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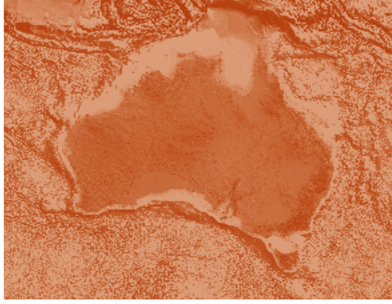

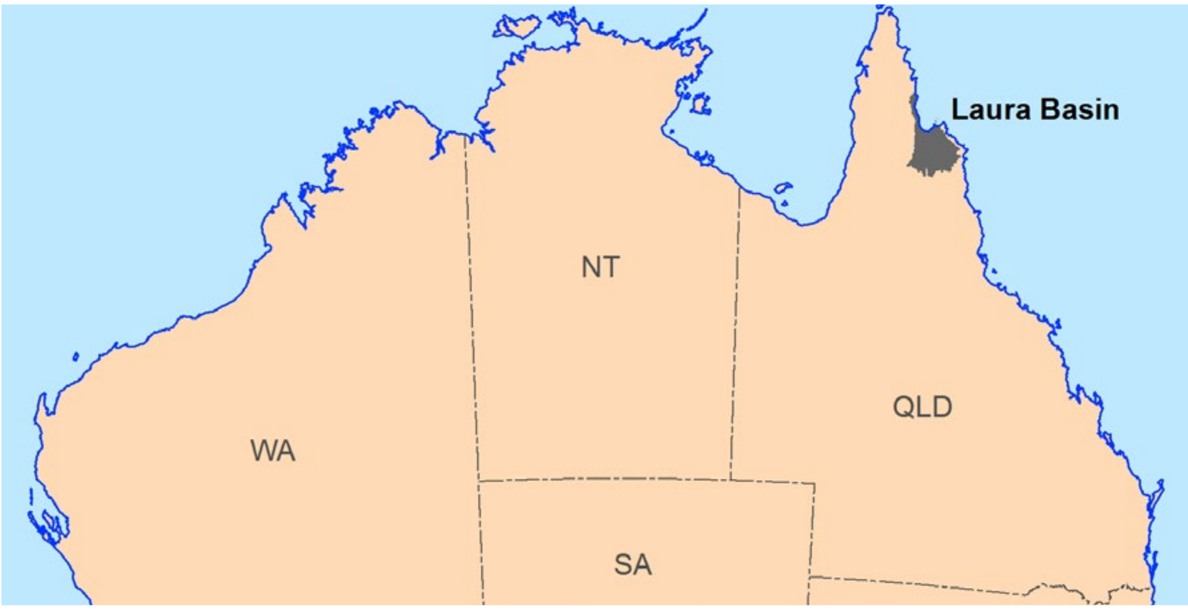

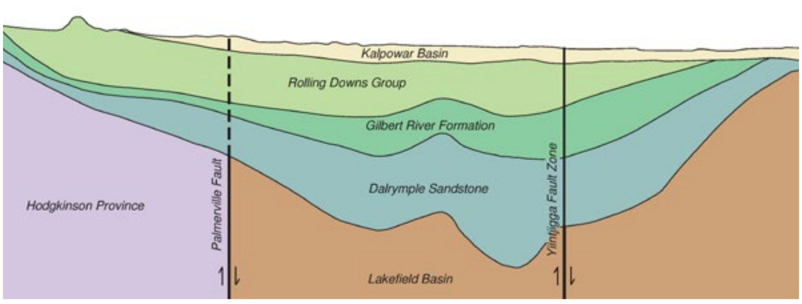

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Regional Hydrogeological Characterisation of the Laura Basin, Queensland

Final technical report for the National Collaboration Framework Regional Hydrogeology Project

Yates, G., Bell, J. G., Fontaine, K., Lewis, S. J., Ransley, T. and Tan, K. P.

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Executive summary

The Laura Basin is a geological basin on south-eastern Cape York Peninsula in northern Queensland. The basin occupies a depression in the modern landscape bounded by the Great Dividing Range in the west and sandstone scarps in the south and the east. The Laura Basin is a sedimentary basin containing rocks deposited between 168–102 million years ago (Ma) during the Middle Jurassic and Early Cretaceous (Mesozoic). Deposition was initiated by thermal sagging of the underlying Permian Lakefield Basin. The strata of the Laura Basin are continuous with the nearby Carpentaria Basin, and thus the Great Artesian Basin (GAB) sedimentary sequence. Overlying the Laura Basin are Cenozoic sedimentary deposits of the Kalpowar Basin, which have been intermittently deposited since approximately 60 Ma.

There are currently no operating coal mines or coal seam gas fields within the Laura Basin. However, there is one proven black coal resource in the Bathurst Range. The Bathurst Range coal deposit (EPC2334) is currently under application for mining as the Wongai Project, a joint venture between the Kalpowar Aboriginal Lands Trust and Aus-Pac Capital Pty Ltd (with an Environmental Impact Statement in preparation). The coal is a high quality coking (thermal) coal with a total resource of 47 Mt. Approximately 25% of the onshore area of the Laura Basin is covered by coal exploration tenements and coal exploration has occurred in the basin for many years (dating back to 1879). The 1960–1980's saw significantly increased exploration for coal in the Basin, and there was also an active petroleum exploration program which targeted the thick Mesozoic and Permian strata in the centre of the basin. Aside from the Bathurst Range, no other economic coal or CSG resources have been identified, although much of the exploration has found thin bands of coal throughout the strata of the Laura Basin and the underlying Lakefield Basin. Two small uneconomic deposits, in up-thrown fault blocks of Permian rocks in the south-east and the south-west of the basin, were mapped in the 1970–1980s; the Little River Coal Measures and the Normanby Formation Coal (previously known as Oaky Creek Coal measures).

The Laura Basin is a bowl-shaped geologic basin with the onshore component of similar east-west and north-south dimensions. The strata have a maximum thickness of about 1 km in the northern-central onshore basin. There are three major stratigraphic units, the Middle to Upper Jurassic Dalrymple Sandstone, deposited in lagoonal-fluvial environments; the Jurassic to Lower Cretaceous Gilbert River Formation, deposited in lagoonal to marginal marine environments; and the Cretaceous (Late Aptian to Albian) Rolling Downs Group, deposited in a shallow marine environment. The rocks of the Dalrymple Sandstone are dominated by sandstone with lesser claystone, siltstone, conglomerate, tuff and coal. The rocks of the Gilbert River Formation are dominantly clay-rich sandstone that is locally glauconitic and interbedded with minor calcareous siltstone, claystone and conglomerate. The Rolling Downs Group has a basal shale unit (the Wallumbilla Formation) with minor siltstone and conglomerate bands overlain by marine silty and sandy claystone. The sediments of the overlying Kalpowar Basin are much thinner in comparison to those of the Laura Basin, and can be grouped into three continuous cycles of erosion and deposition. The Kalpower Basin sediments mainly consist of semi-consolidated to consolidated sand/sandstone, gravel, conglomerate and clay.

The principal aquifers of the Laura Basin are the Gilbert River Formation and the Dalrymple Sandstone. Due to the relatively limited data coverage and the low intensity of groundwater use, the Dalrymple Sandstone and the Gilbert River Formation are commonly classed as a single aquifer hydrostratigraphic unit. There is potentially a region of Normanton Formation sandstone (stratigraphically at the top of the Rolling Downs Group) in the north-eastern Laura Basin. This sand-rich facies of the Rolling Downs Group also functions as an aquifer and may be locally important for spring discharge, particularly on the southern side of Bathurst Range. There are also aquifers in the Cenozoic sediments of the Kalpowar Basin that overlie the Laura Basin.

The main confining unit (aquitard) of the GAB sedimentary sequence is the Rolling Downs Group, in particular the Wallumbilla Formation. The Wallumbilla Formation is stratigraphically located at the base of the Rolling Downs Group, and forms an aquitard that is thickest and most extensive in the central parts of the Laura Basin. It is absent in the north-east of the basin and around the eastern and southern rim and also thins towards the south-west.

The investigation reported here assessed existing datasets and literature to develop an integrated basin-scale conceptual understanding of regional groundwater flow systems in the Laura Basin. This included a hydrostratigraphic framework that identifies the main water-bearing geological formations (aquifers), and their key hydrogeological parameters and connectivity relationships. Additionally, this study also identified CSG and coal-mining activities with potential to impact on water resource systems (groundwater and surface water) beyond tenement boundaries.

Groundwater provides about 95% of the water supply within the basin and is used primarily for stock and domestic purposes (cattle grazing), and water supply for the town of Laura. Groundwater use is generally of low intensity and is typically concentrated around the edge of the basin where the main Mesozoic aquifer outcrops or occurs close to the surface. Artesian groundwater pressures are recorded for many bores and there is currently about 588 ML/yr of groundwater use in the basin. There is limited use of groundwater from the Cenozoic sediments of the Kalpowar Basin.

Previous hydrogeological studies have included the Laura Basin within regional investigations of the groundwater resources of Cape York Peninsula. The hydrostratigraphic units defined by these studies have informed the aquifer-aquitard framework developed in this study. However, there has been limited stratigraphic mapping across the whole basin, as past work has mainly focused on specific parts of the basin for petroleum or coal resource exploration. One of the major tasks of this project was to interpret the stratigraphy of existing borehole logs and map the thickness of the main stratigraphic units at the basin-scale.

Generally, there is limited information available to characterise the groundwater systems of the Laura Basin. In particular, there are <30 hydraulic head measurements for bores in the Mesozoic aquifer and <10 in the Cenozoic aquifers. There are also very few groundwater chemistry records, and identifying the exact hydrostratigraphic unit they are sampled from is difficult due to the variable quality of bore construction records. There are no time-series hydraulic head or groundwater chemistry records available for any bores in the basin, and previous monitoring has been opportunistic for stand-alone research projects, rather than enabled by a systematic and entrenched monitoring program. This affects the capacity to understand groundwater system changes over-time, and particularly its response to stresses (for example groundwater extraction or changes to recharge). Recharge and discharge components are poorly understood and no previous study attempted to analyse the volumes of these components at a basin-scale. Consequently, a new water balance components analysis for this study helped bring together available data to improve understanding of groundwater recharge and discharge in the Laura Basin, and provided a tool for highlighting major data and knowledge gaps.

Desk-based studies have identified groundwater dependent ecosystems for many watercourses across the Laura Basin. Baseflow to streams and lakes and evapotranspiration from the watertable are significant components of the water balance that are currently poorly informed and difficult to estimate. No field-based validation of the groundwater dependent ecosystems in the basin is available, and groundwater discharge processes are poorly constrained. Examination of these potential processes is included in this report, although the significant knowledge gaps restrict both the level of detail and the level of confidence associated with this examination.

New work undertaken for this study included:

- Collation and interrogation of data available for the hydrogeological characterisation of the Laura Basin. This involved extraction of data from state databases and national datasets, the interrogation of open-file company exploration reports and compilation and interrogation of existing literature on the Laura Basin.
- Collation of the main environmental assets and information where available on their water dependence.
- Updated description of the coal resources of the Laura Basin.
- Detailed analysis of the geology and stratigraphy of the Laura Basin such as:
  - Stratigraphic classification of strata from bore lithology records.
  - Development of isopachs of the main stratigraphic units.
- Updated hydrostratigraphic conceptualisation integrating all relevant datasets.
  - Significant within these findings is the improved conceptualisation of the distribution and extent of sub-units of the Rolling Downs Group, and the extent to which the Wallumbilla Formation is a regional aquitard in the Basin.
  - The thickness of the Mesozoic aquifer was mapped.
- Mapping of the potentiometric surface of the Mesozoic aquifer has enabled improved characterisation and conceptualisation of flow systems within the basin.
- A description of basin-scale and sub-regional groundwater flow systems, including the potential influence of faults and lithofacies changes on flow system compartmentalisation and aquifer interconnectivity.
- Development of a first approximation water balance. This is limited by the data availability in the basin and some components have not been estimated. Volumes for estimated components are uncertain due to the paucity of data. The water balance essentially provides a summary of the key components of groundwater recharge and discharge and better enables the identification of knowledge gaps.
- A summary of protection considerations for the groundwater resources of the Laura Basin.
- Identification of the key knowledge in understanding of the groundwater systems of the Laura basin and their interactions with key environmental assets.

The study is focused at the basin-scale. Recommendations for future work that would improve the understanding of the groundwater systems at this scale are:

- A field program focussing on the collection of targeted hydraulic head information across the basin and across named aquifer units. This includes time-series monitoring of groundwater bores in both the Cenozoic aquifers and the Mesozoic aquifer to better understand groundwater dynamics. Ideally this would include the installation and ongoing monitoring of nested monitoring bores to:
  - Better understand the interactions between the Cenozoic aquifers and the Mesozoic aquifer (bores would be nested in the Gilbert River Formation and the Dalrymple Sandstone, in both the areas where the Mesozoic rocks outcrop, and in areas where they are covered by the Kalpowar Basin sediments; one nested monitoring bore would ideally be located towards the centre of the basin where data is most sparse and include bores in the Dalrymple Sandstone, Gilbert River Formation and Cenozoic aquifer),
  - Better understand groundwater interactions within the Mesozoic aquifer, and
  - Better understand the response of aquifers to system stresses, such as groundwater extraction and variations in recharge conditions.
- Investigation of the role and significance of faults acting as either barriers or conduits to groundwater flow.
- Field surveys of desktop-identified groundwater dependent ecosystems, focusing on potential groundwater discharge mechanisms, source aquifer and groundwater discharge volumes.
- A study to better quantify groundwater recharge to the Mesozoic aquifer.

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Abbreviations and acronyms

ABS	Australian Bureau of Statistics
ADWG	Australian Drinking Water Guidelines
AEM	Airborne Electromagnetics
AGSO	Australian Geological Survey Organisation (former name for Geoscience Australia)
AHD	Australian Height Datum
ALUM	Australian Land Use and Management
ANRA	Australian Natural Resource Atlas
ASL	Above Sea Level
ASRIS	Australian Soil Resource Information System
ATP	Authority to Prospect
AWR	Australian Water Resources audit
BFI	Baseflow Index
BMR	Bureau of Mineral Resources (former name for Geoscience Australia)
BOM	Bureau of Meteorology
BRS	Bureau of Rural Sciences
BSL	Below Sea Level
CAPAD	Collaborative Australian Protected Area Database
CA PWA	Central Adelaide Prescribed Wells Area
CO_2	Carbon Dioxide
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CYPLUS	Cape York Peninsula Land Use Strategy
DAFF	Department of Agriculture, Fisheries and Forestry (Australian)
DEM	Digital Elevation Model
DERM	Department of Environment, Resources and Mines (Queensland)
DIWA	Directory of Important Wetlands in Australia

DNRM	Department of Natural Resource Management (Queensland)
DR	Development Report
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
EC	Electrical Conductivity
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
EL	Exploration Licence
ELA	Exploration Licence Application
EPBC	Environment Protection and Biodiversity Conservation Act
ET	Evapotranspiration
GA	Geoscience Australia
Ga	Billions of years ago
GAB	Great Artesian Basin
GBR	Great Barrier Reef
GDE	Groundwater Dependent Ecosystem
GGSS	Greenhouse Gas Storage Solutions
GIS	Geographic Information System
GL	Gigalitre: one billion litres (equivalent to 1000 megalitres, ML)
GMWL	Global Meteoric Water Line
GMA	Groundwater Management Area (Victoria)
GMU	Groundwater Management Unit
GSQ	Geological Survey of Queensland
IBA	Important Bird Areas
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
ILUA	Indigenous Land Use Agreement
IUCN	International Union for the Conservation of Nature and Natural Resources
kL	kilolitre: 1000 litres (cubic litre: m^3)
LMWL	Local Meteoric Water Line
Ma	Millions of years ago

Mcf	Million cubic feet
ML	Megalitre: one million (1,000,000) litres
MODIS	Moderate Resolution Imaging Spectroradiometer
Mt	Million tonnes
NCF	National Collaboration Framework Project Agreement
NCGRT	National Centre for Groundwater Research and Training
NGIS	National Groundwater Information System
NLWRA	National Land and Water Resources Audit
NPA	National Partnership Agreement
NRM	Natural Resource Management
NTU	Nephelometric Turbidity Units
NVIS	National Vegetation Information System
NWC	National Water Commission
OWS	Office of Water Science
OZMIN	Australian Mineral Deposits database
PGE Act	Petroleum and Geothermal Energy Act
pMC	percent Modern Carbon
PER	Public Environmental Report
Qa	Quaternary alluvium
QDEX	Queensland Digital Exploration Reports system
QDNR	Queensland Department of Natural Resources
SA	South Australia
SEO	Statement of Environmental Objectives
SKM	Sinclair Knight Merz
SMOW	Standard Mean Ocean Water
SRTM	Shuttle Radar Topographic Mission
SWL	Standing Water Level
TDS	Total Dissolved Solids

Units

Cm	centimetres
m	metres
km	kilometres
L/s	litres per second
Mm/yr	millimetres per year
gph	gallons per hour
ppm	parts per million
mg/L	milligrams per litre
mS/m	milli-Siemens per metre
S/m	Siemens per metre
µS/cm	micro-Siemens per centimetre
kL	kilolitre: 1,000 litres (cubic litre: m^3)
ML	Megalitre: one million (1,000,000) litres
GL	Gigalitre: one billion litres (equivalent to 1,000 megalitres, ML)
Mcf	Million cubic feet

1 Introduction

1.1 Project overview

This hydrogeological study of the Laura Basin is one of a number of research projects funded by the OWS as part of the wider program of research commissioned by the Department of the Environment (http://www.environment.gov.au/coal-seam-gas-mining/index.html). The overarching aim of this research program is to increase the scientific knowledge base used to underpin regulatory decisions on CSG and large coal mining developments. The broader research program is designed to:

- assist better decision making, regulation, natural resource management and industry practice
- build knowledge about the highest risks to freshwater resources, land and ecosystems, and
- help provide data and knowledge that can support bioregional assessments in priority areas.

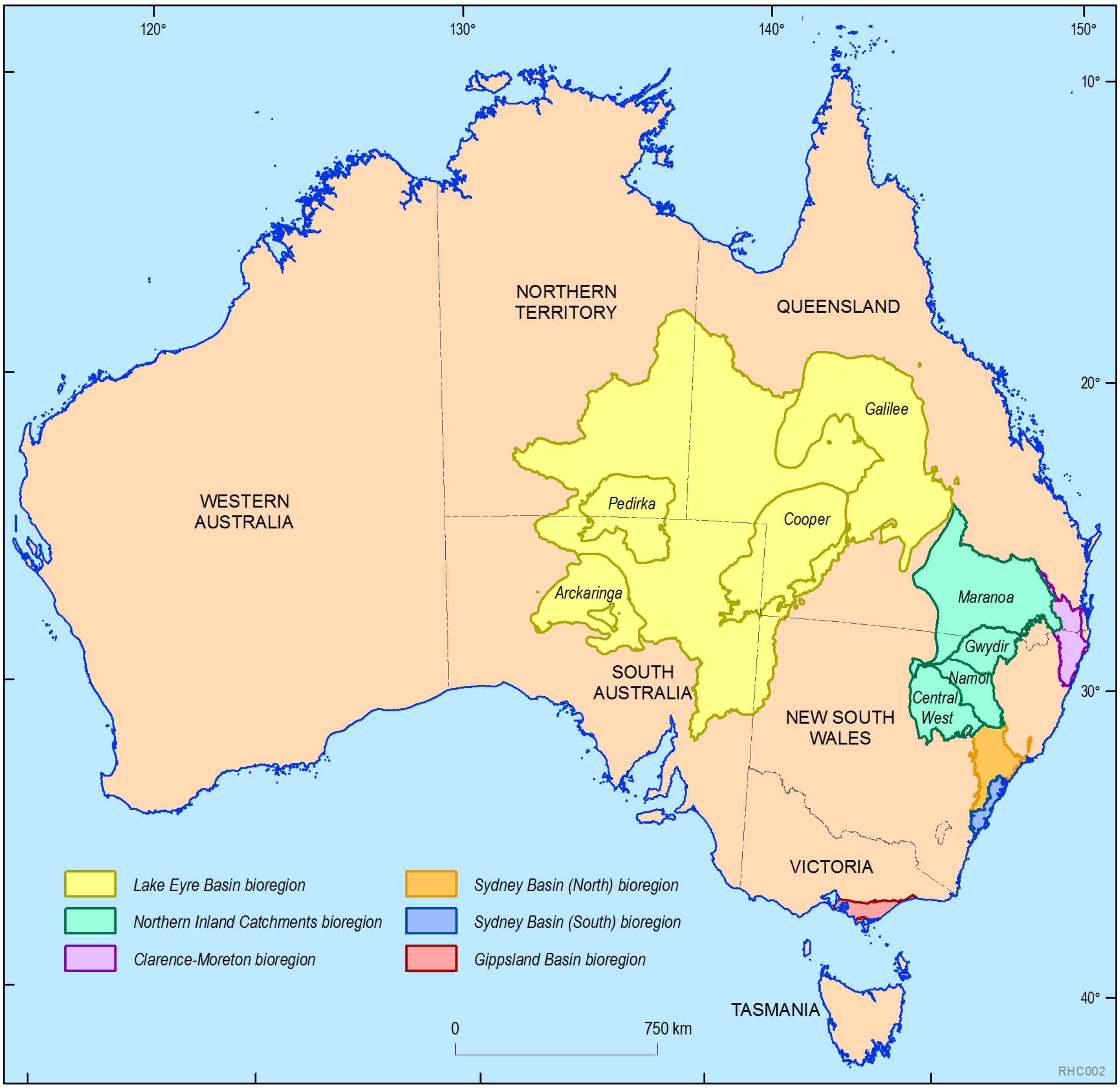


Figure 1.1. Initial bioregional assessment areas.

1.1.1 Geoscience Australia's role in the project

As the custodian of national geoscientific and geospatial data and knowledge GA is well positioned to contribute to the delivery of the IESC research agenda. In recognition of this capability, the Department of the Environment entered into a strategic partnership with Geoscience Australia by signing an overarching Collaborative Head of Agreement in April 2012 and a specific National Collaboration Framework Project Agreement in relation to an integrated program of work to support the assessment of coal seam gas and coal mining developments on groundwater resources in May 2012.

One of the research projects identified under the National Collaboration Framework Project Agreement was the *Regional Hydrogeological Characterisation of Priority Coal Basins Not Covered by Initial Bioregional Assessments*. This project, which focuses in this report on the Laura Basin in Queensland, aligns with the Committee's research priority 1 (aquifers).

The support and funding for this GA project recognised that several medium- to smaller-scale coal-bearing basins in Australia would not initially be investigated as part of the Bioregional Assessment program (Figure 1.1). Australia has approximately 25 onshore sedimentary basins containing significant deposits of brown and black coal (Figure 1.2). These resources are of variable size and geological age and occur in all states, although the largest and most economically significant basins are in Queensland, New South Wales and Victoria.

Figure 1.2. Sedimentary basins in Australia containing identified in situ resources of brown and black coal (after Jaireth and Huleatt, 2012).

1.2 Project objectives and outcomes

The main objective of the *Regional Hydrogeological Characterisation of Coal Basins Not Covered by Initial Bioregional Assessments* project is to develop an improved knowledge base relating to the hydrogeological and groundwater resource characteristics of coal-bearing sedimentary basins that are of strategic national importance but are not the subject of initial Bioregional Assessments. This work has focused particularly on developing an integrated basin-scale conceptual understanding of regional groundwater flow systems, including a hydrostratigraphic framework that identifies the main water-bearing geological formations (aquifers), and their key hydrogeological parameters and connectivity relationships.

1.3 Project basins of interest

Comprehensive knowledge of regional hydrogeological systems within a coal basin provides an important baseline of information that is critical for understanding impacts on water-related assets caused by CSG or coal mining developments. These impacts may affect both surface water- and groundwater-dependent resources, and can involve local- to regional-scale hydrological flow systems.

Preliminary assessment carried out by OWS and GA recognised eight coal-bearing sedimentary that will not be subjected to the initial phase of Bioregional Assessments (Figure 1.3).

These include:

1. Laura Basin (Qld);
2. Maryborough Basin (Qld);
3. Murray Basin (NSW – SA – Vic.);
4. Oaklands Basin (NSW);
5. Otway Basin (Vic – SA);
6. Polda Basin (SA);
7. St Vincent Basin (SA); and
8. Styx Basin (Qld).

The OWS and GA agreed that these eight basins would be the focus of the assessment program carried-out for the *Regional Hydrogeological Characterisation of Coal Basins Not Covered by Initial Bioregional Assessments* project. To maximise the effectiveness of available resources, GA proposed to focuse on the highest priority areas of the Laura, Maryborough, Otway and St Vincent Basins (see Appendix 1 for justification of basin prioritisation).

The information, data, analysis and outputs from this project provide an enhanced and up-to-date knowledge base for the basins of interest. This information will result in the OWS being better informed about water resources and groundwater systems of the coal basins assessed for this study, including recognising the key data and knowledge gaps that may significantly limit the extent of current understanding.

Figure 1.3. Coal-bearing sedimentary basins in eastern and southern Australia identified for this project.

1.4 Project scope

The scope of this project was restricted to desktop assessment. The work program involved the collation, analysis and interpretation of a variety of existing geological, hydrological and other relevant datasets such as topographic, geophysical and remotely sensed data. Relevant scientific and technical literature on the study areas was collected and evaluated. Local subject-matter experts were also approached for consultation and discussion, including professionals employed by state government agencies in Queensland. No new (field or laboratory) data was collected for this study.

1.4.1 In-scope activities

The scope of work included:

- provision of regional hydrogeological characterisations to support assessment of CSG and coal mining developments for selected coal basins not covered by initial Bioregional Assessments;
- a multidisciplinary characterisation of the geology and hydrostratigraphy of the basins of interest; and
- identification of CSG and coal-mining activities with potential to impact on water resources (groundwater/surface water).

1.4.2 Out-of-scope activities

The following activities were considered beyond the scope of this project:

- the collation, analysis and interpretation of hydrogeological and groundwater datasets and information from areas outside of the eight coal basins specified for investigation;
- acquisition of new field-based datasets, such as through drilling of new bores or acquisition of geophysical datasets;
- acquisition of new groundwater analytical data through laboratory testing and analysis;
- detailed environmental impact or vulnerability risk assessments associated with potential CSG or coal mining activities;
- detailed analysis relating to ecology, biology, or surface water features and impacts; and
- numerical modelling simulation of current or projected scenarios (e.g., associated with CSG or coal mine developments) for groundwater volumes/pressures (head), flow or solute transport.

1.5 Report structure and content

1.5.1 Overview of project reports

The key outputs developed by GA for Phase 1 of this project are a series of four technical reports focused on the regional hydrogeology and groundwater systems of the Laura, Maryborough, Otway, and St Vincent basins. Each basin report is a stand-alone document that provides analysis, interpretation and summary of existing data and information compiled on the biophysical, hydrogeological and groundwater systems. The reports are supported by a digital reference library (Endnote format) comprising relevant datasets and existing literature, such as scientific journal articles, government reports, and other technical publications.

In addition to the content provided here, GA was engaged to collate, analyse and report on the hydrogeochemistry data available for the Laura Basin to characterise the following:

- The hydrogeochemistry of the Laura Basin, particularly the groundwater systems within the coal-bearing strata of the Laura Basin;
- the potential impacts of coal mining for the hydrogeochemical processes in the basin; and

- data gaps and future monitoring considerations in the context of possible future development of coal resources in the Laura Basin.

This report has not been undertaken in isolation of the hydrogeochemical characterisation project, although the two projects have released stand-alone products. Further details on the hydrogeochemistry of the Laura Basin can be found in the hydrogeochemistry project report (Ransley *et al.*, 2013).

1.5.2 Structure and content of this report

This report focuses specifically on the regional hydrogeological characterisation of the Laura Basin in far north Queensland. The region included in the study (Chapter 3) is bounded by the Normanby River Catchment and the Laura Basin hydrogeological boundary as defined by the water table mapping undertaken by Kellett *et al.* (2012).

This report includes the following main elements:

- Geography of the Laura Basin including physical geography, land use, environmental assets and resource governance (Chapter 3);
- Geology and geological setting of the Laura Basin (Chapter 4);
- Coal resources and coal resource development (Chapter 5);
- Hydrogeology of the Mesozoic Laura Basin and the overlying Cenozoic Kalpowar Basin (Chapter 6);
- Identification of data gaps and knowledge gaps (Section 6.7, Chapter 8),
- Study conclusions, including a summary of the key regional resource issues in the basin (Chapter 7); and
- Recommendations for future work to address the key knowledge and data gaps (Chapter 9).

For reference, a glossary of geological and groundwater-related terms is also provided following the References section. There are also 4 appendices included in this report. Appendix 1 outlines the rationale for selecting the four basins investigated for this Regional Hydrogeological Characterisation Project. Appendix 2 provides a summary of the relevant resource governance arrangements and existing legislation that are relevant for the management and development of groundwater resources, and coal and CSG resources in Queensland. Appendix 3 provides the current version (2012) of the International Chronostratigraphic Chart, as a reference for the various geological age terms used in this report. The final appendix (Appendix 4) contains a summary of the various coal exploration reports from previous exploration programmes in the Laura Basin.

2 Investigative approach and data summary

2.1 Study approach

A comprehensive desktop review of existing datasets and literature relevant to understanding the hydrogeological regime of the Laura Basin was undertaken for this project. Geological, groundwater and surface water information was collected from state and national databases, existing literature and map publications. Information on the coal resources, environmental assets and human consumptive use of groundwater was also collated.

A key knowledge gap identified early in the project was the lack of existing stratigraphic interpretation of groundwater bore data in the Laura Basin. Consequently, stratigraphic interpretation of available groundwater bore lithology records was undertaken in this project to develop the hydrostratigraphic foundation for the regional hydrogeological characterisation of the Laura Basin.

Groundwater data was interrogated to develop a potentiometric surface of groundwater flow systems in the Laura Basin (as much of this information was previously unavailable). A new potentiometric surface map was developed for this project using selected input datasets. Subsequently, groundwater flow systems were described.

Available information was collated and reviewed to describe aquifer recharge processes, aquifer connectivity and aquifer interactions, structural influences on aquifer connectivity and groundwater, and surface water to groundwater interactions. The key data used to inform this study included climate data, stream gauging data groundwater chemistry, groundwater hydraulic heads, geological mapping and the Groundwater Dependent Ecosystems (GDE) Atlas (BoM, 2012b). Based on the new conceptualisations developed for this project, a first approximation water balance components analysis was undertaken to compare the major groundwater inflow (recharge) and outflow (discharge) components.

Key knowledge and data gaps were identified. Finally, the key coal and groundwater resource issues were summarised and overall recommendations made for future work to address important data gaps.

Queensland Government officers within Queensland Department of Natural Resources and Mines (DNRM) and Queensland Department of Environment and Heritage Protection (DEHP) were contacted to obtain information and discuss elements of the findings of the project.

2.2 Previous work

Prior to this study, only a limited amount of research had been undertaken on the regional geological, hydrogeological and surface water systems of the Laura Basin. The desk-top analysis undertaken for the current project showed that data gaps impact on the level of understanding of these systems. The level of detailed analysis applied to existing data by previous workers has varied because of the different focus and objectives of previous studies. The extent and nature of integration of the existing data and knowledge towards understanding the hydrogeological system of the Laura Basin has also differed between past projects. Importantly, the Laura Basin has commonly been investigated only as a part of more regional-scale studies, e.g., for all of Cape York. In addition, no study has considered the regional-scale impacts of coal resource development for water dependent ecosystems or other consumptive uses.

The Laura Basin has featured in two regional-scale hydrogeological studies covering Cape York Peninsula. These are:

- Groundwater Resources of Cape York Peninsula, Cape York Peninsula Land Use Strategy (CYPLUS) (Horn *et al.* 1995). This study covered the entire Cape York Peninsula area.
- Water Resource Assessment for the Carpentaria Region (Smerdon *et al.* 2012). This project covered the entire Carpentaria region of the Great Artesian Basin.

Focussing on surface water systems, the Laura Basin was included in the following project:

- Water in the Northern North-East Coastal Drainage Division (CSIRO 2009). This project covered the water resources of nine river basins, across an area of 47,000 km^2.

The Laura Basin was also included in the Queensland Carbon Dioxide Geological Storage Atlas (GGSS, 2011) which assessed the potential of Queensland sedimentary basins as reservoirs for CO_2. The findings of this report indicated a low suitability for CO_2 sequestration.

There has been extensive coal resource exploration within the Laura Basin and much of the geological understanding of the Basin has been improved as a result of this work. In addition, the Laura Basin has been covered by work undertaken to characterise the geology of Cape York Peninsula by the Queensland Geological Survey and Geoscience Australia (and its predecessor organisations such as the Australian Geological Survey Organisation (AGSO), and the Bureau of mineral resources (BMR) e.g., (De Keyser and Lucas 1967; De Keyser and Lucas 1968; Gibson *et al.* 1972; Wellman 1995; Bain and Draper 1997b; McConachie *et al.* 1997). However, no comprehensive mapping of the stratigraphy or geological structural elements of the Laura Basin has previously been published.

A full list of references acquired for this study is provided digitally as an Endnote Library accompanying this report. These references and key datasets have informed the findings of the current project and are referenced throughout the report.

2.3 Data collection

2.3.1 Surface water and climate data

Surface water data and climate data were downloaded from the Bureau of Meteorology (BOM) website for sites across the Laura Basin and the Laura-Normanby River Catchment. The specific data sources are referenced throughout the report as these data are presented. Stream gauge data were also downloaded from the Queensland Government Water Monitoring Portal managed by DNRM.

2.3.2 Groundwater and geological data

All existing borehole data was compiled from Queensland Government groundwater bore databases, Geoscience Australia's petroleum well database, and open-file company exploration reports downloaded from the online resource, Queensland Exploration Reports (QDEX), Department of Natural Resources and Mines, Queensland Government. Borehole information was also supplemented by seismic data interpretation from open-file company exploration reports and work previously undertaken to map the basement of the Great Artesian Basin (Nelson *et al.* 2012).

There are two databases that include groundwater bores available from Queensland, DNRM. These are the Healthy Headwaters Database (DNRM 2012a) and the Queensland Bore Database (DERM 2011). In the Laura Basin, these databases include the same bore records, although they differ slightly with respect to the tables of information associated with each bore. Both databases were interrogated for information, as was the National Groundwater Information System (NGIS) managed by the Bureau of Meteorology. These databases are discussed in more detail in Section 4.3.

Boreholes are typically located towards the margins of the Laura Basin. Five deep wells (>1,000 metres) have been drilled at various times from 1960–1990 in the central parts of the basin for petroleum exploration and stratigraphic characterisation.

Other information contained within the bore databases which proved useful for the study included pump testing results, water level data, bore construction records, groundwater chemistry records and information on the artesian or sub-artesian nature of each bore. In the Laura Basin, these records have been maintained and/or populated to varying degrees, for example bore construction records are missing for many bores; and water level data, water chemistry and pump testing records are very sparsely distributed.

In summary, the Laura Basin is an extremely data-limited area with data quality issues that have impacted on analysis and interpretation for this study.

2.4 New analysis and outputs

The project has brought together diverse datasets to develop a new conceptual model of the hydrogeology of the Laura Basin. The focus of the conceptual model is at the regional scale.

Work completed for this study includes:

- Collation and interrogation of data available for the hydrogeological characterisation of the Laura Basin. This involved extraction of data from state databases and national datasets, the interrogation of open-file company exploration reports, compilation and interrogation of existing literature on the Laura Basin. A summary of the main environmental assets was collated. Included in this was a summary of information available on their groundwater dependence. Updated description of the coal resources of the Laura Basin.
- Detailed analysis of the geology and stratigraphy of the Laura Basin, including:
  - Interpretation of the stratigraphy of bore lithology records, and
  - Development of isopachs of the main stratigraphic units in the basin (Section 4.3).
- The hydrostratigraphic conceptualisation of the basin was improved, particularly:
  - An improved conceptualisation of the regional aquitard in the basin, including mapping of its thickness and extent (Section 6.2.2), and
  - The thickness of the regional aquifer system was mapped at the basin-scale for the first time (Section 6.2.1.1).
- Mapping of the potentiometric surface of the Mesozoic aquifer was undertaken enabling characterisation and conceptualisation of flow systems within the basin (see Section 6.5).

- A description of basin-scale and sub-regional groundwater flow systems, including the potential influence of faults and lithofacies changes on flow system compartmentalisation and aquifer interconnectivity (Section 6.5). The key knowledge gaps that affect the capacity to describe these are also highlighted.
- A first approximation water balance was developed. This is limited considerably by the data availability in the basin and some components have not been estimated. Volumes for those components that have been estimated are uncertain due to the paucity of data available. The water balance essentially provides a summary of the key components of groundwater recharge and discharge in the basin, and better enables the identification of knowledge gaps to be addressed by further work (Section 6.6).
- A summary of groundwater protection considerations as they relate to the groundwater resources of the Laura Basin is provided (Section 7.3).
- Identification of the key knowledge gaps for understanding the groundwater systems of the Laura basin and their interactions with key environmental assets and recommendations for future work (Section 9).

3 Geography

3.1 Location and population

The Laura Sedimentary Basin is in far northern Queensland (Figure 3.1). It covers an area of approximately 19,000 km^2 on land and extends off-shore (~16,000 km^2 area) to the north beneath Princess Charlotte Bay. However, the northerly extent of the Laura Basin is not well defined, resulting in several differing interpretations of its maximum offshore extent.

There are very few populated places in the Laura Basin. The only major settlement is the town of Laura, with a population of 80 (ABS 2011a). The main population centre in the wider region is Cooktown (population 1,617 (ABS 2011a)), which is on the coast to the east of the Laura Basin. The region has minimal infrastructure or development and there are relatively few roads, most of which are unsealed. The Peninsular Development Road, which is the only major road that cuts through the basin, provides access to Coen and Cape York Peninsular, further to the north.

3.2 Physiography and land cover

The Laura Basin occupies a natural bowl-like depression in the landscape and is open towards the coast in the north, with mountainous terrain to the south, east and west. Much of the region is a relatively flat-lying near-coastal plain at elevations <200 metres Australian Height Datum (AHD).

The modern drainage within the Laura Basin flows mainly from south to north, with the Normanby River draining most of the basin. The uplands of the Laura Basin consist of dissected sandstone hillslopes (Gilbert River Formation and Dalrymple Sandstone), with lower-lying hills in the south-west and north-east of the basin (formed mainly of rocks of the Rolling Downs Group).

The lowlands of the basin contain extensive areas of sand, derived from weathering and erosion of the Mesozoic sandstone rock units. Further downslope are large alluvial fans. Biggs and Philip (1995) identified four physiographic units in the Laura Basin:

1. Sandstone plateaus,
2. Gently undulating plains of the Central Western Peninsula,
3. Sub-coastal fans and alluvial plains, and
4. Near-coastal plains.

Much of the eastern, southern and western basin margins are covered by Eucalypt woodlands (Figure 3.2). The central parts of the basin are mostly covered by open woodlands and grasslands. Denser vegetation, rainforest and vine thicket, and melaleuca forests and woodlands occur along water courses. There are also extensive areas of inland aquatic ecosystems. Towards the north, grasslands begin to dominate the vegetation type and the woodlands are of a more open nature. In the far north of the basin near the coastline, there is a mix of grasslands, mangroves, salt marsh (chenopod shrublands) and melaleuca forests.

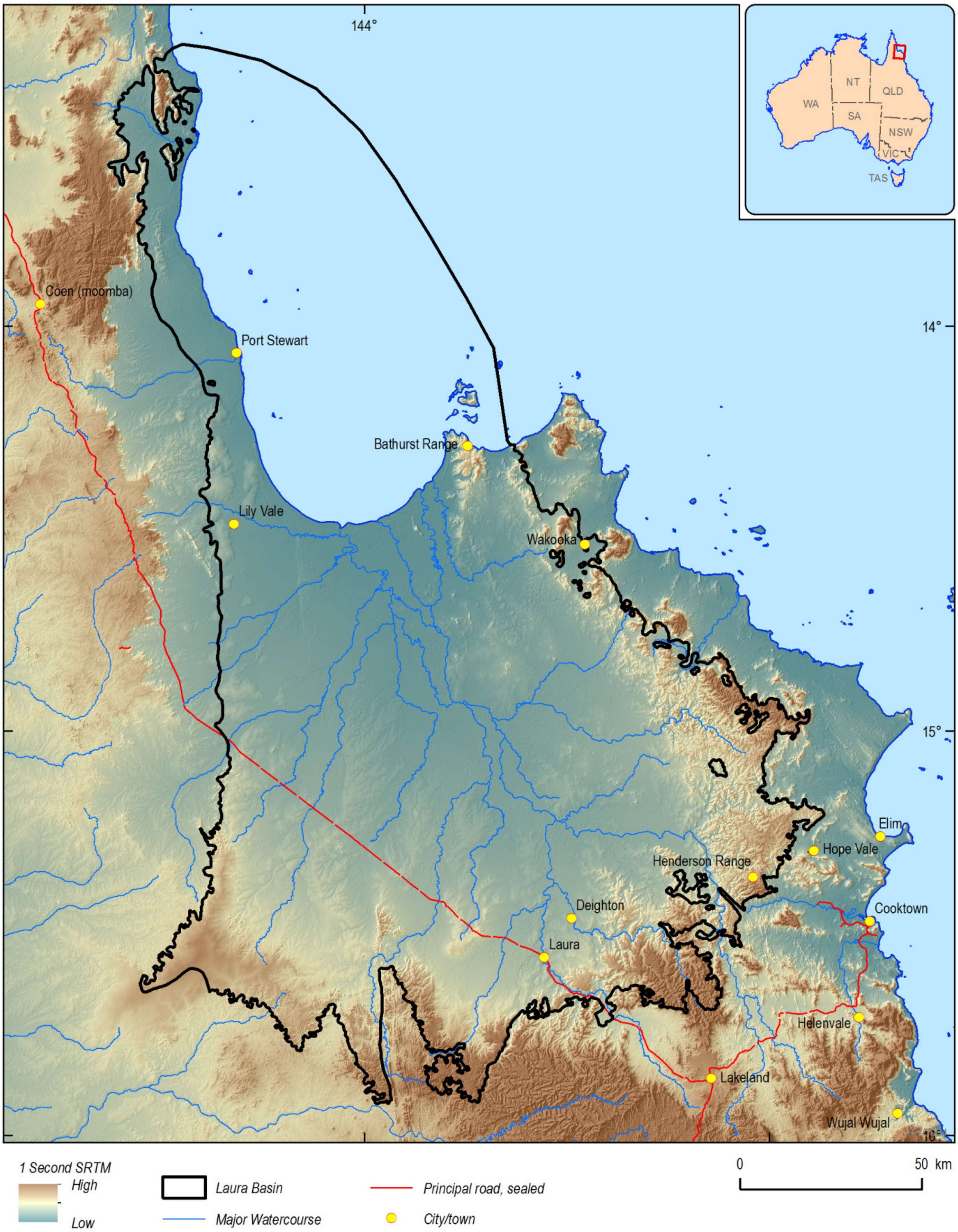


Figure 3.1. Location and topography, Laura Basin (data source: SRTM-derived 1-arc second digital elevation model, Gallant (2011)). The highest topographic point in the Laura Basin is around 600 mAHD.

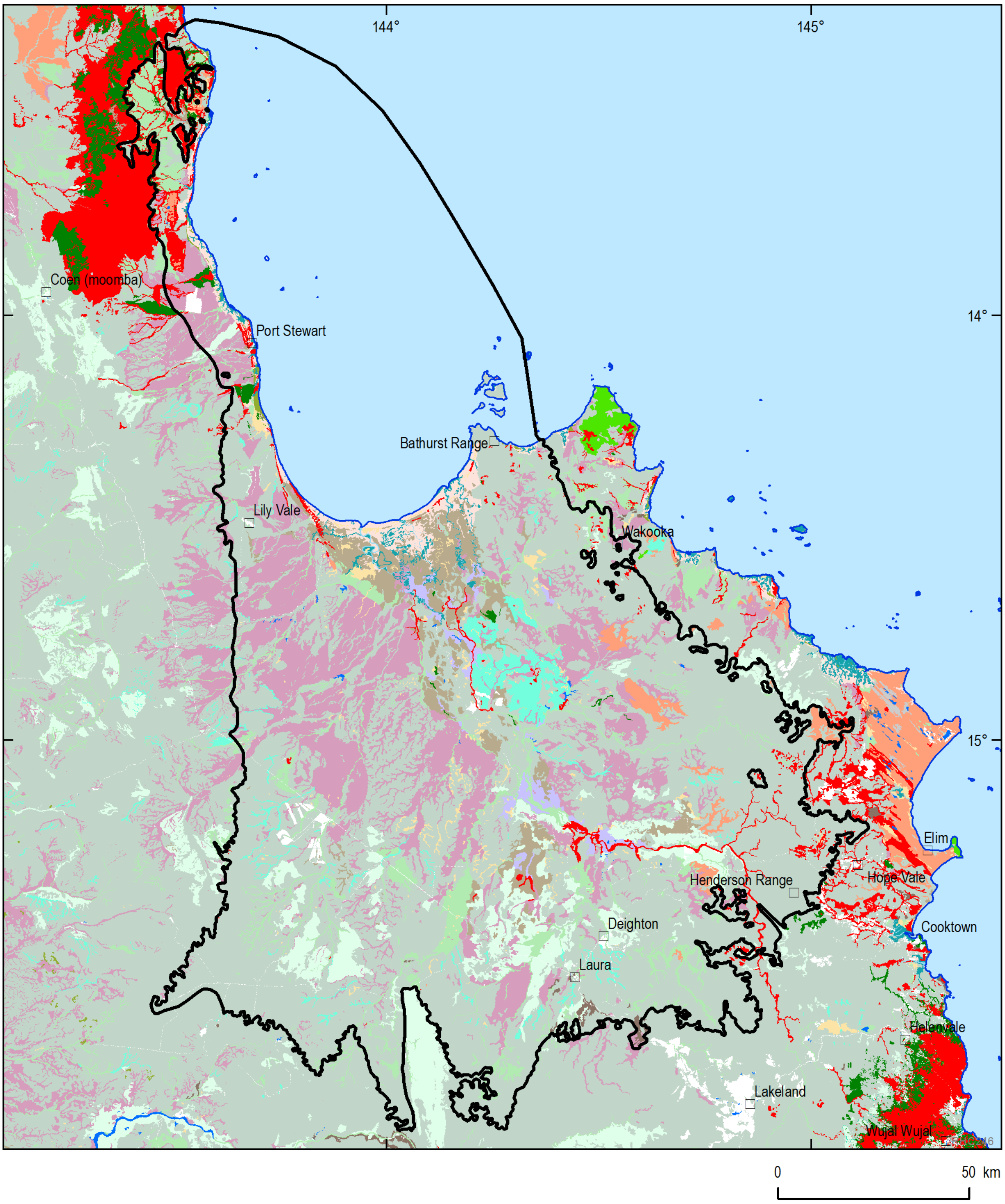


Figure 3.2. National Vegetation Information System (NVIS) land cover map, Laura Basin (data source: DSEWPaC, 2012).

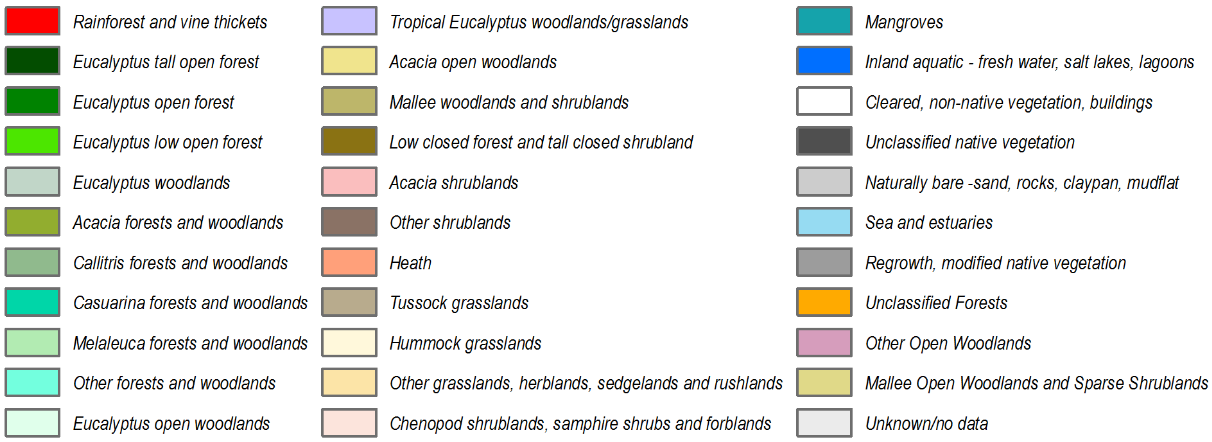


Figure 3.2. National Vegetation Information System (NVIS) land cover map, Laura Basin (data source: DSEWPaC, 2012).

3.3 Climate

The Laura Basin has a tropical climate (Köppen-Geiger climate classification: Tropical Savannah) with maximum daily temperatures averaging 28ºC. Annual precipitation is strongly seasonal and also relatively high compared with most of Australia, and the long-term average is 1,085 mm/yr (Bureau of Meteorology data). The Laura Basin is generally water limited, with average annual potential evapotranspiration (1,890 mm/yr) exceeding average annual rainfall. Rainfall in the Laura Basin is seasonal, monsoonal and trade-wind derived. Figure 3.3 shows the rainfall seasonality and indicates that although average annual rainfall in the Laura Basin is relatively high for Australia, rainfall is in deficit relative to Potential Evapotranspiration (PET) for much of the year. Rainfall is in surplus relative to evapotranspiration for three months of the year. For the months of January and February, rainfall is in surplus by approximately 100 mm.

There are six weather monitoring stations that currently monitor rainfall and evapotranspiration across the Laura Hydrogeological Basin and the Laura-Normanby River catchment (Table 3.1). These stations are located at various sites across the basin but are predominantly in the lowland regions. There is a data gap in weather gauging in higher elevation areas in the east and west of the basin.

Table 3.1. Climate gauging stations, Laura Basin (data source: BOM (2012a)).

Station name	Station ID	Location		Period of record
		Latitude	Longitude	
Fairview Outstation	28010	-15.5	144.28	1890-current
Koolburra	28012	-15.32	143.96	1964-current
Lakefield National Park	28023	-14.93	144.2	1973-current
Laura Post Office	28000	-15.56	144.45	1897-current
Lilyvale Station	28014	-14.49	143.68	1971-current
Violet Vale Station	28031	-14.73	143.59	1982-current

Significant inter-annual rainfall variability is evident in the climate record (Figure 3.4). The rainfall residual mass graph for Laura Post Office indicates a comparatively wet period for 1905–1913, then drier than average conditions until 1970, then a wet period from 1970 until 1981 and then mostly average rainfall conditions until present. Rainfall (Figure 3.5) and potential evapotranspiration also vary spatially across the Laura Basin (Figure 3.6).

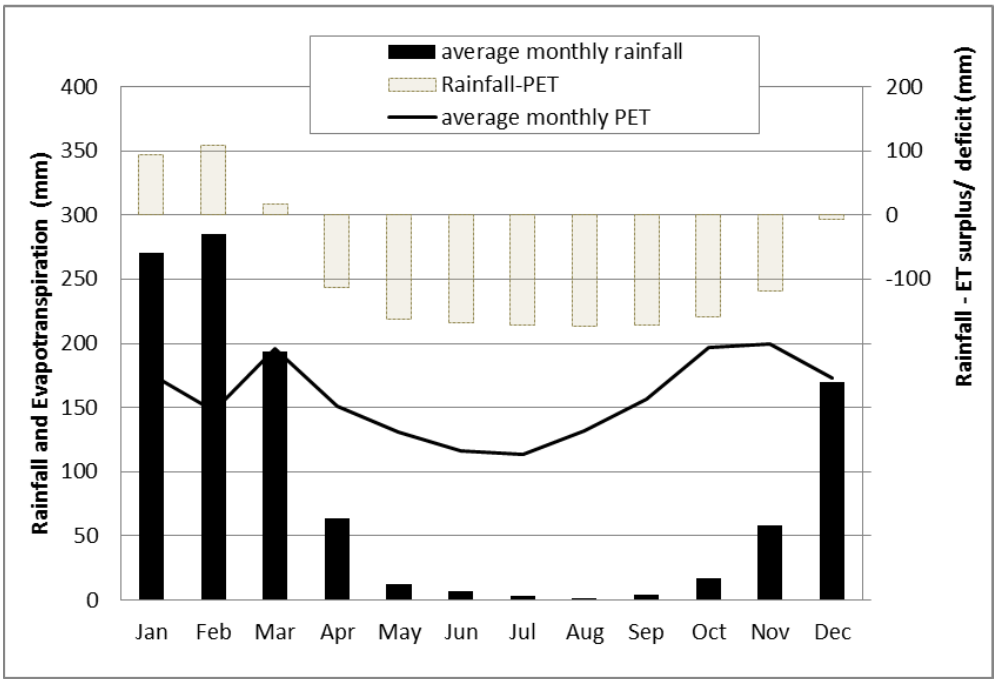


Figure 3.3. Average monthly rainfall, and average monthly potential evapotranspiration, Rainfall-ET surplus or deficit (data source: BOM (2012a)).

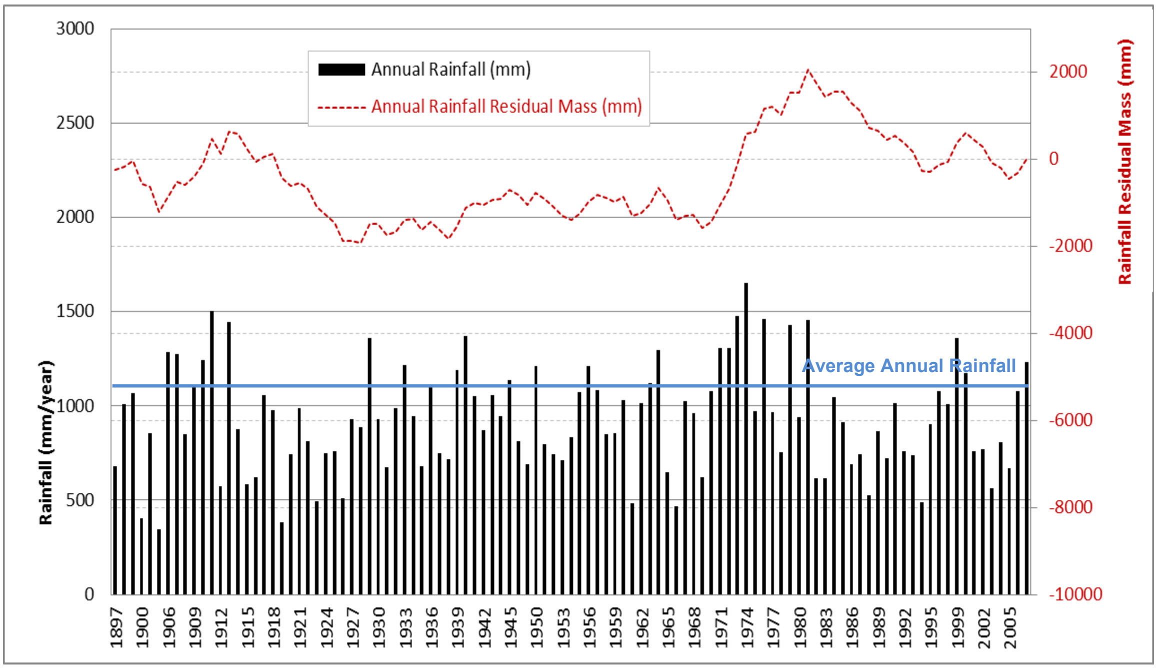


Figure 3.4. Annual rainfall and rainfall residual mass (cumulative sum of annual rainfall minus average annual rainfall), Laura Post Office (station: ID 28000), 1897-2012 (data source: BOM (2012a)).

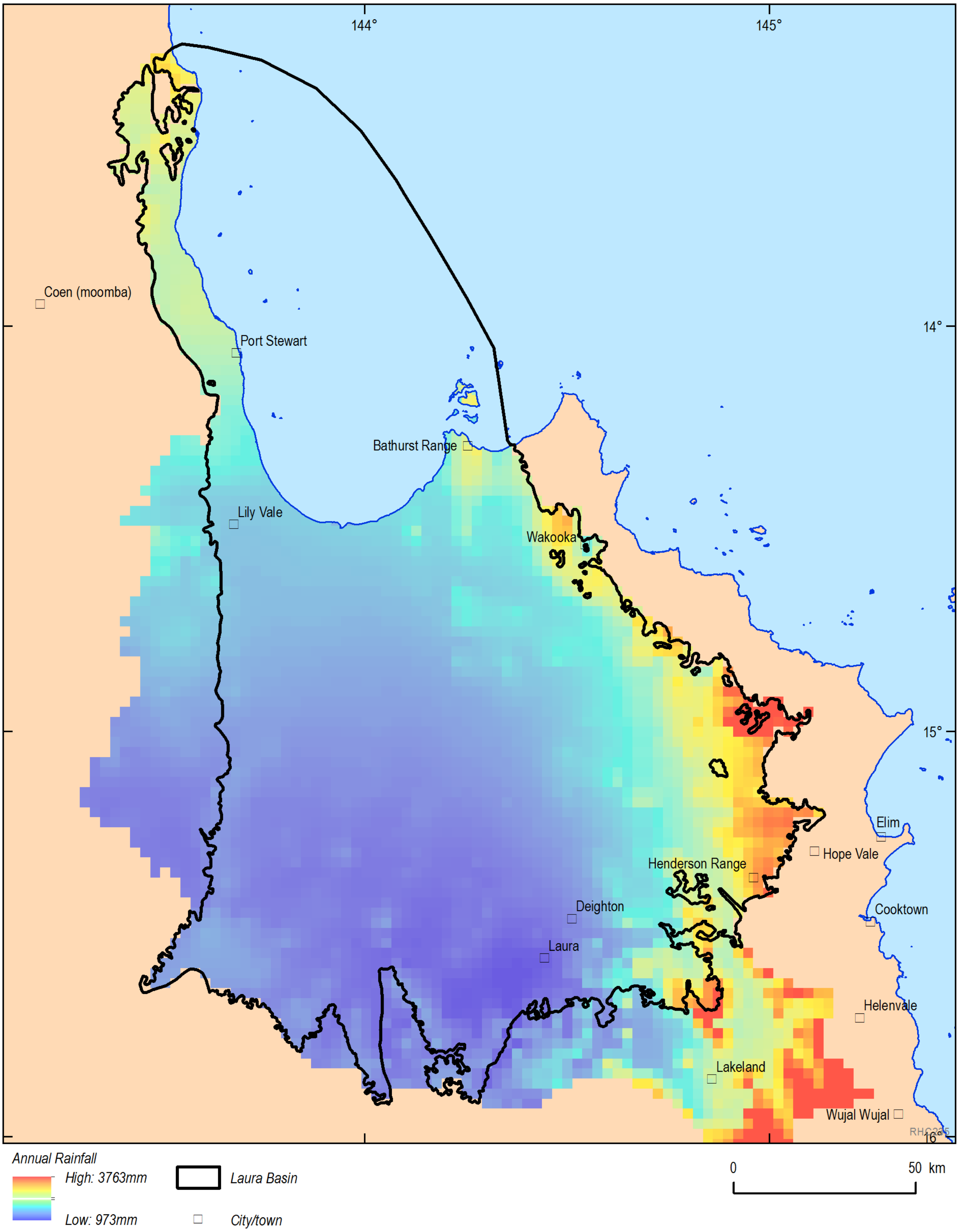


Figure 3.5. Average annual rainfall, for the period 1961-1990, Laura Basin and Laura-Normanby Catchment (data source: BOM (2009)).

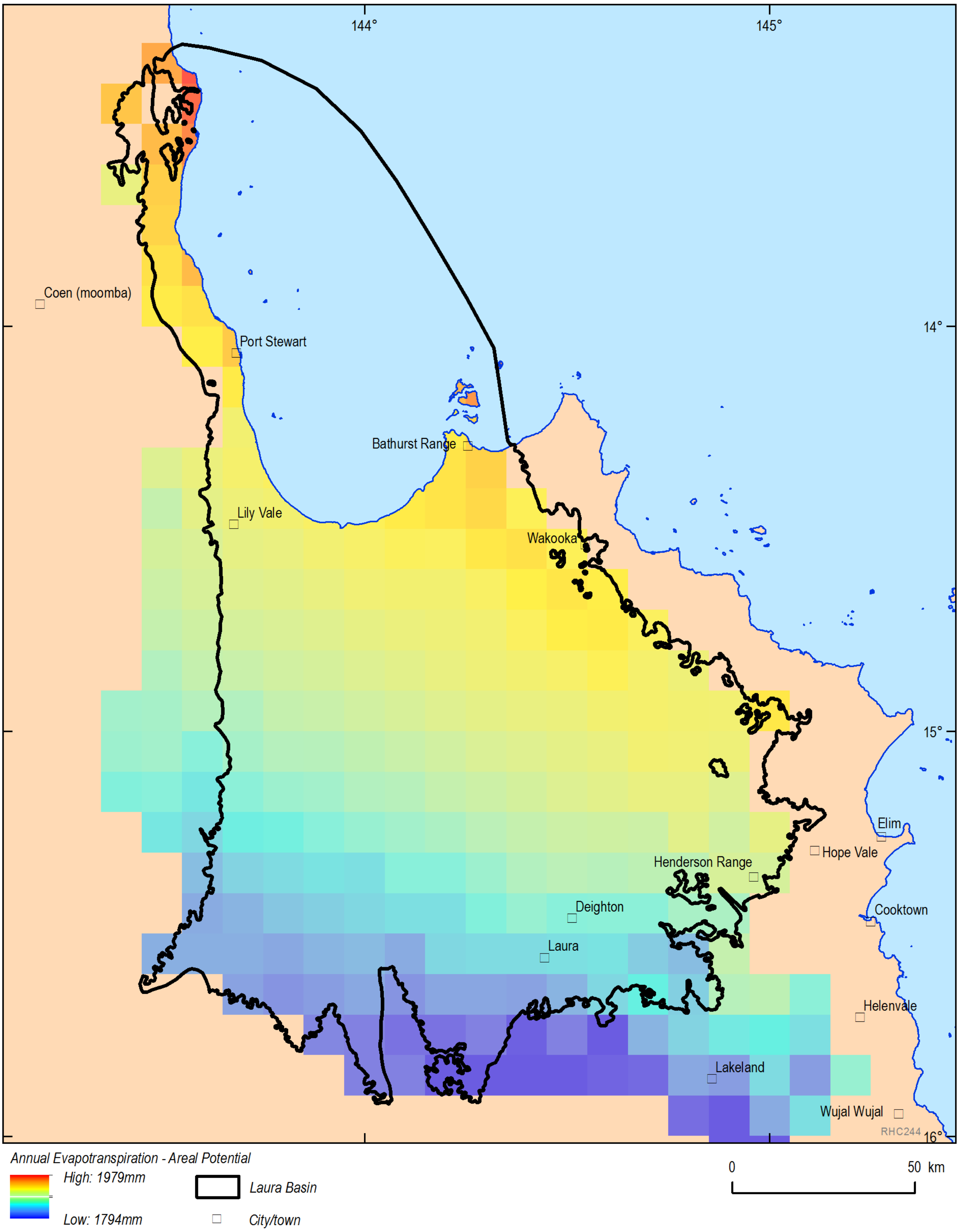


Figure 3.6. Average annual areal potential evapotranspiration for the period 1961-1990, Laura Basin and Laura-Normanby Catchment (data source: BOM (2005)).

3.4 Land use

Land use across the Laura Basin is presented in Figure 3.7. The central part of the basin is covered by nature conservation areas such as National Parks, with most of the remaining area used for stock grazing on natural vegetation. In the south and east, smaller areas of 'other minimal land use' are present. In the far north, areas of production forestry and areas where there is frequent coastal inundation is recorded. There is limited access to much of the basin during the wet season due to seasonal flooding.

Most of the Laura Basin is situated within the Cape York Natural Resource Management Area (NRM). An overview of Natural Resource Governance in Queensland is provided in Appendix 2.

3.5 Indigenous land use agreements and native title

Over half of the Laura Basin is covered by Indigenous Land Use Agreements (ILUA) (Figure 3.8). These include:

- Kalpowar ILUA;
- Rinyirru (Lakefield) National Park (Cape York Peninsula Aboriginal Land) ILUA;
- Melsonby and State ILUA;
- Running Creek ILUA;
- Lilyvale ILUA;
- PNG Gas Pipeline ILUA; and
- Kalinga Mulkay ILUA.

These agreements have different purposes and are made between the state and representatives of indigenous communities. The agreements place caveats on how land and waters, in the area covered by the agreement, will be used and managed in the future. Change in land use in much of the Laura Basin, for example, developing a coal mine in the Bathurst Range, is likely to require assessment within the land and water use and management frameworks set out by these agreements. The Bathurst Range coal deposit is discussed in further detail in Section 5. This area is within the area covered by the Kalpowar ILUA. There has been one successful claim to Native Title in the south-west of the Laura Basin (QC2003/009, Olkola & Thaypan People).

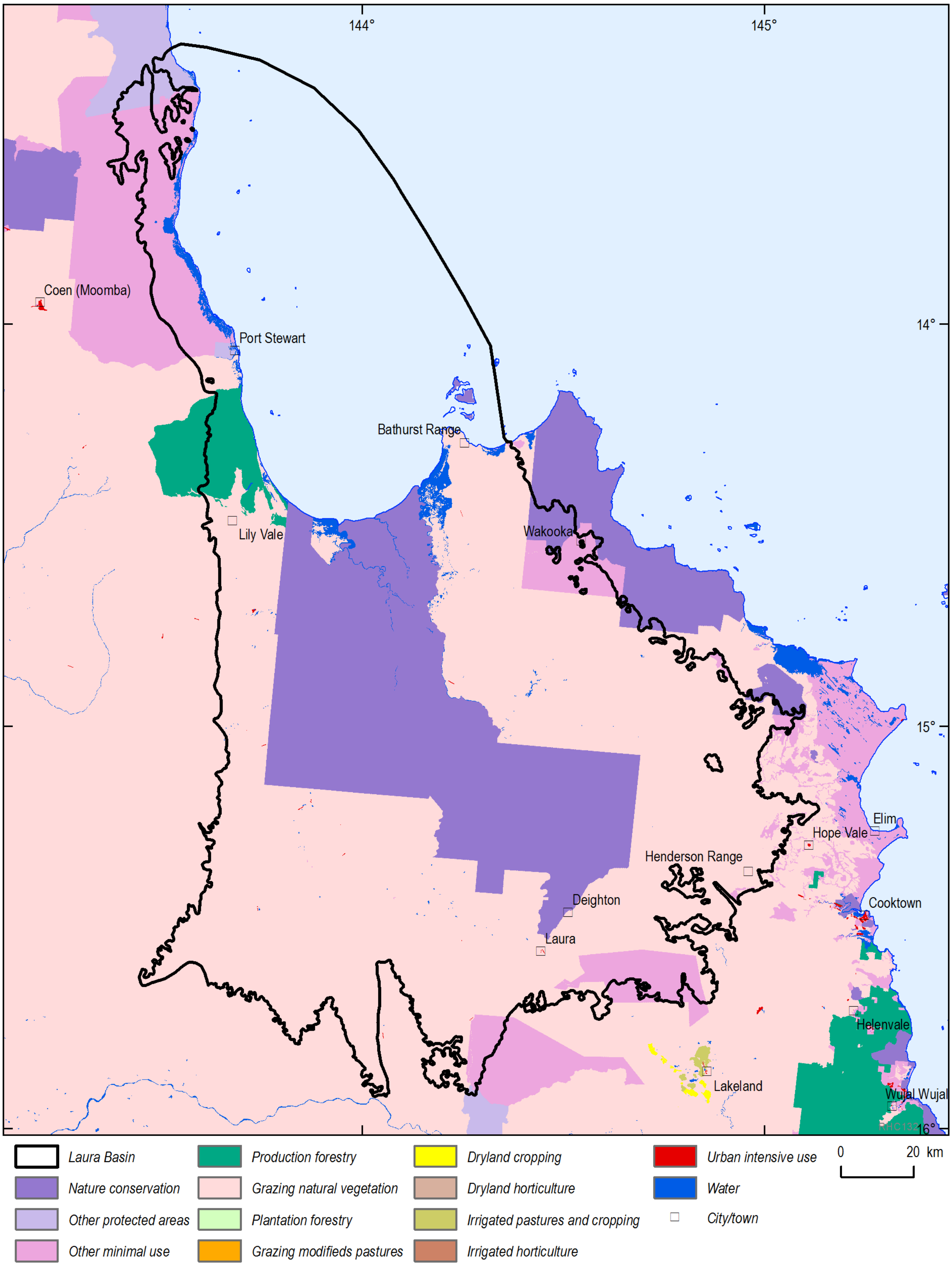


Figure 3.7. Land use classification for the Laura Basin. Most of the Nature Conservation regions shown here are National Parks (data source: (ABARES 2010)).

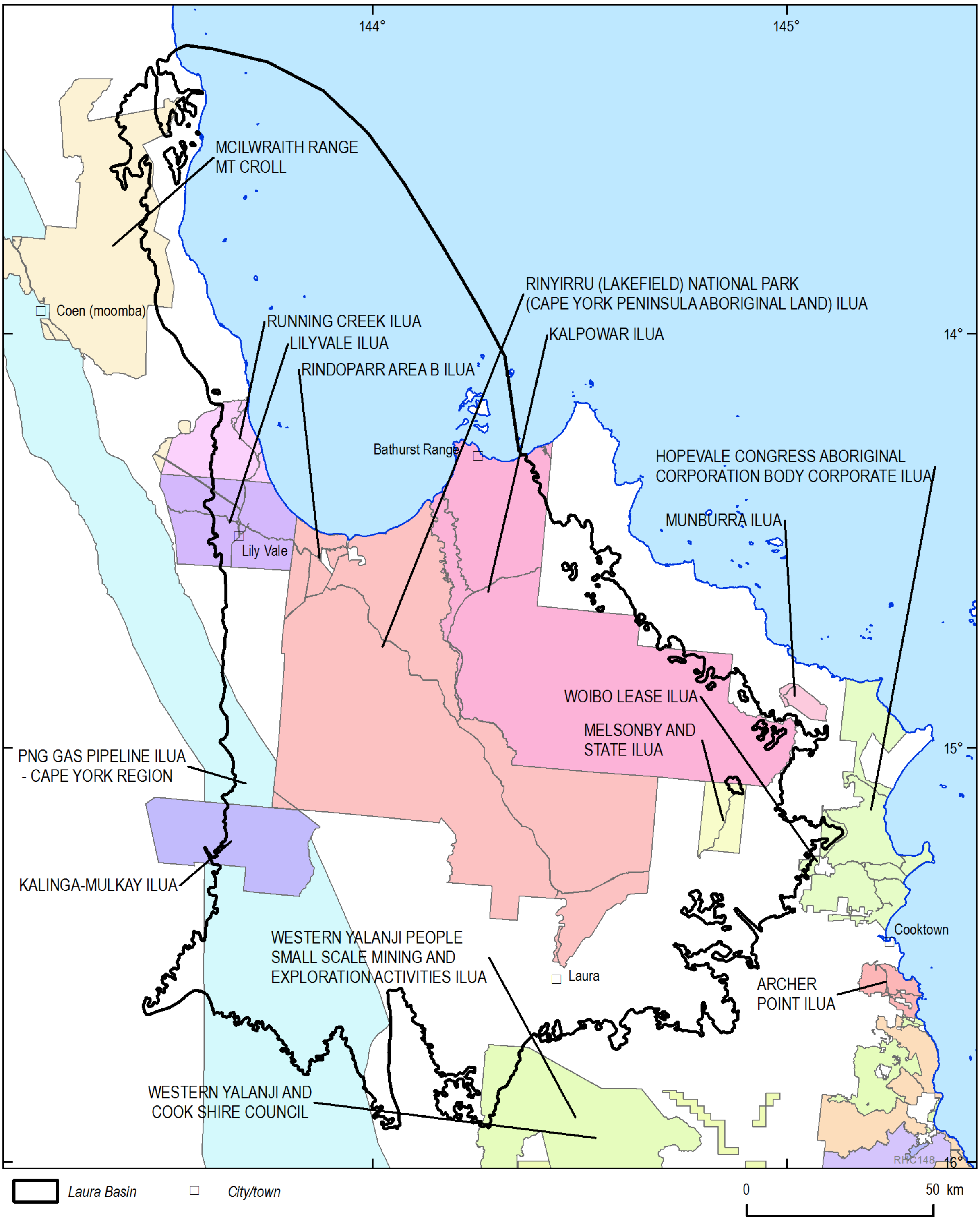


Figure 3.8. Areas covered by Indigenous Land Use Agreements (ILUA), Laura Basin (data source: National Native Title Tribunal (2012)).

3.6 Surface water systems

The Normanby River catchment covers most of the Laura Hydrogeological Basin. Part of the catchment lies outside the south-east and the west of the basin. A small part of the Stewart River catchment also lies within the Laura Basin. The total area of the Normanby River catchment is just under 25,000 km^2.

Figure 3.9 shows the major tributaries of the Normanby River. These include the Hann River, Jack River, Laura River (and Little Laura River), Kennedy River (and North Kennedy River), Deighton River and Morehead River. The Normanby, the North Kennedy, the Hann, and the Morehead rivers meet to the immediate south of Princess Charlotte Bay. While the Normanby River has a separate river mouth to the others, its floodwaters spill to the North Kennedy River (Stanton 2011), around 23 km to the west of the Normanby River. The Marret River and the Bizant River also discharge to Princess Charlotte Bay.

The Normanby River is tidal to around 50 km from its mouth (Bunt and Stieglitz 1999). Most rivers in the Laura Basin are ephemeral, with the Hann River the only perennial stream in the catchment. Perennial flow in the Hann River is supported by groundwater discharge. Surface water and groundwater interactions are discussed further in Section 6.5.4.

3.6.1 Previous work

The CYPLUS work (Horn 1995) and the Northern Australia Sustainable Yields Project CSIRO (2009) both provide an overview of the hydrology of the Normanby River Catchment with a regional context.

3.6.2 River monitoring

3.6.2.1 Surface water discharge

There are 5 stream flow stations actively gauging river flow in the Laura Basin region (Figure 3.10). Four of these are located within the Normanby River Catchment on the Laura River: Hann River, Normanby River (upper catchment), Normanby River (lower catchment). The stations are managed by Queensland Department of Natural Resources and Mines (DNRM), data was obtained from the Queensland Government Water Monitoring Portal (see Table 3.2 for gauge details). Data for three of these gauges is also available from the Bureau of Meteorology Environmental Information System. Records for four additional stream gauges that are no longer active are available for various periods between 1958 and 1989. These include Deighton River (105104A), Kennedy River (105103A), Hann River at Kalinga (105001A) and Jungle Creek at Kalinga (105002A).

Most streams in the Laura-Normanby River catchment cease to flow during the dry season as shown by the flow duration curves in Figure 3.11. An exception to this is the Hann River which flows all year round as demonstrated by the flow duration curve.

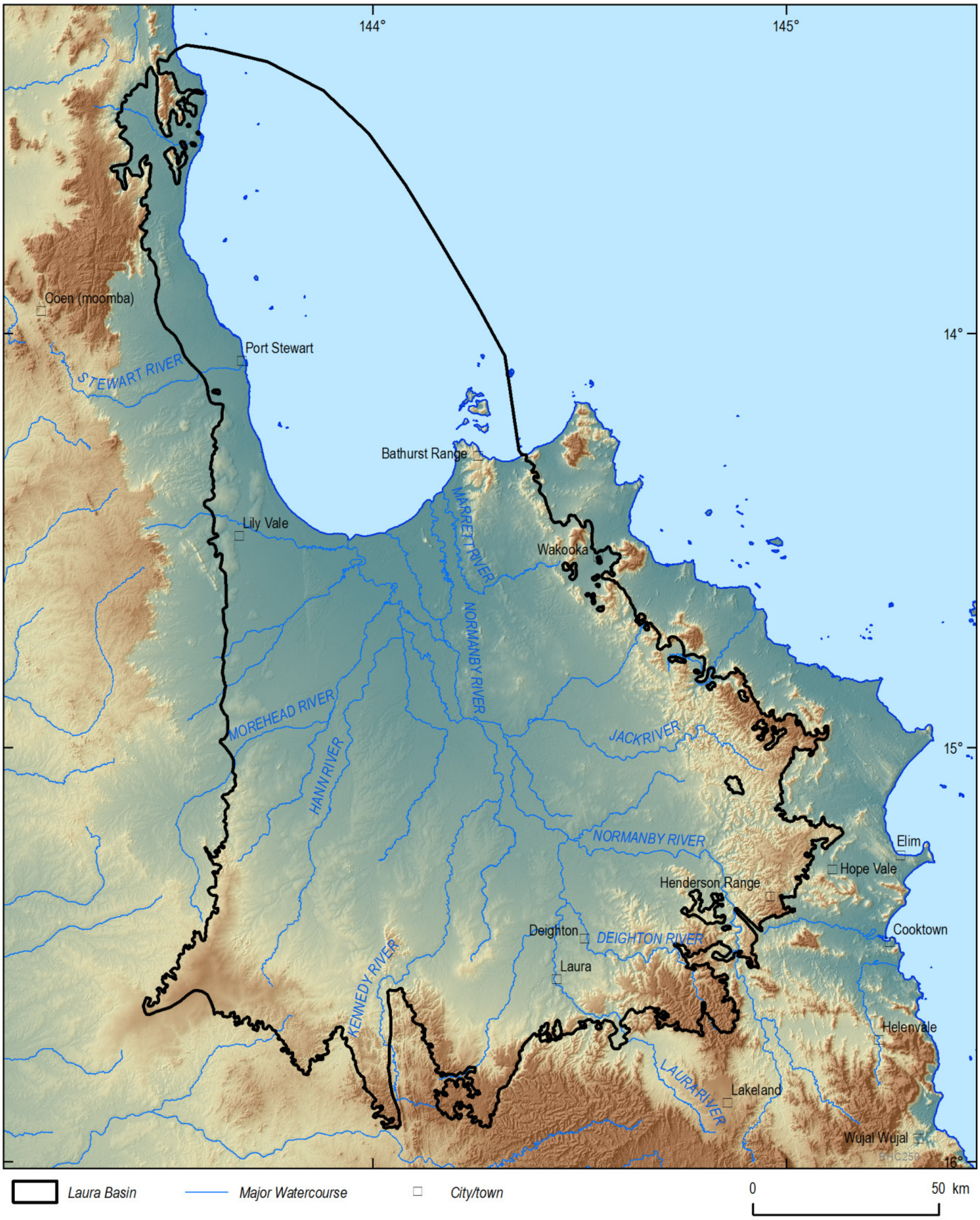


Figure 3.9. Rivers of the Laura-Normanby River (data source: BOM (2012b)).

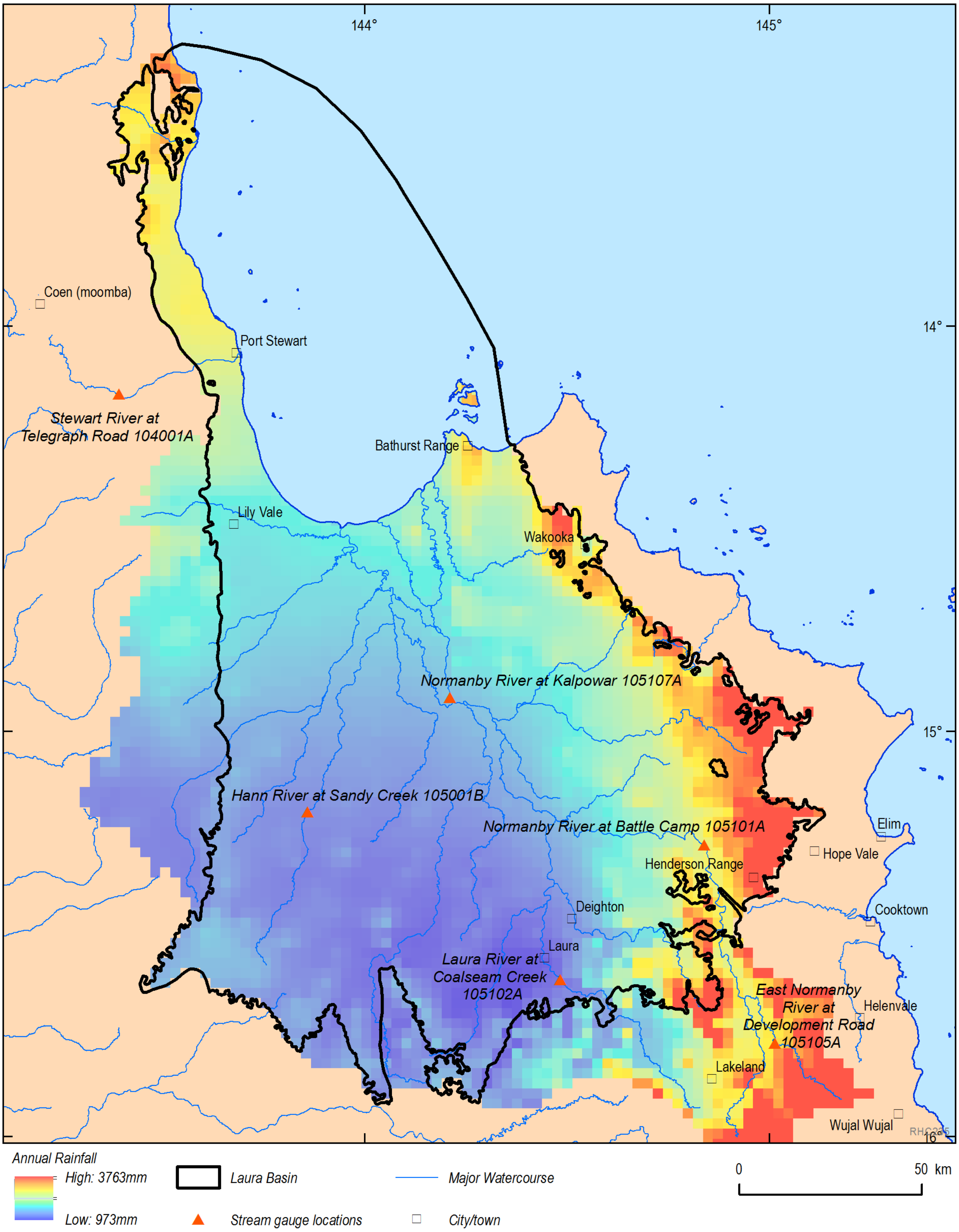


Figure 3.10. Active stream flow gauging Laura Hydrogeological Basin/ Laura-Normanby River catchment (data source: Queensland Water Monitoring Portal, DNRM (2013b)).

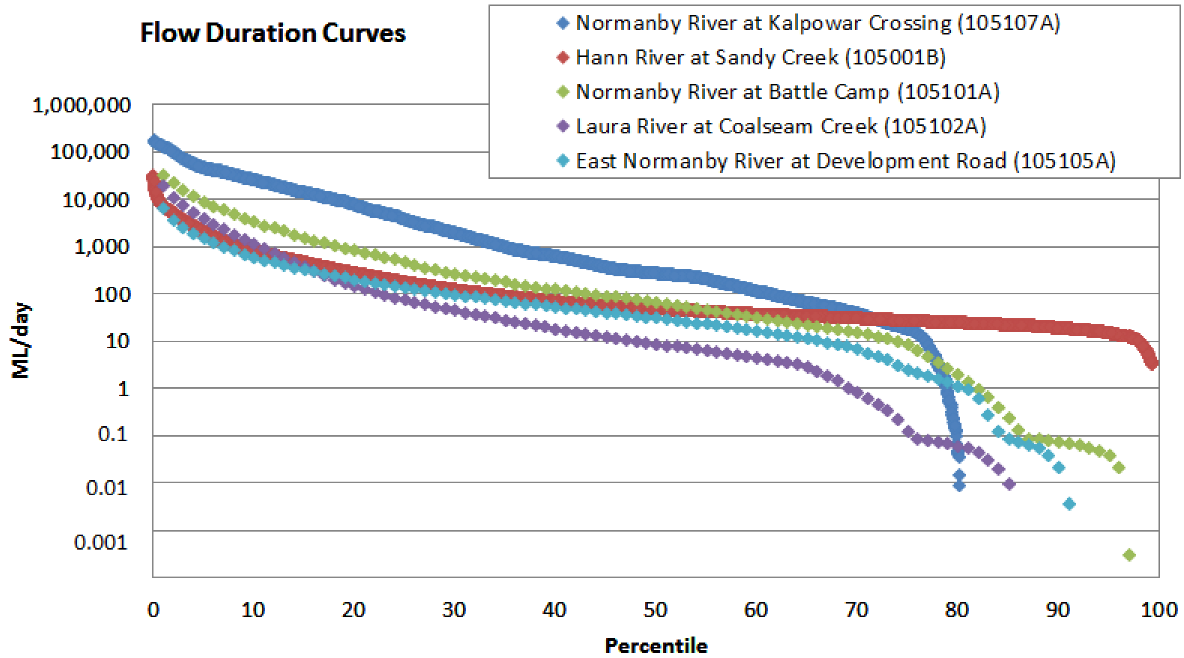


Figure 3.11. Flow duration curves, Laura-Normanby catchment, active stream gauge monitoring sites (data source: Queensland water monitoring portal, DNRM (2013b)).

National 1:250,000 mapping of water courses and lakes differentiates between perennial and ephemeral streams and lakes. Figure 3.12 shows the distribution of perennial streams and lakes in the Laura Basin.

There is also significant inter-annual variation in total river flow. Figure 3.13 shows annual stream flow and cumulative residual mass of stream flow (annual flow minus average annual flow) for four stream gauges in the Laura-Normanby River Catchment.

Table 3.2. Details of active stream gauges, Laura-Normanby River Catchment (data source: Queensland Water Monitoring Portal, DNRM (2013b)).

Station name	Station number	Latitude	Longitude	Record for stream discharge monitoring
Hann River at Sandy Creek	105001B	-15.2	143.86	1968-2013
Normanby River at Kalpowar Crossing	105107A	-14.917	144.211	2005-2013
East Normanby River at Development Road	105105A	-15.7712	145.0137	1970-2013
Laura River at Coalseam Creek	105102A	-15.6133	144.4837	1975-2013
Normanby River at Battle Camp	105101A	-15.2812	144.8387	1976-2013

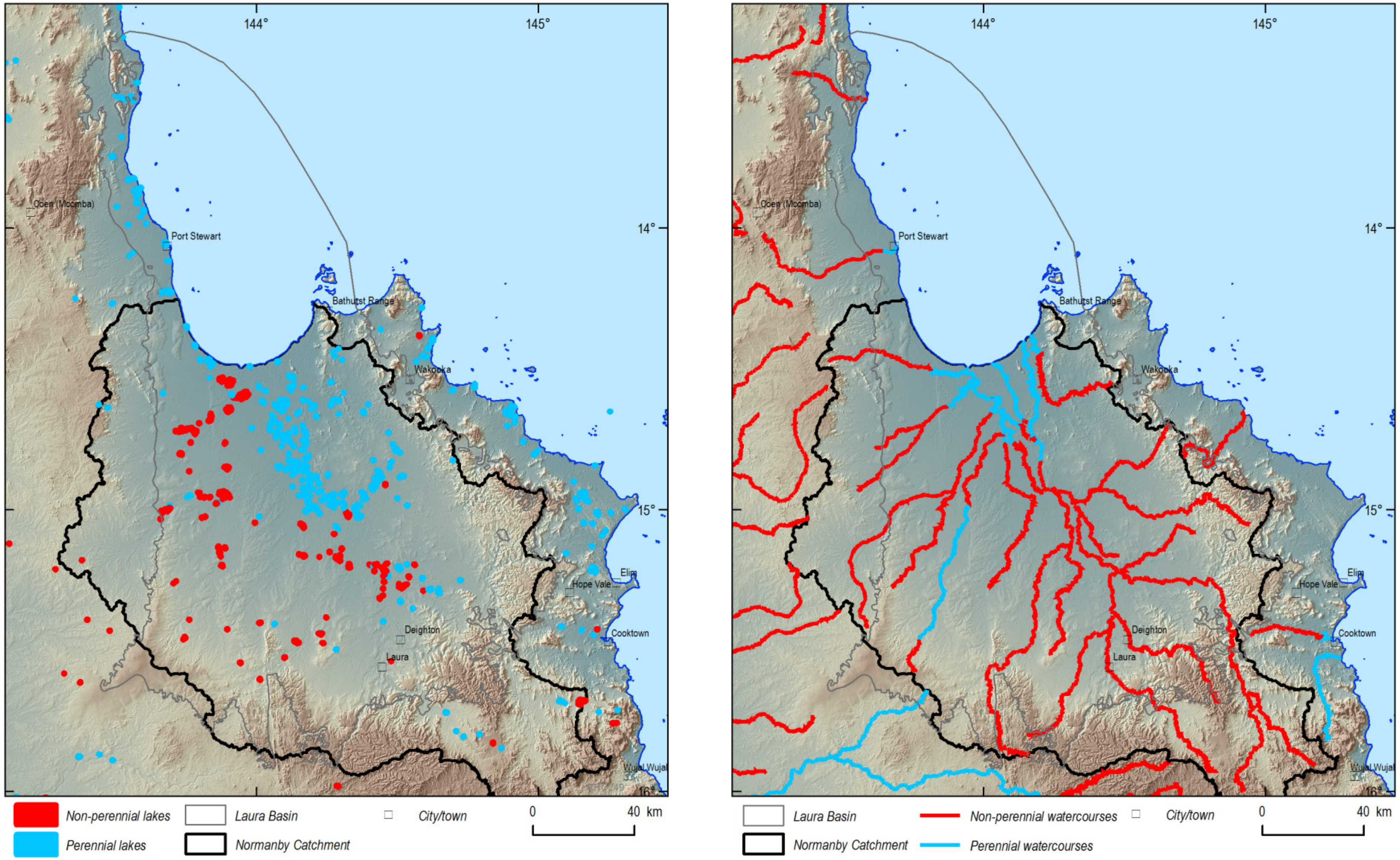


Figure 3.12. Perennial lakes and streams, Laura Basin (data source: BOM (2012b)).

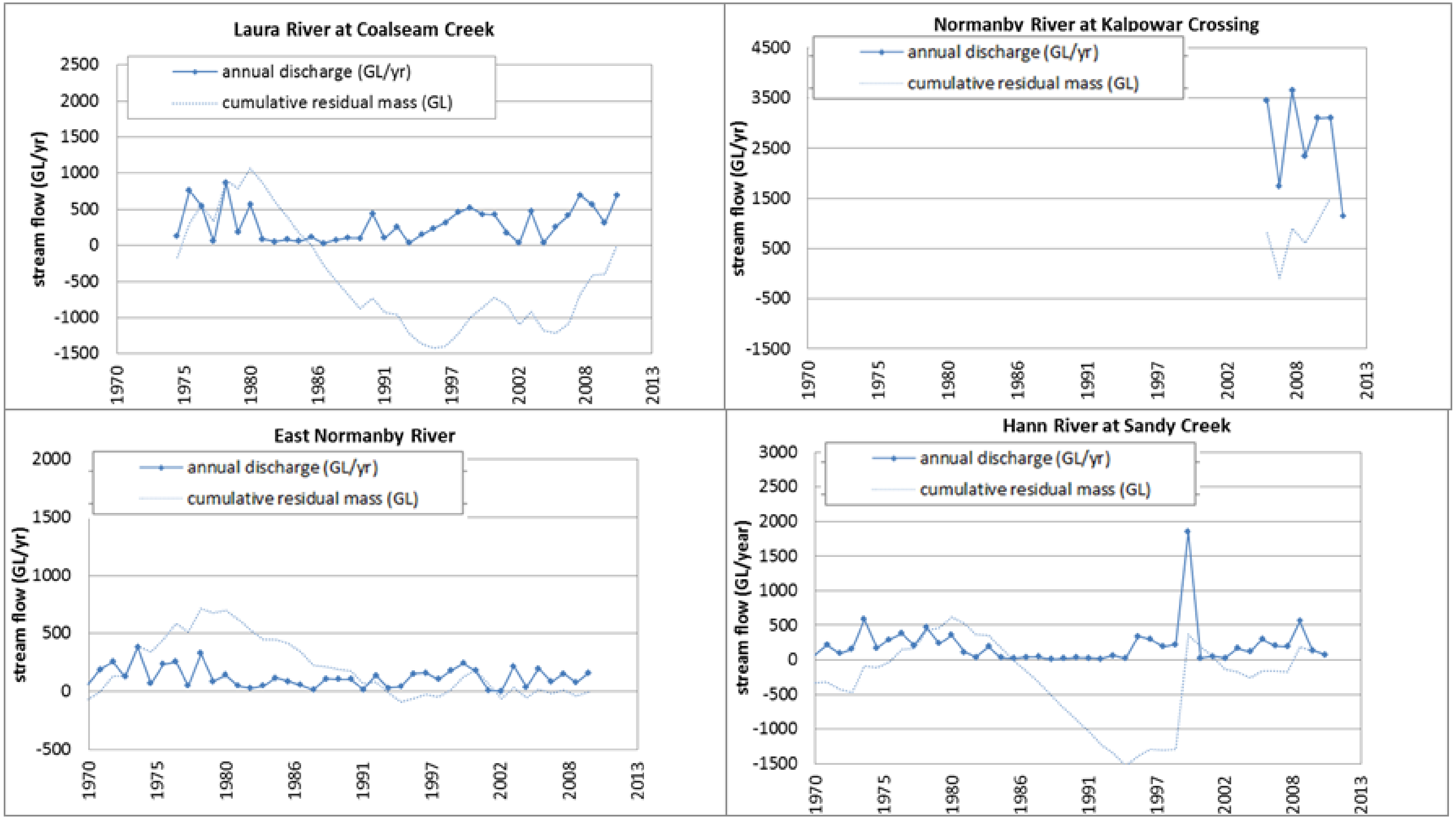


Figure 3.13. Annual stream discharge and cumulative residual mass of stream discharge, Laura-Normanby River catchment (Data Source: Queensland water monitoring portal, DNRM (2013b)).

3.6.2.2 Surface water quality

In the absence of time-series groundwater chemistry data, time-series stream water chemistry can provide a useful indicator of the water quality of regions within a catchment or river basin, against which the influence of land use changes can be compared. Water quality monitoring of surface water bodies is generally managed by Queensland DNRM, summary data is available from Queensland Government Water Monitoring Portal. Complete monitoring records were obtained from DNRM. This data includes major and minor ions, pH, turbidity (NTU), electrical conductivity (µS/cm) and temperature (°C) for stations shown in Table 3.3. Records do not appear to conform to a particular monitoring frequency. There is continuous electrical conductivity monitoring of the Normanby River at Kalpowar Crossing (gauge station ID: 105107A).

Table 3.3. Details of stream water quality monitoring stations (Data source: Queensland Water Monitoring Portal, DNRM (2013b)).

Station name	Station ID	Period of record for water quality monitoring
Hann River at Sandy Creek	105001B	1971-2012
Normanby River at Kalpowar Crossing	105107A	2003-2012
East Normanby River at Development Road	105105A	1972-2012
Laura River at Coalseam Creek	105102A	1971-2012

Figure 3.14 shows the electrical conductivity (EC) and turbidity (NTU) records for each of the gauges. Water quality is generally very good throughout the catchment. Laura River has greater variability in EC than the other gauge stations. Laura River flows over soils that according to Biggs and Philip (1995), have a high salinity risk relative to other soil types in the basin. In addition, the turbidity at the Laura River gauging station is more variable which may indicate soil erosion. Alternatively, the more variable water quality may be the result of more variable flows also recorded at this gauge, and in particular, a resulting variable dilution regime. The water quality of the Laura River is more likely to be the result of the variable surface water regime and possibly saline soil erosion than discharge of some saline groundwater source in the vicinity.

There is small variation in electrical conductivity in the Hann River and the East Normanby River. These sites have the most consistent flow regime (flattest exceedance curve) and the most consistently high flow regime respectively. These are expected to contribute to reduced salinity variability.

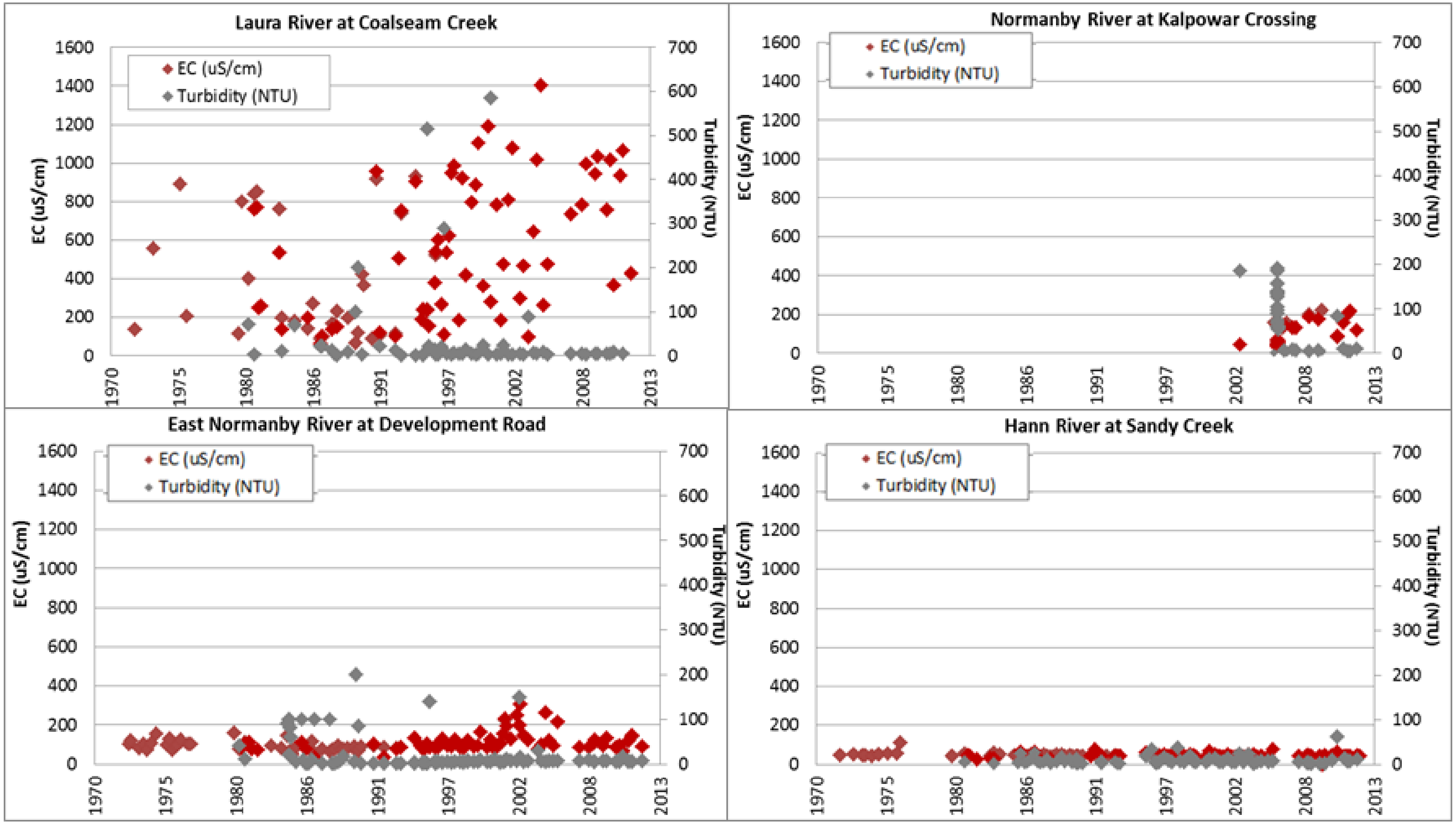


Figure 3.14. Electrical conductivity (µS/cm) and turbidity (NTU) at four stream gauges, Laura-Normanby River Catchment (data source: Queensland Water Monitoring Portal, DNRM (2013b)).

Figure 3.15 shows the relationship between electrical conductivity and stream discharge in the Normanby River at Kalpowar Crossing. Of note is that the water becomes very fresh during high flow events and as flow recedes and ceases, water quality degrades. This is likely to be a result of evaporation of standing pools of water within the river channel but may also be caused by discharge of higher salinity groundwater to pools within the river (as evidenced by the increasing salinity before flow completely stops). There is insufficient information to investigate to what extent this relationship between water quality and discharge holds for other rivers and river reaches in the catchment, however some of the salinity spikes coinciding with the rising limb of the hydrograph suggest the mobilisation of upstream saline pools, indicating that similar process are influencing water quality in areas upstream of the Kalpower Crossing gauging station.

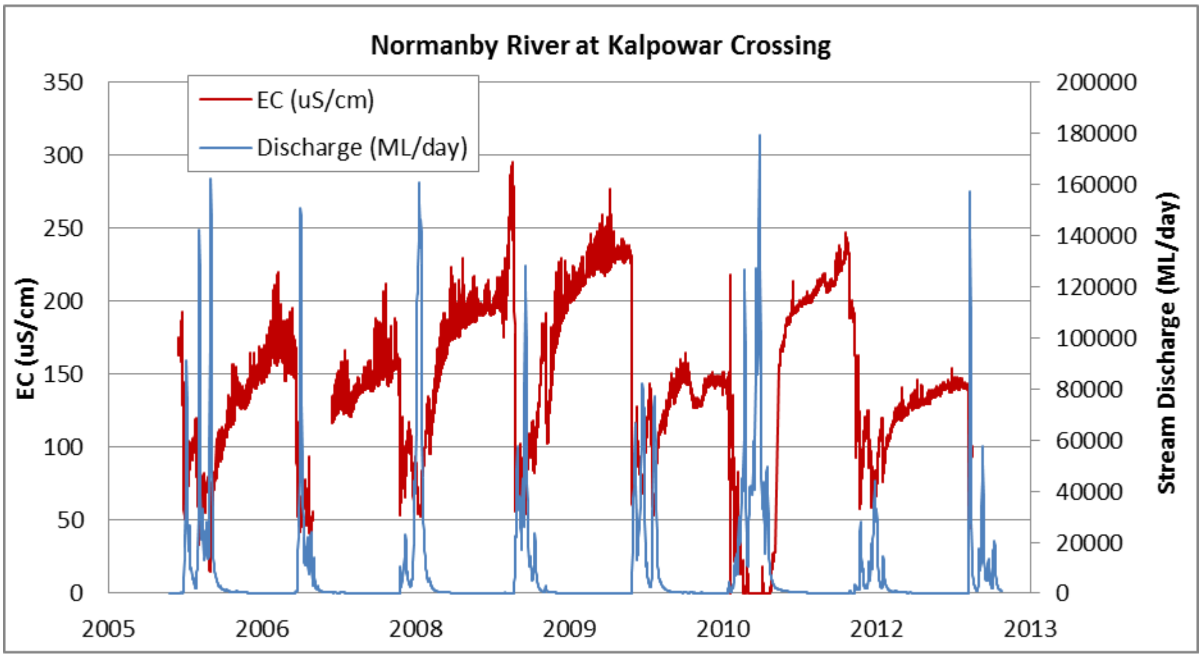


Figure 3.15. Daily stream discharge (ML/day) and electrical conductivity (µS/cm), Normanby River at Kalpowar Crossing (station ID: 105107A) (Data source: DNRM (2013b)).

In addition to this continuous monitoring data, Howley *et al.* (2010) undertook monthly water quality monitoring at 10 sites located across the Laura-Normanby Catchment area over the period June 2006–June 2010 to establish a water quality baseline during the wet and dry seasons, as well as to assess current land use impacts on water quality.

3.6.3 Rainfall-runoff modelling

CSIRO (2009) undertook rainfall-runoff modelling to estimate 77 years of daily catchment flow for three climate scenarios. This included the Stewart River and the Normanby River. There are likely to be uncertainties associated with this modelling given the paucity of stream gauging in the Normanby catchment (CSIRO 2009).

3.6.3.1 Surface water–groundwater interactions

There has been little previous work undertaken to investigate the interaction between surface and groundwater in the Laura Basin.

CSIRO (2009) estimated baseflow contribution to streamflow (i.e., groundwater discharge to streams) for five stream gauges in the Laura Basin as part of the rainfall-runoff modelling undertaken for the Northern Australia Sustainable Yields Project. The results are summarised in Table 3.4. There is no partitioning of the aquifer source of groundwater baseflow to streams, for example, groundwater baseflow calculated in this way may be sourced from Cenozoic aquifers or from the Mesozoic aquifers. Nonetheless, these baseflow index (BFI) values are quite high, particularly in the dry season. These results indicate that groundwater discharge to streams may be important for riverine ecosystem function during the dry season. Other investigations into surface water–groundwater interactions in the Laura Basin are discussed in more detail in Chapter 5.3 (Hydrogeology).

Table 3.4. Baseflow to streams, Laura Basin where BFI is the ratio of average annual baseflow to total average annual flow (Data Source: CSIRO (2009)).

Station	River	Station Name	Annual BFI	Dry Season BFI	Dry season baseflow (GL)
105001A	Hann	Kalinga Homestead	0.30	0.74	7.9
105101A	Normanby	Battle Camp	0.18	0.51	10.8
105102A	Laura	Coalseam Ck.	0.09	0.38	0.8
105103A	Kennedy	Fairlight	0.15	0.48	2.7
105105A	East Normanby	Developmental Rd	0.2	0.57	5.1

3.6.4 River modelling

There are no quantitative river models in the Normanby Catchment (CSIRO 2009). There is currently insufficient data available to undertake such modelling.

3.6.5 Surface water extraction

Surface water use is not licenced or metered in the Laura Basin. The Water Use on Australian Farms Survey (ABS 2011b) estimated 2,654 ML/yr is used from farm dams or tanks and 153 ML/yr from rivers, creeks and lakes within the Normanby River Catchment. A total of 2,807 ML/yr is estimated to be sourced from surface water.

3.6.6 Knowledge gaps

There are limited hydrological and surface water quality data available in the Laura Basin. This limits the scale at which the hydrogeology of the Laura Basin can be characterised and limits the degree to which the potential impacts of any future coal or CSG resource development can be assessed. In particular:

- There is limited information on how the surface water and groundwater systems interact. This is discussed in further detail in Section 6.5.4; and
- Coal resource development and indeed more general land use change (e.g., change in agricultural activities) may impact surface water quality and quantity. Coal resource development is likely to be highly localised with the only proven resource located at Bathurst Head. There is currently no

monitoring of surface water flow or quality in the catchments surrounding Bathurst Head. In addition, there is no monitoring of the nutrient, turbidity or salt loads exported to Princess Charlotte Bay from surface water discharge.

3.7 Environmental assets

The Laura–Normanby Catchment supports a high diversity of habitats including eucalypt forest, woodland, savannah, wetlands, plateau springs, rock outcrops, sandstone gorges, marine swamps, salt marsh, dunes and mangroves (Howley and Stephan 2005).

The sandstone ranges in the Laura area, including west of Fairview, south of Laura, Henderson Range and Battle Camp Range are noted as nationally significant habitat for butterflies (Howley and Stephan 2005).

There are no Ramsar-listed wetlands within the Laura Basin or Normanby River catchment (McJannet *et al.* 2009). The Australian Government (Department of the Environment) lists seven sites in the Laura Basin area as wetlands of national significance (DSEWPaC 2001). These wetlands are likely to have a varying degree of groundwater dependence. Absence of knowledge about the relative surface water and groundwater environmental water resource requirements constitutes a significant knowledge gap within the Laura Basin.

The *Environmental Protection and Biodiversity Conservation Act, 2007* (EPBC Act, 2007) lists ecological communities and species dependent on the springs of the Great Artesian Basin as a Matter of National Environmental Significance (MNES). There are no mapped EPBC-listed springs in the Laura Basin (Miles *et al.* 2012).

3.7.1 Wetlands of national significance

Documented Australian wetlands of national significance in the Laura Basin (DSEWPaC (2001)) are:

- Marina Plains–Lakefield Aggregation,
- Cape Melville–Bathurst Bay
- Laura Sandstone,
- Princess Charlotte Bay Marine Area,
- Violet Vale,
- Jake Lakes Aggregation, and
- Great Barrier Reef Marine Park

Figure 3.16 and Figure 3.17 are maps of the Wetlands of National Significance in the Laura Basin region. The following provides a summary of the key features of each of these wetlands.

3.7.1.1 Marina Plains–Lakefield Aggregation (QLD065)

Located to the south of Princess Charlotte Bay, these are inland wetlands that include permanent rivers, streams and ponds, seasonally inundated areas and floodplains. Most of the site is inundated during the wet season. The site has an area of 391,704 hectares and an elevation of 0–100 m above sea level (m ASL). There are a very large number of ephemeral lakes and lagoons and these contain many species of aquatic plants. This site contains some of the best examples of many vegetation communities on the eastern side of Cape York Peninsula and is a significant habitat for salt water crocodiles (CSIRO 2009). Landforms include gently undulating alluvial plains with many old stream channels and shallow lagoons, old levees and in-filled prior stream channels. Over 100 permanent riverine lagoons have been mapped in the area (Perry and Craven 2004).

3.7.1.2 Laura Sandstone (QLD090)

Located on the headwaters of the Little Laura River at the north-western edge of a sandstone plateau, focussing on perched swamps, this wetland has an area of 1089 ha, and elevation of 0–80 m ASL. The swamps are located at the headwaters of the Little Laura River where surface water drainage features have eroded the sandstone of the Dalrymple Sandstone down to the metasedimentary rocks of the Hodgkinson Province. Springs emerging at the boundary between the porous sandstone and the relatively impermeable Hodgkinson Province rocks maintain baseflow to this site throughout the dry season. Notable flora and fauna are recorded for this site, it is also located within the Quinkan cultural area which contains a large number of indigenous art and occupational sites (Perry and Craven 2004).

3.7.1.3 Violet Vale (QLD078)

Located on the boundary between the Laura Basin and the Coen Inlier, these wetlands occur at the head of a branch of Four Mile Creek, part of an extensive braided channel system that drains the eastern side of the Great Dividing Range between Musgrave Station and Mount Walsh. The area covers 1895 ha with elevations of 40–70 m ASL. Water flow in the channels is seasonal and during the wet season they commonly overflow their banks and spread out to inundate large areas. Landforms include alluvial plain, erosional plain and drainage depressions. The site supports regionally rare or uncommon plant communities (Perry and Craven 2004).

3.7.1.4 Jake Lakes Aggregation (QLD077)

Located on the eastern side of the Normanby River floodplain, the site extends eastward from the Normanby River to take in the floodplain wetlands associated with the Jack River and with Beattie Creek. The area covers 35,018 ha with elevations of <40–43 m ASL. The drainage course of Beattie Creek is braided across a large alluvial plain to the west of the low sandstone range that runs parallel to the coast between Cape Flattery and Cape Melville. The channels leave the plain and enter another low range which causes the channels to coalesce resulting in waters backing up into a series of lakes. Just downstream of the lakes the system enters the floodplain of the Jack River and it is thought that levees constructed near the river further restrict flow, causing water to back up in the lakes and associated swamps. Flow in Beattie Creek is seasonal, however it is likely that baseflow is maintained by spring discharge from the Mesozoic Sandstone aquifers in most years. There are four permanent lakes in the system, two large seasonal lakes and several smaller seasonal lakes. The whole site is flooded for short periods during the wet season and some parts remain inundated for several months. The site is recognised as being of conservation significance (Perry and Craven 2004).

3.7.1.5 Cape Melville–Bathurst Bay (QLD061)

Located south of Bathurst Bay, between Bay Hill to the southwest and Melville Range to the northeast. Bay Creek (otherwise known as Muck Creek) runs through the centre of the site. The area is 5,456 ha. The site is a swampy, level coastal sand plain. The system is seasonal. There is thought to be a significant groundwater input from Melville and Bathurst Ranges. Due to the small catchment size, it is thought that freshwater inputs to the estuary are unlikely to influence the salinity of the water. Landforms include tidal flat, drainage depression and erosional plain. The wetlands are of high wilderness quality. There is a high diversity of plant communities. The mangroves at the mouth of Bay

Creek are amongst the best representative examples on Cape York. A large proportion of the area supports regionally rare or uncommon plant communities and plant species (Perry and Craven 2004)

3.7.1.6 Princess Charlotte Bay Marine Area (QLD072)

Located from the western side of Bathurst Head west to Cape Sidmouth., this marine area extends out to sea to a depth of 6 m and inland to where freshwater influences become dominant. The area is 87,678 ha with elevations of 0–17 m ASL, and mostly less than 5 m ASL. River flow is considered insufficient to influence estuarine salinities into the dry season. The shores of Princess Charlotte Bay are one of the largest tidal wetland systems in Australia. Most of the eastern shore of the bay is of very high wilderness quality, whilst the wilderness quality is lower to the west. The site has the best and most extensive examples of saline flats on the Cape York Peninsula. The site is also an important fish habitat and is protected under the *Fisheries Act, 1994.* The dominant landform is tidal flat (Perry and Craven 2004).

3.7.1.7 Great Barrier Reef Marine Park (QLD100)

The Great Barrier Reef Marine Park is north of the Laura Basin. Across the entire Great Barrier Reef Marine Park (which extends approximately 2,000 km along the eastern coast of Queensland), it is estimated that rivers contribute about half as much freshwater as direct rainfall to the Barrier Reef. As the run-off is localised, it can be expected to be both biologically and physically significant. In addition, fresh groundwater discharges may be both biologically and physically significant. No work on sub-marine groundwater discharge has been undertaken in the Laura Basin. The Great Barrier Reef is the world's largest and most complex expanse of living coral reefs, encompassing many unique forms of life. The reef supports a significant diversity of flora and fauna (Perry and Craven 2004).

3.7.2 Fish habitat areas

Princess Charlotte Bay is declared as a Fish Habitat Area under the Queensland Government *Fisheries Act 1994*. Fish Habitat Areas are part of Australia's nationally representative system of marine protected areas, and fit within the International Union for the Conservation of Nature and Natural Resources (IUCN) Protected Area Management Category VI – 'Managed Resource Protected Area' (Queensland Department of National Parks, Recreation, Sport and Racing, 2013). Approval is required under the *Fisheries Act 1994* to undertake certain activities and works within a Fish Habitat Area.

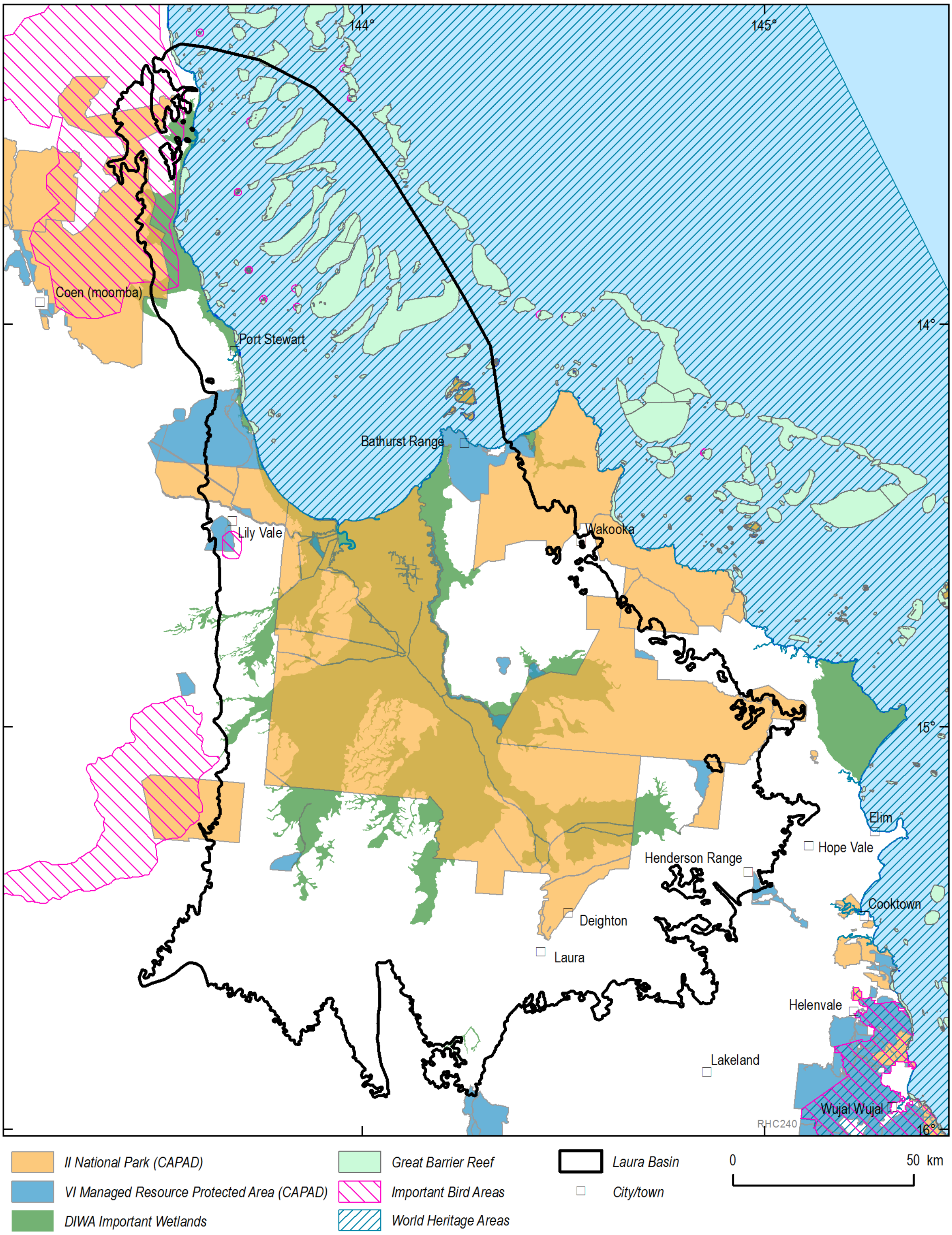


Figure 3.16. National Parks, Managed Resource Protected Areas and Wetlands of National Significance, Laura Basin (data source: DSEWPaC (2010)).

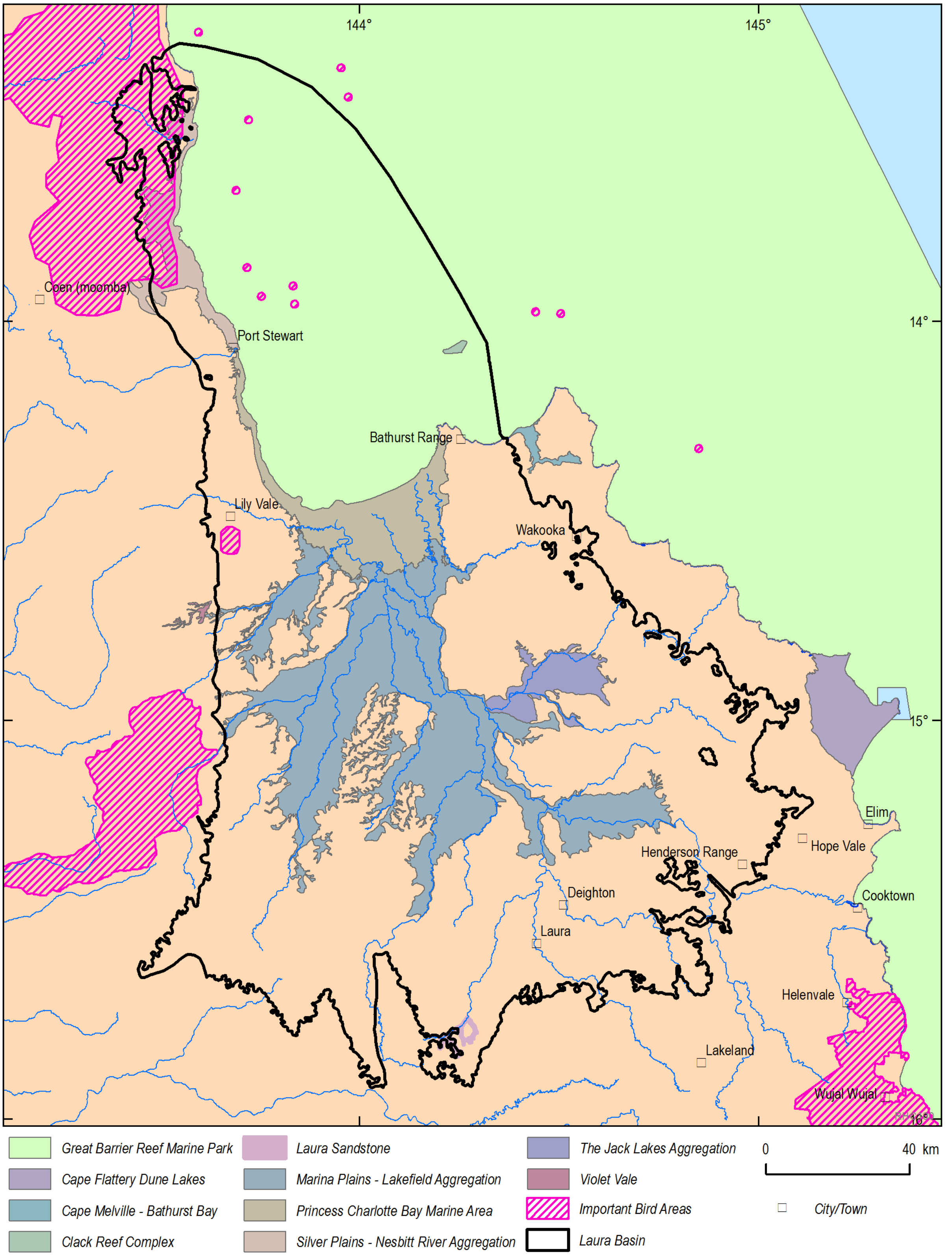


Figure 3.17. Wetlands of national significance (data source: DSEWPaC (2001)).

4 Geology

4.1 Basin setting

The Laura Basin is infilled with sedimentary rocks deposited between 168 and 102 million years ago (Ma) during the Middle Jurassic and Early Cretaceous periods of the Mesozoic (Figure 4.1). Deposition of these sedimentary rocks within the Laura Basin is likely to have been contiguous with the nearby Carpentaria Basin to the west. Uplift of the highlands to the west of the Laura Basin commenced at about 90 Ma, beyond which erosion of the Mesozoic sequences commenced. Prior to erosion, the connection between the Carpentaria and Laura Basins is believed to have been more widespread. Today, sediments in the Laura Basin are connected to the Carpentaria Basin by the Kimba Arch, a 9km wide zone cutting between the Coen and Yambo basement inliers, where up to 60 m of rocks of the Gilbert River Formation and as little as 1.5 m of Wallumbilla Formation drape over the basement rocks (Smerdon *et al.* 2012).

The Laura Basin is bounded to the west and south-west by outcropping older Paleozoic igneous and metamorphic rocks of the Yambo Subprovince and Coen Metamorphics that form part of the Great Dividing Range. To the south and east, the basin is bounded by deformed metasedimentary rocks of the Paleozoic Hodgkinson Province. The Laura Basin also overlies the smaller Late Paleozoic Lakefield Basin which extends northwards offshore (Wellman 1995). Thermal subsidence of the Lakefield Basin is thought to have stimulated deposition of the sedimentary sequences of the Laura Basin (Wellman 1995).

The Laura Basin extends offshore into Princess Charlotte Bay, where its northern limits are poorly defined. The basin covers approximately 34,000 km^2. The onshore area of the basin is approximately 19,000 km^2 (Smerdon *et al.* 2012). The Laura Basin probably increases in thickness to approximately 2,000 m in its offshore area, although the maximum measured thickness of strata is 1,020 m.

Overlying the Laura Basin are Cenozoic sedimentary deposits of the Kalpower Basin. Sediments in the Kalpower Basin likely accumulated in a similar manner to that of the Karumba Basin (which overlies the Carpentaria Basin) where continuous cycles of uplift, erosion, deposition and weathering have caused sediment accretion. The Cenozoic continental deposits of the onshore area are thought to merge into a marine sequence similar to (and continuous with) that of the south-western Papuan Basin (Smart and Senior 1980).

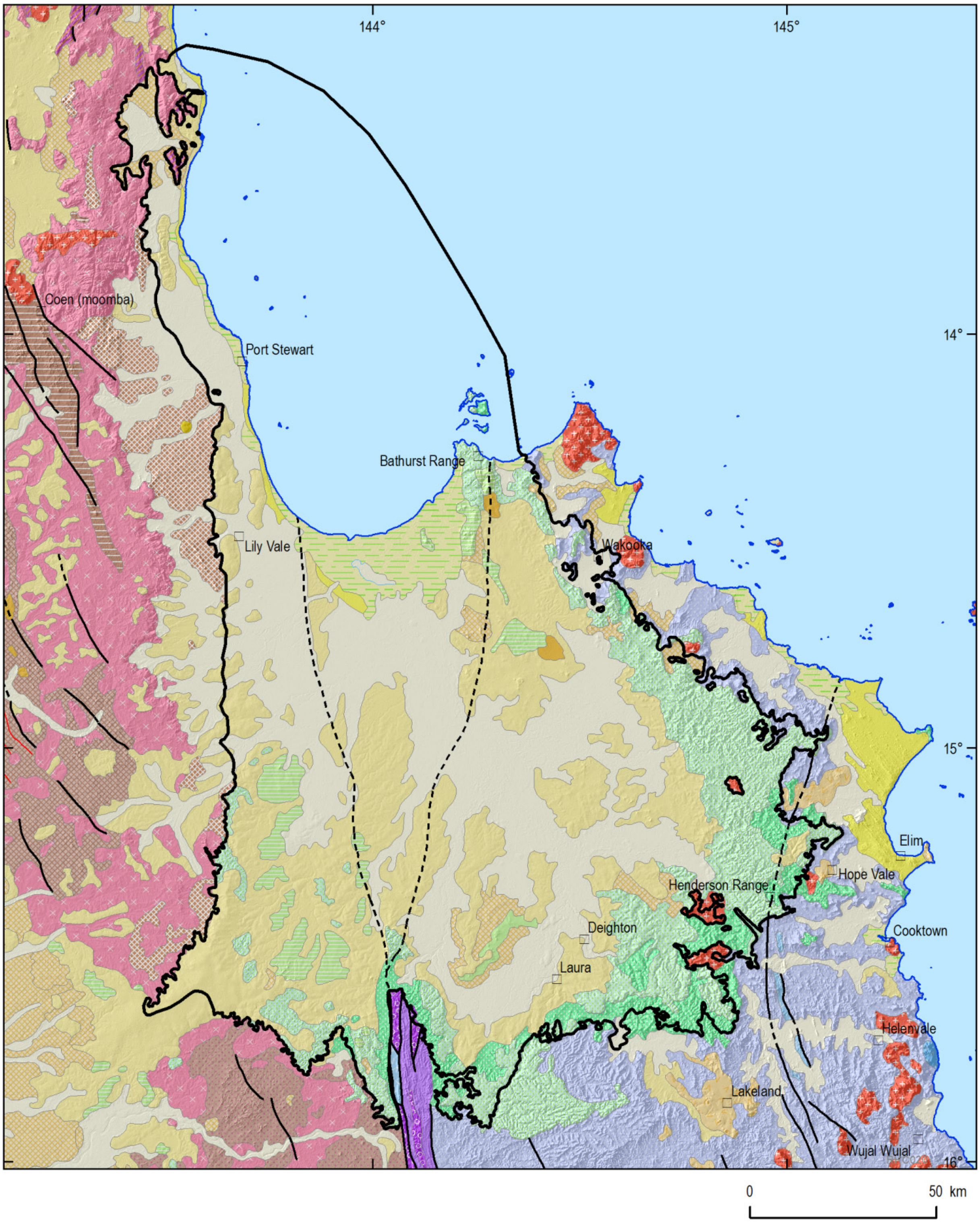


Figure 4.1. Surface geology of the Laura Basin and surrounding region (data source: DNRM (2012b)).

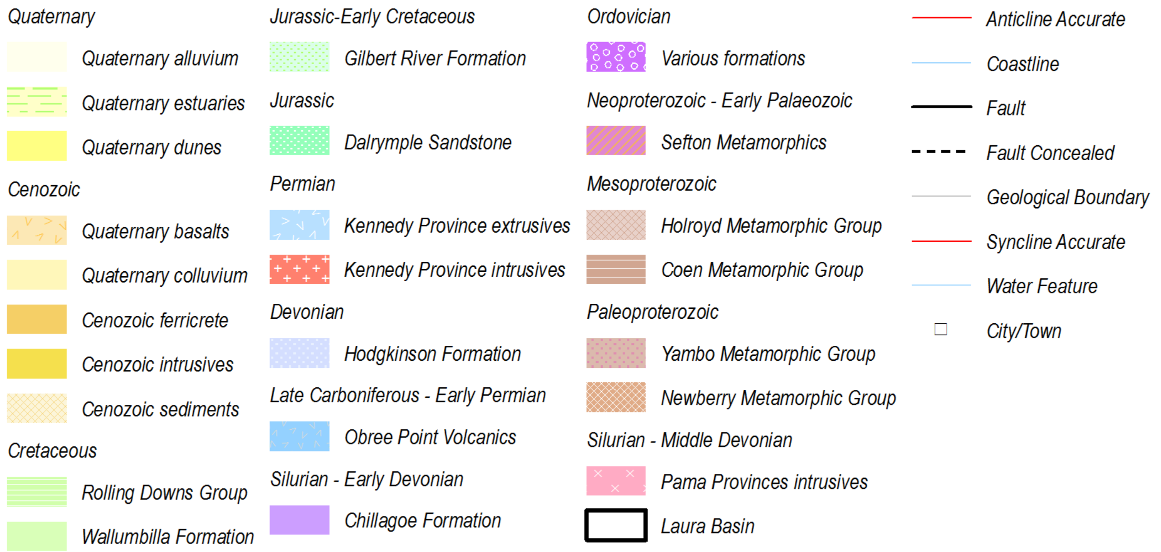


Figure 4.1. Surface geology of the Laura Basin and surrounding region (data source: DNRM (2012b)) (legend relates to map on previous page).

4.2 Stratigraphy

Table 4.1 presents a summary of the stratigraphy of the Laura Basin and the surrounding formations.

Figure 4.2 shows the stratigraphic relationships of rocks of the Laura Basin with equivalent rocks of other Great Artesian Basin sub-basins. The figure also shows the relationship between nomenclature used in the Laura Basin, prior to the recognition of stratigraphic continuity with the Carpentaria Basin, and nomenclature now used.

4.2.1 Paleoproterozoic

Rocks of the Yambo Subprovince and the Coen Metamorphics underlie the Laura Basin to the west of the Palmerville Fault. These include high grade schist, quartzite, ortho and para gneiss, amphibolite, mafic granulite, muscovite-biotite granite, granodiorite, pegmatite rocks that were originally mostly fine, even-grained thin bedded shallow marine clastic sediments that accumulated in an intracontinental basin and were subsequently intruded by metamorphic igneous bodies.

4.2.2 Devonian–Permian

Rocks of the Hodgkinson Province underlie the Laura Basin east of the Palmerville Fault (Bain and Draper 1997b). These are Devonian to Permian age, situated in the south-east of Cape York Peninsula, consisting of deep water siltstones, arenites, conglomerates and basalts. These units have subsequently experienced tectonic compression and have undergone low grade metamorphism (greenschist facies). The beds are now tightly folded and are usually steeply dipping.

Table 4.1. Lithostratigraphic summary of the Laura Basin and surrounding geological domains (see Appendix 3 for the current geological timescale).

Basin	Stratigraphy		Lithology	Depositional environment	Distribution	Age	Max thickness	Coal occurrence
Kalpowar Basin	Brixton Formation (Claraville Cycle)		The formation is made up of 'more or less' consolidated sediments and can generally be divided into an older, mottled and dominantly clayey unit, and an upper less consolidated, coarser and better sorted unit which includes porous sand, pebbly sand and gravel, cemented by limonite and manganese oxides. Basalt pebbles are locally present.	Alluvial fan	The Brixton formation is widespread in the northern part of the Kalpowar Basin overlying the Laura Basin. It probably underlies much of the alluvium on the Normanby Plain, and is well exposed at the base of the scarp along the western margin of the Deighton Tableland. An erosional break separates the Brixton Formation from the underlying Fairview Gravel. The Brixton Formation also rests disconformably on leached Wolena Claystone (Rolling Downs Group). The formation blankets a large part of the intermontane depressions and valleys and the northern coastal plain and in places forms gently dipping fans and wash plains.	Cenozoic	up to 43 m	No
	Lilyvale Beds		Quartzose sand and sandstone, pebble to boulder quartz gravel and conglomerate; generally silicified.	Fluvial	These beds occur in the flat low-lying parts of the Normanby and Jack Plains as well as montane valleys along the western margin of the Laura Basin, against basement on the Hann River, Ebagoola and Coen 1:250,000 sheets. They are unconformable on Mesozoic and older rocks.		up to 50 m	No
	Bulimba Formation							No
	Fairview Gravel		Conglomerate and clay-cemented sandstone. Gravel is of rounded quartz pebbles, pebbles and sand, generally silcreted.	Fluvial	Axial part of the Laura Basin under Princes Charlotte Bay. Poorly exposed in the Fairview Plateau east of 'Kalpowar'. Present in outcrop in the Cooktown sheet and intercepted in Marina 1 and Ebagoola 1.		up to 40 m	No
Laura Basin	Undiff. Rolling Downs Group (formerly the Battle Camp Shale and Wolena Claystone)	Normanton Formation, Wolena Claystone	Basal shale is a marine sequence of variably calcareous and glauconitic shales, with minor siltstone and conglomerate bands overlain by marine silty and sandy claystone with calcareous concretions.	Shallow marine	Eastern side of Cape York Peninsula. Extends offshore into Princess Charlotte Bay where its northern limits are poorly defined. Conformably overlies Gilbert River Formation. Top of unit eroded.	Cretaceous	up to 300 m	No
		Wallumbilla Formation (formerly known as Battle Camp Shale)				Cretaceous (Aptian to Albian)		No
	Gilbert River Formation (formerly the Battle Camp Sandstone)		Quartz to feldspathic clay-rich sandstone that is locally glauconitic, oolitic and calcareous, interbedded with minor calcareous siltstone, claystone and conglomerate.	Lagoonal to marginal marine	Conformable over the Dalrymple Sandstone except in the eastern basin where the contact may be unconformable.	Lower Cretaceous to Jurassic	300 m	Yes
	Dalrymple Sandstone		Quartz to lithic feldspathic sandstone with subordinate claystone, siltstone, conglomerate and tuff. Coal seams up to 3 m thick occur near the base.	Braided fan system close to a source area in the northeast. Coastal lagoon grading to fluvial near the top of the unit	Overlies Lakefield Basin, Yambo Subprovince and Hodgkinson Province.	Middle to Upper Jurassic	600 m	Yes
Upper Permian Sediments	Lakefield Basin		Sandstone, siltstone and shale, basalt and other volcanic rocks.	In part fluvio-deltaic, mostly unknown	The preserved basin is 70 km wide, 200km long. Underlying the western part of the Laura Basin. The basin overlies Proterozoic rocks of the Yambo Subprovince west of the Yintjigga Fault Zone, but probably similar basement east of the fault.	Permian	about 12km	Yes
	Normanby Formation/ Little River Coal Measures		Siltstones, sandstones, carbonaceous shales, tuffs and coals.	Fluvio-deltaic	Small outliers in the region of the southern extent of the Laura basin	Permian		Yes
Hodgkinson Province	Hodgkinson Formation, Chillagoe Formation		Limestone (Chillagoe Formation), deep-water turbiditic sandstone and mudstone (Hodgkinson Formation).	Marine	East of the Palmerville fault, basement to the Laura and Lakefield Basins.	Devonian to Carboniferous		No
Yambo Sub-province	Newberry Metamorphic Group, Dargalong Metamorphics, Yambo Metamorphic Group		High grade schist, quartzite, ortho- and para-gneiss, amphibolite, mafic granulite, muscovite-biotite granite, granodiorite, pegmatite. Original sedimentary rocks were mostly fine, even-grained thin bedded shallow marine clastic sediments.	Original sediments accumulated in an intracontinental basin, intruded by metamorphic igneous bodies	West of the Palmerville Fault, basement to the Laura and Lakefield Basins.	Paleoproterozoic		No

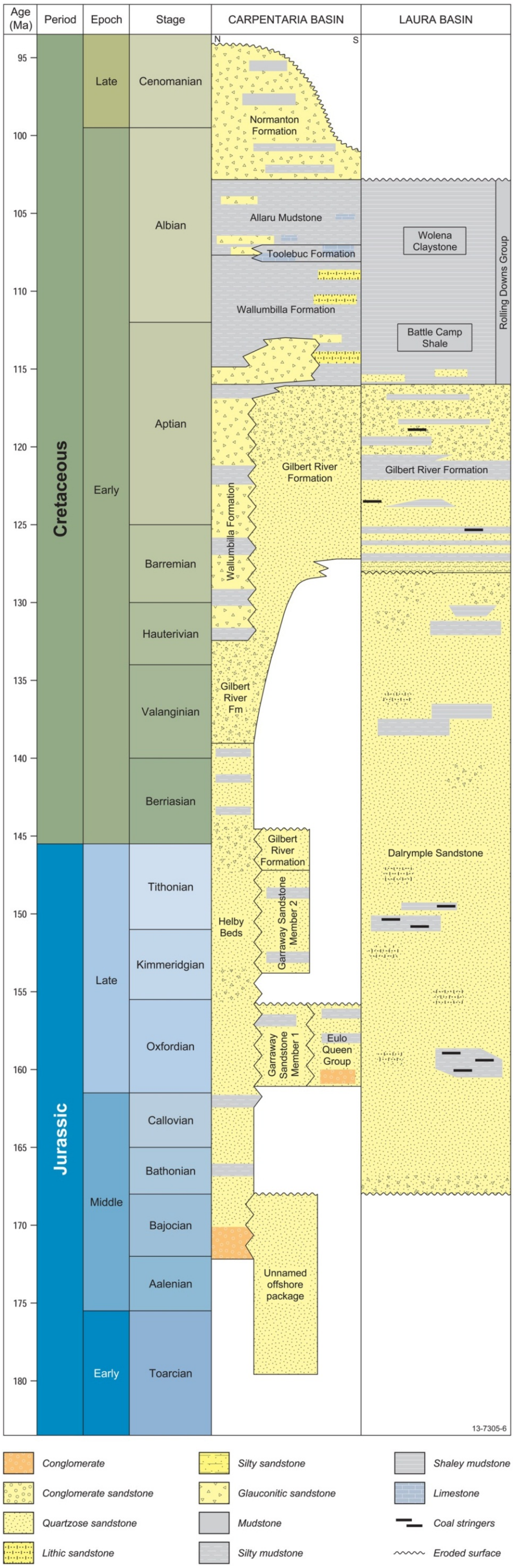


Figure 4.2. Mesozoic sedimentary sequences of the Laura Basin and Carpentaria Basin (after Ransley and Smerdon (2012)).

4.2.3 Permian–Triassic

4.2.3.1 Lakefield Basin

The Lakefield Basin comprises gently-dipping Permian to Triassic sedimentary rocks and volcanics underlying the western part of the Laura Basin. The basin overlies Proterozoic rocks of the Yambo Subprovince west of the Yintjigga Fault Zone and unknown, but probably similar basement, east of the fault. It is bounded on its eastern margin by the Palmerville Fault. The basin is 70 km wide, 200 km long, and greater than 10 km thick (Bain and Draper 1997b). It covers an area of ~10,000 km^2 onshore beneath the north-western Laura Basin, and extends offshore into the Coral Sea.

Lakefield Basin rocks are described from four oil exploration wells, one stratigraphic hole, one exposure on Bathurst Head, and from samples from the base of nine coal exploration holes in the Bathurst Range area (A to P 4020, Sandalwood Creek) (Bain and Draper 1997b).

The Lakefield Basin sedimentary rocks have not been formally named and include indurated sandstones, siltstones, conglomerates, minor sulphides, rare calcite, carbonaceous shales, cherts and volcanic (tuffaceous) interbeds (Bain and Draper 1997b). Sedimentary rocks are reported to be highly indurated and have low porosity.

Trace hydrocarbons have been recorded in the Permian sediments of the Lakefield Basin. A drill stem test from CBT Marina 1 recovered flammable gas in muddy water (ATP61P 1962).

4.2.3.2 Normanby Formation and Little River Coal Measures

Outcropping Permian sedimentary rocks on the COOKTOWN 1:250,000 mapsheet are the Normanby Formation and the Little River Coal Measures (Wellman 1995). These outcrops occur at the margins of the Laura Hydrogeological Basin.

The Normanby Formation crops out in two north-south elongated faulted outliers. The eastern boundary of the outcrop is controlled by the King Plains Fault (Jago 1975). Rock types are sandstone, siltstone, tuff, minor conglomerate and coal. The depositional environment is thought to be fluvial (Jago 1975).

The Little River Coal Measures occur in a narrow fault trough wedged between Pre-Cambrian rocks to the west and Silurian or Devonian rocks to the east (Sturmfels 1957) just outside the southern boundary of the Laura Basin, within the region of the Yintjigga Fault Zone. Rock types include siltstones, sandstones and carbonaceous shales with coal seams. The depositional environment is not thought to be marine based on palynology assessments (Sturmfels 1957).

4.2.4 Jurassic–Cretaceous (Laura Basin)

The Laura Basin Mesozoic sequence began with deposition of the predominantly fluvial/deltaic Dalrymple Sandstone, overlain by the fluvial and marginal marine Gilbert River Formation. The sequence terminates with the entirely marine Rolling Downs Group or, locally, with the Normanton Sandstone. The sediments of the Laura Basin are defined to varying degrees across the Basin. It is difficult to distinguish individual formations within the Rolling Downs Group in the Laura Basin (Bain and Draper 1997b). Geological mapping does not differentiate the sub-units of the Rolling Downs Group north of 16°S. Similarly, the Gilbert River Formation and Dalrymple Sandstone are undifferentiated in the north-east of the Basin. The Laura Basin sequence has a total thickness of approximately 1,000 m on-shore and may increase to a total thickness of 2,000 m offshore (Bain and Draper 1997b).

4.2.4.1 Dalrymple Sandstone

The Dalrymple Sandstone unconformably overlies Devonian–Carboniferous Hodgkinson Province rocks to the east of the Palmerville Fault and overlies the Paleoproterozoic Yambo Subprovince rocks to the west of the fault. Locally the unit overlies Triassic and Permian sedimentary rocks of the Lakefield Basin. The rocks of the Dalrymple Sandstone includes fine- to coarse-grained (pebbly in part) quartzose and sub-labile sandstone with minor mudstone, conglomerate, minor siltstone, shale and coal. The precursor sediments were originally deposited in fluviatile and paralic environments during the Middle to Upper Jurassic (Smart and Senior 1980). It is thick bedded, unstratified and cross bedded and generally well sorted. The unit is a biostratigraphic and lithostratigraphic equivalent of the Loth Formation (Eulo Queen Group) in the southern Carpentaria Basin of the Great Artesian Basin (Smerdon *et al.* 2012).

The Dalrymple Sandstone generally fines upwards from conglomerates into sandstones and siltstones (Horn *et al.* 1995). Dalrymple Sandstone formation thicknesses vary from around 60 m near the outcrop in the eastern part of the basin to over 500 m near the coast at Princess Charlotte Bay (Horn *et al.* 1995). The Dalrymple Sandstone has a known maximum thickness of 544 m, intercepted in a petroleum exploration hole (Marina-1).

Coal seams of up to 3 m thickness occur near the base of the Dalrymple Sandstone (GGSS 2009). Coal has been intercepted in many of the bores now used as water bores (see Healthy Head Waters bore lithology database), and in the stratigraphic well GSQ Ebagoola 1. Up to 12 thin seams have been identified and correlated in the Bathurst Range area (Whitby *et al.* 1996a).

4.2.4.2 Gilbert River Formation

The Gilbert River Formation was identified by McConachie et al. (1990) as being the sequence formerly called the Battle Camp Formation (De Keyser and Lucas 1968). In the eastern Laura Basin, the formation appears to disconformably overlie the Dalrymple Sandstone and this relationship becomes a low angular unconformity on Flinders Island, approximately 10 km north of Bathurst Head (De Keyser and Lucas 1968). The Gilbert River Formation consists of mainly very fine- to coarse-grained, light greenish grey to white, quartzose and sub-labile sandstones with minor mudstone, siltstone and conglomerate. The unit was mainly deposited in a marine environment, and contains glauconite in rocks near the top of the sequence.

The Gilbert River Formation was deposited in lagoonal to marginal marine environments during the Upper Jurassic to Lower Cretaceous (GGSS 2009). De Keyser and Lucas (1968) estimated a thickness of 152 m in the Battle Camp Range, although the formation ranges from almost 0–275 m in the Bathurst Range. It is usually about 75 m thick around the elevated margin of the basin, and has a thickness of 380 m, intercepted in petroleum exploration well Marina 1, which is located in the axis of the basin near the coast (De Keyser and Lucas 1968).

In the south-west and west over the Palmerville Fault Zone the Gilbert River Formation onlaps the Proterozoic and Palaeozoic basement (Horn et al. 1995). The Gilbert River Formation is draped over the Kimba Plateau where it is about 60 m thick (Smerdon et al. 2012).

4.2.4.3 Rolling Downs Group

The Rolling Downs Group (formerly Battle Camp Shale and Wolena Claystone) was deposited in a shallow-marine environment during the Lower Cretaceous. The basal shale is a marine sequence of variably calcareous and glauconitic shales, with minor siltstone and conglomerate bands overlain by marine silty and sandy claystone with calcareous concretions. The Rolling Downs Group crops out within the centre of the basin and has a very restricted extent in the south. Where present, it appears to be an erosional remnant beneath the Cenozoic sediments of the Kalpower Basin (GGSS, 2011).

It is difficult to distinguish individual formations within the Rolling Downs Group in the Laura Basin (Bain and Draper 1997b). Geological mapping does not differentiate the sub-units of the Rolling Downs Group north of 16°S. In addition, Ransley and Smerdon (2012) noted that the Carpentaria Basin sequence contains a greater proportion of sand relative to that of the Eromanga Basin and that this is of particular importance when considering the integrity of the main confining sequence (the Rolling Downs Group aquitard) which contains a greater proportion of sandier facies. This greater proportion of sand may diminish the effectiveness of the Rolling Downs group as an aquitard.

Tectonic and igneous events along the eastern margin of the Australian continent, preceding the opening of the Tasman and Coral seas, decreased the depositional area of the Laura Basin during Late Albian times (Bradshaw and Yeung unpublished). This may explain the limited thickness of Rolling Downs Group sedimentary rocks in the east of the Laura Basin and their change to more sandy facies relative to other areas of the Great Artesian Basin.

This unit has a known maximum thickness of 310 m, intercepted in petroleum exploration well Lakefield 1. The thickness is not well constrained in the central-southern basin (GGSS, 2011).

In the eastern onshore area, at Bathurst Range, an upper unit of the Rolling Downs Group (quartz-rich sandstone) is present and was referred to as the Normanton Sandstone (Whitby *et al.* 1996b). Generally it was deposited as a sequence of beach sediments, dune deposits and fluvial deposits. It is interbedded with the upper glauconitic sandstone of the Rolling Downs Group. In this north-eastern area it is >95 m thick and consists of “clean grey quartz sandstone with medium and large scale cross bedding” (Horn *et al.* 1995).

As part of this study, lithological logs were collected from the Healthy Headwaters database (DNRM 2012a). No stratigraphic information was attached to the lithology and due to the importance of a hydrostratigraphic conceptualisation of the basin the lithological sequences were assigned to the known geological units as part of this study (using consistent lines of geological evidence and knowledge). As a result it became possible to distinguish the Wallumbilla Formation and the Normanton Sandstone units of the Rolling Downs Group. In the south and south-western parts of the Laura Basin, the Wallumbilla Formation is present, reaching thicknesses of up to 280 m. In the north-east of the Laura Basin, the rocks of the Rolling Downs Group appear to be those of the Normanton Formation.

In the Carpentaria Basin, the Wallumbilla Formation is described as interbedded siltstone and coarse to very fine-grained glauconitic sandstone with minor calcareous and rare pyritic phases. It is a marine sequence deposited during Hauterivian epoch of the lower Cretaceous (Bain and Draper 1997b). It is underlain by the Gilbert River Formation.

In the Carpentaria Basin, the Normanton Sandstone is described as a medium- to fine-grained labile glauconitic sandstone with locally common siltstone interbeds and carbonaceous phases (Bain and Draper 1997b). It was deposited in a shallow marine-paralic regressive sequence during the late Albian stage of the Lower Cretaceous (Smart *et al.* 1980).

The continuity and composition of the Rolling Downs Group is important for understanding the extent of the regional-scale aquitard that overlies the Mesozoic aquifers of the Laura Basin. The Rolling Downs Group is discussed further in Section 6.2.

4.2.5 Cenozoic

The Kalpowar Basin overlies the Laura Basin. The Kalpowar Basin is a Cenozoic sedimentary basin that continues to be depositional in modern times. To the east of the Coen and Yambo Inliers, the Kalpowar Basin developed in parallel with the Karumba Basin (located to the west of the Coen and Yambo Inliers), overlying the axial part of the onshore Laura Basin and extending northward offshore under Princess Charlotte Bay. The maximum thickness of the Kalpowar Basin sediments onshore is approximately 70–80 m.

Deposition of the Kalpowar Basin commenced in the Lower Cenozoic and occurred in three continuous cycles of tectonism, erosion, deposition and weathering (Grimes 1980). The Fairview Gravel formed in the initial Cenozoic cycle. It is now exposed as thin mesa caps of conglomerate and quartz sandstone which have been ferruginised and silicified (the Aurukun Surface). A second cycle commenced in the Middle to Upper Cenozoic, initiated by Oligocene uplift along the axis of the present Great Dividing Range. Intrusion of several undated olivine-nephelenite plugs in the northern part of the basin was followed by widespread deposition of the Miocene to early Pliocene Lilyvale Beds. The Lilyvale Beds comprise up to 50 m of clayey quartzose sand, gravel and sandy clay. The Lilyvale Beds were lateritised with the formation of the early Pliocene Kendall Surface. A third cycle of activity commenced with further uplift of the Great Dividing Range in the Pliocene (Grimes 1980). Deposition occurred on most of the Coastal Plains. These three cycles are considered to be equivalents of the Bulimba, Wyaaba and Claraville cycles of the Carpentaria Basin (Smerdon *et al.* 2012).

Up to five phases of alluvial deposition have occurred in the Upper Pliocene and Quaternary. The older alluvial deposits are commonly lateritised and silicified to some degree, e.g., the older talus deposits and fluvial terraces in the Laura Basin (Grimes 1980). Contemporaneous basaltic volcanism occurred in the Piebald and McLean Provinces on the Cooktown 1:250,000 mapsheet. Quaternary fluvial and coastal deposits have continued to be deposited to the present day (Smart and Senior 1980).

The Cenozoic units generally consist of clayey, silty sandstones and claystones with some rounded quartz gravels. Sediments can be consolidated at depths of 20 to 30 m. Near-surface sands and gravels are dispersed across the southern and western parts of the basin and are mostly less than 10m thick. Alluvial sands and gravels are associated with all the major river systems in the basin. They are generally cleaner and coarse-grained in the south-east, but become siltier towards the north-western onshore margins (Horn *et al.* 1995).

Pleistocene to recent alluvial deposits are extensive in the Normanby Plain. They consist of unconsolidated silty and fine sandy clay and are probably up to 30 m thick. They rest on older and mottled alluvial sediments (Brixton Formation) and Cretaceous sedimentary rocks with cut-and-fill relationships. The clay is generally dark grey, dense, swelling, calcareous variety (De Keyser and Lucas 1968).

Coastal sand dune deposits occur around Princess Charlotte Bay. The eastern dunefields have a thickness of 25–30 m and grain sizes range from fine sand to gravel, with the grains generally winnowed into a narrow size range. Around Princess Charlotte Bay, there is a chenier plain approximately 25 km wide, consisting of ridges of sands, fine gravels and shell grit with a relief of only 2 m (Horn *et al.* 1995).

Four named formations occur within the Kalpowar Basin and are described below. Ransley *et al.* (2012) differentiated and mapped these units of the Cenozoic sequence (Figure 4.3).

4.2.5.1 Bulimba Formation & Fairview Gravel (Bulimba Cycle)

The Bulimba Formation consists of interbedded clayey quartzose sandstone, granule conglomerate, clayey sandstone, siltstone and sandy claystone identified in the Karumba Basin. The Fairview Gravel is a thinner and less-extensive basal unit of the Bulimba Formation and is of Paleogene age (Paleocene to Eocene). It is present as small tablelands in the Kalpowar Basin over the Laura area on the Cooktown 1:250,000 mapsheet. The Fairview Gravel unconformably overlies the Laura Basin Mesozoic sequence. Maximum outcrop thickness is 6 m, with 40 m intercepted in stratigraphic well Ebagoola 1, and 30 m in petroleum well Marina 1. The Fairview Gravel consists of conglomerate and clay-cemented sandstone of unknown age. Gravel is of rounded quartz pebbles, pebbles and sand, and is generally silcreted. These sediments were deposited in a fluvial environment and may be a remnant of a more extensive fluvial basin which occupied the eroded central area of the Laura Basin.

4.2.5.2 Lilyvale Beds (Wyaaba Cycle)

The Lilyvale beds are of Neogene age, Miocene to early Pliocene (Table 4.1). They occur in the flat low-lying parts of the Normanby and Jack Plains as well as montane valleys along the western margin of the Laura Basin, and abutting basement on the Hann River, Ebagoola and Coen 1:250,000 mapsheets. The Lilyvale Beds were deposited in fluvial environments. They are unconformable on Mesozoic and older rocks, ranging up to 50 m maximum thickness. They consist of quartzose sand and sandstone, pebble to boulder quartz gravel and conglomerate; and are generally silicified (Radke *et al.* 2012).

4.2.5.3 Brixton Formation (Claraville Cycle)

The Brixton Formation is an Upper Cenozoic sequence; probably of Neogene to Pleistocene age (Table 4.1). It is widespread in the north-eastern part of the Kalpowar Basin. It probably underlies much of the alluvium on the Normanby Plain, and is well exposed at the base of the scarp along the western margin of the Deighton Tableland. An erosional break separates the Brixton Formation from the underlying Fairview Gravel. The Brixton Formation also rests disconformably on the leached Wolena Claystone (Rolling Downs Group) in the east. The formation blankets a large part of the inter-montane depressions and valleys and the northern coastal plain and in places forms gently dipping fans and wash-plains.

The thickness of the Brixton Formation ranges up to 43 m (intercepted in Marina 1). The formation is made up of 'more or less' consolidated sediments and can generally be divided into an older, mottled and dominantly clayey unit, and an upper less consolidated, coarser and better sorted unit which includes porous sand, pebbly sand and gravel, cemented by limonite and manganese oxides. Basalt pebbles are locally present (Radke *et al.* 2012). Bain and Draper (1997b) described the Brixton Formation as Cenozoic to Quaternary alluvium and alluvial fans capped by ferricrete.

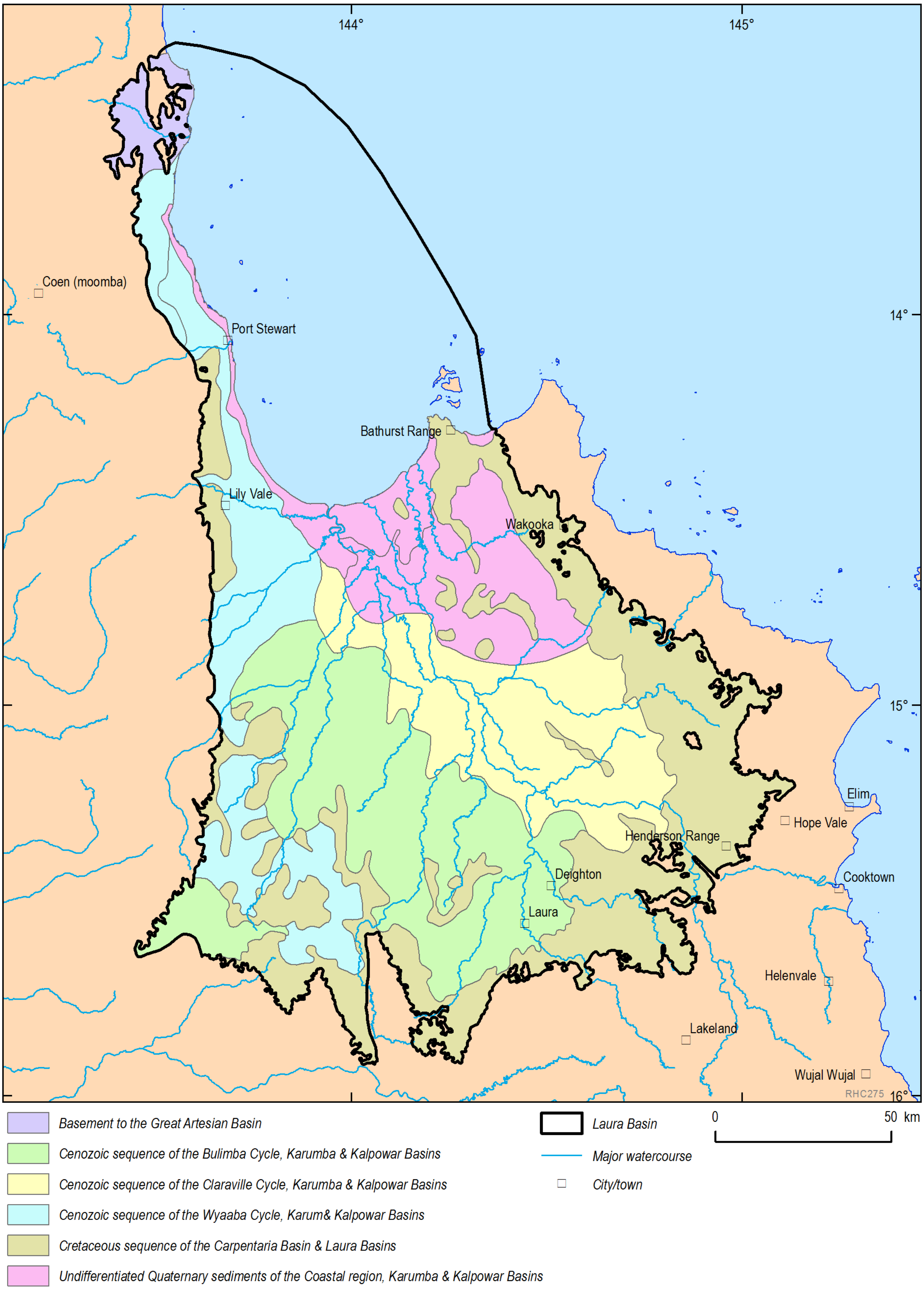


Figure 4.3. Cenozoic Geology, Laura Basin (data source: Ransley et al. (2012)).

4.3 Stratigraphic mapping of the Laura Basin

Prior to this project, there has been limited stratigraphic mapping of the Laura Basin. Much of the work that has been done has either focussed on small areas within the wider basin or used limited existing interpretation of borehole data.

To conceptualise the hydrogeology of the Laura Basin, it was necessary for borehole data to be mapped to produce isopachs (maps of total thickness) of the basin stratigraphy. Existing borehole data was compiled from Queensland Government groundwater bore databases, Geoscience Australia's petroleum well database and open-file company exploration reports downloaded from Queensland Exploration Reports (QDEX), Department of Natural Resources and Mines, Queensland Government. Borehole information was also supplemented by seismic data interpretation from open-file company exploration reports and work previously undertaken to map the basement to the Great Artesian Basin (Nelson *et al.* 2012).

There are two databases that include groundwater bores in Queensland. These are the Healthy Headwaters Database (DNRM 2012a) and the Queensland Bore Database (DERM 2011). In the Laura Basin, these databases include the same bore records, although (and as a note of caution for future projects using these datasets), they differ slightly with respect to the tables of information associated with each bore.

Two hundred and seventy-two (272) drill holes with lithological information were collated by the Queensland Department of Natural Resources and Mines (DNRM 2012a) in the Laura Basin and made available in the Healthy Headwaters dataset. However, at each bore site, the geological formations, rock types and stratigraphic units have not been interpreted in the database. The Queensland Bore Database (DERM 2011) also did not have stratigraphic interpretation records for boreholes in the Laura Basin. The borehole lithological logs were interpreted as part of this project, and stratigraphic units were assigned. The interpreted geological formations were also validated against previous exploration company records, and the results were amended where necessary. These new interpretations have been collated together in a database available on request from Geoscience Australia (Yates and Tan 2013).

Figure 4.4 shows the location and depths of boreholes with lithological information across the Laura Basin. These bores now have stratigraphic interpretations recorded in the database (Yates and Tan 2013). Boreholes are typically located towards the margins of the basin, where the Gilbert River Formation and Dalrymple Sandstone are intercepted at shallower depths relative to the centre of the basin. Five deep wells have been drilled towards the centre of the basin (1960–1990), for the purpose of petroleum exploration and stratigraphic characterisation. The distribution of borehole data means that the depth and thickness of the stratigraphy is poorly constrained towards the centre of the basin.

Several seismic reflection work programs were conducted over the deeper parts of the basin throughout the period 1960–1980. Most of the seismic traverses were oriented east-west with the remainder oriented roughly north-south aligning with the axis of the basin. In the absence of borehole lithological information, these seismic data provide valuable information on the thickness of the sedimentary rock units, depth to the Permian Lakefield basin and Paleozoic basement units. Unfortunately, much of this seismic data is of low resolution and was available only from scanned company reports which limited integration into this study.

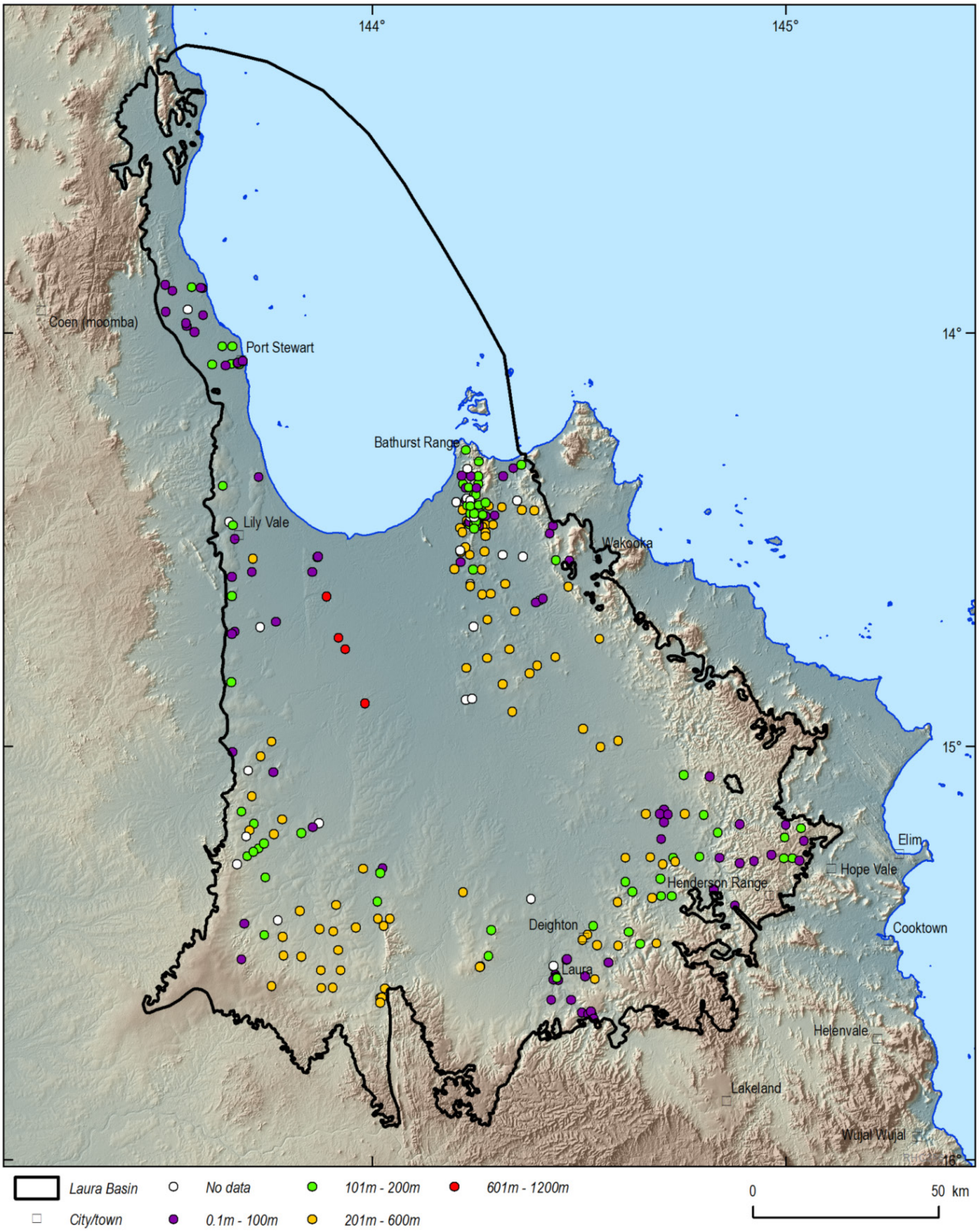


Figure 4.4. Location and depth of bores with lithology information, Laura Basin (data source: Healthy Headwaters Database, DNRM (2012a)).

Figure 4.5 shows the spatial location of two newly developed cross-sections through the Laura Basin, overlain on the regional surface geology map. Figure 4.6 presents these two geological cross-sections. The cross-sections indicate inferred basin boundaries as well as faults. The faults that are represented are from mapping by Raymond (2012) and Senior (unpublished). The fault orientations are vertical in the diagrams and no offsets in the sedimentary untis are mapped as there is insufficient information to provide this insight. The cross-sections thus provides one conceptual model of the basin at the regional scale and others may be possible. Figure 4.7, Figure 4.8, Figure 4.9, and Figure 4.10 present the isopachs for the various formations.

Due to the nature and distribution of the data available for the Laura Basin and the time frames for the project, there is a moderate level of confidence in the structure contour and isopach maps presented here. It is likely that the distribution of the formations is reflected accurately due to the reasonable distribution of datapoints on the basin margins. The moderate confidence in the isopach maps is due to the thickness of lithologies in the centre of the basin where there is less data. The exact thickness of the isopachs at any one location has only a moderate amount of confidence.

The isopachs have not accounted for any truncation in thickness caused by faulting throughout the basin as there is no adequate information to take account of the influence of fault truncations on individual sequences. The work provides a regional-scale geological interpretation to assist in the interpretation of groundwater data so that a conceptual model of the regional scale hydrogeology of the basin could be developed.

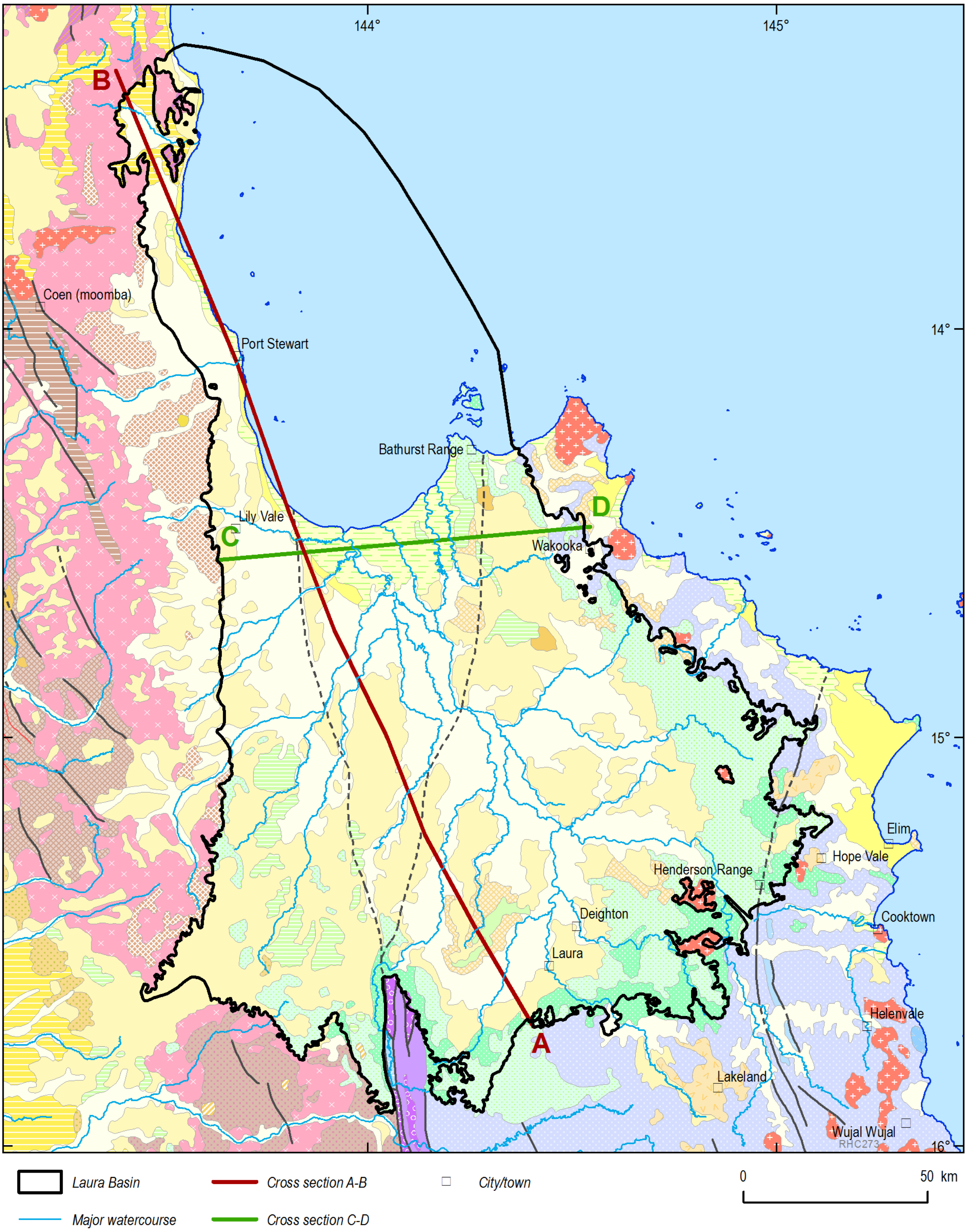


Figure 4.5. Map showing cross-section lines A-B and C-D on the 1: 2,000,000 surface geology (data source: DNRM (2012b)). See Figure 4.1 for surface geology legend.

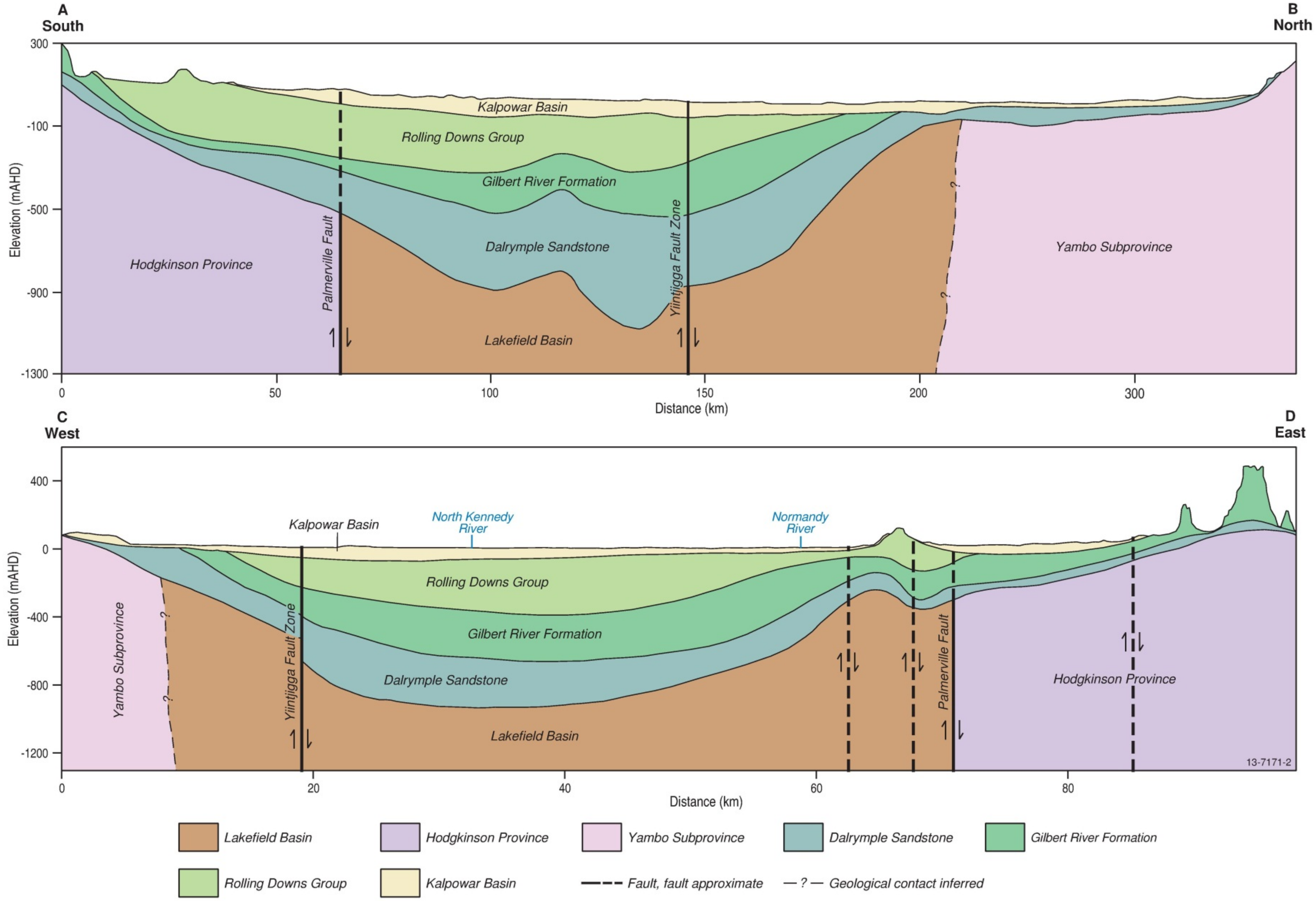


Figure 4.6. Geological cross-sections, Laura Basin. Locations of cross sections are shown on Figure 4.5.

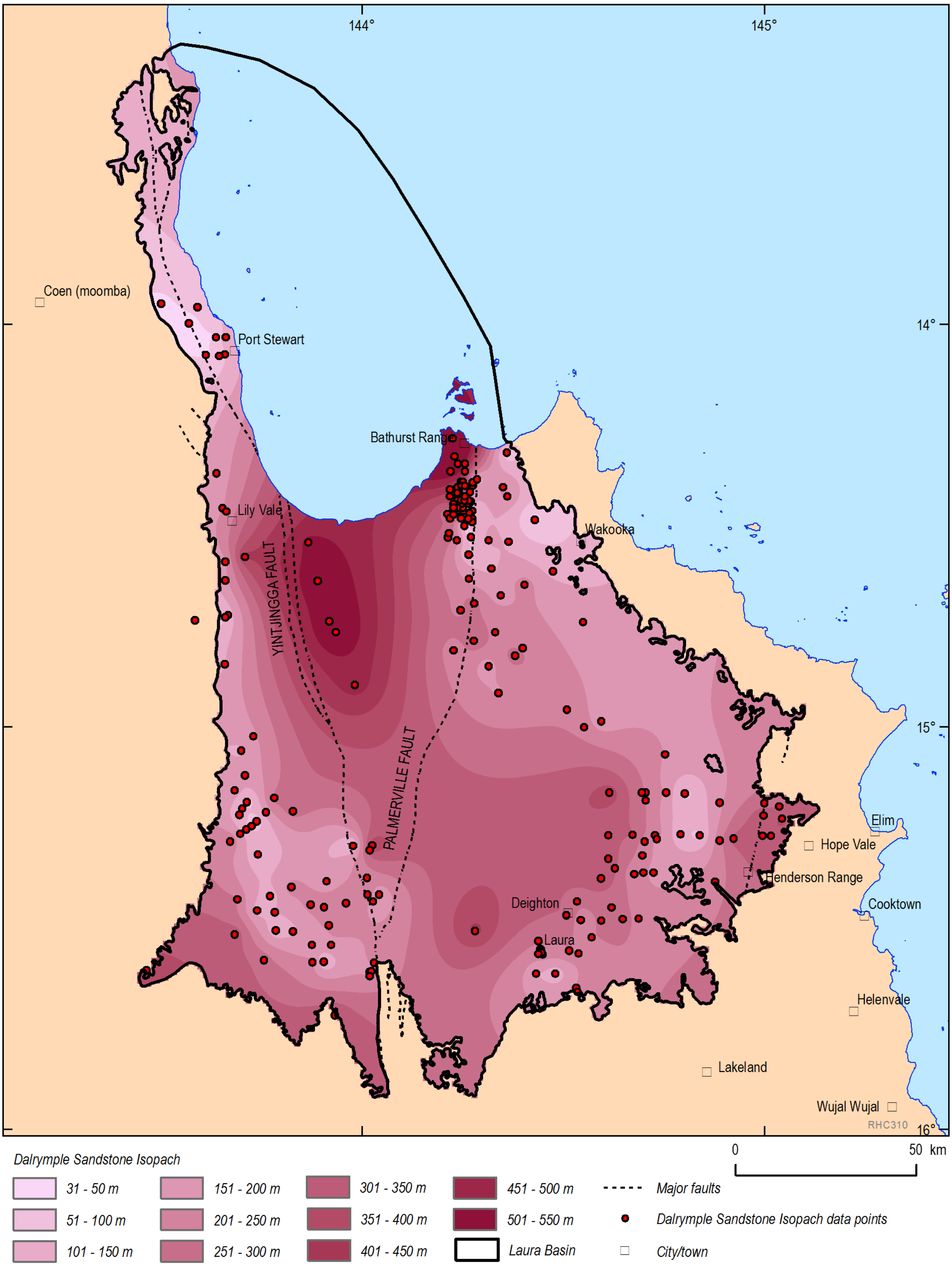


Figure 4.7. Isopach (total inferred thickness), Dalrymple Sandstone, Laura Basin. Base of Dalrymple Sandstone sourced from Nelson et al. (2012).

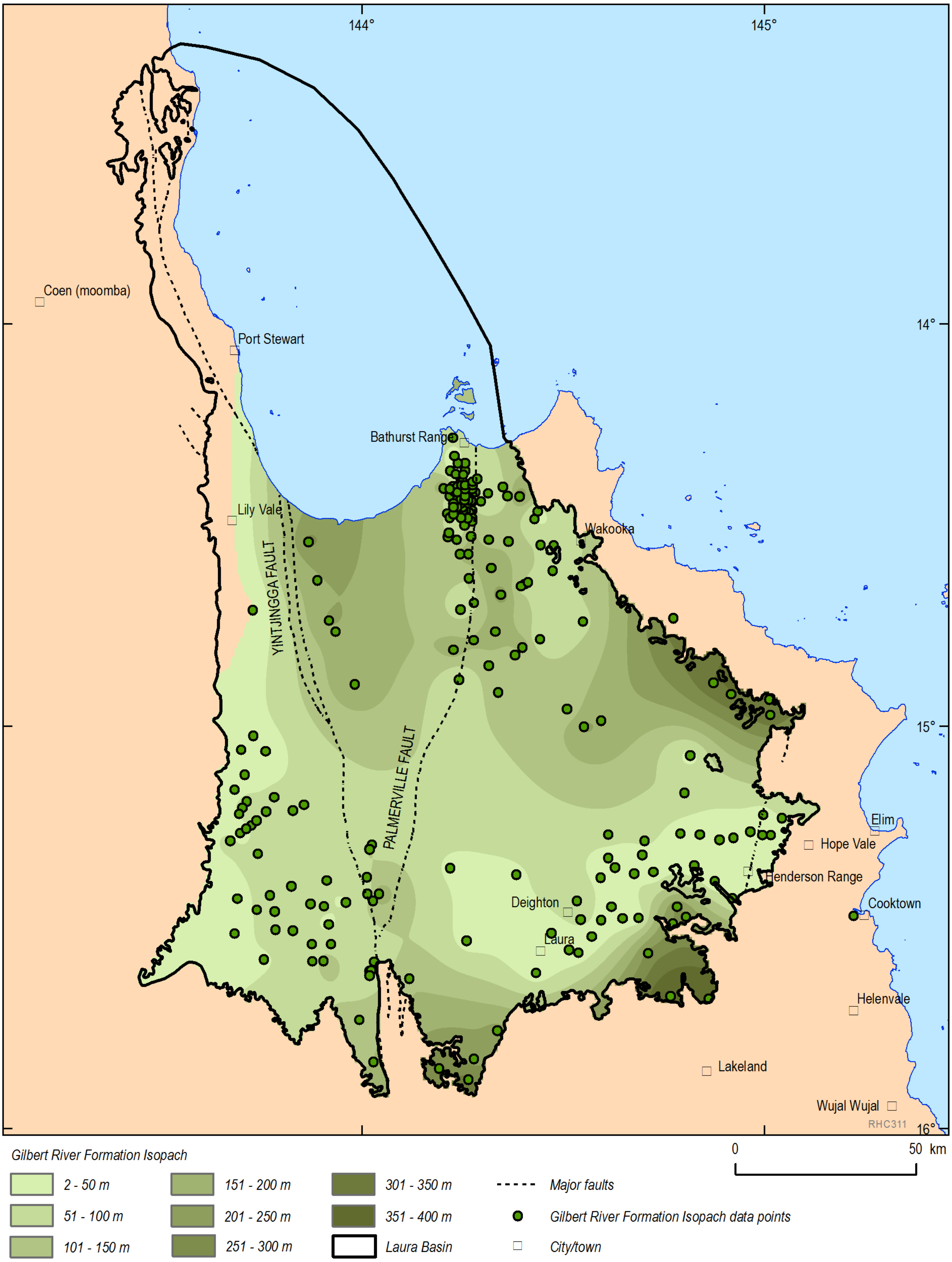


Figure 4.8. Isopach (total inferred thickness), Gilbert River formation, Laura Basin.

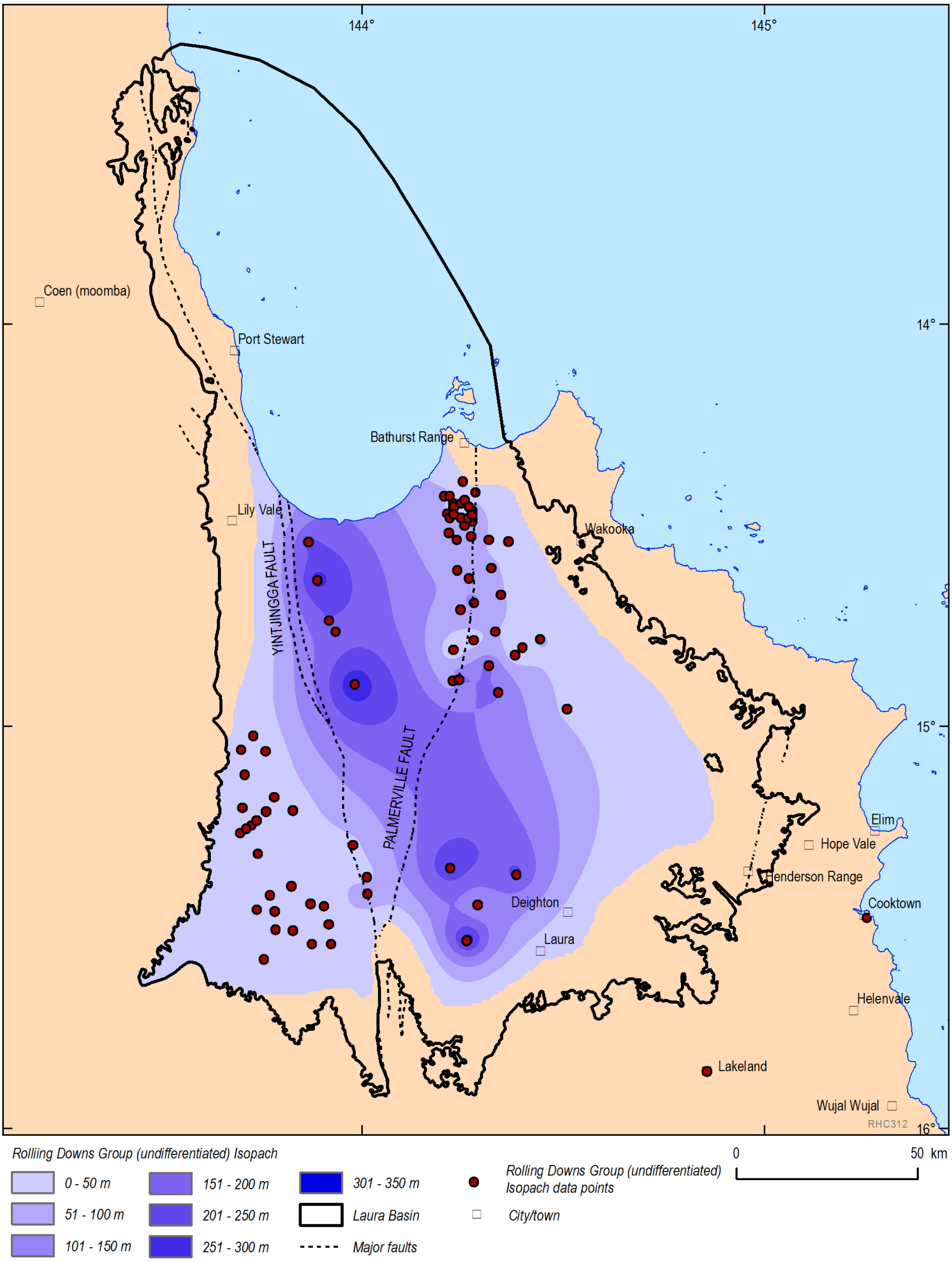


Figure 4.9. Isopach (total inferred thickness), Rolling Downs Group, Laura Basin.

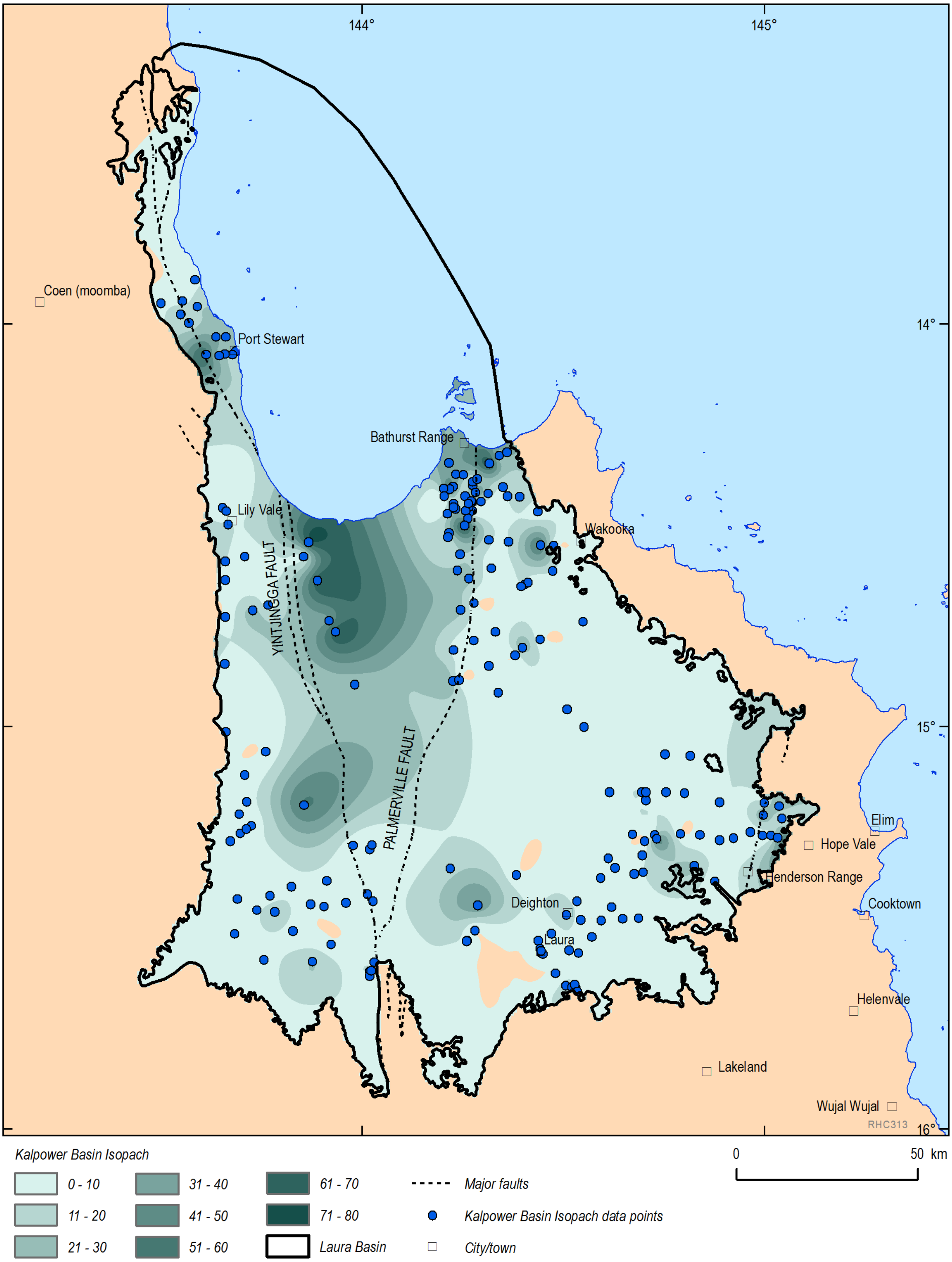


Figure 4.10. Isopach (total inferred thickness) Cenozoic Sediments, Laura Basin.

4.4 Structural geology

The Laura Basin has a complex structural history. Much of this history is inferred from geophysical information due to the paucity of deep drillhole data. Wellman (1995) provided the most exhaustive discussion of the structural history of the Laura Basin and surrounding rocks. Senior (unpublished) undertook a Landsat study that identified faults and lineaments in the Laura Basin. This map provides the most detailed description of the structural elements in the basin that have been active during the Cenozoic.

As discussed in Section 4.1, there are three stacked sedimentary basins in the region of the Laura Basin. The Laura Basin is underlain by a late Paleozoic sedimentary basin, the Lakefield Basin. The Lakefield Basin is inferred from geophysical data to be approximately 70 km wide (E-W), 200 km long (N-S) and >10 km thick (Wellman 1995). Overlying the Laura Basin is the Cenozoic age Kalpowar Basin. The sediments of the Kalpowar Basin are a maximum of 70 m thick.

The Permian and Mesozoic strata of the Laura and Lakefield Basins have been only slightly affected by tectonic movements, and most of their deformation resulted from faulting which continued to the Cenozoic (De Keyser and Lucas 1968).

Figure 4.11 shows the distribution of inferred major structural elements and faults in the Laura Basin.

4.4.1 Folding

McConachie *et al.* (1997) commented that there appears to be little tectonic folding in the Laura Basin and that most folds are a result of drape over basement features and differential compaction. A major north-trending anticline directly east of the Yintjigga Fault Zone (see Figure 4.11), in the region of the deep petroleum exploration wells in the basin, is cited as a possible exception to this. In addition, Whitby *et al.* (1996b) identified a broad anticline in the Bathurst Range area that plunges towards the south. Along with substantial faulting in the Bathurst Range area, this anticlinal structure controls the depth to the coals of the Mesozoic Dalrymple Sandstone in the Bathurst Range. Whitby *et al.* (1996b) inferred two faults in the Bathurst Range that constrain the coal thickness and distribution of the Bathurst Range deposit. The importance of this structural feature and its possible influence on the coal stratigraphy and distribution in the Bathurst Range highlights the usefulness of geological structural information to basin resource characterisation. Although there is a basic understanding of the geological structures of the Laura Basin, detailed structural information in the Laura and Kalpowar Basins remains a significant knowledge gap.

4.4.2 Faulting

Deposition of sedimentary sequences throughout the late Paleozoic and the Mesozoic was significantly influenced by the Palmerville Fault Zone, which is one of the most significant structures in northern Queensland (de Keyser 1963). The Palmerville Fault Zone is demarcated as two lineaments; a north-west trending lineament, the Yintjigga Fault Zone and a north-east trending lineament, the Palmerville Fault.

Wellman (1995) inferred that the Palmerville Fault controls the eastern extent of the Lakefield Basin, Permian sediments and volcanics of the Lakefield Basin, subcrop of the Laura Basin to the west of the fault, and metasedimentary rocks of the Hodgkinson Province and Chillagoe Formation to the east of the fault. Major movements occurred along this fault during the Siluro-Devonian, and Permo-

Carboniferous (Wellman 1995). Senior (unpublished) inferred potential reactivation of the northern part of the fault during the Cenozoic.

The Yintjigga Fault Zone has had a complex history, with movement of various types on a band of fault planes 2–6 km wide at the surface (Wellman 1995). The Yintjigga Fault penetrates through the sediments of the Lakefield Basin, the Laura Basin and the Kalpowar Basin. Between the Permian and Jurassic, there was over 10 km of east-block-down movement on a 60° to 80° west-dipping reverse fault. Post Cretaceous movement is about 0.3 km on a west-dipping reverse fault. During the Upper Cenozoic there was reverse movement on an east-dipping fault that is generally on the eastern margin of the fault zone (Wellman 1995). Structure contours based on a seismic survey in the Marina Plains area in 1981 indicate a change in thickness of the Dalrymple Formation of approximately 200 m across the fault zone (thinner on the western side) and a much smaller change in thickness in the Gilbert River Formation of approximately 10m.

Unlike the Palmerville Fault to the east, the Yintjigga Fault Zone is not the basin margin of the underlying Lakefield Basin and the sediments of the Lakefield Basin are considered to continue across the fault zone to the west where they onlap with the Newberry Metamorphics (Yambo Subprovince rocks), sub-cropping to the Laura Basin (Wellman 1995). The Lakefield Basin is thought to be 10+ km thick, occupying an area formed by subsidence caused by crustal extension. Wellman (1995) postulates that this depositional model allows for a thermal subsidence origin for the Lakefield Basin, whereby sagging of the Lakefield Basin allowed for deposition of the sediments of the Laura Basin.

In addition to the very large Yintjigga Fault Zone and Palmerville Fault structures, there are many smaller faults that likely influence groundwater flow at sub-regional scales. Senior (unpublished) Landsat mapping and the 1:1,000,000 and 1:250,000 scale surface geology mapping indicate cross-cutting orthogonal - sub-orthogonal faults reflecting the dramatic changes in the Australian paleo-stress field (direction of maximum horizontal stress, hereafter referred to as the ‘stress field’) throughout the history of the Laura Basin. In the Cretaceous, the stress-field was in an approximately northwest-southeast orientation. The stress fields in the Eocene were in an approximately east-west orientation and are now in an approximately northeast-southwest orientation (Muller *et al.* 2012). The presence and distribution of these faults may be important for understanding groundwater flow patterns due to their potential control on; groundwater flow system compartmentalisation, where faults may cause barriers to groundwater flow; and aquifer interconnectivity where faults may act as conduits for groundwater flow. The contemporary Australian stress-field is perpendicular to many of the northwest-southeast trending faults, suggesting that movement on these faults could be dilational.

The basement to the Laura and Lakefield Basins differs across the Palmerville Fault. West of the Palmerville Fault is the Proterozoic Yambo Subprovince. East of the Palmerville Fault is the early to middle Paleozoic Hodgkinson Province.

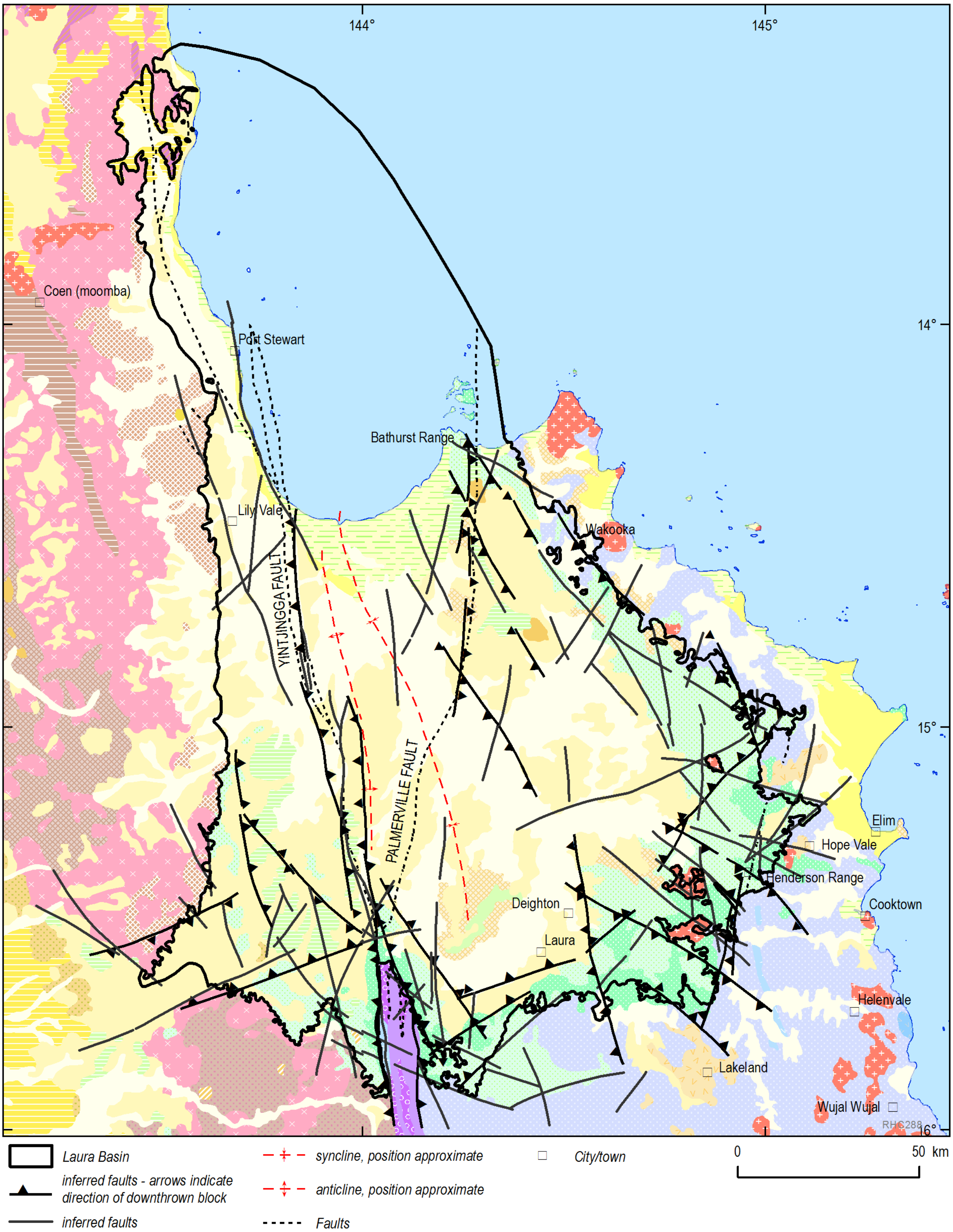


Figure 4.11. Map of faults and inferred structures, Laura Basin (data source: 1: 2,000,000 surface geology DNRM (2012b); Yintjigga Fault Zone and Palmerville Fault, (Raymond (2012)); other faults and structures (Senior (unpublished)).

4.5 Geomorphology

The geomorphic and tectonic history of the Laura Basin post the Lower Cretaceous has defined the contemporary groundwater and surface water flow systems of the Laura Basin. However, there is little data to comprehensively describe the geomorphological evolution of the Laura Basin. A brief summary is provided in this report (Figure 4.12), drawing on the work of Grimes (1980); Smart and Senior (1980); Ollier (1982); Marshallsea *et al.* (2000); Bradshaw and Yeung (unpublished).

4.6 Soils and surface materials

A survey of soils and agricultural suitability of the Cape York Peninsula was undertaken as part of the CYPLUS body of work in 1995 (Biggs and Philip 1995).

Biggs and Philip (1995) reported very limited areas of soil suitable for cropping agriculture within the Laura Basin. Most of the Laura Basin was found to have soils suitable for grazing agriculture. Approximately half the basin was found to be suitable for high, medium or low input enhanced pasture grazing and half was found to be suitable for low intensity grazing of native pastures. Based on these findings, it is expected that future groundwater demands will likely continue to be for stock and domestic entitlements for cattle watering and possibly for irrigation of pasture. Figure 4.13 shows the soil types of the Laura Basin (ASRIS, 2013).

4.6.1 Soil Hazards

4.6.1.1 Salinity

Naturally saline soils and sediments occur in the coastal plains of Princess Charlotte Bay and soils associated with the Rolling Downs Group and Hodgkinson Formation (Victor and Gibson soil types) (Howley and Stephan 2005). Soils in the Laura Basin generally have high levels of natural erosion and low nutrient levels. Significantly accelerated rates of erosion have been observed in association with roads constructed through Victor (Chromosols), Greenant, and Gibson soils (Sodosols). A moderate risk of development of secondary salinity is associated with Gibson and Victor soils (Howley and Stephan 2005). See Biggs and Philip (1995) for a description of soil types. High erosion potential is associated with the polygons depicting locations of Victor, Greenant and Gibson soil types.

Irrigation within the Normanby Catchment area is primarily limited to the basalt soils of the Lakeland Downs region, where the rapidly draining basaltic soils are not considered to be susceptible to secondary salinity (Howley and Stephan 2005). Lakeland Downs is located outside the southern boundary of the Laura Basin. There is currently no irrigation within the Laura Basin.

4.6.1.2 Acid sulfate soils

Acid sulfate soils occur naturally in soils that contain sulfate in addition to iron and organic matter. Acid sulfate soils are a natural hazard that can cause problems if the waterlogged soil dries out and is exposed to oxygen, causing the reduced sulfur and possibly bound metals to oxidise, releasing sulfuric acid and potentially toxic quantities of metals into the environment. The Australian Soil Resource Information System provides a national risk assessment for acid sulfate soils, identifying low, moderate and high potential for acid sulfate soils. Figure 4.13 shows the location of these classifications in the Laura Basin.

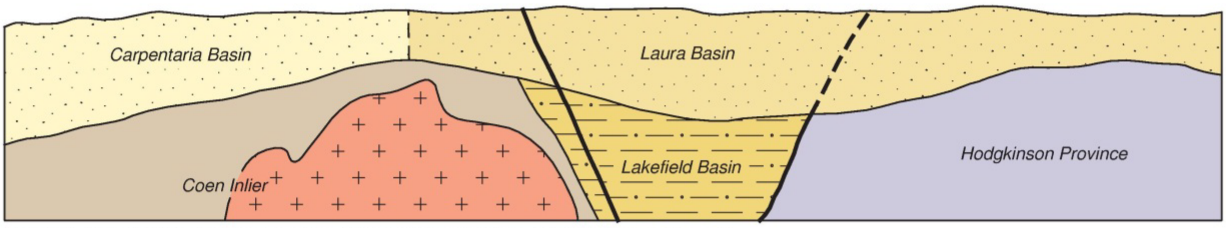


Figure 1. Jurassic to early Cretaceous (200 million years ago to 90 million years ago)
Laura Basin and Carpentaria Basin deposited on Paleozoic rocks. Sands deposited on broad river plains and later silts, sands and muds deposited in a shallow sea.

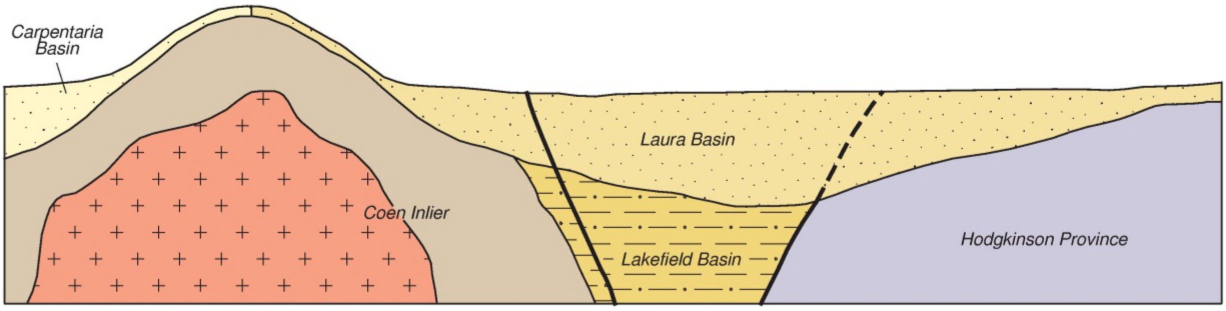


Figure 2. Late Cretaceous (90 million years ago to 65 million years ago)
Doming-up of Eastern Australia as the New Zealand subcontinent rifts from the Australian continental plate causes uplift of the Great Dividing Range (Ollier, 1982). The Kimba Arch begins to form. Erosion of Laura Basin sediments begins.

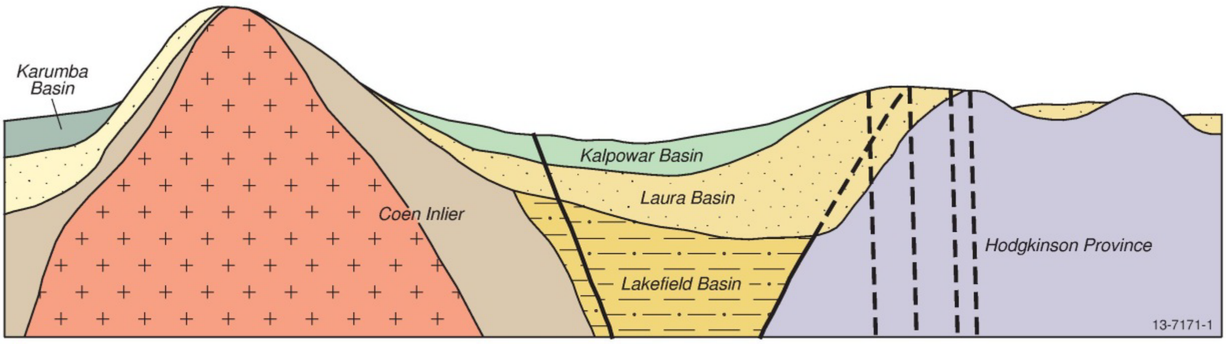


Figure 3. Cenozoic (65 million years ago to present)
Continued uplift of the Great Dividing Range. Faulting on the eastern side of the Laura Basin, uplift of the eastern side of the Laura Basin, erosion of Mesozoic sediments to the east of the modern Laura Basin.
Continuing uplift, erosion, deposition and weathering forming the Cenozoic sediments of the Kalpowar Basin.

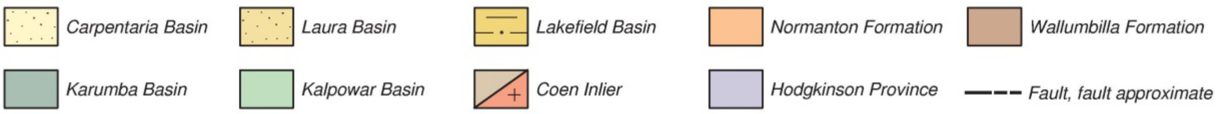


Figure 4.12. Geomorphological and tectonic history of the Laura Basin.

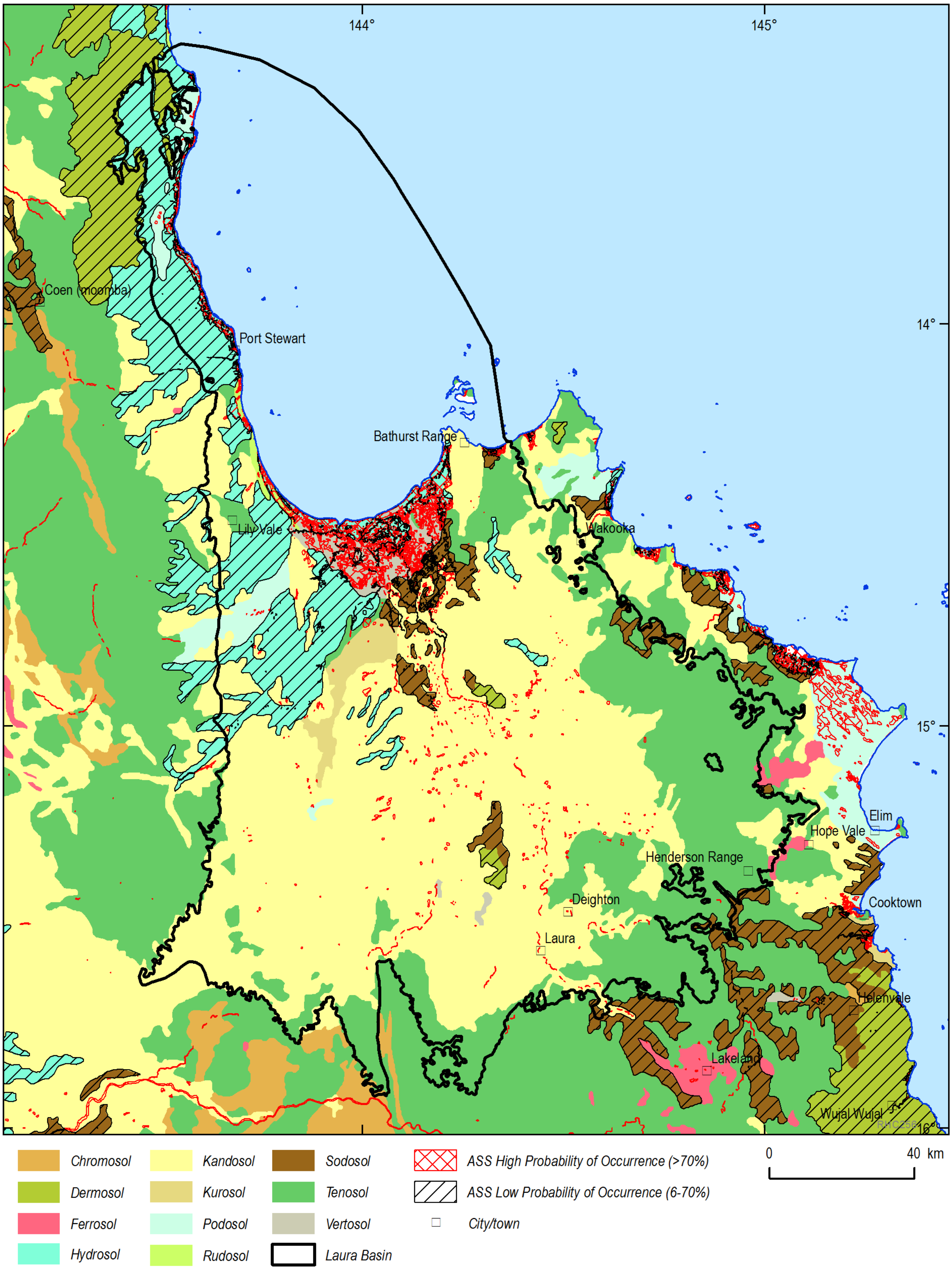


Figure 4.13. Soil type and probability of acid sulfate soil occurrence, Laura Basin (data source: Australian Soil Resource Information System (ASRIS 2013)).

5 Coal and coal seam gas resources

5.1 Distribution and size of deposits

Currently there are no operating coal mines or coal seam gas (CSG) fields within the Laura Basin. The area has been actively explored for coal since as far back as 1879 (Jack 1879). Coal occurs in the late-Paleozoic rocks of the Lakefield Basin and Middle Jurassic rocks of the Laura Basin. Since the 1960s, coal exploration tenements have covered most of the Laura Basin margins where the Dalrymple Sandstone is in outcrop or shallow to the surface, or where the Permian strata have been thrust closer to the surface due to faulting. A more detailed summary of the various coal exploration programs that have been undertaken in the Laura Basin is presented in Appendix 4.

Figure 5.1 shows the distribution of coal exploration tenements across the Laura Basin. Approximately 24% of the basin (4,600 km^2) is currently covered by coal exploration permits. The only defined coal resource in the Laura Basin occurs in the north-eastern corner of the basin flanking the Bathurst Range (Figure 5.1). Thin coal bands are commonly reported in lithological logs intercepting Dalrymple Sandstone throughout the basin and previous seismic work has identified strong reflectors in the Upper Paleozoic rocks of the Lakefield Basin that may be attributed to coal seams (Wellman 1995).

In addition to the Bathurst Range, exploration has focussed on two outcrops of Upper Paleozoic (Permian) sediments to the south-east and south-west of the region at the margin of the Laura Basin. These are the Little River Coal Measures and the Normanby Coal Measures. These measures have been determined by previous workers to be sub-economic.

The coal of the Little River Coal Measures crops out in a narrow, 20 km long, structurally complex, down-faulted block along part of the Palmerville Fault System. The coal is of poor quality (semi-anthracite, with a high ash content) (Denaro and Shield 1993) and the steeply dipping nature of these coals make them challenging/ expensive to mine (Denaro and Shield 1993).

The coal of the Normanby Formation (previously known as Oaky Creek Coal Measures) occurs as three, small, faulted outliers on the extreme south-eastern edge of the Laura Basin (Denaro and Shield 1993). The formation is bounded by well-defined faults against the Hodgkinson Formation and is overlain by unfaulted Dalrymple Sandstone. At least 30 m of impure coal occurs in the western part of the formation. The coal is folded, crushed and faulted. The strata are folded and cut by numerous steep strike-slip faults and several steeply dipping, north-east trending cross-faults. Thickness is considered to be exaggerated by the structural truncation of the formations. The coal is poor quality with a high ash content (Jago 1975).

To date there has been no exploration for coal seam gas in the Laura Basin. Gas within a coal deposit at Bathurst Range was previously analysed and reported in reporting about the coal deposit at Bathurst Range (Whitby *et al.* 1996a). Five samples were collected and results indicated high CO_2 with the main gas components being CO_2 (72.5-97.6%) and CH_4 (27.5-2.4%). Given the coals in the Bathurst Range are close to the surface, high CO_2 values relative to CH_4 are to be expected due to the low desorption pressure for CO_2 relative to CH_4. . For comparison, the Gorgon Conventional Gas field has CO_2 proportions of 11-17% and the Walloon Coal Measures Coal (Surat Basin) Seam Gas composition is typically greater than 98% CH_4 with minor CO_2.

There are also records of minor coal occurrences within the Dalrymple Sandstone outside the Laura Hydrogeological Basin (e.g. around Cape Flattery).

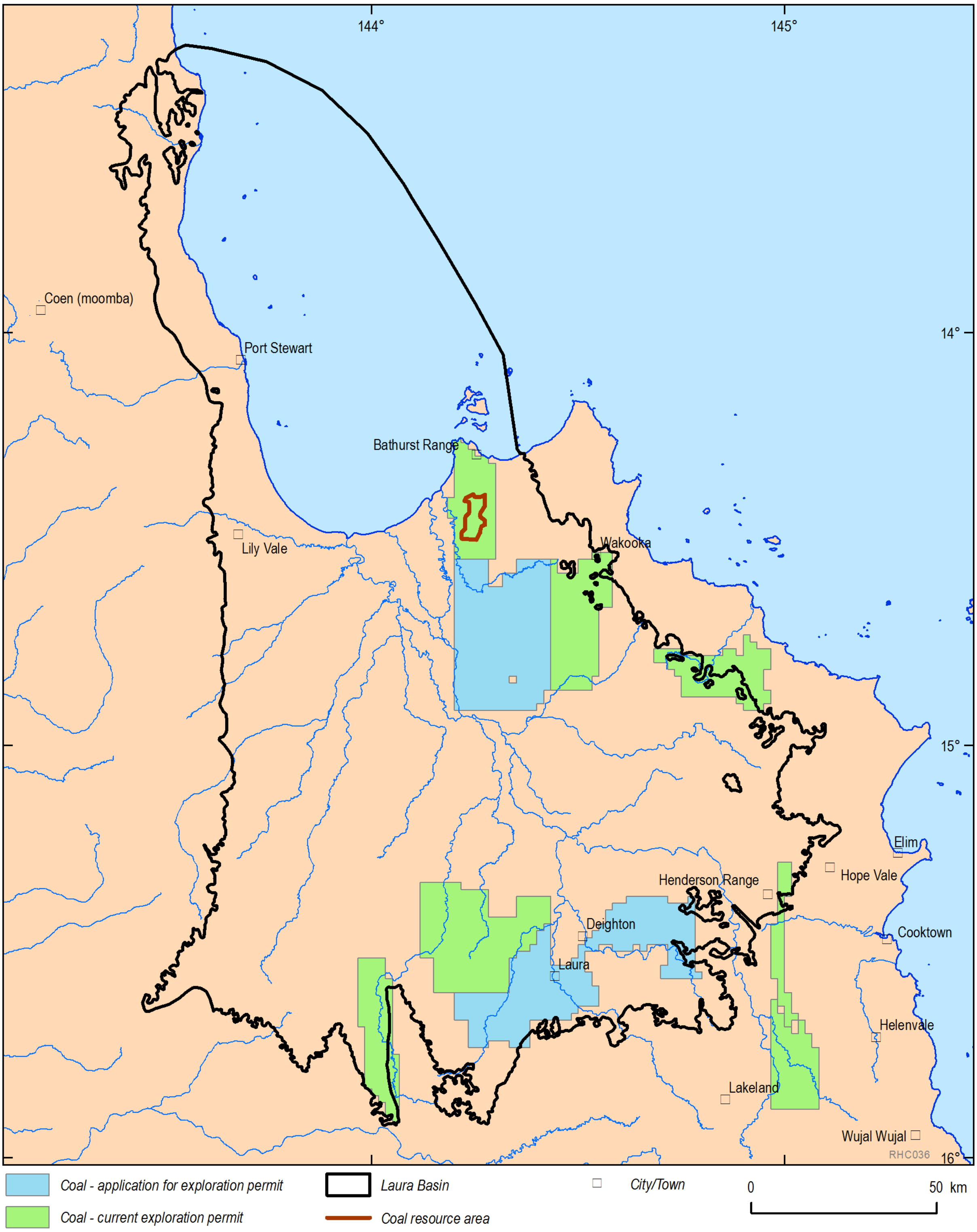


Figure 5.1. Coal exploration permit areas and proven coal resource area, Laura Basin (data source: Queensland Department of Natural Resources and Mines Interactive Resource and Tenement Maps, DNRM (2013a)).

5.2 Current development focus

The Bathurst Range coal deposit consists of relatively thin seams within the Dalrymple Sandstone. The largest of these seams, the Bathurst seam, is generally less than 2 m thick (Whitby *et al.* 1996a). There are 9 seams correlated across the deposit (Whitby *et al.* 1996a). The reported *in situ* resource for the Bathurst Range deposit is 47 million tons (OZMIN 2013).

The Bathurst Range black coal deposit is within coal exploration tenement EPC 2334, located on Kalpowar Station approximately 150 kilometres north-west of Cooktown, bordering Princess Charlotte Bay and Cape Melville National Park. Lakefield National Park is located approximately 3 km to the west of EPC 2334. The Great Barrier Reef Marine Park, a World Heritage Area, extends from the low water mark of the mainland into the Coral Sea.

The Bathurst Range deposit was intermittently subjected to exploration by Utah Development Company, BHP Australia and Bathurst Coal and Power Limited through the period 1970–2000. In 2011, an application to mine the Bathurst Range deposit was submitted to Queensland and Australian Government agencies, as a joint venture between the Kalpowar Aboriginal Lands Trust and Aus-Pac Capital Pty Ltd. This project is called the Wongai Project. Table 5.1 shows the progress of the project. The project area covers reserve, freehold and National Park lands. Freehold and reserve land is held by the Kalpowar Land Act Reserves Trustees Limited and the Kalpowar Aboriginal Land Trust (Brown *et al.* 2012). The project development would include:

- an underground coal mine,
- 20-kilometre conveyor,
- coal stockpiles,
- barge-loading terminal,
- covered coal barges, and
- floating trans-shipper.

Current activity on Kalpowar Station includes recreational fishing and beef pastoral enterprises.

Table 5.1. Wongai Project history (from http://www.dsdip.qld.gov.au/assessments-and-approvals/wongai-project.html), note that this information was current in July 2013.

Date	Activity
Currently	EIS being prepared by proponent.
27 July 2012	Terms of reference for EIS released.
12 May 2012 to 12 June 2012	Draft terms of reference for EIS public consultation.
18 April 2012	Gazettal of 'coordinated project' declaration.
25 November 2011	Revised initial advice statement submitted.
22 September 2011	Project deemed a 'controlled action' by federal environment minister.
25 August 2011	Project referred to federal environment minister.
18 August 2011	Application, including original initial advice statement, submitted.

5.3 Other economic resources

Mining is currently not a major industry in the Laura Basin and Normanby River Catchment. Most of the mines recorded with the Department of Natural Resources and Mines are abandoned gold mines. Other abandoned mines include arsenic, sapphire, copper and gemstone mines. There are several small active gold mines that have been operating in the upper reaches of the Normanby and Laura Rivers for the last 15 to 20 years (Howley *et al.* 2010). Alluvial gold was discovered in the West Normanby River around 1876 (Denaro and Ewers 1995). The Brothers deposit on the West Normanby River has been a major contributor for the approximately 18 kg of gold recovered from the West Normanby River Area. Reconnaissance sampling in the 1980s indicated that high grades of alluvial gold and significant platinum and palladium contents occur in some parts of the Laura River (Denaro and Ewers 1995). These resources are generally located outside the Laura Hydrogeological Basin but within the Laura and Normanby River catchments.

6 Hydrogeology and groundwater systems

6.1 Study area description

The Mesozoic sequences of the Laura Basin are mapped on the 1: 250,000 mapsheets of Hann River, Cooktown, Ebagoola, Coen and Cape Melville. The Laura Basin boundary is based on the geological mapping of the region and the watertable mapping undertaken in the Great Artesian Basin Water Resource Assessment (Kellett *et al.* 2012). The geological units of the Laura Basin extend outside the Laura Basin hydrogeological boundary.

6.2 Hydrostratigraphy

Table 6.1 shows the hydrostratigraphy of the Laura Basin, with these units discussed in detail below.

6.2.1 Aquifers

The principal aquifers of the Laura Basin are the Gilbert River Formation and the Dalrymple Sandstone. There is potentially a region of Normanton Formation sandstone in the north-eastern area of the Laura Basin. This sandier facies of the Rolling Downs Group also behaves as an aquifer and may be locally important for spring discharge, particularly on the southern side of Bathurst Range. Aquifers are also recognised within the Cenozoic sediments of the Kalpowar Basin that overlie the Laura Basin. The focus of this hydrogeological characterisation study was the Gilbert River Formation and the Dalrymple Sandstone.

6.2.1.1 Mesozoic Aquifers: Gilbert River Formation and Dalrymple Sandstone

The Gilbert River Formation and the Dalrymple Sandstone are considered to be one hydrostratigraphic unit as there is no evidence for a contiguous low permeability unit separating them. In addition, data is so sparse and the lithology of the units so similar that in many cases it is difficult to conclusively distinguish them. They are managed together as one unit under the Great Artesian Basin Management Plan (DNRM 2005). An isopach map of the Mesozoic aquifer is shown in Figure 6.1.

The Mesozoic aquifers are thought to be recharged primarily in the areas where the Gilbert River Formation and the Dalrymple Sandstone outcrop. Recharge and discharge processes are discussed further in Section 6.6.

The water yield and quality of the Gilbert River Formation and Dalrymple Sandstone vary considerably across the basin. Aquifer yield ranges between 2 and 15 litres-per-second (L/s) and electrical conductivity (EC) ranges from <500 to 3,000 µS/cm. Water quality tends to deteriorate towards the centre of the basin as a result of longer groundwater residence times (Horn *et al.* 1995). Residence times likely increase towards the centre of the Basin as the distance from recharge areas increases. For more in depth discussion of the groundwater chemistry of the Laura Basin, the reader is referred to the NCF companion report, Ransley *et al.* (2015).

Table 6.1 Hydrostratigraphy of the Laura Basin with hydrostratigraphic equivalents of the Carpentaria Basin (adapted from Smerdon et al. (2012)).

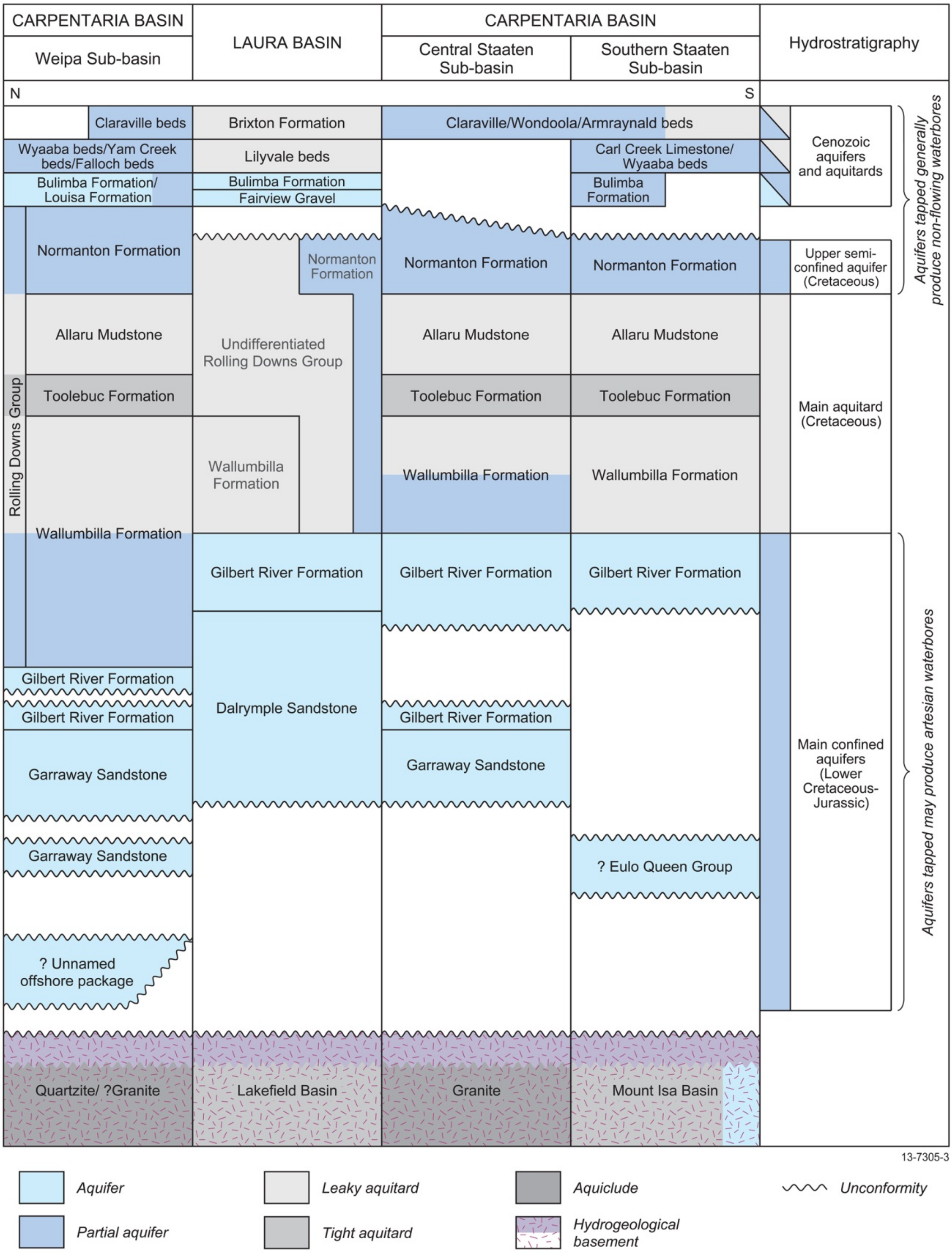


Table 6.2 and Table 6.3 summarise the hydraulic properties recorded for the Gilbert River Formation and the Dalrymple Sandstone in the Laura Basin. Table 6.2 presents transmissivity and storativity values estimated from pump tests undertaken in the north-east and the south of the basin. Transmissivity is equal to hydraulic conductivity multiplied by aquifer thickness. For an estimated aquifer thickness of 600 m, based on the reported transmissivity values in Table 6.3, hydraulic conductivities from pump testing data range between $6x10^{-3}$ to 1.8 m/day.

Table 6.2. Transmissivity and storage coefficients estimated from pump tests, Dalrymple Sandstone and Gilbert River Formation aquifer, Laura Basin (data source: Queensland Bore Database, DERM (2011)).

Aquifer	Transmissivity (m^2/day)			Number of observations- transmissivity	Storage coefficient	Number of observations - Storativity
	Min	Max	Median			
Gilbert River Formation	4	1054	21	5	No data	No data
Dalrymple Sandstone	19	83	42	5	$8x10^{-4}$	1

Note: Four of the transmissivity observations for the Dalrymple Sandstone are from the Laura town water supply bores.

Table 6.3 presents hydraulic conductivity (permeability) and porosity estimated from lab scale tests on core samples taken from petroleum exploration wells in the centre of the basin. The hydraulic conductivity values estimated from the core samples are extremely low. In addition, horizontal conductivities have similar values to vertical conductivities. These results suggest that secondary permeability (e.g., fractures and weathering along bedding planes) may be more significant for groundwater flow relative to the primary, matrix porosity (test pumping measures a far greater intersection of rock than core testing, and is therefore more likely to include secondary porosity in its measurement). Up-scaling of core-scale tests to reflect the likely bulk rock parameters is a challenge common to most hydrogeological investigations.

There is only one storativity value recorded for the entire Laura Basin.

Table 6.3. Hydraulic Conductivity and Porosity estimated from lab scale core tests, Dalrymple Sandstone and Gilbert River Formation (data source: Breeza Plains 1, Lakefield 1 and Marina 1 petroleum exploration well completion reports, GeoscienceAustralia (2013)).

	Hydraulic Conductivity – horizontal (Kh) (m/day)			Hydraulic Conductivity – vertical (Kv) (m/day)			Porosity (%)		
	Min	Max	Median	Min	Max	Median	Min	Max	Median
Gilbert River Formation	$8.3x10^{-6}$	0.013	$3.4x10^{-3}$	$8.3x10^{-6}$	0.016	$5.9x10^{-3}$	11	16	14
Dalrymple Sandstone	$8.3x10^{-6}$	0.16	$8.3x10^{-6}$	$8.3x10^{-6}$	0.062	$8.3x10^{-6}$	6	22	13

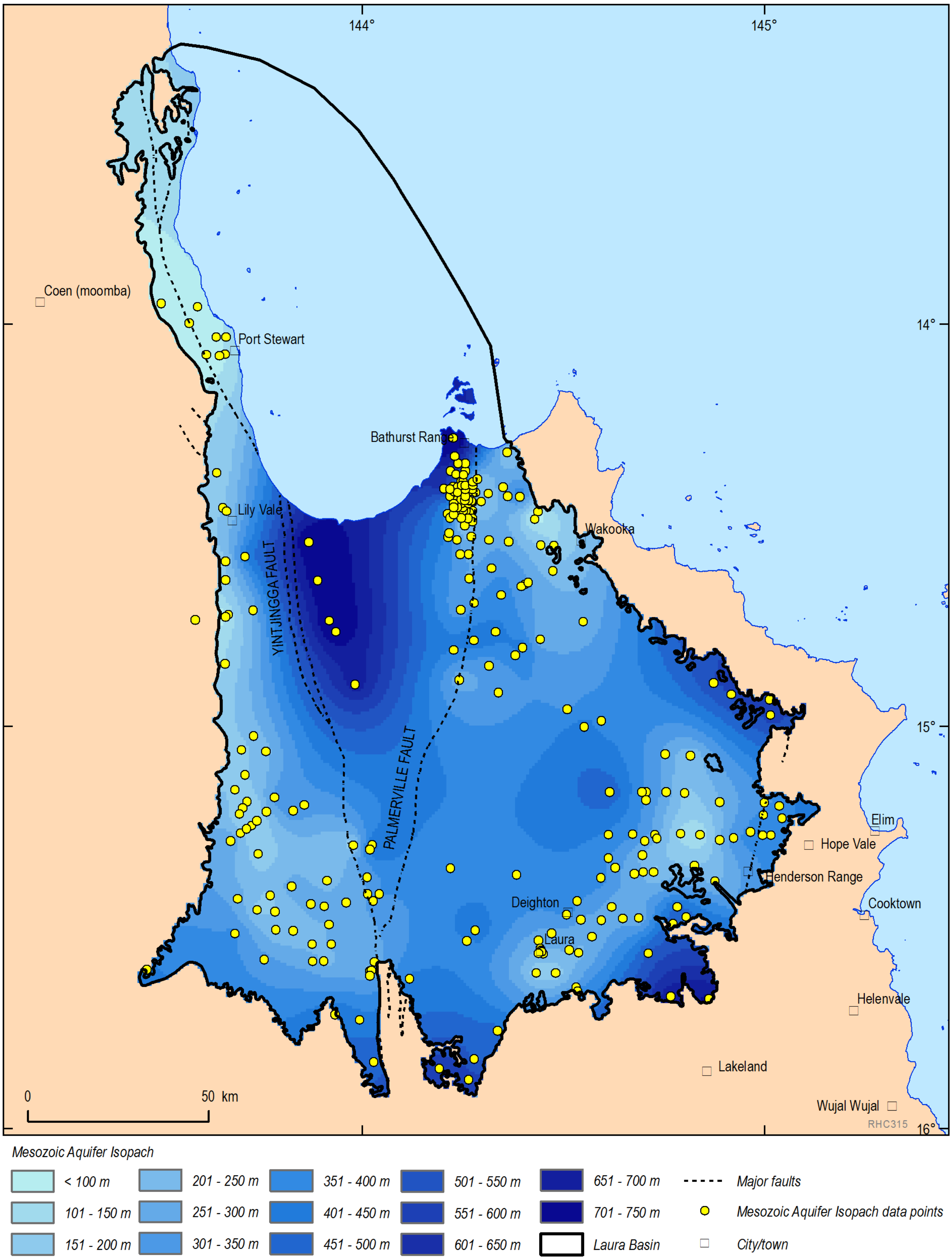


Figure 6.1. Isopach (total inferred thickness), Mesozoic Aquifer, Laura Basin.

6.2.1.2 Cenozoic Aquifers-Kalpowar Basin

Within the Kalpowar Basin, a Cenozoic aquifer system is recognised within the Fairview Gravel. Minor aquifers are recognised for the Lilyvale Beds and the Brixton Formation (Smerdon *et al.* 2012). The town water supply at Laura was, until recently, sourced from the Cenozoic aquifer (it is now sourced from the deeper groundwater of the Dalrymple Sandstone as it is more protected from shallow contamination sources, (Howley and Stephan 2005)). The Cenozoic aquifer in this area provided reliable supplies at pumping rates of 0.1 to 1.0 L/s (Horn *et al.* 1995). Water quality ranged between 100 and 600 mg/L TDS (Horn *et al.* 1995). Horn *et al.* (1995) reported that there appear to be no records of bores in the Cenozoic sediments elsewhere in the basin.

There are no hydraulic property records for aquifers of the Cenozoic sediments in the Laura Basin. The Fairview Gravel is equivalent to the basal units of the Bulimba Formation of the Karumba Basin. Variable aquifer quality is reported for this formation over short distances, although a minor amount of aquifer testing has reported relatively high hydraulic conductivities of between 140 and 335 m/day (Smerdon *et al.* 2012).

6.2.1.3 Groundwater bore distribution and depth

Artesian groundwater pressures (i.e., where the water in a bore rises to above the ground surface) persist across much of the Mesozoic aquifer of the Laura Basin. Bores that are recorded to have artesian pressures are shown in blue in Figure 6.2.

Most bores in the basin generally exploit these artesian pressures and are located in the Mesozoic aquifer. Figure 6.3 presents the depth of bores across the basin. Most bores are >100 m deep and approximately half the bores are > 200 m deep.

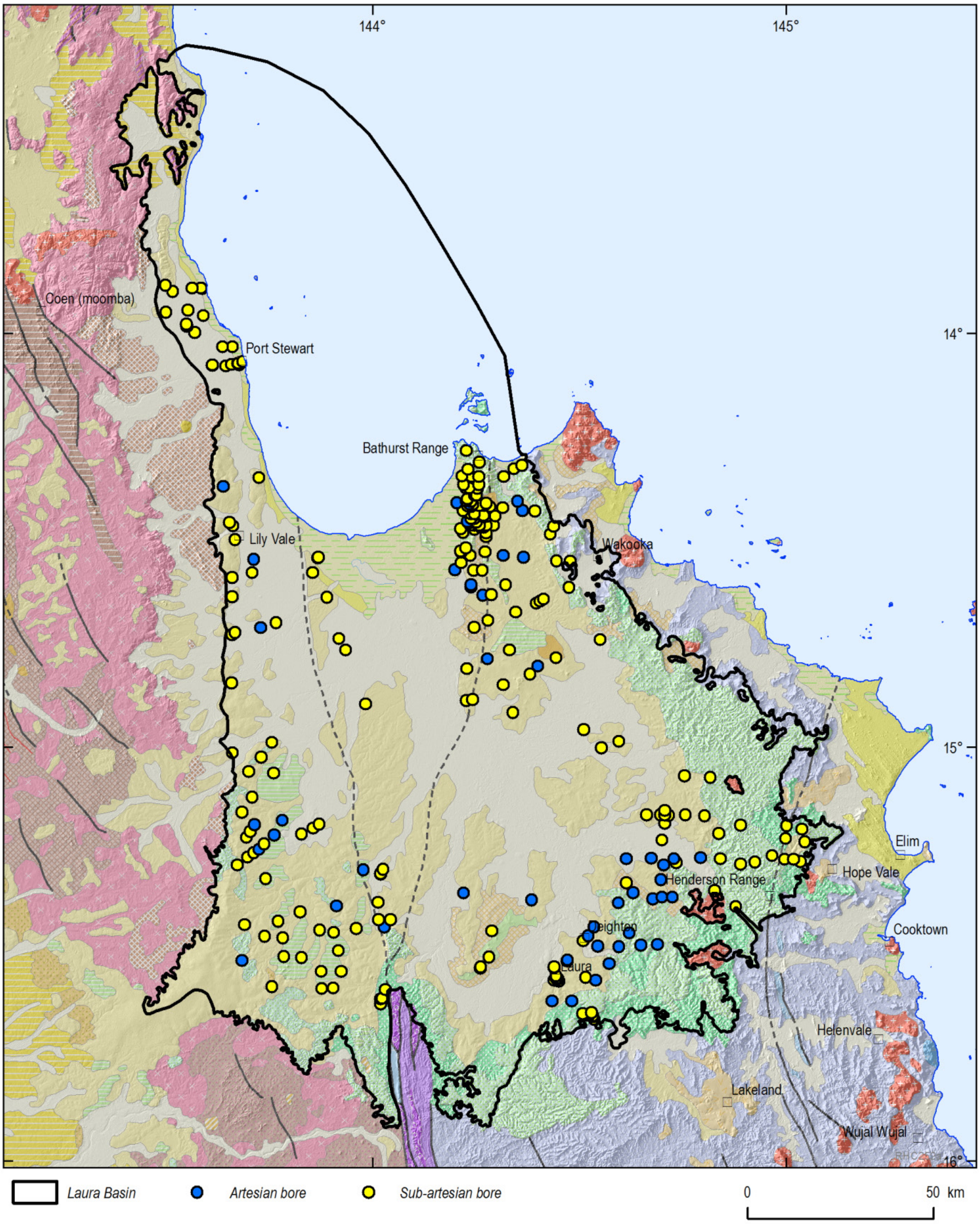


Figure 6.2. Map of artesian and sub-artesian bores, Laura Basin (data source: Queensland Bore Database, DERM (2011)).

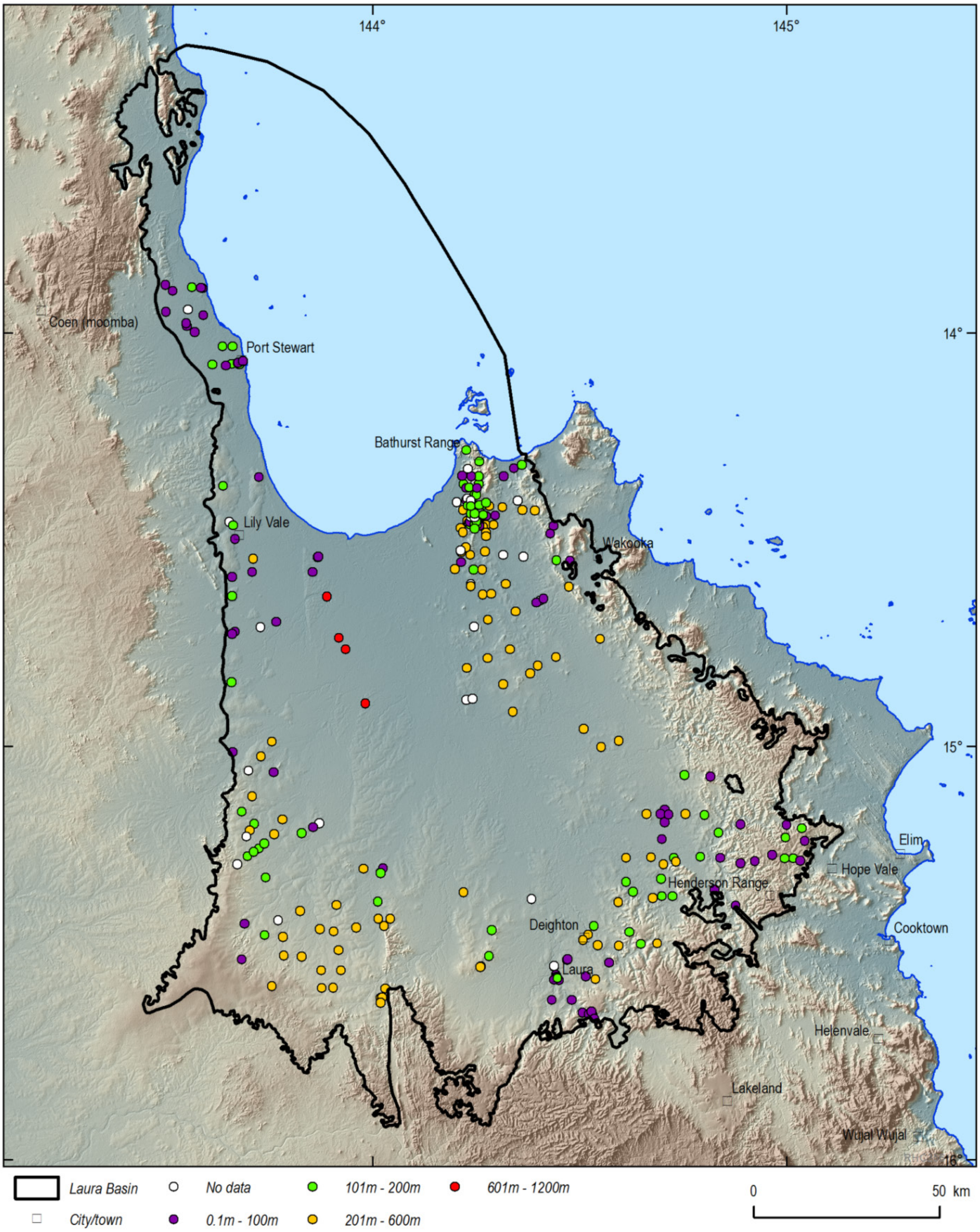


Figure 6.3. Map of bore depth, Laura Basin (data source: Queensland Bore Database, DERM (2011)).

6.2.2 Aquitards

The main confining unit of the GAB sedimentary sequence is the Rolling Downs Group, in particular the Wallumbilla Formation. The Wallumbilla Formation is stratigraphically located at the base of the Rolling Downs Group. The Wallumbilla Formation was mapped in the Laura Basin for the first time in 2011 as part of a study that mapped this formation across the Eromanga, Surat, Carpentaria and Laura Basins using seismic data and borehole data (Dixon and Hodgkinson 2011). Seismic data (generally located towards the centre of the Laura Basin) and a limited number of boreholes with stratigraphic interpretation were used to define the extent and depth of the Wallumbilla Formation in the Laura Basin. The Wallumbilla Formation is represented as extending right to the margins of the Laura Basin by the mapping produced by Dixon and Hodgkinson (2011).

Review of the borehole data and surface geology mapping available for the Laura Basin and the detailed stratigraphic interpretation work undertaken for this hydrogeological conceptualisation project identified that the Wallumbilla Formation does not appear to be present across the entire basin. Consequently, work for this study re-mapped the distribution of the Wallumbilla Formation (Figure 6.4), using the new stratigraphic interpretations of borehole lithology records.

In the Laura Basin, substantial periods of uplift, erosion and deposition have created complexity in the distribution of the Rolling Downs Group. In the south and south-western parts of the Laura Basin, the Wallumbilla Formation is present, reaching depths of up to 293 m in DERM-0000010914 west of the town of Laura. In the north-east of the Laura Basin, the Rolling Downs Group is present as the Normanton Formation. The Normanton Formation is a sand-rich facies of the Rolling Downs Group, occurring towards the top of the stratigraphic sequence. The presence of the Normanton Formation directly overlying the Gilbert River Formation potentially indicates erosion of hundreds of metres of Rolling Downs Group, most likely the Wallumbilla Formation, prior to deposition of the Normanton Formation. The Wallumbilla Formation also appears to be absent in the north-western area of the basin. There also appears to be a strong relationship between the thickest areas of Wallumbilla Formation and the Yintjigga Fault Zone.

The distribution and thickness of the Wallumbilla Formation is likely to play a significant role in the recharge processes to the Mesozoic Aquifer and the interactions between the Mesozoic aquifer and the Cenozoic aquifer (discussed further in Section 6.5).

In areas where the Wallumbilla Formation is present, there is likely to be limited vertical connection between the Cenozoic aquifers and the Mesozoic aquifer of the Laura Basin. However, the Rolling Downs Group (Wallumbilla Formation) does not provide a regional aquitard across all of the Laura Basin. It can be thought of as an aquitard in the south and south-west and throughout the centre of the basin. In the north-east of the basin the Rolling Downs Group becomes much sandier and the Normanton Formation occurs (a unit of the Rolling Downs Group). In places, the Normanton Formation lies directly on top of Gilbert River formation, providing pathways for groundwater flow between the Rolling Downs Group and the Gilbert River Formation. At the margins of the basin, the Gilbert River Formation is in outcrop, providing direct pathways for recharge into the aquifer sequence of the Gilbert River Formation and the Dalrymple Sandstone.

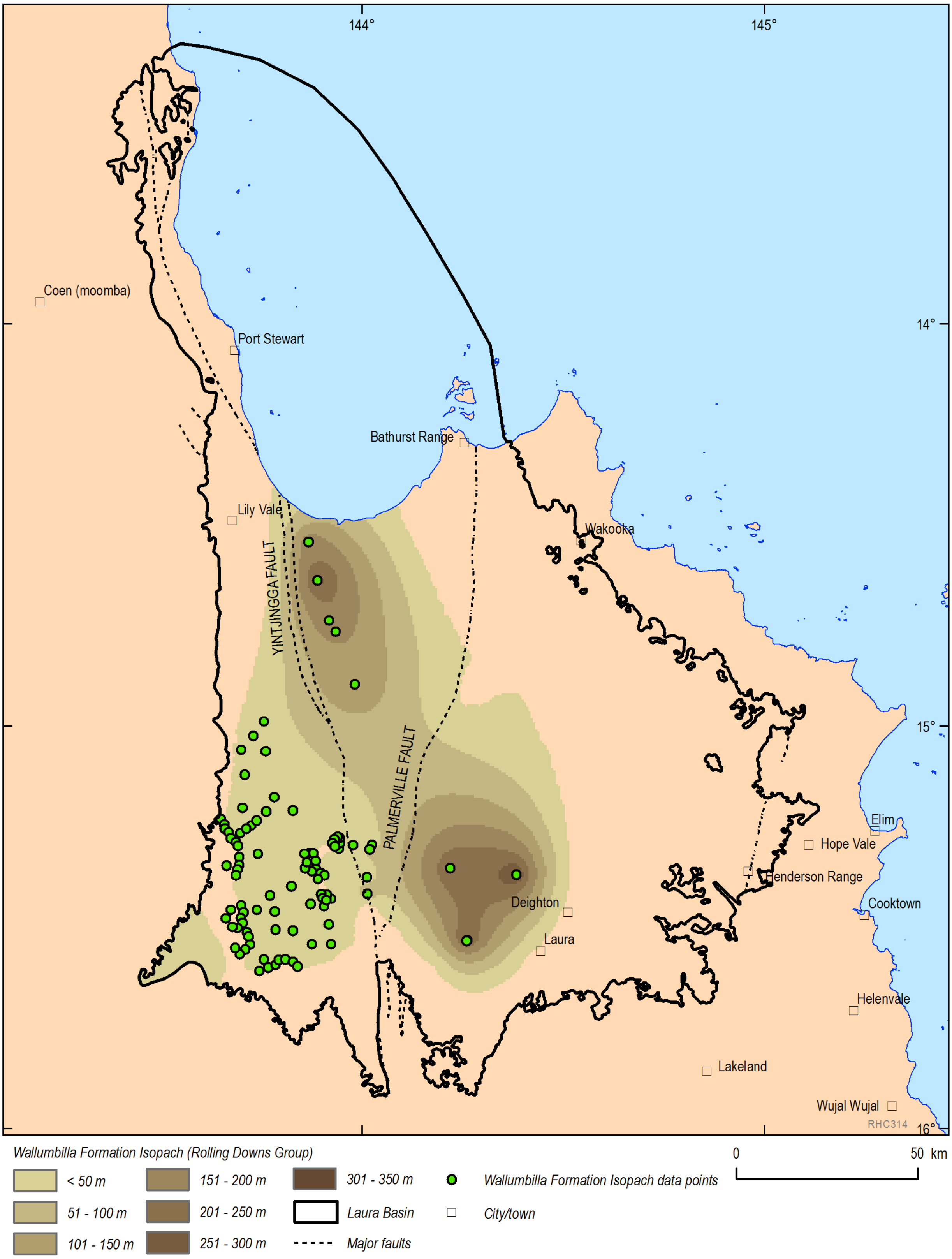


Figure 6.4. Isopach (total inferred thickness) of the Wallumbilla Formation of the Rolling Downs Group, Laura Basin.

6.3 Groundwater hydrochemistry

A project investigating the hydrogeochemistry of the Laura basin was funded by the Office of Water Science as part of the wider program of research commissioned by the IESC (Ransley *et al.* 2015). This report provides:

- A comprehensive geochemical characterisation (ionic, organic, gaseous, radiological, and isotopic (radiogenic and stable)) of groundwater within aquifers and coal seams to determine baseline conditions and, if possible, to distinguish between groundwater within coal seams and that of surrounding aquifers;
- Identifies gaps in our current data and knowledge of CSG hydrogeochemistry; and
- Analyses groundwater quality data with respect to water quality guidelines for aquatic ecosystem protection, drinking water use, primary industries, use by industry, recreation and aesthetics, and cultural and spiritual values (ANZECC and ARMCANZ 2000, DERM 2009), to assess the environmental values of groundwater and the treatment that may be required prior to reuse or discharge.

The results of this work have not been reproduced here as the Hydrogeochemistry project report presents a more comprehensive overview of this information. For further information of the hydrogeochemistry of the Laura Basin, the reader is referred to Ransley *et al.* (2015).

The key findings of the project were:

- Groundwater quality in most of the aquifers in the Laura Basin is generally good based on salinity but tends to become more brackish in the Bathurst Range region and east of Laura Township.
- Assessment of groundwater quality from an environmental values perspective indicated that most groundwater from the Dalrymple Sandstone and Gilbert River Formation aquifers is suitable for stock watering and human consumption. However, fluoride, manganese and iron concentrations exceed the water quality guidelines in some bores and may be of concern for stock watering and human consumption.
- Due to insufficient chemistry data and well construction information it is difficult to differentiate the groundwater chemistry signatures of the Gilbert River Formation and the Dalrymple Sandstone.
- Most groundwater from the Gilbert River Formation and Dalrymple Sandstone aquifers is of Na-HCO_3 type. However, some bores near Princess Charlotte Bay (e.g., Bathurst Head) contain a Na-Cl type water.

6.4 Groundwater models

There are no groundwater models for the Laura Basin (Smerdon *et al.* 2012). The Laura Basin was not included in the groundwater modelling for Great Artesian Basin Water Resources Assessment (Smerdon *et al.* 2012) due to the limited groundwater development within the basin and because it is not connected with the rest of the Great Artesian Basin across the Kimba Arch.

6.5 Groundwater flow system conceptualisation

An important first step to conceptualising groundwater flow systems within an aquifer is to develop potentiometric surfaces of hydraulic head across the aquifer. A potentiometric surface is made up of contours of equal hydraulic head distributed spatially across the aquifer. Ideally the hydraulic head data used to develop a potentiometric surface is collected over a restricted time period and is at a density and distribution that represents the variability in hydraulic head across the aquifer.

Also critically important to conceptualising groundwater flow systems is understanding the recharge and discharge processes of the aquifer and determining groundwater level fluctuations over time in response to variations in recharge conditions or changes in discharge mechanisms or stresses, e.g. changes in groundwater extraction. Groundwater flow system analysis based on steady-state potentiometric surface maps can assist in understanding recharge and discharge processes in an aquifer. To understand how the groundwater system responds to change, time-series groundwater monitoring is critical. Unfortunately though, there is no time-series monitoring of groundwater bores in the Laura Basin. There are up to two water level measurements for some bores and there is no temporal trend evident in these data. This is a significant data gap for the Laura Basin hydrogeology and is discussed further in Chapter 6.7.

One previous study undertook potentiometric surface mapping in North Queensland which included the Laura Basin (Bain and Draper 1997a). This study combined water level records for the Laura Basin together regardless of which aquifers the boreholes were screened in. Due to the presence of confining units within the basin, this approach does not give an adequate representation of the potentiometric surface. In addition, the surface presented by Bain and Draper (1997a) appears to be erroneous towards the basin margins. It was considered appropriate to undertake new potentiometric surface mapping for this project even though there no significant new data currently available (relative to the previous mapping).

Potentiometric surface maps for both the Cenozoic aquifers and the Mesozoic aquifer are presented herein. These are constrained by very disparate data and are appropriate to use as tools for assessing groundwater flow systems at a regional scale only.

6.5.1 Cenozoic aquifers

Kellett *et al.* (2012) interpreted a water table map for the unconfined aquifers of the Laura Basin. This includes the Mesozoic aquifer, where the sedimentary rocks outcrop. Most of the watertable surface is in the Cenozoic sediments. The watertable is shown in Figure 6.5.

Although recharge to the Mesozoic aquifer is considered to be limited to the intake beds, Smerdon *et al.* (2012) proposed that recharge to the Cenozoic sediments of the Kalpowar Basin (including the Lilyvale Beds) is preferentially from vertical infiltration during the wet season over the entire area of its occurrence.

The Cenozoic sediments are thin towards the margins of the Laura Basin. There are thicker deposits (up to 70 m) towards the centre of the basin. There is little recorded groundwater extraction from the Cenozoic aquifers and there has been little work to investigate their role as water sources for groundwater dependent ecosystems. There is little data currently available to undertake this work. Further research into the importance of local flow systems within the Cenozoic aquifers for Groundwater Dependent Ecosystems is warranted (Section 6.5.4).

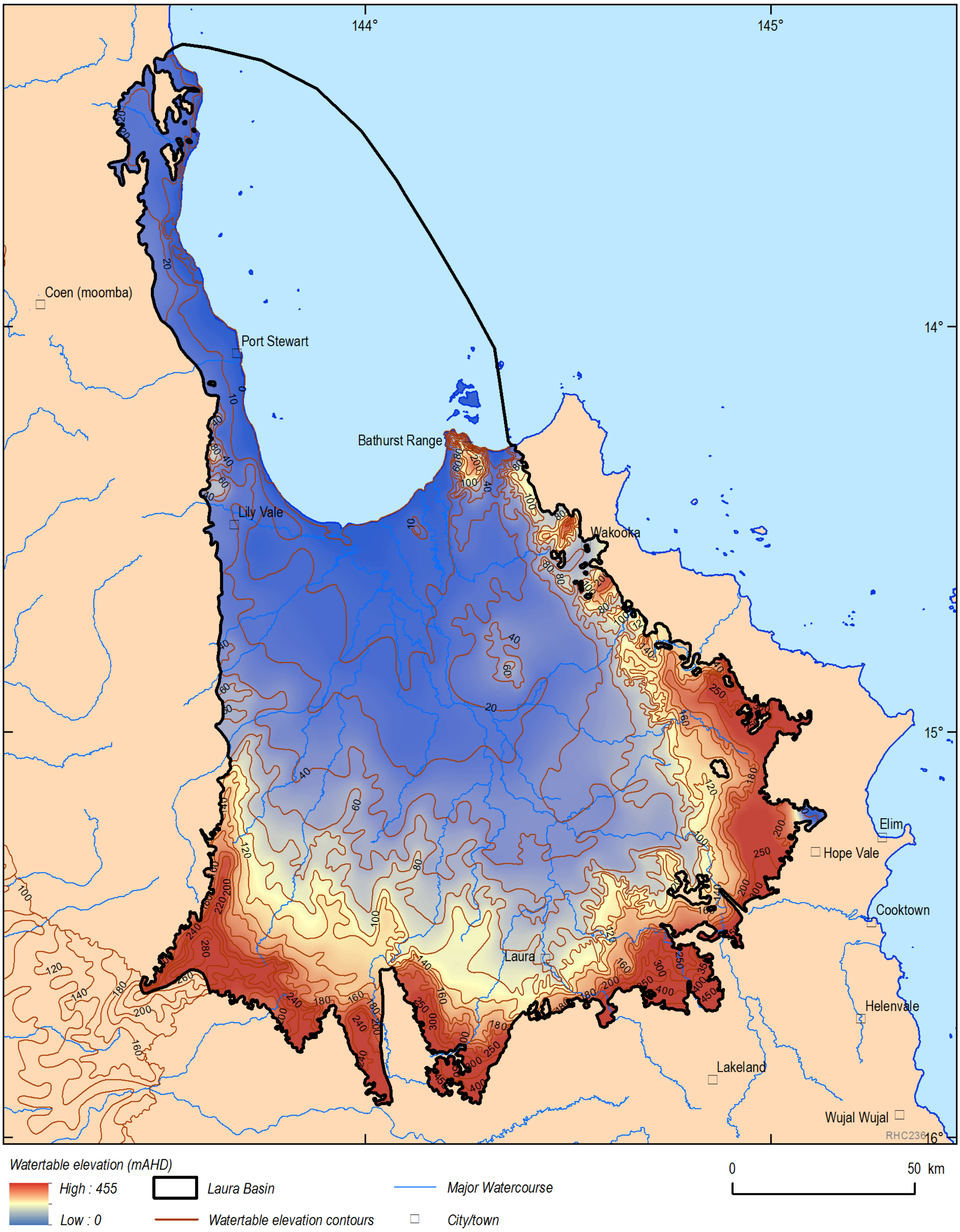


Figure 6.5. Water table map, Laura Basin (from Kellett et al. (2012)).

6.5.2 Mesozoic aquifer

There is very little hydraulic head information available in the Laura Basin. There are 29 hydraulic head records for bores that can be attributed to water level measurements in the Mesozoic aquifer. These measurements were taken over the period 1948 to 2007. Due to the relatively small amount of groundwater pumping in the Laura Basin, it is considered acceptable to combine these data to build a steady-state potentiometric surface, despite the temporal variation in sampling. This approach also assumes that water levels have not been sensitive to climatic drivers. There is no time-series hydraulic head data available to inform an analysis of groundwater level trends with respect to climate or groundwater pumping. The result should be considered indicative only given both the extremely limited spatial coverage of hydraulic head measurements and the assumption that the groundwater system was at steady-state across the period of measurement.

To use this data to build a potentiometric surface, it was necessary to attribute a measurement depth interval (or at least a stratigraphic unit intercept) to each bore. Complete bore construction records are available for 20 of the bores with water levels. For bores with water level data, and no construction details, the aquifer was inferred based on the location and depth of the bore and the lithological record as well as the stratigraphic interpretation undertaken as described in Section 4.3.

One additional hydraulic head value was obtained for the Mesozoic aquifer from the Bureau of Mineral Resources auger drilling program, 1972 (Gibson *et al.* 1972). The hydraulic head records were not corrected for temperature or salinity. This is not expected to affect the potentiometric surface to a more significant degree than the other sources of uncertainty implied in the potentiometric surface contouring exercise due to the very small amount of data available, and because the bores are generally less than 200 m deep and groundwater is relatively fresh (500-3000 µS/cm).

In addition to using the water level data to map the potentiometric surface, drillers' logs for each of the boreholes in the Healthy Headwaters Dataset were searched for 'artesian water'. Anywhere that artesian groundwater was identified within the Mesozoic aquifers the hydraulic head at that location was assigned a value equal to the DEM of the ground surface. Horn et al (1995) reported that artesian pressures in the Laura Basin vary from 1–15 m above the ground surface. Flowing artesian bores in the Laura Basin have in the main, low flow rates (Leon Leach, 2013, pers. comm.). This could be explained by either low hydraulic conductivity aquifers or limited hydraulic potential above the land surface. There is no strong evidence to choose another particular value greater than ground surface, so ground surface was used as hydraulic head as a minimum value. There were five additional hydraulic heads assigned to the dataset using this method.

In total, thirty-five hydraulic head data points were used to contour the potentiometric surface of the Mesozoic aquifer. This surface is presented in Figure 6.6. A dashed line is used for the zero contour as there is insufficient data to constrain how far off-shore (or how close in-shore) this contour might extend.

It should be noted that due to the data limitations within the Laura Basin, the potentiometric surface has been produced at a regional scale as a tool for inferring the directions of regional groundwater flow and the different flow system scales throughout the basin, rather than indicating the hydraulic head at any particular point.

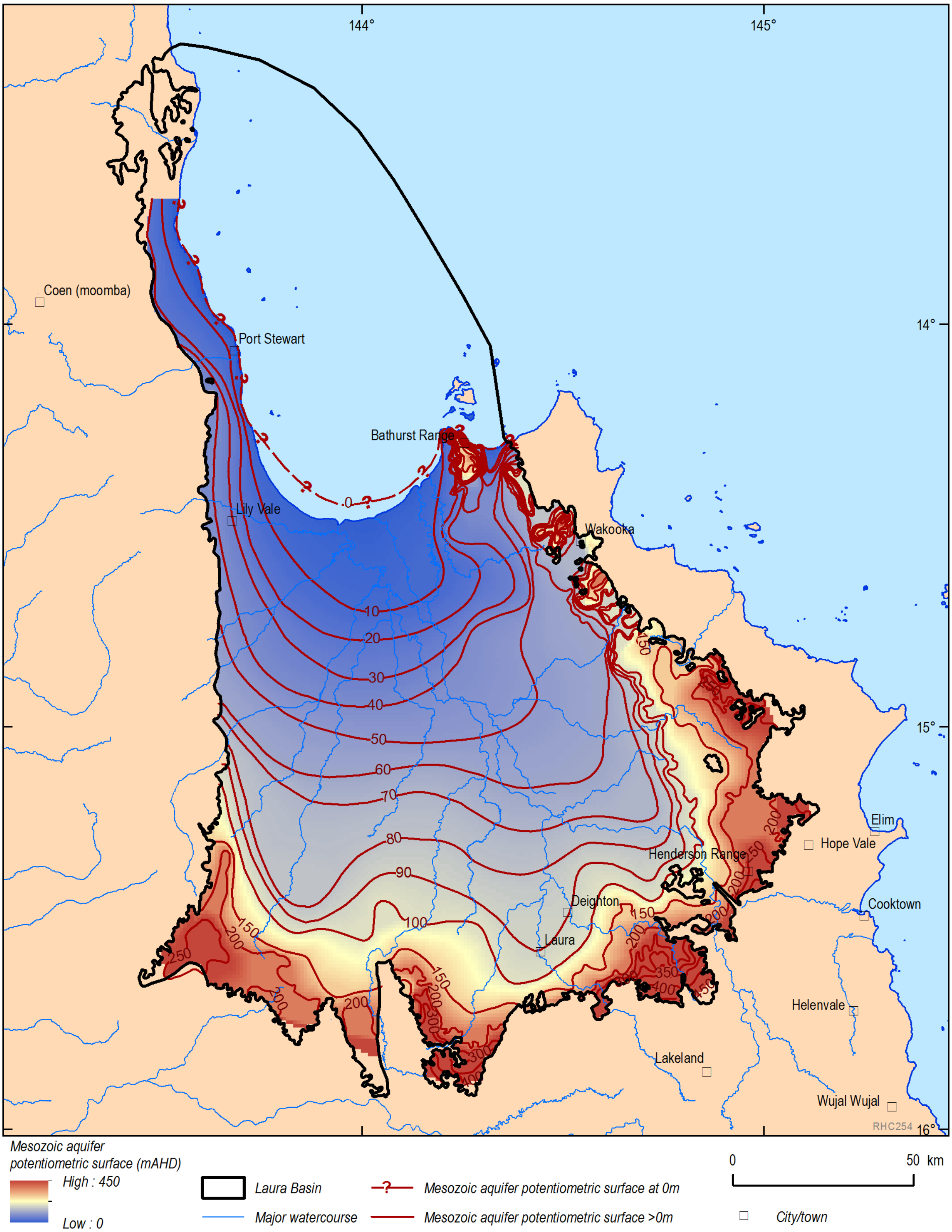


Figure 6.6. Indicative Mesozoic aquifer potentiometric surface, Laura Basin for the purpose of inferring regional scale flow directions. The surface is presented as both contours and a shaded surface.

Figure 6.7 indicates the directions of flow as selected inferred flow-lines, perpendicular to the lines of equal hydraulic head. Only a few flow-lines are presented to highlight the different flow system scales present within the basin. In the elevated areas of the basin, more local scale flow systems are likely, for example, in the Hann River catchment as indicated by the flow lines presented in Figure 6.7 (these flow-lines are drawn to reflect both the potentiometric surface and the baseflow findings presented in Chapter 3). Here, groundwater is recharged in the outcrop areas of the Mesozoic aquifers. Some portion of the recharging water flows back to the surface as baseflow springs and maintains the surface water flows of the Hann River throughout the year. This constitutes a local groundwater flow system. A portion continues within a regional groundwater flow system. These local to intermediate scale flow systems can be found in many upper catchment areas of the Laura Basin, where groundwater is discharged to surface water features such as the Hann River and the Jack River.

6.5.3 Local to sub-regional flow systems

The location of artesian groundwater pressures can be used to infer the types of groundwater flow-systems occurring within the Laura Basin. Given the paucity of other information available to discuss flow-systems, artesian pressures are discussed in detail here. Artesian pressures result from:

- Confinement of aquifers below the Wallumbilla Formation and the Rolling Downs Group more generally;
- Flow system compartmentalisation caused by faults that act as barriers to flow;
- Low permeability Cenozoic sediments directly overlying Mesozoic aquifer sediments providing an aquitard, allowing groundwater pressure to build up in aquifers below; and
- Inter-beds of low-permeability material within the aquifer causing locally confined areas of the aquifer.

Figure 6.8 shows the location of artesian bores. Also shown on the map is the extent and thickness of the Wallumbilla Formation, the extent of the Cenozoic sediments and fault structures inferred by Senior (unpublished) Landsat study.

There are nine records of artesian groundwater pressures in bores within areas where the Wallumbilla Formation exists, and in this area, the Wallumbilla Formation appears to provide an efficient seal (confining bed). However there are many artesian bores east of the area of occurrence of the Wallumbilla Formation, suggesting faults may be acting as barriers to flow or that lower permeability material within the aquifer formations themselves may be providing barriers to flow.

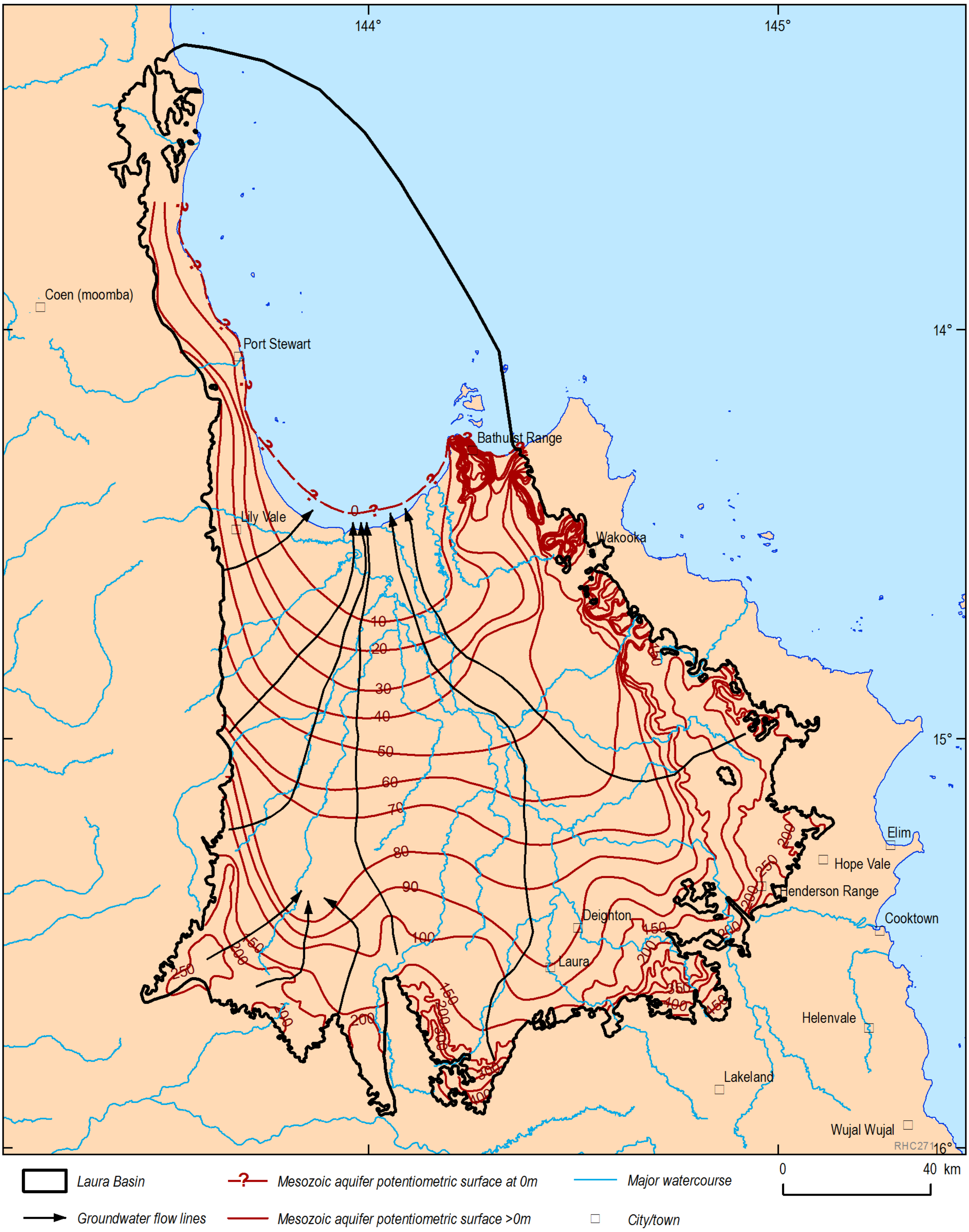


Figure 6.7. Groundwater flow line directions, Mesozoic aquifer (black arrows), Laura Basin.

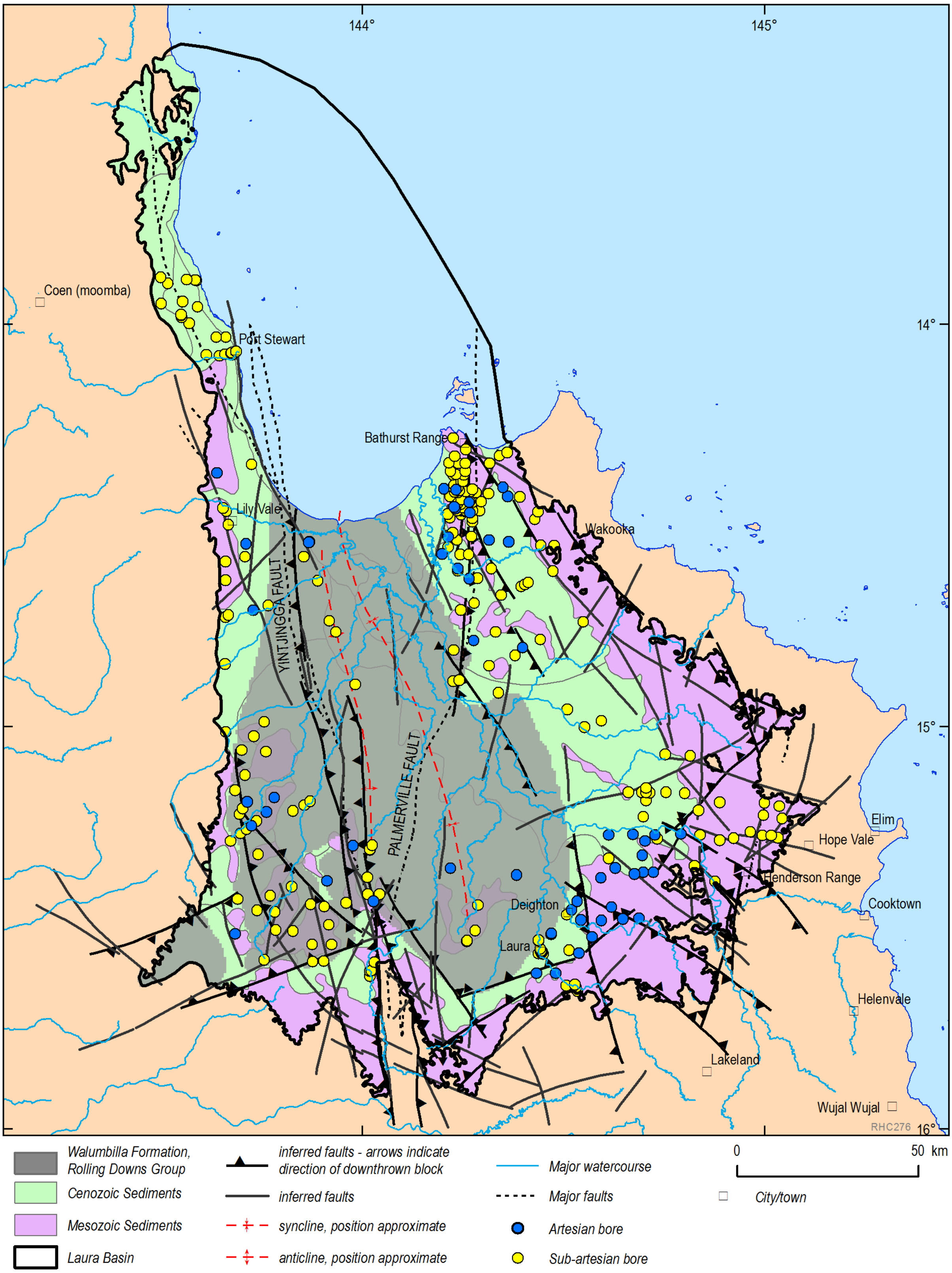


Figure 6.8. Location of artesian bores, Cenozoic sediments, Mesozoic sediments, Wallumbilla Formation aquitard and geologic structure elements (data source: Queensland Bore Database, DERM (2011); Senior (unpublished) Landsat Study).

6.5.3.1 South-west Laura Basin

The Wallumbilla Formation is extensive in the south-west of the Laura Basin. There are only a few records of artesian bores in this area. There are many records of sub-artesian bores in this region. The Hann River drains the area and is the only perennial stream in the upper reaches of the surface water catchments of the Laura Basin (as shown in Figure 3.12). It is believed to be sourced from groundwater discharge from the Mesozoic aquifers in areas where the Wallumbilla Formation is absent (i.e. has been eroded away to expose the Gilbert River Formation and/or the Dalrymple Sandstone).

6.5.3.2 South-east Laura Basin

There are many artesian bores recorded in the south-east of the Laura Basin near the towns of Laura and Deighton, in areas where the Mesozoic Aquifer sediments are in outcrop or subcrop to the Cenozoic sediments. The Cenozoic sediments are either relatively thin (<20 m) or non-existent across this area. The Wallumbilla Formation and the Rolling Downs Group more generally are not present.

Artesian pressure could be caused by the abrupt thinning of the aquifer in this area- there has been significant uplift and erosion of the Mesozoic sandstone units in the area. Some sort of confining layer would need to be present in order for the thinning to cause elevated groundwater pressures such that they are artesian. The absence of the Rolling Downs Group, and the limited thickness of Cenozoic Sediments in this area implies that any confining layers would be located within the aquifer itself, creating local confining conditions. Due to the heterogeneity of the Gilbert River Formation and the Dalrymple Sandstone (the Mesozoic aquifer hydrostratigraphic units), this is plausible.

Another possibility is that faulting in the area provides barriers to groundwater flow so that the groundwater flow system in this area is highly compartmentalised. The abrupt aquifer thinning discussed previously is associated with steep sandstone escarpments of the Gilbert River Formation. Senior (unpublished) interpreted these escarpments to be fault bounded (Figure 6.8).

There are cross-cutting faults in the area. These faults may cause compartmentalisation of the flow system either by bringing lower permeability sediments into contact with higher permeability sediments or if faults are clogged up with clays and rock/or fault gouge as discussed in Section 6.5.5.1. In this high recharge area compartmentalisation of the flow system by cross-cutting barrier faults would have the potential to contribute to artesian pressures.

Another contribution to artesian pressures may be changes in the permeability of the aquifer material along groundwater flow path. This is a possibility given the depositional history of both the Gilbert River Formation and the Dalrymple Sandstone in predominantly fluvial-deltaic environments which could cause significant permeability changes over relatively short distances.

There is no way of verifying the precise reasons for artesian pressures in this area with the current data available. However, the findings indicate that understanding heterogeneity within the aquifer, including faulting and low permeability beds within the aquifer sediments is important for groundwater flow systems at the local- sub-regional scale.

6.5.3.3 North-east Laura Basin

The groundwater flow systems in the Bathurst Range area appear to be particularly controlled by faulting in the area. The compartmentalisation is described by the same process discussed in the south-east of the Laura Basin. Again, the high recharge rates in the outcrop areas of the Bathurst Range and the significant faulting in the area (as inferred by Senior (unpublished)) support the hypothesis that localised flow systems dominate groundwater flow behaviour in the Bathurst Range. This is also supported by the findings of the hydrogeochemistry project undertaken for the Laura Basin (Ransley et al. 2015).

6.5.4 Surface water–groundwater interactions

Surface water–groundwater interactions were discussed briefly in Section 3.6.3.1. Desktop analysis of stream gauge data at six stream gauges across the catchment indicates that groundwater discharge to streams may be significant during the dry season (CSIRO 2009). The Bureau of Meteorology Australian Atlas of Groundwater Dependent Ecosystems (GDE Atlas) was viewed to identify groundwater dependent ecosystems in the Laura Basin. In the Laura Basin, groundwater dependent ecosystems (GDE's) were identified as having low, medium and high potential for the expression of groundwater at the surface based on a desktop study of remotely sensed data. Many of the surface water bodies within the basin are identified as having high potential for some amount of groundwater dependence as shown in Figure 6.9. The CYPLUS body of work (Horn *et al.* 1995) stated that spring flow provides nearly continuous supply to the Hann River, Little Laura, Kennedy, Normanby and Endeavour Rivers. Horn *et al.* (1995) also mapped spring discharge areas across the Laura Basin.

Figure 6.9 shows the areas with most potential for groundwater discharge to surface water across the Laura Basin in addition to the areas identified by Horn *et al.* (1995) as areas with 'numerous springs'.

Although groundwater discharge to surface water is shown to be significant across the Laura Basin, there is little discussion in the literature about which aquifers provide the most significant discharge volumes and what pathways and processes are involved.

6.5.4.1 Potential groundwater discharge pathways to surface water bodies in the Laura Basin

As discussed previously, groundwater discharge to surface water bodies is likely to be significant in the Laura Basin and important for water dependent ecosystem function during the dry season. There are significant challenges to undertaking a comprehensive and definitive analysis of sources, pathways and quantities of groundwater discharge to surface water bodies due to the very small amount of data available. An analysis using the data available is attempted below.

Groundwater discharge to the surface can occur in areas where the relative groundwater hydraulic head is higher than the elevation of the head of water in a stream or lake or the elevation of the ground surface and there is a pathway for groundwater to migrate to a stream or lake or to the land surface. These pathways might be via matrix porosity of the aquifer rock or via discrete fractures that cut through an aquitard to join aquifers with the surface. A schematic of potential pathways for groundwater to flow to surface water bodies is shown in Figure 6.10.

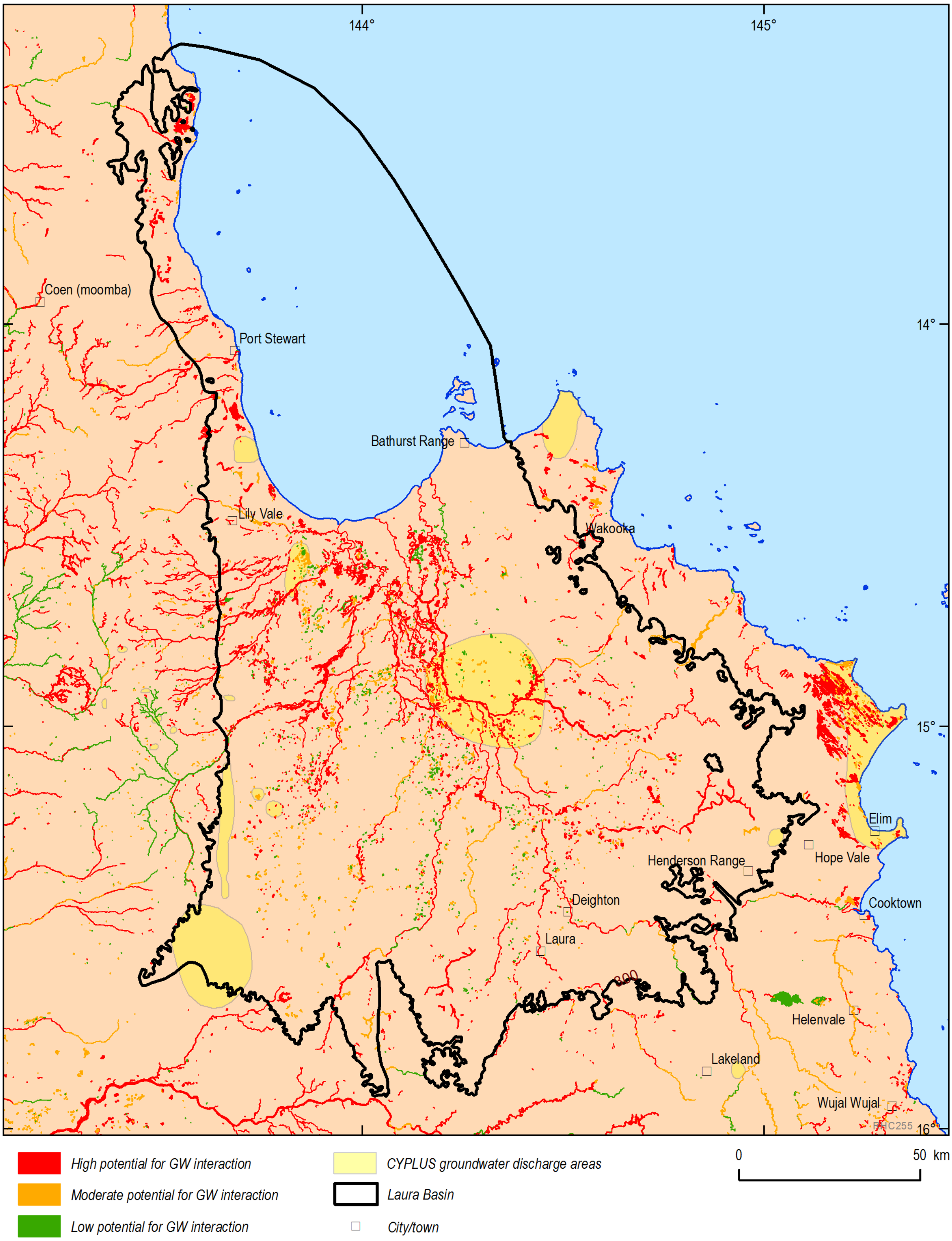
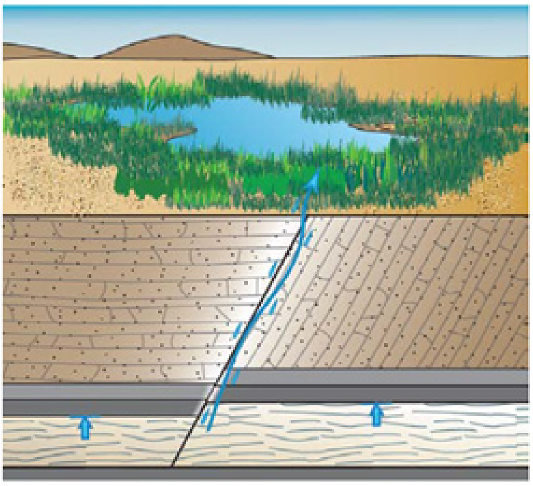
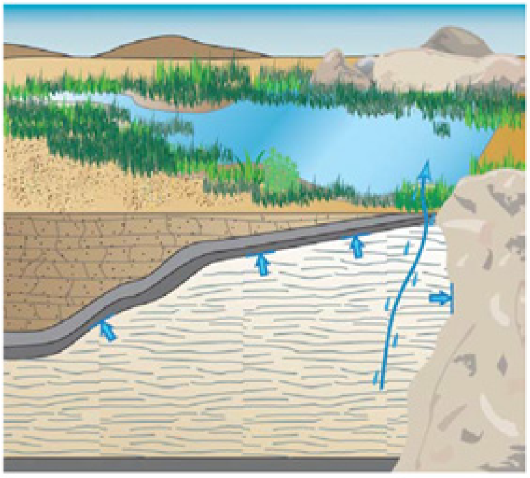


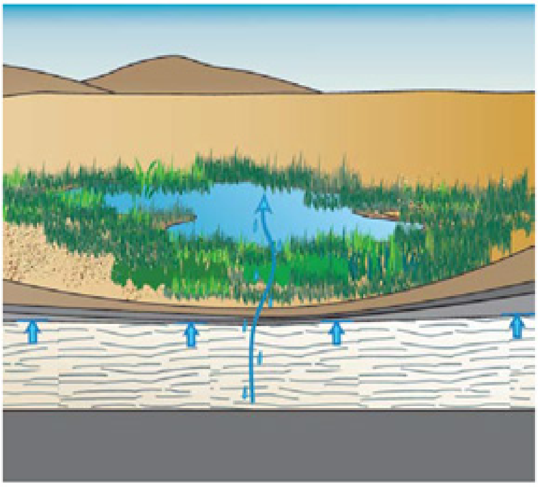
Figure 6.9. Likelihood of potential for discharge of groundwater to surface water systems (data source: GDE Atlas, BOM (2012c)) and areas of spring discharge identified by Horn et al. (1995).



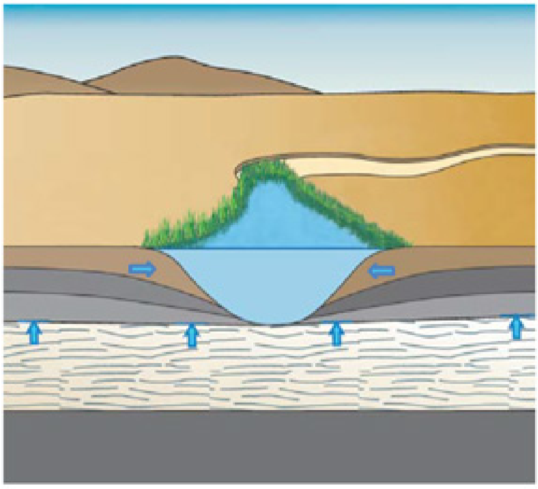
(a) Geological structure type, where water flows upward through a fault



(b) Abutment type, where aquifers abut against an impermeable outcrop



(c) Thin confining type, where water pressure transmits to the surface through a thin aquitard



(c) Surface depression type, where a creek line incises an aquifer

Figure 6.10. Spring discharge types (adapted from Miles et al. (2012), blue arrows show groundwater flow.

One of the key pieces of information missing from the literature on spring discharge in the Laura Basin is which aquifers (i.e., the Cenozoic aquifers or the Mesozoic aquifer) are discharging groundwater to the surface.

Higher permeability facies of the Cenozoic sediments and Quaternary alluvium of the modern drainages may constitute shallow aquifers across the basin. To date, there has been little work to understand the shallow groundwater system of the Laura Basin. Horn *et al.* (1995) commented that groundwater bore drillers in the region reported large seasonal variations in water levels of the Cenozoic sediments and often, failure of bores located within these sediments during the dry season. There is no data available to verify these observations. It is likely that the Cenozoic sediments and the Quaternary alluvium deposits provide some portion of baseflow to streams throughout the year (see Figure 6.10 (d) for a schematic of how this discharge might occur). It is also possible that this source of baseflow is seasonal and may not be the critical source of freshwater discharge during the dry season given the observation of seasonality of water levels within the Cenozoic aquifers.

To assess the likelihood of the Mesozoic aquifers discharging groundwater to streams, water level observations made in bores screened in the Mesozoic aquifers were qualitatively compared with the national 1-arc second digital elevation model (DEM) in areas identified by the GDE Atlas to have a ‘high potential for groundwater expression at the surface’. Table 6.4 summarises the observations made using this approach. The observations indicate there is evidence for both a hydraulic gradient from the Mesozoic aquifer to the surface water bodies and a hydraulic pathway for groundwater to travel from the Mesozoic aquifer to the surface water bodies in most of the cases investigated.

Table 6.4. Comparison of elevations of GDE Atlas polygons with a ‘high potential for groundwater expression at the surface’ with groundwater level observations in the Mesozoic aquifer.

River	Number of Mesozoic aquifer groundwater level observations	Observations
Hann River	2	Groundwater levels at similar elevation to nearby GDE polygons and there are outcrops of Mesozoic aquifer sediments
Laura River	3	Groundwater level observations are slightly higher than the elevations of nearby GDE polygons. There is also limited cover of the Mesozoic aquifer sediments
Deighton River	1	Groundwater level observation is at a similar elevation of nearby GDE polygons. There is also limited cover of the Mesozoic aquifer sediments
Normanby River	3	Groundwater observations are similar to the GDE polygon elevations. There is also limited cover of the Mesozoic aquifer sediments
Jack River	0	No groundwater observations proximal to GDE polygons. There is limited cover of the Mesozoic aquifer sediments
Sandalwood Creek	3	Groundwater levels slightly higher than GDE polygon elevations. Thicker amounts of quaternary alluvium in this area and presence of Rolling Downs Group (more sandy Normanton Formation facies) so less likely to be Mesozoic Aquifer groundwater dependence

The potentiometric surface constructed for the Mesozoic aquifers, mapping of the Rolling Downs Group thickness (isopach) and mapping of the Cenozoic sediment thickness (isopach) also provides a tool for assessing which aquifers are more likely to be interacting with the surface water system. Again, because of the data quality and distribution, interpretation of these surfaces can only be considered indicative.

In the lower part of the Laura-Normanby River catchment (towards the north of the Laura Basin, the Rolling Downs Group is very thick and likely provides a significant barrier to the flow of groundwater from the Mesozoic aquifers to the surface water system. The Cenozoic sediments in this region also thicken (up to 70 m), adding to this barrier. It is therefore expected that the Mesozoic aquifers are more likely to be providing surface water expressions of groundwater in upland areas where they are in outcrop or are covered with only a thin veneer of Cenozoic sediments (for example, in the upper catchment of the Hann River). Cenozoic aquifers are likely to be more important for providing baseflow to streams and other GDE’s in the north of the Basin.

The Normanton Formation of the Rolling Downs Group is also thought to be contributing groundwater to springs in the Bathurst Range area, in particular, to the headwaters of the Marret River.

6.5.5 Inter-aquifer connectivity

Water table mapping for the unconfined aquifers of the Laura Basin was undertaken by Kellett *et al.* (2012). Comparison of the water table mapping with the potentiometric surface of the Mesozoic aquifers indicates areas where there is hydraulic potential for groundwater to migrate from the Cenozoic aquifers to the Mesozoic aquifers and where there is hydraulic potential for water to migrate from the Mesozoic aquifers to the Cenozoic aquifers. The location and thickness of the Wallumbilla Formation of the Rolling Downs Group indicates where migration resulting from these hydraulic gradients is less likely due to the low hydraulic conductivity of this intervening formation. The hydraulic potential for leakage between the Mesozoic aquifer and the Cenozoic aquifers is mapped along with the distribution and thickness of the Wallumbilla formation in Figure 6.11. This map can be interpreted to show that where the Wallumbilla Formation is not present between the Mesozoic aquifer and the Cenozoic aquifers, there is, in the main, a hydraulic potential for upward migration of groundwater from the Mesozoic aquifer to the Kalpowar Basin. There is a hydraulic potential for groundwater to leak downwards from the Kalpowar Basin sediments to the Mesozoic aquifer in a few locations across the basin where the Wallumbilla and the Rolling Downs Group (aside from the Normanton Formation) are absent. However, this area is relatively minor and mostly located in the intake beds of the Mesozoic aquifer.

The Wallumbilla Formation is present throughout the centre of the basin. Where it exists, the hydraulic potential is for groundwater to migrate from the Mesozoic aquifer to the Kalpowar Basin throughout the area where the Wallumbilla Formation is present. If faults provide a conduit for groundwater flow through the Wallumbilla Formation, there may be more leakage from the Mesozoic aquifer to the Cenozoic aquifers that has not been accounted by this assessment. This is discussed further in Section 6.5.5.1

Although a map of potential interaction areas has been presented (Figure 6.11), it must be noted that the data used to map the watertable surface of the Laura Basin and the potentiometric surface of the Mesozoic aquifers is very sparsely distributed and of low quality. This map should therefore be seen as a guide to consider the potential for interaction between the groundwater systems in the Kalpowar Basin aquifers and the Mesozoic sandstone aquifers, rather than as a definitive map of such interactions.

Estimates of groundwater flux via the Cenozoic sediments are provided in Section 6.6.1.2 and Section 6.6.2.4.

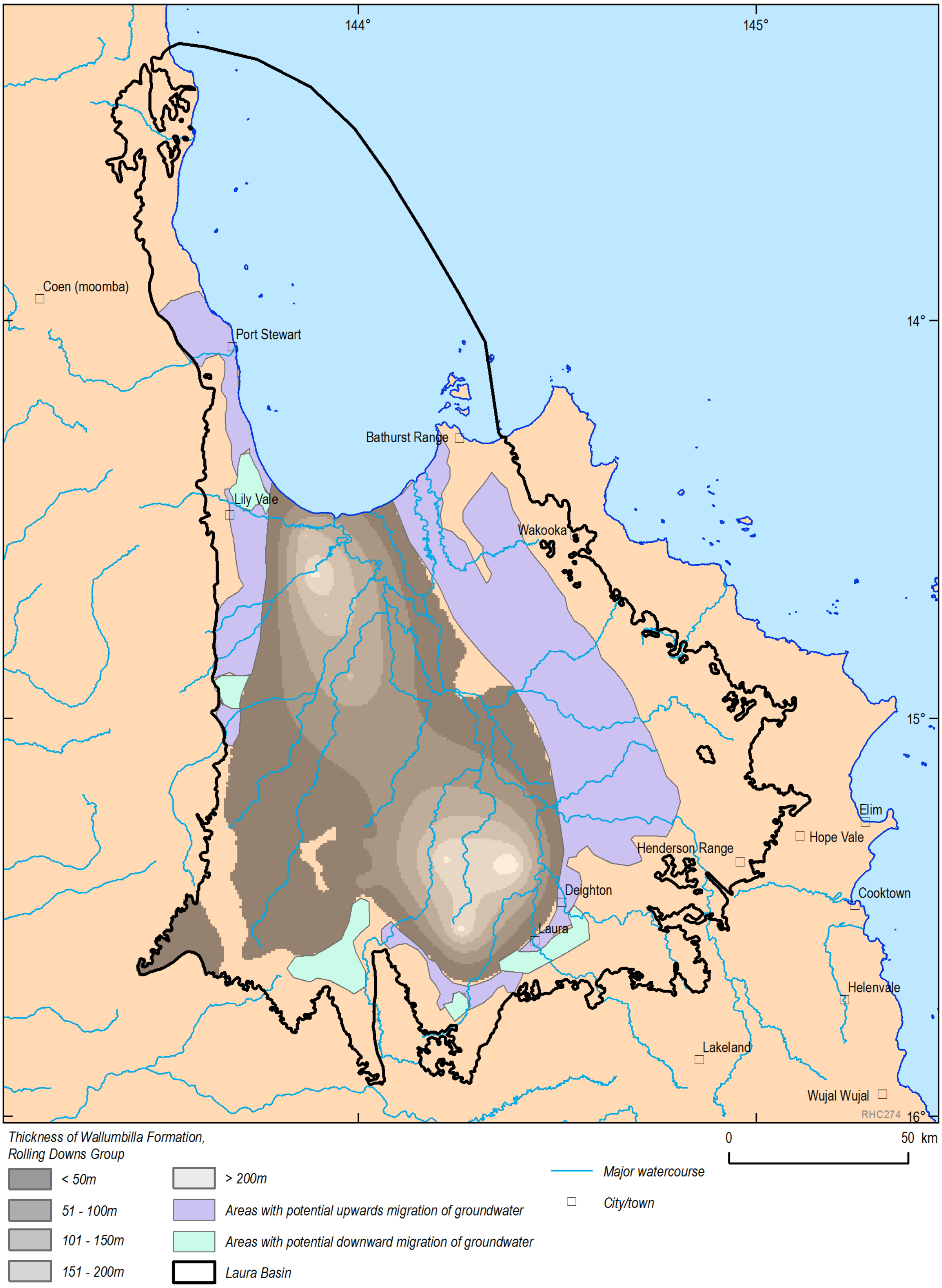


Figure 6.11. Location and thickness of Wallumbilla Formation aquitard and areas of potential upward migration of groundwater from the Mesozoic aquifer to the Cenozoic aquifers (purple) and areas of potential downwards migration of groundwater from the Cenozoic aquifers to the Mesozoic aquifer (blue).

6.5.5.1 Structural controls on connectivity

Faults can provide either conduits for preferential groundwater flow or barriers to groundwater flow. Faults are conduits for flow where movement has been such that areas along the fault have opened up or dilated so that water can flow into and along the fault plane. Fault zones may also be conduits for flow where reactivation of faults in a zone such as the 2–5 km wide Yintjigga Fault Zone has caused a zone of deformation to occur, leaving broken and disrupted zones of *in situ* rock. This fracturing may lead to preferential flow in these areas. Alternatively, faults can act as barriers to groundwater flow. This is particularly the case when movement on the fault has caused grinding up of rock so that grain sizes become very small and inhibit flow. Clogging up of faults can also occur where original rock minerals are weathered to secondary clay minerals that in-fill discontinuities (gaps) that are present in the faulted zone. Faults can also provide barriers to groundwater flow where uplift or down-throw of a permeable rock unit causes it to come into contact with a less permeable rock unit.

The most comprehensive study of faulting in the Laura Basin is an unpublished Landsat Study undertaken by Senior (unpublished). In addition to the very large Yintjigga Fault Zone and Palmerville Fault structures, there are many more local faults that may influence groundwater flow at sub-regional scales. The Senior (unpublished) Landsat map and the 1,000,000 and 250,000 surface geology maps indicate orthogonal to sub-orthogonal faults reflecting the dramatic changes in the Australian paleo-stress field throughout the history of the Laura Basin. In the Cretaceous, the stress-field was in an approximately northwest-southeast orientation. The stress fields in the Eocene were in an approximately east-west orientation and are now in an approximately northeast-southwest orientation (Muller *et al.* 2012). The presence and distribution of these faults may be important for understanding groundwater flow patterns due to their potential control on groundwater flow system compartmentalisation, where faults cause barriers to groundwater flow; and aquifer interconnectivity, where faults act as conduits for groundwater flow. The potential for dilational movement on northwest-southeast trending faults (as discussed in Section 4.4.2), suggests that these faults could potentially allow for fluid transmission. However, without detailed field investigations, the propensity for faults to be conduits for groundwater flow or barriers to flow cannot be better understood.

6.6 Water balance components analysis

The water balance component analysis presented here is restricted to the Mesozoic aquifer.

There is very limited data available to undertake water balance modelling for the Laura Basin For example:

- Bores are generally not metered for extraction;
- There is limited chemistry data or time series hydraulic head data to understand groundwater flow systems, inter-aquifer connectivity and recharge processes;
- Discharge processes are extremely poorly constrained with almost no relevant data to estimate discharge volumes to various pathways.

Because of these limitations, a water balance components analysis is presented. There are likely to be significant errors associated with these volumes and the data is so poor that a systematic analysis of the size of even the errors is not possible. For this reason, range values are not presented. Instead, a best first approximation based on the data available is presented, however it is not intended that these volumes could be used in any other context but to provide an insight into what the relative water balance components might be. Qualitative confidence levels: low, medium and high, are also indicated.

6.6.1 Recharge

The tropical climate creates the potential for a large amount of recharge to occur from rain in the wet season (Smerdon *et al.* 2012). However, the watertable across the region is also relatively high, creating conditions favourable for restricting the amount of recharge. Rainfall that enters the ground also has a tendency to drive localised spring flow, in a process known as 'rejected recharge'. The seasonal dynamics of groundwater recharge and discharge are not well known in the Carpentaria region, especially in terms of a quantitative water budget (Smerdon *et al.* 2012).

6.6.1.1 Diffuse Recharge: Mesozoic aquifer outcrop areas

The Mesozoic aquifer of the Laura Basin is thought to be primarily recharged in outcropping areas. Based on 1:1,000,000 geological mapping, the area of outcropping Dalrymple Sandstone is 1,362 km^2. The area of outcropping Gilbert River Formation is 3,793 km^2. This is a conservative estimate of recharge areas because these formations may extensively subcrop beneath thin veneers of sandy Cenozoic sediments and these areas are not included in the estimate.

There are limited recharge estimates for the Laura Basin. Previous studies have generally extrapolated recharge values from other areas of the Great Artesian Basin to the Laura Basin to estimate groundwater recharge (Kellett 2012). Kellett (2012) nominated that recharge rates of between 10 mm/yr and 50 mm/yr are plausible in the outcrop areas of the Mesozoic sandstones of the Laura Basin. One study, Crosbie *et al.* (2009) estimated recharge at four locations across the Laura Basin using a chloride mass balance approach. These estimates ranged between 28 mm/yr and 78 mm/yr (up to 7% of rainfall). These estimates are located in or close to outcrop areas.

For a given recharge value of 40 mm/yr, diffuse recharge across the outcrop areas is estimated at 206 GL/yr.

6.6.1.2 Leakage from Cenozoic Aquifers

As discussed in Section 6.5.5, there are limited areas within the basin where downward groundwater leakage from the Kalpowar Basin (Cenozoic aquifers) to the Mesozoic aquifers is likely to occur (noting the absence of fault conduit information).

Using Darcy's Law, a very approximate estimation of what this quantity may be (Q $[L^3/T]$) was made based on the area where there is hydraulic potential for leakage from the Cenozoic aquifers to the Mesozoic aquifers, and where the Wallumbilla Formation is not present. The following assumptions were made:

- As discussed in Section 6.5.5, the area (A $[L^2]$) over which leakage may occur is assumed to be the area shown in green in Figure 6.11. This area is approximately 596 km^2.
- Vertical hydraulic conductivity (Kv [L/T]) of the Kalpowar Basin sediments is estimated to be 0.0001 m/day. This number is a best estimate, there has not been any testing of the hydraulic parameters of the Cenozoic aquifers in the Kalpowar Basin, although it is assumed that they are generally layered gravel, sand, silt and clay units with some degree of lateritisation such that vertical hydraulic conductivity is likely to be significantly lower (several orders of magnitude) than horizontal hydraulic conductivity. The Bulimba Formation has been subject to some limited

hydraulic testing in the Karumba Basin, with horizontal hydraulic conductivities ranging from between 140 and 335 m/day (Smerdon *et al.* 2012).

- The average thickness of the Kalpowar Basin sediments (dl [L]) in the areas where there might be downward leakage is 10 m.
- The average hydraulic head difference between the Mesozoic aquifer and the water table (dH [L]) is 10 m.
- Darcy's law assumes a homogenous and isotropic aquifer and takes the form:

$$Q = Kv.A.(dH/dl)$$

The volume calculated in this way is approximately 22 GL/year.

6.6.2 Discharge

6.6.2.1 Spring discharge and baseflow to surface water bodies

Groundwater baseflow to streams is discussed in Section 3.6.3.1 and in Section 6.5.4. CSIRO (2009) estimated baseflow to streams in 5 gauged sub-catchments of the Normanby River. CSIRO (2009) did not discuss whether the baseflow was derived from the either the Mesozoic aquifer or the Cenozoic aquifers or both. Although annual baseflow ratios are presented (see Table 3.4), it is considered inappropriate to apply these to average annual gauged streamflow as the baseflow volumes calculated using the annual BFI applied to the average annual stream discharge appear very large and may more likely reflect discharge from bank storage after high flow events and the limitations of average annual baseflow calculation methods rather than reflecting groundwater discharge to streams. The volumetric estimates for dry season baseflow (presented in Table 3.4) appear more reliable. By adding together the dry season baseflow volumes for each of the rivers presented in Table 3.4, and assuming that the baseflow is all derived from the Mesozoic aquifer, the minimum value for groundwater discharge to streams in the basin is 27.3 GL/yr.

This volume does not provide a complete estimate of groundwater discharge to surface water bodies. For example, the volume does not include discharge to any ungauged streams and rivers. The volume does not reflect any discharge to springs (aside from those which might feed the gauged rivers) and also does not include discharge of groundwater to lakes.

In addition, verification of these modelled baseflow estimates with other methods for estimating baseflow would improve the confidence in the water balance.

6.6.2.2 Submarine discharge

Submarine discharge is likely to occur. It is not possible to identify where this discharge occurs, or to estimate its quantity.

6.6.2.3 Groundwater Evapotranspiration

The Mesozoic aquifer is blanketed by the Rolling Downs Group and the Kalpowar Basin sediments across much of the Laura Basin. The Mesozoic aquifers outcrop around the rim of the basin. It is in this area that the principle evapotranspiration losses from the Mesozoic aquifer may occur. The dominant vegetation type in these areas is a mix of open and closed Eucalypt Woodland including *Corymbia hylandii* woodland, *Eucalyptus tetrodonta* community, *Eucalyptus leptophleba* woodland, *Corymbia nesophila* woodlands, *Eucalyptus chlorophylla* woodlands and *Eucalyptus cullenii* woodlands (Wannan 2010). It is likely that these trees access groundwater for some part of their water needs (Hutley *et al.* 2000) and this water may be accessed at depths of up to 20 m below the ground surface (Leuning *et al.* 2005) will also occur in areas where vegetation is accessing groundwater from the Mesozoic aquifer in areas where the watertable is close to the surface (e.g. riparian areas). Future work could investigate whether MODIS Terra Enhanced Vegetation Index (EVI) data might be used together with land cover datasets to estimate evapotranspiration in riparian zones [MODIS, Moderate Resolution Imaging Spectroradiometer, satellite imagery can be used to differentiate deeply rooted phreatophytes from grassland along reaches of rivers, which the potentiometric surface mapping indicates may potentially be gaining streams]. However, this method is most suited to arid areas where strong vegetation signals can be attributed to vegetation accessing groundwater. Due to the seasonality of rainfall and the limited information on the process that cause perennial water in the hydrologic system (e.g., remnant water from the wet season versus groundwater baseflow and spring discharge), there are significant complexities to using the EVI data for this purpose. However, further work in this area is recommended.

6.6.2.4 Upward Leakage from Mesozoic aquifer to Cenozoic Aquifers of the Kalpowar Basin

Using Darcy's Law, a very approximate estimation of groundwater leakage from the Mesozoic aquifer to the Kalpowar Basin (Q [L^3/T]) was made based on the areas identified as having potential for upward migration of groundwater from the Mesozoic aquifer to the Kalpowar Basin in Section 6.5.5 (the purple area indicated in Figure 6.11). The following assumptions were made in order to make this calculation:

- As discussed in Section 6.5.5, the area (A [L^2]) over which upward leakage may occur is assumed to be the area shown in purple in Figure 6.11. This area is approximately 4,490km^2.
- Vertical hydraulic conductivity (Kv [L/T]) of the Kalpowar Basin sediments is assumed to be 0.0001 m/day. This number is a best estimate as there has not been any testing of the hydraulic parameters of the Cenozoic aquifers.
- The average thickness of the Kalpowar Basin sediments (dl [L]) in the areas where there might be upward leakage is 10 m.
- The average hydraulic head difference between the Mesozoic aquifer and the water table (dH [m]) is 10 m.
- Darcy's law assumes a homogenous and isotropic aquifer and takes the form:

$$Q = Kv.A.(dH/dl)$$

The volume estimated is 160 GL/yr.

6.6.2.5 Groundwater Extraction

There is currently 426 ML/year of groundwater entitlement and stock and domestic usage estimated for bores accessing the groundwater of the Rolling Downs Group, Gilbert River Formation and Dalrymple Sandstone in the Laura Basin (DNRM 2005). Table 6.5 provides a summary of the bore types and volumes for the two Great Artesian Basin management units within the Laura Basin. 160 ML/year are also allocated to the town bore supply at Laura (DNRW 2007) from the Mesozoic aquifers. This volume appears to be additional to the volume of entitlement reported in (DNRM 2005).

The ABS Water Use on Australian Farms Survey (ABS 2011b) reported total groundwater use for the Normanby River Catchment as 588 ML/yr. Taking a conservative approach, the larger volume of 588 ML/yr of groundwater use is taken to be the correct one.

There are no records of volumetric entitlements for bores accessing water in the Cenozoic aquifers (Horn *et al.* 1995). There may be some use for stock and domestic purposes, although it is not possible to estimate these volumes and they are not reported in the literature.

Table 6.5. Number of bores and entitlement, Rolling Downs Group (GAB Management Unit 'Laura 1') and Gilbert River Formation/Dalrymple Sandstone (GAB Management Unit 'Laura 2') (data source: DNRM (2005)).

	Rolling Downs Group	Gilbert River Formation and Dalrymple Sandstone
Artesian controlled	0	16
Artesian uncontrolled	0	3
Ceased to flow & pump assisted	0	1
Artesian condition unknown	0	0
Sub-Artesian	8	6
S&D entitlement (ML/a)	45	369
Total volume of entitlement (excl. S&D) (ML/a)	-	12

6.6.2.6 Water balance summary – Mesozoic aquifer

Table 6.6 summarises the quantitative results of the water balance component analysis. The lack of information available to quantitatively assess the regional groundwater system must be reiterated and there may be order of magnitude errors in these approximations. In addition, some key elements cannot be estimated due to the lack of data. The difference between the inputs and outputs of the water balance, 32 GL/year, is likely to be partitioned between submarine groundwater discharge and other spring discharge. However, it is not possible to determine the relative values.

Figure 6.12 shows the water balance components schematically.

Approaches to improve the understanding of the hydrogeology of the Laura Basin are discussed in Chapter 9.

Table 6.6. Water balance summary, Mesozoic aquifer, Laura Basin.

Water balance component	Volume	Qualitative Confidence Level	Total
In	**GL/yr**		**GL/yr**
Recharge to Mesozoic aquifer outcrop areas	206	low	
Leakage from Cenozoic aquifers	22	low	
Stream/ lake/ wetland leakage to Mesozoic aquifer	n/a		
			225
Out	**GL/yr**		**GL/yr**
Stream baseflow (dry season and for gauged river reaches only)	27.3	medium	
Other spring discharge, wet season baseflow, ungauged catchment baseflow	n/a		
Groundwater extraction	0.6	medium	
Groundwater Evapotranspiration	n/a		
Submarine discharge	n/a		
Upward leakage to Cenozoic aquifers	160	low	
			193

Qualitative Confidence Levels assigned using the following key: low= based on significant assumptions and inference of sparse datasets; medium= based on data of medium confidence or based on high confidence data with significant assumptions applied in methodology; high= based on high confidence data and high confidence methodology.

The water balance components analysis could be improved by the collection of more data and by undertaking further analysis. The following are among some of the tasks that could be undertaken:

- Flow net analysis using the isopachs and the potentiometric surface to estimate recharge to the Mesozoic aquifer by an alternative approach to chloride mass balance. Discharge may also be estimated in this way.
- Collection of rainfall chloride deposition concentrations at locations spread across the Basin to better constrain chloride mass balance estimates of recharge.
- Improved groundwater level collection and potentiometric surface mapping in outcrop areas to better constrain the evapotranspiration estimate. Soil-water balance modelling to estimate evapotranspiration using a different approach (which would require further data acquisition to parameterise the model).
- On-ground surveys of desk-top identified groundwater dependent ecosystems, focusing on potential groundwater discharge mechanisms and seasonality of vegetation health and vigour.
- Hydraulic testing for the vertical hydraulic conductivity of the Cenozoic sediments to better constrain the leakage component estimates.
- More discretised estimation of leakage components rather than taking an average thickness of the Cenozoic sediments (although the accuracy would still be impacted by the lack of hydraulic conductivity data available for the Cenozoic sediments)
- Investigate using MODIS Enhanced Vegetation Index to explore evapotranspiration from riparian zones as a discharge component of the water balance.

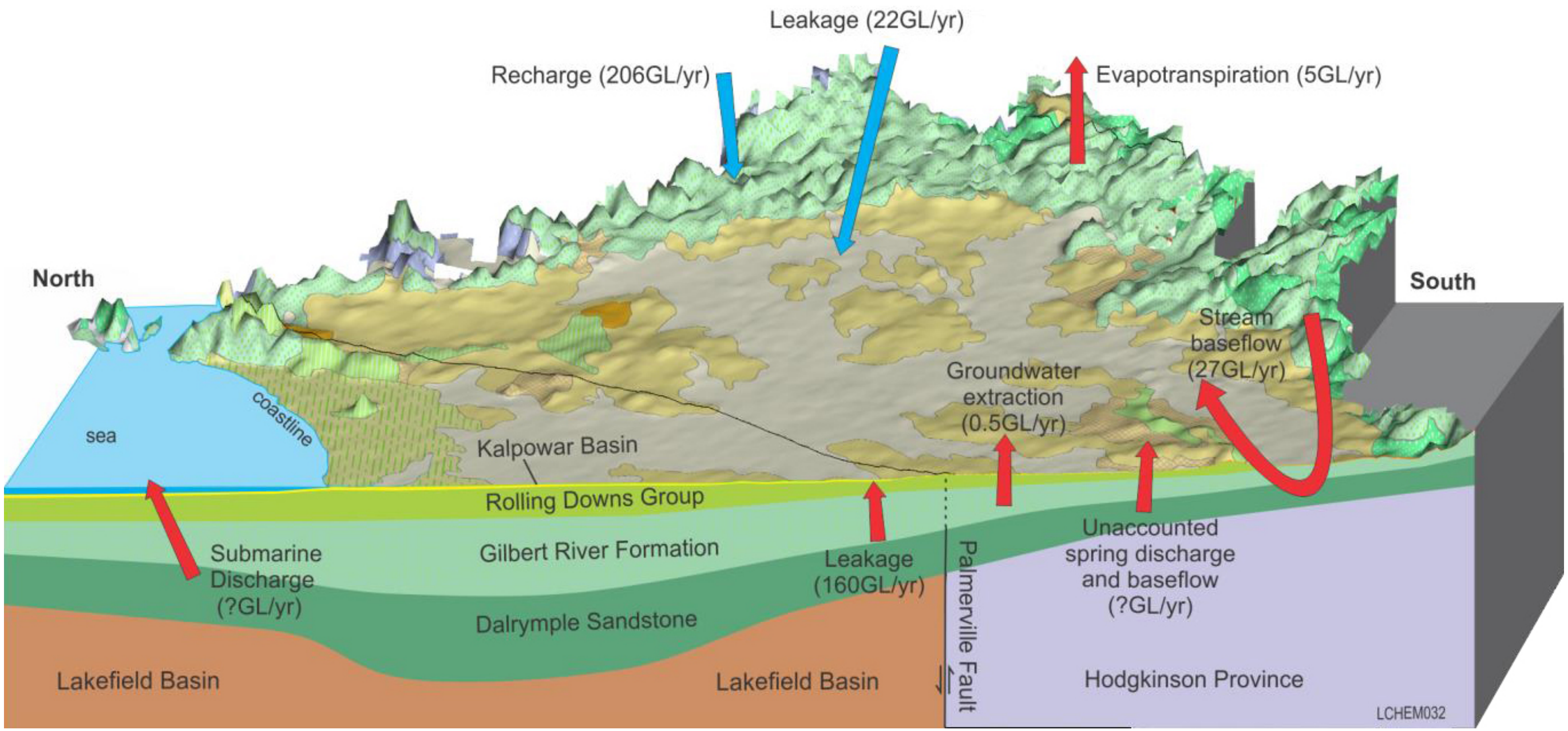


Figure 6.12. Schematic diagram of Mesozoic aquifer water balance component analysis. Blue arrows represent inflows (recharge); red arrows represent outflows (discharge).

6.7 Summary

Table 6.7 and Table 6.8 summarise the key attributes of the hydrogeological conceptualisation of the Laura Basin as described in Section 6.5 and Section 6.6.

Table 6.7. Summary of key attributes of the hydrogeological domain components of the Laura Basin.

	State of current knowledge and conceptual understanding for key components of the hydrogeological domain	Key data gaps and uncertainties for key components of the hydrogeological domain
Hydrostratigraphy	• The principal aquifers of the Laura Basin are the Gilbert River Formation and the Dalrymple Sandstone, known collectively as the Mesozoic aquifer. • There is potentially a region of Normanton Formation sandstone in the north-eastern Laura Basin. This sandier facies of the Rolling Downs Group also behaves as an aquifer and may be locally important for spring discharge, particularly on the southern side of Bathurst Range. • Aquifers are also recognised within the Cenozoic sediments of the Kalpowar Basin that overlie the Laura Basin. • The Wallumbilla Formation of the Rolling Downs Group is a regional aquitard over the central part of the Basin. Importantly, it is not present in the north-east of the Basin.	• Aquifers in the Cenozoic sequences are poorly defined. • The Gilbert River Formation and Dalrymple Sandstone are combined as one aquifer. Further lithostratigraphic research is warranted to better understand the hydrodynamics of these formations at resolution given the compositional heterogeneity of the sediments due to their depositional history. • This project has made a first attempt at differentiating the sub-units of the Rolling Downs Group. Previously there has been limited work to differentiate this group. This is important for understanding the extent to which the Rolling Downs Group behaves as an aquitard. Further work to differentiate and map the sub-units of the Rolling Downs Group is required. • There are only a few deep drill holes towards the centre of the basin which adds uncertainty to the mapped distribution of the hydrostratigraphic units.
Aquifer properties	• Transmissivity data estimated from pump tests ranges between 4-1054 m^2/day for the Gilbert River Formation and 19-83 m^2/day for the Dalrymple Sandstone (10 observations). There is one Storativity value ($8x10^{-4}$) for the Dalrymple Sandstone. • Hydraulic Conductivity and Porosity estimated from laboratory core tests exist for core from three deep petroleum exploration wells in the centre of the Basin. These data are limited in scope and do not coincide with Transmissivity estimated from pump test data. • There are no records of pump test data for the Cenozoic aquifers.	• There is limited information on the hydraulic properties of the Mesozoic aquifer. • There are no estimates for the hydraulic properties of the Cenozoic aquifers.
Conceptual boundaries	• The extent of the Laura Hydrogeological Basin was defined by Kellett et al. (2012) water table mapping. • The base of the Laura Basin is the base of the Dalrymple Sandstone. In the Laura Hydrogeological Basin, the Dalrymple Sandstone is thought to conformably overlie the Hodgkinson Province rocks to the east of the Palmerville Fault, and the Yambo Subprovince to the west of the fault. Locally (throughout much of the Basin), it overlies the Lakefield Basin. Mapping by Nelson et al (2012) was used to define the base of the Laura Basin. • Mesozoic aquifer s are confined where the Gilbert River Formation subcrop to the Wallumbilla Formation (Rolling Downs Group).	• There is low confidence in the base of the Laura Basin at a local resolution due to limited deep drillhole and geophysical data to inform this conceptualisation. Most of the structure of the Laura Basin is caused by drape over basement sediments, the form of which is poorly constrained. • There is poor definition of the confined/unconfined portions of the Mesozoic aquifer in areas where the Gilbert River Formation subcrops to the Cenozoic sediments. This is because there is relatively no hydrostratigraphic differentiation of the Cenozoic sediments in the existing literature and poor data coverage with which to undertake such analysis. The extent of hydraulic interaction between the Mesozoic aquifer and the Cenozoic aquifers is poorly understood.
System stresses	• There is limited groundwater extraction in the Laura Basin due to the low population and development in the region (although groundwater makes up approximately 95% of the water supply in the Basin). • It is likely that current groundwater extraction volumes do not have a major impact on the regional groundwater system.	It is not possible to determine the impact of past groundwater due to the following data gaps: • There is very limited hydraulic head data across the basin. For example, only 29 hydraulic head values were available for the Mesozoic aquifer and these were collected over a period spanning more than 50 years. There are less than 10 hydraulic head measurements in the Cenozoic aquifers. • There is no time-series hydraulic head data for any bores in the Basin such that transient responses of groundwater pressure to changed recharge conditions and/or groundwater extraction are unknown. • Bore construction records are of variable quality such that attributing data to particular hydrostratigraphic units is difficult. • There is no systematic groundwater monitoring regime in the Laura Basin. Given the limited development of groundwater resources it is unlikely to occur in the near future. • For similar reasons, assessing the vulnerability of the groundwater resource and any dependent anthropogenic systems or environmental assets to future changes such as land use change and climate change is difficult. Similarly, assessing the potential future impact of coal mining on Basin water resources will need to be informed by data that does not yet exist.

Table 6.8. Summary of key attributes of the physical groundwater process components of the Laura Basin.

	State of current knowledge and conceptual understanding for key components of the physical groundwater processes in the Laura Basin	Key data gaps and uncertainties for key components of physical groundwater processes in the Laura Basin
Recharge	• A water balance component analysis was undertaken for the Mesozoic aquifer as part of this project and a first approximation water balance was developed including recharge. • Recharge to the Mesozoic aquifer is principally via infiltration of rainfall in outcrop areas of the Gilbert River Formation and the Dalrymple Sandstone. There may be a relatively minor component of recharge to the Mesozoic aquifer via downward leakage from the Cenozoic aquifers • Recharge to the Cenozoic aquifers is thought to be by vertical infiltration during the wet season across the entirety of their occurrence	• There is limited data available to quantify recharge to either the Cenozoic aquifer or the Mesozoic aquifer. • There is limited conceptual understanding of inter-aquifer connectivity or data available to further develop this) to help identify recharge processes via leakage.
Hydrodynamic flow	• At a regional scale, groundwater flows from the outcrop areas of the Mesozoic aquifer to the sea (Princess Charlotte Bay). Along these Basin scale flow paths, water is discharged at more local scales as evapotranspiration, baseflow to streams, rivers and lakes, spring discharge and possibly vertical leakage to the overlying Cenozoic aquifer in areas where the Wallumbilla Formation is not present. • At local to sub-regional scales, faults may play a significant role in compartmentalising flow systems. Lithofacies variations in the Cenozoic sediments and the Mesozoic sediments may also significantly affect flow systems at local to sub-regional scales.	• The conceptualisation of hydrodynamic flow is severely limited by the lack of data in the Basin. The following key areas require further information: • The role of faults in compartmentalising flow systems, • The role of faults in providing increased connectivity within and between aquifers, • The role of permeability variations within aquifers at the local to sub-regional scale resulting from different depositional environments, erosion and weathering regimes that may cause zones of preferential flow within aquifers, • Inter-aquifer connectivity relating to the presence/absence of lower permeability units of the Rolling Downs Group and the interaction of between zones of lower and higher permeability in the Mesozoic aquifer and the Cenozoic aquifers, and • data to inform the seasonal variability of groundwater flow system dynamics.
Discharge	• A water balance component analysis was undertaken for the Mesozoic aquifer as part of this project and a first approximation water balance was developed (Section 6.6 of this report). • Discharge components of the Mesozoic Aquifer water balance include evapotranspiration, baseflow to streams, rivers and lakes, spring discharge and possibly vertical leakage to the overlying Cenozoic aquifer in areas where the Wallumbilla Formation is absent.	• Most water bodies within the Laura Basin are identified as groundwater dependent ecosystems (classified by the BOM GDE Atlas). There is limited data to distinguish which of these are supported by groundwater discharge from the Cenozoic aquifers and which are supported by groundwater discharge from the Mesozoic aquifer. • There is currently limited data to confidently estimate groundwater discharge volumes in the Laura Basin. Some discharge components are completely unknown (e.g. groundwater discharges to the sea).
Surface water – groundwater interaction	• Most water bodies in the Laura Basin are identified as groundwater dependent ecosystems (BOM GDE Atlas). Horn et al (1996) identified zones of spring proliferation and CSIRO (2009) estimated groundwater baseflow to a limited number of gauged stream reaches in the Laura- Normanby River Catchment. • Mechanisms by which groundwater can discharge to the surface have been defined in general terms and mechanisms for discharge in areas local to springs and gaining reaches of streams have been described to a limited extent, however it is not possible to confidently attribute these mechanisms at any particular location given the data and information available.	• There has been no assessment of losing streams and lakes (i.e. water bodies that leak water to aquifers) in the Laura Basin and there is currently no data to undertake such assessment. This type of work would be useful for refining the recharge component of the water balance. • There is limited data to distinguish which GDE's are supported by groundwater discharge from the Cenozoic aquifers and which are supported by groundwater discharge from the Mesozoic aquifer. Limited information and data to estimate the volumes of these interaction flows currently exists. • Most of the work on surface water – groundwater interactions has been undertaken by desktop analysis without any field based validation.

7 Coal and groundwater resources development issues in the Laura Basin

7.1 Coal resource issues

As discussed in Section 5, exploration for coal resources has occurred intermittently in the Laura Basin since 1879. However, only one economic coal resource of 47 Mt has been identified within the basin during this time, located on the Bathurst Range. As summarised in Section 5, there is currently an application to mine this resource, the Wongai Project. Given the relatively mature level of exploration that has occurred previously, there appears to be only limited potential for further coal resource discoveries in the remainder of the Laura Basin.

To date there has been no exploration for coal seam gas in the Laura Basin. There appears to be relatively limited potential for economically feasible CSG extraction to occur in the Laura Basin.

7.2 Groundwater resource issues

Groundwater is critical for the water requirements of the population of the Laura Basin with 95% of total water use sourced from groundwater (Horn *et al.* 1995). Groundwater discharge to springs and river baseflow also appears to be significant for ecosystems across the Basin.

7.3 Groundwater protection considerations for the Laura Basin

The key groundwater protection considerations for the Laura Basin are:

- Protection against over-exploitation of the existing groundwater resource, such that current and future groundwater uses (environmental and anthropogenic) are not adversely impacted;
- Prevention of saline water intrusion into fresh groundwater (e.g. seawater intrusion);
- Point source contamination (e.g. from industrial/sewage plants/ septic systems); and
- Diffuse contamination (e.g. agricultural fertilisers/pesticides, acid-sulphate soil weathering).

Due to the low intensity of land use activities in the Laura Basin, and the low rates and diffuse nature of groundwater extraction, there is generally a low risk of these groundwater protection hazards presenting significant risks in the basin (particularly the Mesozoic aquifers) under the current resource use regime. However, due to the paucity of data in the catchment, it is not possible to estimate impacts that may have occurred as a result of the current land use, surface water use and groundwater use throughout the catchment. For example, in the absence of time-series groundwater monitoring data (both for water quality and hydraulic head), it is not possible to gain a thorough understanding of groundwater system dynamics, or to ascertain whether the current extraction rates are impacting groundwater hydraulic heads, or how these might respond to future climate scenarios. In other areas of the Great Artesian Basin, in areas of more intensive groundwater extraction, hydraulic heads have been falling over time, impacting pumping costs and access to groundwater. It is unlikely that the low intensity use within the Laura Basin is having a similar effect, although, these are the types of groundwater protection considerations that are relevant to a groundwater system study that are not possible to understand with the current level of data available in the Laura Basin.

The results of the water balance assessment help to highlight that water taken from the aquifers will either be taken from storage or will reduce the volume of discharge to other elements of the water balance.

There is no evidence of seawater intrusion into the Mesozoic aquifer as a result of groundwater extraction. Investigation of seawater intrusion risk may need to accompany any proposal for dewatering of strata to facilitate coal mining at the Bathurst Range.

Point source contamination of groundwater of the Mesozoic aquifer is more likely to occur in areas where there is no confining unit, i.e. in outcrop areas or where Cenozoic sediments are thin. Point source contamination of the Cenozoic aquifer in the area surrounding the town of Laura has been reported (Howley and Stephan 2005) and relates to leakage of septic systems.

Any coal mine development would need to have appropriate management systems and mitigation strategies in place to eliminate the risk of release of industrial chemicals and/or hydrocarbons into the environment and into the groundwater system.

Changes to the hydrology of areas where there is a risk of acid sulfate soils may produce the potential for diffuse or point source contamination of groundwater and/or surface water. This could be the case where streams are diverted, flow regimes are changed or aquifers dewatered such that acid sulfate soils are exposed to oxidising conditions. Any such proposed changes accompanying coal resource development will need to have appropriate risk assessments undertaken.

Assessment of the potential for reduced groundwater flow to groundwater dependent environmental receptors will need to accompany any proposed coal resource development activities that either reduce the recharge to aquifers or actively dewater aquifers, thereby reducing the hydraulic heads and changing the hydraulic gradients in aquifers. Such receptors may include:

- Fisheries or elements of fish habitat that are sensitive to changes in salinity (i.e., reduced groundwater discharge to springs and baseflow to streams could change the salinity (and temperature) or water bodies, particularly during the dry season and low flow periods.
- Wetlands and their ecosystems that rely on groundwater discharge.
- Stream reaches and their ecosystems that rely on groundwater discharge for maintenance of flow or maintenance of permanent pools and water quality characteristics.

Assessment of the potential for reduced groundwater flow to groundwater dependent cultural heritage sites and other land use activities that rely on groundwater may also be required. Much of the Laura Basin is used for cattle grazing on unimproved pasture. Groundwater discharge may be economically important to the viability of this industry for maintaining secure water supplies for stock watering. Proposed coal resource development may need to consider whether groundwater regimes may be altered in such a way that this is impacted. Proposed coal resource development may need to assess whether groundwater regimes may be altered such that cultural heritage values (indigenous and non-indigenous) are impacted.

8 Data and knowledge gaps

There are significant data and knowledge gaps that affect the capacity to conceptualise the hydrogeology of the Laura Basin and to provide a reasonably indicative water balance. This project has taken a regional approach to conceptualising the hydrogeological system, commensurate with the project scope and the data available for the basin. Much more data is required to undertake a quantitative assessment of the groundwater system of the Laura Basin. The scope of future work, focusing on the hydrogeology of the Laura Basin and the potential changes imposed by coal or CSG resource development will require new data to be collected. Some of the key knowledge gaps which impact our understanding of the hydrogeology of the Laura Basin include:

- There are only 29 hydraulic head measurements that can be attributed to the Mesozoic aquifer across the Laura Basin.
- There is no time-series (transient) groundwater hydraulic head data available.
- There is limited groundwater quality data with respect to coverage across the Basin and with depth and aquifer type.
- There is no time-series (transient) groundwater quality data.
- Hydraulic head data and groundwater chemistry data are typically not located at the same bores.
- There are limited bore construction records, which introduces uncertainty to assigning hydraulic head values and groundwater chemistry records to specific aquifers. In addition, there are many open-hole bore constructions that can reduce the usefulness of this data. Bores need to be drilled and constructed for the specific purpose of groundwater monitoring of targeted aquifer horizons to improve the quality of data available for the basin.
- There is limited stream gauging.
- There are no nested groundwater monitoring bores to better understand the relationships and connections between aquifers, or to provide a reliable indication of vertical hydraulic gradients.
- There is no rainfall chemistry data (in particular chloride concentration) to better inform chloride mass balance calculations for recharge estimation.
- There is limited hydraulic testing of aquifers to characterise hydraulic properties.
- There is limited data to undertake river modelling (which may be important with respect to assessment of changes to hydrologic systems caused by changed land use/ mining).
- There is no stream gauging in the area near the known coal resource at Bathurst Head.
- Spring and groundwater dependent ecosystem identification is limited to desk top assessments. There does not appear to have been any on-ground validation of these locations and there is no discussion of groundwater discharge pathways to GDE in the existing literature.
- There has not been any assessment of which aquifers (i.e., the Cenozoic aquifers or the Mesozoic aquifer) are most critical to the various GDE identified by the Bureau of Meteorology GDE Atlas and other studies. Note importantly that most of the waterways within the basin have been identified to have a moderate to high likelihood of groundwater dependence according to the GDE Atlas. There is currently limited data to undertake such assessment and this data is insufficient.

- There has been no assessment of the level of groundwater dependence for wetlands within the Laura Basin and there does not appear to be adequate data to undertake such analysis.
- There is limited data to inform the role of geological structures (e.g. faults) on controlling the groundwater flow systems. This will be important for the Bathurst Range coal deposit both from the perspective of understanding groundwater flow processes for assessing groundwater discharge to environmental receptors but also from a geotechnical perspective of developing an underground coal mine in an area known to have aquifer zones where there are artesian groundwater pressures and zones where there are sub-artesian groundwater pressures. The Bathurst Range area appears to have particularly complex structural geological elements.
- Queensland geological mapping (and National Geological mapping) does not appear to have incorporated detailed geological structures that might be identified from Landsat Imagery in the Laura Basin, e.g., as identified by the unpublished work of Senior which was found for this study.
- Possible linkages between reef and submarine groundwater discharge are not known. There is no information available to quantify the volume and locations of sub-marine groundwater discharge and no information to assess how important these might be to marine ecosystems.

9 Future work

As discussed throughout this report, there are significant data and knowledge gaps that impact the extent to which the hydrogeology of the Laura Basin can be described. To further improve the understanding of the groundwater flow systems of the Laura Basin, the following work would be required. Much of this work involves new data collection. Importantly, these recommendations for future work are focussed at improving the basin-scale hydrogeological conceptualisation. Should coal mining be developed in the Laura Basin, a substantial amount of new data will need to be collected to understand the hydrogeology of the area *local* to the development; the environment within and surrounding the development area; and the relationships between the groundwater, surface water systems and the groundwater uses (environmental and human) in the area. It is also noted that groundwater impacts will be just one aspect of the development impacts to be considered.

9.1 Key knowledge and data gaps

There are key data and knowledge gaps that would need to be filled to undertake assessments of groundwater impacts resulting from specific coal development projects in the Laura Basin. These include:

- Surveys for springs and other groundwater discharge mechanisms;
- Monitoring of groundwater parameters (quantity and quality). Any monitoring must be designed with attention to the specific groundwater dependent assets and receptors identified for the project area and the broader sub-region more generally. The intent of a monitoring regime could be threefold:
  - Establish baseline data. There is currently no data in the catchment (aside from the few stream gauges), that could be regarded as a baseline for groundwater.
  - Establish key groundwater system processes and their relationship with climate, current groundwater use, groundwater dependent assets and receptors.
  - Gather data for calibration and validation of predictive groundwater models.
- Map soil hazards and assess the interaction with proposed changes to hydrological conditions.
- Assess the level of dependence of groundwater dependent assets and receptors.

9.2 Future work – hydrogeological system analysis

Recommendations for work that would assist with improving the understanding of the basin-scale hydrogeological system include:

- A field program focussing on the collection of targeted hydraulic head information across the basin and across named aquifer units.
- The installation and ongoing monitoring of nested monitoring bores to:
  - 1. Better understand the interactions between the Cenozoic aquifers and the Mesozoic aquifer (new bores would be nested in the Cenozoic Aquifer and the Mesozoic aquifer); and

  - 2. Better understand groundwater interactions within the Mesozoic aquifer (bores would be nested in the Gilbert River Formation and the Dalrymple Sandstone, in both the areas where the Mesozoic rocks are in outcrop, and in areas where they are covered by the Kalpowar Basin sediments).
  - Bores need to be drilled and constructed for the specific purpose of groundwater monitoring of targeted aquifer horizons to improve the quality of data available for the basin.

- Time-series monitoring of groundwater bores in both the Cenozoic aquifers and the Mesozoic aquifer to better understand groundwater dynamics.
- Investigation of the role of faults acting as either barriers or conduits to groundwater flow. This could be accomplished by either (or both) hydrogeochemical transect studies along flow lines drawn between hydraulic head contours, and pump testing that targets particular structures to test for hydraulic connection across a particular structure.
- Further geological and sedimentological analysis of Laura Basin bore records. This study focussed on assigning stratigraphic units to lithological records to develop the isopachs of stratigraphic units and to be able to assign hydraulic head records and groundwater chemistry records to particular stratigraphic horizons. Further analysis of the bore records might elucidate some of the aquifer anisotropy and inhomogeneity that may be crucial to flow systems at more local scales, for example, the effects of lithofacies variations on flow systems. The paucity of borehole data in the centre of the basin presents a significant limitation to the extent to which this work can be undertaken.

9.3 Future work- water balance components estimation

Following the collection of more detailed hydraulic head data from the basin, the basin-scale water balance estimation could be further developed by undertaking the following:

- Flow net analysis using the isopachs and the potentiometric surface to estimate recharge to the Mesozoic aquifer by an alternative approach to chloride mass balance. Discharge may also be estimated in this way.
- Collection of rainfall chloride deposition concentrations at locations spread across the basin to better constrain chloride mass balance estimates of recharge.
- Improved groundwater level collection and potentiometric surface mapping in outcrop areas to better constrain the evapotranspiration estimate. Soil-water balance modelling to estimate evapotranspiration using a different approach (which would require further data acquisition to parameterise the model).
- On-ground surveys of desktop identified groundwater dependent ecosystems, focusing on potential groundwater discharge mechanisms and seasonality of vegetation health and vigour.
- Hydraulic testing for the vertical hydraulic conductivity of the Cenozoic sediments to better constrain the leakage component estimates.
- More discretised estimation of leakage components rather than taking an average thickness of the Cenozoic sediments (although the accuracy would still be impacted by the lack of hydraulic conductivity data available for the Cenozoic sediments).

- Investigate methods to estimate groundwater evapotranspiration including the use of MODIS Enhanced Vegetation Index for exploring evapotranspiration from riparian zones as a discharge component of the water balance.

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Glossary

Alluvial/alluvium. Non-marine sediments deposited by the action of water.

Anticline. An arch shaped fold of originally flat lying sedimentary layers.

Aquifer. A geological formation, group of formations or part of a formation which is sufficiently porous and permeable to store, and allow the movement of, groundwater. Aquifers may yield quantities of groundwater for consumptive use.

Aquitard. Saturated geological unit that can store large volumes of water but cannot transmit significant quantities of water to production wells. Also can be called a 'confining bed'.

Arenacous. Sediments with sand-sized particles comprising more than 85% of the mass.

Artesian aquifer. A confined aquifer under positive pressure. The potentiometric level of the aquifer is above the land surface, but the aquifer is confined.

Basin. A large depression in the Earth's crust filled by sedimentary or volcanic rocks.

Basin inversion. The relative uplift of a sedimentary basin to surrounding low lying areas from a variety of tectonic processes.

Basement. Bedrock that underlies the geological materials of interest.

Bed/bedding. Layers/layering of sediments or sedimentary rocks that reflect differences in size, composition or colour of constituent grains.

Bedrock. Loose term given to any geological material that underlies the stratum of interest. Bedrock is commonly composed of crystalline rocks such as granite or metasediments.

Borehole. Generalized term for any narrow shaft bored in the ground, either vertically or horizontally

Bore Yield. The amount of water which can be abstracted from a bore (either by pumping or natural artesian flow) over a specific time interval frame. Bore yields are usually measured in litres per second.

Bounding surface. A surface within a sedimentary succession that marks the upper or lower limits of a major mappable unit.

Calcrete. Calcium carbonate ($CaCO_3$) formed in soil or sediments in a semi-arid region under conditions of sparse rainfall and warm temperatures, normally by precipitation of calcium. Calcrete is common in low-lying areas in arid to semi-arid regions, particularly palaeovalleys ('valley calcrete'), and may form aureoles around salt lakes. It is commonly a significant near-surface aquifer in the arid zone.

Carbonate. Refers to CO_3 ions, can be carried in solution in surface water or groundwater and precipitated with Ca, Mg, or Fe ions to form carbonate minerals and rocks.

Catchment. The area of land from which rainwater drains into a river, stream or lake. Catchments are separated from each other by divides or watersheds.

Cemented. The cementation of sedimentary grains by later minerals precipitated from groundwater. Sometimes consolidated is used as an approximate synonym.

Cenozoic. Geological Era extending from 655 million years ago to the present.

Clast. A rock fragment or grain resulting from the breakdown of larger rocks.

Clay. Refers to either grain size or mineralogy (a) an earthy sediment composed of rock or mineral fragments or detrital particles smaller than a very fine silt grain; (b) clay minerals are hydrous aluminium silicates derived largely from feldspars, micas and carbonate by weathering.

Cobbles. River-rocks between 64 and 256 mm across.

Colluvial. Gravity depositional processes found in slope depositional environments forming colluvium.

Colluvium. See colluvial.

Conceptual model. See model.

Conductivity (σ). How the earth or a geological formation conducts electricity. Conductivity is usually measured in milli-Siemens per metre (mS/m). It is the reciprocal of resistivity.

Confined Aquifer. An aquifer that is overlain and underlain by impervious layers (aquitards), and is not associated with the water table.

Conglomerate. A sedimentary deposit formed by cementing gravels and cobbles together with minerals precipitated from groundwater.

Consolidated. See cemented.

Core/coring. Drilling method that recovers intact samples of subsurface materials.

Darcian Vertical Infiltration. Vertical infiltration determined by applying Darcy's Law which describes the flow of a fluid through a porous medium.

Delta A more or less triangular (similar to the Greek letter delta) deposit of sediment built up where a river flows into the sea. Deltas can be river, tide, or wave dominated, depending on which is the most important deposition process acting along the coastline.

DEM. See Digital Elevation Model.

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

Diagenesis. The changes that occur to sediments after they are deposited, including cementation and weathering.

Digital Elevation Models (DEM). Digital representations of the topography of the earth that are important components of geographic information systems (GIS). DEM are obtained by many systems, including ground surveying, airborne radar and laser surveys, or from satellite radar.

Discharge (Groundwater). The flow of groundwater to surface water, bores, between aquifers or the sea.

Discharge (Stream). Amount of water flowing in the stream.

Discharge zone. An area in which subsurface water is discharged to the land surface See also spring.

Dolomite. Calcium-magnesium carbonate, $CaMg(CO_3)_2$.

Dolostone. A sedimentary rock consisting largely of the calcium-magnesium carbonate mineral dolomite, older literature refers to these rocks as dolomite.

Drillhole. A hole in the ground made by a drill; usually made for exploratory purposes. May be drilled by a variety of methods, and at a variety of orientations.

Dissected. A term applied to landscapes which have been extensively eroded by valleys and gullies.

Drawdown. Change in hydraulic head relative to a background condition, indicating the difference in head which has occurred at a given location relative to an initial time at the same location.

Duricrust. A hardened layer formed in the regolith by cementation of soil or sediment, generally by minerals rich in iron, sulfate, silica, or carbonate.

Electrical conductivity (EC). The ability of electrical current to pass through a substance. EC is commonly used to estimate the amount of soluble salt in solution. EC measurements can be made with a range of devices on ground and stream water, soils, and soil-paste extracts. Units of electrical conductivity are commonly given in mS/m, dS/m or μS/cm; 100 mS/m = 1 dS/m = 1000 μS/cm. Here, S is the symbol for Siemens, and the prefixes d is deci (10^{-1}), c is centi (10^{-2}), m is milli (10^{-3}) and μ is micro (10^{-6}).

Ephemeral. Watercourses that are active for only a short period of time.

Estuary. A funnel shaped inlet formed where a river meets the sea along a wave or tide-dominated coastline.

Evapotranspiration. The total water loss from the soil through the combined effects of evaporation and transpiration.

Extensional Fault. A normal fault characterised by vertical movement on an inclined plane that vertically thins and horizontally extends portions of the Earth's crust In normal faults the hanging wall (rock above the fault plane) moves downward relative to the footwall (rock below the fault plane).

Facies. Characteristics or bodies of sediments recognised by the depositional environment.

Fault. Fracture in a rock body along which displacement has occurred. A **normal fault** is an inclined fault in which the hanging wall (rock above the fault plane) appears to have slipped downward relative to the footwall (rock below the fault plane), usually the result of extension, or separation of geological blocks. A **reverse fault** is a fault in which the hanging wall side appears to have been pushed upward relative to the footwall, by compression.

Fault Scarp. A break slope in at the earth surface caused by relative uplift along a fault.

Fracture. Cracks in indurated rocks formed by stress and strain. Fractures along which significant movement has occurred are called faults.

Floodplain. A low-lying area adjacent to a river or stream subject to inundation when that stream floods. Floodplains are often sites of deposition of fine-grained sediments.

Fluvial. River depositional environment.

Fractured Rock Aquifer. Aquifers which store groundwater in the fractures, joints, bedding planes and cavities of the rock mass.

GA. Geoscience Australia.

Gaining Stream. A stream or river-reach into which groundwater flows via the stream bed and/or banks.

Gamma logging. Down-hole geophysical logging techniques that maps the gamma radiation released by naturally occurring uranium, thorium and radioactive potassium. Also referred to as gamma ray logging.

Gamma ray logging. See gamma logging.

Geographical Information Systems (GIS). GIS are computer-based systems for creating, storing, analysing and managing multiple layers of spatial data. These datasets include maps of geology, topography, infrastructure, soils, vegetation, and land use. GIS allow users to create interactive queries to analyse trends and patterns in spatial information.

Geological Basement. Rock mass below a sedimentary platform or cover; or more generally, any rock below sedimentary rocks or sedimentary basins that are metamorphic or igneous in origin.

Geomorphology. The study of landforms.

Geophysics. The study of the Earth by quantitative physical methods, such as magnetics, electromagnetics, gamma ray spectrometry (radiometrics), seismology and gravity.

GIS. See Geographical Information Systems.

Glauconitic. Contains glauconite (A greenish clay mineral of the illite group, found chiefly in marine sands).

Gneiss. Coarse-grained banded crystalline rocks that formed from regional metamorphism; the banding reflects the separation of constituent mafic (dark coloured, iron- and magnesium-rich) and felsic (light-coloured feldspar- and silica/quartz-rich) minerals.

Graben. A depressed or down-thrown block bounded on at least two sides by faults See also half graben.

Granite. A coarse-grained igneous rock consisting mainly of quartz and feldspar.

Granules. Gravel-sized sediment between 2 – 4 mm in diameter.

Gravel. All loose, coarse-grained sediments with grains greater than 2 mm diameter (e.g., granules and cobbles).

Groundwater. Water stored below ground within the pore spaces or fractures of a rock mass.

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

Groundwater Management Unit. A hydraulically connected groundwater system that is defined and recognised by State and Territory agencies for management purposes.

Groundwater models. Models simulate natural groundwater flow or other groundwater characteristics. Numerical groundwater models compute mathematical equations of the physics of groundwater flow processes.

Groundwater mounding. Outward and upward expansion of the water table caused by water injection.

Half-graben. An asymmetric depressed or down-thrown block bounded on only one side by a fault.

Head. A measurement of water pressure representing the total energy at the entrance of a piezometer. Usually measured as a water surface elevation. Differences in head between two or more points can be used to determine hydraulic gradient and direction of groundwater flow. Synonymous with Hydraulic Head.

Horst. A raised or up-thrown block bounded by faults or grabens, which remains stationary or is uplifted while the land has dropped on either side.

Hydraulic Conductivity (K). Hydraulic conductivity is the volume of water flowing through a 1 m^2 cross-sectional area of an aquifer under a hydraulic gradient of 1 m/1 m (100%) in a given time (usually 1 day). Horizontal hydraulic conductivity is designate Kh, vertical Kv.

Hydraulic gradient. With regard to an aquifer, the rate of change of hydraulic head per unit of distance of flow at a given point and in a given direction.

Hydraulic head. The hydraulic head (or potentiometric head) is the height of the watertable above a given datum in an unconfined aquifer (representing the zone of saturated aquifer), and is the potential energy in a confined aquifer above a given datum.

Hydraulic loading. Increased head pressure due to increased water depth.

Hydrochemistry. Study of the chemical characteristics of water.

Hydrodynamics. Study of the motion of fluids.

Hydrodynamic divide. See groundwater divide.

Hydrogeology. The study of geological properties of rocks, soils, and sediments as they relate to groundwater movement and storage.

Hydrological model. See model.

Hydrograph (Stream). Graphical representation showing the variation in time in the water level and/or flow in a surface water body.

Hydrograph (Bore). Graphical representation showing the variation in time in the groundwater level within a bore.

Hydrostratigraphy. The identification of mappable stratigraphic units on the basis of hydraulic properties (aquifer / aquitard).

Induration/indurated. Partial synonym for cemented.

Intertidal. The zone between high and low tide marks, when applied to a sedimentary depositional environment.

Lacustrine. Depositional environments or sediments associated with lakes.

Lagoonal. Deposition environment or sediment associated with lagoons.

LANDSAT. A polar-orbit satellite launched by NASA to collect multispectral images of the Earth surface. Eight satellites have been launched in the series. Commonly written as “Landsat”.

Lignite Peat or brown coal. Carbon-rich material formed from the remains of fossil plants that were deposited in lakes or swamps and subsequently buried, dehydrated and compressed.

Limestone. Sedimentary rock composed of calcium carbonate ($CaCO_3$) of organic, chemical or detrital origin.

Lineament. A linear feature in a landscape that expresses an underlying geological structure such as a fault.

Lithic. A term applied to sand or gravel where the particles are made up of rock fragments.

Lithology. Physical characteristics of a rock or sediment.

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.

Losing Stream. A stream or river reach where the stream bed leaks surface water to an underlying aquifer.

Metadata. Information about the source and accuracy of information used in a GIS.

Metamorphics. General term for rocks that have been recrystallised as a result of heat and pressure.

Metasediments. Sedimentary rocks that have been recrystallised through heat and pressure.

Mica/Micaceous. Platy or flaky silicate minerals formed in metamorphic and igneous environments and also found as minor detrital components of sediments

Model. Used in two senses in this report hydrological models are based on mathematical equations that allow the behaviour of a hydrologic system to be quantitatively predicted; conceptual models are qualitative descriptions of features such as aquifers or coastal landforms.

Mudstone. A sedimentary rock composed of clay and silt, and lacking any bedding structures.

National-scale. A synoptic view of a specific problem (e.g. seawater intrusion) across the nation and cross jurisdictional boundaries. On a specific map scale, typically refers to maps at scales of between 1:1,000,000 and 1:10,000,000.

Neotectonics. Study of current or recent motions and deformations of the Earth's crust.

Paleo-. Prefix meaning old or ancient often now-defunct.

Paleochannels. Former river channels that are recognised in the surface (from aerial or satellite images) or subsurface (typically in AEM surveys or drilling).

Paleogeography. The reconstruction of physical geography of past geologic ages in an attempt to restore areas to their depositional condition.

Paleosol. A buried soil profile representing a former land surface.

Palaeovalley. Ancient valley filling sediments including (but not restricted to) those of paleochannels. Typically palaeovalley sediments are not associated with currently active river processes.

Palynology. The study of pollen and other resistant plant, protist, and fungi microfossils.

Paralic. Deposits laid down on the landward side of a coast, on land subject to marine *transgressions*. Marine and non-marine sediments are typically interbedded.

Permeability. The ability of a material, such as rock or sediment, to allow the passage of a liquid, such as water Permeable gravel and sand, allow free movement, whereas impermeable clays are barriers.

Piezometer. A bore used specifically to monitor water levels or hydraulic head within an aquifer.

Porosity. Open spaces in rocks and sediments that can hold water. Primary porosity formed when the sediments were laid down; these spaces may be variably infilled by cement, leaving remnant primary porosity. Secondary porosity forms through modification of rocks, such as by dissolution of soluble grains, formation of fractures, or solution-forming karst.

Potentiometric head. See hydraulic head.

Potentiometric Surface. A surface which represents the hypothetical level that water under pressure, within a confined aquifer, would rise to if tapped by a bore.

Pump Test. A hydrological assessment; undertaken when an aquifer is ‘stressed’ by pumping or injecting water and noting the water drawdown level over space and time.

Recharge. The entry into the saturated zone of water made available to the water table surface, together with associated flow away from the water table within the saturated zone.

Regolith. The entire unconsolidated or secondarily re-cemented cover that overlies more coherent bedrock, between fresh rock and fresh air that has been formed by weathering, erosion, transport and/or deposition of the older material. Includes weathered rocks, soils, shallow groundwater and sediments.

Regression. A term used in geology, to mean the withdrawal of the sea from a large area of land.

Riparian. Of, on, or relating to the banks of a natural stream.

Risk. The likelihood that harm will occur from exposure to a hazard. For example, salinity risk is a measure of the chance that a salt hazard will cause harm to an asset at some time in the future.

Runoff. Overland flow and steam flow of rainfall not absorbed by the soil.

Salinity. See surface salinity.

Salinity ranges. The following ranges are typically used when discussing groundwater salinity. <1000 mg/L TDS = fresh water, 1001 to 10 000 mg/L = brackish water, 10 001 to 35 000 mg/L = saline water, >35 000 mg/L = hypersaline water.

Seawater intrusion. The landward movement of seawater into coastal aquifers, due to natural or human-related changes in groundwater dynamics.

Sedimentary. Pertaining to deposition of sediments and sedimentary process, for example, a sedimentary rock is a rock once composed of sediments such as sand, gravel, silt, etc.

Seismic, 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 extend and depth of rock layers.

Semi-confined aquifer. An aquifer which is partly overlain and completely underlain by impervious layers.

Shale. A *sedimentary* rock composed of clay particles.

Shoe-string sand. A long narrow body of sand or sandstone in the midst of mud or shale.

Silt. Granular material of a size somewhere between sand and clay

Siltstone. A *sedimentary* rock composed of silt-sized particles.

Spring. A naturally occurring groundwater discharge feature.

SRTM. Digital Elevation Model data collected during the 2,000 STS-99 Shuttle Radar Topography Mission by the Space Shuttle Endeavour. SRTM data is widely available at 3-arc second (~90 m) horizontal resolution and on a restricted basis at 1-arc second (~30 m) horizontal resolution.

Storativity. The volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer

Strandplain. A wave-dominated coastal depositional environment consisting of multiple beach ridges that have been stacked against each other.

Stratigraphy. The study of how different layers of sediments can be related to each other.

Strike-slip Faulting. Where a fault surface is usually near vertical and the footwall moves laterally (either left or right) with very little vertical motion. Strike-slip fault types are defined by the direction of movement of the ground on the opposite side of the fault from an observer and those with left-lateral motion (also known as sinistral faults) and those with right-lateral motion (also known as dextral faults).

Subsidence. Downward movements of the Earth's crust, usually resulting in accumulation of sediments in the resulting depression.

Sub-artesian aquifer. An aquifer containing groundwater under pressure that rises to a level greater than that at which it is first encountered, when tapped by a bore, but does not reach the surface.

Surface salinity. Areas where salt is being deposited in the near-surface environment. Salinity is a natural phenomenon but can be increased through land use practices involving inappropriate types of soil management, vegetation clearing, cropping, and irrigation. Often abbreviated to salinity.

Sustainable yield. The level of groundwater extraction measured over a specified planning timeframe that would, if exceeded, compromise key environmental assets, ecosystem functions or the productive base of the resource associated with the aquifer. Also referred to as the environmentally sustainable level of extraction.

Tectonics. The study of structures in the Earth's crust and the processes that form them, such as earthquakes.

Tidal flat. The flat, generally muddy coastal depositional surfaces cut by channels exposed and flooding during the daily tidal cycle. Tidal flat predominate in tide-dominated coastal environments.

Total Dissolved Solids (TDS)   The amount of material dissolved in water (mostly inorganic salts).

Transgression. A long-term rise in relative sea-level causing flooding of the coastal zone, for example, after the end of the last ice age.

Transgressive. Pertaining to processes or sediments resulting from a Transgression.

Transient. Time-varying. Usually used to describe a very short period pulse of electromagnetic field.

Transpiration. Water given off by plants via pores in the surface tissues. See also evapotranspiration.

Transmissivity (T). A measure of the ability of groundwater to pass through soil, sediment or rock. The capacity of a rock to transmit water under pressure. Expressed as the volume of water flowing through a cross-sectional area of an aquifer that is 1 m x the aquifer thickness under a hydraulic gradient of 100% in a given amount of time (usually 1 day). Transmissivity is equal to the hydraulic conductivity (K) times the aquifer thickness.

Turbidity. Water opacity or clouding due to suspended sediment or particles.

Unconfined aquifer. A type of aquifer in which the upper boundary is defined by the water table Unconfined aquifers are recharged directly from the ground surface.

Unconformity. A bounding surface where the rocks below rest at a different angle to those above, for example, where alluvial gravels rest on bedrock.

Unconsolidated. See uncemented.

Upward fining. Sedimentary particles getting smaller up a sequence (earlier deposits coarser than younger ones). The opposite of upward coarsening.

Vertical infiltration. Downward movement of water from the surface into soil or sediment.

Vulnerability. The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Waterlogging. Permanent wetting of the surface due to groundwater rise.

Watertable. The surface below which an unconfined aquifer is saturated with water See also potentiometric surface.

Weathered/weathering. The physical and chemical changes that a rock undergoes when it is exposed to the atmosphere and shallow groundwater.

Wetlands. Low-lying areas subject to partial or continuous inundation. Also called swamps.

Appendix A Basin prioritisation process

Australia has approximately 25 onshore sedimentary basins containing in situ resources of black or brown coal. These deposits are of variable size and geological age and occur in all states, although the largest and most economically significant basins are in Queensland, New South Wales and Victoria. The main coal-producing basins in these regions will be subjected to the initial phase of Bioregional Assessments announced by Minister Burke in March 2012.

Preliminary research by GA and the Department of the Environment has recognised that there are eight strategically important coal basins spread across Queensland, New South Wales, Victoria and South Australia that currently will not be included in the initial phase of Bioregional Assessments. These are the:

- Laura Basin (Qld, black coal),
- Maryborough Basin (Qld, black coal),
- Murray Basin (Vic-NSW-SA, brown coal),
- Oaklands Basin (NSW, black coal),
- Otway Basin (Vic-SA, brown coal),
- Polda Basin (SA, black coal),
- St Vincent Basin (SA, brown coal), and
- Styx Basin (Qld, black coal).

The characterisation of the hydrogeology and groundwater resources of these eight coal-bearing sedimentary basins will be the key focus of work conducted for this project: *Regional Hydrogeological Characterisation of Priority Coal Basins not covered by Initial Bioregional Assessments*.

Due to the resources, timeframes and operational requirements needed to complete detailed hydrogeological characterisation for these eight coal-bearing basins, the project has been designed to be undertaken in two phases over an approximately 18 month timeframe (October 2012 to April 2014). This approach involves detailed assessment and reporting of the four highest priority basins in Phase 1, followed by the remaining four basins in Phase 2.

The eight basins have been chosen and prioritised based on an assessment of pressures facing the water assets within those basins from current or expected future coal seam gas or coal mining activities. The eight project-specific basins are to be undertaken in the following phased priority order:

1. Phase 1 of the project is focused on the Laura, Maryborough, Otway and St Vincent Basins.
2. Phase 2 of the project is focused on the Murray, Oaklands, Polda and Styx Basins.

The key factors used to develop the basin assessment ranking for Phase 1 of the project include:

Laura Basin

Ranked the #1 basin (selected for Phase 1 on basis of environmental and cultural heritage criteria):

1. All drainage systems in the Laura Basin discharge to the World Heritage-listed Great Barrier Reef Marine Park.
2. Nearly half of the basin area is covered by Australian National Parks.
3. Over half of the basin is covered by Indigenous Land use Agreements.
4. Most available land (i.e., not National Parks) is covered by CSG or coal mining exploration tenements and there is one recognised black coal deposit at Bathurst Range (47 million tonne resource of coking coal).
5. Significant number of wetlands and threatened species.

Maryborough Basin

Selected for Phase 1 on basis of environmental and agricultural land use criteria, as well as the likelihood of short- to medium-term CSG development:

1. Ranked the #2 basin (from the list of 8 basins assessed for this study) for potential future development of CSG production in the short to medium-term (independent ranking provided by Geoscience Australia’s Onshore Hydrocarbon Section).
2. The basin with the most extensive number of threatened species.
3. Large parts of the Maryborough Basin are devoted to high value agricultural activities such as irrigated sugar cane and production or plantation forestry.
4. Much of the basin not used for agriculture is classed as National Park.
5. Significant urban population centres occur at Maryborough, Bundaberg and Hervey Bay.

Otway Basin

Selected for Phase 1 on basis of the current coal mining activity and potential for future CSG developments:

1. Ranked the #3 basin (from the list of 8 basins assessed for this study) for potential future development of CSG production in the short to medium-term (independent ranking provided by GA’s Onshore Hydrocarbon Section).
2. Currently the only basin in the list of 8 that has an operating coal mine (the Anglesea brown coal mine).
3. Hosts several major population centres (Geelong and Warrnambool in Victoria and Mount Gambier in South Australia)

St Vincent Basin

Selected for Phase 1 on basis of population distribution and number of brown coal deposits:

1. The St Vincent Basin contains the largest population of all 8 basins and is host to the capital city of South Australia, Adelaide.
2. Contains six brown coal deposits with a combined tonnage of over 3,000 Mt. There has been considerable interest shown in the past to develop at least one of these deposits (Bowmans).
3. Ranked the #4 basin (from the list of 8 basins assessed for this study) for potential future development of CSG production in the short to medium-term (independent ranking provided by GA's Onshore Hydrocarbon Section).

Phase 2

Key reasons for assigning the Murray, Oaklands, Polda and Styx Basins to Phase 2 of the project include:

- Given the geological and hydrogeological links between the Murray and Oaklands Basins (i.e., the Oaklands Basin is completely overlain by the sediments of the Murray Basin and does not outcrop because of these cover sequences) it is appropriate to develop the regional hydrogeological characterisations for these basins during the same phase of the project. Although the Murray Basin covers a large area, the brown coal deposits are restricted to specific localities and are not currently exploited.
- The Polda Basin occurs in a relatively remote area and sparsely populated area of South Australia where any future coal or CSG operations are considered to have less potential for significant land use conflict. There are also no National Parks or Indigenous Protected areas. The CSG potential in the basin is also ranked low.
- The Styx Basin is very small and sparsely populated. Most of the area has a relatively lower value land use than the other basins (grazing of natural vegetation) assessed for this study. There are also no indigenous protected areas or National Parks in this basin.

Appendix B Resource governance, Queensland

The *Petroleum and Gas (Production and Safety) Act 1994* (or the Petroleum Act 1923) authorises Authority to Prospect and Petroleum leases, and Coal Seam Gas water extraction. CSG water extraction is authorised under the *Petroleum and Gas (Production and Safety) Act 1994* and managed under the *Water Act 2000.* Coal mining is managed under the *Mineral Resources Act 1989* which is administered by the Department of Natural Resources and Mines, Queensland Government. Under the *Mineral Resources Act, 1989*, any application for coal mining that overlaps an area of an authority to prospect (for petroleum products- oil, coal seam gas, natural gas, etc.), must be accompanied by a *CSG Statement* as defined by the *Mineral Resources Act, 1989*.

Environmental management and regulation of the mining industry in Queensland is administered by the Department of Environment and Heritage Protection through the provisions of the *Environmental Protection Act 1994 (Qld)*.

Queensland Government is working on restricting and/or managing development in areas defined to be Strategic Cropping Land under the *Strategic Cropping Land Act, 2011*, and have produced a Trigger Map to assist with the identification of potential Strategic Cropping Land in Queensland (see http://www.nrm.qld.gov.au/land/planning/strategic-cropping/mapping.html#trigger_map). There is no Strategic Cropping Land identified in the Laura Basin. The *Strategic Cropping Land Act, 2011* is administered by the Department of Natural Resource and Mines, Queensland Government.

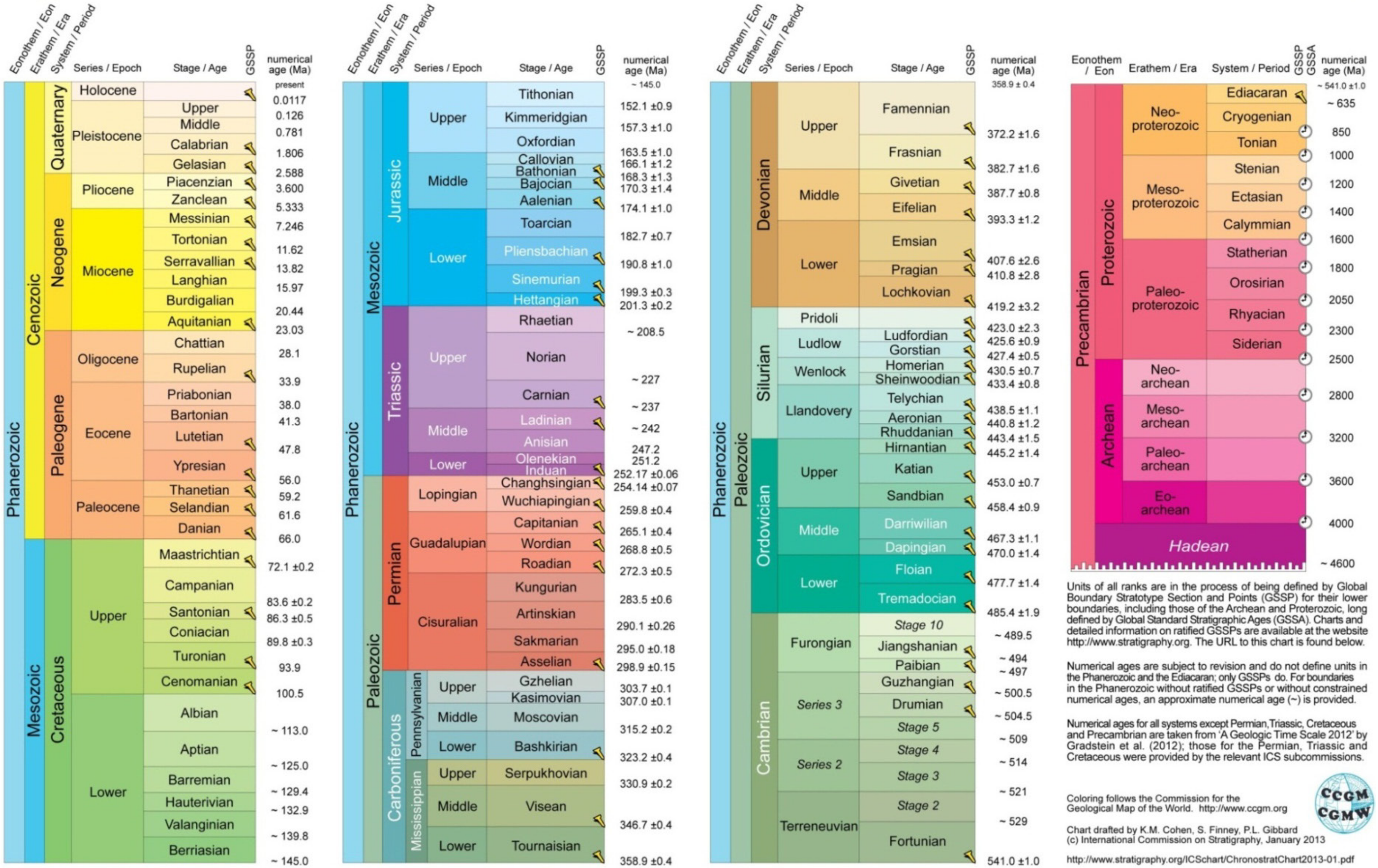
The *Water Act 2000* provides the legislative and institutional framework for water planning and water entitlements for all naturally occurring freshwater resources in the State. Under the Water Act, all rights to use water are vested in the State. The Act specifies the conditions under which a water entitlement is required for the taking of water and provides for the creation of water resource plans and resource operations plans to allocate and manage water. The *Water Act 2000* was amended in December 2010 to modify conditions on water rights for CSG and mining activities (NWC 2012).

Under the *Water Act 2000* the take of surface water from a watercourse, lake or spring requires a water entitlement except for prescribed minor uses such as for stock and domestic purposes. The take of groundwater or overland flow water requires an entitlement only if specified by a water resource plan, a wild river declaration, a moratorium or (for groundwater only) an area declared under the Water Regulation 2002 (NWC 2012).

Groundwater within the Mesozoic sediments of the Laura Basin is managed under the Queensland Government *Water Resource (Great Artesian Basin) Plan 2006* within the Laura Management area. There are two Management units, Laura 1 (Rolling Downs Group) and Laura 2 (Gilbert River formation and Dalrymple Sandstone). The General Reserve (water that is currently unallocated and may be issued as licensed volume) allocated to management unit Laura 1 is 0 ML. The General Reserve allocated to Laura 2 is 500 ML. There are no other Water Resource Plans that cover the Laura Basin.

Appendix C Geological timescale

This appendix contains a reproduction of the current International Chronostratigraphic Chart (Cohen et al., 2013) endorsed by the International Commission on Stratigraphy, and recommended for use in Australia by Geoscience Australia.



Appendix Figure C.1 International Chronostratigraphic Chart (Cohen et al. 2013).

Appendix D Summary of coal exploration history in the Laura Basin

This appendix contains a brief summary of the various coal exploration histories for each of the current coal exploration tenement areas in the Laura Basin (Chapter 5), based on open-file coal exploration reports downloaded from the Queensland Government data base of Company Exploration Reports, QDEX.

EPC2334 (Bathurst Range)

EPC463

Whitby *et al.* (1996a) summarised the results of an exploration drilling program at Bathurst Range undertaken by Bathurst Coal and Power Ltd over the period 12 August 1995 to 10 November 1995. The program aimed at further characterising the Bathurst Seam, previously characterised by Utah Development Company (between 1978 and 1985) and previously referred to as E Seam by Utah Development Company.

The Bathurst Seam occurs within the Jurassic Dalrymple Sandstone in the Laura Basin. The seam is generally less than 2 m thick, and a large proportion of the resource is overlain by more than 100 m of overburden. The coal is a low ash, high energy coking coal (Whitby *et al.* 1996a).

A major feature of the geology and topography in EPC 463 is a broad anticline that plunges towards the south. Outcrops of resistant Dalrymple Sandstone and Gilbert River Formation occur within the axial zone where small escarpments and cliffs in valleys exhibit the best exposure.

To the west, the land surface is dominated by extensive tidal sand flats and the Marrett River (Whitby *et al.* 1996a).

A possible north-north-east trending fault, the Barramundi Fault, which displaces the strata by up to 100 m, may truncate the Bathurst Seam into a western up-thrown block and an eastern downthrown block. The presence of this fault was not confirmed. The Marrett Fault, in the central part of EPC463 appears to strike in a northerly direction and is downthrown on the eastern side (Whitby *et al.* 1996a).

Sedimentary rocks in EPC 463 vary from shallow marine to fluvial deposits of sandstone, siltstone, coal and conglomerate. The Dalrymple Sandstone ranges from about 80–120 m thick in EPC463 and consists of Middle to Late Jurassic coarse-grained, quartz-micaceous sandstone, siltstone and coal. The Dalrymple Sandstone tends to display a high degree of variability, both laterally and vertically, typical of braided river delta deposits (Whitby *et al.* 1996a).

The Early Cretaceous Gilbert River Formation conformably overlies the Dalrymple Sandstone and is extensive and laterally continuous within EPC463. The unit consists of fine- to medium-grained quartz sandstone and sporadic thin siltstone interbeds and is typically from 45–65 m thick. Outcrops of the Gilbert River Formation occur in valley exposures between the hills in the north of EPC463 (Whitby *et al.* 1996a).

Overlying the Gilbert River Formation is the Rolling Downs Group which comprises of the lower Rolling Downs Siltstone and the overlying Normanton Sandstone, both of Early Cretaceous age. The Rolling Downs Siltstone is a sequence of carbonaceous siltstone with minor sandstone and claystone interbeds which is 60–100 m thick. This unit is friable and the rocks readily weather near-surface; outcrops are uncommon. The Rolling Downs Siltstone was deposited in a low-energy environment probably of a fluvial tidal flat or a shallow marine nature (Whitby *et al.* 1996a).

The Normanton Sandstone, which overlies the Rolling Downs Group, consists mainly of coarse-grained quartz sandstone and conglomerate, exposed at the top of hills in the northern and central parts of EPC463. It is up to 100 m thick in EPC 463 (Whitby *et al.* 1996a).

The Jurassic–Cretaceous strata in EPC463 are generally overlain by unconsolidated Cenozoic sand and clay 1–70 m thick, the thickest of which occur on the flanks of the south-plunging anticline (Whitby *et al.* 1996a).

The coal resource deposit where the Bathurst Seam is greater than 1.5 m thick (and where maximum overburden is <400 m) is estimated at 50.8 million tonnes (Indicated Resource) (Whitby *et al.* 1996b). Coal of the Bathurst Seam is thickest in three main areas: Airstrip Deposit; Birthday Plains Deposit; Alkaline Hill Deposit.

Appendix A and B of Whitby *et al.* (1996a) include tables with depth to top of seam and thickness of seam.

Baldwin (1994) developed a geology map of EPC463 including local faulting and outcrop geology. (Baldwin 1994) also described seams other than E Seam (Bathurst Range Seam). E Seam has isopach maps included in the report.

Drilling by Whitby *et al.* (1996b) included 16 non-core drilled holes (4159 m) and 5 cored holes (1,106.8 m). Whitby *et al.* (1996b) included hole locations with collar RLs. Table 6.1 of their report described roof strata (if CSG was being considered here, this information may be useful for conceptualising inter-aquifer connectivity).

Whitby *et al.* (1996b) summarised coal seam gas results as the following: At a depth of 200 m the desorbable gas content in the Bathurst Seam was in the order of 3–4m^3/tonne. The desorbed gas generally comprised more than 75% CO_2 and less than 25% methane.

The Melville Seam indicated a desorbed gas content of 4.65 m^3/tonne at one location at a depth of 320 m. The desorbed gas comprised 86% CO_2 and 14% methane.

Whitby *et al.* (1996b) included information about groundwater. During drilling, inflow rates were measured for each hole using a V-Notch weir and varied from 0.1–25 L/s, and they noted that ‘a large quantity of groundwater is present within the strata above the Bathurst Seam’ (page 22). The higher groundwater inflow rates were recorded from drill holes located within the southern and central parts of the exploration area, particularly near the limbs of the anticline, where inflow rates increased with depth. Appendix D of their report included flow rates and basic water quality parameters as well as standing water levels for the holes drilled. Standing water level values indicate that the direction of groundwater flow is generally from north to south, and the shape of this potentiometric surface appears to be similar to the south-dipping antiform. Some holes were flowing and these were reported to be concentrated on the limbs of the anticline and near the Barramundi Fault. Groundwater pH increases from 5.8 in the north to 8.4 in the south. Electrical conductivity ranges from 200 µS/cm to 1,300 µS/cm, with lower values recorded in the north along the anticline axis. Along the flanks of the anticline, groundwater salinity is higher (>800 µS/cm).

Whitby *et al.* (1996b) included core photographs in their report, as well as structural diagrams, borehole drilling logs, and geotechnical data.

Everett (2001) reported on the exploration in EPC463 to October 2001. Most of this information is contained within the other reports. However, this work also provided a summary of previous drilling (see table below). Everett noted discrepancies (up to 300 m) in historically recorded bore locations relative to actual locations. Appendix B of this report lists drillhole depth, and the location for all bores drilled on EPC463.

Appendix Table D.1 Exploration campaigns in EPC463.

Year	No. holes	Main purpose
1978	17	Initial reconnaissance drilling
1979	15	Concentrated core drilling in prospective areas
1980	2	Limited drilling, detailed traverse mapping to determine limits of prospects
1981	12	As per 1980
1982	8	Coring E seam for quality data
1983	16	As per 1982
1984	0	Mapping to resolve structural anomalies
1985	4	Drilling in northern and eastern areas for further definition
1995	22	Further definition of main resource
1996	11	Identify location for bulk sample and investigate possible min entry sites

(BCP 1996) reported on the drilling program at Bathurst range in 1996. It includes drill logs (written, graphical and geophysics), although no stratigraphic interpretations are provided in this data.

EPC100

(Paine and Reynolds 1972) reported on EPC100 in the north-eastern margin of the Lara Basin, south and west of Cape Melville. Thin coal seams crop out near the south-eastern edge of the basin. This report includes a summary overview of the authority, and a geological cross-section (south-west-west to north-east-east) which indicates significant faulting. There is also a map of the pre-Cenozoic geology.

EPC2686

EPC207

See EPC 2687.

EPC100

See EPC 2334.

EPC250

No results.

EPC251

Murphy (1982b) undertook interpretation and correlation of the stratigraphy in the north-eastern region of the Laura Basin. The report interpreted a minimum depth to the top of the Dalrymple Sandstone in the north and deepening to the south and west of EPC251.

Murphy (1982b) reported on field mapping, seismic survey (two seismic refraction surveys) and a drilling program. There were 2 boreholes drilled (532 m total depth). The report includes stratigraphic interpretation of the boreholes, drill logs, graphic and gamma logs (in Appendix 1). There is limited data and results for the seismic survey (Appendix 2).

EPC290

Murphy (1982a) reported on the work undertaken in EPC290 during 1981. Murphy reported that it is not expected that the prospective Dalrymple Sandstone would be intersected at depths less than 700 m in the Authority. The report includes stratigraphic interpretation for three drill holes and an interpreted cross-section and written, graphical and gamma logs for three holes.

EPC327

Hewitt (1982) reported on work undertaken from 1981 to 1982 in EPC327. This included the drilling of 7 drill holes. The exploration program was designed to test for shallow to moderate depth underground mineable coal in the Jurassic Dalrymple Sandstone or Cretaceous Gilbert River Formation of the Laura Basin. No significant shallow underground coal was discovered.

Desert and Birthday Creeks, two tributaries of Marrett River have their headwaters in the top of the area. Beattie Creek, the main tributary of Jack River, intermittently flows in a south-westerly direction into Jack Lakes, to the west of EPC327.

Much of the work done on EPC327 was infilling work that Utah Development Company had done on EPC207 in 1977. Some of the results of Utah Development Company from EPC207 are presented in this report.

CRA (Hewitt 1982) drilled 3 rotary open holes and 4 rotary partly cored holes (2243.16m). Drilling statistics are reported, as well as geological logs, geophysical logs (gamma, long spaced density, calliper), geological mapping, palynology, groundwater, and coal seams data.

Artesian water was encountered in four exploration drill holes. The report includes depth to water intersected, and estimates of water quality and flow rates. Significant volumes of artesian water were reported at depth (~300–400 m) within the Dalrymple Sandstone. This water was reported to be of good quality.

Minor coal bands were reported in the upper Rolling Downs Group and Gilbert River Formation equivalent and several minor coaly lamellae were intersected in the Jurassic Dalrymple Sandstone. The economic potential of the coal evident from the current drilling was thought to be limited (Hewitt

1982). This report concluded that the area holds little potential for delineating economic shallow underground mineable coal deposits (Hewitt 1982).

Appendix 2 of the report included drill logs, graphical logs, geophysical logs and drill locations along east-west trending and north-south trending cross-sections.

EPC334

Khoo (1981) provided a summary overview of the geology of the area and stated that except for minor small outcrops of the Lower Cretaceous Battle Camp Formation (Gilbert River Formation) and the Jurassic Dalrymple Sandstone in the north, the whole area is covered with Quaternary sediments.

EPC2687

EPC207

UDC (1979) drilled 12 rotary holes with some spot coring. Drill logs are included in Appendix 1 of the report. They also reported on a seismic reflection and refraction survey, and concluded that coal intersected in one drill-hole appeared to have only limited extent and could not identify areas that would warrant further drilling.

UDC (1978) drilled 5 non-core holes in the south-eastern area of EPC 207. No indications of coal in the sections drilled were present. Four of the holes intersected Mesozoic strata, and in each case the section was assigned to the Jurassic Dalrymple Sandstone. One hole reached basement (granite) at 36 m, other holes reached Hodgkinson Formation at depths of ~200 m.

EPC2755

No results.

EPC1875

No results.

EPC2570

EPC333

EPC 333 was granted to Oakbrook Pty in 1980. No exploration was undertaken. The reporting notes that there is coal of sub-economic quantities found in the Permian age Normanby Formation in this area.

EPC196

EPC196 was granted to Utah Development Company in 1976. The authority is situated in the southern part of the Laura Basin, overlapping the town of Laura up to “Battle Camp”, including Welcome Creek, Dighton River and some of the Laura River. There were 24 drillholes completed (4,998.2m in total), with 23 rotary drilled holes with minor coring, and one hole fully cored to basement (DT-77-08) (UDC undated-b).

(UDC undated-b) suggested that the amount of fine-grained sediment recorded in the section is likely to be underestimated due to the drilling method.

The holes intersected a Mesozoic section comprising of the Gilbert River Formation and the Dalrymple Sandstone. Thin coal bands occur in the Dalrymple Sandstone, mainly in the upper part of the unit (generally less than 0.1m thick, thickest layer drilled of 0.45 m).

The study concluded that “no geological controls which would have produced local “coal basins” in which thicker seams could have developed can be distinguished” (UDC undated-b). The report includes gamma logs and borehole drill logs and palynology analyses.

EPC1058

EPC160

UDC (undated-b) did not identify any Permian strata within the Authority. They reported that the Dalrymple Sandstone in the area consists of dominantly sandy facies of medium-grained to coarse-grained quartz sandstone with minor fine-grained facies of siltstone, mudstone and fine-grained sandstone which contain some thin coal seams. They interpreted the depositional environment to be: sandy facies representing the various bar and channel deposits of an extensive braided river system, and the fine-grained facies appear to be the overbank deposits of the relatively restricted floodplain areas of such a system.

Thin coal seams are present in some developments of the fine-grained facies. Seams were reported to be 10-20 cm thick with rare developments up to 50 cm. Reported that many of the minor coal indications noted probably represent only coaly wood fragments, particularly in the sandy facies.

The report noted that individual seams are thin and apparently of limited lateral extent and that the possibility of locating any coal of economic potential in the area is low (UDC undated-b). UDC (undated-a) included borehole drill logs and palynology data.

The UDC (1975) report included a representative geologic log. This reporting does not provide any stratigraphic interpretation except for spot palynology age ranges for cuttings sampled at various depths across boreholes.

EPC167

No results.

EPC172

UDC (1976) reported on exploration undertaken in EPC172. Three non-core holes were drilled (172.3 m). Each hole was drilled to basement through relatively thin section of the Jurassic Dalrymple Sandstone. No Permian sediments were intersected and the Dalrymple Sandstone was found to contain only thin coal bands. The report concludes that no further work is justified in EPC172. The report includes lithological descriptions and includes water intersection depths.

EPC335

This tenement is on the southern margin of the Laura Basin, approximately 220 km west of Cooktown in the Permian Little River Coal Measures. The work aimed to test the coal potential of both the Permian Little River Coal Measures and the Jurassic Dalrymple Sandstone. A Sirotem resistivity survey was carried out, and a five hole drilling program.

The study concluded that high-rank Permian coals are high in ash, and in a geologically unsuitable environment for mining purposes (Seitlinger 1982b).

The Permian Little River Coal Measures occur in the valley of the Little Kennedy River. The valley is bounded to the west by a dissected escarpment of the Jurassic Dalrymple Sandstone, up to 100 m above the valley floor.

The Jurassic and low Cretaceous rocks in the Fairview area are about 460 m thick. Faulting has caused minor displacements, chiefly along the Palmerville Fault, which has raised the Palaeozoic strata about 60 m to the east.

The Permian coal measures occupy a narrow tract of country nearly 26 km long and up to 2 km wide, bounded on both sides by faults. The major Palmerville Fault lies to the west; to the east is a high angle reverse fault (Fairlight Fault) which was associated with the (Late Permian) Hunter-Bowen Orogeny.

The Gilbert River Formation occurs mainly in the southern and western parts of the authority.

The drilling program included 5 holes 301.9 m non-core drilling and 361.1 m core drilling). All holes were vertical.

Seitlinger (1982b) included geophysical logs and borehole drilling logs. Intense fracturing was reported during drilling.

Seitlinger (1982a) noted that Mobil drilled one hole through the Dalrymple Sandstone to test its potential for thick Jurassic coal. It was concluded that the Authority does not contain any areas which could contain sizeable coal deposits, and that any future exploration in the Laura Basin should concentrate on targets of upthrust blocks of Dalrymple Sandstone. The report contains geophysical and geological logs of Jurassic strata as well as resistivity survey interpretation. It also includes coal intersection depths in various drill holes.

Sturmfels (1957) provided a description of the Little River Coal Measures. (Sturmfels 1957) noted that the occurrence of the Permian age Little River Coal measures at the surface in this area is connected with an ‘exceptional structural condition, a hinge-line of considerable magnitude, which is not likely to be repeated elsewhere’ (page 18). The report includes field maps which show the occurrence of springs. This report stresses the sub-economic status of this coal occurrence as well as the low probability of other Permian coals being found in exploitable situations in the region.

EPC2747

No results.

EPC2745

No results.

EPC1059

See EPC 333 above.

EPC169

EPC169 is located in the south-eastern extent of the Laura Basin. Most of the block is located outside the Laura Basin (to the south).

Quinton (1976) reported no economic coal was identified in the area. The major part of the area is occupied by the Hodgkinson Formation. Resting unconformably on the Paleozoic strat is the Jurassic Dalrymple Sandstone which reportedly crops out in the north-eastern part of the area. Quinton (1976) reported that the Cenozoic McLean Basalt rests unconformably on the Hodgkinson Formation in the south of EPC169.

EPC185/EPC171

UDC (1977) reported on exploration in the south-east part of the Jurassic/Cretaceous Laura Basin. The objective of the exploration was to investigate whether the coal-bearing Permian Normanby Formation that are exposed in small fault blocks immediately south of the area also occur beneath the Jurassic/Cretaceous strata of the Laura Basin.

There were 14 rotary drill holes within EPC185 and EPC171. All holes intersected a section of medium- to coarse-grained quartz sandstone which UDC (1977) identified as the ‘Lower Jurassic Dalrymple Sandstone’. In some holes, sedimentary rocks below the Dalrymple Sandstone were ‘tentatively’ identified as Permian (consisting of grey siltstone, black mudstone, both carbonaceous, and quartzose and feldspathic sandstone, with thin coal bands). UDC (1977) noted that these rocks may be Jurassic.

The report also included drillhole logs, graphical logs and gamma logs.

Jago (1975) provided detailed descriptions of the geology and coal resources of the Permian Normanby Formation in EPC169.

North-western and western Laura Basin - not currently under tenement

EPC311

Benade (1981) reported on a seismic refraction survey, and auger drilling for seismic shot holes. This work described the area as having an extensive thin drape of Quaternary sediments, essentially fluvial coastal and minor lacustrine, overlying Mesozoic units which thin and onlap onto Coen Metamorphics Basement to the west. Magnetic data indicates subsurface Cenozoic olivine-bearing nephelenite extrusives under the north-west corner of EPC311.(Benade 1981).

The seismic refraction study included 3 east-west traverses located 20km and 33km apart. The depth of unconsolidated sediments and the surface of the buried bedrock topography was clearly defined in the seismic program, which used two main velocity groupings for interpretive purposes: 100–3,490 metres per second (m/s) for Mesozoic strata; and 4,760–5,540 m/s for basement. The report noted that ‘in general, it would appear that the Mesozoic units wedge out to the west onto basement. Some faulting is indicated and a basement paleo-high is expected’ (page 7) (Benade 1981).

Benade (1981) described the Rolling Downs Group as here consisting of a sequence of thinly laminated dark grey siltstone and very fine-grained grey sandstone beds. This is overlain by a thick unit of quartzose sandstone which may be equivalent to the Normanton Formation.

Murphy (1982c) reported on a drilling program, which had difficulty in drilling to the intended depths due to high water flows. There were 4 holes attempted, and 3 holes were abandoned (total drilling of 464 m depth). Two of the bores intercepted artesian water – in Hole Vv390001, flow started at ~120 m; in Vv410001 flow started at ~40 m. The Palmerville Fault runs along the eastern flank of EPC311.

Murphy (1982c) also includes drill logs (lithological descriptions) – Appendix 1, a palynological report- Appendix 2, major ion analyses – Appendix 3, and gamma, graphical and density logs for bores drilled.

Murphy (1983) reported that there were no significant economic coal intersections at shallow depths in the area. The report uses the geological cross-sections developed in (Benade 1981; Murphy 1982c). Murphy (1983) reported that 5 holes were drilled (incl. the 4 reported in Murphy (1982c) and that one hole (Vv400001) intersected shallow artesian water at 15 m depth (with major ion analysis results presented in the body of the report). The report also includes a cross-section of Dalrymple Sandstone (page 12 of pdf) and mentioned very minor coal interception. There is no stratigraphic interpretation aside from the cross-sections.

EPC368

(Hewitt 1983) reported on coal exploration in EPC368. Hewitt noted that the Stewart River flows during the wet season but is usually dry for approximately four months of the year. Rocky River, in the north of EPC368, and Massy Creek in the centre of EPC368 have permanent fresh water all year. Breakfast and Dinner Creeks, north of the Stewart River and Balcultha and Five Mile Creeks, south of the Stewart River, dry up to separate water holes during the dry season.

Hewitt (1983) reported that in 1973 and 1974, the BMR drilled 6 shallow auger holes on the Coen 1:250,000 mapsheet and 4 shallow auger holes on the Ebagoola 1:250,000 mapsheet within the area covered by EPC368. This information is included in Appendix 2 of his report, and includes lithological descriptions and interpretations.

Hewitt (1983) reported that 12 holes were drilled. Hewitt (1983) reported that the boundary between the Lilyvale Beds and the underlying undifferentiated Mesozoic sandstone sequence is poorly defined because of deep weathering during the Cenozoic.

Hewitt (1983) identified 'undifferentiated Mesozoic Sandstone' in EPC 368 and described it as a biostratigraphic equivalent to the Dalrymple Sandstone or the basal section of the Gilbert River Formation. The undifferentiated Mesozoic Sandstone crops out in the north of EPC368 in Rocky Creek and to the east of EPC368 on Cliff Islands and at the mouth of Running (or Gorge) Creek to the south of EPC368. The report includes geological cross-sections (Plates 3-7). Plate 2 includes a map of the Pliocene to Holocene alluvium, which are described by physiography: i.e. older beach ridges (quartzose sand, clay), coastal alluvium (sand, silt, clay), younger beach ridges (quartzose sand, shelly in part), tidal flats (silty clay, black organic clay), modern stream beds (quartzose sand, sit, clay) etc.

Hewitt (1983) noted that there is a regional decline in coal rank from the east of the Laura basin to the west of the Laura Basin.

There is relevant information included in the following appendices of this report:

- Appendix 2: BMR auger holes,
- Appendix 3: borehole lithological descriptions with stratigraphic interpretation,
- Appendix 4: borehole graphical logs,
- Appendix 5: borehole geophysical logs including long-spaced density, bed resolution density, gamma,
- Appendix 6: palynological report, and
- Appendix 7: petrographic description.