Australian Government

BIOREGIONAL ASSESSMENTS

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

Current water accounts and water quality for the Galilee subregion

Product 1.5 for the Galilee subregion from the Lake Eyre Basin Bioregional Assessment

20 August 2015

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

The Bioregional Assessment Programme

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

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

Department of the Environment

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

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Valuable comments were also provided by Daniel Larsen, Ashley Bleakley (Queensland Government–Department of Natural Resources and Mines) and Jorge Pena Arancibia (CSIRO)

Introduction

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

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

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

The Bioregional Assessment Programme

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

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

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

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

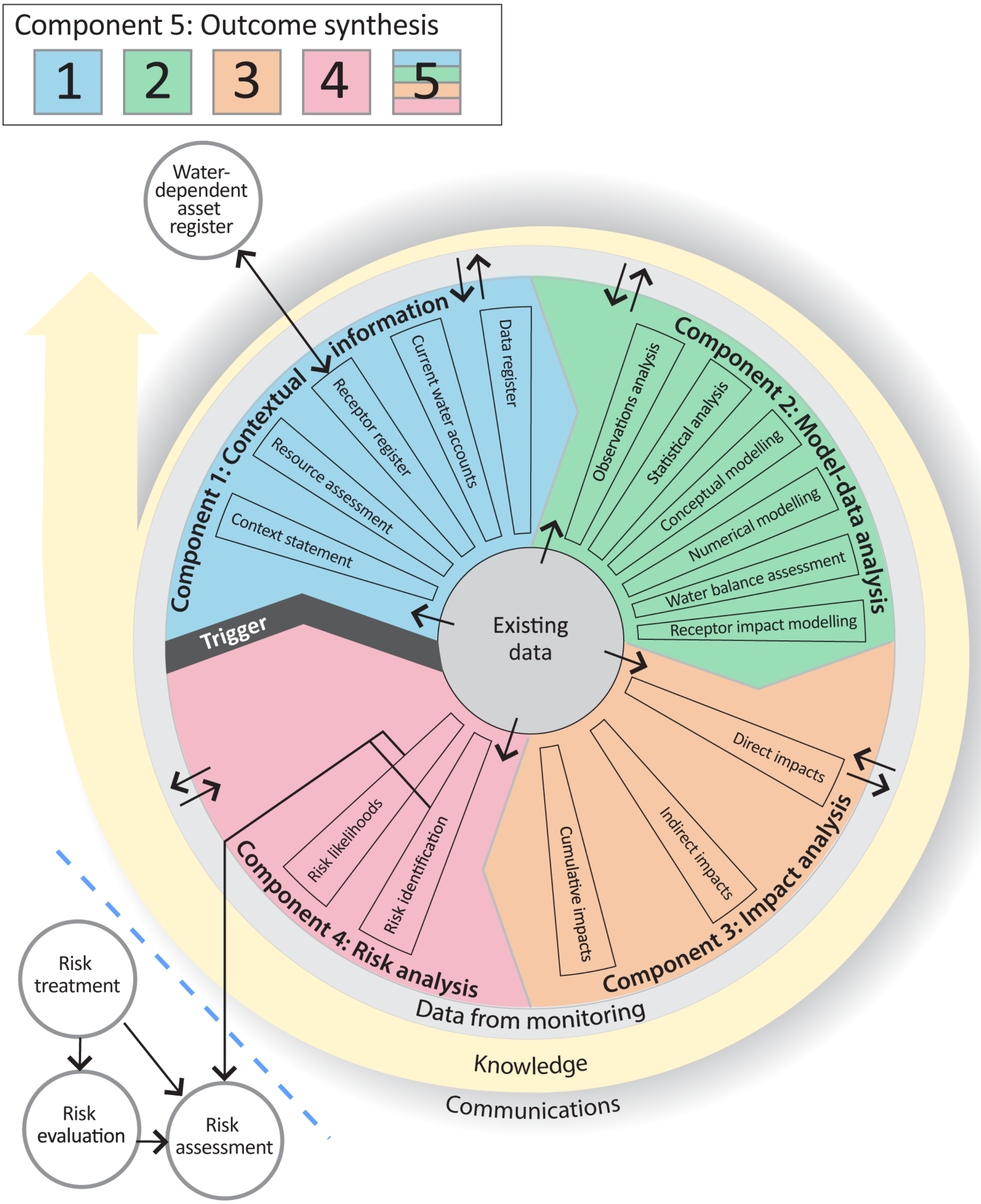


Figure 1 Schematic diagram of the bioregional assessment methodology

The methodology comprises five components, each delivering information into the bioregional assessment and building on prior components, thereby contributing to the accumulation of scientific knowledge. The small grey circles indicate activities external to the bioregional assessment. Risk identification and risk likelihoods are conducted within a bioregional assessment (as part of Component 4) and may contribute activities undertaken externally, such as risk evaluation, risk assessment and risk treatment. Source: Figure 1 in Barrett et al. (2013), © Commonwealth of Australia

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at http://www.bioregionalassessments.gov.au. Submethodologies might be added in the future.

Technical products

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

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

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

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

The PDF of this technical product, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

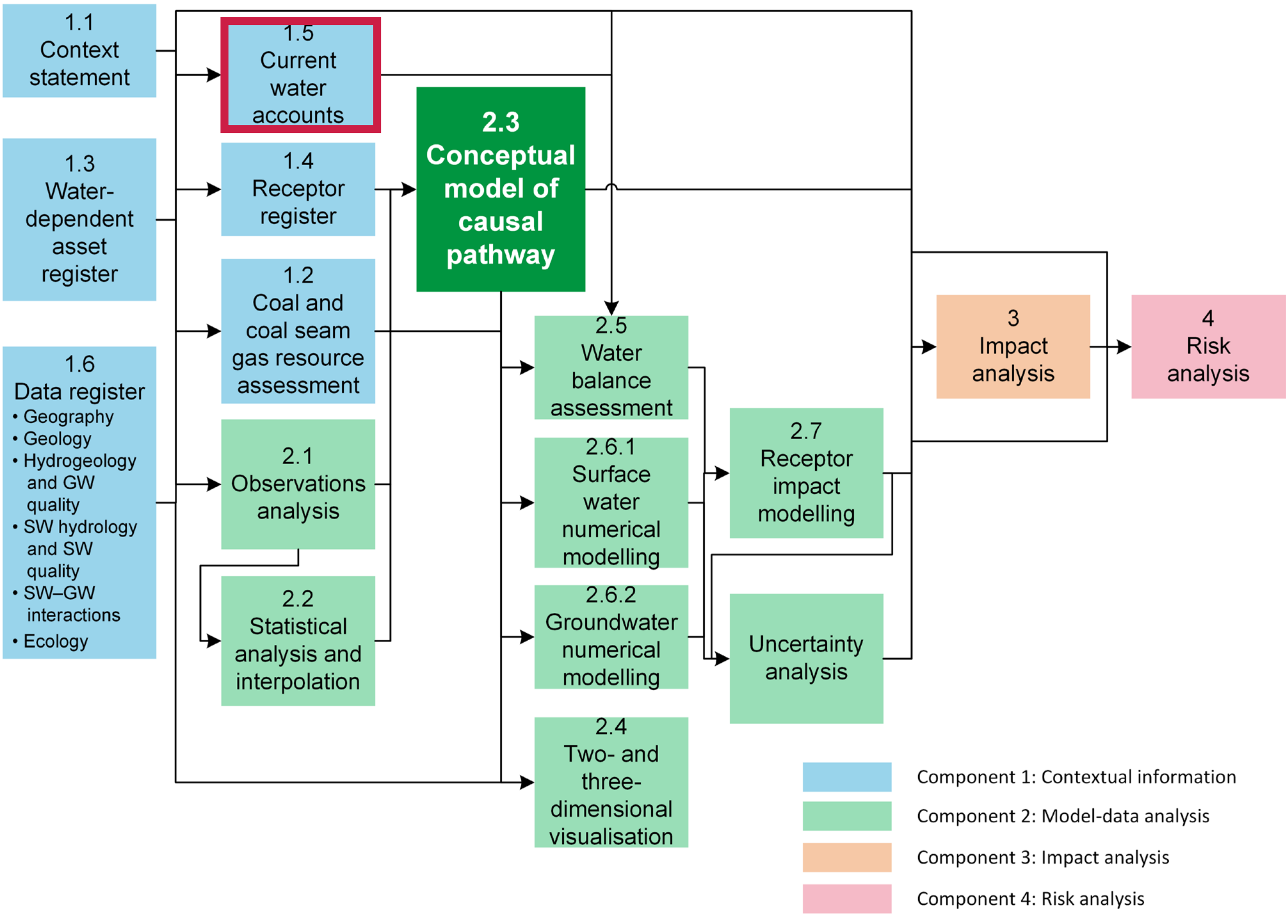


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red rectangle indicates the information included in this technical product.

Table 2 Technical products delivered by the Lake Eyre Basin Bioregional Assessment

For each subregion in the Lake Eyre Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online.

Component	Product code	Title	Section in the BA methodology[b]	Type[a]
Component 1: Contextual information for the Galilee subregion	1.1	Context statement	2.5.1.1, 3.2	PDF, HTML
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	PDF, HTML
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	PDF, HTML, register
	1.4	Description of the receptor register	2.5.1.4, 3.5	PDF, HTML, register
	1.5	Current water accounts and water quality	2.5.1.5	PDF, HTML
	1.6	Data register	2.5.1.6	Register
Component 2: Model-data analysis for the Galilee subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	PDF, HTML
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	PDF, HTML
	2.6.1	Surface water numerical modelling	4.4	PDF, HTML
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	PDF, HTML
Component 3: Impact analysis for the Galilee subregion	3-4	Impact analysis	5.2.1	PDF, HTML
Component 4: Risk analysis for the Galilee subregion		Risk analysis	2.5.4, 5.3	
Component 5: Outcome synthesis for the Lake Eyre Basin bioregion	5	Outcome synthesis	2.5.5	PDF, HTML

[a]The types of products are as follows:
- 'PDF' indicates a PDF document that is developed by the Lake Eyre Basin Bioregional Assessment using the structure, standards, and look and feel specified by the programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

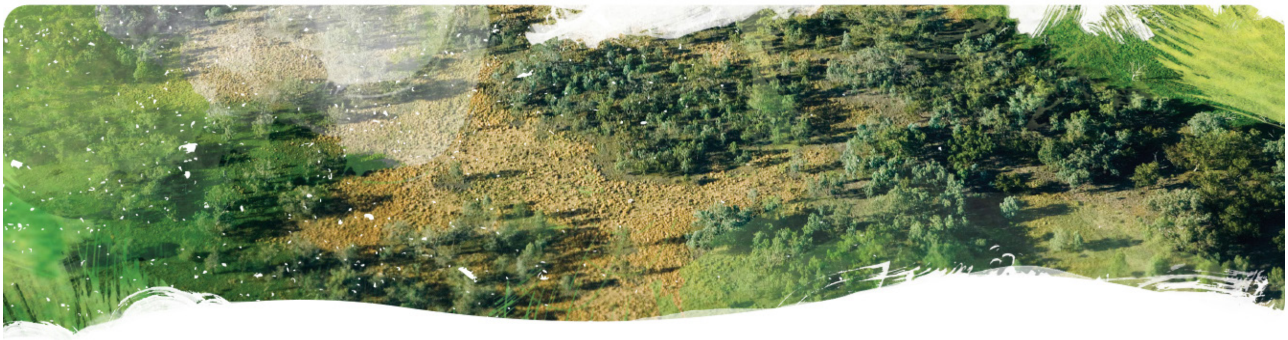
About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Contact bioregionalassessments@bom.gov.au to access metadata (including copyright, attribution and licensing information) for all datasets cited or used to make figures in this product. At a later date, this information, as well as all unencumbered datasets, will be published online.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 9 September 2015, http://www.iesc.environment.gov.au/publications/methodology-bioregional-assessments-impacts-coal-seam-gas-and-coal-mining-development-water.



1.5 Current water accounts and water quality for the Galilee subregion

This product provides current water account and water quality information that will be used in subsequent products in the bioregional assessment.

The water accounts include information about water stores, flows, allocations and use that will be required in the water balance (product 2.5) and in the numerical modelling (product 2.6.1 and product 2.6.2).

This product also provides information about surface water and groundwater quality that will be required for the impact and risk analysis (product 3-4).

1.5.1 Current water accounts

Summary

The Galilee subregion contains the headwaters of six major river basins including the Cooper, Diamantina, Flinders, Burdekin, Fitzroy and Warrego. Of these six river basins, potential coal and coal seam gas resource developments may occur in the Cooper, Flinders and Burdekin river basins. This product summarises water accounts for these three river basins. The surface water resources in the Cooper creek basin have not yet been affected by diversion or major dams and the information on total surface water yield is currently not available. Currently, there are about 50 nominal entitlements as either 'basic right' or 'water access right' amounting to 19.8 GL/year of water for the stream network across the Cooper creek basin. Surface water in the Flinders river basin is also unaffected by diversion or dams. The approximate surface water availability for the basin is 2500 GL/year and the current allocation is less than 2% compared to median annual streamflow. There are 20 nominal entitlements as water access right amounting to 57 GL. In contrast to Cooper and Flinders river basins, streamflows in the Burdekin are highly regulated especially in the downstream part of the basin. There are about 18 nominal entitlements totalling 2.5 GL/year for the stream network located within the Galilee subregion.

A water licence is required for a groundwater bore only under certain regulatory conditions. While groundwater usage may be metered as part of water licensing conditions, actual groundwater usage data are not readily available for groundwater bores in the Galilee subregion. Of the 4712 groundwater bores that are currently in use across the Galilee subregion, only 2281 bores have water licences allocated to them. In total, some 19 GL/year of groundwater are allocated across the subregion as part of a licencing arrangement.

Summarising water licence allocations underestimates the amount of groundwater used in the Galilee subregion as many bores do not have an associated water licence. Some guidelines for the estimation of groundwater usage are outlined in this product. Using these guidelines, it is estimated that for the Galilee subregion some 75 GL/year are drawn from 4712 bores. The largest estimated withdrawals occur from the Hutton-Precipice aquifer system, which comprise a part of the Great Artesian Basin. Notably a significant number of bores have insufficient data to be able to determine which aquifer the groundwater was being drawn from. The most significant current purpose for groundwater use is stock and/or domestic purposes.

Groundwater withdrawals by proposed resource developments are not included in the estimate, as the water licensing requirements are yet to be finalised by the Queensland Government.

1.5.1.1 Surface water

The Galilee subregion contains the headwaters of six major river basins including the Cooper and Diamantina in the west, the Flinders in the north, the Burdekin and Fitzroy in the east and the Warrego in the south (Figure 3). More information about these river basins is available in companion product 1.1 for the Galilee subregion (Evans et al., 2014). There are potential coal resource developments to occur in three (Cooper, Flinders and Burdekin) of these six river basins. The water accounts for these three river basins are described in the following sections.

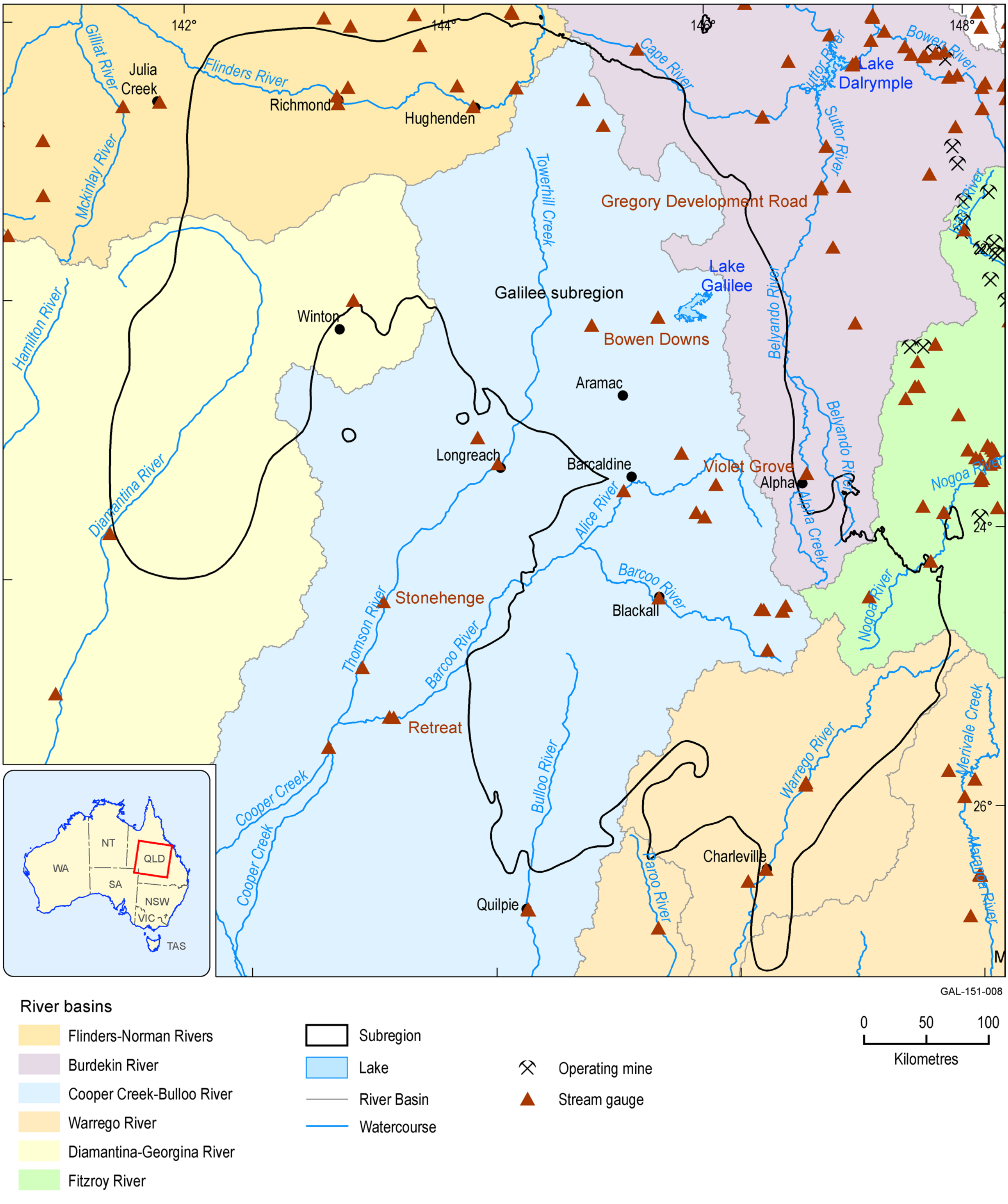


Figure 3 River basins and stream gauges in the Galilee subregion

1.5.1.1.1 Water accounts in the Cooper creek basin

The surface water resources in Cooper Creek and its tributaries (e.g. Thomson and Barcoo rivers) have not yet been affected by diversion or dams or weirs (McMahon et al., 2005). Furthermore, there is no major public water storage within the entire Cooper creek basin. One of the major tributaries of the Cooper Creek is the Thomson River which produces mean annual flow (MAF) of about 1200 GL at Longreach and 2362 GL at Stonehenge. Streamflow in Cooper Creek and its tributaries is seasonal and the groundwater contribution is relatively low. The Barcoo River is another major tributary of Cooper Creek and it produces MAF of between 102 GL at Blackall and 1193 GL at Retreat.

Currently, the information on total surface water yield is not available for the Cooper creek basin. There are about 50 nominal entitlements defined as either 'basic right' or 'water access right' amounting to 19.8 GL of water for the stream network across the river basin (Table 3). The total amount of unallocated water is unknown for the Cooper creek basin. In the 2011 water resource plan for Cooper Creek, the Queensland Government reserved a total of 2 GL of unallocated water (200 ML for general reserve, 1.3 GL for strategic reserve and 500 ML for the town and community reserve) to meet future demand (Department of Environment and Resources Management, 2011).

Table 3 Water permits in the Cooper creek basin in the Galilee subregion

Permit type	Name of river or creek	Number of licences	Entitlements (ML/year)
Basic right	Barcoo River	7	10
Basic right	Lagoon Creek	1	2
Basic right	Thomson River	9	77
Basic right	Towerhill Creek	2	10
Water access right	Alice River	2	64
Water access right	Barcoo River	2	116
Water access right	Collumpton Creek	1	770
Water access right	Cooper Creek	6	16,291
Water access right	Darr River	1	96
Water access right	Douglas Ponds Creek	1	160
Water access right	Hope Creek	1	100
Water access right	Jordan Creek	2	416
Water access right	Lagoon Creek	1	48
Water access right	Landsborough Channel	1	64
Water access right	Ravensbourne Creek	1	160
Water access right	Thomson River	9	761
Water access right	Thomson River (Anabranch)	1	500
Water access right	Towerhill Creek	1	160
Water access right	Valentine Creek	1	32
Total		**50**	**19,837**

Data: Queensland Department of Natural Resources and Mines (Dataset 1)

1.5.1.1.2 Water accounts in the Flinders river basin

Surface water in the Flinders river basin and its tributaries has not yet been affected by diversion of water for irrigated agriculture or major dams or weirs. The MAF in the Flinders River varies between 127 GL at Hughenden and 619 GL at Richmond. The surface water availability for the Flinders river basin is about 2500 GL/year and the current allocation is relatively low compared to median annual streamflow (i.e. ≤2%) (Petheram et al., 2013). There are 20 surface water access licences amounting to 57 GL of water for the stream network in the Flinders river basin that is part of the Galilee subregion (Table 4).

Water in the Flinders river basin is shared and managed under the Gulf Water Resource Plan (WRP) and Resource Operation Plan (ROP). The Gulf WRP was first released in 2007 and amended in 2011 to establish unallocated water reserves to support Indigenous people. The Gulf ROP was first released in 2010 implementing the objectives specified in the WRP 2007. Both the Gulf WRP and ROP were amended in 2014 (Department of Natural Resources and Mines, 2014).

Table 4 Water permits in the Flinders river basin in the Galilee subregion

Permit type	Name of river or creek	Number of licences	Entitlements (ML/year)
Water access right	Double Barrel Creek	1	14,000
Water access right	Eight Mile Creek	1	1,300
Water access right	Flinders River	14	36,780
Water access right	Fraser Creek	1	800
Water access right	McKinlay River	1	1,000
Water access right	Rupert Creek	2	3,200
Total		**20**	**57,080**

Data: Queensland Department of Natural Resources and Mines (Dataset 1)

1.5.1.1.3 Water accounts in the Burdekin river basin

There are a large number of dams and weirs in the Burdekin river basin located on the Burdekin, Haughton and Bowen rivers. The Burdekin Falls Dam (1860 GL capacity), which is the largest dam in Queensland, is the major water storage in this basin and much of its water comes from upper catchments runoff including areas within the Galilee subregion. Although the Burdekin river basin is highly regulated in the downstream part of the catchment, the headwater catchments remain unregulated. The MAF at Violet Grove of Native Companion Creek (a tributary of Belyando River) and at Gregory Road on the Belyando River is 62 and 698 GL respectively. Ten out of eleven proposed coal mine development sites are located in the Burdekin river basin. Out of the ten, seven (Alpha North, Kevins Corner, Alpha, Alpha West, Alpha Waratah, China First and South Galilee) are within the Belyando river sub-basin and three (China Stone, Carmichael and Hyde Park) within the Cape river sub-basin. Current water licences are allocated under Burdekin Haughton and Bowen Broken water supply schemes. The amount allocated depends on availability of water. The maximum allocation under the Burdekin Haughton water supply scheme is 204 GL for the high priority group and 1300 GL for the medium priority group (Department of Environment and Resources Management, 2010). There are about 18 nominal entitlements (as either basic right or water access right) totalling 2.5 GL for the stream network located within the Galilee subregion (Table 5).

Table 5 Water permits in that portion of the Burdekin river basin which lies in the Galilee subregion

Permit type	Name of river or creek	Number of licences	Entitlements (ML/year)
Basic right	Fox Creek	1	7
Water access right	Betts Creek	9	341.5
Water access right	Cape River	7	1,582
Water access right	Expedition Pass Creek	1	600
Total		**18**	**2,530.5**

Data: Queensland Department of Natural Resources and Mines (Dataset 1)

1.5.1.1.4 Gaps

This report has focused on Cooper creek and Flinders and Burdekin river basins because those river basins are the closest to likely coal resource development. Further work may need to be done to estimate water availability in other parts of the Galilee subregion.

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1.5.1.2 Groundwater

1.5.1.2.1 Current water accounts

Product 1.5 provides information on groundwater allocations and an estimate of groundwater usage within the Galilee subregion. Actual measured groundwater usage data are not readily available for bores in the Galilee subregion. A groundwater bore may be required to be metered as part of its water licence conditions. While all bores are registered, not all bores require a licensed water allocation.

Licensed water allocations

Water resource plans (WRPs), groundwater management areas (GMAs), and declared sub-artesian areas have specific rules on what triggers a requirement for a water licence.

Conditions that may trigger a requirement for a water licence include:

- the bore is artesian; regardless of purpose for which the water will be used
- the bore is sub-artesian (non-flowing) and is located within a declared sub-artesian area or a groundwater management area
- sub-artesian (non-flowing) bore is regulated by a water resource plan, specifically the Great Artesian Basin Water Resource Plan (GAB WRP)
- a bore is likely to require a licence if water is to be used for a purpose other than stock and domestic.

In unregulated areas, sub-artesian water can be taken without a licence.

Water licence data for Queensland were obtained from the Bureau of Meteorology (Bioregional Assessment Programme, Dataset 1). Figure 4 shows the distribution of water licence allocations to groundwater bores within the Galilee subregion. The licensed water allocations represent the maximum amount that can be taken for a particular licence. How much is actually used is not available.

In total 2281 bores have a water licence allocated to them. This is in contrast to the number of operational bores recorded in Queensland groundwater bore database, which is 4712 bores. The total volume of licensed groundwater allocations within the Galilee subregion equates to 19 GL/year drawn from 2281 bores, of which 18.5 GL/year is drawn from within the GAB WRP area. Further information on GAB WRP is available in Evans et al. (2014) and Queensland Government (2014a, 2014b).

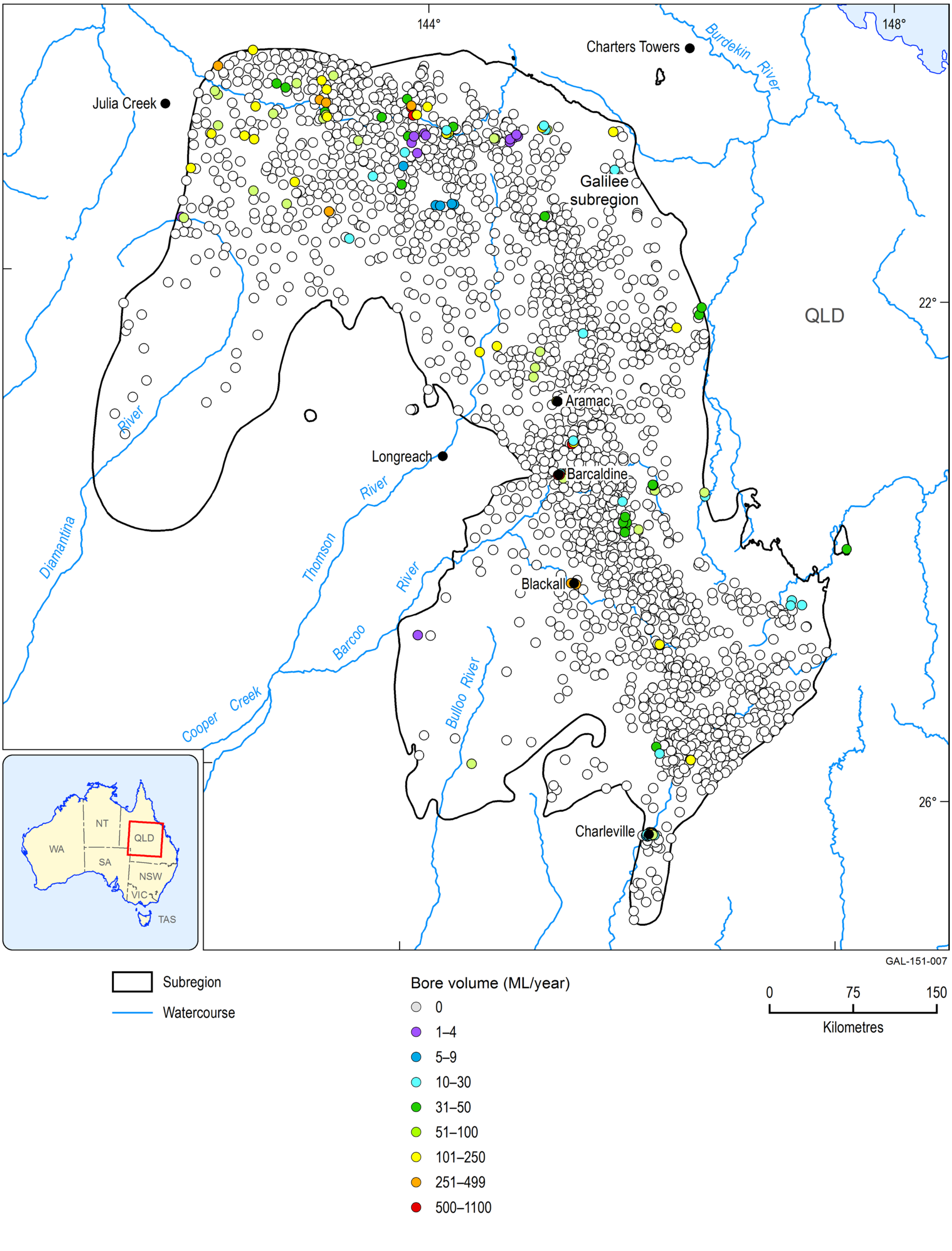

Figure 4 Distribution of groundwater licence allocations (ML/year) per bore across the Galilee subregion

A value of zero means the licence does not specify a volume. The vast majority of bores with no allocation are used for stock and domestic purposes.
Data: Bioregional Assessment Programme (Dataset 1)

An estimate of current groundwater usage

Most bores in the Galilee subregion do not operate under a groundwater licensing arrangement. Thus, summarising groundwater licence allocations can significantly underestimate the annual groundwater withdrawals from aquifer systems. A dataset (Bioregional Assessment Programme, Dataset 2) for estimating yearly groundwater use from all bores, in ML/year, was compiled using the following steps:

1. Relevant bore data in the Galilee subregion was compiled from the Queensland groundwater database extract dated 28 August 2014 (Queensland Department of Natural Resources and Mines, Dataset 3).
2. for each bore, where data are available, incorporate interpreted stratigraphic picks for screened intervals into the dataset
3. for each bore, where data are available, incorporate the most recent standing water level and bore maximum discharge data into the dataset. Maximum discharge will need to be re-calculated from L/second to ML/year
4. from the water licence dataset, incorporate the licensed water allocation volume, bore use and GMA information
5. investigate the bore facility status records. Bore facility status categories include: existing; abandoned but usable; abandoned and destroyed and proposed. Only those classed as 'existing' or 'abandoned but usable' were kept in the dataset. It is assumed that bores in other categories are not functional
6. interrogate bore use records. Remove any bore from the dataset that is tagged as a monitoring bore. It is assumed that monitoring bores are not being used for any purpose other than groundwater monitoring
7. insert two new blank columns, 'BA groundwater usage' and 'groundwater use source' in the dataset. The 'BA groundwater usage' column is where the estimate for annual groundwater usage is recorded for a bore in ML/year. The 'groundwater use source' column is where the decision on how yearly groundwater usage is assigned is recorded
8. populate the 'BA groundwater usage' and 'groundwater use source' columns.

Steps to estimate groundwater usage for each bore are:

1. populate the BA groundwater usage column with water licence allocations that are greater than 0 ML/year. While the full allocation may not actually be used, this will provide a maximum allowable water allocation that could be pumped from a particular area. This has the potential to conserve the unused allocations when estimating groundwater usage for an area
2. sub-artesian bores – 5 ML/year or bore maximum flow rate, whichever is least (D Larsen (Queensland Department of Natural Resources and Mines), 2014, pers. comm.)
3. controlled artesian bore – 30 ML/year or the maximum flow rate, whichever is least (D Larsen (Queensland Department of Natural Resources and Mines), 2014, pers. comm.)
4. uncontrolled artesian bore – use the bore flow rate in ML/year (D Larsen (Queensland Department of Natural Resources and Mines), 2014, pers. comm.)

5. uncontrolled artesian bores missing flow rate and standing water level information – the average flow rate for all uncontrolled artesian bores located within the Galilee subregion was calculated from existing data. The average was then assigned as nominal value for uncontrolled artesian bores with no flow rate data. For Galilee subregion this equated to 124 ML/year.

Using the methods as described above, it was estimated that 75,229 ML/year are extracted across the Galilee subregion from 4712 bores. Figure 5 shows distribution of estimated groundwater usage per bore across the Galilee subregion. It is difficult to ascertain uncertainty for this estimate without having some actual groundwater usage data for comparison.

Groundwater withdrawals by proposed resource developments are not included in this estimate, as the water licensing requirements are yet to be finalised. Further detail on the projected water requirements for the proposed coal and coal seam gas developments will be outlined in companion product 2.3 for the Galilee subregion.

Table 6 shows the number of bores broken down by the licensed purpose. Stock and/or domestic supply purpose was the largest user of groundwater with an estimated 37 GL/year from 2135 bores, followed by town water supply with 42 bores and 8.3 GL/year. An estimated 20 GL/year is drawn from 2434 bores for which no specific purpose was specified in available data. It is likely that the majority of bores with no specified purpose are used for stock and/or domestic.

Figure 6 shows the distribution of bores for each purpose across the subregion.

Table 6 Estimated groundwater usage by purpose for the Galilee subregion

Purpose	Number of bores	Estimated volume (ML/year)
Aquaculture[a]	11	1,944
Construction/roadworks	1	2
Domestic supply[b]	47	3,176
Firefighting	2	10
Industrial	1	400
Irrigation[c]	39	4,124
Town water supply	42	8,300
Stock and/or Domestic[d]	2135	37,018
Not specified	2434	20,255
Total	**4712**	**75,229**

Data: Bioregional Assessment Programme (Dataset 2)
[a]May also include domestic, stock, stock intensive, irrigation or industrial
[b]May also include industrial, irrigation, stock or firefighting
[c]May also include stock and domestic
[d]May include stock intensive

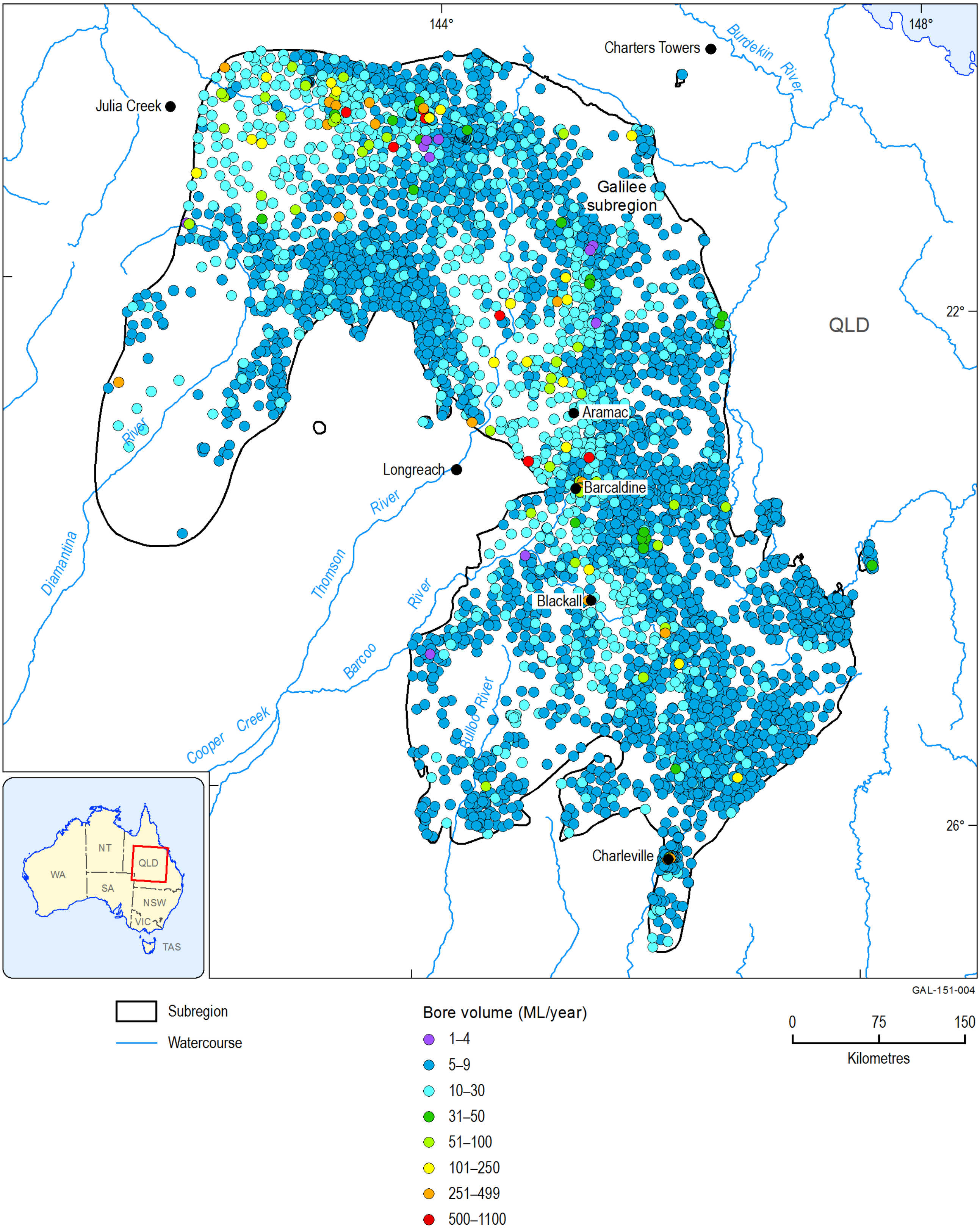

Figure 5 Estimate of groundwater usage per bore across the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2)

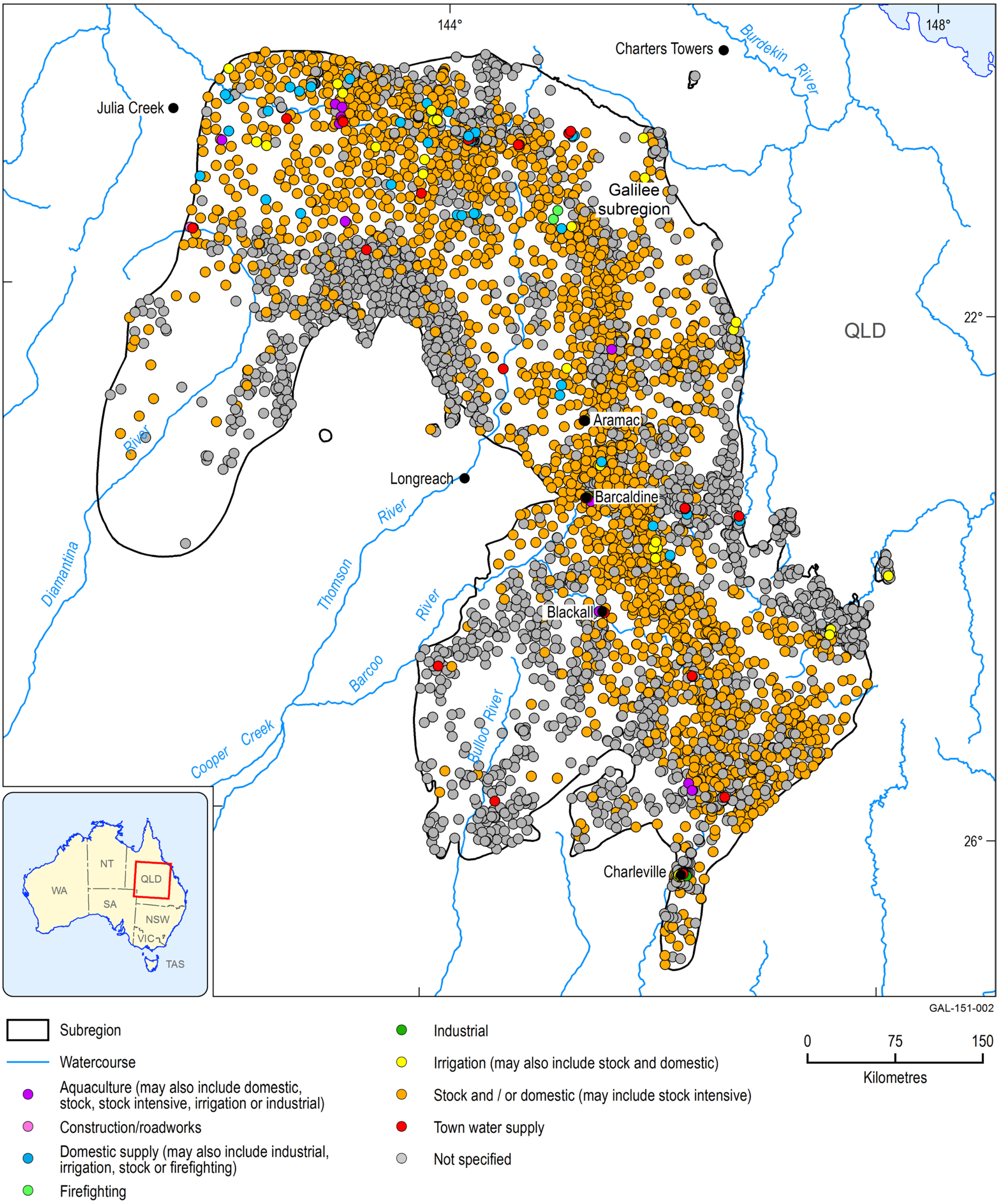

Figure 6 Distribution of purpose of bores in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2)

Table 7 shows number of bores and an estimated volume withdrawn annually on a per aquifer basis. The largest estimated withdrawals on an annual basis occur from the Hutton-Precipice aquifer system, followed by withdrawals from Wyandra-Hooray aquifer system. Notably a significant number of bores (33%) had insufficient data to be able to determine which aquifer system the bore was drawing water.

Figure 7 shows the distribution of bores for each aquifer.

Table 7 Estimate of groundwater usage per aquifer for the Galilee subregion

Aquifer	Total number of bores	Volume (ML/year)
Alluvium	89	602
Basement	3	15
Betts Creek beds	50	298
Cenozoic	132	1,167
Dunda-Rewan	8	90
Hutton-Precipice	656	23,407
Injune Creek Group	272	4,546
Joe Joe Group	37	185
Moolayember Formation	56	525
Ronlow beds	358	5,262
Wallumbilla Formation	242	1,873
Warang-Clematis Group	157	1,445
Winton-Mackunda Formation	489	2,944
Wyandra-Hooray Sandstone	629	17,228
No stratigraphic data	1534	15,642
Total	**4712**	**75,229**

Data: Bioregional Assessment Programme (Dataset 2)

In the Galilee subregion, estimated flows from uncontrolled artesian bores ranged from 4 to 1090 ML/year, with an average of 124 ML/year.

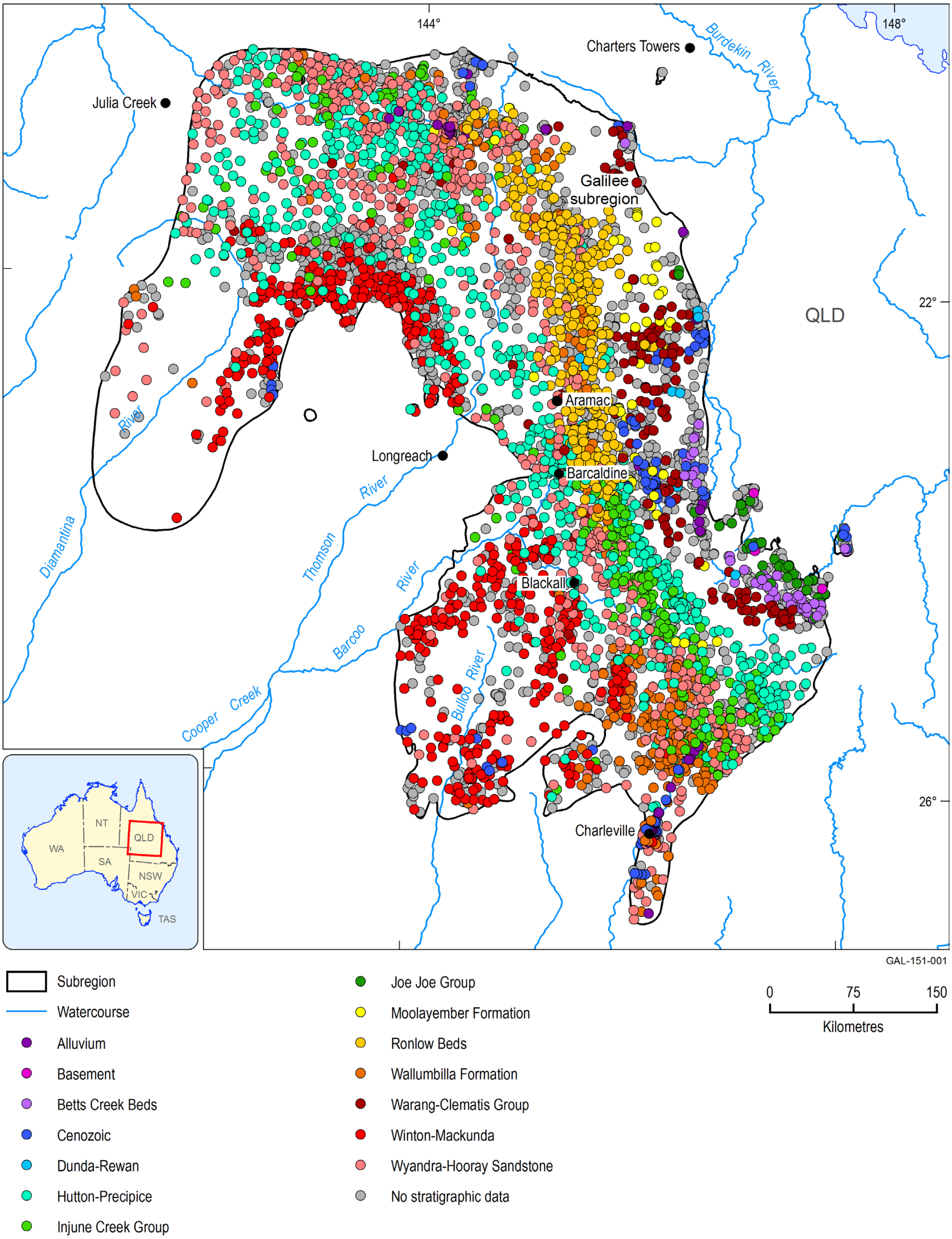

Figure 7 Interpretation showing which aquifer a bore draws groundwater from in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2)

1.5.1.2.2 Water management

Water sharing plans in Queensland are known as water resource plans (WRPs). With the exception of the GAB WRP, WRP areas are defined by surface catchment areas. While seven WRPs cover the Galilee subregion, most bores fall under the GAB WRP. This reduces the number of WRPs of interest to three. These are the GAB WRP (consisting of 13 GMAs), the Fitzroy WRP and the Burdekin WRP. Only portions of these WRPs lie within the Galilee subregion. Figure 8 shows distribution of bores in relation to the three WRPs.

The Galilee subregion encompasses portions of several GMAs (Figure 9). No GMA is completely included within the Galilee subregion. All except two of the GMAs are included as a part the GAB WRP. The GAB WRP includes Warang-Clematis Group and Dunda-Rewan Group aquifers as well as aquifers in the overlying Eromanga Basin.

For the WRPs of interest, Table 8 to Table 11 provides a breakdown of the number of bores and estimated usage in ML/year per aquifer for the Galilee subregion.

Further information on WRPs in the Galilee subregion is available in Section 1.1.4.4 in companion product 1.1 for the Galilee subregion (Evans et al. 2014).

Water trades can only take place using a granted water licence, for which the intended purpose is non-stock and domestic. There is provision in the GAB WRP for temporary and permanent trading (Queensland Government, 2014a). Queensland Government (2014b) details some recent legislative amendments to the GAB WRP.

Queensland Government (2014c) provides data on water trades that occurred under the auspices of the GAB WRP, from 1 July 2007 to 30 June 2014. These data suggest that there have been no water trades in the GAB WRP area that lies within the Galilee subregion. These data show that bulk of water trades under the GAB WRP occurred to the east of the Galilee subregion, in the geological Surat Basin. There are currently no rules in place for trading in the Highlands sub-artesian area in the Burdekin WRP (Queensland Government, 2014d) or the Highlands GMA and Carnarvon GMA in the Fitzroy WRP area (Queensland Government, 2014e).

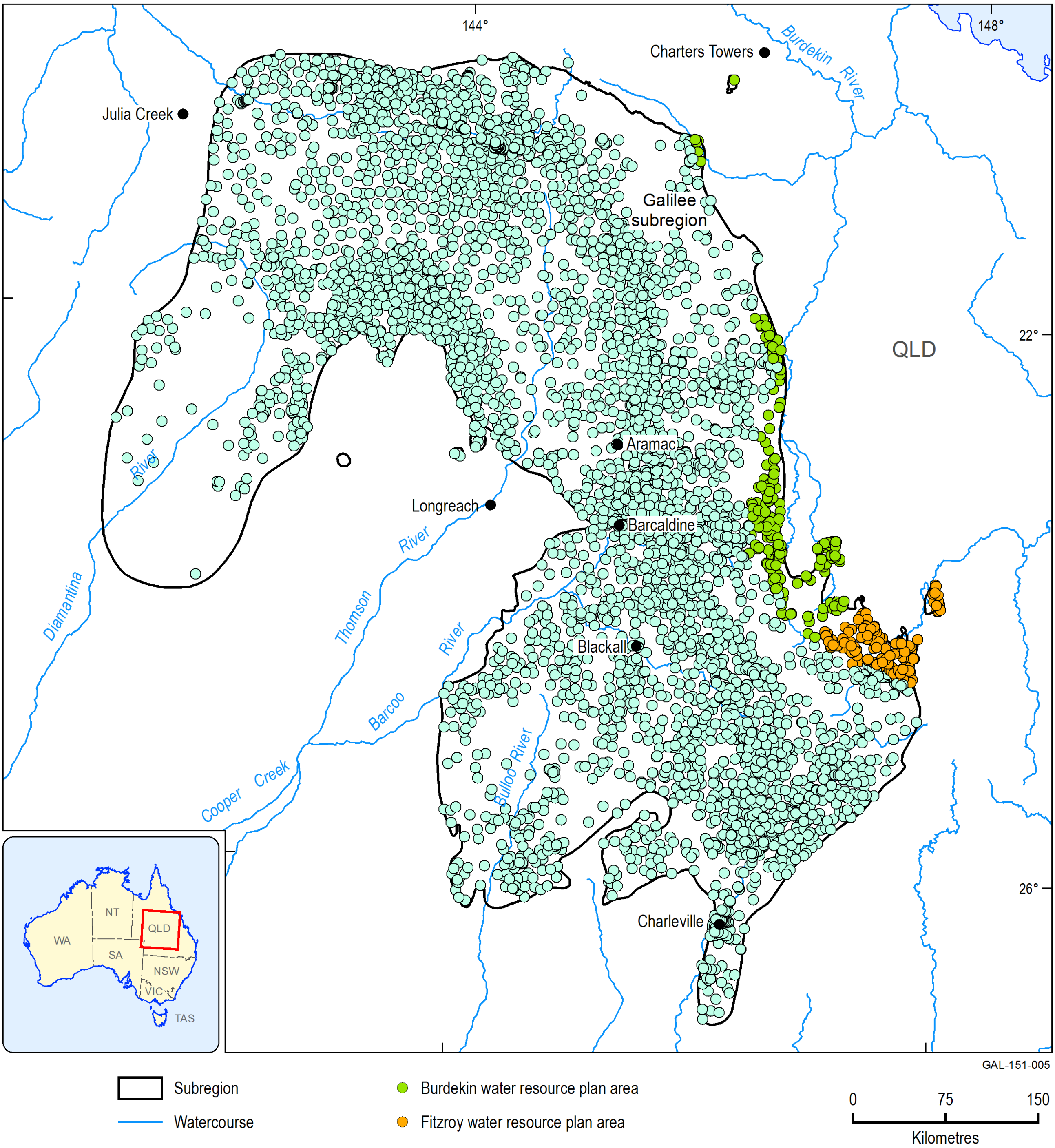

Figure 8 Distribution of bores in the three major water resource plan areas in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2)

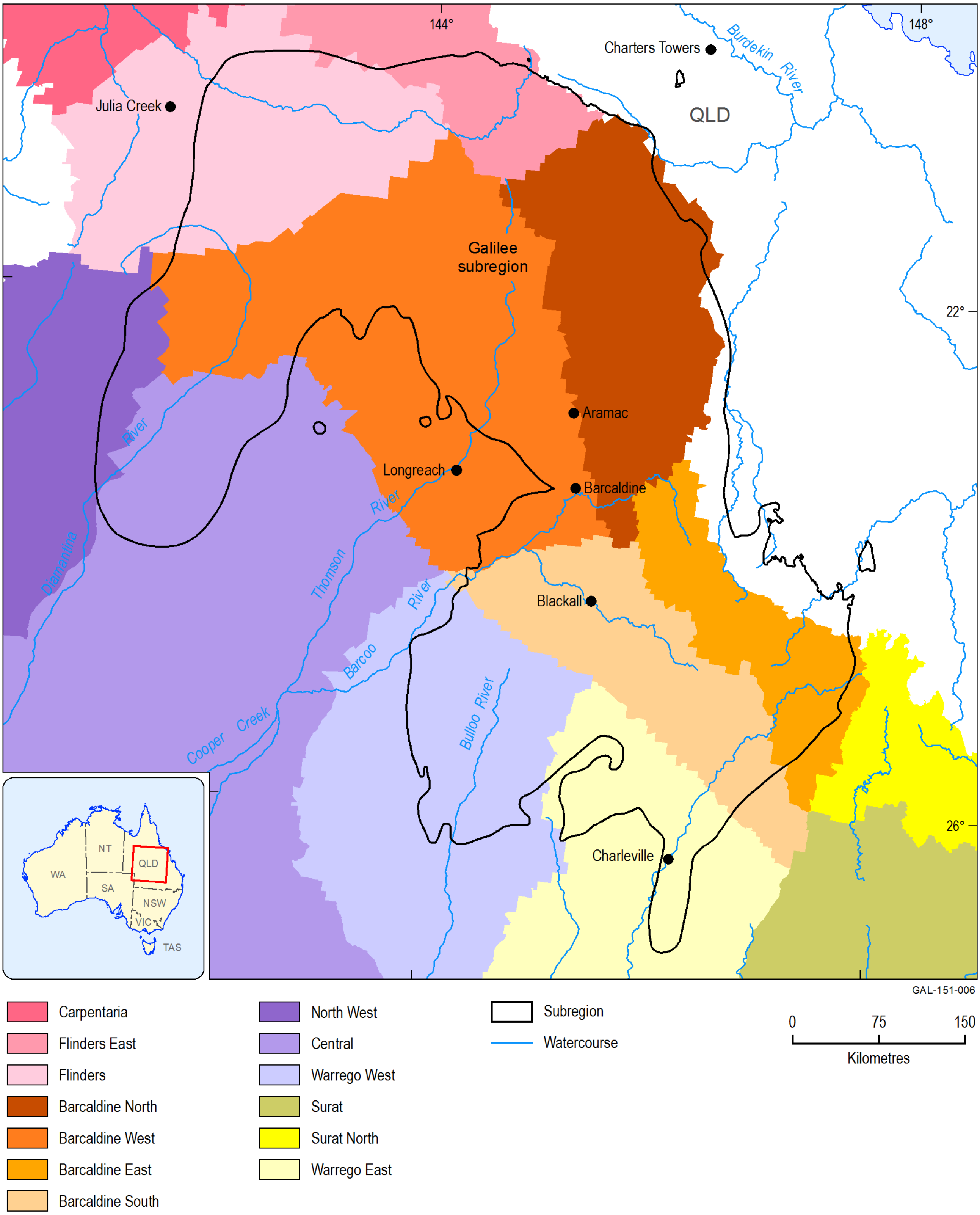

Figure 9 Distribution of groundwater management areas across the Great Artesian Basin for the Galilee subregion

Data: Queensland Government Department of Natural Resources and Mines (Dataset 4)

Table 8 Estimated groundwater use per water resource plan area within the Galilee subregion

Water resource plan area	Number of bores	Volume (ML/year)
Burdekin Catchment Water Resource Plan Area	196	1,772
Fitzroy Catchment Water Resource Plan Area	147	837
Great Artesian Basin Water Resource Plan Area	4369	72,621
Total	**4712**	**75,229**

Data: Bioregional Assessment Programme (Dataset 2)

Table 9 Estimated groundwater use per aquifer for the portion of Burdekin water resource plan that lies within the Galilee subregion

Aquifer	Number of bores	Volume (ML/year)
Alluvium	9	45
Early Paleozoic Basement	2	10
Betts Creek beds	13	65
Cenozoic	12	142
Dunda-Rewan	3	65
Joe Joe Group	13	65
Warang-Clematis Group	3	15
No stratigraphic data	141	1365
Total	**196**	**1772**

Data: Bioregional Assessment Programme (Dataset 2)

Table 10 Estimated groundwater use per aquifer for the portion of Fitzroy water resource plan area that lies within the Galilee subregion

Aquifer	Number of bores	Volume (ML/year)
Early Paleozoic Basement	1	5
Betts Creek beds	29	182
Cenozoic	4	60
Joe Joe Group	21	105
No stratigraphic data	92	485
Total	**147**	**837**

Data: Bioregional Assessment Programme (Dataset 2)

Table 11 Estimated groundwater use per aquifer for the portion of Great Artesian Basin Water Resource Plan area that lies within the Galilee subregion

Aquifer	Number of bores	Volume (ML/year)
Alluvium	80	557
Betts Creek beds	8	52
Cenozoic	116	965
Dunda-Rewan	5	25
Hutton-Precipice	656	23,407
Injune Creek Group	272	4,546
Joe Joe Group	3	15
Moolayember Formation	56	525
Ronlow beds	358	5,262
Wallumbilla Formation	242	1,873
Warang-Clematis Group	154	1,430
Winton-Mackunda Formation	489	2,944
Wyandra-Hooray Sandstone	629	17,228
No stratigraphic data	1301	13,792
Total	**4369**	**72,621**

Data: Bioregional Assessment Programme (Dataset 2)

1.5.1.2.3 Gaps

Information on stratigraphy and screened intervals for bores missing those data would improve the groundwater use estimates on a per aquifer basis. Further investigation of hydrochemistry and groundwater levels may also assist in determining which aquifer a bore is screened in.

For bores with water licences, if actual usage data was to become available this would assist in provision of a more accurate representation of the distribution of groundwater use for some bores within the Galilee subregion.

For uncontrolled artesian bores that are missing flow rate information, 124 ML/year was used as a nominal value as per the steps for estimating groundwater usage as previously outlined in Section 1.5.1.2.1. Actual flow rates from uncontrolled artesian bores would provide a better estimate.

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Datasets

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Dataset 4 Queensland Department of Natural Resources and Mines (2009) Water resource plan - Great Artesian Basin 2006 - management areas. Queensland.. Bioregional Assessment Source Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/121724dd-c448-41d6-b6b5-246542e92963.

1.5.2 Water quality

Summary

Surface water quality in the Galilee subregion is monitored under the Surface Water Ambient Network (SWAN) monitoring programme by the Queensland Government and the Lake Eyre Basin Rivers Assessment (LEBRA) programme under the Lake Eyre Basin (LEB) intergovernmental agreement between Commonwealth, Queensland, South Australian and Northern Territory governments. This product summarises surface water quality for the Cooper, Flinders and Burdekin river basins where there is a potential of future resource developments. The water quality indicators are electrical conductivity (EC) and turbidity, and the data are based on SWAN's 2004 to 2008 and LEBRA's 2011 to 2012 data. The EC values in the Cooper creek basin that is part of the Galilee subregion are generally close to the water quality objective trigger value but the turbidity is generally high. Compared with water quality objective trigger values, EC values in the Flinders river basin are generally high. EC values in the Burdekin river basin are also high compared to water quality objective trigger values but less than those in the Flinders river basin. Turbidity in the Burdekin river basin is very high when compared against the water quality objective. However, as the data period and spatial distribution are limited it is difficult to draw conclusions based on the available water quality data. It is also important to note that trigger values could be different locally from a regional value.

Groundwater quality in the Galilee and Eromanga basin aquifers has been assessed with reference to national guidelines for water quality provided by the National Health and Medical Research Council (2011), and the Australian and New Zealand Environmental and Conservation Council (2000).

Groundwater quality data are largely limited to salinity and major ions analyses. For many of the samples it is difficult to determine which hydrostratigraphic unit a sample was derived due to key missing data such as sample depth.

1.5.2.1 Surface water

There are two main sources of surface water quality data for the Galilee subregion. This includes the Surface Water Ambient Network (SWAN) monitoring programme operated by the Queensland Government (Department of Environment and Resources Management, 2011) and information collected under the Lake Eyre Basin Rivers Assessment (LEBRA) programme (Cockayne et al., 2013; Sternberg et al., 2014). The SWAN monitoring programme has been in operation since 1990 and it monitors water quality parameters at selected stream gauge sites using auto-sensor recorders. The LEBRA programme commenced in 2011 and collects water quality data using data loggers and some in situ sampling. While other water quality data are available, the water quality indicators assessed in this report are electrical conductivity (EC) and turbidity. Data are based on SWAN's 2004 to 2008 and LEBRA's 2011 to 2013 data.

EC is a measure of salinity that is often determined in the field using a conductivity sensor. The EC values are then converted to total dissolved solids (TDS) using an appropriate conversion factor.

The conversion factor depends on the chemical composition of the TDS and can vary between 0.54 and 0.96. A value of 0.67 is commonly used as an approximation if the actual factor is not known.

Current status of water quality in the Galilee subregion has been assessed against the Queensland Water Quality Guidelines (QWQGs) of the Department of Environment and Heritage Protection (DEHP). The QWQGs were derived based on the Australian and New Zealand Environment and Conservation Council (ANZECC) guideline values or descriptive statements for environmental values to protect aquatic ecosystems and human uses of waters (ANZECC/ARMCANZ, 2000). The QWQGs are intended to address the need identified in the ANZECC Guidelines by providing guideline values that are specific to Queensland (Department of Environment and Heritage Protection, 2009).

1.5.2.1.1 Water quality in the Cooper creek basin

The availability of water quality data for the Cooper creek basin is extremely poor compared to other river basins in Australia. There are three water quality monitoring sites (i.e. Bowen Downs, Longreach and Blackall) in the Galilee subregion that occur in the Cooper creek basin. Among the sites, continuous auto-sensor records of EC are available for Longreach station (since 1993). In addition there are three data logger sites in the Galilee subregion operated by the LEBRA programme since 2011. The LEBRA programme also collects occasional in situ measurements every year in its 50 sites within the Lake Eyre Basin, of which 20 are in Queensland.

The EC values in this basin are generally lower than the water quality objective trigger value. The 75th percentile baseflow trigger value for EC is 205 µS/cm for the Lake Eyre region (Department of Environment and Heritage Protection, 2009). A typical example of auto-sensor data at Longreach gauging site is shown in Figure 10 for 2005 to 2013. Gaps in the measured EC auto-sensor dataset represent periods where data were not collected due to either periods of no flow or monitoring equipment failure. EC varies between 44 to 258 µS/cm with a mean of 155 µS/cm. The median EC for baseflow is about 200 µS/cm and for high flow it is 100 µS/cm with an overall median of 157 µS/cm, however occasional high EC values occur anomalously at mid-flow ranges, particularly between 0.1 and 10 m^3/s (Department of Environment and Resources Management, 2011). These may be the result of the ‘first flush’ of a flow event after a dry period, where accumulated salts are cleared from the intermittently flowing watercourse. In general EC levels are low and stable at each of the gauging stations but subject to occasional high pulses at some sites. Data from the LEBRA logger sites also showed a general pattern of increasing EC throughout the low or no flow periods, followed by sharp lowering during high-flow events. At some sites there is a distinct initial rise in EC when the first flood water arrives (Cockayne et al., 2013).

Turbidity in this basin is generally high and subject to varying trends across the basin as a result of local influences. It appears to reverse from a declining trend in the north of Cooper Creek, to an increasing trend before crossing the Queensland–South Australia border (Department of Environment and Resources Management, 2011). Due to the tendency towards forming isolated waterholes during the extended dry seasons in this basin, differing turbidity trends may be more representative of local influences than generally deteriorating water quality further downstream (Department of Environment and Resources Management, 2011). In situ measurements at 17 sites (during spring 2011 and autumn 2012) show the turbidity varies from 4 to 354 NTU (Nephelometric Turbidity Unit), with a mean of 124 NTU across the Cooper creek basin (Cockayne et al., 2013).

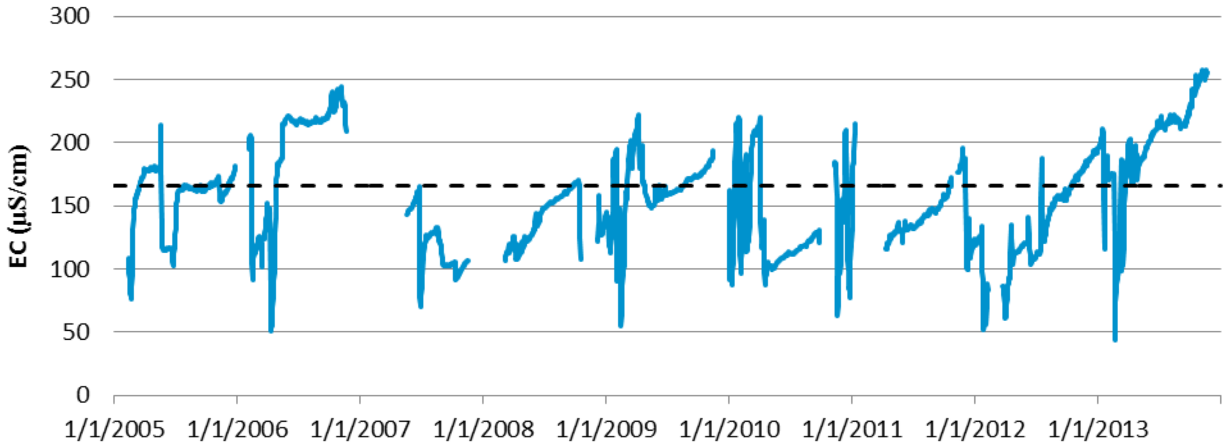

Figure 10 Observed electrical conductivity at gauging station GS 003202A, Thomson River at Longreach for the Galilee subregion

The dashed line (---) shows the water quality objective trigger value.
Data: Queensland Department of Natural Resources and Mines (Dataset 1)

1.5.2.1.2 Water quality in the Flinders river basin

The availability of water quality data for the Flinders river basin is very limited. In the northern part of the Galilee subregion, there is only one water quality monitoring site at Richmond. Continuous auto-sensor data have been available for this site since 2000. In addition some sampled data are also available for Richmond under the SWAN programme.

At Richmond, EC is quite variable at 150 µS/cm during high flows, commonly ranging up to 450 µS/cm as flow declines during dry conditions. Under the Queensland Water Quality Guidelines (QWQGs) the 75th percentile baseflow trigger value for EC is 435 µS/cm for the Gulf region (Department of Environment and Heritage Protection, 2009). Exceptionally high EC values exceeding 3000 µS/cm occasionally occur at flows of between 0.01 and 0.1 m^3/s (Department of Environment and Resources Management, 2011). A typical example of auto-sensor data at Richmond gauging site is shown in Figure 11 for 2005 to 2013. A long data gap can be seen between years. This represents periods where data were not collected primarily due to no flow conditions but sometimes due to monitoring equipment failure. The value of EC varies between 11 to 993 µS/cm with a mean of 397 µS/cm. The median EC for baseflow and high flow are 475 µS/cm and 210 µS/cm respectively, with an overall median of 366 µS/cm. EC values are generally higher for this basin compared to Cooper creek basin.

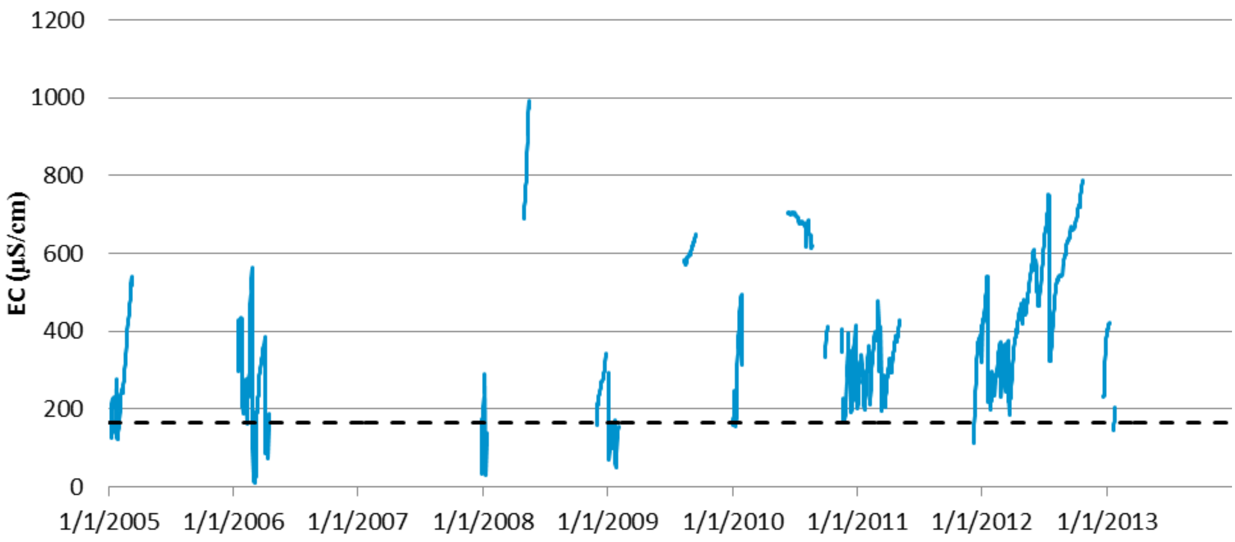

Figure 11 Observed electrical conductivity at gauging station GS 915008A, Flinders river basin at Richmond for the Galilee subregion

The dashed line (---) shows the water quality objective trigger value.
Data: Queensland Department of Natural Resources and Mines (Dataset 1)

From the limited available data a conclusion cannot be drawn on overall water quality. However, where data are available, water quality appears to be in good condition; that is below the water quality objective trigger value. Also, spatial variabilities in the magnitude and ranges of both EC and turbidity were noticed. Although there are some broad regional trends in EC, turbidity appears to be dominated by local influences. There is much uncertainty in condition and trend assessments (Department of Environment and Resources Management, 2011).

1.5.2.1.3 Water quality in the Burdekin river basin

In the Burdekin river basin, there is only one water quality monitoring station, situated at Violet Grove on Native Companion Creek. This is in the eastern part of the Galilee subregion, where most potential coal mining sites are located. It has maintained data records since 1999.

A typical example of gauge data at Violet Grove on Native Companion Creek is shown in Figure 12 for 2000 to 2013. The gap between data represents periods where data were not collected primarily due to no flow conditions. EC varies between 16 to 753 µS/cm with a mean of 285 µS/cm. The median EC for baseflow is about 273 µS/cm and for high flow it is 151 µS/cm with an overall median of 245 µS/cm. EC values are generally higher for this basin compared to Cooper creek basin but less than Flinders river basin.

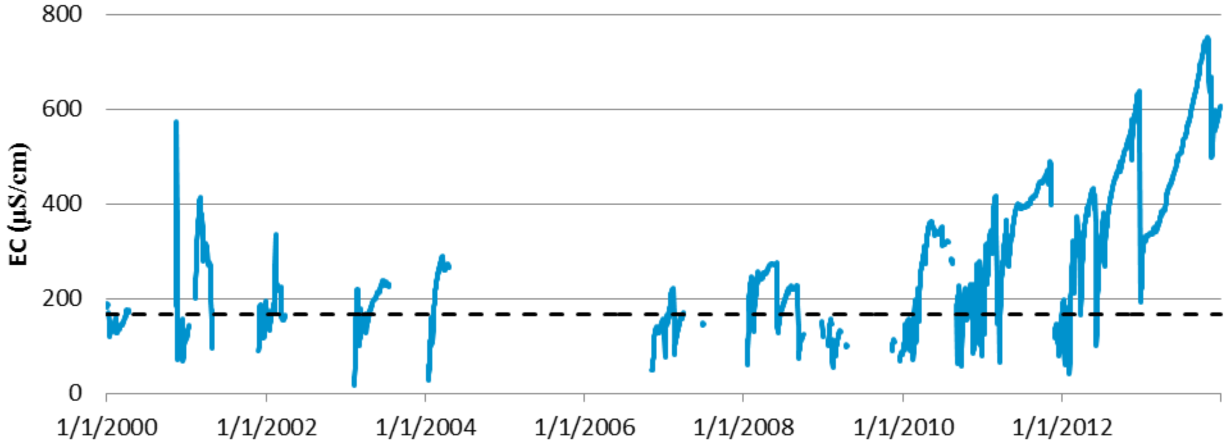

Figure 12 Observed electrical conductivity at gauging station GS 120305A, Burdekin river basin at Native Companion Creek at Violet Grove for the Galilee subregion

The dashed line (---) shows the water quality objective trigger value.
Data: Queensland Department of Natural Resources and Mines (Dataset 1)

The temporal trends observed in the EC of river sites are likely linked to the local climate and flow regime. The lower EC levels were present at the end of the wet season during which time the heavy rainfall would have caused dilution of the salts present in the river. The observed increase in EC as the dry season progressed is likely related to the cumulative effects of the evapo-concentration of the salts and groundwater inputs.

As a part of the Alpha Coal Project, water quality parameters in the upper Belyando river catchment were investigated by Hancock Prospecting Pty Ltd based on available EC and turbidity data from 1978 to 2010. The 20th and 80th percentile values for the gauging site are 105 and 213 µS/cm respectively (Hancock Prospecting, 2010). Under the QWQGs the 75th percentile baseflow trigger value for EC is 170 µS/cm for the Belyando river catchment (Department of Environment and Heritage Protection, 2009).

Turbidity was found to be generally stable across the catchment (Department of Environment and Resources Management, 2011) but it is relatively high compared to Cooper creek basin. The median, 20th percentile and 80th percentiles turbidity values are 200, 57 and 452 NTU respectively (Hancock Prospecting, 2010).

1.5.2.1.4 Gaps

Water quality data for the surface water systems in the Galilee subregion is very limited in terms of data points and number of data. It is therefore difficult to draw a conclusion on overall quality based on available data.

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Dataset 1 Queensland Department of Natural Resources and Mines (2014) Galilee surface water quality gauge data QLD DNRM 2014 v01. Bioregional Assessment Source Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/8cf9d2f5-3f57-4ca4-ab85-9cec9a731cb1.

1.5.2.2 Groundwater

This product provides a baseline assessment of groundwater quality in the Galilee subregion with a focus on salinity, and information on selected trace elements. Water quality is assessed against national guidelines provided by the National Health and Medical Research Council (NHMRC/NRMMC, 2011) and the Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ, 2000).

Before an assessment of groundwater quality can be carried out it is necessary to have a conceptual understanding of hydrologic connectivity between different geological units. To assess the water quality of groundwater in the Eromanga and Galilee geological basins, which together comprise the subsurface geology of the Galilee subregion, geological units were grouped together into hydrogeologic units based on the current conceptual understanding of the hydrodynamics in the subregion (see companion product 1.1 for the Galilee subregion (Evans et al., 2014)). For the Eromanga Basin the hydrogeologic units determined are:

- the Winton-Mackunda Formation – which was not grouped with other units
- Allaru Mudstone, Toolebuc Formation and Wallumbilla Formation: an aquitard separating shallow aquifers from deeper confined systems. Referred to as the Allaru-Wallumbilla grouping
- Wyandra Sandstone Member, Cadna-owie Formation, Hooray Sandstone: a confined aquifer. Referred to as the Wyandra-Hooray grouping
- Westbourne Formation, Adori Sandstone, Birkhead Formation: an aquitard referred to as the Westbourne-Birkhead grouping
- Hutton Sandstone, Boxvale Sandstone Member, Precipice Sandstone: a confined aquifer referred to as the Hutton-Precipice grouping
- the Ronlow beds – which were not grouped with any other units
- Cenozoic rocks – which were separated into basaltic and sedimentary units based on differences in water chemistry. These are referred to as Cenozoic-Basaltic Volcanics, and Cenozoic-Sediments respectively.

For the Galilee Basin the hydrogeologic units determined were:

- the Clematis-Warang Sandstone – which was not grouped with any other units
- the Betts Creek beds – which were not grouped with any other units
- the Moolayember Formation – which was not grouped with any other units and is omitted from the summary below due to scarcity of data
- Rewan Group – which was not grouped with any other units and is omitted from the summary below due to scarcity of data
- Jochmus Formation, Jericho Formation and Aramac Coal Measures: a partial aquifer or leaky aquitard referred to as the Joe Joe Group.

Groundwater chemistry data for these hydrogeologic units were compiled from the Queensland groundwater bore database with some supplementary data from environmental impact statement (EIS) documents for coal developments in the Galilee Basin. Due to the potential for impacts on groundwater levels and quality to cross catchment divides, available groundwater data were considered for the entire subregion, rather than limiting the analysis to drainage boundaries within the subregion.

To assess the potential hazards associated with using groundwater in the subregion, groundwater chemistry data were compared to national guidelines for water quality in which a number of possible water uses were considered: human drinking water, stock drinking water and water for long-term irrigation (defined as up to 100 years).

Trigger values were taken from the Australian Drinking Water Guidelines (ADWG) (NHMRC/NRMMC, 2011) and the National Water Quality Management Strategy (NWQMS) (ANZECC/ARMCANZ, 2000).

Groundwater chemistry data were primarily collated from the Queensland groundwater database (Department of Natural Resources and Mines, 2014). This database contains data from bores drilled from the early 1890s through to the present. Over the decades there have been significant changes in how data from drill-holes are collected, as well as refinements in the general knowledge of the hydrogeology of the subregion. This can have implications for data quality.

In total, data for 5675 samples were available for the Galilee subregion. Of these, 4624 had sufficient stratigraphic data for a sample to be assigned to a hydrogeological unit. All samples had data for total dissolved solids (TDS), but only a fraction of samples had trace element analyses. The number of analyses for trace elements is discussed in Section 1.5.2.2.3.

1.5.2.2.1 Total dissolved solids

TDS trigger values were determined using ADWG values for human consumption and the NWQMS for stock water. The trigger values used for TDS are given in Table 12.

Table 12 Total dissolved solids trigger values

Water use	Total dissolved solids limit (mg/L)[a]	Source
Drinking water	1200	NHMRC/NRMMC (2011)
Stock	4000	ANZECC/ARMCANZ (2000, Table 4.3.1), upper limit for cattle with no adverse effects

[a]Assuming total dissolved solids is equal to 0.65 electrical conductivity

The range of TDS values in the dataset is shown in Table 13. The proportion of samples in exceedance of the different guidelines used can be seen in Table 14. TDS is highly variable in the subregion, with all hydrogeological units showing at least an order of magnitude difference between minimum and maximum values. Median values indicate that most groundwater in hydrogeologic units is appropriate for use as stock water, and water in many hydrogeologic units is appropriate for human consumption (on the basis of TDS). Relatively few units have a median below the threshold for irrigation water. Further discussion of the processes controlling TDS values and their implications will be provided in companion product 2.1 and companion product 2.3 for the Galilee subregion.

Table 13 Total dissolved solids range for hydrogeologic units in the Eromanga Basin and Galilee Basin sequences

Hydrogeologic unit	Minimum value (mg/L)	Maximum value (mg/L)	Mean (mg/L)	Median (mg/L)
Alluvium	59	8,292	1179	711
Cenozoic-Sediments	10	25,040	1426	880
Cenozoic-Basaltic Volcanics	364	4,091	894	782
Winton-Mackunda	79	20,400	3541	2917
Allaru-Wallambilla	170	12,735	2376	1222
Wyandra-Hooray	180	7,136	834	601
Westbourne-Birkhead	133	2,041	597	460
Ronlow beds	189	8,404	609	353
Hutton-Precipice	55	3,579	482	396
Clematis-Warang	103	3,290	574	471
Betts Creek beds	346	2,495	1078	951
Joe Joe Group	175	11,060	1607	928

Data: Bioregional Assessment Programme (Dataset 1)

Table 14 Total dissolved solids exceedance for hydrogeologic units in the Eromanga Basin and Galilee Basin sequences

Hydrogeologic unit	Number of samples	ADWG[a] exceedances (%)	Stock exceedances (%)
Alluvium	143	31%	6%
Cenozoic-Basaltic Volcanics	31	6%	3%
Cenozoic-Sediments	389	21%	6%
Winton-Mackunda	790	87%	34%
Allaru-Wallumbilla	240	52%	23%
Wyandra-Hooray	1303	25%	2%
Westbourne-Birkhead	274	15%	1%
Ronlow beds	289	8%	1%
Hutton-Precipice	870	7%	1%
Clematis-Warang	99	18%	8%
Betts Creek beds	128	30%	9%
Joe Joe Group	43	35%	12%
Total	**4624**	**32%**	**9%**

Data: Bioregional Assessment Programme (Dataset 1)
[a]Australian Drinking Water Guidelines

1.5.2.2.2 Total dissolved solids distribution

Total dissolved solids data for groundwater from bores were used to generate salinity trend maps for the aquifer groups. TDS are routinely measured in the lab as part of a groundwater sample analysis. This differs from EC, which is often used as a measure of salinity in the field.

The salinity trend maps were generated using the 'topo to raster' interpolation method in ArcGIS. This is an iterative finite difference interpolation technique, which allows for surface continuity in sparse datasets. The available salinity data does not represent a single snapshot of water quality at a specific time; rather they provide a general indication of variations in salinity across the subregion. Furthermore, there is likely to be variations in quality of the sample analyses used to create the maps due to the archival nature of the data. Factors affecting archival data can include: use of different analysis methods; improvements in analyses technology over time; analysis accuracy and precision; variations in sample collection methodologies, and different bore construction techniques and quality. The archival nature of the data used means that temporal variation in water chemistry may contribute to the range of values seen in the TDS surfaces. However, the total variability in TDS for each hydrogeologic unit is at least one, and sometimes up to three, orders of magnitude difference, thus any temporal variations are likely to be minor in comparison to spatial variability.

As a quality control measure, some bore data were excluded from construction of these surfaces. Where a single bore had groundwater with high TDS that was anomalous in relation to other bores nearby, or where a single bore had high groundwater TDS with no controls nearby, these bores were excluded from generation of the TDS surfaces. Anomalously high TDS values may represent bores where stratigraphic or screened interval information are suspected to be incorrect, where sample contamination has occurred, or where there were errors in analysis.

Distribution of bores is often limited to within the vicinity of outcrop areas. Results may also be skewed in part through clustering of bores in areas where there is high production due to the presence of relatively fresh water, or alternatively areas with higher salinity are likely to have fewer bores to constrain interpolation. Interpretation of the TDS surfaces should be considered with these uncertainties in mind, and these maps should be treated as an image of regional trends in salinity for the hydrogeologic units in the subregion rather than a predictive tool for determining water quality where there is little bore coverage. It should also be noted that TDS for each hydrogeologic unit is displayed with a different colour gradient dependent on the range of TDS in each hydrogeologic unit, meaning direct comparisons between the maps cannot be made. Using a single scale for all maps would have allowed for comparison between the different hydrogeologic units, but the variability in TDS of the fresher units would not be visible due to the very high TDS values in more saline units.

Allaru-Wallumbilla grouping

Groundwater in the Allaru-Wallumbilla grouping is generally fresh in the north and central parts of the subregion, with some areas of higher salinity (up to 12,654 mg/L TDS) away from outcrop areas around Charleville and on the Maneroo Platform (Figure 13).

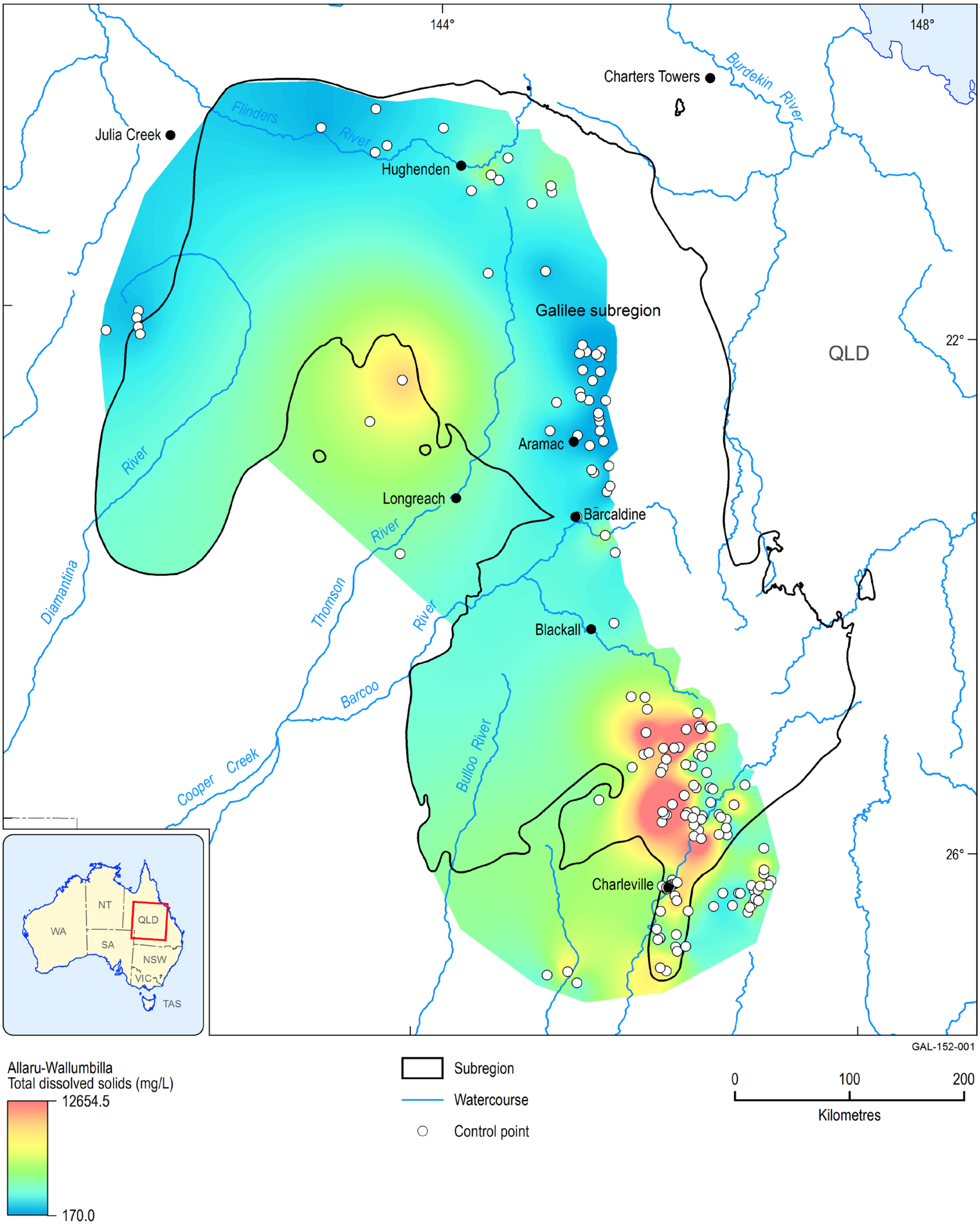

Figure 13 Allaru-Wallumbilla grouping total dissolved solids in the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Betts Creek beds

Bore distribution for the Betts Creek beds is largely limited to the eastern margin of the subregion where the Betts Creek beds and its correlatives outcrop (Figure 14). Away from the outcrop, groundwater quality data are generally only available from petroleum wells.

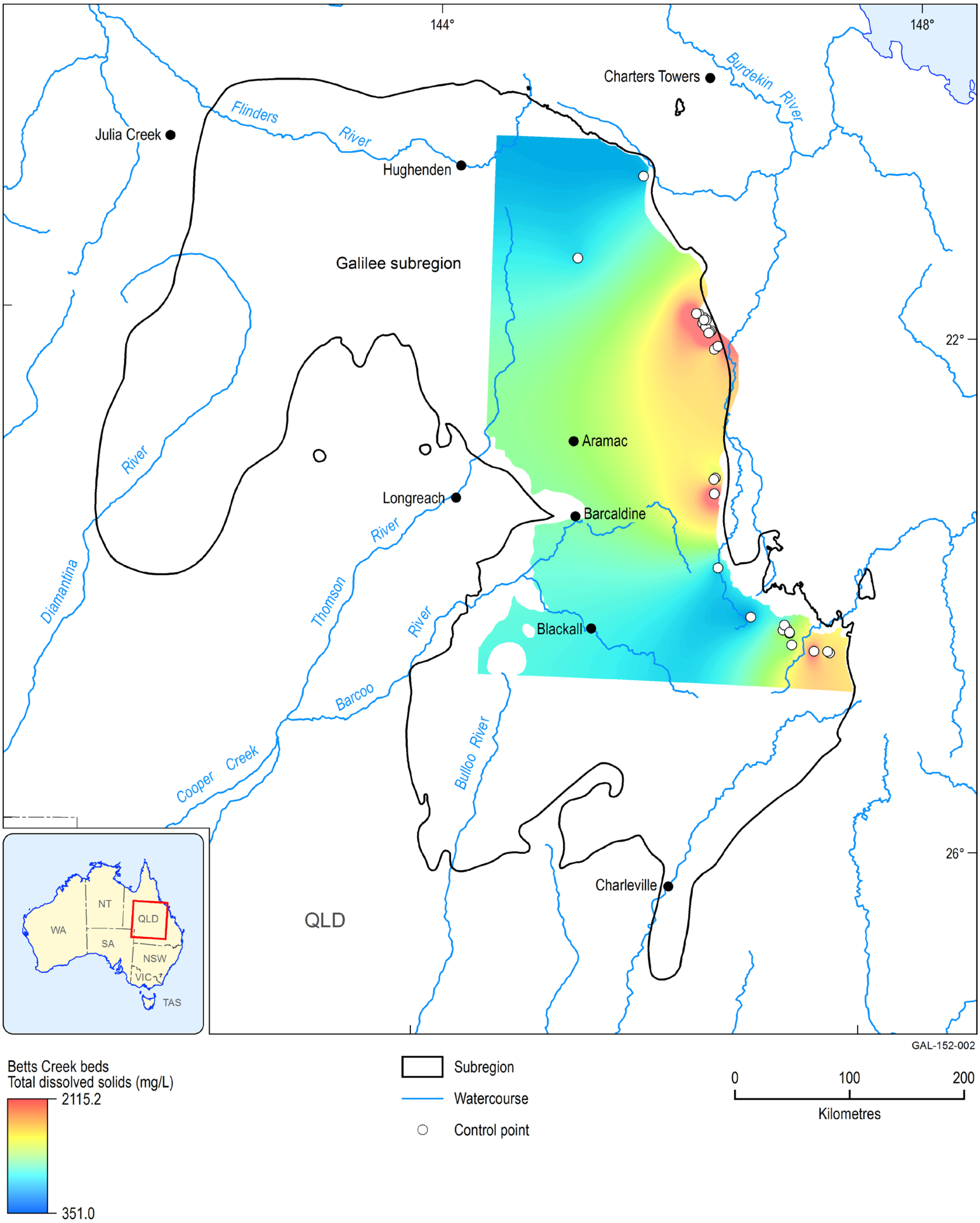

Figure 14 Betts Creek beds total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Clematis-Warang Sandstone

Groundwater in the Clematis-Warang Sandstone is generally fresh to brackish, with an area of higher salinity in the central part of the subregion, just east of Aramac (Figure 15).

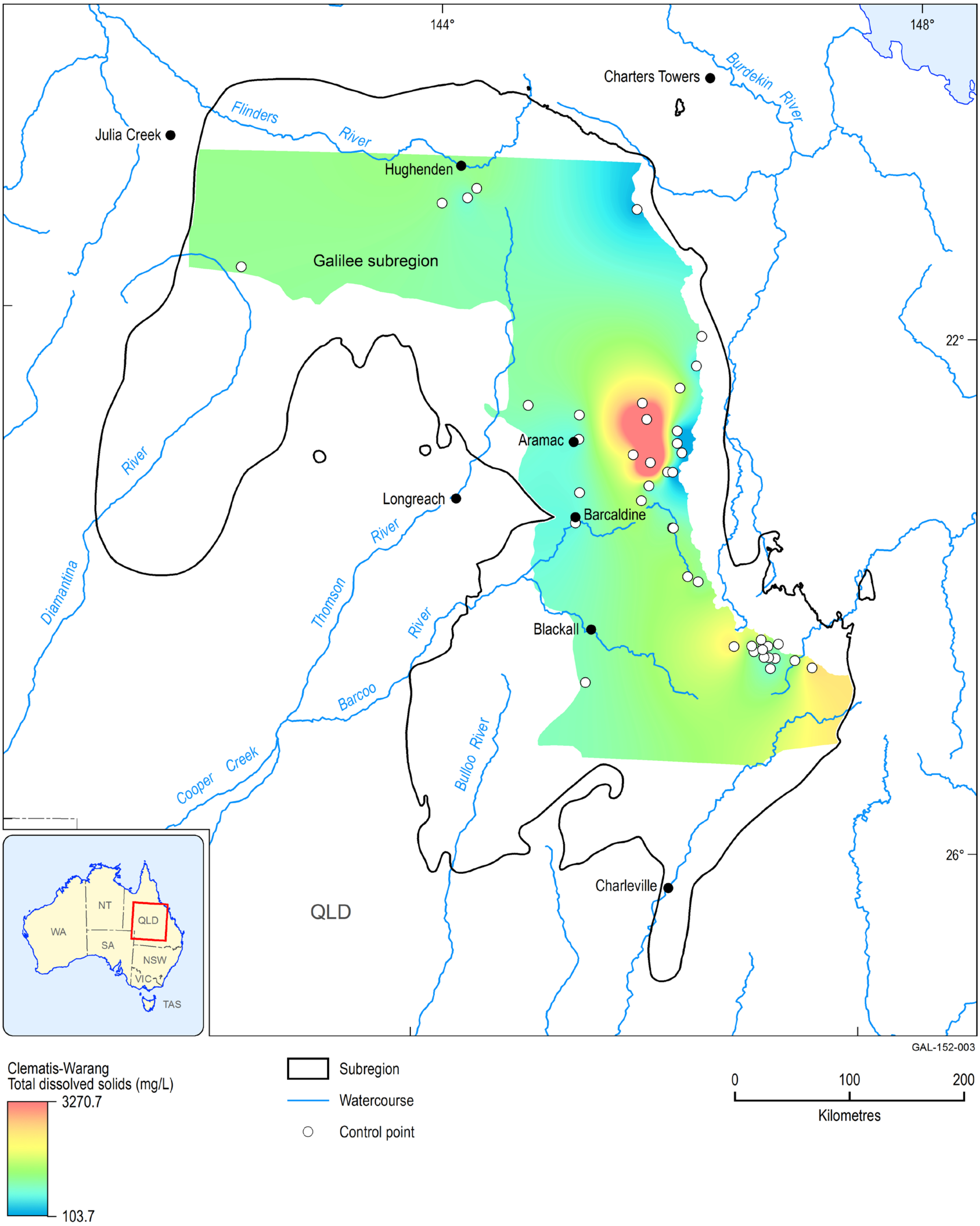

Figure 15 Clematis-Warang Sandstone total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Hutton-Precipice grouping

Groundwater in the Hutton-Precipice grouping is generally fresh around recharge areas along the eastern margin of the aquifer extent. Higher salinity groundwater occurs in deeper parts of the aquifer system, around the western margin of the Galilee subregion, or the vicinity of the Maneroo Platform (Figure 16).

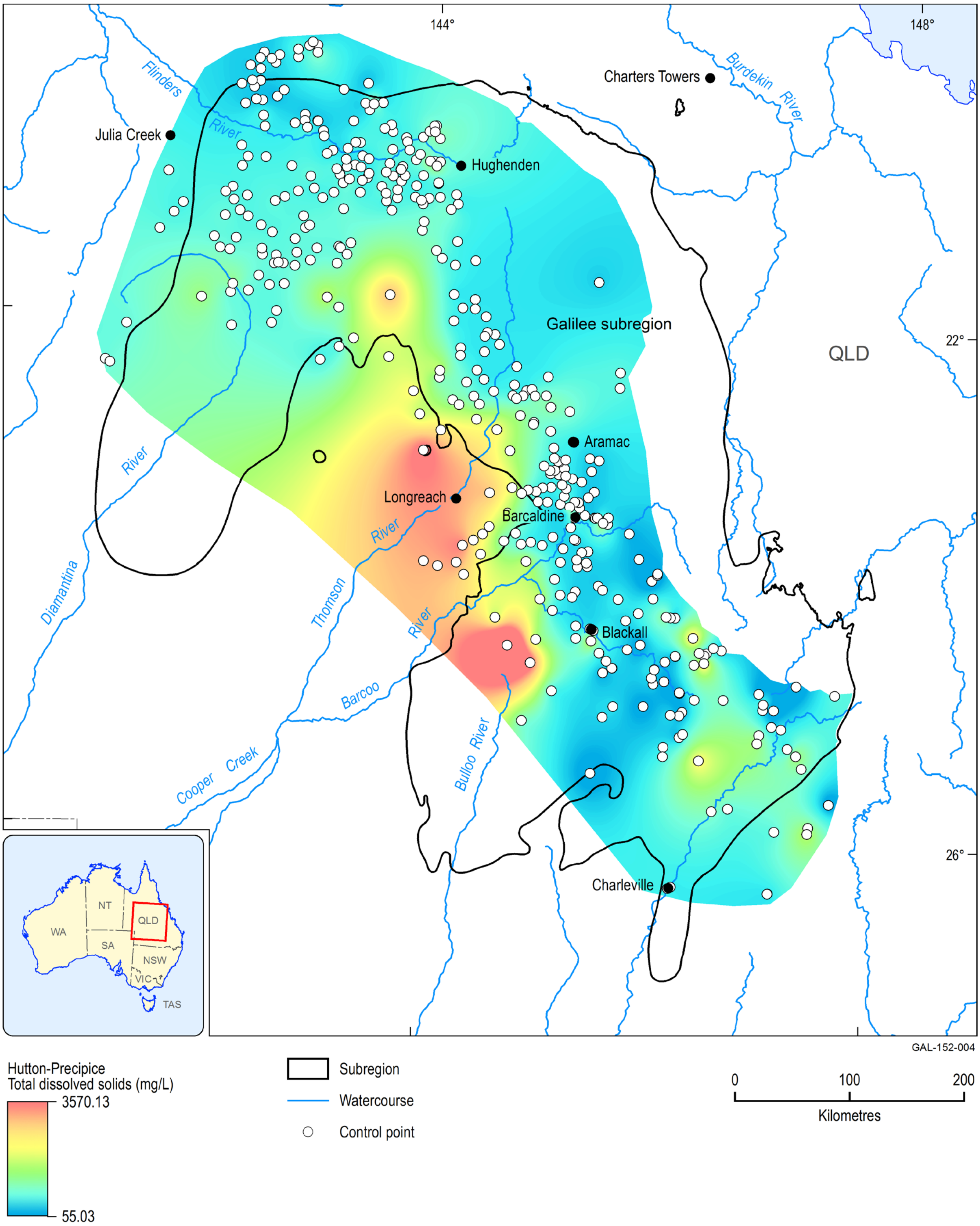

Figure 16 Hutton-Precipice grouping total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Westbourne-Birkhead grouping

Groundwater in the Westbourne-Birkhead grouping is relatively fresh near recharge areas around the eastern margin, with higher salinity areas occurring to the west, on the Maneroo Platform, and in the north of the subregion (Figure 17). Small saline areas, for example in the south-east, around single bores may be due to mis-assigned bores, sample contamination or inter-aquifer leakage.

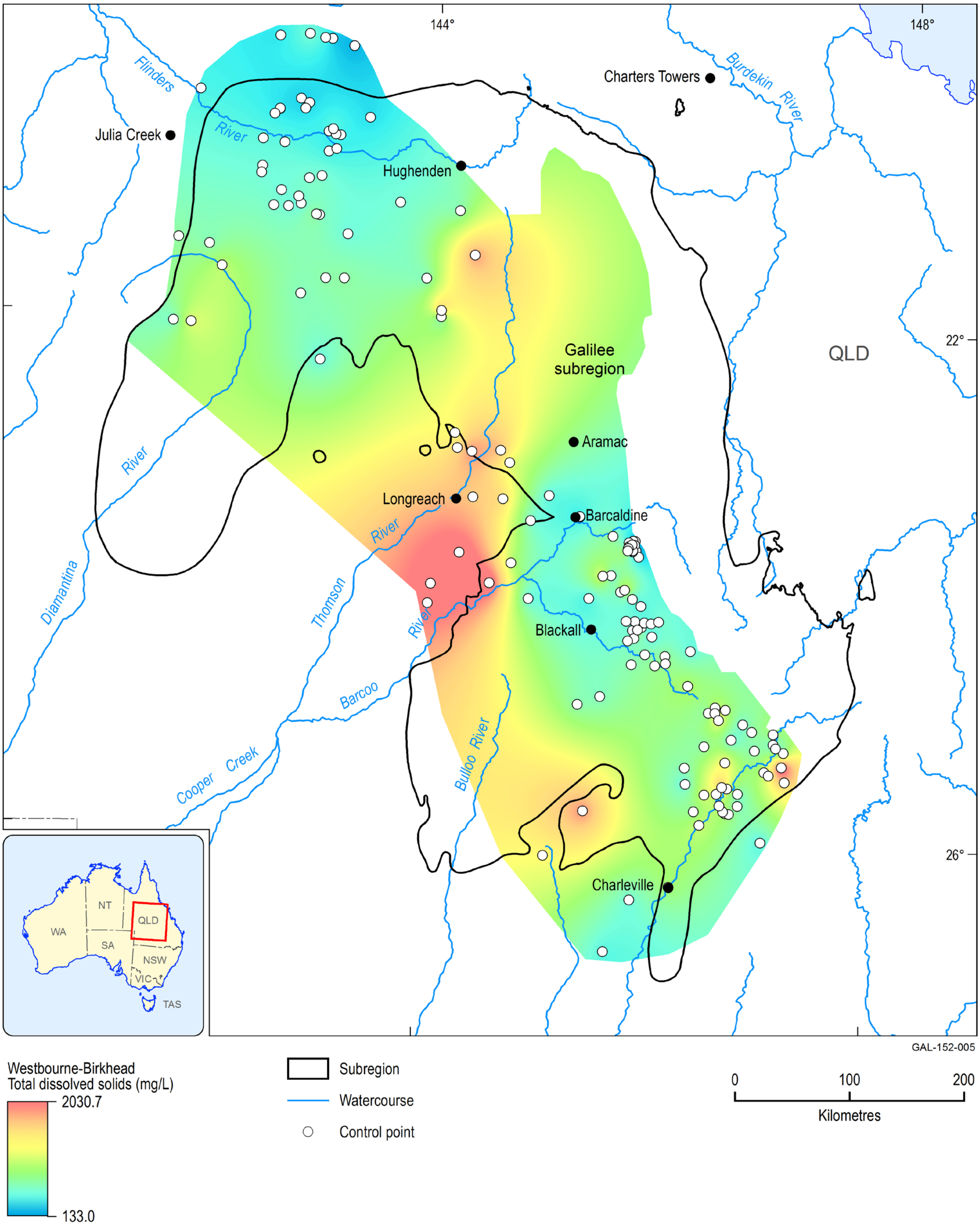

Figure 17 Westbourne-Birkhead grouping total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Winton-Mackunda Formation

Groundwater in the Winton-Mackunda Formation has variable TDS, with higher salinities occurring around the Maneroo Platform and in the south of the subregion (Figure 18).

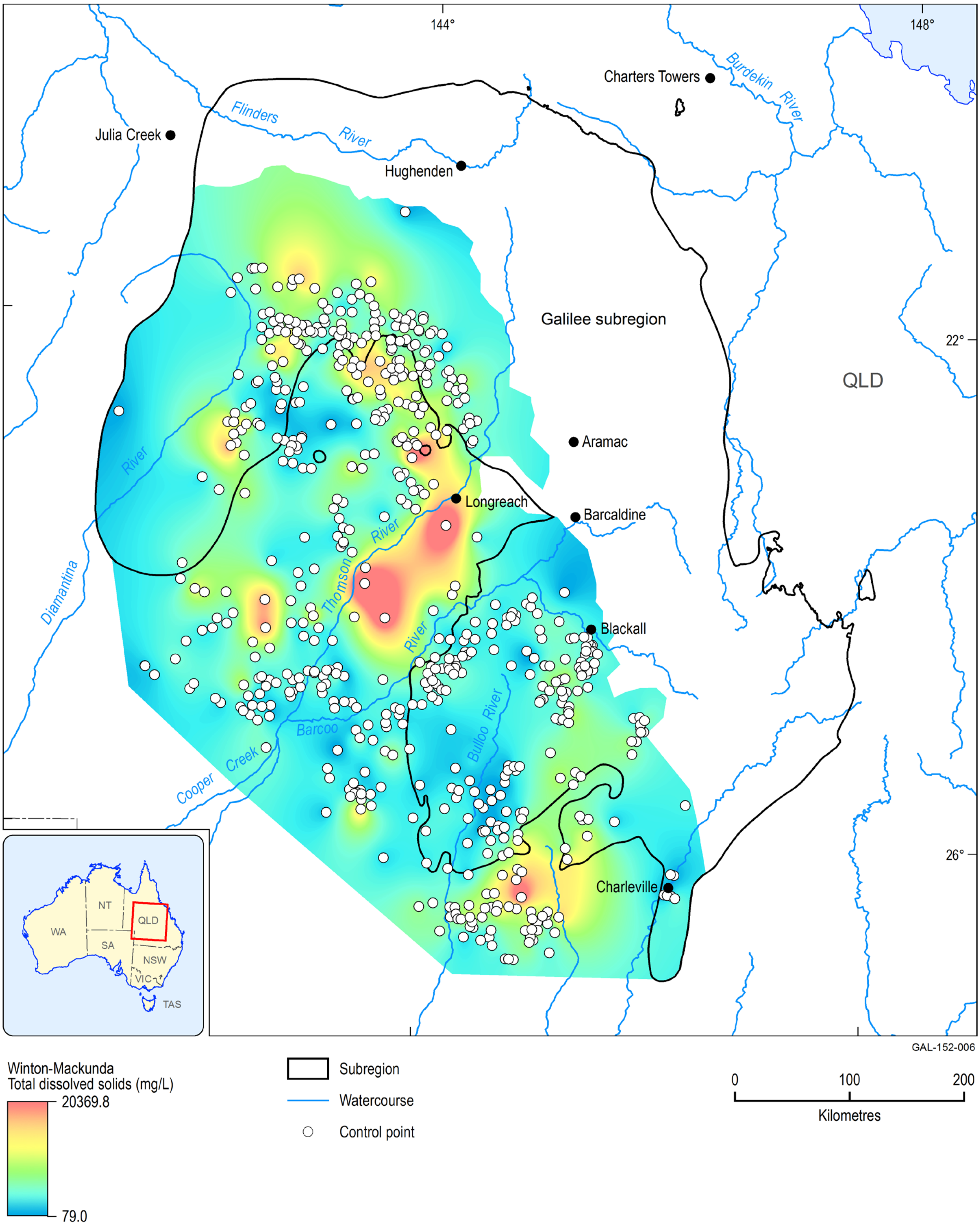

Figure 18 Winton-Mackunda Formation total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

Wyandra-Hooray grouping

Groundwater in the Wyandra-Hooray grouping is generally fresh, with areas of higher salinity in the Maneroo Platform (Figure 19). Small areas of higher salinity centred on single bores may be due to mis-assigned bores, sample contamination or inter-aquifer leakage.

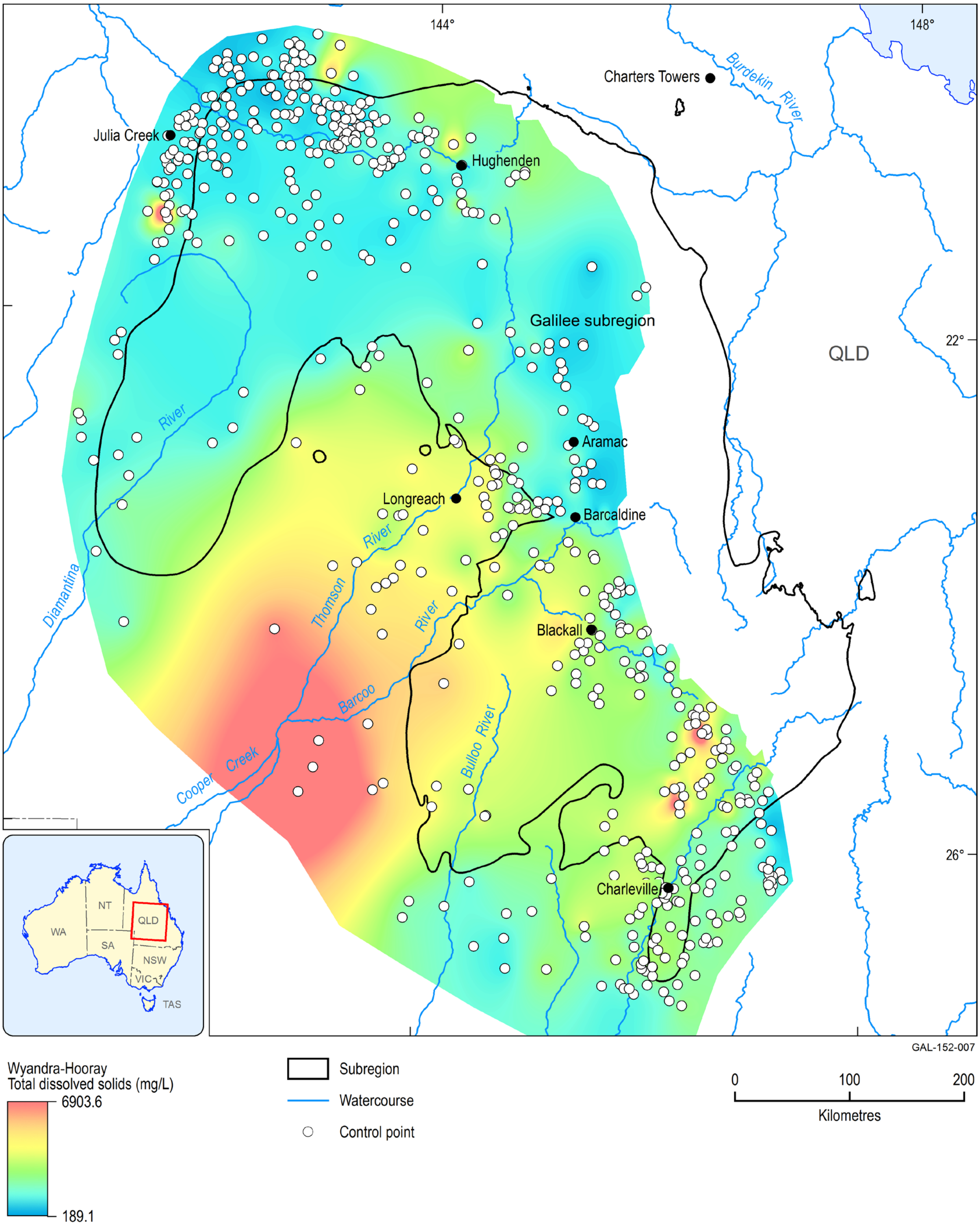

Figure 19 Wyandra-Hooray grouping total dissolved solids surface for the Galilee subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3)

1.5.2.2.3 Trace elements

Exceedances for the trace elements available in the dataset were determined using the ADWG for human consumption (National Health and Medical Research Council, 2011) and for stock water using trigger values in the NWQMS (ANZECC, 2000). Trace element trigger values and number of exceedances in the dataset are summarised in Table 15.

Table 15 Number of analyses and exceedances for trace elements in groundwater of Eromanga and Galilee basins

Parameter	Number of analyses	Fraction in exceedance of guidelines (%)	Minimum value (mg/L)	Maximum value (mg/L)	ADWG[a] trigger (mg/L)	Stock trigger[b] (mg/L)
Silver (Ag)	6	0%	0.001	0.003	0.00002	na
Aluminium (Al)	1075	3%	bd[c]	0.5	0.2[d]	5
Arsenic (As)	49	100%	0.001	0.3	0.001	0.0005
Boron (B)	1118	24%	bd	13.8	4	5
Cadmium (Cd)	3	0%	0.0001	0.0003	0.002	0.01
Cobalt (Co)	18	6%	0.001	0.062	na	1
Chromium (Cr)	26	0%	0.0001	0.03	0.05	1
Copper (Cu)	1053	1%	bd	1.78	2	1
Fluorine (F)	5640	19%	bd	15	1.5	2
Iron (Fe)	5576	5%	bd	148	0.3[d]	na
Mercury (Hg)	1	100%	0.018	0.018	0.001	0.002
Manganese (Mn)	5634	3%	bd	19.24	0.1[d]	na
Molybdenum (Mo)	33	15%	0.001	0.029	0.05	na
Nickel (Ni)	24	4%	0.001	0.032	0.02	1
Nitrate (NO_3)	5576	1%	0.1	505	50	na
Lead (Pb)	2	50%	0.001	0.042	0.01	0.1
Selenium (Se)	2	50%	0.004	0.02	0.01	0.02
Uranium (U)	12	58%	0.001	0.019	0.017	0.02
Zinc (Zn)	1107	1%	bd	7.19	3[d]	2

Data: Bioregional Assessment Programme (Dataset 4)
[a]Table 3.4.1 in Australian Drinking Water Guidelines
[b]Table 4.3.2 in National Water Quality Management Strategy
[c]bd = Below detection limit
[d]Aesthetic water quality trigger (not health related)
'na means 'data not available'

Other water quality concerns

Trace elements with a significant fraction of samples in exceedance of the guidelines include arsenic, fluorine and boron (Table 15, column 2). Trace elements with a small number of samples in exceedance of the guidelines include mercury, cobalt, molybdenum and selenium. However, the number of analyses for these elements is too low to allow any informed statement about potential hazards they may pose.

1.5.2.2.4 Gaps

There are few samples available for many of the hydrogeologic units, in particular the Betts Creek beds and the Clematis-Warang Sandstone. This makes assessing the spatial distribution of water quality difficult, and requires assumptions about water quality over large areas with few control points.

The quality of the hydrochemistry data available for this assessment is difficult to determine, as analytical uncertainties are not reported in the dataset. The dataset includes chemical analyses of differing ages, sometimes decades apart, which will have differing levels of accuracy and precision. Additionally, stratigraphic data are not available for many bores in the dataset. Screened intervals are unknown for some bores, and others were not assigned stratigraphic units in the database. Assigning these bores to stratigraphic units based on depth and local stratigraphic information introduces a considerable amount of uncertainty into the dataset. Useful further work could include cross checking the stratigraphic position assigned to bores with limited stratigraphic information.

A number of potentially harmful trace elements have been omitted from consideration due to scarcity or absence of data. In general, suites of trace element analyses are only available from in the vicinity of coal resource development proposals. Some elements have data available for only one or two hydrogeologic units, while others have no data available at all. Trace elements for which there was only limited data are As, Co, Cd, Cr, Pb, Hg, Ni, U, Se and Mo. Trace elements for which there are no data are Ba, Be, Li, Rn, Sb and V.

Where analyses have been performed several elements have concentrations above ADWG or NWQMS triggers, but the current dataset is too sparse to make any informed statement about trigger value exceedances of these elements. It is possible that hazards will go unidentified due to data scarcity. Further work defining the range and distribution of trace element concentrations in the subregion is required to fully understand the potential hazards they pose.

The Queensland Department of Environment and Heritage Protection is establishing environmental values and water quality objectives under the Environmental Protection (Water) Policy 2009 for all Galilee subregion surface and groundwaters, including the Burdekin river basin (including the Belyando, Suttor, Cape and Bowen sub-basins), the Flinders river basin and Thomson and Barcoo rivers sub-basins during 2015 and 2016 (J Fewling (EHP), 2015, pers. comm.).

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Dataset 4 Bioregional Assessment Programme (2014) QLD Hydrochemistry QA QC GAL v02. Bioregional Assessment Derived Dataset. Viewed 9 September 2015, http://data.bioregionalassessments.gov.au/dataset/e3fb6c9b-e224-4d2e-ad11-4bcba882b0af.

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