Australian Government

BIOREGIONAL ASSESSMENTS

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

Context statement for the Gwydir subregion

Product 1.1 for the Northern Inland Catchments Bioregional Assessment

26 August 2014

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

The Bioregional Assessment Programme

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

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

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Authorship is listed in relative order of contribution.

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Cover photograph

Gwydir River near Pallamallawa

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Bureau of Meteorology
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CSIRO

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Introduction

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

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

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

The Bioregional Assessment Programme

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

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

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

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

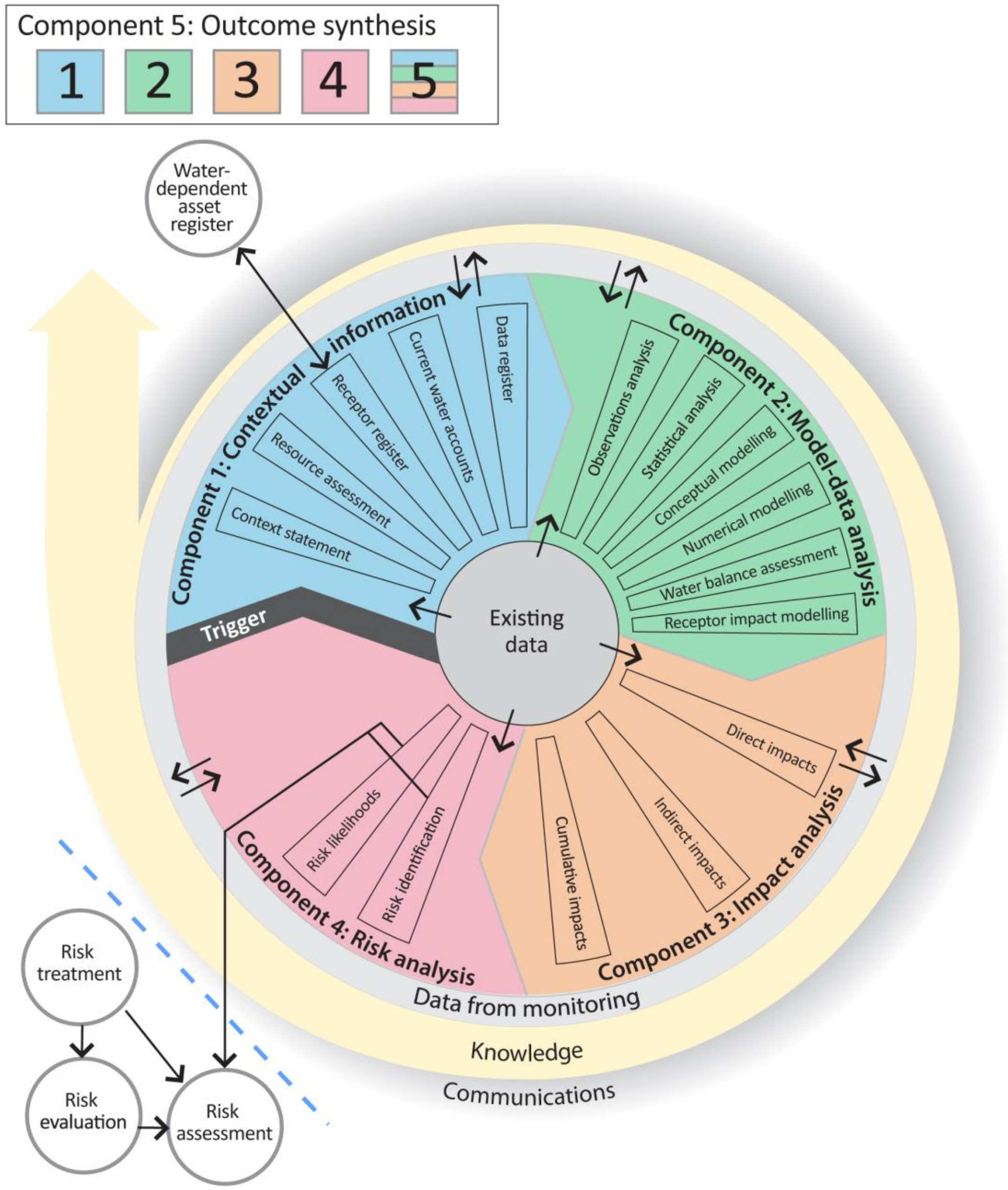

Figure 1 Schematic diagram of the bioregional assessment methodology

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

Technical products

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

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

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

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

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

About this technical product

The following notes are relevant only for this technical product.

- The context statement is a collation of existing information and thus in some cases figures are reproduced from other sources. These figures were not redrawn for consistency (with respect to 'look and feel' as well as content), and the resolution and quality reflects that found in the source.
- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151° East for the Northern Inland Catchments bioregion and two standard parallels of –18.0° and –36.0°.

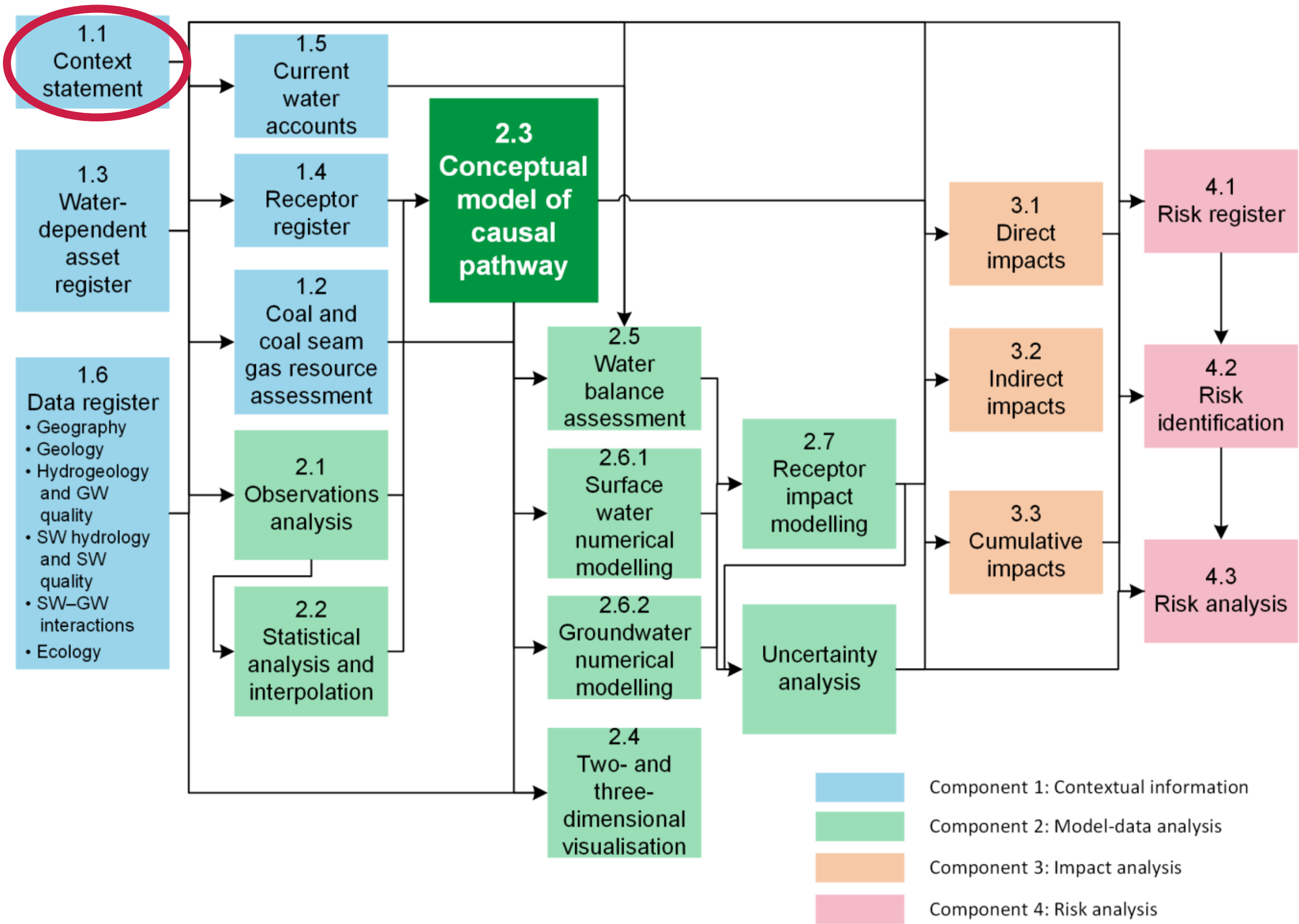

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

The red oval indicates the information covered in this report.

Table 1 Technical reports being delivered as part of the Northern Inland Catchments Bioregional Assessment

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

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

[a]Barrett et al. (2013)
[b]Product 1.5 (Current water accounts and water quality) will be included in the report for product 2.5 (Water balance assessment).
[c]The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 26 August 2014, <http://www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.

1.1 Context statement for the Gwydir subregion

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

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

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

1.1.1 Bioregion

The Gwydir subregion is part of the Northern Inland Catchments bioregion (Figure 3). The Northern Inland Catchments bioregion is located west of the Great Dividing Range in eastern Australia. It includes parts of the northern Murray–Darling Basin in northern New South Wales and southern Queensland. Parts of the northern Murray–Darling Basin that are not underlain by coal are not included. The Northern Inland Catchments bioregion adjoins the Clarence-Moreton bioregion in the north-east, and the Northern Sydney Basin bioregion in the south. It covers an area of about 248,000 km^2.

The Gwydir subregion boundary was the same as the Border Rivers-Gwydir Catchment Management Authority boundary[1] over the extent of the coal-bearing geological basins. The Gwydir subregion does not extend further east than this (Figure 16), so covers a smaller area than the combined Border Rivers-Gwydir river basins in NSW (Figure 29).

The Gwydir Catchment Management Authority was replaced by the North West Local Land Services over the Gwydir subregion in January 2014. Local Land Services regions are generally collations of local government areas, whereas catchment management authorities were based on surface water catchments.

[1] The Gwydir Catchment Management Authority was replaced by the North West Local Land Services over the Gwydir subregion in January 2014. Local Land Services regions are generally collations of local government areas, whereas catchment management authorities were based on surface water catchments.

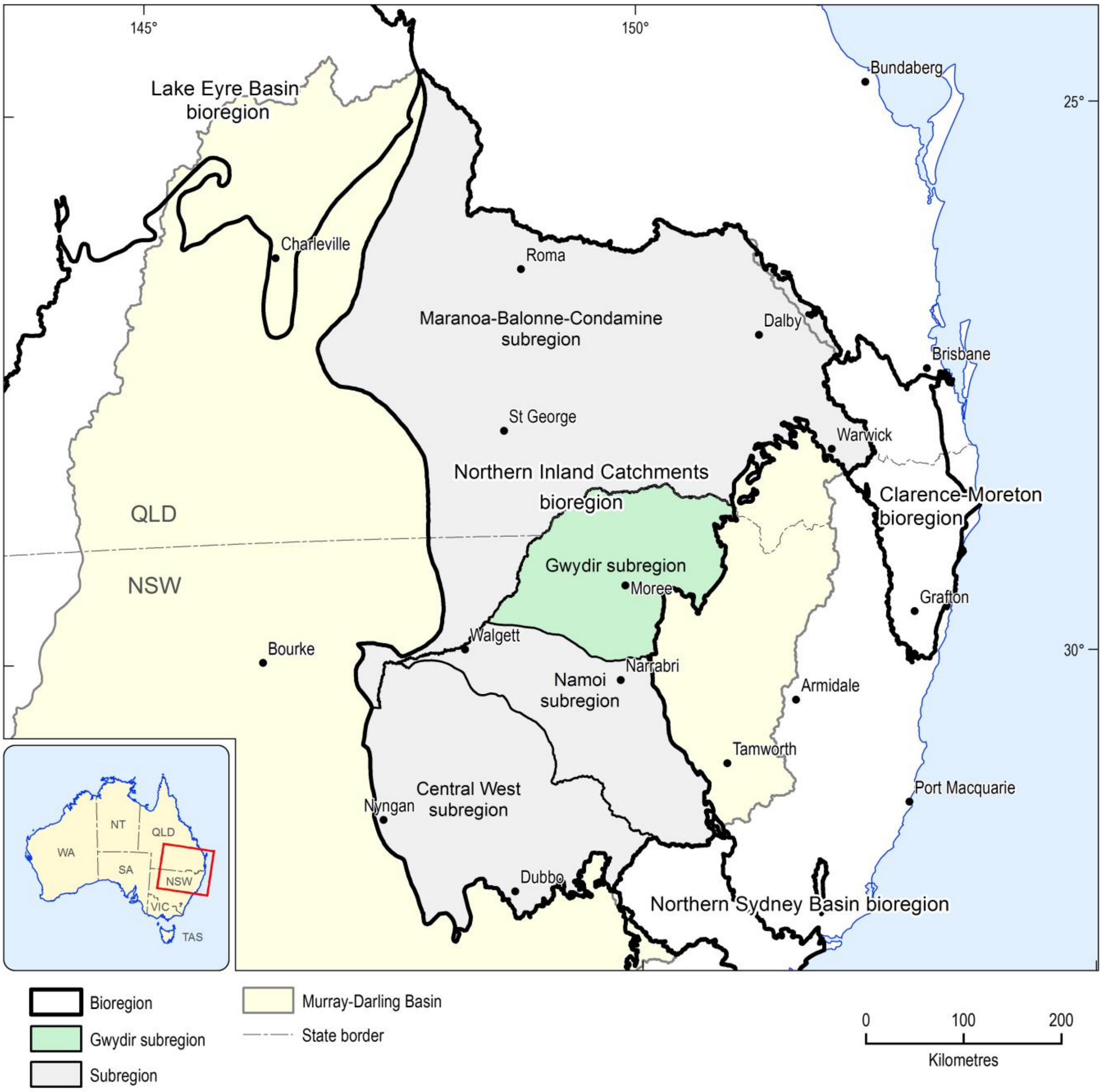

Figure 3 Northern Inland Catchments bioregion and subregions

1.1.2 Geography

Summary

The Gwydir subregion is located within the Murray–Darling Basin (MDB) in northern NSW. It spans an area of 28,109 km^2, extending westward from the lower slopes of the New England Tablelands onto the low-lying riverine plains of the Barwon-Darling system. Maximum and minimum elevations for the subregion itself are 1300 mAHD near Mount Kaputar in the south and 110 mAHD near Collarenebri in the west, respectively.

The main rivers draining the subregion are the Gwydir and Macintyre-Barwon rivers. The Macintyre River rises in the region around Inverell (outside the subregion), flows in a north-westerly direction to Boggabilla then continues west to become the Barwon River near Mungindi. The catchment north of the Macintyre River is in the Maranoa-Balonne-Condamine subregion. The lower end of the Macintyre system is characterised by a complex of distributary streams and lagoon systems that flow away from the main channel when certain river levels are reached. The headwaters of the Gwydir River (outside the subregion) lie between Uralla and Guyra in the New England Tablelands. After descending the tablelands and slopes, the westerly flowing Gwydir River fans out into a number of anabranches and effluent channels, which wend their way to the Barwon River and its floodplains. The subregion's most important water-dependent asset is the Ramsar-listed Gwydir Wetlands on the lower Gwydir and Gingham watercourses, and the Morella Watercourse, Boobera Lagoon and Pungbougal Lagoon on the Macintyre floodplains, which are listed in the *Directory of Important Wetlands in Australia* (Environment Australia, 2001).

The soils of the subregion are overwhelmingly Vertosols, with some variation in the eastern margins where the topography changes from plains to slopes. The Vertosols are well structured and have a good mix of pores for both transmitting and storing water, so plant growth on these soils is typically very good relative to other soil types and they are agriculturally very valuable. Soil condition of the Gwydir subregion is generally good (NSW DECCW, 2010a). The most limiting land and soil hazards in the subregion are soil structure and soil carbon decline, waterlogging and wind erosion. The majority of land is being used 'at capability', meaning the risk of degradation under current land use and management is low (NSW DECCW, 2010b).

The subregion has a heavily modified landscape with very little intact native vegetation cover. Less than 0.4% of land is managed for conservation. The 2010 State of the Catchments report for the Border Rivers-Gwydir region (NSW DECCW, 2010c) rated the vegetation condition as fair and the pressures on land cover as moderate. The main pressures on vegetation extent and condition come from dryland and irrigated agriculture. There are eight endangered ecological communities, protected under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.

The subregion has a mean annual rainfall of 605 mm (1900 to 2011) and is characterised by hot summers and mild winters.

Moree is the major population centre for the subregion with a population of about 7700. Approximately 30% of the employed community work in the agriculture sector (ABS, 2011). The gross value of agricultural production in the Gwydir region in 2010 to 2011 was estimated at $1.43 billion. Regional tourism is also significant, but the reported $784 million in 2011 is from a larger area than the subregion, and perhaps a tenth of this could be attributed to the subregion.

1.1.2.1 Physical geography

The Gwydir subregion is located within the Murray–Darling Basin (MDB) in northern NSW. To the north, it is separated from the Maranoa-Balonne-Condamine subregion by the Dumaresq, Macintyre and Barwon rivers and to the south from the Namoi subregion by the Namoi river basin topographic divide. These boundaries correspond to those for the Border Rivers and Gwydir river basins in NSW, but the eastern, upland part of the Border Rivers and Gwydir river basins is not included within this subregion. The eastern boundary of the Gwydir subregion is defined as the extent of the coal-bearing geology.

The Gwydir subregion spans an area of 28,109 km^2, extending westward from the lower slopes of the New England Tablelands onto the low-lying riverine plains of the Barwon-Darling system. Maximum and minimum elevations for the subregion itself are 1300 mAHD near Mount Kaputar in the south and 110 mAHD near Collarenebri in the west, respectively (Figure 4).

The main rivers draining the subregion are the Gwydir and Macintyre-Barwon rivers. The Macintyre River rises in the region around Inverell (outside the subregion), flows in a north-westerly direction to Boggabilla before continuing west to meet the Barwon River near Mungindi. Sixteen kilometres upstream of Boggabilla the Dumaresq River flows into the Macintyre River, which then becomes the state border. The catchment area to the north of these rivers is part of Queensland and not included within the Gwydir subregion, but in the Maranoa-Balonne-Condamine subregion. The lower end of the Macintyre system is characterised by a complex of distributary streams and lagoon systems that flow away from the main channel when certain river levels are reached. These include Whalan, Callandoon and Dingo creeks, Boomi River and the Little Weir River. The confluence of the Macintyre and Weir rivers marks the start of the Barwon River. The headwaters of the Gwydir River (also outside the subregion) lie between Uralla and Guyra in the New England Tablelands. After descending the tablelands and slopes, the westerly flowing Gwydir River fans out into a number of anabranches and effluent channels, including Moomin Creek, Mehi River, Gingham Watercourse, Carole Creek and Gil Gil Creek, which wend their way to the Barwon River and its floodplains. More detail on the surface hydrology can be found in Section 1.1.5. The subregion’s most noteworthy water-dependent asset is the Ramsar-listed Gwydir Wetlands on the lower Gwydir and Gingham watercourses, and the Morella Watercourse, Boobera Lagoon and Pungbougal Lagoon on the Macintyre floodplains, which are listed in the *Directory of Important Wetlands in Australia* (Environment Australia, 2001) (Section 1.1.7).

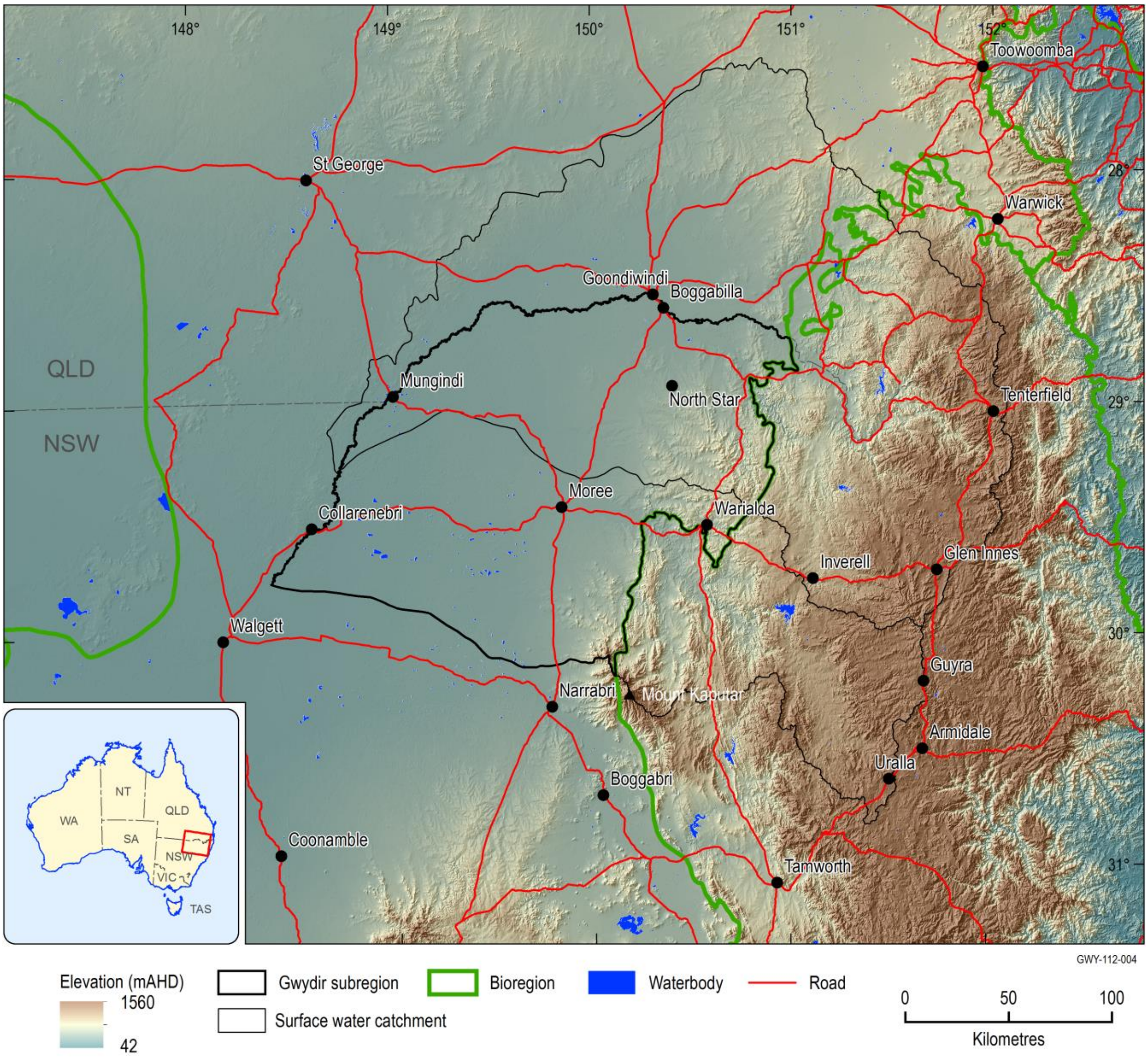

Figure 4 Topography of the Gwydir subregion, generated from three second DEM

Source data: 3 second SRTM derived elevation model (DEM) version 1.0 (Geoscience Australia, 2011a)

1.1.2.1.1 Physiographic regions

Physiographic regions are defined by a suite of landforms which have evolved in response to specific combination of climate and geologic controls (Jennings and Mabbutt, 1986). While the mapping criteria relate to landform attributes, the resultant mapped units can be described in terms of landform, underlying geology, regolith and soils (Pain et al., 2011).

The Gwydir subregion is dominated by the Upper Darling Plains physiographic region which is characterised by branching rivers incised into a regolith of predominantly alluvial sediments (>50%) with minimal saprolite (<20%) (Pain et al., 2011) (Figure 5). Saprolite refers to in situ weathered rock, whereas alluvial sediments indicate depositional environments, where the regolith comprises transported material, rather than material that has weathered in place. The eastern part of the subregion intersects the Cunningham Slopes and Nandewar Peaks physiographic regions. The more northern Cunningham Slopes are characterised by ridge and valley geomorphology in metamorphic rocks with regolith varying between highly weathered bedrock and soil on bedrock over most of the region. The small area of Nandewar Peaks in the south-east corner is a dissected volcanic pile landscape with a predominantly soil on bedrock regolith and other areas of moderately weathered bedrock.

The dominance of one physiographic region in the Gwydir subregion is reflected in the relative uniformity of soil type, land cover and land use.

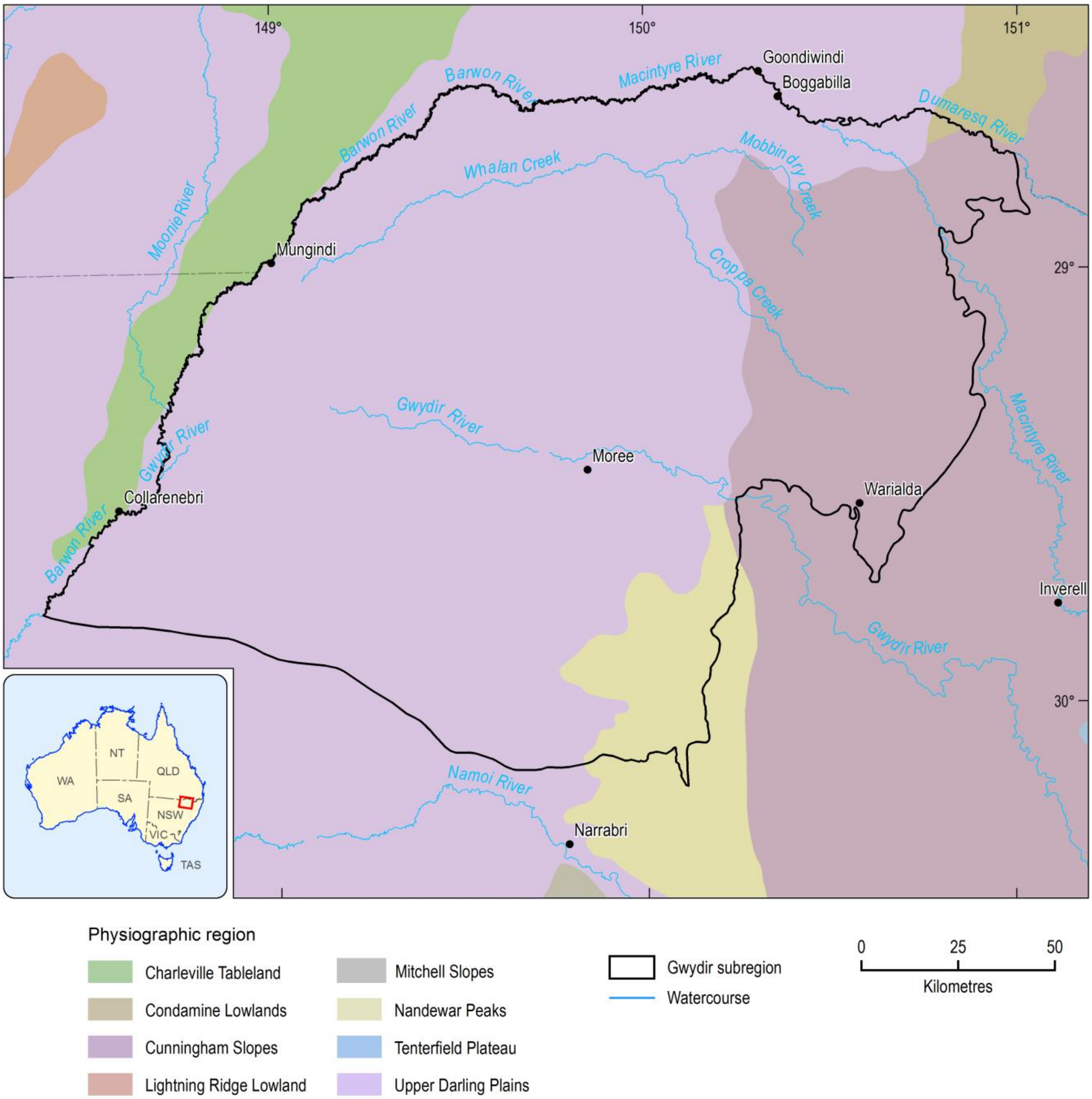

Figure 5 Physiographic regions of the Gwydir subregion

As defined in Pain et al. (2011)

1.1.2.1.2 Soils and land capability

The Gwydir subregion has moderately fertile soils over most of its land surface, with a small strip of highly fertile soils along the Gwydir River valley around Moree and in some northern areas around Boggabilla (NSW OEH, 2012a). In the Australian Soil Classification system (Isbell, 2002), the soils of the Upper Darling Plains physiographic region are overwhelmingly Vertosols (Figure 6, Table 2), which are clay soils with shrink-swell properties that exhibit strong cracking when dry. From an agricultural perspective, they are well structured and have a good mix of pores for both transmitting and storing water, so plant growth on these soils is typically very good relative to other soil types. Vertosols are better suited to irrigated crops such as cotton, wheat, sorghum and rice than rain-fed crops because they can be worked under a very narrow range of moisture conditions. These self-mulching soils can withstand comparatively frequent cultivation without changes to structure.

Vertosols dominate in the Nandewar Peaks and Cunningham Slopes physiographic regions also, but other soils, such as Sodosols (soils having a high exchangeable sodium content), Ferrosols (soils having high free iron and generally high clay content) and Chromosols (soils showing strong texture contrast between surface and deeper soil layers) are significant in the eastern parts of the subregion (Figure 6). Localised areas of Dermosols (well-structured soils with high water holding capacity and high chemical fertility) can be found in the subregion also. The greater variability in soil types reflects the dominance of erosional and transportational surfaces on the slopes, in stark contrast to the depositional environments of the valleys and floodplains.

In the most recent systematic statewide assessment of NSW soil health, commenced in 2008 under the New South Wales Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015 (NSW DECCW, 2010c), soil condition of the Gwydir subregion was assessed as generally good (i.e. small loss of condition relative to a reference condition for a range of soil indicators), with a likelihood of not changing in the future (NSW DECCW, 2010a). Soil condition is the ability of soil to deliver a range of essential services, including habitat for soil biota, nutrient cycling, water retention and primary production. The most limiting land and soil hazards in the subregion are soil structure and soil carbon decline, waterlogging and wind erosion (NSW EPA, 2012). Soil structure is the prime determinant of soil health, a decline in which means that soil permeability and water holding capacity are reduced (e.g. through compaction). Organic carbon is the main biological determinant of soil health and decline occurs when the removal of organic matter from the landscape exceeds its replacement. Wind erosion is a direct function of ground cover with bare soils, particularly Chromosols, more vulnerable to erosion than those where a good vegetation cover is maintained. Land management practices are the primary pressure on soil condition.

Land capability is the inherent physical capacity of the land to sustain long-term land uses and management practices without degradation to soil, land, air and water resources (Dent and Young, 1981). The land and soil capability classification scheme takes account of limitations for sustainable use arising from water erosion, wind erosion, salinity, topsoil acidification, shallow soils/rockiness, soil structure decline, waterlogging and mass movement (NSW OEH, 2012b). Figure 7 shows land and soil capability classification for the Gwydir subregion based on the most limiting hazard. Class 1 represents land capable of supporting most land uses with minimal conservation management, while Class 8 land has many limitations to use and is best left for conservation. For the most part, lands in the subregion are land and soil capability Classes 2 and 3, meaning they can support high impact land uses through easily implemented more intensive management practices. Along streamlines, the land is typically land and soil capability Class 4 and not capable of supporting high impact uses without very specialised management. The Gwydir Wetlands, an area just south of the Mehi River and the eastern margins of the subregion are Class 6 lands and there are localised patches of Class 7 land in the Warrumbungle Ranges and east and north of Warialda, where shallow soils and vulnerability to water erosion and mass movement seriously limit land use options. These areas are best suited to light grazing, forestry and nature conservation (NSW OEH, 2012b).

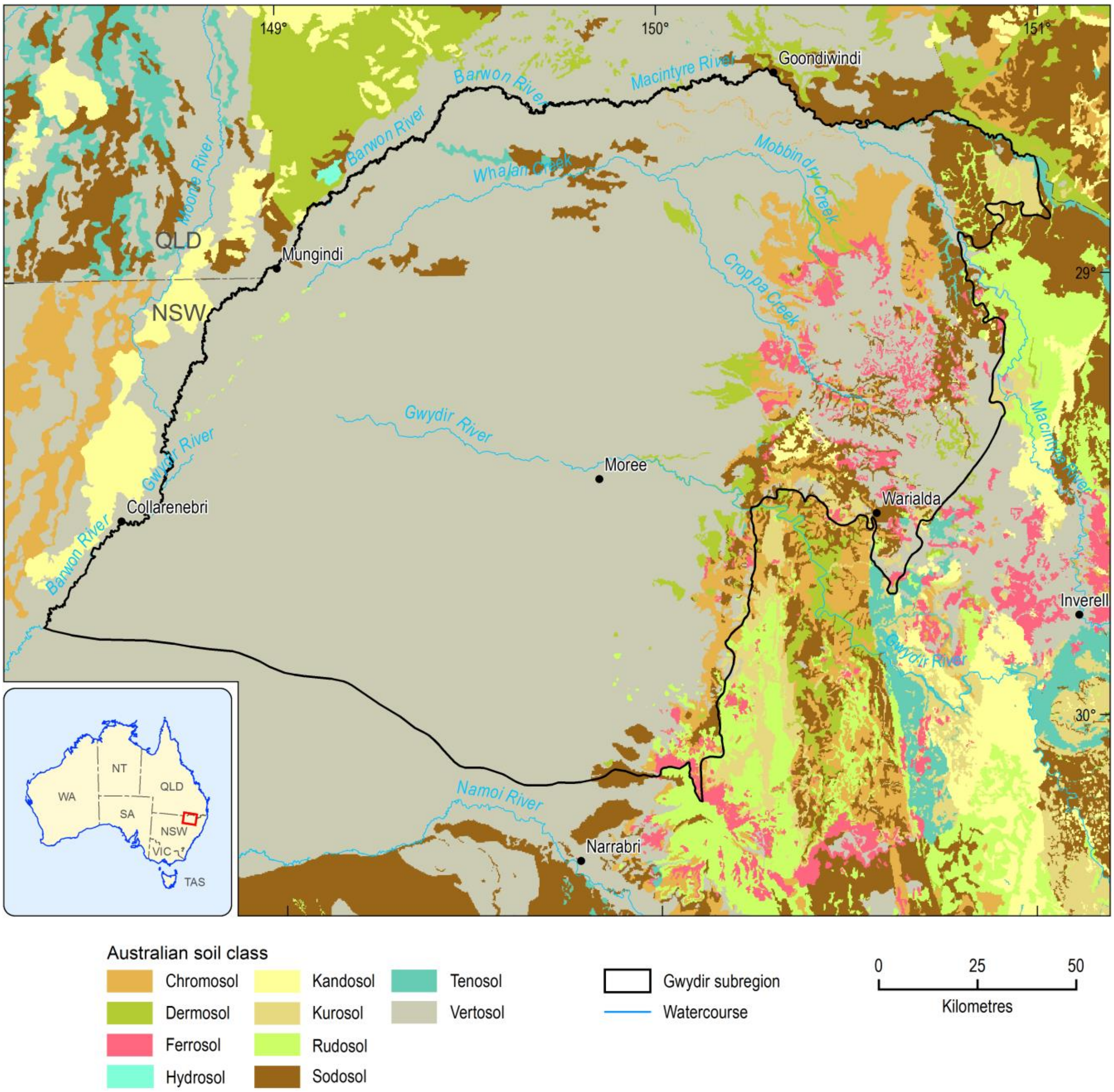

Figure 6 Soils classified using the Australian Soil Classification

Source data: National Soil Grids (ASRIS, 2011)

Table 2 Soils, classified using Australian Soil Classification (Isbell, 2002)

ASC soil class	Percentage of total area of subregion (%)
Vertosols	84%
Sodosols	6%
Chromosols	4%
Dermosols	2%
Ferrosols	2%
Kurosols	1%
Rudosols	1%

In 2009, the former Border Rivers-Gwydir Catchment Management Authority (Border Rivers-Gwydir CMA) and the former NSW Department of Environment, Climate Change and Water (NSW DECCW) assessed the extent to which land was being used within capability in the NSW Border Rivers and Gwydir river basins. In the Gwydir subregion, the majority of land is being used ‘at capability’, meaning that the risk of degradation under current land uses and management is low (NSW DECCW, 2010a).

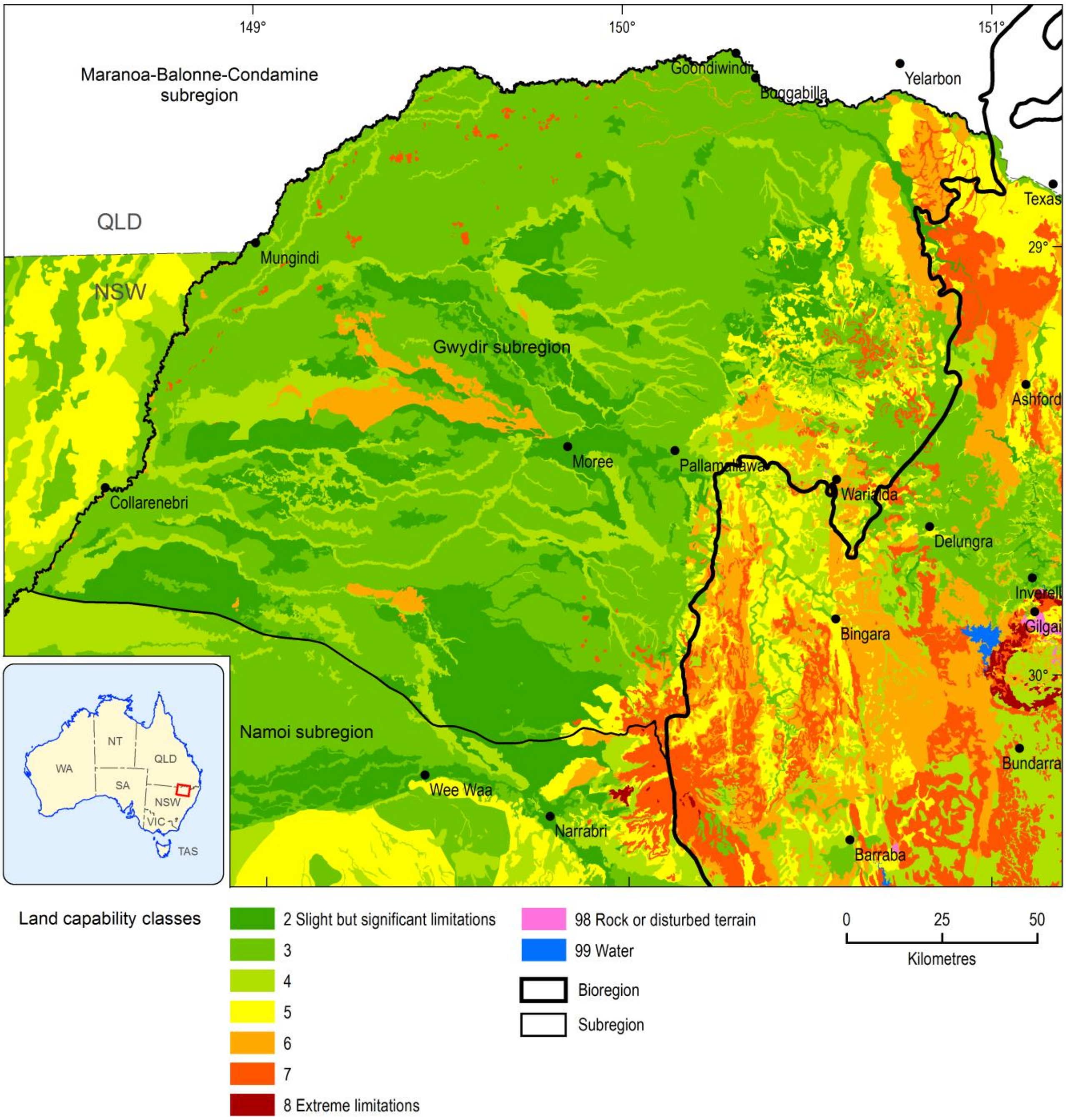

Figure 7 Land and soil capability

Source data: Land and Soil Capability mapping of NSW (NSW OEH, 2013a)

1.1.2.1.3 Land cover

Figure 8 shows the land cover for the subregion in 2008, based on remotely sensed Enhanced Vegetation Index (EVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites that have been post-processed to convert vegetation greenness to a land cover type (Geoscience Australia, 2011b). Pasture and crops are the dominant land covers (54%), with open, scattered and sparse tree covers accounting for 38% of the land cover. Tussock grasses and a small proportion of hummock grasses cover 5% of the land area (Table 3).

The landscape in the subregion has been heavily modified. The majority of the land is classified as 'non-native or other' which means predominantly crops and non-native pastures, with a very small fraction of urban, industrial and infrastructure land cover types. The subregion boasts very little intact native vegetation cover and less than 0.4% of land is managed for conservation. The 2010 State of the Catchment report for the Border Rivers-Gwydir region (NSW DECCW, 2010d) rated the vegetation condition as fair and the pressures on land cover as moderate. However, the subregion has a higher proportion of transformed land cover than the upland areas of the wider Border Rivers and Gwydir river basins, and therefore vegetation condition could well be poor.

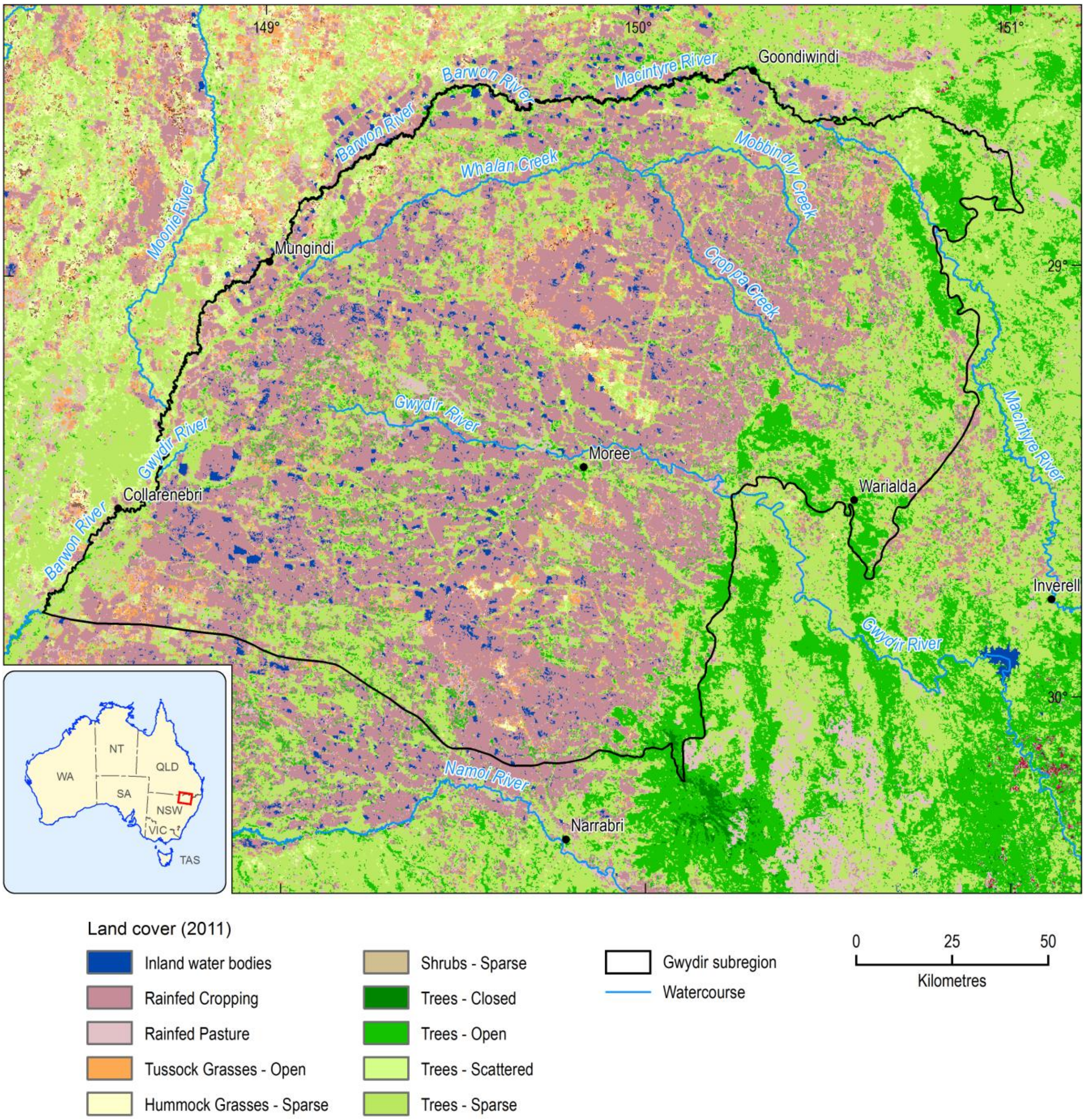

Figure 8 Land cover

Source data: The National Dynamic Land Cover Dataset, Geoscience Australia (2011b)
The methods used to produce the land cover map are not very sensitive to use of irrigation water and irrigated land covers are often mapped as rain-fed covers. For irrigated land covers, the land use map (Figure 9) should be consulted.

Of the remnant communities, the floodplain woodlands of coolibah are the most extensive, with occasional myall woodlands and whitewood and belah woodlands with lignum and mimosa. The plains once supported extensive areas of Mitchell and plains grass communities, but these are now much reduced in the area. They can still be found on the plains south-west of Moree. Other communities occurring on the higher parts of the floodplain include poplar box woodlands, wilga, brigalow, white cypress and silver leaf ironbark (Border Rivers-Gwydir CMA, 2007).

A number of ecological communities, which may once have or still do occur within the subregion are protected under the NSW *Threatened Species Conservation Act 1995* and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Table 4). The marsh club-rush sedgeland at the core of the lower Gwydir Wetlands and found only in the Gwydir valley was listed as an endangered ecological community by NSW in 2010. The riverine plains of the Gwydir and Mehi rivers also support remnant areas of carbeen open forest, myall woodland, and inland grey box woodland (Green et al., 2011, 2012). The Border Rivers-Gwydir Catchment Action Plan 2013 to 2023 has set targets for the Western Plains and Brigalow Country areas to increase native vegetation cover by 2% by 2023 (Border Rivers-Gwydir CMA, 2013).

Seasonal and semi-permanent wetlands occur along the Gingham and Gwydir watercourses. About 40,000 ha of wetlands in the river basin are recognised as being internationally or nationally important.

Table 3 Areas and percentage of subregion for each land cover type in Gwydir subregion

Land cover class	Area (km^2)	Percentage of subregion (%)
Pasture and crops	15,135	53.8%
Trees – Sparse	7,583	27.0%
Trees – Open	2,608	9.3%
Tussock grasses	1,329	4.7%
Inland water bodies and wetlands	641	2.3%
Trees – Scattered	465	1.7%
Shrubs	197	0.7%
Hummock grasses	92	0.3%
Chenopods	32	0.1%
Trees – Closed	24	0.1%
Sedges	1	0.0%

Table 4 Ecological communities in the Gwydir subregion that are listed as threatened under the the *NSW Threatened Species Conservation Act 1995* and the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

Ecological communities	Distribution	EPBC Act listing
Brigalow within the Brigalow Belt South bioregion	Isolated remnants on the Gwydir floodplain, usually on heavy clay soils	Endangered
Coolibah - Black Box Woodlands	On grey, self-mulching clays of periodically waterlogged floodplains, swamp margins, ephemeral wetlands, and stream levees	Endangered
Cadellia pentastylis (Ooline) community in the Nandewar and Brigalow Belt South Bioregions	Extensively cleared, now known in seven main locations on the north-west Slopes in NSW, between Narrabri and Queensland	Not listed
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions	On the riverine plains of the Meehi, Gwydir, Macintyre and Barwon rivers	Not listed
Inland Grey Box (*Eucalyptus microcarpa*) woodland	Occurs on fertile soils of the western slopes and plains of NSW at sites receiving between 375 and 800 mm mean annual rainfall.	Endangered
Marsh club-rush sedgeland	Mainly restricted to the Gwydir Wetlands but may occur elsewhere in the Darling Riverine Plains bioregion	Not listed
Natural grasslands on basalt and fine-textured alluvial plains of northern NSW and southern Queensland	Generally occurs on flat to low slopes, of no more than 5% (or less than 1 degree) inclination	Critically endangered
Semi-evergreen Vine Thicket in the Brigalow Belt South and Nandewar Bioregions	Occurs on rocky hills, in deep, loam, high nutrient soils derived from basalt or other volcanic rocks, in areas which are sheltered from frequent fire.	Endangered
Weeping Myall Woodland	Occurs on red-brown earths and heavy textured grey and brown alluvial soils within a climatic belt receiving between 375 and 500 mm mean annual rainfall	Endangered
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Less than 5% remaining across entire domain – isolated patches	Critically endangered

Source data: NSW DEH (2013a) and Department of the Environment (2013a)
See also section 1.1.7 Ecology

1.1.2.2 Human geography

1.1.2.2.1 Population

It is difficult to put an exact figure on the population of the Gwydir subregion as the area does not align well with the more usual reporting areas (natural resource management region, local government area (LGA), statistical local area, etc.). The Moree Plains LGA, which is almost completely contained within the subregion, has a population of about 14,000 and the Gwydir LGA, of which about 50% is in the subregion, has a population of about 5,000 (ABS, 2011). Therefore a reasonable estimate of the subregion population is about 16,500. The wider NSW Border Rivers and Gwydir river basins have a population of about 65,000. The largest town, Moree, has a population of 7720, while the smaller urban centres of Warialda and Boggabilla have populations of 1120 and 625, respectively (based on Urban Centre Localities, ABS 2011). Population densities range between 0.5 and 0.8 persons/km^2 in the Gwydir and Moree Plains LGA, respectively.

In the 2011 Population Census (ABS, 2011), 3.8% of the Gwydir LGA and 20.8% of the Moree Plains LGA populations indicated they were Indigenous.

In common with many rural communities across Australia, the region is experiencing an ageing population and an overall, long-term population decline, particularly in smaller centres. Greater production efficiencies have been realised through technology advances, which have helped to offset the effects of declining terms of trade and increasing input costs, and better farm equipment has led to reduced labour requirements. The net effect has been reduced employment opportunities on-farm and in farm service industries. Population decline has resulted in a reduction of services and facilities in the region's towns (Border Rivers-Gwydir CMA, 2007). Issues for the Border Rivers-Gwydir regional community are declining profitability from farming due to rising costs of farm inputs and increasing environmental and agricultural weeds, reduced employment in agriculture and declining populations in rural areas more generally (NSW DECCW, 2010e).

1.1.2.2.2 Economic activity

Table 5 summarises the main sectors of employment for the subregion (based on Moree Plains and Gwydir LGA data). Close to 30% of the employed population works in agriculture. Retail, health care and social services, education and training, and public administration and safety account for another 32%. Mining accounts for 0.3% of regional employment.

The gross value of agricultural production in the NSW Border Rivers and Gwydir river basins in 2010 to 2011 was estimated at $1.43 billion, of which $570 million (41%) was from cotton, $557 million (40%) from cereal and legume crops and $260 million (18.5%) from livestock products (ABS, 2012).

Regional tourism figures for the New England North West region (DNSW, 2013) report that visitors to the region in 2012 contributed $784 million to the regional economy. The reporting region for this figure is considerably wider than the subregion and includes the Namoi river basin and the Upper Gwydir, in which towns like Armidale, Glen Innes, Inverell and Tamworth would command a significant proportion of that revenue. The Moree Plains LGA averaged $36 million/year for the four years to September 2011 (DNSW, 2013).

1.1.2.2.3 Land use

The self-mulching black soils of the lower valley are well suited to irrigated agriculture. Irrigation development has occurred rapidly since the early 1960s, and 2150 km^2 are now used to grow crops such as cotton, cereals and oilseeds. Most of the summer crops such as cotton are irrigated, while much of the winter demand is met by rainfall (Green et al., 2011, 2012). Cropping occurs on 51% of the land, of which just over 7% (215,000 ha) is irrigated cropping. A further 35% of the subregion is used for grazing on natural and modified lands. Production and plantation forestry and conservation and other natural environments occur over 9% of the area. Table 6 summarises land use by area in the subregion.

Table 5 Employment profile for Gwydir subregion, expressed by sector as percentage of employed

Industry	Moree Plains LGA (%)	Gwydir LGA (%)	Combined (%)
Agriculture, forestry and fishing	26.0%	38.8%	29.3%
Mining	0.3%	0.4%	0.3%
Manufacturing	4.5%	3.1%	4.1%
Electricity, gas, water and waste services	0.9%	1.3%	1.0%
Construction	5.6%	3.8%	5.1%
Wholesale trade	3.1%	3.0%	3.1%
Retail trade	9.6%	7.0%	8.9%
Accommodation and food services	5.7%	3.7%	5.2%
Transport, postal and warehousing	5.0%	4.0%	4.7%
Information media and telecommunications	0.6%	0.5%	0.6%
Financial and insurance services	2.0%	1.4%	1.8%
Rental, hiring and real estate services	1.1%	0.5%	0.9%
Professional, scientific and technical services	3.4%	1.8%	3.0%
Administrative and support services	1.9%	1.2%	1.7%
Public administration and safety	6.6%	7.4%	6.8%
Education and training	8.1%	7.3%	7.9%
Health care and social assistance	8.1%	9.5%	8.5%
Arts and recreation services	0.3%	0.7%	0.4%
Other services	4.6%	2.5%	4.1%

Source data: National Regional Profile 2007–2011 (ABS, 2011)
LGA is local government area

The distribution of land uses in the subregion is shown in Figure 9, where it is possible to identify two distinct zones. East of Moree, scattered areas of grazing on modified pastures are interspersed through a predominantly cropping landscape. Around Goondiwindi and the more hilly areas of the east, grazing is more widespread than cropping. Both cattle and sheep grazing are undertaken. The eastern margins of the subregion and around Warialda include significant areas of minimal use lands and production forestry. To the west of Moree, cropping is still widespread, but grazing tends to occur on natural vegetation lands, particularly on land adjacent to the lower Gwydir and Gingham wetlands. Irrigated cotton is grown in this zone and is the dominant enterprise in the area. Cereal and oilseed crops are also grown.

Table 6 Land use areas in the Gwydir subregion

Land use	Area (km^2)	Percentage of subregion (%)
Cropping	12,271.3	43.7%
Grazing natural vegetation	5,872.2	20.9%
Grazing modified pastures	4,069.5	14.5%
Irrigated cropping	2,147.5	7.6%
Conservation and natural environments	1,986.3	7.1%
Water	743.1	2.6%
Production forestry	397.9	1.4%
Residential, manufacturing, utilities, transport, services	330.8	1.2%
Land in transition	132.0	0.5%
Plantation forestry	126.8	0.5%
Irrigated horticulture	15.8	0.1%
Mining	6.8	0.0%
Horticulture	5.6	0.0%
Intensive production	3.2	0.0%
Grazing irrigated modified pastures	0.3	0.0%

Source data: ABARES (2012)

Small areas of nature conservation are found in the south-eastern corner adjoining the Namoi river basin and north-east of Warialda on the eastern margin of the subregion. The area around Moree is where most of the intensive land uses occur.

In late 2012, the NSW Government introduced its Strategic Regional Land Use Policy to protect valuable residential and agricultural land across the state from the impacts of mining and coal seam gas activity (NSW Government, 2014). Information was released in January 2014, identifying the areas of biophysical strategic agricultural land – land of high quality soil and water resources capable of supporting high levels of agricultural production – across NSW, which are deemed necessary to support the state's $12 billion per year agricultural industry. Other coal seam gas exclusion zones were also identified (Figure 10).

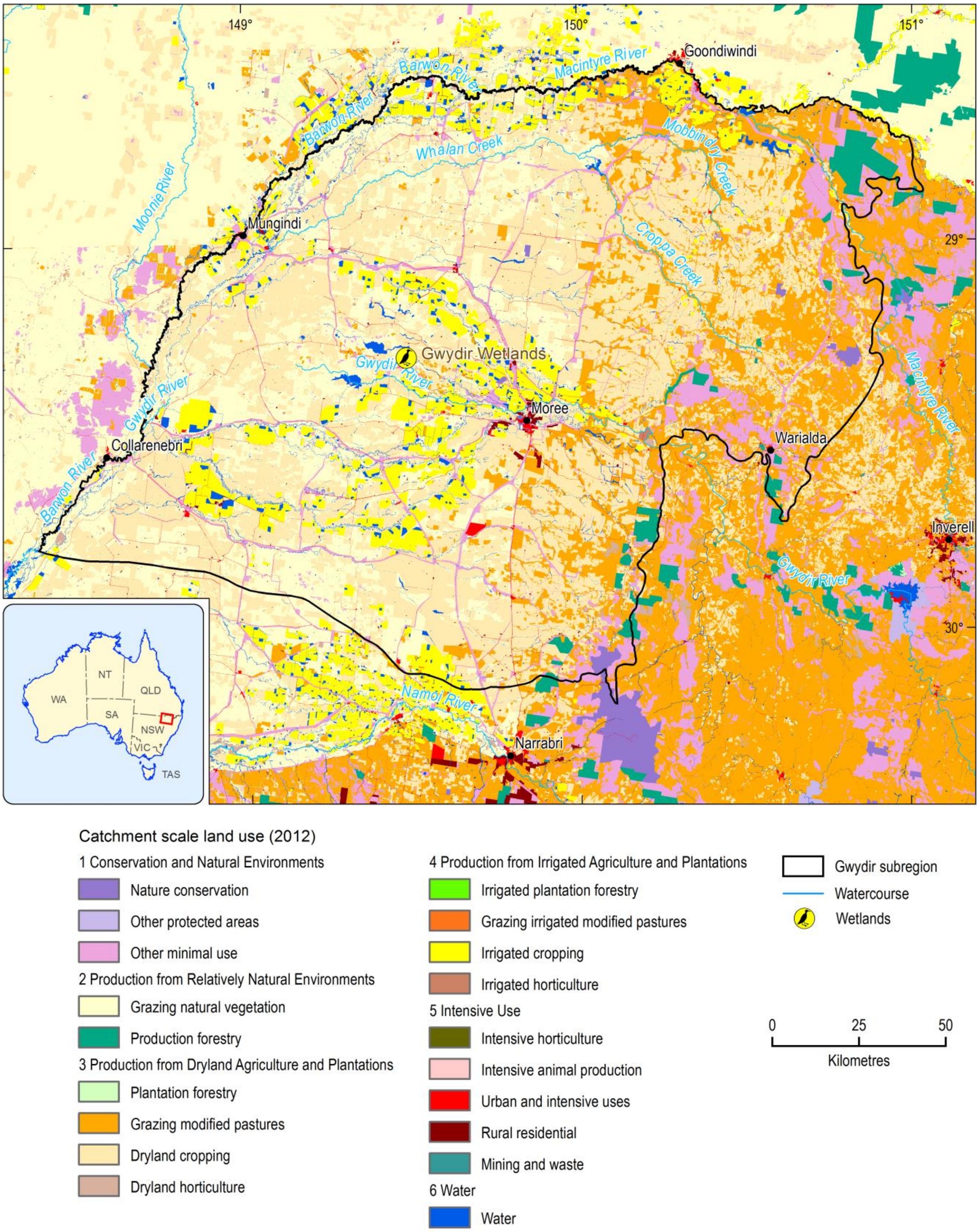

Figure 9 Land use mapping in the Gwydir subregion

Source data: Catchment scale land use mapping for Australia update November 2012 (CLUM Update 11/12) dataset, ABARES (2012)

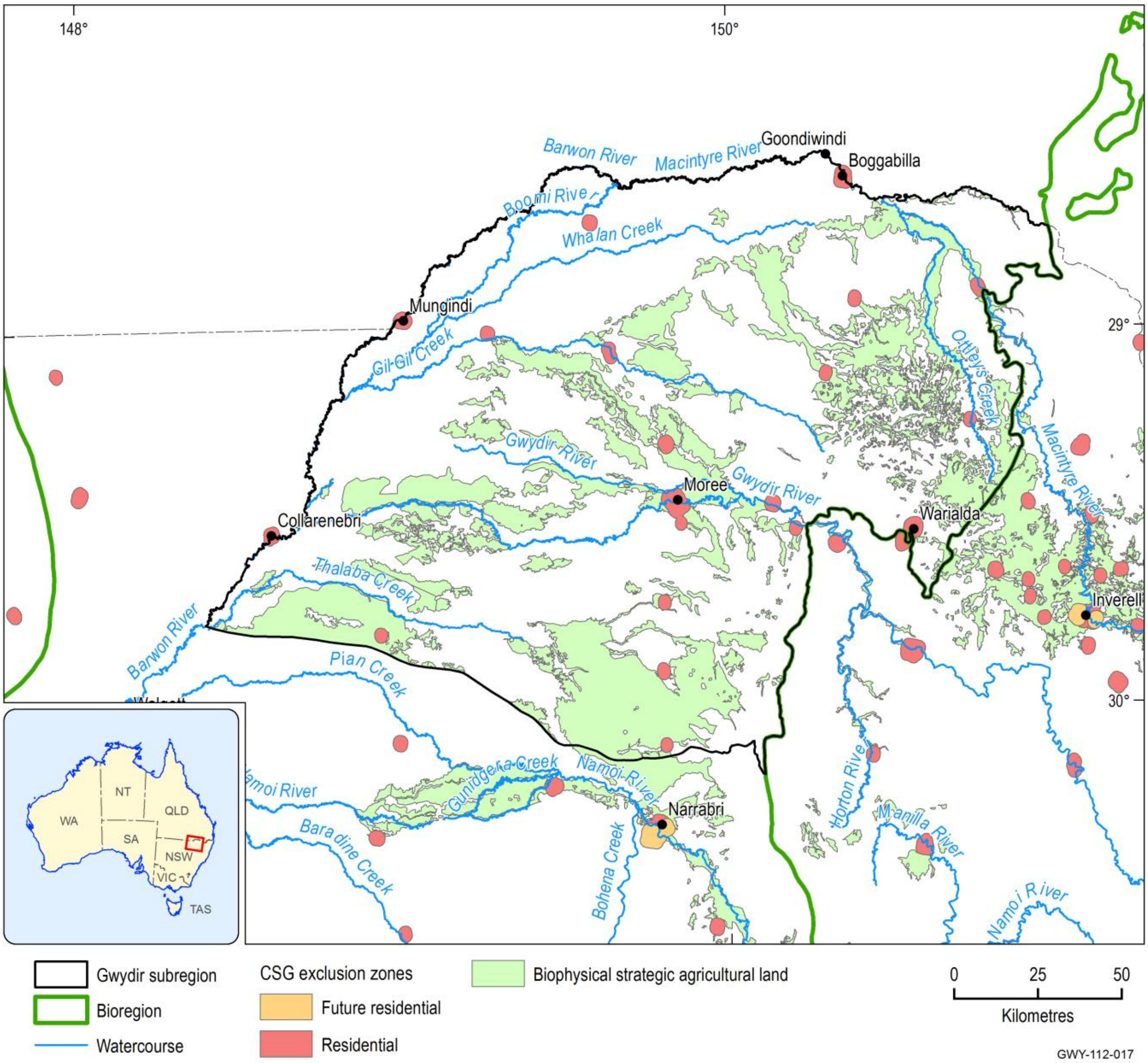

Figure 10 Coal seam gas exclusion zones in the Gwydir subregion

Source data: Strategic Agricultural Lands (NSW Government, 2013)

1.1.2.2.4 Indigenous heritage

The subregion is part of the traditional lands of the Gomeroi people with a small part of the Bigambul people's lands along the Macintyre River. A number of significant Indigenous sites are located within the region, which under section 86(4) of the *New South Wales National Parks and Wildlife Act 1974* (NPW Act) are protected from harm or desecration. Boobera Lagoon on the Macintyre floodplain is believed to be the resting place of *Garriya*, the rainbow serpent, who created the lagoon as well as the surrounding waterways. Boobera Lagoon was also the site of the final stages of a male initiation ceremony. The nearby Northcote Bora Ring was used by Indigenous people from the surrounding country for ceremonial purposes. South-east of Moree, Terry Hie Hie Corroboree Ground and Grinding Grooves was also an important ceremonial place, and is owned by the Moree Aboriginal Land Council (NSW OEH, 2013b). The NPW Act requires that the potential impacts of development on an Indigenous place be assessed.

1.1.2.3 Climate

The climate of the subregion is characterised by hot, dry summers and cool winters. Maximum temperatures average 32 to 33 °C through the summer and 17 to 19 °C through the winter, while typical minimum temperatures in summer are 17 to 19 °C and 5 °C through winter (Figure 11). The Köppen classification system classes the western part of the subregion as hot and persistently dry, while the east is subtropical with a moderately dry winter.

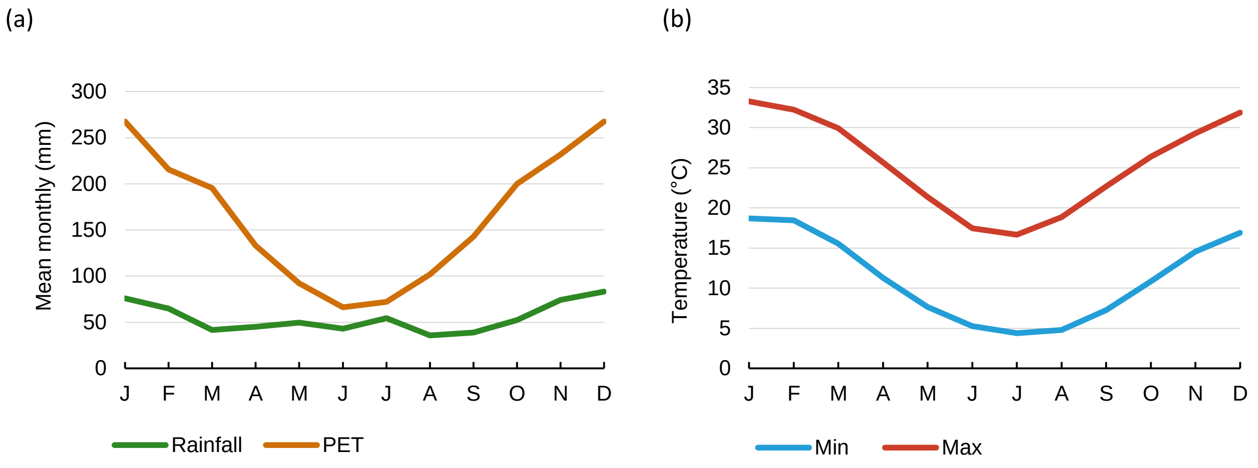

Figure 11 Mean monthly rainfall and potential evapotranspiration (PET) (a) and mean monthly maximum and minimum temperatures (b) over the subregion for the period 1981–2012

Source data: derived from (i) Mean monthly and mean annual rainfall data (BoM, 2013a) and (ii) Mean monthly and mean annual maximum, minimum & mean temperature data (BoM, 2013b)

In the subregion, mean annual rainfall ranges from about 950 mm in the Mount Kaputar area to the south of Moree to about 500 mm south-west of Collarenebri (Figure 12). In the headwaters of the Gwydir and Border rivers, but outside of the subregion, mean annual rainfall exceeds 1200 mm in places. Figure 13 shows the annual time series of rainfall from 1900 to 2011 for the subregion. The annual mean for this period is 605 mm, but it can be seen that there is considerable variability with a low of 310 mm in 1902 and a maximum of 1185 mm in 1950. The orange line, which represents the low frequency trend for the record, shows that the years between 1900 and 1946 were on average drier (530 mm/year) than the latter half of the 20th century (650 mm/year). The millennium drought is not evident in the subregion with the rainfall mean of 605 mm for 2002 to 2009 being the same as that for the full record, although the second driest year since 1900 was in 2002. Rainfall is summer-dominant, varying from 225 mm (75 mm/month) for the December to February period to 135 mm (45 mm/month) between June and August (Figure 11).

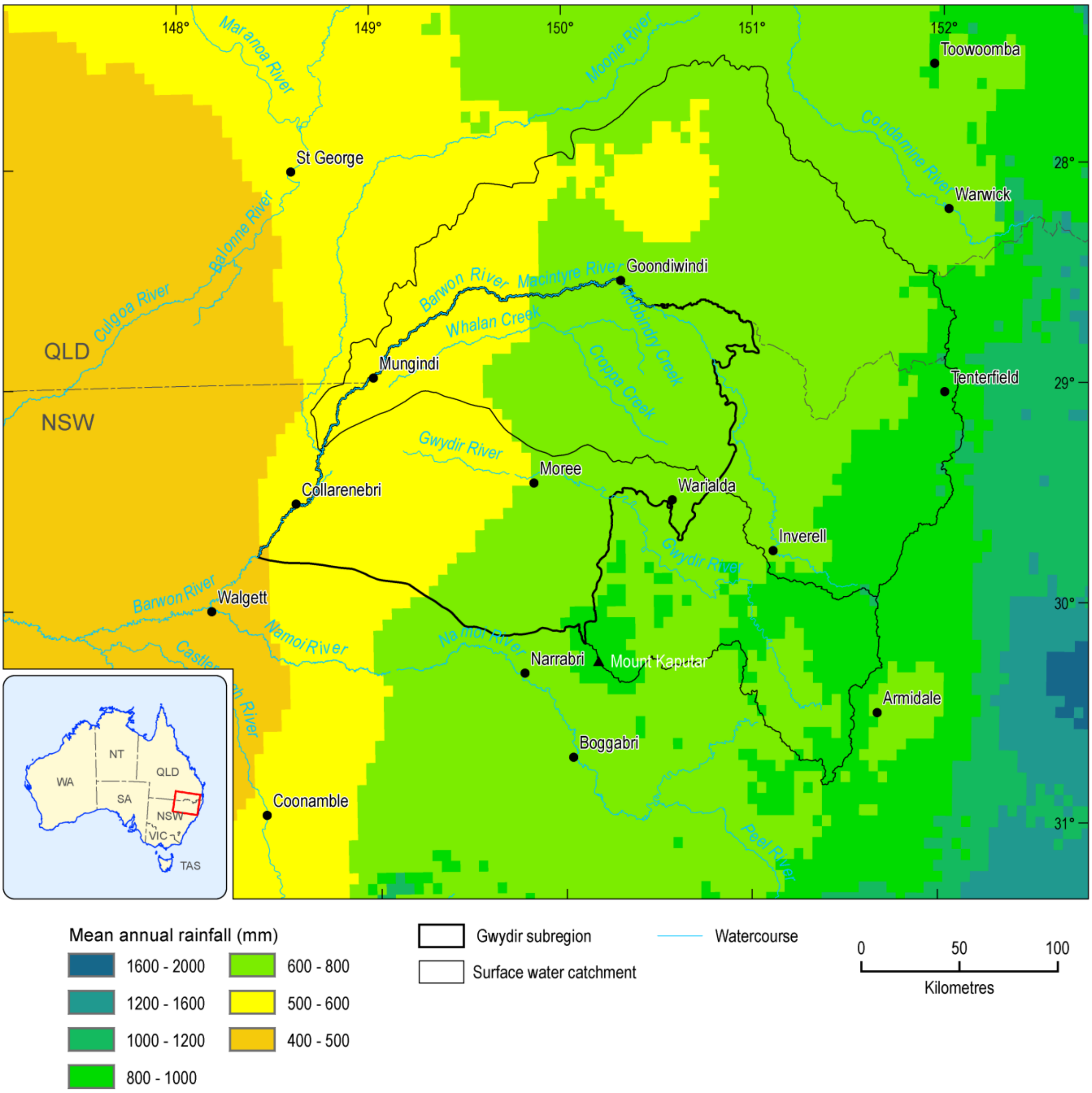

Figure 12 Mean annual rainfall

Source data: BoM (2013c)

Potential evapotranspiration (PET) was calculated on a daily time step using the Penman method with a wind spline for the period 1981 to 2012. The spatial pattern of mean annual PET for this period is shown in Figure 14 and ranges from 1925 mm to 2180 mm across the subregion. Higher rates occur to the west of the subregion and lower rates in the higher elevation, higher rainfall areas to the east. The mean monthly PET varies between 65 mm in June and 265 mm in December and January, reflecting the annual temperature pattern. On average, potential evaporation is limited by water availability throughout the year (Figure 11), so actual evapotranspiration rates are not as high as potential rates.

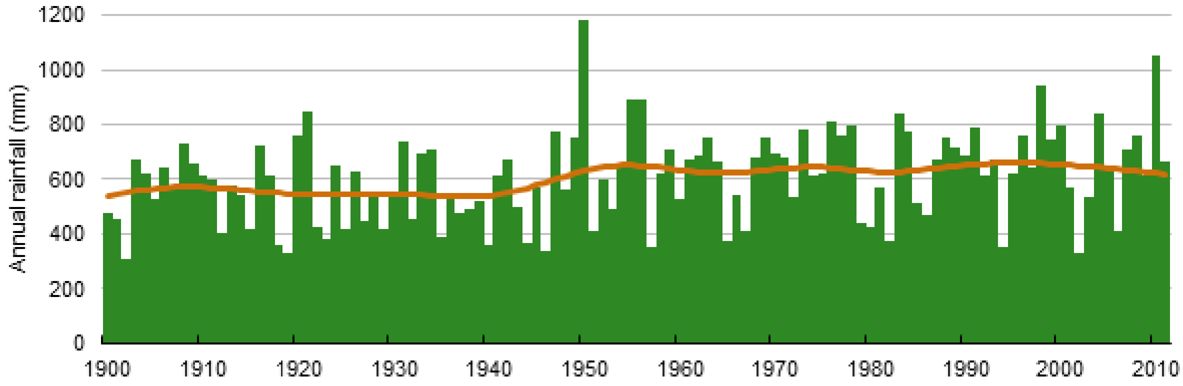

Figure 13 Annual rainfall for 1900 to 2011 averaged over the Gwydir subregion

Source data: BoM (2013c)
The orange line shows the low frequency variability.

In a recent report by the South Eastern Australia Climate Initiative (SEACI) (CSIRO, 2010), the significance of the 1997 to 2009 period was assessed relative to other recorded droughts since 1900 and as an indicator of what the future climate might look like. While it was found that this period was the driest in the 110+ year record for the south-eastern corner of Australia with rainfall 5 to 30% less than the 1895 to 2008 mean, in the Border Rivers-Gwydir subregion, the rainfall was either within 5% or 5 to 20% greater than the long-term mean. Modelled streamflow was estimated to be 5 to 50% greater than the long-term mean across much of the subregion, with only the most westerly areas experiencing runoff reductions. In general, analysis has shown that the impact upon streamflow of a small percentage change in rainfall is enhanced with a 5% reduction in mean rainfall leading to a 10 to 15% reduction in streamflow and a 5% increase in rainfall leading to a 10 to 15% increase in streamflow in south-eastern Australia (Chiew, 2006).

However, the most recent analysis of likely future climate for the region suggests that the probability of runoff reductions is greater than 50%. Post et al. (2012) modelled future runoff at a 5 km grid resolution for south-eastern Australia. The climate series was informed by simulations from 15 global climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, taking into account changes in daily rainfall distributions and seasonal rainfall (and potential evapotranspiration) amounts, for an increase in global mean surface air temperature of 1.0 °C (2030 relative to 1990), and 2.0 °C (2070 relative to 1990). In the Gwydir river basin (including headwaters), the median projection under 1.0 °C of warming is for a 3% reduction (–19 mm) in rainfall (Table 7) and 10% reduction (–4 mm) in runoff (Table 8). In the more northerly Border Rivers river basin, the median projection is a 5% reduction (–31 mm) in rainfall (Table 7) with a 14% reduction (–4 mm) in runoff (Table 8). Across all models, the potential evaporation is projected to increase in the Border Rivers-Gwydir river basins by 2 to 5% by 2030.

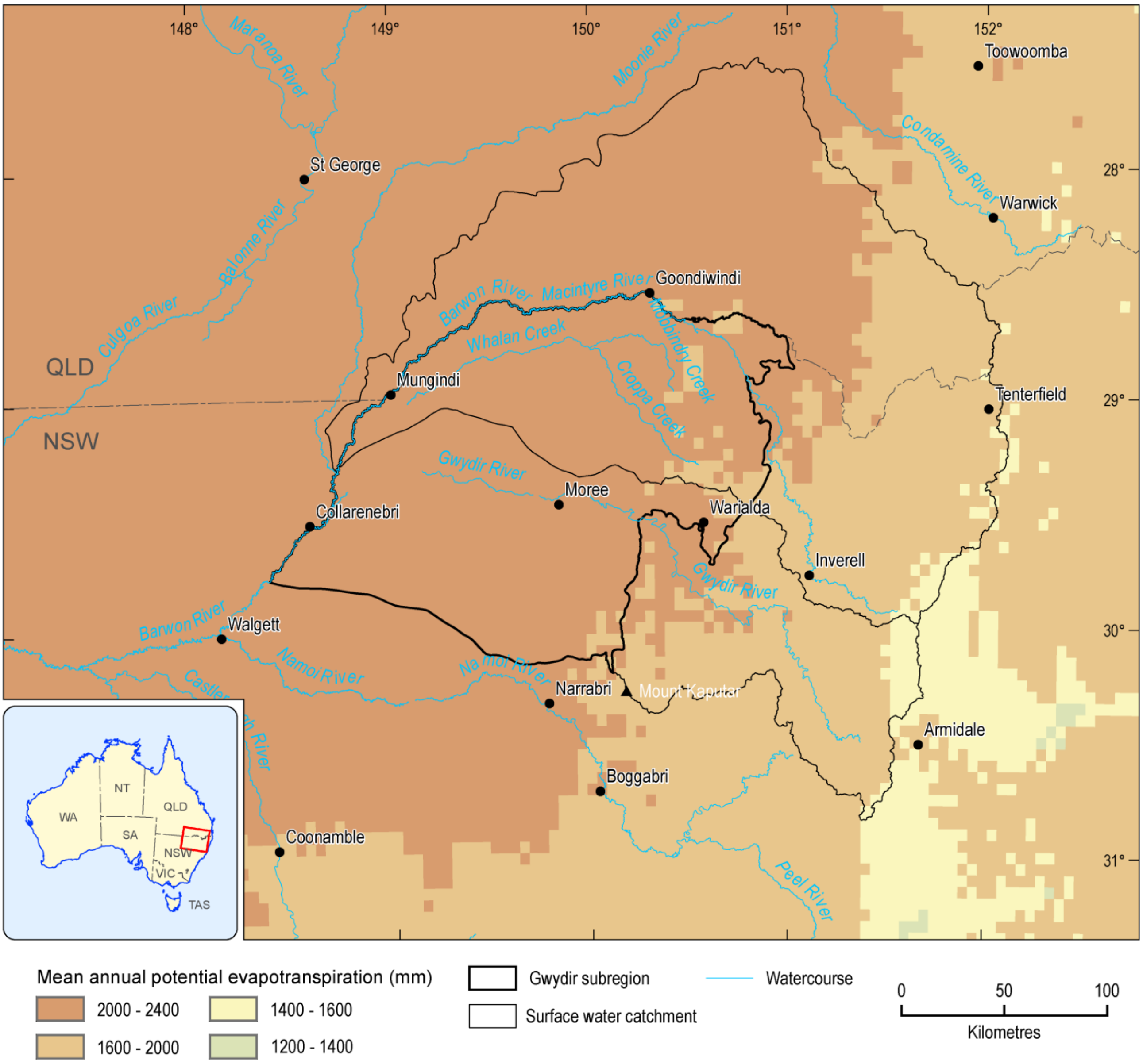

Figure 14 Mean annual potential evapotranspiration

Source data: Donohue et al. (2010)

Table 7 Summary of projected impacts of climate change on rainfall for the broad vicinity of the Gwydir subregion

			1 °C of global warming			2 °C of global warming		
Basin	**Historical rainfall (mm/year)**	**Number of GCMs (out of 15) projecting a decrease in future rainfall**	**Dry extreme**	**Median**	**Wet extreme**	**Dry extreme**	**Median**	**Wet extreme**
Border Rivers	641	10	–11%	–5%	3%	–21%	–10%	6%
Gwydir River	644	10	–10%	–3%	3%	–20%	–6%	6%

Source data: Table 2 in Post et al. (2012)
GCM is global climate model

Table 8 Summary of projected impacts of climate change on runoff for the broad vicinity of the Gwydir subregion

			1 °C of global warming			2 °C of global warming		
Basin	**Historical runoff (mm/year)**	**Number of GCMs (out of 15) projecting a decrease in future runoff**	**Dry extreme**	**Median**	**Wet extreme**	**Dry extreme**	**Median**	**Wet extreme**
Border Rivers	32	11	–30%	–14%	7%	–52%	–25%	22%
Gwydir River	37	11	–28%	–10%	9%	–48%	–17%	24%

Source data: Table 3 in Post et al. (2012)
GCM is global climate model

Figure 15 shows the distribution of rainfall and runoff changes across the year for the historical record (1895 to 2006) and projected changes at Moree. Projected decreases in winter rains will probably result in reduced runoff, while small increases in January and February rain will increase runoff, although there is greater uncertainty in the projections for both rainfall and runoff during January and February. The wider range of projections for runoff than rainfall indicate greater uncertainty in the runoff projections. In particular, the summer and winter runoff projections show much greater variability amongst the global climate models than those for autumn and spring.

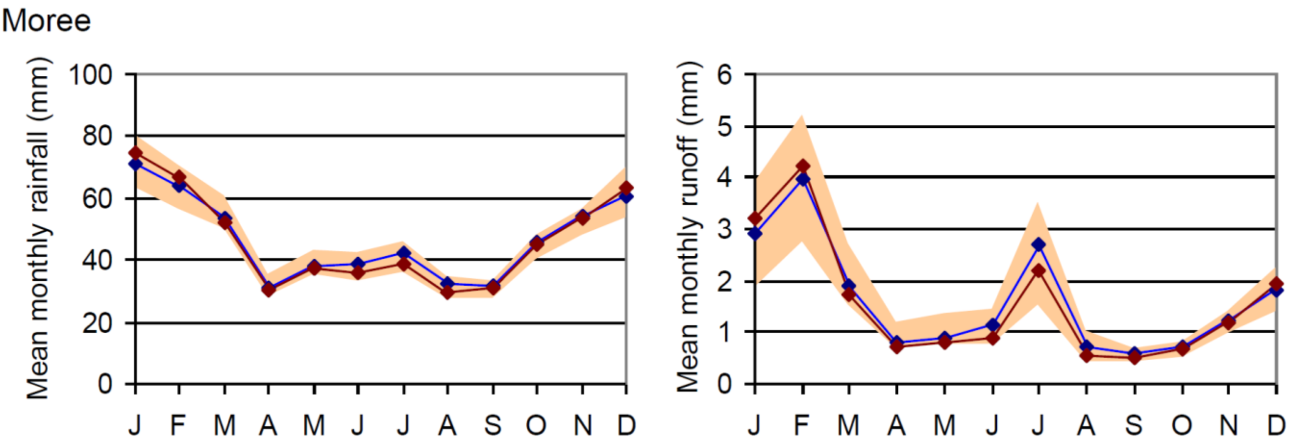

Figure 15 Mean monthly rainfall and runoff for Moree based on historical data (blue line), median climate projections in 2030 (red line) and future 2030 range (beige shading)

Source: Figure 18 in Post et al. (2010)

The implications of a changing climate were considered in the Murray-Darling Basin Sustainable Yields Project for the Gwydir river basin (CSIRO, 2007a) and the Border Rivers river basins (CSIRO, 2007b) in 2030 based on IPCC Fourth Assessment climate change projections and assuming current levels of development. While the mean runoff reduction forecast for these river basins was 9%, slightly less than the 11% and 14% reductions projected in the more recent SEACI report, the assessment of impacts remains relevant. Table 9 summarises impacts on the water resource and wetland inundation events for the median, dry and wet forecast scenarios. For a 9% reduction in runoff and assuming no new development in the river basins (e.g. no construction of new water storages or significant land cover change), the CSIRO estimated a 10% reduction in water availability in both systems, a 6% reduction in end-of-system flows in the Gwydir and a 12%

reduction in Border Rivers, and 8% and 2% reductions in diversions in the Gwydir and Border rivers, respectively. The impact on diversions depends on the class of water: town water would be unaffected by the changes, general security diversions would reduce by 9% (Gwydir) and 1% (Border Rivers) and high security water diversions would increase by 3% (Gwydir).

Under the median future climate, the frequency of large inundation events of the Gwydir Wetlands is expected to remain largely unchanged, but overall flood volumes are projected to decrease, with negative implications for the scale of bird breeding events. At the dry extreme of the climate projections, the interval between large scale wetland inundations is predicted to increase by more than 50% (from 15 months to 3.5 years) with serious impacts on the wetland ecology and potential loss of species (CSIRO, 2007a). In the Border Rivers river basin, the interval between flooding of the anabranches and billabongs on the floodplains between Goondiwindi and Mungindi is projected to increase by 26% under the median scenario, with the mean volume of flood waters reducing by 22%. When flooded, these areas provide large amounts of dissolved organic carbon to the riverine ecosystem which is essential to aquatic ecosystem functioning. Any climate future between the median estimate and the dry extreme would lead to extended periods without hydrological connectivity between the lower Macintyre River and its floodplain and smaller volumes of water which would likely affect instream processes due to reductions in the availability of dissolved organic carbon.

Recharge of the Great Artesian Basin (GAB) intake beds, the GAB alluvium and the Border Rivers alluvium is not projected to change significantly under the median scenario (–1, +2 and +1%, respectively), but with significant increases (+22%) in the Lower Gwydir alluvium (CSIRO, 2007a; CSIRO, 2007b).

It is important to remember that there are considerable uncertainties in the climate change projections and this makes definitive conclusions about the direction and magnitude of changes on water resources difficult to make. However, the SEACI modelling suggests even drier 'best' estimates than the earlier studies, so the weight of evidence is for a shift to drier conditions.

Table 9 Projected impacts of climate change on water resources and wetland inundation in 2030 relative to the historical average (1895–2006)

	Gwydir river basin			Border Rivers river basin		
	Dry	**Median**	**Wet**	**Dry**	**Median**	**Wet**
Water availability (%)	−29%	−10%	+34%	−26%	−9%	+18%
End-of-system flows (%)	−27%	−6%	+33%	−34%	−12%	+26%
Diversions (%)	−25%	−8%	+20%	−17%	−2%	+8%
Average period between important wetland inundation events (%)	+52%	−1%	−39%	+41%	+26%	−11%
Average flooding volume per year (%)	−50%	−20%	+72%	-44%	−22%	+32%

Source data: Tables 4-6, 4-7 and 7-5 in CSIRO (2007a), and Tables 4-6, 4-7 and 7-5 in CSIRO (2007b)

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1.1.3 Geology

Summary

There are three coal-bearing sedimentary basins in the Gwydir subregion: the Bowen, Gunnedah and Surat basins (Figure 16); and these are the main focus of this section. The underlying basement rocks and overlying Cenozoic alluvial and volcanic sequences are not discussed in detail here (refer to Section 1.1.4 for information on the hydrogeology of the Cenozoic sequences).

The Bowen Basin began to form during the Late Carboniferous and Early Permian with tectonic extension and subsidence. Prolonged sedimentation into the Middle Triassic and sporadic volcanic activity bound the basin before the deposition of sediments ceased in the Late Triassic. The Gunnedah Basin is part of the broader Permian-Triassic Bowen-Gunnedah-Sydney depositional system and consequently formed from similar large-scale basin evolutionary processes as the Bowen Basin. Regionally significant volcanism in the Early Permian formed a 2 to 2.5 km thick volcanic sequence which marks the basal part of the Gunnedah Basin. Passive thermal subsidence followed this phase, marked by a period of uniform sedimentation across the basin and deposition of up to 1 km thick of compositionally varied sedimentary rocks. After a time of non-deposition (approximately 30 million years) the Surat Basin formed above most of the Bowen and Gunnedah basins during a period of steady subsidence. A compressional system caused fault reactivation and volcanic activity within the basin to occur before uplift in the Middle Cretaceous halted the formation of the Surat Basin.

The sedimentary infill of all three basins consists mostly of sandstone, siltstone, claystone, coal and volcanic deposits. Coal is mined extensively from other areas of the Bowen and Surat basins, although there are no coal mines in the Gwydir subregion. All three basins are also prospective for coal seam gas (CSG), although there is currently no CSG production within the subregion.

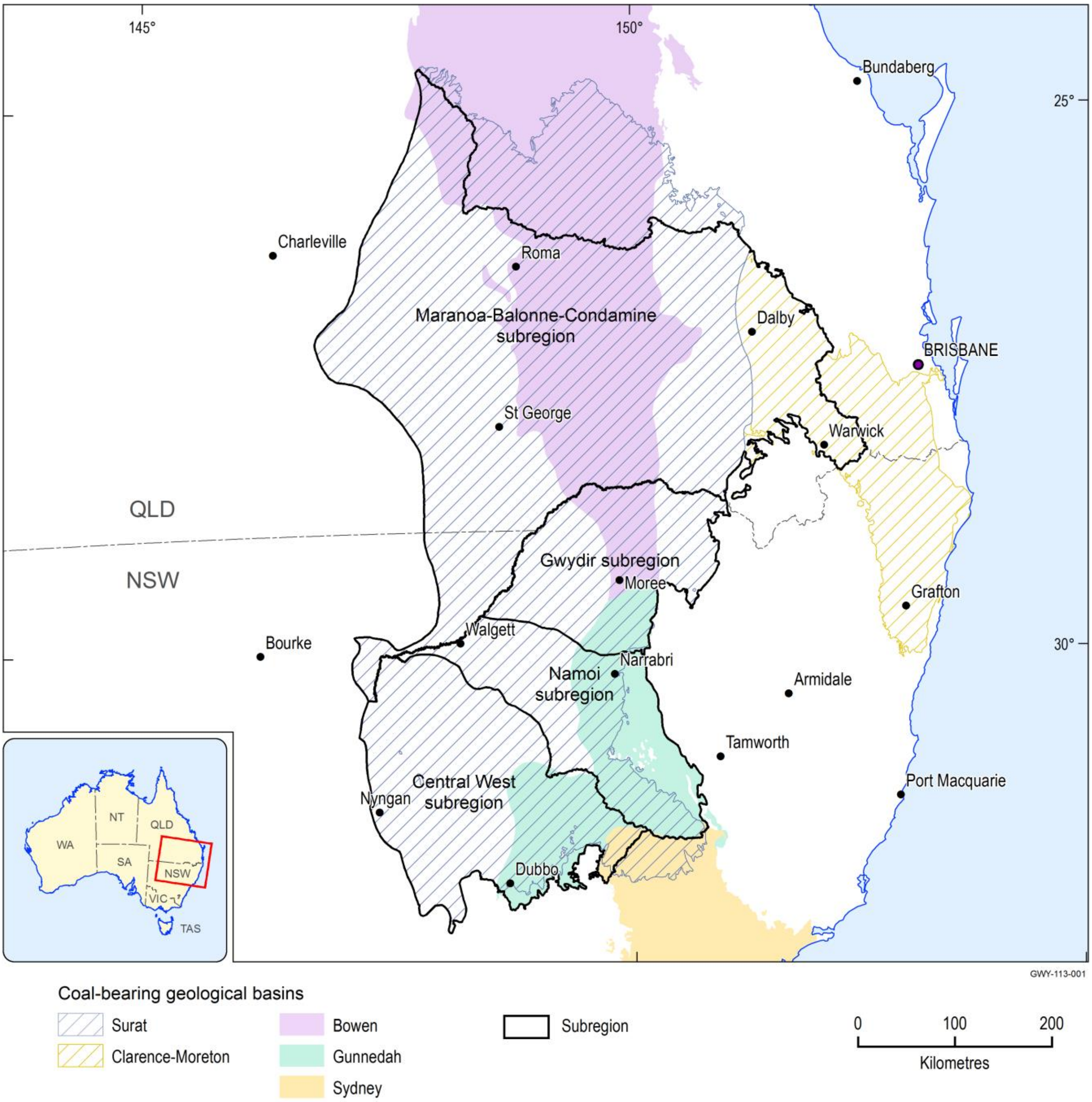

Figure 16 Location of the Gwydir subregion within the Northern Inland Catchments bioregion and its relation to the geological Surat, Bowen and Gunnedah basins

1.1.3.1 Geological structural framework

1.1.3.1.1 Basin extents and regional geological context

The Bowen, Gunnedah and Surat basins are intracratonic, coal-bearing sedimentary basins of significant size and coal and coal seam gas resource potential (Cadman et al., 1998; O'Neill and Danis, 2013). The elongate, north-trending Bowen Basin spans about 200,000 km^2 of central and southern Queensland and extends into northern NSW (Cadman et al., 1998). The Gunnedah Basin covers approximately 15,000 km^2 of NSW, but is part of the larger depositional complex that includes the Bowen Basin to the north and the Sydney Basin to the south (Tadros, 1993; O'Neill and Danis, 2013). Consequently, there are many geological similarities between the Bowen and

Gunnedah basins. The boundary between the Bowen and Gunnedah basins occurs in the Gwydir subregion, south of the Moree High (Totterdell et al., 2009).

The Surat Basin is the largest of the three basins by area and covers approximately 300,000 km^2 of central and southern Queensland and northern NSW. The Surat Basin structurally and stratigraphically overlies much of the southern Bowen Basin and most of the Gunnedah Basin, and also extends beyond the subsurface boundaries of both of these older basins (Exon, 1976).

1.1.3.1.2 Sub-basins

The Bowen and the Surat basins have no formally recognised sub-basins, although both are commonly sub-divided into distinct structural regions, which are associated with specific stratigraphic sequences. In the Gwydir subregion, the southern extent of the Taroom Trough is the main structural domain of the Bowen Basin. In the overlying Surat Basin, this subregion contains the southern Mimosa Syncline region, also known as the Boomi Trough in NSW. The northern part of the Coonamble Embayment in the Surat Basin may also fall within the Gwydir subregion; however, there is uncertainty in the basin and subregion boundaries.

The Gunnedah Basin has two formally recognised sub-basins, the Mullaley and Maules Creek sub-basins, and another sub-basin in the south-west (Oxley sub-basin) which is yet to be widely recognised in the geological literature. The Mullaley and Maules Creek sub-basins both occur in the Gwydir subregion (Figure 17) (O’Neill and Danis, 2013). The Oxley sub-basin (Figure 17) does not occur in the Gwydir subregion. The Mullaley sub-basin is separated from the Maules Creek sub-basin by the Boggabri Ridge, a northerly trending zone of uplifted basement rocks (Figure 17) (O’Neill and Danis, 2013). The sub-basins are the major depositional troughs of the Gunnedah Basin and contain the thickest sedimentary infill sequences (Ward and Kelly, 2013; Stuart-Smith et al., 2010).

1.1.3.1.3 Basin thickness

The sedimentary thickness of the Bowen and Surat basins varies significantly across each area, and in places some units of the basin-wide stratigraphic package are thin or absent (Exon, 1976; Cadman et al., 1998). As displayed in Figure 18, the maximum depth to underlying basement of the sedimentary basins in the Gwydir subregion occurs in a northerly trending elongate depression that cuts through the central and eastern part of the subregion, coincident with the southern extension of the Taroom Trough in the Bowen Basin. The Surat Basin strata in the northern Gwydir subregion have a maximum thickness of 1200 m, but this thins significantly towards the southern edge where there are only a few hundred metres of Surat Basin rocks (Hawke and Bourke, 1984). The entire Gunnedah Basin sequence is up to 3 km thick, and is unconformably overlain in places by up to 180 m of Early Jurassic volcanic rocks known as the Garrawilla Volcanics (Danis et al., 2010; O’Neill and Danis, 2013).

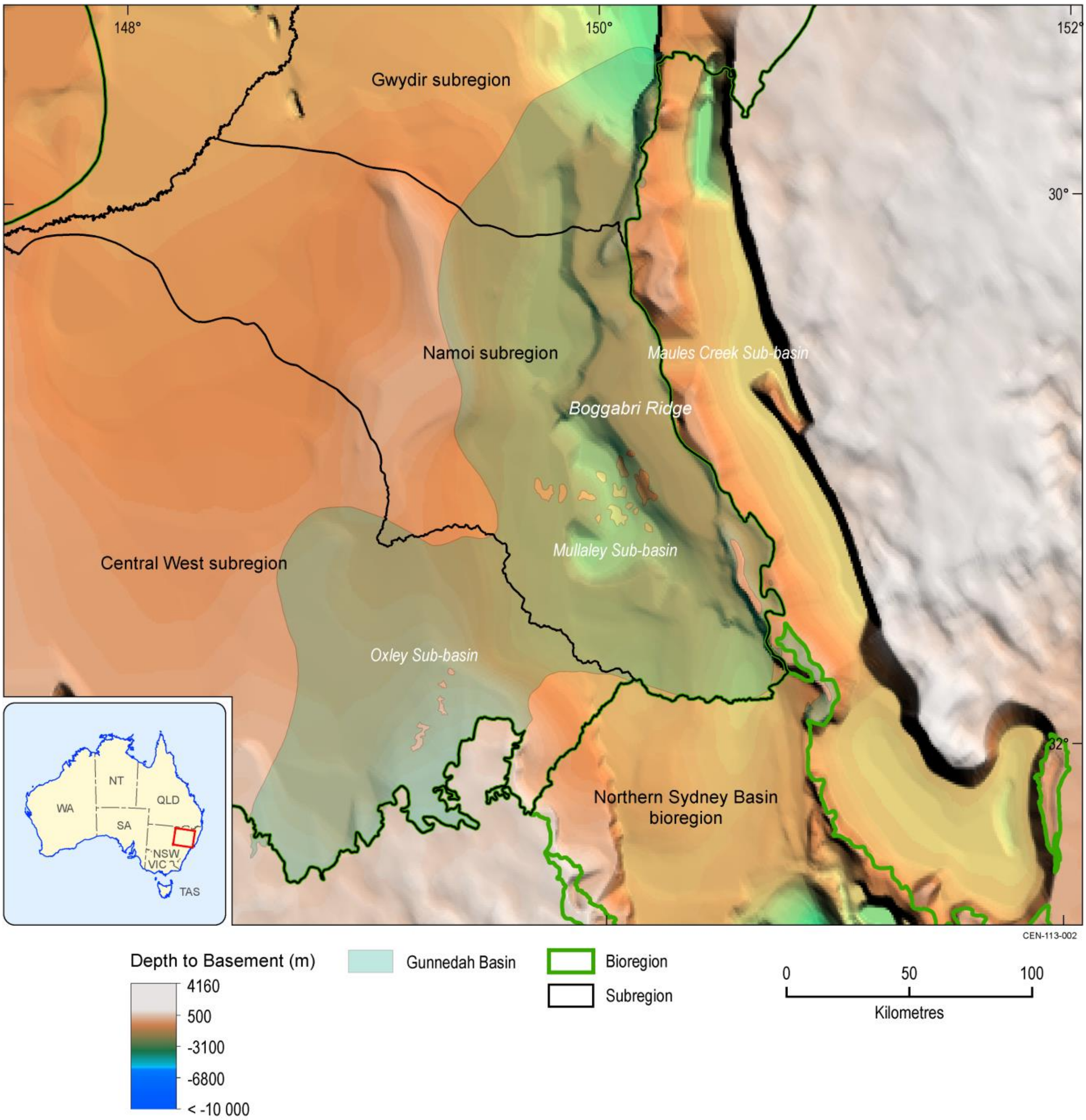

Figure 17 Division of the Gunnedah Basin into sub-basins

Source data: Geoscience Australia (2014)

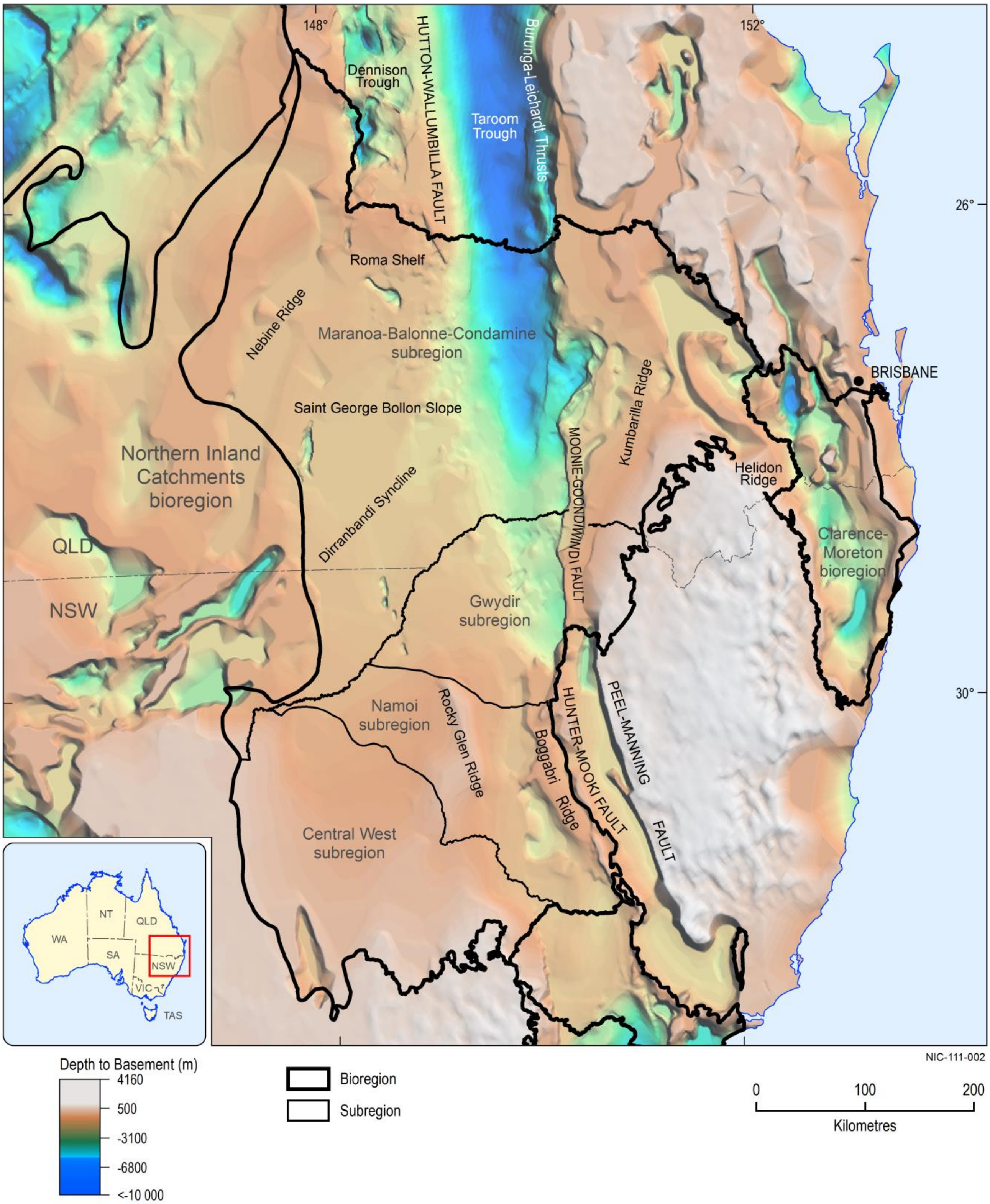

Figure 18 OZSEEBASE map of the Northern Inland Catchments bioregion with major structural elements

Source data: Frogtech (2006); Frogtech (2012)

1.1.3.1.4 Structure

The Bowen Basin is bounded to the east by a network of north-trending faults that include the major Moonie-Goondiwindi Thrust Fault, which continues south of the Auburn Arch into the Gwydir subregion (Cadman et al., 1998). The Taroom Trough (Figure 18) is one of the two major depositional centres for the basin and its southern extent lies within the Gwydir subregion (Cadman et al., 1998). It formed through extensional tectonism during the Late Carboniferous to Early Permian (McKellar, 1998; Fielding et al., 1993). Half-grabens which also formed during this extensional event are evident in the Taroom Trough (Cadman et al., 1998; Elliott, 1989). The Taroom Trough is the only portion of the Bowen Basin to fall within the Gwydir subregion.

The Gunnedah Basin is separated from the Bowen Basin to the north in the Gwydir subregion along a zone of uplifted basement rocks within the vicinity of the Moree High and the Narrabri High (Tadros, 1993; Totterdell et al., 2009). The southern Gunnedah Basin, which lies outside of the Gwydir subregion, is separated from the Sydney Basin by the Liverpool Ridge, Mount Coricudgy Anticline and a line between the towns of Coolah and Dunedoo over the Quirindi Anticline (Beckett et al., 1983; Tadros, 1993; Guoping and Keene, 2007; Danis et al., 2010; O'Neill and Danis, 2013).

The sedimentary rocks of the Gunnedah Basin rest unconformably on Early Permian basal volcanic sequences (O'Neill and Danis, 2013). The Boggabri Ridge (Figure 17) was a leading source of sediment for the basin, but also acted as the structural barrier between the Maules Creek and Mullaley sub-basins (Figure 17) (Danis et al., 2010; Ward and Kelly, 2013). The Gunnedah Basin is bounded by the Lachlan Fold Belt and Rocky Glen Ridge to the west and the New England Fold Belt to the east, along the line of the Hunter-Mooki Fault (Figure 18) (Tadros, 1993; Danis et al., 2010; O'Neill and Danis, 2013; Ward and Kelly, 2013). A small segment of the northern part of the Peel-Manning Fault (Figure 18) also coincides with the Gwydir subregion.

The Moonie-Goondiwindi Fault and the Burunga-Leichhardt Thrusts (Figure 18) are major basement thrust fault systems that extend into the Surat Basin from the underlying Bowen Basin (Exon, 1976; Rohead-O'Brien, 2011). The most dominant structural feature in the Surat Basin part of the Gwydir subregion is the Mimosa Syncline, a reflection of the Bowen Basin's Taroom Trough. This structure forms the major depositional zone of the Surat Basin, and contains the greatest thickness of sedimentary infill (McKellar, 1998; Yago, 1996; Fielding et al., 1993). The Mimosa Syncline is commonly referred to as the Boomi Trough within the NSW portion of the Surat Basin.

1.1.3.2 Stratigraphy and rock type

1.1.3.2.1 The Bowen Basin

There are almost 50 stratigraphic units recognised throughout the Bowen Basin with varying distribution, both spatially and stratigraphically (Australian Stratigraphic Units Database, 2013). However, the only section of the Bowen Basin to fall within the Gwydir subregion is the southern Taroom Trough, which has a distinct stratigraphic assemblage. The most important coal-bearing rock units in the Bowen Basin likely to occur in the Gwydir subregion are summarised below, and are displayed in the Gwydir stratigraphic chart (Figure 19). However, there are currently no coal mining operations or coal seam gas developments in the Gwydir subregion and, given the thickness of the overlying Surat Basin strata in this subregion (up to 1200 m, Hawke and Bourke, 1984), future resource development of this part of the southern Bowen Basin is considered unlikely.

Flat Top Formation

The Flat Top Formation formed in a delta fan to shallow marine setting and is composed of siltstone, sandstone, mudstone, conglomerate, coal and tuff (Draper, 2013).

Banana Formation

The Banana Formation is an assemblage of mudstone, shale, siltstone, sandstone and with minor coal formed during the Late Permian in brackish to marine settings (Green et al., 1997).

Burunga Formation

The Burunga Formation is a Late Permian unit of sandstone, shale, siltstone, tuff and clay with significant lithological variations from region to region (Green et al., 1997). In the southern Bowen Basin this unit appears in three distinct layers, with the upper and lower layers coal measures and the middle layer a marine mudstone (Green et al., 1997). A sub-unit of the Burunga Formation is the Scotia Coal Member, which contains sandstone, shale, siltstone, coal and tuff (Green et al., 1997).

Baralaba Coal Measures

A marine and fluvial unit deposited during the latest Permian, the Baralaba Coal Measures contain a mixed package of sandstone, siltstone, mudstone, coal and tuff (Green et al., 1997). The basal sub-unit of the Baralaba Coal Measures, the Kaloola Member, consists of siltstone, sandstone, tuff and conglomerate (Green et al., 1997).

1.1.3.2.2 The Gunnedah Basin

The Permian rocks in the Gunnedah Basin are a compositionally mixed assemblage of sandstone, siltstone, claystone, tuff and coal (Danis et al., 2010). Bedding is steeply dipping, and the correlation of coal seams across the basin is difficult (O'Neill and Danis, 2013). In contrast to the older Permian rocks, the Triassic strata in the Gunnedah Basin are dominantly sandstone. The stratigraphy of the Gunnedah Basin is shown in Figure 19. Detailed stratigraphic descriptions of all rock units in the Gunnedah Basin are beyond the scope of this report. However, a brief summary of the main coal-bearing units of the basin is provided below, although there are currently no active Gunnedah Basin coal mines in the Gwydir subregion.

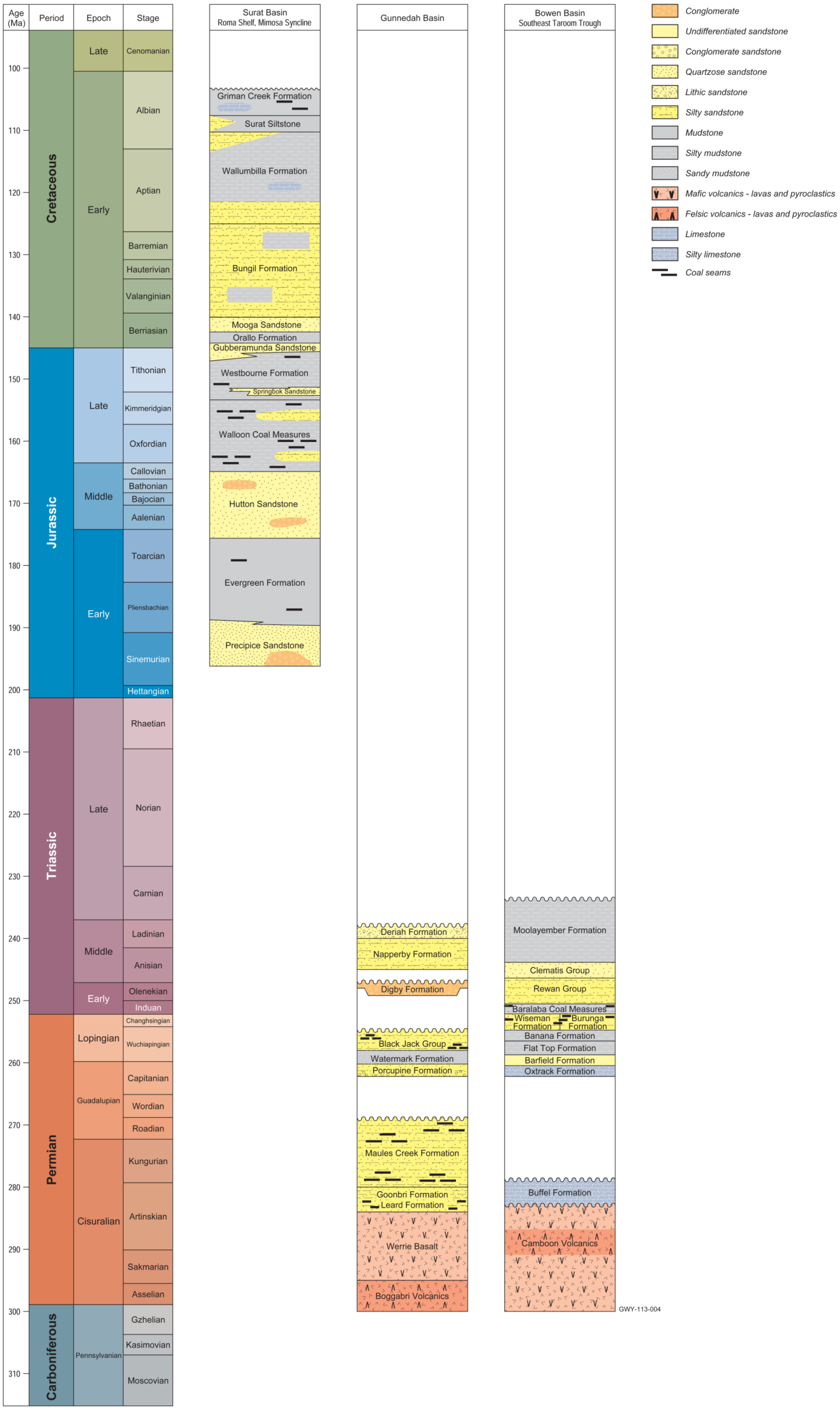

Figure 19 Stratigraphic chart of the Gwydir subregion

Source data: McKellar (1998); Totterdell et al., (2009); Cook and Draper (2013); Australian Stratigraphic Units Database (2013)
This figure has been optimised for printing on A3 paper (297 mm x 420 mm).
The younger sediments overlying the Surat and Gunnedah basins are not shown.

The Maules Creek Formation

The Maules Creek Formation is an Early Permian non-marine formation of marsh plain deposits composed of sandstone, conglomerate, coal, clay pellet beds and carbonaceous claystone (Beckett et al., 1983). This unit can reach a thickness of up to 125 m (Beckett et al., 1983). The coal in this unit is present in a series of up to 25 seams that can reach up to 9 m in thickness (Beckett et al., 1983; Tadros, 1995; Ward and Kelly, 2013).

Pamboola Formation

The Pamboola Formation consists of sandstone, siltstone, claystone, conglomerate and coals (Australian Stratigraphic Units Database, 2013). The Melvilles Coal Member is an important component of this unit and is a high quality and thick coal seam, covering a large area (Hamilton, 1985). It is thickest in the east of the Gunnedah Basin, up to 3.5 m, but thins towards the western boundary (Hamilton, 1985). In the south-east, this seam splits into two (Hamilton, 1985). This unit forms part of the Brothers Subgroup in the Black Jack Group (Australian Stratigraphic Units Database, 2013).

Hoskissons Coal

The Hoskissons Coal unit varies from 2.4 to 18 m thick (Hamilton, 1985). It formed in a lagoonal and swamp environment, and is composed of coal and carbonaceous siltstone (Beckett et al., 1983; Hamilton, 1985). This formation is part of the Coogal Subgroup of the Black Jack Group (Australian Stratigraphic Units Database, 2013).

Benelabri Formation

The Benelabri Formation is composed of interbedded claystone, siltstone, sandstone and coal (Australian Stratigraphic Units Database, 2013). This formation is part of the Coogal Subgroup of the Black Jack Group (Australian Stratigraphic Units Database, 2013).

Clare Sandstone

Clare Sandstone is a sandstone and conglomerate unit of the Coogal Subgroup (Australian Stratigraphic Units Database, 2013). The Clare Sandstone also contains the Breeza Coal Member, a coal unit of variable quality coal and claystone layers (Australian Stratigraphic Units Database, 2013).

Wallala Formation

The Wallala Formation is a unit composed of conglomerate, sandstone, siltstone, claystone, coal and minor tuff (Australian Stratigraphic Units Database, 2013). It forms part of the Black Jack Group within the Nea Subgroup (Australian Stratigraphic Units Database, 2013).

Trinkey Formation

The Trinkey Formation is a formation within the Nea Subgroup, part of the Black Jack Group, composed of claystone, siltstone, sandstone, tuff and stony coal (Australian Stratigraphic Units Database, 2013). The Trinkey Formation is divided into six sub-units, of which four contain coal, namely the Clift Coal Member, the Doona Coal Member, the Springfield Coal Member and the

Whaka Coal Member. The Clift Coal Member is composed of five coal sections of variable quality, as well as inter-layered claystone (Australian Stratigraphic Units Database, 2013). The Doona Coal Member is a coal sub-unit with tuffaceous claystone laminae (Australian Stratigraphic Units Database, 2013). The Springfield Coal Member is mostly coal with minor beds of claystone and tuffaceous claystone throughout (Australian Stratigraphic Units Database, 2013). The Whaka Coal Member is a coal unit with bands of claystone, siltstone and sandstone (Australian Stratigraphic Units Database, 2013).

1.1.3.2.3 The Surat Basin

The stratigraphy of the Surat Basin varies across its 300,000 km^2 area, and distinct lithostratigraphic packages are defined for the main structural domains of the basin. The rock units defined for the NSW part of the Surat Basin (which includes the Coonamble Embayment and the Boomi Trough) differ from those in the better-known Queensland part of the basin. In particular, coal-bearing formations in the Coonamble Embayment region are less common and markedly thinner than in Queensland. For example, the Walloon Coal Measures do not occur in this area, and the stratigraphic correlative, the Purlawaugh Formation, contains only thin coal seams. Below are brief summaries of the coal-bearing stratigraphic units within the Gwydir subregion of the Surat Basin, and the hydrogeologically important Pilliga Sandstone.

Evergreen Formation

The Evergreen Formation is more commonly described from Queensland, although it may occur in far northern NSW. It consists of siltstone, shale, sandstone and coal which formed in a fluvial depositional setting on a coastal plain, with possible deltaic influence (Exon, 1976; Cook and Draper, 2013). The formation contains two sub-units, the Boxvale Sandstone Member and the Westgrove Ironstone Member (Exon, 1976; Cook and Draper, 2013). The Boxvale Sandstone Member, consisting of sandstone, siltstone and coal, was deposited during a brief marine transgression (Exon, 1976).

Walloon Coal Measures

The Walloon Coal Measures are the most significant coal resource in the Surat Basin and the unit targeted for coal mining and CSG within the basin. It is a compositionally varied formation that consists of thinly bedded claystone, shale, siltstone, sandstone (lithic and sublithic to feldspathic arenite), coal seams and minor limestone (Exon, 1976). A muddy pebble conglomerate also occurs in several locations (Exon, 1976). The depositional environment is interpreted as fluvial and swampy plains (Exon, 1976). In Queensland, the Walloon Coal Measures can be sub-divided into four units: the Durabilla Formation, Taroom Coal Measures, Tangalooma Sandstone and the Juandah Coal Measures (Exon, 1976; Swarbrick, 1973). The Taroom Coal Measures are a mixed sequence of sandstone, siltstone and mudstone, with abundant coal and carbonaceous mudstone interbeds (Scott et al., 2004). A mixed assemblage of sandstone, siltstone, mudstone, claystone, tuff and thin coal to carbonaceous mud seams form the Tangalooma Sandstone (Rohead-O'Brien, 2011). The sandstone is commonly heavily cemented or infilled with clay (Rohead-O'Brien, 2011). The Juandah Coal Measures are similar in composition and coal volume to the Taroom Coal Measures (Scott et al., 2004).

Pilliga Sandstone

A Jurassic unit composed of largely quartzose sandstone and conglomerate but with a minor amount of interbedded mudstone, siltstone, shale, fine sandstone and coal, with common carbonaceous fragments (Arditto, 1982; Herczeg, 2008; Australian Stratigraphic Units Database, 2013). The Pilliga Sandstone is an important aquifer within the Coonamble Embayment region (Herczeg, 2008).

Purlawaugh Formation

The Purlawaugh Formation is an Early to Middle Jurassic unit within the Coonamble Embayment composed of sandstone with beds of siltstone, mudstone and rare coal (Radke et al., 2012). The Purlawaugh Formation is the stratigraphic equivalent of the Walloon Coal Measures in the Mimosa Syncline further to the north-north-east of the Gwydir subregion (Radke et al., 2012).

Westbourne Formation

The Westbourne Formation is a Late Jurassic formation of interbedded mudstone, siltstone, sandstone and some coal (Exon, 1976).

Orallo Formation

The Orallo Formation is composed of thin beds of siltstone and mudstone with some sandstone and minor conglomerate and coal deposited by fluvial channels in the Early Cretaceous to Late Jurassic (Exon, 1976).

Drildool beds

The Drildool beds are a Cretaceous unit composed of sandstone, siltstone, mudstone and coal, with some rare breccia and pebble beds (Radke et al., 2012). This unit can be divided into three unnamed sub-units: the lowermost unit is a mix of laminated mudstone, siltstone and muddy sandstone, the middle subdivision is composed of sandstone and siltstone that grade to carbonaceous mudstone and coal, and the upper unit is a mix of laminated mudstone, siltstone and muddy sandstone, much like the lower sub-unit (Radke et al., 2012). The Drildool beds occur in the Coonamble Embayment but are the lateral equivalent of the Bungil Formation in the northern Surat Basin (Radke et al., 2012).

Griman Creek Formation

Griman Creek Formation is a sandstone-dominated unit grading in places to siltstone and mudstone. Minor conglomerate and coal bands occur throughout and are more common in the upper section (Exon, 1976). The lower part of the Griman Creek Formation (Wallangulla Sandstone Member) is interpreted to have formed in a marine environment whereas the upper section (Coocoran Claystone Member) is interpreted as non-marine (Exon, 1976).

1.1.3.2.4 Cenozoic stratigraphy

The youngest geological units in the Gwydir subregion are Cenozoic volcanic deposits and alluvial to lacustrine sediments associated with modern rivers and paleovalleys. The basaltic lavas of the New England Tablelands (Central Province Volcanics) occur in the east of the subregion, and the

Nandewar Volcanic Field (hawaiite, trachyandesite, tristanite, trachyte and tuff) (Stroud and Brown, 1998) in the south-east. These were formed from localised volcanic eruptions during the Paleogene and Neogene, and locally intrude and overlie the Surat and Gunnedah-Bowen Basin strata.

The near-surface alluvial sequences of the main rivers in the Gwydir subregion form important aquifer systems and are further discussed in Section 1.1.4 (hydrogeology). However, as the Cenozoic volcanic rocks and alluvial sediments do not contain any economic coal resources, they are not further discussed in this section.

1.1.3.3 Basin history

1.1.3.3.1 Tectonic setting

The Bowen Basin began forming during the Late Carboniferous and Early Permian during a phase of tectonic extension (Cadman et al., 1998; Elliott, 1989; Draper, 2013). Extensional subsidence during the Early Permian led to the deposition of the earliest known sediments of the basin (Cadman et al., 1998). During this time volcanic rocks were also deposited to the east of the Roma Shelf and into the basin, and andesitic extrusions occurred near the Auburn Arch (Cadman et al., 1998). Deposition ceased in the Bowen Basin during the Late Triassic (Cadman et al., 1998).

The evolution of the Gunnedah Basin is broadly similar to the Bowen Basin, as they both form part of the larger Bowen-Gunnedah-Sydney Basin depositional complex. Mechanical extension during the Early Permian led to rapid subsidence, resulting in development of the Gunnedah Basin (Korsch and Totterdell, 2009; Stuart-Smith et al., 2010; O'Neill and Danis, 2013). The next major phase of basin subsidence was caused by plate flexure due to foreland loading. This was the dominant process driving basin evolution from the latest part of the Early Permian until the Middle Triassic, and led to the deposition of all stratigraphic units in the basin that post-date the Maules Creek Formation. However, subsidence associated with foreland loading was interrupted by a Late Permian to Early Triassic deformational event which halted deposition and caused localised uplift and erosion (Korsch and Totterdell, 2009).

Subsidence continued steadily into the Early Triassic driving deposition (Draper, 2013). During the Late Triassic, deposition ceased, with approximately a 30 million year period of erosion marking the divide between the Permian-Triassic Bowen and Gunnedah basins and the Jurassic-Cretaceous Surat Basin (Cadman et al., 1998). The Surat Basin began forming due to a new phase of thermal subsidence following the Hunter-Bowen Orogeny, after deposition of sedimentary rocks in the Bowen and Gunnedah basins (McKellar, 1998; Fielding et al., 1993). Deposition of most sedimentary sequences is attributed to large inland fluvial systems developed across an alluvial plain, interspersed with swamps, lakes and deltas (Exon, 1976; Rohead-O'Brien, 2011). Sediment input was largely controlled by the steady rate of subsidence (Fielding et al., 1993). Early sedimentation patterns provide evidence for periods of erosion and tectonic reactivation from underlying faults in the Bowen Basin (McKellar, 1998; Fielding et al., 1993). Basin formation ceased once widespread uplift began during the Middle Cretaceous (Yago, 1996). Subsequent volcanic activity in the Cenozoic resulted in localised compression and some folding (Yago, 1996; Fielding et al., 1993; Finlayson et al., 1990).

1.1.3.3.2 Paleozoic volcanism and intrusives

Early Permian volcanic activity in the Bowen Basin formed the Combarngo Volcanics and the Camboon Volcanics, which are the basal formations of the Bowen stratigraphic sequence (Cadman et al., 1998). Further south, tectonic extension during the Late Carboniferous and Early Permian initiated volcanism that gave rise to the Boggabri Volcanics and Warrie Basalt (Danis et al., 2010; O'Neill and Danis, 2013). Thin layers of tuff also occur sporadically throughout some parts of the Gunnedah Basin sequence, for example in the Melvilles and Hoskissons coals (Hamilton, 1985). These provide evidence for minor pyroclastic volcanism in the Late Permian sequences of the Gunnedah Basin.

Reactivation of volcanic activity in the vicinity of the Gunnedah Basin during the Early Jurassic, caused by the separation of Pangaea and eastern Gondwana, led to deposition of up to 180 m of volcanic rocks in the north and west (Danis et al., 2010, O'Neill and Danis, 2013). This Jurassic volcanism, which represents the base of the southern Surat Basin sequence and is known as the Garrawilla Volcanics, also contributed pyroclastic material (e.g. tuff layers) to several younger stratigraphic units, such as the Purlawaugh Formation (Exon, 1976).

Igneous intrusions, such as the Black Jack Sill and Ivanhoe Sill, are common throughout the Gunnedah Basin sequence, and are mostly of Jurassic and Early Cretaceous age (Ward and Kelly, 2013; Pratt, 1998). The thickness of sills varies greatly, from a few centimetres to over 120 m thick (Ward and Kelly, 2013). In places where intrusions are adjacent to coals, the coal seam gas contents are commonly elevated due to micro fracturing of the seam (Ward and Kelly, 2013). Sills have also increased the thermal maturity of coals and led to enhanced hydrocarbon production (Ward and Kelly, 2013).

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1.1.4 Hydrogeology and groundwater quality

Summary

The Gwydir subregion includes groundwater systems in alluvial aquifers, volcanic rocks of the New England Tablelands and Nandewar Volcanic Field, aquifers within the Coonamble Embayment of the Great Artesian Basin, aquifers in the Gunnedah-Bowen Basin and fractured rock aquifers of the Lachlan Fold Belt. The alluvial aquifers and outcrop areas of the Surat Basin in the north-east are the most heavily exploited groundwater systems in the subregion, being used for irrigation, stock and domestic use, and town water supplies.

Groundwater monitoring is undertaken by the state government, being generally limited to the high-use alluvial aquifer systems and parts of the Surat Basin. While water levels are regularly monitored, information on groundwater quality is limited.

The main alluvial groundwater systems in the subregion are the Lower Namoi Alluvium, the Lower Gwydir Alluvium, the NSW Border Rivers Alluvium and the NSW Border Rivers Tributary Alluvium. Groundwater within these areas is contained in the Upper Narrabri Formation and the more productive, deeper Gunnedah Formation. In the deepest paleochannel of the Lower Namoi Alluvium, the Gunnedah Formation is underlain by the productive Cubbaroo Formation. Groundwater in these aquifers is dominantly recharged by stream losses, being generally fresh and supporting irrigation. However, water levels in some areas of the Lower Gwydir Alluvium and Lower Namoi Alluvium have been declining for several decades indicating that extraction is likely to have been occurring above sustainable levels. Water salinity has also increased in places. In the alluvium outside of these main groundwater sources, groundwater salinity reportedly increases and yields typically decrease.

Groundwater from the Surat Basin system that underlies the alluvial aquifers is mostly sourced from the Pilliga Sandstone in the subregion. Waters are generally fresh and suitable for town water, stock and domestic use, but a high sodium adsorption ratio typically renders Great Artesian Basin (GAB) waters unsuitable for irrigation. However, in the east of the subregion the Pilliga Sandstone outcrops at the surface and in this recharge area for the GAB, younger, higher quality water supports irrigation at North Star.

Hydraulic interaction between the overlying alluvial aquifers and underlying Surat Basin is impeded by low permeability confining units at the top of the Surat sequence and the widespread development of a deep saprolitic layer. However, in the deeper paleochannels inter-aquifer flow is possible, where hydraulic heads typically favour upward leakage from the Surat Basin (although this is not universally the case). There is some evidence to suggest that faults act as conduits for upward migration of groundwater to shallower systems in places (e.g. the Peel Fault in the Border Rivers area).

A very limited amount of hydrogeological information was identified during this study for the Gunnedah and Bowen basins. These basins appear to be poorly developed in the subregion due to the presence of shallower, high quality groundwater resources.

The volcanic rocks of the New England Tablelands and Nandewar Volcanic Field are not extensive in the subregion. Where present, they are anticipated to contain local flow systems with low salinity groundwater.

1.1.4.1 Groundwater systems and monitoring

1.1.4.1.1 System boundaries and hydrostratigraphic units

The Gwydir subregion includes the following geological environments that generally represent individual groundwater systems (see Figure 16 for the locations of major geological basins):

- Cenozoic alluvial aquifers associated with current major watercourses (e.g. the Gwydir River and Border Rivers systems) and antecedent systems that form paleovalley infill and a broad alluvial fan system in the west of the subregion
- Cenozoic (Paleogene and Neogene) mafic volcanics overlying Great Artesian Basin (GAB) sedimentary rocks in the east (these are not extensive in the subregion and fall within the GAB groundwater management area)
- Jurassic to Cretaceous sedimentary rocks of the Surat Basin within the Coonamble Embayment of the GAB
- Permian to Triassic Gunnedah-Bowen Basin sedimentary rocks, mostly covered by the GAB except in the south-east
- Paleozoic fractured rock aquifers of the Lachlan Fold Belt, which, within the boundaries of the subregion, are entirely buried and variably underlie the Gunnedah Basin – Bowen Basin and the GAB.

Within these geological environments, Nicholson et al. (2012) reported the work of Smith and Blair (2002) which identified the three-dimensional groundwater flow systems on Figure 20 and Figure 21 for salinity management purposes. These are described briefly below. Sinclair Knight Merz (SKM, 2004) undertook further work on flow system characterisation in the area in 2004 and 2010. However, while the 2004 systems they present are similar to Smith and Blair's, the 2010 work (referenced in Border Rivers-Gwydir CMA, 2013) was not available at the time of writing. Figure 22 shows how current groundwater management areas of the *Basin Plan 2012* (made under the *Water Act 2007*) for the Murray–Darling Basin (MDB), relate to these groundwater flow systems (groundwater management is discussed in detail in Section 1.1.4.4).

Alluvial aquifers

The alluvial aquifers of the Namoi (locally present in the south of the Gwydir subregion), Gwydir and Border Rivers systems (and antecedent systems) are the main groundwater sources for irrigation, stock, domestic and town supply within the subregion. They are associated with a broad area of alluvial deposits in the west of the subregion that are typically divided into the deeper Gunnedah Formation (the fluvio-lacustrine, semi-confined, major resource aquifer) which is everywhere overlain by the more extensive, finer grained, unconfined Narrabri Formation (Barnett et al., 2004; MDBA, 2012a). These formations are also recognised in the narrower valley alluvium of the Dumaresq and Macintyre rivers further east of this area (Figure 22). The division of the alluvial deposits in the Gwydir subregion into the Narrabri and Gunnedah formations is not universally accepted (e.g. Carr and Kelly, 2010), however, for the purposes of this report, they will be referred to as the Narrabri and Gunnedah formations. While not identified in other parts of the subregion, the productive Cubbaroo Formation is present beneath the Gunnedah Formation at the base of the alluvial sequence in the deep Namoi paleochannel in the south (see Section 1.1.4.2).

Carr and Kelly (2010) indicate that the measured thickness of alluvium increases from east to west in the subregion, with a maximum thickness of about 100 m but typically in the range 40 to 60 m. The Narrabri Formation ranges in thickness from 10 to 30 m and the Gunnedah Formation from 35 to 80 m (Barrett, 2009). In Figure 20, the alluvial deposits of the Gunnedah and Narrabri formations are split into several groundwater flow systems including the Western Plains (regional flow system forming the main groundwater resource), the Upper Narrabri Formation (local flow system in shallow deposits with very high salinity) and Dumaresq River.

The Croppa Creek flow system (local flows in near-surface deposits with marginal to saline groundwater) is included in the extent of the Gunnedah and Narrabri subsystems by Barnett et al. (2004). However, this area is shown on geological maps to consist of colluvium rather than alluvium. Since it appears somewhat distinct from the surface Narrabri Formation, it may be more appropriately allocated to a separate system.

Cenozoic Volcanics

The basaltic lavas of the New England Tablelands (Central Province Volcanics) in the east of the subregion and Nandewar Volcanic Field (hawaiite, trachyandesite, tristanite, trachyte and tuff (Stroud and Brown, 1998)) in the south-east were formed from volcanic eruptions during the Paleogene and Neogene and locally intrude and overlie the Surat and Gunnedah-Bowen basin strata. Groundwater is anticipated to occur in local flow systems, and be relatively fresh. However, these systems are not extensive in the subregion, although they might support local small-volume users.

Surat Basin

The Surat Basin of the GAB occurs within a region of about 300,000 km^2 of south-eastern Queensland and north-central NSW (CSIRO, 2012). Within the Gwydir subregion, it directly overlies the Gunnedah-Bowen Basin in the east of the subregion, the New England Fold Belt in the north-east and the Lachlan Fold Belt in the west. The Surat Basin strata, within the subregion, occupy the Coonamble Embayment component of the GAB, and range in age from Late Triassic to Early Cretaceous (Ransley and Smerdon, 2012). Whereas rocks of the Surat Basin are exposed at surface in the east of the subregion, they are covered by Cenozoic sediments in the west.

The top of the Surat Basin in the Coonamble Embayment is defined by the Drildool beds between Narromine and Warren, and by Rolling Downs Group (probably the Griman Creek Formation) north of Warren (Kellett et al., 2012; Burton, 2011). In the east of the subregion, progressively older (stratigraphically lower) units of the Surat Basin outcrop and dip to the west. The basal unit of the Surat Basin in the Coonamble Embayment is the Purlawaugh Formation which is underlain by the Early Jurassic Garrawilla Volcanics (Radke et al., 2012). The Surat Basin contains a sequence of interlayered aquifers and aquitards, with the main aquifer in the Gwydir subregion being within the Pilliga Sandstone.

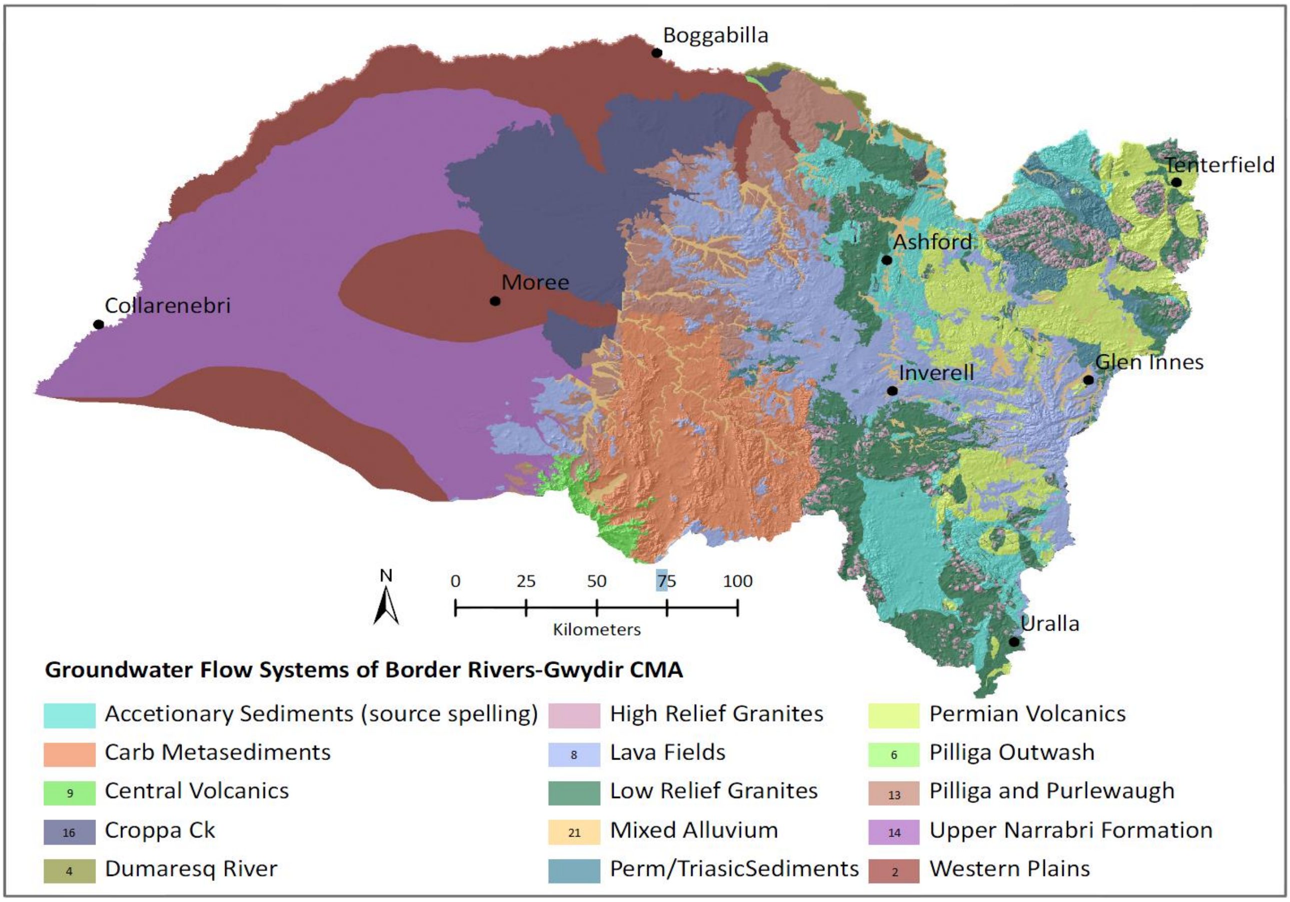

Figure 20 Groundwater flow systems in the Border Rivers-Gwydir area (numbers refer to flow systems in the Gwydir subregion present on Figure 21)

Source: modified from Nicholson et al. (2012)

Gunnedah and Bowen basins

The Gunnedah and Bowen basins are part of an approximately 1700 km long depositional basin system consisting of the Sydney (south), Gunnedah (central) and Bowen (north) basins (Othman, 2003). The Gunnedah Basin is present in the south of the subregion and gives way to the Bowen Basin in the north (see Figure 16). The boundary between the two basins is considered to be in the general area of Moree, associated with basement/structural highs. Both basins directly overlie fractured rocks of the Lachlan Fold Belt. They are covered by Surat Basin sediments throughout most of the subregion although the groundwater management area map in Green et al. (2011a) indicates that the Gunnedah Basin sediments outcrop in a very small area in the south-east.

The Gunnedah Basin contains up to 1200 m of marine and non-marine Permian and Triassic sediments within which coal-bearing strata of the Black Jack Formation and the Maules Creek Formation occur (Tadros, 1995). The main Bowen Basin depocentres are the western Denison Trough and the eastern Taroom Trough (Othman, 2003). Only the Taroom Trough extends into the Gwydir subregion. While it reportedly contains over 10,000 m of sediment in Queensland, it thins to the south so that about 600 m of sediment is present by around latitude 28 S (north of the NSW border). It is reportedly poorly studied in NSW (Totterdell et al., 2009) although attempts have been made at stratigraphic correlation between the basins. The hydrogeology of the Gunnedah-Bowen Basin is poorly explored in the literature in the subregion where development appears limited due to the presence of shallow productive groundwater systems.

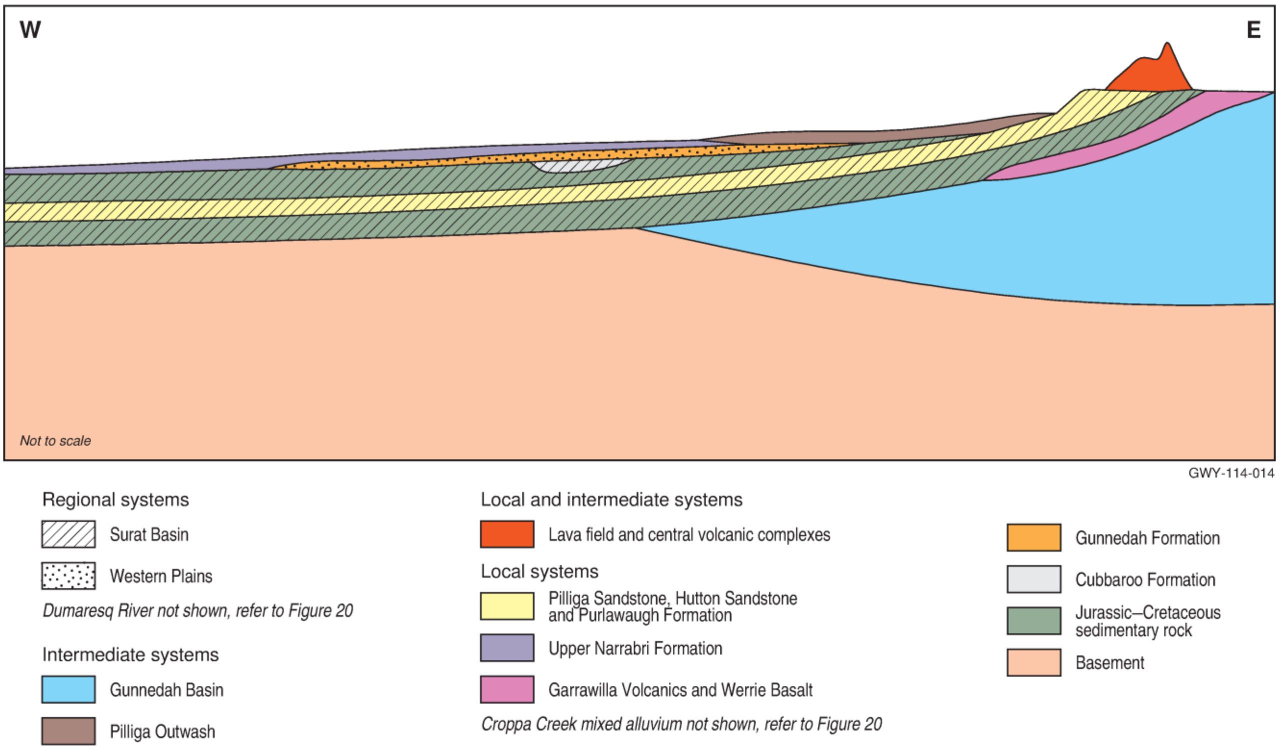

Figure 21 Conceptual model of groundwater flow systems in the Border Rivers-Gwydir area (not to scale)

Source data: informed by cross-section presented in Smith and Blair (2002)

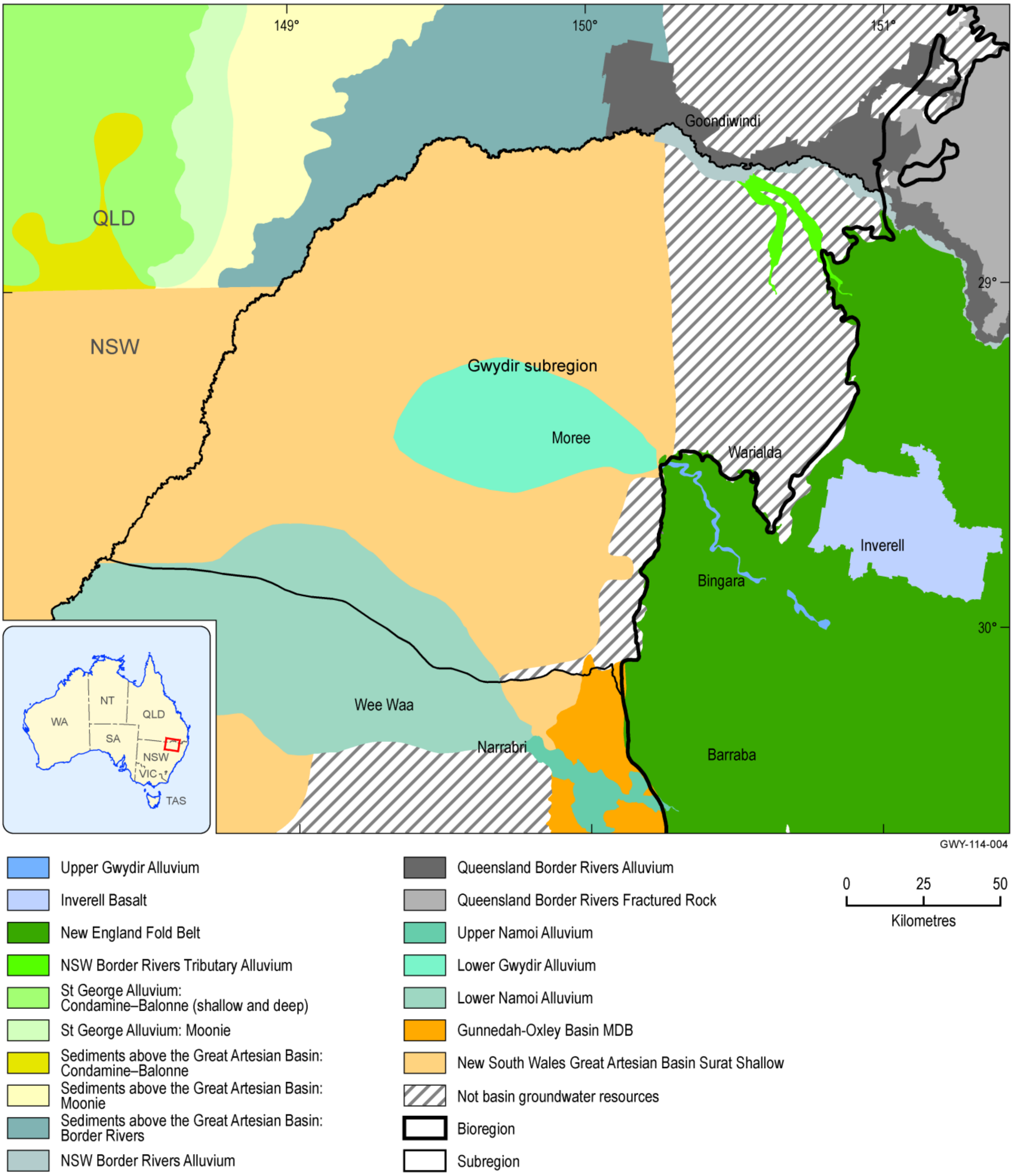

Figure 22 Groundwater sustainable diversion limit resource units for the *Basin Plan 2012*, made under the *Water Act 2007*

The intake beds of the Great Artesian Basin are not managed under the Basin Plan and are shown as 'Not basin groundwater sources' in the figure.

Hydrostratigraphic relationships

Hydrostratigraphic relationships in the Gwydir subregion are presented in Figure 23, which indicates the temporal sequence of geological unit development and relative groundwater flow potential. The Cenozoic aquifers shown in Figure 23 represent the alluvial aquifers in the Gwydir subregion.

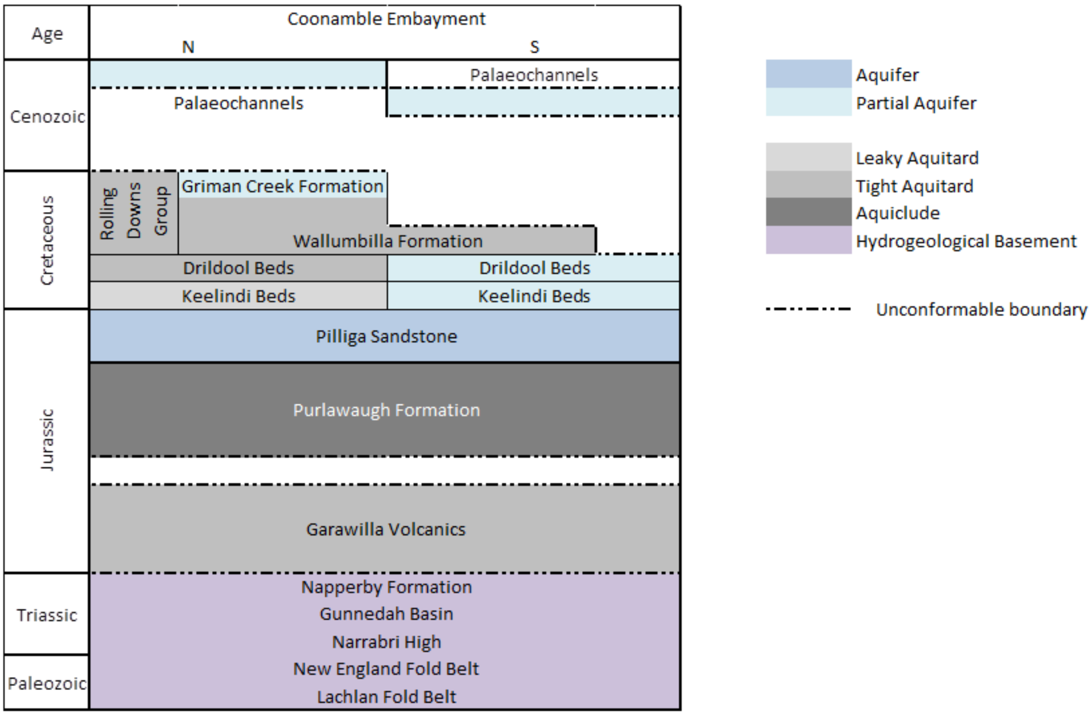

Figure 23 Hydrostratigraphic relationships in the Coonamble Embayment of the Surat Basin

Source: modified from Figure 4.4 in Ransley et al (2012a)

1.1.4.1.2 Groundwater monitoring and assessment

The distribution of groundwater bores in the NSW Government database available through the National Groundwater Information System (BOM, 2014) that have associated water level measurements in the subregion and surrounds is presented in Figure 24. Groundwater monitoring is undertaken by the NSW Government for priority groundwater systems at some of these locations (primarily the major alluvial aquifers in the Gwydir subregion). Apart from some GAB boreholes known to be monitored by the NSW Government, Figure 24 does not identify which groundwater system is monitored by which borehole.

The NSW Government also undertakes data assessment to support local planning requirements and water resource sharing plans for priority groundwater systems such as the Lower Gwydir Groundwater Source (Barrett, 2009) and the Lower Namoi Groundwater Source (Smithson, 2009). Data collection and assessment are also undertaken to support strategies such as the Great Artesian Basin Sustainability Initiative and by industries to meet the requirements of individual development proposals and operational conditions.

In the Lower Gwydir Alluvium (see Figure 25), groundwater level monitoring commenced in the 1970s, with additional sites established up until 2008 (19 new monitoring sites were drilled and installed in a 2007 to 2008 drilling programme). The monitoring network currently includes 65 monitoring bore locations (Barrett, 2009). Groundwater level monitoring is undertaken at a variety of time intervals, and is mostly done manually. Barrett (2009) indicates that there is little in the way of long-term water quality information for the Lower Gwydir Alluvium, although state observation bores were sampled at the time of installation.

Groundwater level monitoring in the Lower Namoi Alluvium (see Figure 25) commenced in the late 1960s and has been performed at 256 locations until the present (Smithson, 2009). Most of these monitoring locations fall within the Namoi river basin rather than the Gwydir subregion. Groundwater level monitoring is undertaken at a variety of time intervals, and is mostly done manually. The collection of groundwater quality data in the Lower Namoi Alluvium has tended to be infrequent and irregular, with limited information available in public state databases. Although groundwater salinity is the main measure of groundwater quality that has been collected in the Namoi subregion (Kelly et al., 2007), there are limited long-term and/or periodic salinity monitoring records available.

The NSW Office of Water (2009a) state that over 500 artesian bores in the NSW portion of the GAB groundwater source have been monitored for pressure, flow, temperature and groundwater quality. However, monitoring has been discontinued in many bores as they were decommissioned, became sub-artesian or were assessed as unsuitable for monitoring due to the poor condition of the bore head. The NSW Office of Water (2009a) indicated that 65 of these GAB bores were being monitored at least once every two years. Of these, a total of 24 are situated in the Gwydir subregion – 14 are situated in the NSW Border Rivers river basin (including some in the intake beds) and ten are situated in the Gwydir river basin (NSW Office of Water, 2009b). Of these 24 bores, 11 were being fitted with telemetered data loggers for real-time monitoring under the GAB monitoring network programme. State monitoring bore networks are also located in the NSW Border Rivers Alluvium. However, a literature search did not identify any publicly available summary of the current status of monitoring in this area as undertaken in the Groundwater Status Reports for the Lower Namoi and Lower Gwydir alluvium.

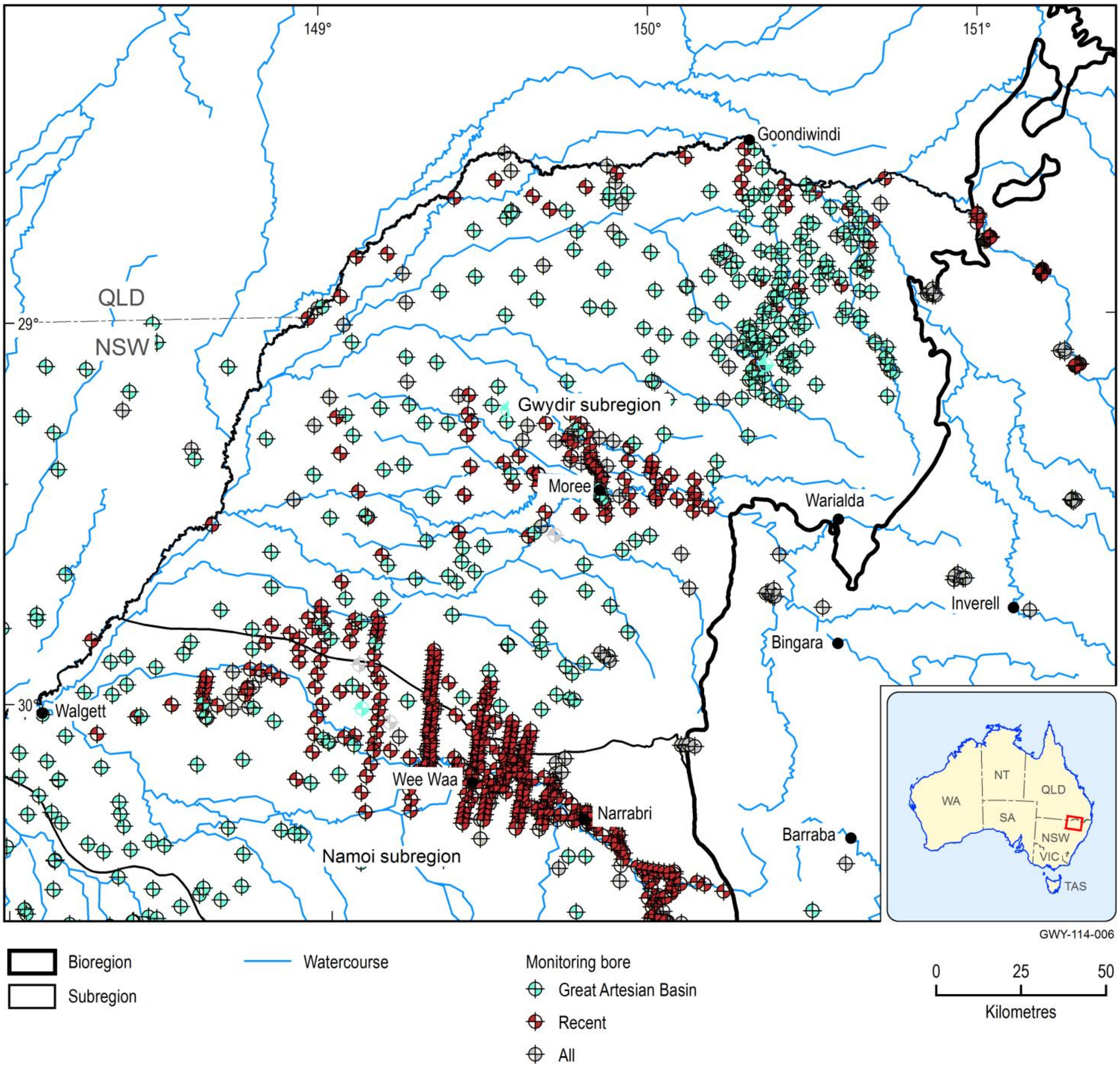

Figure 24 Distribution of NSW groundwater bores in the NGIS database for which at least one groundwater level measurement is recorded

Source data: Bureau of Meteorology (2014)

'Recent' are locations where at least two water levels are reported in the last five years (since 1 January 2008). 'Great Artesian Basin' are those locations where the NSW Government has actively monitored groundwater in the Great Artesian Basin; the remaining groundwater wells may be installed in any of a number of groundwater systems (including the Great Artesian Basin), although many around Moree and Wee Waa appear to be in the Lower Gwydir and Lower Namoi alluvial aquifers.

1.1.4.2 Groundwater levels and flow

1.1.4.2.1 Alluvial aquifers

Shallow groundwater levels are shown on Figure 25 for the alluvium in the Gwydir subregion and surrounds. It is apparent that shallow groundwater generally flows from the high ground in the east towards the west. Refer to Figure 23 for the extent of groundwater systems and management areas discussed below.

Lower Gwydir Alluvium

Barrett (2009) and Carr and Kelly (2010) describe groundwater levels in the Lower Gwydir Alluvium and include a comprehensive review of available hydrographs. This work was undertaken prior to the 2010 floods. Key findings about the Lower Gwydir Alluvium include:

- Groundwater is generally unconfined in the 10 to 30 m thick shallow groundwater system (Narrabri Formation).
- Groundwater in the more productive, deeper (35 to 80 m) groundwater system of the Gunnedah Formation is confined to semi-confined.
- There is no laterally continuous horizon marking the boundary between the two systems. Some authors (e.g. Carr and Kelly, 2010) question whether they are accurately represented as separate hydrostratigraphic (or lithostratigraphic) units.
- Both formations may contain several aquifers that vary in thickness and lateral extent. Aquifers are most extensive in the east near Moree but become more irregular downstream to the west where they grade into finer sediments.
- A high degree of vertical hydraulic connectivity between all depths of the aquifer system is reported by Carr and Kelly (2010) at a regional scale, while clay lenses may limit connectivity locally.
- The dominant aquifer recharge process is leakage from watercourses. This is evident in Figure 25 where groundwater mounding about the Lower Gwydir distributary, downstream of Moree, suggests recharge to the Narrabri Formation, via stream leakage, is occurring. Additional recharge contributions also occur from rainfall infiltration, irrigation and groundwater inflow from the east. Pumping from the deeper, more productive formations induces vertical leakage from overlying aquifers.
- Hydrographs show that groundwater heads have generally fallen with increased groundwater extraction from the deep aquifer since the 1980s, indicating over-extraction has been occurring. This has induced leakage from overlying shallower aquifers and drawdowns in the watertable. Although there was some recovery in the wetter years from 1996 to 2001, declines have subsequently continued. In the far west, declines of over 8 m were recorded since the 1970s (Barrett, 2009). At the edge of the groundwater source, some bores are reported to have shown gradual rising water levels in places.
- Ransley et al. (2012b) show that the thickest alluvium in the area occurs as an east-west trending paleochannel incorporating the Lower Gwydir Alluvium (Figure 25). It meets the Lower Namoi paleochannel south-west of the subregion. This paleochannel is anticipated to have an impact on groundwater flow at the subregional scale.

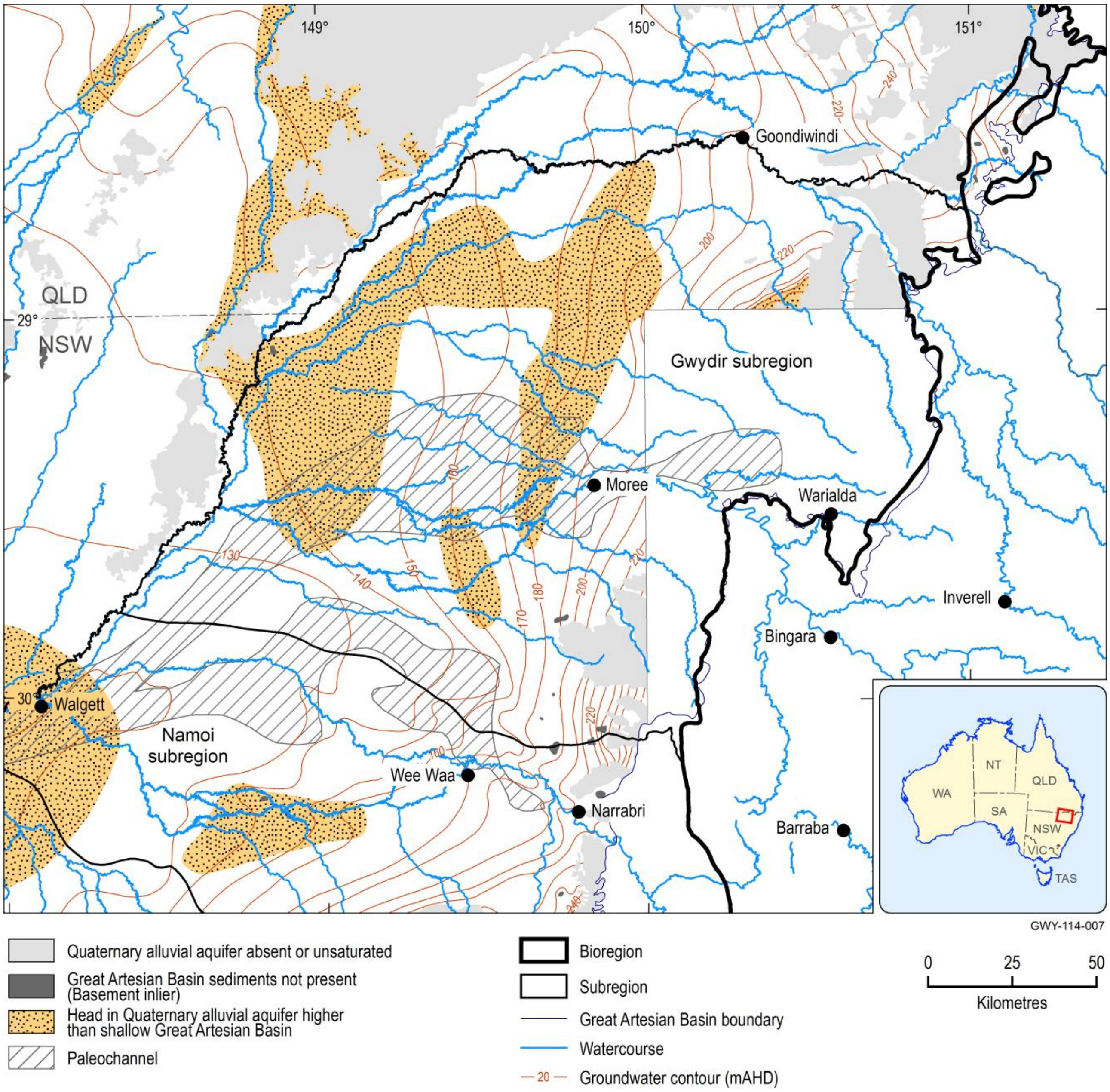

Figure 25 Groundwater levels (post-2000) in the Narrabri Formation showing areas where groundwater heads are higher than in the upper parts of the Great Artesian Basin. The outlines of paleochannels are shown

Source: modified from Kellett and Stewart (2013) with paleochannel outlines modified from Figure 5.9 in Ransley et al. (2012b) Only paleochannels that fall within or partially within the Gwydir subregion are shown. Other paleochannels are known to exist (e.g. in the Border Rivers) but maps of them could not be found in the literature.

Lower Namoi Alluvium

The Lower Namoi Alluvium is only considered briefly here. A more detailed discussion is included in the context statement for the Namoi subregion (Welsh et al., 2014).

- Similarly to in the Lower Gwydir Alluvium, groundwater is present in the shallower Narrabri Formation and the deeper Gunnedah Formation in this area. However, the Cubbaroo Formation is also present at the base of the alluvial sequence in the deepest paleochannel (see Figure 25), consisting of carbonaceous sand and gravel with interbedded clays from which groundwater is also extracted (Kelly et al., 2007).

- In some areas there is limited hydraulic separation between the alluvial formations although there is minimal connectivity in other places (CSIRO, 2007a; Kelly et al., 2007; Parsons Brinckerhoff, 2011).
- Recharge mechanisms are similar to those in the Lower Gwydir Alluvium, although the Cubbaroo and Gunnedah formations are also recharged in part by upward leakage from the GAB (Ransley et al., 2012b) in the main paleochannel. As water levels decline in the alluvium, there is a greater potential for upward leakage.
- Hydrographs show that groundwater levels have generally declined since monitoring commenced in the late 1960s, although there was some recovery from 1996 to 2001 when wetter seasons resulted in reduced extraction and increased recharge. Strong drawdowns are reported in the area of the paleochannel between Narrabri and Wee Waa where deep aquifer pumping has also resulted in leakage from shallow aquifers and reductions in their water levels. South of Wee Waa, Smithson (2009) reports that pumping has resulted in the previously confined deeper aquifer (Gunnedah Formation) becoming unconfined over a considerable area (450 km^2).

NSW Border Rivers Alluvium

- Useable groundwater is restricted to sediments deposited in a narrow valley associated with the Dumaresq and Macintyre rivers. The valley broadens downstream of Keetah Bridge where groundwater generally becomes too saline for use.
- Similar to the Lower Gwydir and Lower Namoi alluvium, an unconfined Narrabri Formation aquifer (10 to 30 m thick) and deeper, confined Gunnedah Formation aquifer (up to 70 m thick) are identified in this area. The coarser sediments of the Gunnedah Formation form a paleochannel that meanders through the valley fill (CSIRO, 2007b).
- The Gunnedah Formation aquifers fine upward into Gunnedah Formation clays of variable permeability that are between 2 and 15 m thick and separate the aquifers from those of the Narrabri Formation (CSIRO, 2007b).
- CSIRO (2007b) indicate that recharge to the Narrabri Formation is mostly from stream losses, with minor contributions from rainfall and excess irrigation, recharge to the deeper Gunnedah Formation being mostly via cross-formational flow, upward leakage from underlying aquifers and infiltration of rainfall and runoff. However, Kellett and Stewart (2013) note that recharge from the Dumaresq River and Macintyre Brook are not strongly manifested in the groundwater surface (see Figure 25) which generally suggests either no significant interaction with streams or discharge to them in many areas (although the area near Goondiwindi is an exception where mounding is evident in the groundwater surface). There is evidence for some upward leakage from the underlying Surat Basin in this area as outlined in the section on groundwater quality below.
- Milne-Home et al. (2007) showed that although average water levels in the Border Rivers Alluvium fell by about 2.5 m in the east near Yelarbon from 1990 to 2005, they increased in the west by about 2.5 m south of Goondiwindi, suggesting that patterns of use vary across the water resource.

1.1.4.2.2 Surat Basin

Groundwater level contours for water in the uppermost units of the Surat Basin presented by Kellett et al. (2012) are shown on Figure 26. The water levels mostly represent water in the Drildool and Keelindi beds in the area, but in the east of the Gwydir subregion the watertable is in the exposed rocks of the Pilliga Sandstone. The groundwater surface tends to be topographically controlled. It suggests minimal interaction between the upper units of the GAB and the Namoi and Gwydir rivers but distortions in the contours near the Border Rivers suggest some interaction in this area.

- The NSW Government (2009) indicates that groundwater recharge mostly occurs along the southern and eastern edge of the GAB via rainfall and streamflow, in an area known as the 'intake beds'. The eastern intake beds outcrop in the east of the Gwydir subregion where water is extracted for irrigation near North Star from the Pilliga Sandstone.
- From the intake beds, groundwater levels are commensurate with general flow to the north and west.
- The vertical hydraulic gradient between the Surat Basin and overlying alluvium generally indicates potential for upward leakage to the alluvial deposits in the subregion except for the locations shown on Figure 25 where the head in the alluvium is higher.
- Groundwater discharges from the GAB via upward leakage to springs and soaks, shallower formations (particularly in paleochannel areas), and extraction bores (artesian and sub-artesian). Mound springs occur to the west of the subregion (e.g. near the Bogan River), while flowing bores occur basinward from Coonamble (Brownbill, 2000). The NSW Government (2009) indicates that more than 80% of the NSW portion of the GAB (of which the Surat Basin is a part) has experienced reduction in groundwater pressure due to extraction (free-flowing and sub-artesian bores). The GAB-associated springs recorded within the subregion (e.g. those along Jardines Creek and Ottleys Creek near Croppa Creek) are reportedly not mound springs. They are fed by 'rejected recharge', where recharge water is restricted from entering the GAB aquifers or flowing basinward, for example by geological structures (NSW Government, 2012).

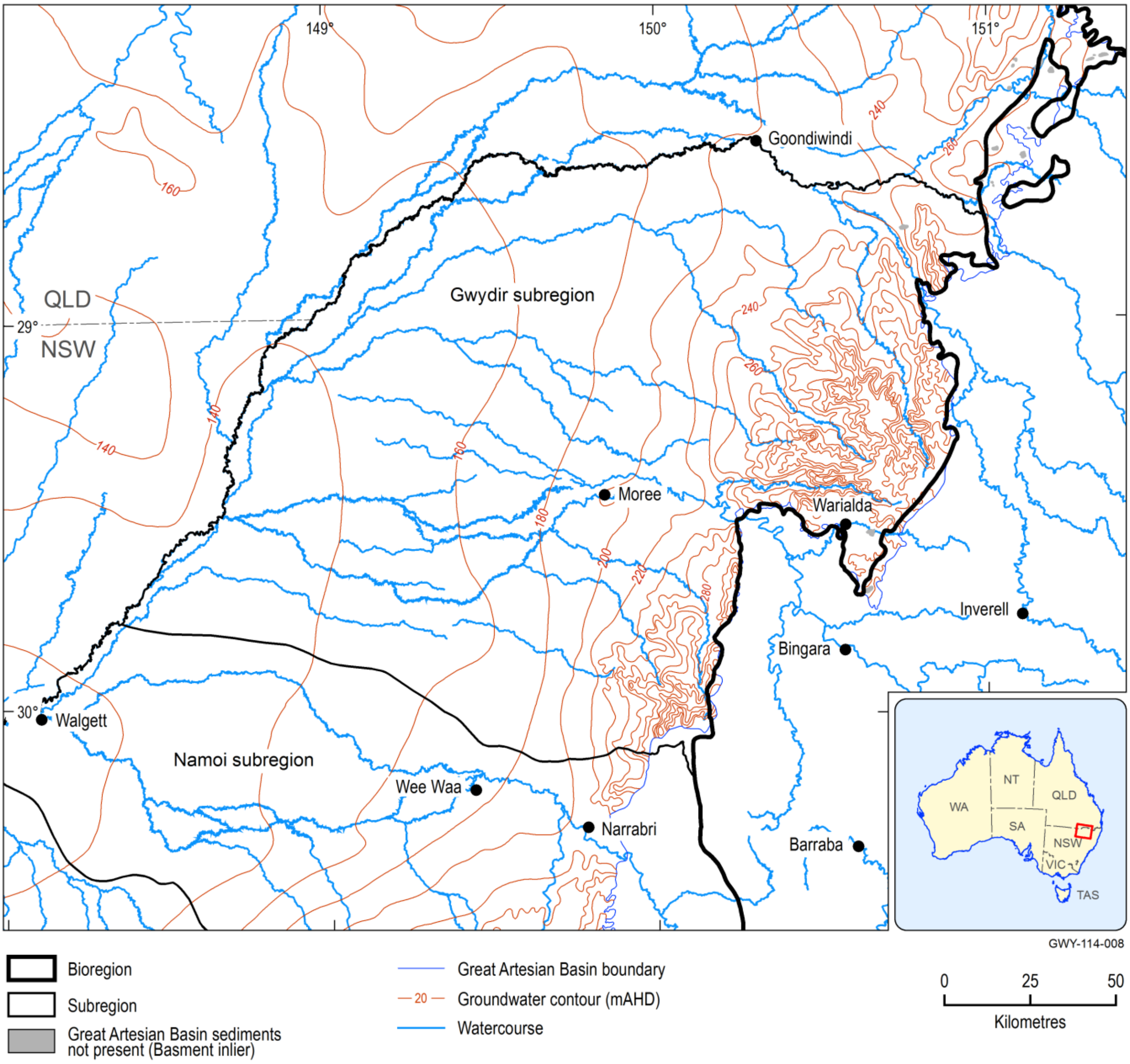

Figure 26 Groundwater level contours for the upper units of the Surat Basin

Source: modified from Figure 5.19 in Kellett et al. (2012)

1.1.4.2.3 Gunnedah-Bowen Basin

No literature relating to groundwater levels and flow in the Gunnedah-Bowen Basin was identified during this study of the Gwydir subregion.

1.1.4.2.4 Aquifer connectivity

As outlined in preceding sections, while the alluvium in the Gwydir subregion is typically separated in literature into the overlying Narrabri Formation and underlying Gunnedah Formation (with the Cubbaroo Formation locally present at the base of the Namoi paleochannel in the far south), the contact between them is difficult to determine lithologically and some question the validity of this separation. Some degree of hydraulic connectivity is often reported between the aquifers of both formations (e.g. Carr and Kelly, 2010), with leakage from the Narrabri Formation commonly cited as a source of recharge to the Gunnedah Formation aquifers.

Kellet and Stewart (2013) indicate that intense weathering of exposed GAB rocks prior to deposition of overlying alluvium resulted in development of a basin-wide saprolite layer. This layer has a low permeability basal portion that is considered to reduce connectivity with overlying systems. Kellet and Stewart (2013) state that in some places the saprolite has been removed by erosion making hydraulic connection possible. Such areas occur beneath paleochannels, of which there are reportedly many in the Surat Basin, commonly occurring beneath or next to modern stream channels. Depending on the relative head levels between the alluvium and GAB, there may be upward or downward flow of water in these areas (see Figure 25).

In the Gwydir subregion, Kellett and Stewart (2013) indicate that areas where upward flow of water from the GAB to the overlying alluvium are highly likely to include:

- the Border Rivers (Macintyre and Dumaresq rivers and Macintyre Brook) upstream of Goondiwindi (there is evidence of upward recharge in groundwater chemistry data near the Peel Fault Zone in this area as outlined in the section on groundwater quality below)
- the Gwydir River upstream of the Mehi River Anabranch
- the Namoi paleochannel (in the south of the Gwydir subregion).

Kellett and Stewart (2013) do not identify any areas in the Gwydir subregion where they consider groundwater flow from the alluvium to the underlying GAB formations to be highly likely.

It is emphasised that relative heads and thus potential flow directions are not fixed and may change over time in response to stresses such as groundwater extraction (e.g. for irrigation or coal seam gas development).

While a degree of hydraulic connection between alluvial aquifers and the topmost units of the GAB thus appears likely in some areas in the subregion, connection with deeper, productive GAB aquifers may still be limited in these places by the hydraulic properties of shallower formations. Recent drilling reported by Barrett (2009), for example, indicates that the Gunnedah Formation is directly underlain by the Bungil Formation of the Surat Basin (correlated to the Drildool beds of the Coonamble Embayment in Figure 23) beneath the Lower Gwydir Alluvium. This unit is described by Radke et al. (2012) as consisting of fine-grained sandstones, siltstones and mudstones. While it is likely that there will be hydraulic connectivity between its upper units in contact with the Gunnedah Formation where they contain water, it is described as a ‘tight aquitard’ (confining bed) in the north of the Coonamble Embayment and probably effectively separates the alluvial systems from deeper GAB aquifers. Geological maps of the area variably indicate much of the alluvium in the west of the subregion to be underlain by the Rolling Downs Group, the Griman Creek Formation or the Blythesdale Group (that is understood to include the Bungil Formation, the Mooga Sandstone and the Orallo Formation).

A preliminary regional-scale desktop assessment of the potential for hydraulic connectivity between the GAB and underlying basins was undertaken as part of the Great Artesian Basin Water Resource Assessment (CSIRO, 2012). Connectivity can occur where aquifers, partial aquifers and leaky aquitards are juxtaposed below and above the base of the GAB (noting that faults may also act as conduits in places through otherwise low permeability formations). Figure 27 shows that hydraulic connectivity between the GAB and underlying formations is relatively poor across much of the subregion except in the south-east where aquifers at the base of the GAB are indicated to overlie partial aquifers of the Gunnedah Basin. In this location, the Surat Basin has a heightened potential connectivity with the underlying Gunnedah Basin strata.

1.1.4.2.5 Local groundwater discharge

Figure 28 shows the locations of springs and other groundwater-dependent ecosystems in the former Border Rivers-Gwydir Catchment Management Authority areas reported by the NSW Office of Water (2009) (note that the Gwydir subregion only occupies the western parts of the areas shown). These systems are areas of groundwater discharge. The main features in the western parts of the subregion are wetlands and waterholes. Some springs are present in the east in the area of the intake beds to the GAB. The NSW Government (2009) highlights that these are not mound springs (GAB-fed systems in the confined, artesian areas of the GAB) but rather 'rejected recharge' from the intake beds.

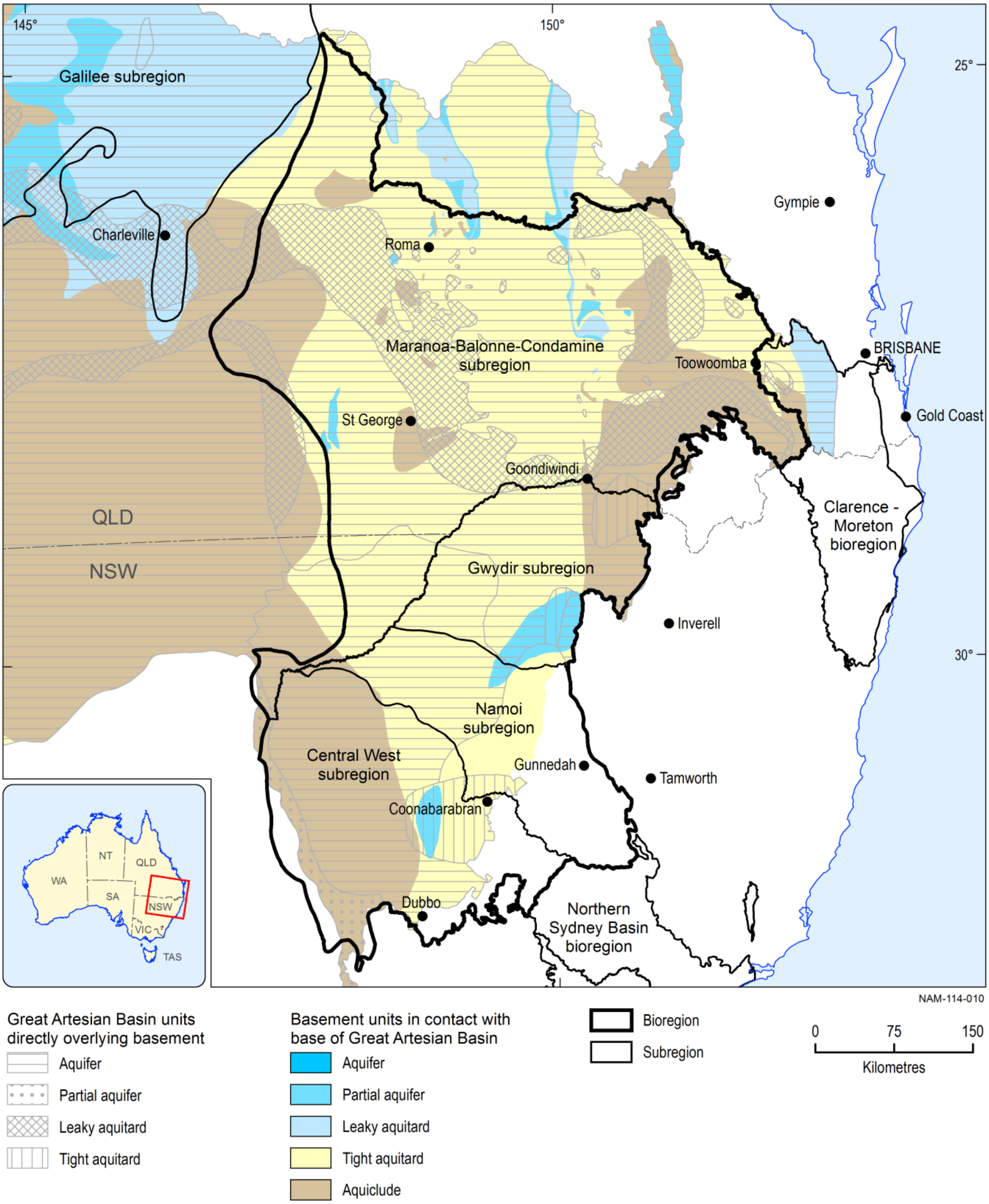

Figure 27 Potential hydraulic interconnection between the Great Artesian Basin and basement units in the Northern Inland Catchments bioregion

Source: modified from Figure 5.7 in CSIRO (2012b)

Figure 28 Distribution of identified groundwater-dependent ecosystems within the former Border Rivers-Gwydir Catchment Management Authority areas

Source: Figure 10 in NSW Office of Water (2009a)

1.1.4.3 Groundwater quality

1.1.4.3.1 Alluvial aquifers

The main alluvial aquifers of the subregion are those associated with the Gwydir, Namoi and Border (Dumaresq and Macintyre) rivers. Limited groundwater quality data were identified for these groundwater systems in the literature, but being used intensively for irrigation, stock and domestic purposes, and town water supplies indicates that they are of relatively good quality. Maps included in Murray–Darling Basin Authority (MDBA, 2012a) show that salinity in the alluvium of the Gwydir subregion generally increases from east to west. Outside of the main alluvial aquifer areas, much of the groundwater has total dissolved solids (TDS) concentrations greater than

14,000 mg/L west of the Lower Gwydir Alluvium. Such high salinity water is of limited use for anthropogenic purposes.

Lower Gwydir Alluvium

MDBA (2012a) includes a map based on Murray-Darling Basin Commission (MDBC, 2000) data which shows that groundwater in the Lower Gwydir Alluvium (see Figure 23) has relatively low salinity, with TDS concentrations across most of the area being in the 0 to 1500 mg/L category. Green et al. (2011a) indicate that much of this water is within the 0 to 500 mg/L category, with salinity increasing towards the far west.

Border Rivers Alluvium

Groundwater in the NSW Border Rivers Alluvium and NSW Border Rivers Tributary Alluvium (Figure 22) is shown in MDBA (2012a) to be relatively fresh, with TDS concentrations mostly in the range 0 to 1500 mg/L. This generally matches work presented by Please et al. (2000) who identified TDS concentrations in this area of less than 1000 mg/L. Please et al. (2000) indicated that salinity increases significantly downstream west of these areas. In the east, groundwater had mixed cationic composition (sodium dominant) but whereas shallow groundwater was dominated by chloride anions, deeper groundwater was dominated by bicarbonate. Further west water was generally sodium and bicarbonate dominated, while high salinity areas in the far west had sodium chloride type waters. Similar findings were reported from a more recent study by Baskaran et al. (2009).

Although groundwater supports irrigation, stock and domestic use, Please et al. (2000) indicate that it does have a high sodium hazard rating in the area in places, particularly close to the Peel Fault Zone (about 45 km east of Goondiwindi) where sodium concentrations are elevated in the alluvial system. This may be due to upward leakage of groundwater from the GAB which is known to have elevated sodium concentrations.

Lower Namoi Alluvium

Maps included in Green et al. (2011b) indicate that groundwater in the east of the Lower Namoi Alluvium is fresh (TDS concentration of 0 to 500 mg/L) and therefore suitable for a variety of uses. Quality decreases to the west, with some areas being defined as saline (TDS concentrations in the range 7,000 to 14,000 mg/L). An increase in groundwater salinity, possibly due to increased saline drainage through the alluvium, has been reported in irrigation areas (Smithson, 2009). Barrett et al. (2006, as cited in Parsons Brinckerhoff, 2011) indicate that groundwater salinity generally increases away from the main recharge areas in the east, and from the mean Namoi River electrical conductivity (EC) of 560 µS/cm to over 30,000 µS/cm in the Narrabri Formation.

McLean (2003) analysed changes in groundwater salinity between the mid-1980s and 1999 and concluded that the salinity of groundwater in the eastern part of the Lower Namoi Alluvium had increased by 100 µS/cm over the preceding 20 years, and in the western portion of the aquifer by several thousand µS/cm. These increases have been attributed to changes in direction of potential flow paths caused by pumping practices (Kelly et al., 2007). The changes in water quality due to pumping were localised and showed no general trends (McLean, 2003).

The results from a recent hydrogeochemical sampling and characterisation project of alluvial groundwater in the Lower Namoi (Parsons Brinckerhoff, 2011) indicated that:

- Major ion chemistry in all aquifers is dominated by sodium and chloride.
- The beneficial use of groundwater has deteriorated at some bores in the Narrabri Formation (no longer suitable for stock), Gunnedah Formation (no longer suitable for some crops including cotton) and Cubbaroo Formation (no longer suitable for some crops including cotton) since monitoring began.
- Some Gunnedah Formation bores showed a long-term increasing trend in salinity, which was attributed to vertical leakage of saline water from the upper aquifer and saline intrusion of pore waters. One Narrabri Formation bore and one Cubbaroo Formation bore also showed a long-term increasing trend in salinity.
- There were no long-term changes in water type identified.

1.1.4.3.2 Surat Basin

Habermehl (2002) states that groundwater quality of the GAB is variable but salinity is generally in the range 500 to 1500 mg/L in the Lower Cretaceous-Jurassic aquifers (of these, the most widely used aquifer in the east is the Pilliga Sandstone (NSW Government, 2009)). The NSW Government (2009) indicates that groundwater quality in the deeper aquifers is more variable although salinity is generally lower than that found in the confining sequence. Groundwater salinity reportedly increases away from the recharge areas in the east (200 mg/L TDS) along groundwater flow paths to the north and west to over 2000 mg/L in places.

Kuske et al. (2011) report that the Cadna-owie Formation (which includes the Pilliga Sandstone) within the Coonamble Embayment has salinity mostly in the range of 250 to 1000 mg/L.

Groundwater in the Lower Cretaceous-Jurassic aquifers is typically of a sodium-bicarbonate-chloride type (chloride becoming more dominant away from the intake beds), and generally suitable for domestic, town supply and stock use (although elevated fluoride concentrations in places – mostly Queensland – may cause issues for stock watering). However, the NSW Government (2009) indicates that it is unsuitable for irrigation in most areas due to its high sodium adsorption ratio. They state that as an exception in the subregion, a combination of lower sodium absorption ratio groundwater and sandy soils supports irrigation in the recharge areas on the eastern margin of the GAB (in the Eastern Recharge Groundwater Source discussed above).

The upper confining units of the Surat Basin (managed under the New South Wales GAB Shallow Groundwater Source Water Sharing Plan to a depth of 60 m) generally consist of low permeability claystone, mudstone, calcrete and shale with minor conglomerate and sandstone (Green et al., 2012). The aquifers they contain are described as sporadic and often low yielding, producing brackish to saline water of limited use.

1.1.4.3.3 Gunnedah-Bowen Basin

Limited information could be found on the quality of groundwater in the Gunnedah-Bowen Basin in the Gwydir subregion. Where the rocks of this basin outcrop in the extreme south-east of the river basin they are shown to contain relatively fresh groundwater (MDBA, 2012a), having TDS concentrations in the range 0 to 1500 mg/L.

Some information from investigations associated with CSG development is available for local areas in the Namoi subregion to the south. Although not directly applicable to the Gwydir subregion, the results provide an indication of what groundwater chemistries may be anticipated. From the limited published data available, the majority of groundwater samples from the non-coal seam formations in the Gunnedah Basin of the Namoi subregion are fresh to slightly brackish, while groundwater samples from the Hoskissons Coal Member are predominantly brackish. An increasing salinity trend was observed in the following order:

Narrabri/Gunnedah<Surat Basin<Napperby/Digby Formation<Black Jack Group<Hoskissons Coal Member (Golder Associates, 2010; Golder Associates, 2011).

Major ion analysis of a very limited number of groundwater samples from the Gunnedah Basin in the Namoi subregion found that groundwater from the Hoskissons Coal Member generally had high concentrations of sodium and bicarbonate and low concentrations of sulfate and chloride. Groundwater from other formations, including the Napperby and Digby formations, was characterised by a range of water types reflecting the heterogeneity of their sedimentary environments (Golder Associates, 2010, 2011). Further information including typical groundwater quality ranges for target coal seams is included in Welsh et al. (2014).

1.1.4.4 Groundwater management and use

Groundwater planning and management is undertaken by the NSW Government via water sharing plans. Water sharing plans allow for management of individual groundwater sources and are effective for ten years from their date of commencement. Individual groundwater systems (excluding those of the GAB) are also represented in the *Basin Plan 2012* (made under the *Water Act 2007*) for the MDB as sustainable diversion limit resource units (see Figure 22/Table 10). Relevant water sharing plans within the Gwydir subregion are listed in Table 10, and aligned with corresponding sustainable diversion limit resource units of the Basin Plan. Extraction limits for these groundwater systems are described within:

- individual water sharing plans, as long-term mean annual extraction limits, and
- the Basin Plan, as baseline diversion limits and sustainable diversion limits (*Water Act 2007*).

Important points regarding water sharing plans and the Basin Plan include:

- With the exception of its topmost confining layers in places (see following dot point), the Surat Basin (a sub-basin of the GAB) is not included in the Basin Plan.
- The GAB Surat Shallow Groundwater Source includes water in the top confining beds of the Surat Basin and overlying alluvial deposits (to 60 m below ground level). It specifically excludes deeper Surat Basin groundwater resources in the productive aquifers.
- The Gunnedah-Oxley Basin MDB sustainable diversion limits resource unit includes the NSW Gunnedah Basin-Bowen Basin system and overlying Oxley sub-basin strata. The ‘Oxley’ component of the basin is not consistently recognised in the literature, but consists of an extension of Pilliga Sandstone in the south-east of the Surat Basin that is hydraulically

separated from the rest of the Surat Basin by a groundwater divide. Oxley sub-basin strata are not present in the Gwydir subregion.

- Discrepancy occurs between long-term mean annual extraction limits (LTAAELs) and sustainable diversion limits (SDLs) in the Gunnedah-Oxley Basin and the GAB Surat Shallow Groundwater Source due to differences in the methodologies used to calculate LTAAELs and SDLs. The Basin Plan specifies that the SDL for the Gunnedah-Oxley Basin is to be reviewed before November 2014.

Groundwater extraction and use varies significantly between the groundwater systems in terms of volumes extracted, extraction as a proportion of estimated limits, and actual water use. Current entitlement levels, entitlement limits and recent annual extraction estimates are provided for each groundwater system in Table 11. Only the figures provided for the Lower Gwydir, Border Rivers and Border Rivers Tributary alluvial aquifers are truly representative of the subregion, as the other groundwater systems extend beyond the subregion boundary.

The alluvial aquifers of the Lower Gwydir, NSW Border Rivers and Lower Namoi are the major sources of groundwater supply in the region. Although most of the Lower Namoi Groundwater Source is contained in the Namoi subregion south of the Gwydir subregion, Smithson (2009) indicates that some extraction occurs within the Gwydir subregion, with several individual bores shown to have extracted 501 to 1000 ML/year on average between 2002 and 2007 (this value exceeded 1000 ML/year in one borehole). Most of the groundwater from these systems is used for irrigation. Extraction for town supply and stock and domestic purposes is also significant (Green et al., 2011a). The NSW Government (2010) indicates that there is consultation between NSW and Queensland on the management of the Border Rivers Alluvium.

Groundwater extraction from the GAB is largely for stock and domestic use, and has been historically elevated by uncontrolled flow from bores. This issue has been progressively addressed by programmes such as the Great Artesian Basin Sustainability Initiative (GABSI), which commenced in 1999. As of June 2012, and including bores controlled prior to GABSI, 252 bores in the NSW Surat Basin had been controlled, with estimated water savings of 53,878 ML/year. A further 120 were still to be controlled as at July 2012 (GABCC, 2012). The Eastern Recharge Groundwater Source of the GAB water sharing plan outcrops in the east of the Gwydir subregion where surface water recharges the GAB aquifers. Groundwater is correspondingly of better quality than the deeper water of the Surat Groundwater Source which underlies the west of the subregion, and is consequently suitable for irrigation. High volume extraction for irrigation is reportedly developed at North Star – Croppa Creek in the northern end of the Eastern Recharge Groundwater Source (NSW Government, 2009). Near Moree, confined groundwater from the Pilliga Sandstone supports a local hot spa industry and the Moree town water supply.

Water in the Gunnedah-Oxley Basin is managed under the water sharing plan for the New South Wales Murray–Darling Basin Porous Rock Groundwater Sources 2012. Limited information was found in the literature on water use from the Gunnedah-Oxley Basin, although the water sharing plan indicates considerable access entitlements. While it is noted that the water sharing plan includes three other groundwater sources in addition to the Gunnedah-Oxley Basin, it states that the majority of licences covered by the water sharing plan are for irrigation, with a significant proportion used for industrial purposes. Town access licences total 112 ML/year and estimated stock and domestic rights for the Gunnedah-Oxley Basin are reported in the water sharing plan to be 5779 ML/year. However, the NSW Department of Primary Industries website (NSW Government, 2014) indicates that bores with sufficient yields for irrigation, municipal or industrial use are rare.

Table 10 Groundwater extraction limits comparison – water sharing plans and Murray–Darling Basin Plan

Groundwater system	Water sharing plan	Date commenced	Sub-component of water sharing plan (and LTAEL[b])	MDB[e] Plan SDL unit (and SDL[c])
Alluvial aquifers	Water Sharing Plan for the Lower Gwydir Groundwater Source 2003	1 October 2006	Lower Gwydir Groundwater Source (32.3 GL/y)	Lower Gwydir Alluvium (33 GL/y)
	Water Sharing Plan for the Upper and Lower Namoi Groundwater Sources 2003	1 November 2006	Lower Namoi Groundwater Source (86 GL/y)	Lower Namoi Alluvium (88.3 GL/y)
	Water Sharing Plan for the NSW Border Rivers Unregulated and Alluvial Water Sources 2012	1 June 2012	NSW Border Rivers Upstream Keetah Bridge Alluvial Groundwater Source (8.085 GL/y)	NSW Border Rivers Alluvium (8.40 GL/y; incorporates Upstream and Downstream Border Rivers Alluvium)
			NSW Border Rivers Downstream Keetah Bridge Alluvial Groundwater Source (0.316 GL/y)	
			Macintyre Alluvial Groundwater Source (0.373 GL/y)	NSW Border Rivers Tributary Alluvium (0.41 GL/y; incorporates Macintyre Alluvial Groundwater Source and Ottleys Creek Alluvial Groundwater Source)
			Ottleys Creek Alluvial Groundwater Source (0.0297 GL/y)	
	Water Sharing Plan for the NSW Great Artesian Basin Shallow Groundwater Sources 2011	14 November 2011	GAB Surat Shallow Groundwater Source (143.335 GL/y)	NSW GAB Surat Shallow (BDL[d] 6.57, SDL 15.5 GL/y)
Surat Basin (within GAB Coonamble Embayment)	Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008	1 July 2008	Eastern Recharge Groundwater Source ([a] 19 GL/y)	na – not MDB[e]
			Surat Groundwater Source ([a] 75 GL/y)	na – not MDB[e]
Gunnedah-Oxley Basin	Water Sharing Plan for the NSW Murray–Darling Basin Porous Rock Groundwater Sources 2012	16 January 2012	Gunnedah-Oxley Basin MDB[e] Groundwater Source (205.64 GL/y)	Gunnedah-Oxley Basin MDB[e] (BDL[d] 22.1, SDL 114.5 GL/y)

[a]These are long-term mean annual net recharge estimates. Annual extraction limits are calculated from these figures by subtracting the volume of planned environmental water – refer to the water sharing plan for the New South Wales Great Artesian Basin Groundwater Sources 2008.
[b]LTAEL – Long-term average extraction limit
[c]SDL – Long-term average sustainable diversion limit
[d]BDL – Baseline diversion limit
[e]MDB – Murray–Darling Basin
na – Not applicable
Where a separate BDL value is not shown for an SDL resource unit, BDL value = SDL value.

Table 11 Groundwater entitlements and extraction

Groundwater system	System is confined to the subregion	Current entitlements (GL/y)	Recent annual extraction (GL/y)	BDL (GL/y)	SDL (GL/y)
Lower Gwydir Alluvium	Yes	32.3	32.91	33	33
Lower Namoi Alluvium	No	86	102.05	88.3	88.3
NSW Border Rivers Alluvium	Yes	15.89	8.63	8.4	8.4
NSW Border Rivers Tributary Alluvium	Yes	1.58	1.73	0.41	0.41
Surat Basin strata and alluvium above 60 m depth	No	NA	NA	6.57	15.5
Surat Basin strata below 60 m depth	No	-	-	-	-
Gunnedah-Oxley Basin strata	No	n/a	n/a	22.1	114.5

Source: MDBA (2012a), and the Commonwealth's *Basin Plan 2012*
BDL – Baseline diversion limit; represents the Murray–Darling Basin Authority's (MDBA's) determination of the limits on groundwater use under existing water management arrangements.
SDL – Long-term average sustainable diversion limit; these come into effect in 2019.
NA – Not available
Recent annual extraction includes metered extraction volumes from licensed bores, and estimated extraction from authorised stock and domestic bores reported in MDBA (2012a).
For the NSW Border Rivers Tributary Alluvium there is no metering of licensed groundwater extraction; extraction has been estimated as total entitlements plus estimated extraction from authorised stock and domestic bores.
No information on current entitlements and recent annual extraction are provided for the Great Artesian Basin Surat Shallow Groundwater Source or the Gunnedah-Oxley Basin Murray–Darling Basin Groundwater Source in MDBA (2012a).
The Surat Basin below 60 m (GAB) is not included in the *Basin Plan 2012* or MDBA (2012a).

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1.1.5 Surface water hydrology and water quality

Summary

Surface water of the Gwydir subregion is based on the Gwydir, Macintyre and Barwon river basins (part of the Border Rivers river basin). Areas drained by the Gwydir River and its distributaries west of Pallamallawa in the Gwydir river basin and by the Macintyre River west of Texas, and catchment areas south of the Macintyre-Barwon River including those of Ottleys, Wallan and Gil Gil creeks are within the subregion. The Gwydir subregion excludes all parts of the Barwon river basin that are on and beyond the right (north) banks of the Barwon and Macintyre rivers, which are instead part of the Maranoa-Balonne-Condamine subregion.

The Gwydir River forms a delta-like structure downstream of Moree resulting in the river flows being diverted into several of its distributaries including the Mehi River, Carole and Gil Gil creeks, and two main channels of the Gwydir River, namely the Lower Gwydir and Gingham watercourses. Mehi River and Gil Gil Creek flow into the Barwon River while both the Gwydir River channels terminate in the Gwydir Wetlands. Since the construction of Copeton Dam (outside of the subregion), there has been a substantial reduction in the extent of the Gwydir Wetlands. The Gwydir is a highly regulated river. The Copeton Dam, which is the only major public water storage in the Gwydir river basin, and several weirs regulate flow within the subregion.

There are about 150 agricultural businesses dealing with irrigation. Most irrigation diversions occur below Pallamallawa through a network of weirs and regulators on the Gwydir River and its distributaries. The total capacity of private on-farm dams and weirs used for collection and diversion of mainly irrigation water is 451 GL. The Mehi River has a long history of flooding with significant flood events occurring roughly every ten years.

The general water quality assessments of both the Border Rivers and Gwydir river basins for total phosphorus and total nitrogen are rated as ‘very poor’. The assessment for turbidity is rated as ‘fair’ for both river basins while salinity is rated as ‘fair’ for the Border Rivers river basin and as ‘poor’ for the Gwydir river basin. Within the subregion, the median of mean monthly electrical conductivity values in the Macintyre River and the Mehi River were 275 and 445 µS/cm, respectively. The overall ecosystem health of both the Gwydir and Border Rivers river basins as reported by the Sustainable Rivers Audit was rated as ‘poor’ for both the 2004 to 2007 and 2008 to 2010 periods.

There are about 16 and 33 stream gauging stations in the Macintyre-Barwon and Gwydir river basins, respectively, that are within the subregion. Streamflow data length varies from a few years to more than 100 years. Modelling using climate change projections for 2030 conditions indicates a likely decrease in future runoff.

1.1.5.1 Surface water systems

The surface water of the Gwydir subregion is based on the Gwydir, Macintyre and Barwon river basins. The Barwon river basin is part of the Border Rivers river basin. The entire subregion lies within the Murray–Darling Basin (MDB) and all rivers of the subregion join the Barwon River. The whole of the Gwydir river basin, including areas outside of the subregion, contributes about 3.4% of the total runoff in the MDB (CSIRO, 2007).

The Macintyre-Barwon river basin within the Gwydir subregion contains the lower Macintyre River before it joints the Dumaresq River at the NSW–Queensland border. The main tributary of the Macintyre River within the subregion is Ottleys Creek. The Macintyre River becomes the Barwon River at the junction where the Boomi River Anabranch begins. The Boomi River is joined by Whalan Creek south of Mungindi and by Gil Gil Creek before flowing into the Barwon River (Figure 29).

The headwaters of the Gwydir River are in the Great Dividing Range near Armidale (outside of the subregion). The river then flows in a westerly direction into Copeton Dam before entering the subregion upstream of Biniguy. Further into the subregion, the broad floodplain of the Gwydir River system begins west of Pallamallawa and extends to the Barwon River. Tributaries of the Gwydir River at the upstream reaches between the Copeton Dam and Pallamallawa are the Mosquito, Warialda, Myall and Macintyre creeks and Horton River. All except Mosquito Creek are outside the subregion.

Beyond Moree the stream network forms a delta-like structure (Figure 29) which merges with the floodplains of the Barwon and Macintyre river basins in the north and the Namoi river basin in the south (NSW DECCW, 2011). East of Moree, the Mehi River Anabranch (to the south) and Gil Gil Creek (to the north) split from the Gwydir River. The Mehi River has a major anabranch, Moomin Creek, and a number of tributaries including Tycannah, Mallowa, Tarran and Goonal creeks. The Thalaba Creek is an anabranch and the Gurley and Wolongimba creeks are tributaries of Moomin Creek. These distributaries inundate the floodplain wetlands during periods of high flows from the upper catchment.

Downstream of Moree at the Tyreel Weir, the Gwydir River splits into Gingham (northern arm) and Lower Gwydir (also called the Big Lather Watercourse) watercourses, both terminating in the Gwydir Wetlands (Figure 29). There are four Ramsar-listed sites in the northern and central areas of the Gwydir Wetlands. Before 1946, the majority of small floods entered the Lower Gwydir Watercourse and only large floods reached the northern Gingham Watercourse. However, due to a 1.6 km long log-jam (the raft) created by the accumulation of timber, debris and sediments in the Lower Gwydir Watercourse downstream of Moree, an increased proportion of flows now enters the Gingham Watercourse (BRG CMA, 2010). However, the Tyreel regulator helps to reregulate the flow by allowing water to be redirected back into the Lower Gwydir River (MDBA, 2012a).

The Gwydir is regulated by the Copeton Dam and several weirs. Before regulation, water inundated the Gingham and Lower Gwydir floodplains and wetlands and only flowed through to the Barwon River in major floods. Water from the Mehi River, and to a lesser extent from Gil Gil

Creek, now frequently flows into the Barwon at low volumes (MDBA, 2014). Since regulation, there has been a substantial reduction in the area of the Gwydir Wetlands (MDBA, 2012a).

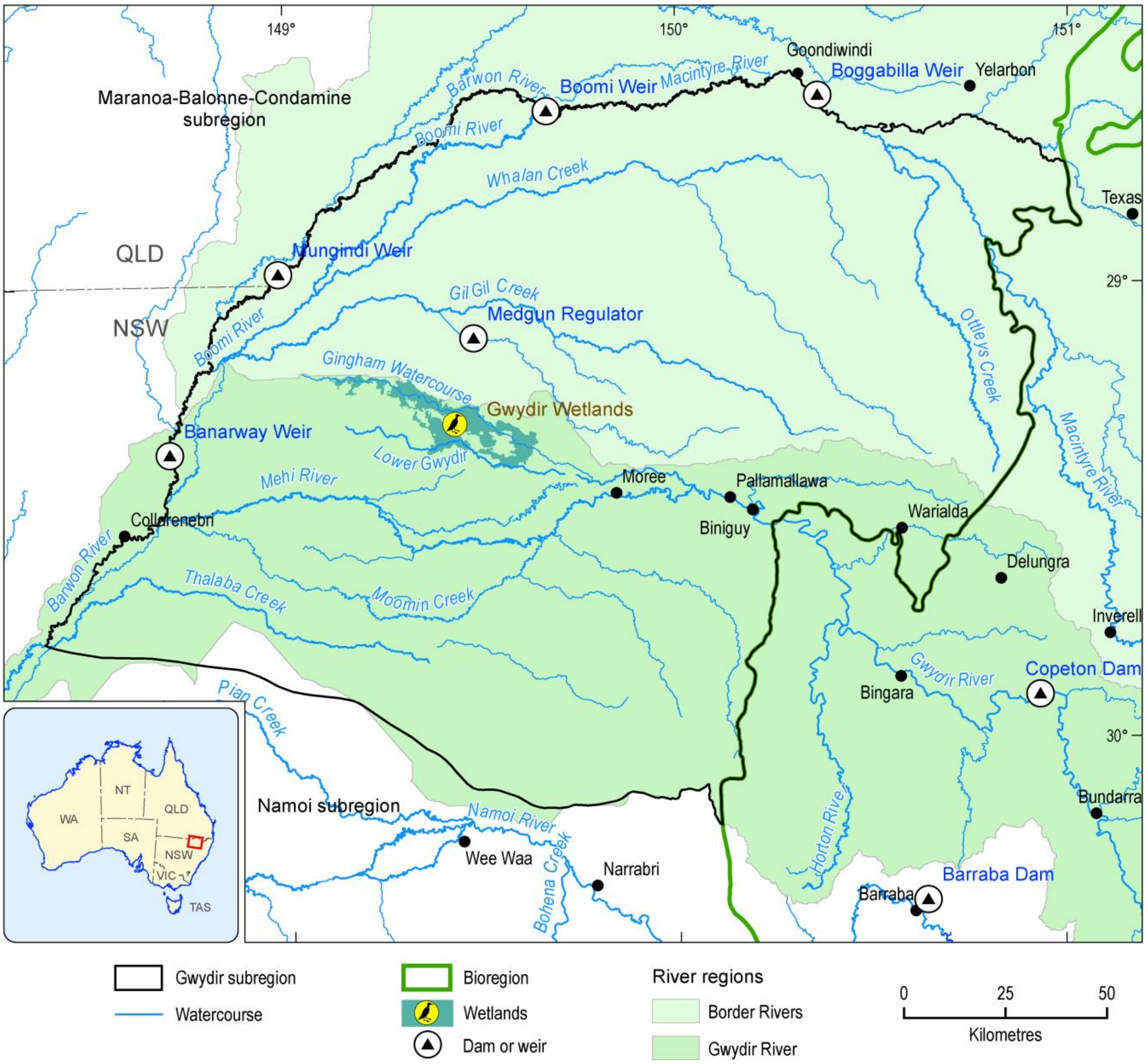

Figure 29 Stream network and main locations in the Gwydir subregion

Source data: Environment Australia (2001)

1.1.5.1.1 Surface water infrastructure

The Copeton Dam (1364 GL capacity, completed in 1973), which is outside of the subregion, is the main public water storage dam on the Gwydir River. It provides for town water supplies, irrigation, stock and domestic use, industry, and environmental flows along the Gwydir River and its distributaries. A series of weirs and regulators assist in diverting water to the various watercourses of the Lower Gwydir catchment (NSW DPI, 2014). Some of the major weirs and regulators in the Gwydir river basin are the Tareelaroi, Boolooroo, Tyreel and Combadello weirs, and Gundare and Mallow Creek regulators.

A number of private on-farm dams also exist for irrigation. The estimated total volume of hillside dams, weirs and ring tanks in the Gwydir river basin is 84, 16 and 351 GL respectively (Webb, McKeown and Associates Pty Ltd, 2007). There are about 150 irrigating agricultural businesses and most irrigation diversions occur below Pallamallawa through a network of weirs and regulators on the Gwydir River and its distributaries (Burrell et al., 2012). The major irrigation districts are near Moree and east of the Gwydir Wetlands on the fertile soils of the floodplain (Carr and Kelly, 2010). The Mehi River and Carole and Gil Gil creeks are channelised to assist with delivery of water to the irrigation industry.

Environmental water requirements have been determined for the Lower Gwydir, Gingham and Mallowa watercourse management units. The flow indicators for these management units are aimed at maintaining wetland and floodplain vegetation to provide conditions favourable for fish and bird breeding (MDBA, 2012a).

Water sharing plan and surface water entitlements

The ten year (2004 to 2014) Gwydir Regulated River Water Sharing Plan (WSP) applies to the section of the Gwydir River downstream of Copeton Dam to the junction of the Gwydir (and its regulated distributary streams) and Barwon rivers. Some of the Gwydir regulated river water sources include sections of: Boomi River, Carole Creek, Gil Gil Creek, Gwydir Pool, Mehi River, Moomin Creek and Tyreel Anabranch (NSW Office of Water, 2013).

The surface water long-term average annual extraction limit of the Gwydir regulated river water source under the WSP is 392 GL (NSW Government, 2014a) and for the whole of the Border Rivers is 399.4 GL to be shared between NSW and Queensland (NSW Government, 2013a). The subregion also borders the Barwon-Darling unregulated river water source for which the long-term average annual extraction limit is 214 GL (NSW Government, 2013b). Table 12 lists the major surface water entitlements in the Gwydir river basin. The share components of the high security, general security and supplementary licences are expressed as a number of unit shares (DIPNR, 2004). The unit share is the share of water allocated to licence holders as determined by the 'Available Water Determination' (AWD) in volume per unit share. Available water determinations are made under section 59 of the *Water Management Act 2000*. The volume of water allocated to a water account is calculated by multiplying the number of unit shares on the licence by the volume per share stated in the AWD (DIPNR, 2004). AWDs are made for each licence category in each water source and are generally made at the start of a water year.

Table 12 Surface water entitlements in the Gwydir river basin

Entitlement type	Share component
High security	19,293 unit shares
General security	509,500 unit shares
Supplementary licences	170,000 unit shares
Domestic and stock	4.2 GL/y
Local water utility	3.8 GL/y

Source data: DIPNR (2004)

Diversion limits and the Basin Plan

The Murray–Darling Basin Authority estimates the surface water long-term average baseline diversion limit for the Gwydir river basin (SS22) to be 450 GL/year (MDBA, 2012b). The limit on interception by runoff dams is set at 125 GL/year (including 1 GL/year of interception by commercial plantations). Therefore, the Murray–Darling Basin Authority estimate of the surface water (baseline) diversions minus the interception by runoff dams in the Gwydir is 325 GL/year (as per Schedule 3 of the Commonwealth's *Basin Plan 2012*). The water recovery effort was 50 GL for the Gwydir as at 31 March 2014; and Transition to new Sustainable Diversion Limits by 2019 is an ongoing process. The 325 GL/year limit includes 314 GL/year from regulated rivers and by floodplain harvesting (excluding take under basic rights), and 11 GL/year from watercourses other than from regulated rivers (excluding take under basic rights).

The sustainable diversion limit (SDL) under the Basin Plan requires that the surface water long-term average diversion limit be reduced from 450 GL/year by 42 GL/year to meet local environmental targets plus any apportionment of the northern Basin zone shared reduction target set by the Basin Plan (MDBA, 2011). The SDL will come into effect in 2019 following the completion of the northern basin review, the operation of the SDL adjustment mechanism and apportionment of any shared reduction target in 2016, all of which may lead to further reductions in the Gwydir SDL resource unit.

1.1.5.1.2 Flooding history and flooding potential

The Mehi River in the Mehi-Gwydir system has a long history of flooding. Significant flood events in the river were observed in 1910, 1921, 1946, 1949, 1950, 1955, 1956, 1971, 1974, 1976, 1984, 1998, 2001 and 2011. The 1955 flood was the highest in the Mehi River reaching a peak flood height of 10.85 m in Moree (SES, 2006). The majority of Moree's local government area is flood prone. In November 2011 Moree experienced its wettest November (221 mm of rainfall in four days) since 1879 with the largest flood peak since 1976 in the Gwydir River at Gravesend (NSW DPI, 2013). This was followed by 185 mm of rainfall from 1 to 3 February 2012, producing another significant flood peak in the Gwydir River. Eco Logical Australia (2011) detailed the extent of inundation due to floods of different magnitudes (up to 15 year average recurrence interval) in the Gwydir Wetlands area from 1996 to 2011. Among other things, it showed that a flood volume of 300 GL experienced in December 2004, estimated to be of 15 year average recurrence interval magnitude, inundated almost the entire wetland.

Major flooding also occurred in the Macintyre River system in 1890, 1921, 1956, 1976, 1983, 1991 and 1996 (MPSC, 2008; NEH, 2011).

1.1.5.2 Surface water quality

The surface water quality indicators given by the percentage of samples exceeding Australian and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines for the protection of the aquatic ecosystems (ANZECC and ARMCANZ, 2000) for turbidity and total phosphorus for 2005 to 2008 at 18 locations within the subregion and at three locations just outside the subregion are shown in Table 13. The guideline values for total phosphorus are 0.02 mg/L for upland sites (>150 m above mean sea level) and 0.05 mg/L for lowland sites. The corresponding values for turbidity are 25 and 50 nephelometric turbidity units (NTU), respectively (NSW Government, 2010). Table 13 shows that at eight locations more than 90% of the samples, and for all locations more than 50% of the samples exceeded the limit for total phosphorus. In contrast, more than 90% of the samples exceed the limit for turbidity at only two locations. No meaningful correlation between the percentage of sites exceeding limits for these two water quality indicators was found.

The NSW Office of Water monitors ambient river water quality at strategic locations and maintains long-term datasets for sites across the Central West. Attributes currently monitored represent general water quality condition and are most likely to demonstrate change over time from a broad-scale implementation of natural resource management perspective (e.g. turbidity, total nitrogen, total phosphorus, electrical conductivity, pH and water temperature) (W Mawhinney, 2014, pers. comm.).

Not all stations in the region record all water quality indicators. Table 14 summarises results of water quality assessments for the Border Rivers and Gwydir river basins based on 33 and 24 sites, respectively (not necessarily all within the subregion). For both river basins water quality in terms of turbidity is rated ‘fair’, while pH and salinity are rated ‘fair’ only for the Border Rivers. All the remaining water quality indicators listed in the table are rated ‘poor’ to ‘very poor’ for both river basins. The nutrients (total nitrogen and total phosphorus) for both basins are rated ‘very poor’ (SEWPAC, 2011). A ‘poor’ rating means that between 25 and 50% of samples complied with ANZECC/ARMCANZ (2000) guidelines for protection of the aquatic ecosystem, and those with less than 25% compliance are classified as ‘very poor’. The overall ecosystem health of both the Border Rivers and Gwydir river basins as reported by the Sustainable Rivers Audit (SRA) is rated as ‘poor’ for both the 2004 to 2007 and 2008 to 2010 periods (MDBC, 2008; Davies et al., 2012). Note that the data in Table 13 and Table 14 and ratings (e.g. ‘poor’) for individual water quality indicators were assessed against the ANZECC and ARMCANZ (2000) water quality guidelines and not against the Basin Plan water quality targets which will be used in the future (W Mawhinney, 2014, pers. comm.). The overall ecosystem health were based on SRA assessments.

The Horton River, and the Myall, Warialda and Tycannah creeks have high salt concentrations (CSIRO, 2007). Analysis for this report using data from NSW Government (2014b) showed that the median of monthly mean of daily electrical conductivity (EC) at a station in the Gwydir river basin (Mehi River at Bronte, 418058) for 2001 to 2013 was 445 μS/cm (10th and 90th percentile values are 257 and 708 μS/cm, respectively). The daily mean water temperature ranges from 10 to 31 °C. For a station in the Border Rivers Basin (Macintyre River at Holdfast, 416012) the median of mean monthly EC is 275 μS/cm (10th and 90th percentile values are 208 and 381 μS/cm, respectively) and the mean daily temperature ranges from 10 to 42 °C (the second-highest value is 34 °C). Trend analysis showed stable trends for EC and water temperature and a rising trend for turbidity in the Mehi River at Bronte. The same results, except with a falling trend for EC, were found for the Macintyre River at Holdfast (NSW Government, 2010).

Table 13 Percentage of samples that exceeded Australian and New Zealand Environment and Conservation Council guidelines for total phosphorus and turbidity at different locations within and outside (in italics) of the Gwydir subregion

Location	Total phosphorus (%)	Turbidity (%)
Dumaresq River at Mauro	91%	26%
Macintyre River at Holdfast	97%	31%
Macintyre River at Salisbury Bridge	62%	21%
Macintyre River at Terrewah	68%	32%
Macintyre River at Konowna	61%	54%
Carole Creek at Garah	76%	62%
Barwon River at Mungindi	55%	53%
Gil Gil Creek at Galloway	100%	96%
Tycannah Creek at Horseshoe Lagoon	100%	13%
Warialda Creek at Warialda	100%	36%
Mehi River at Moree	79%	21%
Mehi River at Bronte	100%	88%
Gwydir River at Yarraman Bridge	52%	10%
Gwydir River at Brageen Crossing	62%	62%
Gwydir River at Allambie Bridge	76%	52%
Moomin Creek at Glendello	89%	83%
Moomin Creek at Iffley	100%	100%
Thalaba Creek at Merrywinebone	91%	87%
Gwydir River at Gravesend Road Bridge	*96%*	*46%*
Macintyre River at Wallangra	*100%*	*44%*
Horton River at Rider (Killara)	*89%*	*36%*

Source data: NSW Government (2010)

Table 14 Water quality assessment for Border Rivers and Gwydir River

River basin	Sites	Turbidity	Salinity	pH	TN	TP
Border Rivers	33	Fair	Fair	Fair	Very poor	Very poor
Gwydir	24	Fair	Poor	Poor	Very poor	Very poor

Source data: SEWPaC (2011)
TN is total nitrogen and TP is total phosphorus

1.1.5.3 Surface water flow

The Gwydir river basin contributes about 3.4% of total runoff in the MDB. The average surface water use is 300 GL/year which is about 60% of total irrigation water entitlements (CSIRO, 2007). At Pallamallawa, the main channel of the Gwydir River flows at its maximum mean daily flow capacity of 2.05 GL (Green et al., 2011) before the flow diversion into its several distributaries begins. The surface water flow regime has changed since the construction of the Copeton Dam in 1973, creating a noticeable reduction in the frequency and magnitude of large flows (MPSC, 2008; Green et al., 2011).

Rainfall in the Gwydir river basin is summer dominated with a mean annual rainfall of 644 mm. On average, the first half of the 20th century was drier than the second half (see Section 1.1.2 Geography for more detail). The mean annual modelled runoff is 41 mm and is relatively uniformly distributed throughout the year (CSIRO, 2007). The runoff coefficient is 6.3% which is higher than in the Maranoa-Balonne-Condamine subregion to the north.

There are 60 active stream gauging stations in the Gwydir river basin, 33 of which are within the subregion. Similarly, about 16 of the 43 stream gauging stations in the Macintyre-Barwon river basin are within the subregion. These stations are managed by the NSW Office of Water and the majority of them are telemetered. The record lengths vary from a few years to more than 100 years. Several of the stations however, have stage only data. Summary statistics from some of the streamflow gauging stations in the subregion are given in Table 15. Full details can be found in NSW Government (2014b).

The impact of climate change examined by the South Eastern Australian Climate Initiative (SEACI) for the Gwydir river basin indicated that 11 of 15 global climate models (GCMs) projected a decrease in future runoff showing a median reduction of 10% and 17% under 1 and 2 degree global warming, respectively (Post et al., 2012). See Section 1.1.2.3 (Geography: Climate) for further details. The CSIRO (2007) study also indicated the effect of projected climate change on future runoff in the Gwydir river basin is a likely decrease of mean annual runoff of about 9% for a 2030 climate based on the median estimate.

Table 15 Selected open stream gauging stations within the Gwydir subregion and summary statistics

Site no.	Station name and location	Record length (years)	Start year	Catchment area (km²)[a]	Mean monthly flow (GL)[b]	Mean annual runoff (mm)
416001	Barwon River at Mungindi	124.0	Dec-1889	44,070	49.5	13.5
416012	Macintyre River at Holdfast	63.5	Jun-1950	6740	32.7	58.2
416047	Macintyre River at Terrewah	29.0	Dec-1984	23,400	33.1	17.0
416048	Macintyre River at Knowna	29.0	Nov-1984	26,000	19.9	9.2
416052	Gil Gil Creek at Galloway	26.5	May-1987	-	4.2	-
418001	Gwydir River at Pallamallawa	122.0	Dec-1891	12,300	60.7	54.9
418002	Mehi River at Moree	76.7	Mar-1937	-	11	-
418004	Gwydir River at Yarraman Bridge	84.3	Aug-1929	12,960	33.4	30.9
418032	Tycannah Creek at Horseshoe Lagoon	42.5	Jun-1971	866	2.5	35.0
418052	Carole Creek at Garrah	33.4	Jul-1980	-	5.6	-
418053	Gwydir River at Bragеen Crossing	33.5	May-1980	-	5.5	-
418058	Mehi River at Bronte	35.0	Nov-1978	-	3.4	-
418060	Moomin Creek at Glendello	29.7	Mar-1984	-	8.7	-
418076	Gingham Channel at Tillaloo	16.5	May-1997	-	4.8	-
418078	Gwydir River at Allambie Bridge	16.6	Apr-1997	-	4.4	-

Source data: NSW Government (2014b)
[a]Catchment areas for a number of gauging stations cannot be determined.
[b]The mean monthly runoff shows some inconsistencies which have not been explored.

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1.1.6 Surface water – groundwater interactions

Summary

Detailed studies of surface water – groundwater interactions have been undertaken in specific areas of the Gwydir subregion but not for the subregion as a whole. General studies have suggested that groundwater discharges to most streams in the higher ground to the east and is recharged by streams in the lower lying areas to the west, although such relationships may be reversed in places depending on flow levels.

There have been some more detailed connectivity studies in the Gywdir subregion using a range of methods including field-based studies, examining groundwater contours and analysing groundwater hydrographs. These studies have investigated smaller river reaches and the results appear contradictory in places. This is likely to be due to variations in the study site and study scale, and climate and rainfall patterns at the time of each study.

1.1.6.1 Connectivity between groundwater and surface water

Assessments of surface water – groundwater connectivity were undertaken as part of the Murray-Darling Basin Sustainable Yields Project (Parsons et al., 2008). The connectivity mapping was based on a snapshot in time of fluxes to or from the major rivers. The assessments used data from June 2006 – a time that represented a historically low-flow period in the subregion (CSIRO, 2007a, 2007b). Results of the connectivity mapping are shown in Figure 30. It is apparent that while many of the systems to the east of Moree are classified as gaining (i.e. groundwater discharges to them), most streams in the west of the subregion are classified as losing (i.e. surface water recharges groundwater). The 'high losing' stream reaches in this area are reportedly associated with a zone of increased hydraulic conductivity which correspondingly results in greater seepage to the subsurface.

The Dumaresq and Macintyre rivers in the north (Figure 5) are mostly classified as losing in the area of the NSW Border Rivers Alluvium and NSW Border Rivers Tributary Alluvium (see Figure 22). While CSIRO (2007b) indicated that comparisons between river levels and groundwater levels over time at select locations commonly showed that the surface water – groundwater level relationship is maintained in most areas where assessed (Figure 30), gaining conditions in some stream reaches in the north could be reversed over short time periods in response to flood events.

In contrast to CSIRO (2007b), Kellett and Stewart (2013) note that recharge to groundwater from the Dumaresq and Macintyre rivers is not strongly manifested in the groundwater surface (see Figure 25) which generally suggests either no interaction with streams or that there is discharge to them in many areas (although the area near Goondiwindi does show groundwater mounding near the Border Rivers). While limited interaction is also suggested by the groundwater contours further south in the area of Moree and surrounds at the scale of individual streams, overall groundwater contours are commensurate with an area of general recharge in the area west of Moree where CSIRO (2007b) classified most river reaches as losing.

Kellett and Stewart (2013) note that the configuration of the shallow GAB groundwater surface suggests that the Border Rivers are drains for GAB groundwater that may contribute a significant component of baseflow to them.

Based on the analysis of groundwater hydrographs, Carr and Kelly (2010) identified zones in the floodplain along the Gwydir River upstream of Moree where aquifers within 100 m depth are locally hydraulically connected to the river and zones where the deep aquifers are disconnected from the shallow aquifers that do not receive direct river recharge. They found that shallow groundwater tables in the Gwydir river basin (e.g. in bores south of Pallamallawa as well as north of Moree) responded to the large flood events for some years but not for others, suggesting that recharge to groundwater may only occur when there is sufficient wetting of the vadose zone and hydraulic loading from flood waters.

Field-based connectivity studies of surface water – groundwater interactions have also been investigated for the Gwydir and Dumaresq rivers (Brownbill et al., 2011; Lamontagne et al., 2011a; Lamontagne et al., 2011b). Connectivity was investigated along a stretch (~30 km) of the Gwydir River downstream of Moree and at two transects (Yarraman Bridge and Brageen Crossing). Lamontagne et al (2011a) reported that the Gwydir River at both transects was losing – disconnected due to a clogging layer (a clay unit 0.5 m or more in thickness) in the streambed and relatively deep groundwater. The surface water and groundwater levels showed limited temporal variation over the monitoring period (March 2009 to March 2010); however, the river remained losing at all times (Lamontagne et al., 2011a).

Connectivity was also investigated along the Dumaresq River (~20 km stretch) and at two transects (Site 1 and Site 2) (Lamontagne et al., 2011b). The Dumaresq River was connected at the two sites visited in October 2009, but Site 1 was gaining and Site 2 was losing to the alluvial aquifer. The surface water and groundwater chemistry indicated that the river reach received some old regional groundwater discharge. Thus, the Dumaresq River is considered to be either a gaining or a flow-through system at the regional scale, at the study reach. The gaining transect had significant bank recharge–discharge cycles during floods but the losing transect was apparently consistently losing (Lamontagne et al., 2011b).

In summation, there is some useful detailed information on connectivity in the Gwydir subregion available for specific locations, however details are lacking in many areas and available information appears contradictory in places. This is likely to be due to variations in study site locations, and climate and rainfall patterns at the time of the studies.

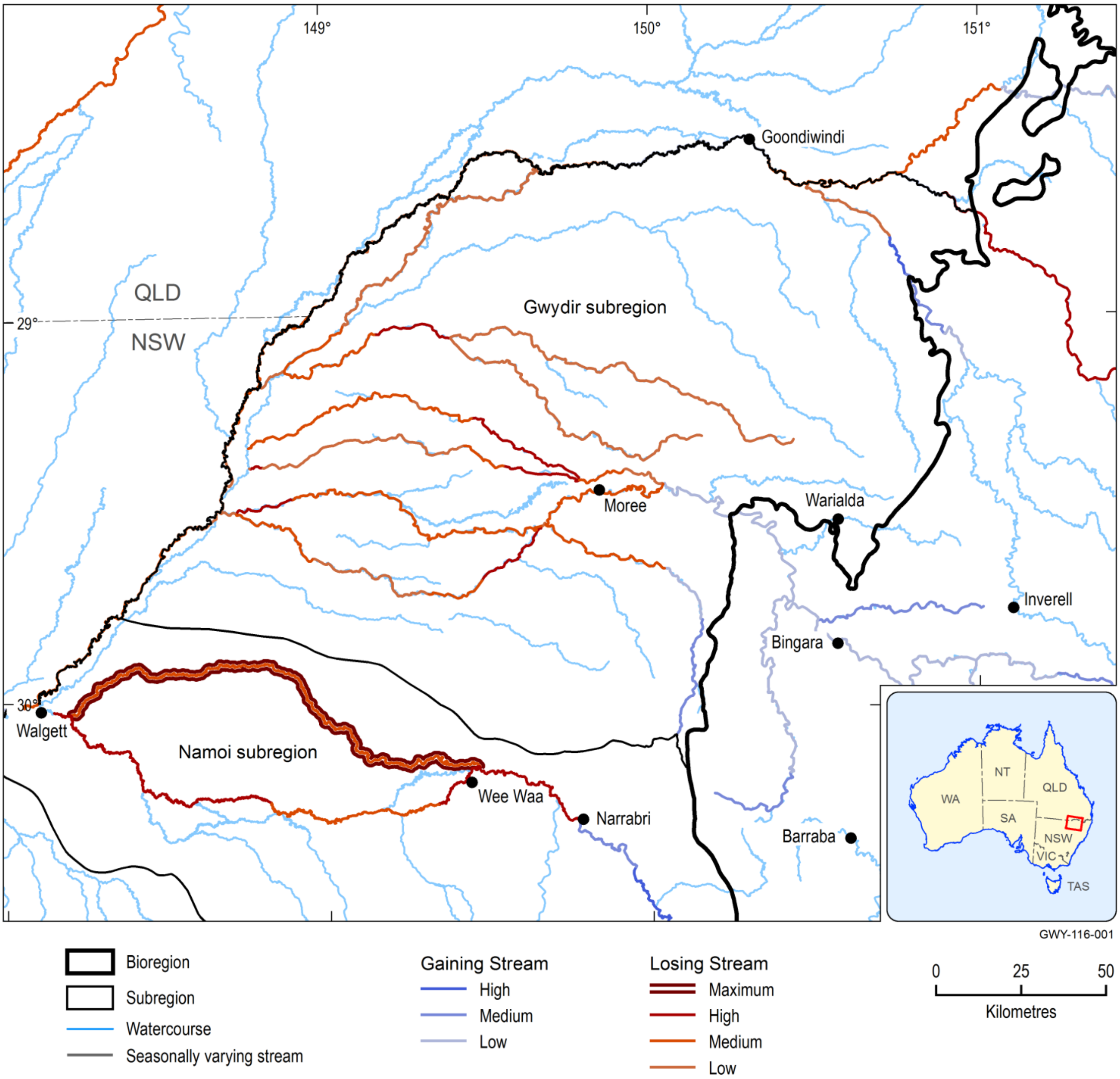

Figure 30 Surface water – groundwater connectivity in the Gwydir subregion. Note that many streams are not classified

Source: modified from Figure 6-2 in CSIRO (2007a) and Figure 6-2 in CSIRO (2007b)
Maximum losing conditions occur where the watertable is separated from the streambed by an unsaturated zone. The additional classification of high, medium or low losing for these reaches refers to the flux from streambed to watertable.

1.1.6.2 Impact of future developments

The impact and uncertainty associated with potential future development of farm dams and plantation forestry on surface water – groundwater interactions were assessed by CSIRO (2007a, 2007b). This impact was considered to be relatively small in the Border Rivers and Gwydir river basins.

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1.1.7 Ecology

Summary

The Gwydir subregion predominately covers two distinct landform types: slopes in the east and plains in the west. There are three Interim Biogeographic Regionalisation of Australia regions within these landforms: Brigalow Belt South, Nandewar and Darling Riverine Plains, that provide a diversity of important habitats for the biota of the subregion. The vegetation communities of the Gwydir slopes are mostly fragmented remnants of forest, grading into woodland further west. The dominant native vegetation across the plains consists of floodplain woodlands and small areas of native grasslands of Mitchell grass and plains grass. The Gwydir subregion is home to numerous threatened species and ecological communities listed under NSW and Commonwealth legislation. These include: amphibians (1 species), mammals (18 species), reptiles (5 species), birds (36 species), and plants (27 species). Among the ten threatened ecological communities, the Coolibah – Black Box Woodlands and marsh club-rush sedgelands tend to occur along floodplain habitats.

The subregion contains approximately 1600 km^2 of seasonal, semi-permanent and permanent wetlands and lagoons, some of which are internationally recognised under the Ramsar List of Wetlands of International Importance. The majority of these wetland systems included in the area are collectively referred to as the Gwydir Wetlands, formed from an inland delta of several rivers to the west of the township of Moree. These wetlands are highly modified by agricultural development and water management, and an allocation of environmental water flows is currently in place to help maintain and restore wetland water requirements. The Gwydir Wetlands are recognised as a refuge for waterbirds in dry times and have been known to support some of the largest waterbird breeding colonies recorded in Australia. Several of these bird species are listed as threatened under NSW and Commonwealth legislation as well as international migratory bird agreements. The wetlands also provide habitat for many types of frogs, fish and insects that, in turn, are food for the nesting waterbirds. The aquatic ecological community of the Gwydir Wetlands, which is part of the natural drainage system of the lowland catchment of the Darling River, is listed under the *New South Wales Fisheries Management Act 1994* as an endangered ecological community, and includes five threatened fish species.

1.1.7.1 Terrestrial ecosystems

The dominant land use in the Gwydir subregion is agriculture based around a mixture of cropping and grazing (Figure 9).

The eastern half of the Border Rivers and Gwydir river basins comprises the ranges and foothills of the Great Dividing Range with elevations from 1500 m to 500 m. The western regions of these river basins comprise flat alluvial plains characterised by numerous anabranches and effluents where the elevation is less than 200 m. There are three distinct landform types across the former Border Rivers-Gwydir Catchment Management Authority area: the tablelands in the east, the slopes further inland and the plains in the western portion. The tablelands are mostly upstream of the Gwydir subregion. The climate grades from temperate (cooler and wetter) in the east of the river basins, to subtropical (hotter and drier) in the west.

The Gwydir – Border Rivers region includes four Interim Biogeographic Regionalisation of Australia (IBRA) regions (OEH, 2011): New England Tablelands, Brigalow Belt South, Nandewar and Darling Riverine Plains. The Gwydir subregion largely excludes the tablelands in the east and excludes all of the Queensland portion of the Border Rivers river basin. The focus of this report is the ecology of the slopes and plains. Table 16 provides a brief overview of the major landforms and biodiversity values across the three IBRA regions that are in the Gwydir subregion.

Table 16 Brief description of the Interim Biogeographic Regionalisation of Australia bioregions occurring in the Gwydir subregion

IBRA bioregion	Landform	Biodiversity values
Brigalow Belt South IBRA subregion	Landscapes derived from extensive basalt flow and quartz sandstones, variable soils and vegetation types.	Supports a variety of forests and woodlands including a number of threatened ecological communities, plant and animal species.
Darling Riverine Plains IBRA subregion	Occupies most of the upper catchment of the Darling and Barwon rivers in northern NSW and southern Queensland and includes the channels and floodplains of the lower reaches of these catchments.	River channels support red gum communities with coolibah and black box communities on floodplains. The bioregion contains 19 plant species and 63 animal species listed under state threatened species legislation.
Nandewar IBRA subregion	Formed on Paleozoic sedimentary rocks on the western edge of the New England Tablelands and includes the Tertiary basalts of Inverell and Kaputar.	The bioregion is characterised by box woodlands and includes 18 plant and 51 animals species listed under state threatened species legislation.

Source data: SEWPaC (2012)

The vegetation communities of the slopes are mostly fragmented remnants of forest grading into woodland further west. Species include white box (*Eucalyptus albens*), rough barked apple (*Angophora floribunda*), mugga ironbark (*Eucalyptus sideroxylon*), grey box (*Eucalyptus microcarpa*), forest red gum (*Eucalyptus tereticornis*) and kurrajong (*Brachychiton* spp.). Extensive areas of the plains region have been cleared for agriculture and the native remnant vegetation is influenced by floodplains and alluvial fans (Green et al., 2012; Green et al., 2011). The dominant native vegetation across the plains consists of floodplain woodlands of coolibah (*Eucalyptus coolibah*) with occasional myall (*Acacia papyrocarpa*) and belah (*Casuarina cristata*). The plains previously supported extensive areas of native grasslands of Mitchell grass and plains grass, and small fragments can still be found on the plains south-west of the township of Moree. Other communities occurring on the higher parts of the floodplain include poplar box woodlands (*Eucalyptus populnea*), wilga (*Geijera parviflora*), brigalow (*Acacia harpophylla*), white cypress (*Calitris columellaris*) and silver leaf ironbark (*Eucalptus melanophloia*) (Border Rivers-Gwydir CMA, 2007).

The western portions of the Border Rivers and Gwydir river basins contain approximately 1600 km^2 of seasonal, semi-permanent and permanent wetlands and lagoons, some of which are internationally recognised under the Ramsar List of Wetlands of International Importance (Green et al., 2012; Green et al., 2011) (Figure 31). There are numerous protected areas covered by local and state reserve systems within the Gwydir subregion (Department of the Environment, 2010) and no national parks. Invasive species were recognised as the key problem in the Border Rivers-Gwydir river basin in a 2007 to 2008 survey. Invasive biota recognised as a major or moderate problem included environmental weeds, introduced animal pests, crop weeds and native pests (Marsh, 2010).

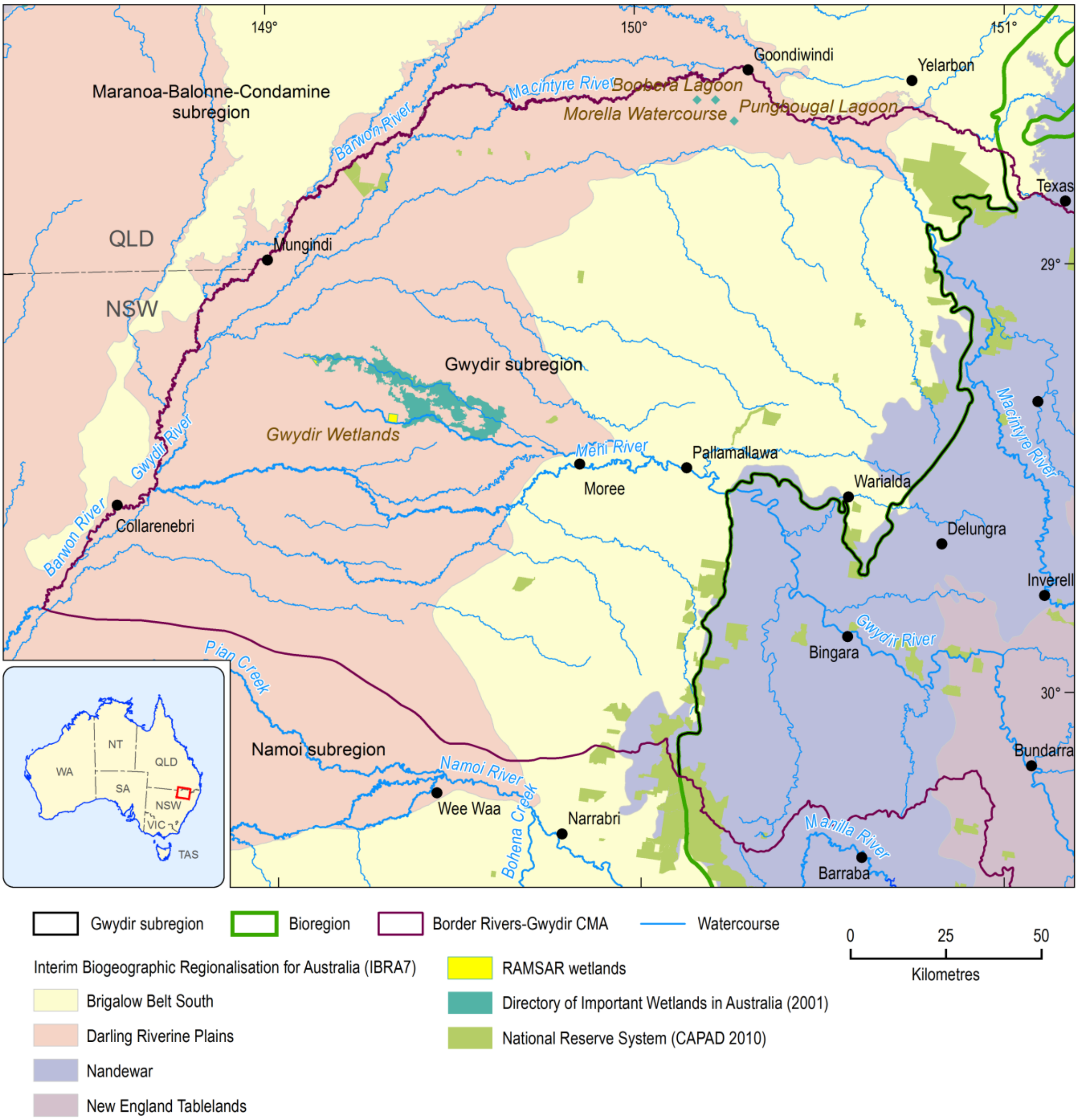

Figure 31 Major river systems, Interim Biogeographic Regionalisation of Australia regions, and nationally and internationally recognised wetlands in the Gwydir subregion

Source data: Department of the Environment (2013b) © Commonwealth of Australia 2013

1.1.7.1.1 Matters of state, national and international environmental significance

There are many state and nationally listed threatened species found in the subregion listed under the *New South Wales Threatened Species Conservation Act 1995,* and the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The state listed species include amphibians (one species), mammals (19 species), reptiles (five species), birds (37 species), fish (four species) and plants (28 species). The six species listed as endangered under the *EPBC Act* include the regent honeyeater (*Xanthomyza phyrgia*), Australian painted snipe (*Rostratula australis*), spot-tailed quoll (*Dasyurus masculatus asculatiusm* (*s lat.*)), Lake Keepit hakea (*Hakea pulvinifera*) and *Tylophora linearis*. An additional 23 species are listed as vulnerable under the *EPBC Ac*t. Table 17 documents the ten threatened ecological communities of the Gwydir subregion under the *New South Wales Threatened Species Conservation Act 1995*, the majority of which are also listed under the Commonwealth's EPBC Act. Current threats to the existing extent and condition of these communities include land clearing, effects from weeds and feral animals, grazing by domestic livestock and the effects of fertiliser. Details on nationally and internationally significant aquatic ecosystems are described in the next section.

Table 17 Threatened ecological communities of the Gwydir subregion listed under the *NSW Threatened Species Conservation Act 1995* and/or the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

Community	Commonwealth status	Description
Brigalow within the Brigalow Belt South bioregion	Endangered	Low woodland or forest community dominated by brigalow *(Acacia harpophylla*), with pockets of belah *(Casuarina cristata*) and poplar box *(Eucalyptus populnea* subsp. *bimbil*).
Coolibah - Black Box Woodland	Endangered	Semi-arid to humid subtropical woodland where coolibah *(Eucalyptus coolibah* subsp. *coolibah*) and/or black box *(Eucalyptus largiflorens*) are the dominant canopy species and where the understorey tends to be grassy. The ecological community is associated with the floodplains and drainage areas.
Cadellia pentastylis (Ooline) community in the Nandewar and Brigalow Belt South Bioregions	Not listed	An unusual and distinctive forest community with the canopy dominated by the tree Ooline (*Cadellia pentastylis*). Other canopy species include White Box (*Eucalyptus albens*), Ironbarks (*E. beyeriana* and *E. melanophloia*), Dirty Gum (*E. chloroclada*), Narrow-leaved Grey Box (*E. pilligaensis*), Green Mallee (*E. viridis*) and White Cypress Pine (*Callitris glaucophylla*). The understorey is made up of a range of shrubs, such as Wattles (*Acacia* spp.), and grasses.

Community	Commonwealth status	Description
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions	Not listed	Exists as woodland or as remnant trees. Characteristic tree species are Carbeen (*Corymbia tessellaris*) and White Cypress Pine (*Callitris glaucophylla*). Associated trees include *Corymbia dolichocarpa, Eucalyptus populnea, E. camaldulensis, Casuarina cristata* and *Allocasuarina leuhmannii.*
Inland Grey Box (*Eucalyptus microcarpa*) woodland	Not listed	Woodlands in which the most characteristic tree species, inland grey box *(Eucalyptus microcarpa*), is often found in association with bimble or poplar box *(Eucalyptus populnea* subsp. *bimbil*), white cypress pine *(Callitris glaucophylla*), kurrajong *(Brachychiton populneus*), bulloak *(Allocasuarina luehmannii*) or yellow box *(Eucalyptus melliodora*), and sometimes with white box *(Eucalyptus albens*).
Marsh club-rush sedgeland	Not listed	Dense stands of marsh club-rush *(Bolboschoenus fluviatilis*) up to 2 m tall. Understorey species include tussock sedge *(Carex appressa*), ribbed spike rush *(Eleocharis plana*), blown grass *(Lachnagrostis filiformis*), water couch *(Paspalum distichum*) and swamp buttercup *(Ranunculus undosus*).
Natural grasslands on basalt and fine-textured alluvial plains of northern NSW and southern Queensland	Critically endangered	Temperate grasslands are typically dominated by tussock grasses in the genera *Austrodanthonia, Austrostipa, Bothriochloa, Chloris, Enteropogon,* or *Themeda.* Representatives of these genera, as well as temperate grassland forbs, are present to some extent throughout the ecological community.
Semi-evergreen Vine Thicket in the Brigalow Belt South and Nandewar Bioregions	Endangered	A low, dense form of dry rainforest generally less than 10 m high, made up of vines and rainforest trees as well as some shrubs.
Weeping Myall woodland	Endangered	Low woodland and low open woodland to low sparse woodland or open shrubland. The tree layer grows up to a height of about 10 m and invariably includes weeping myall or boree *(Acacia pendula*) as one of the dominant or only tree species present.

Community	Commonwealth status	Description
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Critically endangered	Dominance of white box *(Eucalyptus albens*), yellow box *(Eucalyptus melliodora*) or Blakely's red gum *(Eucalyptus blakelyi*) trees and a species-rich understorey of native tussock grasses, herbs and scattered shrubs.

Source data: NSW Department of Environment and Heritage (2013a) and Department of the Environment (2013a)

1.1.7.2 Aquatic species and communities

1.1.7.2.1 Gwydir Wetlands

The Gwydir Wetlands are located on the Lower Gwydir floodplain and consist of a mosaic of wetland types, ranging from semi-permanent marshes and waterholes to floodplain woodlands only inundated by large floods (Torrible et al., 2008). Just east of the township of Moree, the Gwydir floodplain begins to broaden and forms an inland delta with the floodplains of the Barwon-Macintyre valley and Namoi valley to the south. This area covers approximately 102,000 ha (Rogers and Ralph, 2011) and is collectively referred to as the Gwydir Wetlands. It comprises three regions: Gingham Watercourse, Lower Gwydir Watercourse and Mehi, Mallowa and Moomin system (Figure 29). These wetlands are highly modified by agricultural development and water management but retain high ecological values (NSW DECCW, 2011). Environmental water is being provided to the Gwydir Wetlands to support the ongoing restoration of native wetland plant communities and maintain habitat for native animals (NSW DECCW, 2011).

Portions of the Gwydir Wetlands are listed under the Ramsar List of Wetlands of International Importance as they provide a good example of an inland terminal wetland delta system (Figure 29), support a large assemblage of species (including threatened species), are important for maintaining diversity, support many species at important life stages and can sustain large numbers of breeding colonial waterbirds when flooded (Table 18). They include the Windella, Crinolyn, Goddard's Lease and Old Dromana wetlands. The Gwydir Wetlands are also listed in the *Directory of Important Wetlands in Australia* (Environment Australia, 2001) and support a diverse assemblage of rare, endangered and vulnerable species, and when flooded, sustain large numbers of waterbird breeding colonies (see Table 18).

The wetlands contain native plant communities such as marsh club-rush sedgeland and water couch (*Paspalum distichum*), which are inundated frequently by overbank flooding from many small channels. River cooba (*Acacia stenophylla*) and lignum (*Muehlenbeckia florulenta*) are common in and around the margins of the core wetlands (Bowen and Simpson, 2010; Keyte, 1994). On the floodplain, coolibah - black box woodlands fringe the wetlands and form extensive woodlands in a number of areas (Bowen and Simpson, 2010; Keyte, 1994). These plants have many of their natural processes, such as flowering, seeding and germination, determined by the amount of water that is available to them (NSW DECCW, 2011).

Gwydir Wetlands are recognised as a refuge for waterbirds in dry times, and for supporting some of the largest waterbird breeding colonies recorded in Australia. They include species listed as threatened both under NSW and Commonwealth legislation (Table 18), and species listed on international migratory bird agreements (Spencer, 2010). The key habitats for waterbird breeding in the Gwydir Wetlands are floodplain waterholes, in-channel lagoons and floodplain wetlands. These habitats comprise marsh club-rush sedgelands, stands of cumbungi/bulrush (*Typha* spp.), lignum, belah (*Casuarina cristata*), coolibah (*Eucalyptus coolibah*) and river red gum (*Eucalyptus camaldulensis*). Feeding habitats include floodplain waterholes, in-channel lagoons and floodplain areas with freshwater meadows, sedgelands and stands of cumbungi (Spencer, 2010). Colonially nesting species are prominent, and the great egret, intermediate egret, little egret, Nankeen night heron, glossy ibis, Australian white ibis, straw-necked ibis, little pied cormorant and little black cormorant breed in large numbers. Colonially nesting waterbirds need flooding of sufficient volume and duration to inundate colony sites and feeding areas for at least four to five months between August and April (Marchant and Higgins, 1990, 1993).

The wetlands also provide habitat for many types of frogs, fish and insects that, in turn, are food for the nesting waterbirds (Table 18). The aquatic ecological community of the Gwydir Wetlands, which is part of the natural drainage system of the lowland catchment of the Darling River, is listed under the *New South Wales Fisheries Management Act 1994* as an endangered ecological community (Table 18). This listing includes all native fish (all 21 species) and aquatic invertebrates within the natural rivers, creeks, lagoons, billabongs, wetlands, lakes, tributaries and anabranches across the Gwydir Wetlands (Green et al., 2011). Threats to the ecological character of the Gwydir Wetlands Ramsar site include reduced frequency and duration of flooding, invasive plant species such as lippia and water hyacinth, feral animals including foxes, pigs and cats, and pesticide contamination (Department of the Environment, 1999).

1.1.7.2.2 Lower Macintyre River Wetlands

In the Border Rivers river basin; Morella Lagoon, Pungbougal Lagoon and Boobera Lagoon are part of a wetland complex found along a remnant channel of the previous course of the Macintyre River. Boobera Lagoon is one of the few naturally permanent water bodies in the Murray–Darling Basin. The lagoons are fringed by riparian woodland of river red gum and coolibah and are listed under the *Directory of Important Wetlands in Australia* (Environment Australia, 2001).

1.1.7.2.3 Groundwater-dependent ecosystems

The Gwydir subregion contains a diverse range of groundwater-dependent ecosystems, including wetlands, terrestrial vegetation, and instream ecosystems fed by baseflow and springs. The alluvial groundwater management areas of the plains have the highest yield and provide significant irrigation requirements (NSW Department of Environment and Heritage, 2010). The majority of the groundwater-dependent ecosystems identified from field mapping are centred around the Gwydir and Lower Macintyre River wetland and floodplain systems (Bureau of Meteorology, 2013), although the NSW State of the Catchments report noted that there was limited knowledge on the location of groundwater-dependent ecosystems within the Border Rivers-Gwydir river basins, especially for terrestrial ecosystems (NSW Department of Environment and Heritage, 2010). The main pressures on groundwater resources across the subregion are river regulation and agriculture. River regulation has altered the natural river behaviour and the surface water – groundwater interaction with the river system. Agriculture has altered the amount of water that leaks through the root zone from rainfall and through irrigation (NSW Department of Environment and Heritage, 2010).

Table 18 List of threatened communities and species associated with the Gwydir Wetlands

Category	State listed threatened species and communities	Nationally listed threatened species and communities
Communities	Marsh club-rush sedgeland Aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River	Coolibah – black box woodlands
Plants	Braid fern (*Platyzoma microphyllum*)	
Birds	Magpie goose (*Anseranas semipalmata*) Brolga (*Grus rubicunda*) Blue-billed duck (*Oxyura australis*) Black-necked stork (*Ephippiorhynchus asiaticus*) Grey-crowned babbler, eastern subspecies (*Pomatostomus temporalis temporalis*) Hooded robin, south-eastern form (*Melanodryas cucullata cucullata*) Brown treecreeper, eastern subspecies (*Climacteris picumnus victoriae*) Bush stone-curlew (*Burhinus grallarius*) Glossy black-cockatoo (*Calyptorhynchus lathami*) Square-tailed kite (*Lophoictinia isura*) Diamond firetail (*Stagonopleura guttata*) Grey falcon (*Falco hypoleucos*)	Australian painted snipe (*Rostratula australis*) Australasian bittern (*Botaurus poiciloptilus*)
Reptiles		Five-clawed worm-skink (*Anomalopus mackayi*)
Fish and invertebrates	River snail (*Notopala sublineata*) Silver perch (*Bidyanus bidyanus*) Purple spotted gudgeon (*Mogurnda adspersa*) Olive perchlet (*Ambassis agassizii*)	Murray cod (*Maccullochella peelii*)

Source data: NSW Department of Environment and Heritage (2013b), NSW Department of Primary Industries (2013), Department of the Environment (2013a)

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www.bioregionalassessments.gov.au

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