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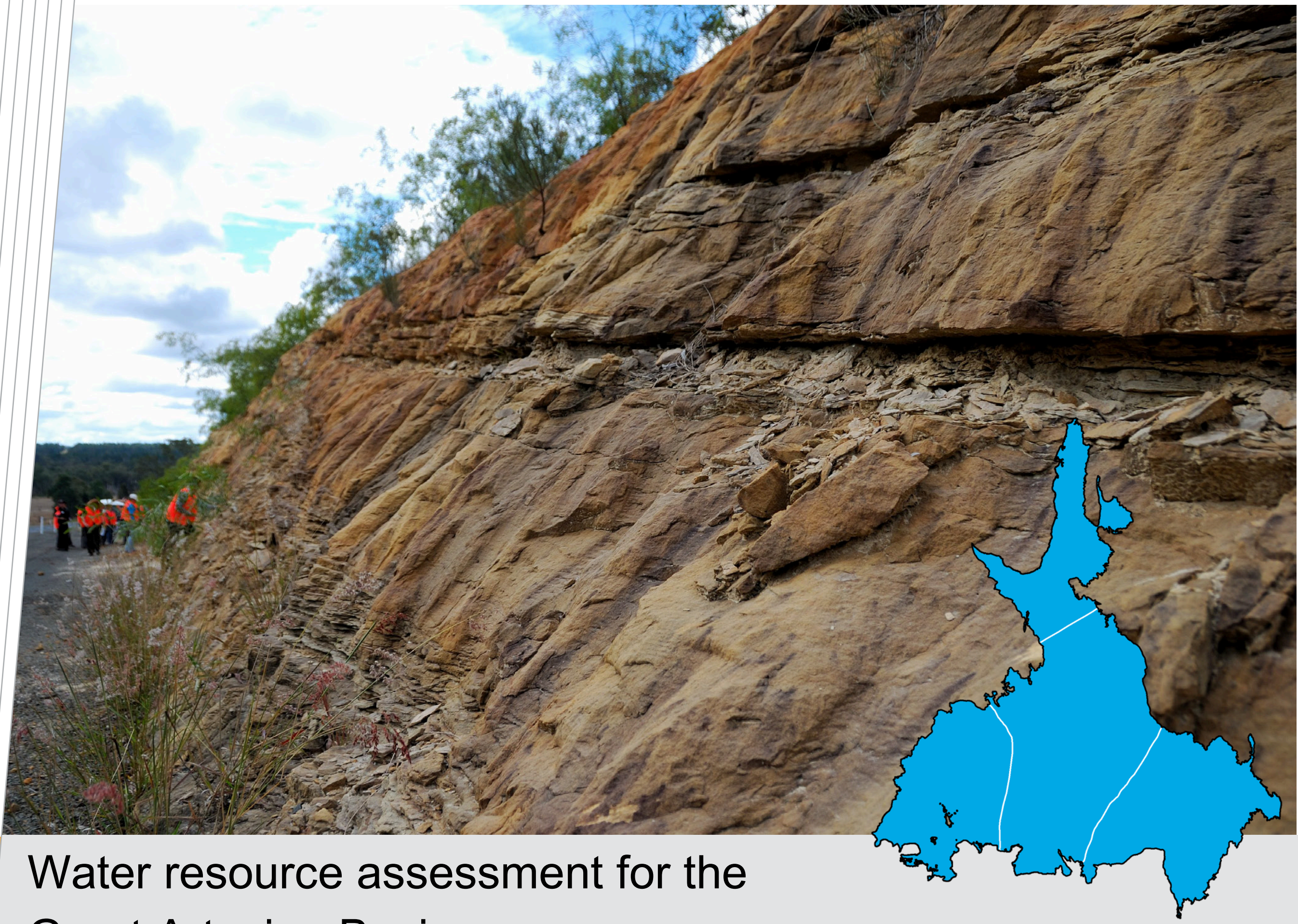

Water resource assessment for the Great Artesian Basin

A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment

Smerdon BD, Ransley TR, Radke BM and Kellett JR

21 December 2012

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Australian Government
Department of Sustainability, Environment, Water, Population and Communities
National Water Commission

Great Artesian Basin Water Resource Assessment acknowledgments

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The Assessment was guided and reviewed by a Steering Committee, which had representatives from the following organisations: Australian Government Department of Sustainability, Environment, Water, Population and Communities; National Water Commission; Australian Bureau of Agricultural and Resource Economics and Sciences; New South Wales Office of Water; the Queensland Department of Natural Resources and Mines (formerly the Department of Environment and Resource Management); Queensland Water Commission; South Australian Department of Environment, Water and Natural Resources (formerly Department for Water); and the Northern Territory Department of Land Resource Management (formerly Northern Territory Department of Natural Resources, Environment, The Arts and Sport – NRETAS).

We are thankful for the input from Frances Marston and David Arnold in the preparation of this report. This report encapsulates the major findings presented in a companion technical report (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). We acknowledge the significant scientific contributions from Hashim Carey, Joseph Bell, Phil O'Brien, Gerard Stewart, Andrew Love, Pauline Rousseau-Gueutin, Richard Cresswell, and Rien Habermehl.

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Cover photograph: Exposure of the Hutton Sandstone Formation in Queensland, which forms a major aquifer in the Great Artesian Basin. Courtesy of CSIRO Land and Water.

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Director’s foreword

Following the November 2006 Summit on the southern Murray-Darling Basin (MDB), the then Prime Minister and MDB State Premiers commissioned CSIRO to undertake an assessment of sustainable yields of surface water and groundwater systems within the MDB. The project (completed in 2008) was a world first for rigorous and detailed basin-scale assessment of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources.

Following the success of the MDB project, the Council of Australian Governments (COAG) agreed to expand the CSIRO assessments of water yield so that, for the first time, Australia would have a comprehensive scientific assessment of water yield in all major water systems across the country. This would allow a consistent analytical framework for water policy decisions across the nation. Thus in March 2008 COAG commissioned three further Sustainable Yields projects (for northern Australia, south-west Western Australia and Tasmania), providing a nation-wide expansion of the assessments. These were completed in September 2009, December 2009 and February 2010, respectively.

Determinations of sustainable yield and/or over-allocation require choices by communities and governments about the balances of outcomes (environmental, economic and social) sought from water resource management and use. These choices are best made on the basis of sound technical information, with the fundamental underpinning information being a robust description of the extent and nature of the water resource.

The Great Artesian Basin Water Resource Assessment (the Assessment), undertaken by CSIRO and partners together with other consultants, provides this fundamental underpinning information for the Great Artesian Basin (GAB).

Consistent with the previous Sustainable Yields projects, this assessment provides an analytical framework to assist water managers in the GAB to meet National Water Initiative (NWI) commitments. A key outcome of the Assessment is to communicate the best available science to the Australian Government in order to advance basin groundwater management under the NWI water reform agenda. It provides an information base that supports both investment and the environment, and that underpins the capacity of Australia’s water management regimes to deal with change both responsibly and fairly (NWI Clause 5). In accordance with NWI Clause 40, the Assessment will inform the implementation of existing water plans through providing information about the status of GAB aquifer systems, data from which could be used to better monitor the performance of water plan objectives, outcomes and water management arrangements. The Assessment will also assist in achieving Action 79 under the NWI in relation to better recognising the different types of surface water – groundwater interactions.

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Data availability

Data produced from the Great Artesian Basin Water Resource Assessment, including map products and GIS data, can be obtained from Geoscience Australia.

For further information on data availability, please visit: <http://www.ga.gov.au/>.

Units of measurement

Measurement unit	Description
KL	kilolitres, 1,000 litres or 1 square metre
ML	megalitres, 1,000,000 litres
GL	gigalitres, 1,000,000,000 litres
TL	teralitres, 1,000,000,000,000 litres
cumecs	cubic metres per second; m^3/sec; equivalent to 1,000 litres per second
mAHD	metres above Australian Height Datum

Acronyms and initialisms

CSG	coal seam gas
GAB	Great Artesian Basin
GABSI	Great Artesian Basin Sustainability Initiative
GABtran	Great Artesian Basin transient groundwater flow model
GIS	geographic information system
QWC	Queensland Water Commission
QWC model	Queensland Water Commission coal seam gas regional groundwater flow model
TDS	total dissolved solids
WCM	Walloon Coal Measures

Executive summary

Since 2007, CSIRO has been undertaking scientific assessments of current and future water availability in major water systems across Australia through its Sustainable Yields projects. To date, rigorous assessments of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources have been completed for the Murray-Darling Basin, northern Australia, south-west Western Australia and Tasmania. The underlying aim has been to provide consistent water resource assessments to guide water policy and water resources planning.

Determinations of sustainable water resource development and allocations require choices by governments and communities about the balance of outcomes (environmental, economic and social) sought from water resource management and use. These choices are best made on the basis of sound scientific information, particularly a robust description of the extent, variability and nature of the water resource. Consistent with the previous Sustainable Yields projects, the Great Artesian Basin Water Resource Assessment (the Assessment) provides an analytical framework to assist water managers in the Great Artesian Basin (GAB) to meet National Water Initiative commitments.

This report describes the findings of the Assessment that have led to advancing the understanding of the GAB. It encapsulates findings that are presented in four region reports and a technical report on conceptualising the GAB that were prepared for the Assessment. Advancing the conceptual understanding of the GAB requires careful evaluation of the geological framework (i.e. the layers of rock), description of how the geology translates into hydrostratigraphy (i.e. the relative ability of specific layers to store and transmit water) and investigation of the groundwater conditions (i.e. watertable, groundwater levels, and inferred movement). It is the geological framework, hydrostratigraphy and groundwater conditions that are the basis for conceptualising water resources in the GAB. The conceptual understanding of the GAB provides the foundation for assessing water availability and providing guidance to water policy and water resource planning.

The Assessment included the evaluation of the potential impacts of climate change and groundwater development, and subsequent risks to springs of the GAB. This work was completed in parallel with updating the conceptual understanding of the GAB. Various scenarios of climate change and groundwater development were investigated by groundwater modelling, mainly using an existing model of the GAB that does not include any of the complexities discovered in the updated conceptual understanding of the GAB. The groundwater model had a simplified conceptualisation (single layer) of the main aquifers spanning the GAB, but has been shown to represent the change in groundwater levels at a large scale. These complexities discovered by the Assessment (identified below) should be considered in the development of new groundwater models. The findings related to impacts of climate change and groundwater development are briefly summarised in this report and presented more fully in a range of other Assessment reports (see Appendix A).

The Assessment focused on aquifers of the Jurassic and Cretaceous periods, which are present across the entire GAB and, throughout the Assessment, are referred to as the Cadna-owie – Hooray Aquifer and equivalents. This report focuses on the findings of the Assessment related to the geology, hydrostratigraphy, hydrogeology and advancing the conceptual understanding of the GAB. The key findings are:

- The long-standing conceptualisation by Habermehl in (1980), which viewed the GAB as a single, large, contiguous groundwater flow system, does not adequately reflect the hydrogeological complexity that governs groundwater movement in the GAB.
- The advanced conceptualisation developed by the Assessment views the GAB as an extensive and complex groundwater basin, rather than a simple, laterally continuous aquifer. The GAB encompasses several geological basins that were deposited at different times in Earth's history, from 200 to 65 million years ago in the Jurassic and Cretaceous periods. These geological basins sit on top of deeper, older geological basins and in turn, have newer surface drainage divisions situated on top of them (e.g. the Lake Eyre and Murray-Darling river basins).
- An updated interpretation of the geology that has led to:
    - Reclassification of the hydrostratigraphy, by expanding the previously defined 'aquifers and aquitards' into five gradations. The new categories include 'aquifer, partial aquifers, leaky aquitards, tight aquitards and aquicludes'. These categories provide a better representation in the variability of

    physical properties associated with geological formations in the GAB and a consistent framework to evaluate groundwater resources.

    - Mapping of locations where underlying geological basins are connected with aquifers of the GAB. In areas where aquifers are connected, groundwater may move from one basin to another. Mapping these locations helps identify where development could impact the GAB or underlying basins.
    - Identification of the extent and thickness of overlying geological basins that were deposited in the Cenozoic Period from 65 million years ago to the present day. The Cenozoic deposits contain at least two significant features that influence the vertical connectivity between the GAB and shallow groundwater systems. These features include the development of additional confining layers to the GAB that potentially reduce vertical connections and the development of paleochannels, which create permeable pathways that potentially increase the vertical connections. The net effect of these features on the water budget of the GAB is unknown.
    - Formal recognition that polygonal faulting in the Rolling Downs Group – a thick sequence of aquitards and partial aquifers overlying the Cadna-owie – Hooray Aquifer and equivalents in the Central Eromanga Basin – has formed potential conduits for upward leakage from the artesian aquifers. The complete effect of polygonal faulting on the water budget of the GAB is unknown.
- The updated understanding of the geological framework has led to a more complex interpretation of the groundwater conditions of the GAB than has been previously shown, including:
    - Regional watertable maps. These provide a basis to evaluate relationships between groundwater recharge and discharge for non-artesian portions of the GAB, as well as a consistent data source to further investigate interaction between groundwater and surface water.
    - Maps of groundwater levels representing the Cadna-owie – Hooray Aquifer and equivalents that account for the potential impact of geological faults on groundwater flow patterns. The amount of vertical displacement from faulting is variable, but interpolation of groundwater levels where faults act as barriers to groundwater flow has led to a new perspective of groundwater conditions.
    - Identification of potential locations where cross-formation flow could be occurring in the GAB by comparing the groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents and regional watertable. Where groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents are greater than the watertable, there is a potential for upward vertical leakage. Where groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents are lower than the watertable, there is a potential for downward vertical leakage.
- Assessment of groundwater level maps for 20-year intervals beginning in 1900 clearly illustrates the decline in groundwater levels in the early part of the last century, but in the most recent decade (circa 2000 to 2010) an increase (recovery) of groundwater levels is evident from bore capping under the Great Artesian Basin Sustainability Initiative and previous government programs.
- Updating the geology and hydrogeology has led to revisions of the boundary of the GAB in the Coonamble Embayment, the western margin in South Australia and the Northern Territory and the western margin near the Gulf of Carpentaria.

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1 Introduction

1.1 Overview of the Assessment

The Great Artesian Basin (GAB) is one of the largest groundwater systems in the world and underlies arid and semi-arid regions in Queensland, New South Wales, South Australia and the Northern Territory (Figure 1.1). It is comprised of sedimentary rock layers that form aquifers and aquitards (confining layers) containing groundwater that is mostly under artesian conditions.

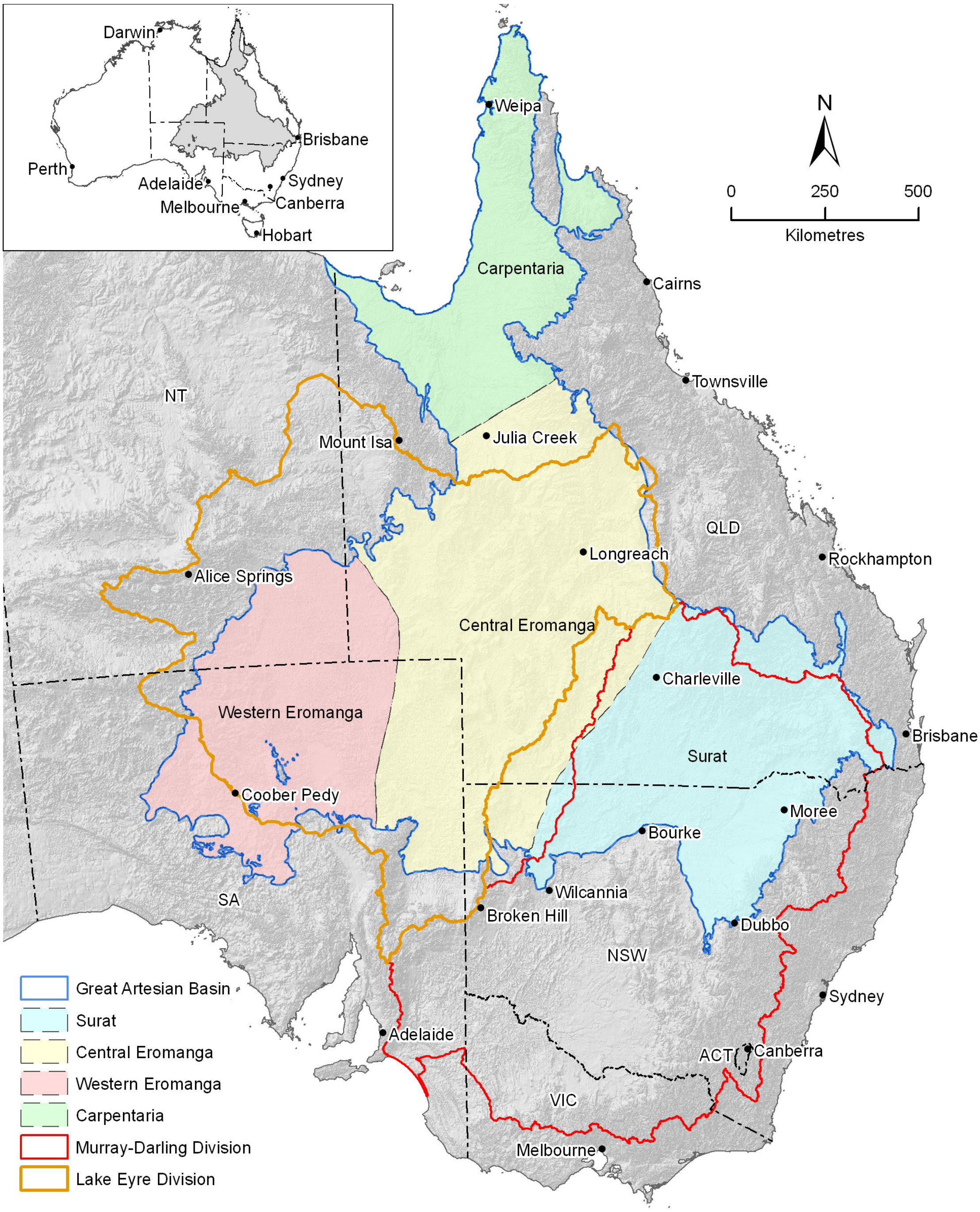

Figure 1.1 Geographic extent of the Great Artesian Basin, selected overlying surface water drainage divisions and reporting regions of the Assessment

Groundwater resources in the GAB support an extensive pastoral industry, inland population centres, mining activities, and other extractive industries – and demand for these resources is increasing. The consequent management issues require a better understanding of how the whole groundwater system operates. Thus an integrated reappraisal of the latest hydrogeology, hydrochemistry and groundwater modelling is timely.

Such a reappraisal was the aim of the Great Artesian Basin Water Resource Assessment (the Assessment). The latest geological and hydrogeological information was assessed to develop an updated description of the GAB, and provide a basis for water policy and water resources planning. The Assessment outlines the current status of groundwater resources in the GAB and the potential impacts of climate change and resource development on those water resources.

The Assessment built on the approach taken by CSIRO and partners for the Murray-Darling Basin, South-West Western Australia, Northern Australia, and Tasmania Sustainable Yields projects. Consistent with these projects, the Assessment provides an analytical framework to assist water managers in the GAB to meet National Water Initiative (NWI) commitments.

1.1.1 Reporting the findings of the Assessment

Reporting of the Assessment is covered by a range of products including four region reports, a whole-of-GAB report (this report) and a number of detailed technical reports. The region reports are aligned with major geological basins, as identified in Figure 1.1, and cover all aspects of the Assessment for each region. This whole-of-GAB report and the region reports are intended for an audience with some policy or scientific background who are interested in the management of water resources. The region reports are summarised in four 16-page summaries intended for a general audience. Similarly, the whole-of-GAB report is summarised in a 12-page synthesis for a general audience.

In addition to the region and summary reports, for those wanting more scientific detail, a series of technical reports contain further information about the following:

- A review of groundwater models for the GAB (Smith and Welsh, 2011).
- Advancement of the conceptual understanding of the GAB, including the geology, hydrostratigraphy, hydrogeology, and hydrodynamics (Ransley and Smerdon, 2012).
- Groundwater modelling to assess the impact of projected climate and groundwater development in the GAB (Welsh et al., 2012a).
- A review of groundwater-dependent ecosystems in the GAB and potential risk from climate change and groundwater development (Miles et al., 2012).

In addition to these technical reports, there are scientific reports describing the development of a three-dimensional computer generated visualisation of the GAB, a lexicon of geological formations of the GAB, and data collected for the Assessment. A list of reports produced by the Assessment is contained in Appendix A.

1.1.2 Approach of the Assessment

The approach of the Assessment included updating the three-dimensional (3D) hydrogeological framework for the GAB, investigation of groundwater conditions (groundwater levels and movement into and out of the GAB), and assessment of the potential impacts of climate change and development regimes on groundwater resources. Considering that groundwater is the primary water resource in the GAB, the Assessment focused on groundwater systems, and surface water was only addressed in terms of interaction with groundwater systems.

The potential impacts of climate change and groundwater development, and subsequent risks to springs of the GAB, was completed in parallel with updating the 3D hydrogeological framework and groundwater conditions. Various scenarios of climate change and groundwater development were investigated by groundwater modelling, the majority of which was completed using an existing model of the GAB (GABtran; (Welsh, 2006)). This model does not include any of the complexities discovered in the updated 3D hydrogeological framework, but has been shown to represent broad scale change in groundwater levels for the GAB. The findings related to impacts of climate change and groundwater development, and the uncertainty in model results, are presented in the four region reports listed in Appendix A and the technical reports by Welsh et al. (2012a) and Miles et al. (2012).

The Assessment focused on the aquifers of the Jurassic and Cretaceous periods, which comprise the majority of the GAB and are present across its entirety (extent shown in Figure 1.1). The aquifers are mostly contained within the Cadna-owie Formation, the Hooray Sandstone, the Pilliga Sandstone, and the Gilbert River Formation. Collectively, these are referred to as the Cadna-owie – Hooray Aquifer and equivalent formations, or 'Cadna-owie – Hooray Aquifer and equivalents' in this report. In some places, the Jurassic and Cretaceous aquifers are connected with adjacent groundwater systems or underlying geological formations of older geological periods. For this reason, defining a groundwater basin boundary is generally more complicated than defining a boundary for a surface water drainage division (e.g. the Lake Eyre or Murray-Darling river basins) because it requires interpretation of the geological formations.

1.1.3 Structure of this report

Advancing the conceptual understanding of the GAB requires careful evaluation of the geological framework (i.e. the layers of rock), description of how the geology translates into hydrostratigraphy (i.e. the relative ability of specific layers to store and transmit water) and investigation of the groundwater conditions (i.e. watertable, groundwater levels, and inferred movement). Just as the study of geology attempts to unravel the history and understand the structure of geological rock systems, the study of hydrogeology focuses on movement of water through these complex geological formations and structures. To help explain the updated view of the GAB developed by the Assessment, this report presents some existing information combined with new information and new interpretations of existing information.

This report focuses on the findings of the Assessment related to the geology, hydrostratigraphy, hydrogeology and advancing the conceptual understanding of the GAB. The conceptual understanding of the GAB is the framework to assess water availability and provide guidance to water policy and water resource planning in the GAB. The structure of the report is as follows:

- Chapter 1 provides an overview of the Assessment and definition of the GAB.
- Chapter 2 presents the findings of groundwater modelling to estimate the impact of climate and groundwater development on groundwater levels in the GAB by 2070 and the risks to springs.
- Chapter 3 summarises the updated geology of the GAB, the hydrostratigraphic framework and major hydrogeological characteristics.
- Chapter 4 describes groundwater conditions including maps of the watertable, groundwater levels in the primary GAB aquifers, and hydrochemical trends.
- Chapter 5 presents findings from the Assessment related to the boundary of the GAB and water budget.

The advanced conceptualisation of the GAB described in this report captures the available knowledge and information and provides an interpretation of the GAB to be used in subsequent analyses, such as for groundwater modelling.

1.2 Definition of the Great Artesian Basin

The GAB is a complex groundwater system that is difficult to visualise and challenging to describe. To help describe the GAB, this report uses scientific terms that may be unfamiliar to some readers – for definitions of these terms, refer to 'Terms and concepts' at the back of the report.

The GAB is defined as a groundwater basin, encompassing several geological basins that were deposited at different times in Earth's history, ranging from 200 to 65 million years old, during the Jurassic and Cretaceous periods. These geological basins sit on top of deeper, older geological basins (Figure 1.2) and in turn, have newer surface drainage divisions situated on top of them (e.g. the Lake Eyre and Murray-Darling river basins).

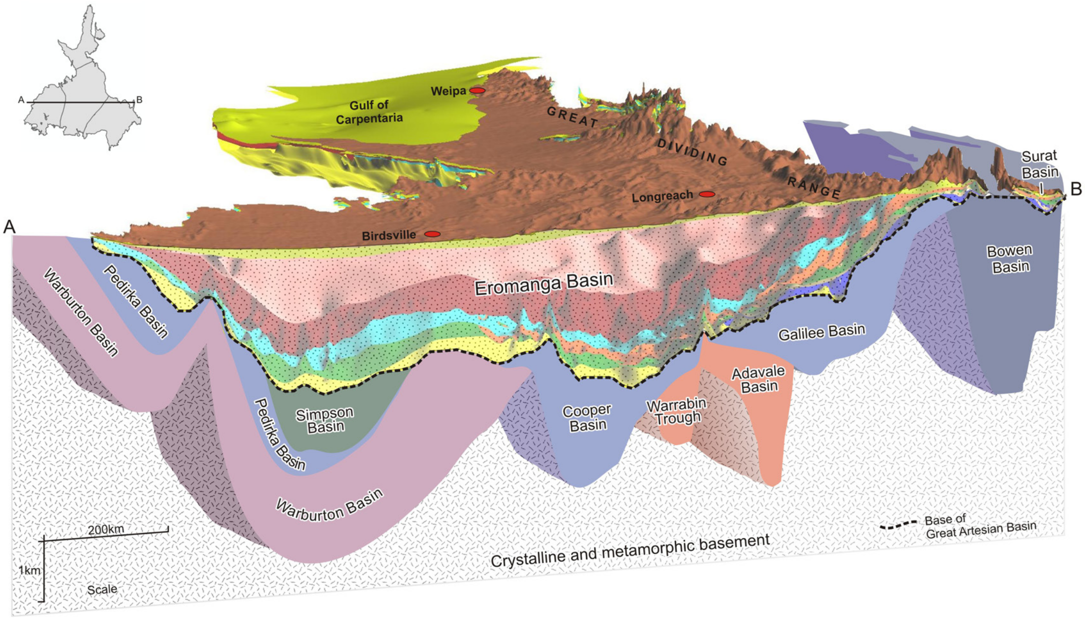

Figure 1.2 Three-dimensional illustration of a slice through the Great Artesian Basin (GAB).
Note: This diagram shows aquifer layers of the GAB and underlying geological basins. Because the GAB is a groundwater entity, some of the GAB aquifers may be in contact with groundwater in underlying basins

The present day topography of the GAB is dominated by low-lying interior plains, bounded to the east by the tablelands and uplands of the Great Dividing Range, and to the west by highlands and plateaus. The ground surface generally slopes toward a depression near Lake Eyre (Figure 1.3). Along the eastern margin, the Great Dividing Range forms a swathe of high ground, reaching elevations up to 900 mAHD. Along the western margin, the Flinders, Gawler and Stuart ranges also form highland areas. At the margins of the GAB, some of the geological formations that form aquifers in the GAB are exposed. Along these margins – referred to as the 'intake beds' – are locations of groundwater recharge for the GAB (Figure 1.4). The Assessment has found that the exposure of two additional overlying geological formations is important for groundwater recharge. These include the Cenozoic aquifers in the Carpentaria region and Winton Formation in the Central Eromanga region (see 5.3.2).

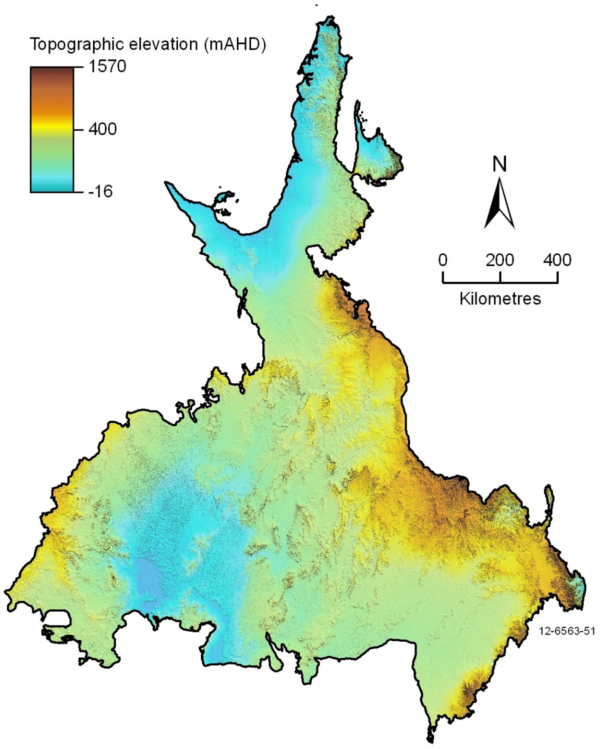

Figure 1.3 Ground surface topography across the Great Artesian Basin

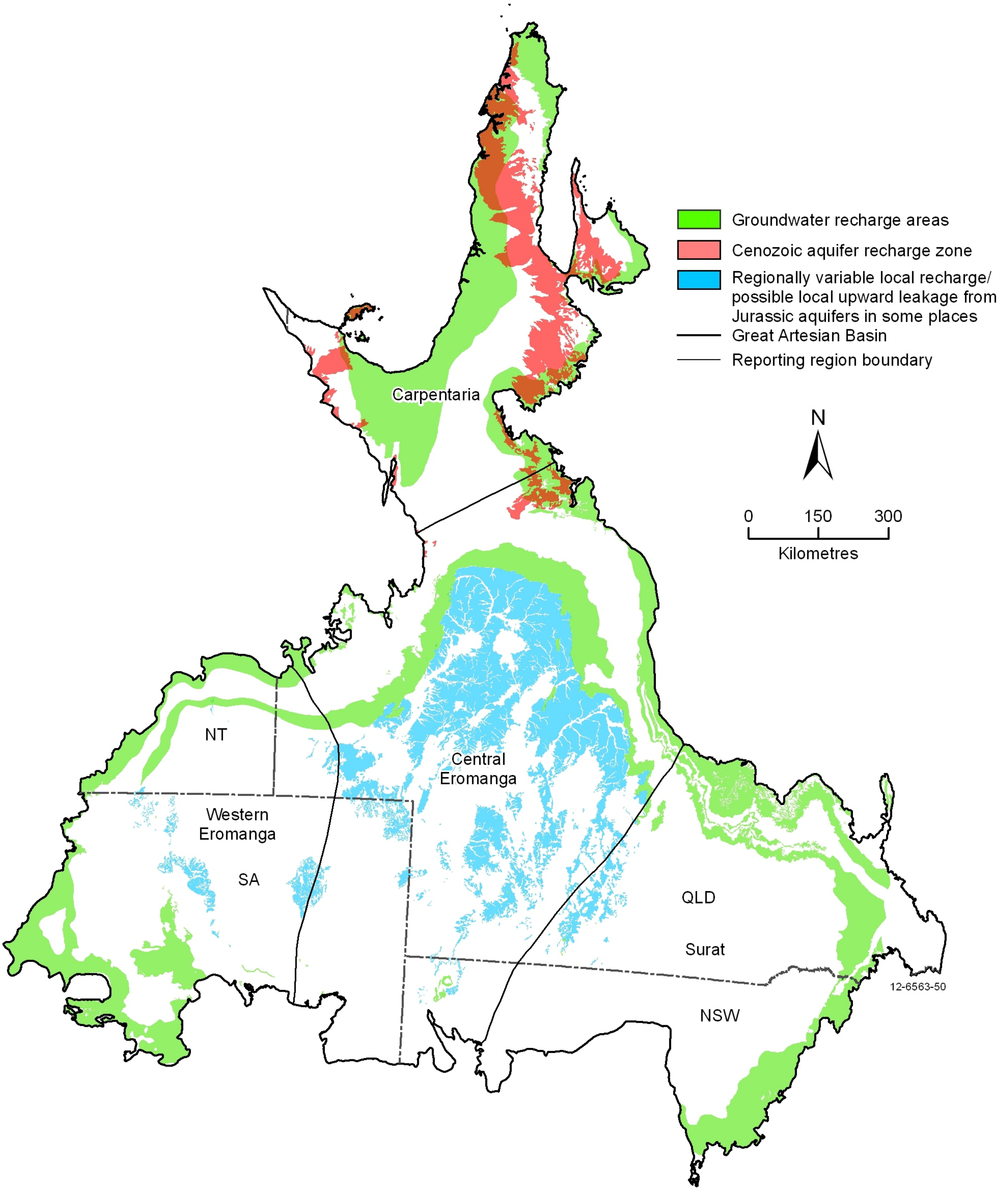

Figure 1.4 Areas of groundwater recharge across the Great Artesian Basin
Note: Cenozoic aquifer recharge zones are only shown for the Carpentaria region to recognise the importance of overlying regional aquifers in this area. Similarly, exposure of the overlying Winton Formation is shown as a regionally variable recharge zone. As a consequence of recent work on the western margin the recharge areas in the Western Eromanga region have subsequently been modified in South Australia and in the Northern Territory

1.3 A brief history of understanding of the Great Artesian Basin

A brief history of the understanding is described here to illustrate the evolution of knowledge for this vast groundwater resource. A more complete history is provided in the companion technical report on the hydrostratigraphy, hydrogeology and system conceptualisation of the Great Artesian Basin (Kellett and Radke, 2012).

The GAB is a significant water resource in the arid inland areas of Australia. The springs of the GAB provided an essential water resource for the survival of the Aboriginal people who inhabited inland Australia. In the 1800s, the European explorers and settlers of Australia used the springs to help them 'open up' the inland. The reliance on springs as a water resource provided a means by which early explorers could navigate the unexplored inland. Springs extend across the diverse landscape of the GAB – from the wet/dry tropics in the north to the arid landscape in the south-western inland areas; springs occur mostly around the margin of the GAB and cluster into major regional supergroups (Fensham and Fairfax, 2003; Fensham et al., 2010; Habermehl, 1982; Habermehl and Lau, 1997) (Figure 1.5).

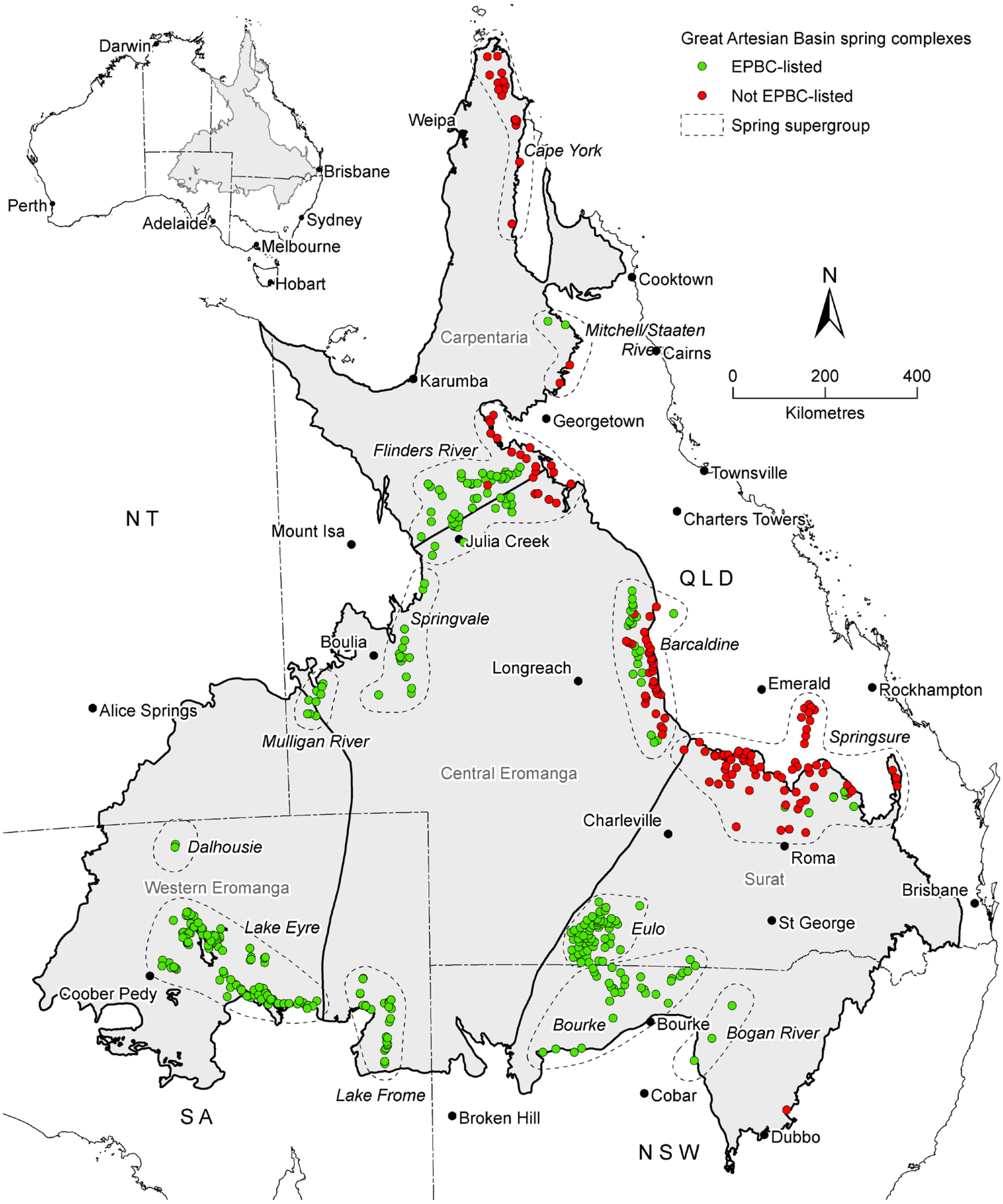

Figure 1.5 Springs of the Great Artesian Basin, clustered into major regional supergroups

Note: map shows listing status of springs under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

Since the late 1800s there has been an evolution of knowledge about the GAB. The nature of the GAB and its hydrogeological characteristics has been progressively studied since the discovery of artesian water in the late 19th century. The first artesian bore in Australia was sunk at Kallara Station in north-western New South Wales in 1878. By the early 20th century, over 1500 flowing artesian bores had been established and the basic shape and characteristics of the GAB were understood. Interpretations of the origin and movement of these artesian waters were continuously debated during the following decades.

While there were several technical reports about the nature of the GAB in early 1900s, Audibert (1976) first recognised that the multilayered aquifers of the GAB did not conform to a simple ‘layer cake’ reservoir system, but rather that aquifers in the Triassic, Jurassic, and early Cretaceous age formations are all somewhat hydraulically interconnected in some parts of the GAB. The GAB was envisaged by Audibert (1976) as a closed system with a topographic low (sink) beneath sea level, so that groundwater could only escape vertically. The mapping of groundwater levels in sub-artesian and artesian aquifers by Audibert (1976) led to the concept that groundwater in the GAB was controlled by vertical (upward) leakage rather than lateral movement over great distances. It was postulated that prominent south-southwest drainage lines observed in the watertable coincided with structural features and likely indicated where prominent upward leakage occurred.

Audibert’s publication was followed by a benchmark review of the GAB (Habermehl, 1980) that developed the simplified concept of lateral throughflow within the artesian aquifers. Habermehl (1980) conceptualised the GAB as a single, large, contiguous groundwater flow system in which aquifers were considered to be laterally continuous across the extent of the entire GAB. In this conceptualisation, groundwater enters the GAB as infiltrating rainwater or surface waters along the margins. Groundwater flow is primarily driven by gravity toward discharge zones in the south-western corner of the GAB and consequently a steady aging of groundwater is expected along definable flow paths. Mixing of groundwater of different origins is considered simple and largely occurring where groundwater converges to a discharge location; interaction with groundwater from other basins is considered limited. This conceptualisation by Habermehl (1980) has been long-standing and forms the basis for many water management plans.

Since the description by Habermehl (1980), there have been numerous studies that have attempted to interpret groundwater flow rates by determining the age of groundwater (Bentley et al., 1986; Collerson et al., 1988; Love et al., 2000; Torgersen et al., 1991) and identifying trends in hydrochemistry (Radke et al., 2000). These studies have revealed a more complex conceptualisation of the GAB than had been previously described. These studies indicate that deeper regions of the GAB contain water that is relatively stagnant, and that preferential flow paths of younger water occur in shallower regions. More recent studies have focused on a better understanding of groundwater recharge (Habermehl et al., 2009; Kellett et al., 2003; Love et al., 2000) to inform groundwater resource management.

Modelling of groundwater flow in GAB aquifers began in the 1970s for the purposes of assessing water resources and predicting environmental impacts of development. A total of four whole-of-GAB models and 18 notable part-GAB models have been developed and are described in the companion technical report about groundwater models (Smith and Welsh, 2011). The evolution of groundwater models of the GAB provides an approach for assimilating data and advancing the conceptualisation of the groundwater system.

2 The effect of future climate and groundwater development

2.1 Modelling groundwater levels from 2010 to 2070

An existing large-scale groundwater model was used to estimate the impact of climate and development on groundwater levels in the Great Artesian Basin (GAB) by 2070. The complete findings related to impacts of climate change and groundwater development, and the uncertainty and limitations in model results are presented in the four region reports listed in Appendix A and the technical reports by Welsh et al. (2012a) and Miles et al. (2012).

The model was originally developed for the Great Artesian Basin Sustainability Initiative (GABSI) in 2006 and simulates groundwater levels in the Cadna-owie – Hooray Aquifer as a single layer spanning the majority of the GAB (GABtran; (Welsh, 2006). The existing large-scale model did not cover Cape York Peninsula, so an additional model was developed for this area. Both of these models use the conceptualisation by Habermehl (1980) and do not include any of the geological complexities discovered by the Assessment. These are the only models to consider the main aquifers across the GAB and that have been shown to represent the change in groundwater levels at such a large scale.

The modelling considered different scenarios of climate and groundwater development. The future climate scenario included a change in rainfall and evaporation, which would produce different groundwater recharge rates occurring at the intake beds in 2070. The future groundwater development scenarios included consideration of changing rates in groundwater extraction, including reductions in extraction due to bore rehabilitation under the GABSI. The modelling scenarios included:

- Scenario A (historical climate and current development)
- Scenario C (future climate and current development)
- Scenario D (future climate and future development).

The future scenarios included the wet extreme, median and dry extreme future climates (i.e. scenarios Cwet, Cmid, Cdry, Dwet, Dmid and Ddry). These future climate scenarios included existing groundwater recharge rates spanning between an average of 36 percent lower under the dry extreme climate and an average of 55 percent higher under the wet extreme climate across the GAB. In addition to the future climate with current (circa 2010) groundwater development, consideration was given to a scenario of future climate with future development, which was created by changing the rates of groundwater extraction.

Figure 2.1 shows the change in groundwater levels under the scenario with median future climate and current groundwater development relative to historical climate and current groundwater development. Under current groundwater development, GASBI and previous government programs had achieved approximately 75 percent of the total expected groundwater savings, and it is assumed that GABSI had been concluded in 2010. Under median future climate scenarios with current groundwater development, it is estimated that groundwater extraction will exceed replenishment in most of the south and west of the Eromanga Basin and in a wide arc along the eastern recharge areas of the north part of the Surat Basin. In the south-east part of the Surat Basin and north part of the Central Eromanga Basin, groundwater levels are estimated to increase due to recharge exceeding groundwater use.

Figure 2.2 shows the change in groundwater levels under the scenario with median future climate and future groundwater development relative to median future climate and continuation of current groundwater development. Under future groundwater development, GABSI is assumed to run to full completion, achieving 100 percent of the total expected groundwater savings. It is estimated that groundwater extraction will exceed replenishment over most of the GAB except where bore densities are high around the Euroka Arch and the Nebine Ridge, and assuming GABSI continues to completion and that all eligible artesian bores remaining to be controlled at 2010 are controlled.

The modelled estimates of groundwater levels are sensitive to rates of groundwater recharge and groundwater extraction. The key difference between Figure 2.1 and Figure 2.2 is attributed to 25 percent of the total expected groundwater savings under GABSI.

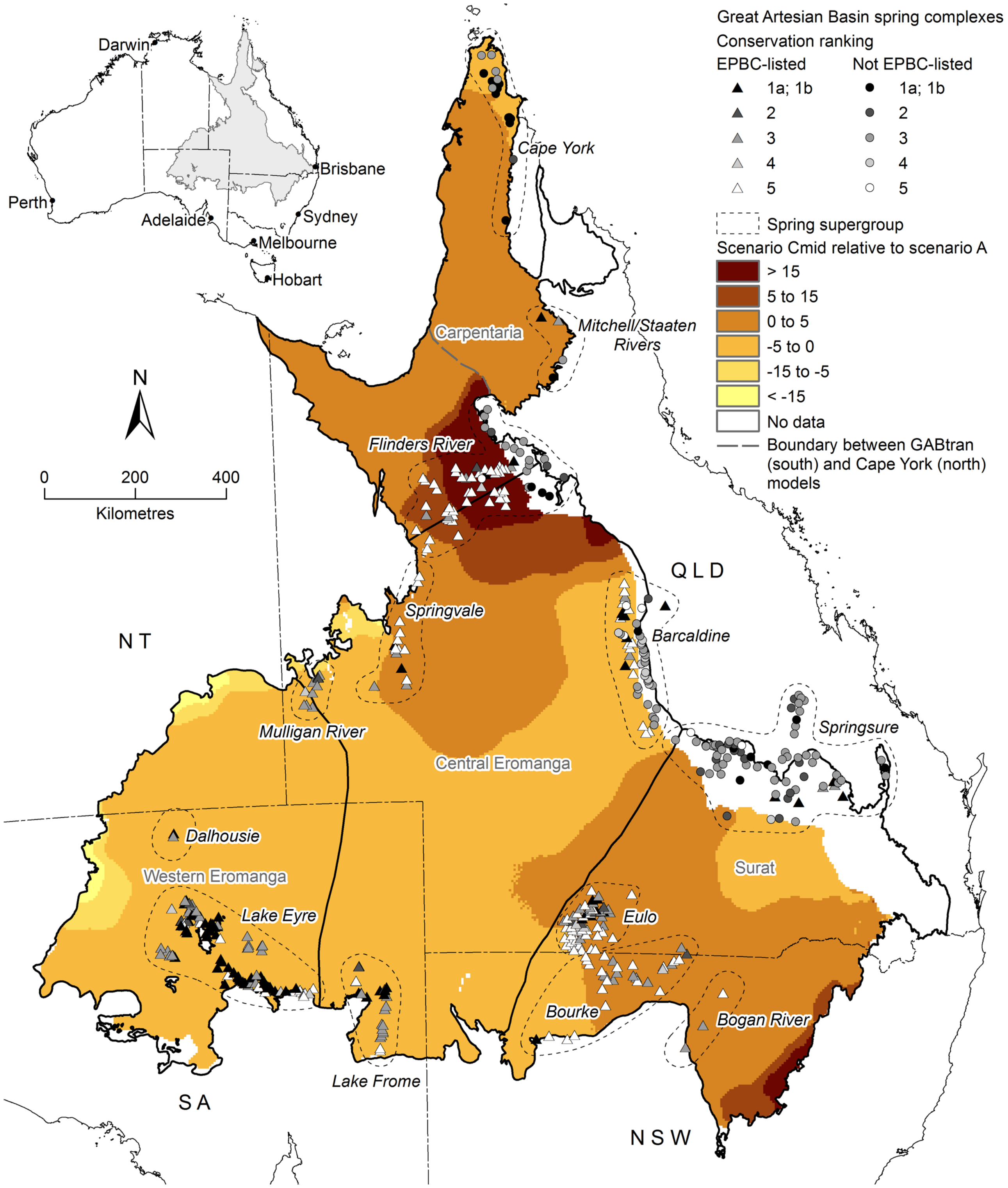

Figure 2.1 The impact of future climate on groundwater levels in the Great Artesian Basin. This figure shows change in groundwater levels under median future climate and continuation of current groundwater development relative to historical climate and current groundwater development.

The conservation rankings for spring complexes within each supergroup are used to establish risk to the springs. For example, spring complexes with a high ranking in an area of groundwater decline could be at greater risk

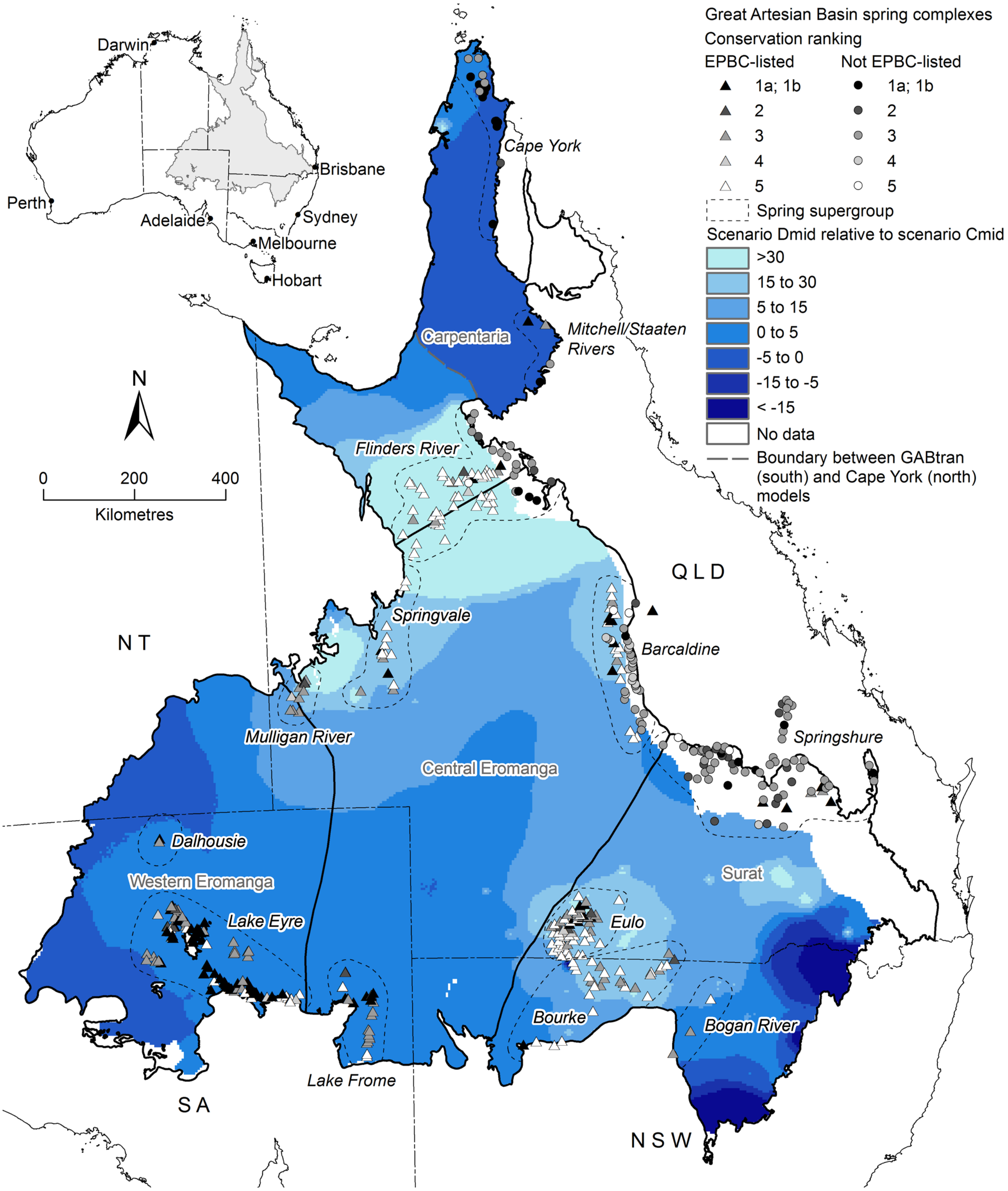

Figure 2.2 The impact of future groundwater development on groundwater levels in the Great Artesian Basin. This figure shows change in groundwater levels under median future climate and future groundwater development relative to median future climate and continuation of current groundwater development. Under future development the GABSI program is assumed to run to full completion whereby all eligible uncontrolled artesian bores are controlled. The conservation rankings for spring complexes within each supergroup are used to establish risk to the springs. For example, spring complexes with a high ranking in an area of groundwater decline could be at greater risk

2.1.1 Modelling the effect of coal seam gas development

The large-scale groundwater model was suitable for estimating the effects of future climate and development across the GAB (Figure 2.3) but not the effects of groundwater extraction related to coal seam gas (CSG) development. CSG development requires extracting groundwater to release gas from the coal. These groundwater extractions occur in different geological formations than are represented in the large-scale groundwater model. For the Surat region, a partnership with the Queensland Water Commission (QWC) was established to use results from the existing groundwater flow model developed by the QWC (Figure 2.3) for assessing the impact of future CSG development.

The groundwater model developed by QWC covers part of the Surat region. Rather than simulating groundwater levels in the Cadna-owie – Hooray Aquifer as a single layer, the QWC model has multiple layers to represent different rock layers in the Surat region. The groundwater extraction for CSG occurs in the Walloon Coal Measures. Impacts on other layers from CSG-related development are likely to occur by changes to the rate of groundwater movement between different layers (vertical leakage), which will cause changes in groundwater levels where groundwater is extracted and in layers above and below. To compare the results of the QWC modelling with those of the large-scale model, the layer representing the Gubberamunda Sandstone was selected, as it is equivalent to the single layer of the large-scale model.

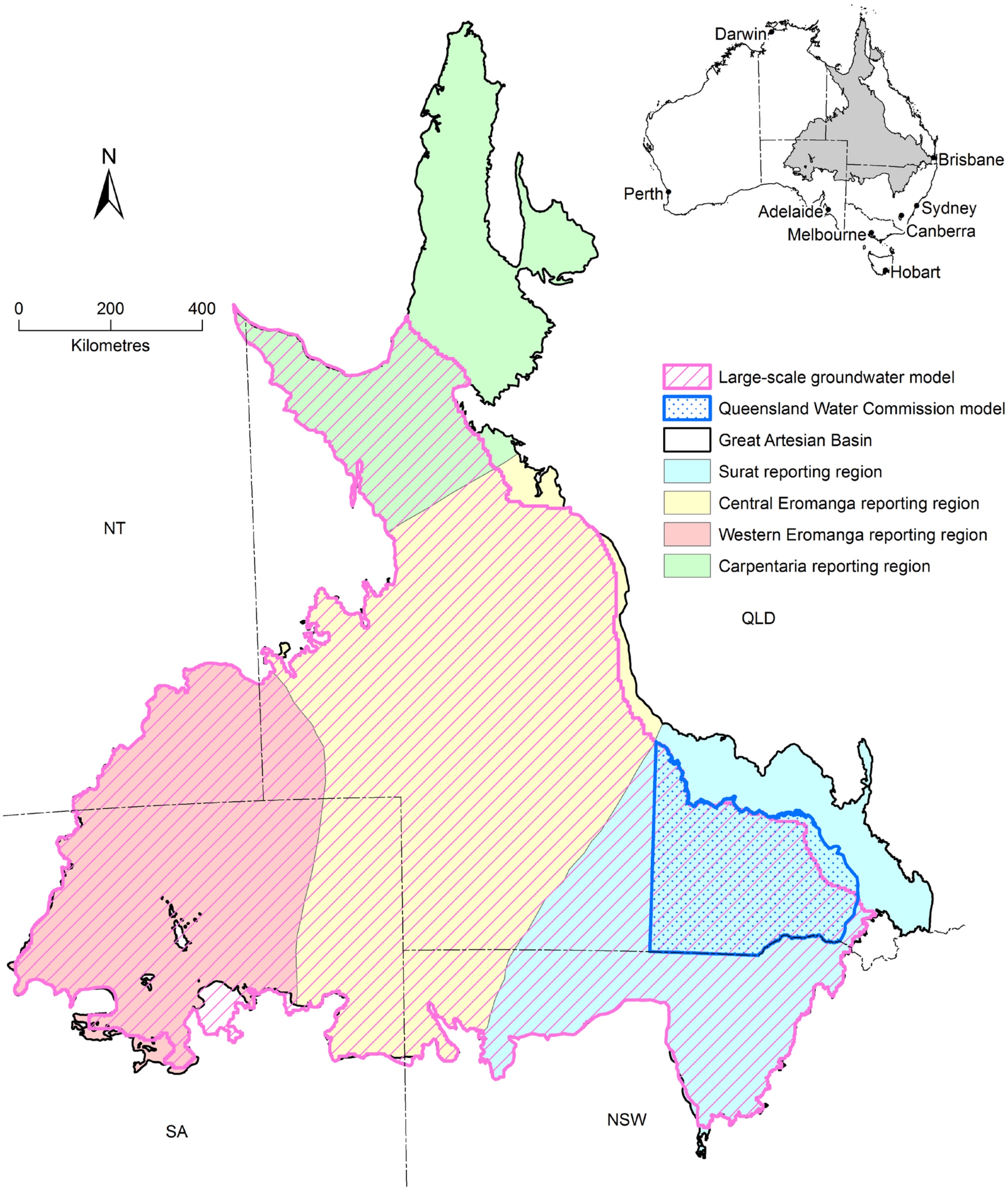

Figure 2.3 Extent of the large-scale groundwater model and the equivalent layer (Gubberamunda Sandstone) in the groundwater model developed by the Queensland Water Commission

CSG development is expected to cease by 2050, so groundwater extraction for CSG development reduces to zero before 2070. In the Gubberamunda Sandstone, the estimated change in groundwater levels is less than 0.2 metres lower across the modelled area (Figure 2.4). The combined effect of all future groundwater development, which includes reduction in extraction due to bore rehabilitation under GABSI and increased extractions related to CSG development, are shown in Figure 2.5. Compared to the increase in groundwater levels resulting from GABSI running to full completion, whereby all eligible uncontrolled artesian bores are controlled, the estimated decrease in groundwater levels from CSG development is relatively small.

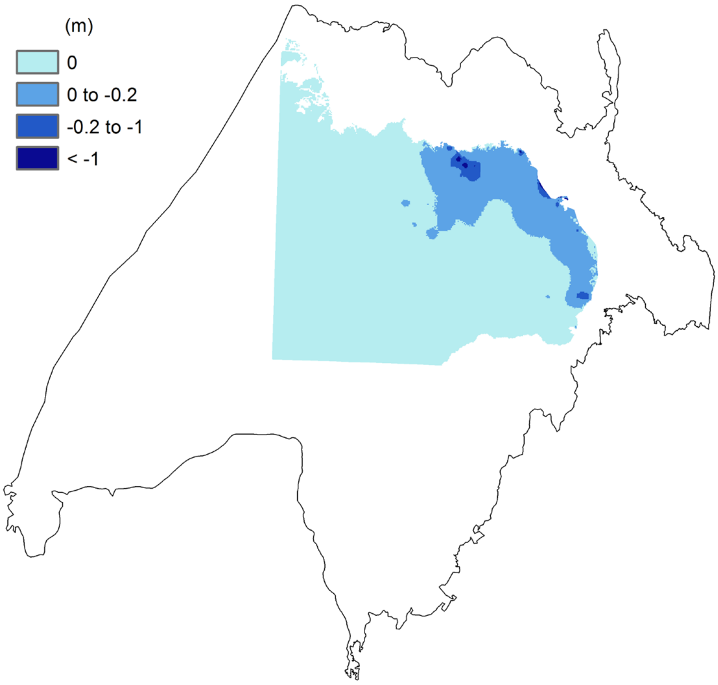

Figure 2.4 Change in groundwater levels at 2075 in the Gubberamunda Sandstone due to coal seam gas development alone

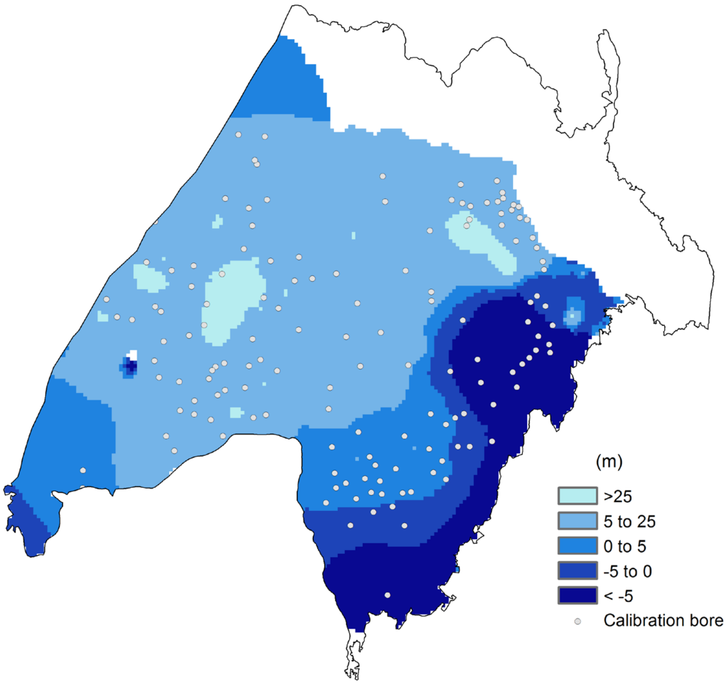

Figure 2.5 Change in groundwater levels at about 2070 due to water bores, petroleum wells, springs and coal seam gas development in the Cadna-owie – Hooray and equivalents

2.2 Impact on Great Artesian Basin springs

The risks and opportunities to GAB springs under future climate and groundwater development scenarios were assessed at the whole-of-GAB scale. The likelihood of a spring flow reduction or increase occurring due to projected changes in groundwater level is based on the magnitude of the predicted change. The greater the projected decline, the greater the likelihood that flow will be reduced and the greater the risk that the ecological values of artesian GAB springs will be reduced. Conversely, the greater the projected rise in groundwater level, the greater the likelihood that flow to artesian GAB springs will be increased and the greater the opportunity that ecological values of the artesian GAB springs will be recovered.

The conservation ranking of springs was used to assess the consequence of changes in spring flow, with the highest conservation ranked springs assumed most likely to suffer from reduced groundwater levels and most likely to benefit from increased groundwater levels. Using the framework, the risks and opportunities to GAB spring values under future climate and groundwater development scenarios were assessed at the whole-of-GAB scale. The Assessment was unable to determine categories of risk and opportunity for many springs along the north-eastern margin of the GAB as they are located outside of the modelled boundaries.

Under median future climate and current groundwater development (Figure 2.1), an increase in groundwater levels in the north-eastern part of the GAB could re-activate spring complexes that were previously inactive. In the south-eastern part of the GAB, many of the spring complexes are currently inactive, so a further decline in groundwater levels will not lead to a higher risk. Groundwater levels in the western part of the GAB are likely to decline and the spring complexes are rated as a high risk. For spring complexes in the northern part of the Carpentaria region, future groundwater levels are similar to current conditions, so risks and opportunities are largely unchanged.

Under median future climate and future groundwater development (Figure 2.2), the level of risk and opportunity for springs in the western GAB (Lake Frome, Lake Eyre and Dalhousie supergroups) is high and all springs have a low opportunity for recovery. For springs in other parts of the GAB there is a shift to a reduction in the risk likelihood and an increase in opportunity for recovery ranking for springs. There is an increased opportunity for recovery of ecological values for springs in the Eulo, Bourke, Flinders River, Barcaldine, Springvale and Mulligan River supergroups. The greatest change is the number of springs that change from low opportunity to medium opportunity under future climate and future groundwater development. This is largely due to the likely recovery in groundwater levels in the vicinity of the Eulo and Bourke supergroups as a result of estimated future bore rehabilitations that improve water use efficiency, such as are currently supported by the GABSI program. This also includes springs in the Barcaldine and Flinders River supergroups that are currently not flowing (conservation ranking 5) but for which rises in groundwater levels are projected. However, with the current level of data and knowledge, it is not possible to assess whether this will be sufficient to return flow to any of these springs.

3 Geology and hydrogeology

3.1 Geological framework

The aquifers of the Great Artesian Basin (GAB) are composed predominantly of sandstones, and confined by aquitards of mudstone and siltstone of Jurassic and Cretaceous age (200 to 65 million years). The GAB is stratigraphically bounded above and below by major unconformities (periods of erosion and no deposition). A Late Triassic unconformity (250 to 200 million years) defines the base of the GAB and a Middle to Late Cretaceous unconformity (90 to 65 million years) defines the top.

The geological basins within the GAB – Eromanga, Surat, Clarence-Moreton, and Carpentaria – share a similar depositional history and tectonic evolution. However, slight differences in the rates of subsidence and deposition are caused by structures inherited from older, underlying basins, especially in the Eromanga and Surat basins. These structural elements create the shape of depression and ridges that are the foundation for the hydrogeological basin observed today (Figure 3.1). A thorough description of the geology of the GAB is provided in two companion technical reports (Kellett and Radke, 2012; Radke and Kellett, 2012).

The deepest part of the Eromanga Basin aligns north-east to south-west, overlying the Cooper, Warrabin and Adavale basins. The central portion of the Eromanga Basin has many geological structures. The Birdsville Track Ridge is a broad saddle that extends in a north-east to south-southwest direction, separating the central portion of the Eromanga Basin from the Poolowanna Trough to the west. The Eulo and Nebine ridges separate the central portion of the Eromanga Basin and all of the Surat Basin. To the north of the deepest part of the Eromanga Basin, the underlying formations rise toward the ground surface, creating the Euroka Arch. All of these ridges provide structural boundaries within the GAB, although the Jurassic and Cretaceous age formations are geologically connected across these boundaries.

In the Surat Basin, the north-south Mimosa Syncline is aligned with the underlying Bowen Basin and extends south to the eastern portion of the Coonamble Embayment. West of the deepest part of the Surat Basin, the base of the Jurassic and Cretaceous age formations rises toward the ground surface in the vicinity of the Eulo and Nebine ridges. The Coonamble Embayment contains the Pilliga Sandstone, which is equivalent to the Cadna-owie – Hooray Aquifer for the purposes of the Assessment. The Clarence-Moreton Basin is generally separated from the Surat Basin by the north-south aligned Kumbarilla Ridge. East of the Kumbarilla Ridge is a complex series of broad ridges and troughs where the Jurassic and Cretaceous age formations of the GAB continuously extend in to the Clarence-Moreton Basin.

In the Gulf of Carpentaria, the Jurassic–Cretaceous Carpentaria and Laura basins are shallow and broad. Both basins become deeper and thicker to the north and extend offshore. The Carpentaria Basin adjoins and is continuous with the Eromanga Basin over the Euroka Arch. The onshore Carpentaria Basin has weak geological connection eastwards over the Kimba Arch with the Laura Basin. However, the Laura Basin is hydrogeologically independent from the Carpentaria Basin.

Significant geological forces have folded and disrupted the sedimentary layering in the GAB. Continental-scale stresses and the movement of large landmasses – referred to as tectonic activity – have reactivated pre-existing faults located in the basement rocks below the GAB. This tectonic activity has shifted the layering and the main artesian aquifers and aquitards of the Central Eromanga Basin have been structurally compromised. In comparison to the composite thickness of the Cadna-owie – Hooray Aquifer and equivalents, the scale of regional tectonic fault displacements infers the complete disruption of continuity in the aquifers locally along these features (Figure 3.2). Where an aquifer becomes disconnected across a fault with a large displacement, lateral groundwater flow in the aquifer meets a barrier. In some locations the regional tectonic fault may extend across many layers and potentially provide a vertical conduit for groundwater to flow upward to overlying aquifers and the surface (Figure 3.2). The effect of regional tectonic faults on groundwater flow in the GAB is not fully understood. Given the widespread deformation within this central part of the GAB, regional tectonic faults are assumed to be a significant impediment to regional lateral groundwater flow. In locations were regional tectonic faults form barriers to groundwater flow, unexpected changes in groundwater levels could occur as a result of groundwater development.

In addition to the regional tectonic faults, a different style of faulting has also disrupted the Rolling Downs Group – a thick sequence of aquitards and partial aquifers overlying the Cadna-owie – Hooray Aquifer and equivalents. Referred to as polygonal faulting, this secondary faulting style has a distinctive surface expression of discrete polygonal shaped areas. Polygonal faults are unique to clay-rich formations such as those in the Rolling Downs Group and faulting is caused by lateral extension. The polygonal faults also form potential conduits for upward leakage from the artesian Cadna-owie – Hooray Aquifer and equivalents (Figure 3.2). The combined presence of regional tectonic faults across GAB aquifers and polygonal faults across GAB aquitards influences patterns of groundwater flow, which will have a role in the water budget (recharge and discharge) for the GAB.

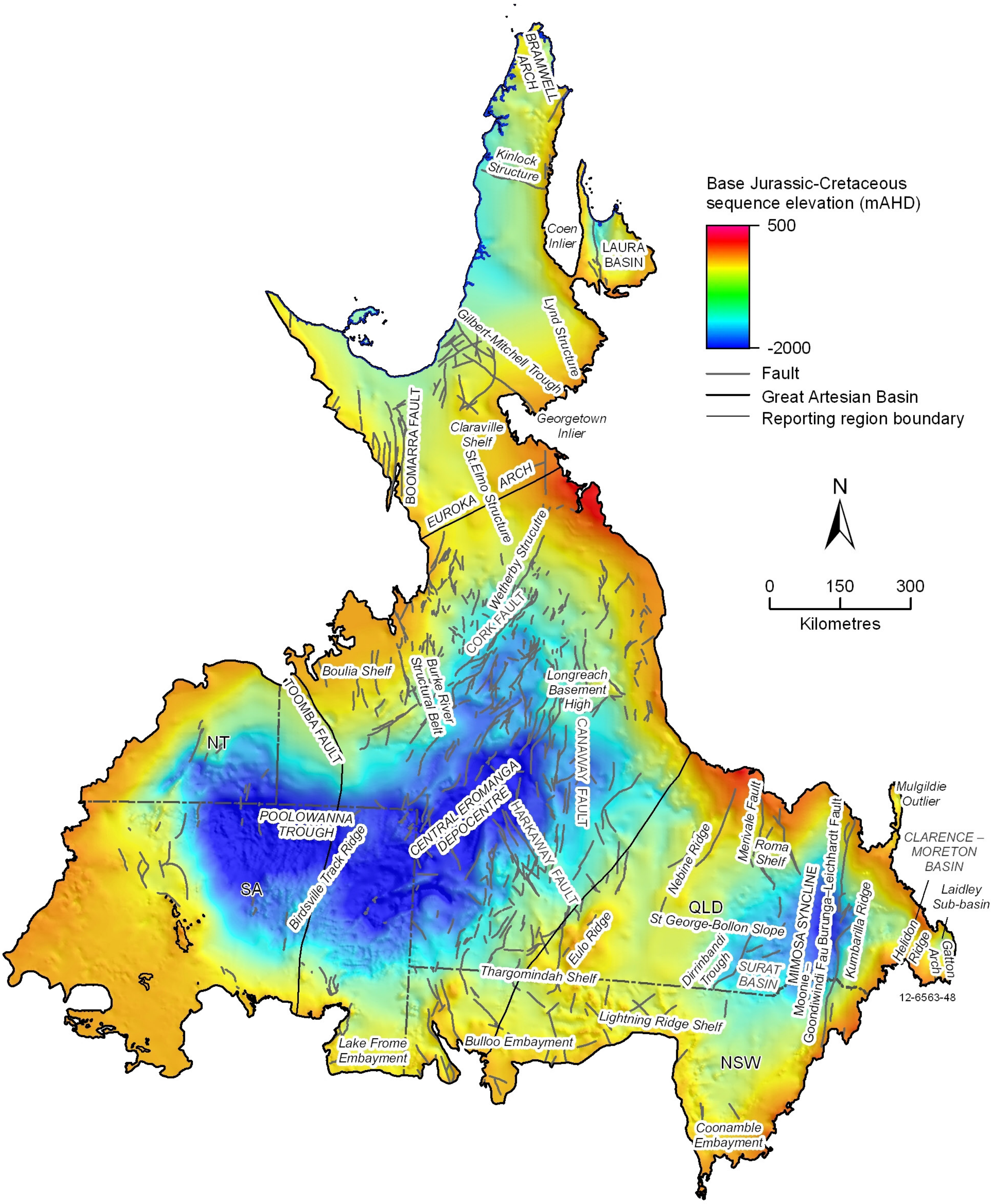

Figure 3.1 Basement elevation of the Great Artesian Basin with structural elements of the Eromanga, Carpentaria, Surat and Clarence-Moreton basins

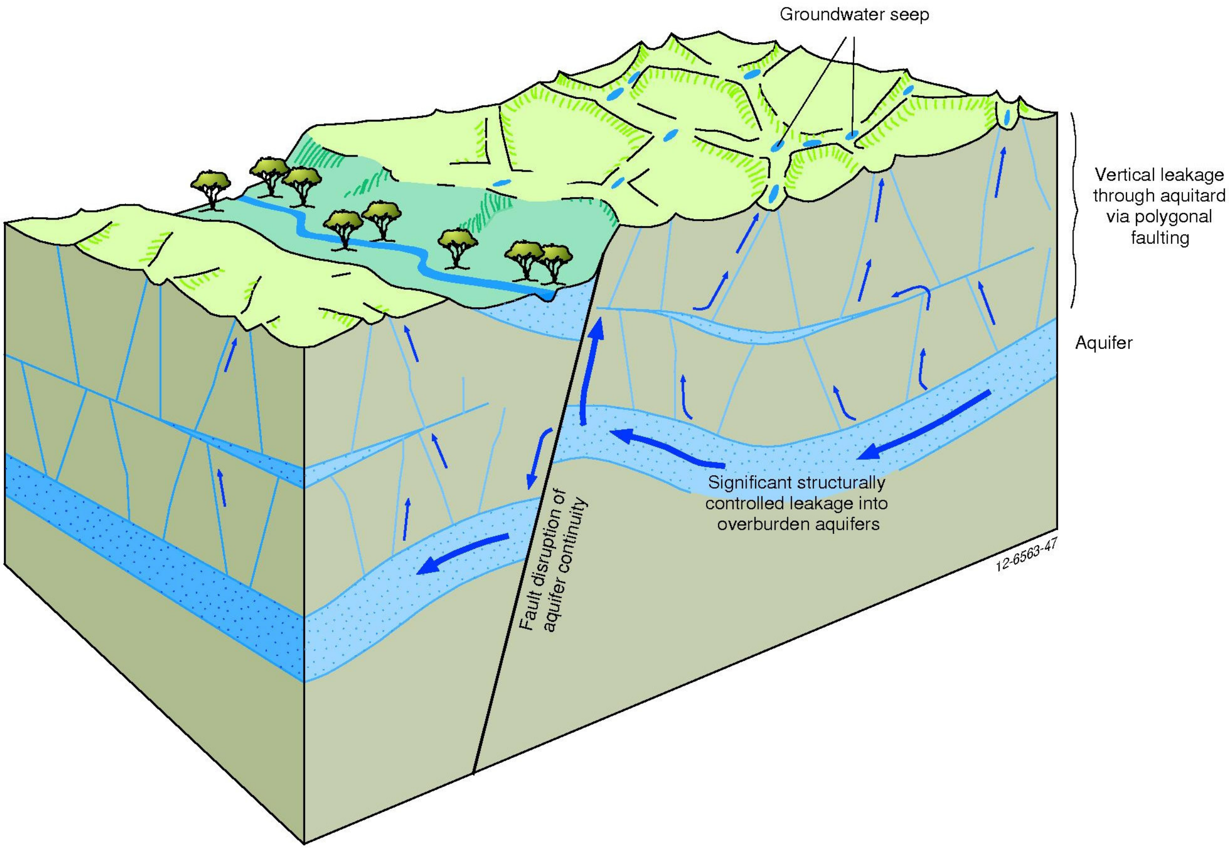

Figure 3.2 Vertical leakage of groundwater through a regional tectonic fault and polygonal faults

Overlying the Middle to Late Cretaceous unconformity that defines the top of the GAB, extensive marine and terrestrial floodplain sediments were deposited in the later part of the Early Cretaceous Period. These deposits form the extensive confining layers over the Cadna-owie – Hooray Aquifer and equivalents. Additional weathering and deposition of sediments continued through the Cenozoic Period.

Cenozoic age sediments cover over the Eromanga, Surat and Carpentaria basins and, although they are extensive, they vary in thickness due to erosion (Figure 3.3). Repeated weathering cycles and uplift of the eastern margin of the GAB created an asymmetric westward tilt to the basin, initiating artesian conditions and westward throughflow within the basin. Close to the eastern uplifted region, drainage became deeply incised, and the erosional sediments created Cenozoic deposits in the Upper Darling tributaries and in the Condamine Basin. Around the western margin of Lake Eyre, extensive paleochannels formed and have been mapped by the Department of Primary Industries and Regions South Australia. The paleochannels are remnant stream channels containing permeable sediments that could modify groundwater flow pathways in the formations overlying the Cadna-owie – Hooray Aquifer and equivalents. The presence of thick Cenozoic sediments also creates regional aquifers in the Carpentaria region that are in contact with the Jurassic–Cretaceous aquifers. In some locations, the Cenozoic sediments form an additional confining layer on the GAB.

The asymmetry in uplift preserved weathering thickness and the deeper basin accumulations of sediments of the Lake Eyre Basin. The Lake Eyre and Karumba basins are major depocentres with over 500 m of sediment and are expected to contain more localised groundwater flow systems within the GAB. Across the GAB, differential weathering and deposition have created numerous smaller basins overlying the Jurassic–Cretaceous sequence. These shallower basins are the basis for alluvial deposits and associated groundwater systems overlying the GAB.

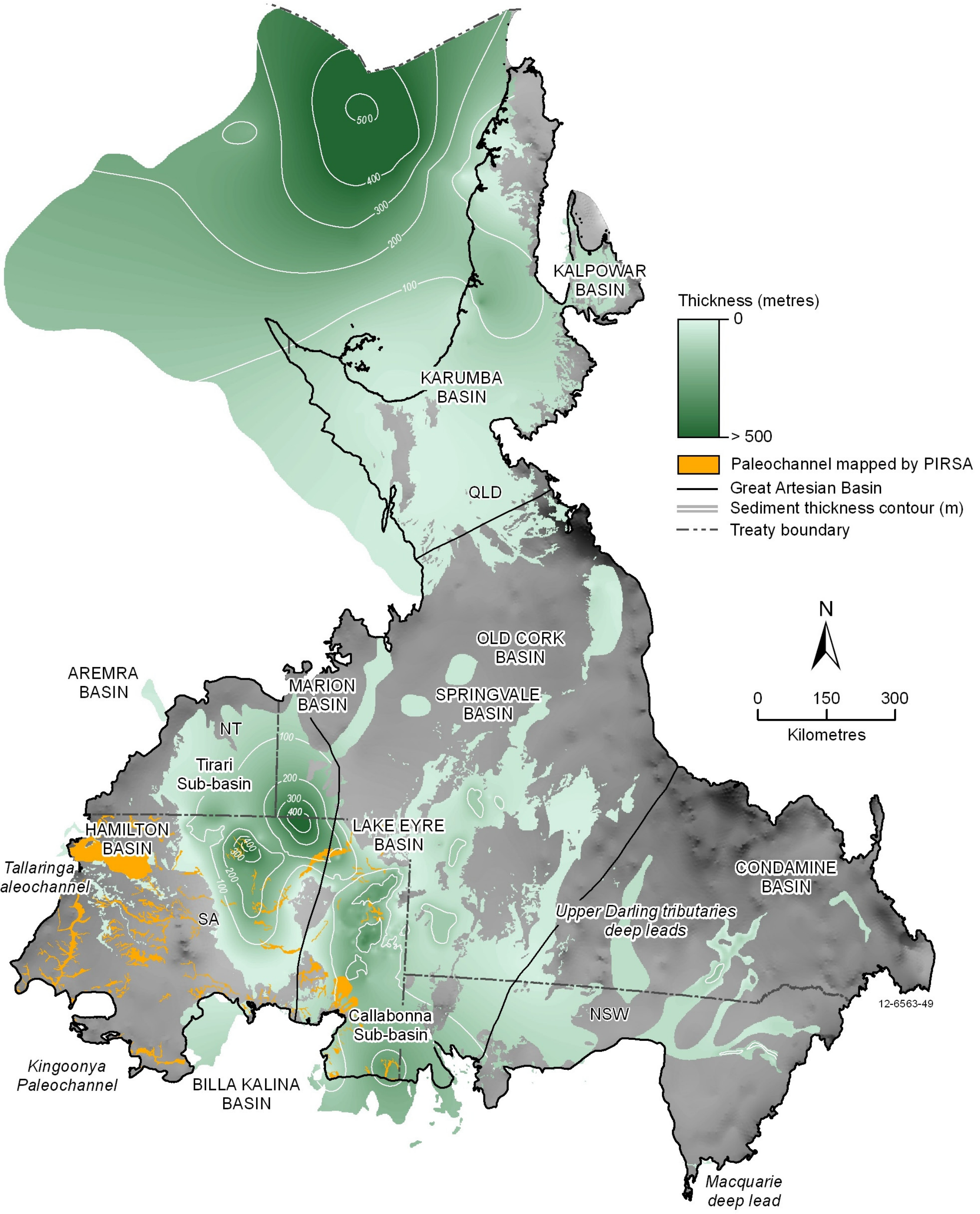

Figure 3.3 Thickness of Cenozoic sediments (Neogene and Paleogene periods only) over the Great Artesian Basin. Paleochannels have been mapped by the Department of Primary Industries South Australia (PIRSA) and would also be present in the Upper Darling tributaries deep leads. There is potential for vertical connection between the Great Artesian Basin where paleochannels exist in the absence of Cenozoic sediments

3.2 Hydrostratigraphy

A regional-scale understanding of the GAB has evolved steadily over the last century through comparison and correlation of many separate and geographically isolated studies. As a result, there are close to 50 different geological formations that have been formally identified in the Eromanga, Carpentaria, Laura, Surat and Clarence-Moreton geological basins. The formal definition of geological formations is continually being revised to accommodate new information determined from subsurface investigations by geological exploration and mapping. A compilation of the geological descriptions (nomenclature, age, distribution, rock types, and hydrological properties) for all formations in the GAB was developed as part of the Assessment (see the companion technical report by Radke et al. (2012)).

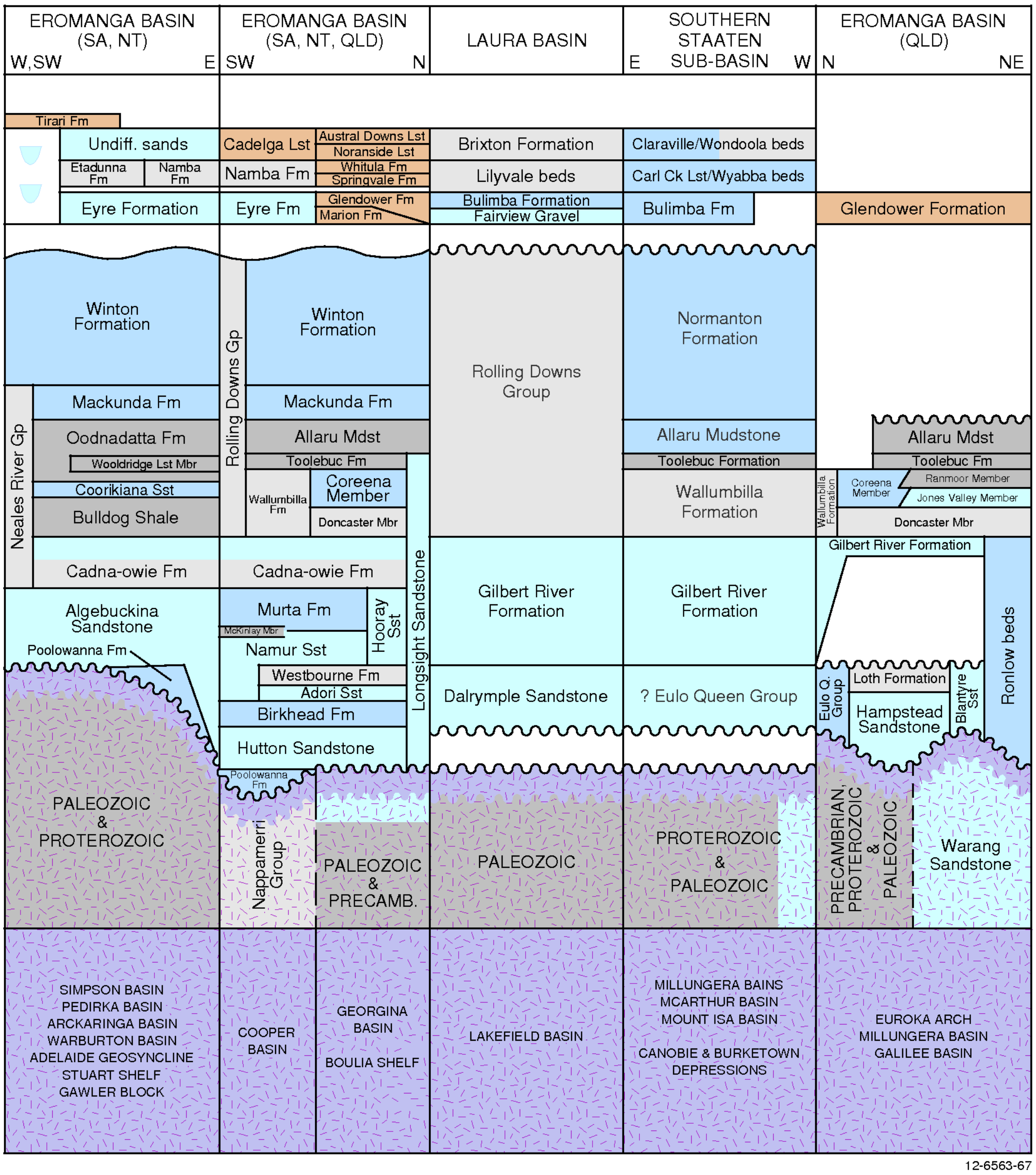

Figure 3.4 Hydrostratigraphic sequence of the Eromanga and Carpentaria basins
Note: the terms Adelaide Rift Complex and Adelaide Geosyncline are used synonymously by the Assessment

A significant outcome of the compilation by Radke et al. (2012) is the updated correlation of the hydrostratigraphic units for the GAB (Figure 3.4 and Figure 3.5). The previous basin-wide binary categorisation of ‘aquifers and aquitards’ has been reclassified to include more variability in properties of hydrostratigraphic units. The result is a more realistic gradational classification that includes ‘aquifer, partial aquifer, leaky aquitard, tight aquitard and aquiclude’ (Radke and O'Brien, 2012). These categories provide a better representation in the variability of physical properties associated with geological formations in the GAB and a consistent framework to evaluate groundwater resources. The hydrostratigraphic framework (Figure 3.4 and Figure 3.5) could guide future development of groundwater models in the GAB.

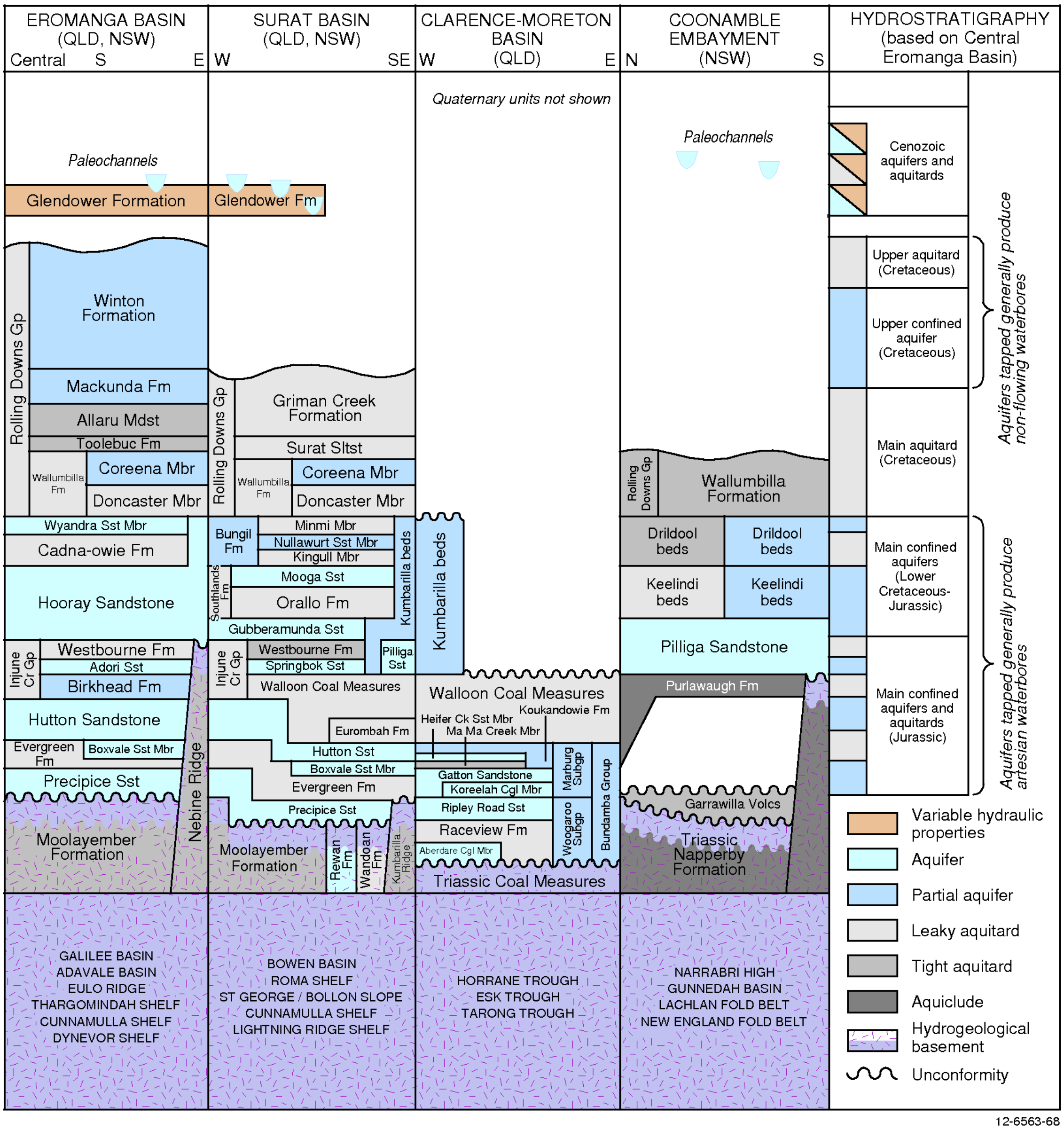

Figure 3.5 Hydrostratigraphic sequence of the Surat and Clarence-Moreton basins

3.3 Vertical connectivity of basins

The Jurassic to Middle Cretaceous age sediments in the GAB were deposited on top of older geological basins (Figure 1.1). It is these underlying basins that cause the GAB to have its structure and general shape. Basins that underlie the GAB include the Bowen, Cooper, Galilee, Pedirka, Simpson and Arckaringa basins. Because the GAB is situated on top of these deeper geological basins, there are some locations where GAB aquifers are connected to aquifers in the deeper basins.

Potential hydrogeological connection exists with aquifers in several underlying basins. The potential connections form a patchwork across the GAB (Figure 3.6), with approximately 50 percent overlap in the Eromanga Basin, 10 percent in the Surat Basin, and 5 percent in the Carpentaria Basin. The Warang and possibly the Clematis sandstones in the Galilee and Bowen basins, with sufficiently high groundwater levels, were the reason for the former inclusion of these Triassic sequences in the GAB by Habermehl (1980).

In addition to the underlying, deeper geological basins, the GAB is also overlain by shallower geological basins. Extensive Paleogene–Neogene age sedimentary basins (deposits of the Cenozoic Period) have covered the Jurassic–Cretaceous sequence of the GAB. The valleys of major watercourses in the Cenozoic Period also contain thick accumulations of alluvial sediments (Quaternary sediments). The erosion of sediments from these historical watercourses and subsequent deposition elsewhere in the GAB have caused the Cenozoic deposits to develop very hard surface crusts in some locations. Hard crusting reduces the permeability and could minimise the connectivity between the modern day surface hydrology and underlying groundwater systems, but the extent across the GAB is unknown.

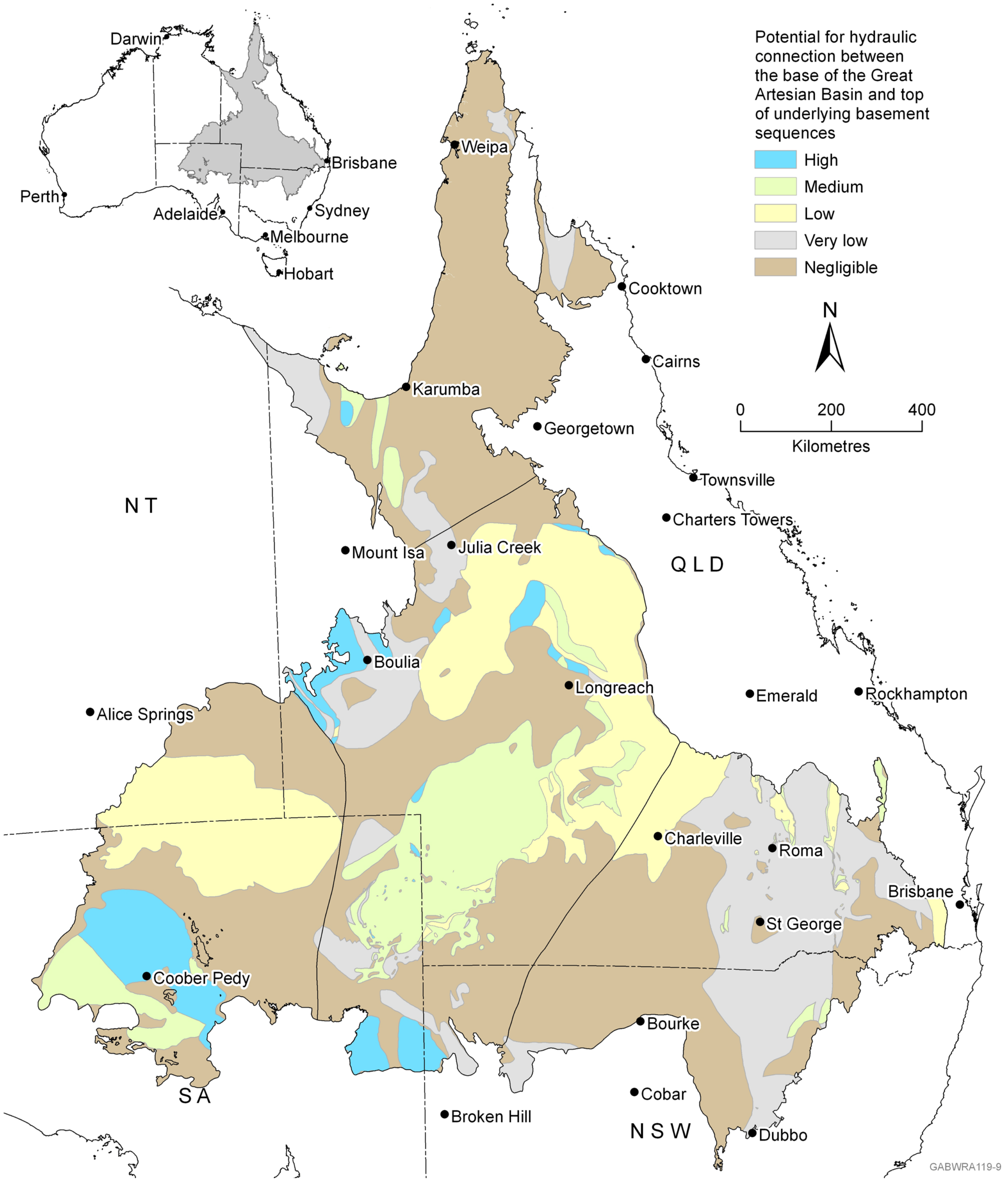

Figure 3.6 Potential connection between the Great Artesian Basin and underlying geological basins
Note: map does not imply connection above formations at the base of the Great Artesian Basin

Although the vertical connections have not been estimated for these upper layers of the GAB, the mapped extent of Cenozoic deposits shown in Figure 3.7 illustrates where overlap with the Jurassic–Cretaceous sequence could occur.

Conversely, where Cenozoic deposits have been eroded in the GAB, paleochannels could have formed that potentially increased the connectivity between the surface hydrology and underlying groundwater systems.

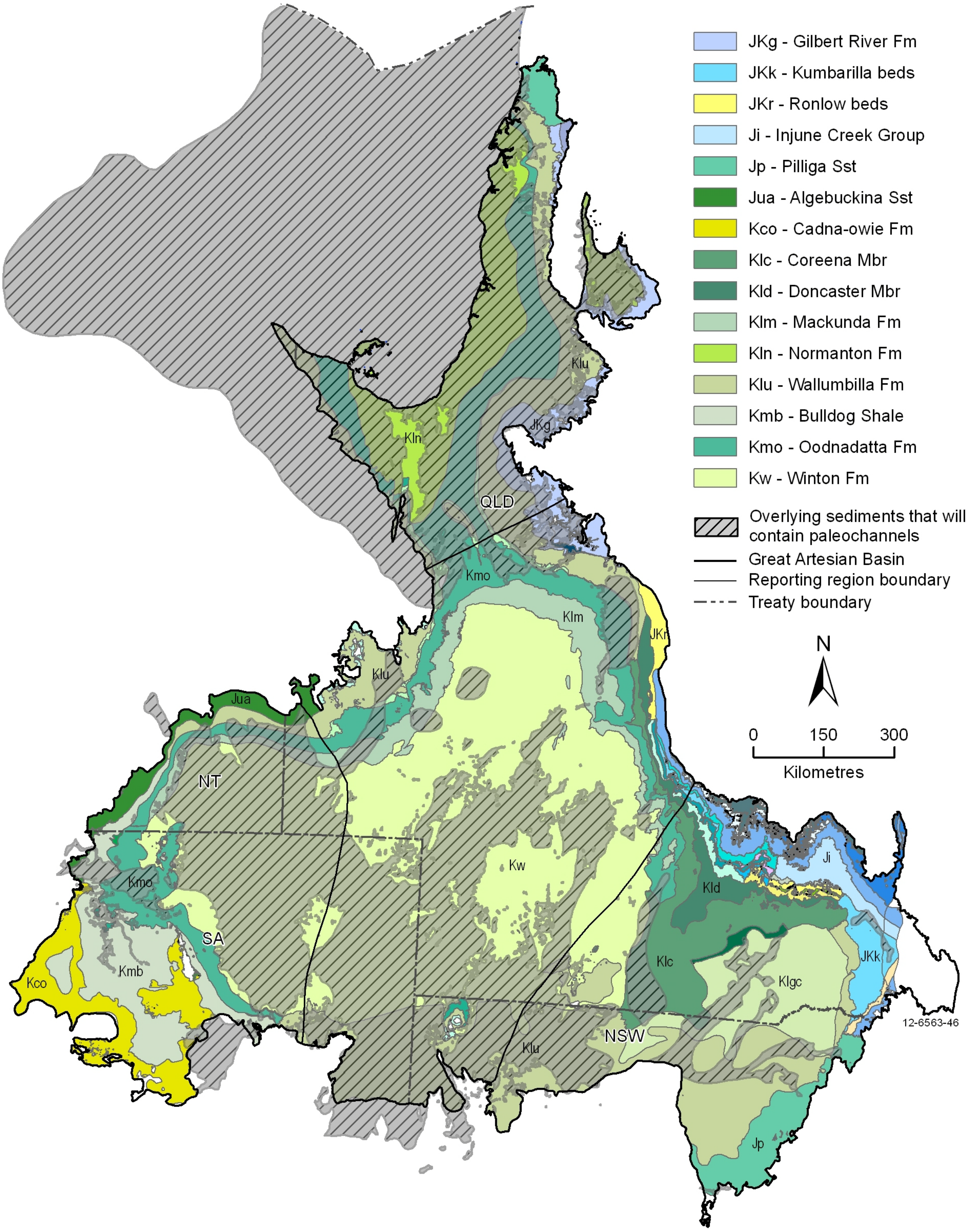

Figure 3.7 Extent of Cenozoic deposits (Neogene and Paleogene periods only) overlying the Jurassic–Cretaceous sequence of the Great Artesian Basin
Note: Fm = formation, Mbr = member, Sst = sandstone

4 Groundwater conditions

4.1 Regional watertable

The primary focus of groundwater research in the Great Artesian Basin (GAB) has been on artesian conditions of the Cadna-owie – Hooray Aquifer and equivalents, with little attention on the Early Cretaceous sub-artesian aquifers (Audibert, 1976). However, the Early Cretaceous aquifers contain the watertable over large parts of the GAB, which is an important groundwater condition to understand. The shape of the watertable and whether groundwater levels of the Cadna-owie – Hooray Aquifer and equivalents are located above or below it reflects the hydrological regime (recharge and discharge) and underlying geological structures.

For the GAB, information regarding the watertable is very sparse. To create a map of the watertable for the entire GAB (Kellett et al., 2012), the Assessment contoured available data from state agency databases, geological surveys and water authorities, and from unpublished Bureau of Mineral Resources records and consultants' reports. The Assessment found that across the GAB, the watertable generally mimics the ground surface topography.

There are additional subtle features evident in the watertable and a number of areas-of-interest have been presented in Kellett et al. (2012). Unlike the underlying confined aquifer system, there are local recharge mounds in the watertable within the Early Cretaceous aquifers in the central portion of the Eromanga Basin. There is also, some groundwater mounding present on the Eulo Ridge. Presence of a watertable ridge along the entire extent of the Eulo and Nebine ridges would form a groundwater divide between the Surat and Eromanga basins. However, the watertable mounding along the Eulo Ridge is not continuous and it appears that a small amount of groundwater flow occurs between the Surat and Eromanga basins.

The watertable surface also reveals the Diamantina River and Cooper Creek as potentially draining the watertable. Mapping the watertable elevation in the vicinity of river channels reveals how the groundwater interacts with river water. Further analysis of the watertable surface mapping in relation to baseflow of inland rivers and creeks could be achieved by relating the depth to watertable and location of permanent water features, such as waterholes. In many places where the rivers have cut braided channels through rolling hills, the watertable surface is markedly depressed about the river axes indicating the river drains the regional watertable. At a broad scale this results in a 'leaky landscape' for the GAB, where groundwater provides baseflow to rivers and is lost to evapotransiration. It is possible that one of the the sources of this groundwater is diffuse discharge from deeper aquifers in the GAB. Satellite imagery (MODIS Enhanced Vegetation Index) differentiates deeply rooted plants that rely on groundwater from vegetation along reaches of rivers, which the watertable map indicates may potentially be a natural drain for groundwater. For the stream channels of the Central Eromanga Basin, evapotranspiration losses were estimated from Enhanced Vegetation Index integration with watertable mapping. Surface water – groundwater interaction appears to be diminished where the streams open out into alluvial plains or terminal wetlands.

4.2 Cadna-owie – Hooray Aquifer and equivalents

The artesian aquifers have previously been studied more extensively than the regional watertable as noted above. Measurement of artesian conditions in the GAB started in the early 1900s and was used to prepare maps of groundwater levels for specific aquifers for particular years or time intervals in basin-wide studies. In the Assessment, groundwater level data were collated for an analysis of historical groundwater conditions, grouped into five 20-year increments from 1900 to 2000, and the most recent decade (2000 to 2010). The maps are shown in Figure 4.1 and were interpolated considering the presence of major regional tectonic faults. Where a regional tectonic fault had caused a vertical offset in the Cadna-owie – Hooray Aquifer and equivalents, the fault was assumed to act as a barrier to groundwater flow.

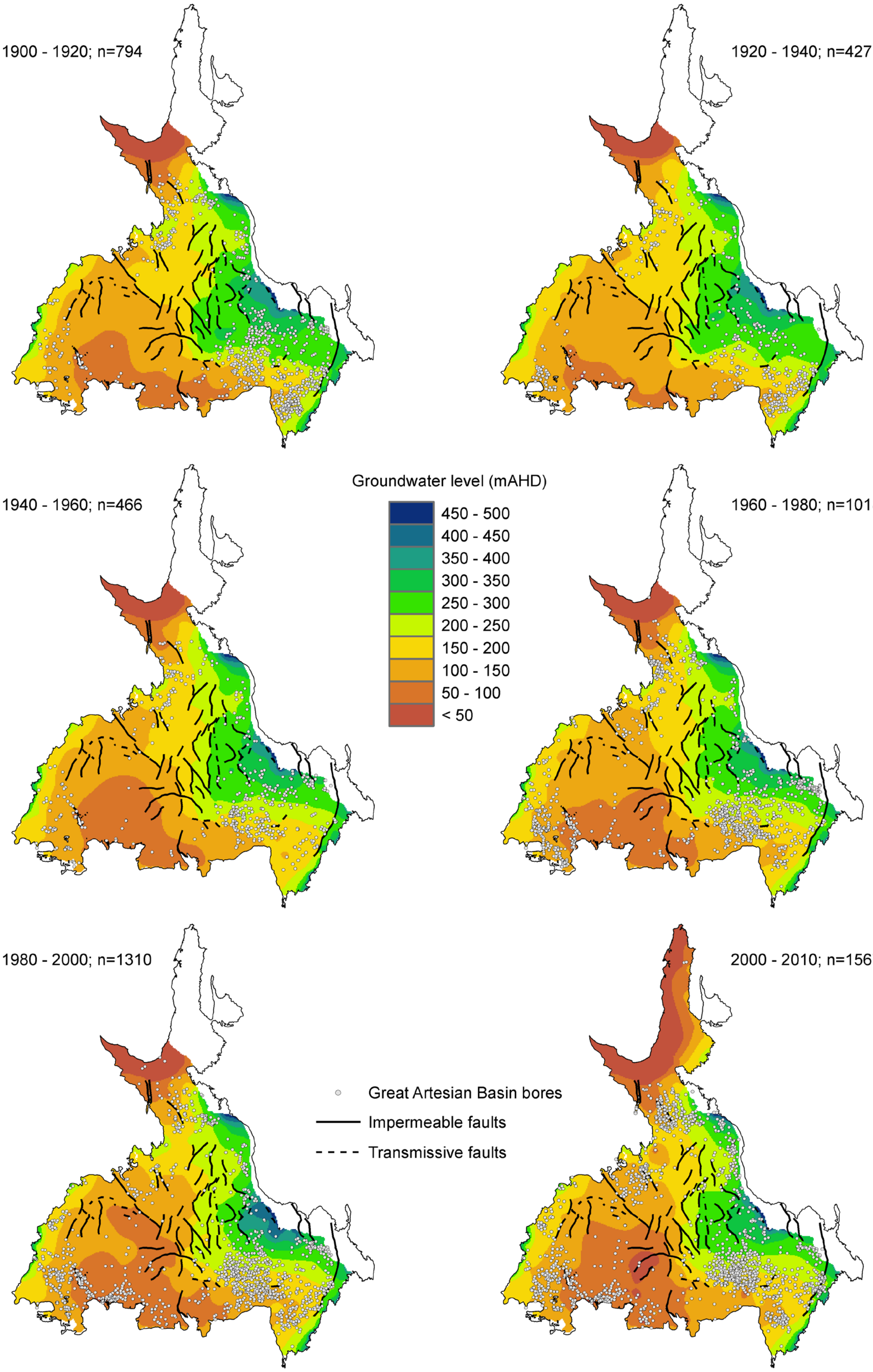

Figure 4.1 Maps of groundwater levels for the Cadna-owie – Hooray and equivalents across the Great Artesian Basin since the start of groundwater development

Note: the most recent map (2000 to 2010) includes results from modelling of equivalent aquifers in the Cape York region, which has insufficient measured data to create groundwater levels as was done for the remainder of the Great Artesian Basin

This figure (Figure 4.1) illustrates the spatial distribution of groundwater levels, from which groundwater flow directions can be inferred, and the influence of regional tectonic faults on groundwater levels can be investigated. The broad-scale trend in groundwater levels remains consistent with previous interpretations of groundwater conditions in the GAB (Audibert, 1976; Habermehl, 1980; Habermehl and Lau, 1997; Welsh, 2000), with higher groundwater levels along the Great Dividing Range and the lowest levels in the vicinity of Lake Eyre. However, the inclusion of regional tectonic faults as barriers illustrates the Cadna-owie – Hooray Aquifer and equivalents as a non-contiguous groundwater system, assuming that some of the faults form barriers – which is not completely known in the GAB.

Extensive regional tectonic faulting in the central portion of the Eromanga Basin, oriented north to south, provides a major constraint to the distribution of groundwater levels and the direction of groundwater flow. These barriers establish semi-isolated sections of the Cadna-owie – Hooray Aquifer and equivalents where groundwater throughflow is diminished (or absent).

Semi-isolated groundwater is also evident from the distribution of alkalinity and total dissolved solids (TDS) for the Cadna-owie – Hooray Aquifer and equivalents as shown in Figure 4.2 (Cresswell, 2012). This finding has been shown previously by Radke et al. (2000), but additional data and the inclusion of regional tectonic faulting on the maps correlates well with the groundwater level data. Contiguous groundwater flow pathways only appear to be possible in the Surat Basin and western portion of the Eromanga Basin. In the Surat Basin, the Eulo and Nebine Ridges add further constraint to the spatial distribution of groundwater levels, resulting in the trend for groundwater flow pathways to converge on the western edge of the Surat Basin. In the western portion of the Eromanga Basin, the hydraulic gradient is quite low, indicating extremely limited recharge and very slow groundwater flow.

The major geological structures that approximately differentiate the Surat, Eromanga, and Carpentaria basins are the Eulo and Nebine ridges and Euroka Arch, respectively. The spatial distribution of groundwater levels (Figure 4.1) indicates that a hydraulic connection exists across each of these structures. However, it should be noted that groundwater divides in the Cadna-owie – Hooray Aquifer and equivalents are faintly apparent across each of these structures. The rate of groundwater movement between the Surat, Eromanga, and Carpentaria Basins is expected to be minimal. In the eastern portion of the Surat Basin, a complex groundwater divide exists with the Clarence-Moreton Basin that depends on both deeper geological structures and shallower groundwater conditions. This complex connection with the Clarence-Moreton Basin is not apparent in Figure 4.1, but will be presented in Section 5.2. In the western portion of the Eromanga Basin, groundwater flow pathways indicate that groundwater movement is occurring from the central portion of the Eromanga Basin toward the west.

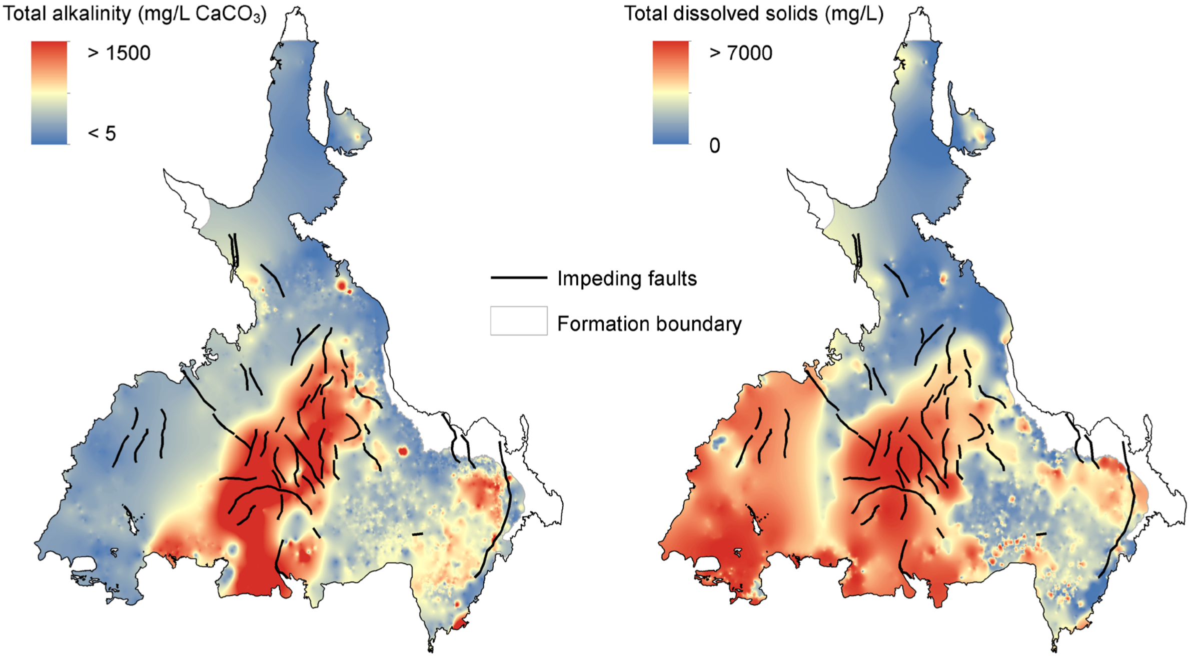

Figure 4.2 Total alkalinity (left) and total dissolved solids (right) for the Cadna-owie – Hooray Aquifer and equivalents

Figure 4.3 shows the difference in groundwater level between the first 20-year increment (1900 to 1920) and the most recent increment (2000 to 2010). For selected bores across the GAB, hydrographs are shown (Figure 4.3) to illustrate the temporal change in groundwater levels that has occurred in different parts of the GAB. Areas of large decline, ranging up to several tens of metres, correlate with areas of high bore densities in the eastern parts of the GAB. The drilling of the bores and the subsequent discharge of artesian water caused this decline. During the early stages of development the large number of free flowing bores discharged large amounts of groundwater. High initial discharge from individual bores (and from the GAB as a whole) during the early years of groundwater extraction was mainly the result of the release of groundwater from elastic storage of the confined aquifers. By comparison, groundwater levels in the western portion of the Eromanga Basin are fairly stable, with only a slight decline on the eastern part, near the Cooper Basin. The most recent increment (2000 to 2010) illustrates groundwater level recovery in selected bores that is attributed to the GABSI program.

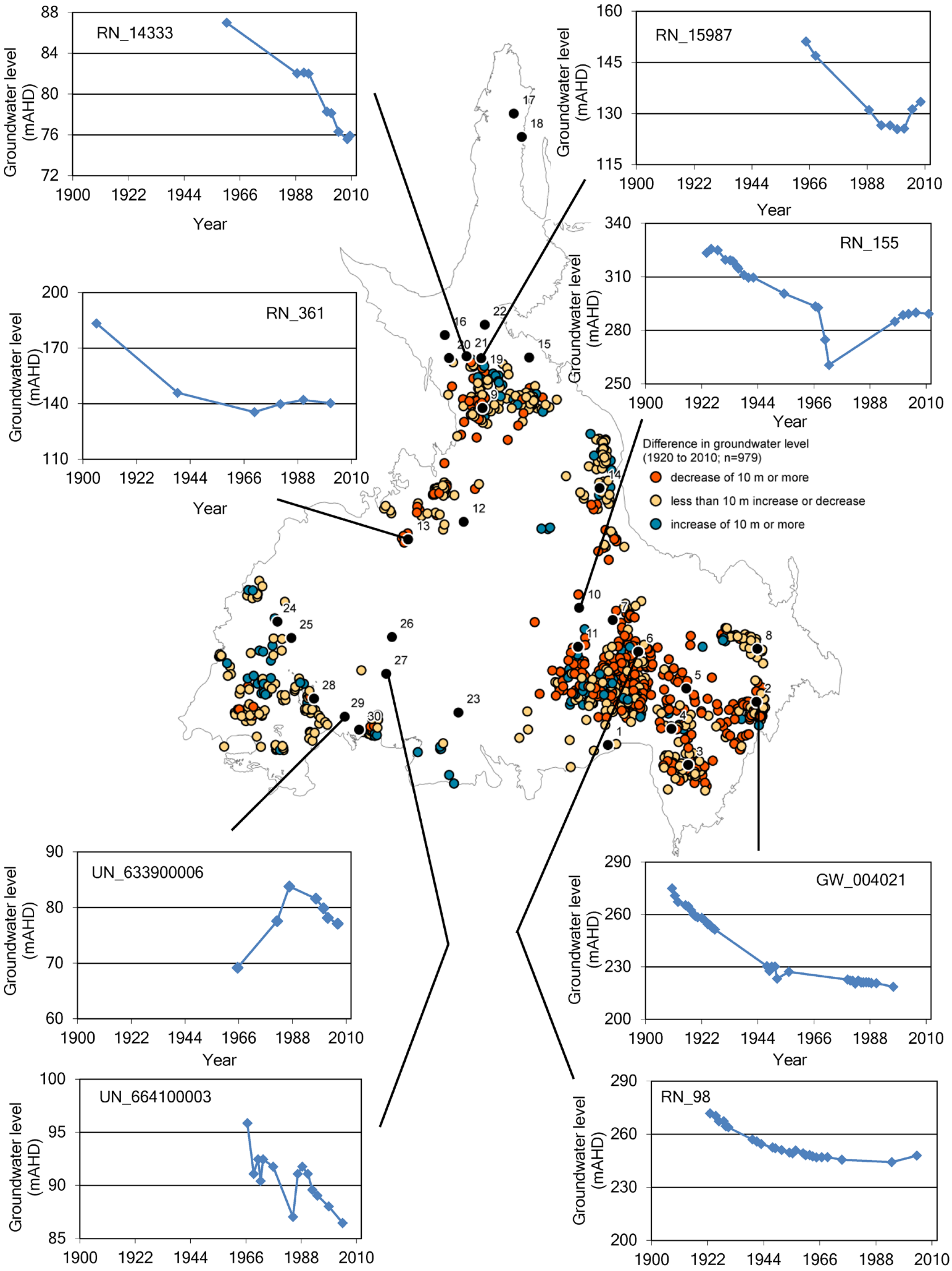

Figure 4.3 Difference in groundwater levels between early development and modern day including selected hydrographs

4.3 Evidence of vertical leakage

In multi-layered groundwater basins such as the GAB, vertical leakage can occur naturally by groundwater flow across layers (cross-formational flow) or be induced due to flow within or outside the bore casing within drill-holes. The latter mechanism has been studied for bores in in the GAB for parts of the Eromanga Basin and the Surat Basin (Habermehl, 2009) but the net effect on the water budget of the GAB is unknown. In Queensland, 10 bores out of the 68 bores investigated showed leakage and in New South Wales, 12 bores out of the 31 bores investigated showed leakage.

Cross-formational flow occurs where a vertical gradient in groundwater level exists between two formations and there is sufficient permeability to allow groundwater flow between them. The rate of groundwater movement from one formation to another is therefore a function of the connectivity in terms of permeability between the two units and the magnitude of the gradient between them.

To illustrate potential locations where cross-formation flow could be occurring in the GAB, groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents were compared with the regional watertable (Figure 4.4). Where groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents are greater than the watertable, there is a potential for upward vertical leakage. Where groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents are lower than the watertable, there is a potential for downward vertical leakage. It must be noted that mapping this comparison in Figure 4.4 only indicates where there is a potential driving force for vertical groundwater flow to occur (i.e. a difference in groundwater levels). The existence of potential upward vertical leakage (blue tones in Figure 4.4) also suggests that the confining layers overlying the Cadna-owie – Hooray Aquifer and equivalents generally have a low permeability. Conversely, areas of potential downward vertical leakage (orange tones in Figure 4.4) also suggests that the confining layers have additional conduits that promote higher permeability (e.g. polygonal faulting).

Across most of the GAB the groundwater levels of the Cadna-owie – Hooray Aquifer and equivalents are greater than the watertable. This result simply illustrates that the majority of the GAB is likely to be under artesian conditions (if the groundwater levels are also greater than the ground surface elevation), as would be expected, and that upward vertical leakage could occur from lower aquifers through the overlying (leaky) aquitards and subsequently into and through the shallower aquifer systems. Figure 4.4 also reveals areas along the margins of the GAB where the watertable elevation is greater than the groundwater levels of the Cadna-owie – Hooray Aquifer and equivalents. These areas indicate a potential for groundwater recharge conditions (downward vertical flow) to occur. In addition to the margins of the GAB, the potential for recharge conditions are apparent across many parts of the Eulo and Nebine ridges, and several parts in the centre of the Eromanga Basin where mounding was observed in the watertable. The data presented in Figure 4.4 indicates the potential for vertical leakage that requires investigation at a finer spatial scale, but provides a line of evidence regarding vertical leakage. For selected locations across the GAB, there is sufficient groundwater level data to confirm some of the recharge and discharge patterns through analysis of pressure-depth profiles (Smerdon et al., 2012), confirming this line of evidence.

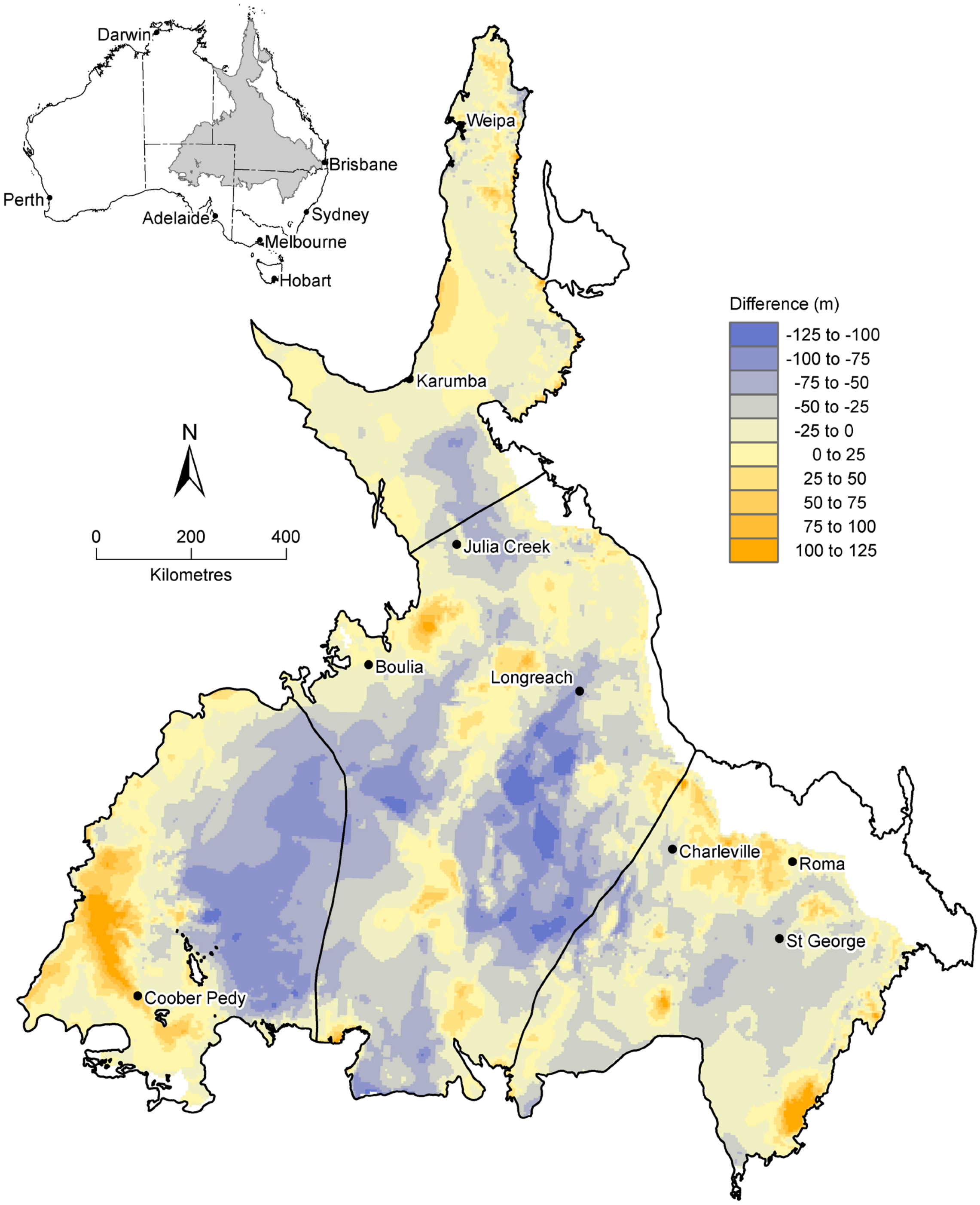

Figure 4.4 Difference between the regional watertable and groundwater levels in the Cadna-owie – Hooray and equivalents across the Great Artesian Basin

Note: Positive values (orange tones) indicate potential for downward flow and negative values (blue tones) indicate potential for upward flow. This map only indicates where there is a potential driving force for vertical groundwater flow to occur and not actual flow conditions

Selected hydrochemical trends provide another line of evidence regarding vertical groundwater leakage in the GAB (Cresswell, 2012). Chlorine-36 (^{36}Cl) shows a regional spatial pattern that succinctly delineates groundwater recharge (Figure 4.5), where in general, the ^{36}Cl to Cl ratio is diminished in the central portion of the Eromanga Basin and relatively high at major recharge regions. The potential for groundwater discharge is somewhat revealed in concentrations of fluoride, which is not present in significant concentrations in groundwater recharge. Fluoride is an element thought to derive from deeper granites and the concentration distribution across the GAB (Figure 4.6) suggests areas where vertical leakage from underlying aquifers into the GAB is prevalent. In particular, prominent fluoride concentrations around Longreach and extending down to the Queensland – New South Wales – South Australia corner can be correlated with deep granites (Radke, 2009) suggesting that vertical leakage is occurring at this location.

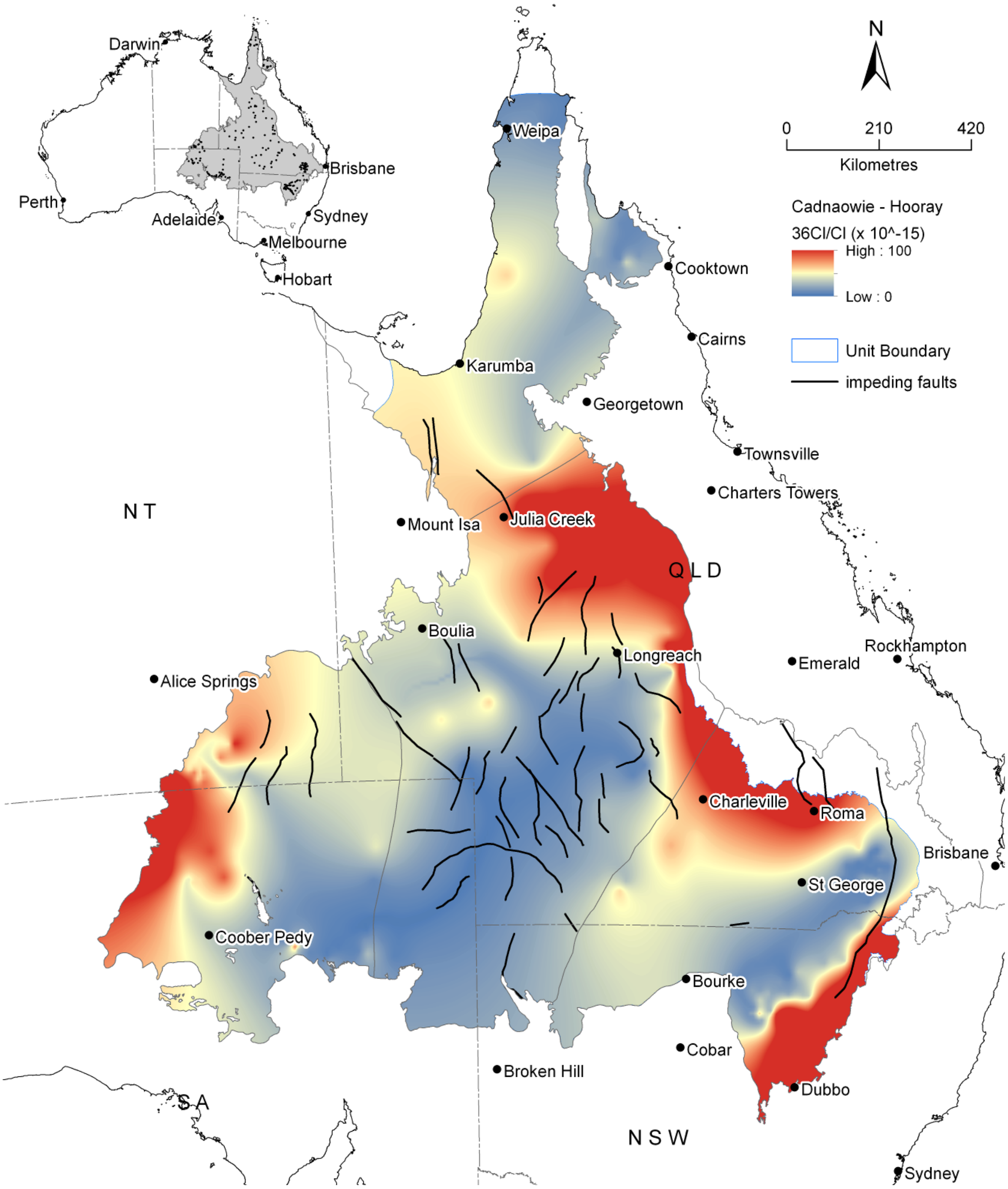

Figure 4.5 Ratio of chlorine-36 to chloride in the Cadna-owie – Hooray Aquifer and equivalents. High values are indicative of recharge areas

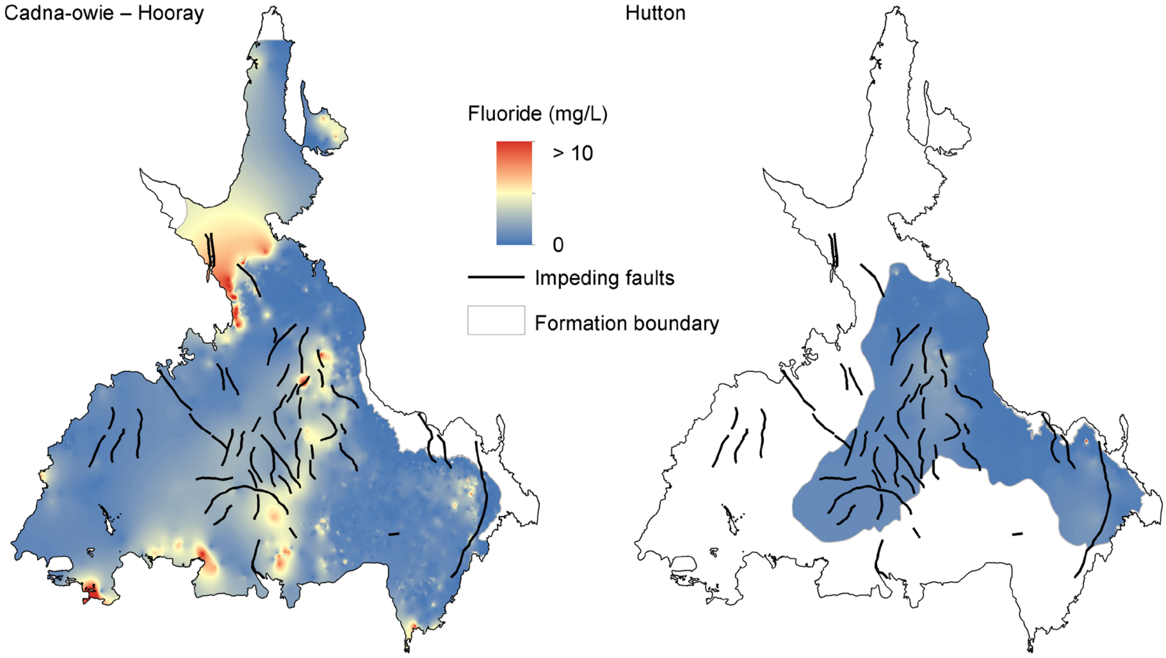

Figure 4.6 Fluoride concentrations for groundwaters in the Cadna-owie – Hooray Aquifer and equivalents (left) and Hutton aquifer (right) High values (red) indicate areas where upward leakage could be occuring

5 Advancing the understanding of the Great Artesian Basin

5.1 Updating the conceptual model

Geological understanding of the Great Artesian Basin (GAB) has grown steadily since the late 19th Century, and the concept of a simple layered hydrogeological system comprising continuous and relatively uniform aquifers separated by aquitards emerged. With attempts to quantitatively model such an idealised system from the 1970s onwards (Audibert, 1976; Seidel, 1980; Welsh, 2000), it became apparent that the geological framework and aquifer characteristics of the GAB fell short of predictability. While the simple layered through-flow concept (of aquifers and aquitards defined by major lithostratigraphic units) may be applicable in some areas in the GAB, it falls short of describing the complexity in the GAB and does not adequately address vertical connections with underlying and overlying geological basins. Distinction between aquifers and aquitards, based on hydrogeological characteristics is often difficult. Additionally, structural disruptions exist within the GAB sequence through regional tectonic faulting and polygonal faulting.

To address some of these concerns, the hydrostratigraphy of the Jurassic–Cretaceous GAB sequence has been revised in the Assessment to better represent the gradational or overlapping nature of hydraulic properties between some aquifers and aquitards. The Assessment also provides evidence for structural disruption in the GAB sequence and the potential influence on groundwater levels by regional tectonic faulting with displacements ranging up to 400 m. The central Eromanga Basin has experienced the greatest structural deformation from both faulting and folding. The existence of these structural disruptions is likely to significantly impact on groundwater through-flow within the GAB sequence. Polygonal faulting is also shown to be pervasive within the Rolling Downs Group sequence of the Eromanga Basin. In the central part of the Eromanga Basin and in the southern Carpentaria Basin, intra-formational polygonal faulting pervades the entire Rolling Downs Group aquitard, and can extend up through the Winton-Mackunda Aquifer to the surface. Although displacements by polygonal faulting are relatively small, the pervasiveness of this phenomenon is considered to significantly increase vertical leakage and hence reduce the effectiveness of aquitards.

The Assessment has also mapped where the Jurassic–Cretaceous GAB sequence may be in contact with groundwater resources associated with underlying and overlying geological basins. Where aquifers are connected, there is potential for groundwater to move from one basin to the other resulting in potentially unanticipated impacts on groundwater resources. Understanding the hydraulic connectivity between geological basins is vitally important for a complete water balance for the GAB as well as for assessing of the impacts of future development of connected hydrogeological basins.

5.2 Updating the boundary of the Great Artesian Basin

The boundary of the GAB has been progressively modified with more detailed and critical geological and hydrogeological mapping. Prior to the Assessment, the most comprehensive definition of the entire GAB was that offered by Habermehl and Lau (1997). More recently a revised boundary for the South Australian portion of the GAB was produced for the Great Artesian Basin (Eromanga Basin) hydrogeological map (Sampson et al., 2012a; 2012b). The Assessment has benefited from more recent geological mapping, access to airborne geophysical surveys and drillhole data. As a result, significant changes to the boundary have been made in the Surat and Carpentaria basins.

In the Coonamble Embayment, a reinterpretation of the western extent of the GAB has shifted this hydrogeological boundary between 10 and 30 km eastward and the southern extent approximately 60 km further south (Figure 5.1). This revision was based on new airborne geophysical surveys and drilling.

In the Carpentaria Basin, a revised location of the western extent of the GAB has been identified and is taken to be the mapped structural boundary between the Proterozoic basement rocks and the sediments of Karumba and Carpentaria basins (identified as South-west Carpentaria in Figure 5.1). Here the reinterpreted boundary lies up to approximately 35 km to the west of the Habermehl and Lau (1997) boundary. In Queensland, groundwater management in the western portion of the Carpentaria reporting region had already been considered as part of the GAB in the Water Resource Plan and Resource Operations Plan.

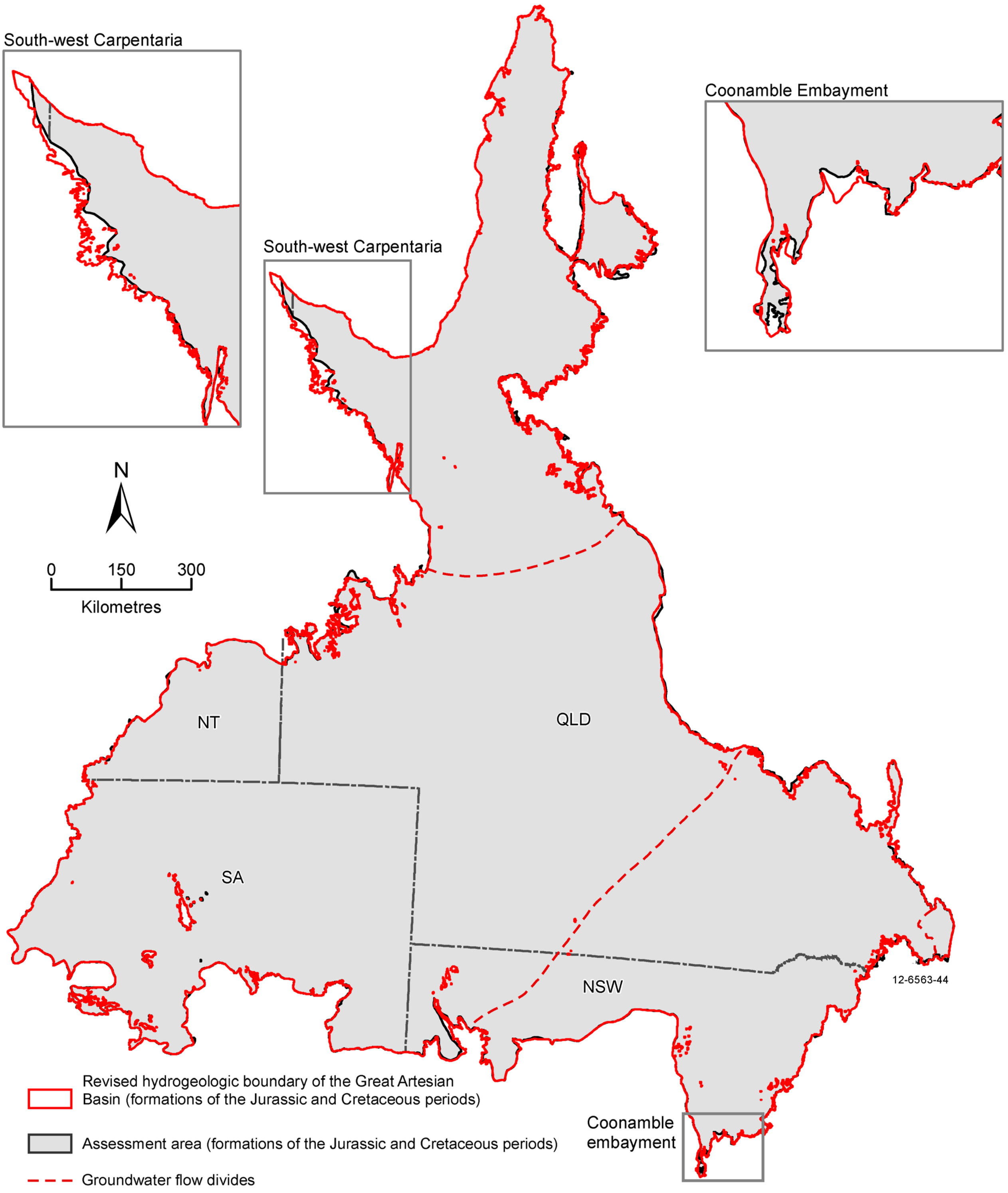

Figure 5.1 Revised hydrogeological boundary of the Great Artesian Basin

Note: groundwater flow divides were determined from maps of groundwater levels and the regional watertable

5.2.1 Updating understanding of groundwater divides

Figure 5.1 also illustrates major groundwater divides within the boundary of the GAB. The groundwater divide between the Surat Basin and the Clarence-Moreton Basin has been redefined. In Queensland, groundwater in the Clarence-Moreton Basin has always been considered as part of the GAB, with a specific groundwater management area idenitified in the GAB Water Resource Plan and Resource Operations Plan. Stratigraphic data from drill holes has allowed geological modelling of the subsurface that indicates the presence of a ridge between the Clarence-Moreton and Surat basins, informally named the Helidon Ridge, that is most likely to act as a groundwater divide within the lowermost Jurassic units of the sequence. However, watertable mapping for the upper units (including the Walloon Coal Measures) indicates that the groundwater divide follows the edge of the Great Dividing Range (Figure 5.2). These differences represent the dynamic nature of a groundwater basin and geological structures.

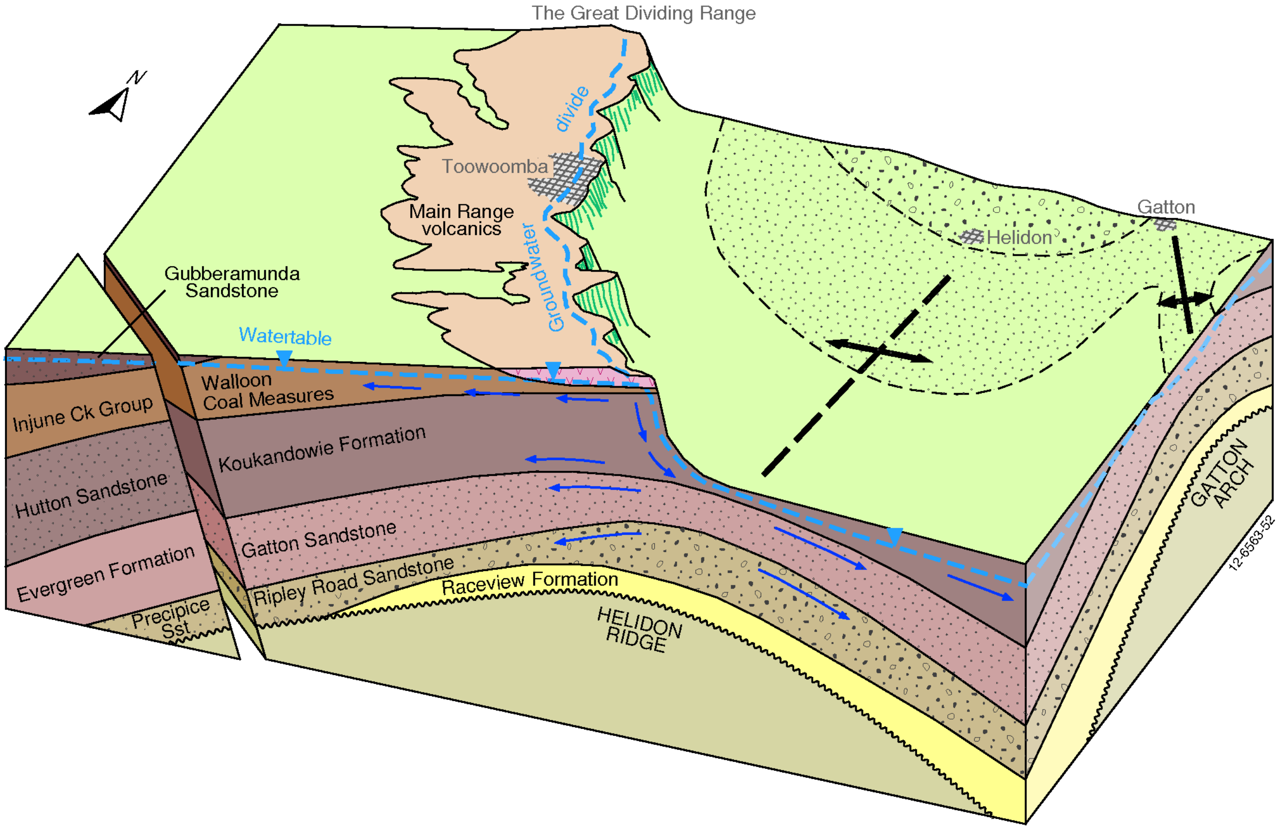

Figure 5.2 Conceptual diagram showing the groundwater divide occuring in the watertable and the influence of the Helidon Ridge on deeper groundwater

5.3 Updating the groundwater budget

Groundwater recharge and discharge mechanisms were reviewed as part of the Assessment. There are three different recharge mechanisms that occur in the GAB: diffuse recharge, ephemeral river recharge (direct and indirect) and mountain system recharge. Along the eastern and western margins of the GAB, diffuse recharge occurs where the confining beds of the Injune Creek Group and Rolling Downs Group are discontinuous or absent and potentially where the groundwater levels in the Cadna-owie – Hooray Aquifer and equivalents are below the regional watertable. In these areas, the Cadna-owie – Hooray Aquifer and equivalents are exposed at the ground surface where recharge occurs from direct infiltration – these areas are referred to as the intake beds. Recharge from ephemeral rivers can occur ‘directly’ where the river channel crosses a GAB intake bed or ‘indirectly’ where episodic flow events in an arid zone river cause a pulse of recharge. The direct form of ephemeral river recharge is thought to occur on the western slopes of the Great Dividing Range, where rivers, creeks and alluvial groundwater systems overlie the intake beds. The indirect form of ephemeral river recharge is thought to occur on arid zone rivers along the western margin of the GAB. Mountain system recharge occurs where infiltration through an uplifted region and stream runoff from the same uplifted region combine to recharge groundwater in an adjacent valley or low-lying region. The process typically occurs in mountainous regions with aquifers in adjacent valleys, but has also been recently recognised as a recharge mechanism in the western margin of the GAB.

Discharge from the GAB aquifers occurs naturally in the form of concentrated outflow from artesian springs, vertical diffuse leakage from the Lower Cretaceous–Jurassic aquifers upwards to the regional watertable, and as artificial discharge by means of free or controlled artesian flow and pumped extraction from water bores drilled into the aquifers.

5.3.1 Cadna-owie – Hooray Aquifer and equivalents

For the GAB, like many other semi-arid to arid zone aquifers around the world, the current rate of recharge is significantly less than discharge. Groundwater currently stored in the Cadna-owie – Hooray Aquifer and equivalents is a legacy from higher recharge rates that occurred during much wetter periods in the Pleistocene age (up to 2.5 million years ago). The individual components of the groundwater budget are provided in Table 4.1 based on the most recent estimates presented in Smerdon et al. (2012) and additional sources of information. In a complex and large groundwater system such as the GAB, there is a degree of uncertainty for each component of the water budget. This can lead to a range of values, which either have been determined from a single method (having a range of uncertainty – such as diffuse discharge) or from the findings of different studies (such as recharge). Estimated diffuse recharge (by the chloride mass balance method) and diffuse discharge are based on relatively simple relationships and the extrapolation of point measurements to a broad spatial scale. For recharge, this includes concentrations of chloride in precipitation and groundwater. For diffuse discharge, this includes the permeability (expressed as hydraulic conductivity) that is assumed to represent the entire thickness of a geological formation and the proportion of the region that may have preferential flow pathways. Considering these uncertainties, the regional water budget components presented should be considered indicative budget, rather than exact budget.

Table 5.1 Summary of water budget components for the Cadna-owie – Hooray Aquifer and equivalents

Reporting region	Groundwater recharge				Bore extraction
	Chloride mass balance[1]	Chloride mass balance[2]	Assessment modelling[3]	Conceptual diagrams[4]	Assessment modelling[3]
Surat	157	295	185	237	232
Central Eromanga	162	264	165	142	155
Western Eromanga	7	N/A	40	7	60
Carpentaria	N/A	N/A	101	432	64
Total	326	559	491	818	511
Reporting region	**Spring discharge**		**Diffuse discharge[5]**		
	Habermehl (1982)	5% preferential pathways	10% preferential pathways	15% preferential pathways	
Surat	14	46	92	139	
Central Eromanga	25	62	124	185	
Western Eromanga	24	37	72	109	
Carpentaria	N/A	N/A	N/A	N/A	
Total	63	145	288	433	

[1] Smerdon et al. (2012)
[2] Kellett et al. (2003) and Habermehl (2009)
[3] GABtran and Cape York models, Welsh et al. (2012b)
[4] Ransley et al. (2012)
[5] method described by Harrington et al. (2012)

5.3.2 Basin conceptual diagrams

The updated conceptualisation of the GAB hydrogeological system has revealed mechanisms affecting recharge and discharge that were either unknown or poorly understood. In an effort to articulate the key findings of the Assessment and the potential influence on components of the water budget, this section presents schematic water budgets for the Carpentaria, Eromanga and Surat basins (see also Ransley et al., (2012)). The conceptual diagrams draw together the water budget components presented in Table 5.1 with known recharge and discharge values for other geological formations as well as unquantified estimates to develop a first-order approximation for each basin.

Carpentaria Basin

Three regional aquifer systems have been recognised in the Carpentaria Basin, including the Jurassic–Cretaceous Eulo Queen Group and equivalents, the overlying Gilbert River Formation, the Normanton Formation and the Bulimba-Wyaaba-Claraville aquifers. For the Carpentaria Basin intake beds (Figure 5.3), recharge was estimated at 432 GL/year by approximating the results of Kellet et al. (2003). For the Karumba Basin (Figure 5.3), recharge was estimated at 177 GL/year in the Claraville Beds, 181 GL/year for the Wyaaba Beds and approximately 4500 GL/year for the Bulimba Formation. This gives an approximate total recharge of 4800 GL/year for the Karumba Basin and combined approximate total of 5200 GL/year for the Carpentaria and Karumba basins. Discharge from baseflow springs on Cape York is estimated to be 630 GL/year. Groundwater discharge as baseflow could be greater than recharge to the Jurassic to Cretaceous aquifers. Although there is not sufficient data to prove this, it is suggested that the source of baseflow must also be originating from the Cenozoic aquifers of the Karumba Basin. Only 10 GL/year is extracted by bores and the remainder of discharge from the basin is assumed to be through evapotranspiration and submarine groundwater discharge. A lack of groundwater data prevents quantification of many water budget components, but it is evident that groundwater cycling in the uppermost aquifer systems is driven dynamically by the tropical climate.

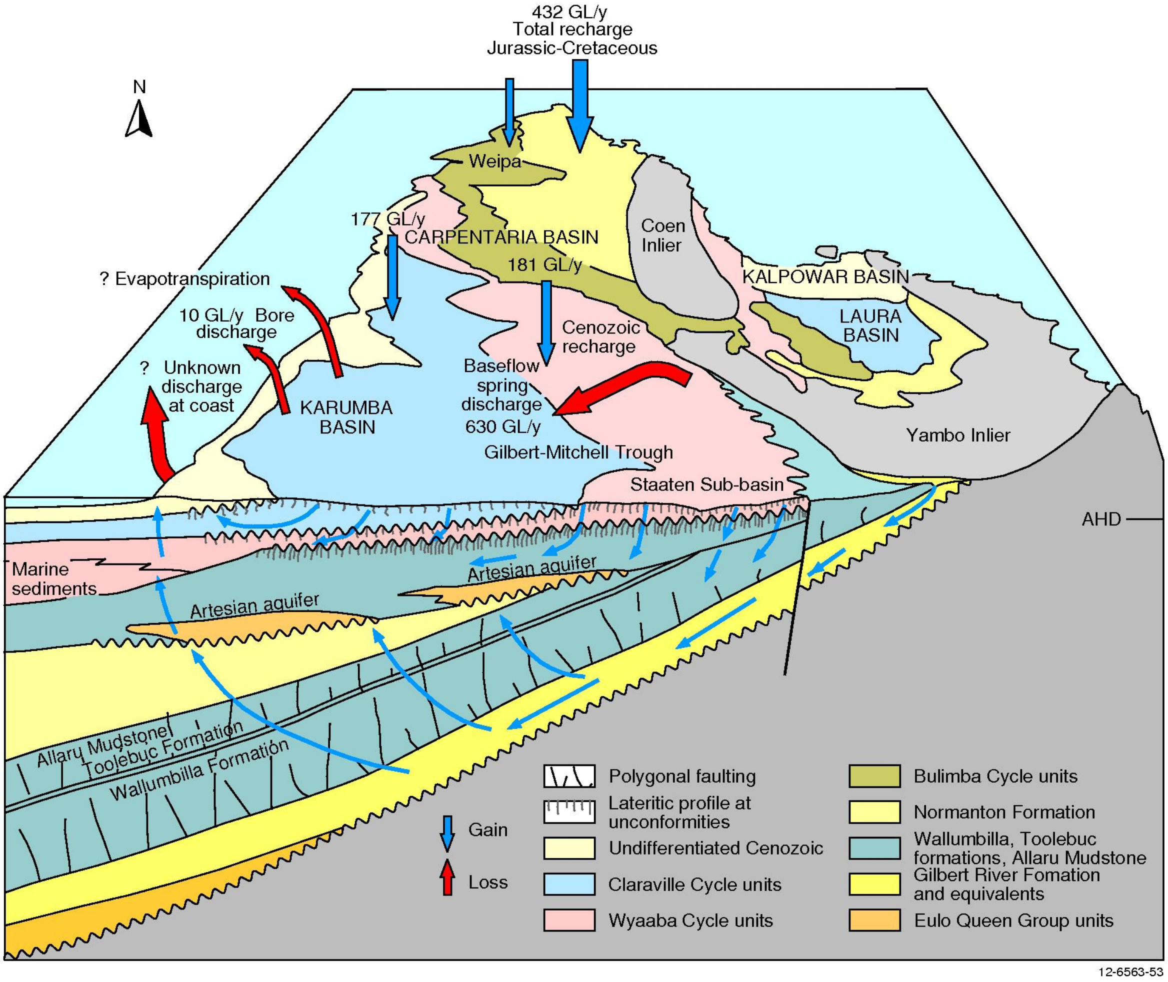

Figure 5.3 Hydrogeological framework and groundwater balance for the Carpentaria Basin

Eromanga Basin

The geological history of the Eromanga Basin underpins the nature of the geological formations observed today and groundwater connections with shallower Cenozoic basins. These overlying deposits contain complex shallow groundwater systems that are sometimes used for domestic and agricultural purposes. For the Eromanga Basin (Figure

5.4), recharge was estimated at 142 GL/year for the Jurassic–Cretaceous intake beds on the western slopes of the Great Dividing Range and 164 GL/year for the Winton and Mackunda formations (121 GL/year for the Winton Formation and 43 GL/year for the Mackunda Formation). These recharge values illustrate the importance of considering shallower basins in the updated conceptualisation of the GAB hydrogeological system, as they contain significant groundwater resources. Groundwater discharge was estimated at 487 GL/year for bores, springs and diffuse discharge, which is greater than the sum of recharge. Evapotranspiration has been estimated at a minimum of 44 GL/year. The relationship between diffuse discharge from GAB aquifers, evapotranspiration from riparian vegetation and baseflow to inland rivers and creeks is important but poorly understood. This dynamic hydrological relationship could be crucial for longevity of groundwater dependent ecosystems.

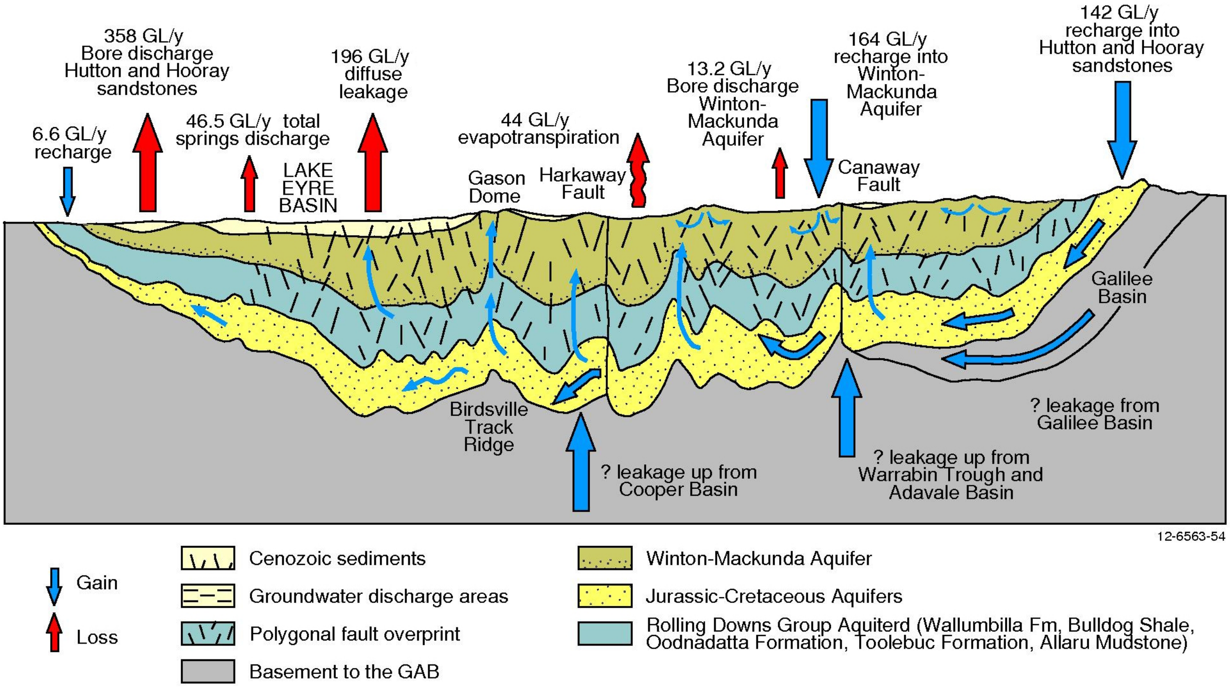

Figure 5.4 Detailed hydrogeological framework and groundwater balance of the Eromanga Basin

Surat Basin

The Surat Basin has been the focus of many groundwater investigations and has also had a significant level of groundwater development. The combination of societal need for water resources and groundwater research have driven a growing understanding of the Surat Basin. In the Surat Basin (Figure 5.5), recharge to the Jurassic aquifers consists of 237 GL/year in the intake beds and recharge to the Griman Creek formation (equivalent to the Winton and Mackunda formations in the Eromanga Basin) is significantly less (approximately 1 GL/year; (Cresswell, 2003; Kellett et al., 2004)). Discharge from the Surat Basin includes 127 GL/year from bore abstractions, approximately 12 GL/year from the Springsure Group springs, small additional spring discharges (much less than 1 GL/year), approximately 12.5 GL/year as baseflow discharge to the Dawson River and Mulgildie Basin, approximately 25 GL/year as rejected recharge, and an unknown amount of groundwater throughflow to the Eromanga Basin. Discharge from the Griman Creek Formation consists of 3 GL/year from bore abstractions and an unknown but likely high amount of evapotranspiration (approximately 56 GL/year). Thus the Griman Creek Formation is likely to be experiencing a decline in storage of approximately 50 GL/year, but some of this deficit should be replenished by upward leakage from the Hooray (equivalent) aquifer (potentially 93 GL/year) and by downward leakage from alluvial groundwater systems.

The potential impacts of coal seam gas production in the intake beds of the northern Surat Basin are as yet not fully understood. Although the target formation for gas and water production is the Walloon Coal Measures, there is expected to be leakage generated in the Springbok Sandstone, Hutton Sandstone and Gubberamunda Sandstone aquifers.

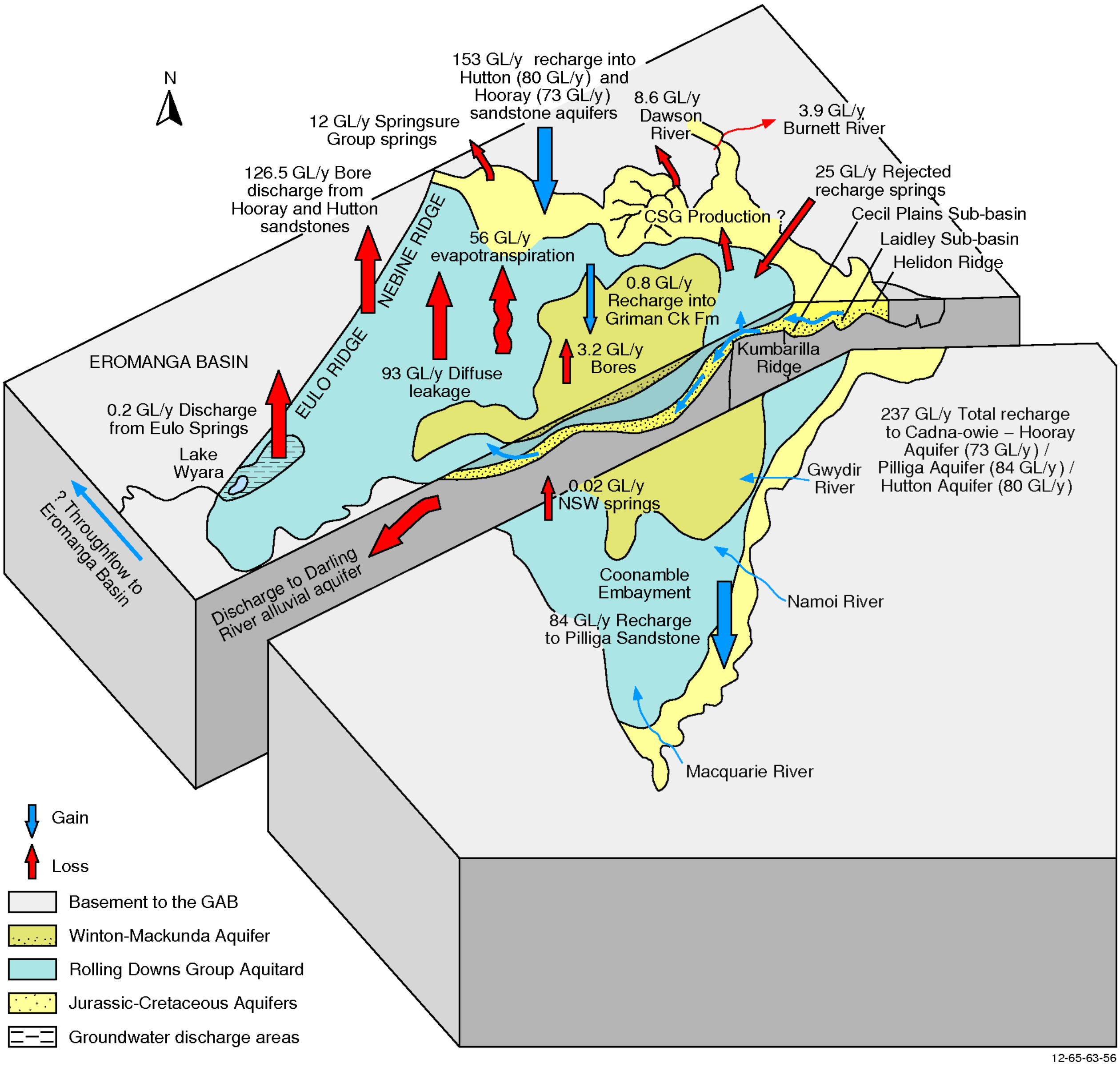

Figure 5.5 Hydrogeological framework and groundwater balance of the Surat Basin

5.4 Implications for groundwater modelling

The long-standing conceptualisation by Habermehl (1980) viewed the GAB as a single, large, contiguous groundwater flow system in which aquifers were considered to be laterally continuous across the extent of the entire GAB. The Assessment provides an updated interpretation of the geology and hydrogeology of the GAB. This interpretation is more complex than had been previously shown.

The Assessment also evaluated groundwater response to current and future climate and groundwater development through modelling scenarios (Welsh et al., 2012a). The modelling used the GABtran model (Welsh, 2006) that was built on the Habermehl (1980) conceptualisation, which is a simplified representation of the groundwater conditions of the Cadna-owie – Hooray Aquifer and equivalents.

Groundwater modelling provides a rigorous numerical approach to evaluate the conceptual understanding of a groundwater system. A groundwater model represents the complex real world in a relatively simple form. The process of conceptualisation is meant to capture available knowledge and information of a groundwater system and translate these into a representation to be used in subsequent analysis, such as a groundwater model. During this process real-world complexity is balanced against its certainty and requirement in the subsequent analysis.

The Assessment has shown that the GAB is more complex than previously described and that complexity in the geological structure and layering create complexity in the hydrogeology. None of these complexities have been included in the GABtran groundwater model (Welsh, 2006) used in the Assessment (Welsh et al., 2012a). The implications of including any of the additional complexities in a groundwater model of the GAB is unknown. It can be reasonably assumed that in order to maintain a calibrated model, significant revision of the parameters of the existing groundwater model would be required. A difference in model layer thickness, hydraulic properties, or leakage from other layers would lead to a different modelling outcome. Should a new groundwater model be developed for the GAB, some of the additional complexity for the GAB should be considered. Inclusion of multiple layers, connectivity with overlying and underlying geological formations, and the presence of faults in a new regional-scale groundwater could potentially improve the predictive ability under future scenarios of climate change and groundwater development. However, such an advanced and complex model would require sufficient data and improved knowledge of key physical processes to achieve a representative groundwater condition. At present, groundwater data are sparse across most of the GAB and clustered in highly developed areas.

It should also be noted that while an advanced groundwater model of the GAB may fulfil an academic function, modelling groundwater conditions at a smaller scale may give results better fit for a specific purpose, such as impact from groundwater extraction. An example of a new model that is fit for purpose is the model developed by the Queensland Water Commission (QWC). Rather than simulating groundwater conditions in the Cadna-owie – Hooray Aquifer as a single layer, the QWC model has multiple layers to represent different rock layers in the Surat region – the aquifers and aquitards.

5.5 Knowledge and information gaps

The collation, analysis, and interpretation of geological and hydrogeological knowledge for the GAB are ongoing. To continue advancing the understanding of the GAB, refining the conceptualisation and developing more robust groundwater models, will rely on closing the following knowledge gaps:

- Quantification of the rate of groundwater movement between the GAB and underlying and adjacent geological basins.
- Quantification of the rate of groundwater movement between the GAB and overlying geological basins and shallow groundwater systems.
- More detailed understanding of the effects of geological structures on groundwater flow:
  - faults and the effect on groundwater movement (i.e. barrier or conduit for flow)
  - polygonal fault systems and the effect on vertical groundwater movement (i.e. inter-aquifer leakage)
- The rate and distribution of groundwater recharge and discharge in the Carpentaria region.
- Additional knowledge of groundwater levels in the central part of the Eromanga Basin, where data are highly sparse.
- More complete characterisation of hydraulic properties (i.e. porosity and permeability), especially of aquitards.
- Assessment of scaling the hydraulic properties from typical lab and field testing to the geological formation scale.
- The processes and variability in vertical leakage/cross-formational flow.
- More comprehensive understanding of the Winton-Mackunda aquifer, including hydraulic properties, distribution of groundwater levels and hydrogeochemistry.

The GAB is a vast groundwater basin and detailed information is very sparse, often clustered in a few areas. Sufficient data are required to monitor the water resource, and continue to test and develop concepts of how it works. The following information gaps should be addressed to assist closing the knowledge gaps:

- Regionally comprehensive in-field measurement of permeability values for each system of aquifers and aquitards.
- Dedicated nested monitoring bores within multiple formations in artesian areas to obtain vertical groundwater levels (i.e. profiles) to assess vertical leakage.
- Estimates of vertical leakage/cross-formational flow at the formation scale.
- Additional groundwater level data, particularly in the Hutton Sandstone and deeper formations.
- More consistent coverage and availability of geophysical log data, including gamma ray, neutron density, and resistivity.

6 References

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

Bentley HW, Phillips FM, Davis SN, Habermehl MA, Airey PL, Calf GE, Elmore D, Gove HE and Torgersen T (1986) Chlorine 36 dating of very old groundwater. The Great Artesian Basin, Australia. Water Resources Research 22(13), 1991–2001.

Collerson KD, Ullman WJ and Torgersen T (1988) Ground waters with unradiogenic $^{87}Sr/^{86}Sr$ ratios in the Great Artesian Basin, Australia. Geology 16(1), 59–63.

Cresswell R (2003) Chlorine-36 analysis of pore fluids from diamond drill cores from the Lower Balonne area, Queensland. Bureau of Rural Sciences, Canberra.

Cresswell RC (2012) Chapter 8: Regional hydrogeochemistry. In: Ransley TR and Smerdon BD (eds) 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.

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

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. Department of Environment and Resource Management, Brisbane, Queensland.

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

Habermehl MA (1982) Springs in the Great Artesian Basin, Australia – their origin and nature. Bureau of Mineral Resources, Canberra, Australia.

Habermehl MA (2009) Inter-aquifer leakage in the Queensland and New South Wales parts of the Great Artesian Basin. Final report for the Australian Government Department of Environment and Water Resources, Heritage and Arts. Bureau of Rural Sciences, Canberra.

Habermehl MA, Devonshire J and Magee J (2009) Sustainable groundwater allocations in the intake beds of the Great Artesian Basin in New South Wales (recharge to the New South Wales part of the Great Artesian Basin). Final report for the National Water Commission. Bureau of Rural Sciences, Canberra.

Habermehl MA and Lau JE (1997) Hydrogeology of the Great Artesian Basin Australia (Map at scale 1:2,500,000). Australian Geological Survey Organisation, Canberra.

Kellett J, Pearce B, Coram J, Herczeg A, Wilkinson K and Cresswell R (2004) Groundwater. In: Chamberlain T and Wilkinson K (eds) Salinity investigations using airborne geophysics in the Lower Balonne area Southern Queensland. National Action Plan for Salinity and Water Quality. Bureau of Rural Sciences, Australia, 81–138.

Kellett JR, Bell JG, Stewart GA and Ransley TR (2012) Chapter 6: Regional watertable. In: Ransley TR and Smerdon BD (eds) 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.

Kellett JR and Radke BM (2012) Chapter 1: Introduction. In: Ransley TR and Smerdon BD (eds) 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.

Kellett JR, Ransley TR, Coram J, Jaycock J, Barclay DF, McMahon GA, Foster LM and Hillier JR (2003) Groundwater Recharge in the Great Artesian Basin Intake Beds, Queensland. Final Report for the NHT Project #982713 Sustainable Groundwater Use in the GAB Intake Beds, Queensland. BRS, Natural Resources and Mines, Queensland Government, Brisbane, Queensland.

Love AJ, Herczeg AL, Sampson L, Cresswell RG and Fifield LK (2000) Sources of chloride and implications for ^{36}Cl dating of old groundwater, southwestern Great Artesian Basin, Australia. Water Resources Research 36(6), 1561–1574.

Miles C, White M and Scholz G (2012) Environment. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Radke BM (2009) Hydrocarbon and Geothermal Prosepctivity of Sedimentary Basins in Central Australia; Warburton, Cooper, Perdirka, Galilee, Simpson and Eromanga Basins. Geoscience Australia, Canberra.

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. Bureau of Rural Sciences, Canberra.

Radke BM and Kellett JR (2012) Chapter 2: Jurassic–Cretaceous geology. In: Ransley TR and Smerdon BD (eds) 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.

Radke BM, Kellett JR, Ransley TR and Bell JG (2012) Lexicon of the lithostratigraphic and hydrogeological units of the Great Artesian Basin and its Cenozoic cover. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Radke BM and O'Brien PE (2012) Chapter 4: Stratigraphy of the Great Artesian Basin. In: Ransley TR and Smerdon BD (eds) 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.

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.

Ransley TR, Smerdon BD and Radke BM (2012) Chapter 9: Advancing the understanding of the Great Artesian Basin. In: Ransley TR and Smerdon BD (eds) 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.

Sampson L, Wohling D, Jensen-Schmidt B and Fulton S (2012a) South Australia and Northern Territory Great Artesian Basin (Eromanga Basin) hydrogeological map – part 1. Department of Environment, Water and Natural Resources, South Australian Government, Adelaide.

Sampson L, Wohling D, Jensen-Schmidt B and Fulton S (2012b) South Australia and Northern Territory Great Artesian Basin (Eromanga Basin) hydrogeological map – part 2. Department of Environment, Water and Natural Resources, South Australian Government, Adelaide.

Seidel G (1980) Application of the GABHYD groundwater model of the Great Artesian Basin, Australia. Bureau of Mineral Resources Journal of Australian Geology and Geophysics 5, 39–45.

Smerdon BD, Rousseau-Gueutin P, Love AJ, Taylor AR, Davies PJ and Habermehl MA (2012) Chapter 7: Regional hydrodynamics. In: Ransley TR and Smerdon BD (eds) 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.

Smith AJ and Welsh WD (2011) Review of groundwater models and modelling methodologies 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.

Torgersen T, Habermehl MA, Phillips FM, Elmore D, Kubik P, Jones BG, Hemmick T and Gove HE (1991) Chlorine-36 dating of very old groundwater 3. Further studies in the Great Artesian Basin, Australia. Water Resources Research 27(12), 3201–3213.

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

Welsh WD (2006) Great Artesian Basin transient groundwater model. Bureau of Rural Sciences, Canberra. Viewed 15 October 2012, <http://adl.brs.gov.au/brsShop/data/gabtransient1.pdf>.

Welsh WD, Moore C, Turnadge C, Smith AJ and Barr TM (2012a) Modelling of climate and development. A technical report to the Australian Government fromthe CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Welsh WD, Moore C, Turnadge C, Smith AJ and Barr TM (2012b) Modelling of climate and groundwater development. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia.

Appendix A Reports published by the Assessment

More information about the Great Artesian Basin Water Resource Assessment can be found at <http://www.csiro.au/science/Great-Artesian-Basin-Assessment.html>. This appendix lists all reports published by the Assessment.

Data reports

Hartcher MG, Davies PJ, Ransom GC, Turnadge CJ, Welsh WD, Taylor AR and Miles C (2012) Data acquisition and management. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~20 pp.

Ransom GC and Ransley TR (2012) Data delivery and custodianship. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~25 pp.

Region reports

Smerdon BD, Welsh WD and Ransley TR (eds) (2012) Water resource assessment for the Carpentaria 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.

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.

Smerdon BD and Ransley TR (eds) (2012) Water resource assessment for the Surat region. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~125 pp.

Smerdon BD, Welsh WD and Ransley TR (eds) (2012) Water resource assessment for the Western 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.

Summary reports

CSIRO (2011) The Great Artesian Basin Water Resource Assessment. Project overview. CSIRO Water for a Healthy Country Flagship, Australia. 2 pp.

CSIRO (2012) The Great Artesian Basin Water Resource Assessment: Update, January 2012. CSIRO Water for a Healthy Country Flagship, Australia. 4 pp.

CSIRO (2012) The Great Artesian Basin Water Resource Assessment: Update, September 2012. CSIRO Water for a Healthy Country Flagship, Australia. 2 pp.

Smerdon BD, Welsh WD, Marston FM and Ransley TR (2012) Water resource assessment for the Carpentaria region. Summary of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~16 pp.

Smerdon BD, Marston FM and Ransley TR (2012) Water resource assessment for the Central Eromanga region. Summary of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~16 pp.

Smerdon BD, Marston FM and Ransley TR (2012) Water resource assessment for the Surat region. Summary of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~16 pp.

Smerdon BD, Welsh WD, Marston FM and Ransley TR (2012) Water resource assessment for the Western Eromanga region. Summary of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~16 pp.

Technical reports

Smith AJ and Welsh WD (2011) Review of groundwater models and modelling methodologies. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~60 pp.

Miles C, White M and Scholz G (2012) Assessment of the impacts of future climate and groundwater development on Great Artesian Basin springs. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~50 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.

Radke BM, Kellett JR, Ransley TR and Bell JG (2012) Lexicon of the lithostratigraphic and hydrogeological units of the Great Artesian Basin and its Cenozoic cover. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~175 pp.

Welsh WD, Moore CR, Turnadge CJ, Smith AJ and Barr TM (2012) Modelling of climate and groundwater development. A technical report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~105 pp.

Three-dimensional visualisation report

Nelson GC, Carey H, Radke BM and Ransley TR (2012) The three-dimensional visualisation of the Great Artesian Basin. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~15 pp.

Whole-of-GAB reports

Smerdon BD, Ransley TR, Radke BM and Kellett JR (2012) Water resource assessment for the Great Artesian Basin. A report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~50 pp.

Smerdon BD, Marston FM and Ransley TR (2012) Water resource assessment for the Great Artesian Basin. Synthesis of a report to the Australian Government from the CSIRO Great Artesian Basin Water Resource Assessment. CSIRO Water for a Healthy Country Flagship, Australia. ~12 pp.

Terms and concepts

The Great Artesian Basin (GAB) is a complex groundwater entity that is difficult to visualise and challenging to describe. To help describe the GAB and improve knowledge of groundwater resources, this report uses scientific and technical terms that may be unfamiliar to many readers. The definitions provided in this section are intended to assist readers understand most of the concepts covered by the report. However, it was beyond the scope of the Assessment to provide a full glossary – there are numerous other sources easily accessed online including:

> The National Water Commission's information about groundwater. Viewed 24 October 2012, <http://archive.nwc.gov.au/library/topic/groundwater/groundwater-essentials>.
>
> United States Geological Survey Water Science School groundwater basics. Viewed 30 October 2012, <http://ga.water.usgs.gov/edu/mearthgw.html>.
>
> United States Geological Survey Water Science School water science glossary of terms. Viewed 30 October 2012, <http://ga.water.usgs.gov/edu/dictionary.html>.
>
> United States Geological Survey Ground Water Glossary. Viewed 30 October 2012, <http://pubs.usgs.gov/gip/gw/glossary.html >.
>
> United States Geological Survey what is groundwater?, Viewed 30 October 2012, <http://pubs.usgs.gov/of/1993/ofr93-643/>.
>
> Oregon Water Science Centre glossary of hydrologic terms. Viewed 30 October 2012, <http://or.water.usgs.gov/projs_dir/willgw/glossary.html#A>.
>
> Houghton Mifflin (USA) website for teachers; includes glossary of geological terms. Viewed 30 October 2012, <http://college.hmco.com/geology/resources/geologylink/index.html>.

Anticline: an arch-shaped fold of originally flat lying sedimentary layers.

Aquiclude: a geological material that does not transmit water. Generally, this definition is meant to imply extremely limited movement of water even at the scale of geological time.

Aquifer: a permeable geological material that can transmit significant quantities of water to a bore, spring, or surface water body. Generally, 'significant' is defined based on human need, rather than on an absolute standard.

Aquitard (confining layers): a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

Artesian: a general term used when describing certain types of groundwater resources. **Artesian water** is underground water confined and pressurised within a porous and permeable geological formation. An **artesian aquifer** has enough natural pressure to allow water in a bore to rise to the ground surface. **Sub-artesian water** is water that occurs naturally in an aquifer, which if tapped by a bore, would not flow naturally to the surface. **Artesian conditions** refer to the characteristics of water under pressure. **Artesian springs** result when water from a confined aquifer naturally reaches the surface, either because of faulting which fractures overlying aquitards, or because the aquifer is close to the surface at the margins of the basin.

Basement: the crust below the rocks of interest. In hydrogeology it means non-prospective rocks below accessible groundwater. Commonly refers to igneous and metamorphic rocks which are unconformably overlain by sedimentary beds or cover material, and sometimes used to indicate 'bedrock' (i.e. underlying or encasing palaeovalley sediments).

Basin inversion: the relative uplift of a sedimentary basin to surrounding low lying areas from a variety of processes, with compressional folding being a dominant process referred to in this report.

Bolide: an extraterrestrial body which impacts the earth at high velocity. Generic term used to imply that the precise nature of the impacting body is unknown.

Craton: a large stable mass of rock that forms a major structural unit of the Earth's crust.

Depocentre: centre of deposition within a sedimentary basin. This is usually the deepest point within a sedimentary basin.

Diachronous: apparently similar features or events that vary in age at different locations. These features can be sedimentary rocks, erosional surface, or areas of uplifts.

Drainage division: the area of land where surface water drains to a common point. There are 12 major drainage divisions in Australia. At a smaller scale, surface water drainage areas are also referred to as river basins, catchments, or watersheds.

Drawdown: the lowering of groundwater level resulting from the extraction of water, oil or gas from an aquifer.

Elluviated: the lateral or downward movement of suspended material in by percolation of water.

Eustatic: global sea level change.

Facies: a distinctive rock unit that forms under certain conditions of sedimentation. In the context of this report, the term facies represents the change of depositional environment of sediments

Fluvial sediments: sediments deposited by rivers.

Geological basin: layers of rock that have been deformed by mega-scale geological forces to become bowl-shaped. Often these are round or oblong with a depression in the middle of the basin.

Geological formation: geological formations consist of rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time.

Groundwater (hydrogeology): water that occurs within the zone of saturation beneath the Earth's surface. The study of hydrogeology focuses on movement of fluids through geological materials (e.g. layers of rock).

Groundwater basin: a groundwater basin is a non-geological delineation for describing a region of groundwater flow. Within a groundwater basin, water enters through recharge areas and flows toward discharge areas.

Groundwater divide: a divide that is defined by groundwater flow directions that flow in opposite directions perpendicular to the location of the divide.

Groundwater flow (hydrodynamics): within a groundwater basin, the path from a recharge area to a discharge area is referred to as a groundwater flow system, where travel time may be as short as days or longer than centuries, depending on depth. The mechanics of groundwater flow – the hydrodynamics – are governed by the structure and nature of the sequence of aquifers.

Groundwater flow model: a computer simulation of groundwater conditions in an aquifer or entire groundwater basin. The simulations are representations based on the physical structure and nature of the sequence of aquifers and rates of inflow – from recharge areas – and outflow – through springs and bores.

Groundwater level: in this report refers to the elevation of equivalent freshwater hydraulic head at 25 °C

Groundwater recharge and discharge: recharge occurs where rainfall or surface water drains downward and is added to groundwater (the zone of saturation). Discharge occurs where groundwater emerges from the Earth, such as through springs or seepage into rivers.

Half-graben: a valley formed by movement on a fault.

Hydrodynamic divide: see *groundwater divide*.

Hydrostratigraphy (hydrogeological unit): geological formations that have similar hydraulic properties and are connected laterally. These are grouped as a single hydrogeological unit or hydrostratigraphic layer.

Inversion (basin): see *basin inversion*.

Intake beds: areas where the major aquifers of the GAB are exposed at the ground surface and become recharged. The GAB intake beds are generally located along the western slopes of the Great Dividing Range.

Lateritisation: a soil-forming process occurring in humid tropical and subtropical areas. The process involves the chemical weathering and deposition of metallic oxides (laterite) in and under the uppermost soil layer which contains organic matter.

Leaky aquitard: a semi-permeable geological material that can transmit groundwater. Although regionally non-productive, it may be classed as a very low yielding aquitard that is sometimes used to produced groundwater where no other source is available.

Lithology: the character of a rock; its composition, structure, texture, and hardness.

Lithostratigraphy: the classification by physical rock type of sedimentary layering or stratification. Changes in rock type resulting from changes in depositional environment are known as depositional facies change.

Orogeny, Orogenesis: the forces and events that lead to the deformation of the Earth’s lithosphere (crust and upper mantle) resulting in the formation of mountains.

Paleochannel: refers to the main channel of ancient rivers, sometimes called the ‘thalweg’, the lowest point of incision along the river bed where coarser sediments are commonly deposited. Former river channels that are recognised in the surface (from aerial or satellite images) or subsurface (typically in aerial electromagnetic surveys or drilling).

Palaeosol: former soil preserved by burial under lithified sediments or volcanic deposits.

Paludal: sediment accumulated in a marsh environment.

Partial aquifer: A permeable geological material with variable groundwater yields that are lower than in an aquifer and range from fair to very low yielding locally.

Permeability: a measurement describing the ability of any fluid (water, oil) to pass through a porous material. Values vary widely, with higher values corresponding to aquifers (i.e. highly permeable) and lower values corresponding to aquitards (i.e. less permeable).

Phyllite: a metamorphic rock similar to schist with coarser grains.

Saprolite: weathered or decomposed bedrock.

Schist: a metamorphic rock that has parallel bands of minerals.

Senescence: aging.

Seismics, seismic survey: the study of vibrations of the earth and their propagation through the ground. A seismic survey, is the acquisition of seismic data using artificial sources to induce vibrations in the earth. Provides information on the lateral extent and depth of rock layers.

Spring complex: clusters of springs that share similar water chemistry and are related to common geological features are known as ‘**spring groups**’; clusters of spring groups that share similar geomorphological settings and are referred to as ‘spring complexes’; clusters of spring complexes are referred to as ‘**supergroups**’.

Subduction: the downward movement of a tectonic plate under another resulting from the convergence of the two plates. Considered a force in orogenies.

Subsidence: downward movements of the Earth’s crust.

Syncline: a basin or ‘U’ shaped fold of originally flat lying sedimentary layers.

Tight aquitard: a semi-permeable geological material with very low to negligible transmission of water on a regional scale.

Unconformity: a boundary between two rock units that represents a significant period of time in which no sediment is deposited.

Volcanogenic sediment: sediments containing material that is derived from volcanic activity.

Watertable: the surface where the groundwater level is balanced against atmospheric pressure. Often, this is the shallowest water below the ground.

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