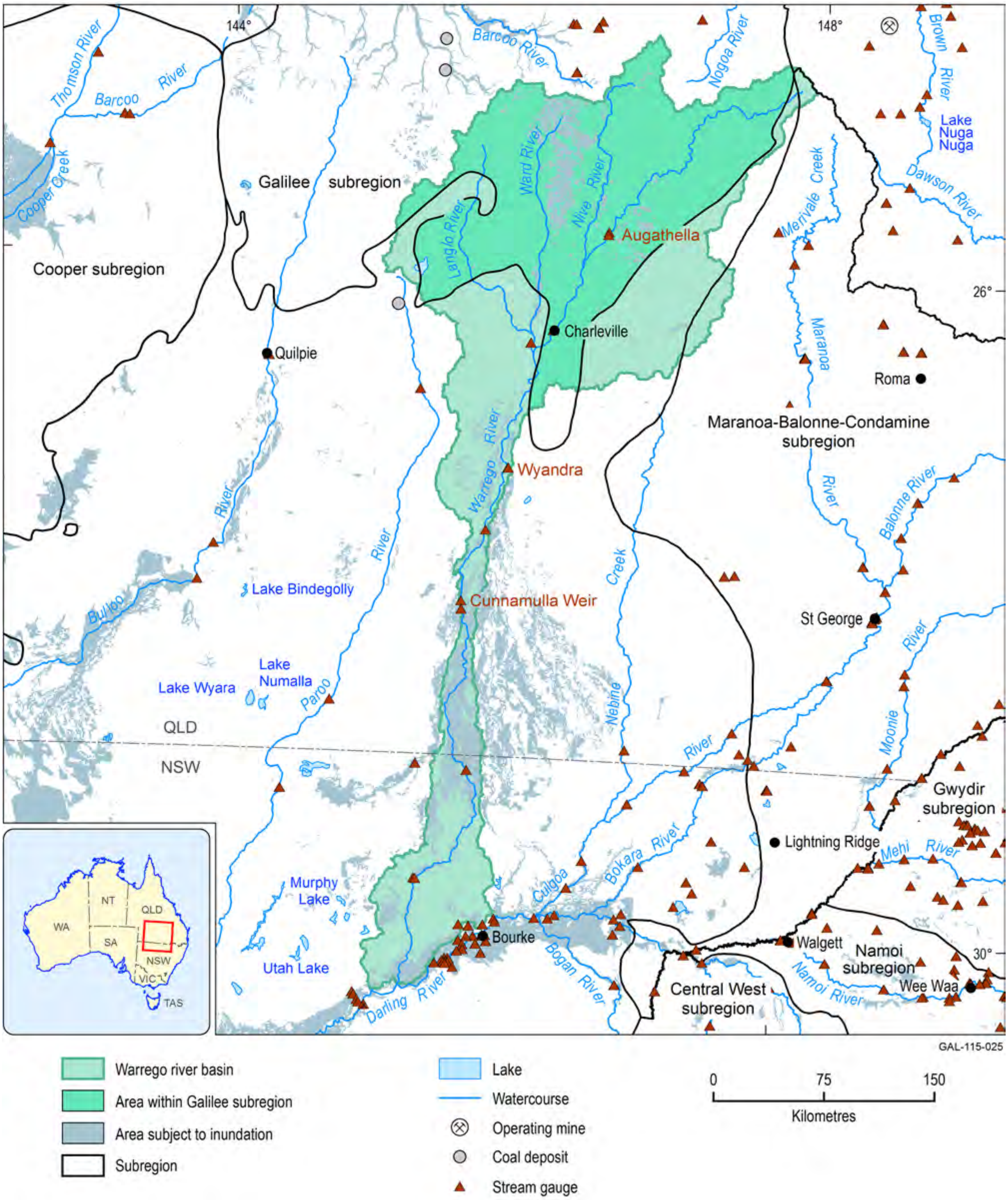


Figure 43 Warrego river basin showing major stream network, water assets and location of mining activities in this subregion

### 1.1.5.2 Surface water quality

The Queensland Government operates a number of stream gauges to monitor water quality under its nine Aquatic Ecosystem Provinces (AEPs) across the state (DERM, 2011b). The Cooper-Bulloo and Diamantina river basins are part of the Lake Eyre AEP, the Flinders river basin is part of the Gulf AEP, the Burdekin and Fitzroy river basins are part of Central AEP and the Warrego river basin is part of the Murray–Darling AEP. The department has about 190 water quality measuring sites including manual and automated sampling. The frequency of sampling varies depending on operational conditions. These measurements generally include electrical conductivity, temperature, pH, turbidity, nutrients, dissolved oxygen and total alkalinity (DERM, 2012).

The availability of water quality data for the Cooper-Bulloo and Diamantina river basins is extremely poor due to logistic and accessibility difficulties associated with monitoring such a vast and sparsely populated area. There are six monitoring sites for water quality data in these basins, of which three are located within the Galilee subregion (Bowen Downs, Longreach and Blackall). Among the sites, continuous auto sensor data are available for Longreach station since 1993 and five or more sampled data are available for Nappa Merrie on Cooper Creek and Autumnvale on the Bulloo River. In addition there are three data logger sites in the Galilee subregion operated by the Lake Eyre Basin Rivers Assessment (LEBRA) program since 2011 (Cockayne et al., 2012). The LEBRA program also operates occasional in situ measurements in its 20 sites all across the LEB. As reported by DERM (2011b), salinity is low and stable at each of the gauging stations but subject to occasional high pulses at some sites. Turbidity is high and subject to varying trends as a result of local influences. It appears turbidity decreases from upstream to downstream and then increases again before the Cooper Creek crosses the Queensland–South Australia border. At Longreach, the median EC is about 200 µS/cm at baseflow and 100 µS/cm at high flows, however occasional high EC values occur anomalously at mid-flow ranges, particularly flows of between 0.1 and 10 $m^3/s$ (DERM, 2011b). Data from the LEBRA logger sites also showed a general pattern of increasing salinity throughout the low and no flow periods, followed by sharp lowering during high flow events. At some sites there is a distinct initial rise in salinity when the first flood water arrives (Cockayne et al., 2012).

In the Flinders river basin, there are two stream gauges for water quality measurement, one in the Galilee subregion at Richmond and the other at Walkers Bend on the downstream reach of the Flinders River. Continuous auto sensor data are available for Richmond since 2000 and five or more sampled data are available for Walkers Bend. As reported by DERM (2011b), water quality within the Flinders river basin is reasonably good. Both salinity and turbidity differ between upstream and downstream of the basin. At Richmond EC is quite variable, being around 150 µS/cm at high flows, but commonly ranging up to 450 µS/cm as flow declines during dry conditions. Exceptionally high EC values exceeding 3000 µS/cm occasionally occur at flows of between 0.01 and 0.1 $m^3/s$ (DERM, 2011b).

In the Burdekin and Fitzroy basins there are 78 stream gauges for water quality monitoring including one in the Galilee subregion at Violet Grove on Native Companion Creek, many of them have auto sensor records and a large number of sampled data. Overall, salinity is low across the Burdekin and Fitzroy river basins but TN, TP and turbidity concentrations are high at many sites. Rising salinity trends were found in the upper Burdekin and at the end of the system gauging site on the Fitzroy River (DERM, 2011b). Recorded data (2000–2011) at Violet Grove on Native Companion Creek show EC of between 100 and 500 µS/cm, with an mean of 198 µS/cm.

The availability of water quality data in the Warrego river basin is relatively poor. There is only one water quality monitoring site, at Cunnamulla Weir which is located outside the Galilee subregion boundary at about the middle reach of the Warrego River. At Cunnamulla Weir, salinity is high compared to Queensland in general. EC values ranged from as high as 800 µS/cm during baseflow, to 100 to 180 µS/cm at high flows (DERM, 2011b).

### *1.1.5.3 Surface water flow*

The Galilee subregion contributes surface water to six river basins (Cooper-Bulloo, Diamantina, Flinders, Burdekin, Fitzroy and Warrego) by its numerous headwater streams. Each of these river basins are characterised by large variations in discharge and flow duration. Streamflow monitoring sites are relatively sparse in the Galilee subregion. A list of available stream gauges within and adjacent to the Galilee subregion along with their length of record is given in Table 7. Detail of streamflow characteristics of the six river basins that are included in the Galilee subregion are described in the subsequent sections.

**Table 7 List of stream gauges in the Galilee subregion and surrounding areas located in six river basins that are part of Galilee hydrological study**

| Gauge no | Name | Catchment area ($km^2$) | Mean annual flow (GL) | Drainage basin | Data period |
|---|---|---|---|---|---|
| 011202A | Bulloo River at Autumnvale | 26,760 | 726 | Bulloo | 1967–present |
| 011203A | Bulloo River at Quilpie | 15,390 | 517 | Bulloo | 1949–present |
| 003103A | Cooper Creek at Nappa Merrie | 237,000 | 1,607 | Cooper | 1949–present |
| 003101A | Cooper Creek at Currareva | 150,220 | 3,642 | Cooper | 1966–1988 |
| 003203A | Thomson River at Stonehenge | 87,810 | 2,362 | Cooper | 1966–present |
| 003202A | Thomson River at Longreach | 57,590 | 1,228 | Cooper | 1969–present |
| 003301A,B | Barcoo River at Retreat | 51,663 | 1,193 | Cooper | 1999–present |
| 003204A | Cornish Creek at Bowen Downs | 22,830 | 338 | Cooper | 1968–present |
| 003303A | Barcoo River at Blackall | 8,782 | 102 | Cooper | 1969–present |
| 003302A | Alice River at Barcaldine | 7,918 | 55 | Cooper | 1968–present |
| 003205A | Darr River at Darr | 2,700 | 49 | Cooper | 1969–present |
| 002101A,B | Diamantina River at Birdsville | 115,200 | 1,261 | Diamantina | 1949–1988 |
| 002104A | Diamantina River at Diamantina Lakes | 54,130 | 1,835 | Diamantina | 1966–present |
| 002105A | Mills Creek at Oondooroo | 2,642 | 30 | Diamantina | 2007–present |
| 915003A | Flinders River at Walkers Bend | 106,300 | 3,429 | Flinders | 1969–present |
| 915012A | Flinders River at Etta Plains | 46,130 | 1,569 | Flinders | 1972–present |
| 915008A | Flinders River at Richmond | 17,380 | 619 | Flinders | 1971–present |
| 915004A | Flinders River at Hughenden | 2,519 | 127 | Flinders | 1969–1988 |

| Gauge no | Name | Catchment area ($km^2$) | Mean annual flow (GL) | Drainage basin | Data period |
|---|---|---|---|---|---|
| 915015A | Flinders River at Glendower | 1,958 | 154 | Flinders | 1972–present |
| 915010A | Dutton River at Perisher | 1,458 | 50 | Flinders | 1971–1988 |
| 915208A | Julia Creek at Julia Creek | 1,353 | 32 | Flinders | 1970–present |
| 915011A | Porcupine Creek at Mt Emu Plains | 540 | 35 | Flinders | 1972–present |
| 120015A | Burdekin River at Hydro Site | 114,700 | 7,166 | Burdekin | 1977–present |
| 120301B | Belyando River at Gregory Road | 35,411 | 698 | Burdekin | 1976–present |
| 120302B | Cape River at Taemas | 16,074 | 726 | Burdekin | 1968–present |
| 120305A | Native Companion Creek at Violet Grove | 4,065 | 62 | Burdekin | 1968–present |
| 130219A | Nogoa River at Duck Ponds | 27,130 | 787 | Fitzroy | 1992–present |
| 130209A | Nogoa River at Craigmore | 13,876 | 488 | Fitzroy | 1972–present |
| 130202A,B | Nogoa River at Raymond | 8,380 | 285 | Fitzroy | 1945–1988 |
| 130213A | Claude River at Clarke lagoon | 1,498 | 50 | Fitzroy | 1972–1988 |
| 120307A | Cape River at Pentland | 775 | 58 | Burdekin | 1969–present |
| 423202C | Warrego River at Cunnamulla weir | 48,690 | 529 | Warrego | 1961–present |
| 423203A | Warrego River at Wyandra | 42,870 | 653 | Warrego | 1967–present |
| 423201A | Warrego River at Charleville | 16,590 | 264 | Warrego | 1926–1978 |
| 423205A | Ward River at Binnowee | 14,670 | 471 | Warrego | 1999–present |
| 423204A | Warrego River at Augathella | 8,070 | 48 | Warrego | 1967–present |

### 1.1.5.3.1 Cooper creek-Bulloo river basin

Water in the Cooper creek basin is predominantly derived from runoff from headwater catchments. The Thomson and Barcoo rivers that originate in the Galilee subregion play an important role in flow into Cooper Creek. Transmission losses are generally very high. The long term (1901–2003) average modelled runoff coefficient in the Cooper creek basin varies from a low of 1.2% for the Alice River at Barcaldine to a high 6.6% for the Thomson River at Stonehenge. The runoff coefficients are 5.8% at Currareva and 1.6% at Nappa Merrie (McMahon et al., 2005).

Streamflow in Cooper Creek and its tributaries varies greatly between years from almost no flow to significant flooding, and between months with no flow for some months. Figure 44 shows an example of yearly and monthly flow distribution based on observed data (1967–2011) at Stonehenge. Streams are ephemeral and carry water mostly between December and May. The maximum monthly flow varies depending on the location of the gauging site and contributing catchment area, with some sites having very high flows (up to 15,900 GL/month, on the Cooper Creek at Currareva). Both annual and monthly flows generally increase down the basin, although there are exceptions to this trend. On average there is flow in Cooper Creek at Nappa Merrie about 60% of the time. The flow duration curves are steep for all gauging sites in the Cooper creek basin, confirming the observation that streamflow is highly variable and that there is little groundwater contribution to the overall flow (McMahon et al., 2005).

Due to its low gradient, water propagates very slowly on the floodplain and for a big flood it takes around 16 days for the water to pass through the floodplain with a wave speed of 0.3 m/s, while for a small flood the speed can be as low as 0.1 m/s (Costelloe et al., 2003). The long travel time allows the air and earth to absorb much of the water on the flat floodplain. On average the water of the Cooper Creek reaches Kati Thanda – Lake Eyre only once in every six years (Kingsford et al., 1999). For the biggest flood in the recorded history of Cooper Creek in 1974, around 25,000 GL of water inundated the creek and 40% of the water was lost by the time the flood peak arrived in Callamurra near the Queensland–South Australia border. For flow events below 5,000 GL the transmission loss is often above 80% (McMahon et al., 2005).

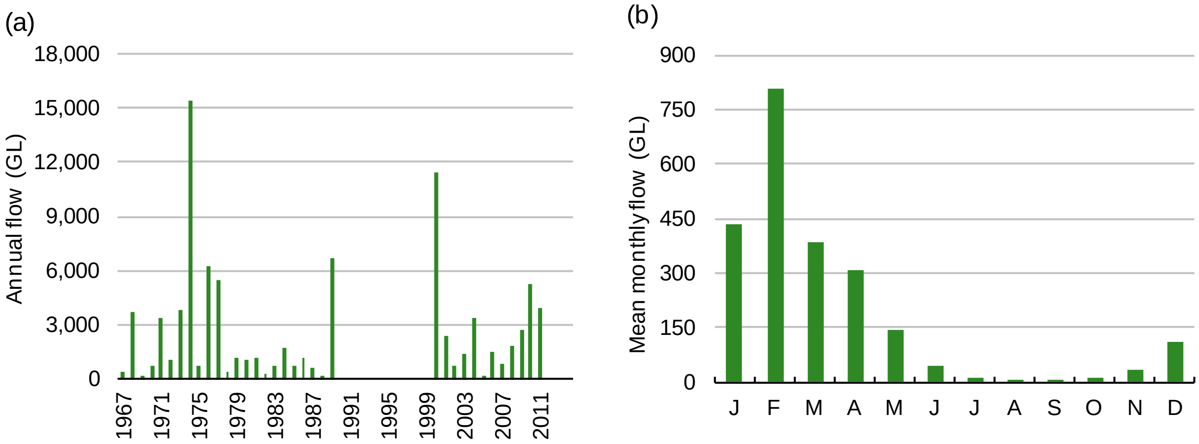


**Figure 44 Flow distribution at Stonehenge on the Thomson River in Cooper creek basin (a) annual and (b) mean monthly (Gauging Station: 003203A)**

### 1.1.5.3.2 Diamantina river basin

The flow regimes of the Diamantina River are dominated by late summer flow events resulting from highly variable monsoonal rainfall in the upper catchments. Due to the location of the basin, which includes semi-arid and arid regions, the streams are ephemeral (Knighton and Nanson, 2001). Like many arid zone rivers, the Diamantina river basin has few gauging sites to record streamflow, with two stations currently operating, one at Oondooroo on the Mills Creek and the other at Diamantina Lakes on the Diamantina River (Figure 39). These two stream gauges are within the Galilee subregion. Streamflow varies greatly between years from almost no flow to significant flooding (Figure 45a) and between months with almost no flow in August, September and October (Figure 45b). The maximum monthly flow varies depending on the location and contributing catchment area, with some gauges having high maximum mean monthly flows of up to 574 GL at Diamantina Lakes and 926 GL at Birdsville. On average, this basin contributes some inflow to Lake Eyre North every two years (Kotwicki, 2005). At Diamantina Lakes, cease-to-flow conditions occur approximately 53% of the time.

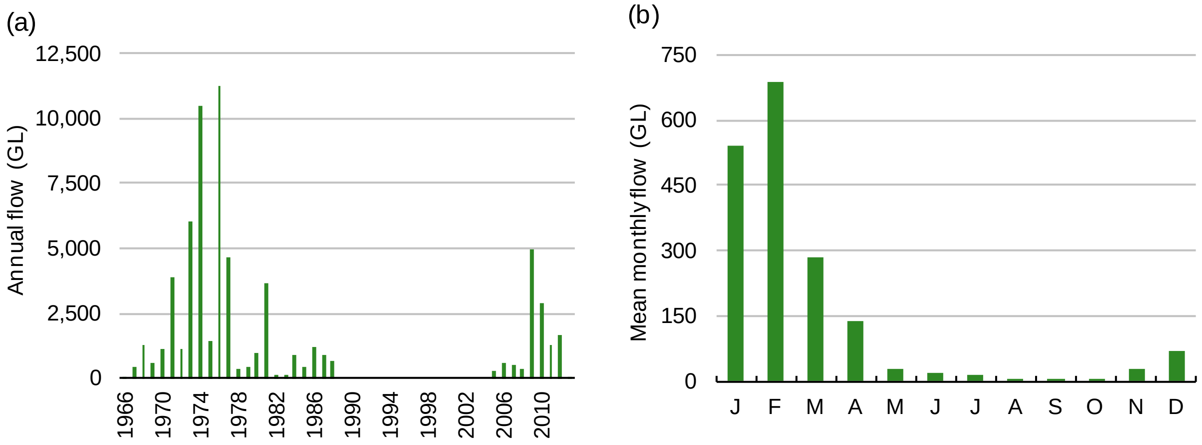


**Figure 45 Flow distribution at Diamantina Lakes on the Diamantina River (a) annual and (b) mean monthly (Gauging Station: 002104A)**

### 1.1.5.3.3 Flinders river basin

The flow regimes of the Flinders river basin are characterised as dry seasonal (i.e. high annual variability and dry for more than half of the year). The Flinders River has five stream gauges with four gauges currently operating at Glendower, Richmond, Etta Plains and Walkers Bend, and one station currently closed at Hughenden (Figure 39). Three upstream gauges (Glendower, Hughenden and Richmond) are located within the Galilee subregion. Streamflow in the Flinders River varies greatly between years ranging from no flow to big flood (Figure 46a) and between months with no flow for some months (Figure 46b). The Flinders River and its tributaries are ephemeral and carry water mostly between December and April. At Richmond, mean monthly and maximum flow are 52 and 340 GL respectively. The average surface water availability in the Flinders river basin is 2023 GL/year and on average about 107 GL/year (or 5%) of this water is used for consumptive purposes (CSIRO, 2009).

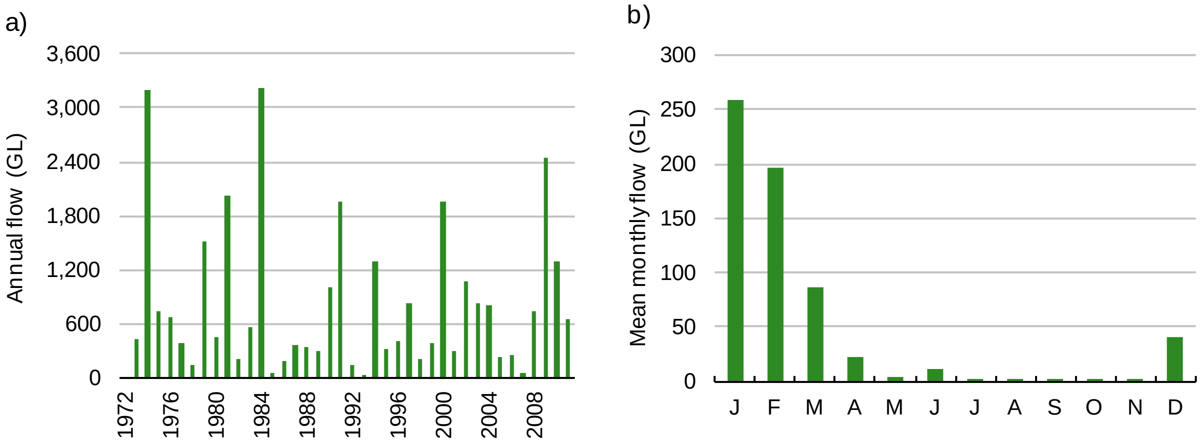


**Figure 46 Flow distribution at Richmond on the Flinders River (a) annual and (b) mean monthly (Gauging Station: 915012A)**

### 1.1.5.3.4 Burdekin river basin

The flow regime of the basin varies between locations ranging from perennial to dry seasonal. Streamflow is well monitored in the lower part of the basin while only a few gauges are available in the upper part of the basin (Figure 41). Stream gauges at Pentland on Cape River and Violet Grove on Native Companion Creek are located in the Galilee subregion but they capture only a fraction of flow draining from the Galilee subregion. The next available stream gauges that capture much of the flow draining from Galilee are located at Taemas on the Cape River and Gregory Development Road on the Belyando River. An example of annual flow at Taemas shows high annual variability although there are at least some flows in each year (Figure 47a). Monthly flows also vary largely between months with almost no flow from July to October (Figure 47b). More than 80% of flows occur between January and March. The mean annual flow at the basin outlet is 9300 GL with an inter-annual range (400–53,000 GL) which covers two orders of magnitude (Post, 2009).

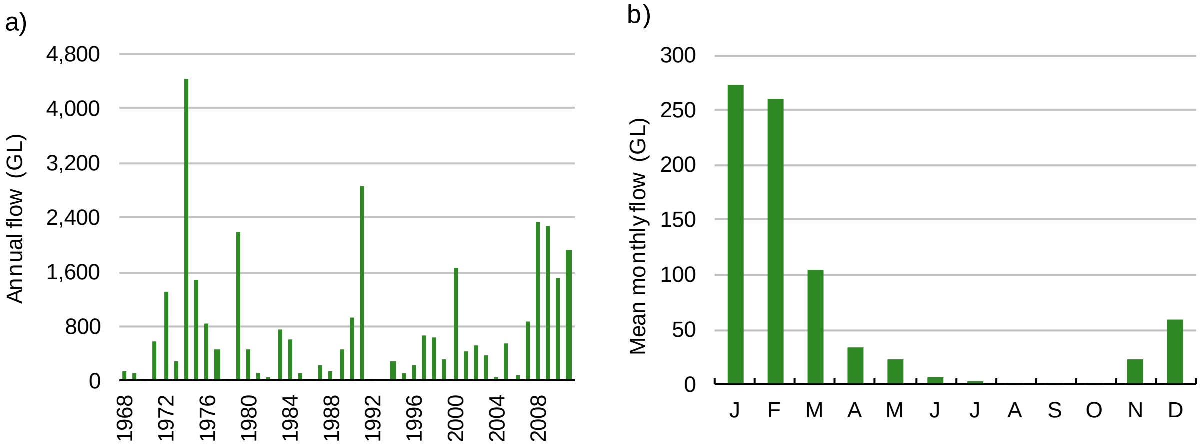


**Figure 47 Flow distribution at Taemas on the Cape River in Burdekin river basin (a) annual and (b) mean monthly (Gauging Station: 120302B)**

### 1.1.5.3.5 Fitzroy river basin

The Fitzroy river basin comprises both perennial and seasonal streams. There are a large number of stream gauges across the basin including two gauges within Galilee subregion, one at Clare Lagoon on the Claude River (a tributary of Nogoa River) and the other at Raymond on the Nogoa River (Figure 42). An example of annual flow at Duck Ponds shows a prolonged low flow period followed by wet years (Figure 48a). The majority of flows occur during high flow events between December and March (Figure 48b). The Nogoa River is a relatively small tributary of the Fitzroy River and it produces a mean annual flow of 212 GL at Fairbairn Dam. The mean annual flow at the downstream end of the Fitzroy River is 4316 GL, which is about 20 times more than Nogoa River flow.

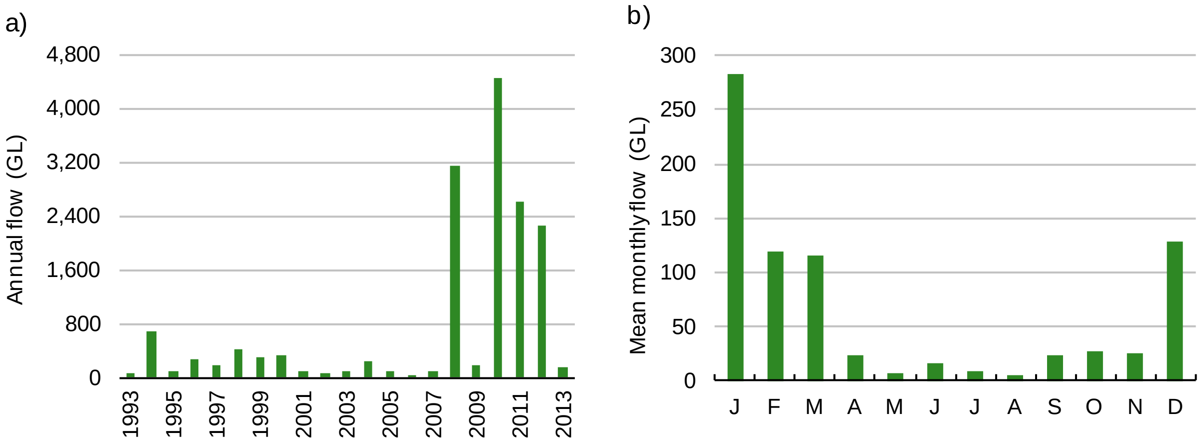


**Figure 48 Annual and mean monthly flow distribution at Duck Ponds on the Nogoa River in Fitzroy basin (Gauging Station: 130219B)**

### 1.1.5.3.6 Warrego river basin

The flow regime of the Warrego basin is characterised as perennial. There are seven stream gauges on the Warrego River including two gauges within Galilee subregion at Augathella and Charleville. Streamflow in the Warrego River is highly variable between years having minimum of 31 GL and maximum of 3042 GL between 1967 to 2011 (Figure 49a). Mean monthly flow varies between months with the majority of flows occurring between December and April (Figure 49b). Transmission losses are generally high in the basin and it produces a basin mean runoff of about 1.7%. The stream gauge at Charleville captures streamflow that originates in the Galilee subregion, producing a mean annual flow of 263 GL.

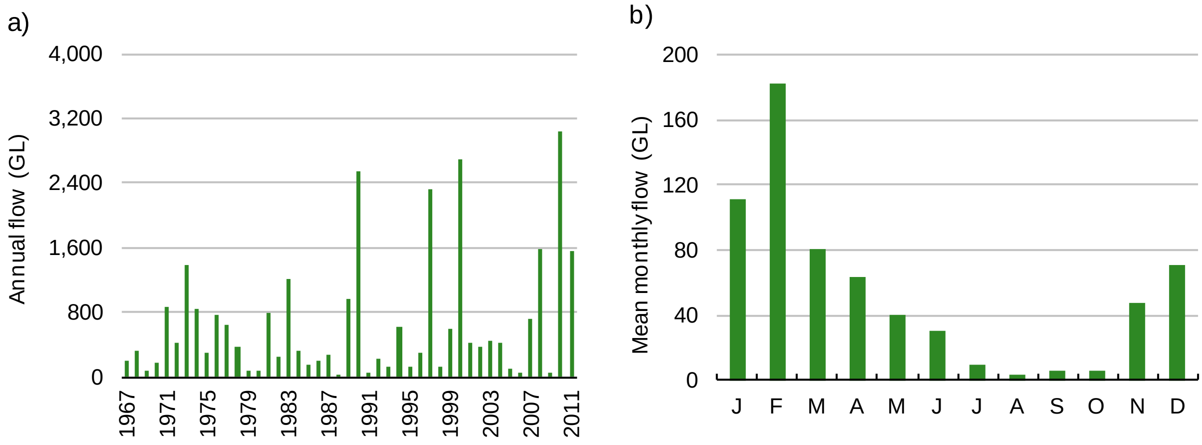


**Figure 49 Annual and mean monthly flow distribution at Wyandra on the Warrego River (Gauging Station: 423203A)**

## *References*

Amir MSII, Khan MMK, Rasul MG, Sharma RH and Akram F (2013) Numerical modelling for the extreme flood event in the Fitzroy Basin, Queensland, Australia. International Journal of Environmental Science and Development 4 (3), 346–350.

Bureau of Meteorology (2013) Flood warning system for the Diamantina River. Viewed 26 October 2013, <www.bom.gov.au/qld/flood/brochures/diamantina/diamantina.shtml>

Bureau of Meteorology (2014) Flood warning system for the Thomson, Barcoo rivers and Cooper Creek. Viewed 19 March 2014, <www.bom.gov.au/qld/flood/brochures/cooper/cooper.shtml>

Cockayne, B., Schmarr, D., Duguid, A., & Mathwin, R. (2012) Lake Eyre Basin Rivers Assessment 2012 Monitoring Report, A report to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), Canberra, ACT.

Costelloe JF, Grayson RB, Argent RM and McMahon TA (2003) Modelling the flow regime of an arid zone floodplain river, Diamantina River, Australia. Environmental Modelling and Software 18, 693–703.

CSIRO (2009) Water in the Flinders-Leichhardt region of the Gulf of Carpentaria Drainage Division. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia.

DERM (2010) Burdekin Basin Resource Operations Plan 2010. Water Planning North, Department of Environment and Resources Management, Brisbane.

DERM (2011a) Cooper Creek water resource plan 2011. Water Planning South West, Water Allocation and Planning, Department of Environment and Resources Management, Brisbane.

DERM (2011b) Ambient Surface Water Quality in Queensland. Water Planning Ecology, Department of Environment and Resources Management. Brisbane.

DERM (2012) Operations Support policy: Surface Water Ambient Water Quality Network, Department of Natural Resources and Mines, Queensland Government, Report No. WMP014, Brisbane.

DNRM (2013) Gulf Draft Resource Operations Plan Amendment, Overview Report, Department of Natural Resources and Mines, Queensland Government, Brisbane

Dutta D, Karim F, Ticehurst C, Marvanek S and Petheram C (2013) Floodplain inundation mapping and modelling in the Flinders and Gilbert Catchments, A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia

Kingsford RT, Curtin AL and Porter J (1999) Water flows on Cooper Creek in arid Australia determine ‘boom’ and ‘bust’ periods for waterbirds. Biological Conservation 88, 231–248.

Knighton AD and Nanson GC (2001) An event-based approach to the hydrology of arid zone rivers in the Channel Country of Australia. Journal of Hydrology 254, 102–123.

Kotwicki V (2005) Floods of Lake Eyre. Viewed 19 February 2014, <www.k26.com/eyre/index.html>

McMahon TA, Murphy R, Little P, Costelloe JF, Peel MC, Chiew FHS, Hays S, Nathan R and Kandel DD (2005) Hydrology of Lake Eyre Basin, Final Report, A report to the Australian Government Natural Heritage Trust, Sinclair Knight Merz (SKM) Pty Ltd., Melbourne.

Post DA (2009) Regionalizing rainfall-runoff model parameters to predict the daily streamflow of ungauged catchments in the dry tropics. Hydrology Research 40, 433–444.

Walker KF, Puckridge JT and Blanch SJ (1997) Irrigation development on Cooper Creek, central Australia-prospects for a regulated economy in a boom-and-bust ecology. Aquatic Conservation: Marine and Freshwater Ecosystems 7, 63–73.

## 1.1.6 Surface water – groundwater interactions

**Summary**

Existing studies in the Galilee subregion are largely focused on the potential for surface water – groundwater interactions to occur between surface water bodies and Great Artesian Basin (Eromanga Basin) aquifers. Knowledge of surface water – groundwater interactions involving aquifers in Cenozoic sequences is limited. There also appears to be limited information on surface water – groundwater interactions in areas where Galilee Basin sediments outcrop, along the eastern margin of the Galilee subregion.

Significant compilations of data exist for groundwater-related features such as springs and wetlands across the Galilee subregion. However, much of the focus of these databases is on the hydrology and ecology of the feature of interest, and less on hydrogeological issues.

Regional hydrogeological studies for the Great Artesian Basin indicate that there are aquifers that have potential to contribute baseflow to streams in the Galilee subregion. These aquifers identified include the Hooray Sandstone and its equivalents, the Ronlow beds and the Clematis Group. Regional shallow watertable mapping suggests that the Diamantina and Cooper creeks may also have potential to interact with surface water features.

Preliminary potentiometric surface maps produced as part of the bioregional assessment suggest that there is potential for the east flowing Carmichael and Belyando rivers to act as groundwater drains for the Warang Sandstone, Dunda beds and Clematis Group aquifers (see also Section 1.1.4.3). Their potential for connectivity is likely to be higher where these Galilee Basin aquifers outcrop near major waterways.

From existing literature, information on groundwater – surface water interactions for the Galilee subregion appears to be largely derived from regional scale desktop studies. Significant data compilations exist for features such as springs and wetlands across the Galilee subregion (e.g. Queensland Government, 2013). However, the focus here seems to be towards characterisation of the features' hydrology and ecology, with less on hydrogeological issues.

Numerous spring complexes exist in the Galilee subregion (Figure 50). Miles et al. (2012) noted 55 spring complexes in the Barcaldine spring supergroup alone although this work is largely restricted to springs within the Great Artesian Basin (GAB). Further information on wetlands and groundwater dependent ecosystems in the Galilee subregion can be found in Section 1.1.7.

The report by the Queensland Department of Natural Resources (QDNR, 2005) includes a summary of water features for which there is potential for baseflow contribution from Great Artesian Basin aquifers. Maps showings specific stream reaches with potential for baseflow contribution are included in Appendix 1 of QDNR (2005). Aquifers identified by QDNR (2005) with potential to contribute to river baseflow include the Hooray Sandstone and its equivalents, the Ronlow beds and the Clematis Group. QDNR (2005) also identified some river reaches that could provide recharge to aquifer systems. The streams identified in the QDNR (2005) desktop study which could potentially receive baseflow from the aforementioned aquifers were P R Creek (Lake

Buchanan outflow), Dyllingo Creek (a tributary of the Carmichael River), Lake Galilee outflow, Reedy Creek (south of Lake Galilee), Alice River and Patrick Creek (a tributary of the Alice River). For all of these streams with the exception of Dyllingo Creek, the source aquifers were identified as GAB (Hooray Sandstone or Ronlow beds) by QDNR (2005). For Dyllingo Creek, the baseflow was assessed as being sourced from the Clematis Group. QDNR (2005) also noted the presence of two high conservation value springs in the vicinity of Dyllingo Creek. It should be noted that QDNR (2005) did not investigate areas where there are outcropping Late Carboniferous to Permian Galilee Basin sediments, along the eastern margin of the Galilee subregion.

Estimates of baseflow will be considered as part of surface water modelling projects for major catchments in the Galilee subregion. This information will be reviewed and assessed as part of later components of the Galilee bioregional assessment.

Preliminary potentiometric surface maps produced as part of the bioregional assessment suggest there is potential for the east flowing Carmichael and Belyando rivers to act as groundwater drains for the Warang Sandstone, Dunda beds and Clematis Group aquifers. Their potential for connectivity is likely to be higher where these Galilee Basin aquifers outcrop near major waterways. The pressure surface for the Clematis Group aquifer is shown in Figure 32 of Section 1.1.4 (this report). The potentiometry shows a groundwater sink at less than or equal to 300 mAHD centred about the Carmichael River/Dunda Creek area. Since the channels of both of these streams are significantly lower than this, there is the potential for baseflow from the Clematis Group to these streams and the Belyando River, provided a pathway exists. This will be more fully investigated in future components of the Galilee bioregional assessment.

Ransley and Smerdon (2012) found evidence that suggested that the shallow watertable may be interacting with surface water along significant reaches of the Diamantina River and Cooper Creek. They suggested that some reaches of these drainage systems may be receiving baseflow from shallow aquifer systems, that is, there is potential for the shallow groundwater system to discharge to surface drainage. This is evident along significant reaches of the Diamantina River and Cooper Creek, within the Galilee subregion.

Using remote sensing techniques, Ransley and Smerdon (2012, Figure 6.25) identified reaches along Cooper Creek and the Diamantina River where riparian vegetation was likely to be drawing from shallow groundwater systems. Again, this was evident along the major channel ways of the Diamantina River and Cooper Creek within the Galilee subregion.

Existing studies in the Galilee subregion are largely focused on the potential for surface water – groundwater interactions to occur between surface water bodies and Great Artesian Basin (Eromanga Basin) aquifers. Knowledge of surface water – groundwater interactions involving aquifers in Cenozoic sequences is limited. There also appears to be limited information on surface water – groundwater interactions in areas where Galilee Basin sediments outcrop, along the eastern margin of the Galilee subregion. Understanding surface water – groundwater interactions along the eastern margin of the Galilee subregion is important as there are proposals to develop a number of large coal mines.

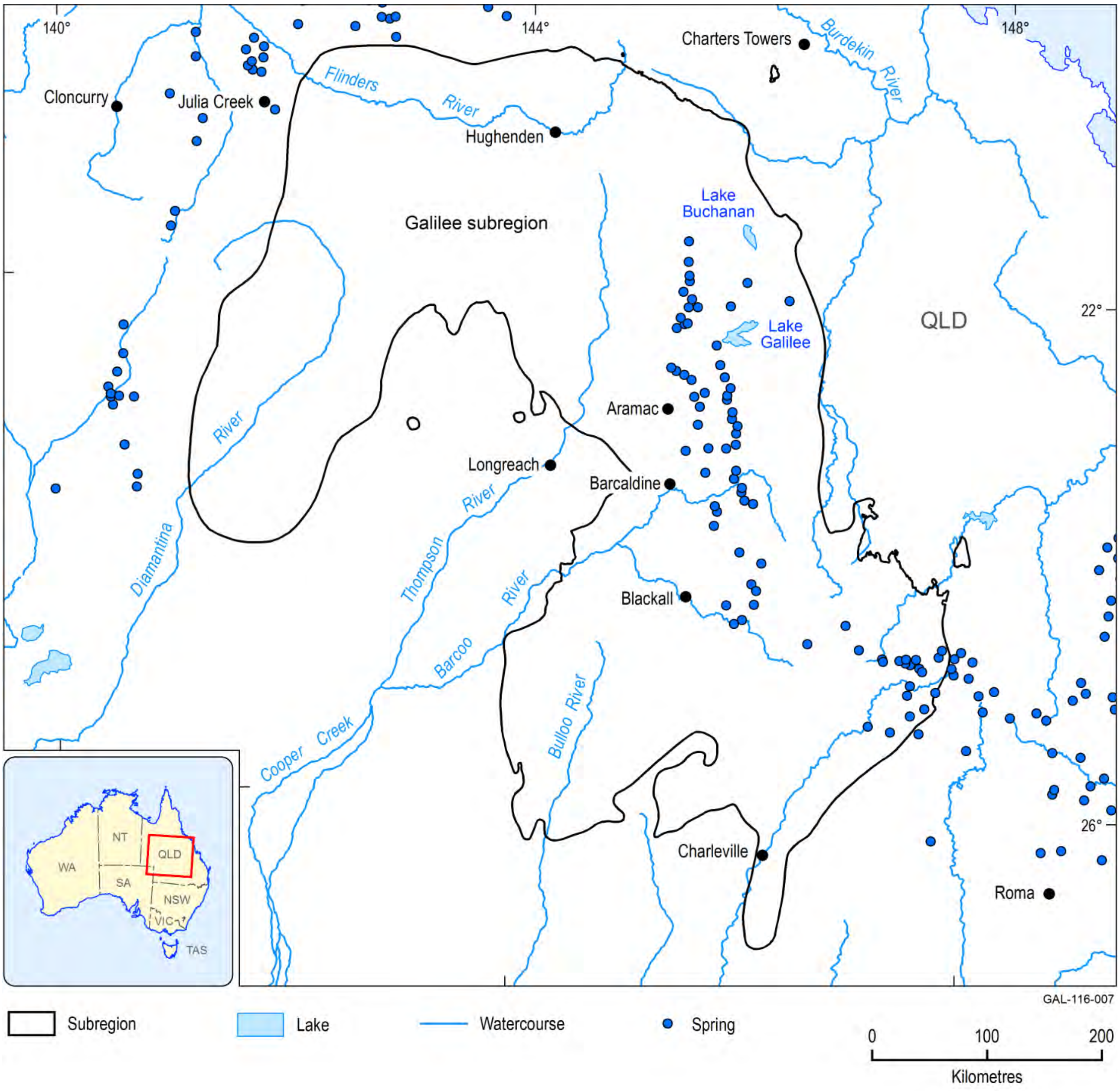


**Figure 50 Major spring complexes in the Great Artesian Basin, located within the Galilee subregion**

Source data: spring complexes after Figure 1.5, Smerdon et al. (2012).

## *References*

Miles C, White M and Scholz G (2012) Assessment of the impacts of future climate and groundwater development on Great Artesian Basin springs. Great Artesian Basin Water Resource Assessment.

QDNR (2005) Hydrogeological Framework Report for the Great Artesian Basin Water Resource Plan Area. Version 1. Report prepared by the Queensland Department of Natural Resources and Mines 2005. 155 pp.

Queensland Government (2013) Queensland Government Wetland Info website Wetland Info Queensland Department of Environment and Heritage Protection, accessed 1 December 2013.

Ransley TR and Smerdon BD (eds) (2012) Hydrostratigraphy, hydrogeology and system conceptualisation of the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. 285 pp.

Smerdon BD, Ransley TR, Radke BM and Kellett JR (2012) Water resource assessment for the Great Artesian Basin. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. 56 pp.

## 1.1.7 Ecology

### *Summary*

The Galilee subregion has a high diversity of ecological communities and species as a consequence of the interactions between its large area, several biologically significant climatic gradients, the biogeographic effects of eight river basins, and the importance of landscape form driving water and soil redistribution in semi-arid environments of inland Australia. This diversity is expressed through the presence of 31 subregions of the Interim Biogeographic Regionalisation for Australia (IBRA; Department of the Environment, 2014a) and 46 major vegetation subgroups of the National Vegetation Information System (NVIS; Department of the Environment, 2014b). Pastoral grazing is by far the most frequent land use (>95%) and conservation reserves occupy around 3%.

The most common terrestrial vegetation NVIS subgroups are (i) Mitchell grass (*Astrebla*) tussock grasslands, (ii) Eucalyptus open woodlands with a grassy understorey, and (iii) cleared, non-native vegetation. Other vegetation subgroups occur with lower frequency and form a complex mosaic that gradually changes from north-east to south-west across the subregion. The woody components of these vegetation types have been subject to clearance over 16% of the subregion, mainly to the east, with the aim of improving pasture productivity. The annual rate of clearance has declined since 2005. Pasture components are reported to have stable condition, except for a recent decline in the north-east corner.

Wetlands listed formally in *A directory of important wetlands in Australia* (DIWA; Department of the Environment, 2014c) occupy 0.3% of the area of the Galilee subregion, and riverine floodplains that are also potentially water dependent occupy a further 15.5% of the area.

As rivers and streams are all intermittent, the durations of flow and non-flow periods, and the depth of water, together determine the number of species locally per unit area and degree of species sharing amongst rivers and residual waterholes. The ecology of rockholes (shallow depressions that collect local rainwater) and outcrop springs (springs of water that has percolated through rock layers in the immediately surrounding area) is poorly studied, as is the ecology of the species that occur within aquifers below ground level (stygobiota). However, discharge springs (springs of water that had percolated through rock layers over long distances and from which water emanates under pressure) are better studied, and numerous locally endemic species of plant, mollusc and fish have been identified. The ecology of both discharge springs and stygobiota is understood to depend on relatively stable water regimes, compared with the highly intermittent character of other aquatic habitats in the region. As a result of water drawdown for agriculture, discharge springs have been subject to significant degradation over the last century. Only 36% of the 300 springs complexes (local clusters of springs) identified in the Great Artesian Basin in 1900 are still active. There are no data on impacts of agricultural drawdown on stygobiota. Discharge springs have also been subject to invasion by exotic plants and disturbance by sheep, pigs, horses and donkeys. Riverbanks and waterholes are generally assessed to be in better condition.

In the Galilee subregion, 38 species and seven ecological communities are listed nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*, of which 15 species and two ecological communities are water-dependent beyond incident rainfall: (i) the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin and (ii) the Coolibah - Black Box Woodlands of the IBRA Darling Riverine Plains and the Brigalow Belt South bioregions. A further 102 species are listed under Queensland's *Nature Conservation Act 1992*.

### *1.1.7.1 Ecological systems*

The Galilee subregion includes a very high level of ecological spatial variability and turnover (gamma and delta diversity) as a consequence of its large area (248,000 km$^2$) which includes important interactions between the following large-scale environmental factors:

- the large variety of surface geological types and soil types along gradients from the top of the Great Dividing Range towards the Gulf of Carpentaria (to the north), towards the Great Barrier Reef (to the east), towards the Darling River (to the south) and towards Kati Thanga – Lake Eyre (to the south-west) (see sections 1.1.3 and 1.1.2.1.2)
- the rainfall and temperature gradients induced by orographic effects over the Great Dividing Range
- the rainfall and temperature gradients from near-coast (subtropical, higher rainfall, temperature range modulated by oceanic effects) to far inland (arid, low rainfall, more extreme temperature ranges on both seasonal and daily bases) (see Section 1.1.2.3)
- the gradient in seasonality of rainfall across the latitudinal range from 19° South (strongly summer dominated) to 29° South (less predictable and only weakly summer dominated)
- the strong influences of surface water redistribution after rain, even in landscapes with modest degrees of topographic relief, and of access to near-surface groundwater, as is typical of Australian arid and semi-arid landscapes (e.g. Stafford Smith and Morton, 1990)
- the variety of biogeographic influences arising within the eight main river basins that drain to the north, east, south and south-west, and thus each interact with the diverse biota in other surrounding regions and subregions (see Section 1.1.5).

As an indication of the variability within the Galilee subregion, 31 Interim Biogeographic Regional Assessment (IBRA) subregions (Figure 51) and 46 major vegetation subgroups defined in the National Vegetation Information System (NVIS) v4.1 classification (Figure 52, Table 8) are represented. About half of the subregion is dominated by subtropical savannah vegetation communities, where mean annual rainfall is in the range 600 to 800 mm. Mitchell grass (*Astrebla*) tussock grasslands and Eucalyptus open woodlands with a grassy understorey are the most common NVIS major subgroups in this zone. The remaining half is dominated by semi-arid vegetation communities, where mean annual rainfall is in the range 300 to 600 mm, of which Mulga open woodlands are the most common NVIS major subgroup.

Wetlands and springs listed in *A directory of important wetlands in Australia* (DIWA; Department of the Environment, 2014c) occupy 0.3% of the area of the subregion and include representation of 21 NVIS v4.1 major vegetation subgroups (Table 8). Nationally mapped riverine floodplains that are also potentially water dependent, at least in part on a seasonal or multi-year basis through flooding and/or elevated watertable, occupy a further 15.5% and include all 46 vegetation subgroups found within the Galilee subregion (Table 8 and Figure 53). For both the DIWA wetlands and the riverine floodplains, the mapped areas include areas of vegetation subgroups that have low likelihood of being dependent on water in excess of local incident rainfall and sourced from subterranean and/or surface water flows (hereafter termed *water-dependent* as per *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (BA methodology; Barrett et al., 2013)). The inclusion of non-water-dependent ecosystems in DIWA wetlands and riverine floodplains is due to the coarse resolution of existing map polygons which include some areas that are sufficiently distant from water bodies and/or sit well above ecologically accessible groundwater. The remaining 84.2% of the area is of terrestrial vegetation subgroups with limited likelihood of being water-dependent.

Land use includes 21 of the 37 Australian Land Use and Management (ALUM) classification scheme secondary classes, but their occurrence is highly non-uniform (see Figure 10 in Section 1.1.2). Pastoral cattle grazing of native and semi-natural pasture, on both freehold and leasehold lands (Figure 54), is by far the greatest land use (95.4% of the area, approximately two-thirds on leasehold), which is consistent with the predominance of subtropical savannah and semi-arid climates, landscapes and vegetation community types. Conservation is the principal land use for 3.0% of the area, which is below the national average of 8.6% in the Australian National Reserve System (excluding lands of private and Indigenous landholders who have conservation amongst multiple land use objectives) and below the Queensland average of 7.5% (Department of the Environment, 2012).

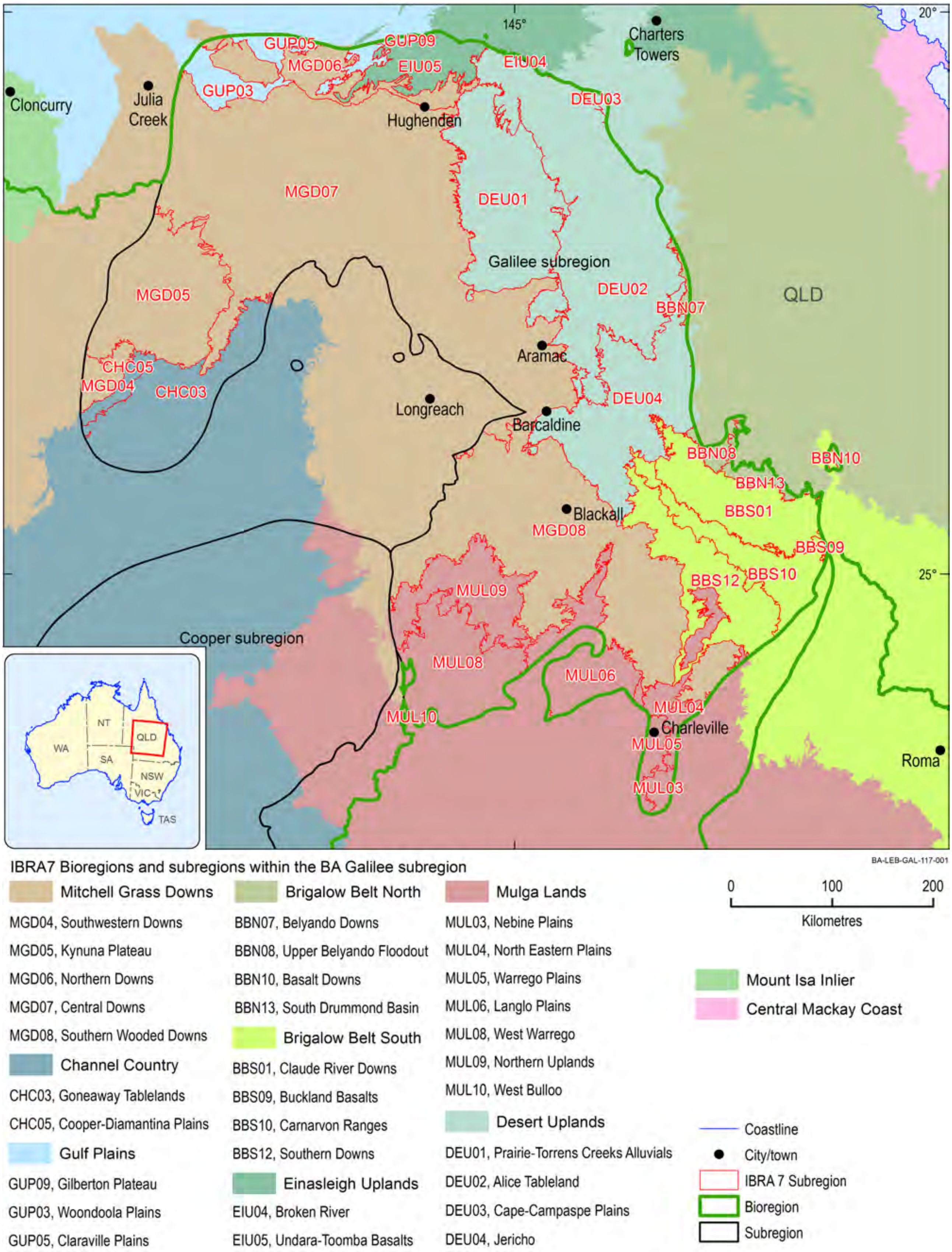


**Figure 51 Interim Biogeographic Regionalisation for Australia (IBRA) subregions within the Galilee subregion**

Source data: IBRA version 7 (2012) ©Commonwealth of Australia 2012 Sub IBRA boundaries produced by ERIN for the National Reserve Systems Section, Australian Government Department of Sustainability, Environment, Water, Population and Communities, Canberra, May 2012

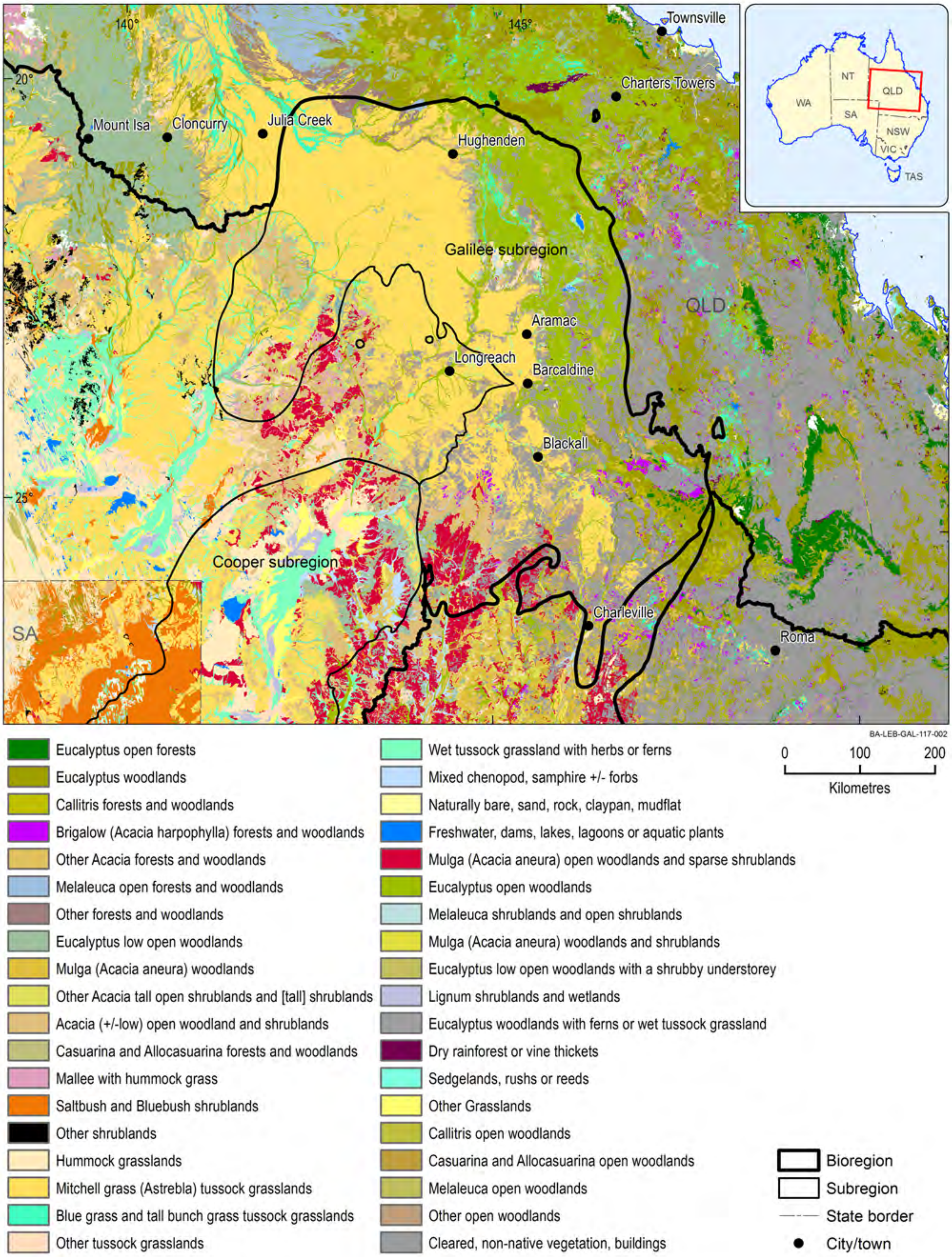


**Figure 52 National Vegetation Information System (NVIS) major vegetation subgroups**

Source data: NVIS v4.1 major vegetation subgroups, ERIN Vegetation Team, Department of the Environment, Canberra, 2013

**Table 8 National Vegetation Information System (NVIS v4.1) major vegetation subgroups in the Galilee subregion**

DIWA is *A directory of important wetlands in Australia* (Department of the Environment, 2014c)

| Vegetation subgroups (in descending order of area) | Area of subgroup in subregion (ha) | Area of subgroup in subregion, as percentage of total area of subgroups (%) | Area of DIWA wetlands in the subgroup (ha) | Area of DIWA wetlands in the subgroup, as percentage of total area of subgroups (%) | Area of watercourses and floodplains in subgroup (ha) | Area of watercourses and floodplains in subgroup, as percentage of total area of subgroups (%) |
|---|---|---|---|---|---|---|
| Mitchell grass (*Astrebla*) tussock grasslands | 8,161,495 | 32.89% | 0 | 0.00% | 1,408,258 | 5.68% |
| Eucalyptus open woodlands with a grassy understorey | 4,094,284 | 16.50% | 2,830 | 0.01% | 637,173 | 2.57% |
| Cleared, non-native vegetation | 3,991,376 | 16.08% | 1,421 | 0.01% | 339,685 | 1.37% |
| Acacia (+/- low) open woodlands and sparse shrublands +/- tussock grass | 1,270,217 | 5.12% | 4,408 | 0.02% | 157,386 | 0.63% |
| Mulga (*Acacia aneura*) open woodlands and sparse shrublands +/- tussock grass | 832,756 | 3.36% | 3,169 | 0.01% | 37,343 | 0.15% |
| Eucalyptus woodlands with a tussock grass understorey | 804,423 | 3.24% | 645 | <0.01% | 130,518 | 0.53% |
| Other Acacia forests and woodlands | 688,740 | 2.78% | 2,164 | 0.01% | 79,814 | 0.32% |
| Acacia (+/- low) open woodlands and sparse shrublands with hummock grass | 456,367 | 1.84% | 0 | 0.00% | 6,425 | 0.03% |
| Eucalyptus low open woodlands with hummock grass | 441,267 | 1.78% | 131 | <0.01% | 20,299 | 0.08% |
| Acacia (+/- low) open woodlands and sparse shrublands with a shrubby understorey | 437,307 | 1.76% | 0 | 0.00% | 12,728 | 0.05% |
| Wet tussock grassland with herbs, sedges or rushes, herblands or ferns | 393,972 | 1.59% | 16,479 | 0.07% | 296,017 | 1.19% |
| Mulga (*Acacia aneura*) woodlands and shrublands +/- tussock grass +/- forbs | 387,675 | 1.56% | 1,523 | 0.01% | 8,778 | 0.04% |
| Other tussock grasslands | 386,968 | 1.56% | 3,210 | 0.01% | 136,241 | 0.55% |
| Eucalyptus low open woodlands with tussock grass | 358,370 | 1.44% | 1,884 | 0.01% | 177,395 | 0.71% |

| Vegetation subgroups (in descending order of area) | Area of subgroup in subregion (ha) | Area of subgroup in subregion, as percentage of total area of subgroups (%) | Area of DIWA wetlands in the subgroup (ha) | Area of DIWA wetlands in the subgroup, as percentage of total area of subgroups (%) | Area of watercourses and floodplains in subgroup (ha) | Area of watercourses and floodplains in subgroup, as percentage of total area of subgroups (%) |
|---|---|---|---|---|---|---|
| Eucalyptus woodlands with a shrubby understorey | 264,839 | 1.07% | 0 | 0.00% | 7,703 | 0.03% |
| Blue grass (*Dicanthium*) and tall bunch grass (*Chrysopogon*) tussock grasslands | 242,495 | 0.98% | 0 | 0.00% | 116,054 | 0.47% |
| Brigalow (*Acacia harpophylla*) forests and woodlands | 237,637 | 0.96% | 2 | <0.01% | 9,288 | 0.04% |
| Other open woodlands | 212,029 | 0.85% | 0 | 0.00% | 19,337 | 0.08% |
| Other Acacia tall open shrublands and shrublands | 201,233 | 0.81% | 0 | 0.00% | 20,980 | 0.08% |
| Other forests and woodlands | 146,973 | 0.59% | 0 | 0.00% | 39,748 | 0.16% |
| Callitris forests and woodlands | 126,239 | 0.51% | 0 | 0.00% | 8,596 | 0.03% |
| Mixed chenopod, samphire +/- forbs | 105,319 | 0.42% | 8,178 | 0.03% | 51,568 | 0.21% |
| Mallee with hummock grass | 92,570 | 0.37% | 0 | 0.00% | 6,086 | 0.02% |
| Eucalyptus open woodlands with shrubby understorey | 85,648 | 0.35% | 0 | 0.00% | 44,480 | 0.18% |
| Hummock grasslands | 69,516 | 0.28% | 28 | <0.01% | 3,104 | 0.01% |
| Eucalyptus open forests with a grassy understorey | 62,810 | 0.25% | 0 | 0.00% | 140 | <0.01% |
| Melaleuca shrublands and open shrublands | 40,583 | 0.16% | 0 | 0.00% | 405 | <0.01% |
| Acacia (+/- low) open woodlands and sparse shrublands with chenopods | 40,205 | 0.16% | 0 | <0.01% | 3,161 | 0.01% |
| Freshwater, dams, lakes, lagoons or aquatic plants | 25,604 | 0.10% | 18,083 | 0.07% | 22,371 | 0.09% |
| Melaleuca open forests and woodlands | 24,111 | 0.10% | 0 | 0.00% | 1,860 | 0.01% |
| Eucalyptus low open woodlands with a shrubby understorey | 23,785 | 0.10% | 0 | 0.00% | 659 | 0.00% |
| Eucalyptus open forests with a shrubby understorey | 20,133 | 0.08% | 0 | 0.00% | 10,795 | 0.04% |

| Vegetation subgroups (in descending order of area) | Area of subgroup in subregion (ha) | Area of subgroup in subregion, as percentage of total area of subgroups (%) | Area of DIWA wetlands in the subgroup (ha) | Area of DIWA wetlands in the subgroup, as percentage of total area of subgroups (%) | Area of watercourses and floodplains in subgroup (ha) | Area of watercourses and floodplains in subgroup, as percentage of total area of subgroups (%) |
|---|---|---|---|---|---|---|
| Mulga (*Acacia aneura*) woodlands and shrublands with hummock grass | 17,481 | 0.07% | 0 | 0.00% | 170 | <0.01% |
| Other shrublands | 15,478 | 0.06% | 0 | 0.00% | 2,118 | 0.01% |
| Naturally bare, sand, rock, claypan, mudflat | 12,422 | 0.05% | 0 | 0.00% | 2,975 | 0.01% |
| Dry rainforest or vine thickets | 10,739 | 0.04% | 0 | 0.00% | 0 | <0.01% |
| Saltbush and/or Bluebush shrublands | 10,680 | 0.04% | 0.01 | <0.01% | 9,089 | 0.04% |
| Lignum shrublands and wetlands | 5,697 | 0.02% | 0 | 0.00% | 3,545 | 0.01% |
| Mulga (*Acacia aneura*) open woodlands and sparse shrublands with hummock grass | 5,019 | 0.02% | 0 | 0.00% | 7 | <0.01% |
| Sedgelands, rushs or reeds | 4,907 | 0.02% | 242 | <0.01% | 2,484 | 0.01% |
| Melaleuca open woodlands | 2,568 | 0.01% | 11 | <0.01% | 559 | <0.01% |
| Casuarina and Allocasuarina forests and woodlands | 1,079 | <0.01% | 11 | <0.01% | 196 | <0.01% |
| Callitris open woodlands | 986 | <0.01% | 0 | <0.01% | 36 | <0.01% |
| Eucalyptus woodlands with a hummock grass understorey | 292 | <0.01% | 0 | <0.01% | 3 | <0.01% |
| Casuarina and Allocasuarina open woodlands with a tussock grass understorey | 211 | <0.01% | 191 | <0.01% | 197 | <0.01% |
| Eucalyptus woodlands with ferns, herbs, sedges, rushes or wet tussock grassland | 17 | <0.01% | 0 | <0.01% | 17 | <0.01% |
| **Total** | **24,814,524** | **100.00%** | **64,610** | **0.26%** | **3,835,791** | **15.46%** |

Source data: (1) NVIS v4.1 major vegetation subgroups, ERIN Vegetation Team, Department of the Environment, Canberra, 2013. (2) *A directory of important wetlands in Australia*, third edition (Environment Australia, 2001), with additions for wetlands listed after 2001 (last update 23 March 2010). (3) Watercourses and floodplains from the combination of all other datasets listed as sources for Figure 3

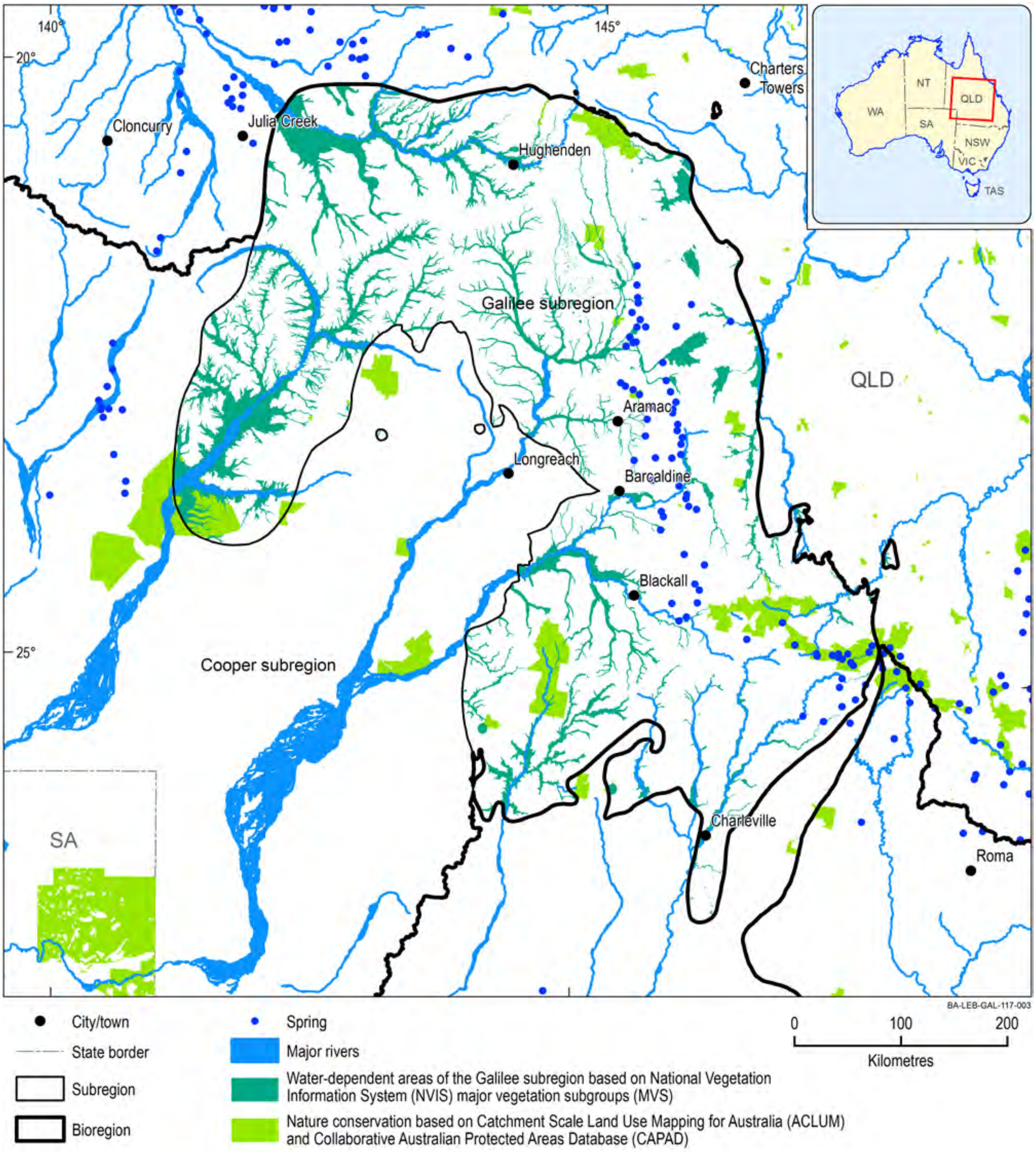


**Figure 53 Conservation areas (including wetlands listed in *A directory of important wetlands in Australia*), springs and riverine floodplains with potential for water dependence**

Source data: (1) *A directory of important wetlands in Australia*, third edition (Environment Australia, 2001), with additions for wetlands listed after 2001 (last update 23 March 2010). (2) *Collaborative Australian Protected Areas Database* (CAPAD, 2010). Australian Department of Sustainability, Environment, Water, Population and Communities. (3) Environmental Resources Information Network (ERIN). Australian Department of Environment. (4) Catchment Scale Land Use Mapping for Australia, Update November 2012 (CLUM Update 11/12). Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). (5) National Vegetation Information System (NVIS v4.1) major vegetation subgroups. Department of Environment. (6) GEODATA TOPO 250K Series 3 Topographic Data. Geoscience Australia

**Table 9 Australian Land Use and Management (ALUM) Classification (version 7) land use classes in the Galilee subregion**

| ALUM secondary land use class | Area in subregion (ha) | Area in subregion, as percentage of total (%) |
|---|---:|---:|
| Grazing natural vegetation | 23,662,649 | 95.36% |
| Nature conservation | 750,647 | 3.03% |
| Other minimal use | 231,263 | 0.93% |
| Production forestry | 84,751 | 0.34% |
| Marsh/wetland | 54,977 | 0.22% |
| Cropping | 10,081 | 0.04% |
| Services | 5,477 | 0.02% |
| Lake | 4,232 | 0.02% |
| Reservoir/dam | 2,711 | 0.01% |
| Residential | 2,452 | 0.01% |
| River | 1,375 | 0.01% |
| Transport and communication | 1,175 | <0.01% |
| Irrigated cropping | 826 | <0.01% |
| Mining | 530 | <0.01% |
| Manufacturing and industrial | 476 | <0.01% |
| Intensive animal husbandry | 432 | <0.01% |
| Managed resource protection | 297 | <0.01% |
| Irrigated perennial horticulture | 85 | <0.01% |
| Waste treatment and disposal | 78 | <0.01% |
| Utilities | 10 | <0.01% |
| **Total** | **24,814,524** | |

Source data: Catchment Scale Land Use Mapping for Australia Update November 2012 (ALUM Update 11/12) dataset. Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)

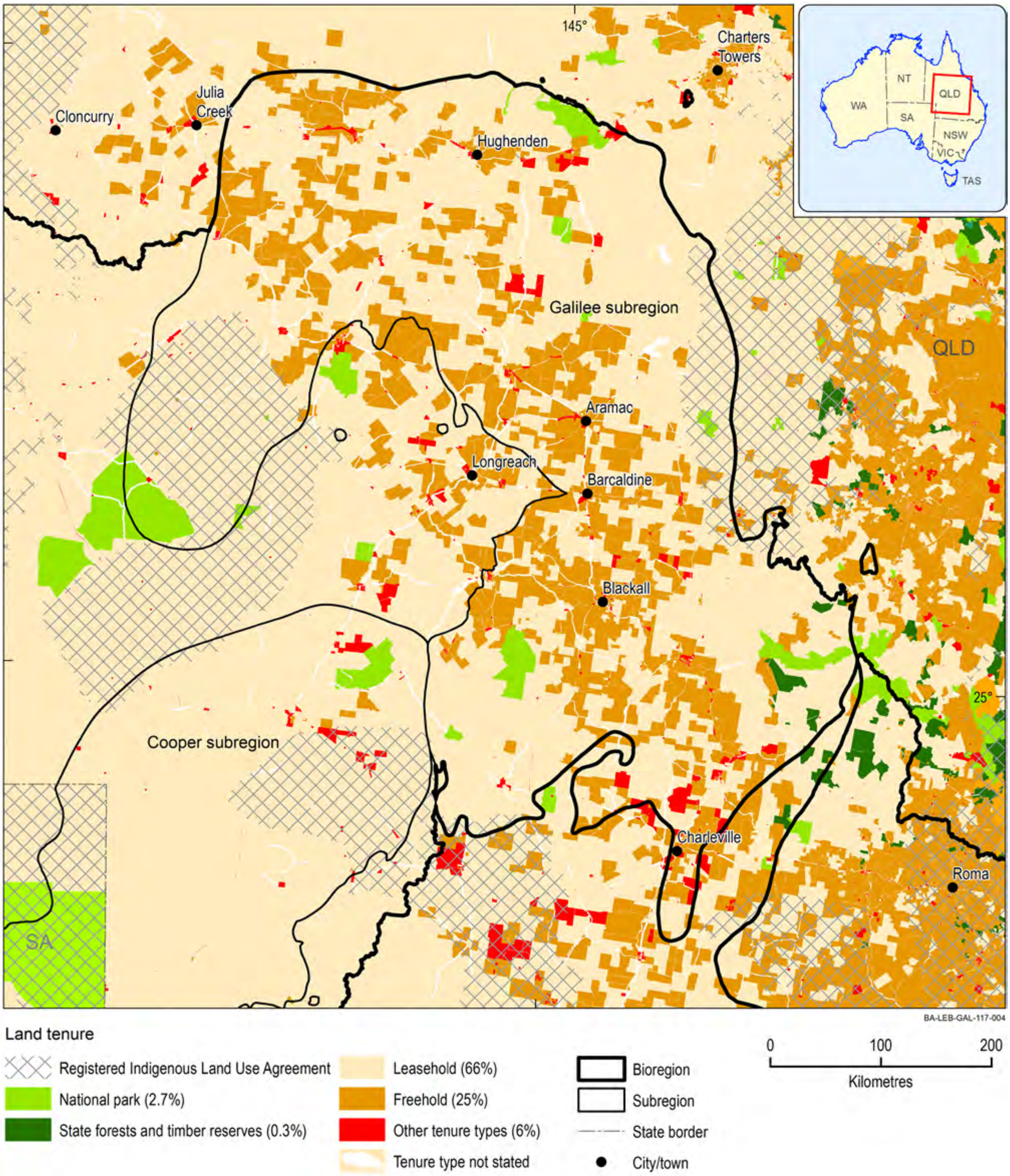


**Figure 54 Land tenure as at 2009**

Source data: Queensland Digital Cadaster Database (DCDB). Supplied by Queensland Department of Natural Resources and Mines, download date 12/01/2014. Protected Area data are from Queensland Protected Areas Database 5 December 2012. Supplied by the Queensland Department of National Parks, Recreation, Sport and Racing

### *1.1.7.2 Terrestrial species and communities*

#### 1.1.7.2.1 Principal vegetation types and distribution patterns

Mitchell grass (*Astrebla*) tussock grasslands is the most widespread terrestrial NVIS v4.1 major vegetation subgroup in the Galilee subregion (32.9% by area, occurring as a largely treeless vegetation type on cracking clay soils and primarily in the northern half of the subregion), followed by Eucalyptus open woodlands with a grassy understorey (16.5%, primarily along the Great Dividing Range in the east of the subregion) and cleared, non-native vegetation, which becomes more abundant towards the south. Twelve other vegetation subgroups each cover 1 to 5% of the subregion (250,000 to 1,250,000 ha each) and 35 vegetation subgroups each cover less than 1% of the subregion (<250,000 ha each). Together with the three most widespread vegetation subgroups, the other less common subgroups form a complex mosaic that grades from north-east to south-west along the main rainfall gradient, but also responds locally to topographic and edaphic variation.

#### 1.1.7.2.2 Recent change and trend

Very early in the Euro-Australian settlement of central and western Queensland, both Mitchell grass tussock (*Astrebla*) grasslands and Eucalyptus open woodlands with a grassy understorey were recognised as vegetation types with a combination of climatic and edaphic characteristics that would yield high livestock productivity under pastoral grazing systems (Orr and Holmes, 1984; Burrows et al., 1988). After more than a century of extensive cattle grazing, the bulk of these two vegetation types in the Galilee subregion are now classed as ‘modified’, according to the Vegetation Assets, States and Transitions (VAST) classification of Thackway and Lesslie (2001), meaning that the dominant structuring native species are present, but their levels of dominance have been significantly altered, and their natural regenerative capacity is limited or at risk under past and/or current land use or land management practice. According to Thackway and Lesslie (2001), any further modification would involve replacement of the native dominant species by adventive, exotic plant species, and thereby become a class of non-native vegetation.

Concentrated in the eastern parts of the Galilee subregion, 16.1% of the area has been historically and permanently cleared of its native vegetation to make way for non-native pasture, crops, urban development, etc. For the remaining native vegetation, tree clearance remains a source of disturbance and change in the subregion, and occurs primarily to provide or improve the quality of native or semi-natural pasture for cattle. The Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA, 2012) reported tree clearance during 2010 to 2011 by analysing satellite data in grid cells of 7’30” latitude x 7’30” longitude. Clearance was detected in more than half of the grid cells in the east, centre and south of the subregion, mainly in areas of open woodland characterised by brigalow (*Acacia harpophylla*), mulga (*Acacia aneura*) and other acacias and almost exclusively on freehold lands (DSITIA, 2012). The maximum rate of clearance was approximately 5% of a grid cell cleared in the single year, but where clearance occurred the rates were most frequently less than 2% of a grid cell. These rates are all substantially lower than in the past and are part of a trend of declining rates of tree clearance since 2005. In addition, at least two-thirds of the clearance is estimated to be of regrowth, rather than previously uncleared native vegetation (DSITIA, 2012).

As part of Queensland activities for the Australian Collaborative Rangeland Information System (ACRIS), Bastin et al. (2014) have recently completed an analysis of trend in condition of the non-woody component of the native terrestrial vegetation across Queensland's rangelands, including all non-forested parts of the Galilee subregion. Using multitemporal remote sensing data and analyses based on landscape heterogeneity and functionality, Bastin et al. report that most IBRA subregions within the Galilee subregion showed approximately stable to slightly improving range condition over the period 1988 to either 2003 or 2005 (depending of drought sequences), with the exception being the Alice Tableland IBRA subregion (lying between Hughenden, Pentland, Alpha and Barcaldine, in the north-east of the Galilee subregion) in which range condition declined during the reporting period.

### 1.1.7.2.3 Species and ecological communities of national significance

Table 10 lists species of national significance listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) that are known to occur in the Galilee subregion through specimens or human observations, or for which their occurrence is likely based upon analysis of the distribution of suitable habitat. Of those species, 23 have been identified as having low or no water dependence in the sense of the BA methodology (Barrett et al., 2013) and thus can be considered terrestrial: 15 plants, two reptiles, two birds and four mammals.

Five terrestrial ecological communities are EPBC listed, as are Coolibah – Black Box Woodlands that are associated with the periodically waterlogged floodplains and margins of various wetlands (Table 10). All occur only in the south-eastern quadrant of the subregion (Figure 55), on relatively fertile soils with relatively high rainfall, and also in areas of largely freehold land, and thus have been subject to selective historical clearance (see Fensham et al. (1998)), grazing, introduction of non-native plant species, and other forms of disturbance. The White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland in the subregion have the highest EPBC rating (critically endangered).

### 1.1.7.2.4 Species of regional significance

Table 11 lists taxa of regional significance under Queensland's *Nature Conservation Act 1992*. There are 102 taxa that occur in the Galilee subregion but are not also listed nationally.

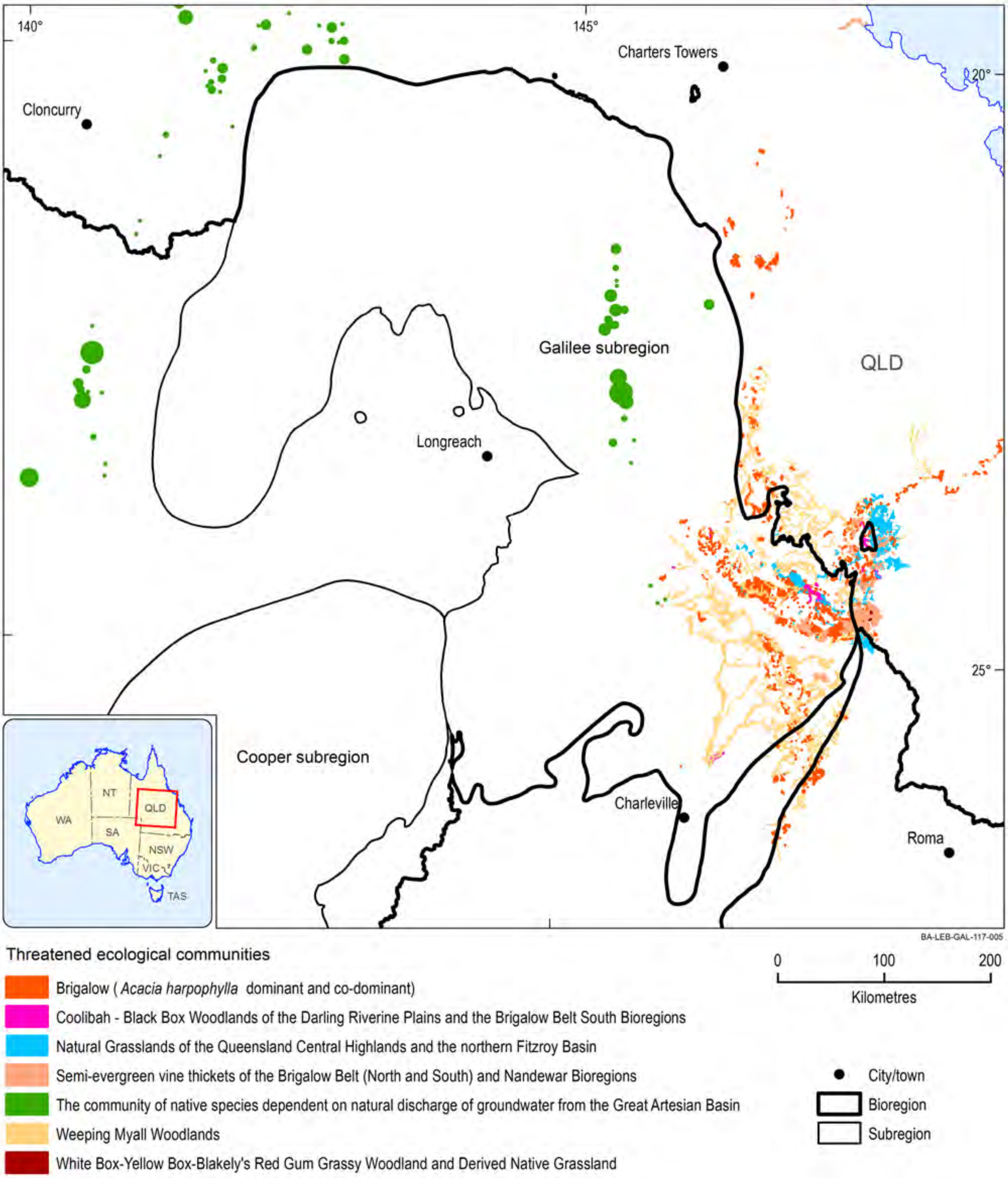


**Figure 55 Threatened ecological communities under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999***

Source data: Database of Communities of National Environmental Significance. Department of Sustainability, Environment, Water, Population and Communities, Canberra, 2013

**Table 10 Species and ecological communities in the Galilee subregion that are listed as threatened nationally under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)**

| Biodiversity asset group | Scientific name | Common name | Status under the EPBC Act | Occurrence in subregion | Endemicity in subregion | Water dependence | Comments on water dependence |
|---|---|---|---|---|---|---|---|
| **Plants** | | | | | | | |
| | *Acacia ammophila* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Acacia crombiei* | Pink gidgee | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Acacia deuteroneura* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Acacia peuce* | Waddy, waddi, waddy-wood, Birdsville wattle | Vulnerable | Likely | Low | Low | No specific mention of water dependence |
| | *Aristida annua* | | Vulnerable | Likely | Low | Low | No specific mention of water dependence |
| | *Austrobryonia argillicola* | | Endangered | Likely | High | Low | No specific mention of water dependence |
| | *Bertya calycina* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Cadellia pentastylis* | Ooline | Vulnerable | Likely | Low | Low | No specific mention of water dependence |
| | *Dichanthium queenslandicum* | King blue-grass | Endangered | Known | Low | Low | No specific mention of water dependence |
| | *Eriocaulon carsonii* | Salt pipewort, button grass | Endangered | Likely | Low | High | Flowing mound springs |
| | *Eryngium fontanum* | Blue devil | Endangered | Likely | High | High | Wetlands associated with artesian springs |
| | *Eucalyptus virens* | | Vulnerable | Likely | Moderate | Low | No specific mention of water dependence |
| | *Hakea maconochieana* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Lawrencia buchananensis* | | Vulnerable | Likely | High | High | Sandy surface on edge of lake |
| | *Livistona lanuginosa* | Waxy cabbage palm | Vulnerable | Likely | Low | High | Streambanks and gullies |
| | *Marsdenia brevifolia* | | Vulnerable | Likely | Low | Low | No specific mention of water dependence |

| Biodiversity asset group | Scientific name | Common name | Status under the EPBC Act | Occurrence in subregion | Endemicity in subregion | Water dependence | Comments on water dependence |
|---|---|---|---|---|---|---|---|
| | *Melaleuca kunzeoides* | | Vulnerable | Likely | High | High | Not strictly associated with springs, however springs may provide important habitat |
| | *Rhaphidospora bonneyana* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Sclerolaena blakei* | | Vulnerable | Likely | High | Low | No specific mention of water dependence |
| | *Sclerolaena walkeri* | | Vulnerable | Likely | Moderate | Moderate | Saline river flats and watercourses |
| | *Xerothamnella parvifolia* | | Vulnerable | Likely | Moderate | Low | No specific mention of water dependence |
| **Fish** | | | | | | | |
| | *Chlamydogobius micropterus* | Elizabeth Springs goby | Endangered | Likely | High | High | Freshwater mound springs |
| | *Chlamydogobius squamigenus* | Edgbaston goby | Vulnerable | Likely | High | High | Freshwater springs and pools |
| | *Scaturiginichthys vermeilipinnis* | Redfin blue eye, redfin blue-eye | Endangered | Likely | High | High | Freshwater mound springs |
| **Reptiles** | | | | | | | |
| | *Denisonia maculata* | Ornamental snake | Vulnerable | Known | Low | High | Habitat that is favoured by its prey (frogs) |
| | *Egernia rugosa* | Yakka skink | Vulnerable | Known | Low | Low | No specific mention of water dependence |
| | *Lerista vittata* | Mount Cooper striped lerista | Vulnerable | Known | Low | Low | No specific mention of water dependence |
| **Birds** | | | | | | | |
| | *Amytornis barbatus barbatus* | Grey grasswren (bulloo) | Vulnerable | Known | Low | High | Swampy floodplains |
| | *Geophaps scripta scripta* | Squatter pigeon (southern) | Vulnerable | Known | Low | High | Suitable water bodies to drink on a daily basis: permanent or seasonal rivers, creeks, lakes, ponds, waterholes and artificial dams |

| Biodiversity asset group | Scientific name | Common name | Status under the EPBC Act | Occur-rence in subregion | Endemi-city in subregion | Water depend-ence | Comments on water dependence |
|---|---|---|---|---|---|---|---|
| | *Neochmia ruficauda ruficauda* | Star finch (eastern), star finch (southern) | Endangered | Likely | Low | Moderate | Grasslands and grassy woodlands that are located close to bodies of fresh water |
| | *Pedionomus torquatus* | Plains-wanderer | Vulnerable | Likely | Moderate | Low | No specific mention of water dependence |
| | *Pezoporus occidentalis* | Night parrot | Endangered, migratory | Likely | Moderate | Low | No specific mention of water dependence |
| | *Poephila cincta cincta* | Black-throated finch (southern) | Endangered | Known | Low | Moderate | Riparian habitat, freshwater wetlands |
| | *Rostratula benghalensis (sensu lato)* | Painted snipe | Endangered, migratory | Likely | Low | High | Shallow terrestrial freshwater (occasionally brackish) wetlands |
| **Mammals** | | | | | | | |
| | *Dasyuroides byrnei* | Kowari | Vulnerable | Likely | Low | Low | No specific mention of water dependence |
| | *Lasiorhinus krefftii* | Northern hairy-nosed wombat, yaminon | Endangered | Likely | High | Low | No specific mention of water dependence |
| | *Onychogalea fraenata* | Bridled nail-tail wallaby | Endangered | Known | Moderate | Low | No specific mention of water dependence |
| | *Sminthopsis douglasi* | Julia Creek dunnart | Endangered | Known | High | Low | No specific mention of water dependence |
| **Ecological communities** | | | | | | | |
| | Brigalow (*Acacia harpophylla* dominant and co-dominant) | | Endangered | Known | Moderate | Low | No specific mention of water dependence |
| | Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions | | Endangered | Known | Low | High | Associated with periodically waterlogged floodplains, swamp margins, ephemeral wetlands, and stream levees |
| | Natural Grasslands of the Queensland Central Highlands and the northern Fitzroy Basin | | Endangered | Known | Moderate | Low | No specific mention of water dependence |

| Biodiversity asset group | Scientific name | Common name | Status under the EPBC Act | Occurrence in subregion | Endemicity in subregion | Water dependence | Comments on water dependence |
|---|---|---|---|---|---|---|---|
| | Semi-evergreen vine thickets of the Brigalow Belt (North and South) and Nandewar Bioregions | | Endangered | Known | Moderate | Low | No specific mention of water dependence |
| | The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin | | Endangered | Known | High | High | Entirely dependent on discharge springs |
| | Weeping Myall Woodlands (Acacia pendula dominant or co-dominant) | | Endangered | Known | Low | Low | Not associated with active drainage channels and are rarely if ever flooded |
| | White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland | | Critically Endangered | Historical records only | Very low | Low | No specific mention of water dependence |

Source data: Department of Environment, Canberra, 2013

**Table 11 Species in the Galilee subregion that are listed as threatened under Queensland's *Nature Conservation Act 1992* and *Nature Conservation (Wildlife) Regulation 2006* (updated to 27 September 2013), and under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)**

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland's legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| **Plants** | | | | | |
| | Acanthaceae | *Rhaphidospora bonneyana* | | Vulnerable | Vulnerable |
| | Acanthaceae | *Xerothamnella parvifolia* | | Vulnerable | Vulnerable |
| | Amaranthaceae | *Ptilotus brachyanthus* | | Endangered | |
| | Amaranthaceae | *Ptilotus maconochiei* | | Near threatened | |
| | Amaranthaceae | *Ptilotus pseudohelipteroides* | | Near threatened | |
| | Apiaceae | *Actinotus paddisonii* | Clustered flannel flower | Near threatened | |
| | Apiaceae | *Eryngium fontanum* | | Endangered | Endangered |
| | Apocynaceae | *Cerbera dumicola* | | Near threatened | |
| | Araliaceae | *Hydrocotyle dipleura* | | Vulnerable | |
| | Asteraceae | *Brachyscome tesquorum* | | Near threatened | |
| | Asteraceae | *Calocephalus* sp. *(Eulo M.E.Ballingall MEB2590)* | | Near threatened | |
| | Asteraceae | *Calotis suffruticosa* | | Near threatened | |
| | Asteraceae | *Peripleura scabra* | | Near threatened | |
| | Asteraceae | *Picris barbarorum* | | Vulnerable | |
| | Asteraceae | *Rhaponticum australe* | | Vulnerable | Vulnerable |
| | Asteraceae | *Rhodanthe rufescens* | | Near threatened | |
| | Asteraceae | *Vittadinia decora* | | Near threatened | |
| | Campanulaceae | *Wahlenbergia islensis* | | Near threatened | |
| | Chenopodiaceae | *Atriplex lobativalvis* | | Near threatened | |
| | Chenopodiaceae | *Atriplex morrisii* | | Vulnerable | |
| | Chenopodiaceae | *Sclerolaena blackiana* | Black's copperburr | Near threatened | |
| | Chenopodiaceae | *Sclerolaena blakei* | | Vulnerable | Vulnerable |
| | Chenopodiaceae | *Sclerolaena walkeri* | | Vulnerable | Vulnerable |
| | Cucurbitaceae | *Austrobryonia argillicola* | | Endangered | Endangered |
| | Cycadaceae | *Cycas couttsiana* | | Near threatened | |
| | Cyperaceae | *Cyperus clarus* | | Vulnerable | |
| | Eriocaulaceae | *Eriocaulon aloefolium* | | Endangered | |
| | Eriocaulaceae | *Eriocaulon carsonii* | | Endangered | Endangered |

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland's legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| | Eriocaulaceae | *Eriocaulon carsonii* subsp. *carsonii* | | Endangered | |
| | Eriocaulaceae | *Eriocaulon carsonii* subsp. *euloense* | | Endangered | |
| | Eriocaulaceae | *Eriocaulon carsonii* subsp. *orientale* | | Endangered | |
| | Eriocaulaceae | *Eriocaulon giganticum* | | Endangered | |
| | Euphorbiaceae | *Bertya calycina* | | Vulnerable | Vulnerable |
| | Euphorbiaceae | *Bertya pedicellata* | | Near threatened | |
| | Euphorbiaceae | *Euphorbia sarcostemmoides* | Climbing caustic | Vulnerable | |
| | Fabaceae | *Desmodium macrocarpum* | | Near threatened | |
| | Fabaceae | *Indigofera oxyrachis* | | Vulnerable | |
| | Fabaceae | *Sesbania erubescens* | | Near threatened | |
| | Fabaceae | *Zornia pallida* | | Near threatened | |
| | Frankeniaceae | *Frankenia scabra* | | Near threatened | |
| | Goodeniaceae | *Goodenia angustifolia* | | Near threatened | |
| | Haloragaceae | *Haloragis exalata* subsp. *velutina* | | Vulnerable | Vulnerable |
| | Haloragaceae | *Myriophyllum artesium* | | Endangered | |
| | Lauraceae | *Endiandra dichrophylla* | Coach walnut | Near threatened | |
| | Laxmanniaceae | *Lomandra teres* | | Vulnerable | |
| | Mimosaceae | *Acacia ammophila* | | Vulnerable | Vulnerable |
| | Mimosaceae | *Acacia crombiei* | Pink gidgee | Vulnerable | Vulnerable |
| | Mimosaceae | *Acacia deuteroneura* | | Vulnerable | Vulnerable |
| | Mimosaceae | *Acacia islana* | | Vulnerable | |
| | Mimosaceae | *Acacia peuce* | Waddy | Vulnerable | Vulnerable |
| | Mimosaceae | *Acacia polyadenia* | | Near threatened | |
| | Mimosaceae | *Acacia spania* | | Near threatened | |
| | Myoporaceae | *Eremophila tetraptera* | | Vulnerable | |
| | Myrtaceae | *Corymbia clandestina* | | Vulnerable | Vulnerable |
| | Myrtaceae | *Kardomia squarrulosa* | | Vulnerable | |
| | Myrtaceae | *Leptospermum pallidum* | | Near threatened | |
| | Myrtaceae | *Melaleuca kunzeoides* | | Vulnerable | Vulnerable |
| | Myrtaceae | *Micromyrtus rotundifolia* | | Vulnerable | |
| | Myrtaceae | *Syzygium buettnerianum* | New Guinea satinash | Near threatened | |

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland's legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| | Myrtaceae | *Thryptomene hexandra* | | Near threatened | |
| | Poaceae | *Aristida burraensis* | | Near threatened | |
| | Poaceae | *Arthraxon hispidus* | | Vulnerable | Vulnerable |
| | Poaceae | *Dichanthium queenslandicum* | | Vulnerable | Endangered |
| | Poaceae | *Sporobolus pamelae* | | Endangered | |
| | Poaceae | *Sporobolus partimpatens* | | Near threatened | |
| | Polygalaceae | *Polygala pycnantha* | | Near threatened | |
| | Proteaceae | *Grevillea kennedyana* | | Vulnerable | Vulnerable |
| | Proteaceae | *Hakea maconochieana* | | Vulnerable | Vulnerable |
| | Rhamnaceae | *Discaria pubescens* | | Near threatened | |
| | Rubiaceae | *Oldenlandia spathulata* | | Endangered | |
| | Rutaceae | *Boronia eriantha* | | Near threatened | |
| | Rutaceae | *Drummondita calida* | | Vulnerable | |
| | Scrophulariaceae | *Elacholoma hornii* | | Near threatened | |
| | Scrophulariaceae | *Rhamphicarpa australiensis* | | Near threatened | |
| | Surianaceae | *Cadellia pentastylis* | Ooline | Vulnerable | Vulnerable |
| Fish | | | | | |
| | Gobiidae | *Chlamydogobius micropterus* | Elizabeth Springs goby | Endangered | Endangered |
| | Gobiidae | *Chlamydogobius squamigenus* | Edgbaston goby | Endangered | Vulnerable |
| | Pseudomugilidae | *Scaturiginichthys vermeilipinnis* | Redfin blue eye | Endangered | Endangered |
| **Amphibians** | | | | | |
| | Hylidae | *Cyclorana verrucosa* | Rough-collared frog | Near threatened | |
| **Reptiles** | | | | | |
| | Boidae | *Aspidites ramsayi* | Woma | Near threatened | |
| | Chelidae | *Emydura subglobosa worrelli* | Diamond head turtle | Near threatened | |
| | Diplodactylidae | *Strophurus taenicauda* | Golden-tailed gecko | Near threatened | |
| | Elapidae | *Acanthophis antarcticus* | Common death adder | Near threatened | |
| | Elapidae | *Antaioserpens warro* | Robust burrowing snake | Near threatened | |
| | Elapidae | *Furina barnardi* | Yellow-naped snake | Near threatened | |
| | Elapidae | *Oxyuranus microlepidotus* | Western taipan | Near threatened | |

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland's legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| | Elapidae | *Pseudechis colletti* | Collett's snake | Near threatened | |
| | Pygopodidae | *Paradelma orientalis* | Brigalow scaly-foot | Vulnerable | |
| | Scincidae | *Ctenotus ariadnae* | | Near threatened | |
| | Scincidae | *Ctenotus capricorni* | | Near threatened | |
| | Scincidae | *Ctenotus schevilli* | | Near threatened | |
| | Scincidae | *Ctenotus septenarius* | | Near threatened | |
| | Scincidae | *Ctenotus serotinus* | | Near threatened | |
| | Scincidae | *Egernia rugosa* | Yakka skink | Vulnerable | Vulnerable |
| | Scincidae | *Lerista cinerea* | | Near threatened | |
| | Scincidae | *Lerista wilkinsi* | | Near threatened | |
| **Birds** | | | | | |
| | Acanthizidae | *Pyrrholaemus brunneus* | Redthroat | Near threatened | |
| | Accipitridae | *Accipiter novaehollandiae* | Grey goshawk | Near threatened | |
| | Accipitridae | *Erythrotriorchis radiatus* | Red goshawk | Endangered | Vulnerable |
| | Accipitridae | *Lophoictinia isura* | Square-tailed kite | Near threatened | |
| | Anatidae | *Stictonetta naevosa* | Freckled duck | Near threatened | |
| | Anatidae | *Tadorna radjah* | Radjah shelduck | Near threatened | |
| | Cacatuidae | *Calyptorhynchus lathami* | Glossy black-cockatoo | Vulnerable | |
| | Cacatuidae | *Lophochroa leadbeateri* | Major Mitchell's cockatoo | Vulnerable | |
| | Ciconiidae | *Ephippiorhynchus asiaticus* | Black-necked stork | Near threatened | |
| | Climacteridae | *Climacteris erythrops* | Red-browed treecreeper | Near threatened | |
| | Columbidae | *Geophaps scripta scripta* | Squatter pigeon (southern subspecies) | Vulnerable | Vulnerable |
| | Estrildidae | *Erythrura gouldiae* | Gouldian finch | Endangered | Endangered |
| | Estrildidae | *Heteromunia pectoralis* | Pictorella mannikin | Near threatened | |
| | Estrildidae | *Poephila cincta cincta* | Black-throated finch (white-rumped subspecies) | Endangered | Endangered |
| | Falconidae | *Falco hypoleucos* | Grey falcon | Near threatened | |
| | Maluridae | *Amytornis barbatus* | Grey grasswren | Near threatened | |

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland’s legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| | Meliphagidae | *Anthochaera phrygia* | Regent honeyeater | Endangered | Endangered |
| | Meliphagidae | *Epthianura crocea* | Yellow chat | Vulnerable | |
| | Meliphagidae | *Grantiella picta* | Painted honeyeater | Vulnerable | |
| | Meliphagidae | *Melithreptus gularis* | Black-chinned honeyeater | Near threatened | |
| | Meliphagidae | *Melithreptus gularis laetior* | Golden-backed honeyeater | Near threatened | |
| | Pedionomidae | *Pedionomus torquatus* | Plains-wanderer | Vulnerable | Vulnerable |
| | Psittacidae | *Neophema pulchella* | Turquoise parrot | Near threatened | |
| | Psittacidae | *Pezoporus occidentalis* | Night parrot | Endangered | Endangered |
| | Psittacidae | *Psephotus pulcherrimus* | Paradise parrot | Presumed extinct | Extinct |
| | Rostratulidae | *Rostratula australis* | Australian painted snipe | Vulnerable | Endangered |
| | Scolopacidae | *Numenius madagascariensis* | Eastern curlew | Near threatened | |
| | Strigidae | *Ninox strenua* | Powerful owl | Vulnerable | |
| | Turnicidae | *Turnix melanogaster* | Black-breasted button-quail | Vulnerable | Vulnerable |
| **Mammals** | | | | | |
| | Dasyuridae | *Dasycercus blythi* | Brush-tailed mulgara | Vulnerable | Vulnerable |
| | Dasyuridae | *Dasycercus cristicauda* | Crest-tailed mulgara | Vulnerable | Endangered |
| | Dasyuridae | *Dasyuroides byrnei* | Kowari | Vulnerable | Vulnerable |
| | Dasyuridae | *Sminthopsis douglasi* | Julia Creek dunnart | Endangered | Endangered |
| | Macropodidae | *Onychogalea fraenata* | Bridled nailtail wallaby | Endangered | Endangered |
| | Macropodidae | *Petrogale purpureicollis* | Purple-necked rock-wallaby | Vulnerable | |
| | Megadermatidae | *Macroderma gigas* | Ghost bat | Vulnerable | |
| | Muridae | *Notomys fuscus* | Dusky hopping-mouse | Endangered | Vulnerable |
| | Muridae | *Pseudomys australis* | Plains rat | Endangered | Vulnerable |
| | Peramelidae | *Macrotis lagotis* | Greater bilby | Endangered | Vulnerable |
| | Potoroidae | *Caloprymnus campestris* | Desert rat-kangaroo | Presumed extinct | Extinct |
| | Vespertilionidae | *Chalinolobus picatus* | Little pied bat | Near threatened | |

| Biodiversity asset type | Family | Scientific name | Common name | Status under Queensland's legislation | Status under the EPBC Act |
|---|---|---|---|---|---|
| | Vespertilionidae | *Nyctophilus corbeni* | Eastern long-eared bat | Vulnerable | Vulnerable |
| | Vombatidae | *Lasiorhinus krefftii* | Northern hairy-nosed wombat | Endangered | Endangered |

Source data: Queensland Government (2013)

### *1.1.7.3 Aquatic species and communities*

#### 1.1.7.3.1 Classification of aquatic habitats

The aquatic habitats in the Galilee subregion can be classified using the work of Jaensch (1999), Eamus et al. (2006), Kennard et al. (2010) and Fensham et al. (2011). None of these four classifications alone describes the range of water-dependent ecosystems at a consistent resolution sufficient for the BA methodology (Barrett et al., 2013), but in combination they provide robust coverage of the range of water-dependent ecosystem types.

Jaensch (1999) developed a classification of the wetlands of the south-western quadrant of Queensland, which included most of the Galilee subregion and all of the Lake Eyre Basin drainages as far as the South Australian border (Table 12). Fifteen of the wetland classes occur within the Galilee subregion and the remaining six occur nearby in the river basins that drain south-west from the subregion.

Table 12 Wetland types of south-western Queensland, as defined by Jaensch (1999)

| Wetland type | | Presence in subregion:<br>Yes = present<br>Near = present in Lake Eyre Basin, to the west or south |
|---|---|---|
| **Waterholes and watercourses** | | |
| 1 | Permanent river reaches and waterholes | Yes |
| 2 | Wooded watercourses | Yes |
| 3 | Shrubby floodplain watercourses | Yes |
| 4 | Watercourses without trees and shrubs | Yes |
| **Freshwater lakes** | | |
| 5 | Permanent, isolated freshwater lakes | Yes |
| 6 | Oxbows (cut-off river bends) | Yes |
| 7 | Temporary freshwater lakes without grassland | Near |
| 8 | Temporary freshwater lakes with couch grassland | Near |
| **Saline lakes** | | |
| 9 | Semi-permanent saline lakes | Yes |
| 10 | Temporary saline lakes | Yes |
| **Swamps** | | |
| 11 | Gibber and interdunal claypan aggregations | Near |
| 12 | Isolated claypans and canegrass swamps | Near |
| 13 | Sedge swamps | Yes |
| 14 | Forb meadows on floodplains | Near |
| 15 | Lignum swamps | Near |
| 16 | Bluebush swamps | Yes |
| 17 | Cooba shrubby swamps | Yes |
| 18 | Eucalypt wooded swamps | Yes |
| 19 | Acacia/belah wooded swamps | Yes |
| **Springs** | | |
| 20 | Artesian springs | Yes |
| **Rockholes** | | |
| 21 | Rockholes in arid upland | Yes |

Eamus et al. (2006) proposed three simple primary classes of groundwater-dependent ecosystems:

- ecosystems dependent on the surface expression of groundwater, including baseflow rivers and streams, wetlands, some floodplains and mound springs. This class of groundwater-dependent ecosystems requires a surface expression of groundwater, which may, in many cases, then soak below the soil surface and thereby become available to plant roots
- ecosystems dependent on the subsurface presence of groundwater, often accessed via the capillary fringe (non-saturated zone above the saturated zone of the watertable) when roots penetrate this zone. No surface expression of groundwater is required in this class of groundwater-dependent ecosystems. In this product, this class (specifically the Coolibah – Black Box Woodlands) has already been discussed in Section 1.1.7.2, and will not be considered further
- aquifer and cave ecosystems. These ecosystems include karstic, fractured rock and alluvial aquifers. The hyporheic zones of rivers and floodplains is considered in this category because these ecotones often support species that are obligate groundwater inhabitants.

Through an analysis of stream gauge data from across Australia, Kennard et al. (2010) developed a classification of surface water flow regimes for creeks, rivers and river segments. Four of twelve flow regime classes occur in watercourses in the Galilee subregion:

- unpredictable intermittent
- predictable summer highly intermittent
- unpredictable summer intermittent
- variable summer intermittent.

Within the bounds of the subregion, the ‘unpredictable intermittent’ flow regime class was only identified in the upper parts of the Flinders river basin, the northern-most river basin. Each of the other three flow regime classes was found at least once in most of the other seven river basins represented in the subregion. Where data were available for more than one stream gauge along a single river or creek, different stretches were assigned to different flow regime classes, indicative of systematic longitudinal variation of flow patterns or analytical difficulty leading to somewhat similar flow patterns being assigned to different regime classes. Although with different seasonality and predictability, all observed river flow regimes are intermittent, meaning that the rivers largely dry up and retreat to waterholes between major flow events (Kennard et al., 2010).

Fensham et al. (2011) developed a classification of permanent water bodies and natural wetlands, along rivers and elsewhere, for an area that substantially overlaps the subregion:

- waterholes – enlarged segments of an ephemeral or seasonal river or watercourse which hold water after streamflow has ceased
- rockholes – natural hollows in rocky landscapes, formed from fracturing and weathering, which store water from local runoff

- outcrop springs (referred to as *recharge springs* in the earlier terminology of Fensham and Fairfax (2003)) – dependent on groundwater and occurring where sediments that form the aquifer are outcropping
- discharge springs – dependent on groundwater that emanates through confining beds (aquitards) in areas remote from where the aquifer receives its inputs.

The three classifications described above, while individually incomplete, can be combined to form a classification with 11 possible classes as the basis of analysing aquatic ecology in water bodies in the Galilee subregion:

- permanent lakes (both saline and semi-saline)
- impermanent lakes (both saline and semi-saline)
- permanent waterholes
- impermanent waterholes
- swamps
- permanent rockholes
- impermanent rockholes
- permanent outcrop springs
- impermanent outcrop springs
- discharge springs (always permanent in the subregion)
- subsurface water bodies or aquifers.

### 1.1.7.3.2 Diversity and ecological drivers in aquatic habitats

There is a growing, but not yet comprehensive, literature on the key ecological drivers of aquatic communities of the Galilee subregion from which important principles are summarised in this section.

***Lakes***

Silcock (2009) identified four permanent to semi-permanent major lakes in the Galilee subregion: Lake Galilee (almost permanent), lakes Dunn and Huffer (semi-permanent), and Lake Buchanan (highly dynamic, and usually dry by the middle of each dry season). All are located in the Desert Uplands IBRA bioregion in the centre and east of the Galilee subregion. All are semi-saline playas fringed by one or more classes of swamp in the sense of Jaensch (1999), especially samphire associations and Eucalypt wooded swamp or Acacia/belah wooded swamp (Caring for Our Country, 2012a, 2012b). While these lakes are known as important habitat for waterbirds, including some EPBC-listed species, the lakes' ecology is not well studied.

There are numerous small, infrequently filled playas in the central Galilee subregion. In addition, the rivers draining from the Galilee to the south and west (the Diamantina, Cooper, Bulloo, Paroo and Warrego) have impermanent lakes associated with major floods overflowing into low-lying areas of floodplains (Jaensch, 1999).

### *Rivers and waterholes*

As foreshadowed in the above description of Galilee subregion flow regime classification of Kennard et al. (2010), temporal patterns of water and of depth of water are the overriding drivers of ecological characteristics of aquatic community type, species diversity and species abundance (Silcock, 2009) – with spatial connectivity as a secondary (and often related) driver.

In the northern Flinders river basin, with its relatively reliable annual flow regimes, Leigh et al. (2010a) found the macroinvertebrate community to be ‘dynamically stable’, able to respond to relatively predictable change across seasons. By contrast, in rivers of the Lake Eyre Basin, those in the Bulloo and Paroo river basins, and the Warrego River (with their more irregular flow regimes), diversity of invertebrates, fish and birds at a broad scale follows a boom and bust cycle. Booms are associated with high-flow periods and better water quality (Shiel et al., 2006; Kingsford et al., 2010; Sheldon and Fellows, 2010) – or more specifically to sequences of flows that are able to fill all ‘hydrological sponges’ in a river system (Leigh et al., 2010b). For invertebrates and fish, booms result from population dynamics entirely within the river systems, but for nomadic waterbirds – which Kingsford et al. (2010) describe as ‘time and space travellers’ – diversity is not determined locally or by any one river system, but instead by the probability of viable resource patches across all river systems in inland Australia.

In the inland rivers, as floods recede and water flow is no longer continuous, waterholes and riverine wetlands take on the role of refugia, habitats to which a species population retreats and persists during times of environmental stress (Marshall et al., 2006; Silcock, 2009; Sheldon et al., 2010; Puckridge et al., 2010). Refugia during the dry period are important areas for the survival of species and persistence of water-dependent communities. Their physical habitat characteristics (e.g. surface area, depth, underwater benches, eroding banks and snags) influence aquatic species diversity and evenness. For example, fish community and macroinvertebrate composition changes with the size, depth and structural diversity of the refugia (Balcombe et al., 2006; Arthrington et al., 2010; Puckridge et al., 2010).

Connectivity within and between inland river systems is the spatial analogue of temporal variation in flow rate, and the two are interlinked as larger floods or flood sequences permit spatial connection between locations that are geographically and hydrologically more distant within a river basin. Balcombe et al. (2006), Leigh and Sheldon (2009), Fensham et al. (2011) and Kerezsy et al. (2013) have all emphasised the role of connectivity between, or conversely isolation of, waterholes and wetland refugia. Kerezsy et al. (2013) demonstrated that in the Georgina-Mulligan river basin, in the western Galilee subregion, connectivity interacts with life history strategies of fish, so that species can be identified as either extreme or conservative dispersers. Connectivity within river systems during times of flood has also been identified as the most probable reason for the low level of endemism observed in waterholes in inland river systems (Fensham et al., 2011).

However, isolation between river systems is also important for species distribution and endemism. For example, Australian smelt, carp gudgeon and Cooper Creek catfish occur only in the Cooper river system, while golden goby and banded grunter are only in the Georgina-Diamantina river system (Fensham et al., 2011; Kerezsy et al., 2013).

Despite the documented importance of connectivity along river systems, connectivity between aquatic and adjacent terrestrial ecosystems has been observed to be relatively weak. Using stable isotope techniques, Bunn et al. (2003) and Fellows et al. (2007), in the Cooper Creek, and Jardine et al. (2013) in the Flinders River, have found that aquatic food webs in waterholes during non-flow periods depend almost exclusively on autochthonous carbon sources from within the waterhole or falling into the waterhole from the littoral zone, and very little from surrounding terrestrial sources. Likewise Arthington et al. (2010) could find little influence of medium-scale ‘watershed’ characteristics on fish assemblage structure in waterholes.

Shiel et al. (2006) has shown the significance of water salinity in determination of zooplankton diversity and assemblage composition in the Lake Eyre Basin rivers. The study observed generally lower species richness in sites of higher salinity, but concluded that the effects of salinity were site-specific and involved thresholds of change. The authors suggested that the threshold level for salinity at a site was probably dependent on the time span between flushing events of fresher water relative to the life history characteristics and physiological tolerances of individual species.

On the east side of the Great Dividing Range, the Burdekin river basin stands somewhat in contrast to the other river basins described above. Pusey et al. (1998) found the fish fauna on the Burdekin River (above the dam) to have low diversity compared with other eastern river basins, but comprised of a combination of species with northerly and southerly distributions. With its more continuous flow, the key drivers of fish species composition were flow rate, substrate (sand versus gravel or cobble) and presence of snags and coarse debris, which lead to an upstream–downstream gradient of composition and abundance. An equivalent gradient may also occur along the Belyando River, a tributary of the Burdekin River in the east of the Galilee subregion.

### *Swamps*

Jaensch (1999) details a variety of types of swamps that are associated with the margins of rivers, oxbows, waterholes, lakes and springs, or the lower-lying parts of river floodplains. The dynamics and ecology of these wetlands is most likely determined primarily by surface water hydrology and seasonal or infrequent flooding from rivers and lakes, although in the wetland classes containing trees (e.g. Eucalypt wooded swamps and Acacia/belah wooded swamps), the trees are likely to be accessing groundwater. With the exclusion of the dependence of the trees on groundwater, the biodiversity and ecology of swamps are poorly studied in comparison with other wetland habitat types. Swamps are often mapped as terrestrial ecological communities and form part of the subregion’s complex clinal mosaic of vegetation shown in Figure 51.

### *Rockholes*

Fensham et al. (2011) observed that rockholes are poorly known in the eastern Lake Eyre Basin. They document 18 permanent rockholes in three clusters in Tertiary sandstone ranges to the west and south of Winton (in the Diamantina and Cooper Creek catchments). Data were available on the biota of only five rockholes. All major groups of aquatic organisms had low diversity and abundance, and there was no evidence of endemism.

### *Outcrop springs*

Fensham et al. (2011) mapped outcrop springs in three groups in the Cooper Creek catchment: between Windorah and Winton, between Windorah and Blackall, and north-east of Blackall, on the western slopes of the Great Dividing Range. More species were observed in outcrop springs than in rockholes, but all species observed were widespread. Geographically isolated populations of three species of plant, one species of mollusc (*Sermyla* sp.) and one species of fish (*Mogurnda clivicola*, the Flinders Ranges mogurnda) were observed, but no endemism was evident.

### *Discharge springs*

Discharge springs have been studied to a much greater extent than outcrop springs. Fensham and Fairfax (2003) estimated that before 1900 there were 300 discharge spring complexes, or local clusters of springs, in the Great Artesian Basin (excluding Cape York Peninsula), of which only 36% (108 complexes) are still active. Most of these spring complexes lie within the Galilee subregion or, given the groundwater and surface water hydrology described in the previous sections, are likely to fall within the preliminary Assessment extent of potential development impacts from this subregion. Fensham et al. (2011) record 49 of those original spring complexes in the Georgina-Diamantina and Cooper Creek catchments of the Lake Eyre Basin, and 25 remain active. Because of their in-transit association with basement rocks, the water is generally alkaline (Fensham et al., 2011).

Because the groundwater has a very long residence time in the Great Artesian Basin, discharge springs show minimal fluctuations in flow rates, and their biota are adapted to relatively stable environmental conditions (i.e. there is low resilience and low resistance to environmental change in the biota).

Isolation of discharge springs complexes means that they have the highest rates of endemism of any surface aquatic habitat type (Fensham and Price, 2004; Fensham et al., 2011). Almost half of all species recorded from discharge springs in the Great Artesian Basin are endemic to the area. *Jardinella*, a genus of snail, is represented by 12 locally endemic species. Each of the three species of fish that are listed under the EPBC Act is restricted to a single springs complex. The significance of endemism led Fensham and Price (2004) to rank the discharge springs on degree of species endemism, as a basis for conservation prioritisation.

There is a substantial number of Great Artesian Basin discharge spring complexes in South Australia, to the west and south of Kati Thanda – Lake Eyre (see Greenslade et al., 1985; Zeidler and Ponder, 1989; Tyler et al., 1990; Harris, 1992). These springs are hydrologically connected to the Great Artesian Basin, but lie outside of the Galilee subregion. Their ecological characteristics are driven by similar factors and they also exhibit high levels of endemism.

### *Subsurface aquatic habitats*

In the Galilee subregion, there is little information on the diversity and ecology of stygobiota, the suite of organisms that inhabit subterranean groundwater habitats. Humphreys (2006) and Tomlinson and Boulton (2010) report that the biodiversity of Australia's subsurface groundwater-dependent ecosystems is inconsistently characterised. Invertebrates (especially crustaceans) are well characterised only in the major artesian basins of Western Australia, while microbial, fungal and protozoan diversity is virtually unexplored throughout Australia.

From the analysis of the ecological characteristics of groundwater environments by Tomlinson and Boulton (2010), it is, however, possible to identify, in principle, two sets of key drivers for subsurface ecosystems:

- The stygobiota is adapted to relatively stable environmental conditions compared with surface aquatic environments (except Great Artesian Basin discharge springs), and thus is likely to depend strongly on the stability of the groundwater regime and other abiotic environmental factors (i.e. there is low resilience and resistance amongst stygobiota).
- Because detritivorous microbes, rather than plants, are the basis of the food chain, ecosystem structure depends on carbon and nutrient inputs through vertical ecotones – the vadose zone in soil under terrestrial vegetation, and the hyporheic and littoral zones of springs, rivers and wetlands – and changes in resource fluxes through these ecotones could lead to change in stygobiota diversity and abundance.

### 1.1.7.3.3 Recent change and threatening processes

Ecological changes to –and potentially threatening processes for – rivers, waterholes, rockholes and outcrop springs are poorly documented for the Galilee subregion. Choy et al. (2002) undertook a survey of the ecological condition of reaches of the Georgina and Diamantina rivers and Cooper Creek and concluded that they were in generally good condition except for bank damage by cattle. However, Silcock (2009) indicated that river waterholes are being slowly degraded by the cumulative impacts of cattle, feral animals, native herbivores and their consequent total grazing pressure during dry periods.

Non-native fish seem to be a lesser threat in the rivers of the subregion than in other parts of Australia. Costelloe et al. (2010) observed that non-native fish are disadvantaged by, and their invasions have been hampered by, the extremely variable flow regimes in Lake Eyre Basin rivers and wetlands.

Change in discharge springs have been the subject of much closer scrutiny, because of both the large number of springs that have become inactive and the sensitivity of the remaining active springs to ecological impact. The past and current threatening processes are (Fensham and Fairfax, 2003; Fensham et al., 2011; Kerezsy and Fensham, 2013):

- drawdown of groundwater for stock, irrigated agriculture and mining – a significant driver of inactivity and diminishment of springs
- excavation, including dredging, conversion to dams, wells, draining, and construction of raised concrete structures that limit surface flows away from the point of discharge. At least one form of excavation affects 26% of active springs (Fensham and Fairfax, 2003)
- impoundments
- exotic plants (23 species recorded by Fensham and Fairfax (2003)), including plant species for ponded pastures (e.g. *Brachiara mutica, Echinochloa polystachya* and *Hymenachne acutiglumis*)

- pests, especially the mosquito fish (*Gambusia holbrooki*; see Kerezsy and Fensham (2013) for more details) and the cane toad (*Bufo marinus*)
- feral animals, such as pigs, horses and donkeys (throughout the Great Artesian Basin area of Queensland), and camels (in western desert areas)
- sheep grazing aquatic and littoral vegetation, and subsequent erosion of exposed soils (in southern areas).

Fensham and Fairfax (2003) record only three discharge spring complexes in national or conservation parks. Subject to effective management plans, park status affords those spring complexes protection against some of the threatening processes above, but aquifer drawdown is a more diffuse process that would also require coordinated management actions in surrounding lands regardless of designation.

### 1.1.7.3.4 Species and ecological communities of national significance

Fifteen aquatic species are listed under the EPBC Act and are known to occur, or are likely to occur, in the Galilee subregion: six plants, three fish, one reptile, and five birds (Table 10). The three fish species and the plant *Eriocaulon carsonii* are exclusively associated with Great Artesian Basin discharge springs, while the other species are associated with a wider variety of aquatic habitats.

The community of native species dependent on discharge springs in the Great Artesian Basin is the principal aquatic ecological community listed under the EPBC Act for the subregion (Table 10). This community has become the focus of intense management concern as a result of its high levels of endemicity and the many potentially threatening processes that have been identified (e.g. Wilson, 1995; Fensham and Price, 2004; Queensland Environmental Protection Agency, 2005; Fensham et al., 2010; Fensham et al., 2011; Kerezsy and Fensham, 2013). Queensland Environmental Protection Agency (2005) provided a list of species of ‘conservation significance’ because they are dependent upon and confined to discharge springs (Table 13), but only some are also formally protected under either national or state legislation.

**Table 13 Great Artesian Basin discharge springs species of conservation significance**

| Asset type | Scientific name | Common name |
|---|---|---|
| **Ferns and allies** | | |
| | *Thelypteris confluens* | |
| | *Cyathea exilis* | |
| | *Cyathea feline* | |
| **Herbs** | | |
| | *Eryngium fontanuma* | Thornless blue devil |
| | *Eriocaulon carsoniia* | Salt pipewort or button grass |
| | *Myriophyllum artesiuma* | Water or artesian milfoil |
| | *Hydrocotyle dipleuraa* | |
| | *Peplidium* sp. | |
| **Grasses** | | |
| | *Sporobolus pamelaea* | Spring grass or spring dropseed |
| | *Eragrostis fenshamii* | Springs lovegrass |
| | *Arthraxon hispidus* | Hairy-joint grass |
| | *Fimbristylis* sp. | |
| | *Fimbristylis blakei* | |
| **Trees and shrubs** | | |
| | *Calophyllum bicolour* | |
| **Molluscs** | | |
| | 18 species of freshwater snail (from the families Hydrobiidae, Bithyniidae and Planorbidae) including *Jardinella isolata* | |
| **Crustaceans** | | |
| | *Caridinia thermophila* | Freshwater shrimp |
| | *Ponderella bundoona* | Freshwater isopod |
| | *Ponderella ecomanufactia* | Freshwater isopod |
| **Fish** | | |
| | *Chlamydogobius squamigenusa* | Edgbaston goby |
| | *Chlamydogobius micropterusa* | Elizabeth Springs goby |
| | *Scaturiginichthys vermeilipinnisa* | Red-finned blue-eye |
| **Birds** | | |
| | *Epthianura crocea croceaa* | Yellow chat (gulf subspecies) |

Source data: Queensland Environmental Protection Agency (2005)

[a] Species that also have national or state threatened status.

### 1.1.7.3.5 Species of regional significance

For the 102 taxa (including some subspecies) listed under Queensland's *Nature Conservation Act 1992* but not also listed under the EPBC Act, there has been no formal assessment of which are associated with aquatic habitat types. However, it is possible to identify 12 taxa with clear water dependence using record and habitat data from the *Atlas of living Australia* (Atlas of Living Australia, 2014):

- plants:
  - salt pipewort (*Eriocaulon carsonii*, all three subspecies)
  - *Hydrocotyle dipleura* (no common name)
  - artesian milfoil (*Myriophyllum artesium*)
  - spring grass or spring dropseed (*Sporobolus pamelae*)
  - *Sporobolus partimpatens* (no common name)
- reptiles:
  - *Emydura subglobosa* ssp. *worrelli* (diamond-head turtle)
- birds:
  - black-necked stork (*Ephippiorhynchus asiaticus*)
  - freckled duck (*Stictonetta naevosa*)
  - radjah shelduck (*Tadorna radjah*)
  - yellow chat (*Epthianura crocea*).

### ***References***

Arthington AH, Olden JD, Balcombe SR and Thoms MC (2010) Multi-scale environmental factors explain fish losses and refuge quality in drying waterholes of Cooper Creek, an Australian arid-zone river. Marine and Freshwater Research 61, 842–856.

Atlas of living Australia (2014) Atlas of living Australia website. Viewed 20 February 2014, <www.ala.org.au>.

Balcombe SR, Arthington AH, Foster ND, Thoms MC, Wilson GG and Bunn SE (2006) Fish assemblages of an Australian dryland river: abundance, assemblage structure and recruitment patterns in the Warrego River, Murray–Darling Basin. Marine and Freshwater Research 57, 619–633.

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Bastin G, Denham R, Scarth P, Sparrow A and Chewings V (2014) Remotely sensed analysis of ground-cover change in Queensland's rangelands, 1988–2005. The Rangeland Journal, in press.

Bunn SE, Davies PM and Winning M (2003) Sources of organic carbon supporting the food web of an arid zone floodplain river. Freshwater Biology 48, 619–635.

Burrows WH, Scanlan JC and Rutherford MT (eds) (1988) Native Pastures in Queensland: the Resources and Their Management. Queensland Department of Primary Industries, Brisbane.

Caring for Our Country (2012a) Caring for Our Country Business Plan 2012-13, Protecting Critical Ecosystems, Lake Buchanan. Viewed 18 March 2014, <www.nrm.gov.au/resources/publications/bp-2012-13/pubs/sig-hevae-lake-galilee-qld.pdf>.

Caring for Our Country (2012b) Caring for Our Country Business Plan 2012-13, Protecting Critical Ecosystems, Lake Galilee. Viewed 18 March 2014, <www.nrm.gov.au/resources/publications/bp-2012-13/pubs/sig-hevae-lake-galilee-qld.pdf>.

Choy SC, Thomson CB and Marshall JC (2002) Ecological condition of central Australian arid-zone rivers. Water Science and Technology 45, 225–232.

Costelloe JF, Reid JRW, Pritchard JC, Puckridge JT, Bailey VE and Hudson PJ (2010) Are alien fish disadvantaged by extremely variable flow regimes in arid-zone rivers? Marine and Freshwater Research 61, 857–863.

Department of the Environment (2012). CAPAD 2012 [Collaborative Australian Protected Area Database]. Viewed 18 December 2013, <www.environment.gov.au/node/34737>.

Department of the Environment (2014a) Australia's bioregions (IBRA) website. Viewed 20 February 2014, <www.environment.gov.au/topics/land/national-reserve-system/science-maps-and-data/australias-bioregions-ibra>.

Department of the Environment (2014b) National Vegetation Information System (NVIS) website. Viewed 20 February 2014, <www.environment.gov.au/topics/science-and-research/databases-and-maps/national-vegetation-information-system>.

Department of the Environment (2014c) A directory of important wetlands in Australia. Department of the Environment, Canberra. Viewed 20 February 2014, <www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database/directory-important>.

DSITIA (2012) Land cover change in Queensland 2009–10. Statewide Landcover and Trees Study Report. Department of Science, Information Technology, Innovation and the Arts, Brisbane. Viewed 19 December 2013, <nrm.qld.gov.au/slats/reports-spatial-products.html>.

Eamus D, Froend R, Loomes R, Hose G and Murray B (2006) A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. Australian Journal of Botany 54, 97–114.

Environment Australia (2001) A directory of important wetlands in Australia, Third Edition. Environment Australia, Canberra.

Fellows CS, Wos ML, Pollard PC and Bunn SE (2007) Ecosystem metabolism in a dryland river waterhole. Marine and Freshwater Research 58, 250–262.

Fensham RJ and Fairfax RJ (2003) Springs wetlands of the Great Artesian Basin, Queensland, Australia. Wetlands Ecology and Management 11, 343–362.

Fensham RJ, McCosker JC and Cox MJ (1998) Estimating clearance of *Acacia*-dominated ecosystems in central Queensland using land-system mapping data. Australian Journal of Botany 46, 305–319.

Fensham RJ, Ponder WF and Fairfax RJ (2010) Recovery plan for the community of native species dependent on natural discharge of groundwater from the Great Artesian Basin. A report to Department of the Environment, Water, Heritage and the Arts, Canberra. Queensland Department of Environment and Resource Management, Brisbane. Viewed 20 December 2013, <www.environment.gov.au/biodiversity/threatened/publications/recovery/great-artesian-basin-ec.html>.

Fensham RJ and Price RJ (2004) Ranking spring wetlands in the Great Artesian Basin of Australia using endemicity and isolation of plant species. Biological Conservation 119, 41–50.

Fensham RJ, Silcock JL, Kerezsy A and Ponder W (2011) Four desert waters: setting arid zone wetland conservation priorities through understanding patterns of endemism. Biological Conservation 144, 2459–2467.

Greenslade J, Joseph L and Reeves A (eds) (1985) South Australia's mound springs. Nature Conservation Society of South Australia Inc., Adelaide.

Harris CR (1992) Mound springs: South Australian conservation initiatives. The Rangeland Journal 14, 157–173.

Humphreys WF (2006) Aquifers: the ultimate groundwater-dependent ecosystems. Australian Journal of Botany 54, 115-132.

Jardine TD, Hunt RJ, Faggotter SJ, Valdez D, Burford MA and Bunn SE (2013) Carbon from periphyton supports fish biomass in waterholes of a wet-dry tropical river. River Research and Applications 29, 560–573.

Jaensch R (1999) The status and importance of Queensland's south-western wetlands. Report by Wetlands International - Oceania to the Environmental Protection Agency, Brisbane.

Kennard MJ, Pusey BJ, Olden JD, Mackay SJ, Stein JL and Marsh N (2010) Classification of natural flow regimes in Australia to support environmental flow management. Freshwater Biology 55, 171–193.

Kerezsy A, Balcombe SR, Tischler M and Arthington AH (2013) Fish movement strategies in an ephemeral river in the Simpson Desert, Australia. Austral Ecology 38, 798–808.

Kerezsy A and Fensham R (2013) Conservation of the endangered red-finned blue-eye, *Scaturiginichthys vermeilipinnis*, and control of alien eastern gambusia, *Gambusia holbrooki*, in a spring wetland complex. Marine and Freshwater Research 64, 1–13.

Kingsford RT, Roshier DA and Porter JL (2010) Australian waterbirds – time and space travellers in dynamic desert landscapes. Marine and Freshwater Research 61, 875–884.

Leigh C, Burford MA, Sheldon F and Bunn SE (2010a) Dynamic stability in dry season food webs within tropical floodplain rivers. Marine and Freshwater Research 61, 357–368.

Leigh C and Sheldon F (2009) Hydrological connectivity drives patterns of macroinvertebrate biodiversity in floodplain rivers of the Australian wet dry tropics. Freshwater Biology 54, 549–571.

Leigh C, Sheldon F, Kingsford RT and Arthington AH (2010b) Sequential floods drive 'booms' and wetland persistence in dryland rivers: a synthesis. Marine and Freshwater Research 61, 896–908.

Marshall JC, Sheldon F, Thoms M and Choy S (2006) The macroinvertebrate fauna of an Australian dryland river: spatial and temporal patterns and environmental relationships. Marine and Freshwater Research 57, 61–74.

Orr DM and Holmes WE (1984) Mitchell grasslands. In: Harrington GN, Wilson AD and Young MD (eds) Management of Australia’s Rangelands. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Melbourne, 241–254.

Puckridge JT, Costelloe JF and Reid JRW (2010) Ecological responses to variable water regimes in arid-zone wetlands: Coongie Lakes, Australia. Marine and Freshwater Research 61, 832–841.

Pusey BJ, Arthington AH and Read MG (1998) Freshwater fishes of the Burdekin River, Australia: biogeography, history and spatial variation in community structure. Environmental Biology of Fishes 53, 303–318.

Queensland Environmental Protection Agency (2005) Wetland management profile: Great Artesian Basin spring wetlands. Ecosystem Conservation Branch, Environmental Protection Agency, Brisbane.

Queensland Government (2013) Wildlife Online: species list. Viewed 21 March 2014, <www.qld.gov.au/environment/plants-animals/species-list/>.

Shiel RJ, Costelloe JF, Reid JRW, Hudson P and Powling J (2006) Zooplankton diversity and assemblages in arid zone rivers of the Lake Eyre Basin, Australia. Marine and Freshwater Research 57, 49–60.

Sheldon F, Bunn SE, Hughes JM, Arthington AH, Balcombe SR and Fellows CS (2010) Ecological roles and threats to aquatic refugia in arid landscapes: dryland river waterholes. Marine and Freshwater Research 61, 885–895.

Sheldon F and Fellows CS (2010) Water quality in two Australian dryland rivers: spatial and temporal variability and the role of flow. Marine and Freshwater Research 61, 864–874.

Silcock J (2009) Identification of permanent refuge waterbodies in the Cooper Creek & Georgina-Diamantina River catchments for Queensland and South Australia. Final report to South Australian Arid Lands Natural Resource Management Board, Port Augusta.

Stafford Smith DM and Morton SR (1990) A framework for the ecology of arid Australia. Journal of Arid Environments 18, 255–278.

Thackway R and Lesslie R (2005) Vegetation Assets, States, and Transitions (VAST): Accounting for vegetation condition in the Australian landscape. Technical report, Bureau of Rural Sciences, Canberra.

Tomlinson M and Boulton AJ (2010) Ecology and management of subsurface groundwater dependent ecosystems in Australia – a review. Marine and Freshwater Research 61, 936–949.

Tyler MJ, Twidale CR, Davies M and Wells CB (eds) (1990) Natural History of the North East Deserts. Royal Society of South Australia, Adelaide.

Wilson BA (1995) Artesian Springs of the Great Artesian Basin in Queensland. An unpublished report to the Queensland Department of Environment and Heritage and Australian Nature Conservation Agency. States Cooperative Assistance Program project SCAP S012, Department of Environment and Heritage, Toowoomba.

Zeidler W and Ponder WF (eds) (1989) Natural History of Dalhousie Springs. South Australian Museum, Adelaide.

www.bioregionalassessments.gov.au

Australian Government
Department of the Environment
Bureau of Meteorology
Geoscience Australia

CSIRO