Australian Government

BIOREGIONAL ASSESSMENTS

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

Context statement for the Central West subregion

Product 1.1 for the Northern Inland Catchments Bioregional Assessment

29 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>.

Department of the Environment

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

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Authorship is listed in relative order of contribution.

Cover photograph

Macquarie Marshes, on the north-western end, between Carinda and Warren, NSW

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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.

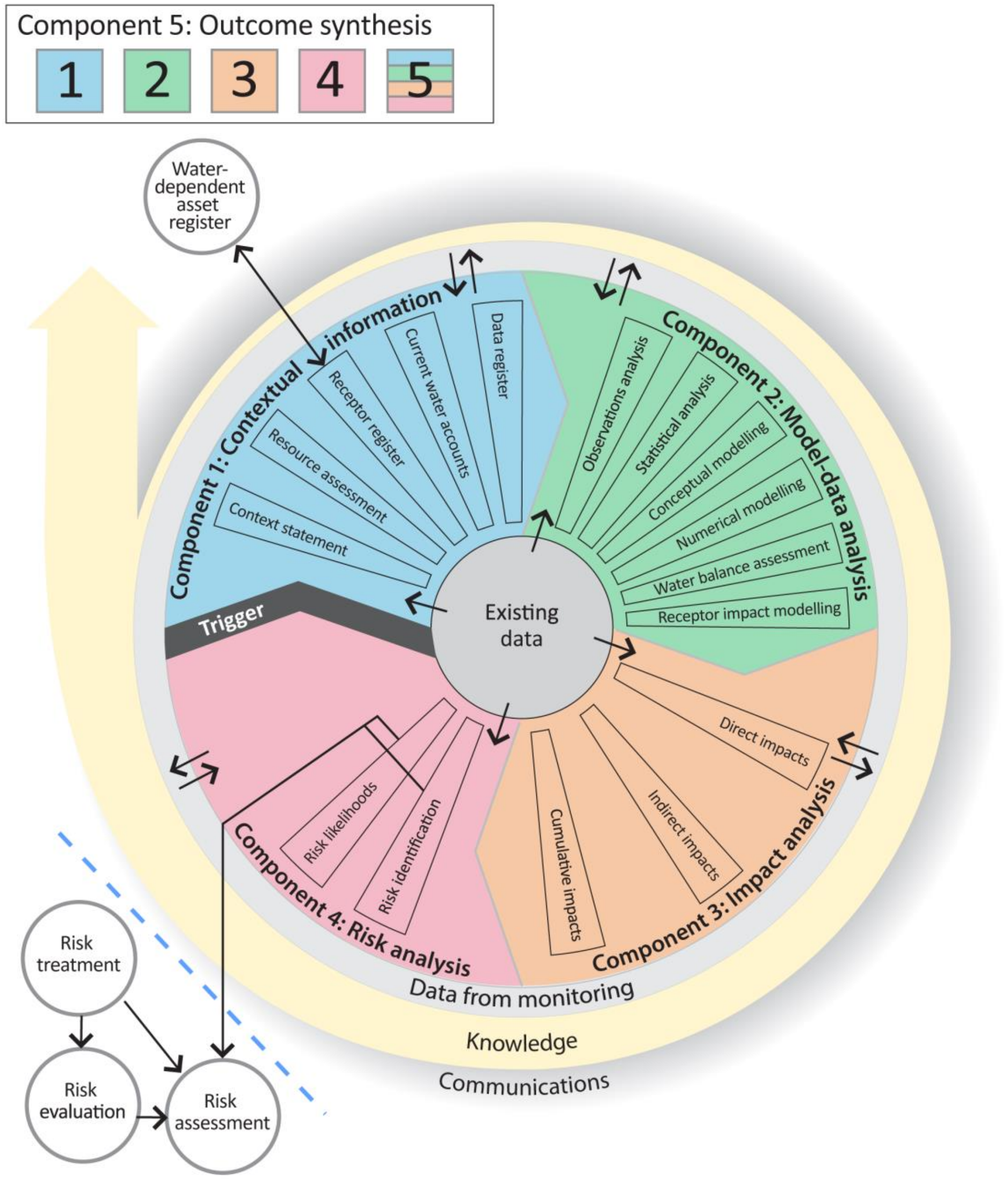

Figure 1 Schematic diagram of the bioregional assessment methodology

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 2shows 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°.

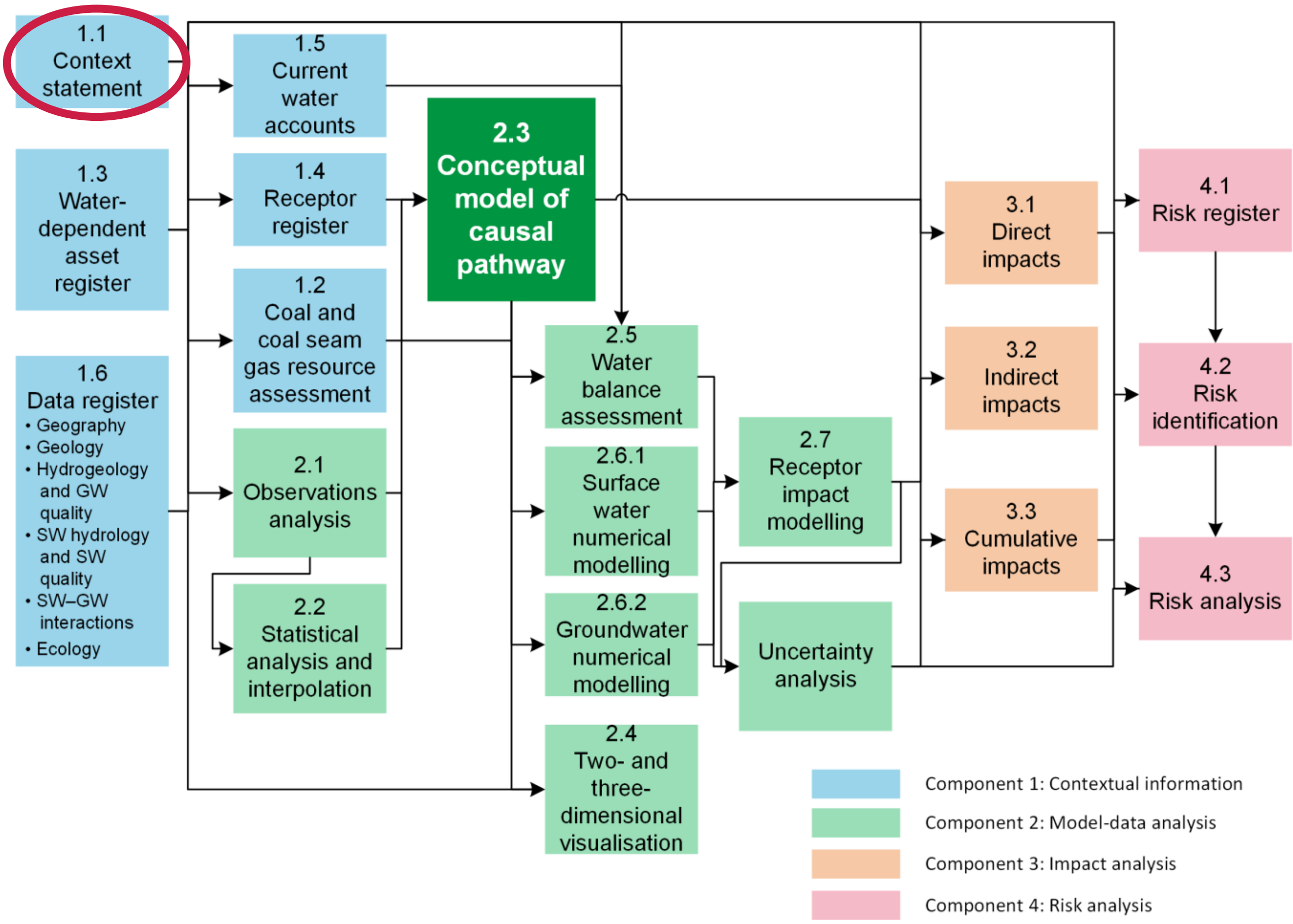

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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 Central West 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 Central West 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 Central West 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 Central West 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 29 August 2014, <http://www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.

1.1 Context statement for the Central West 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 and coal seam gas 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 Central West 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 NSW 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 Central West subregion boundary was the same as the NSW Central West Catchment Management Authority boundary[1] over the extent of the coal-bearing geological basins. The north-eastern boundary approximately follows the boundary between the Namoi river basin, outside the subregion, and the Castlereagh river basin, inside the subregion (Figure 28). East to west, the southern boundary follows the top of the Great Dividing Range across the geological Sydney Basin, then follows the southern extent of the geological Surat and Gunnedah basins. The western boundary follows the extent of the geological Surat Basin (Figure 16).

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[1] The Central West Local Land Services replaced the Central West Catchment Management Authority over the Central West 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.

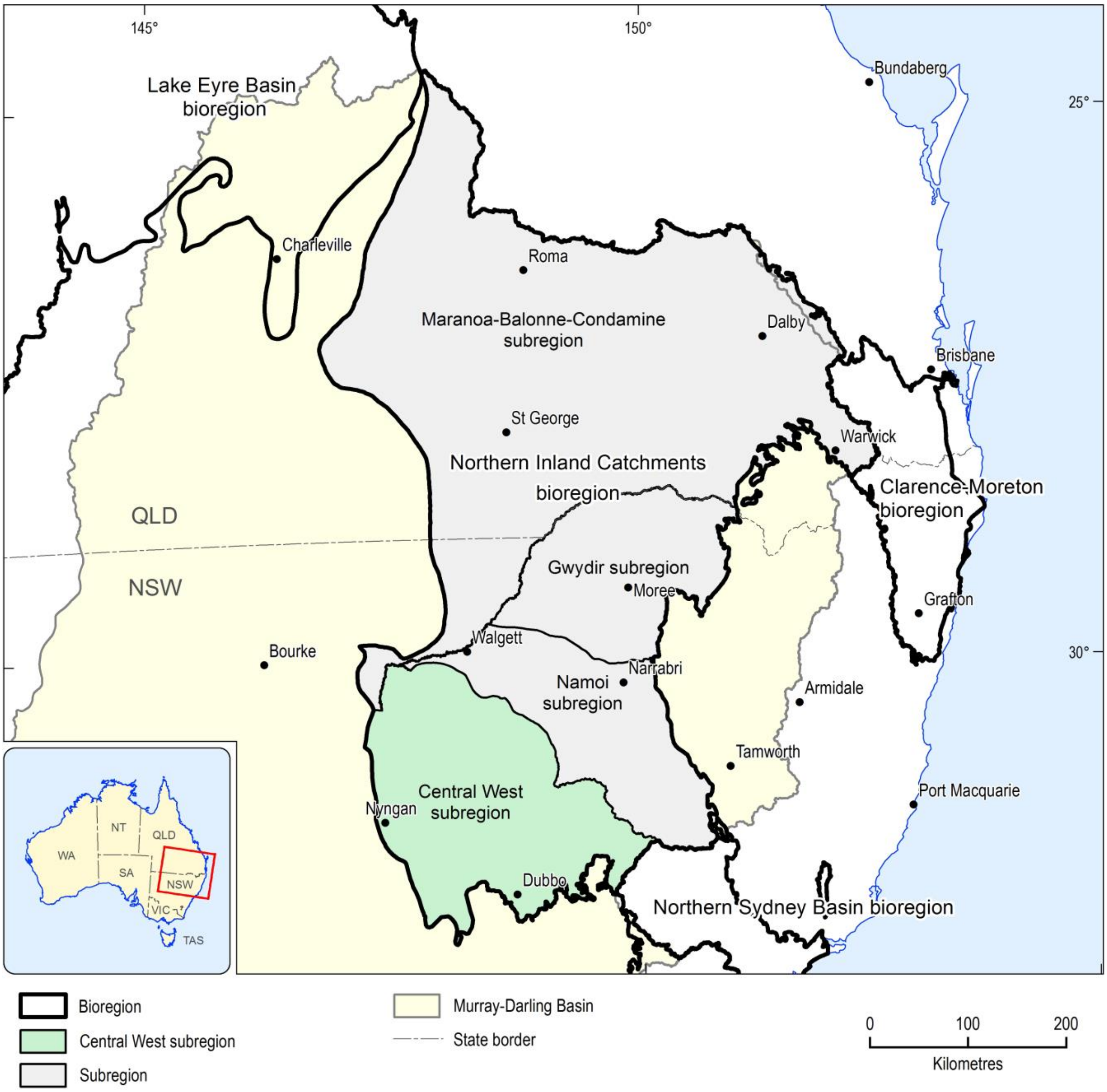

Figure 3 Northern Inland Catchments bioregion and subregions

1.1.2 Geography

Summary

The Central West subregion, of the Northern Inland Catchments bioregion, is located within the Murray–Darling Basin (MDB) in central NSW. It spans an area of 46,735 km^2, extending from the plains around Dubbo across the low-lying alluvial plains of the Macquarie and Castlereagh river systems north-west to the Barwon River floodplains. Maximum and minimum elevations for the subregion itself are 1235 and 95 mAHD in the Warrumbungle Ranges and near Brewarrina, respectively.

The main rivers draining the subregion are the Macquarie, Castlereagh and Bogan rivers. The headwaters of the Macquarie River, including the Cudgegong river basin and the Burrendong, Ben Chifley and Windamere dams that regulate river flows in the Macquarie river basin, lie outside the subregion. The southern part of the Bogan river basin is also outside the subregion. The subregion's most significant water-dependent asset is the Macquarie Marshes, located toward the lower end of the river basin. There are very few wetlands in the Castlereagh river basin, but woodlands and shallow wetland complexes occur on some of the effluents in the lower river basin.

The dominant soils on the Upper Darling Plains and Cobar Plains are grey and brown Vertosols and red Chromosols. 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. The main land and soil hazards in the subregion are soil salinity and waterlogging, structural decline, carbon decline, acidification 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, 2010a). However soil acidification is widespread in the Dubbo-Coonabarabran area (NSW OEH, 2013a).

The subregion has undergone significant modification of its land cover, with an estimated 62% of the land cleared of native vegetation. Much of the remnant vegetation occurs as a large number of small, isolated patches on the less fertile and productive soils and a smaller number of scattered larger reserved remnants. The 2010 State of the Catchment report for the Macquarie, Castlereagh and Bogan river basins (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 agriculture. Intensive uses and irrigated agriculture and plantations have small, localised impacts around Dubbo and along the Macquarie River between Dubbo and the Macquarie Marshes. NSW recognises eight endangered ecological communities in the Central West subregion, five of which are listed as endangered and one as critically endangered under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*.

The subregion has a mean annual rainfall of 520 mm (1900 to 2011) and is characterised by hot summers and mild winters.

Dubbo is the major population centre for the subregion with a population of about 40,000. Coonabarabran, Coonamble, Gilgandra and Nyngan are smaller population centres within the subregion. Approximately 30% of the employed community outside of Dubbo works in the agriculture sector (ABS, 2011). The gross value of agricultural production in the Central West region in 2010 to 2011 was estimated at $1.37 billion. Regional tourism is also significant and the reported $1.13 billion in 2011 is from a much larger area than the subregion; perhaps a quarter to one-third of this could be attributed to the subregion.

1.1.2.1 Physical geography

The Central West subregion of the Northern Inland Catchments bioregion is located within the Murray–Darling Basin (MDB) in central NSW. To the north, it is bounded by the Namoi subregion and a small section of the Maranoa-Balonne-Condamine subregion to the north-west. It abuts the Hunter subregion to the east (Figure 3). The southern and western boundaries of the subregion correspond to the aquifer extents of the Oxley Basin, Great Artesian Basin, Great Artesian Basin Alluvial and Lower Macquarie Alluvium groundwater management areas, which is as far as the coal-bearing geology extends.

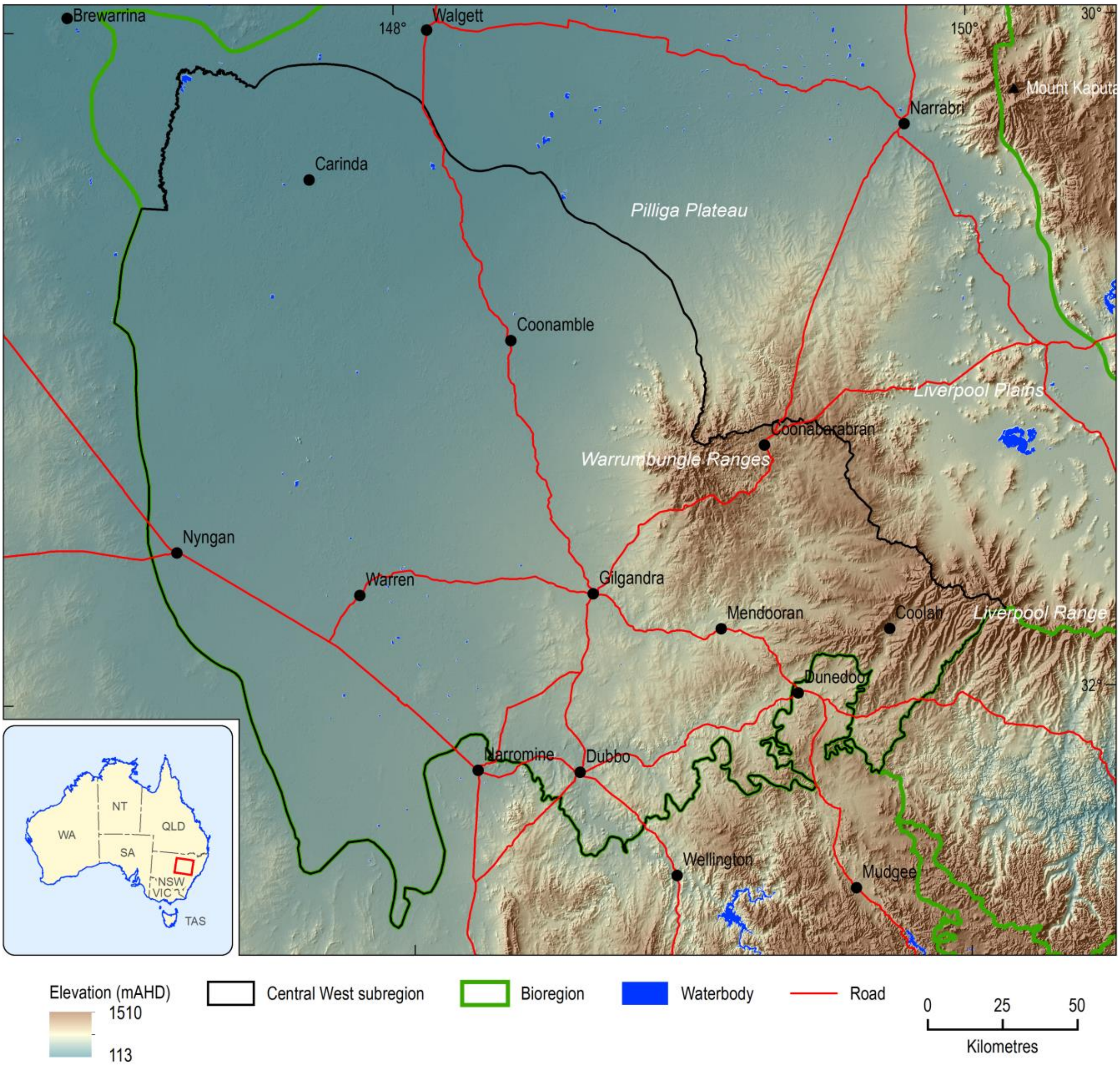

Figure 4 Topography of the Central West subregion, generated from three second digital elevation model (DEM)

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

The Central West subregion spans an area of 46,735 km^2. It extends from the plains around Dubbo across the low-lying alluvial plains of the Macquarie and Castlereagh river systems north-west to the Barwon River floodplains. Maximum and minimum elevations for the subregion are 1235 and 95 mAHD in the Warrumbungle Ranges (east of Coonabarabran) and near Brewarrina, respectively (Figure 4).

The Macquarie, Castlereagh and Bogan rivers are the main rivers draining the subregion. The Talbragar River joins the Macquarie River just downstream of Dubbo and is also within the subregion, including its headwaters around Coolah, west of the Hunter River divide. The headwaters of the Macquarie River, including the Cudgegong river basin and the Burrendong, Ben Chifley and Windamere dams that regulate river flows in the Macquarie river basin, lie outside the subregion. The southern part of the Bogan river basin is also outside the subregion.

The Macquarie River is formed by the joining of the Campbell and Fish rivers that drain a high plateau area near Oberon in the Great Dividing Range (Figure 4). The river flows northward through steep, confined valleys to Burrendong Dam upstream of Wellington. The Cudgegong River also flows into Burrendong Dam. Downstream of the dam, the Macquarie River continues in a north-west direction through Wellington, into the subregion near Dubbo and on to Narromine. It is joined by several major tributaries in this section. Beyond Narromine, a complex system of anabranches and distributary creeks connect the Macquarie, Darling and Bogan rivers. More detail on the surface hydrology can be found in Section 1.1.5. The subregion's most important water-dependent asset is the Macquarie Marshes, located toward the lower end of the subregion (Section 1.1.7, Figure 37).

The Castlereagh River rises in the Warrumbungle Ranges in the north of the subregion and flows east to Coonabarabran, then south to Binnaway, before sweeping around to the north-west where it enters the Macquarie River north of Carinda. It is unregulated and has no major storages. In its lower reaches, many smaller creeks combine with the Castlereagh to form an extensive floodplain that carries water from the Castlereagh to the Barwon River during floods. There are very few wetlands in the Castlereagh river basin, but woodlands and shallow wetland complexes occur on some of the effluents in the lower river basin.

Dubbo is the major population centre for the subregion with a population of about 40,000. Coonabarabran, Coonamble, Gilgandra, Narromine and Nyngan are smaller population centres within the subregion. Approximately 30% of the employed community outside of Dubbo works in the agriculture sector (ABS, 2011).

The subregion has a mean annual rainfall of 520 mm (1900 to 2011) and is characterised by hot summers and mild winters (see Section 1.1.2.3 for more details).

1.1.2.1.1 Physiographic regions

Physiographic regions are defined by a suite of landforms which have evolved in response to a 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 Central West subregion is dominated by the Upper Darling Plains physiographic region (Figure 5), which is characterised by branching rivers incised into a regolith of predominantly alluvial sediments (>50%) with minimal saprolite (<20%) (Pain et al., 2011). Saprolite refers to in situ weathered rock, whereas alluvial sediments indicate depositional environments, where the regolith comprises transported sediments. To the east of Gilgandra and taking in the Talbragar catchment is the Mitchell Slopes physiographic region. This is a transitional landscape from tablelands, stepping down the slopes and breaking into detached hills. The regolith is dominated by highly weathered bedrock and residual materials with smaller areas of moderately weathered bedrock. The Merriwa Plateau region around Coolah is characterised by rolling hills on a basalt upland with sandstone cliffs. The regolith is moderately weathered to highly weathered bedrock. The dissected volcanic outcrops of the Warrumbungle Peaks near Coonabarabran form a small physiographic region with a soil-on-bedrock regolith (Pain et al., 2011).

The shift from tableland and slopes regions to the floodplains of the Upper Darling Plains is associated with a change in the dominant soil types and native vegetation communities (see Section 1.1.2.1.2 and Section 1.1.2.1.3).

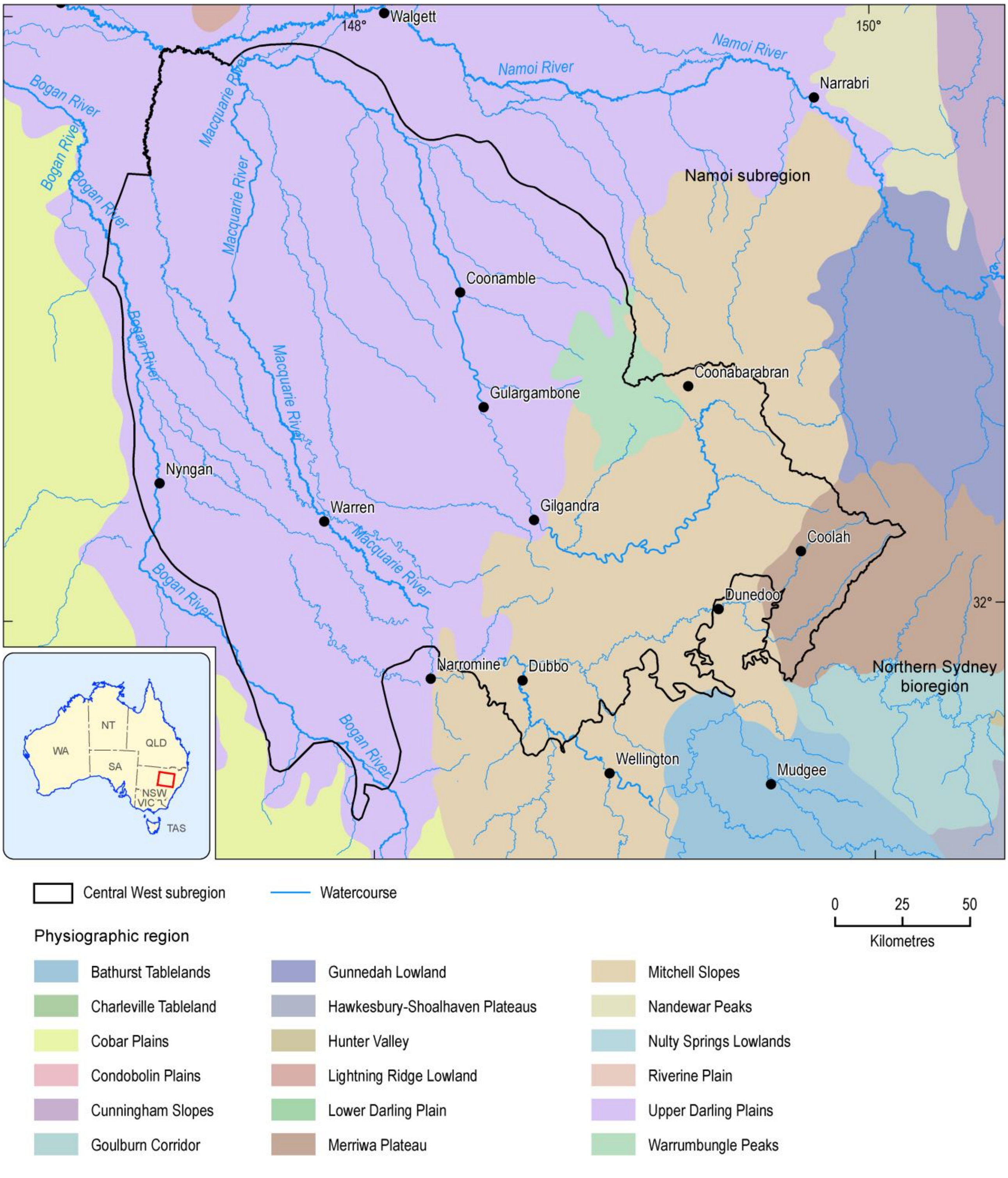

Figure 5 Physiographic regions of the Central West subregion

As defined in Pain et al. (2011)

1.1.2.1.2 Soils and land capability

The subregion comprises a wide range of soil types (Figure 6), but the dominant soils on the Upper Darling Plains and Cobar Plains are grey and brown Vertosols and red Chromosols (Australian Soil Classification system, Isbell, 2002) (Table 2). The Vertosols 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. Because Vertosols can be worked under a very narrow range of moisture conditions, they are better suited to irrigated crops such as cotton, wheat, sorghum and rice than rain-fed crops. Chromosols exhibit a strong texture contrast between the upper and lower horizons. They are among the most widespread soils used for agriculture in Australia, particularly those with red subsoils (Isbell, 2002). A narrow belt of Dermosols occur along the Macquarie channel, which have structured horizons at depth, but lack strong texture contrast between upper and lower horizons. They can be hard to differentiate from Vertosols. Other significant soils in the subregion are Sodosols (soils with strong texture contrast between the upper soil horizons and the lower sodic horizons) and Ferrosols (soils having high free iron and generally high clay content), both of which occur extensively in the Castlereagh and Talbragar catchments, and Tenosols (soils with weak pedologic organisation apart from the upper horizon) around Dubbo. Sodic soils have disproportionately high levels of sodium ions, which make them inherently unstable. They disperse readily in water and are, hence, highly erodible. They impede water infiltration, reduce water holding capacity, and ultimately limit plant growth.

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. In the most recent systematic state wide assessment of NSW soil health, commenced in 2008 under the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015 (NSW DECCW, 2010d), soil condition on the Lower Darling Plains and Cobar Plains was assessed as generally good (that is, a small loss of condition relative to a reference condition for a range of soil indicators), but on the Sodosols and red Chromosols of the Mitchell Slopes, soil condition was generally assessed as fair (that is, noticeable loss of soil function relative to a reference condition), with some indicators giving a poor rating (NSW DECCW, 2010b). The main land and soil hazards in the subregion are soil salinity and waterlogging, structural decline, carbon decline, acidification and wind erosion. Salinity reflects an accumulation of salt in the soil or on the ground surface, with the potential to cause profound terrestrial and aquatic ecosystem damage, including massive erosion. It is commonly associated with waterlogging and sodic soils, and is a problem in the region around Dubbo and towards Coonabarabran. Structural decline and carbon decline are issues for the Lower Darling Plains soils.

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, 2012). Figure 7 shows land and soil capability classifications for the Central West subregion based on the most limiting hazard. Much of the Upper Darling Plains is classed as land and soil capability Classes 2 and 3. Class 2 indicates very good cropping land with fertile soils and short, low slopes.

Limitations can be managed with readily available, easy to implement management practices. Class 3 is capable of supporting most land uses, but more intensive management practices are needed to avoid moderate-severity degradation from water erosion, wind erosion, soil acidification, salinisation, structural decline and/or loss of organic carbon. In the Warrumbungle and Liverpool ranges, land and soil capability Classes 5, 6 and 7 are more extensive, reflecting the steeper terrain. These lands can support a variety of low intensity land uses, such as grazing, forestry and nature conservation. On the Vertosols in the west of the region, significant areas of Class 6 and 7 lands reflect vulnerability to wind erosion. Highly specialised management practices can overcome some limitations to cropping on Class 5 land, but Classes 6 and 7 indicate low to very low capability land, best suited to light grazing, forestry and nature conservation (NSW OEH, 2012). In 2009, the former Central West Catchment Management Authority and the former NSW Department of Environment, Climate Change and Water assessed the extent to which land was being used within capability in the former Central West catchment management area. In the subregion, the majority of land is being used ‘at capability’, meaning that the risk of degradation under current land use and management is low (NSW DECCW, 2010a). However, acidification, the trend towards increasingly acid soils, caused by inappropriate management practices (for example from over-intensive use, allowing excessive leaching, overuse of nitrogen fertilisers and insufficient use of lime) is widespread in the Dubbo-Coonabarabran area (DECWW, 2010a).

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

ASC soil class	Percentage of total area of subregion (%)
Vertosols	41%
Chromosols	27%
Sodosols	14%
Ferrosols	5%
Tenosols	4%
Kurosols	3%
Kandosols	3%
Dermosols	2%
Rudosols	1%

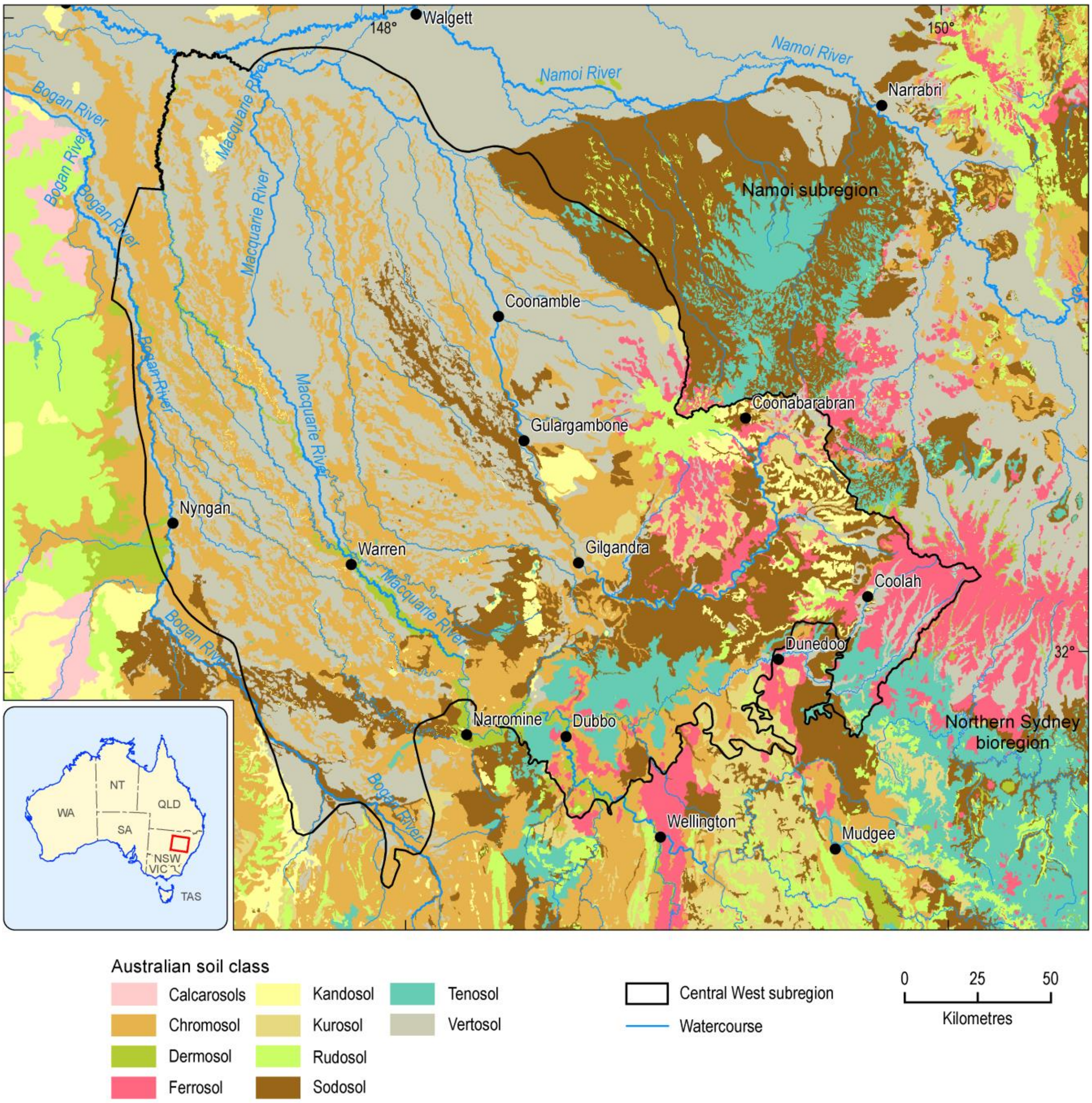

Figure 6 Soils classified using the Australian Soil Classification

Source data: National Soil Grids (ASRIS, 2011)

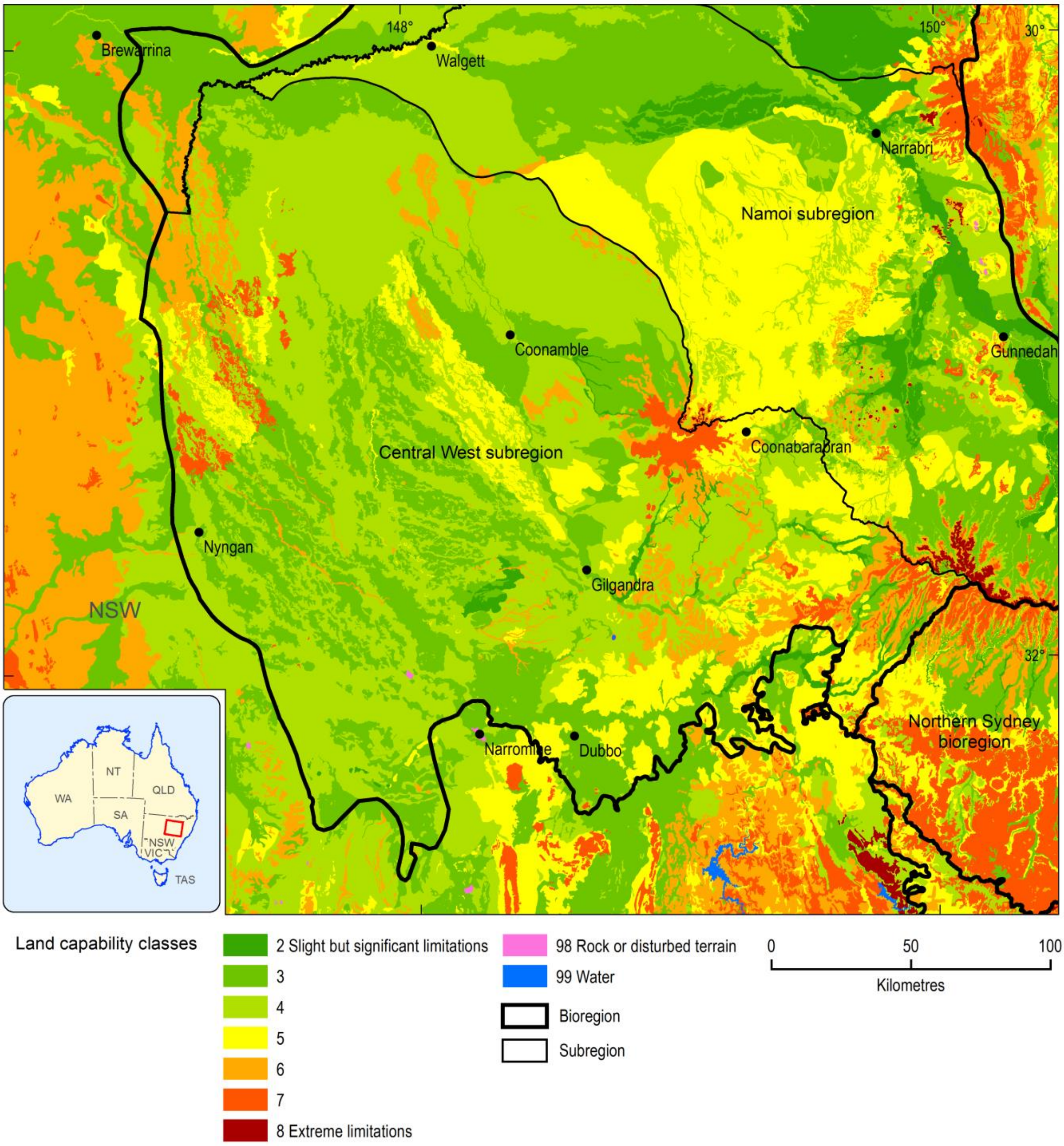

Figure 7 Land and soil capability

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 Enhance Vegetation Index (EVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Terra and Aqua satellites that are post-processed to convert vegetation greenness to a land cover type (Geoscience Australia, 2011b). In the area up-catchment of Dubbo, Gilgandra and Coonabarabran, there are extensive areas of open woodland and scattered trees among pasture lands. In the north and west, cropping and pasture lands dominate, with areas of scattered to sparse tree cover along distributary channels and in the Macquarie Marshes. Table 3 summarises the extents of different land cover types.

The region has undergone significant modification of its land cover, with an estimated 62% of the land cleared of native vegetation. This has included reducing much of the cover to a large number of small, isolated remnants on the less fertile and productive soils, and a smaller number of scattered larger reserved remnants (CW CMA, 2013). Across the subregion, there is a trend of increasing native vegetation cover from south-east to north-west (Goldney et al., 2007). 'Non-native' and 'native/non-native mosaic' land covers dominate the north-south swathe of land between Dubbo and Nyngan. 'Intact native' vegetation cover peppers this area but becomes more extensive and dominant in the north-west of the subregion (NSW DECCW, 2010c). There are sizable tracts of 'intact native' vegetation north-east of Dubbo and on the Warrumbungle Ranges around Coonabarabran, both of which are managed for conservation and not subject to severe pressures.

Table 3 Area and percentage of subregion for each land cover type in Central West subregion

Land cover class	Area (km^2)	Percentage of subregion (%)
Pasture and crops	23,436	50.1%
Trees – Sparse	14,672	31.4%
Trees – Open	5,580	11.9%
Tussock grasses	1,708	3.7%
Trees – Scattered	705	1.5%
Hummock grasses	247	0.5%
Shrubs	136	0.3%
Trees – Closed	147	0.3%
Inland water bodies and wetlands	71	0.2%
Chenopods	27	0.1%
Sedges	4	0.0%

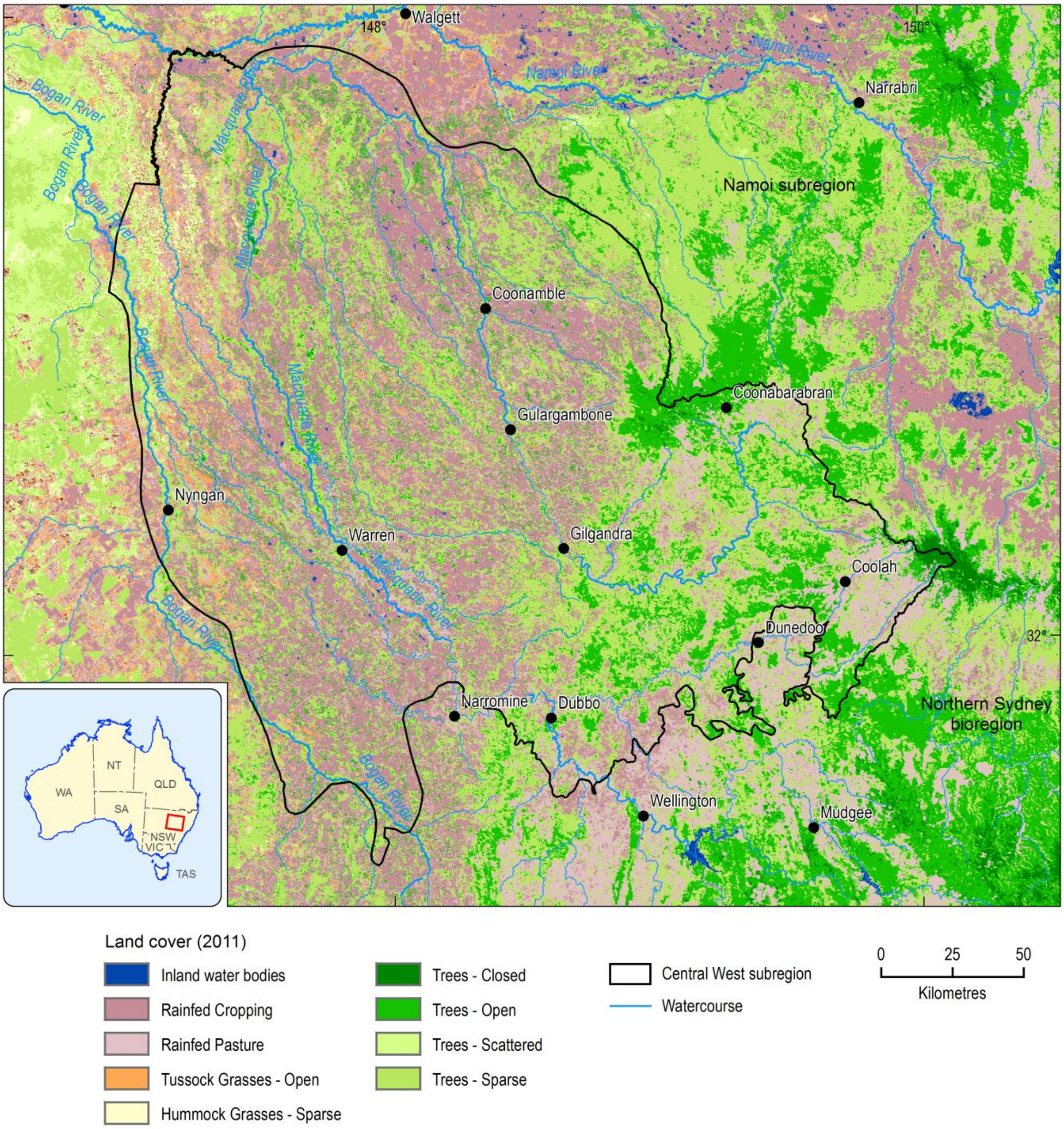

Figure 8 Land cover in the Central West subregion

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.

The 2010 State of the Catchment report for the Macquarie, Castlereagh and Bogan river basins (NSW DECCW, 2010c) rated the vegetation condition as fair and the pressures on land cover as moderate. Across the region, only 2% of land cover is deemed ‘residual’, referring to native vegetation community structure, composition and regenerative capacity that is intact and has not undergone significant perturbation from land use or land management practices. A further 25% of land cover is classified as ‘modified’, meaning native vegetation community structure, composition and regenerative capacity is intact, but the community has been perturbed by land use and management practices. The remaining 73% of the region comprises transformed and replaced land covers, which reflect varying degrees of modification that compromise the ability of the native vegetation cover to recover or re-establish. The main pressures on vegetation extent and condition come from dryland agriculture and plantations (76%). Intensive uses (2%) and irrigated agriculture and plantations (1%) have small, localised impacts around Dubbo and along the Macquarie River between Dubbo and the Macquarie Marshes.

Of the remnant vegetation, there are large areas of dry sclerophyll forest north of Dubbo dominated by box, red gum and ironbark trees with a sub-canopy of cypress pine. These forests are a southern extension of the Pilliga scrub community that have formed on alluvial sediments washed out from the surrounding sandstone ranges. The lower part of the Macquarie river basin is dominated by riverine and floodplain woodlands with river red gum trees along the watercourses and black box trees dominant on the floodplain (Green et al., 2011).

The subregion boasts the Macquarie Marshes, which span an area of 2000 km^2 of floodplain between Marebone Weir and Carinda in the north-west of the subregion. Owing to their size, diversity of wetland types, extent of wetland communities and large-scale colonial waterbird breeding events, they are nationally and internationally important. The southern marshes consist of a series of individual wetland systems, including Back, Buckiinguy, Monkey and Monkeygar swamps and Mole Marsh. The northern marshes consist of extensive areas of common reed and river red gum woodlands (CSIRO, 2008). The Ramsar listed part of the Marshes covers 19,850 ha and includes the Macquarie Marshes Nature Reserve plus two additional areas of private property land (NSW OEH, 2013b).

Eight endangered ecological communities, listed under the *NSW Threatened Species Conservation Act 1995*, occur within this subregion. On 13 August 2013, the wetlands and inner floodplains of the Macquarie Marshes were listed by the Commonwealth under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) as critically endangered. The EPBC Act also protects the critically endangered natural grasslands on basalt and fine-textured alluvial plains of northern NSW and southern Queensland that occur in the subregion. More information on the ecology of the subregion can be found in Section 1.1.7.

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 Central West subregion as the area does not align well with the more usual reporting areas (river basins, local government areas (LGAs), statistical local areas, etc.). The subregion contains significant parts of the Bogan, Coonamble, Dubbo, Gilgandra, Narromine, Walgett, Warren and Warrumbungle LGAs, with small segments of Wellington, Parkes, Lachlan, Mid-Western Regional, Upper Hunter and Brewarrina LGAs. The 2011 Population Census for the eight larger LGAs gives a combined population almost 79,000 people, of whom 51% (40,500) live in the Dubbo LGA. Coonabarabran (2575), Narromine (3790), Coonamble (2445), Gilgandra (2665) and Warren (1525) urban centre localities (ABS, 2011) account for another 9200 (12%). The population density varies from 11.8 persons/km^2 (Dubbo LGA) to 0.2 persons/km^2 (Bogan and Walgett LGAs).

In the Australian Bureau of Statistics (ABS, 2011) census, 12 to 14% of the population in the Dubbo, Gilgandra, Warren and Bogan LGAs indicated they were of Indigenous origin, with a slightly lower proportion (9%) in the Warrumbungle LGA. In Narromine, Walgett and Coonamble, Indigenous people comprise 20%, 28% and 30% of the population, respectively.

Results of a survey of economic sustainability and social wellbeing in the Macquarie, Castlereagh and Bogan river basins, taken as part of the NSW State of the Catchments reporting (NSW DECCW, 2010e), showed that economic sustainability and social wellbeing vary across the region. Respondents considered regional centres and the upper catchment (that is, outside of the subregion) to be faring well, while Indigenous communities were faring less well. There were concerns about the declining number of people in commercial agriculture (10% decline in employment between 1996 and 2006), the rising costs of farm inputs and reduced farm incomes and rural subdivisions impinging on agricultural land. Mining was seen as beneficial for the local economy, but creates greater competition for water and farm labour.

1.1.2.2.2 Economic activity

Approximately 32,450 people are employed in the eight main LGAs in the Central West subregion. Table 4 summarises the main sectors of employment for the subregion (based on national regional profile data by LGA (ABS, 2011)). 15% of the employed population work in agriculture[2], although if Dubbo town is excluded from the statistic, it is closer to 30% across the subregion. In Dubbo, health care and social services, retail, education and training and public administration and safety account for 44% of employment. These sectors account for 36% of employed people in the wider area. Mining accounts for 1.4% of regional employment.

The gross value of agricultural production in the Central West region in 2010 to 2011 was estimated at $1.37 billion, of which $117 million (8.5%) was from cotton, $555 million (40.5%) from cereal and legume crops and $513 million (37%) from livestock products and $67 million (5%) from oil seeds (ABS, 2012).

Regional tourism figures for the Central West region (DNSW, 2013) report that in 2012 visitors to the region brought in $1.136 billion. The reporting region for this figure is considerably wider than the subregion and includes Lachlan river basin and the Upper Macquarie catchment, in which towns like Bathurst, Orange, Mudgee and Cowra would command a significant proportion of that revenue. For the four years to September 2011, the Dubbo LGA averaged $175 million/year from visitors, Warrumbungle LGA averaged $36 million, Walgett LGA $30 million, and Gilgandra LGA $11 million (DNSW, 2013).

[2] The ABS Census defines a category of employment as Agriculture, forestry and fishing. It is assumed that in the Central West subregion, forestry and fishing are not significant in this statistic.

Table 4 Employment profile for the Central West subregion, expressed by sector as percentage employed. Data are from the National Regional Profile 2007 to 2011

Industry	Dubbo LGA %	Other LGAs %	Combined %
Arts and recreation services	1.6%	1.0%	1.3%
Accommodation and food services	7.3%	5.5%	6.6%
Administrative and support services	2.5%	1.9%	2.2%
Agriculture, forestry and fishing	3.3%	29.6%	15.0%
Construction	7.4%	4.7%	6.3%
Education and training	9.3%	9.3%	9.4%
Electricity, gas, water and waste services	1.5%	1.4%	1.5%
Financial and insurance services	2.4%	0.9%	1.8%
Health care and social assistance	14.8%	11.3%	13.4%
Information media and telecommunications	1.1%	0.4%	0.8%
Manufacturing	6.8%	2.9%	5.2%
Mining	0.9%	1.9%	1.4%
Professional, scientific and technical services	4.3%	2.6%	3.6%
Public administration and safety	7.5%	7.0%	7.3%
Rental, hiring and real estate services	1.4%	0.5%	1.0%
Retail trade	12.5%	8.7%	11.0%
Transport, postal and warehousing	4.9%	4.4%	4.7%
Wholesale trade	4.1%	2.8%	3.5%
Other services	4.7%	3.1%	4.1%

Source: ABS (2014)
The six ‘Other’ local government areas (LGAs) are Bogan, Coonamble, Gilgandra, Narromine, Warren and Warrumbungle.

1.1.2.2.3 Land use

Land use in the subregion is dominated by extensive agriculture with 63% of the subregion area used for grazing on natural and modified lands and 23% for cropping. Forestry, conservation and other natural environments account for about 10% of the subregion area. While economically important, irrigated cropping covers only 2% of the valley. Cotton is the main irrigated crop, but wheat and cereals, fodder and pasture, lucerne, oilseeds and vegetables are also grown. Table 5 summarises land use in the subregion.

Three land use zones can be distinguished in Figure 9. In the north-west, around the Macquarie Marshes, grazing on natural vegetation dominates production systems. Through the central subregion, grazing on modified pastures and cropping systems intermingle, with grazing on modified pastures becoming more dominant in the east and around Nyngan. In the eastern third, grazing on modified pasture lands predominates, but with extensive areas of minimal use lands. North-east of Dubbo and south of Gilgandra there are sizable areas of production forestry, as well as north-east of Coonamble on the border with the Namoi subregion. The Macquarie Marshes, Warrumbungle Ranges and a small belt of land in the upper Talbragar catchment on the Namoi-Hunter divide are used for nature conservation. The lands around Dubbo are a focus for intensive land uses.

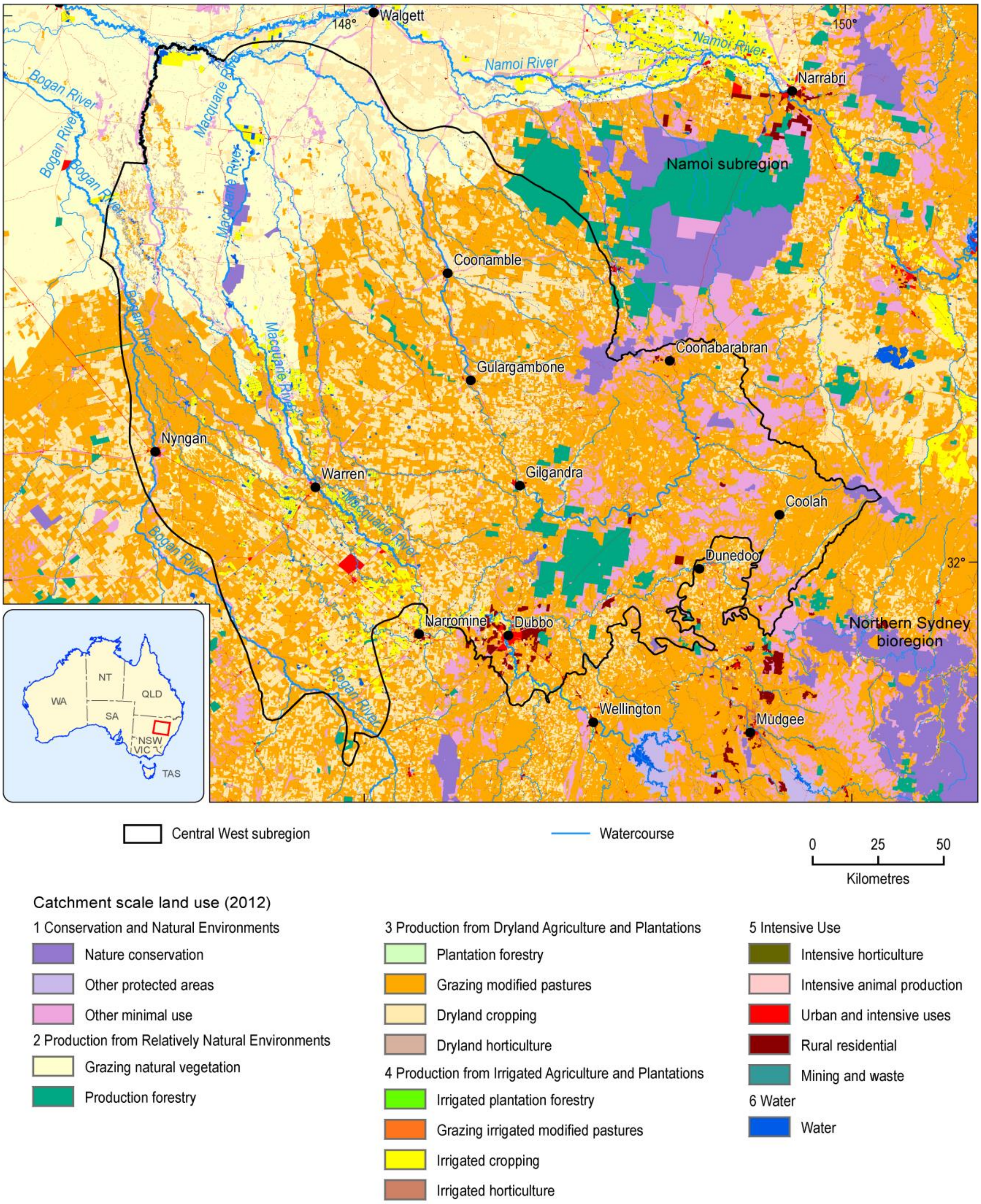

Figure 9 Land use in the Central West subregion

Source data: Catchment scale land use mapping for Australia update November 2012 (ABARES, 2012)

Table 5 Land use areas in the Central West subregion

Land Use	Area (km^2)	Percentage
Grazing modified pastures	21321.8	45.6%
Cropping	9,896.6	21.2%
Grazing natural vegetation	7,898.1	16.9%
Conservation and natural environments	3,381.9	7.2%
Production forestry	1,245.0	2.7%
Irrigated cropping	946.2	2.0%
Residential, manufacturing, utilities, transport, services	767.8	1.6%
Water	698.5	1.5%
Land in transition	473.7	1.0%
Plantation forestry	49.3	0.1%
Grazing irrigated modified pastures	34.0	0.1%
Mining	9.0	0.0%
Irrigated horticulture	8.2	0.0%
Intensive production	3.9	0.0%
Horticulture	0.5	0.0%

Source: ABARES (2012)

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).

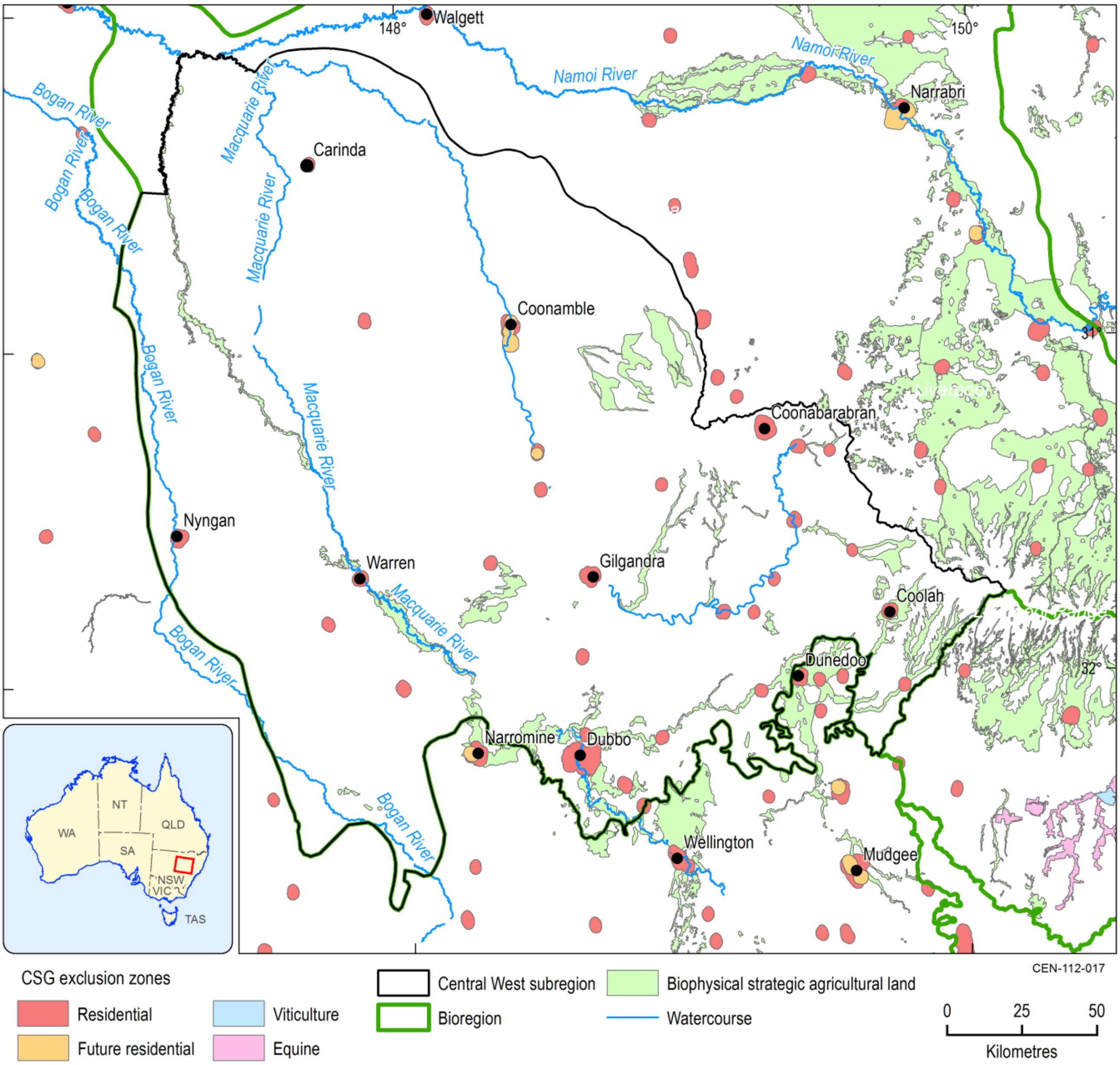

Figure 10 Coal seam gas exclusion zones in the Central West subregion

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

1.1.2.2.4 Indigenous heritage

The Macquarie river basin formed part of the lands originally occupied by the Wiradjuri, Wailwan, Wongaibon and Ngemba Aboriginal nations. The name Wiradjuri means 'people of the three rivers' and refers to the Macquarie, Lachlan and Murrumbidgee rivers, which were the primary source of food for the Wiradjuri people. The Wailwan people inhabited the area between Gilgandra and Brewarrina, centred around the town of Warren and including the Macquarie Marshes. The Wongaibon people occupied lands to the west of Nyngan in the west of the subregion.

Terramungamine Aboriginal Place, near Dubbo, is the only Indigenous burial ground listed under section 86(4) of the *NSW National Parks and Wildlife Act 1974* (NPW Act), which protects listed sites from harm or desecration. The area is covered by the Terramungamine Indigenous Land Use

Agreement and is managed by Dubbo City Council. Scarred trees, grinding groves, Indigenous burials and other Indigenous objects can be found there. There are other significant Indigenous sites near Narromine, north-west of Nyngan and north-east of Coonabarabran, that are located outside the subregion.

1.1.2.3 Climate

The climate of the subregion is characterised by hot, dry summers and cool winters. Maximum temperatures average 32 to 34 °C through the summer and 16 to 18 °C through the winter, while minimum temperatures are typically about 17 to 19 °C in summer and 5 °C through winter (Figure 11). Using the Köppen climate classification, the north-west is classed as hot and persistently dry. There is a narrow subtropical belt with no dry season through the centre of the subregion (Nyngan to Coonamble), and in the south and east the climate is temperate with no dry season and hot summers.

The mean annual rainfall of the subregion is 500 mm. Across the subregion, it ranges from 1070 mm/year in the Warrumbungle Ranges to 440 mm/year in the north-west. Higher mean rainfall also occurs in the hills east of Coolah. At Dubbo, mean rainfall is 575 mm/year and at Nyngan in the west it is 450 mm/year (Figure 13). The headwaters of the Macquarie River have been included in Figure 13 to show rainfall in the higher runoff yielding areas of the surface water basin. Figure 12 shows the annual time series of rainfall from 1900 to 2011 for the subregion. The annual mean for this period is 520 mm, but it can be seen that there is considerable variability with a low of 260 mm in 1902 during the federation drought and a maximum of 1160 mm in 1950. The orange line shows the low frequency trend for the record. The years between 1900 and 1946 were on average drier (455 mm/year) than the latter half of the 20th century (565 mm/year). The millennium drought is weakly evident in the subregion with the rainfall mean of 490 mm/year for 2002 to 2009 being 30 mm/year less than for the full record. Rainfall is summer-dominant, varying from 175 mm (60 mm/month) for the December to February period to 115 mm (40 mm/month) between June and August (Figure 11).

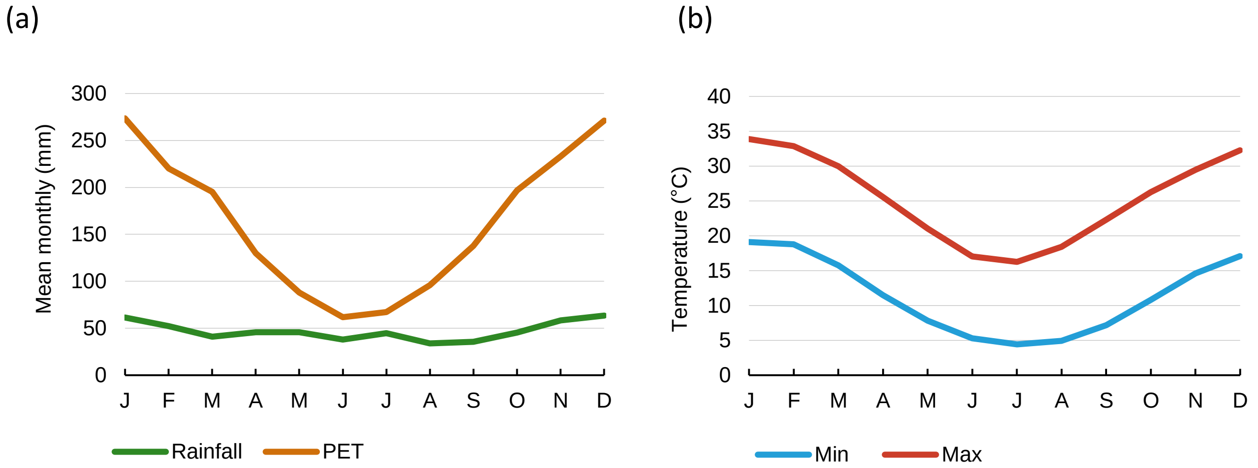

Figure 11 Mean monthly rainfall and potential evapotranspiration (a) and mean monthly maximum and minimum temperatures (b) over the subregion

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

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, including the headwaters of the Macquarie River which are outside the subregion. Mean annual PET ranges from 1640 mm in the south-east around Coolah to 2150 mm in the north-west and east of Coonamble. Higher rates occur to the west of the subregion and lower rates in the higher elevation, higher rainfall areas to the south-east. Mean monthly PET ranges from 60 mm in June to 270 mm in December and January, reflecting the annual temperature pattern (Figure 11). On average, potential evaporation is limited by water availability throughout the year (Figure 11), so actual ET rates are not as high as the potential.

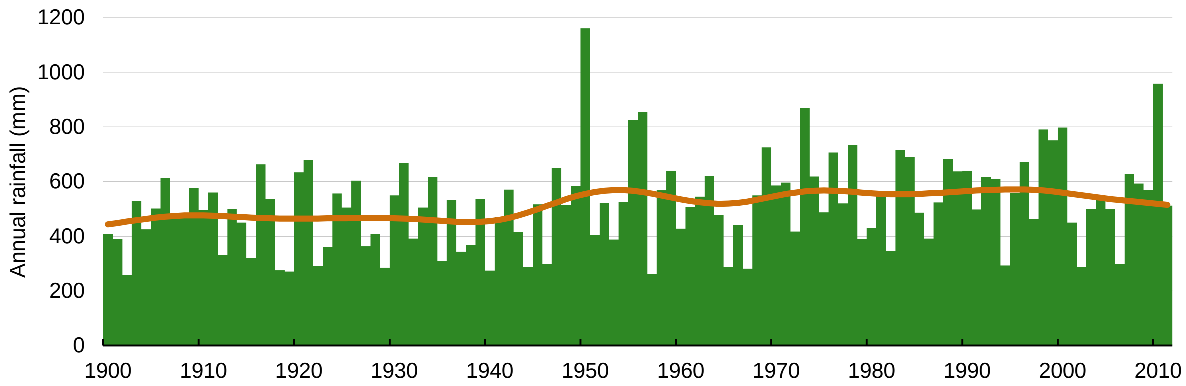

Figure 12 Annual rainfall averaged over the Central West subregion for 1900 to 2011. The orange line shows the low frequency variability

Source data: Bureau of Meteorology (2012)

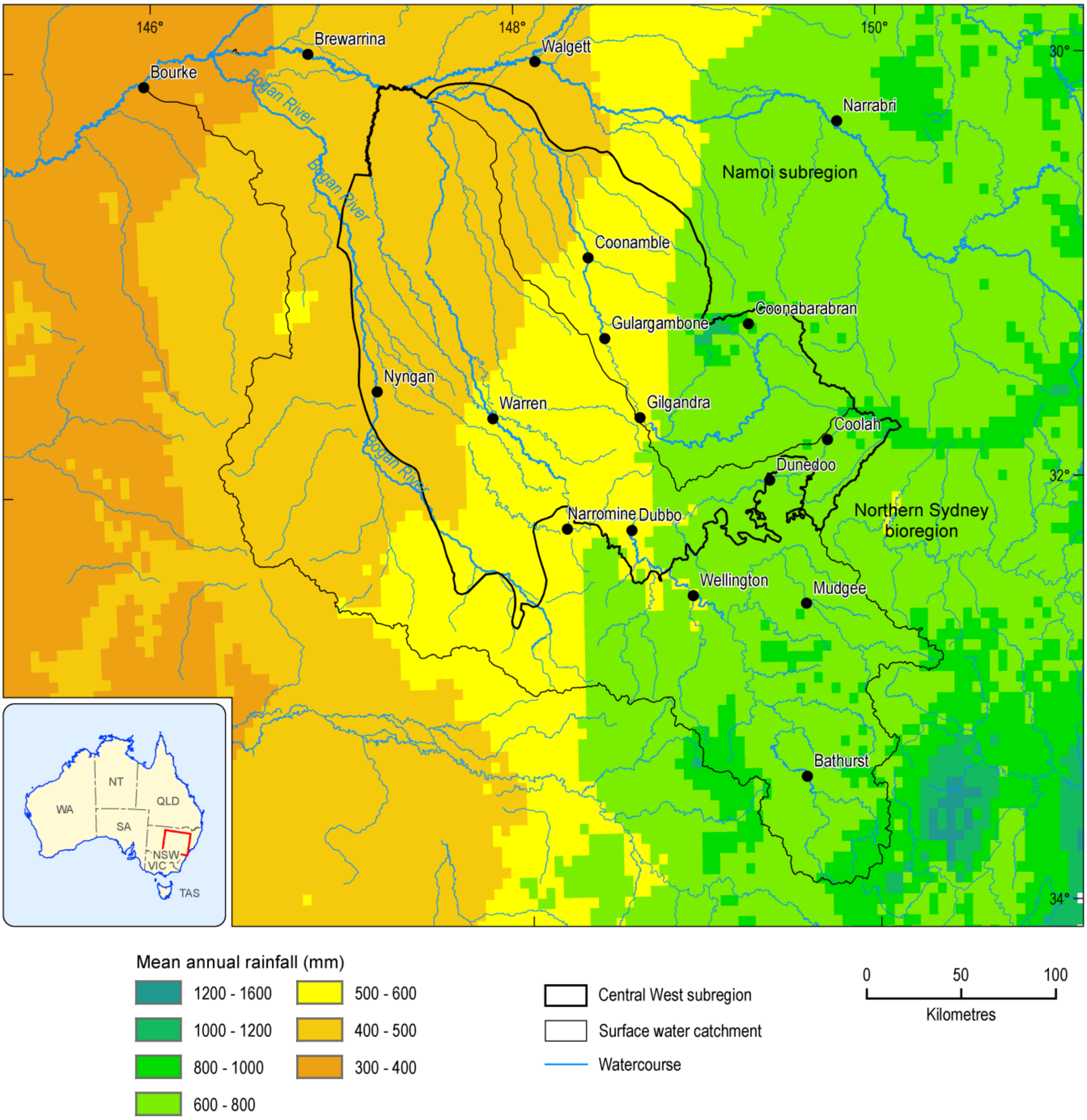

Figure 13 Mean annual rainfall distribution

Source data: Bureau of Meteorology (2013c)

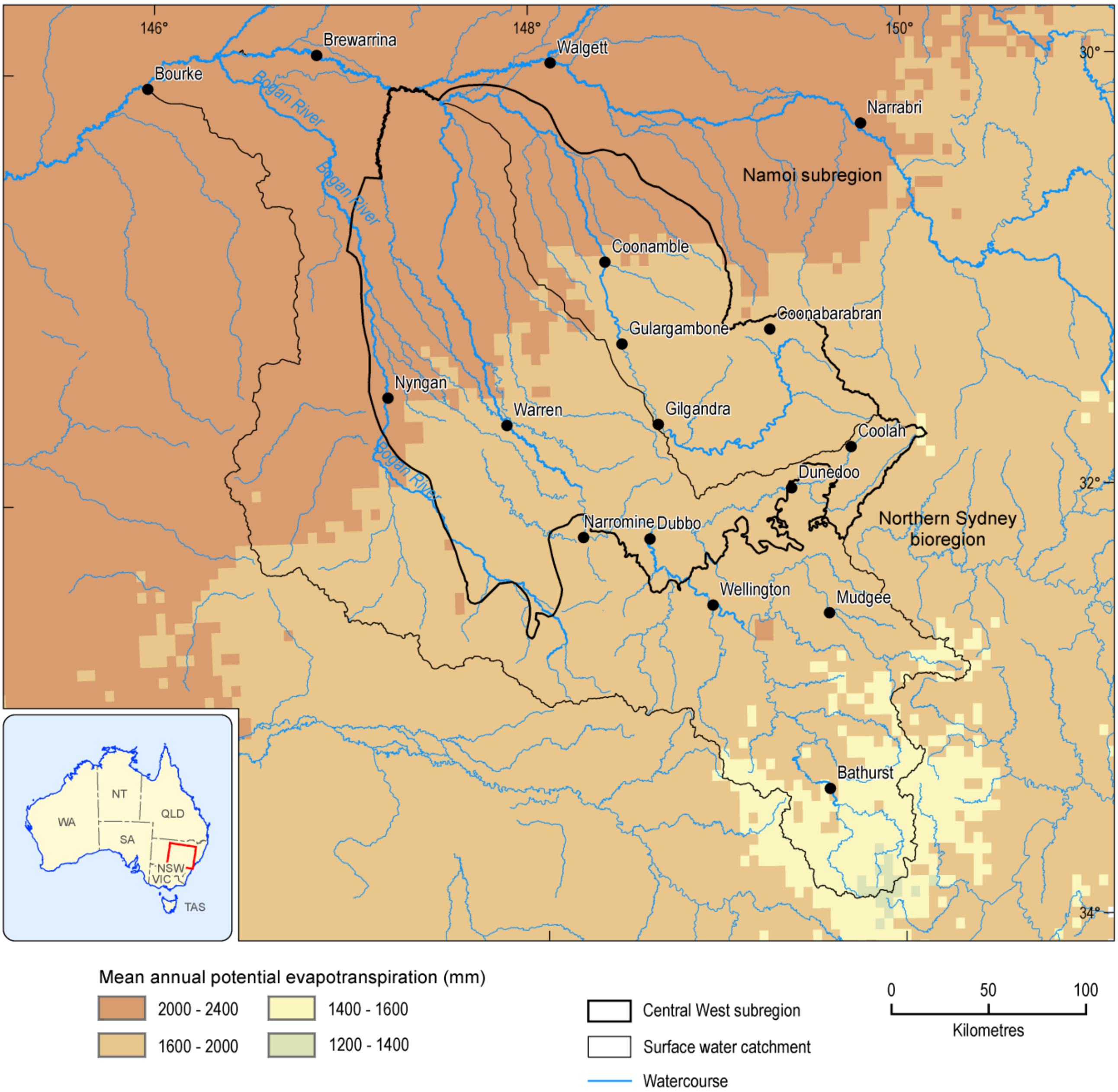

Figure 14 Mean annual potential evapotranspiration distribution

Source data: Bureau of Meteorology (2014)

In a recent report by the South Eastern Australian Climate Initiative (SEACI) (CSIRO, 2010), the significance of the period from 1997 to 2009 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 Central West subregion, the rainfall was either within 5% (southern margins of subregion) or 5 to 20% greater (north and western subregion) than the long-term mean. However, modelled streamflow was estimated to be 5 to 30% lower in those areas where rainfall showed little change from the long-term mean and 5 to 50% greater for the more northerly areas where the 1997 to 2009 rainfall was above the long-term mean. In general, analysis has shown that the impact on 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 Macquarie-Castlereagh river basin, the best estimates under 1.0 °C of warming are for a 1% reduction in mean rainfall (–5 mm) (Table 6) but with small increases likely in the summer months and decreases in the winter months (Figure 15). Across all models, the potential evaporation was projected to increase 2 to 5% (26–66 mm). The net result under 1.0 °C of warming is a projected 8% reduction (–3 mm) in runoff (Table 7), again with small increases in the summer months and more significant reductions through the winter (Figure 15).

Table 6 Summary of projected impacts of climate change on rainfall for the Macquarie-Castlereagh river basin

		1 °C of global warming			2 °C of global warming		
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**
544	9	–9%	–1%	3%	–19%	–3%	6%

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

Table 7 Summary of projected impacts of climate change on runoff for the Macquarie-Castlereagh river basin

		1 °C of global warming			2 °C of global warming		
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**
33	12	–25%	–8%	5%	–42%	–12%	13%

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

Figure 15 shows the distribution of rainfall and runoff changes across the year for the historical record and projected changes at Dubbo. Projected decreases in winter rains will likely result in reduced runoff, while small increases in January to March rain will increase runoff. The wider range of projections for runoff than rainfall indicates greater uncertainty in these across the full year.

Dubbo

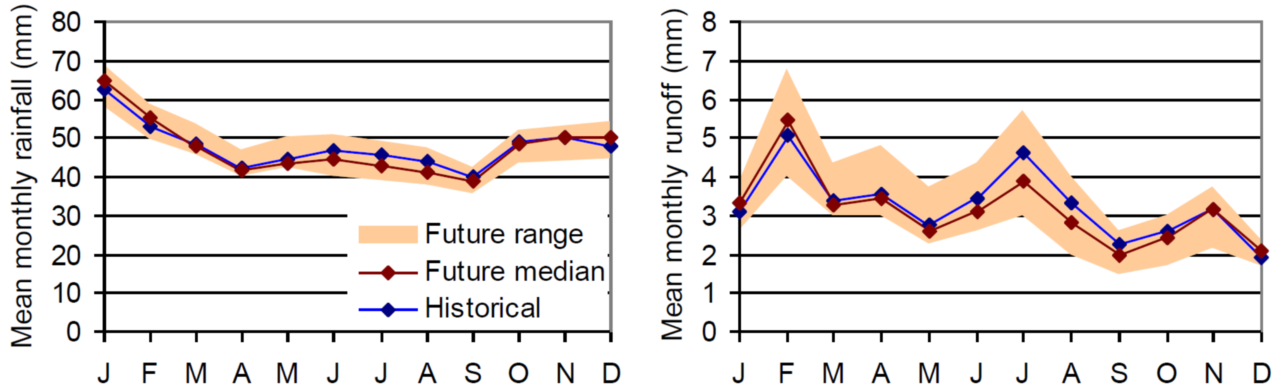

Figure 15 Mean monthly rainfall and runoff for Dubbo based on historical data (blue line), median climate projections in 2030 (red line) and future 2030 range (beige shading)

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

The implications of a changing climate were considered in the sustainable yield report for the Macquarie-Castlereagh river basin in 2030 based on IPCC Fourth Assessment climate change projections and assuming current levels of development (CSIRO, 2008). The mean runoff reduction forecast for this river basin in this report was 6%, slightly less than the 8% reduction projected in the more recent SEACI report, but the assessment of impacts remains relevant. Table 8 summarises impacts on the water resource for the Macquarie-Castlereagh river basin and wetland inundation events for the Macquarie Marshes. For a 6% reduction in runoff and assuming no new development in the catchments (for example, no construction of new water storages or significant land cover change), the CSIRO estimated an 8% reduction in water availability, a 9% reduction in end-of-system flows and a 4% reduction in diversions, with the impact on diversions depending on the class of water. Under median and drier climate futures, the frequency of large inundation events will reduce and the overall flood volumes will also decrease. These reductions would reduce the scale of bird breeding events. At the dry extreme of the climate projections, there would be serious impacts on the wetland ecology and potential loss of species (CSIRO, 2008).

Table 8 Projected impacts of climate change on water resources and wetland inundation in 2030 relative to the historical average (1895 to 2006)

	Dry	Median	Wet
Water availability (%)	−25%	−8%	+25%
End-of-system flows (%)	−28%	−9%	+41%
Diversions (%)	−16%	−4%	+12%
Average period between important wetland inundation events (%)	+24%	+10%	−25%
Higher flood level volume (%)	−38%	−16%	+21%
River losses to groundwater (GL/y)	+0.3	0	−0.4

Source: CSIRO (2008, their tables 4-6, 4-7, 7-2 and p.86)

In the lower Macquarie Alluvium groundwater management unit, river losses under the median development pathway would not change, but for the dry development pathway losses are projected to increase by 0.3 GL/year. Recharge is not projected to change significantly under the median development pathway.

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.

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1.1.3 Geology

Summary

There are three large coal-bearing sedimentary basins within the Central West subregion, namely the Surat Basin, the Gunnedah Basin and the Sydney Basin (Figure 16). The geology of the underlying basement rocks and the overlying Cenozoic alluvial and volcanic deposits is not discussed in detail here (refer to Section 1.1.4 for information on the hydrogeology of the Cenozoic sequences). The part of the Surat Basin within the Central West subregion is the Coonamble Embayment. For the Gunnedah Basin, which structurally and stratigraphically underlies the Surat Basin, this section focuses on the Oxley sub-basin and the western part of the Mullaley sub-basin (Figure 17). Only the northern-most section of the Sydney Basin falls within the Central West subregion.

The Gunnedah Basin started forming in the Late Carboniferous, during a period of volcanic activity and mechanical plate extension that resulted in rapid subsidence. Passive thermal subsidence followed this phase, marked by a period of uniform sedimentation across the basin. Deposition centred on a series of half-grabens that formed deeper troughs across the basin, particularly along the western margin. The Gunnedah Basin is bounded largely by older geological fold belts and structural highs, such as the New England and Lachlan orogens. The eastern margin coincides with a major thrust fault system known as the Hunter-Mooki Thrust. The rocks of the Gunnedah Basin are sandstone-dominated, with siltstone, claystone, tuff and coal less abundant, although these are more common in the upper half of the basin infill sequence.

After the initial phase of extension and subsidence, the Gunnedah Basin was affected by the Late Permian to Early Triassic Hunter-Bowen Orogeny that caused widespread contractional deformation. This tectonic phase was later overwhelmed by rapid tectonic subsidence that brought an end to the evolution of the basin in the Middle Triassic.

The Sydney Basin was deposited continuously with its northern counterpart, the Gunnedah Basin. Several phases of volcanic activity have been noted throughout the basin. Sedimentation was largely controlled by changed in the sea level during formation. Like the Gunnedah Basin, the Sydney Basin is also bounded by the New England Fold Belt and the Hunter-Mooki Thrust. However the Sydney Basin’s easternmost edge is bounded by the offshore continental margin.

Deposition in the younger Surat Basin commenced in the Early Jurassic. The sedimentary rocks of the Surat Basin formed above volcanic rocks (the Garrawilla Volcanics) during renewed subsidence. This was followed by a compressional tectonic regime, with active volcanic intervals and fault reactivation phases. During the latest Early Cretaceous, uplift brought an end to the deposition of the Surat Basin infill sequence. The Surat Basin, which contains up to 2500 metres of sedimentary infill, is largely composed of sandstone, siltstone, mudstone, shale, coal, conglomerate, volcanic and tuff deposits.

1.1.3.1 Geological structural framework

1.1.3.1.1 Definition of the basins

The Surat, Gunnedah and Sydney sedimentary basins are large intracratonic basins. The Surat Basin sits upon the Gunnedah and Sydney basins, which are built on Late Carboniferous to Early Permian continental basement rocks. The Gunnedah and Sydney basins have also been described as continental rift basins that later transformed into foreland basins (Cadman et al., 1998; O'Neill and Danis, 2013).

1.1.3.1.2 Basin extent and regional geological context

The Gunnedah Basin is a Permian and Triassic basin in NSW, covering approximately 15,000 km^2 with about 36% of the basin falling within the Central West subregion (Tadros, 1993; O'Neill and Danis, 2013). The Permian to Triassic age Sydney Basin covers a portion of NSW, with 44,000 km^2 of the Sydney Basin falling onshore with a further 5,000 km^2 located offshore (Cadman et al., 1998). The Surat Basin unconformably overlies the uppermost unit of the Gunnedah Basin (Deriah Formation), and also extends beyond its boundaries (Figure 16). The Surat Basin is approximately 300,000 km^2; of which 18% coincides with the Central West subregion. The Surat Basin is part of the larger subsidence-depositional system, which also includes the Eromanga, Carpentaria and Clarence-Moreton basins. These basins have formed across large parts of Queensland and northern NSW (Smerdon and Ransley, 2012).

1.1.3.1.3 Sub-basins

There are currently no formally recognised sub-basins in the Surat Basin. However, the basin is commonly divided into distinct tectonostratigraphic regions based on the structural features that have controlled both the location and thickness of the sedimentary sequences. The structural region for the part of the Surat Basin in the Central West subregion is known as the Coonamble Embayment. The sedimentary infill of the Coonamble Embayment is relatively thin compared to parts of the Surat Basin in Queensland (Figure 18).

The Gunnedah Basin is commonly divided into three sub-basins. However, the south-western sub-basin of the Gunnedah Basin, the Oxley sub-basin (Figure 17), is not yet widely accepted in the geological literature (O'Neill and Danis, 2013). The rest of the Gunnedah Basin in the Central West subregion is part of the Mullaley sub-basin, (Figure 17) (O'Neill and Danis, 2013). The Mullaley sub-basin is separated from the Maules Creek sub-basin further to the north by the north-trending Boggabri Ridge (O'Neill and Danis, 2013). These sub-basins were the major depositional troughs during sedimentation of the Gunnedah Basin (Ward and Kelly, 2013; Stuart-Smith et al., 2010).

The subregion includes part ofthe northern Sydney Basin, where there are limited data (FrogTech, 2007). Various authors divide the Sydney Basin into northern, central and southern sections; others choose north-eastern, western, central and southern. FrogTech (2007) termed the section in this subregion as part of the Blue Mountains Plateau and the Western Onshore Basin. There appears to be no official divisional guide for the Sydney Basin, with many investigations choosing subdivisions suited to their own work.

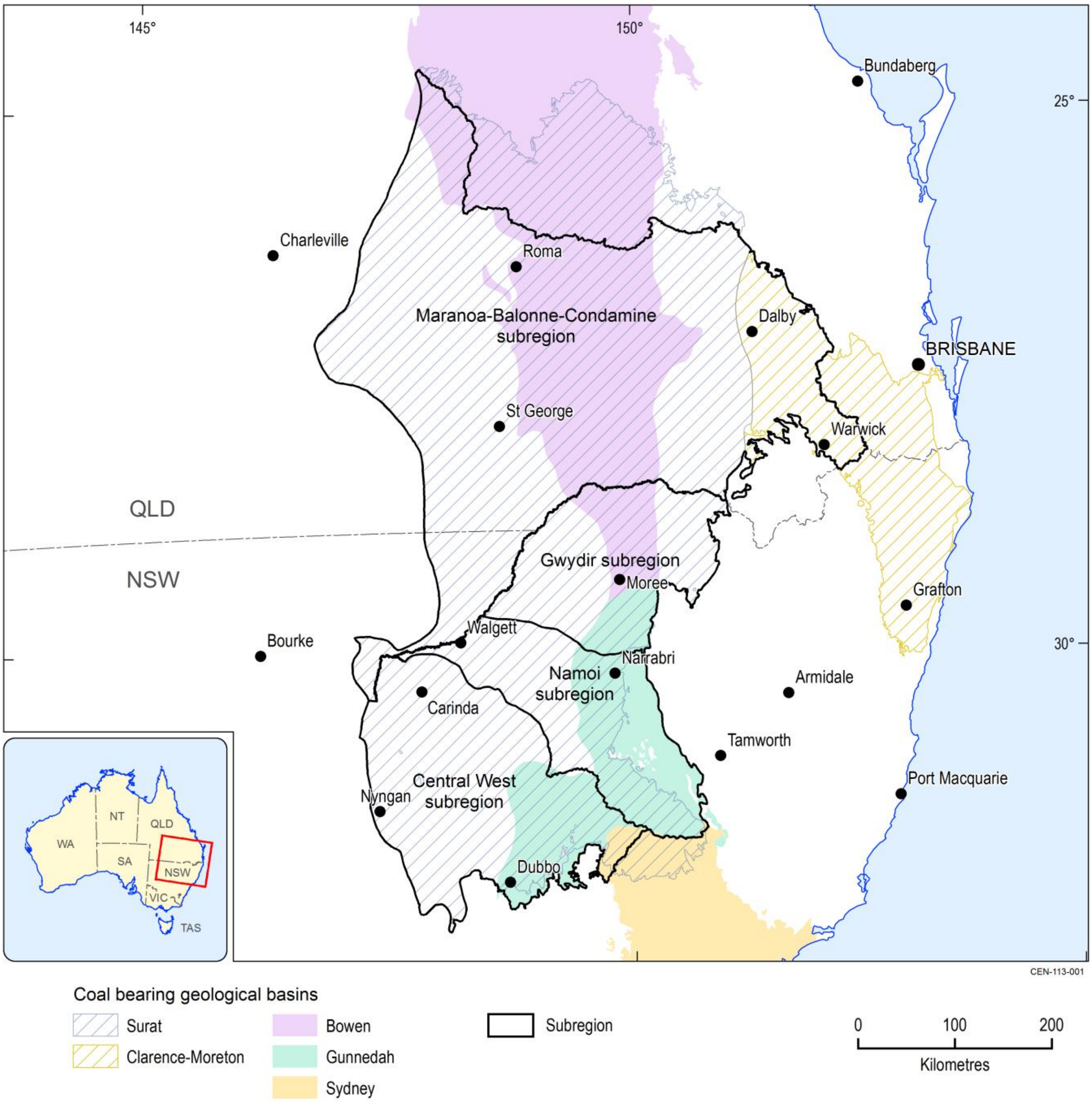

Figure 16 Location of the Central West subregion within the Northern Inland Catchments bioregion and its relation to the geological Surat, Gunnedah and Sydney basins

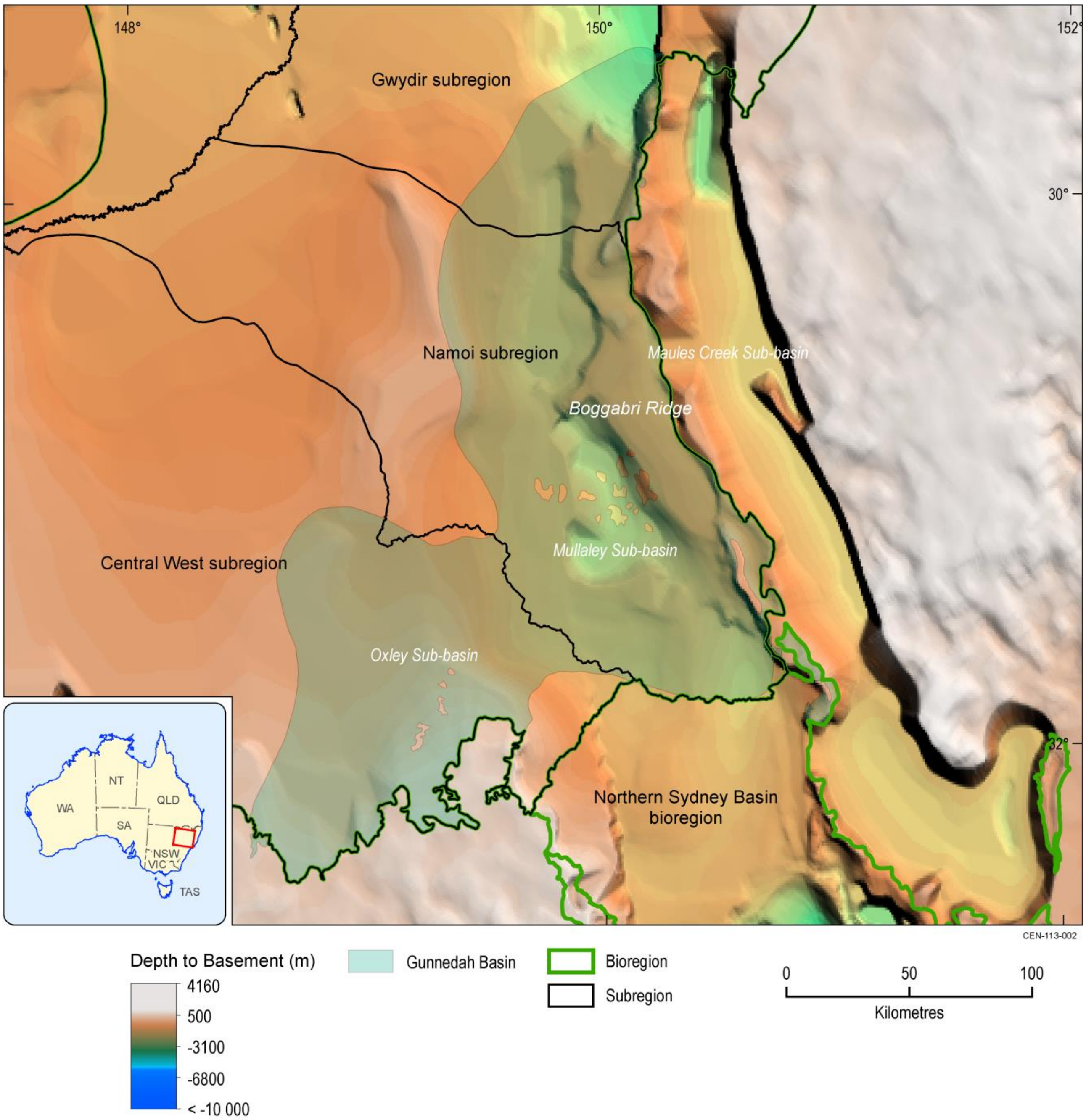

Figure 17 Division of the Gunnedah Basin into sub-basins

Source data: Geoscience Australia (2014)

1.1.3.1.4 Basin thickness

The sedimentary and volcanic infill of the Gunnedah Basin has a maximum thickness of about 3000 m. These sequences are overlain by up to 180 m of Early Jurassic volcanic rocks (Garrawilla Volcanics) (Danis et al., 2010; O'Neill and Danis, 2013). The Surat Basin sequence is thinner in comparison, with a maximum thickness close to 1000 m in the Central West subregion. However, its thickness varies spatially and it may also thin out and disappear in some parts of the Coonamble Embayment that coincide with the Central West subregion (McElroy, 1969; Exon, 1976).

The Coonamble Embayment region of the Surat Basin overlies the Gunnedah Basin in the Central West subregion. The total thickness of strata in both of these basins is relatively thin, less than 1000 m (Figure 18). A single trough in the south-west of the basin (Figure 18) indicated a rapid thickness change to roughly 1000 m, however there has been little to no work completed at the locality of this trough to provide an in depth stratigraphical or structural study.

Up to 4000 m, or more, of sedimentary rock can be attributed to the Sydney Basin with variations dependent on the structural elements of the basin, and up to 5900 m in the north (Mayne et al., 1974; Bradley et al., 1985; Cadman et al., 1998).

1.1.3.1.5 Structure

The sedimentary rocks of the Gunnedah Basin rest unconformably on troughs and structural highs of Late Carboniferous to Early Permian volcanic rocks (Boggabri Volcanics and Werrie Basalt) and the basement rocks of the Ordovician to Early Carboniferous Lachlan Fold Belt (O’Neill and Danis, 2013). The Boggabri Ridge (Figure 17) was a major source of sediment input to the basin, but also acted as a 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 Hunter-Mooki Fault (Figure 18) (Tadros, 1993; Danis et al., 2010; O’Neill and Danis, 2013; Ward and Kelly, 2013).

The Gunnedah Basin is contiguous (that is, strata inter-finger) with the Bowen Basin to the north, and the Sydney Basin to the south (Danis et al., 2010; O’Neill and Danis, 2013). The Gunnedah Basin is separated from the Bowen Basin by the Moree High and the Narrabri High, and from the Sydney Basin by the Liverpool Ridge, the Mount Coricudgy Anticline and the Quirindi Anticline (Beckett et al., 1983; Tadros, 1993; Guoping and Keene, 2007; Danis et al., 2010; O’Neill and Danis, 2013). Structurally, the basin is characterised by a series of half-grabens and structural highs that formed during the Hunter-Bowen Orogeny (O’Neill and Danis, 2013). Detritus within the basin was mostly derived from the erosion and weathering of the older Paleozoic uplands adjacent to the basin, such as the Lachlan Fold Belt (Hamilton, 1991).

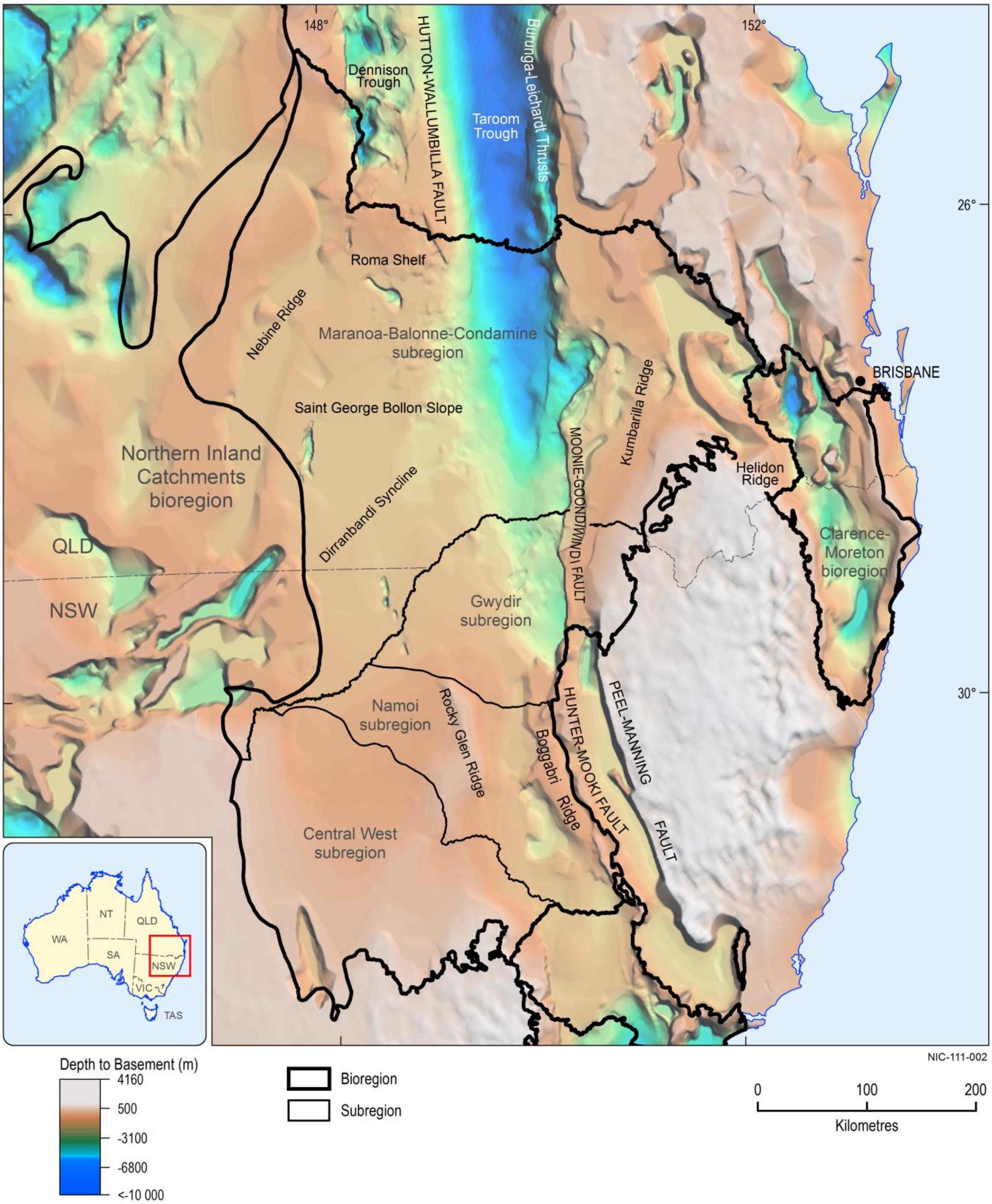

Figure 18 OZSEEBASE map of the Northern Inland Catchments bioregion with major structural elements

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

Deposition was continuous with the Gunnedah Basin and Sydney Basin so the exact boundary between the basins is questionable, with original investigations placing the division over the Mount Coricudgy Anticline but more modern work places it with the Liverpool Range (Bembrick et al., 1973; Harrington et al., 1989; Cadman et al., 1998). Some older studies include the northern portion of the Sydney Basin, between the Mount Coricudgy Anticline and the Liverpool Range, in the Gunnedah Basin. The basin is bounded in the west and the south by the onlap of sediments onto the Lachlan Fold Belt (Bembrick et al., 1973; Mayne et al., 1974; Cadman et al., 1988). In the north-east the Hunter-Mooki Thrust and New England Fold Belt control the limit of the basin's extent with a zone of reverse faulting, including some sub-parallel to parallel thrust faults, while the south-eastern offshore limit of the basin is bounded at the continental shelf (Mayne et al., 1974; Harrington et al., 1989; Cadman et al., 1998). At the north-eastern boundary of the basin a series of normal faults have developed in relation the north-trending folds (Mayne et al., 1974). A series of anticlines (Lochinvar and Sedgefield) and domes (Belford and Loder) are separated from the Muswellbrook Anticline by a large synclinal structure (Mayne et al., 1974). The Lochinvar Anticline occurs near the Elderslie and Mathews Gap Faults, both of which have displacements up to 300 m, but parts of this anticline have been affected by the Radforslee and Greta overthrusts (Mayne et al., 1974). Most folding and faulting in the Lochinvar Anticline region has been attributed to the Hunter-Bowen Orogeny, with structures to the central and south of the basin forming later (Mayne et al., 1974). Further uplift during the Miocene and Early Pliocene resulted in the faulted and folded peneplain structures that form sections of the bordering New England Fold Belt and the Blue Mountains (Mayne et al., 1974).

The OZSEEBASE dataset (FrogTech, 2006) currently provides the most comprehensive interpretation of geological structures, published to date, in the Central West subregion (Figure 19). A series of roughly north-west trending reverse faults segment the western to central part of the subregion and are spaced 10 to 25 km apart. These are major basement structures that have undergone multiple episodes of displacement over a prolonged geological history. In the western part of the subregion there is significantly greater intensity and diversity of faulting. In this area, which coincides with the Gunnedah Basin, the most common fault types are north-north-west trending reverse faults and north-west trending strike-slip faults that have a sinistral sense of movement. Several of the reverse faults in this area are also major basement structures with a strike length greater than 150 km.

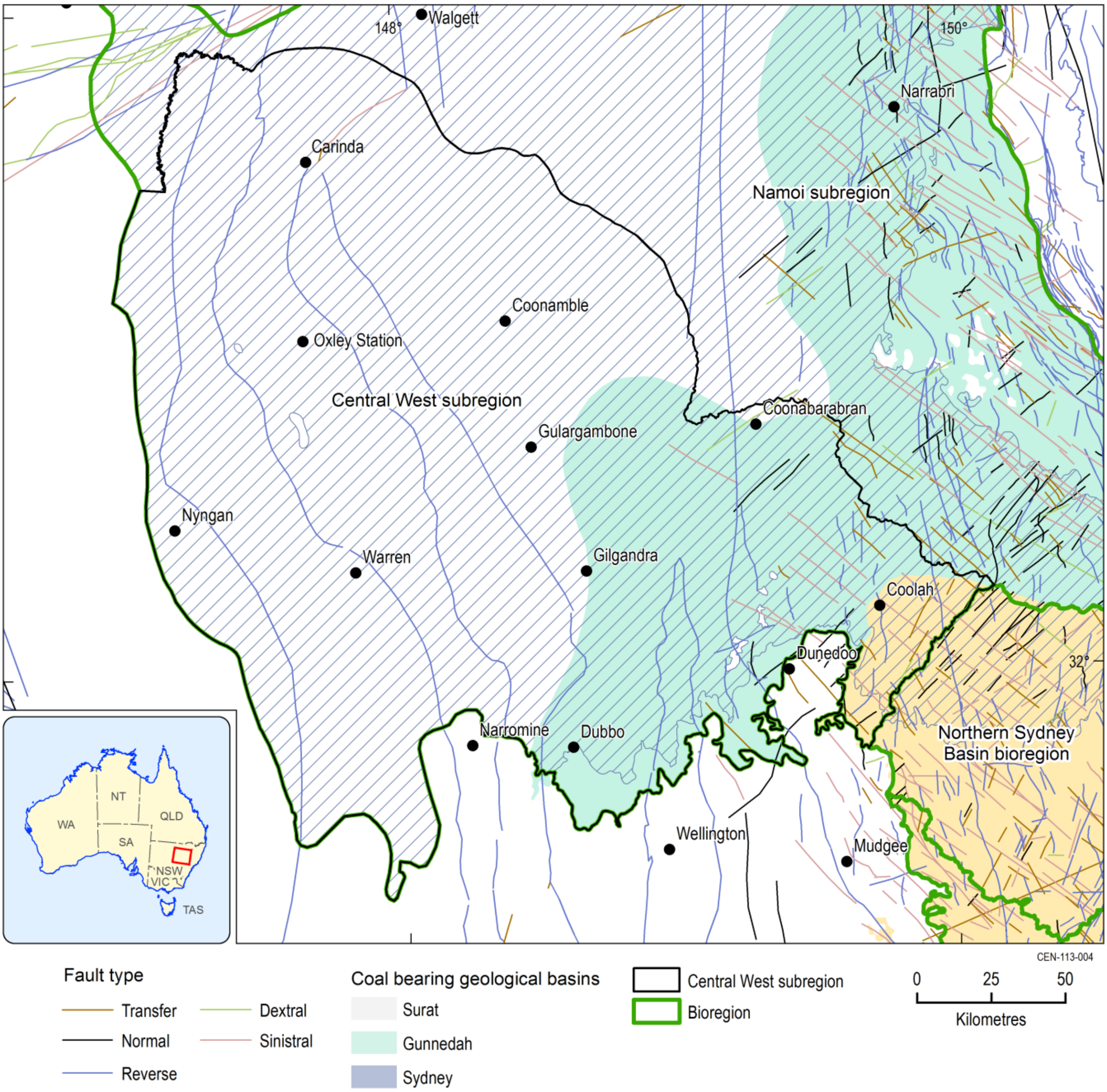

Figure 19 Fault location and orientation within the Surat and Gunnedah basins in the Central West subregion

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

1.1.3.2 Stratigraphy and rock type

1.1.3.2.1 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 20. Detailed stratigraphic descriptions of all rock units in the Gunnedah and Surat basins are beyond the scope of this report. However, a brief summary of the main coal-bearing units of each basin is provided below.

Goonbri Formation

The Goonbri Formation is an Early Permian lake deposit characterised by a coarsening-upward sequence. The lowermost section is dark, massive siltstone, the central section is interbedded fine-grained sandstone and siltstone, and the uppermost section is fine- to medium-grained sandstone (Etheridge, 1986; Australian Stratigraphic Units Database, 2013). Thin coal seams are present in this unit (Australian Stratigraphic Units Database, 2013).

Maules Creek Formation

The Early Permian Maules Creek Formation contains mostly non-marine marsh plain deposits composed of sandstone, conglomerate and coal, with some clay pellet beds and carbonaceous claystone (Beckett et al., 1983). It occurs in the basal part of the Bellata Group and is up to 125 m thick (Beckett et al., 1983). The upper part of the unit shows evidence for marine transgression and change to a deltaic depositional environment (Beckett et al., 1983). Coal in this unit occurs in a series of up to 25 seams with a maximum thickness of nine metres (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). A distinctive sub-unit, the Melvilles Coal Member, is a high quality and thick coal seam that covers a large portion of the basin (Hamilton, 1985). It is thickest in the east of the 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

This 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 also part of the Coogal Subgroup of the Black Jack Group (Australian Stratigraphic Units Database, 2013).

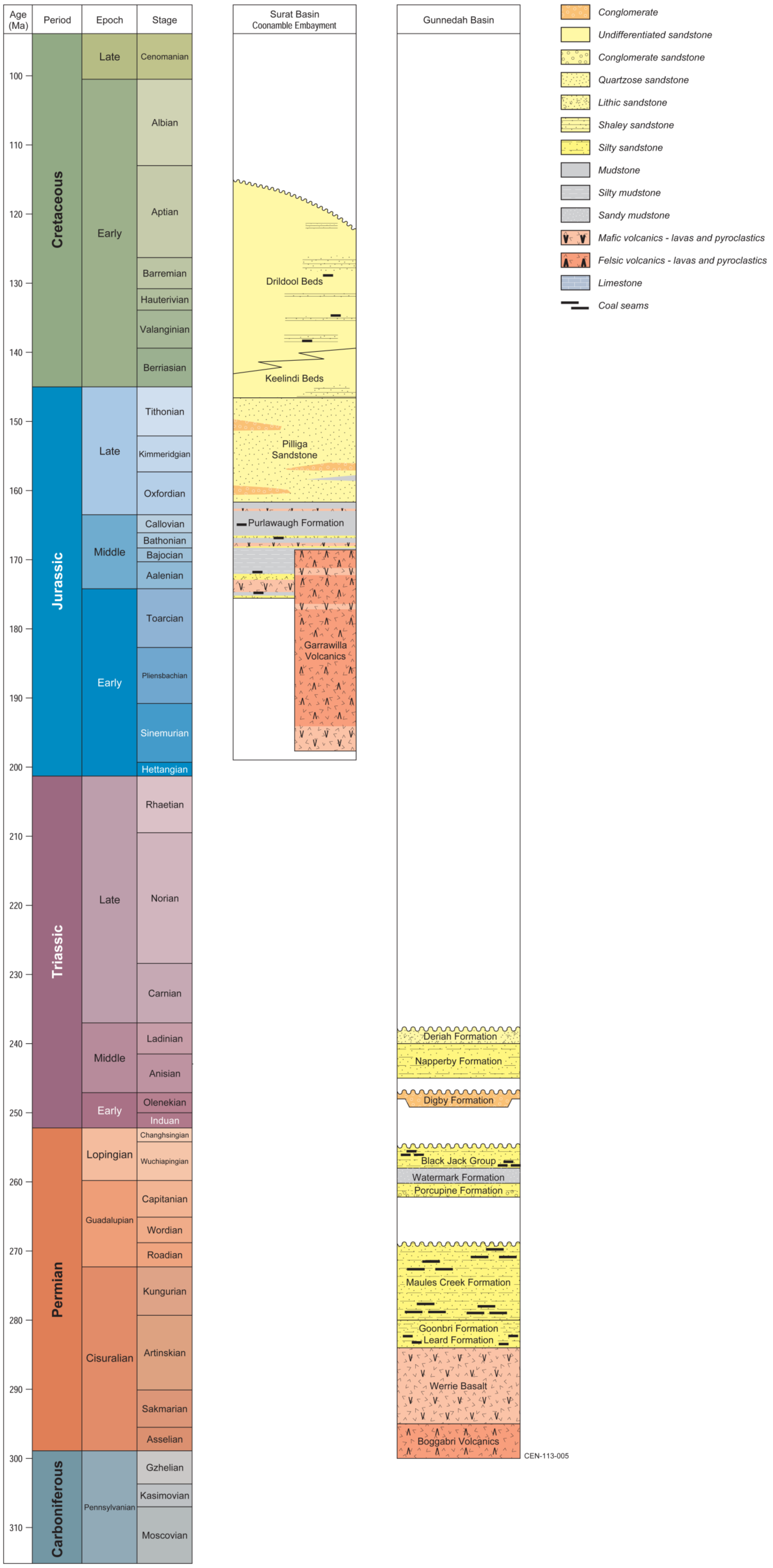

Figure 20 Stratigraphic chart for the Central West subregion

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.
Source data: derived from data presented in McKellar (1998); Totterdell et al. (2009); Cook and Draper (2013); Australian Stratigraphic Units Database (2013)

Clare Sandstone

The Clare Sandstone is a sandstone and conglomerate unit of the Black Jack Group's Coogal Subgroup (Australian Stratigraphic Units Database, 2013). The Clare Sandstone contains the Breeza Coal Member, a coal-rich unit of variable quality coal and alternating 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 in the Nea Subgroup, part of the Black Jack Group, and is composed of claystone, siltstone, sandstone, tuff and stony coal (Australian Stratigraphic Units Database, 2013). The Trinkey Formation is divided into six sub-units, four of which contain coal, namely the Clift Coal Member, Doona Coal Member, Springfield Coal Member and Whaka Coal Member. The Clift Coal Member is composed of five coal sections of variable quality, as well as inter-layered claystone that separates the coal seams (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 predominantly coal with 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).

1.1.3.2.2 The Surat Basin

The stratigraphy of the Surat Basin varies across its 300,000 km^2 area. Distinct lithostratigraphic packages are defined for the main structural domains of the basin. The rock units defined for the southern NSW part of the Coonamble Embayment (Figure 20) differ from those in the better-known Queensland part of the Surat Basin. In particular, coal-bearing formations in the Coonamble Embayment 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 that are uneconomic. Only minor coal-bearing units occur in the part of the Surat Basin that is in the Central West subregion.

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, however carbonaceous fragments are common (Arditto, 1982; Herczeg, 2008; Australian Stratigraphic Units Database, 2013). The Pilliga Sandstone is an important aquifer unit within the Coonamble Embayment region (Herczeg, 2008).

Purlawaugh Formation

The Early to Middle Jurassic Purlawaugh Formation is composed of sandstone with beds of siltstone, mudstone and minor coal (Radke et al., 2012). Rare coal measures occur in this unit (Radke et al., 2012).

Drildool beds

The Cretaceous Drildool beds are composed of sandstone, siltstone, mudstone and coal, with rare breccia and pebble beds (Radke et al., 2012). This unit can be divided into three unnamed sub-units: the lowermost is a mixed assemblage of laminated mudstone, siltstone and muddy sandstone, the central section is composed of sandstone and siltstone that grade to carbonaceous mudstone and coal, and the upper sub-unit consists of laminated mudstone, siltstone and muddy sandstone, much like the lower sub-unit (Radke et al., 2012).

1.1.3.2.3 The Sydney Basin

The Permian to Triassic rocks in the Sydney Basin are a compositionally mixed assemblage of sandstone, siltstone, conglomerate, shale, claystone, tuff and coal (Mayne et al., 1974). The stratigraphy of the Sydney Basin is shown in Figure 21. Detailed stratigraphic description of all rock units within the Sydney Basin is beyond the scope of this report. However, a brief summary of the main coal-bearing units of the northern portion of the basin is provided below.

Greta Coal Measures

The Greta Coal Measures are a unit of varying facies such as siltstone, conglomerate, sandstone, carbonaceous shale with thinly bedded clay-ironstone and coal seams deposited in alluvial fan and fan delta environments (Mayne et al., 1974; Harrington et al., 1989; Australian Stratigraphic Units Database, 2013). The Greta Coal Measures are composed of several sub-units and coal members (Australian Stratigraphic Units Database, 2013).

Maitland Group

The Maitland Group is a unit with fewer subdivisions than the Greta Coal Measures, but one in particular is noted as containing up to eight coal seams: the Mulbring Siltstone (Harrington et al., 1989).

Singleton Supergroup

The Singleton Supergroup is a very largely diverse group composed of several facies units. Three of the four main subdivisions within the Singleton Supergroup are important coal-bearing sequences: the Newcastle Coal Measures, the Tomago Coal Measures and the Wittingham Coal Measures (Australian Stratigraphic Units Database, 2013). The Newcastle Coal Measures are composed of varying assemblages of sandstone, conglomerate, siltstone, shale, carbonaceous shale, coal and tuff subdivided into 32 units and coal seams (Mayne et al., 1974; Australian Stratigraphic Units Database, 2013). The Tomago Coal Measures are also subdivided into several units (29 sub-units) and are composed of siltstone, sandstone, coal, tuff, claystone and conglomerate deposited during a transition from prodelta to delta plain environments (Harrington et al., 1989; Australian Stratigraphic Units Database, 2013). The Wittingham Coal Measures also have a large number of subdivided units, totalling 30 internal divisions, composed of a variation of coal, claystone, siltstone, sandstone and conglomerate (Mayne et al., 1974; Harrington et al., 1989; Australian Stratigraphic Units Database, 2013).

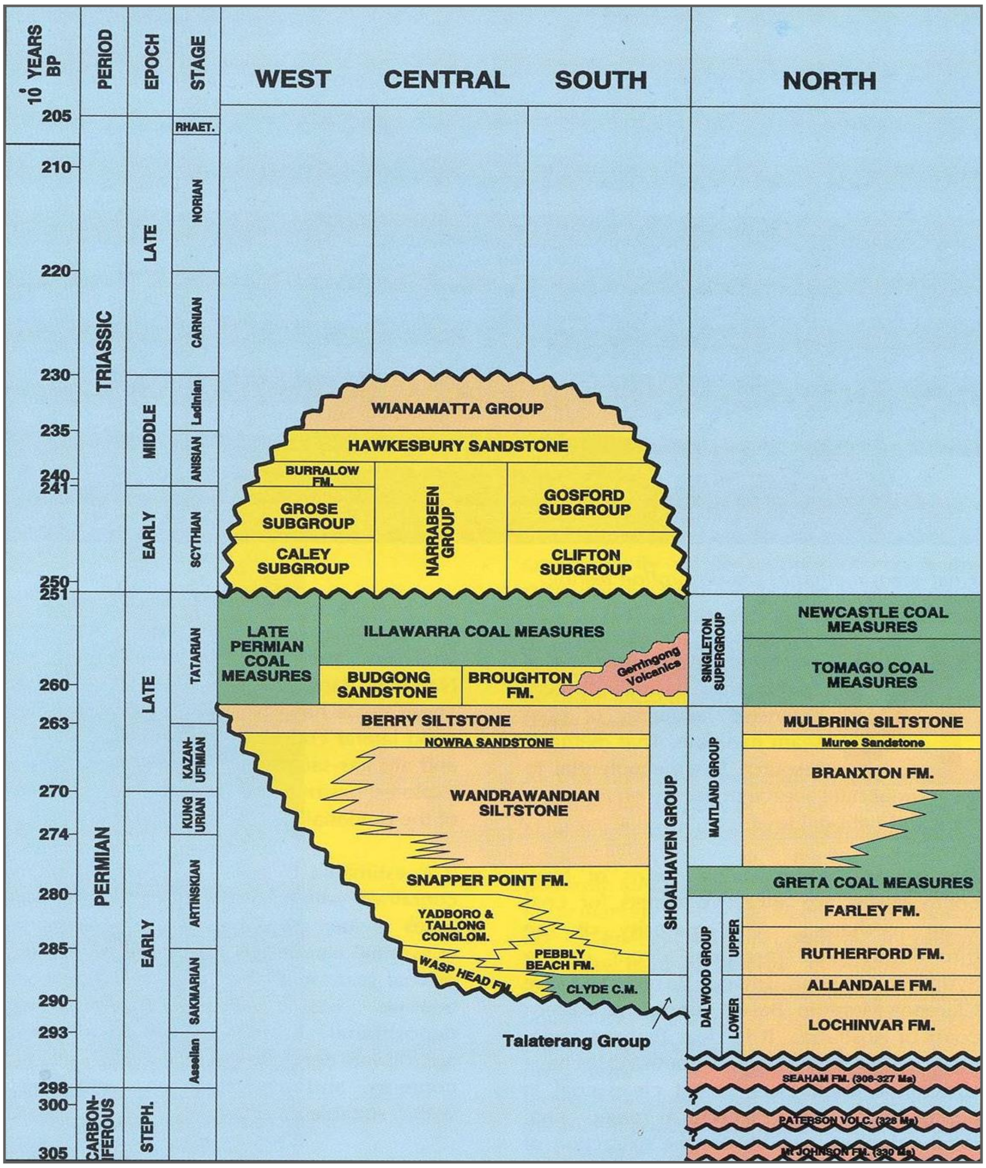

Figure 21 Stratigraphic chart of the Sydney Basin

Source: FrogTech (2007)

1.1.3.2.4 Cenozoic stratigraphy

The youngest geological units in the Central West subregion are Cenozoic volcanic rocks, and alluvial to lacustrine sediments associated with modern rivers and paleovalleys. The dominantly mafic lavas and pyroclastic rocks of the Warrumbungle Volcanics have a restricted spatial distribution within about 40 km west and south-west of Coonabarabran. The basaltic Liverpool Range Volcanics occur only in the far east of the subregion. Both of these units were formed from localised volcanic eruptions during the Eocene (Liverpool Range Volcanics) and Miocene (Warrumbungle Volcanics), and locally intrude and overlie the Surat and Gunnedah basin strata.

The near-surface alluvial sequences of the main rivers and paleovalleys in the Central West subregion (which include the Macquarie, Castlereagh and Talbragar rivers) 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 evolution

Rapid subsidence caused by mechanical extension during the Early Permian initiated development of the Gunnedah Basin. This resulted in the widespread deposition of a thick package of volcanic rocks (Werrie Basalt and Boggabri Volcanics) and inter-layered lacustrine sedimentary rocks (Totterdell et al., 2009). The next major phase of basin subsidence was caused by plate flexure due to foreland loading (Totterdell et al., 2009). 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 (Totterdell et al., 2009). However, subsidence associated with foreland loading was interrupted by a Late Permian to Early Triassic deformational event that halted deposition and caused localised uplift and erosion (Korsch and Totterdell, 2009).

During the Middle to Late Triassic, the deposition of the sedimentary sequences in the Gunnedah Basin ceased (O’Neill and Danis, 2013). This was caused by a major contractional event that was widespread in the basin, and led to significant uplift and erosion (Tadros, 1993; Danis et al., 2010; O’Neill and Danis, 2013). Extensive mafic igneous activity occurred throughout the Gunnedah Basin (and nearby regions) in the Late Triassic and Early Jurassic, including volcanic eruptions (Garrawilla Volcanics) and emplacement of shallow crustal intrusive rocks (Danis et al., 2010; O’Neill and Danis, 2013). Following this magmatic activity renewed basin subsidence was driven by tilting of the eroded platform sequence associated with nearby plate subduction (Cadman et al., 1998). This led to the widespread deposition of the fluvial to marginal marine sedimentary sequences of the Surat Basin, with mostly continuous sedimentation from the Early Jurassic to the Early Cretaceous (Totterdell et al., 2009).

The Early Permian brought a rise to the formation of the basin during marine transgression, which was briefly interrupted by a progradation in the northern section of the basin, forming the Greta Coal Measures. Transgression then continued into the early Late Permian when the regressive or transgressive Muree and Nowra sandstones were deposited (Mayne et al., 1974; Harrington et al., 1989; Cadman et al., 1998). It was during the Middle Permian that the Hunter-Mooki Thrust activated and stayed active through to the Late Permian (Cadman et al., 1998). At this time the continued uplift of the adjacent New England Fold Belt resulted in regressive deposition interrupted by small marine insurgences (Mayne et al., 1974; Cadman et al., 1998). During the end of the Late Permian, continued Hunter-Mooki Thrust activity uplifted the New England region ceasing coal swamp environments (Cadman et al., 1998). Basin-wide subsidence then brought on a marine regression, followed by a transgression event (Mayne et al., 1974; Bradley et al., 1985; Cadman et al., 1998). A rift also formed in the Sydney region and propagated west through the basin, known as the Ayr Volcanic Rift (Harrington et al., 1989). Maturation data suggest the deposition and removal of sediments during the Jurassic and Cretaceous extensional tectonism. A compressive regime returned to the basin in the Tertiary (Cadman et al., 1998).

1.1.3.3.2 Paleozoic volcanism and intrusion

Extension during the Late Carboniferous and Early Permian brought on a volcanic phase that gave rise to the Boggabri Volcanics and Werrie 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 Melville and Hoskissons coal seams (Hamilton, 1985). These provide evidence for minor pyroclastic volcanism in the Late Permian sequences of the Gunnedah Basin. Reactivation of volcanic activity in the Gunnedah Basin during the Jurassic, caused by the separation of Pangaea and eastern Gondwana, led to deposition of the Garrawilla Volcanics in the north and west of the Gunnedah Basin (Danis et al., 2010; O'Neill and Danis, 2013).

Igneous intrusions, such as the Black Jack Sill and Ivanhoe Sill, are common throughout the Gunnedah Basin sequence, and are thought to be 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, 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).

Three main phases of volcanic activity, the Permian to Carboniferous New England Fold Belt, the Mesozoic New Zealand Fold Belt and the Cretaceous to Tertiary Tasman Rift Valley and Tasman Sea (Mayne et al., 1974). The oldest sedimentary rocks within the Sydney Basin are composed, at least in part, of volcanic material similar to that of the New England Fold Belt (Mayne et al., 1974). The material recovered in several deep wells is thought to be a remnant of a diatreme from the Triassic period (Mayne et al., 1974). Various sills, plugs, flows and tuffs of Permian, Jurassic, Cretaceous and Triassic age are located within the Sydney Basin (Mayne et al., 1974).

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1.1.4 Hydrogeology and groundwater quality

Summary

The Central West subregion includes groundwater systems in alluvial aquifers associated with major streams (including their precursors), volcanic rocks of the Warrumbungle and Liverpool ranges (Cenozoic Basalts), aquifers of the Great Artesian Basin (GAB), aquifers in the Gunnedah-Oxley Basin, and fractured rock aquifers of the Lachlan Fold Belt. These aquifers are incorporated into NSW water sharing plans, as well as the Murray–Darling Basin Plan.

Groundwater monitoring is undertaken by the NSW Government, and is generally limited to high-use alluvial aquifer systems and parts of the GAB. Additional monitoring may be undertaken by proposed resource developments and other actions with environmental conditions placed on their approval.

Groundwater is mainly sourced from the upper alluvial aquifers, and is most heavily used in the Lower Macquarie River system. Groundwater in the alluvial systems is generally of good quality, and reasonably fresh. There is some salinity variation and zonation in the alluvial systems, such as the highly saline zones adjacent to the Bogan River and salinity stratification in the (Pleistocene) Trangie Formation aquifer (Macaulay and Kellett, 2009). Water from the alluvial systems is used for town supply, irrigation, stock and domestic use.

Groundwater in the Cenozoic Basalts occurs in local flow systems and is generally fresh.

Groundwater in the Surat Basin system is found in the Drildool and Keelindi beds, as well as the Pilliga Sandstone. Between Narromine and Warren, these three aquifers are combined and referred to as the 'Sandstone Aquifer'. Waters are generally fresh, and suitable for town water, stock and domestic use. Downstream of Warren, the high sodium adsorption ratio renders GAB waters generally unsuitable for irrigation use.

Water from the Gunnedah Basin groundwater system is of variable quality and generally low salinity. It is not used widely in the subregion as it underlies the alluvial and GAB systems in the eastern part of the subregion.

Watertable elevation in the Central West subregion decrease from the south to the north and north-west, and the groundwater flows in this direction. Recharge to the alluvial systems is dominated by flood recharge, with some component of rainfall contributing. Recharge to the basalt aquifers occurs by diffuse recharge from rainfall. Recharge to the GAB aquifers occurs in areas of outcrop to the south and south-east, with potential recharge via leakage from the lowermost alluvial system where it is in direct contact with unweathered GAB units. Studies by Radke et al. (2000) and Macaulay and Kellett (2009) identified leakage from the Macquarie and Castlereagh rivers as important local recharge sources for the GAB. Little is known about the recharge dynamics of the Gunnedah Basin system. It is likely to be recharged in outcropping areas and may be supplied by vertical leakage from the overlying GAB where the hydraulic gradient is downward.

Discharge from the alluvial systems is via seepage and baseflow, with some potential leakage to the GAB aquifers. Discharge from the basalt systems is as seepage, and local contributions to stream baseflow. Discharge from the GAB occurs as throughflow, as well as some component of vertical leakage to the Gunnedah Basin and possibly upwards into the alluvial systems. No information is available about discharge from the Gunnedah Basin.

1.1.4.1 Groundwater systems and monitoring

1.1.4.1.1 System boundaries and hydrostratigraphic units

The Central West subregion includes the following geological environments (from youngest to oldest) which represent individual groundwater systems:

- alluvial aquifers associated with major streams, including the Macquarie, Talbragar and Castlereagh rivers
- Miocene and Eocene basalts of the Warrumbungle and Liverpool ranges (Cenozoic Basalts)
- the portion of the Surat Basin that lies within the Coonamble Embayment of the Great Artesian Basin (GAB)
- the Gunnedah Basin
- a small portion of north-western Sydney Basin[3]
- fractured rock aquifers of the Lachlan Fold Belt, which, within the boundaries of the subregion, occur south-east of the Warrumbungle Ranges, north-east of Nyngan and east of the Bogan River.

The spatial configuration of the system boundaries is represented by sustainable diversion limits (SDL) resource units which are shown in plan view in Figure 22. Smithson (2010) provides hydrogeological cross-sections across the Upper Macquarie river basin within the subregion, providing representative context for the alluvial aquifer systems. Appendix A of EMGA Mitchell McLennan Pty Ltd (2012) provides conceptual hydrogeological cross-sections of the area surrounding the proposed Cobbora coal mine, which provide context for the Gunnedah Basin system and interactions with the alluvial system. The geological basin boundaries for the Surat and Gunnedah basins are shown in Figure 16.

[3] The Sydney-Gunnedah-Bowen Basin is essentially a continuous geological feature so basin boundaries are somewhat arbitrary; however the subdivisions are accompanied by changes in stratigraphic nomenclature. The boundary between the Gunnedah and Sydney Basins is considered by some authors to be the Mount Coricudgy Anticline (Tadros, 1993) and by others as the Liverpool Range (Stewart and Alder, 1995). Both the Sydney and Gunnedah Basins are overlain by the Surat Basin.

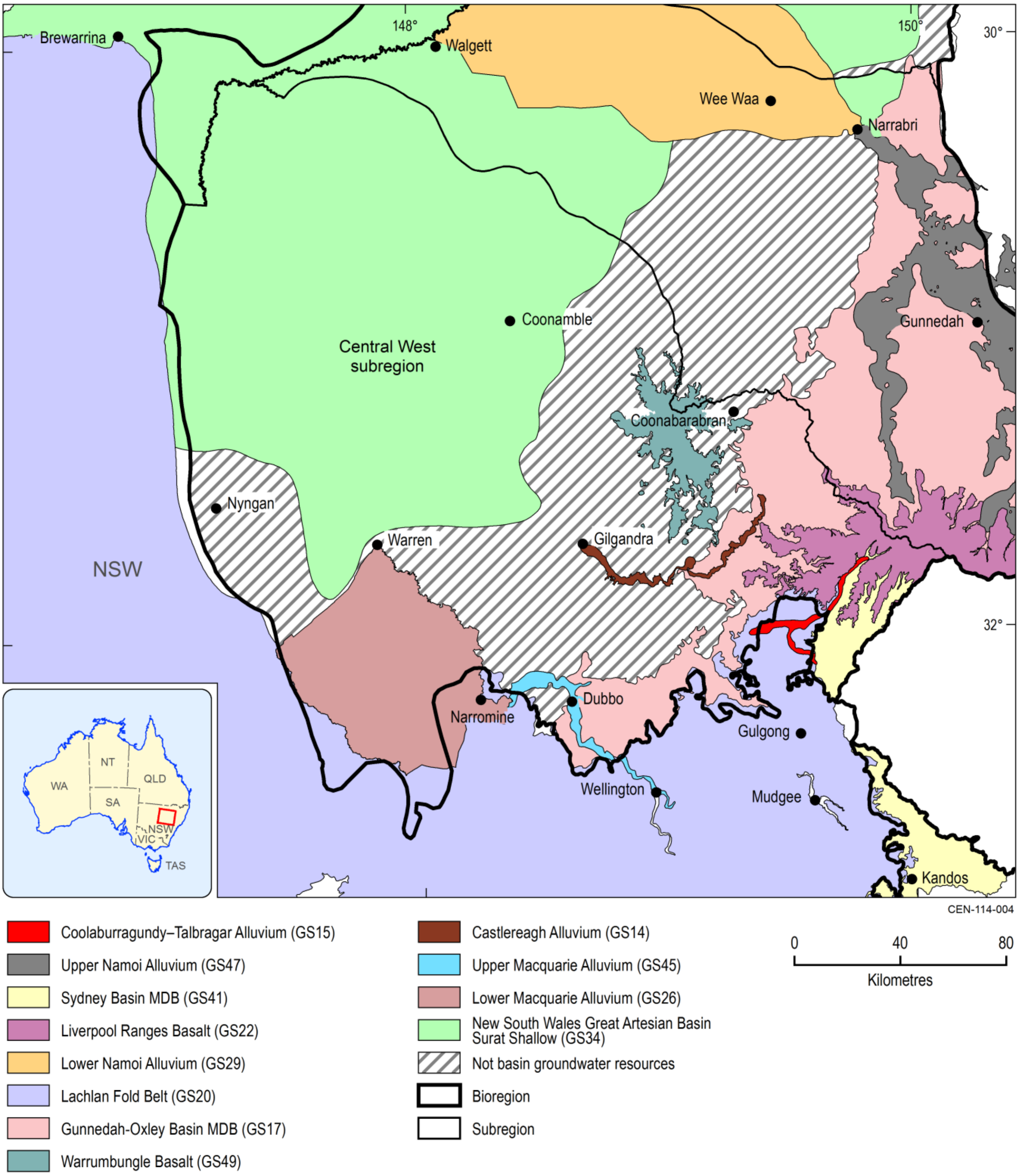

Figure 22 Map of groundwater systems represented by groundwater sustainable diversion limit resource units for the *Basin Plan 2012*, made under the *Water Act 2007*

The area shown as 'Not basin groundwater resources' corresponds to areas of Pilliga Sandstone outcrop and subcrop.

Alluvial aquifers

The alluvial aquifers of the Macquarie river basin are the main groundwater sources for irrigation and town supply in the subregion. The 'Upper Macquarie' Alluvium extends from Wellington downstream to Brummagen Creek (between Dubbo and Narromine, Figure 22). The 'Lower Macquarie' Alluvium extends downstream from this point to Warren, and spans the area between the Macquarie and Bogan rivers. Significant alluvial aquifers are also associated with the Castlereagh and Talbragar rivers (Figure 22, Figure 25).

Alluvial aquifers extend to depths of up to 160 m below the Lower Macquarie River downstream of Narromine (Macaulay and Kellett, 2009), and to lesser depths in other catchments and upstream areas. The deepest parts of the alluvial aquifer system are coincident with the Southern Paleovalley of Macaulay and Kellett (2009), which underlies the lower slopes and plain of the Lower Macquarie and Bogan rivers between Narromine and Dandaloo. These paleovalley sediments have been found to be Pliocene in age (Macphail, 2008), and are equivalent to the Gunnedah Formation. Upper (Quaternary) and Lower (Neogene) units have been identified in the main deposits of the Upper Macquarie River downstream of Wellington (Smithson, 2010) and also within the Lower Macquarie river basin (Giambastiani and Kelly, 2010). The Murray–Darling Basin Authority (MDBA, 2012) refers to these units as the Narrabri and Gunnedah Formations respectively (in accordance with the geology of the Namoi valley to the north), but this nomenclature is not universally accepted. Smithson (2010) provides cross-sections of the Upper Macquarie Alluvium for a variety of locations. Downstream of Narromine, Quaternary deposits can be divided into four formations (Macaulay and Kellett, 2009), comprising the Marra Creek, Bugwah, Carrabear, and Trangie formations. The Gunnedah Formation is the main alluvial aquifer, while aquifers also occur within coarser-grained units of the Narrabri Formation (including the Bugwah and Carrabear Formations in the Lower Macquarie river basin). Across much of the Central West subregion, the alluvial units unconformably overlie units of the Surat Basin, except toward the south-eastern boundary, where they overlie the Gunnedah-Oxley Basin.

Cenozoic Basalt aquifers

The Warrumbungle and Liverpool ranges basalts were formed during the Miocene and Eocene by shallow igneous activity. They locally intrude and overlie the Surat and Gunnedah-Oxley basin strata as volcanic plugs and dikes, and also as lava flows. They contain minor, fractured rock aquifers (Figure 22).

Great Artesian Basin aquifers

The Surat Basin occupies approximately 300,000 km^2 of south-eastern Queensland and north-central NSW (Kellett et al., 2012). It directly overlies the Gunnedah Basin in the east of the Central West subregion, and the Lachlan Fold Belt in the west. The Surat Basin strata occupy the Coonamble Embayment component of the GAB, and range in age from Late Triassic to Early Cretaceous (Kellett et al., 2012). Strata crop out in the central part of the subregion, are largely buried by Cenozoic alluvial sediments in the west, and are absent in the east.

The top of the Surat Basin in the Coonamble Embayment is defined by the Drildool and Keelindi beds between Narromine and Warren, and by undifferentiated Rolling Downs Group (probably the Griman Creek Formation) north of Warren (Kellett et al., 2012; Burton, 2011). The basal unit is the Garrawilla Volcanics. The Drildool and Keelindi beds comprise a large portion of Surat Basin strata in the subregion. Towards the southern and eastern boundaries of the Central West subregion, the Surat Basin sediments comprise the Pilliga Sandstone and Purlawaugh Formation. The Surat Basin contains a sequence of interlayered aquifers and aquitards. The main aquifer in the Surat Basin sequence is within the Pilliga Sandstone, with significant aquifers present in the Drildool and Keelindi beds (Kellett et al., 2012).

The 'Oxley sub-basin' is not formally recognised in 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. Maps by both Schlumberger Water Services Australia (2012) and the NSW Office of Water (2012) indicate the Oxley sub-basin cropping out in the Central West subregion in the area between the Warrumbungle and Liverpool range basalts. MDBA (2012) presents the Oxley sub-basin as disconnected units within the Upper Macquarie and Upper Castlereagh catchments.

Gunnedah Basin aquifers

The Gunnedah Basin directly overlies fractured rocks of the Lachlan Fold Belt and contains up to 1200 m of marine and non-marine Permian and Triassic sediments within which the coal-bearing strata of the Black Jack Formation and the Maules Creek Formation occur (Schlumberger Water Services Australia, 2012). Strata are exposed in the eastern part of the region, occur at depth beneath the Surat Basin in the central parts, and are absent in the west (NSW Government, 2013c).

The Triassic Napperby Formation marks the top of the Gunnedah Basin in this subregion. This is underlain by the Digby Formation, which overlies the Dunedoo Formation. The basal units are the Goonbri and Leard formations. Where these are not present, the coal-bearing Maules Creek Watermark and Porcupine Creek Formations are the basal units (Schlumberger Water Services Australia, 2012; EMGA Mitchell McLennan Pty Ltd, 2012).

Sydney Basin aquifers

The main hydrogeological units identified in the north-western part of the Sydney Basin are the Quaternary alluvium, Cenozoic paleochannel deposits, Triassic Narrabeen Group sediments, Permian coal measures and the basal units of the Early Permian Shoalhaven Group, Nile sub-group and Marrangaroo Formation (RPS Aquaterra, 2011). The principal aquifers are associated with the Permian sediments, including the Ulan coal seam, and within some parts of the Cenozoic paleochannel deposits. The Triassic Narrabeen Group and weathered granite basement also provide some groundwater resource potential. The Shoalhaven Group sediments and Quaternary alluvium are considered to contain only localised aquifers with minor groundwater potential (Mackie Environmental Research, 2009; RPS Aquaterra, 2011).

Hydrostratigraphic relationships

Hydrostratigraphic relationships of the Surat and Gunnedah Basins in the Central West subregion are outlined in Figure 23, and indicate the temporal sequence of geological unit development, and relative hydrostratigraphic classification. The Cenozoic aquifers and aquitards shown in Figure 23 represent the upper and lower alluvial aquifers in the Central West subregion. A more specific subregional hydrostratigraphic relationship diagram is not available.

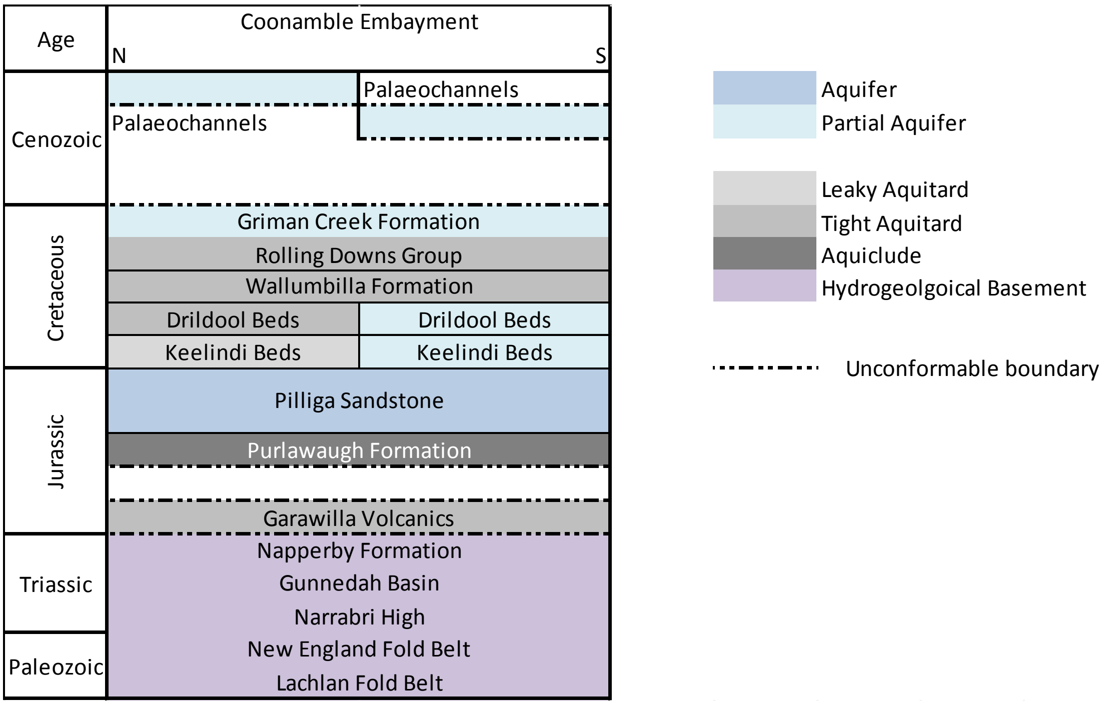

Figure 23 Hydrostratigraphic relationships in the Surat and Gunnedah basins

Source: Modified from Figure 5.9 in Kellett et al. (2012)

1.1.4.1.2 Groundwater monitoring and assessment

Groundwater monitoring is undertaken by the NSW Government for priority groundwater systems – primarily the major alluvial aquifers. Figure 24 shows the distribution of all bores from the National Groundwater Information System (NGIS) dataset (Bureau of Meteorology, 2013) with at least one water level measurement, overlain by the subset of those bores that have more than two water level readings between 1 January 2008 and 20 February 2013. It is apparent from the distribution of monitoring bores that the focus for monitoring is on alluvial aquifer systems.

In the Upper Macquarie river basin, groundwater level monitoring commenced in 1970, with additional sites being established up until 2009. The monitoring network consists of 65 bores at 45 sites (Smithson, 2010). Groundwater level monitoring is undertaken at a variety of time intervals, and is mostly done manually. Groundwater quality sampling and analysis are carried out infrequently, and in the Upper Macquarie were last undertaken in 2009 to 2010.

Monitoring networks also exist in the Lower Macquarie catchment and the Macquarie Marshes area in the north of the subregion.

The NSW Government also undertakes monitoring in the GAB. The NSW Office of Water (2009) states 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 (2009) indicated that 65 of these GAB bores were being monitored at least once every two years. A subset of this network occurs in the Central West subregion.

Additional non-government groundwater monitoring networks include:

- local governments that source town supplies from groundwater (for example, Dubbo City Council)
- individual development proposals that require environmental assessments (for example the proposed Cobbora coal mine, which is intended to mine coal from the Flyblowers Creek, Ulan Upper and Ulan Lower coal seams of the Permian Dunedoo Formation of the Gunnedah Basin)
- other developments that are required to undertake monitoring and reporting.

Groundwater assessment is undertaken by NSW Government for priority groundwater systems, such as the Upper Macquarie alluvial aquifers (e.g. Smithson, 2010), to support local planning requirements and the development and amendment of water resource sharing plans. Data collection and assessment has also been 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.

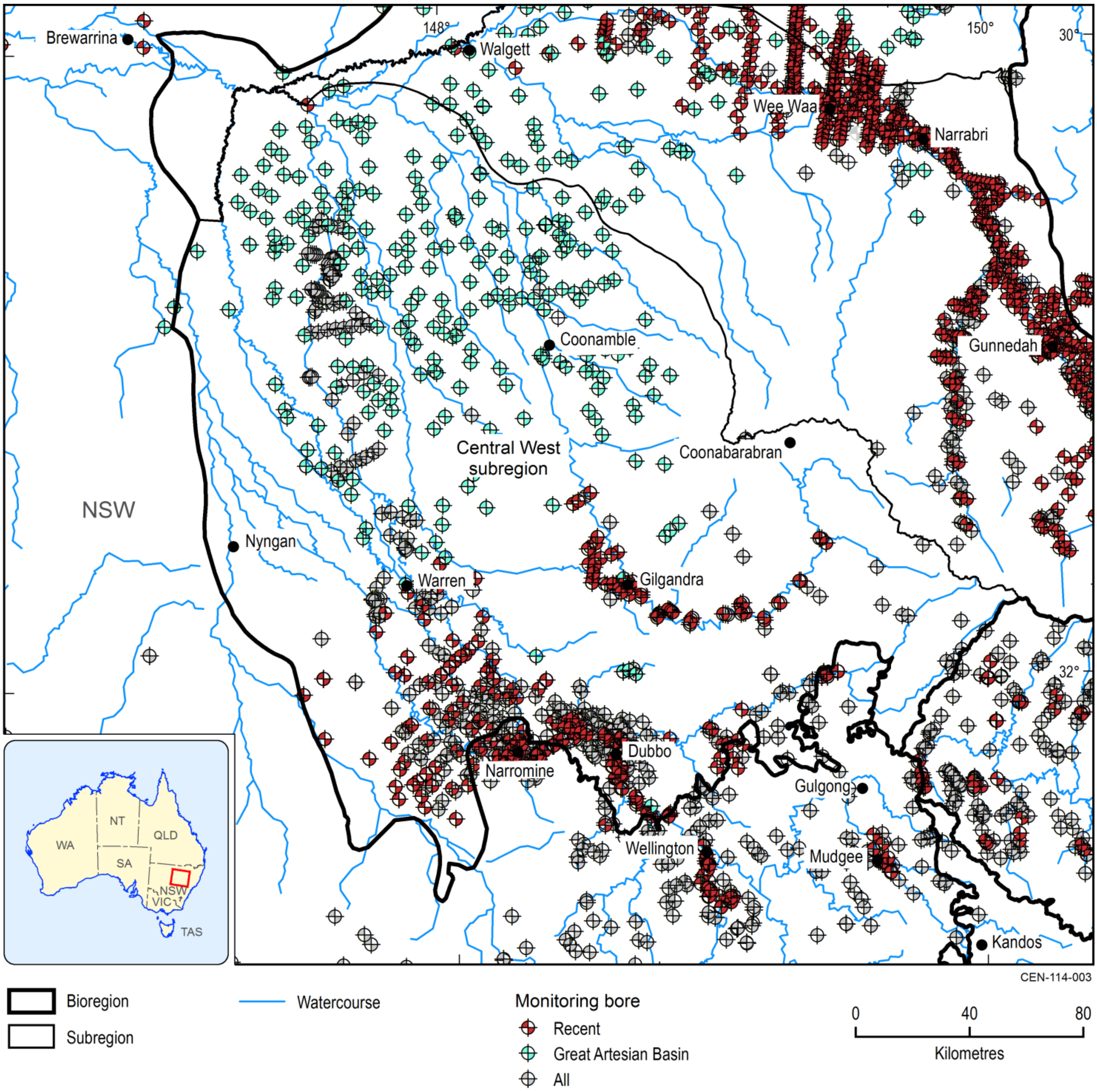

Figure 24 Distribution of NSW groundwater bores in the NGIS database for which at least one groundwater level measurement is recorded

'Monitoring bores recent' are locations where at least two water levels are reported in the last five years (since 1 January 2008). 'Monitoring bores GAB' 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).
Source data: Bureau of Meteorology (2013)

1.1.4.2 Groundwater levels and flow

1.1.4.2.1 Alluvial aquifers

Smithson (2010) describes groundwater levels in the Upper Macquarie Alluvium. This work was undertaken prior to the 2010 La Niña- related floods and key findings include:

- Groundwater is generally unconfined in the upper aquifer down to 25 m, then partly confined below this.
- The lower aquifer is unconfined to partially confined, and is likely to be more confined in its deepest sections below 55 m.
- The upper and lower aquifers are mostly well connected – laterally and vertically.
- Groundwater levels responded to the main river flood events of 1990, 1998 and 2000 – especially in bores close to the river.
- The Macquarie River has a combination of gaining and losing reaches, and this changes with flood recharge and drought events.
- Since the onset of the drought in 2002 groundwater levels have declined in all parts of the aquifer, with falls of between 0.5 and 9 m. Prior to this, the long-term trend was mostly stable, except in the Dubbo area (up to 18 m decline since commencement of monitoring in the early 1970s), where seasonal pumping drawdown (of between 1.5 and 6 m) also occurs.
- Since 2002 some parts of the aquifer are showing changed lateral or vertical hydraulic gradients.

Groundwater flow in the Gunnedah Formation aquifer is shown in Skelt et al. (2004) to be generally in a north-westerly direction. These authors delineate flow directions in the Narrabri Formation (and equivalents) to be generally parallel to existing waterways, also in a north-westerly direction.

Giambastiani and Kelly (2010) analysed 141 bore hydrographs in the Macquarie-Bogan Catchment for long-term trends in standing water level from 1988 to 2008. In the Gunnedah Formation aquifer, depressurisation has occurred in areas with the highest level of abstraction, and the system in these areas has not reached a new equilibrium. Water levels in the Narrabri Formation groundwater system in the southern part of the subregion (around Trangie, Narromine and Gin Gin) show a rising trend over the period of analysis. It is thought that this is due to increased recharge as a result of increased deep drainage from irrigation flow-through (Giambastiani and Kelly, 2010).

Recent measurements (post-2000) of the groundwater level in the alluvial aquifer systems in the Central West subregion are shown in Figure 25. The watertable aquifer shows the same trend as that identified by Skelt et al. (2004), with the groundwater level decreasing to the north and north-west, parallel to topography.

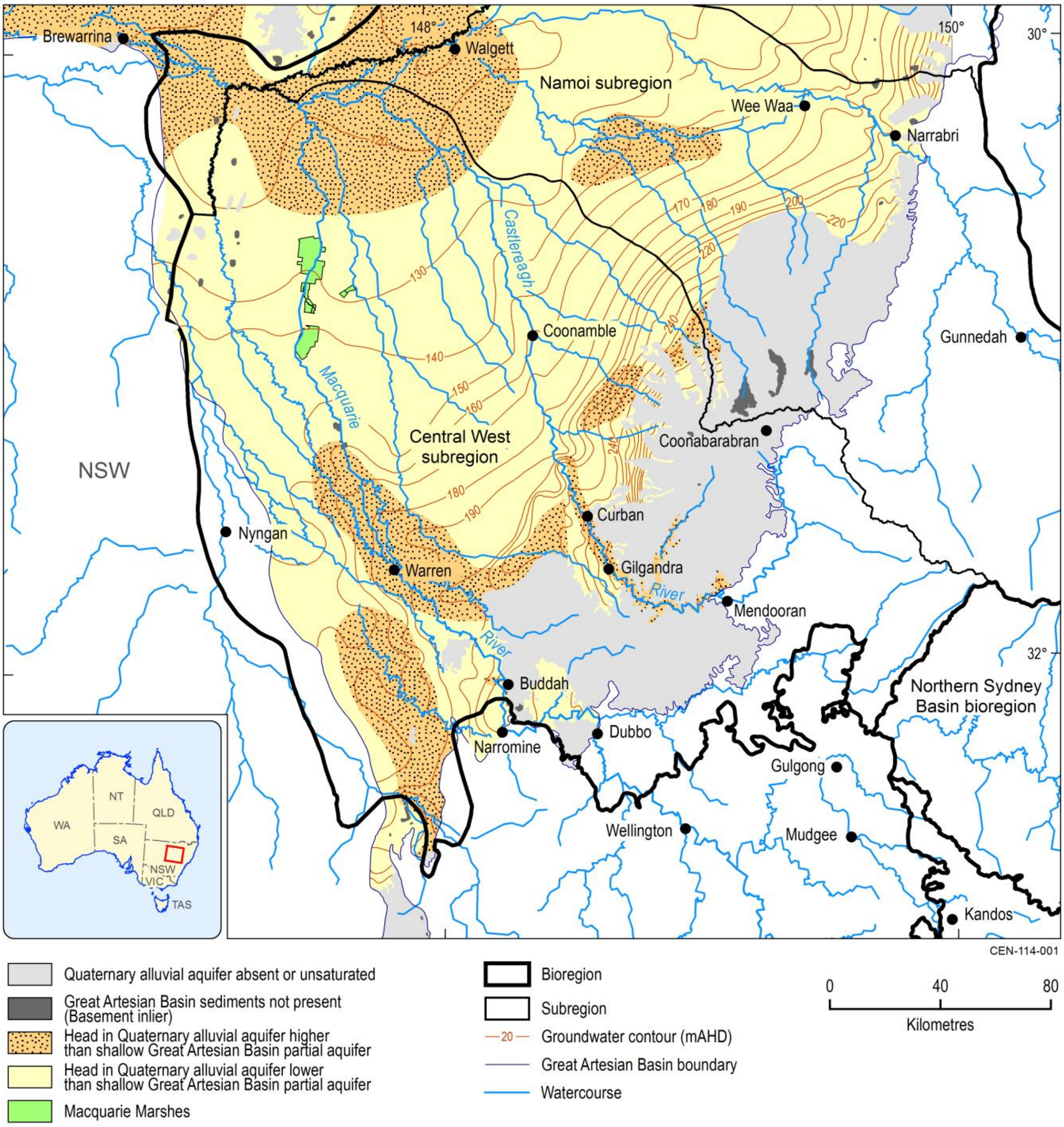

Figure 25 Groundwater flow for the alluvial aquifer systems in the Central West subregion

Source data: Modified from Kellett and Stewart (2013)

Skelt et al. (2004) summarise the recharge and discharge characteristics of the alluvial aquifer systems in the Central West subregion. Recharge is seasonal and episodic. It is dominated by flood recharge, especially in the lower reaches of the streams associated with alluvial aquifers. Volumes are dependent upon the nature of the material directly above the watertable and the frequency and intensity of flooding.

Discharge typically occurs into drainages and where properties of the overlying materials change significantly. Minor discharge from the alluvial systems also occurs at breaks-in-slope (Skelt et al., 2004).

Cenozoic Basalts

No information is available on groundwater levels in the Cenozoic Basalts. However, it is expected that these would be local flow systems, with groundwater flow generally following surface elevation contours, and providing baseflow to local streams and leakage to underlying aquifers of the Gunnedah-Oxley and Surat basins.

Due to the nature of the basalt groundwater systems, recharge occurs across the landscape. Discharge occurs locally as seepages where geological changes impede flow paths, or topography changes significantly. Where streams incise this aquifer system, the basalts may contribute to baseflow (Skelt et al., 2004).

1.1.4.2.2 Great Artesian Basin

Surat Basin

Figure 26 is modified from the regional potentiometric surface developed for the Surat Basin by Kellett et al. (2012) as part of the Great Artesian Basin Water Resource Assessment. The surface was developed using all available groundwater data and shows that the groundwater in the uppermost GAB units flows from south-east to west and north-west. Generally, the watertable aquifer in the Coonamble Embayment lies within the Drildool and Keelindi beds (adjacent to the southern boundary of the GAB) north-west to Warren, and then into the Rolling Downs Group. The watertable tends to be topographically controlled. Within the confined aquifer systems of the Surat Basin in the subregion, groundwater flow is to the north and west, driven by recharge in the southern and eastern margins of the subregion. In the area around Carinda and the Bogan River, mound springs occur, as do flowing bores basinward from Coonamble (Brownbill, 2000). Potentiometric surface mapping for the uppermost unit of the GAB in the Central West subregion shows flow to be from the intake beds towards the west and north-west, trending more northerly toward the Surat Basin (Figure 26).

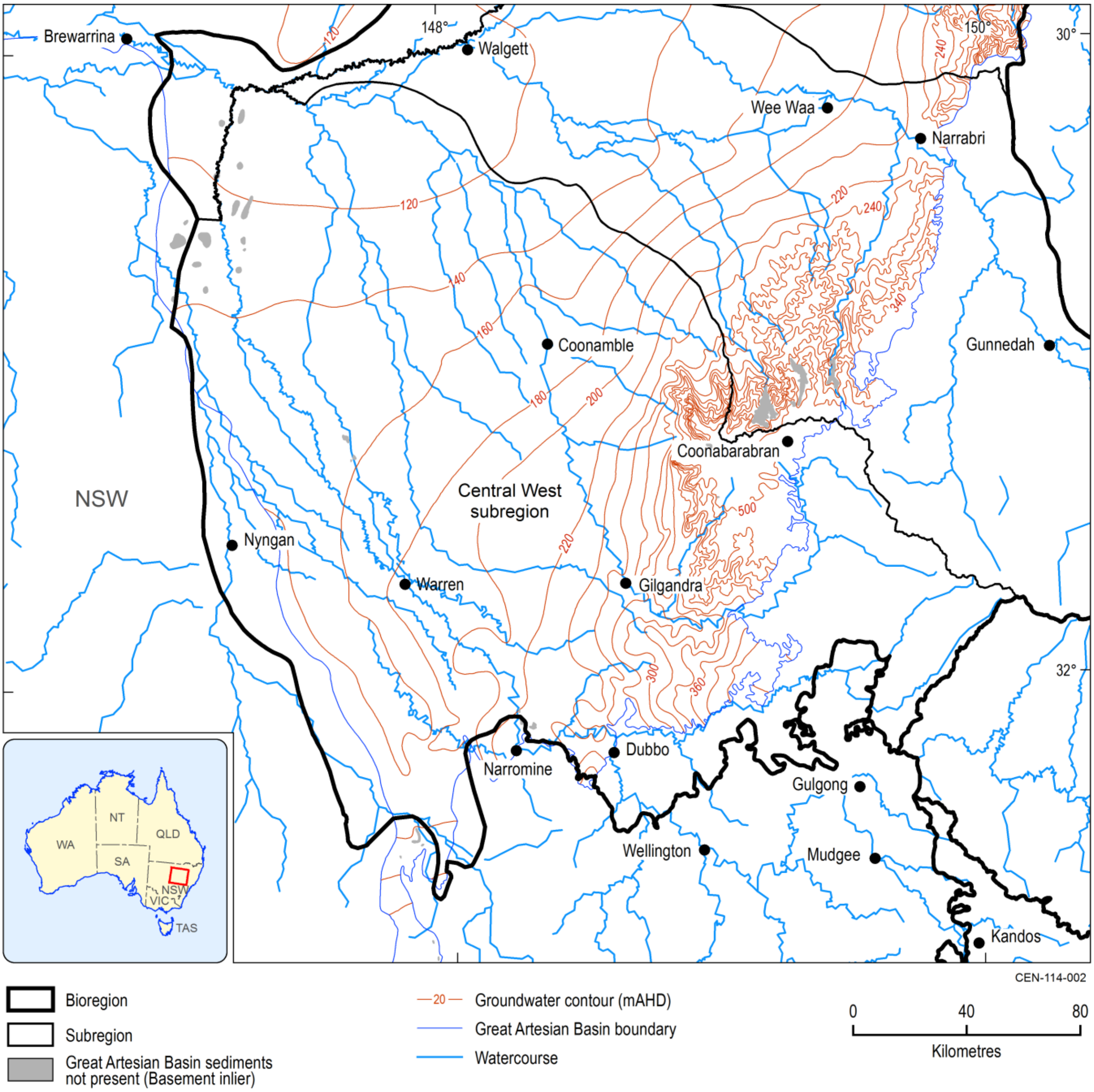

Figure 26 Potentiometric surface map of the uppermost unit of the Great Artesian Basin in the Central West subregion

Source data: Modified from Figure 5.19 in Kellett et al. (2012)
Generally this is the Rolling Downs Group, but in the southern and eastern parts of the subregion may be the Drildool beds, Keelindi beds or Pilliga Sandstone.

1.1.4.2.3 Gunnedah Basin

Information relating to groundwater levels and flow for the Gunnedah Basin in the Central West subregion is only available from EMGA Mitchell McLennan Pty Ltd (2012). Data for this study are limited to the area adjoining the southern boundary of the subregion, approximately 40 to 70 km east of Dubbo. This indicates that flow is influenced by stratigraphic dip, aquifer depth and structural architecture. Generally, flow is to the north and north-west. Groundwater levels range from about 450 mAHD to about 340 mAHD adjacent to the Talbragar River, which are lower than the GAB potentiometric levels in the region of about 400 to 300 mAHD where GAB aquifers are present in this area. The limited spatial extent of the data used to derive this information affects the ability to extrapolate outside the Cobbora Project Area.

1.1.4.2.4 Inter-aquifer connectivity

As outlined in preceding sections, while the alluvium in the subregion is typically separated in literature into the overlying Narrabri Formation and underlying Gunnedah Formation, the contact between them is lithologically difficult to determine in places and some authors question the validity of this separation. Some degree of hydraulic connectivity is reported between the aquifers of both formations (e.g. Giambastiani and Kelly, 2010), with leakage from the Narrabri Formation cited as a potential source of recharge to the Gunnedah Formation aquifers.

Intense weathering of exposed GAB rocks prior to deposition of overlying alluvium resulted in development of a basin-wide saprolite layer (Kellett and Stewart, 2013). The base of the saprolite has low permeability, which is considered to reduce connectivity with overlying hydrostratigraphic units. In some places the saprolite has been removed by erosion making hydraulic connection possible (Kellett and Stewart (2013). Such areas occur beneath paleochannels, of which there are reportedly many in the Surat Basin, which commonly occur beneath or adjacent 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 (Figure 25, Figure 26).

In the Central West subregion, Kellett and Stewart (2013) indicate that areas where downward flow of water from the alluvium to the underlying GAB are likely to include:

- the Buddah kink on the Macquarie River, 20 km north of Narromine.
- the Castlereagh River between Mendooran and Curban.

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

A preliminary regional scale desktop assessment of the potential for hydraulic connectivity between the GAB and underlying formations was undertaken as part of the Great Artesian Basin Water Resource Assessment (Kellett et al., 2012). Such connectivity can occur where aquifers, partial aquifers and leaky aquitards are juxtaposed at the base of the GAB and the top of underlying formations. Figure 27 shows that such hydraulic connectivity is unlikely across most of the subregion. Generally, the formations underlying the GAB are interpreted as being aquicludes or tight aquitards, and the base of the GAB consists of an aquifer or partial aquifer. In the area to the west of Coonabarabran, however, the underlying formation is interpreted to be an aquifer, while the base of the GAB is here identified as a tight aquitard.

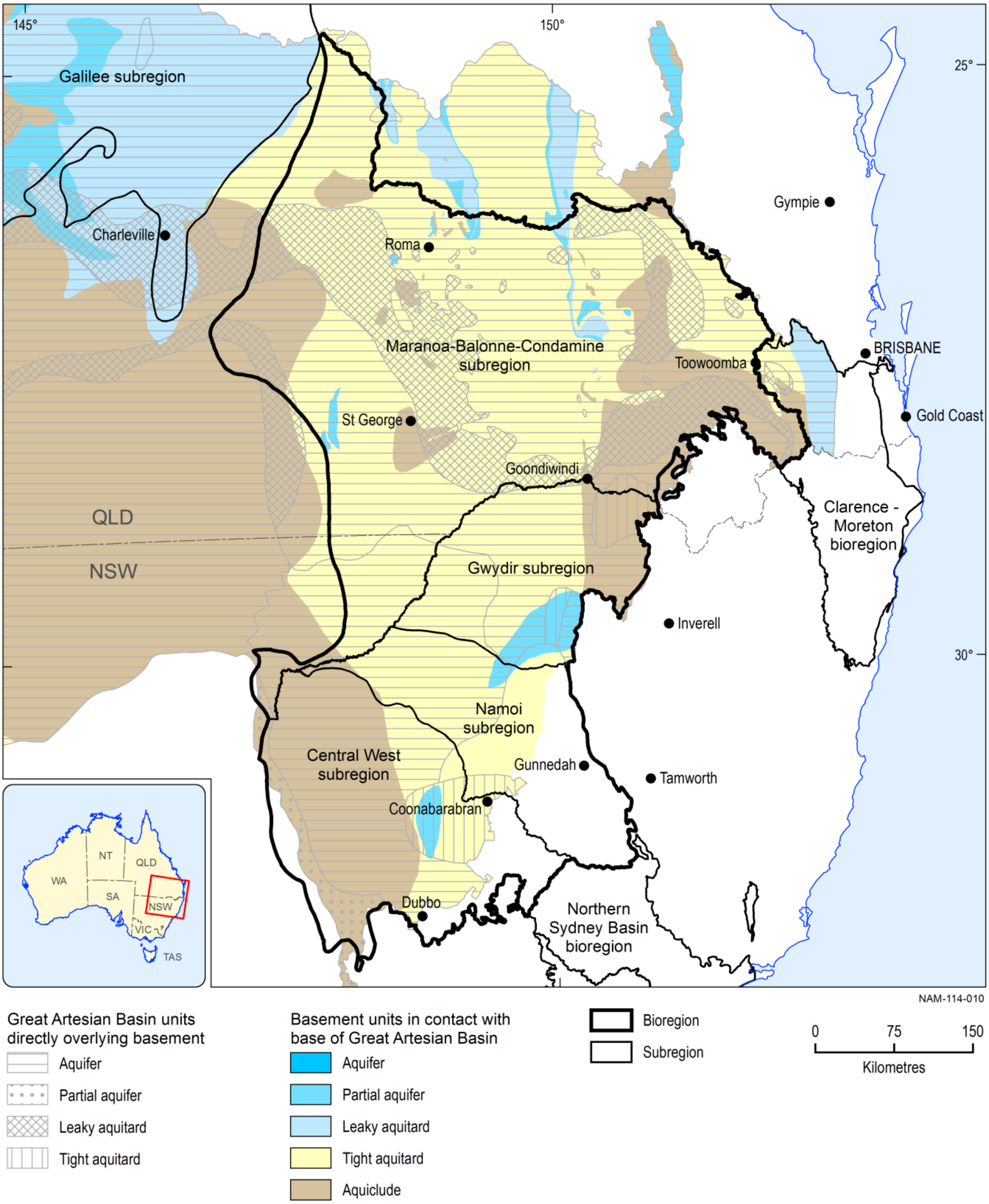

Figure 27 Potential hydraulic interconnection between the Great Artesian Basin and basement units in the Northern Inland Catchments bioregion

Source data: Modified from Figure 5.7 in Kellett et al. (2012)

The Macquarie Marshes

A comprehensive multi-disciplinary study of the Macquarie Marshes by Macaulay and Kellett (2009) showed that the marshes are connected to the shallow alluvial groundwater system. This system is hosted within the Quaternary sediments of the Lower Macquarie Alluvium. Previous work described in the study identified the potential for GAB aquifers to provide water to the marshes, due to artesian conditions being recorded in bores in the area. Macaulay and Kellett (2009) state that this would require a conduit linking the Pilliga Sandstone aquifer to the Cenozoic sediments, through several hundred metres of intervening Rolling Downs Group, Drildool beds and Keelindi beds. Macaulay and Kellett (2009) showed, based on three-dimensional geophysical mapping, that a thick, continuous saprolite layer separates the Macquarie Marshes from the Pilliga Sandstone. This layer, interpreted as highly weathered Rolling Downs Group, acts as an impermeable barrier, blocking upward leakage from the Pilliga Sandstone. No potential conduit for upward leakage was identified. Geochemical sampling also highlighted that the water in the shallow alluvial system associated with the Macquarie Marshes was distinct from GAB waters, as well as being much younger than would be expected if GAB waters were contributing to the system.

Macaulay and Kellett (2009) showed that groundwater in the Quaternary aquifers underlying the Macquarie Marshes are part of a groundwater throughflow system, not a discharge zone. These aquifers are recharged in a highly evaporative regime. The marshes themselves occupy a natural low in the landscape, and salts have accumulated over a long period. These salts are bound to clays and dissolved in shallow groundwater in the Quaternary aquifers.

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 Macquarie River. The lower alluvial aquifer of the Southern Paleovalley and the upper Quaternary aquifer of the Macquarie Marshes are distinct hydrostratigraphic units (Macaulay and Kellett, 2009). Groundwater salinity (as determined from electrical conductivity) of both the Upper and Lower alluvial aquifers of the Upper Macquarie is summarised in Table 9. In general, groundwater salinity is less in the Lower aquifer than in the Upper aquifer, and is lower upstream of Dubbo than downstream (Smithson, 2010).

EMGA Mitchell McLennan Pty Ltd (2012) describe groundwater electrical conductivities (EC) of the upper Talbragar alluvial deposits between 2009 and 2012 in the area immediately adjacent to the Cobbora Coal Project. EC was reported to range from approximately 1850 to 6950 μS/cm, with a mean of approximately 3650 μS/cm. The pH ranged from 6.2 to 8.0, with a mean of 7.1. MDBA (2012) depicts the alluvial deposits of the Castlereagh and Talbragar rivers as having groundwater salinity of mostly less than 1500 mg/L.

Table 9 Upper and Lower Macquarie alluvial aquifer salinity

Formation	Location	Range of electrical conductivity (μS/cm)	Mean electrical conductivity (μS/cm)	Range of salinity (mg/L)	Mean salinity (mg/L)
Upper alluvial aquifer	Upstream of Dubbo	300–1,718	896	192–1,100	573
	Downstream of Dubbo	288–18,700	2,433	184–11,968	1,557
Lower alluvial aquifer	Upstream of Dubbo	251–832	479	161–532	307
	Downstream of Dubbo	312–804	519	200–515	332
Basement	Sandstone	599–15,700	5,309	383–10,048	3,398

Source data: Smithson (2010)

The Southern Paleovalley contains a high yielding basal alluvial aquifer, from which good quality (EC <1000 μS/cm) groundwater is extracted for irrigation (Macaulay and Kellett, 2009). However, much of the area contains higher salinities, and levels of up to 26,900 μS/cm were observed at depths of about 10 to 15 m beneath the Macquarie Marshes. MDBA (2012) depicts the upper formations (down to 50 m depth) in the Lower Macquarie river basin as mostly having groundwater with salinity less than 1,500 mg/L, but with some zones, especially towards the Bogan River, having salinity over 3,000 mg/L and as high as 14,000 mg/L.

Cenozoic Basalts

MDBA (2012) depicts the Warrumbungle Basalt groundwater salinity as being less than 1500 mg/L, with the Liverpool Ranges being similar but with some higher salinity groundwater of up to 3000 mg/L within the western extremities.

1.1.4.3.2 Great Artesian Basin

Groundwater quality of the GAB varies but generally has salinity of 500 to 1500 mg/L in the Lower Cretaceous-Jurassic aquifers (Habermehl, 2002; Kellett and Stewart, 2013). The groundwater is of a Na-HCO_3-Cl type, and generally suitable for domestic, town supply and stock use. However it is unsuitable for irrigation in most areas due to its high sodium adsorption ratio. Kuske et al. (2011) identified the Cadna-owie Formation within the Coonamble Embayment as having salinity mostly in the range of 250 to 1000 mg/L. Macaulay and Kellett (2009) identify water in the Drildool and Keelindi beds with electrical conductivities of 1145 μS/cm and 1070 μS/cm within the Central West subregion.

MDBA (2012) depicts the Oxley sub-basin as having groundwater salinity varying up to 3,000 mg/L in the upper reaches of the Castlereagh and Talbragar Rivers, and increasing downstream to levels of 3,000 to 14,000 mg/L in areas between Dunedoo and Gilgandra.

Areas of high conductivity, inferred to represent high salinities, are shown in Macaulay and Kellett (2009) along the Bogan River, in the west of the subregion. However, detailed discussion was not provided.

1.1.4.3.3 Gunnedah Basin

Varying groundwater quality conditions have been reported by EMGA Mitchell McLennan Pty Ltd (2012) following drilling in the vicinity of the proposed Cobbora coal mine in the upper reaches of the Talbragar catchment. Data are summarised in Table 10.

Table 10 Groundwater quality in the Gunnedah Basin – proposed Cobbora mine

Aquifer group	EC range (µS/cm)	EC mean (µS/cm)	pH range	pH mean
Triassic	827–9060	3993	5.8–7.7	6.5
Permian	556–9030	1618	5.3–12.2	6.5

Source data: EMGA Mitchell McLennan Pty Ltd (2012)

1.1.4.4 Groundwater management and use

Groundwater planning and management is undertaken by the NSW Government via water sharing plans, which provide the means for managing individual groundwater systems and are effective for ten years from their date of commencement. Individual groundwater systems (excluding those of the GAB) are also represented in the Commonwealth's *Water Act 2007 – Basin Plan 2012*, for the Murray–Darling Basin. Relevant water sharing plans within the Central West subregion are listed in Table 11, and aligned with corresponding groundwater 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 average extraction limits
- the Basin Plan as baseline diversion limits and sustainable diversion limits.

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 NSW Lachlan Fold Belt extends beyond the Murray–Darling Basin, so the water sharing plan long-term mean annual extraction limit will be larger than the MDBA sustainable diversion limit.

Discrepancy occurs between long-term mean annual extraction limits (LTAELs) 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 the LTAELs 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 use of the water. Current entitlement levels, entitlement limits and recent annual extraction estimates are provided for each groundwater system in Table 12. Only the figures provided for the Castlereagh, Talbragar and Lower Macquarie alluvial aquifers are truly representative of the subregion, as the other groundwater systems extend beyond the subregion boundary.

The alluvial aquifers of the Upper and Lower Macquarie River are the major sources of groundwater supply in the region. Most of the groundwater from these systems is used for irrigation. Extraction for town supply is also significant, with the city of Dubbo being a major user of groundwater in the Upper Macquarie (Smithson, 2010). Gilgandra also relies on groundwater (Castlereagh Alluvium; Piscopo, 2001).

Groundwater extraction from the GAB is largely for stock and domestic use, and has been historically elevated with a total extraction in the Surat Groundwater Source of about 75,000 ML/y, of which about 90% was lost through leakage and evaporation from bore drains (NSW Government, 2009). This has been progressively addressed by programmes such the Great Artesian Basin Sustainability Initiative, 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). In the Lower Macquarie river basin within the Central West subregion, the sandstone units within the Keelindi and Drildool beds form a locally significant source of water for stock and domestic use, along with groundwater from the overlying alluvial deposits (Macaulay and Kellett, 2009).

Water in the Gunnedah-Oxley Basin sustainable diversion limit resource unit is managed under the water sharing plan for the NSW Murray–Darling Basin Porous Rock Groundwater Sources 2012 (NSW Government, 2013c). Limited information was found in the literature on water use from the Gunnedah-Oxley Basin, although the water sharing plan indicates considerable additional groundwater could be made available for use in the future. The water sharing plan includes three other groundwater sources in addition to the Gunnedah-Oxley Basin, and 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/y and estimated stock and domestic rights for the Gunnedah-Oxley Basin are reported in the water sharing plan to be 5779 ML/y (NSW Government, 2013c).

Table 11 Comparison of water sharing plans and the Murray–Darling Basin Plan

Groundwater system	Water Sharing Plan	Date commenced	Sub-component of Water Sharing Plan (and LTAEL[b])	Murray–Darling Basin Plan SDL unit (and BDL/SDL[c])
Alluvial aquifers	Water Sharing Plan for the Castlereagh River (below Binnaway) Unregulated and Alluvial Water Sources 2012 (NSW Government, 2012a)	1 October 2011	Castlereagh Alluvial Groundwater Source (0.62 GL/y)	Castlereagh Alluvium (0.62 GL/y)
	Water Sharing Plan for the Macquarie Bogan Unregulated and Alluvial Water Sources 2012 (NSW Government, 2012b)	4 October 2012	Talbragar Alluvial Groundwater Source (3.47 GL/y)	Collaburragundry-Talbragar Alluvium (3.47 GL/y)
			Upper Macquarie Alluvial Groundwater Source (17.93 GL/y)	Upper Macquarie Alluvium (17.9 GL/y)
	Water Sharing Plan for the Lower Macquarie Groundwater Sources 2003 (69,293 ML/y) (NSW Government, 2011)	1 October 2006	n/a	Lower Macquarie Alluvium (70.7 GL/y minus GAB comp)
	Water Sharing Plan for the NSW Great Artesian Basin Shallow Groundwater Sources 2011 (NSW Government, 2012c)	14 November 2011	GAB Surat Shallow Groundwater Source (143.33 GL/y)	NSW GAB Surat Shallow (6.57/15.5 GL/y)
Warrumbungle and Liverpool ranges basalts	Water Sharing Plan for the NSW Murray–Darling Basin Fractured Rock Groundwater Sources 2012 (NSW Government, 2013b)	16 January 2012	Warrumbungle Basalt Groundwater Source (0.571 GL/y)	Warrumbungle Basalt (0.55 GL/y)
			Liverpool Ranges Basalt MDB Groundwater Source (19.07 GL/y)	Liverpool Ranges Basalt (2.16 GL/y)
Surat Basin (within GAB Coonamble Embayment)	Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources 2008 (NSW Government, 2013a)	1 July 2008	Southern Recharge Groundwater Source ([a]42.4 GL/y)	n/a – not MDB
			Surat Groundwater Source ([a]75.0 GL/y)	n/a – not MDB
Gunnedah-Oxley Basin	Water Sharing Plan for the NSW Murray–Darling Basin Porous Rock Groundwater Sources 2012 (NSW Government, 2013c)	16 January 2012	Gunnedah-Oxley Basin MDB Groundwater Source (205.64 GL/y)	Gunnedah-Oxley Basin MDB (22.1/114.5 GL/y)
Fractured rock aquifers of the Lachlan Fold Belt	Water Sharing Plan for the NSW Murray–Darling Basin Fractured Rock Groundwater Sources 2012 (NSW Government, 2013b)	16 January 2012	Lachlan Fold Belt MDB Groundwater Source (875,652 ML/y)	Lachlan Fold Belt (142.4/259.0 GL/y)

[a] These are long-term average net recharge estimates. Annual extraction limits are calculated from these figures by subtracting the volume of planned environmental water – refer to NSW Government (2013a).
[b] Long-term average extraction limit (LTAEL)
[c] Baseline diversion limit (BDL)/Sustainable diversion limit (SDL). Where only one number is listed, the SDL is equal to the BDL.

Table 12 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)
Castlereagh River alluvial below Binnaway	Yes	0.58	0.72	0.62	0.62
Collaburragundry-Talbragar River alluvial	Yes	6.03	2.84	3.47	3.47
Upper Macquarie River alluvial (above Narromine)	No	32.65	18.26	17.9	17.9
Lower Macquarie River alluvial (below Narromine)	Yes	69.29	46.84	70.7	70.7
Warrumbungle Basalt	No	0.01	0.55	0.55	0.55
Liverpool Ranges Basalt	No	0.33	2.16	2.16	2.16
Surat Basin strata and minor alluvial above 60 m depth	No	NA	NA	6.57	15.5
Surat Basin strata below 60 m depth	No	na	na	na	na
Gunnedah-Oxley Basin strata	No	NA	NA	22.1	114.5

Source data: Commonwealth's *Water Act 2007 – Basin Plan 2012*
BDL – Baseline Diversion Limit; represents the MDBA's determination of the limits on groundwater use under existing water management arrangements.
SDL – Long-Term Average Sustainable Diversion Limits; these come into effect in 2019.
Recent annual extraction includes metered extraction volumes from licensed bores, and estimated extraction from authorised stock and domestic bores.
For the Warrumbungle and Liverpool ranges basalts there is no metering of licensed groundwater extraction; extraction has been estimated as total entitlements plus estimated extraction from authorised stock and domestic bores.
NA signifies that no information on current entitlements and recent annual extraction are provided for the GAB Surat Shallow Groundwater Source or the Gunnedah-Oxley Basin MDB Groundwater Source in MDBA (2012).
na signifies that the Surat Basin below 60 m (Great Artesian Basin) is not included in the Basin Plan (2012) or MDBA (2012).

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1.1.5 Surface water hydrology and water quality

Summary

The Central West subregion of the Northern Inland Catchments bioregion includes the Macquarie, Castlereagh and Bogan river basins. Areas of the Macquarie river basin upstream of Wellington and areas to the west of the Bogan River lie outside of the subregion. The Macquarie is a regulated river. The three major public water storages in the Macquarie river basin, namely Burrendong, Windamere and Chifley dams, are all upstream of the subregion. There are several off-river storages and weirs in the Macquarie River and its tributaries, totalling 943 GL of storage capacity. The Macquarie Marshes lies in the lower reaches of the Macquarie River before it joins the Castlereagh River and flows into the Barwon-Darling River. There are seven off-river irrigation water supply schemes in the Macquarie river basin that are part of the Macquarie valley irrigation scheme. The Castlereagh is an unregulated river and there are no major public water storage dams in the Castlereagh river basin.

The Macquarie River downstream of Narromine is prone to major flooding. A Macquarie River floodplain management plan covers the area from Narromine to Oxley Station. Floodwaters escape from the Macquarie River channel and enter different creeks, shallow lakes and swampy depressions during high flows. The towns of Gilgandra and Nyngan in the Castlereagh and Bogan river basins, respectively, have experienced major floods in the past, notably in 1955, 1990, 2000 and 2010. In the downstream reaches, floodwater from the Barwon River flows into the Castlereagh River through connecting channels.

Water quality indicators such as total phosphorus, turbidity, electrical conductivity and water temperature are measured in the Macquarie and Castlereagh river basins. The total phosphorus concentration is higher than the Australian and New Zealand Environment and Conservation Council limits for protecting the aquatic ecosystem at almost all observation points in the Macquarie River, while the turbidity is mostly within the limits. For two sites in the subregion, electrical conductivity and water temperature data showed the median of mean monthly electrical conductivity to be below 553 μS/cm and the mean monthly temperature ranged from 5 to 30 °C.

There are more than 60 stream gauging stations in the Macquarie and Bogan river basins, some of which have more than 100 years of flow records. The Castlereagh river basin has about eight gauging stations whose data lengths vary from a few years to more than 60 years. Modelling using climate change projections for 2030 conditions indicates a likely decrease in future runoff.

1.1.5.1 Surface water system

The surface water system of the Central West subregion is based on the Macquarie, Castlereagh and Bogan river basins (Figure 28). The full extent of these river basin areas is shown in Figure 5 (Geography chapter, Section 1.1.2.3). A relatively small area of the Marra Creek catchment in the Barwon-Darling basin, that is not part of the Macquarie river basin, also contributes to the surface water of the subregion. Catchment areas for the upper reaches of the Macquarie River (upstream of Dubbo) and the western side of the Bogan River are outside the subregion.

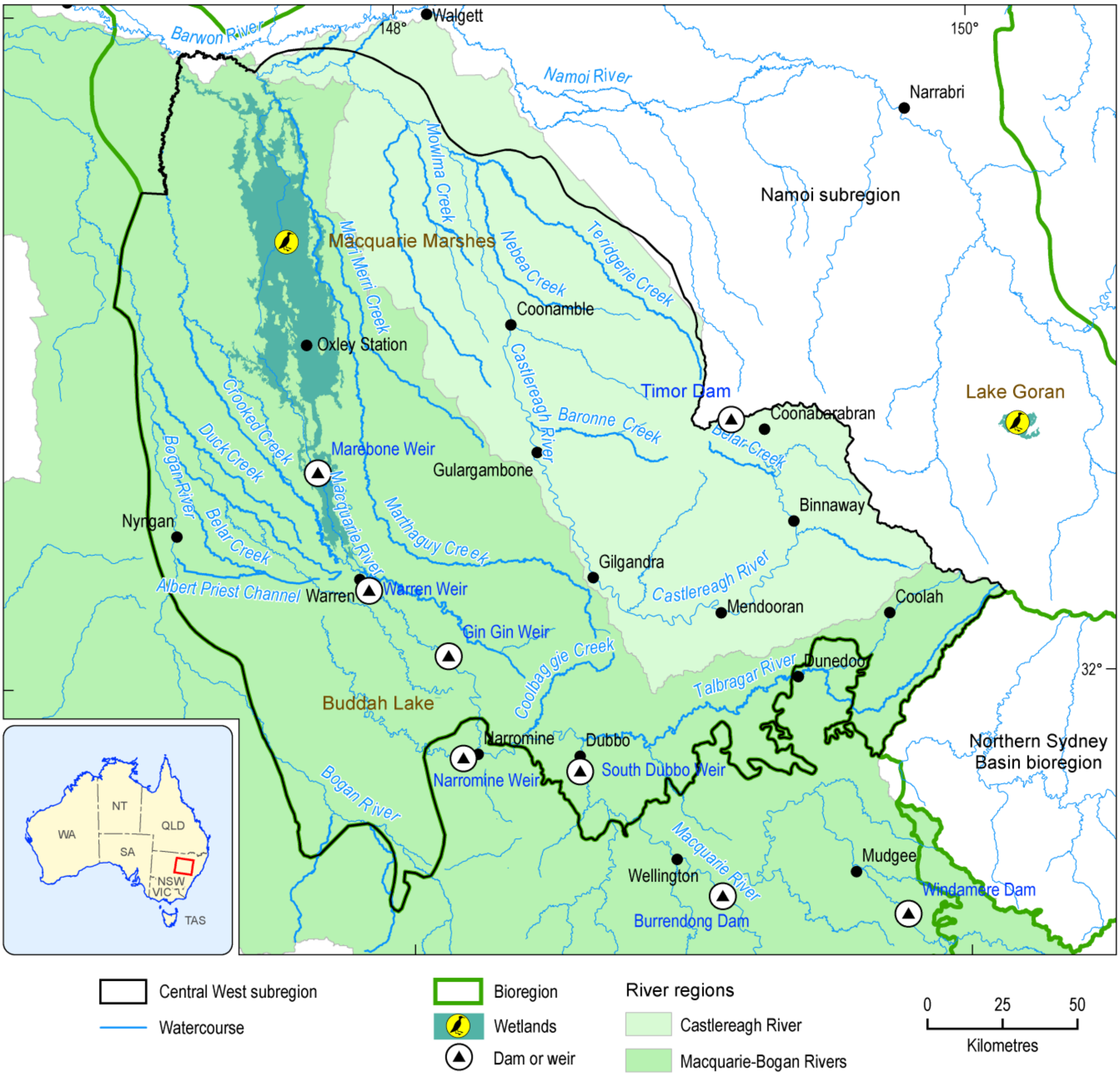

Figure 28 Central West subregion showing stream networks of Macquarie, Castlereagh and Bogan river basins, major tributaries and towns

Source data: Environment Australia (2001)

This report deals with surface water related to the Macquarie, Castlereagh and Bogan rivers within the subregion only. The total combined basins of these three rivers contribute about 8.4% of the total runoff in the Murray–Darling Basin (CSIRO, 2008).

Major surface water resources in the subregion include the three main rivers, wetlands and water storages. The main wetland of the subregion is the Macquarie Marshes located in the lower reaches of the Macquarie River. The tributaries of the Macquarie River *within* the Central West subregion are the Talbragar River, and Marthaguy, Coolbaggie, Ewenmar and Merri Merri creeks. Crooked Creek is an anabranch of the Macquarie River that bifurcates downstream of Warren.

Crooked Creek joins the Marra Creek flowing into the Barwon River at the northern boundary of the subregion.

The main tributaries of the Castlereagh River are Belar, Baronne, Binnia, Nedgera, Teridgerie, Terrawinda, Nebea, Mowlma, Womat and Wanourie creeks (DIPNR, 2004a). The main tributaries of the Bogan River within the subregion are Duck, Gunnigbar, Genaren and Bullock creeks.

The Macquarie River (about 626 km long) is a major tributary of the Barwon River and is formed by the convergence of the Campbells and Fish rivers rising south of the subregion in the Great Dividing Range (NSW Government, 2010). The Macquarie River flows northward through steep gorge areas before flowing into Burrendong Dam upstream of Wellington. The river then flows through Wellington, enters the Central West subregion upstream of Dubbo and passes through Dubbo and Narromine. Downstream of Narromine a complex system of anabranches and distributary creeks connects the Macquarie and Bogan rivers. Downstream of the Macquarie Marshes the Macquarie River is joined by the Castlereagh River, then flows into the Barwon River upstream of Brewarrina.

The Castlereagh River (about 540 km long) rises in the Warrumbungle Ranges and flows through Coonabarabran before entering hilly country. The river then flows through Binnaway, Mendooran, Gilgandra, Gulargambone and Coonamble and joins the Macquarie River downstream of the Macquarie Marshes. The floodplain between the Barwon and Castlereagh rivers is intersected by Womat and Wanourie creeks. These creeks carry flows from the Barwon River to the Castlereagh River during major floods (CSIRO, 2008). The annual mean contribution of the Castlereagh River to the Barwon River is 71 GL (Webb, McKeown and Associates Ltd, 2007). The Castlereagh River above Binnaway is regarded as a stressed river because, relative to the natural flows in the creek, the potential demand for extraction by water users is high. If everyone pumped water at the same time, there would not be enough water for all existing water users and the environmental needs of the river (DIPNR, 2004a). Restrictions are put in the relevant WSP on total and individual daily extraction limits to restrict access licence holders from taking more than a certain volume of water per day (see, for example, NSW Government, 2014a; NSW Office of Water, 2011).

The headwaters of the Bogan River (about 620 km long), in the Harvey Ranges between Parkes and Peak Hill, are upstream of the Central West subregion. The river then flows north-west through a broad, flat landscape through Nyngan and leaves the subregion about 100 km further downstream. The Bogan River joins the Barwon River just upstream of where the Barwon and Culgoa rivers join to form the Darling River. The annual mean inflow from the whole of the Macquarie-Bogan system to the Darling River is about 888 GL (Webb, McKeown and Associates Ltd, 2007).

The area of the combined drainage basins of the Macquarie, Castlereagh and Bogan rivers is approximately 84,850 km^2 (CMA CW, 2013), which is much greater than the Central West subregion area (46,735 km^2).

1.1.5.1.1 Surface water infrastructure

The Macquarie is a regulated river (CSIRO, 2008). The major public water storages in the Macquarie river basin are Burrendong Dam on the Macquarie River (1188 GL, completed 1967), Windamere Dam on the Cudgegong River (368 GL, completed 1984) and Chifley Dam on the Campbells River (31 GL, completed 1956), all of which are upstream of the subregion. The Warren and Marebone weirs are the two main weirs in the Macquarie River that are within the subregion. The others are Narromine, Gin Gin, Dubbo City Council, and Dubbo State Water weirs. The total volume of major dams, town water supply dams, weirs and farm storages in the Macquarie river basin is 2530 GL, including 1587 GL of storage in the Burrendong, Windamere and Chifley dams, 264 GL of on-farm hillside dams, 21 GL in weirs and 110 GL in ring tanks respectively (Webb, McKeown and Associates Ltd, 2007). The Macquarie Marshes are estimated to have a storage capacity of 500 GL (CSIRO, 2008).

The Castlereagh is an unregulated river and has no major public water storages (NSW Office of Water, 2012). However there are a number of smaller dams and weirs in the Castlereagh river basin. One of them is the Timor Dam, which is a water supply dam for the town of Coonabarabran (NSW Government, 2006).

The agriculture of the Central West subregion is highly dependent on irrigation. The area of the Macquarie Valley irrigation district – including areas outside of the Central West subregion – is about 13,000 km^2. There are seven off-river supply schemes supplying water to different properties in the district (MDBA, 2013). They are the Nevertire, Tenandra, Buddah Lake, Greenhide, Narromine, Trangie-Nevertire and Marthaguy schemes. There are highly developed irrigation areas near Buddah Lake.

Water sharing plan and surface water entitlements

The ten-year Macquarie and Cudgegong Regulated River Water Sharing Plan (WSP) commenced on 1 July 2004. Within the Central West subregion, the Plan applies to sections of the regulated Macquarie River from the upper limit of Burrendong Dam to Monkeygar Creek offtake, tributaries of the Bogan River and the Marra Creek (NSW Office of Water, 2014). Some of these regulated water sources include sections of Bulgeraga, Crooked, Bena Billa, Duck and Gunningbar creeks.

The surface water long-term annual extraction limit within the Macquarie and Cudgegong regulated river water source (excluding the Bogan River) under the WSP is 392 GL (NDWE, 2009; NSW Government, 2014b, Appendix 1). Table 13 lists the major surface water entitlements. The share components of the high security, general security and supplementary licences are expressed as a number of unit shares (DIPNR, 2004b). The unit share is the share of water allocated to licence holders as determined by the Available Water Determinations (AWDs) in volume per unit share. AWDs 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 AWDs (DIPNR, 2004b). AWDs are made for each licence category in each water source and are generally made at the start of a water year.

Table 13 Surface water entitlements in the Macquarie and Cudgegong regulated rivers

Entitlement Type	Share component
High security	19,419 unit shares
General security	632,428 unit shares
Supplementary licences	50,000 unit shares
Domestic and stock	14.26 GL/y
Local water utility	22.68 GL/y

Source data: DIPNR (2004b)

Diversion limits and the Basin Plan

The Murray–Darling Basin Authority estimates the surface water long-term average baseline diversion limit for the Macquarie-Castlereagh river basin (SS20) to be 734 GL/year (MDBA, 2012). This limit includes 380 GL/year from regulated and major unregulated rivers, and 44 GL/year from minor unregulated rivers (excluding basic rights). The limit on interception by runoff dams is set at 310 GL/year (including 44 GL/year of interception by commercial plantations). The sustainable diversion limit under the Murray–Darling Basin Plan requires that the surface water long-term average diversion limit be reduced from 734 GL/year by 65 GL/ year to meet local environmental targets plus any apportionment of the northern Basin zone shared reduction target set by the Basin Plan. 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 Macquarie-Castlereagh SDL resource unit.

1.1.5.1.2 Flooding history and flooding potential

The Macquarie River floodplain management plan covers an area of 26,000 km^2 along the Macquarie River from Narromine to Oxley Station upstream of the Macquarie Marshes (NDECC, 2008). The Burrendong Dam has a significant mitigating effect on minor to medium sized floods within the floodplain management plan area. In the Macquarie River, flooding is confined within the river banks upstream of Narromine. However much of the flow of large flood events leaves the river and flows through several shallow lakes and natural depressions in the reach between Narromine and Gin Gin. The overflows from the left bank, however, are restricted to a narrow floodplain due to the land elevation (NDECC, 2008). The floodplain below Gin Gin is considerably wider. Figure 28 shows the distributed channel network downstream of Warren through which flood waters enter different creeks, including the Marra Creek.

The recorded floods in the Macquarie River at Narromine suggest that the area experienced its largest flood in 1955, followed by 1990, 1971, 2000, 1998 and 1976 (NDECC, 2008). More recently, the whole of the Central West subregion again experienced a large flood in December 2010, considered to be the largest flood event since 1990 (MRFF, 2010). The towns of Gilgandra and Nyngan have a long history of flooding including in 1955, 1990, 2000 and 2010.

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 (ANZECC and ARMCANZ, 2000) for turbidity and total phosphorus for protecting the aquatic ecosystem for 2007 to 2008 at four locations within the subregion and at eight locations outside of the subregion are shown in Table 14. 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. Table 14 shows that all sample locations in the Macquarie river basin, except at Turon River, overwhelmingly exceed the limit for total phosphorus. Within the subregion, most samples meet the turbidity guidelines except in the Talbragar River.

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 (for example, turbidity, total nitrogen, total phosphorus, electrical conductivity, pH and water temperature) (W Mawhinney, 2014, pers. comm.).

Not all monitoring stations in the region record all water quality indicators. Table 15 summarises water quality assessments for the Macquarie-Bogan and Castlereagh river basins at 17 sites and one site, respectively. Except for turbidity and pH, all the water quality indicators listed in the table were rated ‘poor’ to ‘very poor’ (DSEWPaC, 2011). Note that data in Table 14 and Table 15 were assessed against the ANZECC water quality guidelines and not against the Basin Plan water quality targets which will be used in the future (W Mawhinney, 2014, pers. comm.).

Chapter 9 of the Basin Plan describes water quality and salinity management plan including types and key causes of water quality degradation in the Basin (MDBA, 2012). It also contains water quality targets for different water use purposes such as irrigation, fresh water-dependent ecosystems for different ecosystem types and recreational water.

Data from NSW Government (2013) show that the median of mean monthly daily electrical conductivities (EC) at a station in the Castlereagh river basin (Castlereagh River at Hidden Valley, 420017) for 2002 to 2013 is 335 μS/cm and the daily mean water temperature ranges from 5 to 30 °C. For a station in the Macquarie river basin (Macquarie River at Carinda, 421012) the median of mean monthly EC is 553 μS/cm and the mean daily temperature ranges from 9 to 30 °C. Trend analyses for EC, temperature and turbidity were also done, however data confidence for all sites for all indicators was considered to be low (NSW Government, 2010).

Table 14 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 of (in italics) the Central West subregion

Location	Total Phosphorus (%)	Turbidity (%)
Talbragar River at Elong Elong	100%	56%
Macquarie River at Molong Rail Bridge	88%	0%
Macquarie River at Warren Weir	100%	8%
Macquarie River at Carinda	75%	0%
Fish River u/s Taran Road Bridge	*75%*	*0%*
Turon River at Sofala	*11%*	*14%*
Macquarie River at Bruinbun	*100%*	*42%*
Macquarie River at Burrendong Dam	*80%*	*8%*
Bell River at Newrea	*100%*	*9%*
Cudgegong River at Rylstone Bridge	*100%*	*0%*
Cudgegong River at Yamble Bridge	*100%*	*36%*
Little River at Arthurville No 2	*88%*	*9%*

Source data: NSW Government (2010)

Table 15 Water quality assessment for Macquarie-Bogan and Castlereagh rivers

River basin	Sites	Turbidity	Salinity	pH	TN	TP
Castlereagh	1	Good	Very poor	Good	Poor	Very poor
Macquarie-Bogan	17	Good	Poor	Fair	Very poor	Very poor

Source data: DSEWPaC (2011)
TN total nitrogen; TP total phosphorous

1.1.5.3 Surface water flow

The Macquarie-Castlereagh river basin contributes about 8.4% of total runoff and uses slightly less than 4% of the surface water diverted for irrigation in the Murray–Darling Basin. The mean annual rainfall in the subregion is about 520 mm (1900 to 2011; see Section 1.1.2.1). Rainfall is slightly higher during January and February but is fairly uniform for the rest of the year. The mean annual modelled runoff is 35 mm (1985 to 2006) for whole of the Macquarie-Castlereagh river basin and is reasonably uniform throughout the year (CSIRO, 2008). The indicative runoff ratio based on mean annual rainfall and runoff is 6.7%. The mean annual modelled runoff over the ten-year period 1997 to 2006 is 33 mm, slightly lower than the long-term runoff value.

Sixty-three stream gauging stations in the Macquarie river basin, including six on the Bogan River and eight in the Castlereagh river basin, are still operational. These stations are managed by the NSW Office of Water and the majority of the stations are telemetered. The record lengths vary from a few years to more than 100 years. Summary statistics from some of the streamflow gauging stations in the Macquarie and Castlereagh river basins are given in Table 16. Full details can be found in NSW Government (2013).

The impact of climate change by the South Eastern Australian Climate Initiative (SEACI) for the whole Macquarie-Castlereagh river basin indicated that 12 of 15 GCMs projected a decrease in future runoff showing a median reduction of 8% and 12% under 1 °C and 2 °C global warming, respectively (Post et al., 2012). See Section 1.1.2.3 (Climate) for further details. The CSIRO (2008) study also indicated the effect of projected climate change on future runoff in the whole of the Macquarie-Castlereagh river basin is a likely decrease of runoff of about 6% for 2030 climate based on the median estimate.

Table 16 Selected open stream gauging stations in the Macquarie, Castlereagh and Bogan river basins within the Central West subregion and summary statistics

Site no.	Station Name and Location	Record Length (yr)	Start Year	Catchment Area (km^2)[a]	Mean Monthly Flow (GL)[a]	Mean Annual Runoff (mm)
420003	Belar Creek at Warkton (Blackburns)	61.9	Dec-1951	133	1.05	101
420004	Castlereagh River at Mendooran	61.0	Nov-1952	3,600	7.79	26.8
420007	Castlereagh River at Binnaway	48.5	May-1965	1,590	5.98	46.4
420017	Castlereagh River at Hidden Valley	33.7	Feb-1980	1,166	3.98	41.6
421001	Macquarie River at Dubbo	128.0	Jun-1885	19,600	97.9	60.0
421003	Macquarie River at Wellington	104.8	Jan-1909	14,130	83.6	61.6
421004	Macquarie River at Warren Weir	115.0	Jan-1898	26,570	56.38	25.4
421011	Marthaguy Creek at Carinda	87.5	Apr-1926	6,475	12.00	22.8
421012	Macquarie River at Carinda	87.5	Apr-1926	30,100	11.94	4.95
421014	Macquarie River at Warren Town	80.8	Jan-1933	26,570	73.44	29.9
421018	Bell River at Newrea	74.3	Jul-1939	1,620	10.68	77.2
421022	Macquarie River at Oxley Station	72.8	Jan-1941	3,565	26.88	19.7
421031	Macquarie River at Gin Gin	59.3	Jul-1954	26,940	147.22	65.6
421039	Bogan River at Neurie Plains	54.5	May-1959	14,760	7.25	5.79
421042	Talbragar River at Elong Elong	49.0	Nov-1964	3,050	4.34	17.9
421083	Bogan River at Dandaloo	46.2	Aug-1967	612	2.76	57.2
421127	Macquarie River at Baroona	31.5	May-1982	25,700	91.8	42.8

[a]The catchment areas and flow values are taken from the source given in the caption. There are inconsistencies in their values at different locations along the Macquarie River.

Source data: NSW Government (2013)

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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 Central West 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 south-east, and is recharged by streams in the lower lying areas to the west and north-west, although such relationships may be reversed in places depending on flow levels.

1.1.6.1 Connectivity between groundwater and surface water

Connectivity between groundwater and surface water largely occurs via alluvial aquifers and varies in space and time. For example, the Macquarie River has a combination of gaining and losing reaches that changes with flood recharge and drought events. A connectivity map for the Central West subregion identifying zones where streams are dominantly gaining or losing, and zones where seasonal variability occur, is given in Figure 29. This map was produced using relative water levels for groundwater and surface water at a single point in time, and has not been further verified by analyses at multiple points in time, or by identifying losses and gains between stream gauging stations. CSIRO (2008) note that while their assessment is generally consistent with previous hydrogeological interpretations of the catchment and numerical modelling results for the Lower Macquarie Alluvium, an exception is the Lower Macquarie groundwater model (Bilge, 2007) predicting that the Macquarie River around Narromine is more highly losing than shown in the assessment, and that the Bogan River is ‘low losing’ rather than ‘maximum losing’.

For the Upper Macquarie Alluvium between Wellington and Dubbo, the upper and lower aquifers are hydraulically connected. Water levels throughout the aquifer responded to the main river flood events of 1990, 1998 and 2000 with near-river parts of the aquifer showing a rapid response. Smithson (2010) concluded that the Macquarie River in this area had a combination of gaining and losing reaches, and that this changed with flood recharge and drought events. Field-based connectivity studies carried out over a 30 km stretch of the Upper Macquarie River centred on Narromine showed the river to be losing disconnected, with a small proportion showing losing disconnected characteristics (Brownbill et al., 2011).

Figure 30 shows a hydrograph from the Baroona gauging station (25 km east of Narromine) on the Macquarie River superimposed on water levels in the Quaternary aquifer from a monitoring bore 1.2 km from the river. This hydrograph shows that the river here is potentially gaining, as indicated by the higher elevation of the watertable compared to the river stage during low-flow conditions. The high degree of interaction is highlighted by the strong correlation between rises in the river hydrograph and groundwater levels. At this scale, the response in groundwater level to high-flow events appears to be instantaneous for the 1990 and 1998 events; however the actual response in groundwater level lags the flood peak by a few days, and by up to a month for the December 2000 flood event.

Groundwater from Cenozoic Basalts and Gunnedah Basin strata is likely to provide baseflow to surface water in the southern parts of the subregion, where Gunnedah Basin rocks abut Great Artesian Basin (GAB) and alluvial units (EMGA Mitchell McLennan Pty Ltd, 2012). Discharge to springs and seeps is likely to be via short run, local flow systems, and not from the deeper, regional flow systems of the Gunnedah Basin.

Kellett and Stewart (2013) show that there is potential leakage from the alluvium of the Castlereagh River to the Pilliga Sandstone where CSIRO (2008) identifies the river as being 'medium losing'. This supports the contention of riverine recharge to the Pilliga Sandstone in the Castlereagh River valley proposed by Radke et al. (2000).

Significant flow losses from the Macquarie River further downstream in the reach between Narromine and Warren have been consistently recorded since river discharge measurements began.

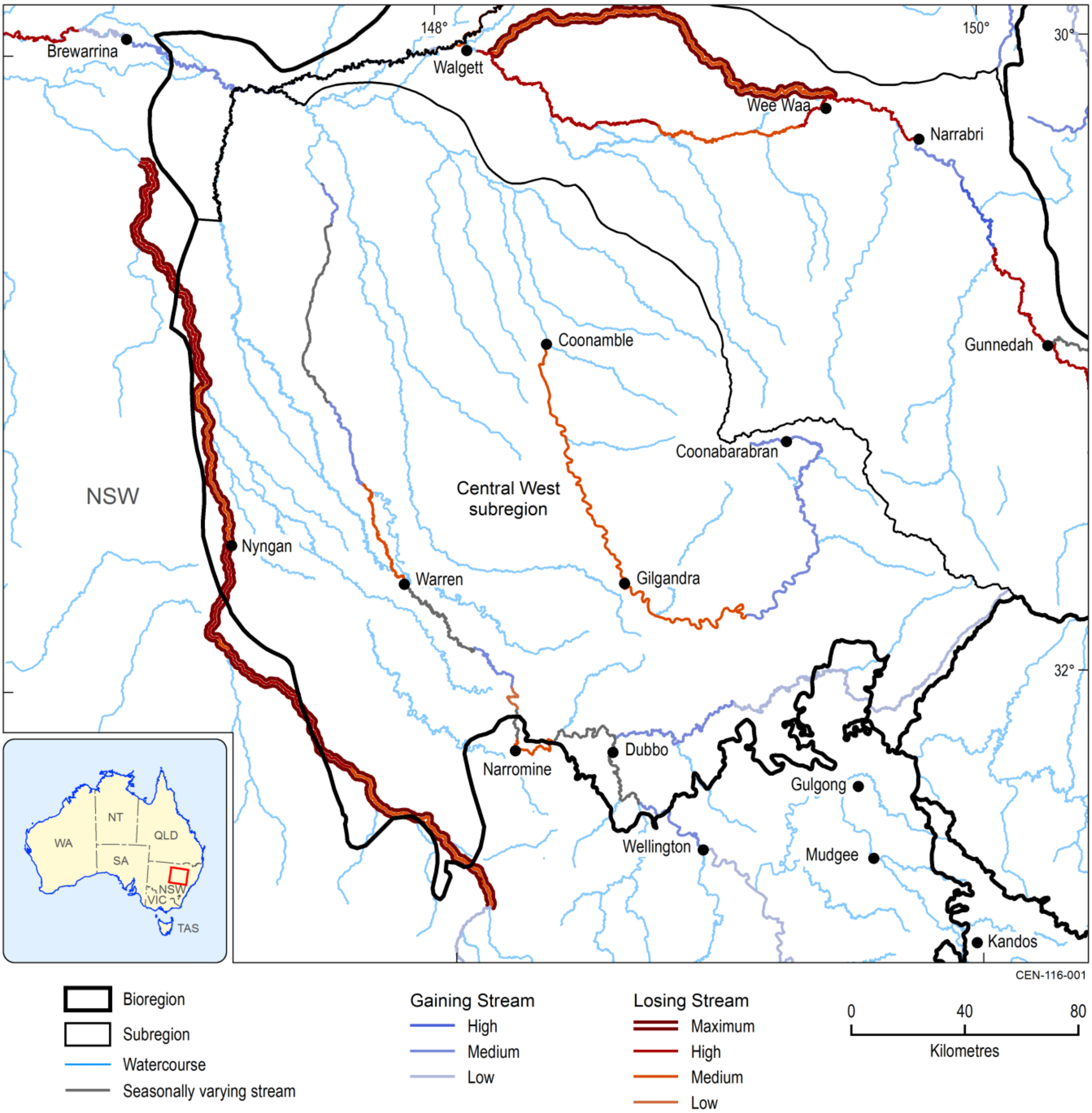

Figure 29 Surface water – groundwater connectivity in the Central West subregion

Note that many streams are not classified. 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 referring to the flux from streambed to watertable.
Source data: modified from CSIRO (2008)

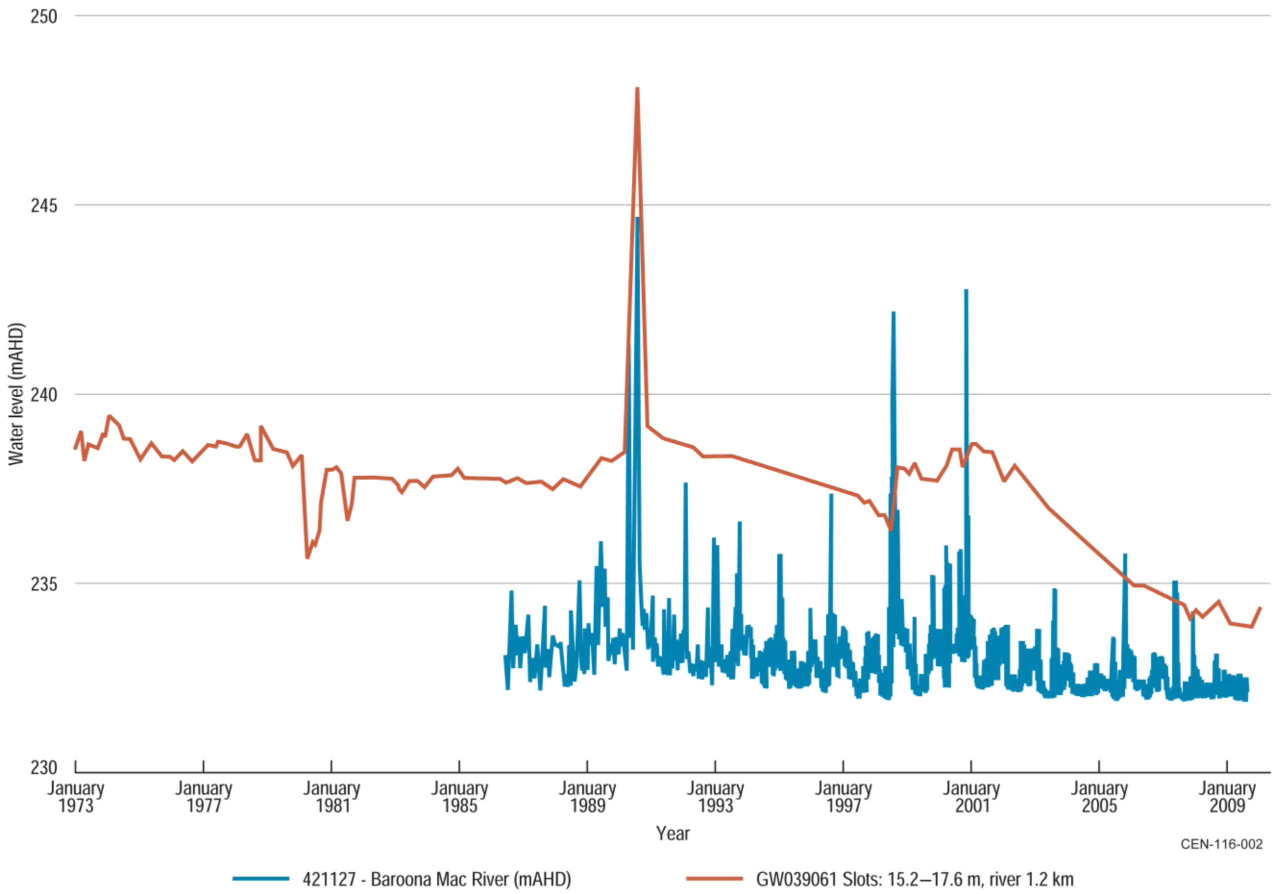

Figure 30 Macquarie River hydrograph (blue line) superimposed on water levels in the Quaternary aquifer (red line) 1.2 km from the river at the Baroona gauging station (25 km east of Narromine)

Source data: modified from Smithson (2010)

Figure 31 shows deuterium levels in groundwater of flowing artesian water bores in the Pilliga Sandstone aquifer in the Coonamble Embayment. This shows a plume of depleted water ($-45\ ^0/_{00} \leq \delta^2H \leq -42\ ^0/_{00}$) in the southern region of the Coonamble Embayment basinward from where the Macquarie and Castlereagh rivers cross the intake beds. Waters with depleted isotopic signatures such as this are characteristic of heavy rainfall at high altitudes. Therefore the isotopically light patterns in Figure 31 are interpreted as having been generated by heavy rainfall in the headwaters of both of these streams, which was sufficient to produce river flows greater than certain threshold values and aquifer recharge by river leakage during these high-flow periods. Aquifer recharge occurs by downward leakage from the streams at some point where the Macquarie and Castlereagh rivers traverse the intake beds. When river stage is high, water percolates laterally through permeable alluvium exposed in the river banks and recharges the Cenozoic aquifers. If the hydraulic gradient between the Cenozoic aquifers and the Pilliga Sandstone is downward, then the Pilliga Sandstone aquifer will also be recharged from these high-flow events that occur periodically in the Macquarie and Castlereagh river systems.

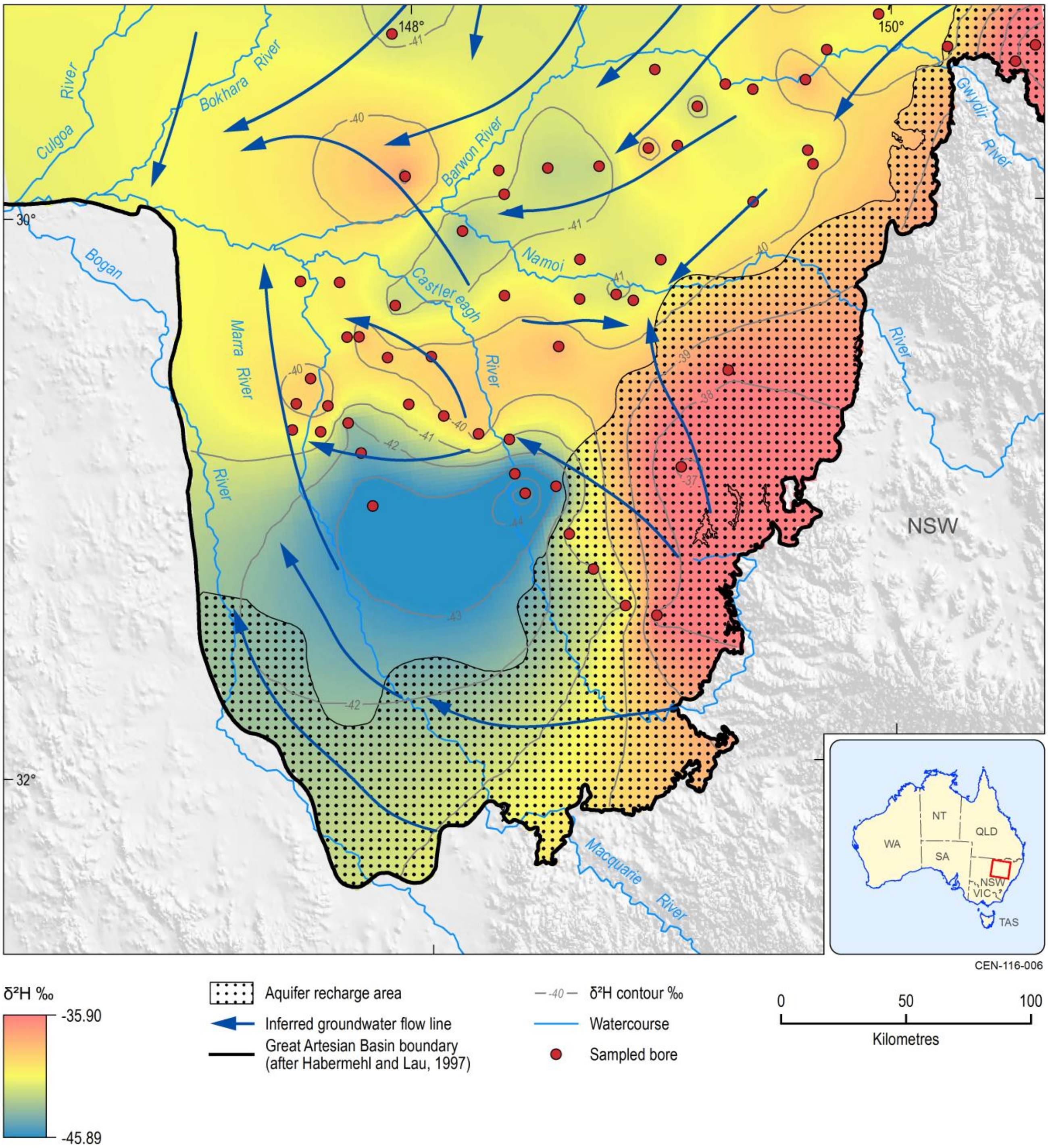

Figure 31 Deuterium in groundwater of the Pilliga Sandstone aquifer in the Coonamble Embayment, which incorporates the Central West subregion

Source data: Radke et al. (2000)

A study using airborne electromagnetic surveying identified many areas where the Macquarie River is connected to groundwater in the alluvial aquifers (Macaulay and Kellett, 2009). Several airborne electromagnetic conductivity-depth sections show potential river leakage from the Macquarie River to the adjacent alluvial aquifer systems, indicating a highly connected system.

Figure 25 shows the watertable elevation in the Quaternary alluvial aquifer of the Coonamble Embayment in the Central West subregion. The stippled brown regions demarcate areas where water levels in the Quaternary alluvial aquifer are higher than the regional watertable in the uppermost GAB partial aquifer and yellow areas indicate areas where the GAB regional watertable is coplanar with or higher than the water levels in the alluvium. A higher water level in the alluvium than that in the GAB aquifer is a necessary but not sufficient condition for downward leakage and recharge from the alluvium to the GAB formations. A second condition which must be satisfied is that a pathway exists for inter-formational groundwater flow. During the Late Cretaceous to the early part of the Paleogene, the exposed GAB rocks were subjected to prolonged and intense weathering that produced a thick, basin-wide layer of saprolite. The lower part of the saprolite is clay-rich and of very low permeability. This is the zone of leachate accumulation of silica, clay minerals and salts. This layer prohibits vertical fluid flow.

The same airborne electromagnetic survey detected the lower impermeable saprolite as a layer of high bulk conductivity which forms a continuous blanket over the GAB rocks and prevents hydraulic connection between the Quaternary alluvium and the GAB sequence. However, in places where the saprolite has been removed by erosion, hydraulic connection is possible and highly likely. Such areas occur beneath Neogene paleochannels where erosion during their formation was sufficient to completely remove the saprolite. There are many such paleochannels in the Surat Basin and they either underlie modern stream channels (e.g. the Warrego and Castlereagh rivers) or are buried adjacent to them (for example, the Namoi and Dirranbandi paleovalleys).

Figure 29 shows two areas in the Central West subregion where it is highly likely that significant surface water – groundwater interaction occurs. In both cases the rivers are losing streams during periods of high flow. The first is the Castlereagh River from Mendooran to 25 km north of Curban. This is most likely the source of river leakage from the Castlereagh River to the Pilliga Sandstone aquifer shown in Figure 29. This reach of the Castlereagh River is underlain by a paleochannel at least 100 m deep and the basal alluvial beds contain Neogene pollens (Martin, 1981). The deep alluvium lies directly on unweathered Early Cretaceous rocks of the GAB.

The second area in Figure 29 is a small but important site of surface water – groundwater interaction in the Macquarie River at the Buddah kink, 20 km north of Narromine. There is no Neogene paleochannel here but the saprolite on the GAB beds has been partially eroded by Cenozoic avulsion and channel switching by the Macquarie River (Macaulay and Kellett, 2009).

Figure 25 shows extensive areas where the watertable in the Quaternary alluvium is higher than the hydraulic head of the uppermost GAB partial aquifer. Three of these areas are located around Warren, to the west of Narromine and between Walgett and Brewarrina. There is unlikely to be any downward leakage from the alluvium to the GAB as Macaulay and Kellett (2009) report that the impermeable saprolite forms a continuous aquitard. The higher watertables in the alluvium of the two southern areas (Warren and west of Narromine) have been generated by irrigation water perched on top of the saprolite. There is negligible surface water – groundwater interaction in these areas.

Flight line 26181 of the airborne electromagnetic survey (Figure 32) reported by Macaulay and Kellett (2009), is an east – west oriented line intersecting the Macquarie River in the vicinity of the Buddah kink. This cross-section shows thick (25 to 40 m) conductive saprolite on the Keelindi beds, underlying 5 to 10 m of resistive soil sloping down towards the Macquarie River. A 25 m thick band of conductive material to the west of 610000 mE (Figure 32) was interpreted by Macaulay and Kellett (2009) to be saprolite on the Drildool beds. A bore on the western side of the river at

Buddah intersected 28 m of Quaternary sediments overlying a thin saprolite. This is represented in Figure 32 as a moderately conductive band between 10 and 15 m thick. Saprolite underlying the Macquarie River has been partially eroded by incision; this is shown as a depression extending from 610000 mE to 618000 mE in Figure 32. This was subsequently filled with alluvium. The upper confined sandy aquifer intersected in drilling from 12 to 21 m depth was interpreted as being the Bugwah Formation channel fill sediments, and the lower confined sandy aquifer (35 to 48 m depth) as the Carrabear Formation channel fill, both of which contain fresh groundwater (Macaulay and Kellett, 2009).

The clay layer between these two sandy aquifers forms a mostly continuous band, but is eroded between 612000 mE and 613000 mE and infilled by Bugwah Formation sediments. This erosion feature may permit vertical leakage between these two aquifers. Material between 50 and 80 m below the Macquarie River was interpreted to represent unweathered Keelindi beds overlying Pilliga Sandstone, however some of this material, below 130 m depth, could be granite. This material was interpreted to be gently dipping basinward, to the north-west (Macaulay and Kellett, 2009).

Possible leakage pathways from the river to the alluvium and then into the underlying Mesozoic sequence were examined by Macaulay and Kellett (2009). Keshwan's (1995) estimates of aquifer recharge from river leakage were based on hydraulic parameters derived from control bore GW036977. On 5 and 6 October 1991, Keshwan estimated that the river stage was 2.5 metres higher than the potentiometric surface of the Carrabear Formation aquifer in the bore, creating the potential for water to flow from the river to the aquifer.

The airborne electromagnetics indicate a high degree of connectivity between the river and the alluvium in its banks from the highly resistive 10 metre-thick surface band of alluvium adjacent to the channels. Furthermore, the airborne electromagnetics indicates hydraulic connection between the western-most channel in the section (at Buddah) and both sand aquifers in bore GW036977. At the time of flying, the wetted resistive zone of the top aquifer extended 2 km westward and 4 km westward for the bottom aquifer. Importantly, the underlying saprolite appears to be breached and displaced in the intervals from the bore to 616000 mE, 616500 to 617000 mE, 618000 to 618500 mE and possibly 612000 to 613000 mE. These breaches were identified as potential pathways for groundwater flow from the alluvium to the Mesozoic aquifers (Macaulay and Kellett, 2009).

The airborne electromagnetic survey reported by Macaulay and Kellett (2009) depicts the hydrological situation at Buddah after several years of drought. A survey flown during high river stage, at a time when maximum river leakage to the alluvium is occurring (as postulated by Keshwan, 1995) may show more pronounced hydraulic connectivity between the river and the alluvium, and the Mesozoic aquifers. Keshwan (1995) estimated a maximum potential leakage from the river channel to the aquifer of about 50 ML/day under conditions of high river flow (> 2500 ML/day) for the Buddah kink of the Macquarie River, and potential aquifer recharge from river leakage in the reach from Baroona to Gin Gin of 450 ML/day.

Therefore the two necessary conditions for downward leakage from the river to the alluvium and thence to the GAB regional aquifers were satisfied for the Macquarie River at Buddah. Firstly, the work by Keshwan (1995) established the existence of the downward hydraulic gradient from the alluvium to the GAB aquifer at a certain threshold river flow, and secondly, the airborne electromagnetic (AEM) demonstrated the existence of pathways for fluid transfer (Macaulay and Kellett, 2009).

Comparable analysis and estimation of river leakage losses to groundwater have not as yet been undertaken for the Castlereagh River.

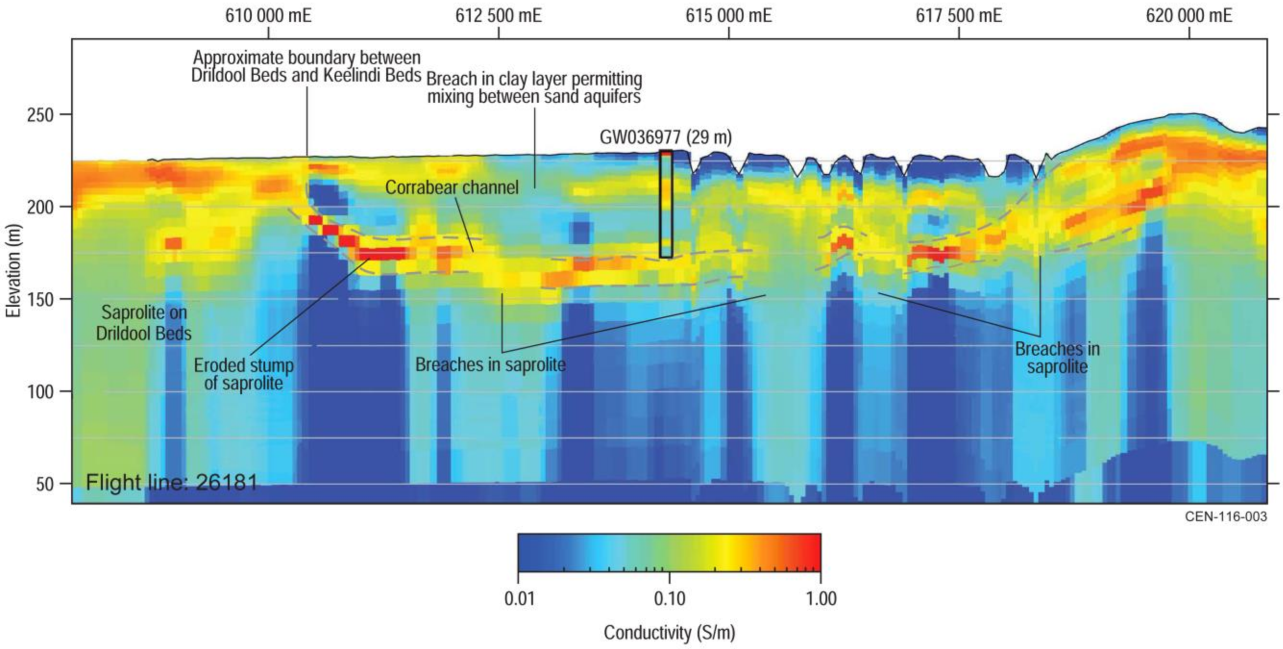

Figure 32 Airborne electromagnetic flight line 26181, perpendicular to the Macquarie River at Buddah

Source data: modified from data presented in Figure A1.5 from Macaulay and Kellett (2009)

Macaulay and Kellett (2009) report several instances of flush zones in the Quaternary alluvium as a result of periodic flooding of the Macquarie River. These can be seen in cross-sections as resistive plumes in the alluvium adjacent to the river channel. Figure 33 shows one such feature at 'Elengarah', 20 km upstream of Warren. The river channel is at 594000 mE, and is about 10 m deep. The flush zone was interpreted to extend to about 20 m depth on the western side of the river, as indicated by a resistive wetted perimeter (Macaulay and Kellett, 2009). Drilling intersected 14 m of Marra Creek Formation sediments overlying Bugwah Formation gravel, which overlie weathered Drildool beds at 27 m depth. Groundwater in the gravels was interpreted to represent a mix between river water and more saline regional groundwater (Macaulay and Kellett, 2009). The possible maximum lateral extent of the flooding-related flush zone is shown in Figure 33.

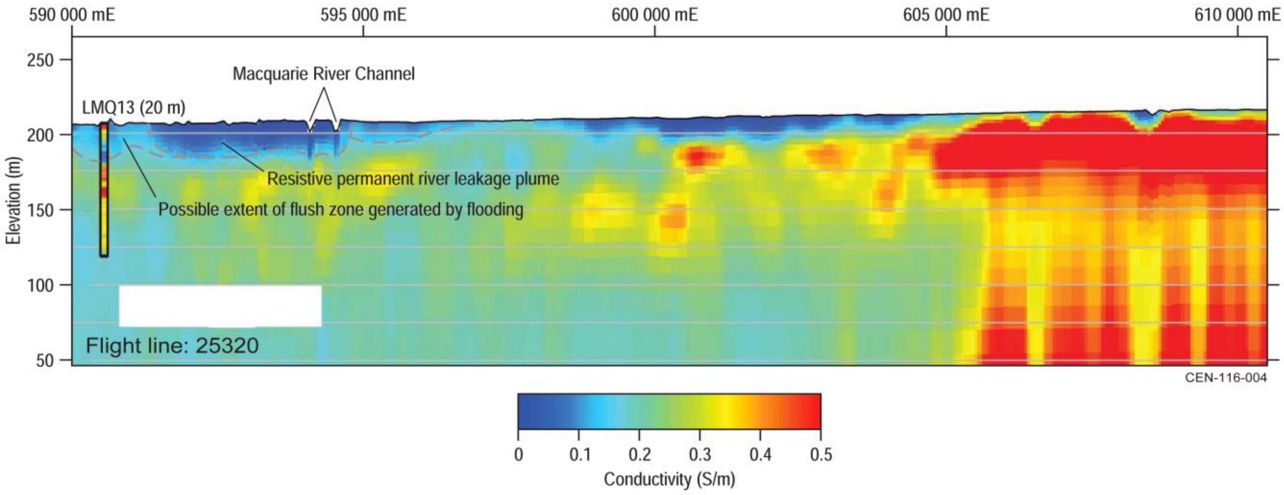

Figure 33 Airborne electromagnetic flight line 25320 showing flush zones in the Quaternary alluvium generated by flooding of the Macquarie River at 'Elengarah'

Source data: modified from data presented in Figure A1.2 from Macaulay and Kellett (2009)

The Macquarie Marshes are an internationally recognised Ramsar-listed wetland complex occupying an area of about 220,000 ha within the Macquarie River floodplain in the Central West subregion. It was thought that the Macquarie Marshes received upward leakage from the Pilliga Sandstone to supplement floodwater from the Macquarie River in sustaining vegetation (e.g. Brereton, 1994; Wolfgang, 2001).

A comprehensive multi-disciplinary study of the Macquarie Marshes was reported by Macaulay and Kellett (2009). This system is hosted within the Quaternary sediments of the Lower Macquarie Alluvium. Macaulay and Kellett (2009) identified high groundwater salinity levels of up to 44,600 μS/cm at depths of 4 to 8 m below the Macquarie Marshes. This provides evidence that water in the marshes is not sustained by upwards flow from the GAB. Macaulay and Kellett (2009) also concluded that there is no hydraulic connection between the fresh water lens from flooding and the shallow groundwater system; that is, there is not surface water – groundwater connection in the Macquarie Marshes.

The airborne electromagnetic results also showed the importance of the Rolling Downs Group as a spatially extensive unit, acting as a highly effective aquitard. Additionally, clay-rich weathered zones in the units immediately underlying the alluvial aquifers act as effective barriers to upward leakage. This is highlighted in flight line section 20990, which traverses the northern Macquarie Marshes (Figure 34). This cross-section clearly shows the continuous aquitard formed by the saprolite on top of the Rolling Downs Group which precludes any vertical upward transmission of groundwater from the Pilliga Sandstone. Inspection of every flight line through the Macquarie Marshes revealed no breaches in the saprolite anywhere although there is clearly vertical displacement.

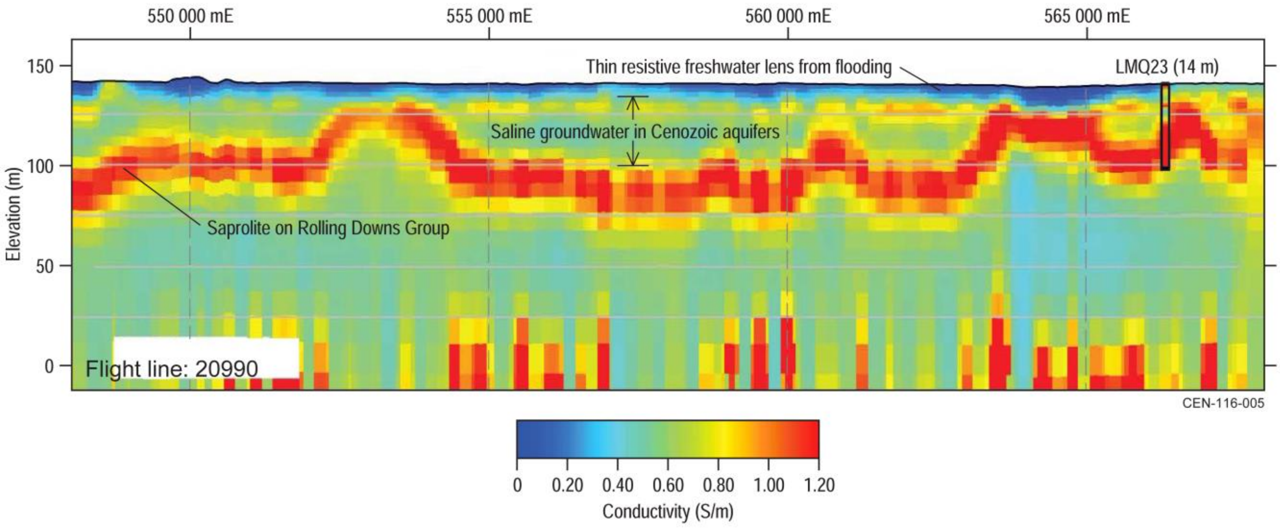

Figure 34 Airborne electromagnetic flight line 20990 through the northern Macquarie Marshes showing an irregular, wavy band of high conductivity corresponding to the saprolite on the Rolling Downs Group

This feature is continuous everywhere beneath the Macquarie Marshes, precluding any upward leakage from the Pilliga Sandstone.
Source: Figure 6.5 from Macaulay and Kellett (2009)

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 was assessed by CSIRO (2008). This impact was considered to be small in the Bogan, Macquarie and Castlereagh river basins. Uncertainty regarding runoff and streamflow was low given the high number of gauging stations in the river basins. The largest source of uncertainty in the assessment was associated with climate projections.

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1.1.7 Ecology

Summary

The Central West subregion, located in central western NSW, includes the Castlereagh, Bogan and Macquarie river basins. Landforms in the area can be broadly classified into three types: the tablelands in the upper catchments to the east, the slopes to the west of the tablelands, and the alluvial floodplains of the lower valleys of the major rivers. This variety of landforms provides a number of important habitats for the vast array of plant and animal species, although many of the native communities are degraded and under pressure from changing land use and water regimes. The Central West subregion is home to numerous endangered and threatened wildlife and ecological communities. Large tracts of important wetland and floodplain communities occur in the western portions of the subregion, including the Ramsar-listed Macquarie Marshes on the lower floodplains of the Macquarie River, which contain large tracts of red gum woodlands and threatened coolibah-black box woodlands. These marshes are also a significant nesting site for over 40 species of waterbirds and provide breeding habitat for endangered and threatened aquatic species such as the trout cod, Murray cod and silver perch. In the upper tablelands of the Macquarie, Castlereagh and Bogan river basins, groundwater supports many aquatic and terrestrial ecosystems. There are 65 aquatic and terrestrial threatened species including 16 migratory species listed in the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* that are predicted or known to occur within the Macquarie, Castlereagh and Bogan river basins. Also included are 26 plant, four reptile, one amphibian, four fish, six bird and eight mammal species. Over 140 species are listed in NSW's *Threatened Species Conservation Act 1995* and NSW's *Fisheries Management Act 1994*.

1.1.7.1 Ecological systems

The Macquarie, Castlereagh and Bogan river basins covers an area of approximately 85,000 km^2 and is home to approximately 185,000 people. It contains a large variety of vegetation, landforms and communities, including 82 broad vegetation types that provide habitat for over 550 vertebrates (Central West CMA, 2011a). Many species and communities are listed as threatened or endangered (Central West CMA, 2011b). Land use in the Macquarie-Bogan river basin is dominated by extensive agriculture with over 80% of the river basin being used for grazing, 9% for dryland cropping and 5% for forestry, conservation and other native landscapes (Green et al., 2011). More information on land use is provided in Section 1.1.2.2.3.

Broadly speaking, the Macquarie, Castlereagh and Bogan river basins can be subdivided into three areas in an east to west direction: the central west tablelands, the central west slopes and the central west plains. This broad gradation depicts regional scale changes in landforms and climates. The central west tablelands, which are mostly upstream from the subregion, generally have an elevation of between 450 and 1000 m. The topography through this area is mostly undulating to hilly and there can be significant variation in soils over very short distances. Soils are mostly derived from sandstone granite shale/slate and basalt parent materials (Central West CMA, 2008c).

The slopes area lies west of the tablelands area at lower altitudes of between 250 and 700 m above sea level. The topography ranges from steep hills to gently undulating landscapes and alluvial river plains. The geology is based on a series of faults and folds of sedimentary parent material in the southern part of the area, interspersed with granite intrusions and basalts from old volcano and overland flows. The northern part of the slopes region is made up of the southernmost edge of the Great Artesian Basin. Soils range from highly fertile alluvium and basalts to deep sands of the Pilliga Sandstone. Soil salinity is a major issue, particularly in the Talbragar and Little river basins (Central West CMA, 2008b).

The plains area lies to the west of the slopes area. This area consists of broad flat plains with occasional rocky outcrops, and occurs between 150 and 300 m above sea level. The plains are dominated by lower rainfall semi-arid rangelands, and the western portion is characterised by braided channels and associated floodplains (Central West CMA, 2008d).

Prior to European settlement the subregion supported a complex mosaic of forests, temperate and semi-arid woodlands, wetlands and grasslands (Green et al., 2011). Subsequently much of the natural vegetation has been cleared for livestock production and intensive agriculture (Central West CMA, 2009). The Central West subregion is comprised of five Interim Biogeographic Regionalisation of Australia (IBRA) bioregions (NSW Government, 2011, Figure 35). The Darling Riverine Plains and Brigalow Belt South IBRA bioregions dominate the Central West subregion, primarily associated with the Gunnedah Lowlands and Mitchell Slopes, respectively (Figure 6). Smaller areas of the Sydney Basin IBRA bioregion (on the Merriwa Plateau) and the NSW South Western Slopes IBRA bioregion and Cobar Peneplain IBRA bioregion (associated with the Gunnedah Lowlands) also occur in the south of the subregion. Brief descriptions of the characteristics of these IBRA bioregions are shown in Table 17.

The Central West subregion contains several areas of national and international significance. These include:

- Macquarie Marshes – listed on the Ramsar List of Wetlands of International Importance, the National Heritage Register and the National Trust Register
- Pilliga Scrub – the largest native forest area in NSW dominated by mixed cypress pine (*Callitris* sp.) and eucalypt woodlands
- Goobang National Park – the largest remnant forest woodland in the Central West
- Warrumbungle Ranges – a dormant volcanic landscape and national park popular for hiking and climbing (Central West CMA, 2008a).

In addition to these, there are 23 national parks estate sites listed within the Macquarie, Castlereagh and Bogan river basins with approximately 1300 km^2 of reserved habitat in the Macquarie-Bogan river basin alone. With the exception of the Macquarie Marshes, most of these reserves are in the tablelands and slopes areas (Green et al., 2011).

Table 17 Brief description of the Interim Biogeographic Regionalisation of Australia (IBRA) bioregions in the Central West subregion

IBRA bioregion	Landform	Biodiversity values
Brigalow Belt South	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 endangered ecological communities, plant and animal species.
Cobar Peneplain	Prominent topographical landscape of rolling downs and flat plains punctuated by stony ridges and ranges and formed on the Lachlan Fold Belt.	Vegetation is mainly open woodlands of bimble or poplar box, red box and white cypress. This IBRA bioregion supports 19 plant species listed in NSW's *Threatened Species Conservation Act 1995* (TSC Act).
Darling Riverine Plains	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 river basins.	River channels support red gum communities, with coolibah and black box communities on floodplains. The region contains 19 plant species and 63 animal species listed in the TSC Act.
NSW South Western Slopes	A large area of foothills and ranges comprising the western fall of the Great Dividing Range, and comprised of a wide variety of rock and soil types across the region.	Higher rainfall regions to the east are characterised by woodlands dominated by white box, grading to communities dominated by grey box and white cypress pine in the west. The TSC Act lists 36 threatened plant species and 67 animal species.
Sydney Basin	Geological basin filled with horizontal sandstones and shales of Permian to Triassic age that overlie older rocks of the Lachlan Fold Belt.	Diverse range of vegetations types as a result of high diversity in soil and landform types. The IBRA bioregion contains 152 plant species and 116 animal species listed in the TSC Act.

Source data: NSW Government (2011)
The South Eastern Highlands IBRA bioregion is upstream from the Central West subregion.

Figure 35 Interim Biogeographic Regionalisation of Australia (IBRA) bioregions and wetlands in the Central West subregion

Source data: IBRA version 7 (2012) ©Commonwealth of Australia 2012

1.1.7.2 Terrestrial species and communities

1.1.7.2.1 Threatened ecological communities

It has been estimated that only 38% of the subregion's natural vegetation remains. Of the 82 vegetation types identified, 14 have less than 1000 ha of their pre-European extent remaining and 20 have less than 30% remaining. Thirty-one communities have between 30 and 70% of their pre-European extent remaining and ten have more than 70% remaining (Central West CMA, 2011a). Loss and degradation of habitat remain key threatening processes in the subregion, and restoring habitat and improving the extent and connectivity in the landscape are key state and regional targets (Central West CMA, 2011b). The largest remaining blocks of native vegetation are in national parks, state forests or travelling stock routes. The Goonoo Community Conservation Area within the subregion is the second largest forest remnant remaining in inland NSW (Central West CMA, 2012). Twenty-one broad vegetation groups are not represented in reserves, and only 12 have more than 15% of their extent in conservation areas (Central West CMA, 2011a). Six threatened ecological communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) occur within the Macquarie, Castlereagh and Bogan river basins (Table 18). Endangered communities in the upper catchment include the Tableland Basalt Forest (listed under NSW's *Threatened Species Conservation Act 1995* (TSC Act) in the Sydney Basin and South Eastern Highlands IBRA regions, and the grassy woodland community White Box-Yellow Box-Blakely's Red Gum Grassy Woodland (listed under the EPBC Act). The Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South IBRA bioregions is an endangered community (listed under the EPBC Act) that occurs on the floodplains of the lower Macquarie and Bogan rivers, and is threatened by fragmentation, overgrazing, weed invasion and alteration of flood regimes.

Eleven threatened ecological communities are listed by the NSW Office of Environment and Heritage. Of these the Mount Canobolas *Xanthoparmelia* Lichen Community is endemic to the Orange region (Table 19), which is upstream of the Central West subregion.

In addition to the communities listed in Table 18 and Table 19, several estates of national significance occur within the Macquarie, Castlereagh and Bogan river basins. These include the Greater Blue Mountains area (listed World Heritage Property, National Heritage Property) and the Warrumbungle National Park and Jenolan Caves (listed National Heritage Properties).

Table 18 Threatened ecological communities in the Macquarie, Castlereagh and Bogan river basins listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

Threatened ecological community	Status under the EPBC Act	Presence
Buloke Woodlands of the Riverina and Murray-Darling Depression Bioregions	Endangered	May occur
Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions	Endangered	Likely
Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia	Endangered	Likely
Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland	Critically endangered	Likely
Weeping Myall Woodlands	Endangered	Likely
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland	Critically endangered	Likely

Table 19 Threatened ecological communities in the Macquarie, Castlereagh and Bogan river basins listed under the NSW's *Threatened Species Conservation Act 1995 (TSC Act)*

Threatened ecological community	Status under the TSC Act	Presence
Artesian Springs Ecological Community	Endangered	Known
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregions	Endangered	Known
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregions	Endangered	Known
Coolibah-Black Box Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain and Mulga Lands Bioregion	Endangered	Known
Fuzzy Box Woodland on alluvial Soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South Bioregions	Critically endangered	Known
Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South Bioregions	Endangered	Known
Mount Canobolas *Xanthoparmelia* Lichen Community	Endangered	Known
Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes bioregions	Endangered	Known
Tableland Basalt Forest in the Sydney Basin and South Eastern Highlands Bioregions	Endangered	Known
Tablelands Snow Gum, Black Sallee, Candlebark and Ribbon Gum Grassy Woodland in the South Eastern Highlands, Sydney Basin, South East Corner and NSW South Western Slopes Bioregion	Endangered	Predicted
White Box Yellow Box Blakely's Red Gum Woodland	Endangered	Known

1.1.7.2.2 Threatened species

There are 49 aquatic and terrestrial species and 16 migratory species (all birds) listed under the EPBC Act as predicted or known to occur within the Macquarie, Castlereagh and Bogan river basins. The aquatic and terrestrial species include 26 plant, four reptile, one amphibian, six bird and eight mammal species. Listed animal species predicted or known to occur in the river basins are shown in Table 20.

A total of 139 threatened species listed under the TSC *Act* occur or did occur within the Macquarie, Castlereagh and Bogan river basins. A breakdown of numbers of species within major life-form groups is shown Table 21. An extensive study conducted in the Macquarie, Castlereagh and Bogan river basins assessed the status of all vertebrate species occurring in the subregion and classed them as secure, declining, regionally vulnerable or regionally extinct. From a total of 424,698 fauna records consisting of 551 native vertebrate species and 32 introduced species, 194 (35.2%) were assessed as regionally secure and 313 (56.8%) as regionally vulnerable and regionally endangered. Overall, 65% of species recorded were classed as declining, with reptiles and mammals being the most over represented in the regionally at risk category (Central West CMA, 2008a).

Habitat loss represents the major threat to biodiversity in the Central West subregion; however, other threats include introduced plant and animal species, soil erosion, and inappropriate land uses such as lakebed cropping, exploitation of natural resources and climate change (Central West CMA, 2008a).

Table 20 Threatened animal species predicted or known to occur in the Macquarie, Castlereagh and Bogan river basins listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)

Species	Status under the EPBC Act	Presence
Regent honeyeater (*Anthochaera phrygia*)	Endangered	Breeding known to occur within area
Australasian bittern (*Botaurus poiciloptilus)*	Endangered	Species known within area
Swift parrot (*Lathamus discolour*)	Endangered	Species known within area
Mallee fowl (*Leipoa ocellata*)	Vulnerable	Species known within area
Superb parrot (*Polytellis swainsonii*)	Vulnerable	Breeding known to occur within area
Australian painted snipe (*Rostratula australis*)	Endangered	Species known within area
Booroolong frog (*Litoria booroolongensis*)	Endangered	Species known within area
Large-eared pied bat, large pied bat (*Chalinolobus dwyeri*)	Vulnerable	Species known within area
Spot-tailed Quoll (*Dasyurus maculatus maculatus* SE mainland population)	Endangered	Species known within area
South eastern long eared bat (*Nyctophilus corbeni*)	Vulnerable	Species known within area
Koala (*Phascolarctos cinereus*)	Vulnerable	Species known within area
Brush-tailed rock-wallaby (*Petrogale penicillata*)	Vulnerable	Species known within area
New holland mouse, pookila (*Pseudomys novaehollandiae*)	Vulnerable	Species known within area
Pilliga mouse, poolkoo (*Pseudomys pilligaensis*)	Vulnerable	Species known within area
Grey-headed flying fox (*Pteropus poliocephalus*)	Vulnerable	Species known within area
Broad-headed snake (*Hoplocephalus bungaroides*)	Vulnerable	Species known within area
Five-clawed worm skink (*Anomalopus mackayi*)	Vulnerable	Species known within area
Pink-tailed worm-lizard (*Aprasia parapulchella*)	Vulnerable	Species known within area
Border thick-tailed gecko (*Uvidicolis sphyrurus*)	Vulnerable	Species or habitat likely to occur within area

Source data: Presence information from NSW Office of Environment and Heritage (2013)

Table 21 Number of threatened species in the Macquarie, Castlereagh and Bogan river basins listed under the NSW's *Threatened Species Conservation Act 1995*

	Presumed extinct	Critically endangered	Endangered	Vulnerable	Total
Fauna					
Amphibian	0	1	3	1	**5**
Birds	0	1	11	39	**51**
Invertebrates	0	0	2	0	**2**
Mammals	2	0	2	18	**22**
Reptiles	0	0	1	5	**6**
Flora					
Algae	0	0	0	0	**0**
Fungi	0	0	0	0	**0**
Plants	0	2	20	31	**53**

Source data: NSW Government (2010e)

1.1.7.3 Aquatic species and communities

The Macquarie, Castlereagh and Bogan river basins contains a variety of wetland types including upland wetlands, semi-arid floodplains, inland billabongs and freshwater lakes. Mapping and prioritisation of wetlands in the Macquarie, Castlereagh and Bogan river basins has identified 11 *Directory of Important Wetlands in Australia* classifications throughout the area. There are 1,058,000 ha of wetlands, classified and mapped in 33,747 wetland units. High priority wetlands include the Macquarie Marshes, upper catchment wetlands, for example Billywillinga Creek wetlands near Bathurst, and lower floodplain wetlands such as Pangee Creek wetlands in the Bogan catchment (Central West CMA, 2008a). Overall, wetlands are in poor condition and face significant pressures from modification or changes to catchment structures and processes (e.g. urbanisation), changes in flow regimes and water quality, and degradation of wetland habitat (NSW Government, 2010d). Native fish populations are extremely poor and there are high numbers of exotic fish species, for example common carp (*Cyprinus carpio*), redfin (*Perca fluviatilis*), and brown and rainbow trout (*Salmo trutta, Oncorhynchus mykiss*). Macro invertebrate diversity is poor, and water quality trends in salinity, turbidity, nutrients, pesticides and thermal pollution are increasing (MDBA, 2010). High priority wetlands and rivers in the Macquarie, Castlereagh and Bogan river basins are shown in Figure 36.

The Macquarie Marshes are a large diverse wetland system in the lower Macquarie River. The site was listed on the Ramsar List of Wetlands of International Importance in 1986. It is significant because of the diversity of wetland types, its highly abundant and diverse waterbird populations and its support for colonial nesting and nationally threatened species. The critical processes and components that support the site's ecological character are its hydrology, its aquatic ecosystems, and the diversity of wetlands that support waterbird breeding and nationally threatened species. Current threats to the site include water management (both flow regimes and structures), dryland salinity, fire management, pest management, channel erosion and climate change. In 2009, after a prolonged drought, the site was noted as having experienced a change in ecological character from a semi-permanent to an ephemeral wetland system. The cause of this was associated with changes to the flow regime resulting from river regulation and extraction. A ten-year response strategy has been developed by the NSW Government to restore the system to good health (NSW Government, 2012). The Macquarie Marshes have seen some of the largest waterbird breeding events in Australia (NSW Government, 2010a) and contain a range of vegetation types including river red gum woodland, water couch grasslands, coolibah-black box woodlands, lignum swamps, cumbungi and river cooba. These diverse environments provide habitat for 211 bird species, eight species of mammal, 15 frog species, 56 reptile species and 24 native fish species (Green et al., 2011).

The aquatic community of the Macquarie and Bogan rivers is part of the endangered aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River, and includes 21 native fish species and hundreds of native invertebrate species that are found within the Darling River and associated streams, wetlands and anabranches (Green et al., 2011).

The Macquarie, Castlereagh and Bogan river basins contain a diverse range of groundwater dependent ecosystems, including wetlands, terrestrial vegetation, instream ecosystems fed by baseflow, limestone cave systems (e.g. Wellington Caves), springs and mound springs (e.g. Cuddie Springs) (Central West CMA, 2011b). In the upper catchment, groundwater discharge contributes to stream baseflow and springs, and these systems support a range of aquatic and terrestrial ecosystems. The alluvial groundwater management areas of the plains have the highest yield and provide for significant irrigation requirements (NSW Government, 2010c).

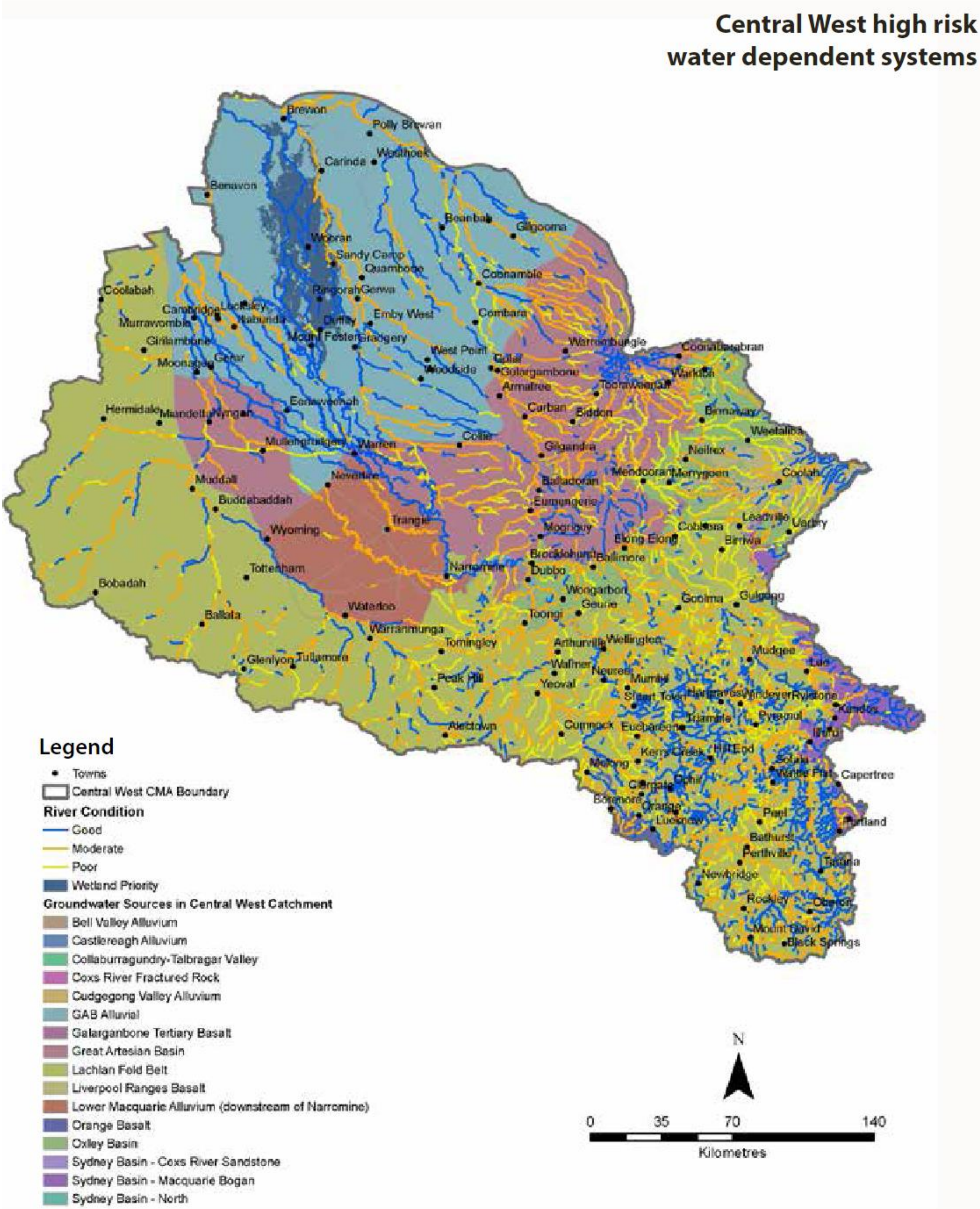

Figure 36 High priority rivers and wetlands in the Central West Catchment and their relation to groundwater resources

Source: Figure 27 in Central West CMA (2011b)

1.1.7.3.1 Threatened species

Four species predicted or known to occur in the Macquarie, Castlereagh and Bogan river basins are listed under the EPBC Act, the endangered trout cod and the vulnerable Murray cod, the critically endangered silver perch and endangered trout cod. A further three species listed under NSW's *Fisheries Management Act 1994* are known to occur in the natural resource management region. These include the purple-spotted gudgeon, the olive perchlet and the river snail. Aquatic species listed as threatened or endangered under either the EPBC Act or the NSW's *Fisheries Management Act 1994* are listed in Table 22.

All native fish in the lower Macquarie river basin typically recruit during spring and early summer, and thus appropriate flow regimes during this period are critical to the long-term survival of these species. For most species warmer temperatures are also important during this time. Winter and spring flood regimes are critical to provide floodplain food sources for adult fish prior to spawning (NSW Government, 2010a). The Macquarie Marshes are recognised as a refuge for waterbirds during dry times. Seventy-six species have been recorded in the marshes and 44 of these have been recorded breeding (NSW Government, 2010a), however bird numbers are showing a long-term decline (NSW Government, 2010b). Similarly, numbers of red bellied black snakes in the marshes are also in decline and this is believed to be linked to declines in frog numbers, a key component of their diet.

Table 22 Threatened aquatic species in the Macquarie, Castlereagh and Bogan river basins listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the NSW's *Fisheries Management Act 1994* (FM Act)

Species	Status under the FM Act	Status under the EPBC Act	Presence
Macquarie perch (*Macquaria australasica*)		Endangered	Species or species habitat may occur within area
Murray cod (*Maccullochella peelii*)		Vulnerable	Species known within area
Olive perchlet (*Ambassis agassizii*)	Endangered population		Species known within area
Purple-spotted gudgeon (*Mogurnda adspersa*)	Endangered		Species known within area
River snail (*Notopala sublineata*)	Endangered		Species known within area
Silver perch (*Bidyanus bidyanus*)	Vulnerable	Critically Endangered	Species known within area
Trout cod (*Maccullochella macquariensis*)	Endangered	Endangered	Species known within area

Source data: Presence information from NSW Government (2013)

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