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 Clarence-Moreton bioregion

Product 1.5 from the Clarence-Moreton Bioregional Assessment

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

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Authorship is listed in relative order of contribution.

Cover photograph

Rainforest waterfall in Border Ranges National Park, NSW, 2008

Credit: Liese Coulter, CSIRO

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- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.

Introduction

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

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made 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.

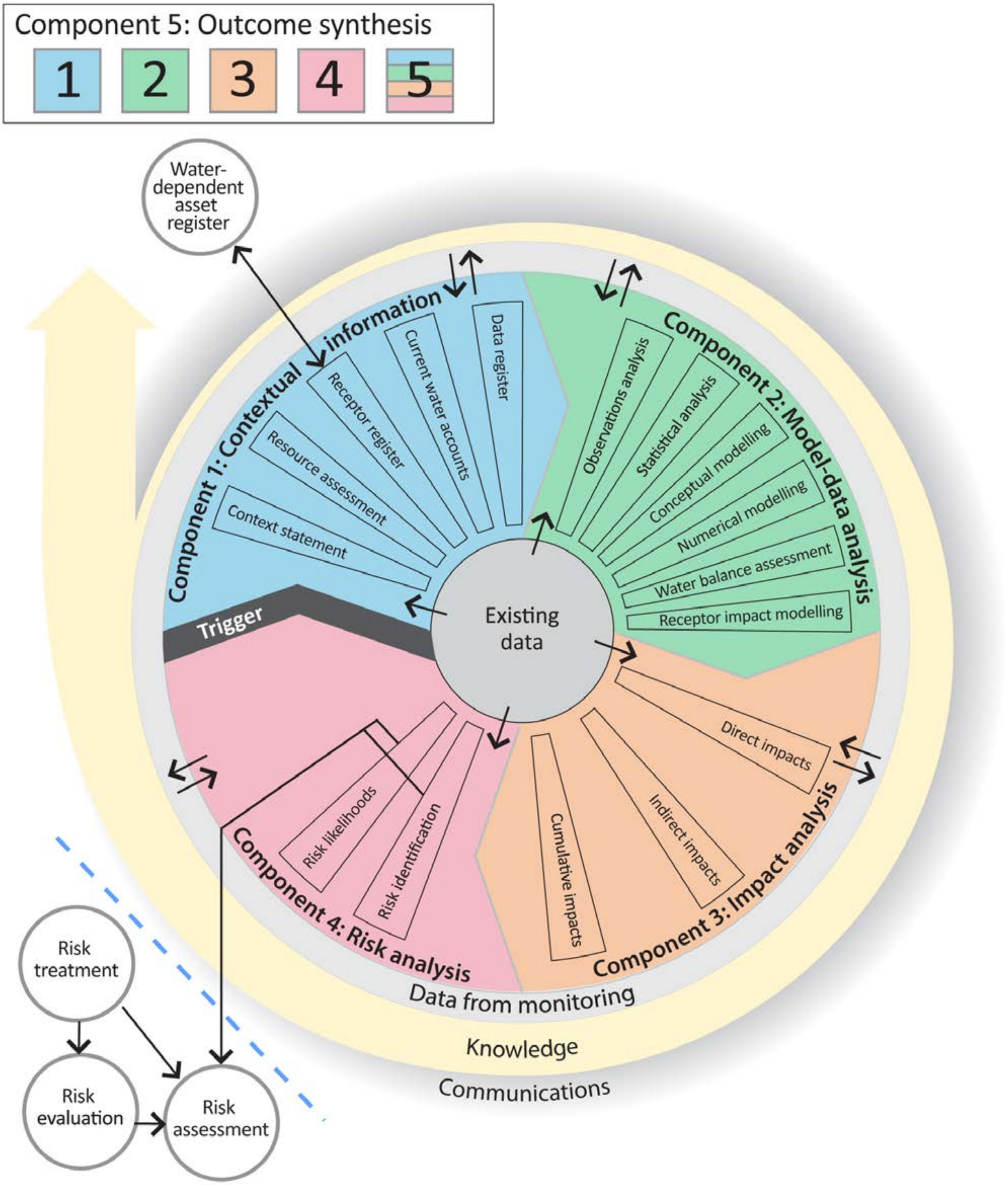

Figure 1 Schematic diagram of the bioregional assessment methodology

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.

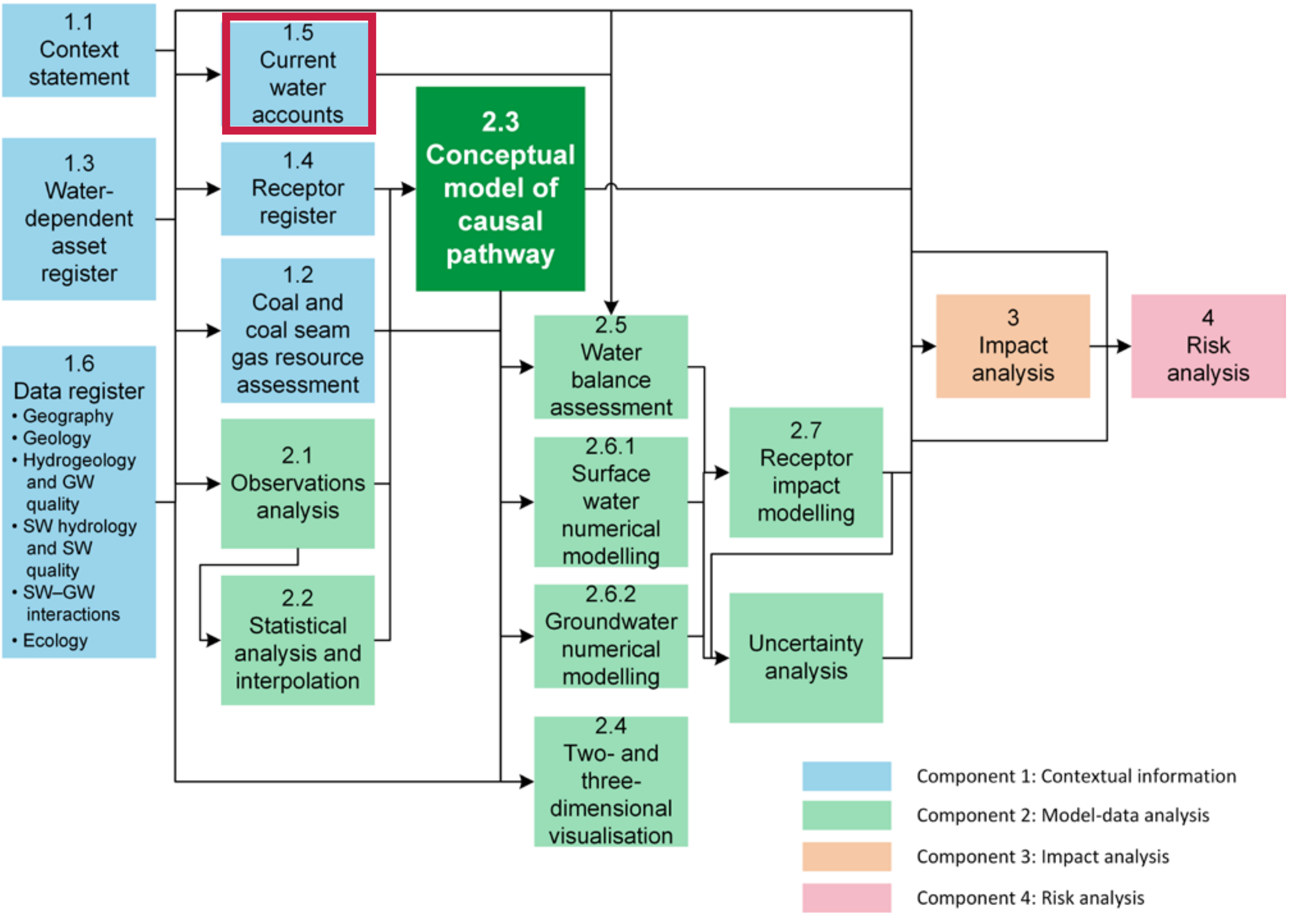

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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

Table 2 Technical products delivered by the Clarence-Moreton Bioregional Assessment

For each subregion in the Clarence-Moreton 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 Clarence-Moreton bioregion	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 Clarence-Moreton bioregion	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	Not produced
Component 3: Impact analysis for the Clarence-Moreton bioregion	3-4	Impact analysis	5.2.1	PDF, HTML
Component 4: Risk analysis for the Clarence-Moreton bioregion		Risk analysis	2.5.4, 5.3	
Component 5: Outcome synthesis for the Clarence-Moreton 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 Clarence-Moreton 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.
- 'Not produced' indicates that the product was not developed. A webpage explains why and points to relevant submethodologies (Table 1).

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 151.0° East for the Clarence-Moreton 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 created date. Where a created date is not available, the publication date or last updated 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 20 November 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 Clarence-Moreton bioregion

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

Current coal and coal seam gas (CSG) development and exploration, which may impact water resources are primarily located in an area to the west of the town of Casino in the Richmond river basin. The surface water accounts were only determined for the Richmond river basin as this is the area being modelled. The Richmond river basin includes the Richmond and Wilsons rivers with small contributions from Eden Creek and Shannon Brook. There are two main reservoirs (Toonumbar and Rocky Lake) and a few small dams and weirs that supply water to agricultural, domestic and municipal users. The combined storage volume in the main reservoirs is 25 GL. The main surface water resource of the Richmond river basin is the Richmond River. In the Richmond river basin, permits to extract surface water amount to 99.8 GL/year.

The groundwater accounts were also restricted to the model domain of the numerical groundwater model, whose boundaries were constrained by knowledge of the geology, previous studies in the Clarence-Moreton Basin and Surat Basin, and common modeling practise. The analysis lacks measurement of actual groundwater usage, hence, it was estimated using the allocation data in the NSW state groundwater database (Bioregional Assessment Programme, Dataset 2 in Section 1.5.1.2). Those estimates indicated that 88.1% of the bores have allocations of less than or equal to 5 ML/year. Of the estimated water usage, 49.5% and 42% is allocated for irrigation and domestic/stock bores, respectively. The Richmond River alluvium and Lamington Volcanics represent the two main groundwater supply aquifers with much smaller allocations in the Grafton Formation and the Walloon Coal Measures. The NSW water sharing plans are developed to preserve surface water and groundwater by balancing the competing demands of different types of water usages. They are defined based on surface river basins and groundwater systems.

1.5.1.1 Surface water

The modelling boundary (as defined in companion products 2.6.1 and 2.6.2 for the Clarence-Moreton bioregion) is smaller than the preliminary assessment extent (PAE) since the coal resource development pathway is confined to an area within the Richmond river basin. The surface water modelling area is therefore restricted to within the Richmond river basin, for which the water accounts are being reported.

The Richmond River, located in far-north NSW, drains an area of 7020 km^2 from its headwaters in the Border Ranges and the Richmond Range. Further details on the Richmond river basin, including its location in the Clarence-Moreton bioregion, are given in companion product 1.1 for the Clarence-Moreton bioregion (Rassam et al., 2014). Current coal and CSG development and exploration, which may impact water resources are primarily located in the western part of the subregion (west of Casino). Figure 3 shows a detailed stream network, storages, irrigated land and historical coal mines in the Richmond river basin. There is a single mapped mineral deposit just outside the Richmond river basin, which is the Tabulam iron ore deposit (Figure 3). The major tributaries to the Richmond River upstream of Casino include Iron Pot and Eden creeks (Figure 3). The major tributaries to the Richmond River downstream of Casino include Wilsons River and Coopers, Terania, Leycester, Sandy and Bungawalbin creeks and Shannon Brook. There are numerous other minor tributaries.

Water storages in the basin include Toonumbar Dam (capacity 11 GL excluding flood storage), which stores water for hydro-power, irrigation, stock and town water; and Rocky Lake (capacity 14 GL excluding flood storage), which provides water for the towns of Lismore and Ballina. There are four weir structures on the Richmond River near Casino and one on the Wilsons River that provides water to Mullumbimby in the Brunswick river basin. Irrigated pastures are found around the alluvial flats of the Richmond and Wilson rivers and groundwater is used to irrigate fruit and nut crops on the Alstonville Plateau. With only two main water storages and a few weirs, most of the flows in the Richmond river basin are largely unregulated.

The remainder of this product describes:

- water volumes held in surface water storages
- surface water permits and allocations
- data gaps.

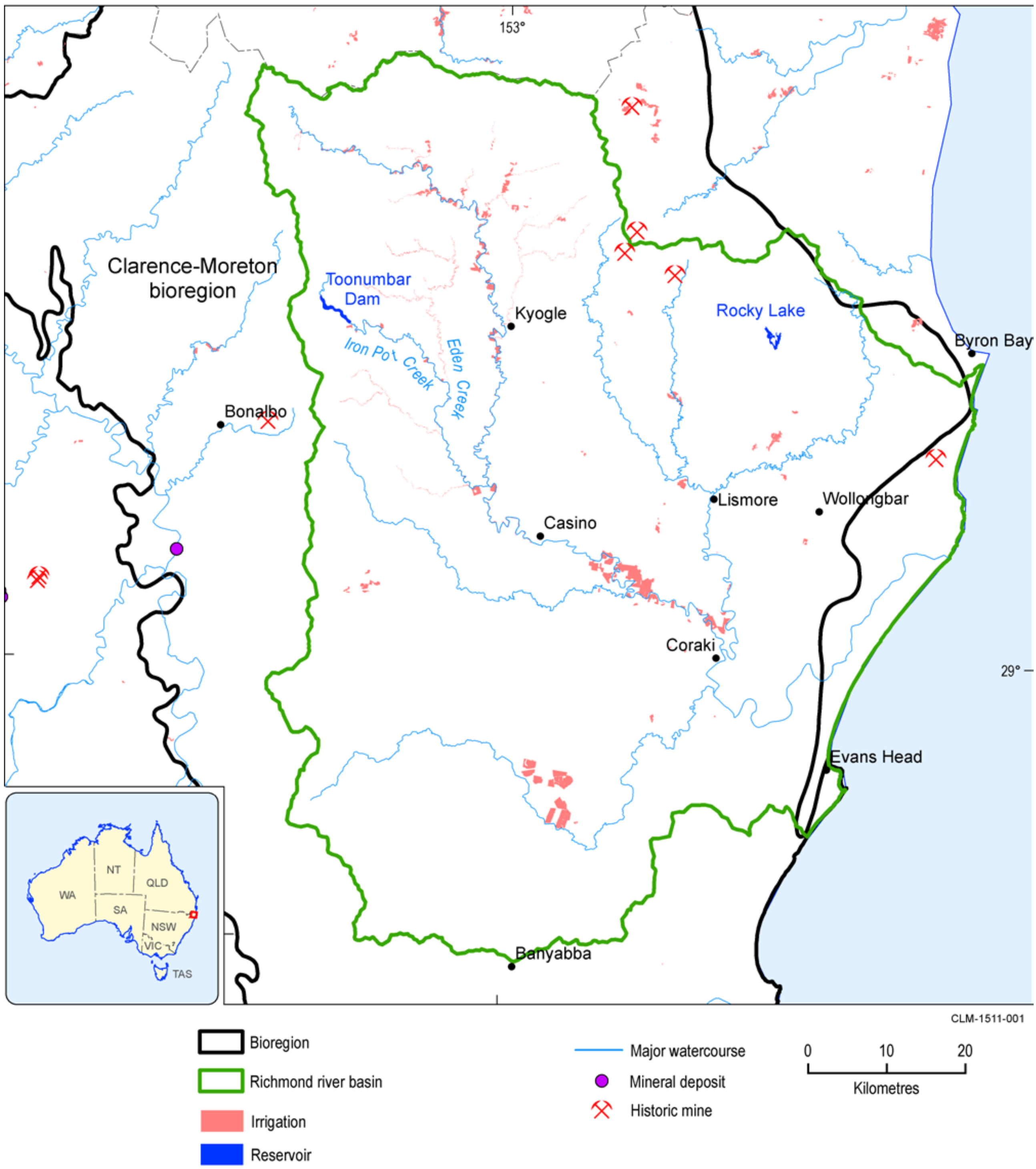

Figure 3 Tributaries of the Richmond River, town centres, irrigation areas and historical coal mines

Data: Streamflow gauge locations obtained from NSW Office of Water (2015). Coal mine and resource data sourced from the OZMIN database (Geoscience Australia, 2013), information current as of December 2012

1.5.1.1.1 Water accounts in the Richmond river basin

With only two main water storages (Toonumbar Dam and Rocky Lake) and a few weirs, flows in the Richmond River are largely unregulated. Storage volumes are summarised in Table 3 and Table 4. The mean daily volume (2004–05 to 2011–12) was 10.59 GL (range 7.29 to 14.05 GL) in Toonumbar Dam. The mean daily volume (2008–09 to 2011–12) was 13.85 GL (range 9.11 to 15.52 GL) in Rocky Lake. The combined mean daily storage was 24.44 GL.

Inflows to the Toonumbar Dam are ungauged but flows are measured below the dam at Iron Pot Creek at Toonumbar (203023). Losses from the Toonumbar Dam storage occur through continual controlled stream releases to supply downstream irrigation and flood releases when storage capacity is exceeded. Mean flows at Iron Pot Creek at Toonumbar were 36.9 GL/year (range 4.1–83.5 GL/year). Other sources of outflow such as evapotranspiration from the reservoir surface also account for losses from the storage.

Table 3 Storage volumes at the start (July) of the water year, inflows and outflows for Toonumbar Dam (11 GL capacity excluding flood storage) in the Richmond river basin

	Volume (GL) (July 1)	Minimum volume (GL)	Maximum volume (GL)	Outflow (GL/y)
2004–05	11.01	7.81	11.01	5.1
2005–06	9.15	7.29	11.70	16.8
2006–07	11.01	9.28	11.12	4.1
2007–08	9.30	8.45	14.05	65.0
2008–09	11.13	10.95	12.52	42.6
2009–10	11.23	10.22	11.85	19.6
2010–11	11.13	10.87	12.73	83.5
2011–12	11.22	11.00	12.18	58.2

Data: Outflow volumes for Toonumbar Dam were obtained from NSW Office of Water (2015). Volumes were obtained from the Bureau of Meteorology (Dataset 1)

Table 4 Storage volumes at the start (July) of the water year for Rocky Lake (14 GL capacity excluding flood storage) in the Richmond river basin

	Volume (GL) (July 1)	Minimum volume (GL)	Maximum volume (GL)
2004–05	NA	NA	NA
2005–06	NA	NA	NA
2006–07	NA	NA	NA
2007–08	NA	NA	NA
2008–09	14.01	9.11	15.52
2009–10	14.08	11.39	14.56
2010–11	14.01	13.20	15.22
2011–12	14.11	13.61	15.21

NA = data not available
Data: Volumes were obtained from the Bureau of Meteorology (Dataset 1)

Surface water licences and entitlements

In the Richmond river basin, licences amount to 99,881 ML/year. Table 5 summarises surface water licences by purpose and Table 6 by type and water source (definitions of some terms are given in Table 8 of Section 1.5.1.2). Figure 4 shows the geographic distribution and extraction volumes for each licence.

Table 5 Licences grouped by purpose in the Richmond river basin

Purpose	Number of licences	Volume (ML/y)
Town Water Supply	8	6,397
Town Water Supply, Stock	4	2,620
Town Water Supply, Stock, Industrial, Domestic	6	12,358
Town Water Supply, Industrial	4	544
Town Water Supply, Domestic	2	120
Recreation - Low Security	4	100
Stock	5	15
Stock, Industrial, Irrigation	3	573
Stock, Irrigation	14	729
Stock, Irrigation, Domestic	62	745
Stock, Domestic	31	123
Stock, Domestic, Irrigation	10	101
Stock, Domestic, Farming, Irrigation	6	190
Stock, Farming	2	8
Commercial	2	4
Industrial	6	226
Industrial, Stock, Domestic	2	10
Industrial, Irrigation	14	2,547
Industrial - Sand & Gravel	1	37
Irrigation	1199	56,974
Irrigation, Recreation - Low Security	1	41
Irrigation, Stock	2	18
Irrigation, Stock, Domestic	6	141
Irrigation, Industrial	2	795
Irrigation, Industrial (Low Security)	2	66
Irrigation, Domestic	58	653
Irrigation, Farming	129	9,384
Domestic	82	198
Domestic, Stock	4	16
Domestic, Stock, Irrigation	6	45
Domestic, Irrigation	18	158

Purpose	Number of licences	Volume (ML/y)
Domestic, Irrigation, Stock	5	152
Farming	32	152
Farming, Stock, Domestic	2	9
Farming, Irrigation	39	2,723
Farming, Irrigation, Industrial	6	204
Farming, Domestic	10	17
Aquaculture	2	30
Aquaculture, Irrigation	2	168
Conservation of Water, Irrigation	7	345
Experimenal/Research	1	145
TOTAL	1801	99,881

Data: NSW Office of Water (Dataset 2)

Table 6 Licences grouped by river or creek in the Richmond river basin

Asset type	Water source	Number of licences	Volume (ML/y)
Basic Right	Alstonville Area	26	77
Basic Right	Bangalow Area	26	40
Basic Right	Coopers Creek	12	18
Basic Right	Coraki Area	4	9
Basic Right	Eden Creek	1	4
Basic Right	Evans River	1	1
Basic Right	Gradys Creek	3	6
Basic Right	Kyogle Area	5	50
Basic Right	Leycester Creek	5	67
Basic Right	Myall Creek	1	1
Basic Right	Richmond Regulated	4	6
Basic Right	Shannon Brook	4	15
Basic Right	Terania Creek	9	17
Basic Right	Tuckean Area	16	28
Basic Right	Upper Richmond River	4	9
Basic Right	Wyrallah Area	1	4
Water Access Right	Alstonville Area	182	7,474
Water Access Right	Bangalow Area	257	5,927
Water Access Right	Broadwater Area	3	360

Asset type	Water source	Number of licences	Volume (ML/y)
Water Access Right	Coopers Creek	169	5,708
Water Access Right	Coraki Area	203	17,917
Water Access Right	Doubtful Creek	12	185
Water Access Right	Eden Creek	18	524
Water Access Right	Gradys Creek	50	2,340
Water Access Right	Kyogle Area	163	10,265
Water Access Right	Lennox Area	2	42
Water Access Right	Leycester Creek	56	964
Water Access Right	Myall Creek	9	1,419
Water Access Right	Richmond Regulated	80	10,258
Water Access Right	Sandy Creek	6	342
Water Access Right	Shannon Brook	23	436
Water Access Right	Terania Creek	122	14,808
Water Access Right	Tuckean Area	164	4,961
Water Access Right	Upper Richmond River	55	2,232
Water Access Right	Wyrallah Area	105	13,367
	TOTAL	1801	99,881

Water access right refers to the right conferred by law to hold or take water from a water resource.
Data: NSW Office of Water (Dataset 2)

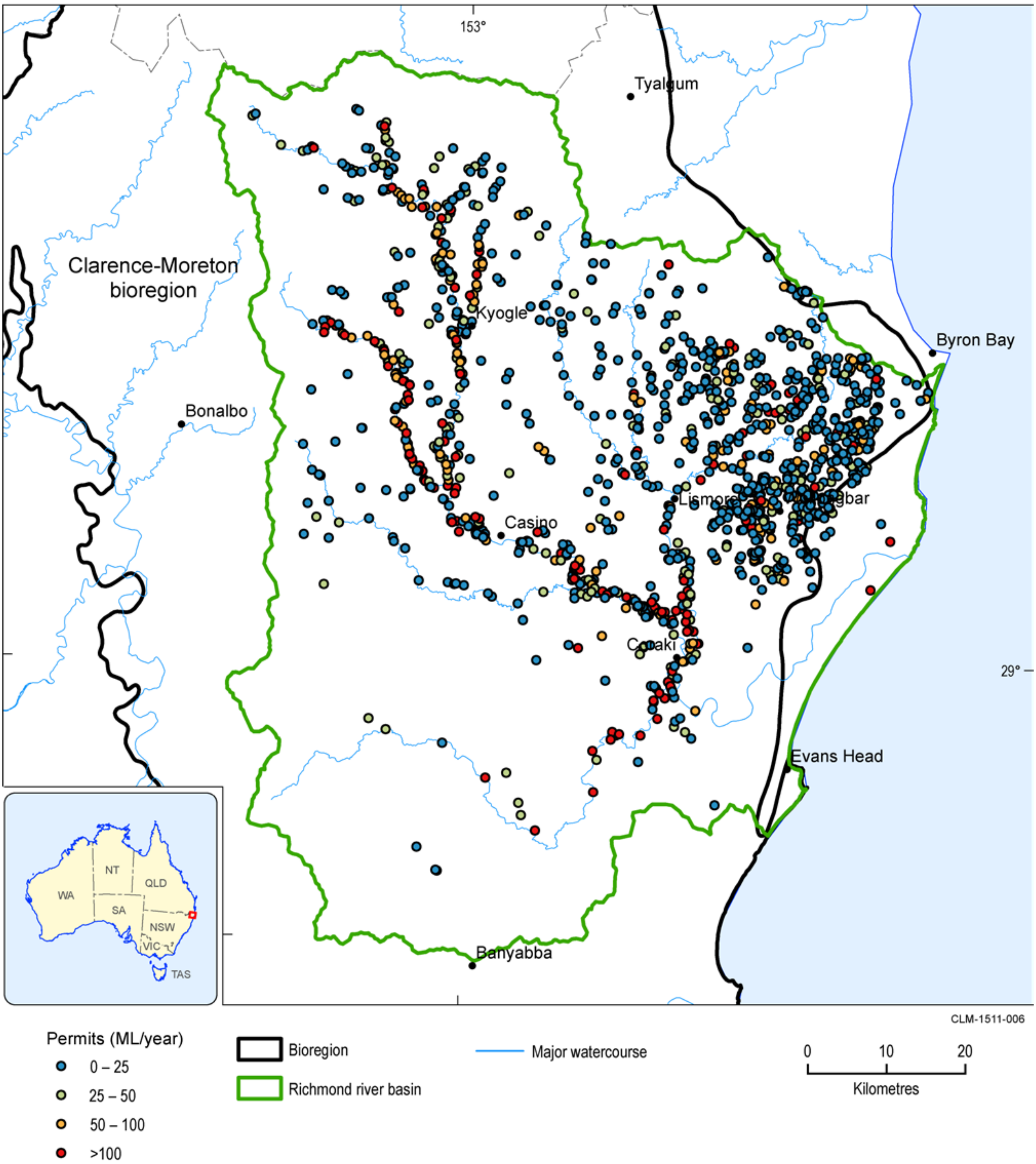

Figure 4 Location of surface water licences in the Richmond river basin (the colour scale indicates the amount of allocated water)

Data: NSW Office of Water (Dataset 2)

1.5.1.1.2 Gaps

There are several unknown water sources and volumes including:

- ungauged tributary inflow
- ungauged runoff
- surface water – groundwater interactions.

Some of the sources not included here are implicitly considered, for example, reservoir rainfall and evaporation would be reflected in changes in the storage volume.

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Datasets

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1.5.1.2 Groundwater

Analyses of the groundwater accounts were restricted to the area for which a groundwater model will be constructed. The model domain extent and its boundaries were defined based on the following criteria:

- The model's outermost boundaries were determined based on previous modelling studies in the Clarence-Moreton Basin (Parsons Brinkerhoff, 2013) and Surat Basin (QWC, 2012; Moore et al., 2014) and common modelling practice. They were placed to encompass the potential impact zone from previous studies and to be far enough from the coal seam gas development area, such that they do not interfere with the modelling results, that is, it eliminates boundary effects. The distance between the likely development centre and the model boundaries varies from approximately 30 to 70 km.
- Model boundaries should follow existing geological and/or hydrological boundaries.
- Important receptors within and/or close to the development area should be within the areal extents of the groundwater model.

The groundwater model covers a large part of the Richmond river basin, but extends beyond its western border (Figure 5). Hereinafter, the areal extent of the groundwater model is referred to as the model domain.

There are 3934 bores from the National Groundwater Information System (NGIS) (Bureau of Meteorology, Dataset 1) located within the model domain, 3096 of which have construction information that is required to assign bores to aquifers. Among the bores with screen and/or depth information, 145 bores are recorded as being inactive bores, that is, they are labelled as NON (non-functional), RMV (removed), DCM (decommissioned), PRP (proposed), RPL (replaced), or ABN (abandoned) for status (Bureau of Meteorology, Dataset 1). Note that bores in this analysis with unknown status are considered as being active to guarantee that the groundwater model does not under-estimate the likely impacts. There are 2698 of the 2951 active bores that have enough information to be assigned to an aquifer. Furthermore, 187 monitoring bores and 6 exploration bores were excluded from this analysis due to their limited groundwater usage. For the purposes of this report, the total number of bores that were analysed was 2505.

1.5.1.2.1 Current water accounts

Actual measured groundwater usage data are not available for bores within the model domain; hence, they were estimated using the allocation data in the NSW state groundwater database (Bioregional Assessment Programme, Dataset 2). It is assumed that 100% of the allocation will be used. Not all bores require a licence to extract water, for example, stock bores under the basic water right. When an allocation entry is missing for a bore, the median value of the bores with allocations within the same purpose group was adopted. For example, 827 domestic bores are not tied with allocations in the model domain, while 429 domestic bores have allocations. The median allocation of the 429 bores was assigned to the other 827 domestic bores as assumed current water usage. Using this interpolation method, the resulting estimates for water usage are shown in Figure 5, which demonstrate that 88.1% of the bores have allocations of less than or equal to 5 ML/year.

Table 7 and Figure 6 show the estimated water usage categorised by purposes. The NGIS and NSW state groundwater database both have a purpose record for most bores of interest; however, the records in the two databases are not always consistent. The NGIS was used as the primary reference for definition purposes. When an assignment was deemed to be unreasonable on a judgment basis, the definition in the NSW state groundwater database was adopted. The definitions of the purpose codes of the NGIS are described in Table 8. Almost half of the water (49.5%) is consumed by irrigation and 42% of the estimated water usage is attributed to domestic and stock bores. The total volume of groundwater consumed by other users is significantly less that that extracted for irrigation and stock/domestic use.

Table 7 Estimated groundwater usage categorised by purpose in the model domain of the groundwater model for the Clarence-Moreton bioregion

Purpose[a]	Number of bores	Total volume (ML/y)	Mean volume per bore (ML/y)	Median volume per bore (ML/y)
COMS	2	40	20	20
HUSE	1301	2,774	2.13	2
INDS	29	348	12	12
IRAG	212	5,750	27.12	15
RECN	7	97	13.86	10
STOK	950	2,097.5	2.21	2
WSUP	4	512	128	105
Total	2505	11,618.5	29.3	2

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2)
[a]Refer to Table 8 for the code definition

Table 8 Bore purpose code definition in the National Groundwater Information System (NGIS) for the Clarence-Moreton bioregion

Code	Definition
COMS	Water supply for commercial activities i.e. a service business that does not fabricate a product
HUSE	Water supply for household needs e.g. washing, toilet
INDS	Water supply for manufacturing and industry
IRAG	Water supply for irrigated agriculture
RECN	Recreational purposes
STOK	Water supply for livestock
WSUP	Water supply, e.g. town water supply

Data: Bureau of Meteorology (2013)

The estimated water usage by aquifers is described in Table 9 and Figure 7. The Richmond River alluvium and Lamington Volcanics represent the two main groundwater supply aquifers in the model domain with 3474 ML/year and 6501.5 ML/year allocated to 672 and 1325 bores screened in those two aquifers, respectively. Bores screened in the Grafton Formation and the Walloon Coal Measures are allowed to pump 964 ML/year and 514 ML/year, respectively. The sum of the estimated water usage for the other five hydrogeological units represents only 165 ML/year. Although 1833 of the 2505 bores are screened in the bedrock aquifers, most of them were drilled in the unconfined part of the bedrock aquifers (i.e. non alluvial).

Table 9 Estimated groundwater usage categorised by hydrogeological units in the model domain of the groundwater model for the Clarence-Moreton bioregion

Hydrogeological unit	Number of bores	Total volume (ML/y)
Alluvium	672	3474
Lamington Volcanics	1325	6501.5
Grafton Formation	308	964
Bungawalbin Member	29	60
Kangaroo Creek Sandstone	28	66
Walloon Coal Measures	127	514
Koukandowie Formation	8	14
Gatton Sandstone	2	14
Woogaroo Subgroup	6	11

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2)

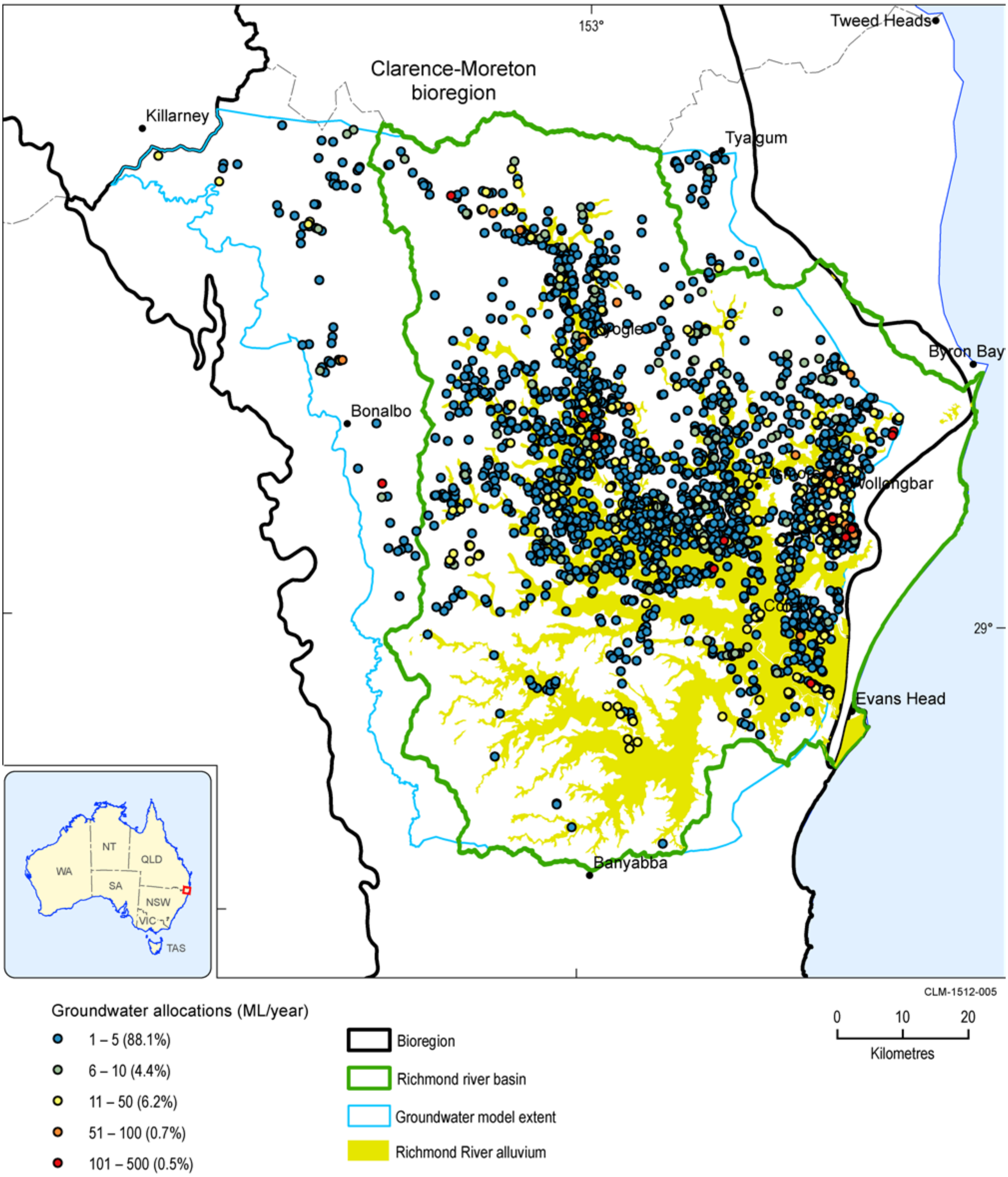

Figure 5 Estimate of groundwater usage per bore within the model domain of the groundwater model for the Clarence-Moreton bioregion. The estimation was based on available allocation data with an assumption that 100% of the allocation will be used

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2)

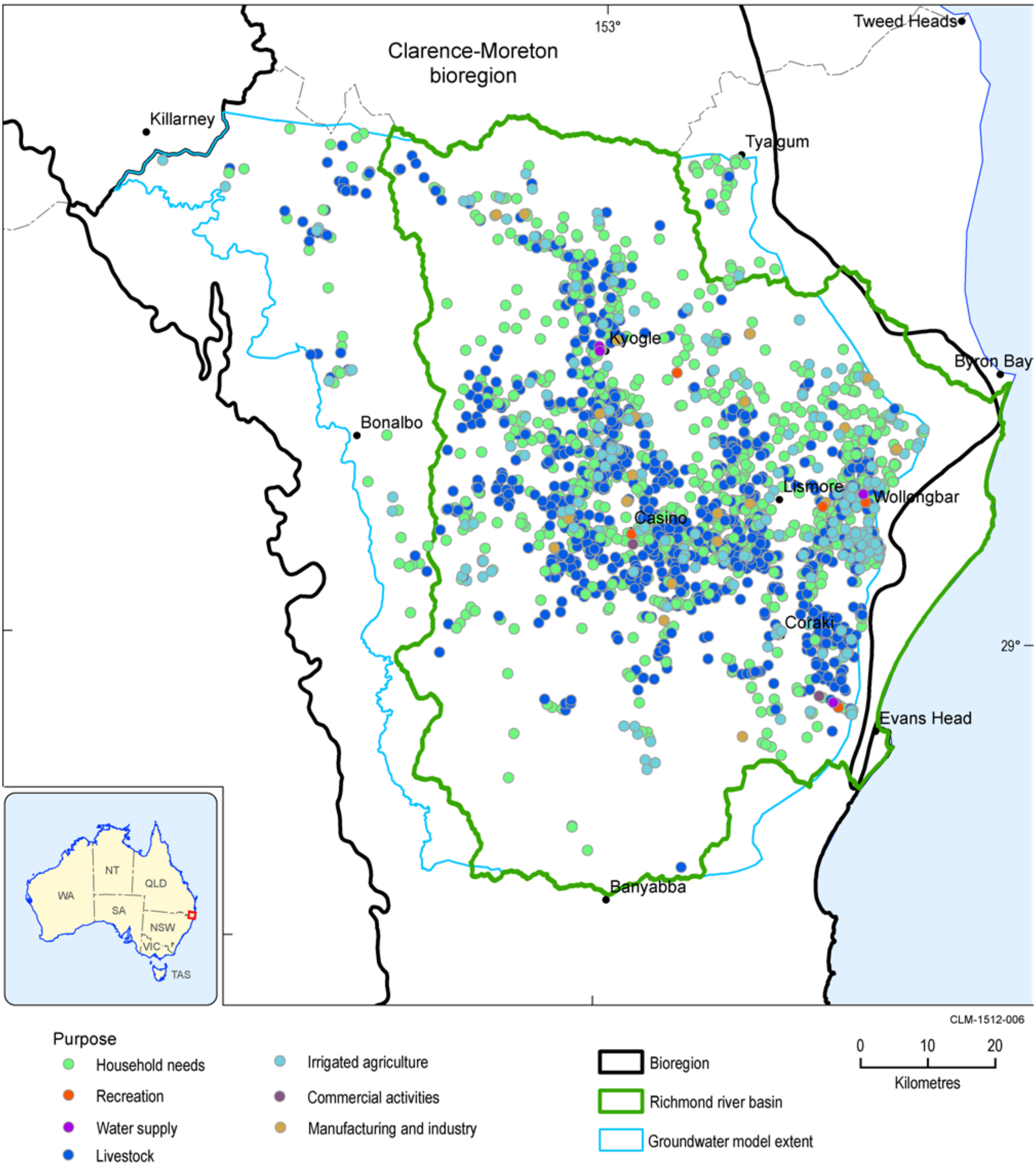

Figure 6 Distribution of bores classified by purpose within the model domain of the groundwater model for the Clarence-Moreton bioregion

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2)

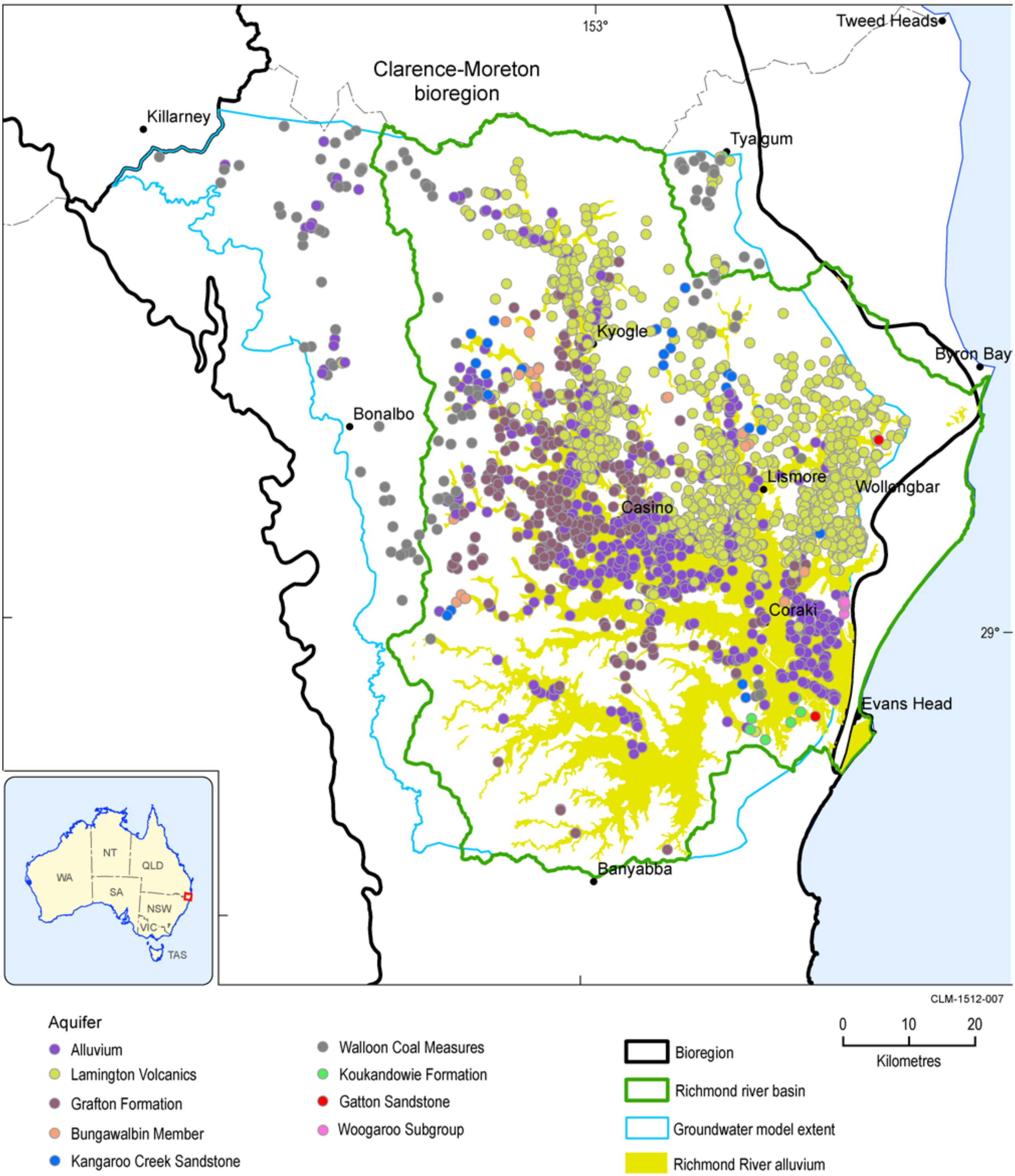

Figure 7 Distribution of bores classified by aquifer within the model domain of the groundwater model for the Clarence-Moreton bioregion

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2)

1.5.1.2.2 Water management

In NSW, water sharing plans (WSPs) are developed to preserve surface water and groundwater by balancing the competing demands by different types of water users. They are defined based on surface river basins and groundwater systems. The model domain is covered mainly by the WSP for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources, although it is also associated with three other WSPs (Figure 8). The public exhibition of the Draft Water Sharing Plan for the Clarence Unregulated and Alluvial Water Sources was being finalised as this report was being drafted (DPI, 2015a). The WSP for the Alstonville Plateau Groundwater Sources overlaps with the WSP for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources, however, it was developed specifically for the Cenozoic basalt aquifer between Lismore and Alstonville. The water sharing plan was originally due in July 2014, but its due date has been extended to July 2015. There has been a proposal to merge this WSP into the North Coast Fractured and Porous Rock Groundwater Sharing Plan to form a uniform WSP for the fractured and porous rock groundwater sources on the North Coast of NSW (DPI, 2015b). More details about these WSPs can be found in NSW Office of Water (2015).

Table 10 provides a breakdown of the number of bores and estimated usage in ML/year as per WSPs. It is shown that 1967 bores (79% of the total) within the model domain are managed under the WSP for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources; 49 Walloon Coal Measures bores, 19 alluvial bores, and 1 basalt bore are located in the Draft Water Sharing Plan for the Clarence Unregulated and Alluvial Water Sources; 434 bores (17% of the total) are screened in the Alstonville basalt that is managed by the WSP of the Alstonville Plateau Groundwater Sources.

Table 10 Estimated groundwater usage categorised by water sharing plan in the model domain of the groundwater model for the Clarence-Moreton bioregion

Hydrogeological unit	Number of bores	Total volume (ML/y)
The Richmond River Area Unregulated, Regulated and Alluvial Water Sources	1967	7877
The Alstonville Plateau Groundwater Sources	434	3212
The Clarence Unregulated and Alluvial Water Sources	69	449
The Tweed River Area Unregulated and Alluvial Water Sources	35	80

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2), NSW Office of Water (Dataset 3)

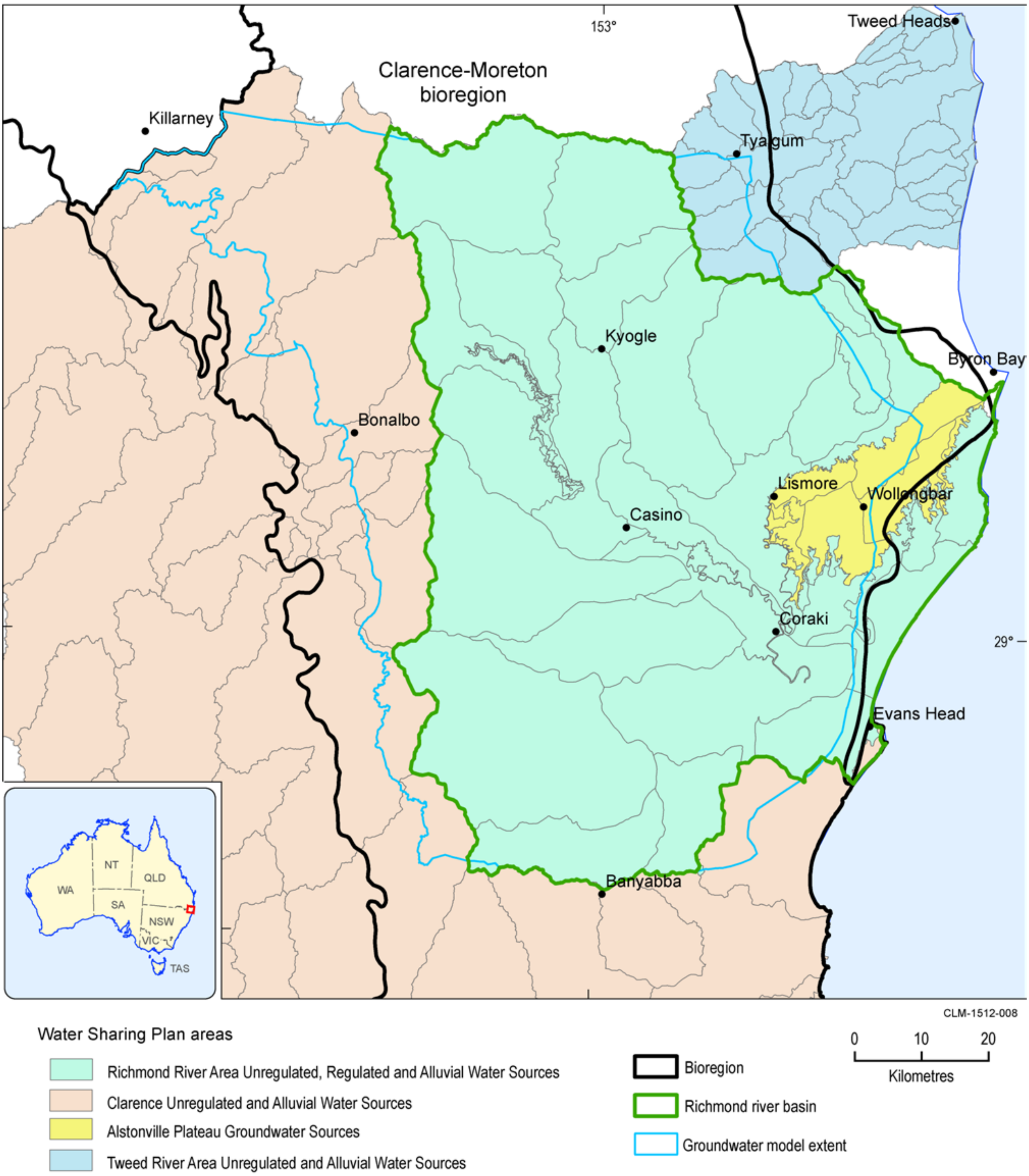

Figure 8 Distribution of water sharing plans (WSP) within the model domain of the groundwater model for the Clarence-Moreton bioregion

Data: Bureau of Meteorology (Dataset 1), Bioregional Assessment Programme (Dataset 2), NSW Office of Water (Dataset 3)

1.5.1.2.3 Gaps

The water account analysis presented in this report was based on allocation data rather than metered actual water usage. This type of analysis generally overestimates the actual groundwater usage. Uncertainties also exist in the allocation data with many bores lacking allocation entries in the NSW state groundwater database. There are inconsistencies between the NGIS and the NSW state groundwater database regarding the purpose information of the bores. Although great efforts were allotted to assign bores to different aquifers, the accuracy of the assignment cannot be guaranteed either due to the lack of stratigraphy boundary information or due to its inferior quality.

References

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Datasets

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1.5.2 Water quality

Summary

The largest collection of water quality data (groundwater and surface water) for the Richmond river basin is maintained by the New South Wales Government. These data include continuously collected water quality parameters and targeted sampling campaigns. Continuously collected surface water quality data are not widely available for gauging locations in the Richmond river basin and most of the measurements that are available only commenced in 2013. Continuous surface water quality measurements include salinity (represented by electrical conductivity) and water temperature and are collected in the tidal reaches of the system. Changes in continuously measured electrical conductivity is linked to flow conditions in the river basin.

Targeted surface water sampling campaigns have been carried out in the past with databases held by both the NSW Department of Environment and Heritage (Dataset 1), and the New South Wales Office of Water (Dataset 2). A large number of surface water quality parameters have been monitored through the Richmond river basin but the most commonly reported are electrical conductivity, pH and turbidity. Using the Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC/ARMCANZ, 2000), most water quality parameters were found to fall within acceptable levels, however, there were times where limits were exceeded for the most commonly reported parameters.

Groundwater quality data are available from the New South Wales Office of Water for more than 500 bores within the Richmond river basin. Parameters that are most commonly measured are salinity (represented by electrical conductivity) and pH, collected over a time span from 1971 to 2007. The freshest groundwater within the Richmond river basin is contained within the Lamington Volcanics. Groundwater salinity within the alluvial aquifers is more variable, ranging from very fresh to saline, depending on the location within the river basin. Only limited water quality measurements exist for the deeper bedrock aquifers within the Richmond river basin; to provide a baseline understanding of groundwater quality within the major aquifers, observations from other areas within the Clarence-Moreton bioregion are also reported in this report.

1.5.2.1 Surface water

This product summarises water quality information in the Richmond river basin. Surface water quality may be directly impacted by runoff from areas altered by coal mines or coal seam gas (CSG) developments (areas cleared of vegetation, service roads, and site processing facilities), discharge of mine or CSG waters and leaking of hydrocarbons. A number of physical and chemical parameters may be altered by potential coal and CSG developments, including turbidity, suspended solids, pH, heavy metals concentration, salinity, and the presence of hydrocarbons. It is worth noting that there is currently a lack of data on the presence of hydrocarbons as a result of coal mining and CSG operation and development in the Clarence-Moreton bioregion.

The National Land and Water Resources Audit provides the only consistent bioregion-wide assessment of water quality (NLWRA, 2001). The National Land and Water Resources Audit provided data on the export of sediment, nutrient and phosphorus for the Richmond river basin and these were summarised in Section 1.1.5 of companion product 1.1 for the Clarence-Moreton bioregion (Rassam et al., 2014). A follow up report for the National Land and Water Resources Audit (NLWRA, 2002a, 2002b) presented broader regional assessments and developed indices to facilitate comparison of basin and river condition. Section 1.1.5 also summarised some targeted monitoring campaigns reported in the scientific literature for the Richmond river basin. The Richmond River County Council monitors electrical conductivity, pH, dissolved oxygen, temperature and turbidity at four locations within the estuary.

The NSW Office of Water conducts two types of monitoring: continuous monitoring in river gauging stations and targeted monitoring campaigns for a specific duration and purpose (NSW Office of Water, 2014). The remainder of this section will include a description of these two types of water quality monitoring products.

1.5.2.1.1 Water quality in the Richmond river basin

Continuous monitoring

Of the active streamflow gauging sites in the Richmond river basin there are only two with continuous salinity and water temperature measurement datasets that are over one year in duration. These two gauges are Bungawalbyn (203450) and Richmond at Oakland Road (203470) and both are stations that only report river level as they are within the tidal zone of the basin. Monitoring of water quality parameters (salinity and temperature) at these two locations only commenced in early 2013. Data on the same parameters is also available for the Richmond River at Coraki (203403) but only since early 2014.

The data for Bungawalbyn (203450) and Richmond at Oakland Road (203470) can be seen in Figure 9 and Figure 10 for the 2013 to 2014 water year. For both sites, the monitoring locations exhibit seasonal water temperature characteristics which are likely to reflect variations in incoming solar radiation. On the other hand the salinity (expressed as electrical conductivity) in both systems seems to exhibit an increasing trend through the dry season, possibly in relation to decreases in baseflow and larger tidal influence, and then an abrupt decrease following a large flow event in March 2014. The salinity at Bungawalbyn ranges from 200 µS/cm after a large flow has been through the system (indicated by a big change in level) to nearly 1300 µS/cm before the next flushing event. A similar trend is shown at the Richmond River at Oakland Road although at this site maximum salinity is less than 800 µS/cm. These systems experience quite large ranges of salinity which may reflect variations in baseflow and tidal influences.

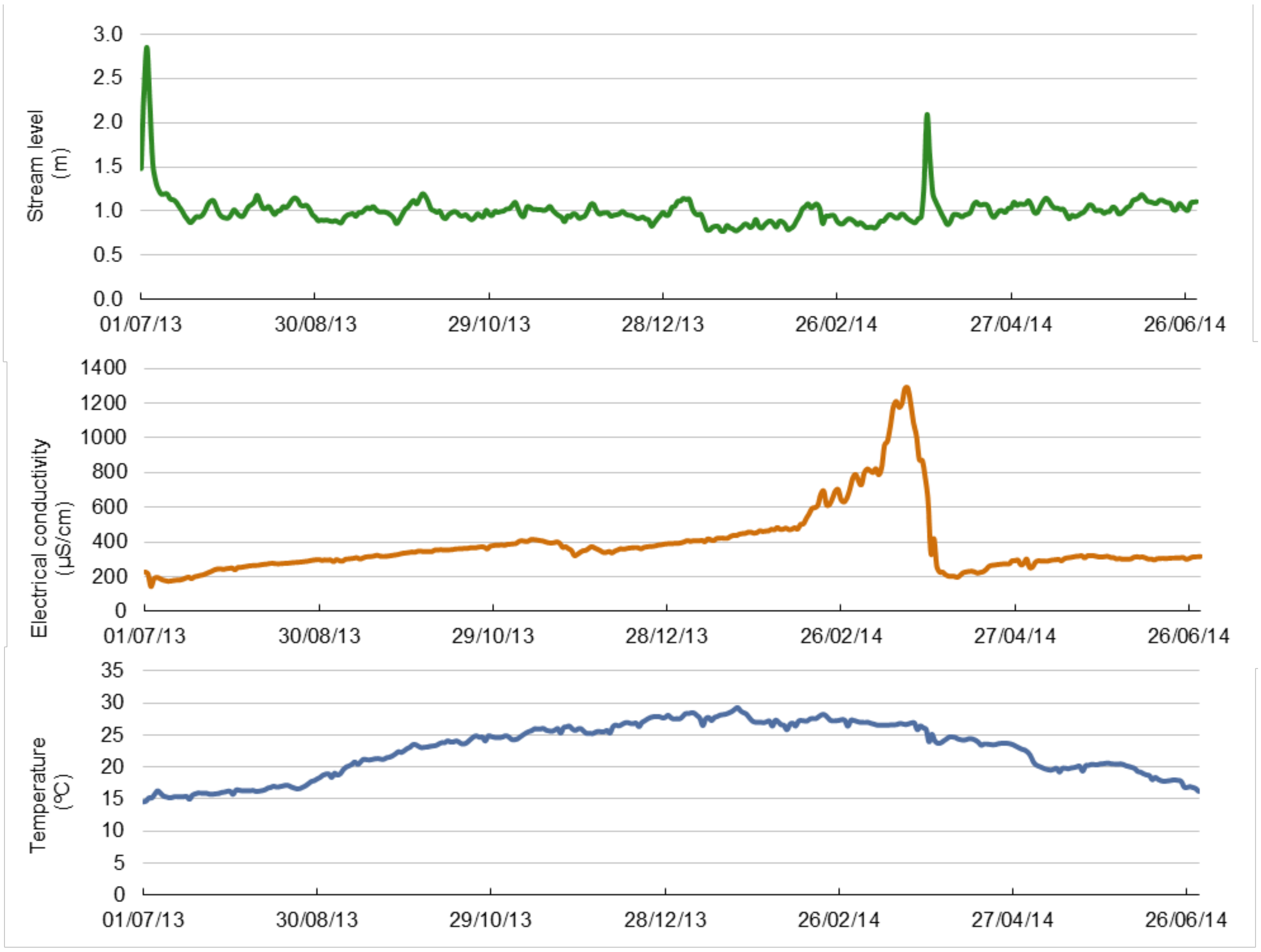

Figure 9 Stream level (top), electrical conductivity (middle) and water temperature (bottom) at gauge 203450 Bungawalbyn for the 2013 to 2014 water year for the Clarence-Moreton bioregion

Data: NSW Office of Water (Dataset 3)

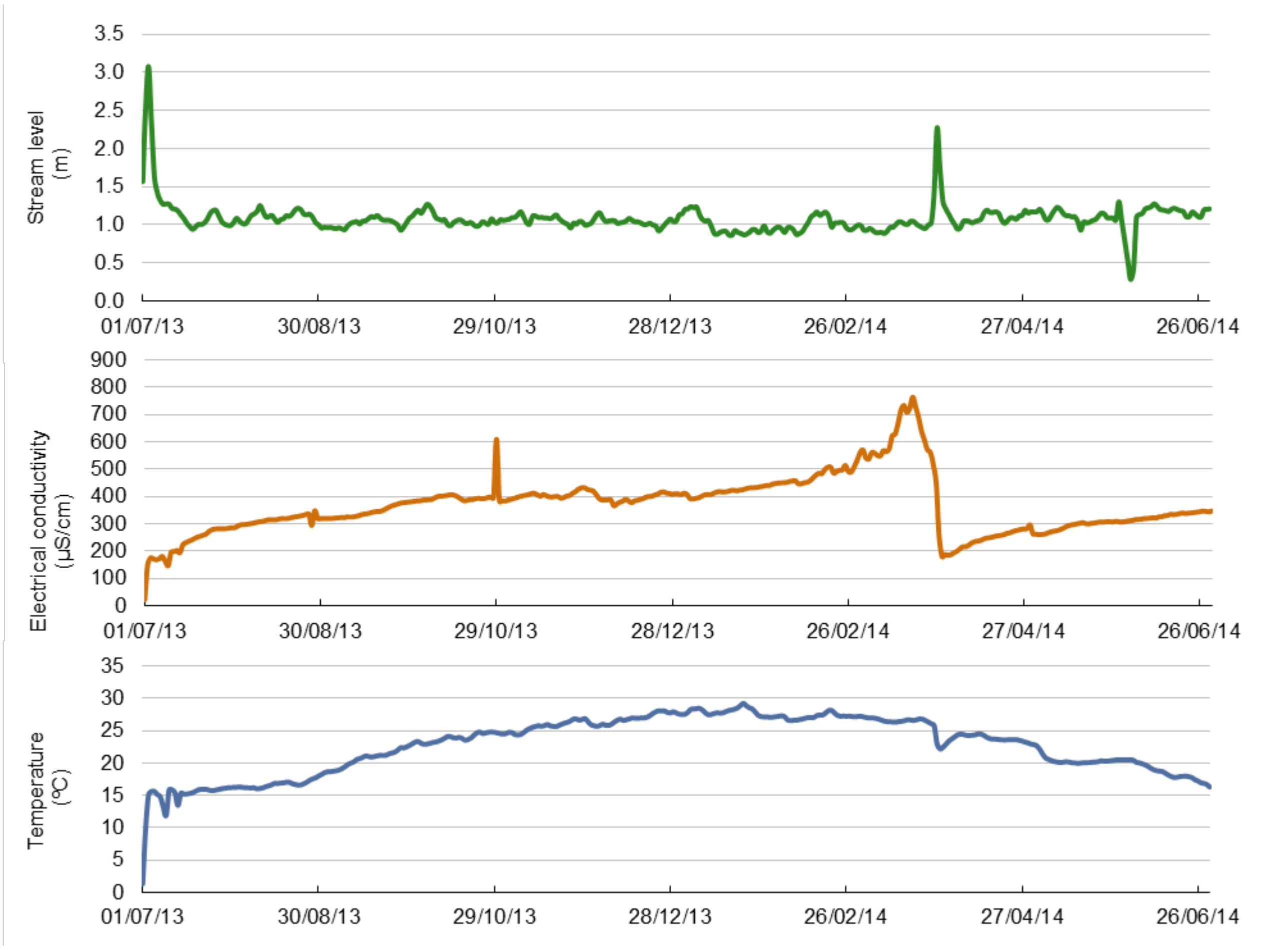

Figure 10 Stream level (top), electrical conductivity (middle) and water temperature (bottom) at gauge 203470 Richmond at Oakland Road for the 2013 to 2014 water year for the Clarence-Moreton bioregion

Data: NSW Office of Water (Dataset 3)

Targeted monitoring

A range of other water sampling campaigns have also been undertaken to collect data for various reports and projects; some of these are summarised below. There are two main datasets to draw upon here: 1) the NSW Department of Environment and Heritage Historic Water Quality Data (Dataset 1), and 2) NSW Office of Water Data (Dataset 2).

State of the catchments – Northern Rivers Region (Dataset 1)

In 2010, the NSW Government undertook a *State of the catchments* report for the Northern Rivers region, which includes the Richmond river basin (DECCW, 2010). In this report trends in water temperature, electrical conductivity and turbidity were presented for Richmond River at Kyogle, Wilson River at Eltham and Richmond River at Casino. This report acknowledges that there is low confidence in electrical conductivity and temperature data due to data gaps and errors and medium confidence in turbidity which was not measured past 2000.

Water Quality of Tweed, Brunswick, Richmond and Clarence rivers (Dataset 1)

This is an extensive dataset of more than 500 samples collected from 48 locations between 15 May 1994 and 12 April 1995. Water quality parameters available include turbidity, total phosphorus, total nitrogen, pH and temperature.

Other data (Dataset 1)

There are also two very small datasets which form part of the Coastal State Recreation Areas dataset (samples in 2006 and 2008) and the Monitoring River Health Initiative (samples collected between 1994 and 1999) (Turak et al., 2000). These both include measurements of electrical conductivity, turbidity, pH and temperature. The Coastal State Recreation Areas dataset has measurements for four locations in the Richmond river basin, while the Monitoring River Health Initiative dataset includes targeted observation from 31 sites with data collected six monthly.

New South Wales Office of Water dataset (Dataset 2)

The NSW Office of Water has a very large database of water quality data collected over many years and includes data collected at locations in the Richmond river basin. The types of water quality parameters collected in the Richmond river basin are extremely diverse (e.g. nutrients, temperature, and aquatic biota) but the three most commonly reported parameters are electrical conductivity (>2900 readings), pH (>2200 readings) and turbidity (>1890 readings). The locations where electrical conductivity was measured, the number of samples collected and their mean, minimum and maximum values are shown in Table 11. Matching analysis for pH and turbidity readings is shown in Table 12 and Table 13, respectively.

The Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC/ARMCANZ, 2000) sets acceptable levels for electrical conductivity in the upland and lowland rivers of NSW catchments at between 30 and 350 µS/cm, and 125 and 2200 µS/cm, respectively. Mean values for the Richmond river basin fall within this range however maximum values exceed these ranges at times. Higher electrical conductivity values in the lowland areas are likely to reflect tidal influences in the lower reaches of the Richmond River.

Table 11 Sampling locations, gauge number, number of samples collected and mean, maximum and minimum electrical conductivity measurements for the Clarence-Moreton bioregion

Station name	Station number	Number of samples	Mean (µS/cm)	Maximum (µS/cm)	Minimum (µS/cm)
Coopers Creek at Repentance	203002	113	76	108	30
Richmond River at Casino	203004	212	314	625	1
Richmond River at Wiangaree	203005	70	240	408	116
Lynchs Creek at Wiangaree	203006	65	155	545	50
Terania Creek at Blakes	203007	49	132	839	32
Back Creek at Bentley	203009	96	475	700	105
Leycester Creek at Rocky Valley	203010	112	416	1080	120
Byron Creek at Binnaburra	203012	108	110	345	58

Station name	Station number	Number of samples	Mean (µS/cm)	Maximum (µS/cm)	Minimum (µS/cm)
Wilsons River at Federal	203013	94	93	267	57
Wilsons River at Eltham	203014	262	103	330	1
Goolmangar Coffee Camp	203015	81	235	440	73
Upper Horseshoe Creek	203017	70	164	265	83
Eden Creek at Upper Eden	203018	67	233	320	130
Eden Creek at The Ford	203019	3	224	300	130
Terania Creek at Keerong	203022	82	125	850	36
Ironpot Creek at Toonumbar	203023	191	197	412	16
Coopers Creek at Ewing Bridge	203024	88	94	343	41
Maron Creek at Alstonville	203025	53	90	152	60
Richmong River at Grevillia	203026	47	860	1500	348
Findon Creek at Terrace Creek	203027	63	287	385	170
Fawcetts Plain	203028	85	261	452	90
Myrtle Creek at Rappville	203030	78	300	865	121
Eden Creek at Ettrick	203032	90	384	535	154
Ironpot Creek at Toonumbar VG	203033	7	167	193	137
Eden Creek at Doubtful	203034	92	393	1230	243
Ironpot Creek at Ettrick	203035	107	297	2010	83
Giggergunyah Range River	203036	19	67	81	39
Duck Creek at Alstonville	203037	97	75	249	43
Peraces Creek at Booyong	203038	100	100	135	62
Maguires Creek at Teven	203039	88	105	599	54
Gum Creek at Rous Mill	203040	23	70	150	54
Shannon Brook at Yorklea	203041	96	993	2970	120
Battens Bight at Camir	203044	23	130	286	77
Myall Creek at Gibberagee	203045	27	297	1000	73
Bennys Creek at Eureka	203046	1	96	96	96
Richmond River at Kyogle	203900	67	267	375	143
Goolmangar Creek at Nimbin	203901	7	326	1000	132

Data: NSW Office of Water (Dataset 2)

The Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC/ARMCANZ, 2000) sets acceptable pH in the upland and lowland rivers of NSW catchments at between 6.5 and 7, and 6.5 and 8, respectively. Mean values are at times outside of these values and maximum and minimum values often sit outside of the guideline values.

Table 12 Sampling locations, gauge number, number of samples collected and mean, maximum and minimum pH measurements for the Clarence-Moreton bioregion

Station name	Station number	Number of samples	Mean (pH)	Maximum (pH)	Minimum (pH)
Coopers Creek at Repentance	203002	82	7.1	8.6	6.6
Richmond River at Casino	203004	182	7.8	9.2	6.3
Richmond River at Wiangaree	203005	71	7.6	8.3	7.2
Lynchs Creek at Wiangaree	203006	44	7.4	7.8	7.1
Terania Creek at Blakes	203007	47	7.1	7.6	6.7
Back Creek at Bentley	203009	62	7.6	8.1	7.2
Leycester Creek at Rocky Valley	203010	76	7.4	8.1	7.0
Byron Creek at Binnaburra	203012	83	7.1	7.6	6.2
Wilsons River at Federal	203013	62	7.1	8.1	6.6
Wilsons River at Eltham	203014	116	6.9	7.6	5.9
Goolmangar Coffee Camp	203015	51	7.2	7.6	6.9
Upper Horseshoe Creek	203017	45	7.5	8.0	7.0
Eden Creek at Upper Eden	203018	46	7.5	8.0	7.2
Terania Creek at Keerong	203022	46	7.1	7.6	6.8
Ironpot Creek at Toonumbar	203023	177	7.4	8.4	6.0
Coopers Creek at Ewing Bridge	203024	53	7.0	7.4	6.3
Maron Creek at Alstonville	203025	53	6.7	7.5	6.2
Richmong River at Grevillia	203026	47	7.8	8.4	7.4
Findon Creek at Terrace Creek	203027	43	7.7	8.6	6.9
Fawcetts Plain	203028	53	7.4	7.9	7.0
Myrtle Creek at Rappville	203030	78	6.9	7.7	6.3
Eden Creek at Ettrick	203032	62	7.6	8.4	7.3
Ironpot Creek at Toonumbar VG	203033	1	7.2	7.2	7.2
Eden Creek at Doubtful	203034	66	7.6	8.2	7.3
Ironpot Creek at Ettrick	203035	81	7.5	8.3	7.1
Giggergunyah Range River	203036	18	6.8	7.1	6.5
Duck Creek at Alstonville	203037	75	6.6	7.5	6.0
Peraces Creek at Booyong	203038	78	7.0	7.3	6.0
Maguires Creek at Teven	203039	89	7.0	8.1	6.2
Gum Creek at Rous Mill	203040	2	7.4	7.6	7.2
Shannon Brook at Yorklea	203041	96	7.6	8.8	6.9
Battens Bight at Camir	203044	24	6.6	7.3	6.0

Station name	Station number	Number of samples	Mean (pH)	Maximum (pH)	Minimum (pH)
Myall Creek at Gibberagee	203045	24	6.7	7.5	6.3
Bennys Creek at Eureka	203046	1	7.1	7.1	7.1
Richmond River at Kyogle	203900	64	7.7	8.6	7.3
Goolmangar Creek at Nimbin	203901	6	7.4	7.8	6.5

Data: NSW Office of Water (Dataset 2)

The Australian and New Zealand Guidelines for Freshwater and Marine Water Quality (ANZECC/ARMCANZ, 2000) sets acceptable levels for turbidity in the upland and lowland rivers of NSW catchments at between 2 and 25 NTU (Nephelometric Turbidity Unit), and 6 and 50 NTU, respectively. Mean values for the Richmond river basin fall within these ranges however maximum values exceed these ranges at times.

Table 13 Sampling locations, gauge number, number of samples collected and mean, maximum and minimum turbidity measurements for the Clarence-Moreton bioregion

Station name	Station number	Number of samples	Mean (NTU)	Maximum (NTU)	Minimum (NTU)
Coopers Creek at Repentance	203002	68	3.1	22.0	0.7
Richmond River at Casino	203004	196	12.0	232.0	0.1
Richmond River at Wiangaree	203005	57	2.5	18.0	0.5
Lynchs Creek at Wiangaree	203006	34	2.2	18.0	0.4
Terania Creek at Blakes	203007	35	4.5	50.0	0.9
Back Creek at Bentley	203009	41	4.7	54.0	0.4
Leycester Creek at Rocky Valley	203010	62	8.6	150.0	0.6
Byron Creek at Binnaburra	203012	70	3.0	15.0	0.6
Wilsons River at Federal	203013	51	3.1	16.0	0.8
Wilsons River at Eltham	203014	217	5.5	45.0	0.6
Goolmangar Coffee Camp	203015	39	3.4	15.0	0.6
Upper Horseshoe Creek	203017	33	3.8	27.0	0.4
Eden Creek at Upper Eden	203018	36	3.9	25.0	0.4
Terania Creek at Keerong	203022	36	3.6	20.0	0.8
Ironpot Creek at Toonumbar	203023	82	6.2	70.0	0.5
Coopers Creek at Ewing Bridge	203024	43	3.8	24.0	0.8
Maron Creek at Alstonville	203025	42	3.4	15.0	0.8
Richmong River at Grevillia	203026	37	5.5	52.0	0.4
Findon Creek at Terrace Creek	203027	33	3.6	23.0	0.4
Fawcetts Plain	203028	43	5.0	45.0	0.4
Myrtle Creek at Rappville	203030	65	7.4	44.0	0.8

Station name	Station number	Number of samples	Mean (NTU)	Maximum (NTU)	Minimum (NTU)
Eden Creek at Ettrick	203032	50	3.1	25.0	0.3
Ironpot Creek at Toonumbar VG	203033	1	2.1	2.1	2.1
Eden Creek at Doubtful	203034	54	6.1	60.0	0.6
Ironpot Creek at Ettrick	203035	68	5.9	84.0	0.6
Giggergunyah Range River	203036	10	2.1	7.9	0.7
Duck Creek at Alstonville	203037	61	3.4	67.5	0.6
Peraces Creek at Booyong	203038	66	2.6	19.0	0.7
Maguires Creek at Teven	203039	74	2.6	14.0	0.7
Gum Creek at Rous Mill	203040	1	8.0	8.0	8.0
Shannon Brook at Yorklea	203041	80	15.2	434.0	0.7
Battens Bight at Camir	203044	19	24.4	67.0	1.6
Myall Creek at Gibberagee	203045	24	23.1	305.0	1.8
Bennys Creek at Eureka	203046	1	7.1	7.1	7.1
Richmond River at Kyogle	203900	57	5.5	170.0	0.4
Goolmangar Creek at Nimbin	203901	6	5.3	11.0	3.0

Data: NSW Office of Water (Dataset 2)

1.5.2.1.2 Gaps

There is a lack of data on the presence of hydrocarbons as a result of coal mining and CSG operation and development. These data are important for reasons outlined in Section 1.5.2.1.

References

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Datasets

Dataset 1 NSW Department of Environment and Heritage (2009) NSW Department of Environment and Heritage Historic Water Quality Data. Bioregional Assessment Source Dataset. Viewed 23 March 2015, http://data.bioregionalassessments.gov.au/dataset/4c5f7318-2567-4614-aa35-46aa0eb045f2.

Dataset 2 NSW Office of Water (2013) NSW Office of Water Surface Water Quality Extract 28_nov_2013. Bioregional Assessment Source Dataset. Viewed 23 March 2015, http://data.bioregionalassessments.gov.au/dataset/21234479-eabe-46f9-8af5-9f30847a18ba.

Dataset 3 NSW Office of Water (2015) Richmond stream gauge data. Bioregional Assessment Source Dataset. Viewed 23 March 2015, http://data.bioregionalassessments.gov.au/dataset/03f59f6b-8d06-4513-b662-db7c4c2d2909.

1.5.2.2 Groundwater

This section provides information on groundwater salinity (represented by electrical conductivity or EC) and pH. In addition, it provides basic information on selected trace elements to highlight limitations of the available data, as only a limited number of groundwater samples have been analysed for most trace elements in the Richmond river basin. Further statistical analysis and interpretation conducted on the major ion chemistry of groundwater within the Clarence-Moreton bioregion will be provided in companion product 2.1-2.2 of the bioregional assessment (Raiber et al., 2015), and additional information on water quality and the characteristics of major aquifers are presented in companion product 1.1 for the Clarence-Moreton bioregion (Rassam et al., 2014).

Groundwater quality and chemistry data were compiled from the NSW groundwater bore database (Bureau of Meteorology, Dataset 1). In this database, 501 bores within the Richmond River groundwater model boundary have records for electrical conductivity, and 502 records exist for pH, whereas only a fraction of groundwater bores have trace element chemistry records. Sampling dates range from 1971 to 2007. The time span of four decades over which samples have been collected has implications on data quality, this is attributed to significant changes to sampling protocols, database procedures and most importantly advances in analytical accuracy and precision (e.g. a significant reduction in methods' detection limits has occurred).

There are 3934 bores from the National Groundwater Information System (NGIS) (Bureau of Meteorology, Dataset 1) located within the Richmond River groundwater model domain, 3096 of which have construction information (e.g. screened interval depth) that is required to assign bores to aquifers. However, the majority of groundwater bores contained in the Bureau of Meteorology dataset for the Richmond river basin do not have any stratigraphic records. Without the assignment of the screened interval to a discrete stratigraphic unit, it would be impossible to report on the groundwater quality characteristics of different aquifers. Through data quality checks and interpretations of lithological logs, which are available for most bores, followed by integration of the lithological logs into a preliminary three-dimensional geological model for further checks in the spatial context, it has been possible to generate stratigraphic logs for most groundwater bores. This then allowed assignment of most bores to individual aquifers. The procedure is described in detail in companion product 2.1-2.2 of the Clarence-Moreton Bioregional Assessment (Raiber et al., 2015). Results for EC and pH were only reported for bores where the hydrostratigraphic unit at the screened interval was determined with a high degree of confidence; bores screened across multiple aquifers were not considered.

To assess the potential hazards associated with using groundwater in the Richmond river basin, groundwater chemistry data were compared to national guidelines for water quality in which a number of possible water uses were considered. Water uses considered were: human drinking water, stock drinking water and water for long-term irrigation (defined as up to 100 years). For the assessment of potential adverse impacts associated with using groundwater in the Richmond river basin, groundwater quality parameters were compared to water quality national guidelines provided by the National Health and Medical Research Council (NHMRC and NRMMC, 2011) and the Australian and New Zealand Environment and Conservation Council (ANZECC/ARMCANZ, 2000).

1.5.2.2.1 Electrical conductivity

Electrical conductivity values that represent salinity for the Richmond river basin are presented in Table 14.

Values higher than the EC of seawater (approximately 50,000 µS/cm) were not considered in the assessment. It is possible in coastal catchments that seawater or estuarine water leaks into shallow aquifers. In the Richmond river basin, estuaries and tidal rivers extend far inland (up to Casino), and it is therefore possible that elevated salinities are related to leakage from estuaries or tidal rivers. However, this would still only explain EC's less than that of seawater. Areas where elevated groundwater salinities are observed are located too far from the coast to be explained by seawater intrusion. In areas in Australia where hypersaline salt lakes are present, these can leak into underlying aquifers. However, as there are no hypersaline salt lakes within the Richmond river basin, values higher than seawater are considered incorrect, most probably resulting from either erroneous field measurements and/or database entries. Consequently, 57 measurements ranging from 70,000 to 4,850,000 µS/cm were excluded from calculations of the minimum, maximum and median values presented in Table 14. As only limited water quality records are available for most sedimentary bedrock formations in the Richmond river basin, bioregion-wide range of values (including the Queensland part of the Clarence-Moreton bioregion) are reported in Table 14 to give an indication of the possible range of values for different sedimentary bedrock aquifers, assuming basin-wide similar controls of water quality.

In total, 959 values were compared to Australian Drinking Water Guidelines (ADWG) trigger values for human consumption (NHMRC and NRMMC, 2011) and the National Water Quality Management Strategy (NWQMS) for stock and irrigation water (ANZECC/ARMCANZ, 2000). As a full comprehensive analysis was not conducted for many sampling sites, EC is reported here in favour of total dissolved solids (TDS) concentration similar to other bioregions (e.g. Namoi subregion). The trigger values used for EC are given in Table 14 and are derived from the TDS concentrations in the guidelines, using an approximate conversion factor of 0.64, as recommended in the guidelines and as conducted in other bioregions (e.g. Namoi subregion). The range of EC values in the data is shown in Table 14 together with the proportion of samples in exceedance of the different guidelines.

Insufficient EC data exist for most aquifers, and thus, no spatial interpolation was conducted. Instead, maps showing EC ranges were generated for key aquifers within the Richmond river basin groundwater model domain. For less than 3% of the groundwater bores 10 or more EC measurements exist, and for more than 70% of the groundwater bores only one EC measurement is recorded in the database.

Richmond River alluvium

The EC of alluvial groundwater quality samples within the Richmond river basin ranges from 40 to 48,500 µS/cm, with a median of 885 µS/cm (based on 383 samples) (Table 14 and Figure 11). Approximately 35% of the samples collected from alluvial aquifers exceed the ADWG trigger of 1500 µS/cm, and approximately 10% and 9% exceed the ANZECC (2000) trigger for irrigation and stock water, respectively. The ECs in the headwaters where the alluvial aquifers overlie the Lamington Volcanics and near the coast within the Richmond river basin are generally low. These low salinities indicate that recharge rates are generally high here. The low salinity of alluvial groundwaters within the extent of the Lamington Volcanics (Figure 11 and Figure 12) also confirms that there is a close hydraulic connection between the Richmond River alluvium and the underlying basalt in the headwaters, where the alluvium primarily consist of coarser sediments such as boulders, gravel and sand. In contrast, higher EC were reported for the central part of the Richmond river basin near Casino (Figure 11). Recharge rates here are likely to be lower due to presence of thick low permeability floodplain sediments at the top of the alluvium, which limit the downwards percolation of water and result in higher rates of evapotranspiration prior to recharge.

Basalt (Lamington Volcanics)

The EC of basalt groundwater samples within the Richmond river basin ranges from 50 to 9250 µS/cm, with a median of 499 µS/cm (based on 249 samples) (Table 14) (Figure 12). Only 13.7% of the samples collected from the basalts exceed the ADWG trigger of 1500 µS/cm, whereas 2.8% and 2.4% exceed the ANZECC/ARMCANZ (2000) trigger for irrigation and stock water, respectively. This suggests that the basalts of the Lamington Volcanics contain the freshest groundwater within the Richmond river basin, and highlights the significance of the Lamington Volcanics as a major recharge area within the Clarence-Moreton bioregion. The role of the Lamington Volcanics as a source of high baseflow volumes was also discussed by Brodie et al. (2007) and in the companion product 1.1 for the Clarence-Moreton bioregion (Rassam et al., 2014).

Grafton Formation undifferentiated

The EC of groundwater quality collected from the Grafton Formation (Piora and Rappville Members undifferentiated) within the Richmond river basin ranges from 80 to 10,100 µS/cm, with a median of 1250 µS/cm (based on 60 samples). Approximately 47% of all samples collected from the Grafton Formation exceed the ADWG trigger of 1500 µS/cm, whereas 3.3% of samples exceed the ANZECC/ARMCANZ (2000) trigger for irrigation.

Orara Formation undifferentiated

No groundwater quality samples from the NSW groundwater database were assigned to the Orara Formation.

Walloon Coal Measures

Within the Richmond river basin, the EC of Walloon Coal Measures groundwater quality samples ranges from 400 to 4460 µS/cm, with a median of 1030 µS/cm (based on 16 samples). Of the samples, 25% exceed the ADWG trigger of 1500 µS/cm, whereas no samples exceed the ANZECC/ARMCANZ (2000) triggers for irrigation or stock water.

Within the entire Clarence-Moreton bioregion, the EC of the Walloon Coal Measures ranges from 86 to 26,500 µS/cm, with a median of 4095 µS/cm based on 92 samples. Approximately 75% of all Walloon Coal Measures groundwater quality samples within the Clarence-Moreton bioregion exceed the ADWG trigger of 1500 µS/cm, and a considerable proportion exceeds the ANZECC/ARMCANZ (2000) triggers for irrigation (approximately 25%) and stock water (approximately 7.6%). The considerable difference to the Walloon Coal Measures groundwater quality within the Richmond river basin probably suggests that the limited number of samples within the Richmond river basin does not provide a representative overview on the EC distribution or that the Walloon Coal Measures samples follow a different evolutionary pathway in the Richmond river basin.

Koukandowie Formation

No EC measurements exist within the Richmond river basin groundwater model boundary for bores screening the Koukandowie Formation. However, bioregion-wide, the EC of bores screening the Koukandowie Formation ranges from 765 to 20,000 µS/cm (median 4750 µS/cm based on 21 samples). Approximately 14.3% of all Koukandowie Formation groundwater quality samples within the Clarence-Moreton bioregion exceed the ADWG trigger of 1500 µS/cm, and a considerable proportion exceeds the ANZECC/ARMCANZ (2000) triggers for irrigation (approximately 24%) and stock water (approximately 5%).

Gatton Sandstone

No EC measurements exist within the Richmond river basin groundwater model boundary for bores screening the Gatton Sandstone. However, bioregion-wide, the EC of 218 groundwater quality samples collected from bores screening the Gatton Sandstone ranges from 92 to 39,000 µS/cm with a median of 5000 µS/cm. Most Gatton Sandstone groundwater samples (approximately 91%; Table 14) within the Clarence-Moreton bioregion exceed the ADWG trigger of 1500 µS/cm, and a considerable proportion exceeds the ANZECC/ARMCANZ (2000) triggers for irrigation (approximately 30%) and stock water (approximately 3%). This indicates that the Gatton Sandstone contains the most saline groundwater of all sedimentary bedrock formations within the Clarence-Moreton bioregion.

Woogaroo Subgroup

No EC measurements exist within the Richmond river basin groundwater model boundary for bores screening the Woogaroo Subgroup. However, throughout the Clarence-Moreton bioregion, the EC of 237 groundwater quality samples collected from bores screened within the Woogaroo Subgroup ranges from 65 to 20,000 µS/cm, with a median of 870 µS/cm (Table 14). Most samples (68.3%) have EC values below the ADWG trigger values, and only very few samples exceed the ANZECC/ARMCANZ (2000) triggers for irrigation and stock water, respectively. This indicates that the Woogaroo Subgroup contains the freshest groundwater of all sedimentary bedrock formations within the Clarence-Moreton bioregion.

Table 14 Electrical conductivity (EC) in Richmond river basin groundwater model domain compared to water guidelines

	Number of analyses	Minimum value (µS/cm)	Maximum value (µS/cm)	Median value (µS/cm)	ADWG[a] trigger (µS/cm)	Fraction in exceedance of guidelines (%)	Irrigation trigger[b] (µS/cm)	Fraction in exceedance of guidelines (%)	Stock trigger[c] (µS/cm)	Fraction in exceedance of guidelines (%)
All bores undifferentiated Richmond river basin	959	40	48,500	780	1500	29.5%	8000	7.5%	20,000	6.2%
Richmond River alluvium	383	40	48,500	885	1500	34.5%	8000	9.7%	20,000	8.6%
Lamington Volcanics (basalts)	249	50	9,250	499	1500	13.7%	8000	2.8%	20,000	2.4%
Grafton Formation undifferentiated (Piora and Rappville)	60	80	10,100	1250	1500	46.7%	8000	3.3%	20,000	0%
Walloon Coal Measures	16	400	4,460	1030	1500	25.0%	8000	0%	20,000	0%
Walloon Coal Measures (CLM bioregion-wide)	92	86	26,500	4095	1500	75.3%	8000	25.0%	20,000	7.6%
Gatton Sandstone (CLM bioregion-wide)	218	92	39,000	5000	1500	90.8%	8000	29.4%	20,000	2.8%
Koukandowie Formation (CLM bioregion-wide)	21	765	20,000	4750	1500	14.3%	8000	23.8%	20,000	4.8%
Woogaroo Subgroup (CLM bioregion-wide)	237	65	20,000	870	1500	31.7%	8000	1.7%	20,000	0.4%

[a]Based on Australian Drinking Water Guidelines NHMRC and NRMMC (2011) and approximate conversion from TDS to EC. TDS >900mg/L is considered poor.
[b]Based on Table 4.2.5 in the National Water Quality Management Strategy ANZECC/ARMCANZ (2000).
[c]Based on National Water Quality Management Strategy ANZECC/ARMCANZ (2000) and approximate conversion from TDS to EC. TDS >13,000mg/L is the maximum concentration when a decline in health of stock would be expected (ANZECC/ARMCANZ, 2000).
Data: Bureau of Meteorology (Dataset 1), Queensland Department of Natural Resources and Mines (Dataset 2)

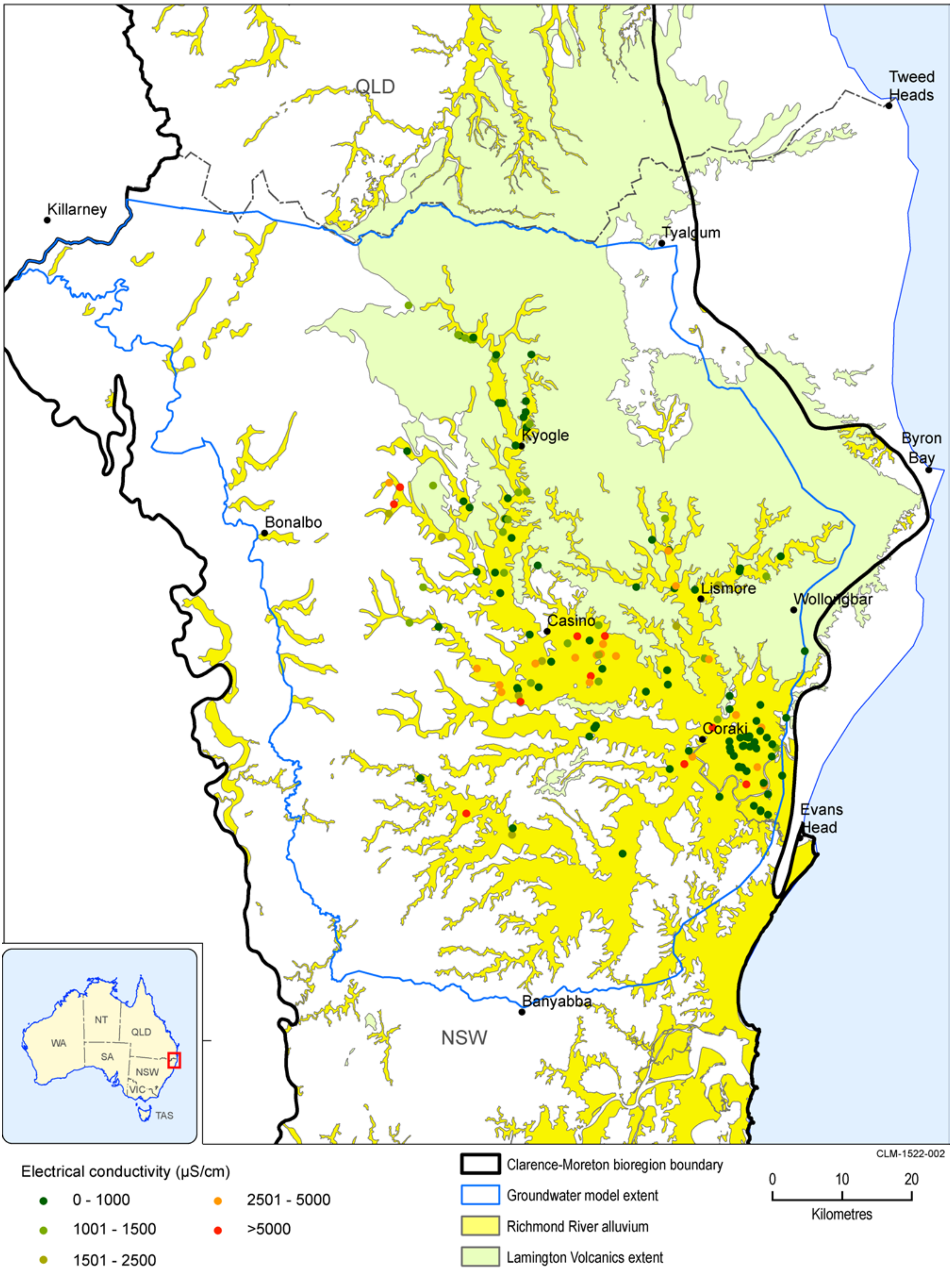

Figure 11 Distribution of electrical conductivity (EC) from alluvial groundwater bores in the Richmond river basin

Data: Bioregional Assessment Programme (Dataset 3)

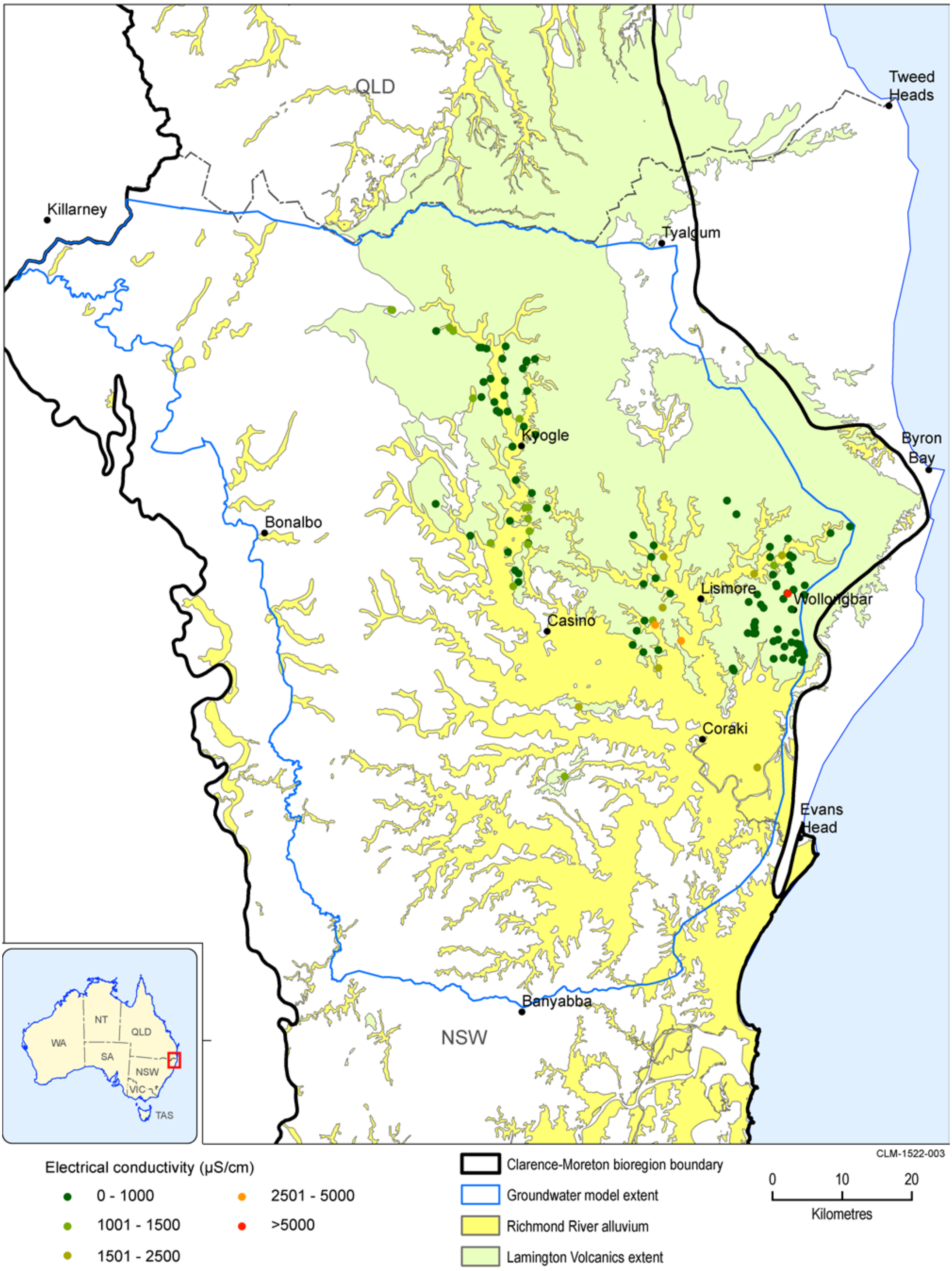

Figure 12 Distribution of electrical conductivity (EC) from Lamington Volcanics (basalt) groundwater bores in the Richmond river basin

Data: Bioregional Assessment Programme (Dataset 4)

One of the problems with pH measurements in the NSW and Queensland groundwater databases is that it is not always clear if the reported value represents the field measurement or the laboratory measurement, and particularly for samples that were collected decades ago, there is considerable uncertainty. In the Queensland Department of Natural Resources and Mines Groundwater Database (Dataset 2), most reported values appear to be laboratory measurements, whereas no information on whether the values represent field or laboratory measurements is provided for NSW.

The pH of groundwater samples in the Richmond river basin varies from 2.8 to 14.0 (Table 15). However, the median pH of most aquifers is within a narrow range from 7.1 to 7.5. The notable exceptions are the median pH of the Walloon Coal Measures (bioregion-wide), the Koukandowie Formation (bioregion-wide) and the Gatton Sandstone (bioregion-wide), which are higher and range from 7.9 to 8.2. While it is unusual for groundwater samples to have pH higher than approximately 9, selected bores within the Walloon Coal Measures and the Gatton Sandstone in the Clarence-Moreton bioregion have been visited during a previous study (Raiber, unpublished data), and these visits have confirmed that a high pH in a similar range as reported in the groundwater database occurs at these sites.

Table 15 Minimum, maximum and median pH for the aquifers in the Richmond river basin and Clarence-Moreton bioregion-wide for selected sedimentary bedrock aquifers

	Minimum pH	Maximum pH	Median pH
All samples (aquifer undifferentiated)	3.0	12.6	7.2
Richmond River alluvium	3.2	8.8	7.1
Basalt	4.4	12.6	7.2
Grafton Formation undifferentiated (Piora and Rapville members)	5.0	8.1	7.5
Walloon Coal Measures (Richmond river basin)	5.0	9.0	7.3
Walloon Coal Measures (Clarence-Moreton bioregion-wide)	5.9	12.0	8.2
Gatton Sandstone (Clarence-Moreton bioregion-wide)	5.2	14.0	7.9
Koukandowie Formation (Clarence-Moreton bioregion-wide)	6.2	8.7	8.1
Woogaroo Subgroup (Clarence-Moreton bioregion-wide)	2.8	9.0	7.2

Data: Bureau of Meteorology (Dataset 1), Queensland Department of Natural Resources and Mines (Dataset 2)

1.5.2.2.2 Trace elements

Only a very limited number of measurements are available for most trace elements, with the exception of aluminium, fluoride, iron and nitrate (Table 16). Exceedances for the trace elements available in the dataset were assessed using the ADWG for human consumption (NHMRC and NRMMC, 2011) and NWQMS (ANZECC/ARMCANZ, 2000) for stock watering and irrigation water (Table 16).

Due to the small number of measurements, the data presented in Table 16 do not provide a representative overview of the variability within the Richmond river basin and hence should be considered with caution. In addition, for some trace elements, difficulties can arise due to the absence of reported detection limits; as an example, this is evident for lead (Pb) where most samples are reported as 0.02 mg/L, and are therefore formally in exceedance of the AWDG trigger of 0.01 mg/L. However, it appears likely that most of these values represent the detection limit, and the actual value may therefore be smaller.

Table 16 Number of analyses and exceedances for trace elements in the Richmond river basin. Concentrations of metals are based on soluble form

	Number of analyses	Minimum value (mg/L)	Maximum value (mg/L)	ADWG[a] trigger (mg/L)	Fraction in exceedance of guidelines (%)	Irrigation trigger[b] (mg/L)	Fraction in exceedance of guidelines (%)	Stock trigger[c] (mg/L)	Fraction in exceedance of guidelines (%)
Aluminium (Al)	29	0.01	6.2	0.2[e]	3.4%	5	3.4%	5	3.4%
Arsenic (As)	17	bd[d]	0.01	0.01	5.9%	NA	0.0%	NA	0.0%
Barium (Ba)	3	bd[d]	bd[d]	2	0.0%	NA	NA	NA	NA
Boron (B)	4	bd[d]	3.3	4	0.0%	0.5	25.0%	5	0.0%
Cobalt (Co)	0	NA	NA	NA	NA	0.05	NA	1	NA
Chromium (Cr)	19	0.01	0.06	0.05	5.0%	1	0.0%	1	0.0%
Copper (Cu)	26	bd[d]	0.06	2	0.0%	1	0.0%	1	0.0%
Fluoride (F)	511	bd[d]	20	1.5	1.6%	1	2.2%	2	1.0%
Iron (Fe)	66	bd[d]	3.7	0.3[e]	24.2%	0.2	24.2%	NA	NA
Manganese (Mn)	26	bd[d]	1.3	0.1[e]	46.2%	0.2	19.2%	NA	NA
Molybdenum (Mo)	0	NA	NA	0.05	NA	0.01	NA	NA	NA
Nickel (Ni)	0	NA	NA	0.02	NA	0.2	NA	1	NA
Nitrate (NO_3)	977	bd[d]	35.02	50	0.0%	NA	NA	NA	NA
Lead (Pb)	NA	NA	NA	0.01	NA	2	NA	0.1	NA
Zinc (Zn)	27	0.01[d]	0.92	3[e]	0.0%	2	0.0%	2	0.0%

[a]Table 3.4.1 in Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011)
[b]Table 4.2.10 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[c]Table 4.3.2 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[d]Below detection limit
[e]Aesthetic water quality trigger (not health related). NA = data not available
Data: Bureau of Meteorology (Dataset 1)

1.5.2.2.3 Gaps

The coverage of bores with available groundwater quality data is limited for the deeper sedimentary bedrock hydrogeological units in the Richmond river basin. This likely reflects that these deeper units have to date not been extensively utilised as groundwater supply aquifers (most of the groundwater extraction occurred from the basalts and the alluvium, as also highlighted in Section 1.5.1 of this product).

The quality of the hydrochemistry data available for this assessment is difficult to determine. Analytical uncertainties or detection limits are not reported in the NSW groundwater quality dataset (Bureau of Meteorology, Dataset 1). The dataset includes groundwater chemistry records that were collected from 1970 to 2007, and the different analytical techniques used during this long period of time involve different levels of accuracy and precision that result in inherent uncertainties. A lack of information on sampling protocols, particularly for trace elements, provides a further source of uncertainty.

The stratigraphic unit at the screened interval is unknown for many bores in the Richmond river basin. As this information is crucial to assess the differences of groundwater quality for different aquifers, one of the biggest challenges was to determine the stratigraphy of the bores, including the identification of the stratigraphic unit at the bore screen from the lithological logs. Following extensive initial data quality checks, this was achieved for a large number of bores by converting the lithological logs to stratigraphic logs and importing the data into a three-dimensional geological modelling software (followed by further substantial cross-checking), as discussed in detail in companion product 2.1-2.2 for the Clarence-Moreton bioregion (Raiber et al., 2015).

Most trace elements have data available for only a few groundwater sampling sites. Where analyses have been performed, several elements have concentrations above ADWG or NWQMS triggers, but the current dataset is too sparse and the quality too uncertain to make conclusions about trigger value exceedances of these elements. Therefore, additional work is required to understand the range and distribution of trace element concentrations in the Richmond river basin.

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