Australian Government

BIOREGIONAL ASSESSMENTS

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

Context statement for the Namoi subregion

Product 1.1 from the Northern Inland Catchments Bioregional Assessment

3 June 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 <www.bioregionalassessments.gov.au>.

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Gulligal Lagoon, which is located about half way between Gunnedah and Boggabri on the western side of the Namoi River, New South Wales. Courtesy of Neal Foster

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Introduction

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

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

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

The Bioregional Assessment Programme

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

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

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

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

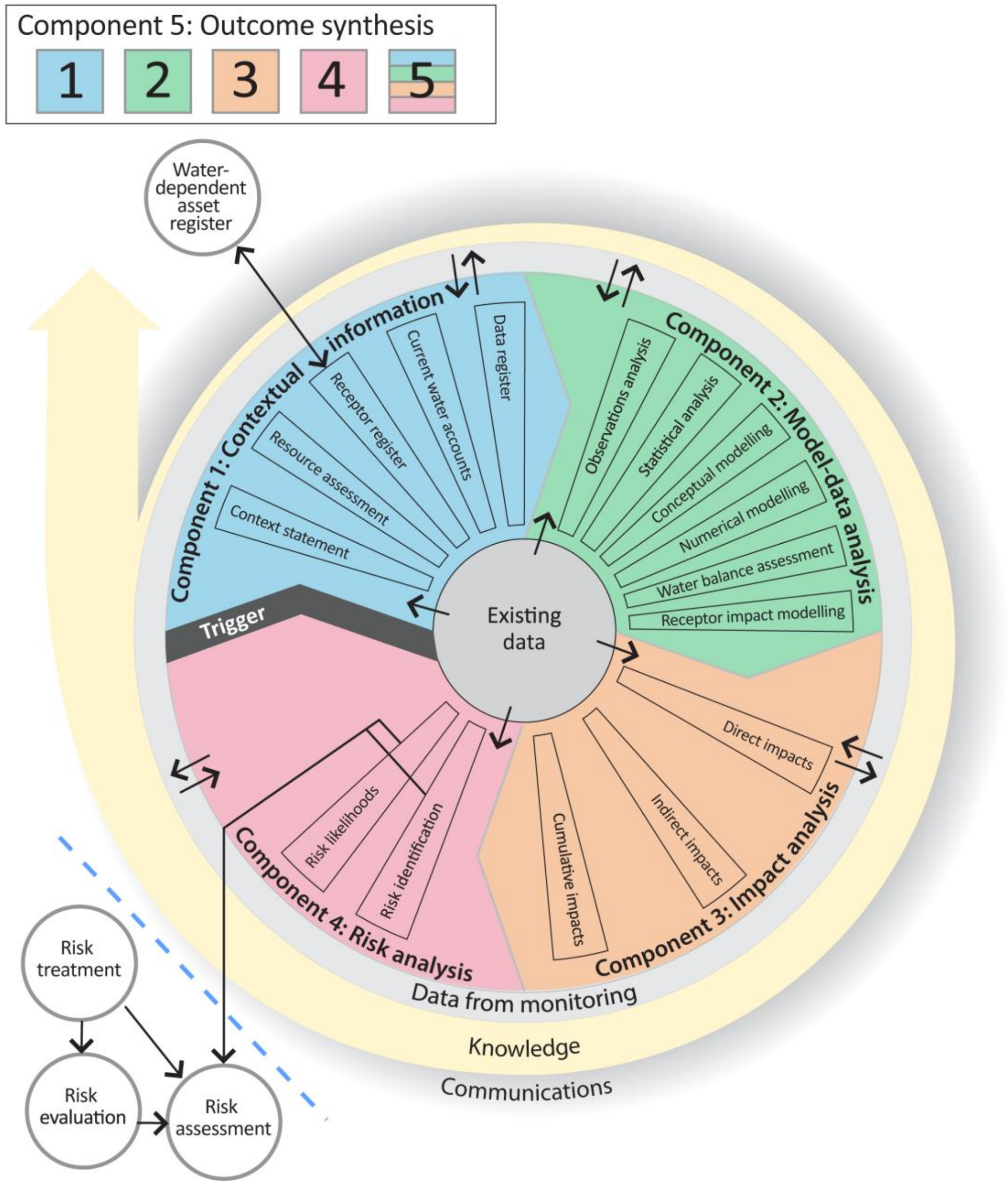

Figure 1 Schematic diagram of the bioregional assessment methodology

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

Technical products

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

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

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

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

The PDF of this technical product, and the additional material, are available online at the following website: <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.
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- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151.0° East for the Northern Inland Catchments bioregion and two standard parallels of –18.0° and –36.0°.

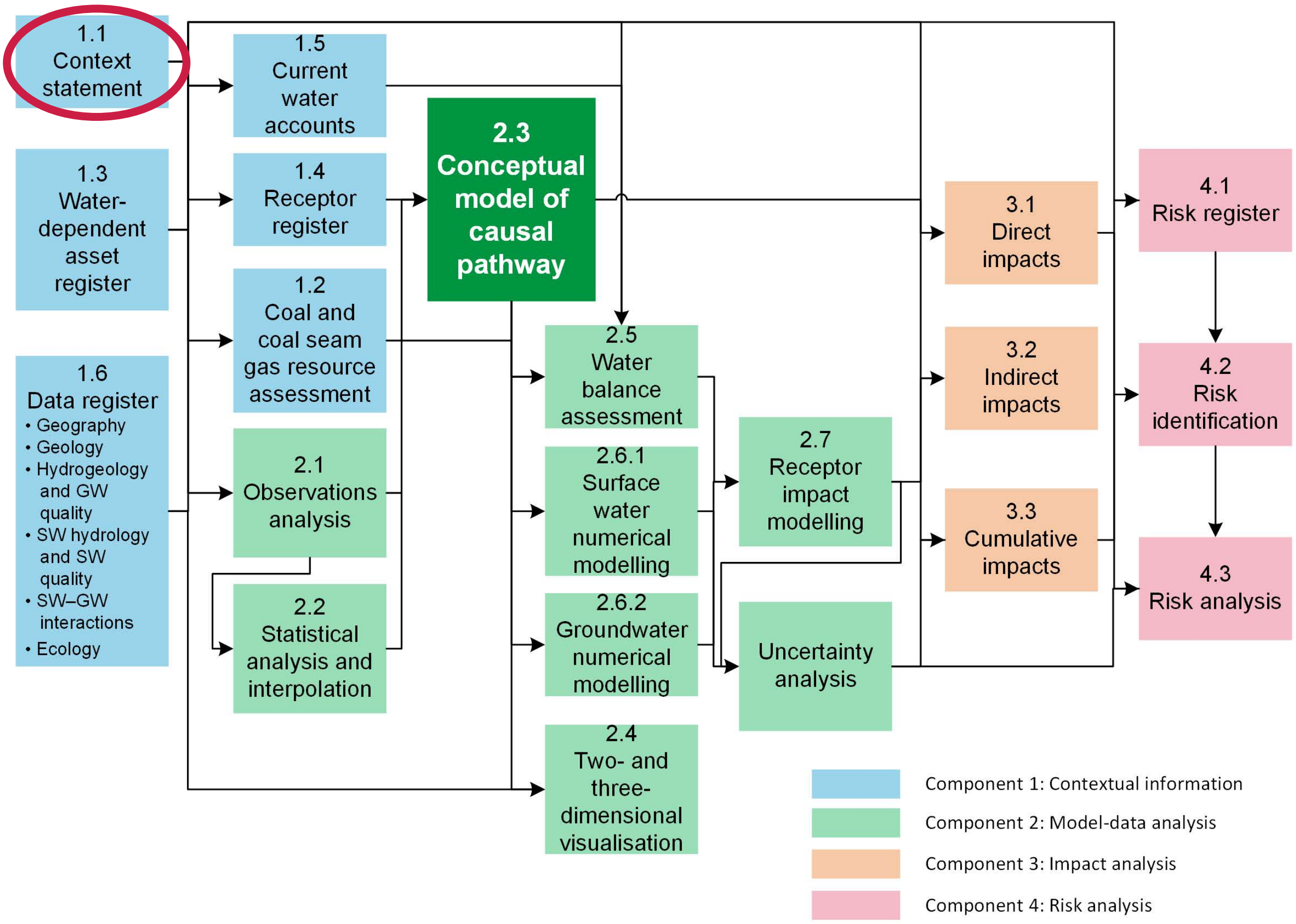

Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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 Namoi 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 Namoi 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 Namoi 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 Namoi 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 bioregion	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 1 November 2013, <www.environment.gov.au/coal-seam-gas-mining/pubs/methodology-bioregional-assessments.pdf>.

1.1 Context statement for the Namoi subregion

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

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

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

1.1.1 Bioregion

The Namoi subregion is part of the Northern Inland Catchments bioregion (Figure 3). The Northern Inland Catchments bioregion is located west of the Great Dividing Range in eastern Australia. It includes parts of the northern Murray–Darling Basin in northern New South Wales and southern Queensland. Parts of the northern Murray–Darling Basin that are not underlain by coal are not included. The 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 Namoi subregion boundary is the same as the Namoi Catchment Management Authority boundary over the extent of the coal-bearing geological basins. The Namoi subregion does not extend further east than this, so covers a smaller area than both the Namoi Catchment Management Authority and the Namoi river basin.

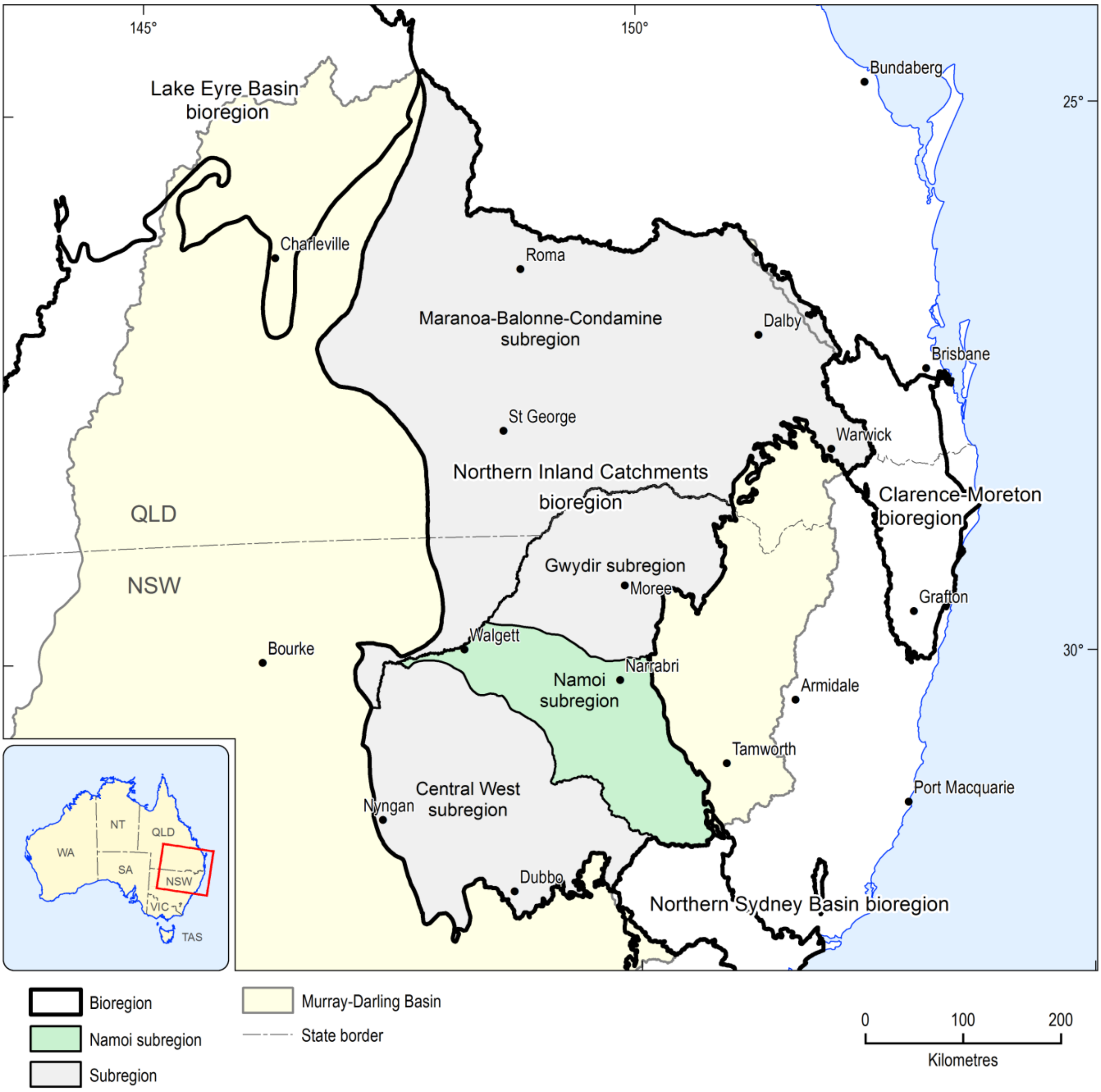

Figure 3 Northern Inland Catchments bioregion and subregions

1.1.2 Geography

Summary

The Northern Inland Catchments bioregion covers an area of approximately 248,000 km^2, of which the Namoi river basin covers 42,000 km^2 and the Namoi subregion covers approximately 29,300 km^2. The Namoi subregion is smaller than the Namoi river basin because the eastern part of the river basin does not overlie a coal-bearing geological basin. The Namoi subregion landscape is characterised by highlands in the east and south and a broad floodplain in the west with the highest point being 1400 m AHD on the flanks of Mt Kaputar in the north-east. Soils are typically clay and sandy- or clay-loams.

Drainage is dominated by the Namoi River, which flows east to north-west and west, and its tributaries and distributaries, the Mooki River, Coxs Creek, Pian Creek and Turragulla Creek. There are many ecologically important small lagoons, natural and artificial wetlands and floodplain woodlands, which can be inundated during a 1-in-2 year event. Lake Goran is listed as a wetland of national significance.

Approximately 27,000 people live in the Namoi subregion, concentrated along the Namoi River, mainly between Gunnedah and Narrabri. The subregion intersects four local government areas. Prior to European settlement the river basin was inhabited by the Gomeroi people.

In 2001, native vegetation was estimated to cover 62% of the Namoi river basin, the remainder having been cleared for cropping and grazing. Of the remnant vegetation, much has been substantially altered. In the subregion, nature conservation areas cover 2065 km^2, approximately 7% of the total area. About 40% of the subregion is used for grazing, 23% for dryland cropping and horticulture, 10.5% for forestry and 5% for irrigated crops such as cotton and wheat. The economic value of agricultural production in 2010-11 was estimated to be $1.12 billion (ABS, 2012), of which 25% was from irrigated cotton.

Water is extracted from surface water and groundwater resources for irrigation, livestock and domestic use. The Namoi river basin as a whole uses approximately 2.6% of the total surface water diverted for irrigation in the Murray–Darling Basin and 15.2% of the total groundwater resource that is extracted from the Murray–Darling Basin (CSIRO, 2007, p.14). Water is allocated through state licences. Some water requirements for the Namoi subregion are met from the upstream dams, such as the Keepit and Split Rock dams on the Namoi River and the Chaffey Dam on the Peel River. In the lower Namoi, lagoons and major weirs are regulated to supply water for domestic, irrigation and stock use. Water is also extracted from some creeks and rivers (such as Pian Creek and Gunidgera Creek). Some of the lower areas are semi-arid but experience significant flooding at times. Other natural hazards include bushfires, storms and flooding. Flash flooding also occurs in other parts of the river basin. High winds, heavy rain and associated landslips have also been known to occur.

The climate is typically cooler and wetter in the east and hotter and drier in the west. Annual average potential evapotranspiration is highest in the north-east of the subregion, and lower

in the west and south-west. In contrast, average annual actual evapotranspiration exhibits a strong decreasing gradient from east to west. Annual rainfall varies from about 500 mm to 1100 mm with most rainfall typically occurring in the summer months. Climate modelling investigations by CSIRO (2007), Chiew et al. (2009) and Vaze et al. (2008), summarised in the Namoi Catchment Action Plan (Namoi CMA, 2012a), suggest a drier and warmer future in this area. Estimates of future climate show a 5% decrease in rainfall and a 1 °C increase in temperature by 2030 relative to 1990, based on a moderate emissions scenario. Although annual rainfall will decrease, the modelling suggests that summer rainfall events will be more intense. A warmer, drier climate will mean an increase in potential evapotranspiration and drier soils, and has the potential to change flood behaviour in the Namoi River, although this latter change has not been modelled. These changes could cause land degradation and erosion. The more intense summer rainfall events and drier winters will “more likely than not increase the risk of dryland salinity” (Namoi CMA, 2012a p. 89). Wind erosion is expected to increase, and as surface water availability reduces, groundwater resources will be in greater demand while also being subject to reduced recharge (Namoi CMA, 2012a p. 89).

1.1.2.1 Physical geography

1.1.2.1.1 Physiography

Figure 3 shows the location of the Namoi subregion within the Northern Inland Catchments bioregion. Most of the boundary of the Namoi subregion is coincident with the former Namoi Catchment Management Authority boundary, except in the east where the Hunter-Mooki Thrust System, which marks the eastern extent of the coal, defines the boundary. Since the faulting is not vertical (see Figure 16 cross-section), the coal seam is known to extend slightly east of the surface expression of the fault line.

The topography of the subregion is characterised by highlands in the east and south, and a broad floodplain in the west. Figure 4 shows a digital elevation model of the area, with the highest elevation of 1400 m in the Nandewar Range to the north-east (Mount Kaputar, which is 1508 mAHD, lies just outside the subregion), the Liverpool Ranges in the south-east and the Warrumbungle Ranges to the north of Coonabarabran. These areas are characterised by steeper slopes (>20°) than elsewhere in the subregion. The Namoi river basin slopes largely towards the north and west, with most slopes having gradients less than 1.5°. The subregion’s lowest point of approximately 95 mAHD is west of Walgett.

The area south-east of Narrabri is characterised by river valleys with broad floodplains bounded by low hills. West of Narrabri there is low topographic relief, with the land forming an extensive alluvial plain. The plain is dissected by flood runners[1], billabongs and warrambools[2] that only flow during times of high flow. The Namoi River splits into divergent distributaries near Wee Waa. The major channels are the Namoi River, Pian Creek, Gunidgera Creek and Turragulla Creek (Figure 36). Moving westward, the channels form a single, main channel, approximately 10 km east of Walgett.

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[1] A flood runner is a small distributary or anabranch that flows only during periods of high flow in the stream it branches from.

[2] A warrambool is an overflow channel or tributary containing water only during flood events.

At Walgett the Namoi River joins the Barwon River, which joins the Darling River beyond the boundaries of the bioregion.

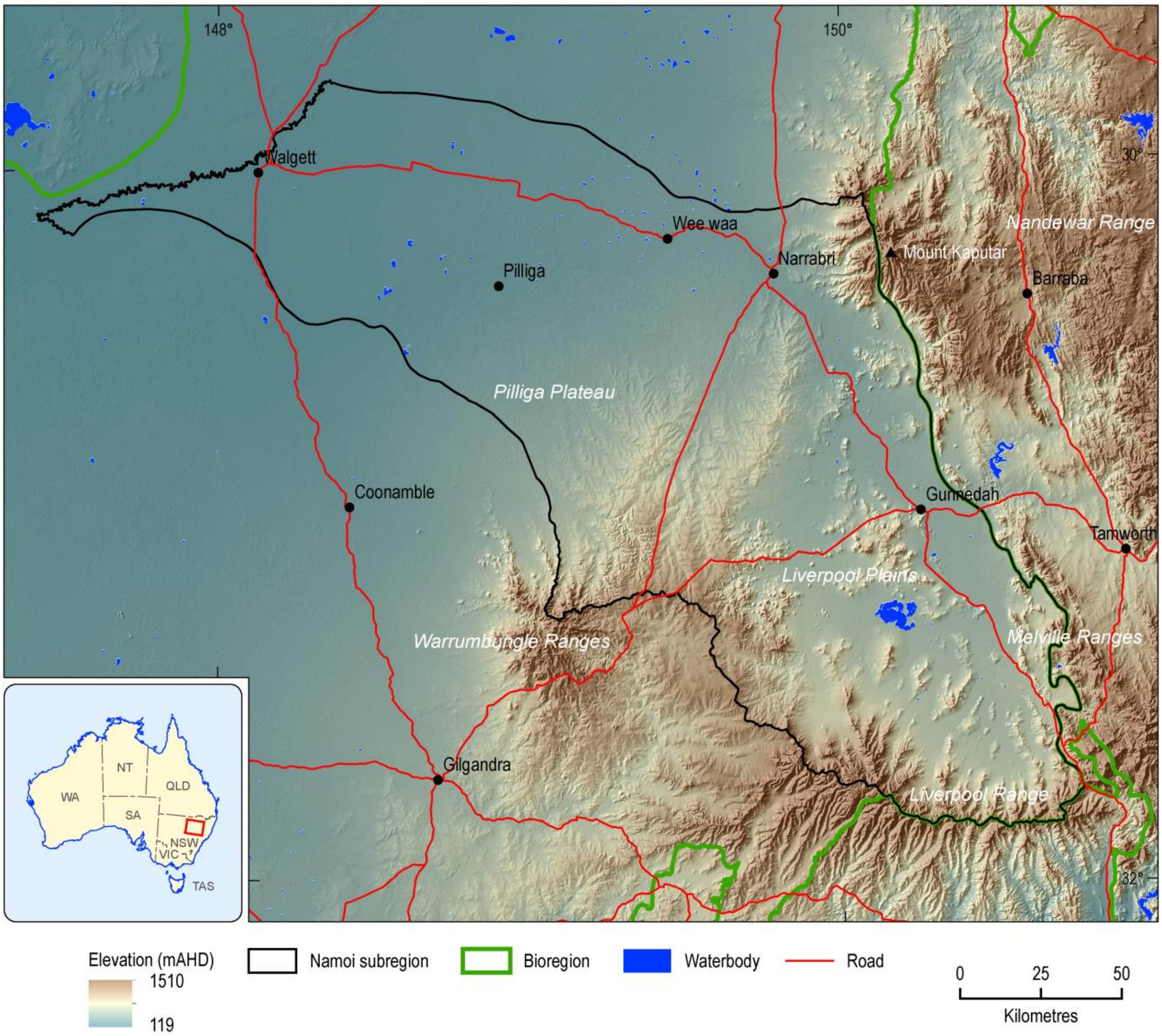

Figure 4 Digital Elevation Model showing topography and main mountain ranges

Thoms et al. (1999) described a distinct physiographic boundary slightly east of Narrabri that separates the eastern and western regions of the Namoi river basin. The boundary reflects a north-south outcrop of Pilliga sandstone, which widens to the south to form a plateau of erosion-resistant sandstone at an elevation of about 400 m AHD, sometimes referred to as the Pilliga Plateau (Figure 4). The zone of eroded sands surrounding the plateau is referred to as the Pilliga Sandsheet. This boundary coincides with distinct changes in the geomorphology of the river basin (described below). A third distinctive physiographic region is the Liverpool Plains, which are alluvial plains occupying 1.2 million hectares to the south of Narrabri and significant for their agricultural production (Figure 4). The Liverpool Plains are bounded to the south by the Liverpool Ranges, to the east by the Melville Ranges and to the west by the Warrumbungle Ranges and Pilliga Plateau.

The upland area east of Narrabri and the Hunter-Mooki Fault is where the Namoi, Peel, Manilla and Macdonald rivers originate and where the major water storages are located. Although this area is not part of the Namoi subregion, it is an important source of the subregion's water. Lampert and Short (2004) undertook a geomorphic assessment of the whole of the Namoi river basin drainage system to provide a basis for prioritisation of river conservation and rehabilitation efforts. In these upland areas, common drainage features include gorges (irregular, V or U shaped with valley controlled geometry and sinuosity), floodplain pockets (single, bedrock or terrace confined with low sinuosity channels), and bedrock controlled gravel channels (single, symmetrical to asymmetrical within partly confined valleys).

The geomorphology of the Liverpool Plains is described in Dawes et al. (2000). Erosion of the basaltic Liverpool Ranges began in the Miocene, and as the climate dried in the Pleistocene the depositional environment changed from braided streams, depositing interbedded clays with sand and gravel layers (the Gunnedah Formation), to lower energy meandering streams depositing finer-grained black, grey and brown clays (the Narrabri Formation). The lower energy system is consistent with the current conditions, resulting in the formation of fertile and productive alluvial plains. The Liverpool Plains are drained by the Mooki River and Coxs Creek, the catchments of which are fully contained within the subregion.

West of the Hunter-Mooki Fault, the slopes of the river valleys emerging from the upland areas of the catchment decrease significantly and the valleys widen progressively to form the extensive floodplains of the western subregion. Thoms et al. (1999) characterised the rivers in this region as typically 'meander' or 'anabranch'. In the 'anabranch' type rivers the main channel is relatively stable, but can experience some bank erosion, and the system is multi-channelled during floods. In 'meander' type rivers the main channel commonly experiences bank erosion and is a source and store for sediment transfer.

Young et al. (2002) investigated the geomorphology of the floodplains west of Narrabri. Paleochannels across the floodplain are typically significantly larger than the modern channels suggesting the flows that formed them were approximately twice the magnitude of modern Namoi flows. Sediments to the south of the main Namoi channel in this region are dominated by sands eroded from the Pilliga outcrops to the south and east. River channel properties, such as meander length and sediment particle size, indicate that discharge in the river basin decreases in a downstream direction. Examination of paleochannel properties suggests this characteristic of the river basin is consistent between the modern period and geological record. Young et al. (2002) suggested that dissipation of discharge into a number of paleochannels across the northern part of the floodplain would account for downstream discharge declines.

Thoms et al. (1999) noted that the alluvial plains across this region consist of alternating beds and lenses of gravel, sand and silt-clay sediments up to 150 m thick. This is consistent with the findings of Young et al. (2002) and therefore the recharge capacity across the alluvial plain will be highly variable, dependent on the presence of sandy sediments and a lack of sealing by finer clayey sediments from the more recent depositional history. The broad, sand-filled paleochannels provide localised alluvial groundwater sources.

1.1.2.1.2 Soils and land capability

Soils are an integral part of the Namoi river basin, providing nutrient cycling, water and organic storage, a resource base and natural environment. Namoi CMA (2012b) identified that improved groundcover would have significant outputs in relation to soil-organic matter, -carbon, -permeability and nutrient cycling. Some soils are compacted by stock and grazing activities and erosion of the top few centimetres of soil could seriously deplete nutrient capital (Tongway and Ludwig (1990), cited by Namoi CMA, 2012b), although Tongway and Ludwig (1990) studied an area to the west of the Namoi subregion.

The Namoi CMA (2012b) describes some soil types and classifications in the Namoi river basin. Soils in the area are typically clays, clay loams or sandy loams. High clay contents mean high water holding capacities when saturated, impeded drainage and hard setting surfaces, which restrict infiltration during heavy rainfall. The Australian Soil Resource Information System (ASRIS, 2011), which provides nationally consistent data and information on Australia's soil and land resources, provides 55 soil descriptions across the Namoi river basin including for clays, friable red and brown soils, gravels, sandy earths and hard, red and yellow soils. Figure 5 shows soils as defined by the Australian Soil Classification (Isbell, 1996). The State of the Catchments (2010b) statement on soil condition reported that soils in the region are typically 'Fair' ('Noticeable loss of soil function. Noticeable deterioration against reference condition') to 'Good' ('Slight loss of soil function. Noticable but not significant deterioration against reference condition'). The soil classed as 'Fair' is typically on forestry land and also on grazing land close to Gunnedah and Narrabri.

The State of the Catchments report (2010c, Land Management within Capability) for the Namoi reported that on average land is being managed at capability, which was given a rating of 'Fair'.

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 LSC 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 6 shows land and soil capability classification for the Namoi subregion based on the most limiting hazard. The vertosols of the lower Namoi floodplain and the Liverpool Plains are mostly LSC classes 3 and 4 with narrower belts of Class 2 land along the major river valleys. Class 2 indicates very good cropping land with fertile soils and short, low slopes, which 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 a range of hazards, while Class 4 lands are generally not capable of sustaining high impact land uses without use of specialised management practices requiring high levels of knowledge, expertise, inputs, investment and technology. Limitations are more easily managed for lower impact land uses like grazing. On the kandasols and sodosols of the Pilliga Plateau, most of the land is characterised as having severe limitations (Class 5), with localised areas of very severely limited land (Class 6). These lands can support a variety of land low intensity land uses, such as grazing, forestry and nature conservation. Highly specialised management practices can overcome some limitations to cropping on Class 5 land, but more limited lands are best suited to light grazing, forestry and nature conservation. The steeper slopes of the Liverpool Ranges and Warrumbungles are not capable of sustaining any disturbance and are best left undisturbed and managed for conservation, although grazing of native vegetation is pursued on some of these lands.

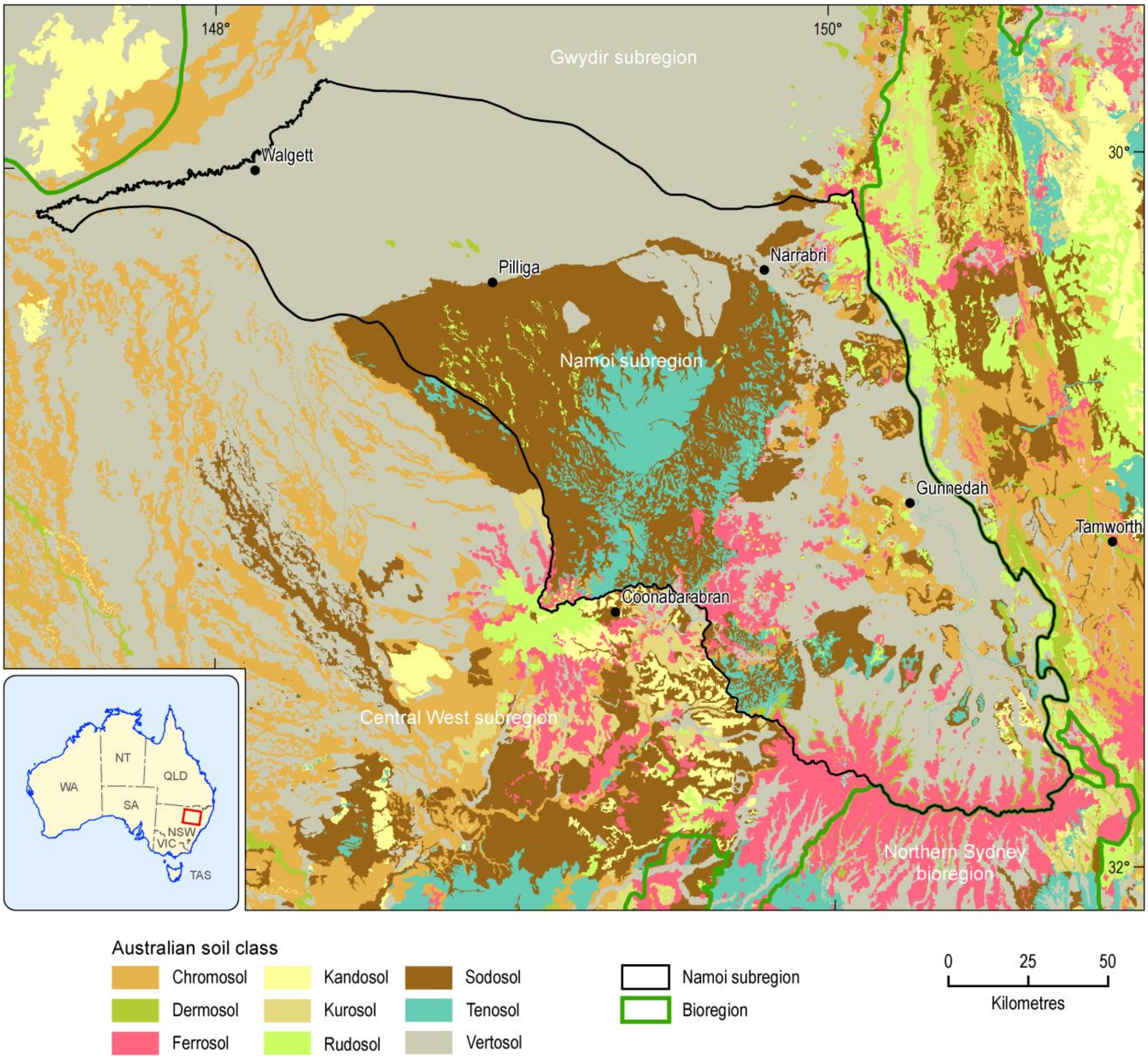

Figure 5 Major soil types

Soil types: chromosol (abrupt increase in clay down the horizon), dermosol (less structural contrast than chromosol), ferrosol (contains iron oxide >5%), kandosol (clay may exceed 15%, weakly structured), kurosol, (strongly acidic with clay), sodosol (contains moderate sodium), tenosol (contains up to 15% clay), vertosol (clay-rich, shrink/swell properties, strongly cracking when dry).
Source data: Australian Soil Classification, ASRIS (2011)

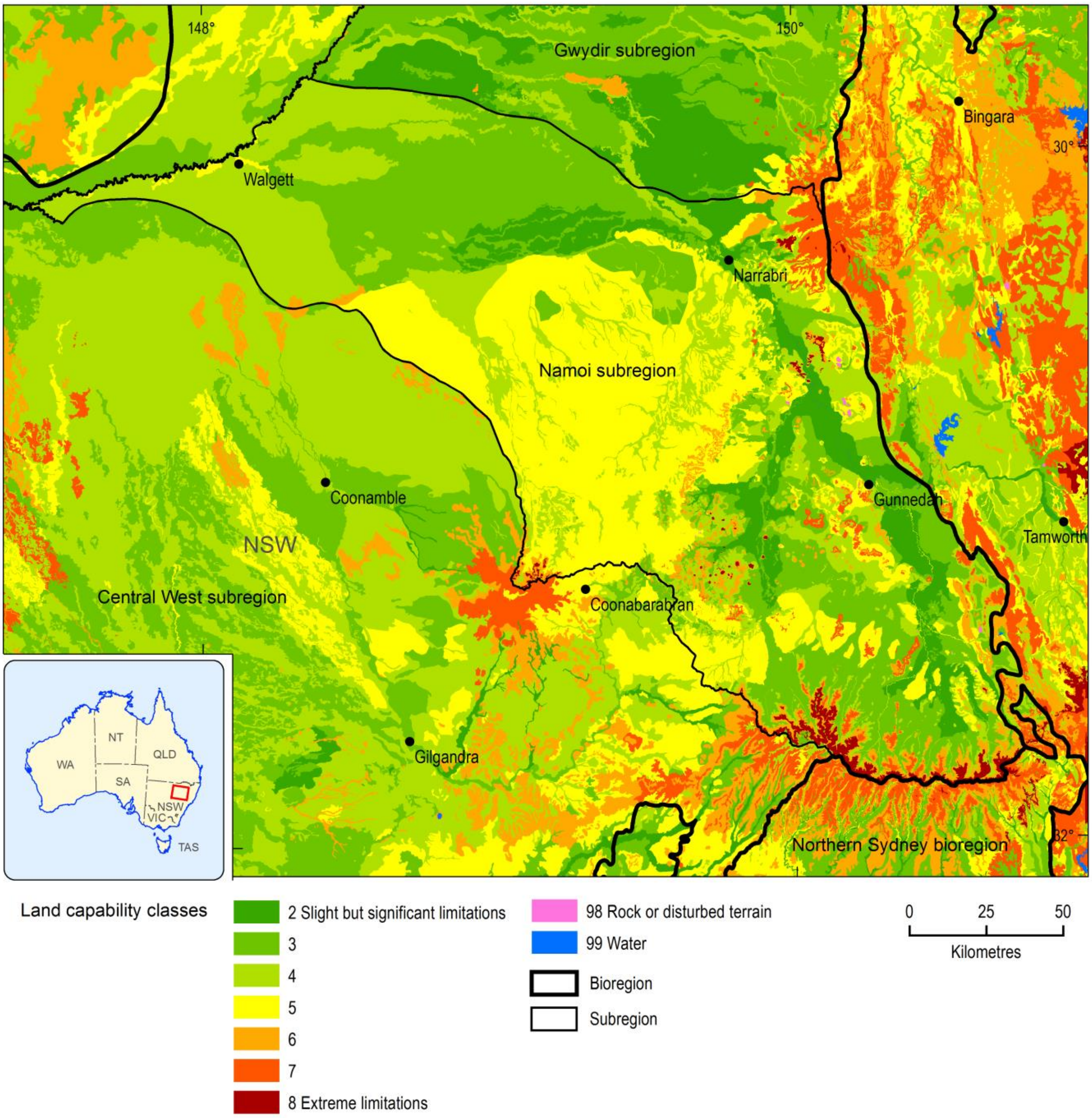

Figure 6 Land and soil capability

Source data: Land and Soil Capability Mapping – New England/North West Strategic regional landuse priority area, NSW OEH (2013)

1.1.2.1.3 Land cover

Mapping of land cover for the subregion is shown in Figure 7. This mapping was undertaken using time series Enhanced Vegetation Index (EVI) data obtained by the satellite-mounted Moderate Resolution Imaging Spectroradiometer (MODIS). The EVI data have a 250 m by 250 m pixel size and use vegetation greenness to identify the amount of photosynthesis occurring, which is then related to different vegetated land cover types (Geoscience Australia, 2013). Three distinct areas are evident: the Liverpool Plains area, which is dominated by rainfed cropping covers in the lower lying areas and sparse to open tree cover on more elevated areas; a large core between Coonabarabran and Narrabri, which is dominated by sparse to open tree cover and areas of sparse shrubs; and the western alluvial plains area where rainfed cropping lands are dissected by stringers of sparse to open woodlands, with a smattering of small water bodies and appearance of areas of tussock grasses in the western most areas towards Walgett.

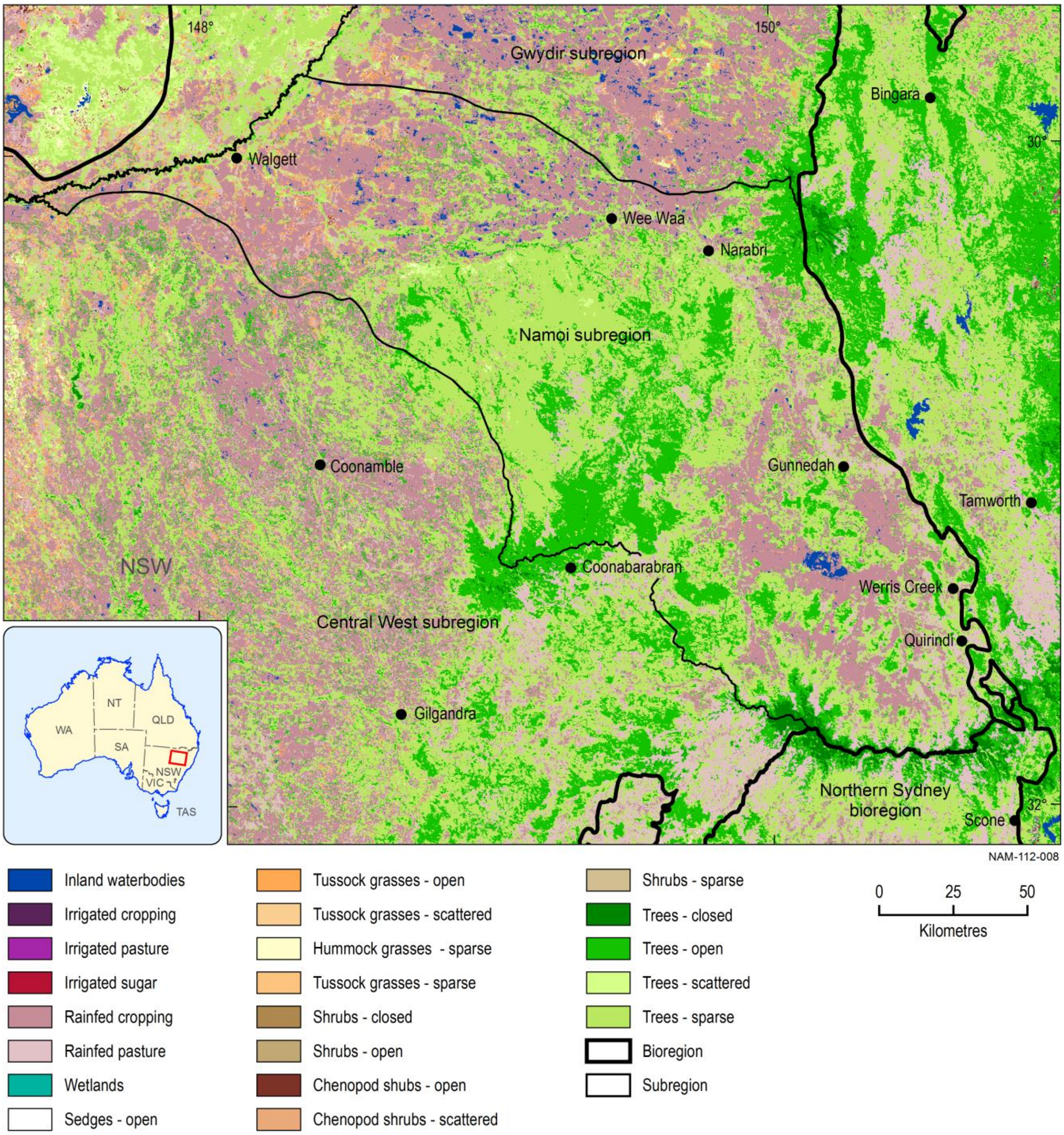

Figure 7 Land cover mapping from MODIS data

Source data: ABARES (2013)

In 2001, the extent of native vegetation was estimated at 62% of the Namoi river basin area, with the remaining having been cleared for cropping and grazing (Namoi Catchment Management Board, 2002). Of the remnant vegetation, a significant proportion of this has been substantially altered. Some native grasses remain on grazing land, but much of the understorey has been removed (Namoi CMA, 2006). The proportion of current native vegetation that is a result of revegetation is uncertain. Revegetation activities are encouraged by the Namoi CMA (2006) and Greening Australia (2003).

The upper Namoi river basin hosts open box woodlands on the slopes and temperate to subalpine forests in the ranges, whereas the Liverpool Plains supports some endangered native grasslands. River oaks and willows dominate riverine vegetation and river red gums grow along some streams. A study by Cotton Catchment Communities CRC (2009) identified six broad vegetation communities in the floodplain of the lower Namoi River including carbeen woodlands, riparian woodland, coolibah or black box woodland, bimble box woodland, river red gum forest and weeping myall dominated regions.

Downstream of Narrabri there are many small lagoons and floodplain woodlands. Eco Logical Australia (2008) identified over 1800 natural wetlands and over 900 artificial wetlands (such as dams, weir pools), nearly half of which would be inundated by a 1-in-2 year flood event.

Away from the main river, Lake Goran is a significant wetland area and although the lake is rarely full, the centre of the lake is artificially fed by diversion of creeks by agricultural activities (Green et al., 2011; Banks, 1995). When dry, the lakebed is cropped and when flooded, it provides a habitat for waterbirds and is listed as a wetland of national significance (DSEWPC, 2013).

1.1.2.2 Human geography

1.1.2.2.1 Population

The present population of the wider Namoi river basin is approximately 100,000 people (Green et al., 2011). Most inhabitants live along the Namoi River and its tributaries. The largest urban centre in the Namoi river basin, but located outside the subregion, is Tamworth on the Peel River with a population of 36,131 (Australian Bureau of Statistics, 2013). In the subregion itself, the population is approximately 27,000. The largest town is Gunnedah with 9,340 people, followed by Narrabri and Walgett with 6,930 and 6,454 people, respectively. Table 2 shows the main population centres in the river basin according to the 2011 census (Australian Bureau of Statistics, 2013).

Table 2 Main population centres

Locality	Population	Median age
Tamworth (outside subregion)	36,131	40
Gunnedah	9,340	39
Narrabri	6,930	38
Walgett	6,454	41
Wee Waa	2,089	36
Barraba (outside subregion)	1,537	52
Boggabri	1,189	40

Source data: Australian Bureau of Statistics (2013)

Five local government areas (LGAs) are represented within the Namoi river basin, four of which intersect the Namoi subregion (Narrabri, Gunnedah, Liverpool Plains and part of Tamworth). The Namoi Aboriginal Advisory Committee includes communities represented by traditional owners and native-title holders, custodians, elders groups, Aboriginal corporations and the local Aboriginal Land Councils (Namoi CMA, 2013). The Namoi Aboriginal Advisory Committee has a strategic role in providing advice on Aboriginal cultural values to the Namoi Catchment Management Authority. The river basin was inhabited by the Gomeroi people prior to European settlement. Based on figures for 2005 (Hyder Consulting, 2009), of the four local government areas represented in the Namoi subregion, Tamworth LGA had the greatest labour force by number (approximately 20,000), but most of these would be working outside the subregion. The Gunnedah LGA had the smallest labour force of approximately 3700 and the highest unemployment rate (6.3%) in the Namoi river basin. The Narrabri LGA had the lowest unemployment rate (4.2%). The majority of workers in the region described their occupations as management, professional, technicians or trades workers (Hyder Consulting, 2009).

1.1.2.2.2 Land use

ABARES (2012) land use data for the Namoi subregion (Table 3) shows that livestock grazing on natural and modified pastures accounts for about 40% of land use in the area. Approximately 5% of the subregion is used for irrigated agriculture, primarily cotton, but also other broadacre crops, including wheat, typically on the alluvial floodplains. Dryland cropping accounts for about 23% of land use, forestry for almost 11%, nature conservation 7% and the remaining 14% is largely divided between wetlands, water bodies, minimal use landscapes and residential. In 2010-11, agriculture in the wider Namoi river basin contributed $1,122 million to the regional economy, of which 25% was from cotton production.

Table 3 Land use areas in the Namoi subregion

Land use	Area (km^2)	%
Conservation and natural environments	4777	16.3
Grazing natural vegetation	3546	12.1
Production forestry	3065	10.5
Plantation forestry	37	0.1
Grazing modified pastures	8266	28.2
Cropping	6869	23.4
Horticulture	1.4	0.0
Land in transition	193	0.7
Grazing irrigated modified pastures	16	0.1
Irrigated cropping	1553	5.3
Irrigated horticulture	3	0.0
Intensive production	5	0.0
Residential, Manufacturing, Utilities, Transport, Services	468	1.6
Mining	11	0.0
Water	493	1.7

Source data: ABARES (2012)

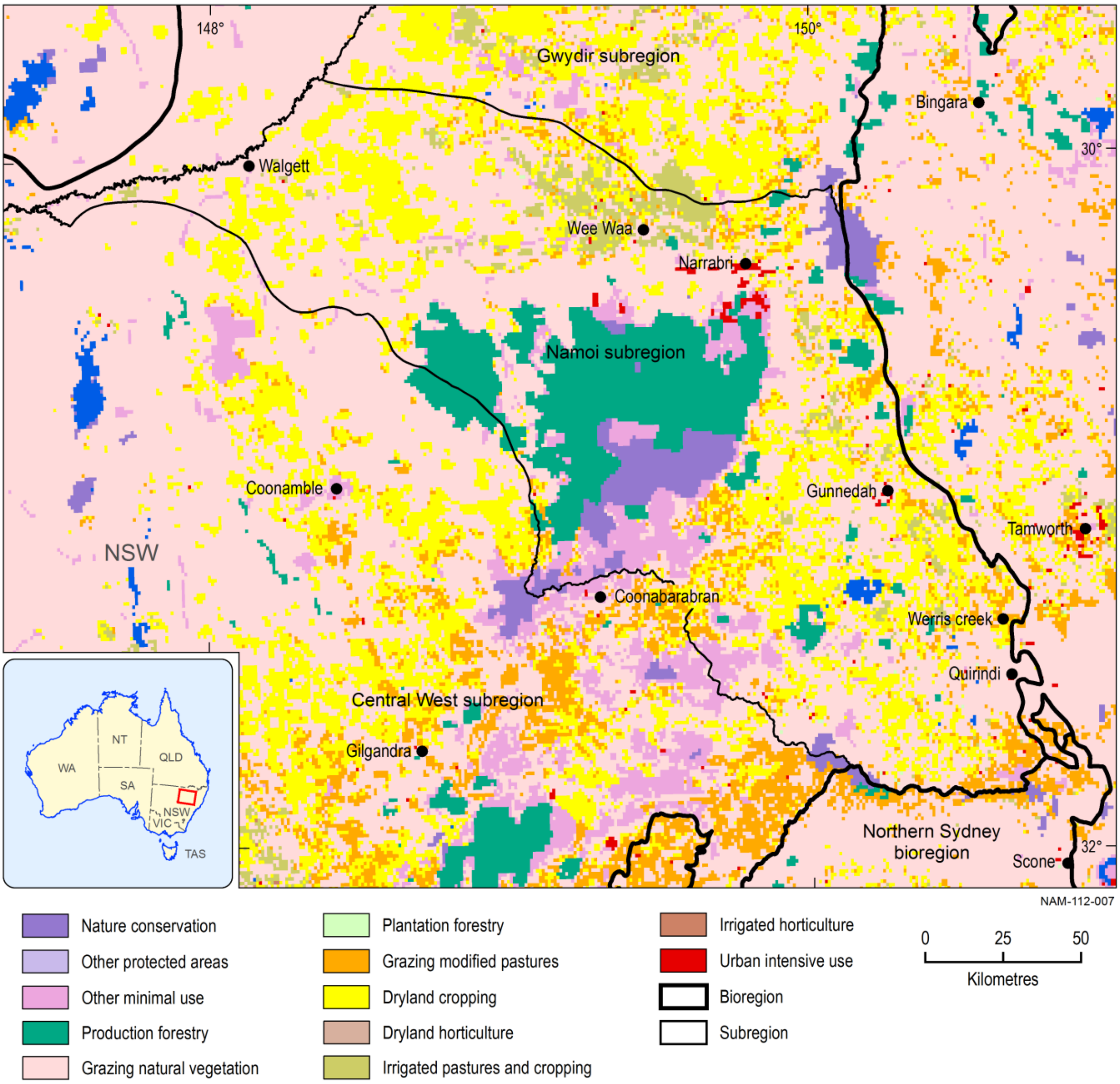

Figure 8 Land use types

Land use data obtained from the Australian Land Use 50 m May 2006; however the coverage of this data layer was incomplete. Where data were not available the image has been appended with 2001–02 Land Use of Australia, Version 3. This has resulted in minor inconsistencies, such as areas of 'Grazing modified pastures' likely being synonymous with 'grazing natural vegetation' in some locations in the west of the region.
Source data: ABARES (2013)

The land use distribution pattern for the subregion is shown in Figure 8. The distribution of land uses largely reflects soil type and geology and proximity to water. Irrigated crops and pastures are grown in the alluvial areas from the east of the subregion to west of Wee Waa. Beyond the area where irrigation is viable, opportunistic dryland cropping is undertaken when soil moisture is sufficient, and grazing on natural vegetation dominates. Land conservation and forestry is extensive through the central area of the subregion and includes dry sclerophyll forest and the 'Pilliga Scrub', which is predominantly Callitris species.

National parks and nature reserves occupy 2065 km^2 of the subregion. The parks protect a broad range of native habitat and woodland types including cypress pine, hill red gum, river oak, iron bark and isolated patches of rainforest and semi-arid to subalpine areas and heathlands. The Pilliga Sandstone outcrop has not been cleared for agriculture, largely due to the poor soils and lack of surface water availability. The Pilliga Scrub, incorporating the Pilliga State Forest and the Pilliga Nature Reserve, is the largest remaining native forest on the Australian mainland (NSW Department of Environment, 2013 and Section 1.1.7). It is managed for production forestry in the north and nature conservation in the south. Its connection with adjacent forests makes this an important conservation area as habitat for threatened species such as the Pilliga mouse, eastern pygmy possum, koala, glossy black-cockatoo, swamp wallaby and brush-tailed rock wallaby (Green et al., 2011). In other parts of the region where soils or terrain make agriculture difficult, for example in the mountain ranges to the south and north, the areas are either reserved for nature conservation or classed as 'minimal use'.

1.1.2.2.3 Water use

The main rivers in the river basin include the Namoi River (on which Keepit Dam is situated upstream of the subregion) and the Peel River (which is upstream of the subregion and is regulated by Chaffey Dam). No large-scale dams are present in the Namoi subregion although in the lower Namoi, a large number of lagoons occur and two major weirs are in operation to regulate water for domestic, irrigation and stock use (Green et al. 2011). Water is extracted from some creeks and rivers such as the Pian Creek and Gunidgera Creek (off the Namoi River) to supply water for irrigation, and private weirs and off-creek storages also exist (Green et al., 2011). Some parts of the river basin such as the large area of low elevation south-west of Narrabri are semi-arid but occasionally experience significant flooding. Table 4 lists the main water controls in the Namoi river basin. More complete information on water use in the Namoi subregion is provided in Section 1.1.5.

Table 4 Main water storage and controls

Storage or control	Location	Capacity
Keepit Dam (outside of subregion)	Namoi River	426,000 ML, irrigation, town water for Walgett, flood mitigation, hydropower
Split Rock Dam (outside of subregion)	Manilla River	397,000 ML, augments supply from Keepit Dam, supplies users on Manilla River
Chaffey Dam	Peel River	62,000 ML, regulates flow of Peel River, augments supply to Tamworth
Dungowan Creek Dam	Dungowan Creek	6,300 ML, town water for Tamworth
Three weirs on Namoi (one outside of subregion)	Two on Namoi River downstream of Narrabri	Hold and regulate flows to improve supply
Gunidgera Weir	Downstream of Wee Waa on Namoi River	1,900 ML, assists re-regulation, creates height in river to allow regulated flows to be transferred to Gunidgera and Pian creeks
Weeta Weir		280 ML, provides storage for downstream irrigation, currently not used
Rossmore Weir	Pian Creek	Controls river with reduced flow

Source data: NSW Department of Primary Industries (2013)

About 2.6% of the total surface water diverted for irrigation in the Murray–Darling Basin is used by the Namoi river basin. Additionally, the Namoi river basin uses 15.2% of the total groundwater resource extracted from the Murray–Darling Basin (CSIRO, 2007).

Water from the Chaffey and Dungowan dams meets the needs of the Tamworth town water supply, stock and domestic users and irrigation from the Peel catchment. An annual allocation system provides water allowances to licence holders in the Peel catchment after essential water has been designated for future requirements, delivery and storage losses. If resources increase, allocations may also increase throughout the 'water year' (1 July to 30 June) and when river flow exceeds water user and environmental needs, supplementary access is declared, allowing water to be extracted without annual entitlements being debited. At the end of the water year, unused allocations are forfeited. Tamworth City Council has town water supply entitlements of 16,400 ML/year from Chaffey Dam, 5,600 ML/year from Dungowan Creek Dam and 10 ML/year from the Peel Alluvium, and irrigators have an entitlement of 30,911 ML/year (Green et al., 2011). The groundwater supply from the Peel catchment is also licensed, entitling 51,000 ML/year extraction from alluvial and fractured groundwater sources, which is used for irrigation and stock watering through nearly 5000 bores in the area (Green et al., 2011).

In the Namoi subregion, the Namoi River provides water through regulated flows from Spilt Rock Dam and Keepit Dam and some downstream weirs. The dams are operated as a combined resource but the upper and lower Namoi operate under different allocation methods. The upper Namoi operates on an annual system and requires that full allocation is achieved before additional water is shared with the lower Namoi, whereas the lower Namoi operates on a continuous system where accounts are not reset, allowing users to operate according to their own requirements. When river flows exceed user requirements, additional access to water is provided without debiting users' accounts (Green et al., 2011).

Groundwater in the Namoi river basin can be accessed from more than 18,000 bores that are licensed to provide 343,000 ML of groundwater per year. Under the New South Wales *Water Management Act 2000*, a water sharing plan was prepared to establish rules for sharing water between the environment and water users, including water trading and annual water allocations, over a 10-year period. Further details are discussed in Section 1.1.5.

1.1.2.3 Climate

The climate across the Namoi subregion varies from cooler and wetter in the east to hotter and drier in the west. Figure 9 shows the Köppen Key Climate Groups for the region, showing temperate areas in the east and south, moving to subtropical areas west of Narrabri. The subtropical zone extends south-east along the main Namoi River channel to Gunnedah.

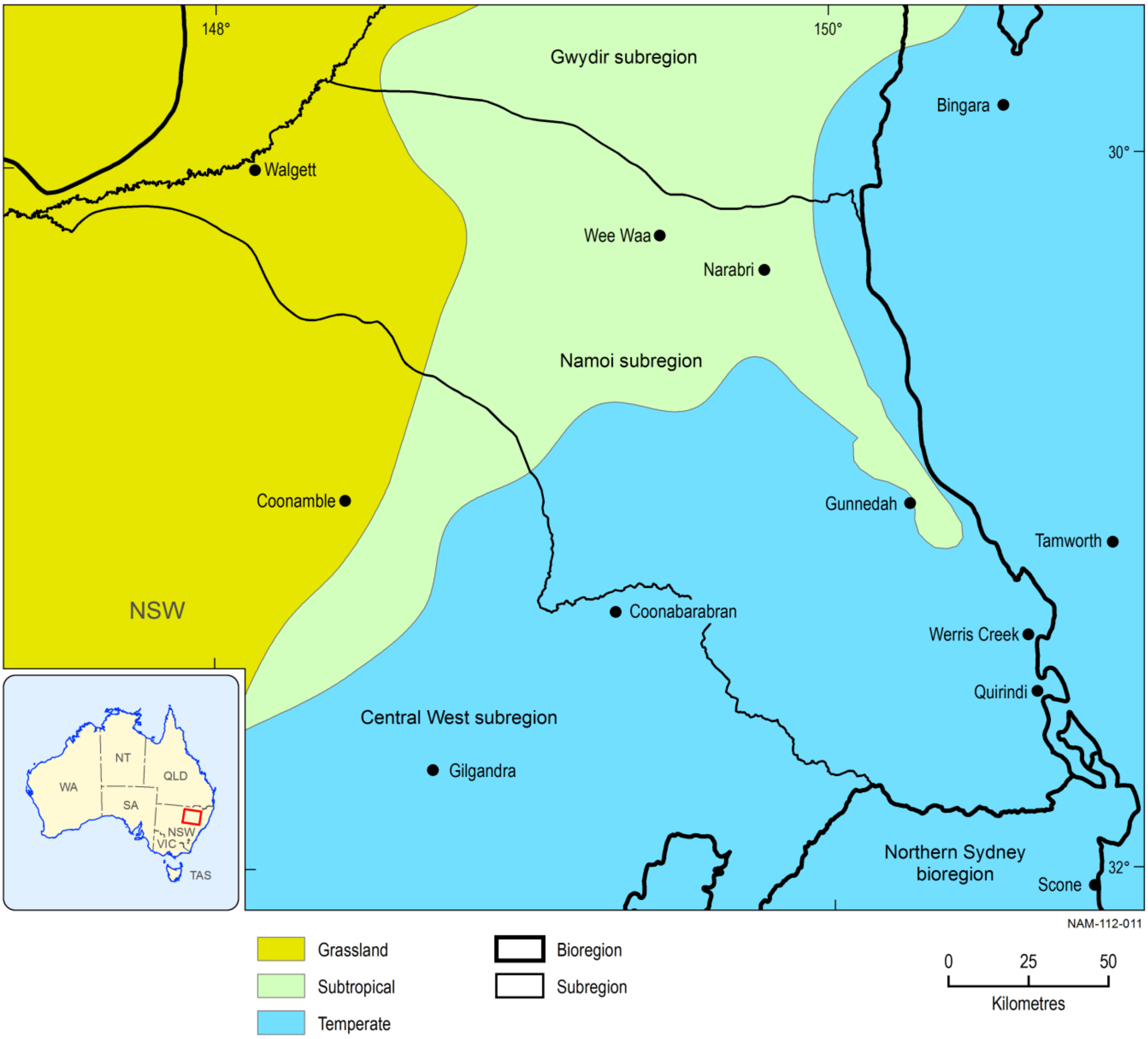

Figure 9 Köppen key climate groupings

Climate zone boundaries in the Köppen classification system are based on the concept that native vegetation distribution limits can define climate zones
Source data: ABARES (2013)

Mean annual rainfall varies significantly across the region from less than 495 mm/year in the west to over 1100 mm/year in the highlands to the east and south (Figure 10). Mean monthly rainfall and temperature patterns are shown in Figure 11 for Narrabri (climate station 54120) (Bureau of Meteorology, 2013a). The lowest average rainfall typically occurs in April and August (April and May for Tamworth). Most rainfall typically occurs in the summer months (December to February). Widespread drought has occurred in the past, lasting for several years in the Namoi river basin, and severe water shortage typically occurs in the subregion from May to December each year. Flooding also occurs quite frequently and is recorded in the Emergency Management Australia Disasters Database for 1998, 2000 and 2004 (Hyder Consulting, 2009).

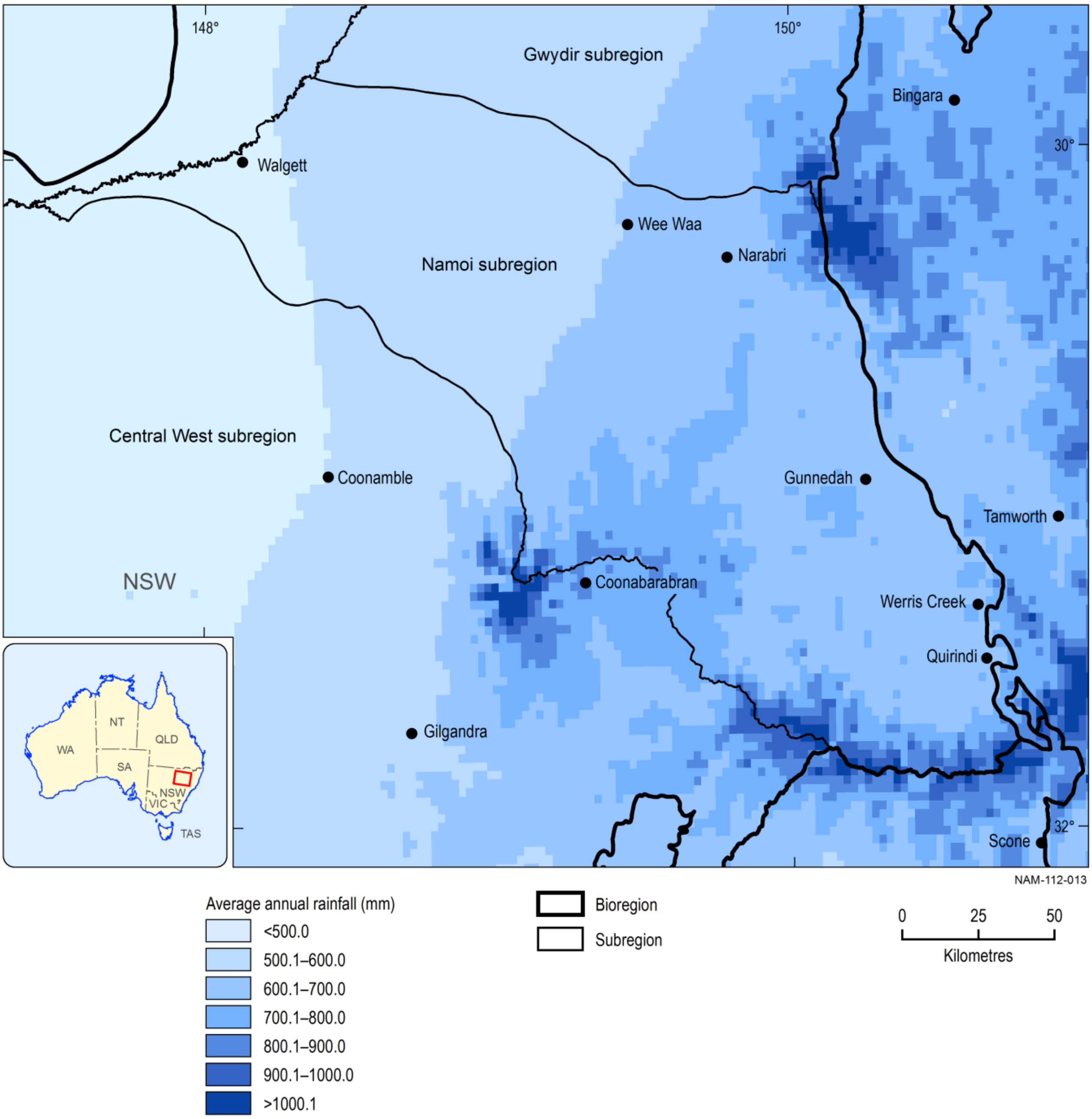

Figure 10 Gridded mean annual rainfall

Source data: Bureau of Meteorology (2013d)

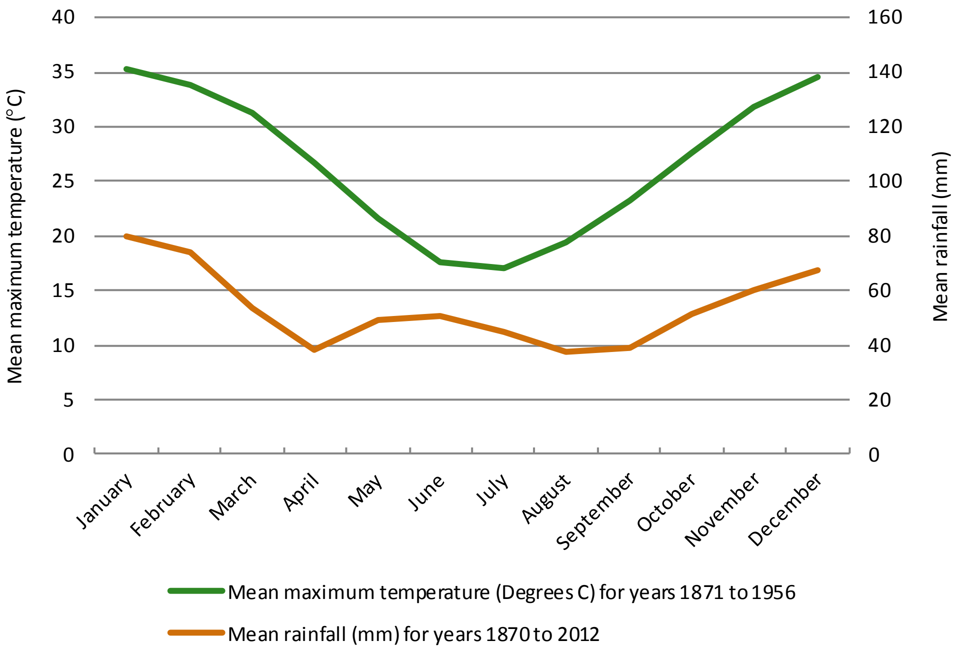

Figure 11 Mean monthly rainfall (mm) and mean maximum temperature at Narrabri weather station (054120)

Table 5 provides a summary of climate statistics for a selection of climate stations located across the subregion (Figure 12). The climate stations are listed according to position in the region, moving east to west, showing changing climate characteristics across the region. Bucking the trend of decreasing rainfall with distance westward, the average annual rainfall at Gunnedah is lower than that recorded at Narrabri and Baradine. This effect may be due to the orographic effects of the higher terrain adjacent to the two latter sites.

Table 5 Climate statistics for selected climate stations

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
055049 Quirindi Post Office 1882 to present Elevation: 390 m													
Mean rainfall (mm)	81.1	65.9	53.1	41.9	44.5	50.9	48.4	45.1	46.5	60.1	65.4	80.5	683.9
Mean maximum temperature (°C)	32.2	31.3	29.3	24.9	20.4	16.6	15.9	17.9	21.5	25.2	28.5	31.1	24.6
Mean minimum temperature (°C)	16.4	16.1	13.5	8.9	5.0	2.8	1.6	2.4	5.0	8.7	12.0	14.7	8.9
055023 Gunnedah Pool 1876 to present Elevation: 285 m													
Mean rainfall (mm)	71.7	67.3	47.7	37.5	42.5	43.6	42.7	41.3	40.3	55.1	62.2	70.0	622.2
Mean maximum temperature (°C)	34.0	32.9	30.7	26.4	21.3	17.6	16.9	18.9	22.8	26.7	30.3	32.9	26.0
Mean minimum temperature (°C)	18.4	18.1	15.8	11.4	7.1	4.3	3.0	4.2	7.0	10.8	14.2	16.8	10.9
054120 Narrabri Bowling Club 1870 to present Elevation: 213 m													
Mean rainfall (mm)	80.2	73.9	53.6	38.2	48.9	50.9	44.9	37.4	39.1	51.2	59.9	67.7	646.0
Mean maximum temperature (°C)	35.3	33.9	31.3	26.8	21.6	17.6	17.0	19.4	23.3	27.7	31.8	34.5	26.7
Mean minimum temperature (°C)	19.4	18.6	16.3	11.7	7.4	4.9	3.4	4.6	7.5	11.7	15.3	18.0	11.6
053002 Baradine Forestry 1944 to present Elevation: 302 m													
Mean rainfall (mm)	83.5	68.3	46.7	38.5	46.6	42.1	42.5	40.4	42.7	57.4	56.0	63.5	628.3
Mean maximum temperature (°C)	33.5	32.3	30.3	25.9	21.1	17.5	16.7	18.5	22.1	26.2	29.5	32.4	25.5
Mean minimum temperature (°C)	18.4	18.3	15.3	10.2	6.4	3.6	2.2	3.0	6.0	9.8	13.4	16.3	10.2
052026 Walgett Council Depot 1878 to present Elevation: 133 m													
Mean rainfall (mm)	62.4	59.3	39.7	34.0	39.1	35.4	32.4	28.0	27.4	37.6	40.4	44.1	479.5
Mean maximum temperature (°C)	35.4	34.0	31.4	26.8	21.8	18.0	17.4	19.8	23.8	28.1	31.9	34.6	26.9
Mean minimum temperature (°C)	20.4	19.9	17.1	12.5	8.2	5.5	4.2	5.6	8.6	12.8	16.3	18.9	12.5

Source data: Bureau of Meteorology (2013d)
Climate station locations are shown in Figure 12.

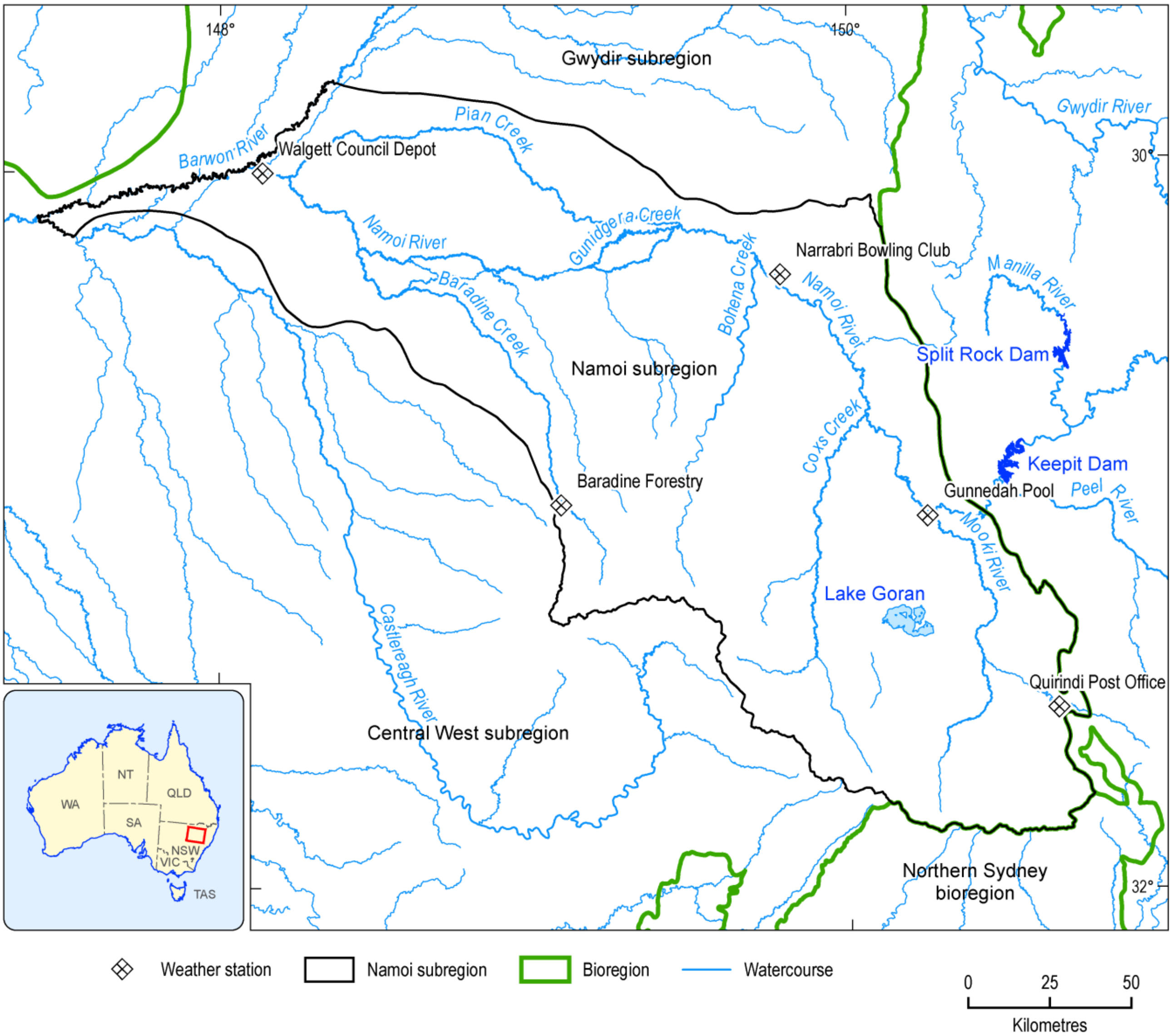

Figure 12 Locations of weather stations listed in Table 5

Within the subregion, mean annual potential evapotranspiration is lowest along the south-western boundary to Walgett (less than 1300 mm/year), and rises to approximately 1400 mm/year near Narrabri, with values increasing from south-west to north-east (Figure 13). In contrast, mean annual actual evaporation has a strong gradient, increasing from west to east.

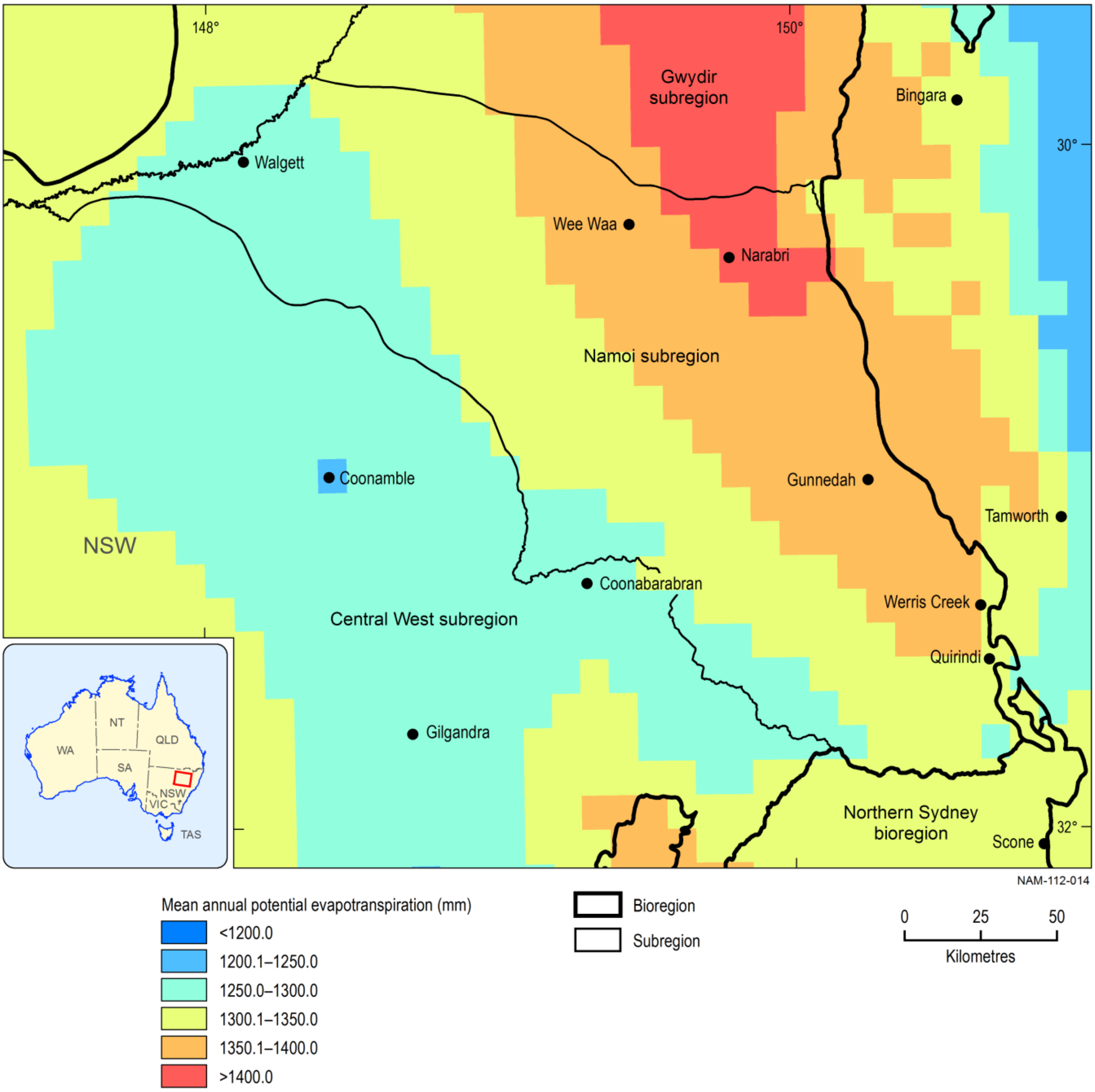

Figure 13 Gridded annual average potential evapotranspiration

Source data: Bureau of Meteorology (2013d)

In a recent report by the South Eastern Australian Climate Initiative (SEACI) (CSIRO, 2010), the significance of the period between 1997 to 2009, which is the driest 13 year period on record in south-eastern Australia, was assessed relative to other recorded droughts since 1900 as an indicator of what the future climate might look like. While this period is the driest in the 110+ year record in the south-eastern corner of Australia, with rainfalls 5 to 30% less than the 1895 to 2008 average, in the Namoi subregion, the rainfall was either within 5% of, or 5 to 20% greater than the long-term average. Modelled streamflow was estimated to be 5 to 50% greater than the long-term average across much of the subregion, with only the most westerly areas experiencing runoff reductions. In general, analysis has shown that the impact on streamflow of a small percentage change in rainfall is enhanced, with a 5% reduction in average 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, climate change modelling, which attempts to predict future climates in response to global warming, suggests that the probability of runoff reductions occurring in the Namoi area is greater than 50%. Post et al. (2012) modelled future runoff at a 5 km grid resolution for the Murray–Darling Basin. Their climate series was informed by simulations from 15 global climate models used in the IPCC Fourth Assessment Report, taking into account changes in daily rainfall distributions and seasonal rainfall (and potential evapotranspiration) amounts for an increase in global average surface air temperature of 1.0 °C (2030 relative to 1990). In the northern Murray–– Darling Basin, there was significant variability between models, with future streamflow projected to be between -29% and +12% of current averages, with a median of -10%. In the Namoi river basin (subregion plus headwaters), the median projection was a 1% reduction (–6 mm) in mean annual rainfall with small increases in summer rainfall, but reductions in autumn, winter and particularly spring rainfall. Across all models, potential evaporation was projected to increase by 2 to 5%. The net result is a projected 7% reduction (–2 mm) in mean annual runoff. At the dry end of the forecast ensemble, runoff could be 27% lower (–8 mm) than the current average, while at the wetter end, increases of 10% (+3 mm) of current runoff were predicted. Figure 14 shows the distribution of rainfall and runoff changes across the year for the historical record and projected changes for Tamworth. The wider range of projections for runoff compared to rainfall indicate greater uncertainty in these projections, and within the runoff projections, the summer and winter runoff projections are more uncertain than those for autumn and spring.

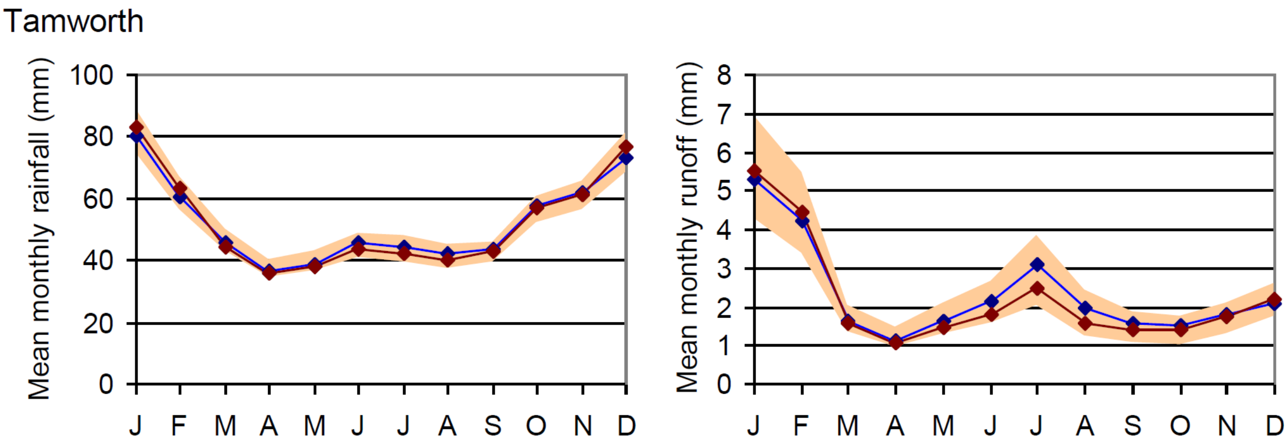

Figure 14 Mean monthly rainfall and runoff for Tamworth based on historical data (blue line), median climate projections in 2030 (red line) and future range (beige shading)

Source: Post et al. (2010)

Climate change projections were also developed for the CSIRO Murray-Darling Basin Sustainable Yields project and reported for the Namoi surface water catchment in CSIRO (2007). Three global warming scenarios were analysed in 15 global climate models (GCM) to provide a spectrum of 45 climate variants for the year 2030. The methods used to develop the climate variants are described in detail in Chiew et al. (2008). The analysis provided modelled estimates of changes in climate variables for high, medium and low global warming scenarios relative to the climate in 1990. The method also took into account different changes in each of the four seasons as well as changes in daily rainfall distribution. All 45 future climate variants were used in the rainfall-runoff modelling undertaken in the study; however, three variants – a 'dry', a 'mid' (best estimate – median) and a 'wet' variant – were presented in more detail.

The impacts of the different climate scenarios on surface water flows are summarised in CSIRO (2007), which suggests that, under the best estimate 2030 climate, the hydrology of the billabongs and wetlands of the Namoi River would not change greatly from the conditions in 2007. However, under the 'dry extreme' scenario for 2030 there would be a 36% increase in the average period between flood events, although flooding volumes would reduce by 28%. The changes would lead to a considerable change in connectivity between the river, billabongs and wetlands causing an alteration in nutrient transfer processes that would affect resident aquatic fauna in the area. A wet-extreme scenario for 2030 would see a return to pre-development values of average and maximum periods between events and the average event would increase to greater than pre-development volumes. The report stated that this would cause annual flooding to exceed pre-development volumes.

Table 6 Summary of potential climate change impacts assuming no mitigation or adaptation takes place

Asset	Cause	Impact
Vegetation cover	drier soils	reduced cover
Soil	heavy, sporadic rain and intense storms plus reduced vegetation cover	erosion, increased sodicity in soil
Slopes	heavy, sporadic rain and intense storms	gully erosion
Plains	wetter summers and drier winters	Increased wind erosion, increased dryland salinity from overdrying and hyperwetting of soils combined with decreased rootzone (due to reduced vegetation),
Groundwater recharge	reduction in recharge	changed hydrology, possible aquifer collapse and changes in chemistry
Surface water	reduced/changes in rainfall	reduced availability, increased pressure on groundwater, water quality, biodiversity loss
Drainage system	hotter, drier, increased evapotranspiration	drier soil, changes in flood behaviour (modelling not yet specific)

Source data: Namoi CMA (2012a)

Namoi CMA (2012a) has identified potential climate change impacts on landscape assets, summarised in Table 6. Potential impacts include a decrease in land cover, leading to a reduction in rooting density and depth, and increased soil erosion caused by prolonged, extreme dry periods with more intense rainfall events and storms. As summarised by the Namoi Catchment Action Plan (CMA, 2012a) land degradation caused by increased wind erosion, drying soils and heavy summer rainfall could be compounded by seasonal 'hyperwetting [of] soils' (Namoi CMA, 2012a p. 254). A diminished rootzone and increased soil wetness during the summer is projected to increase recharge of groundwater aquifers, leading to groundwater table rises and a greater risk of dryland salinity outbreaks. A drier, warmer climate means an enhanced evapotranspiration potential and reduced surface water availability, which is likely to increase the demand on groundwater, already stressed by a reduction in recharge.

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1.1.3 Geology

Summary

The Namoi subregion has two distinct basement geological elements. From east to west (also oldest to youngest) these are: Upper Paleozoic to Lower Mesozoic Gunnedah Basin sedimentary sequences, and Mesozoic sedimentary rocks of the Surat Basin. These all overlie the Middle Paleozoic rocks of the Lachlan Fold Belt (Figure 15 and Figure 16). East of the subregion there are Middle Paleozoic metasedimentary rocks of the New England Orogen. The New England Orogen lies outside the Namoi subregion and its internal architecture is beyond the scope of this narrative.

The Gunnedah Basin forms part of the larger Permo-Triassic Bowen-Gunnedah-Sydney Basin system and is the principal geological domain of this assessment as it contains alluvial and deltaic coal-bearing sequences. The basin system initially formed in a back arc extensional setting in the middle of the Paleozoic. This was followed by a period of thermal subsidence, and subsequent foreland basin downwarping. Uplift and erosion resulted from the development of the adjacent New England Orogen. During the Mesozoic, sedimentary sequences of the Surat Basin were deposited over large parts of the Gunnedah Basin. In more recent geological times, extensive Cenozoic intrusive and extrusive volcanic activity has occurred across the basin within a transpressional tectonic regime.

The oldest coal-bearing sequences in the Gunnedah Basin are in the Lower Permian Maules Creek Formation. This formation occurs in the Maules Creek Sub-basin in the east of the Gunnedah Basin, and is >800 m thick adjacent to the Mooki Thrust (Collins, 1991). The sedimentary rocks of the Maules Creek Formation consist of lithic conglomerate, sandstone, siltstone, and claystone with coal seams up to 8 m thick. These were originally deposited in alluvial environments dominated by braided streams. The start of the Upper Permian was characterised by marine transgression and the deposition of the shallow marine Watermark and Porcupine formations of the Millie Group.

Fluvial sedimentary environments were re-established by the middle of the Upper Permian with the deposition of the economically important Black Jack Group. The Pamboola Formation of the Black Jack Group consists of lithic sandstone, siltstone, claystone, conglomerate and intercalated coals, and varies in thickness from 89 m in the north to >206 m in the southeast. The most significant coal seams of the formation were formed in a lower delta plain environment and are contained within the Melvilles Coal Member. This unit is generally 2.5 to 3.5 m, but reaches up to 5 m thick near Boggabri.

After a brief marine transgression, represented by deposition of the Brigalow / Arkarula Formation, fluvial systems redeveloped and the Coogal Subgroup was deposited. Early deposition in this subgroup formed the Hoskissons Coal Member, the most economically significant coal unit in the Gunnedah Basin. The Hoskissons Coal Member is up to 18 m thick and consists of inertinite-rich coal with subordinate layers of fine-grained sandstone, carbonaceous siltstone, claystone and tuff. The coal was formed during peat accumulation across an extensive fluvial plain.

The Upper Permian Wallala and Trinkey formations comprise the ~300 m thick Nea Subgroup and the final phase of Permian deposition. These formations contain several coal seams, including the extensively developed Clift and Springfield coal members.

The Lower Triassic Digby Formation formed from a series of coalesced conglomerate fans which inundated and buried the coal swamp delta plain deposits of the Black Jack Group. The Middle Triassic saw the onset of lacustrine to regressive deltaic sequences and deposition of the Napperby Formation. Minor occurrences of coal also occur in the Middle Triassic Deriah Formation.

Sedimentary rocks of the Surat Basin overlie the Gunnedah Basin in the western part of the Namoi Catchment and thicken to the west, although these have no reported economic value where they underlie the Namoi river basin. The most recent phase of regional sedimentation deposited fluvial sediments of Neogene and Quaternary age over the Gunnedah Basin successions in the central Namoi river basin, and directly on top of Surat Basin rocks in the west.

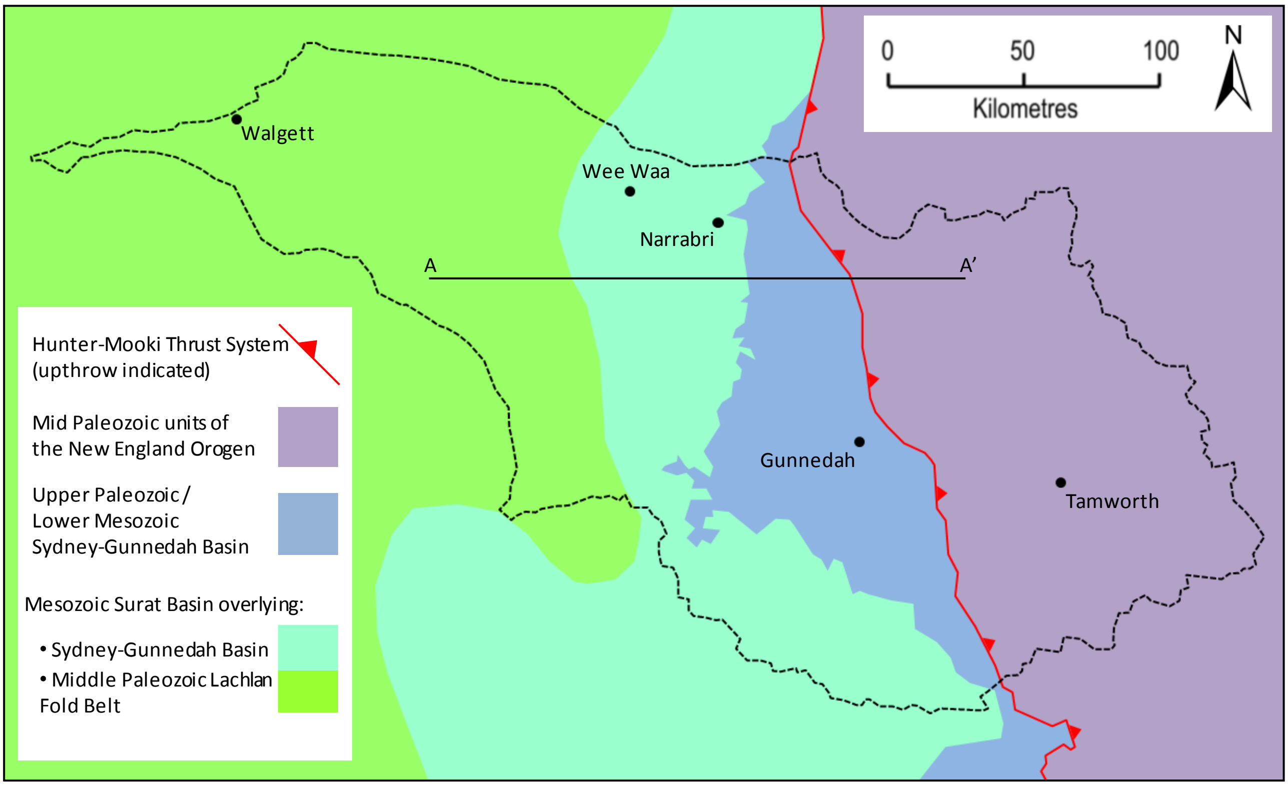

Figure 15 Paleozoic and Mesozoic geological domains in the Namoi area

Bold dashed line shows former Namoi Catchment Management Area (CMA) boundary. Cenozoic units of volcanic rocks and recent alluvium are omitted. The position of schematic cross-section (Figure 16) is indicated (A-A')

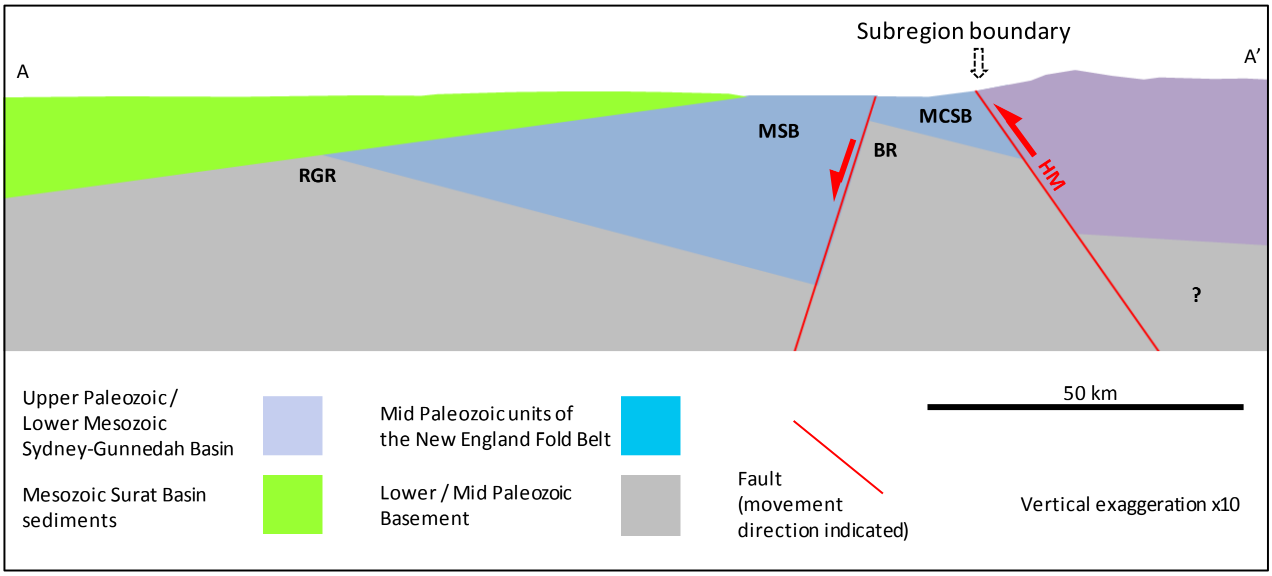

Figure 16 Schematic east-west cross-section for the Gunnedah Basin in the Namoi area

The Hunter-Mooki Thrust System (HM) in the east uplifts greenschist facies units probably indicating uplift on this fault approaching 10 km. The Boggabri Ridge (BR) and Rocky Glen Ridges (RGR) are north-south oriented structures defined from gravity data delineating the large-scale, half-graben, Mullaley (MSB) and Maules Creek (MCSB) sub-basins. The two categories of Surat Basin sedimentary rocks in Figure 15 are combined here.

1.1.3.1 Basin history

1.1.3.1.1 Tectonic evolution

During the Permian and Triassic Periods, eastern Australia was part of an active Gondwanan convergent plate margin influenced by a west-dipping subduction system. The Lower Permian to Middle Triassic Bowen and Gunnedah basins formed in a back-arc setting, which was initially extensional, but switched to contractional in the Middle Permian. This led to the development of a major west-directed, retroforeland thrust belt in the New England Orogen, with significant static crustal loading and the formation of a major foreland basin phase in the adjacent Bowen and Gunnedah basins to the west (Korsch and Totterdell, 2009b).

The Bowen and Gunnedah basins have been affected by several contractional events, particularly in the Upper Permian and Lower Triassic. These were related to the development of the retroforeland thrust belt in the New England Orogen. The regional structural style changes from the eastern part of the basins, adjacent to the Hunter-Mooki Thrust System, to the western area of the basins which were not physically affected by the retrothrust belt. In the east, new thrusts were hard-linked to the growing thrust wedge further to the east, which propagated westwards and consumed the eastern part of the basin. In the western part of the basin, the transmission of far-field compressional stresses led to reactivation of Lower Permian extensional faults as thrusts, commonly with the formation of fault-propagation anticlines above the fault tip, and the partial inversion of rift-fill sequences. New thrusts and backthrusts also developed (Korsch and Totterdell, 2009b).

There were several periods of non-deposition and contraction in the Bowen and Gunnedah basins, described above, during a sustained period of rapid subsidence and sedimentation during foreland loading. The contractional events were mostly short-lived (each less than a few million years) in an overall period of thrust-loaded subsidence that lasted for 30 to 35 million years. A final contractional event in the Upper Cretaceous was related to the cessation of sedimentation in the Surat Basin (Korsch and Totterdell, 2009a). Fluvial-derived Neogene and Quaternary sediments were deposited on top of the Gunnedah Basin in the central Namoi river basin and directly on top of Surat Basin in the west.

Thickness and burial

The maximum stratigraphic thickness for all units of the Gunnedah Basin is just over 4 km. However, as many units do not occur evenly over the entire basin, the actual maximum thickness of the Gunnedah Basin sequence at any given location is mostly 1 to 2 km.

The sedimentary thickness removed by erosion from the Bowen-Gunnedah-Sydney Basin system since deposition increases consistently from north to south, ranging from a few hundred metres in the southern Bowen Basin, to 2 km in the northern Sydney Basin, and up to 4 km further south. Consequently, the Gunnedah Basin has probably had between 0.5 and 2 km of sedimentary rocks removed by erosion (Korsch and Totterdell, 2009a, 2009b).

The average depth/reflectance gradient of 0.25/km is consistent with a high geothermal gradient in the 30–40 degrees / km range (Korsch and Totterdell, 2009b).

1.1.3.1.2 Volcanism and intrusives

A period of extensional volcanism in the Lower Permian produced the Werrie Basalt and Boggabri Volcanics at ~290–280 Ma as a result of back-arc rifting of the initial Gunnedah Basin. These units have a restricted spatial distribution around Narrabri and Gunnedah, although they may locally exceed 1.5 km thick (Figure 17).

Tuffs occur in the Sydney Basin in the Upper Permian at about 260 Ma, which indicates that volcanism was associated with the development of Upper Permian arc tectonism on the New England Orogen.

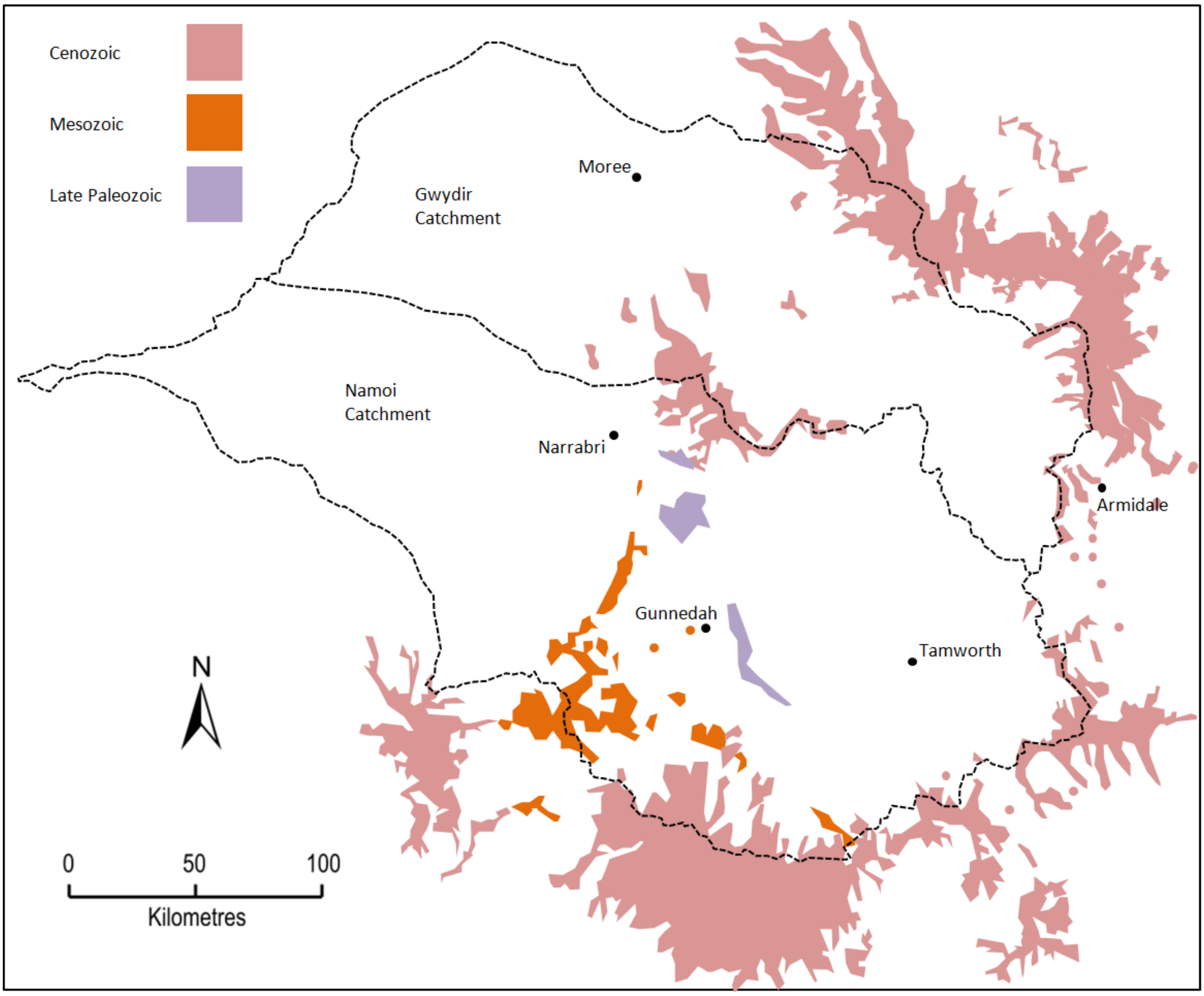

Figure 17 Outcropping volcanic rocks associated with the Namoi and Gwydir river basins

It should be noted that the Cenozoic volcanic rocks appear to have a significant influence on defining river basin boundaries.
Source data: derived from data described in Wellman and McDougall (1974), Dulhunty (1967), Stewart and Alder (1995)

The Garrawilla Volcanics form the basal unit of the Surat Basin and are variously dated between 215 and 177 Ma (Stewart and Alder, 1995). The volcanic rocks comprise dolerite, basalt, trachyte, tuffs and breccias. Alkaline intrusive plugs are associated with these volcanic rocks (Dulhunty, 1967).

Cenozoic volcanic rocks, sills and plugs are extensive throughout eastern New South Wales and range in age from 70 to 5 Ma. Several large outcrop and subcrop areas of extrusive rock occur near the Namoi area, including the Barrington, Walcha, Nandewar, Warrumbungle and Liverpool Range volcanos. The Liverpool and Nandewar ranges are the nearest to and thus most significant in terms of impact for the main coal bearing sections of the Gunnedah Basin. These are dated at about 40 Ma and 18 Ma, respectively (Wellman and McDougall, 1974).

Gurba and Weber (2001) reported that the Gunnedah Basin coal sequences are intersected by both Triassic and Cenozoic intrusive rocks. From map evidence and published reports (Golder Associates, 2010) the intrusives are commonly associated with faulting and are contemporaneous with the Lower Jurassic Garrawilla Volcanics (200 to 180 Ma).

1.1.3.2 Geological structural framework

1.1.3.2.1 Structures

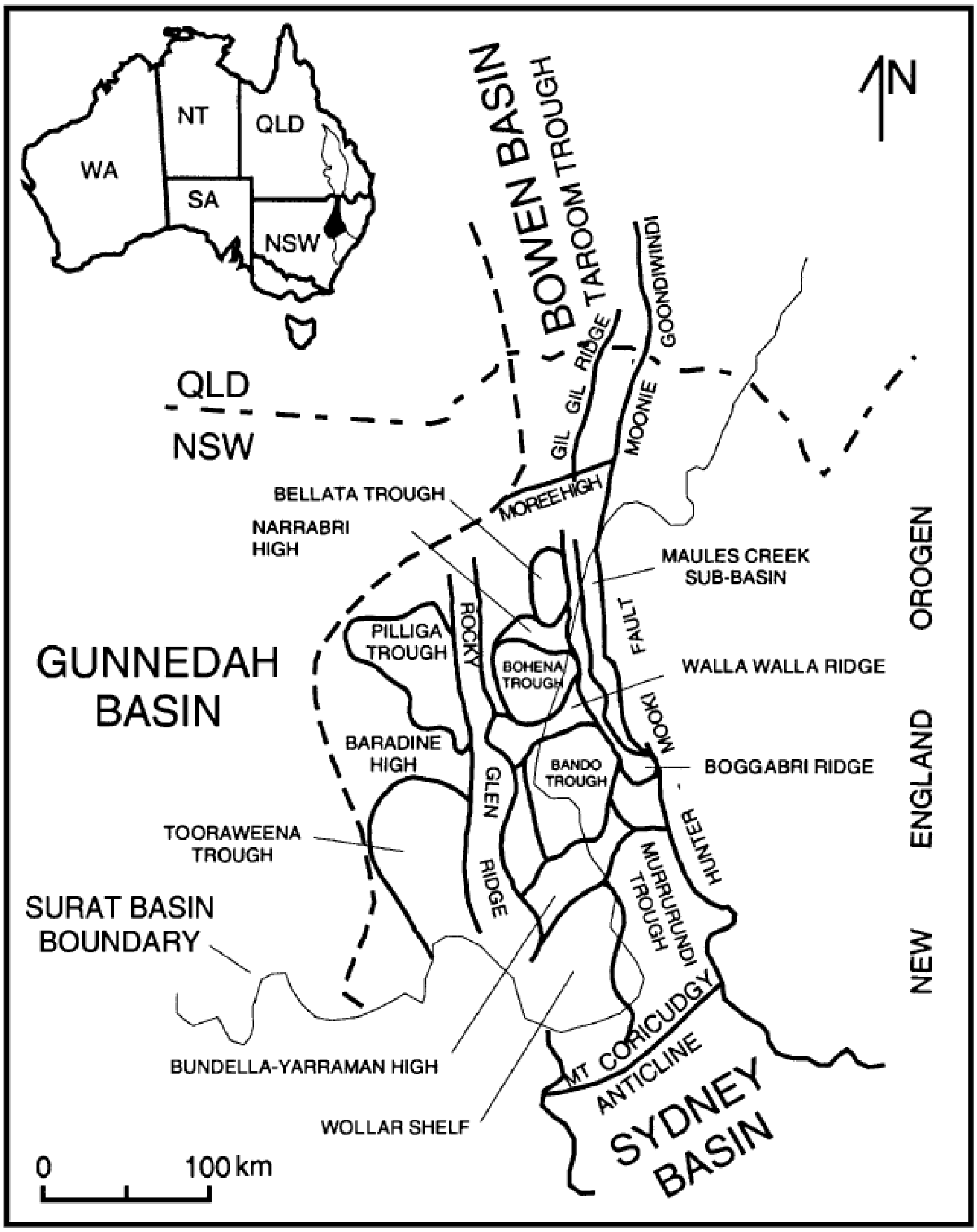

Figure 18 Subdivisions of the Gunnedah Basin

The subdivisions were initially proposed in Tadros (1988). The major Mullaley Sub-basin is subdivided here into the Bellata, Bohena and Bando troughs. Subsequent exploration has highlighted issues with these subdivisions. The Walla Walla Ridge (WWR) and Narrabri High (NH) are possibly not quite such significant internal structures as initially proposed (UPCS, 2000). The Pillaga Trough has no Gunnedah Basin fill and the western boundary of the basin has been revised eastwards.
Source: Figure 1 in Othman and Ward (2002). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from Elsevier.

The most prominent geological structure in the Namoi river basin is the Mooki Thrust (Figure 18), a constituent of the Hunter-Mooki Thrust System which forms the eastern boundary of the Bowen–Gunnedah–Sydney Basin system (Collins, 1991). These major faults are conceptualised as having been hard-linked to the westward propagating retroforeland thrust belt of the New

England Orogen to the east (Korsch et al., 1997; Korsch, 2004). No evidence has been found to demonstrate that these faults are reactivated normal faults, in contrast to structures further west (Korsch and Totterdell, 2009a).

Gravity data reveals north-south oriented troughs and ridges in the Gunnedah Basin which have been cited as evidence for folding in front of the Hunter-Mooki Thrust System. However, it is possible that these large-scale troughs represent the Lower Permian topographic experession of initial rifting of the Gunnedah Basin (Korsch and Totterdell, 2009b). Anticlinal structures in the Gunnedah Basin related to episodic inversion of the basin throughout the Permian and into the Lower Triassic have been documented from seismic evidence. To some extent fault reactivation has also continued into the Cenozoic with Surat Basin sedimentary rocks being folded and faulted, although penetration by reactivated faults is not extensive (Korsch and Totterdell, 2009a).

Recent work has overlooked transpression as being the driving mechanism for the Cenozoic structures (Korsch et al., 2009b). Anticlines within the Permian Gunnedah Basin sequence are mostly oriented northeast-southwest. These may be intersected by minor normal faults with displacements locally exceeding 150 m, which strike perpendicular to anticlinal hinges. These orientations provide evidence for the former existence of a transpressional tectonic system postdating the Triassic (Stewart and Alder, 1995).

Information on the location and characteristics of faults that structurally disrupt the Gunnedah Basin rock strata in the Namoi subregion is available from several sources. Existing state-wide geology maps indicate that a sub-parallel network of north-west oriented faults occur in the southern part of the subregion. The OZSEEBASE dataset (FrogTech, 2006; FrogTech, 2013) currently provides the most comprehensive interpretation of structures in the Namoi subregion and shows a complex network of sub-parallel and cross-cutting faults, particularly in the eastern half where the rocks of the Gunnedah Basin occur at or close to the surface (Figure 19, Figure 20). The most intense faulting occurs in a zone adjacent to the Hunter-Mooki Thrust Fault, which is a major basement structure that coincides with the eastern boundary of the subregion. Many of these faults have distinct sub-linear surface expressions that run parallel with the dominant north-north-west structural trend. Deeper faults further west of this zone are interpreted based on geophysical data (magnetics and gravity), as there is scant outcrop of the Gunnedah Basin rocks in the region due to extensive cover of younger sedimentary strata, such as those of the overlying Surat Basin. The most common fault types in the Namoi subregion are thrust faults (36%), transfer faults (20%), and strike-slip faults with dominantly sinistral movement (20%).

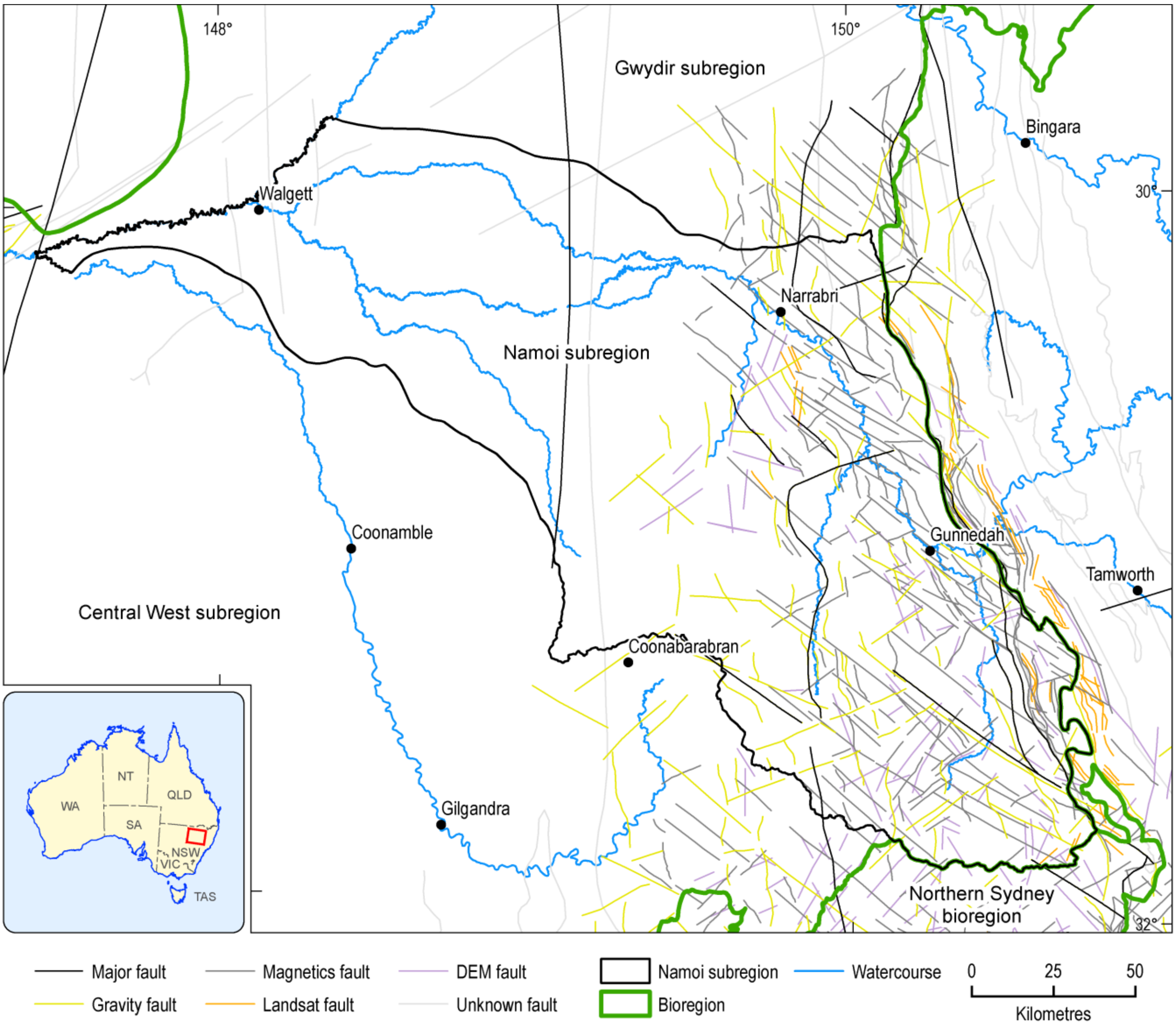

Figure 19 Inferred geological faults in the Namoi subregion by the source of information used to determine them

Source data: (i) FrogTech (2006) and (ii) FrogTech (2013)

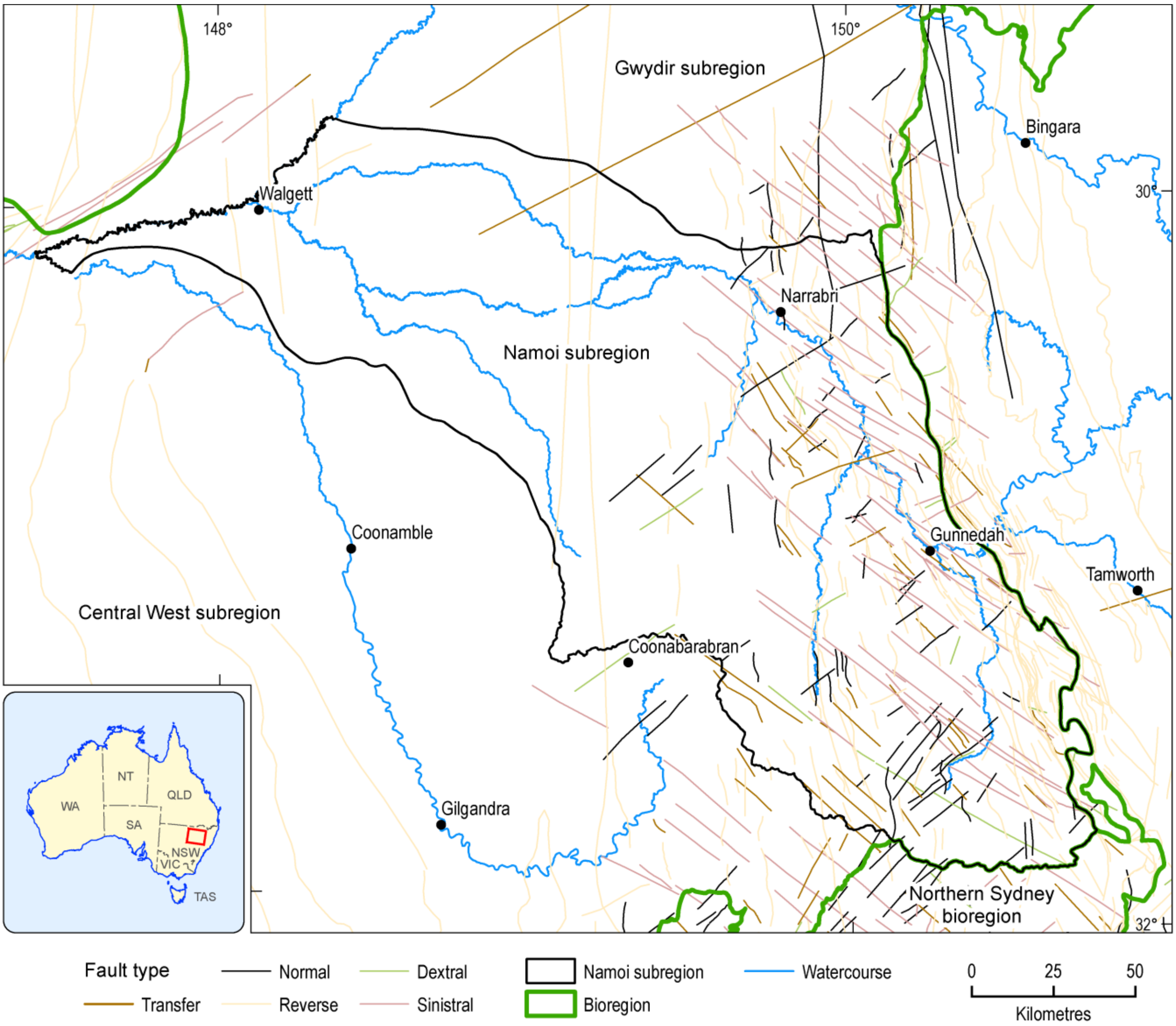

Figure 20 Inferred geological faults in the Namoi subregion by fault type

Source data: (i) FrogTech (2006) and (ii) FrogTech (2013)

1.1.3.2.2 In situ stress

During the 1990s, Hillis et al. (1999) (and references therein) compiled an extensive, Australia-wide database of in situ stress measurements. The measurements were obtained from sites across Australia, including areas of the Bowen and Sydney basins. No data are available for the Gunnedah Basin specifically, but maximum stress directions for the nearby Sydney Basin are mainly oriented north-northeast, north-east, and east-west. Compared to the Bowen Basin, stress directions in the Sydney Basin are more varied, suggesting that local features, such as density contrasts and structures, significantly influence stress orientations. This is particularly true for the Hunter Coalfield of the Sydney Basin, just south of the Gunnedah Basin, where stress orientations are bimodal (Hillis et al., 1999).

The Geoscience Australia earthquake database indicates that there has been no significant neotectonic activity in the region of the Namoi river basin. No earthquakes exceeding 1.5 magnitude have been recorded in the database for the area.

1.1.3.3 Stratigraphy and rock type

1.1.3.3.1 Gunnedah Basin

Following a review of work by researchers between the 1940s and 1990s, Tadros (1993) provided a detailed description of the stratigraphy of the Gunnedah Basin and also proposed a new stratigraphy. Subsequently, the stratigraphic nomenclature has undergone minor revisions (Figure 21[3]). In recent sequence stratigraphic studies that correlated the lithostratigraphy, sedimentary sequences, main tectonic events and basin phases of the Surat and Bowen–Gunnedah basins, Totterdell et al. (2009) have shown that the same series of basin-forming processes recognised in the Queensland portion of the Surat and Bowen basins also occurred in the Surat and Bowen–Gunnedah basins in NSW. However, there are minor differences in the timing and duration of the basin phases (Totterdell et al., 2009).

[3] Note that some geological units described herein are not shown in Figure 21.

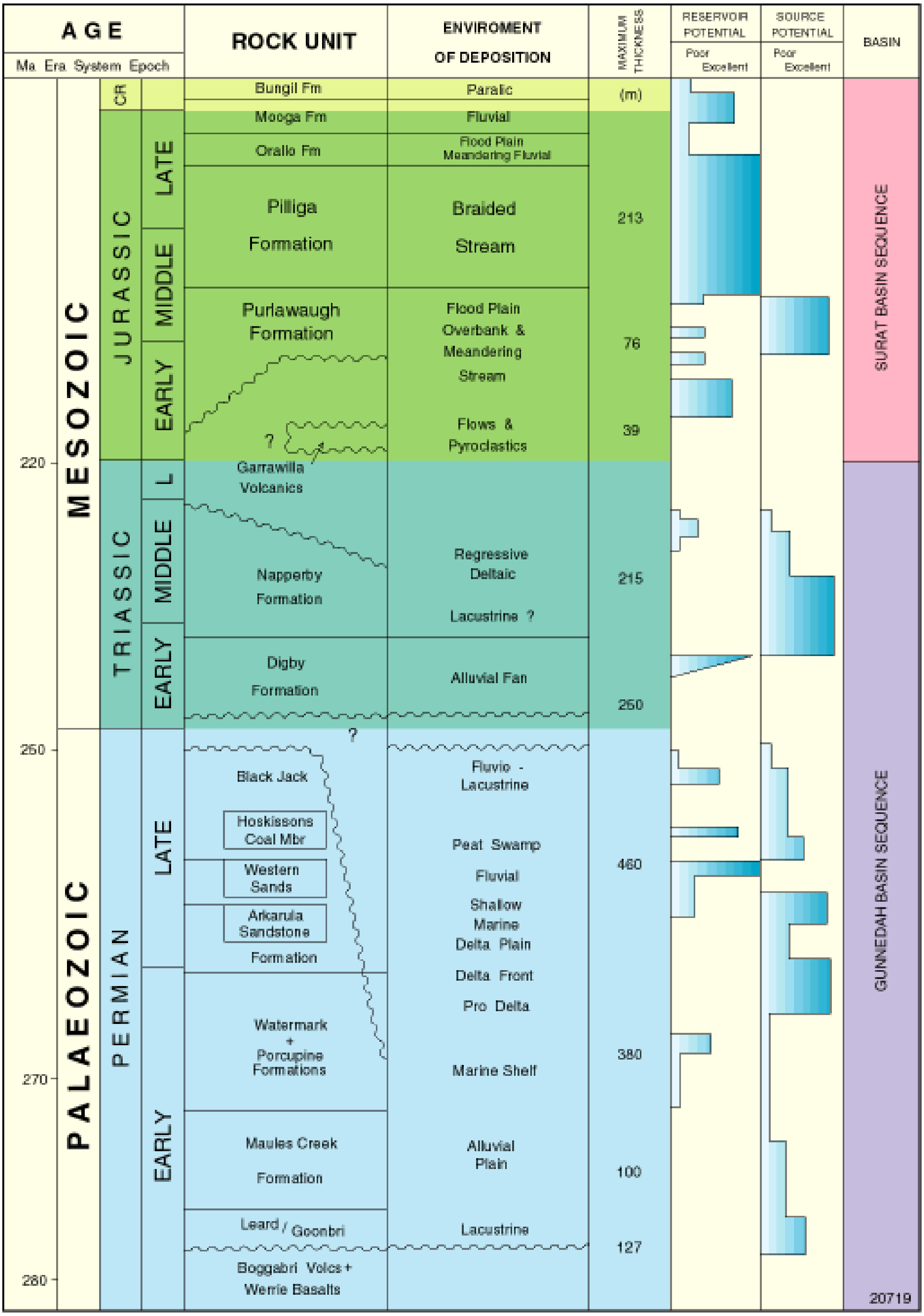

Figure 21 Stratigraphic column for the Gunnedah Basin and the overlying Surat Basin sediments

The column 'Reservoir Potential' indicates the potential of the rocks of the formation to store hydrocarbons. The column 'Source Potential' indicates the potential of the rocks of the formation to produce hydrocarbons.

Source: NSW Department of Trade and Investment (2013). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from NSW Department of Trade and Investment.

Bellata Group

- Leard and Goonbri formations: the Lower Permian Leard Formation is the basal unit in the Gunnedah Basin sequence and rests unconformably on the weathered volcanic basement (Hamilton et al., 1989). These sedimentary rocks were deposited in dominantly lacustrine environments which were a relatively common feature of the early stages of continental rifting for the upper part of Supersequence A (Totterdell et al., 2009). The formation is commonly 12 to 18 m thick (maximum thickness of 32 m) and consists of buff coloured kaolinised pelletoidal claystone, conglomerate, sandstone and siltstone, commonly interbedded with coal (Tadros, 1993). Clasts contained within the strata are kaolinite clay pellets generally <25 mm in diameter. Many of the colluvial deposits of the Leard Formation are derived from the weathering of the basal volcanic rocks (Tadros, 1995). The Goonbri Formation is a lacustrine lithic sandstone and siltstone. In the Maules Creek Sub-basin it is >125 m thick, and in the Bellata and Bohena troughs of the Mullaley Sub-basin it may be up to 106 m thick. It consists mainly of dark, organic-rich siltstone, thin layers of coal and siltstone-claystone laminite, and fine to medium-grained sandstone (Tadros, 1993).

Boggabri Volcanics and Werrie Basalt

The floor of the Gunnedah Basin sequence consists of Lower Permian silicic volcanic rocks in the west, and intermediate to mafic and silicic volcanic rocks in the east (Tadros, 1993). The silicic volcanic rocks in the east are exposed along the Boggabri Ridge and are known as the Boggabri Volcanics, whereas the intermediate to mafic rocks which crop out in the east are correlatives of the Lower Permian Werrie Basalt (Hamilton et al., 1989). Towards the west of the basin, underneath the Rocky Glen Ridge and the Gilgandra Sub-basin, there are metavolcanic and metasedimentary sequences of the Lachlan Fold Belt (Tadros, 1995). Together with the lacustrine deposits of the Goonbri and Leard formations, these mafic and felsic volcanic rocks comprise Supersequence A as defined by Totterdell et al. (2009).

- Maules Creek Formation: this formation is a thick unit in the Maules Creek Sub-basin. It is well developed east of the Boggabri Ridge and reaches a thickness of >800 m adjacent to the Hunter-Mooki Thrust System. It is equivalent to Supersequence B as recognised by Totterdell et al. (2009), and consists of a thick succession of coarse-grained clastic sedimentary rocks, mudstone and coal. West of the Boggabri Ridge in the other sub-basins it is normally <100 m thick. In the Maules Creek Sub-basin it consists of lithic conglomerate, sandstone, siltstone, claystone and coal seams of up to 8 m thick (Tadros, 1993). Sedimentary sequences occur as both large- and small-scale fining-upward cycles of conglomerate and coarse-grained sandstone to mudstone and coal. Deposition occurred mainly in braided streams (Totterdell et al., 2009). To the west of the ridge the Maules Creek Formation is divided into three lithologically distinct zones: a quartz-rich sandstone zone in the north, a central volcanogenic zone in the central region and a south-eastern zone with fine-grained sedimentary rocks rich in coal (Tadros, 1995).

Millie Group

- Porcupine Formation: a marine transgression followed the end of sedimentation of the Maules Creek Formation and led to the deposition of the Porcupine Formation. This unit is up to 10 m thick along the western margin of the Mullaley Sub-basin, 20 to 60 m thick in the north, and 30 to 186 m thick in the south and south-east of the sub-basin (Tadros, 1993). The Porcupine Formation forms part of Supersequence C, which includes shallow marine to deltaic sedimentary rocks of the entire Millie Group up to the lower Black Jack Group (Pamboola and Arkarula formations) that unconformably overlie the dominantly fluvial Supersequence B (Totterdell et al., 2009). The Porcupine Formation consists of an upwards-fining sequence with pebble conglomerate at the base through sandstone to shale and siltstone near the top. Deposition began when fan deltas deposited conglomeratic sediments onto the marine shelf (Totterdell et al., 2009). Bioturbation occurs throughout the unit.

- Watermark Formation: the shallow marine Watermark Formation occurs over much of the Mullaley Sub-basin and has a maximum recorded thickness of 230 m in the Breeze-Quirindi area (Tadros, 1995). The lower part of the formation forms an upward-fining, sandy siltstone, dark grey siltstone and claystone sequence containing common fossil zones and intense bioturbation and burrowing. The upper part is divided into two units, which together form a major upward-coarsening sequence (Hamilton et al., 1989).

Black Jack Group

- Brothers Subgroup
  - **Pamboola Formation:** the Upper Permian Pamboola Formation comprises lithic sandstone, siltstone, claystone, conglomerate and intercalated coal, and varies in thickness from 89 m in the north to >206 m in the south-east (Tadros, 1993). The sequence is generally upward-coarsening and contains fine- to coarse-grained sandstone with finely macerated organic matter and coaly fragments (Tadros, 1993). The most significant coal seams of the formation formed within a lower delta plain environment and are contained in the Melvilles Coal Member (Hamilton et al., 1989). The unit is generally 2.5 to 3.5 m thick in the eastern part of the Mullaley Sub-basin but may be up to 5 m thick in the area of Boggabri. These are moderate to high-vitrinite coals with layers of fine-grained sandstone, carbonaceous siltstone, and claystone (Tadros, 1995).
  - **Arkarula/Brigalow Formation:** this formation occurs over much of the Mullaley Sub-basin south of Narrabri and ranges in thickness from 22 m in the Gunnedah Colliery area to 51 m in the north of the sub-basin. It is a shallow marine, upward-fining sequence, characterised by fine- to medium-grained sandstone at the base and finely interbedded sandstone and siltstone, laminated organic-rich siltstone, oscillation ripples, load casts and mud drapes at the top. To the north of Narrabri well-sorted, medium-grained sandstone with a pebbly base is common (Tadros, 1995). In the western and northern areas of the Mullaley Sub-basin the Arkarula Formation laterally grades into and is locally overlain by the Brigalow Formation, which consists of medium and coarse-grained pebbly quartzose and sandstone with subordinate fine-grained sandstone and thinly bedded siltstone and carbonaceous siltstone (Tadros, 1995).
- Coogal Subgroup: the sedimentary sequence from the onset of the Coogal Subgroup deposition to the top of the Trinkey Formation is equivalent to Supersequence D as recognised by Totterdell et al. (2009). It marks a return to a non-marine depositional environment with fluvial channel to floodplain and peat swamp deposits, resulting in regionally extensive coal formation.

- Hoskissons Coal Member: consists of inertinite-rich coal with subordinate layers of fine-grained sandstone, carbonaceous siltstone, claystone and tuff, which extends over much of the Mullaley Sub-basin. It ranges in thickness between >1 m and 18 m (Tadros, 1993). The coal is upward-dulling with the lower section containing lower mineral content compared to the upper section. The lower section is divided into two plies and the upper section is divided into three plies. Along the western margin of the sub-basin the coal is split by the Clare Sandstone (Tadros, 1995). The fluvially-influenced coal was formed during peat accumulation across an extensive floodplain.
- Benelabri Formation: this formation is an organic-rich, mudstone-dominated unit above the Hoskissons Coal Member, present mainly in the eastern half of the Mullaley Sub-basin north of the Liverpool Range (Tadros, 1993). Totterdell et al. (2009) interpreted the formation as being deposited as the base-level continued to rise and accommodation reached its maximum. Contained within the Benelabri Formation are the Caroona and Howes Hill coal members. The formation thickness varies between 20 and 30 m but is up to 35 m in the north and ~69 m in the southeast (Tadros, 1995). The formation consists of upward-coarsening sequences, each consisting of organic-rich mudstone at the base, grading into mudstone/siltstone in the middle and mainly sandstone at the top. The Caroona Coal Member is confined to the southeastern corner of the Mullaley Sub-basin and is 2.3 to 3.4 m thick. It consists of a bright basal section, a dull and minor bright layered middle section and a bright upper section. The Howes Hill Coal Member is more extensive than the Caroona Coal Member and varies in thickness between 1 and ~5 m, with the coal having an upward-dulling profile (Tadros, 1995).
- Clare Sandstone: in the Mullaley Sub-Basin the Clare Sandstone is a few metres thick in the west and up to 95 m in the southeast. The rocks of this formation are mainly medium- and coarse-grained sandstone with subordinate quartz conglomerate (Tadros, 1995). The top of the unit contains an upward-fining sequence of interlaminated siltstone and claystone topped with the Breeza Coal Member. This coal unit extends over much of the southern Mullaley Sub-basin and is between 5 and 7 m thick.

- Nea Subgroup
  - **Wallala Formation:** this formation consists of lithic conglomerate, sandstone, siltstone, claystone and coal, with minor tuffaceous units and is up to 55 m thick (Tadros, 1995). These sediments are thought to be derived from the New England Orogen to the east (Totterdell et al., 2009). A conglomerate, which is up to 5 m thick and contains variable amounts of silicic and mafic volcanic rock fragments, dominates the sequence in the east and south-east. The top of the formation is commonly upward-fining.
  - **Trinkey Formation: this f**ormation occurs from Narrabri to Quirindi where it is up to 258 m thick. The formation consists mainly of finely bedded claystone, siltstone and fine-grained sandstone, and has some thinly bedded to massive tuffaceous sedimentary layers and coaly matter or stony coal seams. It also contains conglomerate beds up to 40 m thick in the areas between Gunnedah, Mullaley and Quirindi (Tadros, 1995). The formation contains several coal seams, including the extensively developed Clift and Springfield coal members. The former coal member is an upward-dulling coal which can exceed 10 m

thickness, whereas the latter consists of several upward-dulling cycles up to ~5 m thick (Tadros, 1995).

Digby Formation

Deformation due to a contractional event in the Upper Permian resulted in erosion and led to the development of an essentially flat peneplain. Consequently, Supersequences E and F, which are recognised in the Bowen Basin, are not present in the Gunnedah Basin. The Lower Triassic, coarse-grained clastic sedimentary rocks of Supersequence G (i.e. the Digby Formation) were thus deposited directly on the Trinkey Formation (top of Supersequence D) in the Gunnedah Basin (Totterdell et al., 2009). The three lithological units of the Digby Formation are variably distributed across the basin, varying in thickness from 20 m in the north and northeast to >220 m in the south-east (Tadros, 1993). According to Hamilton et al. (1989) the formation appears to have formed from a series of major coalesced conglomerate fans which inundated and buried the older coal swamp delta plain of the Black Jack Group in the Upper Permian. The formation unconformably truncates the rocks of the Black Jack Group, the Watermark Formation and the Porcupine Formation in the northern part of the Gunnedah Basin. South of Narrabri it rests on various horizons of the Black Jack Group (Tadros, 1993). The Digby Formation consists mainly of lithic and quartz conglomerate, sandstone, and minor fine-grained sedimentary rocks (McDonald and Skilbeck, 1996).

Napperby Formation

The lacustrine to regressive deltaic sequence of the Triassic Napperby Formation (the Lower Triassic Supersequence H as recognised by Totterdell et al. (2009)) has three units. The lowermost unit is a finely laminated, dark grey siltstone 18 to 45 m thick which contains siderite and Fe-sulfides, indicative of deposition in a restricted near-shore environment. The middle unit is a sandstone/siltstone laminite that may have been deposited in a tidal flat setting. The uppermost unit consists of siltstone with minor interbedded claystone and fine-grained sandstone which developed in a regressive deltaic system (Hamilton et al., 1989; Othman et al., 2001). According to Totterdell et al. (2009) it is an aggradational to progradational coarsening-upward succession of lacustrine delta claystone, siltstone and sandstone in most parts of the basin. The units of the Napperby Formation are widely distributed across the basin, except for areas of the Maules Creek Sub-basin (Tadros, 1993).

Deriah Formation

The Deriah Formation is divided into a lower and an upper part, the former interpreted as deposits of a sandy alluvial fan and the latter as deposits of mixed load streams in point bars, levees, crevasse splays and poorly to well-drained swamps, as well as freshwater lacustrine environments (Tadros, 1993). Coarse to very coarse-grained granule-bearing sandstone occurs at base, and fine- to medium-grained green lithic sandstone and rare siltstone and claystone beds occur at the top of the lower unit. The upper unit comprises lithic sandstone and dark grey mudstone with minor plant roots and coal layers (Tadros, 1993). This formation is equivalent to Supersequence I which was deposited in fluvial, floodplain and lacustrine environments by a westerly prograding fluvial system (Totterdell et al., 2009).

1.1.3.3.2 Surat Basin

In the Namoi river basin the Jurassic and Lower Cretaceous sedimentary rocks of the Surat Basin unconformably overlie much of the Permian-Triassic sequence in the western half of the Gunnedah Basin (Gurba et al., 2009). The Garrawilla Volcanics generally form the base of the Surat Basin (Figure 21). Totterdell et al. (2009) noted that the Surat Basin megasequence consists of the fluvial to marginal marine sedimentary rocks of the Lower Jurassic to Lower Cretaceous, and includes four major depositional cycles, Supersequences J to M, of which Supersequences K to M are the equivalents of the Purlawaugh, Pilliga, Orallo and Mooga formations (Stewart and Alder, 1995; Totterdell et al., 2009).

Garrawilla Volcanics

According to Totterdell et al. (2009) the Late Triassic–Early Jurassic igneous rocks of the Garrawilla Volcanics, which consist of tuffs and flows of mafic volcanic rocks, have formed topographic highs onto which the Surat Basin sequences were deposited, indicating that this magmatism pre-dated deposition of the Surat Basin sediments. Ages reported for these igneous rocks range from 218+8 to 142+6 Ma (Martin, 1993). Martin (1993) has attributed an upper mantle origin and the geochemical signature of intraplate basalts to these extrusive and intrusive rocks which occur mainly as bodies or sills.

Purlawaugh Formation

The Purlawaugh Formation, which is part of the Surat Basin sequence (Supersequence K as recognised by Totterdell et al. (2009)) is of Lower to Middle Jurassic age. The meandering fluvial and lacustrine sedimentary sequences, which extend northward into Queensland, have an average thickness of 30 m around Narrabri, but can be up to 76 m thick in other areas. Overlying the Gunnedah Basin, the formation commonly consists of a basal unit of mainly sandstone formed by meandering fluvial channel/point bar deposits, and is medium- to coarse-grained and partly conglomerate-rich. The upper unit consists of interbedded siltstone, shale, thin coal and sandstone interpreted as floodplain, channel margin and meandering stream deposits (Stewart and Alder, 1995).

Pilliga Sandstone

The Pilliga Sandstone was deposited by braided fluvial streams (Stewart and Alder, 1995). It also contains minor interbeds of siltstone and mudstone (Goscombe and Coxhead, 1995). The Pilliga Sandstone and the Orallo Formation are the equivalents of Supersequence L, the beginning of which marks a period of basin-wide fluvial incision prior to the deposition of a thick succession of braided-stream sandstone sequences (Totterdell et al., 2009).

Orallo Formation and Mooga Sandstone

In the far west of the Namoi subregion the Pilliga Sandstone is conformably overlain by non-marine to marine sandstone, siltstone, shale and mudstone of the Orallo and Mooga formations (Stewart and Alder, 1995).

1.1.3.3.3 Cenozoic fluvial stratigraphy

The Cenozoic alluvium includes the Upper and Lower Namoi formations, and the Gunnedah and Narrabri formations. These are described in the Hydrogeology Chapter.

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1.1.4 Hydrogeology and groundwater quality

Summary

There have been a number of major investigations and research projects focusing on the water resources of the Namoi subregion, the most recent being the Namoi Catchment Water Study (NCWS) (SWS, 2010; 2011; 2012a; 2012b). There have also been a large number of smaller, local scale projects undertaken by government, mining proponents, research organisations, consultants and community organisations. These have focussed on shallow groundwater systems (<150 m) with an emphasis on alluvial groundwater systems and dryland salinity. Despite the large number of investigations undertaken, there are still many gaps in our understanding of groundwater, especially in the deeper coal-bearing basins.

The hydraulic characteristics of the alluvial aquifers in the Namoi subregion are generally reasonably well understood, although very little information or data are available for the rock units beneath the alluvial deposits. The coal and coal seam gas (CSG) resources are hosted within these deeper units and industry have obtained the most valuable and comprehensive datasets for these units.

Good quality groundwater in high yielding aquifers is present across wide areas of the alluvial plain and Great Artesian Basin (GAB) in the coarser sand and gravel sediments of the Gunnedah Formation. Consequently, groundwater resources in the Namoi are the most intensively developed in NSW and the subregion has one of the highest levels of groundwater extraction within the Murray–Darling Basin (CSIRO, 2007). Groundwater levels in the subregion have generally been falling at a rate of 0.5 m/year since the late 1960s/early 1970s due to over-extraction, with water levels stabilising or recovering during wetter years. In 2006–2007, many parts of the Namoi subregion experienced their lowest groundwater levels on record.

Aquifer connectivity in the alluvial system is well understood in some locations at a local scale, although it is poorly understood across the whole Namoi subregion. Potential hydraulic connectivity exists between the alluvial aquifers and the GAB where the main paleochannel is present in the Lower Namoi (see Figure 22). In other locations, the saprolite covering the GAB sedimentary sequences largely impedes connectivity between the systems. The assessment that the saprolite on the GAB sequence forms an aquitard is based on calibration drilling for the AEM survey in the neighbouring Lower Macquarie River Valley (Macaulay and Kellett, 2009) to the south, and also on the Lower Balonne AEM survey to the north (Kellett et al, 2006). In both of these areas the lower part of the saprolite on the Rolling Downs Group of the GAB was found to form a tight aquitard, and it is assumed that the saprolite in the Lower Namoi Valley behaves similarly. The degree of connectivity between the alluvium, GAB and Gunnedah Basin aquifers is a key component for determining any impacts on water resources within the subregion due to CSG or large coal mining extraction. Most of the Lower Namoi GAB sequence overlies Lachlan Fold Belt rocks which form hydraulic basement. In contrast, alluvium directly overlies Gunnedah Basin aquifers in the Upper Namoi, and it is likely there is

hydraulic connection between them. However, information and data on this interconnectivity are limited.

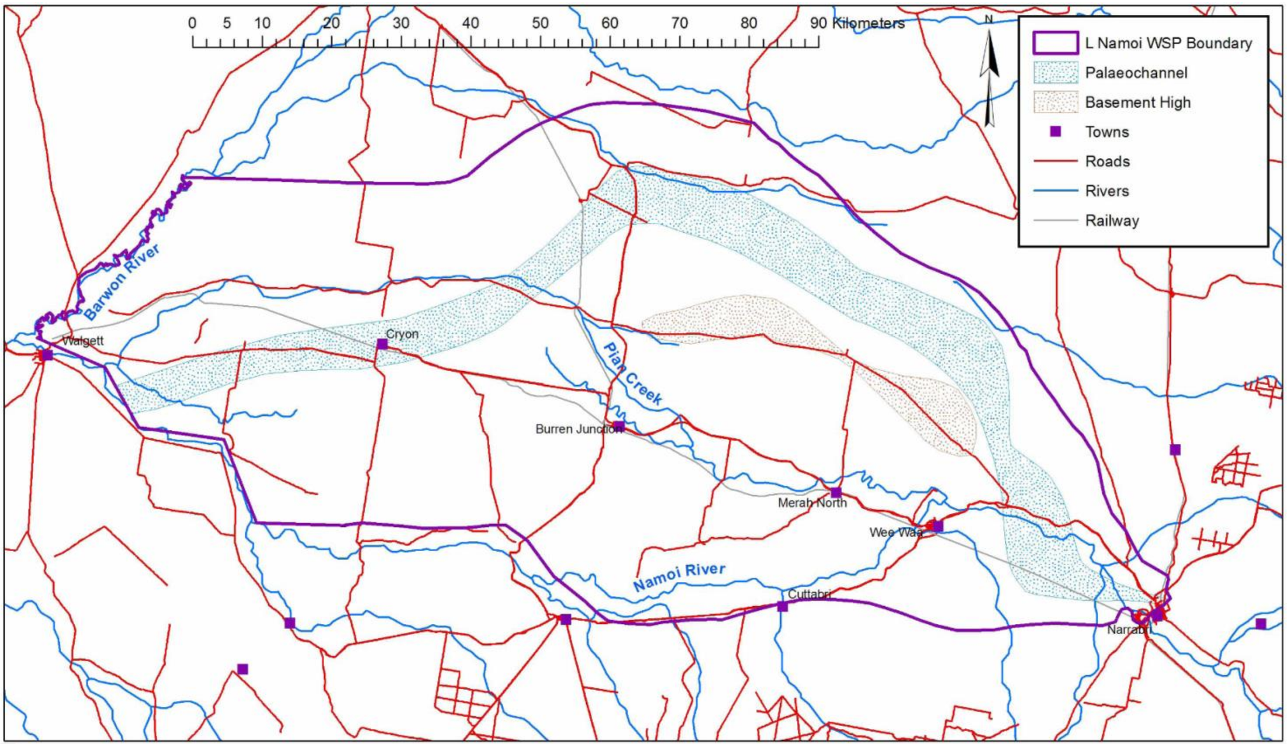

Figure 22 Location of Paleochannel within the Lower Namoi Alluvium

Source: Figure 8 in Smithson (2009). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from NSW Department of Primary Industries.

1.1.4.1 Hydrostratigraphic units

The Namoi subregion can be described as four broad hydrogeological regions:

1. Alluvial material along the low lying river valleys and floodplains. These are the Narrabri, Gunnedah, and Cubbaroo formations and are often subdivided into the Upper and Lower Namoi alluvium.
2. Surat Basin within the Coonamble Embayment of the GAB in the central and western parts of the subregion.
3. Jurassic sandstones and Permian Gunnedah Basin sedimentary rocks underlying and surrounding the alluvial deposits in the east of the subregion.
4. Lower Permian volcanic rocks of the Lachlan Fold Belt underlying the Gunnedah Basin and GAB deposits.

The eastern boundary of the Gunnedah Basin and the Namoi subregion is marked by the Hunter-Mooki Fault, an east dipping thrust fault. The fault developed during thrusting of the New England Fold Belt over the Sydney-Bowen Basin and marks a distinct break in the bedrock geological domains (Mullard, 1995 and Section 1.1.3).

1.1.4.1.1 Alluvial aquifers

Alluvial sediments of the Upper and Lower Namoi are usually subdivided into three formations: the uppermost Narrabri Formation, the Gunnedah Formation and the Cubbaroo Formation in the Lower Namoi area. These formations consist mainly of sand, gravel and clay and their thickness is largely controlled by the bedrock topography (Barrett, 2012). Contouring of the base of the alluvial sediments indicates they form continuous units across the Hunter-Mooki Fault, extending beyond the eastern boundary of the Namoi subregion.

The uppermost Narrabri Formation dates from the Pleistocene to recent and is generally 30 to 40 m deep, but can be up to 70 m deep. It predominantly consists of extensive clays with minor channel sands and gravel beds. This is the watertable aquifer which is generally low yielding and low to medium salinity. The aquifer is highly stressed due to over-extraction in accordance with permitted allocation. The Narrabri Formation aquifer is known to be highly interactive with the Namoi and Mooki rivers (Ransley et al., 2012a).

Underlying the Narrabri Formation is the confined to semi-confined aquifer of the Gunnedah Formation, dating from the Pliocene to early Pleistocene, and comprised of moderately well-sorted sands and gravels with minor clay beds up to 70 m thick (Kelly et al., 2007; Ransley et al., 2012a). The Gunnedah Formation is the most extensive and productive aquifer in the subregion yielding good quality water that is used for irrigation (Giambastiani et al., 2012). The aquifer in the Gunnedah Formation is also highly stressed due to over-extraction.

The Cubbaroo Formation is present in the Lower Namoi at the base of the alluvial sequence and is a confined aquifer of the Middle to Late Miocene (Ransley et al., 2012a). Cubbaroo Formation sediments occur below 90 m and consist of carbonaceous sand and gravel with interbedded clays (Kelly et al. 2007; Ransley et al. 2012a). The Cubbaroo Formation is associated with the main paleochannel, which is limited to the central and northern parts of the valley and does not generally follow present drainage lines. The sediments in the palaeochannels are coarser than other alluvial formations, allowing for higher extraction rates (Barrett, 2012).

In some areas there is no hydraulic separation between the unconsolidated alluvial formations and they act as a single aquifer, for example in the far western and eastern part of the subregion. In other areas, hydrograph analysis indicates there is minimal connectivity (CSIRO, 2007; Kelly et al., 2007; Parsons Brinkerhoff, 2011).

Hydraulic characteristics of the Narrabri and Gunnedah formations are generally well documented, which is not the case for deeper formations. The hydraulic properties of the alluvial aquifers are highly variable (0.008-31 m/day (Golder Associates 2010)) depending on the presence of sand or clay lenses, but hydraulic conductivity generally increases with depth and in the palaeochannel.

Kelly et al. (2007) emphasised that the alluvial sequences as described generally under-represent the complexity of the sequence and the interplay between clay, sand and gravel beds. The dominant sediments are sometimes reversed with clays dominant in the Gunnedah Formation at some locations and sand and gravel dominant in the Narrabri Formation at others. This complexity of alluvial deposits is to be expected, and it adds to the difficultly in conceptualising the hydraulic parameters and flow pathways within the alluvial aquifer sequence.

1.1.4.1.2 Great Artesian Basin

In the north and west of the Namoi subregion the alluvium is underlain by the Jurassic and Cretaceous rocks of the Surat Basin (a sub-unit of the larger GAB) (Kelly et al., 2007; Green et al., 2011; Barrett, 2012). The GAB is comprised of sedimentary rock layers that form aquifers and aquitards containing groundwater that is mostly under artesian conditions (CSIRO, 2012). The extent of the Surat Basin in the Namoi subregion is shown in Figure 23.

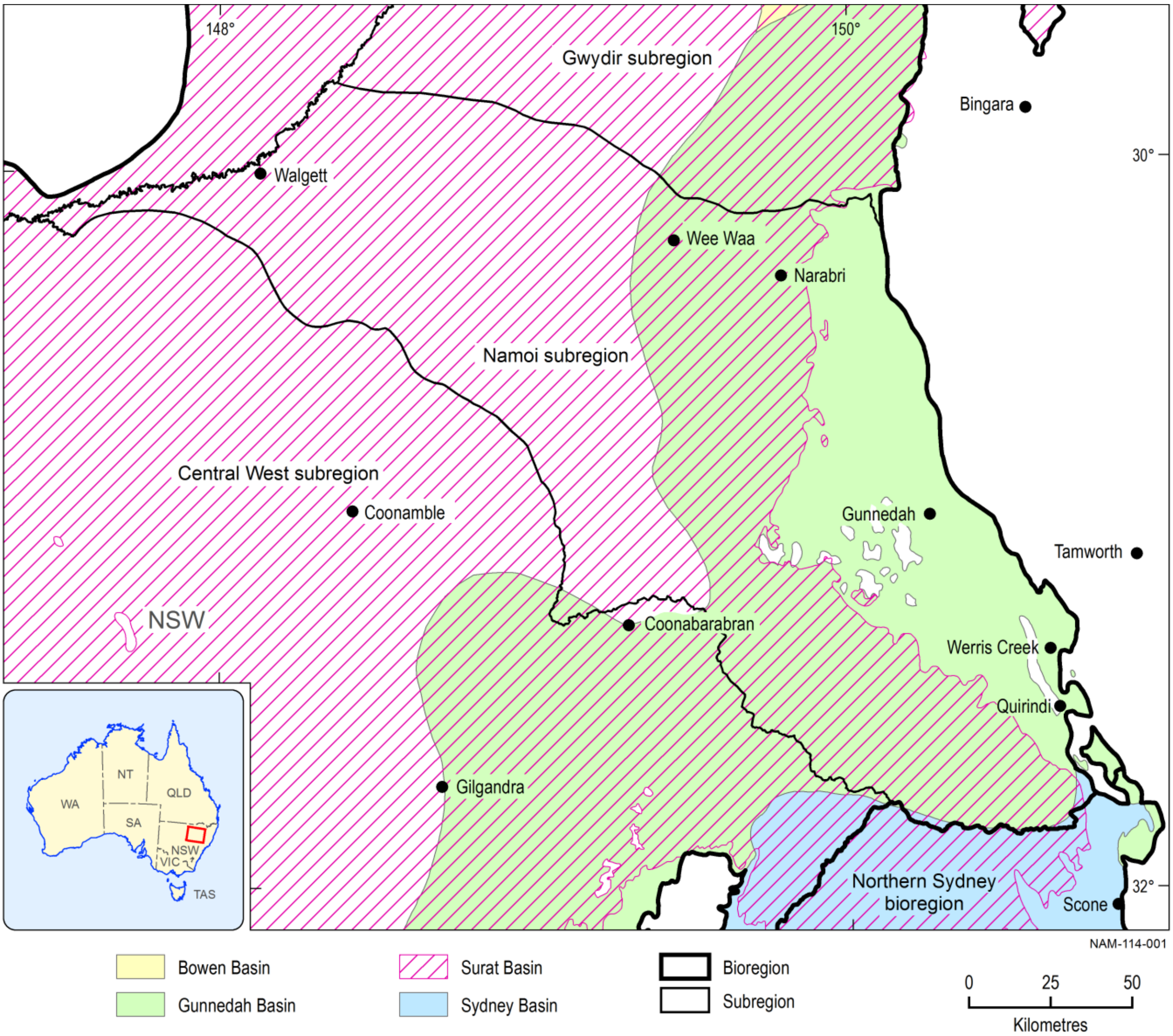

Figure 23 Geological basins of the Namoi subregion including the Surat Basin and Gunnedah Basin

The Surat Basin in the Namoi subregion is part of the larger Coonamble Embayment of the GAB, and ranges in age from Upper Triassic to Lower Cretaceous (Ransley and Smerdon, 2012). The Coonamble Embayment is widely believed to be hydrogeologically isolated from the northern part of the Surat Basin and the main areas of the GAB (Herczeg, 2008; Radke et al., 2000).

The main GAB aquifer in the Namoi subregion is the Jurassic Pilliga Sandstone and its outcrop in the central part of the Namoi subregion marks the boundary of the GAB (CSIRO, 2012). The Pilliga Sandstone is a well-sorted coarse-grained sandstone, highly porous and permeable and producing high yields of good quality groundwater (Radke et al., 2000). Underlying the Pilliga Sandstone is the Purlawaugh Formation, which outcrops in small areas in the south of Namoi subregion. The Purlawaugh Formation unconformably overlies the Garrawilla Volcanics of the Gunnedah Basin. The alluvial sequence in the far west of the Namoi subregion is underlain by undifferentiated Rolling Downs Group (probably Griman Creek Formation) which overlies the Pilliga Sandstone and Purlawaugh Formation.

A stratigraphic table of the Cretaceous and Jurassic GAB sediments, and underlying Permian-Triassic Gunnedah Basin is shown in Figure 24. The overlying alluvial sediments are absent from this stratigraphic sequence.

Hydraulic conductivities of GAB sandstone aquifers, including the Pilliga Sandstone, range from 0.1 to 10 m/day, with most tests at the lower end of the range (GABCC, 2010). Aquaterra (2009) reported hydraulic conductivities for encountered geological units in the Narrabri Coal Mine Stage 2 Longwall Project. Several zones of elevated hydraulic conductivity were observed in the Garrawilla Volcanics and Pilliga Sandstone (up to 0.4 m/day). All other hydrogeological units indicated a wide range of conductivities, but generally quite low, ranging from 0.0005 to 0.03 m/day, with the higher conductivities generally in subcrop areas.

The GAB Water Resource Assessment (CSIRO, 2012) included an updated correlation of the hydrostratigraphic units for the GAB (Figure 24).

Figure 24 indicates that the Wallumbilla Formation is a tight aquitard, the Pilliga Sandstone is an aquifer and the Purlawaugh Formation is an aquiclude (CSIRO, 2012), suggesting limited vertical connectivity with the underlying units.

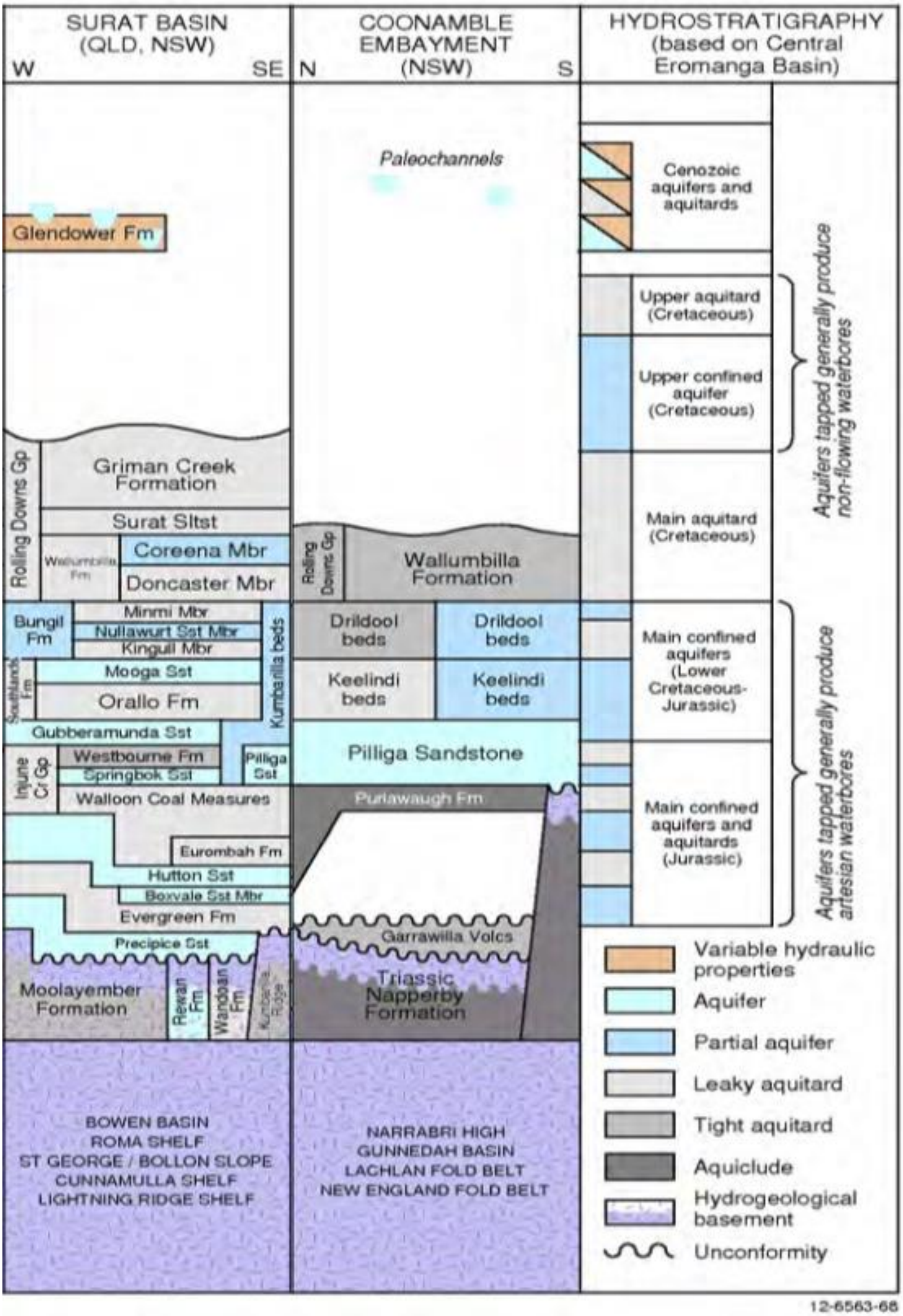

Figure 24 Hydrostratigraphic sequence of the Surat Basin and Coonamble Embayment

Source: modified from Figure 5.9 in CSIRO (2012)

1.1.4.1.3 Gunnedah Basin

The sedimentary and volcanic rocks of the Permian-Triassic Gunnedah Basin underlie the eastern part of the Namoi subregion (see Figure 23) and are comprised of up to 1200 m of interbedded sandstone and siltstones of marine and non-marine origin with intercalated coals (Kelly et al., 2007; Barrett, 2012). The Gunnedah Basin unconformably overlies the Lachlan Fold Belt, which is the effective hydrogeological basement of the Namoi subregion. A stratigraphic table of the Gunnedah Basin sediments is shown in Figure 21.

The Gunnedah Basin is also known as the Gunnedah-Oxley Basin. The 'Oxley' component of the basin is not consistently recognised in literature, but is described in SWS (2011) as *'a stranded portion of the Surat Basin'* that is '*hydraulically disconnected'* and comprises *'Pilliga Sandstone equivalent sediments'*. It '*directly overlies the Gunnedah Basin' and is 'located in the south of the* (Namoi) *catchment and to the west of Quirindi and forms a localised groundwater resource'*. Mapping by SWS (2011) indicates the Oxley Basin outcropping in the south of the Namoi subregion.

The Gunnedah Basin sedimentary rocks are the focus of coal mining and CSG exploration within the Namoi subregion. Coal seams within the Permian Black Jack and Maules Creek formations occur both at depth and as surface outcrops. The principal seams for CSG exploration are the Hoskissons Coal Member, which lies within the Permian Black Jack Group; and the Bohena seam within the Maules Creek Formation (SWS, 2011). The Hoskissons seam, and associated minor seams, are also being targeted by open-cut and underground coal mining operations where they occur nearer to the surface (DPI, 2009).

In general, the coal beds within the Gunnedah Basin are considered to have a low hydraulic conductivity compared to the overlying alluvial aquifers (SWS, 2011). Hydraulic conductivity of the Hoskissons Coal Member at the Kahlua CSG site has been estimated from drill stem tests to range from about 0.33 to 3.3 m/day (Golder Associates, 2010; 2011), however much smaller values were obtained from testing at the Narrabri Mine (0.0086–0.02 m/day (Aquaterra, 2009)). Hydraulic conductivity values of the Upper Black Jack Group and the Digby Formation are assumed to be one to two orders of magnitude less, and thus are assumed to be aquitards (Golder Associates, 2010, 2011).

Bores are screened into the Napperby Formation and the Ulinda Sandstone (Digby Formation) in some places, but to a much lesser extent than the alluvial sequences as they are low yielding and not continuous. The Clare Sandstone is the only formation in the Black Jack Group with potential as a groundwater resource but due to its depth and the presence of more productive and shallower alluvial aquifers, the Clare Sandstone is not significantly utilised (Golder Associates, 2011).

There are a significant number of localised faults within the Gunnedah Basin sequence, with estimated displacements of up to 120 m (Tadros, 1993) which have the potential to cause a large disconnection across geological units. This faulting was not captured in the SWS study, although SWS anticipated that some of these faults may have a significant effect on groundwater flow characteristics (SWS, 2011).

The hydrogeology of Gunnedah Basin sedimentary rocks that host coal and CSG target seams is poorly understood and documented, because the focus of groundwater studies has traditionally been on unconsolidated alluvium. Consequently, there is very little published information on the hydraulic properties of the Gunnedah Basin. A small number of private wells do access these formations, mainly where the alluvium is absent, although they are not considered major groundwater resources. Hydraulic properties are limited to either testing work completed by the coal and CSG companies or published values for similar formations in other areas (Golder Associates, 2010, 2011; SWS, 2011).

1.1.4.1.4 Hydrogeological basement

Lower Permian volcanic rocks (the Boggabri Volcanics and Werrie Basalt) of the Lachlan Fold Belt form an effective basement for much of the Gunnedah Basin (Tadros, 1995) and the wider Namoi subregion. This basement varies in depth, forming a series of generally north-south trending ridges and troughs. Very little data exists on the hydraulic properties of the basal volcanic rocks (SWS, 2011).

A depth to economic basement map, developed under the SEEBASE Project, defines basement as the base of the Permian sedimentary material overlying the basement volcanics (SRK Consulting, 2011). This map is shown below in Figure 25.

The Hunter-Mooki Fault marks a distinct break in the bedrock geological formations. It is not known if there is significant groundwater flow across the fault to any great depth (SWS, 2011). In their geological model, SWS (2011) assumed there was minimal deep groundwater connection across the fault, given the properties of the geological strata involved and the lack of data to suggest otherwise.

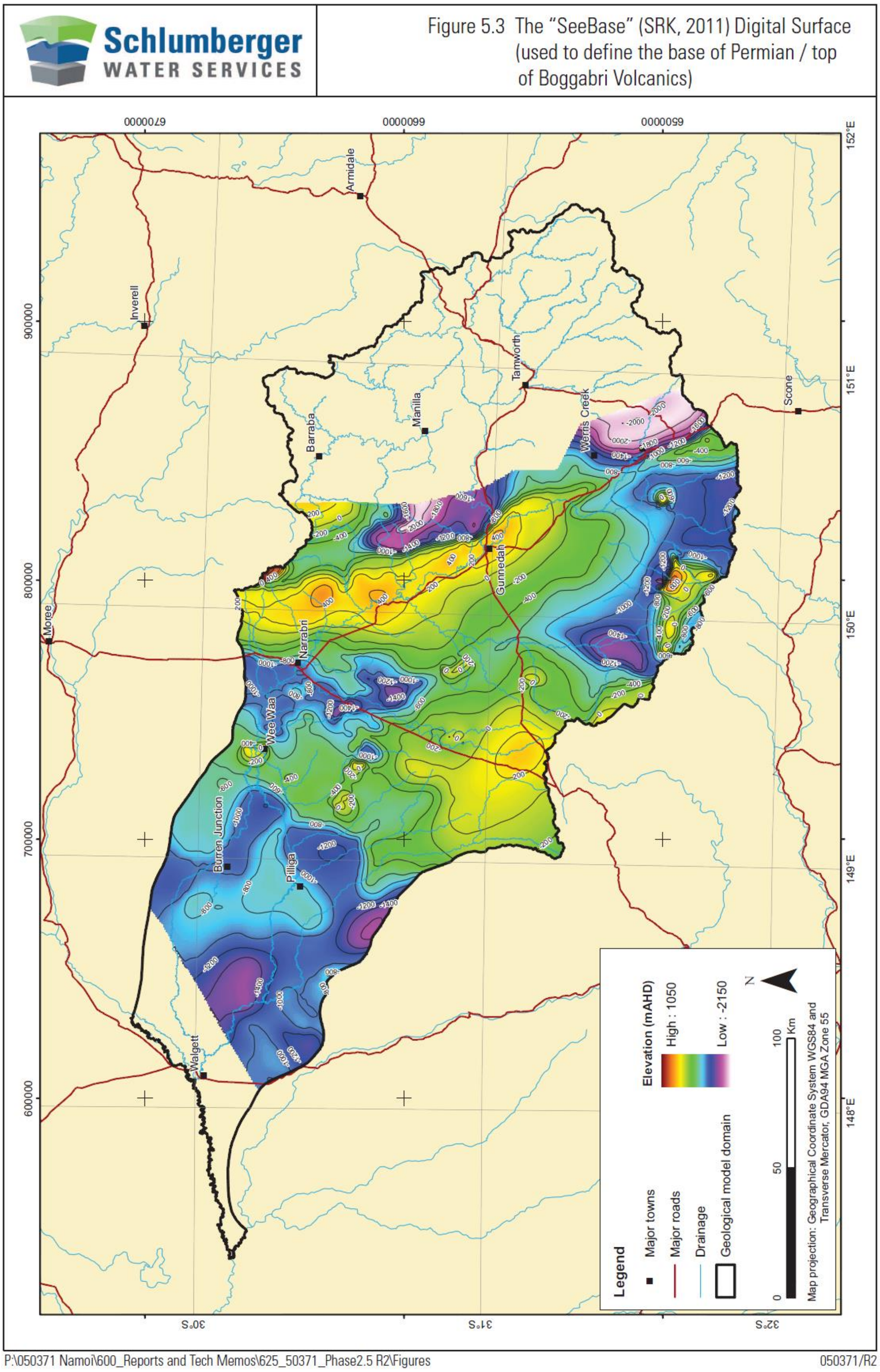

Figure 25 The 'SEEBASE' (SRK Consulting, 2011) digital surface (used to define the base of Permian sediments/top of the Boggabri Volcanics)

Source: SWS (2011). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from NSW Department of Trade and Investment.

1.1.4.2 Groundwater systems

1.1.4.2.1 Groundwater levels and flow paths

Alluvial aquifers

Regionally, groundwater gradients in the alluvial aquifers indicate flow from the east in a north-westerly to westerly direction away from the Namoi River (Parsons Brinckerhoff, 2011) and the groundwater flow systems within the major aquifers are generally local to intermediate in scale (CSIRO, 2007).

SWS (2011) developed a water level contour map for the wider Namoi catchment using average water levels for non-GAB bores. Watertable mapping indicates that groundwater flow in the Upper Namoi is generally south to north draining into the Lower Namoi through a bedrock constriction north of Narrabri (SWS, 2011; Barrett, 2012). Groundwater in the Lower Namoi generally flows from east to west.

Narrow geological constrictions along the Upper Namoi River valley have affected the deposition of the alluvial sediments, thereby restricting groundwater flow in the Upper Namoi Alluvium. Gins Leap north of Boggabri is the location of a major groundwater flow constriction due to aquifer geometry/extent (SWS, 2011).

The alluvial sequence is considered to be continuous over the Hunter-Mooki Fault which forms the boundary between underlying Mesozoic and Paleozoic strata so groundwater in the Narrabri and Gunnedah formations is likely to flow into the Namoi subregion from the east (SWS, 2011).

There is primarily downward flow of groundwater from the Narrabri to the Gunnedah formations in the eastern part of the subregion, however vertical hydraulic gradients are reversed at the western margin. In some locations which usually show potential for upward flow, heavy pumping of groundwater over the irrigation season reverses the flow potential (Parsons Brinckerhoff, 2011; Barrett, 2012).

Recent measurements (post-2000) of the watertable in the Narrabri Formation are shown in Figure 26. Groundwater mounds are developed about the Namoi River and its anabranch, Pian Creek, in the watertable in the Narrabri Formation. This indicates that these streams leak into the Narrabri Formation. The magnitude of this bed underflow leakage is estimated to be about 42 GL/year (CSIRO, 2007). Corroborating evidence is provided by Parsons et al. (2008) based on groundwater levels relative to surface water levels. Parsons et al. (2008) classify Pian Creek as a maximum losing stream and the Namoi River between Narrabri and Walgett as a medium to high losing stream.

In Figure 26, the Northern Namoi Paleochannel is depicted as a groundwater drain in the Narrabri Formation. The drain is generated by the large amount of groundwater pumping for irrigation mostly from the Gunnedah Formation over the Lower Namoi Valley but especially in the palaeochannel. While actual groundwater extraction in the Lower Namoi in the past three wet years has been below 50 GL/year (NSW Office of Water, 2013), the annual extraction limit for the Lower Namoi in 2013-2014 is set at 90.2 GL, and actual extraction over the past two decades has commonly exceeded 100 GL /year (Smithson, 2009). The groundwater pumping from the Gunnedah Formation induces significant downward leakage from the Narrabri Formation.

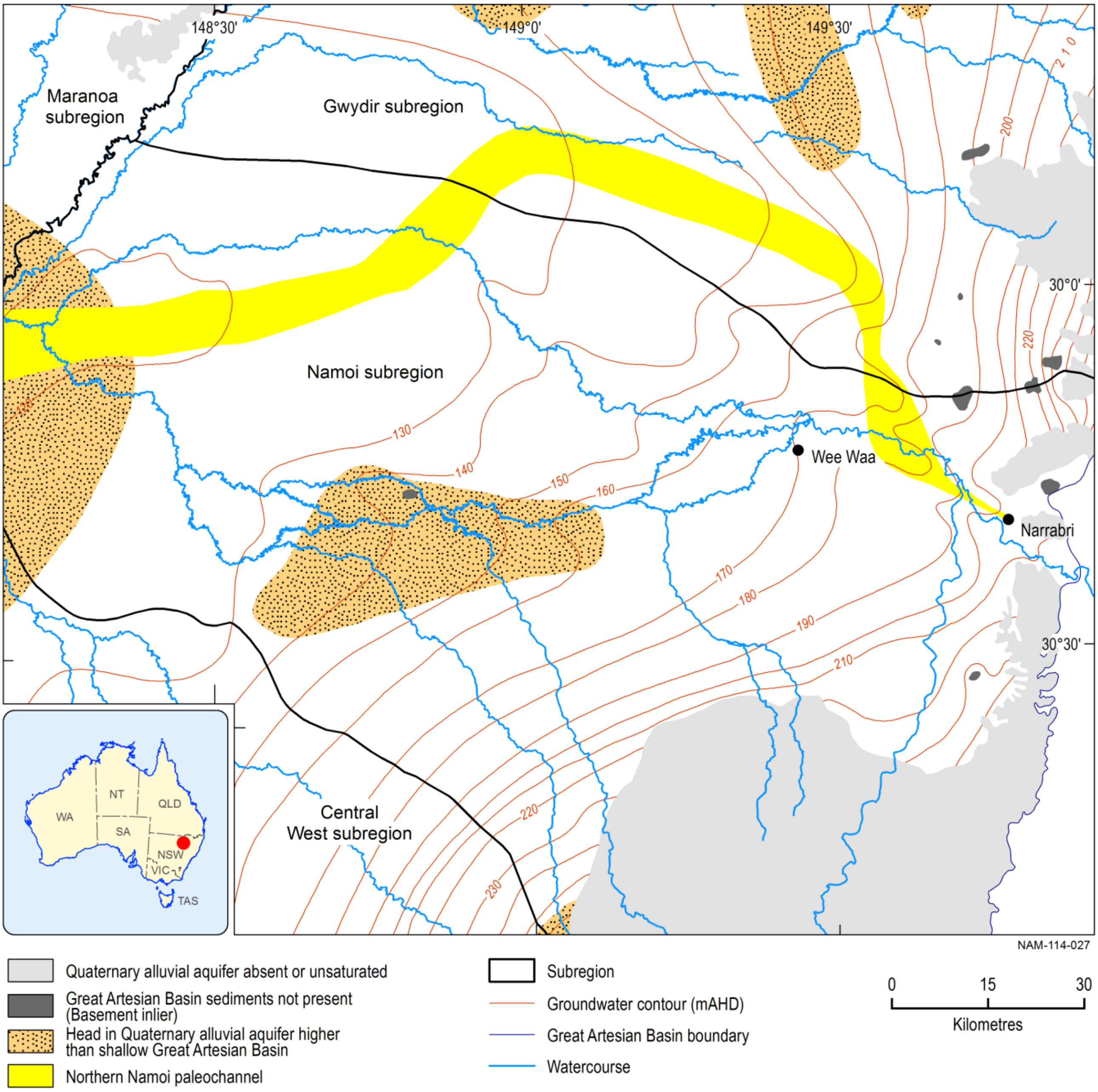

Figure 26 Watertable in the Narrabri Formation

Groundwater levels in alluvial aquifers in the Upper and Lower Namoi groundwater management areas have been monitored at 331 and 256 monitoring bore locations respectively, for the past 30 to 40 years (Smithson, 2009; Barrett, 2012). In some areas it can be difficult to distinguish between groundwater in the Narrabri and Gunnedah Formations at they can act as a single aquifer.

Groundwater in the alluvial aquifers is generally shallower at the eastern extent of the subregion, gradually becoming deeper from south to north in the Upper Namoi (Barrett, 2012). At Narrabri groundwater is around 4 to 12 m below ground level, becoming progressively deeper towards the west, and is around 25 to 34 m below ground level at Cryon. Long-term groundwater level declines at the western end of the valley, where usage is low, are most likely related to extraction higher in the valley limiting throughflow (Smithson, 2009).

In general, groundwater levels in the alluvial aquifers have responded to rainfall variability and associated variability in groundwater use. Groundwater levels have generally been falling since the late 1960s/early 1970s due to over-extraction, with water levels stabilising or recovering during wetter years when there has been reduced extraction. In 2006–07, many parts of the Namoi subregion experienced their lowest groundwater levels since monitoring commenced (Smithson, 2009; Burrell et al., 2011; Barrett, 2012).

The contrast between drier and wetter seasons affects groundwater levels as a result of differing rates of river recharge to the groundwater system, and changes to groundwater demand for irrigation. Where the surface water system is highly connected to the aquifer system, a wetter regime coincides with higher flows in the river, and an associated higher pressure head to promote recharge to the aquifer. The reduced demand for extractions would also be contributing to this shift in trend (Burrell et al., 2011). Such sites are also likely to recharge GAB aquifers via bed underflow leakage through the alluvium palaeochannel (Kellett et al., 2012). This effect is reduced in areas where the river is disconnected from the alluvial aquifers.

Hydrographs often show seasonal variations in groundwater levels in the alluvial aquifers in phase with groundwater extraction for irrigation. These variations are generally characterised by periods of falling and/or fluctuating groundwater levels from spring to autumn and an increase or stabilisation of groundwater levels during winter, in accordance with irrigation schedules. As there is little excess rainfall over evaporation even in the winter months, the observed seasonality is considered to be caused by changes in groundwater abstraction.

Great Artesian Basin

The first recorded bores tapping the GAB in the Namoi were noted in the 1890s. Historically bores were left uncapped, resulting in artesian water, where present, leaving the system and causing a decrease in pressure (SWS, 2011). The lowering of the potentiometric surface of the main GAB aquifers has caused it to fall below the ground surface in several areas and as a result flows from artesian water bores in those areas have ceased or diminished (CSIRO, 2012). Data from the NSW government database indicates groundwater levels near Pilliga, close to the Namoi recharge zone, fell from around 200 mAHD in 1915 to around 170 mAHD by the late 1980s (SWS, 2011).

Figure 27 is modified from the regional potentiometric surface developed for the Surat Basin as part of the Great Artesian Basin Water Resource Assessment (CSIRO, 2012). The surface was developed using all available groundwater data and shows that the groundwater in the GAB aquifers flows from south-east to west and north-west. The watertable lies in the main GAB aquifer in New South Wales, the Pilliga Sandstone. It then passes into thin bands of Keelindi and Drildool Beds and then into undifferentiated Rolling Downs Group to the west, outside of the Namoi subregion (CSIRO, 2012). In contrast to the Narrabri Formation groundwater contours in Figure 26, the potentiometric surface in the uppermost GAB aquifer (Figure 27) does not generally show any obvious groundwater/surface water interaction along the Namoi River and its anabranch, Pian Creek (the potentiometric surface is not distorted/impacted near these surface water features). One possible exception is the area just downstream of Narrabri at the confluence with Bohena Creek.

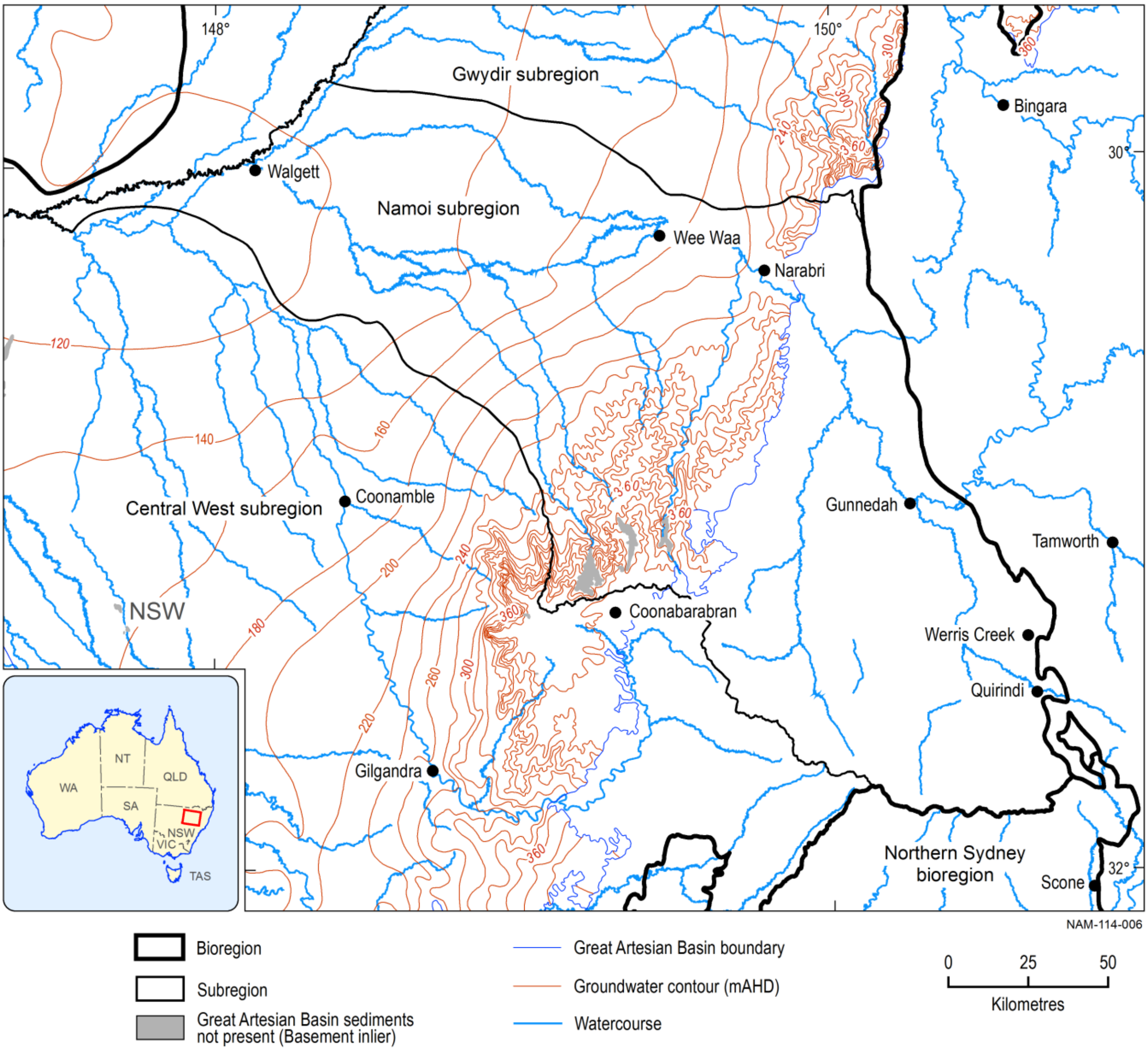

Figure 27 Potentiometric surface of groundwater in the uppermost Great Artesian Basin aquifer

Source data: modified from CSIRO (2012)

Except for a small area at Pilliga, heads in the regional GAB watertable (Figure 27) are above heads in the Narrabri Formation (Figure 26). This is in marked contrast to the situation in the early 1990s where Williams (1997) showed the head in the alluvium as lying above the regional GAB watertable except for a small area at Narrabri West. This means that in approximately 20 years there has been a reversal in the head differential between the two flow systems due to groundwater pumping for irrigation. The dotted area at Pilliga in Figure 26 probably indicates a zone where groundwater in the alluvium is perched above the regional GAB watertable aquifer since it is likely that the saprolite aquitard on the Griman Creek Formation is preserved there.

Gunnedah Basin

There is very little published information relating to the hydraulic properties of the Gunnedah Basin hard rock aquifers, so groundwater levels and flow paths are largely unknown.

1.1.4.2.2 Groundwater quality

The collection of groundwater quality data in the Namoi subregion has tended to be infrequent and irregular, and undertaken by a range of agencies including government departments, research organisations and consultants. These studies have tended to be very site specific and short-term, and show a large amount of spatial variability. Documentation relating to sampling methodologies and instruments is often lacking and the limited transfer of data into central databases makes the interpretation of historical chemical data difficult (Kelly et al., 2007). SWS (2011) note that for a catchment the size of the Namoi, there is very little groundwater quality data available from the NSW Office of Water Pinneena database. According to the database, water quality records have been collected from 1991 onwards, however, there are insufficient water quality data to establish the variation in major ion chemistry over time. Additionally, the depth from which samples have been taken can be difficult to determine because in locations with nested piezometers installed the database does not distinguish from which depth the measurement was taken (SWS, 2011).

Groundwater salinity is the main measure of groundwater quality that has been collected in the Namoi subregion because this has been a prominent issue in several areas due to shallow watertables and an increase in irrigation water salinity in some areas (Kelly et al., 2007; Timms et al., 2010). However, there are limited long-term and/or periodic salinity monitoring records in the NSW Office of Water database and historic single point values are often grouped into numerical classes or are descriptive (e.g. fresh, brackish, salty, etc.) (SWS, 2011).

Figure 28 shows suitability of groundwater in the alluvium (based on salinity) for various purposes (Green et al., 2011). Groundwater is generally less saline in the Upper Namoi area, increasing away from the Namoi River and downstream. Previous studies also indicate that the alluvial aquifers are often fresher at depth (Lavitt, 1999; McLean, 2003; Parsons Brinckerhoff, 2011).

An increase in groundwater salinity, possibly due to increased saline drainage through the alluvium, has been reported in some irrigation areas of the Lower Namoi since the 1990s. Groundwater salinity appears to have increased during the 1990s at some sites in the Upper Namoi as well, possibly limiting beneficial use (Timms et al., 2010).

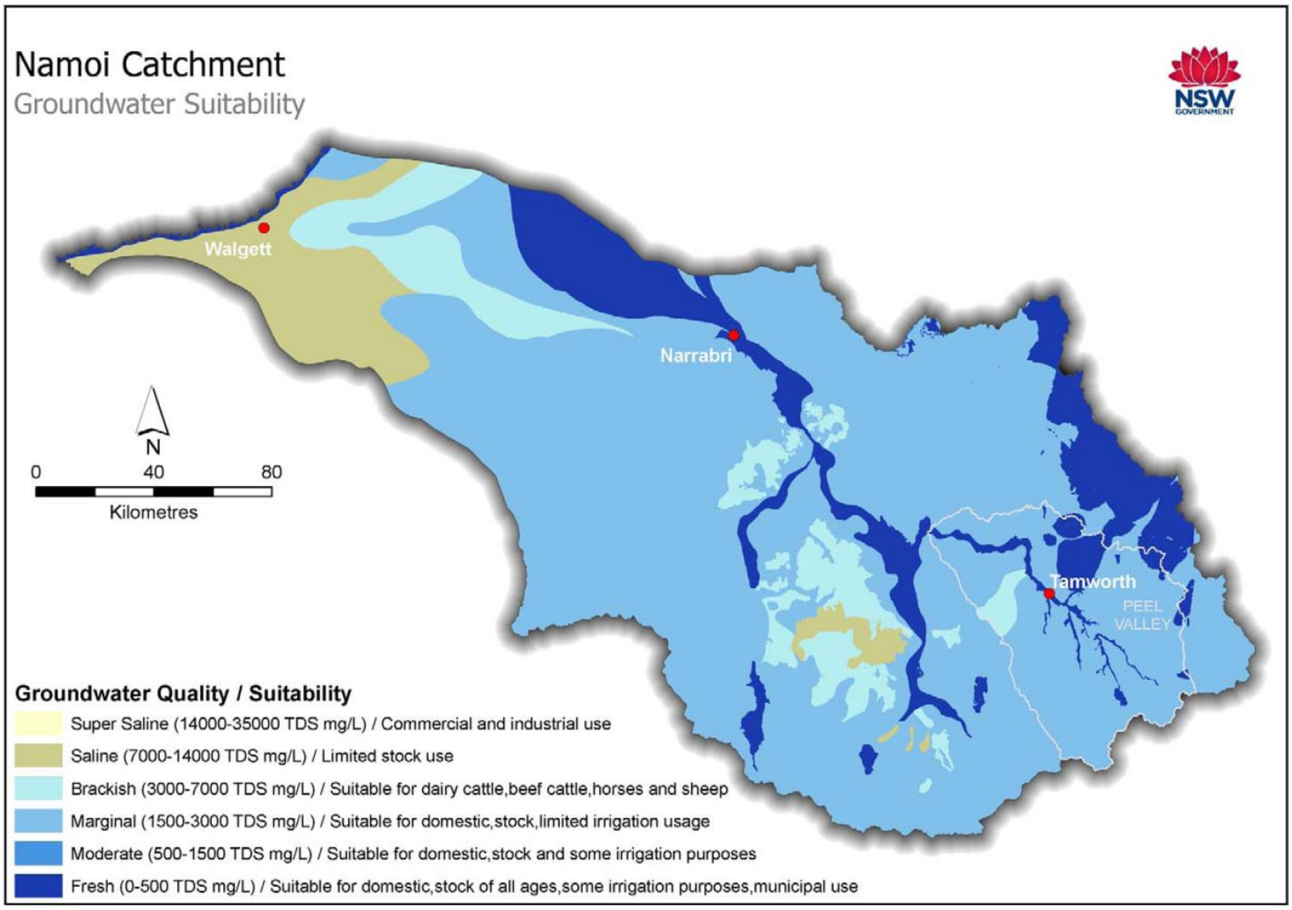

Figure 28 Alluvial groundwater quality and suitability in the Namoi area

Source: Figure 13 in Green et al. (2011)

As discussed above there are very few groundwater chemistry data in the NSW government database, however a number of research projects have analysed groundwater chemistry in the Namoi subregion, as summarised below.

Upper Namoi

Groundwater salinity across the Upper Namoi Alluvium is generally less than 1500 µs/cm, with areas of higher salinity up to 7000 µs/cm (Barrett, 2012).

Lavitt (1999) found that groundwater in the shallow alluvium (Narrabri Formation) of the Mooki catchment had a highly variable composition but was more similar to river water than the deeper (Gunnedah formation) alluvial aquifers. This implies a limited vertical connection within the alluvium under natural conditions in this area. Timms and Acworth (2002) found a similarly disconnected alluvial system in the upper Mooki catchment, with a low rate of vertical leakage between the shallow and deeper alluvial layers.

Lavitt (1999) found samples from the deeper alluvial units were similar to the surrounding hard rock units, suggesting hydraulic connection between the deeper alluvium and shallow hard rock aquifers. However, it may also indicate the source rock of the deeper alluvium is similar to the hard rock aquifers, or that the water in the deeper alluvium is older and more chemically evolved than in the shallow alluvium.

Similarly, Timms and Acworth (2002) found that the water chemistry of the deeper Mooki alluvium was similar to that of the Liverpool Ranges Volcanics and Gunnedah Basin sediments. Similar results were found in the Coxs Creek catchment.

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

- The Narrabri Formation is dominated by sodium and chloride. Major ion chemistry in the Gunnedah Formation is spatially variable, indicating the aquifer is laterally discontinuous with zones of differing salinity and major ion composition.
- Groundwater quality has deteriorated in some bores in the Narrabri Formation (no longer suitable for stock) and Gunnedah Formation (from irrigation to stock).
- Some bores in the Gunnedah Formation showed a long-term increasing trend in salinity, which is attributed to either downward leakage of saline water where aquitards are thin or absent, or to leakage of saline water from clay aquitards as a result of depressurisation where persistent abstraction has occurred.
- Processes influencing the major ion composition of groundwater include mixing, ion exchange, weathering of silicate minerals and clays and dissolution and precipitation of minerals such as carbonates and gypsum.
- A change in water type has occurred in some Gunnedah Formation bores where salinity is increasing.

Lower Namoi

Groundwater salinity generally increases away from the main recharge areas in the east (Figure 28), and from the mean Namoi River EC of 560 µS/cm to over 30,000 µS/cm in the Narrabri Formation (Barrett et al., 2006, as cited in Parsons Brinckerhoff, 2011).

McLean (2003) analysed changes in groundwater salinity between the mid 1980s and 1999 and concluded that the salinity of groundwater in the eastern part of the Lower Namoi had increased by 100 µS/cm over the last 30 years, and in the western portion of the aquifer by several thousand µS/cm. These increases have been attributed to changes in direction of potential flow paths caused by pumping practices (Kelly et al., 2007). The changes in water quality due to pumping were localised and showed no general trends (McLean, 2003).

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

- Groundwater levels have declined by 1.5 to 4 m since the late 1970s.
- Major ion chemistry in all aquifers is dominated by sodium and chloride.
- The beneficial use of groundwater has deteriorated at some bores in the Narrabri Formation (no longer suitable for stock), Gunnedah Formation (no longer suitable for some crops including cotton) and Cubbaroo Formation (no longer suitable for some crops including cotton) since monitoring began.
- Some Gunnedah Formation bores showed a long-term increasing trend in salinity, which was attributed to vertical leakage of saline water from the upper aquifer and saline intrusion of

pore waters. One Narrabri Formation bore and one Cubbaroo Formation bore also showed a long-term increasing trend in salinity.

- Processes influencing the major ion composition of groundwater include mixing, ion exchange, reverse ion exchange, and dissolution and precipitation of minerals such as carbonates and gypsum.
- There were no long-term changes in water type identified.

Great Artesian Basin

Groundwater in the Pilliga Sandstone aquifers in the Namoi subregion is generally of good to fair quality and suitable for stock and domestic use. Salinity in the most widely-used aquifers is low but becomes more variable with depth. Groundwater salinity generally increases from the recharge areas along the groundwater flow path towards the north and west (GABCC, 2010). The increasing salinity trend may be a consequence of soluble ions leaching from overlying or underlying formations with marine depositional histories, the mixing of dilute recharge waters with saline waters present within deeper parts of the GAB and the dissolution or weathering of evaporates, carbonate minerals or incongruent dissolution of feldspars, micas or clay minerals along the flow path (Herczeg et al., 1991).

Following infiltration in the recharge zones, groundwater in the GAB aquifers tends to evolve from mixed cation-bicarbonate-chloride to sodium-bicarbonate-chloride dominant groundwater as a result of carbon dioxide production, carbonate dissolution, ion exchange and aluminosilicate weathering (Herczeg et al., 1991; Radke et al., 2000).

GAB groundwater tends to have high concentrations of sodium. This renders the water unusable for irrigation in most places due to high sodium absorption ratios in both the soil and applied groundwater. However, further north in the North Star/Yallaroi area, a combination of lower sodium groundwater and sandy soils allows irrigation to occur in the recharge areas on the eastern margin of the Basin. Sodium concentrations as low as 25 mg/L occur in the recharge areas, increasing progressively to over 1000 mg/L in the far west (GABCC, 2010).

Alkalinity (as bicarbonate) is the dominant anion and chloride concentrations are very low in the eastern recharge areas and the Coonamble Embayment (<50 mg/L) (GABCC, 2010).

Studies of stable isotope ratios of oxygen and deuterium ($\delta^{18}O$ and $\delta^{2}H$) show that GAB groundwater is isotopically heavier (below the meteoric water line) than rainfall, indicating groundwater has probably undergone evaporation or other processes. Plots of samples from specific regions, such as the recharge areas, central parts and discharge areas of the GAB provide different patterns. All $\delta^{18}O$ and $\delta^{2}H$ plots indicate that the artesian groundwater is meteoric in origin (CSIRO, 2012).

Chlorine-36 data for the New South Wales portion of the GAB indicate flow systems increasing in age along the inferred hydraulic gradient, with indicative groundwater ages ranging from less than 5000 years, within the highland areas and river alluvial valleys in the recharge zone, to greater than 200,000 years, in the western part of the Coonamble Embayment (Radke et al., 2000). The inferred horizontal flow rates are 4 m/year in the alluvial fans that abut the Great Dividing Range, decreasing to less than 1 m/year as groundwater traverses towards the plains (Herczeg, 2008).

Gunnedah Basin

Groundwater chemistry data from Gunnedah Basin sedimentary sequences is limited to localised investigations around prospective CSG operations. From the limited published data available, most groundwater samples from the non-coal seam formations in the Gunnedah Basin are fresh to slightly brackish. In contrast, groundwater samples from the Hoskissons Coal Member are predominantly brackish. An increasing salinity trend was observed in the following order:

Narrabri/Gunnedah < Pilliga Sandstone < Napperby/Digby Formation < Black Jack Group < Hoskissons Coal (Golder Associates, 2010, 2011).

Major ion analysis of a very limited number of groundwater samples in the Gunnedah Basin shows groundwater from the Hoskissons Coal Member generally has high concentrations of sodium and bicarbonate, with the lowest concentrations of sulfate and chloride. Groundwater from other formations, including the Napperby and Digby formations, is characterised by a range of water types reflecting the heterogeneity of the sedimentary environment (Golder Associates, 2010, 2011).

Eastern Star Gas (now Santos) published typical values for produced water from their target coal seams in the Gunnedah Basin (Eastern Star Gas, 2006). These values are summarised in Table 7. Typical of CSG co-produced water, it is high in TDS and is of sodium-bicarbonate water type.

Santos has also published groundwater quality data for the Hoskissons Coal Member and the wider Gunnedah Basin units as shown in Table 7. Similarly to the Eastern Star Gas data, the groundwater in the coal seam is dominated by sodium and bicarbonate, although the absolute values for the Hoskissons seam are lower than those provided by Eastern Star Gas. These results are typical of the water composition in coal seams exploited for gas (low in calcium, magnesium and sulfate and dominated by sodium, bicarbonate, and often chloride where there are marine associations) (Van Voast, 2003). The water quality of the Gunnedah Basin units is noticeably different to the coal seams and generally better quality (Golder Associates, 2010).

Table 7 Indicative groundwater quality data from coal seams in the Gunnedah Basin

Parameter (mg/L unless stated)	Bibblewindi-1 produced water[1]	Hoskissons Coal Member[2]	Gunnedah Basin strata (excluding coal seams)[3]
pH	8.0	7.97	7.27
EC µS/cm	14,500	5,337	2,463
TDS	10,200	3,240	1,712
Ca	14	6.78	55.1
Mg	6	8.07	84.1
Na	3,930	1,337	313
K	120	11	9.51
HCO_3	7,340	3,166	698
Cl	1,320	297	349
SO_4	4	2.56	126
CO_3	<1	102	N/A

Source data:[1] Eastern Star Gas (2006). Sample collected 25 July 2006; [2] Golder Associates (2010). Mean groundwater values from Santos' Longlea and Georges Island wells; [3] Golder Associates (2010). Mean groundwater values from 15 to 17 samples

1.1.4.2.3 Groundwater recharge

Recharge to the alluvial aquifer system mainly occurs in the east via several mechanisms including from the Namoi River and its tributaries, especially during major flooding events, rainfall infiltration, irrigation, through flow from surrounding aquifers and catchments, and on-farm water losses. Recharge can also occur via upward leakage of groundwater from the underlying aquifers (Salotti, 1997; CSIRO, 2007; Parsons Brinckerhoff, 2011).

Rainfall recharge

Rainfall recharge in the western part of the Namoi subregion is considered to be low. The Lower Namoi catchment groundwater model indicates that diffuse recharge from rainfall is a minor recharge source (Merrick, 2001a). Timms et al. (2012) found that the watertable at the western extent of the subregion near Walgett occurs at 20 m depth and that there is generally no significant groundwater level response to large rainfall events, indicating little diffuse rainfall recharge. The lack of groundwater level response was expected given the large water holding capacity of the surface clays and the low hydraulic conductivity limiting vertical groundwater flow. High frequency groundwater level data indicated that recharge is <0.6% of annual rainfall during very wet years and is limited to localised areas of the plains. The mean long-term rainfall recharge rate could be as low as 0.01%. Considering the uncertainties involved, recharge is considered very small or negligible (Timms et al., 2012). This is in contrast to rapid groundwater level response to rainfall detected in the Upper Namoi catchment, resulting in elevated groundwater levels which then dissipate during dry periods (Timms et al., 2001; Timms and Acworth, 2005).

River recharge

The streams on the alluvial plain flow across the top of the Narrabri Formation. At the eastern and western margins of the plain, the rivers are in direct hydraulic contact with the watertable. An unsaturated zone develops between these points where the watertable falls below the streams, and surface water recharges the underlying aquifer while streamflow persists.

Irrigation recharge

Groundwater recharge as a result of irrigation may represent a significant component of recharge in some areas and be an important mechanism for rising groundwater and salinity, especially in cracking clay soils, however estimates of groundwater recharge from irrigation vary considerably.

Lysimeter studies undertaken near Narrabri showed drainage ranged from approximately 30 to 50 mm/year during the cotton irrigation season, was 23 mm under fallow and negligible under wheat. Peak drainage rates occurred 25 hours after irrigation at over 3 mm/day then declined exponentially over about a week to 0.5 mm/day. The results from the lysimeter were compared to estimates of deep drainage by chloride mass balance, with the latter underestimating drainage by 55% (Ringrose-Voase and Nadelko, 2011).

Seasonal drainage from the root zone appeared to recharge the watertable at 16 m depth within weeks at a rate of 0 to 0.7 mm/day, however the result remains tentative (Ringrose-Voase and Nadelko, 2011). Under furrow irrigation Timms and Acworth (2002) found shallow groundwater levels increased by up to 3 m during the irrigation season and then declined rapidly, not showing a general rising trend. Kelly and Acworth (2005) used resistivity imaging to show that deep drainage occurs in isolated zones and that under furrow irrigation water drains beyond 5 m within 24 hours. More work is needed to understand if this water migrates laterally, returns to the surface water flows or moves downwards to recharge deeper aquifers.

Recharge from overlying and underlying aquifers

The Gunnedah Formation is mainly recharged via infiltration from the overlying Narrabri Formation. In general, there is a downward movement of groundwater from the Narrabri Formation to the Gunnedah Formation in the east, while at the western margin the direction is reversed (CSIRO, 2007). The aquifers of the Cubbaroo and Gunnedah Formations are also recharged in part by upward leakage from the GAB (Ransley et al., 2012a).

The Great Artesian Basin recharge

Recharge of the GAB aquifers takes place chiefly along the south and eastern fringe of the GAB, in an area known as the ‘intake beds’, and is derived from rainfall and streamflow. The location of the GAB intake beds in the Namoi is shown in Figure 29. Localised recharge can be relatively fast and effective depending on the depth and configuration of the regional watertable and the hydraulic characteristics of the overlying material (CSIRO, 2012).

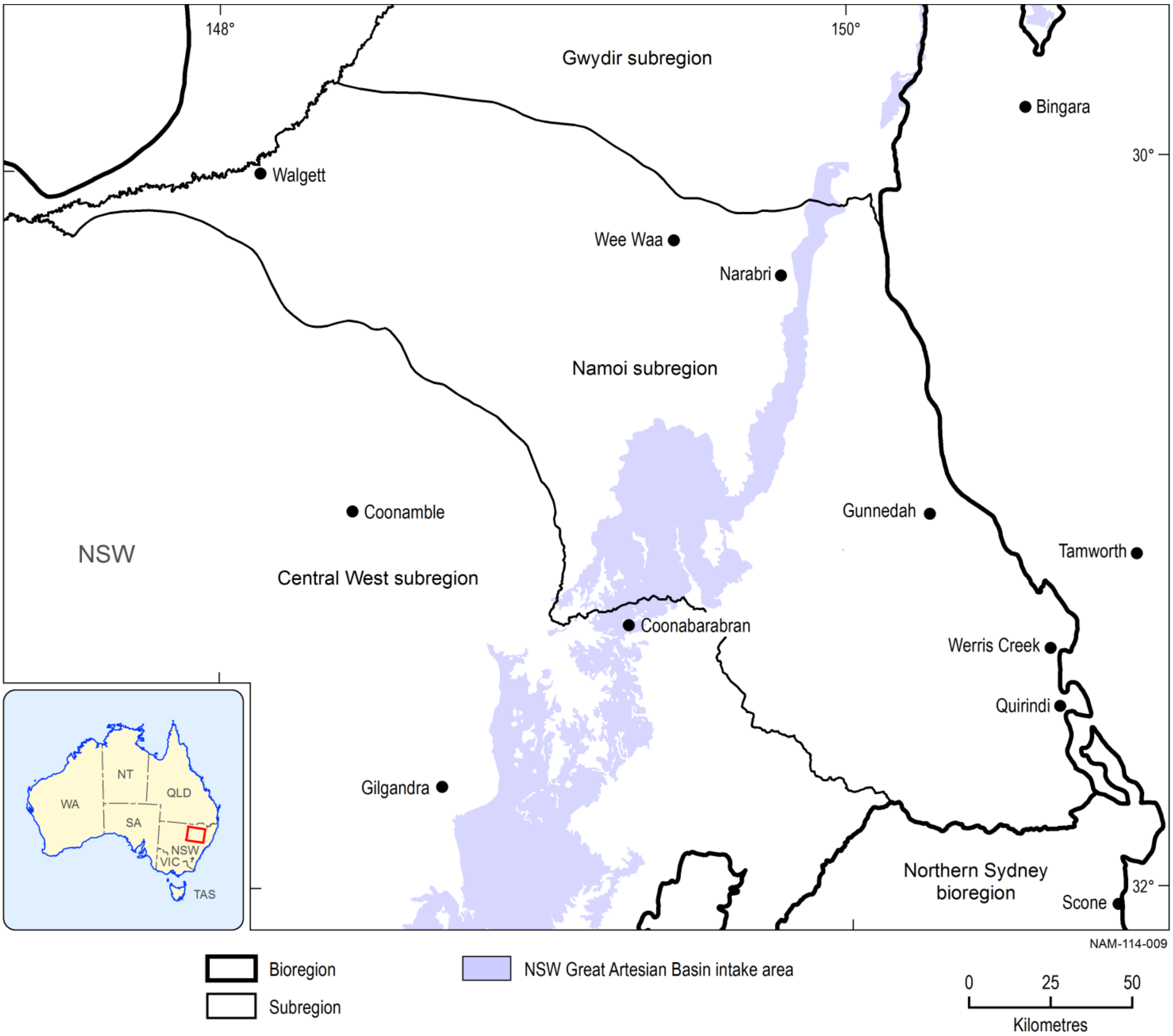

Figure 29 Groundwater recharge areas for the Great Artesian Basin in New South Wales

The recharge rates for the Pilliga Sandstone intake beds are difficult to determine and there have been wide ranging estimates over nearly two orders of magnitude. The most recent assessment of recharge to the wider Pilliga Sandstone was undertaken as part of the GAB Water Resource Assessment, using chloride concentrations in groundwater and rainfall (CSIRO, 2012). The recharge flux in the entire Pilliga Sandstone intake beds was calculated as 84,000 ML/year. This estimate is compatible with the Queensland data and is also reasonably close to the recharge estimate made by DPI (2009) for the New South Wales GAB water sharing plan of 61,400 ML/year (less than 2% of rainfall) (Kellett et al., 2012).

1.1.4.2.4 Groundwater discharge

Groundwater in the alluvial aquifers can discharge to the Namoi River and other creeks or tributaries where the rivers are connected and gaining (short river reaches in the Upper Namoi River). The alluvial aquifers will also discharge groundwater vertically where hydraulic properties permit, into the deeper alluvial units, the GAB or the Gunnedah basin. Groundwater in the far west of the subregion moves slowly through the alluvial aquifers to the south-west out of the region and cannot discharge to the surface as the Namoi River bed is located at least 10 m above the watertable (Timms et al., 2012).

1.1.4.2.5 Aquifer connectivity

Alluvial aquifers

The greatest aquifer interaction in the Namoi subregion occurs through horizontal and vertical connections within and between alluvial aquifers. The alluvial areas are heterogeneous deposits and although they are commonly subdivided into the Narrabri and Gunnedah formations, the actual boundary depth is difficult to determine from geological bore logs (SWS, 2011).

Aquifer connectivity can be assessed by hydrograph analysis of nested bores screened in different aquifers. The more similar the hydrographs between the bores, the more likely that the aquifers are in good hydraulic connection. There are a large number of nested bores in the Namoi subregion that could be used to assess connectivity between alluvial aquifers, however studies to date have only selected a few bores for this analysis. Consequently, while leakage between the Narrabri and Gunnedah formations has been shown to occur in parts of the Namoi subregion, the extent of this connectivity is unknown.

Connectivity has also been demonstrated by extraction from the Gunnedah Formation inducing leakage from the overlying Narrabri Formation, in some cases resulting in dewatering of the upper aquifer (Barrett, 2012). The depth at which the alluvial systems react to deep abstractions varies over short distances (SWS, 2011).

The Great Artesian Basin aquifers

Close to the margins of the GAB, palaeochannels of overlying alluvium can be incised into aquifer units such as the Pilliga Sandstone, resulting in upward leakage where the palaeochannel has eroded the saprolite. Such connectivity is poorly known but is considered to be highly variable across the region (Ransley et al., 2012b) and may be significant where these palaeovalleys occur. The contribution of the GAB aquifers to the alluvium in the water balance of the Lower Namoi model has previously been calculated as approximately 3.8 $m^3/d/km^2$ (Herczeg, 2008, as cited in SWS, 2011). Estimations of upward leakage from the GAB aquifer into alluvial palaeochannels suggest this volume to be approximately 1450 ML/year for 400 km^2 of palaeochannel (similar to 3.8 $m^3/d/km^2$). Where palaeochannels are absent, the GAB rocks are overlain by a layer of saprolite which greatly limits connectivity between the GAB and the overlying alluvial aquifers. Water pressures in the GAB have fallen significantly since the aquifers were first tapped, and the potential for upward movement of water into the alluvium will have reduced as the pressure gradient has fallen.

A preliminary desktop assessment of the potential for hydraulic connectivity between the GAB with the overlying alluvium and underlying basins was undertaken as part of the Great Artesian Basin Water Resource Assessment (CSIRO, 2012). Connectivity can occur where aquifers and leaky aquitards are juxtaposed below and above the base of the GAB. Figure 30 shows that the hydraulic connectivity between the GAB and underlying Gunnedah Basin appears to be variable but limited across the Namoi subregion (CSIRO, 2012). There may be some connectivity in the northern part of the subregion between the GAB and the underlying Gunnedah Basin, as indicated in Figure 30.

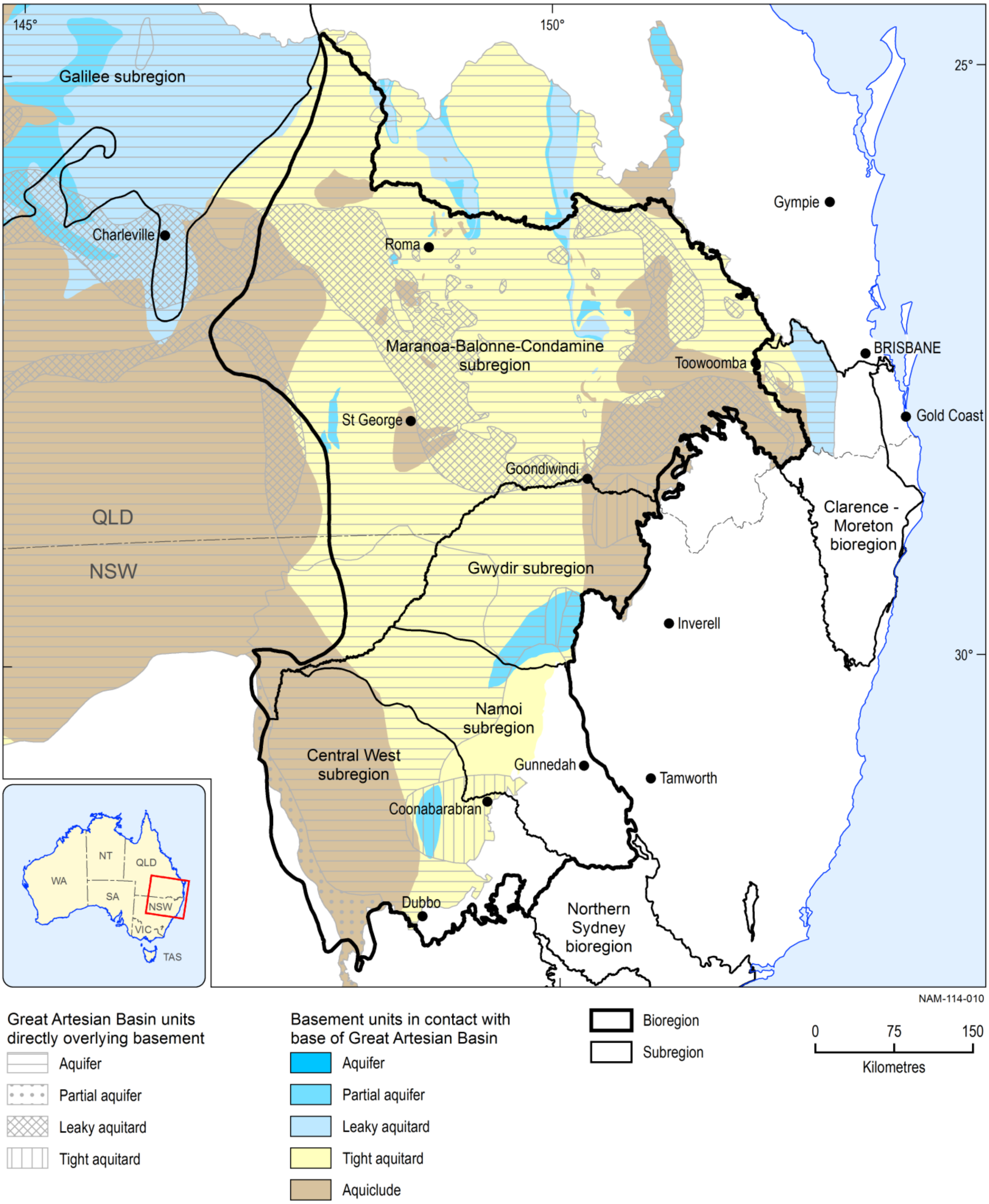

Figure 30 Potential hydraulic interconnection between the Great Artesian Basin and basement units in the Namoi subregion

Source data: derived from data described in CSIRO (2012)

Many of the active and planned coal mines and CSG operations have completed site specific numerical groundwater models (e.g. RCA Australia, 2005; Golder Associates, 2010) which have predicted only small changes in water levels outside the targeted areas, indicating they assume limited connectivity in these locations.

Gunnedah Basin aquifers

The degree of connectivity between the alluvium, GAB and Gunnedah Basin aquifers is a key component for determining any impacts on water resources within the subregion due to coal mining or CSG extraction. However, information and data on connectivity are very limited and represent a significant knowledge gap. Comprehensively defining the connection between different geological basins and the role of large-scale development on groundwater in the Namoi subregion would require closing some of the following knowledge gaps:

- Quantifying the hydraulic connection between the shallow alluvial aquifers, the GAB and underlying geological basins. While potential 'windows' of connectivity between basins and between surface and groundwater have been identified, the rates of groundwater exchange remain unknown.
- The controlling mechanisms for vertical leakage (cross-formational flow) for the multiple layers of aquifers and aquitards present in the Namoi subregion. Understanding these mechanisms is critical for determining the effect of depressurisation proposed for CSG development in the region.
- The hydraulic properties of aquitards and response to changes in groundwater pressure within adjacent aquifers. Where several layers of aquifers and aquitards are present, pressure changes caused by groundwater extraction will propagate at various rates in various directions, depending on the physical properties unique to each aquifer and aquitard layer (CSIRO, 2012).

1.1.4.3 Groundwater regulation and management

The wider Namoi catchment has been divided into 12 groundwater management units (GMUs), as defined by the NSW state government in accordance with the Murray–Darling Basin Plan for regulation and management purposes. Eight of the 12 GMUs occur in the Namoi subregion (Figure 31).

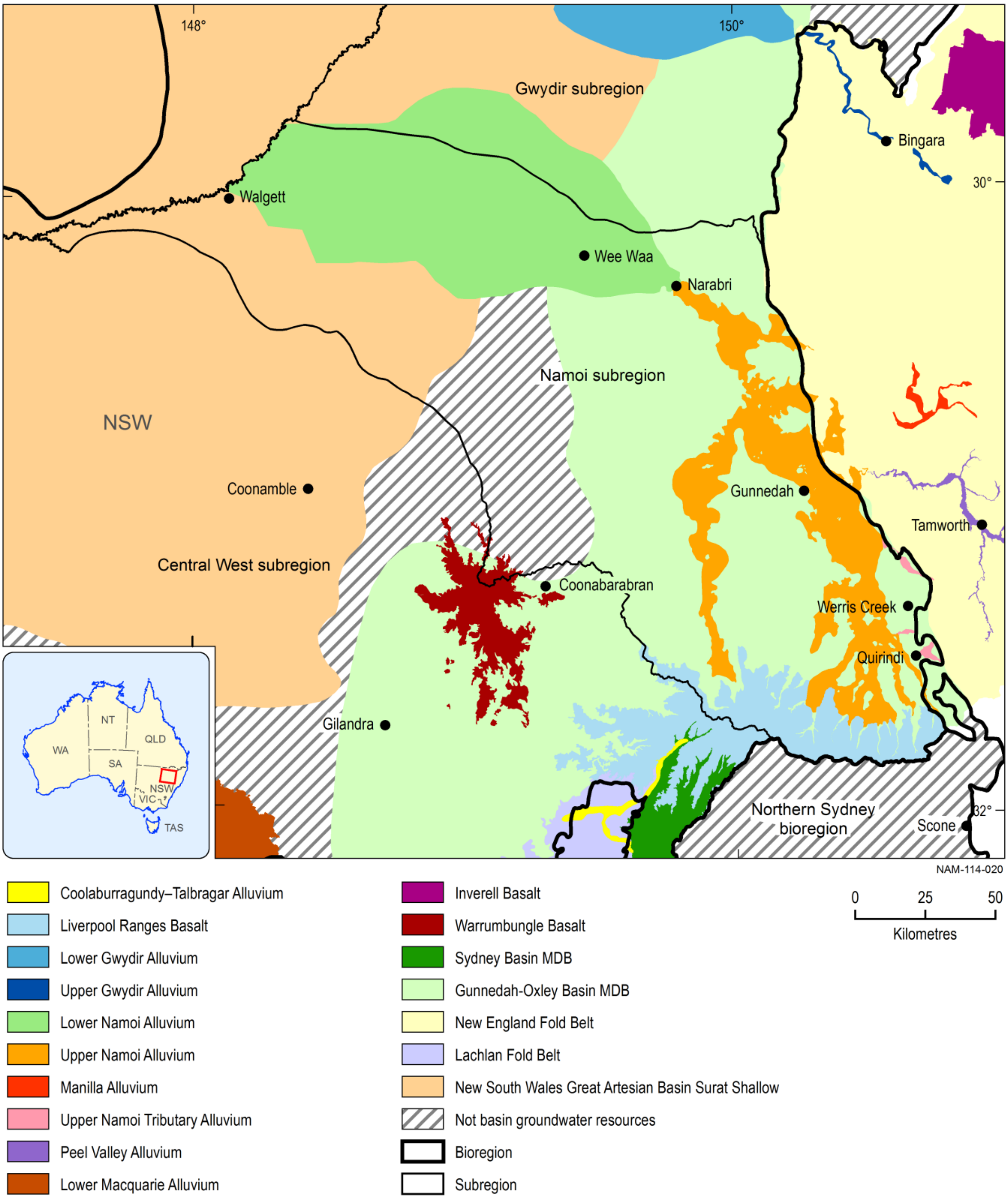

Figure 31 Groundwater management units in the Namoi subregion

The units are based on geology and groundwater and surface water catchment divides (SWS, 2011) and are categorised as alluvial, fractured rock or porous rock groundwater management areas, as described in Table 8.

Table 8 Groundwater Management Units in the Namoi subregion

Alluvial GMUs	Fractured rock GMUs	Porous rock GMU
Upper Namoi Alluvium	Liverpool Range Basalt	Great Artesian Basin
Lower Namoi Alluvium		Gunnedah Basin
Great Artesian Basin Alluvium		Oxley Basin
Miscellaneous alluvium of the Barwon Region		

For the purposes of water management in NSW, the Upper and Lower Namoi Alluvium GMUs are referred to as the Upper and Lower Namoi Groundwater Sources, respectively. These groundwater sources include all water in the unconsolidated alluvium sediments. Both of these are managed under a water sharing plan that commenced in 2006 (Green et al., 2011). The Water Sharing Plans are legal documents and set out the recharge, environmental water provisions, extraction requirements, share components and extraction limits for the groundwater sources (Green et al., 2011).

The Lower Namoi Groundwater Source extends approximately 160 km west from Narrabri and covers an area of approximately 7630 km^2. The alluvium is up to 120 m deep and some bores are very high yielding (Green et al., 2011). The water sharing plan for the Lower Namoi estimates average annual recharge of 86,000 ML/year and requires the annual extraction limit to be reduced from approximately 105,000 ML in 2006–07 to 86,000 ML in 2015. This extraction limit includes 21,010 ML of supplementary water Access Licences. After the 2014-2015 water year there will be no groundwater available under Supplementary Water Access Licenses (NSW Department of Infrastructure, Planning and Natural Resources 2006; NSW Office of Water 2013).

The Upper Namoi Groundwater Source extends about 175 km south from Narrabri and includes the unconsolidated sediments associated with the Namoi River and its tributaries (including Mooki River and Coxs Creek) upstream of Narrabri. It covers an area of 3800 km^2, and is divided into 12 separate groundwater zones based on hydrogeological features.

The Upper Namoi water sharing plan reduces entitlement from 301,000 to 122,000 ML by the 2016–2017 water year (July–June). There are approximately 1100 production bores in the Upper Namoi groundwater source, all of which are metered and have usage recorded at regular intervals (two to six readings per year) (Barrett, 2012).The Upper Namoi has a large volume of carryover held in accounts, hence the volume of water available for use exceeds annual plan extraction limits.

Groundwater in the GAB is covered by the NSW Great Artesian Basin Groundwater water sharing plan and the NSW Great Artesian Basin Shallow Groundwater plan. According to the NSW Department of Water and Energy (DPI, 2009), GAB sequences in the western part of the Namoi subregion form part of the Southern Recharge Groundwater Source and the Surat Basin Groundwater Source, as defined in the NSW Great Artesian Basin Groundwater Sources Water Sharing Plan. The Surat Groundwater Source underlies the subregion west of Narrabri and the Southern Recharge Water Source underlies the middle of the catchment around Narrabri (Green et al., 2011).

The remaining GMUs not included in the above plans are covered by macro water sharing plans based on aquifer type (e.g. alluvial, fractured rock or porous rock GMUs). These plans apply where there is less intensive water use.

1.1.4.4 Current and historical groundwater use

Groundwater resources in the Namoi are the most intensively developed in NSW and the subregion has one of the highest levels of groundwater extraction within the MDB (CSIRO, 2007). There are over 18,000 bores in the Namoi catchment which are licensed to provide over 343,000 ML of groundwater entitlement per year. Aquifer licences cover a variety of purposes including irrigation, industrial, stock and domestic water.

Over-allocation of the alluvial aquifers in the past has led to the Namoi being included in the Achieving Sustainable Groundwater Entitlements program; a program to reduce allocation in key inland catchments in NSW. The program is being implemented through the water sharing plans in the region as discussed above, and by 2016 will result in a reduction of the groundwater allocation in the Upper Namoi groundwater source of almost 60% (179,800 ML/year) and in the Lower Namoi groundwater source of 50% (86,200 ML/year) (MDBA, 2012).

Figure 32 below shows annual groundwater usage in the Lower Namoi from 1991–92 to 2007–08 with predicted water use based on the annual extraction limit set by the water sharing plan. Groundwater use in the Lower Namoi groundwater source has fluctuated significantly since 1991, ranging from approximately 45,000 ML in 1998–99 to 165,000 ML in 1994–95, usually in response to rainfall variability and the associated variability in surface water and groundwater use. In the Lower Namoi a combined total of 228,999 ML was pumped in the two seasons 2006–07 and 2007–08. Groundwater use was high in these years due to the low availability of surface water as a result of the Millennium drought. Groundwater use between 2008–09 and 2012–13 has been considerably lower than the early 2000s, ranging from approximately 30 to 80 GL. This is likely to be a result of in the introduction of the water sharing plan, limiting the amount of water irrigators can extract, and higher rainfall resulting in greater availability of surface water and reduced additional water requirements for irrigation.

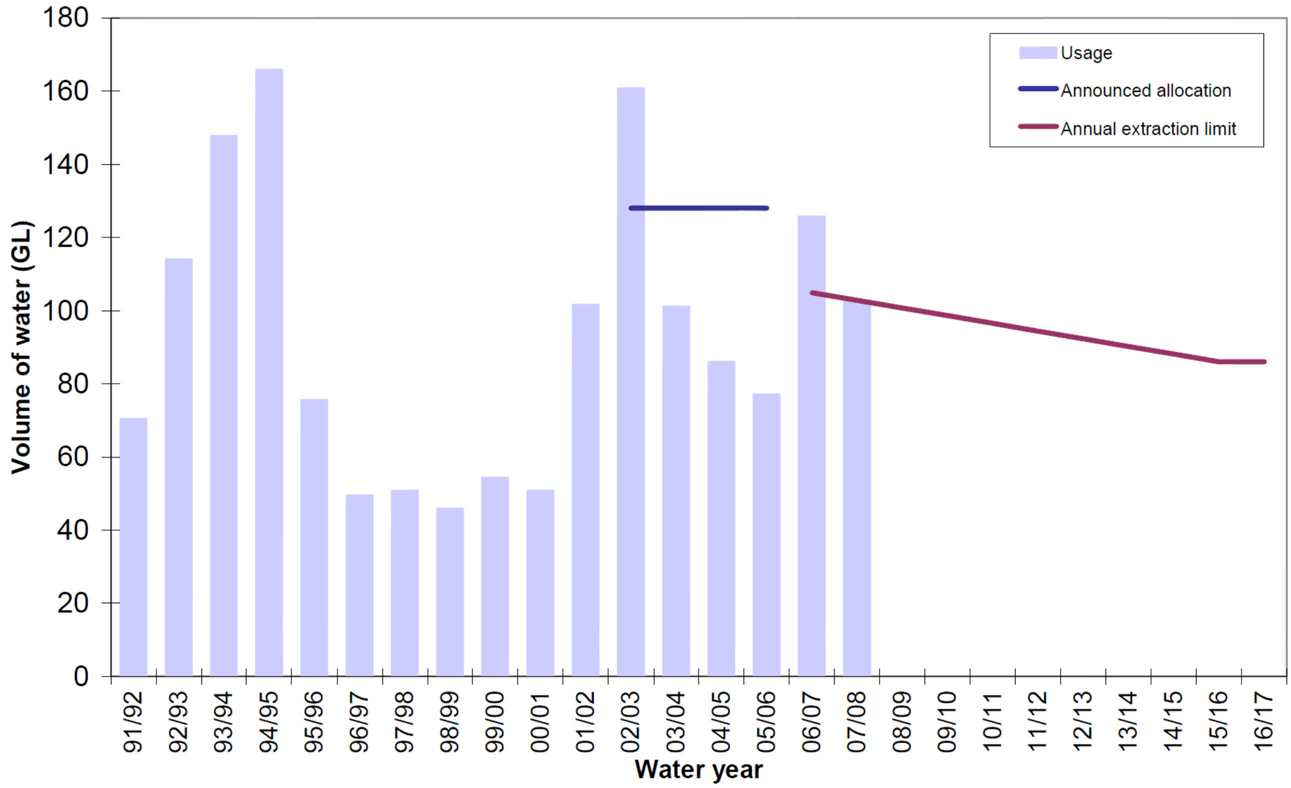

Figure 32 Lower Namoi groundwater usage since 1991–92

Source: Figure 3 in Smithson (2009).This figure is not covered by a Creative Commons Attribution. It has been reproduced with permission from NSW Department of Primary Industries.

There are approximately 1100 production bores in the Upper Namoi groundwater source, all of which are metered with usage recorded two to six times a year (Barrett, 2010). A comparison of annual groundwater usage since 1997–98 against the estimated average annual recharge for all zones in the Upper Namoi groundwater source is presented in Figure 33. Groundwater use in the Upper Namoi has varied significantly, ranging from approximately 55,000 ML in 2010–11 to 147,000 ML in 2001–02. Similar to the Lower Namoi, this variability has been driven by the rainfall pattern and associated availability of surface water, and the introduction of the water sharing plan. Usage across the Upper Namoi groundwater source has generally been well below the estimated average annual recharge since 2007–08.

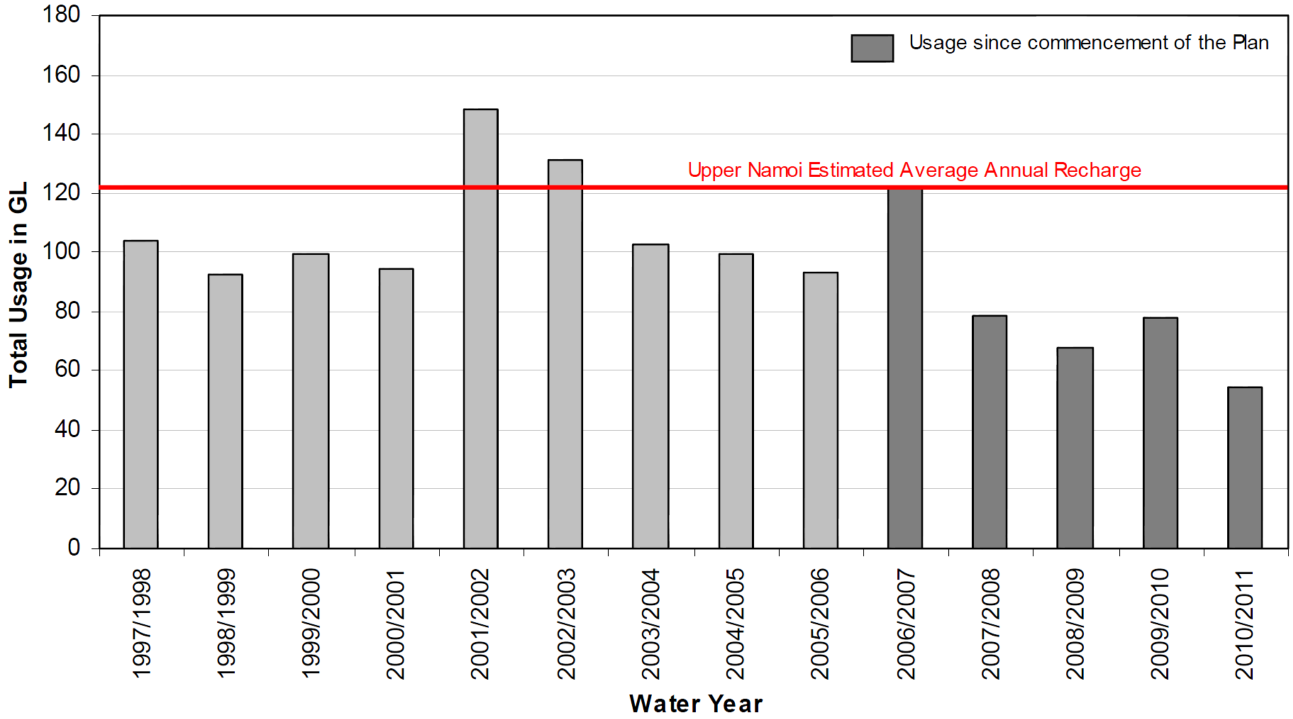

Figure 33 Total groundwater use in the Upper Namoi groundwater source 1997–98 to 2010–11

Source: Figure 4 in Barrett (2012)

A comparison of annual groundwater usage against the water sharing plan's extraction limits for the groundwater source of the Upper Namoi is provided in Table 9 (see Figure 34 for zone locations). Usage in Upper Namoi Zones 2, 3 and 5 was close to or greater than the plan extraction limit for 2006–07. However since the first year of the plan, both the water available for extraction and the annual usage in these zones have been declining. Since the plan began, the three-year average usage for all the zones in the Upper Namoi has been well below the extraction limits, attributed to a combination of wetter climatic conditions and greater availability of surface water, and the introduction of the water sharing plan.

Table 9 Comparison of annual groundwater usage against the water sharing plan extraction limits for zones in the Upper Namoi groundwater source (in ML)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9	Zone 10	Zone 11	Zone 12	Total
EXTLIM	2,100	7,200	17,300	25,700	16,000	14,000	3,700	16,000	11,400	4,500	2,200	2,000	122,100
2006–2007													
EXTLIM plus SWAL Access plus 5%	4,009	13,186	25,787	39,874	19,648	14,700	3,892	21,499	11,970	4,725	2,326	2,914	164,530
Usage	2,238	12,218	28,068	30,654	19,697	1,952	2,678	19,028	3,258	0	988	1,266	122,045
% of Usage per WSP Extraction Limit	56%	93%	109%	77%	100%	13%	69%	89%	27%	0%	42%	44%	
2007–2008													
EXTLIM plus SWAL Access plus 5%	4,009	12,561	24,940	38,442	19,648	14,700	3,892	20,977	11,970	4,725	2,326	2,914	161,104
Usage	1,530	10,635	10,008	23,455	16,438	1,023	946	11,495	1,911	0	467	573	78,481
% of Usage per WSP Extraction Limit	38%	85%	40%	61%	84%	7%	24%	55%	16%	0%	20%	20%	
2008–2009													
EXTLIM plus SWAL Access plus 5%	3,792	11,935	24,094	37,010	19,648	14,700	3,892	20,455	11,970	4,725	2,326	2,914	157,461
Usage	1,260	10,314	9,501	20,291	12,428	676	941	9,043	2,141	17	641	432	67,685
% of Usage per WSP Extraction Limit	33%	86%	39%	55%	63%	5%	24%	44%	18%	0%	28%	15%	
2009–2010													
EXTLIM plus SWAL Access plus 5%	3,576	11,310	23,247	35,578	19,648	14,700	3,892	19,933	11,970	4,725	2,326	2,914	153,819
Usage	1,425	6,560	17,809	19,623	16,542	1,132	698	11,628	1,449	0	591	628	78,085
% of Usage per WSP Extraction Limit	40%	58%	77%	55%	84%	8%	18%	58%	12%	0%	25%	22%	

EXTLIM – Extraction limit
SWAL – Supplementary water access licences
WSP – Water sharing plan
Source data: Table 3 in Barrett (2010)

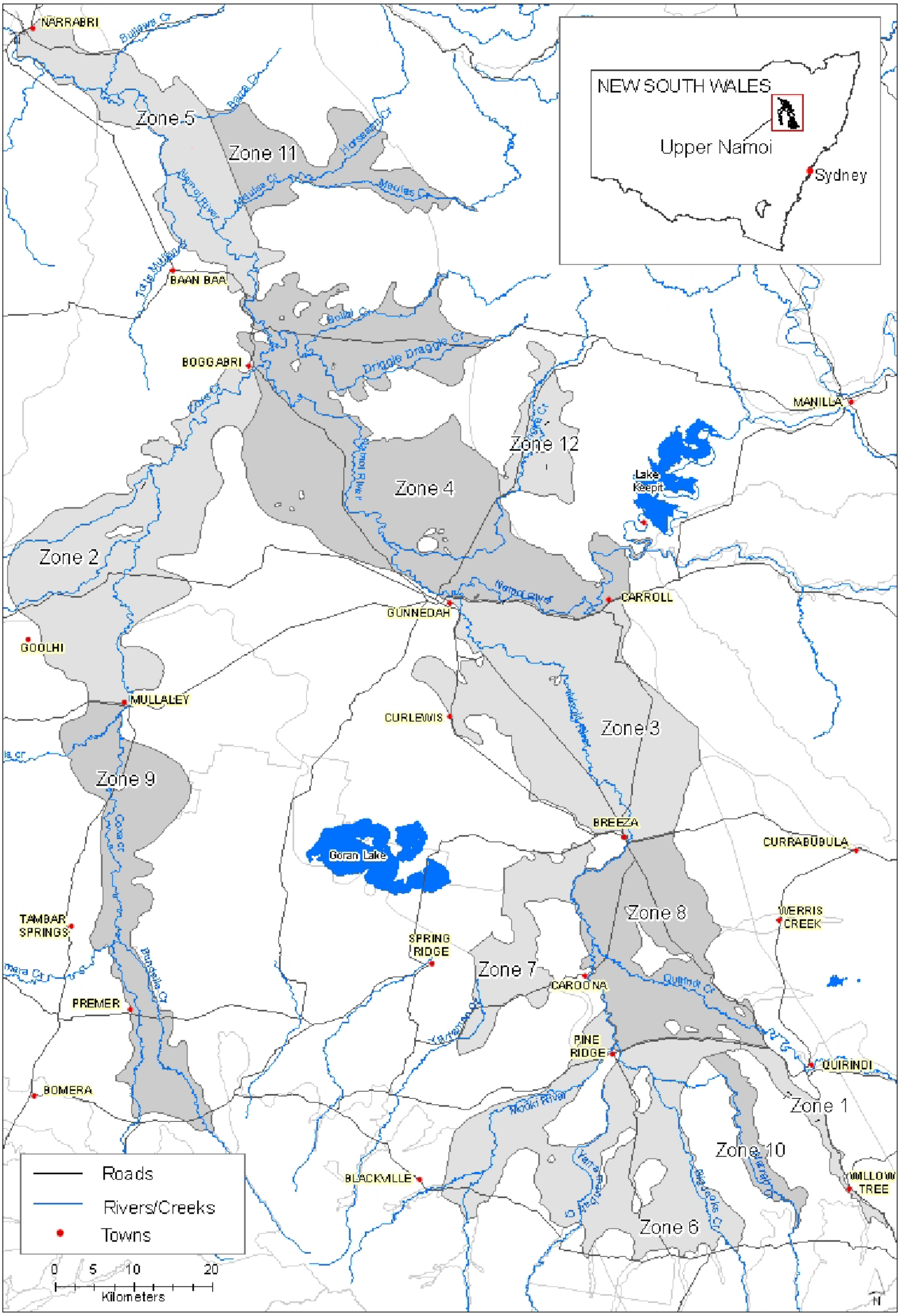

Figure 34 Upper Namoi groundwater source zones

Source: NSW Department of Environment, Climate Change and Water (Barrett, 2010)

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1.1.5 Surface water hydrology and water quality

Summary

The Namoi subregion lies within the Namoi river basin. The Namoi river basin is based around the Namoi, Peel and Manilla rivers. It is bounded by the Great Dividing Range in the east, the Liverpool and Warrumbungle ranges in the south and the Nandewar Range and Mount Kaputar in the north.

The main surface water resource of the Namoi subregion is the Namoi River. The average annual rainfall in the Namoi river basin varies from more than 1100 mm/year east of the subregion to about 600 mm/year near Gunnedah to less than 500 mm/year west of Walgett. The average Class A pan evaporation increases from less than 1200 mm/year east of Tamworth, to about 1600 mm/year near Gunnedah, and about 2100 mm/year west of Walgett. There are three large dams and a few small dams that supply water to agricultural, domestic and municipal users in the Namoi river basin. The major tributaries of the Namoi River are the Peel River, Manilla River, McDonalds River, Mooki River, Coxs Creek, Pian Creek (anabranch), Gunidgera Creek (anabranch), Bohena Creek and Baradine Creek. Lake Goran is the largest inland surface water body in the subregion. It is shallow and occupies up to 82 km^2 when full, but evaporates completely during dry periods.

There are approximately 68 streamflow gauging stations with continuous flow measurements in the Namoi river basin. The average annual flow in the Namoi River at Gunnedah between 1900 and 2011 was 669 GL. Two of the largest annual flows, 3305 and 3871 GL, were experienced in 1955 and 1956 respectively. The 1956 flood also resulted in the largest inundation area in the basin.

An example surface water balance for the Namoi river basin shows that only about 6% of the total inflow was used under general licence in 2011–12 (Figure 35). However, the average diversion for years from 2005–06 to 2011–12 was 21.8%. The ten-year Water Sharing Plan imposes long-term annual extraction limits on surface water resources from major tributaries in the Namoi river basin, ensuring that approximately 73% of long-term yearly flows are protected for environmental health. The sustainable diversion limit under the Murray–Darling Basin Plan requires that the long-term average surface water diversion limit be reduced from the current water sharing plan limits of 508 GL/year (Namoi SDL resource unit baseline diversion limit includes the Peel river basin water sharing plan). This will be reduced by 10 GL/year to meet local environmental targets set by the Basin Plan (for more details see Section 1.1.5.2).

The water quality of the Namoi River and its tributaries is generally acceptable for irrigation and other farming activities. However, the water quantity and quality along with physical conditions of rivers and creeks of the Namoi subregion have been affected by anthropogenic activities. Lack of flow data for lower order streams and limitation of water quality modelling for many mining by-products are significant knowledge and data gaps.

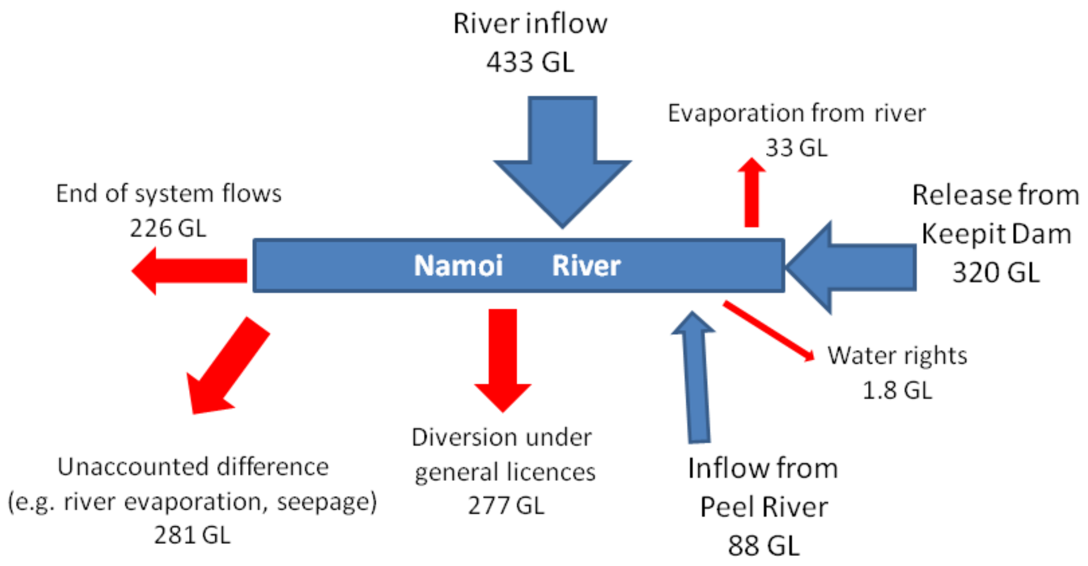

Figure 35 Surface water balance of the Lower Namoi River for 2012–13

1.1.5.1 Surface water hydrology and water quality

The Namoi river basin drains an area of 42,000 km^2 flowing from east to west from its headwaters in the Great Dividing Range (CSIRO, 2007; MDBA, 2012). Further details on the Namoi river basin and the Namoi subregion, including what proportion of the river basin is inside the subregion, are given in Section 1.1.2 Geography. The main surface water resource of the Namoi subregion is the Namoi River. Its approximate mean flow upstream of Walgett (station ID 419091) between 1999 and 2009 was 269.4 GL/year. The major tributaries of the river upstream of Narrabri are Peel, Manilla, McDonalds and Mooki rivers and Coxs Creek (Figure 36). The tributaries downstream of Narrabri are Pian (anabranch), Gunidgera (anabranch), and Baradine and Bohena creeks (Green et al., 2011). There are numerous other minor tributaries. See Figure 37 for a detailed stream network.

The lowland floodplain downstream of Narrabri supports small lagoons, wetlands and anabranches and is important for a range of aquatic habitats (MDBA, 2012; SKM, 2011). Detailed information about water resources including water supply, rainfall, climate and other features of the area is given in Green et al. (2011) and CSIRO (2007).

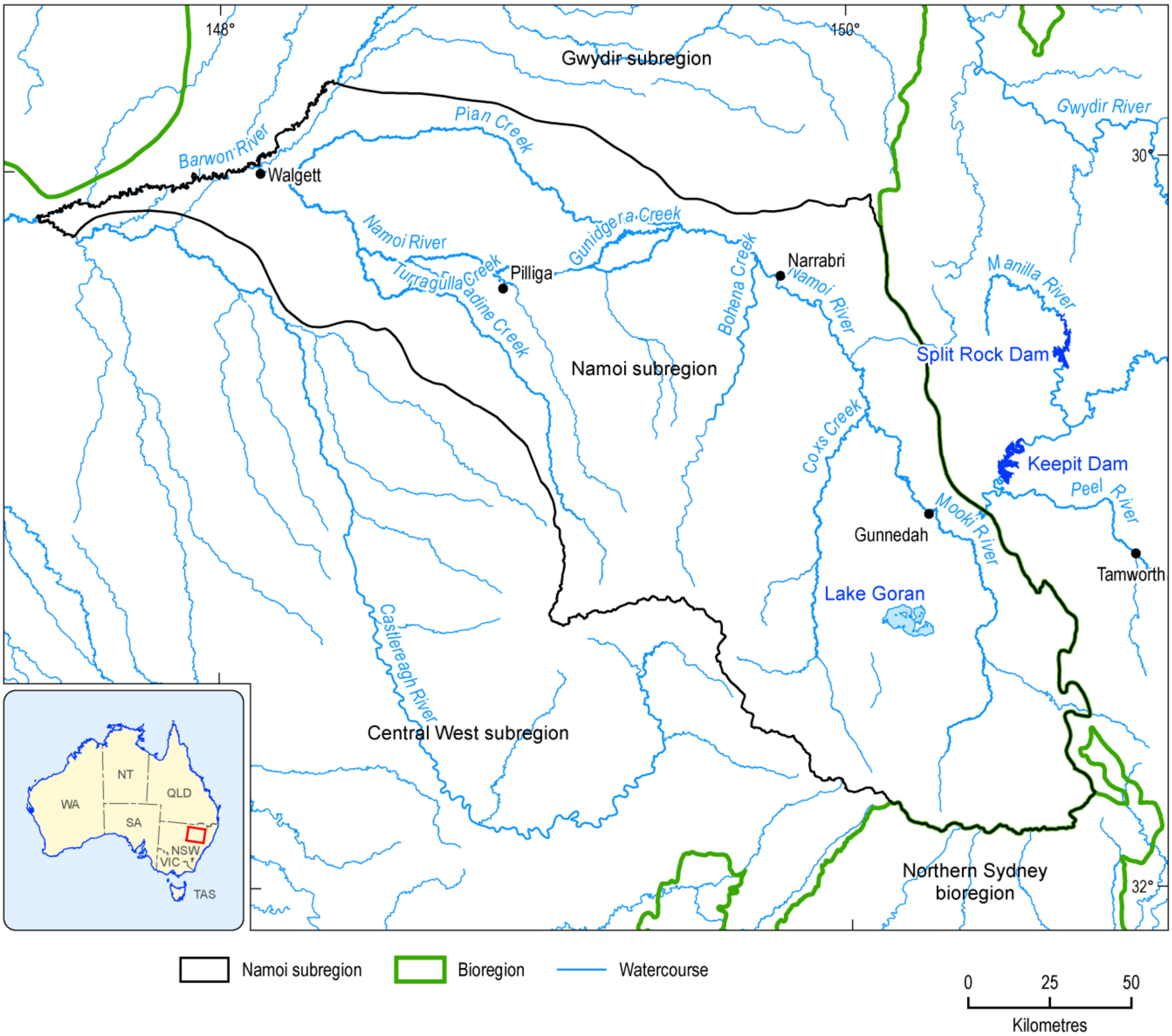

Figure 36 Tributaries of the Namoi River, major dams and town centres

1.1.5.1.1 Catchments and subcatchments

Peel catchment (4669 km^2)

The Peel catchment is the main catchment in the eastern part of the basin. The Peel River contributes an average annual flow of 280 GL to the Namoi River, flowing from the western side of the Great Dividing Range to its confluence with the Namoi River downstream of Keepit Dam. A number of tributaries contribute to the Peel River including Duncans, Dungowan, Goonoo Goonoo, Moore, Timbumburi, Tangarratta and Attunga creeks, and Cockburn River. Some of the tributaries (e.g. the Cockburn River, Goonoo Goonoo Creek and Dungowan Creek) are perennial for most years. The Peel River is regulated by Chaffey Dam (NSW Office of Water, 2010). Although Peel River contributes to the Namoi subregion flow, the entire Peel catchment lies outside of the subregion.

Mooki catchment (3870 km^2)

The Mooki catchment is located in the south-east of the Namoi river basin. Its major tributaries are the Phillips, Warrah and Quirindi creeks. Lake Goran, the largest natural water body in the Namoi subregion, occupies 82 km^2 when full and is located in the Mooki River catchment (Zhang et al., 1997; Green et al., 2011). Water sharing plans to regulate water use in the Mooki River and its tributaries have been developed (NSW Office of Water, 2012).

Coxs catchment (4040 km^2 at Boggabri)

Coxs catchment, located in the southern part of the Namoi subregion, covers about 9.5% of the area of the Namoi river basin. Its main tributaries include Washpen, Dunnadie, Kerringle, Quia and Cobblar creeks. The catchment contains good agricultural soils and is a highly productive area for agriculture (NCMA, 2011).

Manilla catchment (1795 km^2 at Upper Manilla)

This catchment is located in the north-east of the Namoi river basin and is outside of the Namoi subregion. The tributaries joining the Manilla River are Ironbark, Barraba, Connors and Borah creeks, and the Macdonald River. The Split Rock Dam is on the Manilla River.

Baradine catchment (4883 km^2)

This catchment lies in the western part of the Namoi subregion. The Baradine Creek flows in a north-westerly direction originating from hills west of the Newell Highway, to its confluence with the Namoi River east of Walgett (Figure 36). Baradine Creek is an ephemeral creek with an average annual flow at Kienbri No. 2 gauging station (with a catchment area of 1000 km^2) of about 14 GL (Green et al., 2011).

Bohena Creek catchment (830 km^2)

The Bohena catchment is located south of Narrabri and is drained by Bohena, Cowallah and Bibblewindi Creeks. Less than 160 km^2 of this catchment, mainly in the northern part, is cleared and is used for sheep and cattle grazing. The rest of the catchment is used for biodiversity conservation (NCMA, 2013).

1.1.5.1.2 Surface drainage networks and associated features

The Namoi river basin is well drained by the Namoi River and its tributaries for most areas east of Pilliga (Figure 37). The surface drainage network extends through different landscape units ranging from uplands with steep terrain to flat low lying alluvial plains (Lampert and Short, 2004). The area surrounding Lake Goran is internally drained and has a low density of natural surface water drainage. About two-thirds of the Namoi river basin is relatively flat. The low lying alluvial flood plains of the Namoi subregion are less densely drained than the areas in the east of the basin, possibly due to the flat terrain.

Irrigated agriculture covers approximately 5.3% of the Namoi subregion (see Table 3), the majority of which is located downstream of Narrabri (CSIRO, 2007). Therefore the surface water drainage network resulting from irrigation channels is not as extensive as the natural drainage network.

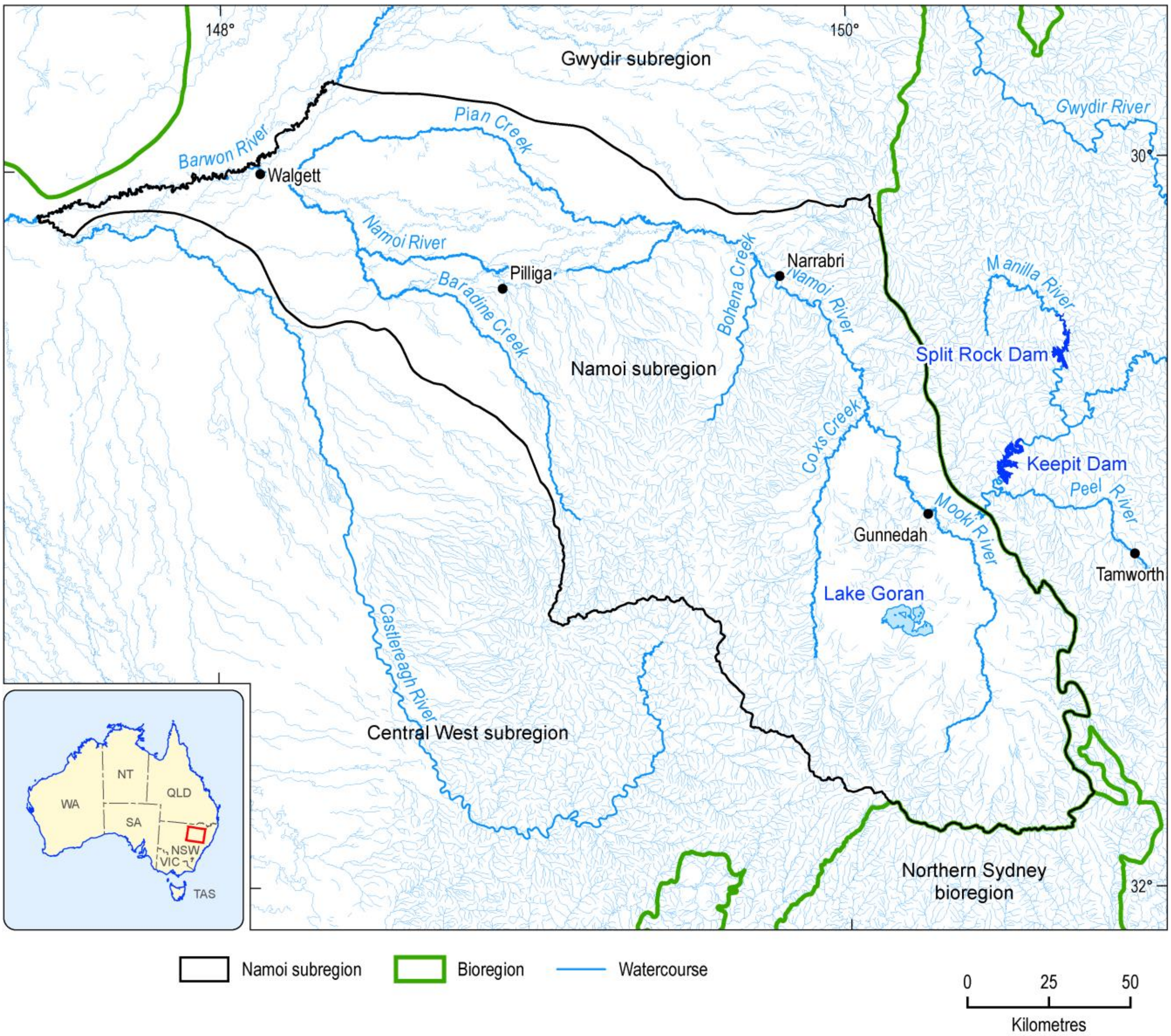

Figure 37 Natural surface water drainage network

1.1.5.1.3 Surface water infrastructure

There is much surface water infrastructure such as major and minor public water storage dams, farm dams, culverts, causeways, fords, streamflow gauging weirs, bed control structures, floodgates and bridges in the Namoi river basin including open-channel conveyance systems for irrigation. For a fish passage barrier study, a total of 496 instream structures were assessed by the NSW DPI (2006b). The three major dams in the Namoi river basin lie outside of the Namoi subregion. They are:

5. Keepit Dam (426 GL, on the Namoi River)
6. Chaffey Dam (62 GL, on the Peel River)
7. Split Rock Dam (397 GL, on the Manilla River).

These dams supply water to irrigators, the main water users in the basin, although Keepit Dam was originally built for flood mitigation. A smaller dam (Dungowan Dam, 6 GL, on Dungowan Creek in the Peel River system, not shown) supplies water to the city of Tamworth – the largest urban centre in the basin. Additionally, there are farm dams with an estimated capacity of 160 GL spread across the Namoi river basin (Basin Plan – item 11 Schedule 3).

Namoi River and its tributaries have more than 75 weirs on them owned by the State Water and different shire and regional councils (NSW DPI, 2006a, 2006b). Some of the main weirs are the Mollee, Gunidgera, Weeta, Namoi (downstream of Keepit Dam) and Walgett weirs. Most of these weirs are used for irrigation diversions. See NSW DPI (2006b) for further detail.

1.1.5.1.4 Streamflow volume and river flow metrics

There are about 116 streamflow gauging stations (many of which have been discontinued) of which sixty-eight have continuous flow monitoring gauges (NSW Office of Water, 2010). The mean daily flows at selected gauges, summarised in Table 10, show that streamflow record periods vary from nearly 30 years to more than 100 years. The Namoi River at Gunnedah (catchment area of 17,100 km^2) has the highest mean daily flow. The effect of weirs and other diversions on the Namoi River below Gunnedah is evident from the lower mean daily flow further downstream (e.g. Namoi River at Bugilbone).

The annual flow hydrograph of the Namoi River at Boggabri (Figure 38) and the plot of cumulative difference from the long-term annual mean of 773 GL (Figure 39) show mostly lower than long-term average flows during 1937 to 1948 and 2001 to 2009 (see Burrell and Ribbons (2006) for further interpretation of cumulative differences from the mean plots). From 1937 to 2012, 71% of yearly flow values have been less than long-term mean with 50% of the flow less than half the long-term mean. During this period, 13% of the flows are twice the long-term mean. This suggests annual flows in the Namoi River at Boggabri are characterised by mostly below average flow with periodic occurrence of very large flows.

Similar plots for the Namoi River at Gunnedah (upstream of Narrabri) show mostly lower flows than the long-term annual mean of 669 GL occurring during 1911 to 1949 and 1979 to 2011 (Figure 40 and Figure 41). For the past 33 years, flows have been above the long-term annual mean in only six years. Also, the river flow has continuously been below the long-term mean since 2001 (except in 2010) suggesting a drought of more than 10 years. These impacts on flow could be further affected by the Namoi Catchment Management Authority's (NCMA) ten-year Catchment Action Plan (2010–2020), which sets biodiversity targets aiming to achieve at least 30% and 70% woody vegetation cover in cleared and intact catchments respectively (NCMA, 2011).

Overall, Figure 38 to Figure 41 show the impacts of combined climate and land use changes and catchment development since the 1950s on Namoi River flows. A more detailed assessment is needed to ascertain the relative effect of each of these factors.

Table 10 Mean daily flow for selected gauging stations in the Namoi river basin

Gauging stations	Catchment Area (km2)	Mean daily flow (ML)	Period of record
Namoi River downstream of Keepit Dam	5,700	972	1924–2009
Namoi River at Gunnedah	17,100	1922	1891–2009
Narrabri Creek at Narrabri	25,120	1512	1891–2009
Namoi River downstream of Gunidgera Weir	28,500	1364	1976–2009
Namoi River at Bugilbone	31,100	1569	1951–2009
Manilla River at Upper Manilla	1,795	165	1941–2009
Macdonald River at Retreat	1,760	435	1965–2009
Peel River at Carroll Gap	4,670	766	1923–2009
Mooki River at Breeza	3,630	296	1957–2009
Coxs Creek at Boggabri	4,040	231	1965–2009
Baradine Creek at Kienbri 2	1,000	38	1981–2009
Pian Creek at Waminda	–	241	1972–2009
Gunidgera Creek downstream of regulator	–	323	1975–2009

Source: Green et al. (2011)

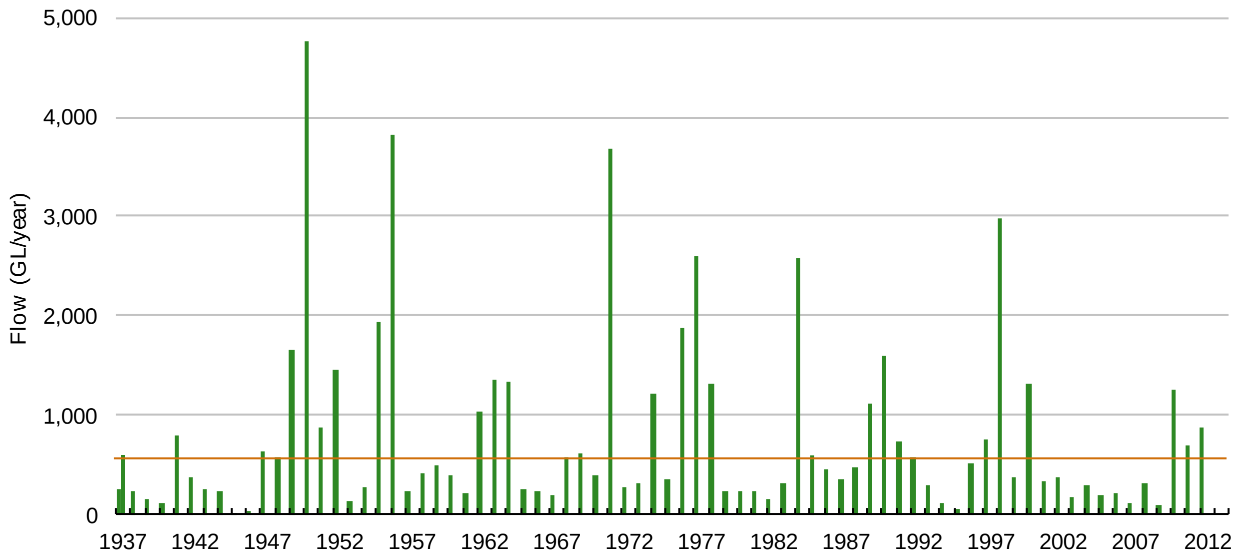

Figure 38 Annual flows in the Namoi River at Boggabri (419012)

Orange line shows the long-term mean (773 GL).

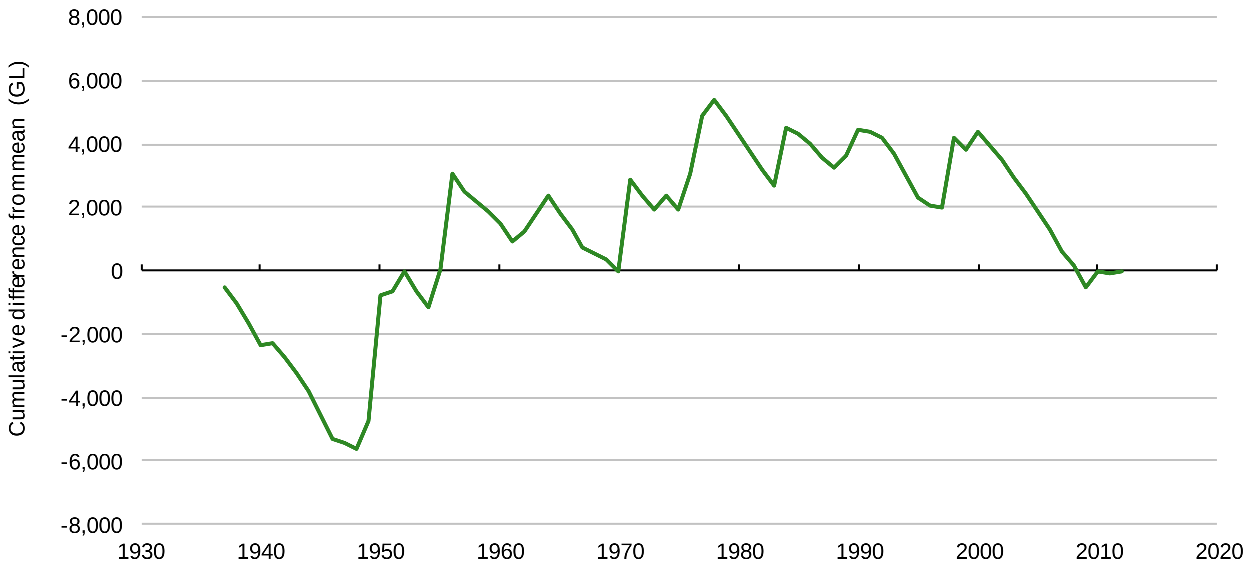

Figure 39 Cumulative differences from the long-term annual mean for the Namoi River at Boggabri

Source data: NSW Water Information (waterinfo.nsw.gov.au/)

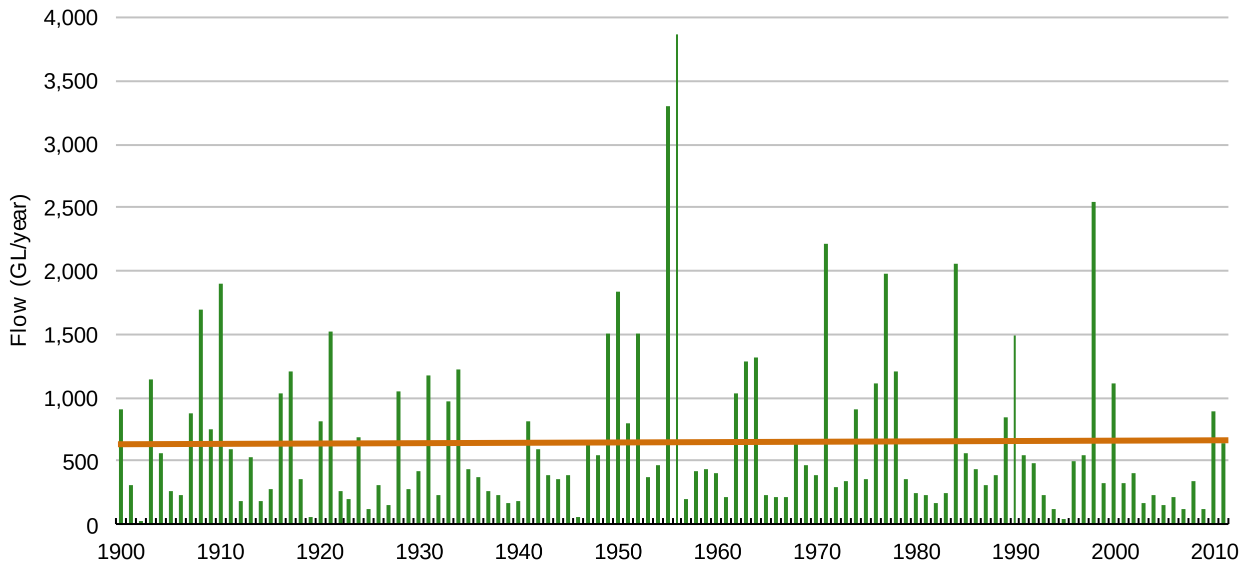

Figure 40 Annual flows in the Namoi River at Gunnedah (419001)

Orange line shows the long-term mean (669 GL).
Source data: Pinneena v 9.3

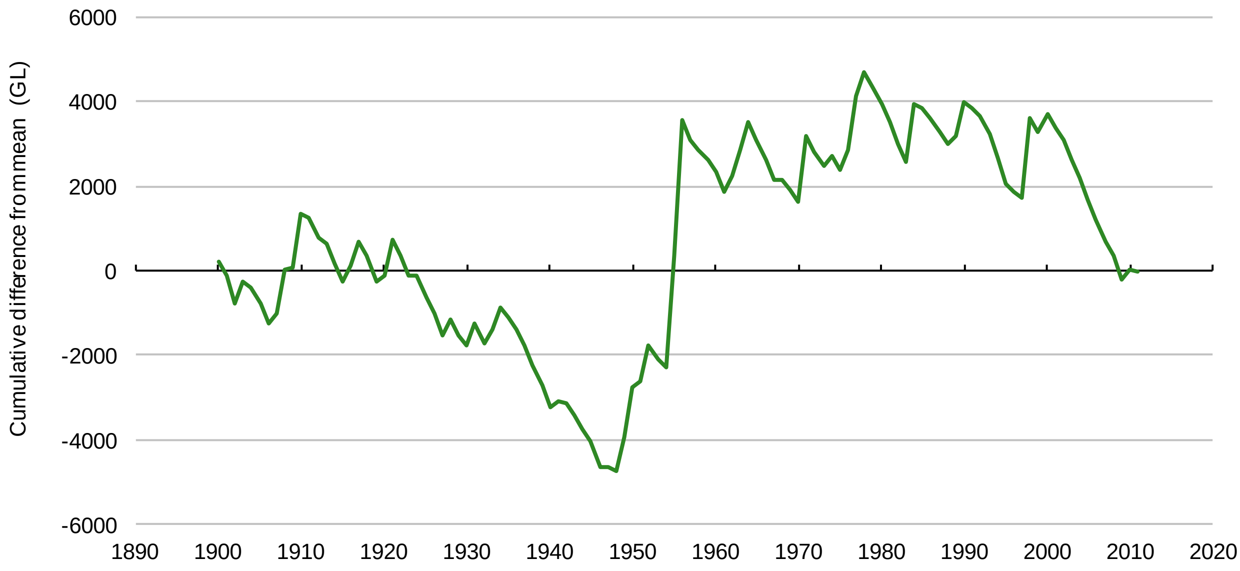

Figure 41 Cumulative difference from the long-term annual mean for the Namoi River at Gunnedah

1.1.5.1.5 Surface water storage data

Figure 42 shows the variations in annual volume of stored in the three major dams. The dam water storages generally reflect the annual rainfall pattern in the area (see Figure 45).

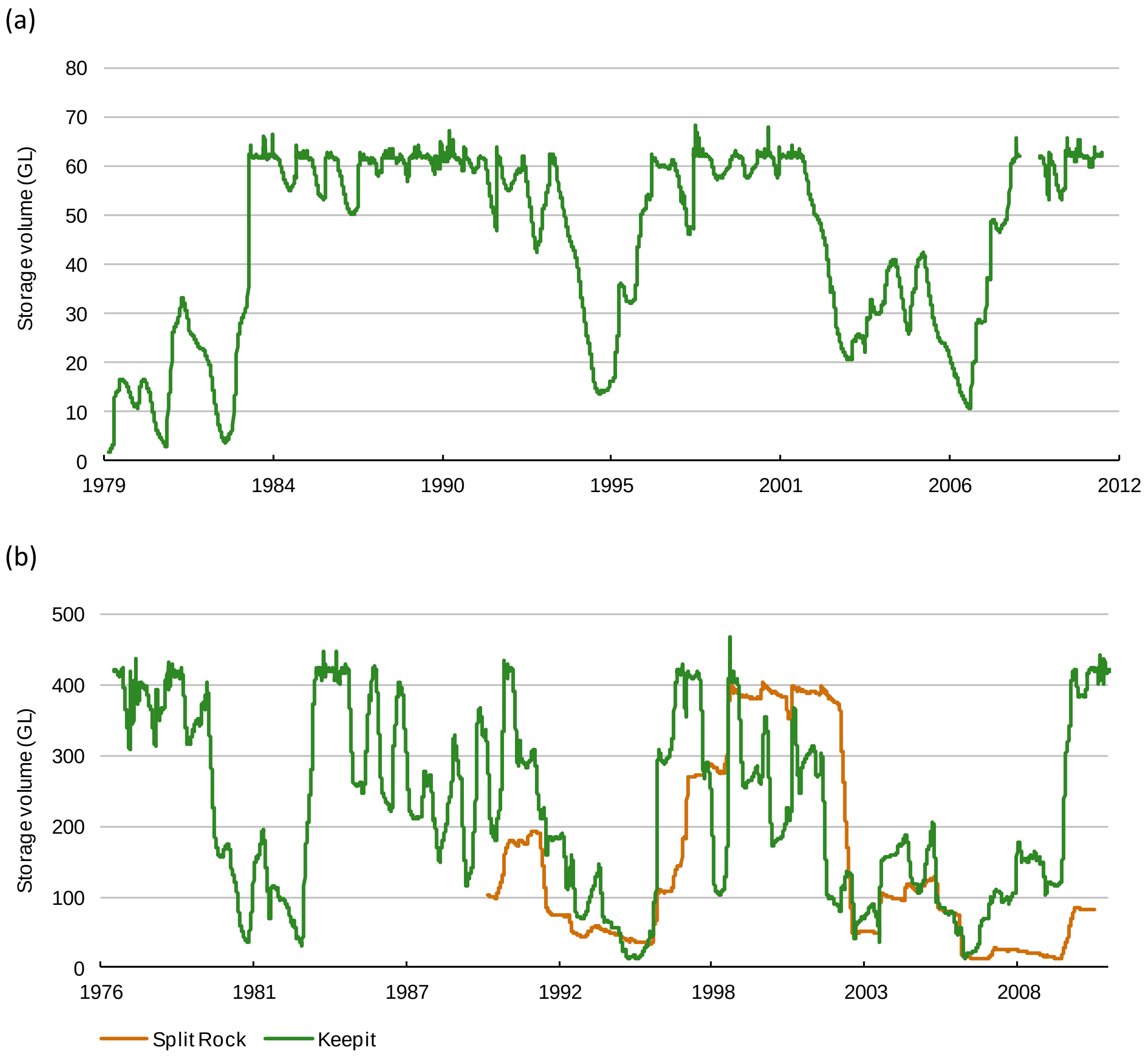

Figure 42 Water storages (a) Chaffey Dam and (b) Split Rock and Keepit dams in the Namoi river basin

Source data: Pinneena v.9 and NSW Waterinfo (2013)

1.1.5.1.6 Water quality

Basic water quality indicators such as electrical conductivity (EC), turbidity, total suspended solids, and nutrients were monitored on a monthly basis for the five-year Namoi Water Quality Project (NWQP) study, starting in July 2002 (Mawhinney, 2011). Residues of herbicides and insecticides were also measured. The study found that majority of sites had median electrical conductivity (EC) results that did not meet the ANZ Environmental and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australian and New Zealand (ARMCANZ) default trigger values for the protection of aquatic ecosystems of south-eastern Australia. Median total phosphorus and total nitrogen in excess of the ANZECC and ARMCANZ default trigger values in conjunction with low flows were also experienced. The study reports that despite not meeting the default trigger values of EC the water was still suitable for irrigation and although the heightened nutrients provided favourable conditions for the growth of toxic blue-green algae they did not eventuate in high volumes due to a lack of other causation factors (Mawhinney, 2011). The project findings are summarised here:

1. Electrical conductivity:
    a. Mooki River at Breeza and Ruvigne and upstream reaches of Coxs Creek showed the highest median electrical conductivity, ranging from around 1000 to 1300 µS/cm. For all other locations on the Namoi River downstream of Boggabri, including the Pian anabranch, median EC values were below 650 µS/cm which is a low salinity level for irrigation water (Mawhinney, 2011).
2. Total phosphorus:
    a. All sites in the Namoi river basin were found to have high enough total phosphorus concentration present to encourage algae growth. Although increased total phosphorus can encourage blooms of toxic blue-green algae, other factors such as water temperature, turbidity, and stagnant water pooling are also important factors in sustaining algal growth. A much higher concentration of total phosphorus (>0.2 mg/L) was found in the Mooki River at Ruvigne and in Coxs Creek at Boggabri. The alluvial soils in these two catchments are naturally high in phosphorus. These soils, when eroded, get into the river system and transport the associated phosphorus downstream (Mawhinney, 2011).
3. Total nitrogen:
    a. High concentrations of median total nitrogen (>1.5 mg/L) were found in the Mooki River at Ruvigne, in Coxs Creek at Boggabri and in Pian Creek at Waminda between July 2002 and June 2007 which were higher than in the 1990–2000 period for Mooki River and Coxs Creek. The 1990–2000 data for Pian Creek at Waminda are unavailable for comparison. The other sites had nitrogen levels similar to or lower than 1990 to 2000 historical data.
4. Turbidity and total suspended solids:
    a. The majority of suspended sediments in the Namoi River are derived from the Mooki River and Coxs Creek catchments and caused by gully and channel bank erosion (Caitcheon et al., 1999). These two catchments are the largest sources of suspended solids to the Namoi River.
    b. Generally, turbidity increases downstream in the Namoi River (Olley and Scott, 2002). The turbidity levels found during the NWQP at a majority of sites in the Namoi River compare well with levels from the previous ten years, indicating no significant change in turbidity over the years.
5. Herbicides:
    a. Residues of the herbicide Atrazine, used to control annual grasses and broad leaf weeds in summer crops, are still detected at sites in the Mooki and Coxs catchments. The detection rate and concentrations have fluctuated over time with low values observed during dry years.
6. Insecticides:
    a. There has been a rapid decline in the detection of insecticide (endosulfan) residues since 1998–99. See Mawhinney (2011) for further details.

1.1.5.1.7 Flooding history

Figure 43 shows the flooding extent of the largest flood event in the Namoi river basin in 1956, attributed to two wetter years due to the La Niña events of 1955 and 1956. These were the two strongest recorded La Niña events in Australia (Bureau of Meteorology, 2013). The annual total rainfalls for 1955 and 1956 were well above the annual long-term mean at several sites in the basin. For example, annual rainfalls in Narrabri for the two years were 872 and 850 mm respectively (cf. the long-term average of 649 mm/year). Although these are not among the highest rainfalls for the basin, residual effects of a wetter year in 1955, coupled with the above-average rainfall in 1956, most likely created the conditions that led to the 1956 flood (O'Gorman, 2010).

The Namoi river basin also experienced much wetter years in 1963, 1964, 1977, 1978, 1988, 1991, 1999, 2004 and 2010, however the flooding extents in these years were less than that in 1956. This could be due to the flood mitigation effects of the Keepit Dam (completed 1960), the Split Rock Dam (completed 1987) and the Chaffey Dam (completed 1979). The increased numbers of farm dams capturing runoff and other diversions due to growth in economic development in the basin since 1956 may also have moderating effects on floods in the basin (see e.g. Green et al., 2011; NCMA, 2011).

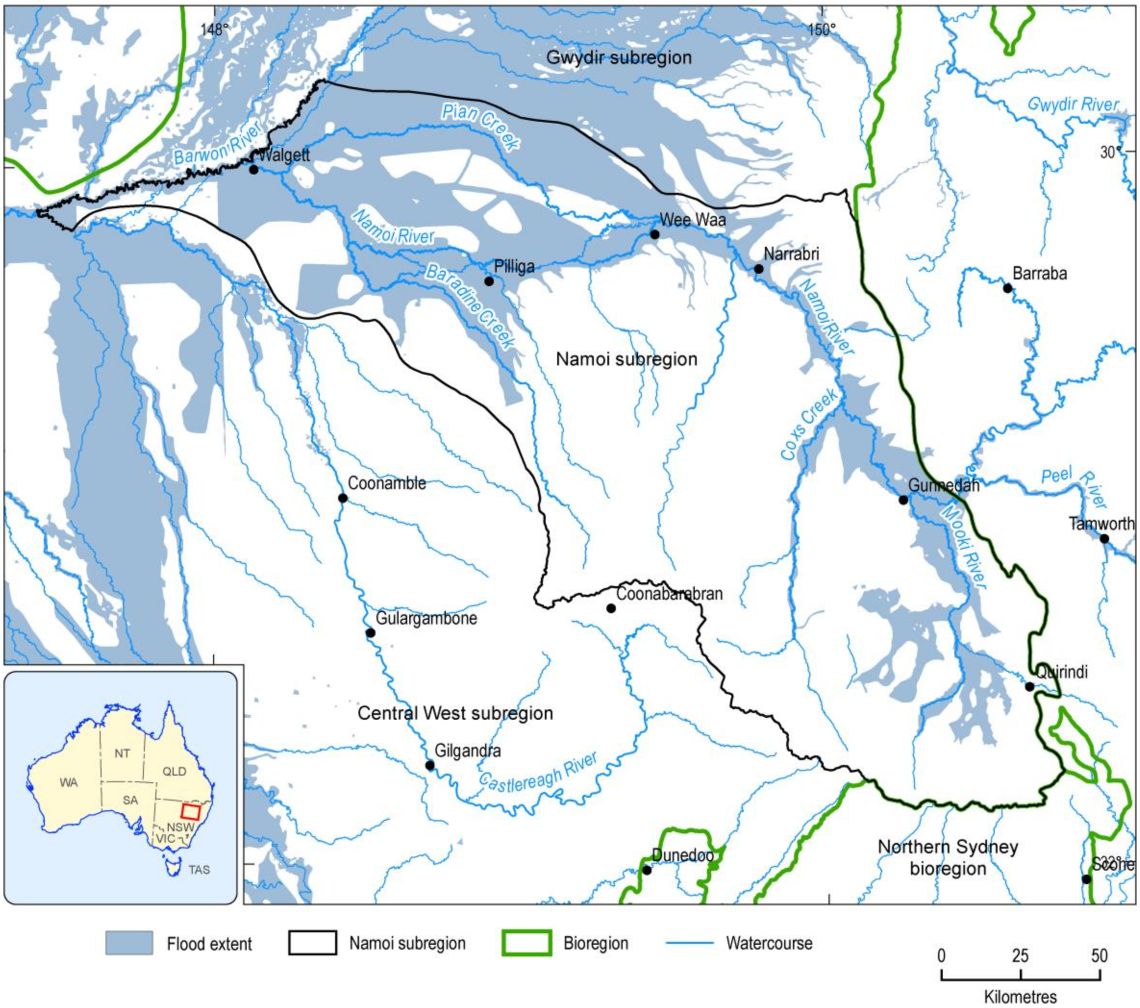

Figure 43 Extent of flooding in the Namoi river basin in 1956

Source data: data for Figure 43 were digitised by Laurie, Montgomerie and Pettit Pty Ltd on contract to the NSW Water Resources Commission from the Namoi Floodplain Atlas produced in 1979 using aerial photographs and from on-ground knowledge and Commission records.

1.1.5.2 Current water sector allocations

The water balance components of the Lower Namoi River (Figure 44), prepared by the NSW Office of Water, show that in 2012–13 about 33% of total inflow was diverted under access licences while 27% was used for environmental water purposes (end-of-system flow) (Burrell et al., 2014). These values can vary from year to year depending on whether it is an average, dry or wet year (Table 11). Compared to the other two years, 2010–11 and 2011–12 were wet years, with annual rainfall totals for both years well above the long-term average across the entire basin (Burrell et al., 2013). Higher proportions of total flow were diverted under general licences for the drier years of 2009–10 and 2012-2013 than for the wetter years of 2010–11 and 2011–12 (see Table 11).

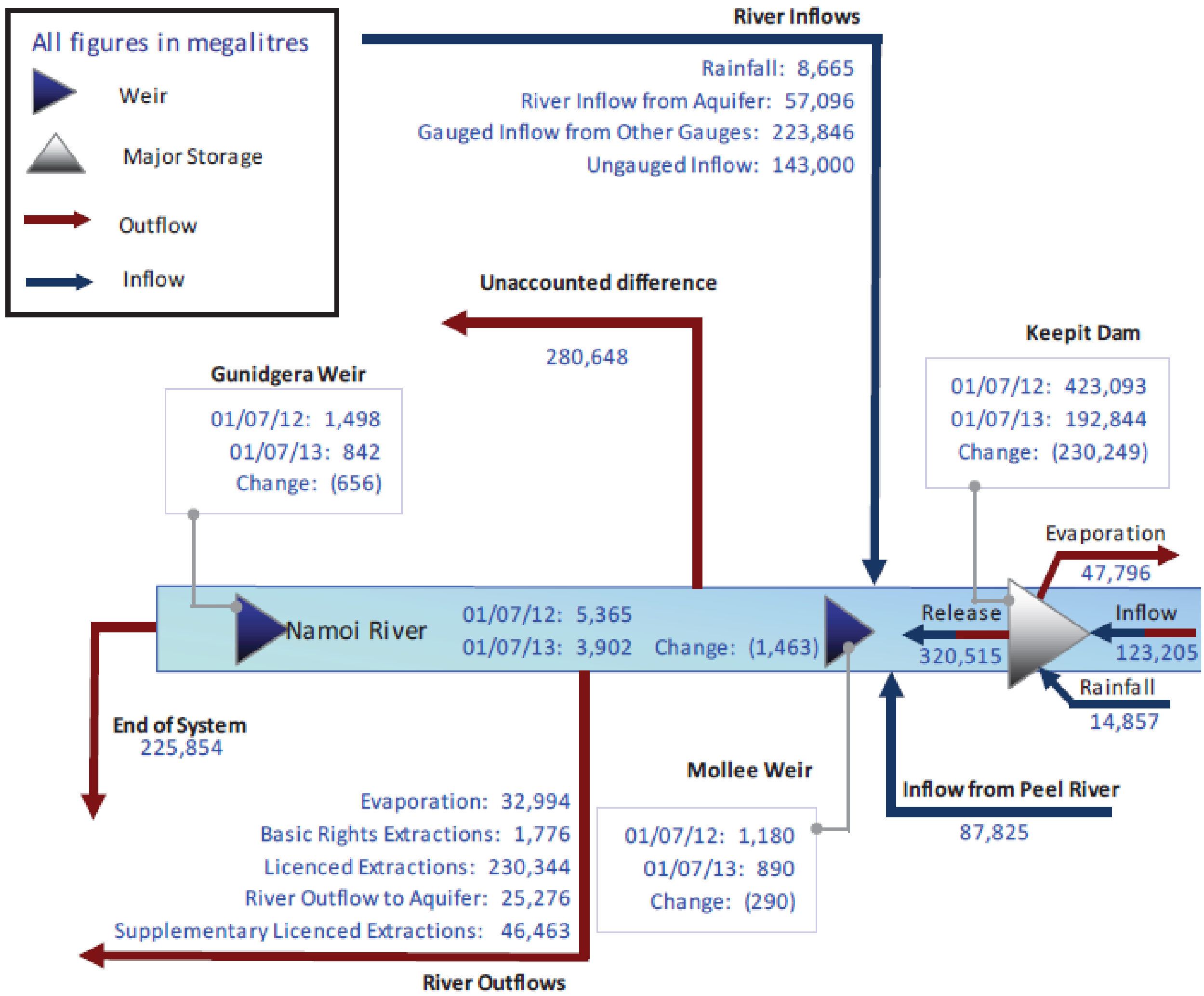

Figure 44 Lower Namoi River physical flows mass balance diagram for 2012–2013

Source: modified from 2012-13 Namoi Physical Flows Mass Balance Diagram, Burrell et al. (2014, p18)

Table 11 Main components of Lower Namoi River water balance from 2009–10 to 2012–13 showing different flow allocations from year to year

Year	Net water diverted under general licences (% of total flow)	End-of-system flow (% of total flow)	Total inflow (GL)
2009–10	16%	60%	440
2010–11	7.4%	80%	2005
2011–12	7.0%	45%	1829
2012-13	33	27%	841

Source data: Burrell et al. (2011a, 2011b, 2013, 2014)

1.1.5.2.1 Water Sharing Plan and restriction on surface water extractions

The ten-year Water Sharing Plan (WSP) (2004–2014) under the New South Wales *Water Management Act 2000* establishes long-term average annual extraction limits for Upper Namoi and Lower Namoi Regulated River Water Sources. The aim is to maintain or protect low flows for environmental purposes and to provide equitable access to users (DIPNR, 2004). The Upper Namoi Regulated River Water Source is the water between the banks of all rivers, from the dam wall of Split Rock Dam to the dam wall of Keepit Dam (NSW Office of Water, no date). The Lower Namoi Regulated River Water Source is the water between the banks of all rivers, from the dam wall of Keepit Dam to the junction of Namoi River and Barwon River at Walgett. The Upper Namoi and Lower Namoi Regulated River Water Sources do not include the Peel River.

The Water Sharing Plan for unregulated and alluvial water sources of the Namoi river basin started in October 2012. The plan comprises 22 water sources upstream and downstream of Keepit Dam (NSW Government, 2012).

Levels of extraction in the Namoi subregion are governed by WSP long-term extraction limits and the Murray–Darling Basin Cap. The WSP sets a long-term extraction limit of 238 GL/year from the regulated rivers in the Namoi river basin (excludes Peel catchment regulated river diversions under WSP (MDBA, 2011a). These limits were designed under the environmental water rule, which ensures that flows in the lower reaches of rivers are maintained to reflect natural flow patterns (DIPNR, 2004). All flows above the long-term extraction limit, which amount to approximately 73% of yearly flow in the river on a long-term average basis, are protected for the health of the environment. To protect end-of-system flows, minimum flows are to be maintained in the Namoi River at Walgett during the months of June (≥21 ML/d), July (≥24 ML/d) and August (≥17 ML/d) when water stored in Split Rock and Keepit dams is more than 120 GL (DIPNR, 2004; Barma Water Resources et al., 2012).

Diversion limits and the Basin Plan

The Murray–Darling Basin Authority estimates the surface water long-term average baseline diversion limit for the Namoi river basin (including Peel valley) to be 508 GL/year (MDBA, 2011b). This limit includes 265 GL/year from regulated and major unregulated rivers, and 78 GL/year from minor unregulated rivers (excluding basic rights). The limit on interception by run-off dams is set at 165 GL/year (including 5 GL/year of interception by commercial plantations).

The environmental water requirements of the region have been estimated at between 998 and 1090 GL/year, which is between 31 and 123 GL/year greater than currently available for the environment (MDBA, 2011b). Twenty key environmental assets including Lake Goran, the Namoi and Peel rivers and 17 other rivers and creeks that are potentially dependent on environmental water (see Section 1.1.7 Ecology) have been identified in the region (MDBA, 2010, p 63). Therefore the sustainable diversion limit under the Murray–Darling Basin Plan requires that the surface water long-term average diversion limit be reduced from 508 GL/year by 10 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 Namoi SDL resource unit.

1.1.5.2.2 Rainfall and evapotranspiration

Climate is discussed in Section 1.1.2 Geography. The mean annual rainfall in the Namoi river basin varies from more than 1100 mm/year east of the subregion to about 600 mm/year near Gunnedah to less than 500 mm/year west of Walgett (Figure 10). Rainfall is seasonal with the highest monthly rainfall at Gunnedah being in summer and the lowest during the months of April to September. The average Class A pan evaporation increases from less than 1200 mm/year east of Tamworth, to about 1600 mm/year near Gunnedah, and about 2100 mm/year west of Walgett (Green et al., 2011).

There have been more occurrences of annual rainfalls that are above the long-term mean (622 mm) in Gunnedah since the late 1940s (Figure 45). In comparison, annual rainfall in Narrabri is reasonably uniform with spells of a few years below the long-term mean (653 mm) (Figure 46).

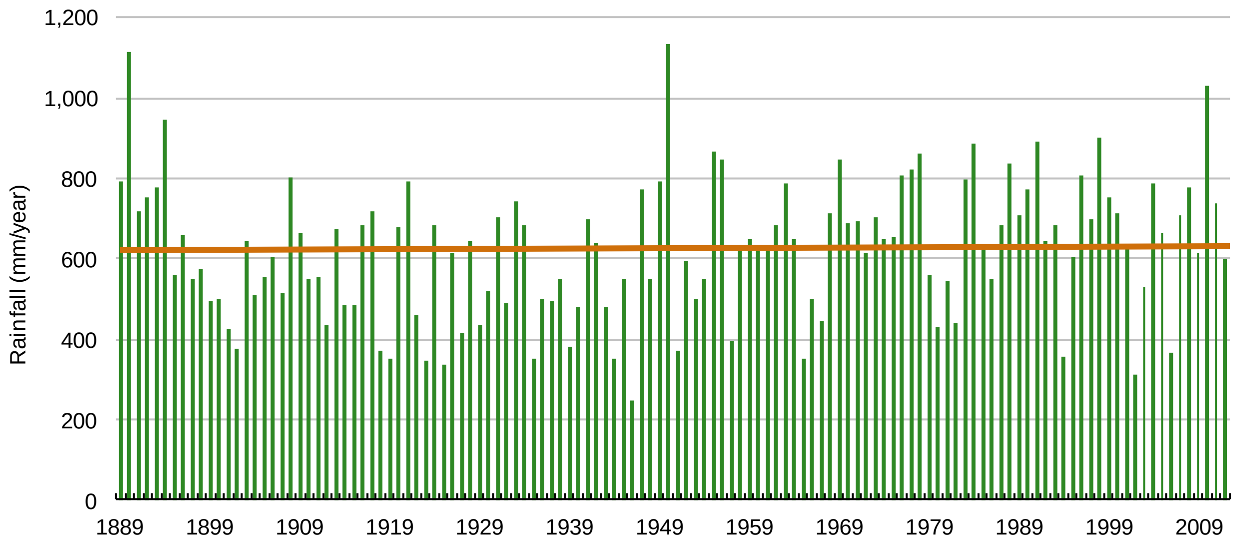

Figure 45 Total annual rainfall at Gunnedah

Orange line shows the long-term annual mean (622 mm)

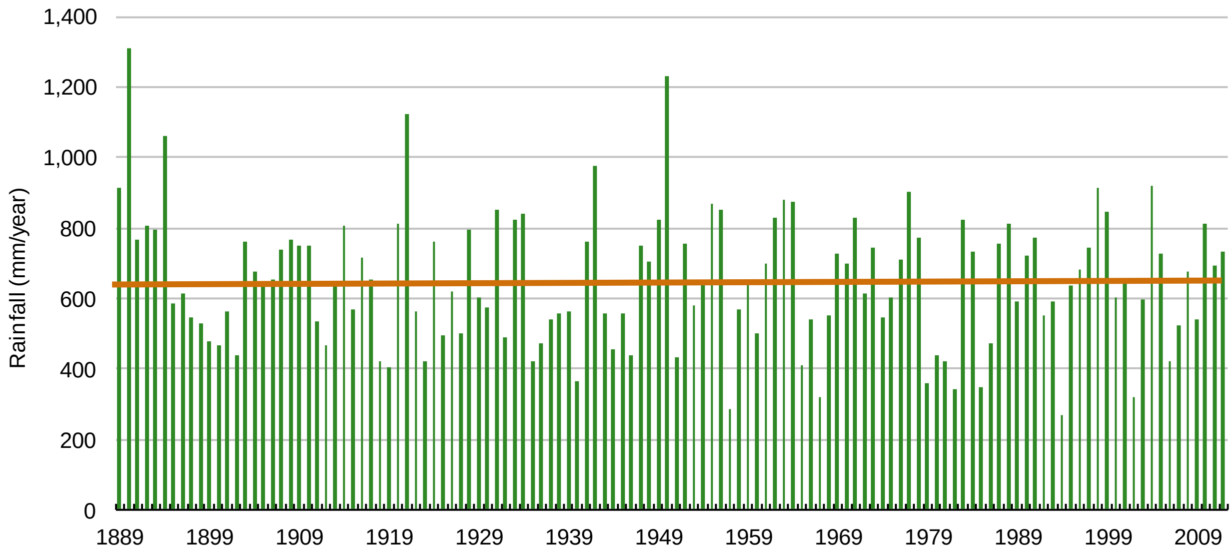

Figure 46 Total annual rainfall at Narrabri

Orange line shows the long-term annual mean (651 mm)

1.1.5.2.3 Water allocations, licences, extractions and use

Water is allocated to different sectors of water users as per their entitlements. The main sectors are agricultural (including stock water use), domestic, municipal and industrial. The major water users in the Namoi river basin are general security licence holders with a total annual entitlement of 255 GL/year, of which about 10 GL/year is located on the Upper Namoi between Split Rock and Keepit dams (Table 12). The Namoi river basin uses 2.6% of the surface water diverted for irrigation in the Murray–Darling Basin (CSIRO, 2007). Regulated river water and groundwater usage is metered, while usage from unregulated water including floodplain harvesting is currently not metered (Barma Water Resources et al., 2012).

Rapid irrigation development has occurred in the Namoi river basin since the early 1960s, using up to 112,400 ha of land to grow crops (CSIRO, 2007). Major irrigation diversions are made from Keepit, Split Rock and Chaffey dams and Mollee and Gunidgera weirs. The total allocation of water share issued for the regulated Namoi River is nearly 378.9 GL (Table 12) (Green et al., 2011).

High security entitlement of 8 GL exists for town water supply needs for Manilla and Walgett. Stock and domestic replenishment flow rules are also in operation for the Pian Creek system ensuring up to 14 GL in any water year is set aside for delivery downstream of Dundee Weir (see NSW Office of Water (2010) for entitlements relating to other water sources, and further details). When available water in a river cannot be stored, supplementary water access is declared for users to divert water from the river in accordance with their entitlements. A total licensed supplementary cap in the Lower Namoi of 110 GL/year has been implemented.

Table 12 Namoi regulated river share components as at 30 June 2010

Access licence category	Total share component (ML)	
	Upper Namoi	Lower Namoi
Domestic and stock	76	1,745
Domestic and stock (stock)	5	257
Domestic and stock (domestic)	11	17
Local water utility	150	2,271
General security	9,724	245,222
High security	80	3,418
High security (research)		486
Supplementary		115,469
Total	10,046	368,885

Source data: Green et al. (2011)

1.1.5.2.4 Human impacts on the surface water system

Rivers and creeks in the Namoi subregion have been impacted by water regulation and other anthropogenic causes including agriculture and livestock farming. Typically the flow frequency and quantity (e.g. peak discharge and low flows) have been affected (Thoms et al., 1999). Human activities have also affected the physical condition and water quality of the waterways. For example, the Mooki River, Coxs Creek, lower parts of the Namoi River, and the Cockburn River are in ‘very poor physical condition’ as a result of poor land use and farming practices including extraction of sand and gravel. Varying degrees of higher nutrient concentrations along the Namoi River are caused by effluent disposal from sewage treatment plants and unsewered villages (Thoms et al., 1999, page 22).

Increased instances of sediments in creek water due to unrestricted access of livestock have been found. Increased sediment gives rise to increased turbidity and load of other pollutants (e.g. heavy metal, pesticide and nutrients) that are attached to the sediments (Thoms et al., 1999). As described in Section 1.1.5.1.6, residues of pesticides, herbicides and other agricultural chemicals resulting from farming activities, have been detected in rivers and creeks in the Namoi river basin.

1.1.5.2.5 Impacts of climate change on water availability

Yearly flows in the Namoi River at different locations have declined due to frequent below average rainfall since 2000 (see Section 1.1.5.1.4). This is also reflected in the lower volume of water storages in the three major dams (Figure 42) suggesting that water availability in Namoi river basin has been directly affected by climate change and variability.

Impact of future climate

CSIRO (2007) found that future mean annual runoff in the basin is likely to decrease by 6%. The effects of future extreme climate due to a high global warming scenario range from a 31 to 39% reduction in mean annual runoff. The impacts of a low global warming scenario range from a 10% reduction to a 10% increase in mean annual runoff. These effects were assessed for current development pathways in the basin. Effects of climate change with future developments on runoff, end-of-system flow and other aspects of water availability are also described in CSIRO (2007). A study undertaken by the NSW Office of Water also provides estimates of future climate on water availability across NSW (including the Namoi river basin) (Vaze et al., 2008; Vaze and Teng, 2011) suggesting a change in mean annual runoff of ±20% depending on the 15 global circulation models used.

1.1.5.2.6 Impacts of land cover change on water availability

Land use change has a considerable impact on water availability. Although the effects of land use (and other related changes, e.g. water use change) can be seen in the flow reduction in Namoi River at Narrabri (Figure 38 and Figure 39), no study seems to quantify the impacts of these changes on water availability.

Along with land cover change due to agricultural activities, the detention and/or interception of surface runoff in pits of open-cut mines also affects water availability, which affects downstream surface water availability (Schlumberger Water Services, 2012).

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1.1.6 Surface water – groundwater interactions

Summary

Assessments of surface water – groundwater connectivity undertaken in the Namoi subregion indicate that creeks and rivers are generally losing systems with the exception of reaches of the Namoi River between Boggabri and Narrabri which are predominantly gaining systems. The lower reaches of the Namoi River form a losing system and Pian Creek is classified as maximum losing. Maules Creek, in the north-east of the subregion, is also in connection with groundwater and is variably gaining and losing. Rivers and creeks to the east of the Hunter-Mooki Fault System (and therefore in the Namoi river basin but outside the Namoi subregion) tend to be gaining.

1.1.6.1 Connectivity mapping

Assessments of surface water – groundwater connectivity were undertaken as part of the Murray-Darling Basin Sustainable Yields Project (Parsons et al., 2008). The connectivity mapping was a snapshot in time of fluxes to or from the major rivers in the Namoi river basin. The assessment used data from June 2006, a time that represented a historically low flow period in the Namoi River (CSIRO, 2007). Results of the connectivity mapping are shown in Figure 47 and include the Peel catchment to the east of the Hunter-Mooki Fault System, outside the Namoi subregion. The creeks and rivers reaches in the highland areas of the Peel and Manilla rivers are predominantly gaining. The river changes from gaining to losing and back to gaining in the upper to mid Namoi reaches, including the Mooki River and Coxs Creek. The lower reaches of the Namoi River form a losing system and Pian Creek are classified by CSIRO (2007) as maximum losing (i.e. the water table is separated from the stream by an unsaturated zone. The stream itself is classified as a medium losing stream based on flux). This result is generally consistent with previous hydrogeological interpretations of the region (Ivkovic, 2006).

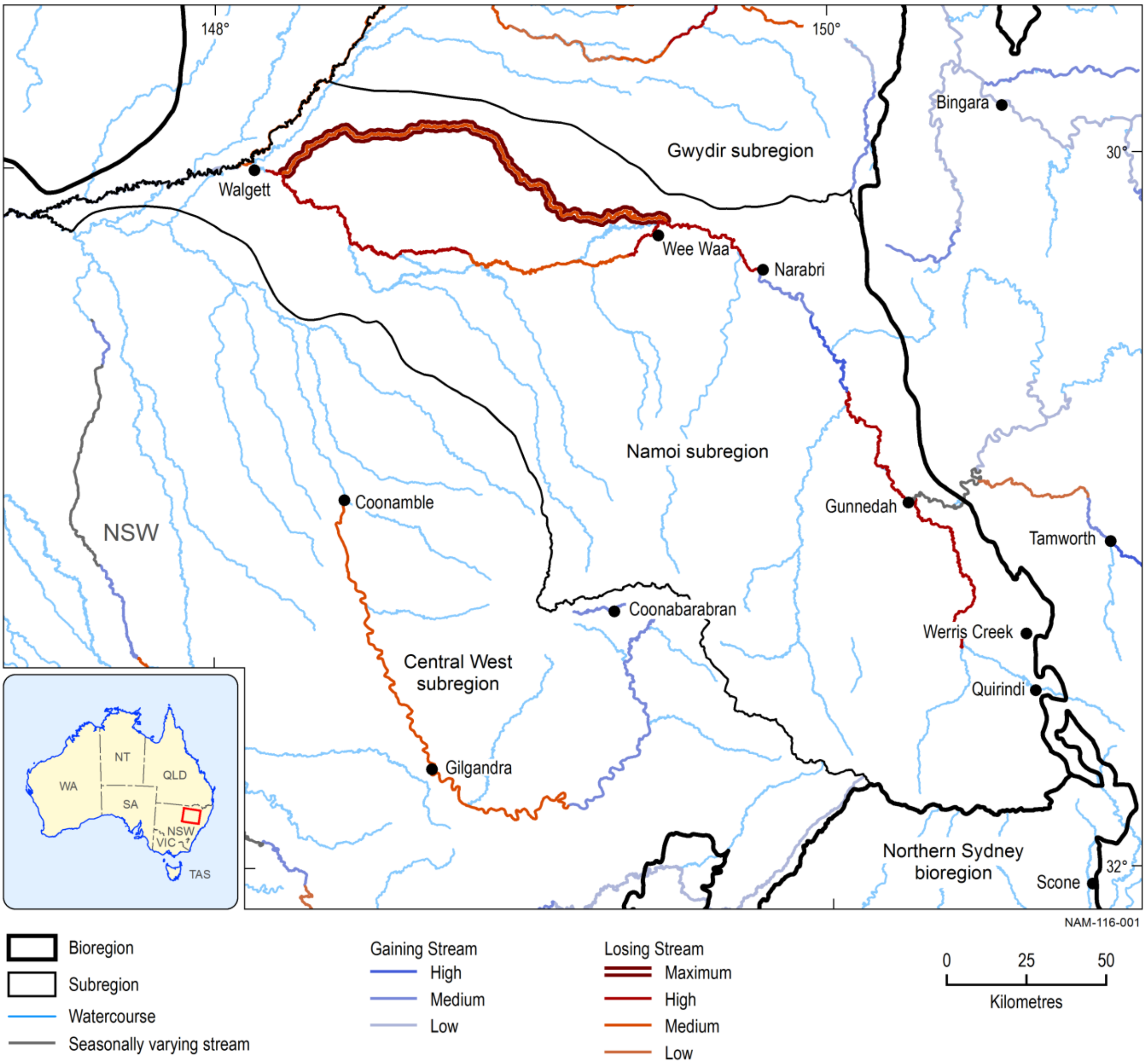

Figure 47 Surface water – groundwater connectivity in the Namoi river basin

Gaining rivers in upper reaches, varied conditions for mid-Namoi and losing for lower Namoi
Source data: derived from data presented in CSIRO (2007)

The river fluxes observed are roughly related to the depth of unconsolidated sediments. The sediments in the upper Namoi are relatively shallow and the watertable is shallow, resulting in generally gaining river conditions. As the depth of sediments increases on the upper alluvial plain and the groundwater levels fall relative to the river, losing conditions persist. Passing through the bedrock constriction at Gins Leap Gap, the depth of sediments decreases and there is a rise in the watertable causing a reduction in river losses or a change to gaining conditions. The depth of sediments increases rapidly as the river opens out onto the lower Namoi plain, and river losses are generally medium to high with the river and groundwater often disconnected (CSIRO, 2007).

Lamontagne et al. (2011) investigated surface water and groundwater connectivity at two locations along the Namoi River downstream of Narrabri, as part of the Interconnection of Surface and Groundwater Systems – River Losses from Losing/Disconnected Stream project (Brownbill et al., 2011). The project aimed to determine whether losing-connected or losing-disconnected conditions were present at two locations (Old Mollee and Yarral East), using a range of techniques including a piezometer transect, the hydraulic conductivity and infiltration rates of the streambed, and groundwater chemistry. The Namoi River at Old Mollee and Yarral East was losing-connected at the time of sampling (16-20 November 2009). Lamontagne et al. (2011) concluded that this section of the river is unlikely to become losing-disconnected due to the absence of a clogging layer in the streambed. Instead, a decline in the watertable would result in an increase in the infiltration rate, resulting in the river eventually drying out rather than becoming disconnected. The groundwater chemistry results indicated that groundwater recharge occurs during floods and under low flow conditions (Lamontagne et al., 2011).

There have been numerous other studies into surface water – groundwater connectivity in Maules Creek and the Namoi River between Boggabri and Narrabri using a combination of geological data, geophysical methods, hydraulic data, and groundwater salinity, temperature and water chemistry data (Barrett, 2010). The results indicate that there is significant connectivity between surface water and groundwater in these areas that varies both spatially and temporally (Andersen and Acworth, 2007; Andersen and Acworth, 2009; Andersen et al., 2010; Rau et al., 2010; Giambastiani et al., 2012; McCallum et al., 2013).

As a result of this surface water – groundwater connectivity, historical groundwater use has impacted, and will continue to impact, on streamflow in the tributaries of the Namoi River. The lower Namoi River has changed from a substantial gaining river prior to development to a largely losing river. CSIRO (2007) estimated that the total average impact on tributary streamflow by 2010 would be a loss to groundwater of 19 GL/year more than that included in the current river planning models. The current level of groundwater extraction is expected to eventually reduce average streamflow by an additional 36 GL/year to reach the total 99 GL/year impact (CSIRO, 2007).

It is highly likely that water in the Pilliga Sandstone aquifer is providing baseflow to the Namoi River at the eastern extent of the outcropping Great Artesian Basin (GAB) units. These baseflows are fed by ‘rejected recharge’, which occurs where water is restricted from entering the aquifer, mainly due to geology, and as a result discharges at the surface (Department of Water and Energy, 2009). The river model of the Lower Namoi used in groundwater management plans has an average inflow of 8.3 GL/year from the GAB (Herczeg, 2008).

For the purpose of water sharing plans in New South Wales, a highly connected system is defined as a system in which 70% or more of the groundwater extraction volume is derived from streamflow within a single irrigation season. All other systems are considered ‘less highly connected’ (NSW Office of Water, 2012). According to this definition, shallow aquifers that are highly connected to the river system are common in the Peel and Upper Namoi and as a result, groundwater levels are highly dependent on surface water flows (Green et al., 2011). The groundwater areas covered by the New South Wales GAB shallow groundwater sources water sharing plan are considered to have a relatively low connection to the surface waters in the same areas (NSW Office of Water, 2011). There is no specification for areas where the GAB sediments outcrop beneath the Namoi River.

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1.1.7 Ecology

Summary

Namoi environments have been considerably altered since European settlement due to expansion of agriculture. Agriculture covers 77% of the land and is now the main land use, dominated by grazing and cropping. Forestry, natural landscapes and conservation areas comprise another 19%. Despite these significant land use changes, many ecologically significant habitats still remain in the Namoi. The variation in climate combined with the variety of landforms results in a range of different ecosystems, communities and species residing in forests, woodlands, rangelands, riparian areas and the agricultural production landscape. The river basin also contains a wide range of aquatic habitats including large areas of anabranch and billabong wetlands downstream of Narrabri, including the endangered Darling River ecological community.

The Namoi river basin supports a diversity of landscapes (Table 13) including the Liverpool and Kaputar ranges, the rolling hills of the sedimentary slopes, the floodplains of the Liverpool Plains and Darling Riverine plains in the west of the river basin.

Vegetation in the upper Namoi includes open box woodlands on the slopes and temperate and sub-alpine forests in the ranges. The Liverpool Plains contain endangered native grasslands and the riparian vegetation is dominated by river she-oaks and willows with river red gum communities along the major streams. Approximately 3200 km^2 of native woodlands and forests are protected in national parks and nature reserves. East of Tamworth the Warrabah National Park approximates 40 km^2 of habitat along the Namoi River. East of Narrabri, the Kaputar National Park protects a range of communities including rainforest patches, semi arid to sub-alpine woodlands and forests and heathlands on the high plateaus and peaks. The Pilliga Nature Reserve in the upper catchment of Bohena Creek is the largest reserve in the region. The Pilliga state forest is the largest remaining area of dry sclerophyll forest west of the Great Diving Range in New South Wales and its size and connection to adjacent forests makes it an important habitat for a range of threatened species including the endemic Pilliga mouse.

There are 152 entities listed under the New South Wales *Threatened Species Conservation Act 1995* plus four species listed on the Commonwealth's *Environmental Protection, Biodiversity and Conservation Act 1999* in the Namoi river basin. Of these entities, 86 species are vulnerable, 27 species endangered and four species are critically endangered (see Table 15, Table 16 and Table 17).

There are approximately 2770 wetlands totalling 46,398 ha in the Namoi river basin. Lake Goran, a wetland of national importance, is a large internal drainage basin south of Gunnedah, covering more than 60 km^2. While ephemeral in nature, agricultural activities and structural works have resulted in the deepest parts of the lake being more frequently inundated. During dry periods, the lakebed is intensively cropped, but when flooded the lake provides extensive habitat for large numbers of water birds. Gulligal Lagoon near Gunnedah is

a semi-permanent wetland that is connected to the Namoi River and is filled during flooding events and from river surface flows (Eco Logical Australia, 2008).

There are a number of groundwater-dependent ecosystems (GDEs) that occur in the Namoi river basin. However, there are significant knowledge gaps in relation to the location, condition and water requirements of these GDEs.

The Namoi Catchment Action Plan is a recent document dealing with the future management of the catchment's natural resources. It takes an integrated view of ecology, society and natural resource use with a resilience focus, and lists a range of assets and strategies for monitoring and improving the environmental integrity of these assets (see Table 19, Table 20 and Table 21).

1.1.7.1 *Namoi river basin setting*

Table 13 Management units of the Namoi river basin

Land management unit	Key features	Extent (ha)
Sedimentary hill tops and steep slopes (generally >15%)	Sedimentary or metamorphic hilltops. Soils are shallow lithosols and skeletal red-brown earths. Vegetation is characterised by natural pastures with open woodlands to open forests.	396,023
Sedimentary slopes (generally 8–15%)	A midslope land unit fringing the Liverpool Plains, Duri Hills and East Pilliga Hills. Soils are moderately shallow lithosols and red-brown earths with scattered rocky outcrops. Vegetation includes natural pastures, woodlands and forests.	442,300
Sedimentary footslopes (2–8%)*	Transition zone between the hillslopes and floodplains. Soils are deep red earths, red-brown earths and solodic soils with moderate fertility. Potential for perched watertables. Tree vegetation is a mixture of box, casuarinas and cypress. Major land use in native and improved pasture.	329,621
Sandy Pilliga footslopes	Occur at the transition zone from the hills to floodplain associated with the Pilliga sandstones. Soils are deep solodic soils and earthy sands with very sandy to sandy loam topsoil, with low fertility. Vegetation is mainly a mixture of white cypress casuarina type associations.	226,292
Riparian corridor*	Defined as the 20 m wide buffer from each streambank. Soil and vegetation types vary based on base geology and geomorphology. The riparian corridor is dynamic with varied geomorphology and large variance in water level.	93,827
Upland bogs and swamps*	Small peaty valley fills in the New England tablelands and the Liverpool Ranges. Recognised as significant water storages that release water gradually into the upper reaches of the river basin.	2,881
Central black earth floodplains*	Exist in association with major creeks and rivers in the central part of the river basin, consisting of floodways and floodplains. Soils are typically deep black earths, brown or grey clays and earthy sands. The land units support both farming and maintenance of native vegetation including river red gum communities. Floodplains have been extensively cleared for cropping. High quality groundwater occurs where alluvium overlays coarse gravels.	347,800
Recent western floodplains*	Includes recent floodplains along the Namoi River and Pian Creek within the Darling Riverine plains. Consists of inset meander plains and backplains dominated by very deep grey clays and minor black earths. High quality groundwater is common in deep gravels. Land use includes grazing and native or improved pastures. Flooding is common.	165,420

Land management unit	Key features	Extent (ha)
High western floodplains	Dominated by back plains which are a mixture of older alluvium and modern alluvium associated with less frequent flooding. Soils are dominated by grey clays with high subsurface salinities. Has been extensively cleared but Coolibah communities are scattered throughout.	178,030
Dry western floodplains	Characterised by a lack of major flooding and dominated by the oldest clay back plains along the former path of the Namoi. Dominated by a mixture of grey clays and brown clays. Subsoil sodicity and salt levels are high. The major land use is grazing of native pastures. Coolibah and River Coolibah communities are common, with low saltbush and mitchell grass understorey.	282,682
Central mixed floodplain soils*	Dominated by extensive meander plains with variable black earths, brown and grey clays, red-brown earths and hardsetting duplex soils. Deep freshwater aquifers are found where the alluvium sits on coarse gravel fill over basement material, recharged from surface streams with gravel beds well-connected to the underlying aquifers. Native vegetation is bimble box, white box, rough barked apple, river red gum and Myall with localised treeless plains dominated by plains grass.	224,822
Western hardsetting floodplains	Generally associated with the Bugwha formation, a series of coarse and sandy sediments. Soil types vary considerably with solodic and very sodic grey and brown earths common, very susceptible to scalding. Land use is grazing on native pastures. Vegetation includes bimble box, grey box black box, Coolibah, belah, bull oak wilga, warrior bush, leopardwood and buddah. Understorey consists of Acacia and saltbush.	115,058
Flat Pilliga outwash	Dominates the central and north-western sections of the Pilliga outwash. Dominated by deep solodic soils with sandy to loamy sand topsoils. Land use is diverse dominated by forestry and nature reserves with vegetation ranging from low heaths to open forests and woodlands.	441,308
Colluvial black earths (2–8%)	Alluvial plains and slopes between 2–8% derived from volcanic geological material. Soil predominantly black earths >2 m and reducing as slope increases. Land use is mainly summer and winter cropping on slopes less than 5% and grazing on higher slopes. Mostly cleared of native vegetation, although some box communities and isolated trees remain.	229,887
Basaltic slopes and hills (8–20%)	Flanking the southern edge of the Liverpool Plains with some occurrences associated with the Garrawilla, Warrumbungle and Nandewar basalts. Soils range from black earths to brown clays, red-brown earths with soil depth decreasing with increasing slope. This is a major recharge area with shallow watertables, and salinity is a minor problem associated with basalt flow edges. Vegetation is usually scattered timber of white and yellow box, Myall and rough barked apple with some river red gum along watercourses.	153,396
High fertility basalt uplands	A feature of the crest of the Liverpool Ranges and southern parts of the New England table lands. Soil types include Krasnozems, with black earths and chocolate soils common in lower rainfall areas. Land use is dominated by forestry and nature reserves. Vegetation is generally tall open forest grading to low alpine woodlands at elevation above 1100 m.	43,143
Steep basaltic hills (>20%)*	Basalt hill with slopes >20% flanking the southern edge of the Liverpool Plains with some occurrences with the Garrawilla, Warrumbungle and Nandewar basalts. Soils are shallow and range from black earths to prairie to brown clays, red-brown earths to lithosols on upper slopes and skeletal area. A major source of recharge into groundwater systems. Some grazing occurs on lesser slopes with deeper soils in valleys or hilltops. Vegetation is usually uncleared consisting of white and yellow box, Myall and rough barked apple.	103,987

Land management unit	Key features	Extent (ha)
Tableland granites	A feature of the New England tablelands part of the Namoi. Soils are earthy and siliceous sands as well as soloths and solodic soils. Land use is dominated by grazing on improved pasture, with some minor forestry and nature reserves. Soil acidity is common with some areas of salinity occurring in cleared areas. Vegetation is generally low open woodland with minor areas of open forest in wetter areas.	193,445
Tablelands sedimentary hills	A feature of the central parts of the New England Tablelands. Soils dominated by silty solodic soils and soloths. Land use is dominated by grazing on improved pastures, with some forestry, cereal cropping and horticulture. Induced soil acidity is common with some salinity in drier areas. Vegetation is generally tall open forest with some areas of low woodland and alpine woodland at higher elevations.	67,960
Peel floodplain*	The Peel floodplain from the main drainage for the Duri Hills, in the eastern and central Tamworth Ford belt section. This land management unit (LMU) is dominated by high quality chernozems utilised for cropping and intensive pasture production. High quality groundwater is common in this LMU, but the system is stressed. Vegetation is largely cleared but remnant river red gum, yellow box and rough barked apple occurs. Broad-scale flooding a feature of this landscape.	10,487
Duri hills	Low undulating hills between the New England tablelands and the Liverpool Plains. Soils are red-brown earths or non calcic brown soils. Soils are generally less than 1.5 m. Land use is dominated by a mosaic of winter cropping and grazing on improved and native pastures. Vegetation has been largely cleared but remanets are dominated by white and grey box.	144,827
Disturbed lands	Generally small road base quarry sites or landfill. Several large mining areas make up most of this LMU. Poorly protected disturbed sites form significant sediment and pollution sources in the Namoi.	2,519

*Characterised by high quality water resources

Source data: Namoi CMA (2009)

Major primary industries in the Namoi river basin include cotton, livestock production, grain and hay, poultry horticulture and forestry. The economic output from these industries is over $1 billion with dry land and irrigated agriculture contributing over half of this (Green et al., 2011). The major land use in the river basin is sheep and cattle grazing (over 61% of the river basin). Wheat, cotton and other broad acre crops are grown on the alluvial floodplains; there is over 800 km^2 of irrigation for cotton and in excess of 300 km^2 irrigated pasture and fodder crops. Extensive areas of native woodland (mostly Pilliga scrub) and forests occur in the middle of the Namoi river basin to the south of Narrabri and account for approximately 18% of the river basin. Major land use statistics are shown in Table 14.

Table 14 Land use statistics for the Namoi river basin

Land use type	Extent (km^2)	Proportion of river basin (percentage)
Grazing	25,727	61.2%
Dryland cropping and horticulture	6,810	16.2%
Forestry	4,339	10.3%
Native landscapes	2,136	5.1%
Conservation	1,351	3.2%
Irrigation	1,259	3.0%
Residential	256	0.6%
Lakes, rivers, dams	139	0.3%
Wetland	12	<0.1%
Mining	7	<0.1%

Source data: Green et al. (2011)

1.1.7.2 Namoi Catchment Action Plan

The Namoi Catchment Action Plan provides strategic directions for natural resource management in the Namoi river basin. The Namoi Catchment Action Plan aims to provide a pathway for managing stressors to ensure that the economic and natural resource requirements are balanced. The vision of the Namoi Catchment Action Plan is to deliver on 'Resilient communities and landscapes for the future'.

The action plan is divided into four themes: biodiversity, land, water and people. Critical thresholds are identified along with related targets and actions in each theme. The long-term targets are aimed at avoiding critical thresholds. These thresholds are identified using expert input, thus the action plan provides a summary of key processes and assets to be protected into the future, and will provide valuable context for assessing the impacts of mining on the Namoi subregion.

1.1.7.2.1 Biodiversity theme

The Biodiversity theme is defined as 'the variety of all life forms; different plants, animals, the genes they contain and the ecosystems in which they live' (Namoi CMA, 2013a, p.16). Overall, biodiversity is in decline in the Namoi. Figure 48 shows priority subcatchments close to biodiversity thresholds. The action plan seeks to address the decline in biodiversity through additional reserved habitats and on-ground conservation projects. The Namoi Catchment Action Plan identifies ten assets which depend on biodiversity. These are discussed in more detail in Section 1.1.7.6.3.

The plan identifies four key biodiversity targets that are designed to avoid crossing eight key thresholds. The four key biodiversity targets are:

- By 2020 there is an increase in native vegetation extent and vegetation does not decrease to less than 70% in less cleared subcatchments and 30% in over-cleared subcatchments, and no further Regional Vegetation Community decreases to less than 30% extent as identified by the 2010 baseline.
- By 2020 maintain sustainable populations of a range of native fauna species by ensuring that no further Regional Vegetation Community decreases to less than 30% extent as identified by the 2010 baseline.
- By 2020 contribute to the recovery of priority viable threatened species, species and communities.
- By 2020 no new invasive species are established in the river basin and the spread of key emerging invasive plants and animals is limited.

To achieve these biodiversity targets a number of key thresholds have been defined for the Namoi. These include:

- woody vegetation cover maintained at 30% in cleared subcatchments
- woody vegetation cover at 70% in intact subcatchments
- 61% of the Regional Vegetation Communities maintain 30% extent.

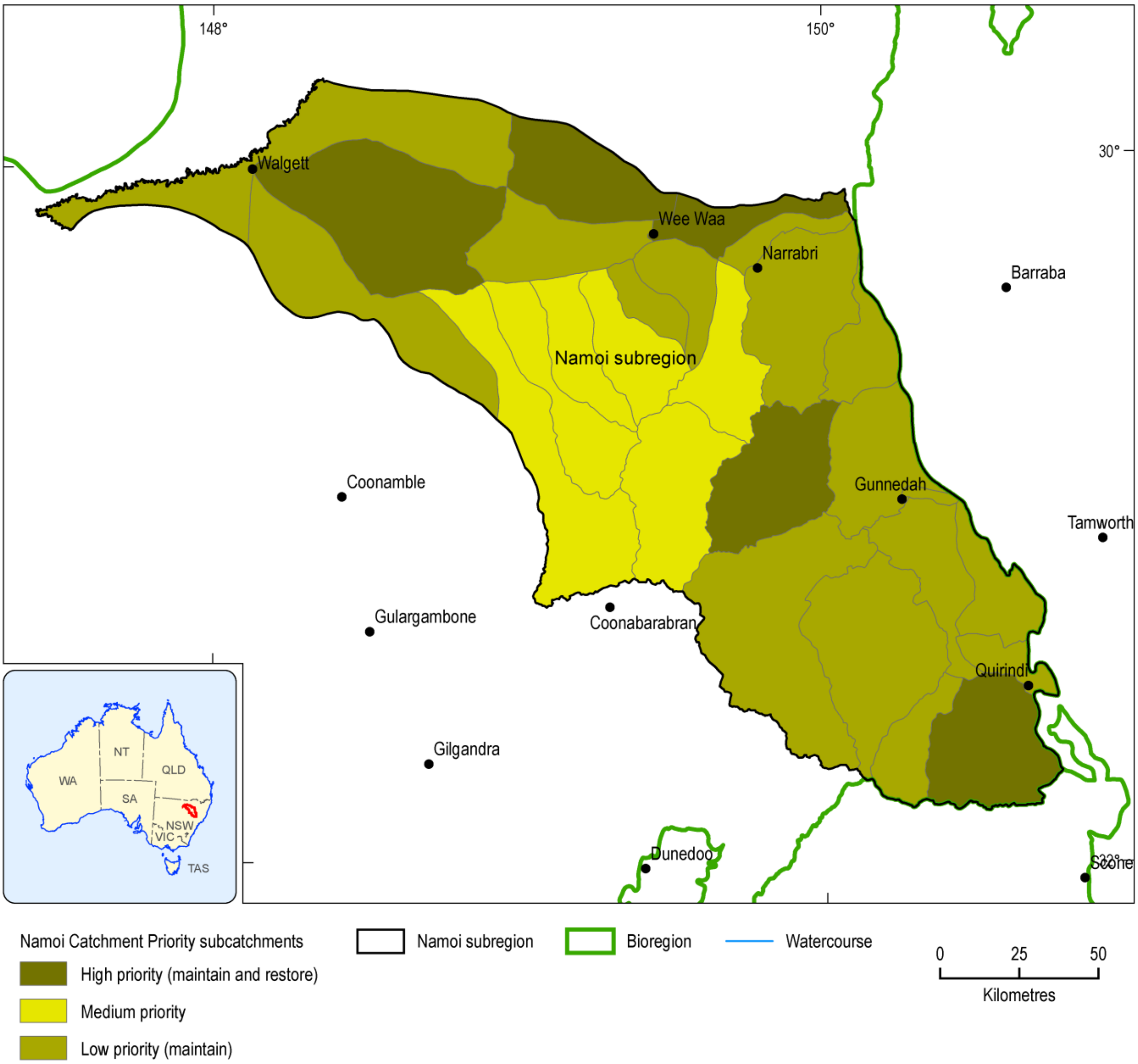

Figure 48 Priority subcatchments close to biodiversity thresholds based on 2010 mapping in the Namoi Land theme

High priority catchments are those that are close to land biodiversity targets. Dark green is a high priority for vegetation restoration as the subcatchment is approaching the 30% extent remaining threshold. Light green represents a priority for maintenance and the subcatchment is above the 70% threshold. Note that an updated version is under consideration in the revised Catchment Action Plan (Namoi CMA, 2013b)

1.1.7.2.2 Land theme

The Land theme is defined as 'healthy soil and functional landscapes that are managed in a way that maintains optimal choices for future generations' (Namoi CMA, 2013a, p. 17) and is based on the premise that land and soils underpin native vegetation, water and economic activity. In the Namoi, deep productive soils underpin economic activity across the river basin. The Namoi Catchment Action Plan defines healthy soils as an asset and soil health is currently variable across the river basin. The major target for the land theme is: 'by 2020 there is an improvement in soil health as measured by an increase in groundcover at the paddock, subcatchment and catchment scales'.

Groundcover is chosen as an indicator of soil health in the Namoi Catchment Action Plan because it plays a major role in soil structure, organic matter content and permeability. Land assets are discussed in more detail in Section 1.1.7.6.1.

1.1.7.2.3 Water theme

The Water theme is defined as 'surface and groundwater systems consisting of the riverine zone made up of stream bed and banks, wetlands and floodplain together with aquifers both confined and unconfined. It also includes riparian vegetation, aquatic biota and water quality and covers access to water, both for people and environmental values' (Namoi CMA, 2013a, p. 18). The Namoi Catchment Action Plan identifies 15 water assets. These are addressed in more detail in Section 1.1.7.6.2.

Targets for the maintenance of water assets include:

- By 2020 there is an improvement in the condition of those riverine ecosystems that had not crossed defined geomorphic thresholds as at the 2010 baseline.
- By 2020 there is an improvement in the ability of groundwater systems to support groundwater-dependent ecosystems and designated beneficial uses.
- By 2020 there is an improvement in the condition of regionally important wetlands, and the extent of those wetlands is maintained.

These targets are designed to avoid crossing several thresholds including:

- Surface water flow quantity is at 66% of natural (pre-development) condition with sensitivity to natural frequency and duration.
- Geomorphic condition is good (against benchmark condition).
- Recruitment of riparian vegetation is higher than attrition of individual trees, shrubs or groundcover species.
- Agricultural and urban water supply aquifers do not cross into lower levels of beneficial use regarding quality.
- Alluvial aquifers are not drawn down below long-term historical maximum drawdown levels.
- Groundwater levels do not drop below the rooting depth of groundwater dependent vegetation ecosystems.
- Wetland is not drained, dammed or otherwise physically modified.

1.1.7.2.4 People and communities theme

The People and Communities theme is defined as 'the social and economic elements of the catchment in relation to how they are underpinned by natural resources, an asset for increasing resilience and a driver of system changes' (Namoi CMA, 2013a, p. 18). People and communities represent an important component of the natural systems of the Namoi river basin. The people theme recognises the intricate linkages between humans, society and the natural world. The Namoi Catchment Action Plan sets targets where:

- Natural resource management decisions contribute to social wellbeing.
- There is an increase in the adaptive capacity of the community.
- There are no clearly-defined thresholds relating to people. However, the plan recognises building resilient communities by increasing adaptive capacity and sustaining or improving wellbeing as important priorities (Namoi CMA, 2013a).

The Namoi Catchment Action Plan identifies a range of assets grouped into the four areas of capital – human, social, manufactured and financial – although these assets are not directly water dependent.

1.1.7.3 Ecological significance

There are a number of factors that contribute to the ecological significance of the Namoi river basin. The variation in climate combined with the variety of landforms results in a range of different ecosystems, communities and species residing in forest, woodlands, rangelands, riparian areas and the agricultural production landscape. The river basin contains a wide range of aquatic habitats including large areas of anabranch and billabong wetlands downstream of Narrabri. Although the Namoi does not contain extensive or nationally recognised wetland complexes, the floodplains downstream of Narrabri support many small lagoons, wetlands and anabranches as well as flood runners and extensive areas of floodplain woodlands (MDBA, 2012). Lake Goran is the only wetland of national importance in the river basin. However, there are numerous wetland communities that provide a range of aquatic habitats, and important refugia during drought.

In the Namoi CMA region there are 152 entities listed under the New South Wales *Threatened Species Conservation Act* plus four species listed in the EPBC Act. Of the 152 listings, 86 species are listed as vulnerable, 27 species are listed as endangered and four species are listed as critically endangered. There are also two populations listed as endangered and 15 communities listed as ecologically endangered.

1.1.7.4 Terrestrial species and communities

The Namoi river basin supports a diversity of landscapes including the Liverpool and Kaputar ranges, the rolling hills of the sedimentary slopes, and the floodplains of the Liverpool Plains and Darling Riverine plains in the west of the river basin (Green et al., 2011). Vegetation in the upper Namoi includes open box woodlands on the slopes and temperate and sub-alpine forests in the ranges. The Liverpool Plains contain endangered native grasslands, and the riparian vegetation is dominated by river oaks and willows with river red gum communities along the major streams (Green et al., 2011). Ninety-seven regional vegetation communities were recognised to occur within the Namoi (Namoi CMA, 2011), However recent updates of this earlier mapping have revised this to 70 regional vegetation communities that were existed prioir to European colonisation and 3 derived regional vegetation communities (EcoLogical Australia 2013). Over 3200 km^2 of native woodlands and forests are protected within national parks and nature reserves. East of Tamworth the Warrabah National Park approximates 40 km^2 of habitat along the Namoi River. East of Narrabri the Kaputar National Park protects rainforest patches, semi-arid to sub-alpine woodlands and forests and heathlands on the high plateaus and peaks. The Pilliga Nature Reserve in the upper catchment of Bohena Creek is the largest reserve in the river basin protecting extensive areas of Pilliga scrub containing iron box woodlands and small areas of river red gum, yellow box, white box and angophora. White and black cypress are commonly associated with the iron bark. The Pilliga scrub is the largest remaining area of dry sclerophyll forest west of the Great Dividing Range in New South Wales and its size and connection to adjacent forest habitat makes it an important habitat for a range of threatened species including the endemic Pilliga mouse (Green et al., 2011).

1.1.7.4.1 Species/communities of national significance

Table 15 presents species or communities that occur in the Namoi river basin and are listed under the EPBC Act.

Table 15 Nationally listed biodiversity assets of the Namoi river basin

Asset	Theme	EPBC Act listing	Presence
Birds			
Great egret (*Egretta alba*)	Biodiversity	Migratory	Known
Glossy ibis (*Plegadis falcinellus*)	Biodiversity	Migratory	Known
Latham's snipe (*Gallinago hardwickii*)	Biodiversity	Migratory	Known
Marsh sandpiper (*Tringa stagnatilis*)	Biodiversity	Migratory	Known
Common greenshank (*Tringa nebularia*)	Biodiversity	Migratory	Known
Sharp-tailed sandpiper (*Calidris acuminate*)	Biodiversity	Migratory	Known
Caspian tern (*Hydroprogne caspia* or *Sterna caspia*)	Biodiversity	Migratory	Known
White-throated needletail (*Chaetura caudacuta* or *Hirundapus caudacutus*)	Biodiversity	Migratory	Known
Clamorous reed-warbler (*Acrocephalus stentoreus*)	Biodiversity	Migratory	Known
Superb parrot (*Polytelis swainsonii*)	Biodiversity	Vulnerable	Known
Aquatic species			
Murray cod	Biodiversity	Vulnerable	Known
Non Aquatic species			
Booroolong frog (*Litoria booroolongensis*)	Biodiversity	Endangered	Known
Bell’s turtle (*Elseya belli*)	Biodiversity	Vulnerable	Known
Five-clawed worm-skink	Biodiversity	Vulnerable	Known
Ecological communities			
Coolibah-Black box woodlands	Biodiversity/Land	Endangered	Known

Source data: Thurtell and Wettin (2012)

1.1.7.4.2 Species/communities of regional significance

Table 16 presents species or communities that occur in the Namoi river basin and are listed as threatened species by the NSW Office of Environment and Heritage (2012).

Table 16 Species and communities of the Namoi river basin listed as threatened in New South Wales

Asset	Theme	NSW Status	Presence
Birds			
Superb parrot (Polytelis swainsonii)	Biodiversity	Threatened	Known
Australasian bittern (Botaurus poiciloptilus)	Biodiversity	Vulnerable	Known
Barking owl (Ninox connivens)	Biodiversity	Vulnerable	Known
Black-breasted buzzard (Hamirostra melanosternon)	Biodiversity	Vulnerable	Known
Black-necked stork (Ephippiorhynchus asiaticus)	Biodiversity	Endangered	Known
Black-tailed godwit (Limosa limosa)	Biodiversity	Vulnerable	Known
Blue-billed duck (Oxyura australis)	Biodiversity	Vulnerable	Known
Brolga (Grus rubicund)	Biodiversity	Vulnerable	Known
Diamond firetail (Stagonopleura guttata)	Biodiversity	Vulnerable	Known
Freckled duck (Stictonetta naevosa)	Biodiversity	Vulnerable	Known
Gilbert's whistler (Pachycephala inornata)	Biodiversity	Vulnerable	Known
Magpie goose (Anseranas semipalmata)	Biodiversity	Vulnerable	Known
Painted snipe (Rostratula benghalensis)	Biodiversity	Endangered	Known
Red goshawk (Erythrotriorchis radiates)	Biodiversity	Critically endangered	Known
Regent honeyeater (Xanthomyza Phrygia)	Biodiversity	Endangered	Known
Grey falcon (Falco hypoleucos)	Biodiversity	Vulnerable	Known
Square-tailed kite (Lophoictinia isura)	Biodiversity	Vulnerable	Known
Turquoise parrot (Neophema pulchella)	Biodiversity	Vulnerable	Known
Aquatic species			
River snail (Notopala sublineata)	Biodiversity	Endangered	Known
Purple spotted gudgeon (Mogurnda adspersa)	Biodiversity	Endangered	Known
Silver perch (Bidyanus bidyanus)	Biodiversity	Vulnerable	Known
Olive perchlet (Ambassis agassizii)	Biodiversity	Endangered	Known
Freshwater catfish (Tandanus tandanus)	Biodiversity	Endangered	Known
Non aquatic species			
Brush-tailed phascogale (Phascogale tapoatafa)	Biodiversity	Vulnerable	Predicted
Davies’ tree frog (Litoria daviesae)	Biodiversity	Vulnerable	Known
Glandular frog (Litoria subglandulosa)	Biodiversity	Vulnerable	Known
Greater broad-nosed bat (Scoteanax rueppellii)	Biodiversity	Vulnerable	Known
Pale-headed snake (Hoplocephalus bitorquatus)	Biodiversity	Vulnerable	Known
Sloane’s froglet (Crinia sloanei)	Biodiversity	Vulnerable	Known
Squirrel glider (Petaurus norfolcensis)	Biodiversity	Vulnerable	Known
Stripe-faced dunnart (Sminthopsis macroura)	Biodiversity	Vulnerable	Known

Asset	Theme	NSW Status	Presence
Ecological communities			
Aquatic ecological community in the natural drainage system of the lowland catchment of the Darling River	Biodiversity /Water	Endangered ecological community	Known
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains Bioregions	Biodiversity /Land	Endangered ecological community	Known
Cadellia pentastylis (Ooline) community in the Nandewar and Brigalow Belt South Bioregion	Biodiversity /Land	Endangered ecological community	Known
Carbeen Open Forest Community in the Darling Riverine Plains and Brigalow Belt South Bioregions	Biodiversity /Land	Endangered ecological community	Known
Carex Sedgeland of the New England Tableland, Nandewar, Brigalow Belt South and NSW North Coast Bioregion	Biodiversity /Land	Endangered ecological community	Known
Fuzzy Box Woodland on alluvial soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South Bioregions	Biodiversity /Land	Endangered ecological community	Known
Howell Shrublands in the New England Tableland and Nandewar Bioregions	Biodiversity /Land	Endangered ecological community	Known
Inland Grey Box Woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South Bioregions	Biodiversity /Land	Endangered ecological community	Known
McKies Stringybark/Blackbutt Open Forest in the Nandewar and New England Tableland Bioregions	Biodiversity /Land	Endangered ecological community	Known
Myall Woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western	Biodiversity /Land	Endangered ecological community	Known
Native Vegetation on cracking clay soils of the Liverpool Plains	Biodiversity /Land	Endangered ecological community	Known
New England Peppermint (Eucalyptus nova-anglica) Woodland on basalts and sediments in the New England Tableland Bioregion	Biodiversity /Land	Endangered ecological community	Known
Ribbon Gum-Mountain Gum-Snow Gum Grassy Forest/Woodland of the New England Tableland Bioregion	Biodiversity /Land	Endangered ecological community	Known
Semi-evergreen Vine Thicket in the Brigalow Belt South and Nandewar Bioregions	Biodiversity /Land	Endangered ecological community	Known
White Box Yellow Box Blakely's Red Gum Woodland	Biodiversity /Land	Endangered ecological community	Known

Source data: Thurtell and Wettin (2012)

1.1.7.5 Aquatic species and communities

The Namoi River forms part of the Darling River endangered ecological community (NSW *Fisheries Management Act*). The community occurs in lowland riverine environments with meandering channels and provides a variety of aquatic habitats including deep channels and pools, wetlands, gravel beds and floodplains. The reach of the Namoi River between Narrabri and Boggabri forms part of the Namoi Aquatic Habitat Initiative Namoi Demonstration Reach, a collaboration between the Namoi CMA, Murray–Darling Basin Authority (MDBA), NSW Department of Industry and Investment and land owners (Commonwealth Environmental Water Office, 2012).

Downstream of Narrabri the flow regimes of the Namoi River are significantly reduced and floodwaters spread out over vast floodplains supporting many small lagoons, wetlands and anabranches as well as floodplain runners and extensive areas of floodplain woodlands (Commonwealth Environmental Water Office, 2012). A number of aquatic species protected under state and federal legislation occur in the Namoi river basin. Four aquatic species known to occur in the river basin are listed as endangered in the NSW *Fisheries Management Act* (see Table 17).

Table 17 Aquatic species of conservation significance in the Namoi river basin

Asset	Status
River snail (*Notopala sublineata*)	*Endangered
Olive perchlet (*Ambassis* agassizii)	*Endangered
Purple spotted gudgeon (*Mogurnda adspersa*)	*Endangered
Silver perch (*Bidyanus bidyanus*)	*Vulnerable
Murray cod (*Maccullochella peelii*)	**Vulnerable

*Listed under the New South Wales Fisheries Management Act 1994
**Listed under the Australian government's Environment Protection and Biodiversity Conservation Act 1999

1.1.7.5.1 Wetlands

There have been a number of mapping and categorisation programs for wetlands of the Namoi river basin. Early mapping by Green and Dunkerley (1992) was followed up with mapping exercises by Hale et al. (2006) and a wetlands assessment and prioritisation by Eco Logical Australia (2008 and Figure 49). Approximately 2766 wetlands totalling 46,398 ha have been mapped in the Namoi river basin (Eco Logical Australia, 2008). Of these, 1829 were identified as being natural wetlands and 937 identified as being artificial wetlands (dams, weirs, storages, etc.) (Commonwealth Environmental Water Office, 2012). Using spatial analysis, Eco Logical Australia (2008) conducted simple hydrological assessments finding that nearly half of the wetlands in the Namoi river basin had experienced a 1-in-2 year flood event. Eco Logical Australia (2008) also developed a prioritisation framework that ranked wetlands based on ecological values and exposure to threats. Subsets of the wetlands were identified for field sampling that included characterisation of vegetation hydrology and disturbance regimes. Classification of wetlands was based on the New South Wales wetland monitoring, evaluation and reporting (MER) classification scheme that includes climate, wetland type, water regimes and vegetation.

The wetland assessment and prioritisation process has provided important baseline information on the ecological values and associated threatening processes for wetlands of the Namoi. While Lake Goran is the only nationally recognised wetland, Eco Logical Australia (2008) identified several other wetlands that may be of regional significance. Twenty one natural wetlands have wetland dependent threatened species within a 500 m radius.

Major threats to wetlands throughout the Namoi are land use, salinity and water regulation. Key threatening processes identified on the New South Wales threatened species list are shown in Table 18. Ten percent of the natural wetlands are directly adjacent to land used for intensive agriculture and over 30% are in areas of high or very high salinity hazard. Sixty five percent of the wetlands characterised as being of high ecological importance are under high or moderate threat (Eco Logical Australia, 2008).

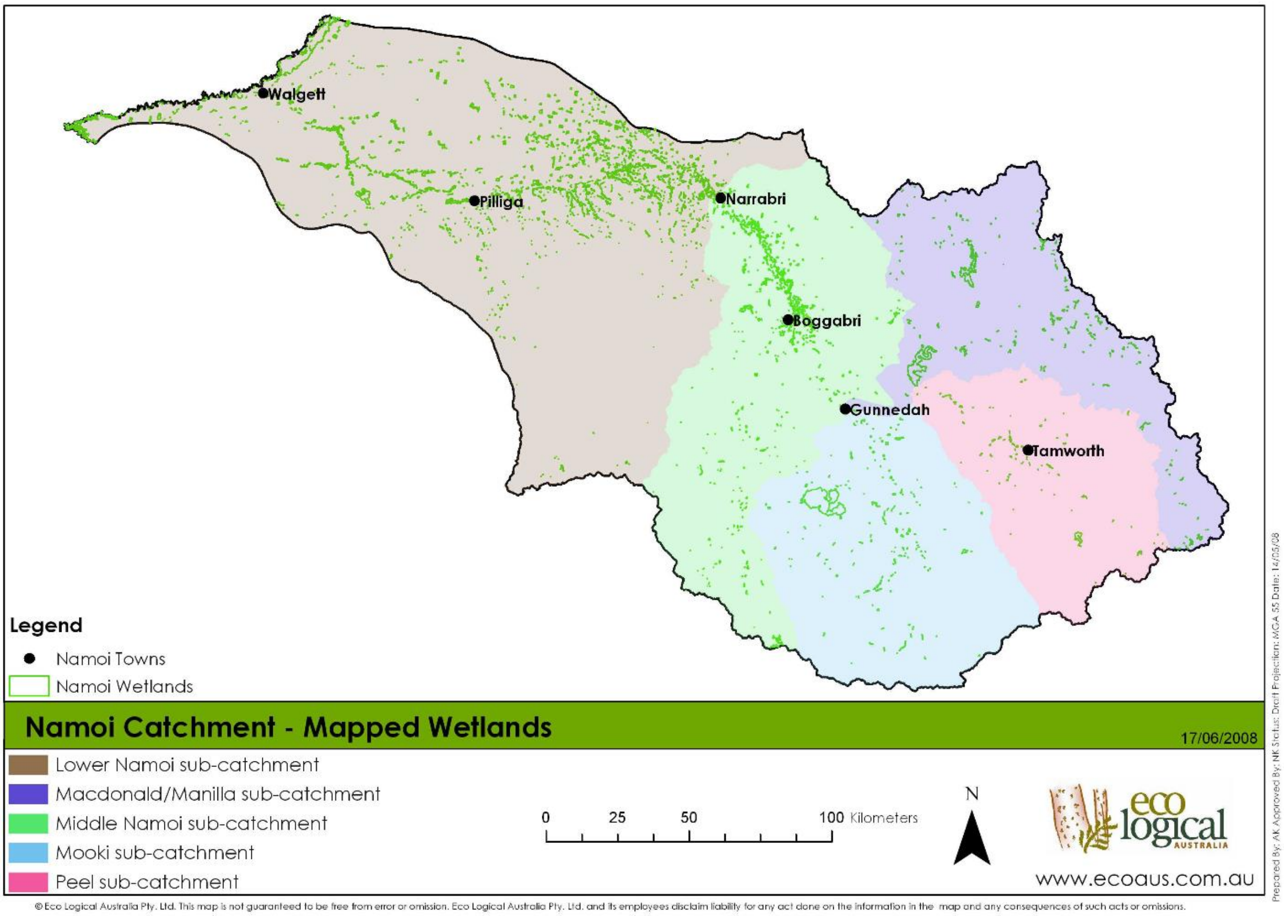

Figure 49 Wetlands of the Namoi river basin mapped during the wetlands assessment and prioritisation project

Source: Figure 2 in Eco Logical Australia (2008). This figure is not covered by a Creative Commons Attribution licence. It has been reproduced with permission from Namoi Catchment Management Authority.

Table 18 Threatening processes relevant to the wetlands of the Namoi river basin

Threat	Type of threat	Occurrence
Infection of frogs by amphibian chytrid	Disease	Predicted
Alteration of natural flow regimes	Habitat loss/change	Predicted
Clearing of native vegetation	Habitat loss/change	Predicted
Human caused climate change	Habitat loss/change	Predicted
Loss of hollow-bearing logs	Habitat loss/change	Predicted
Invasion and establishment of cane toads	Pest animal	Predicted
Competition and grazing by European rabbits	Pest animal	Predicted
Predation by the plague minnow (Gambusia holbrooki)	Pest animal	Predicted
Predation, habitat degradation, competition and disease transmission by feral pigs	Pest animal	Predicted
Loss and degradation of native plant and animal habitat by invasion of escaped garden plants, including aquatic plants	Weed	Predicted

Source data: NSW Office of Environment and Heritage (2012)

National significance

Lake Goran is a large internal drainage basin south of Gunnedah, covering more than 60 km^2. While ephemeral in nature in recent years diversion of local creeks associated with agricultural and structural works has meant that the deepest parts of the lake have resulted in more frequent inundation regimes. During dry periods the lakebed is intensively cropped but when flooded the lake provides extensive habitat for large numbers of water birds, and thus is listed as a wetland of national significance (Green et al., 2011).

Regional significance

Gulligal Lagoon near Gunnedah is a semi permanent wetland that is connected to the Namoi River and is filled during flooding events and from river surface flows. The lagoon is a 4.2 km long channel that is dominated by river red gum (*Eucalyptus camaldulensis*) woodlands and is known to provide important habitat for native fish species including the olive perchlet and purple spotted gudgeon. As the lagoon was restocked with breeding pairs of the purple spotted gudgeon in 2009, fish monitoring since then provides important baseline data on trends in populations (Commonwealth Environmental Water Office, 2012).

The reach of the Namoi River between Boggabri and Narrabri is characterised by a number of long, narrow lagoons that represent prior channels of the Namoi River. Barbers Lagoon, a major anabranch of this reach, covers approximately 134 ha and is about 22 km long (Commonwealth Environmental Water Office, 2012).

1.1.7.5.2 Groundwater-dependent ecosystems

Groundwater-dependent ecosystems include floodplains, wetlands, riparian areas and springs. These ecosystems provide important environmental services including potable water, habitat for fish, invertebrates and aquatic and terrestrial flora and fauna. They can also play an important role in the removal of wastes and containments or provide important cultural and aesthetic values (Tomlinson and Boulton, 2008). However knowledge of the process that regulates function in groundwater-dependent systems has lagged behind that of ecosystems dependent on surface water. There has been a concerted effort to address these knowledge gaps and there is now improved understanding of many aspects of the function and distribution of groundwater-dependent ecosystems (see, for example, the GDE Atlas (BOM, 2013)). Despite this several important knowledge gaps with respect to GDE function remain.

Groundwater-dependent ecosystems are generally categorised into six broad types:

- karsts and caves
- groundwater-dependent wetlands
- aquifers
- baseflow rivers and streams
- terrestrial vegetation
- estuarine and near shore environments.

Eamus et al. (2006) simplify this list into three groups that cover each of the communities described above:

- aquifer and cave systems
- all ecosystems dependent on the surface expression of groundwater (e.g. river baseflow systems, springs and estuarine systems)
- all ecosystems dependent on the subsurface presence of groundwater via the capillary fringe and these typically include terrestrial vegetation communities such as river red gum communities.

Typically the water requirements for these ecosystems can be characterised by the interactions between depth to watertable, pressure, quality and temperature (Hatton and Evans, 1998), although in reality the water requirements of very few groundwater-dependent ecosystems in Australia have been considered to this level of detail.

There are a number of groundwater-dependent ecosystems that occur in the Namoi area. However, there are significant knowledge gaps in relation to the location, condition and water requirements of these GDEs. The 2010 NSW state of the catchment report for groundwater in the Namoi region maps the occurrence of high priority GDEs within the river basin, but these refer mainly to springs (Figure 50). Terrestrial communities dependent on springs are not considered. However, the GDE Atlas <www.bom.gov.au/water/groundwater/gde/map.shtml> identifies a number of ecosystems that have high potential for reliance on groundwater associated with rivers, springs and wetlands and terrestrial ecosystems with moderate to high potential for reliance on subsurface groundwater resources, for example forests and woodlands associated with the Pilliga outwash. Furthermore, floodplain communities such as the river red gum black box forests have been intensively studied in other parts of Australia and have been demonstrated to exhibit groundwater dependency (Akeroyd et al., 1998; Doody et al., 2009; Holland et al., 2006; O'Grady et al., 2009; Thorburn et al., 1994).

Extensive mapping of GDES has been attempted by SKM 2010 using the Sebal algorithm (Bastiaanssen et al., 1998). Sebal uses a surface energy balance approach to estimate evapotranspiration using remotely sensed data, and that can be used to identify areas in the an image where evapotranspiration exceeds rainfall, and this index is used as an indicator of groundwater use. Using these procedures (SKM, 2010) identified a total of 118,688 ha of the catchment were identified as being highly likely to be dependent on groundwater, including terrestrial vegetation and extensive areas within the Pilliga nature reserve, riparian vegetation and wetlands (Figure 50).

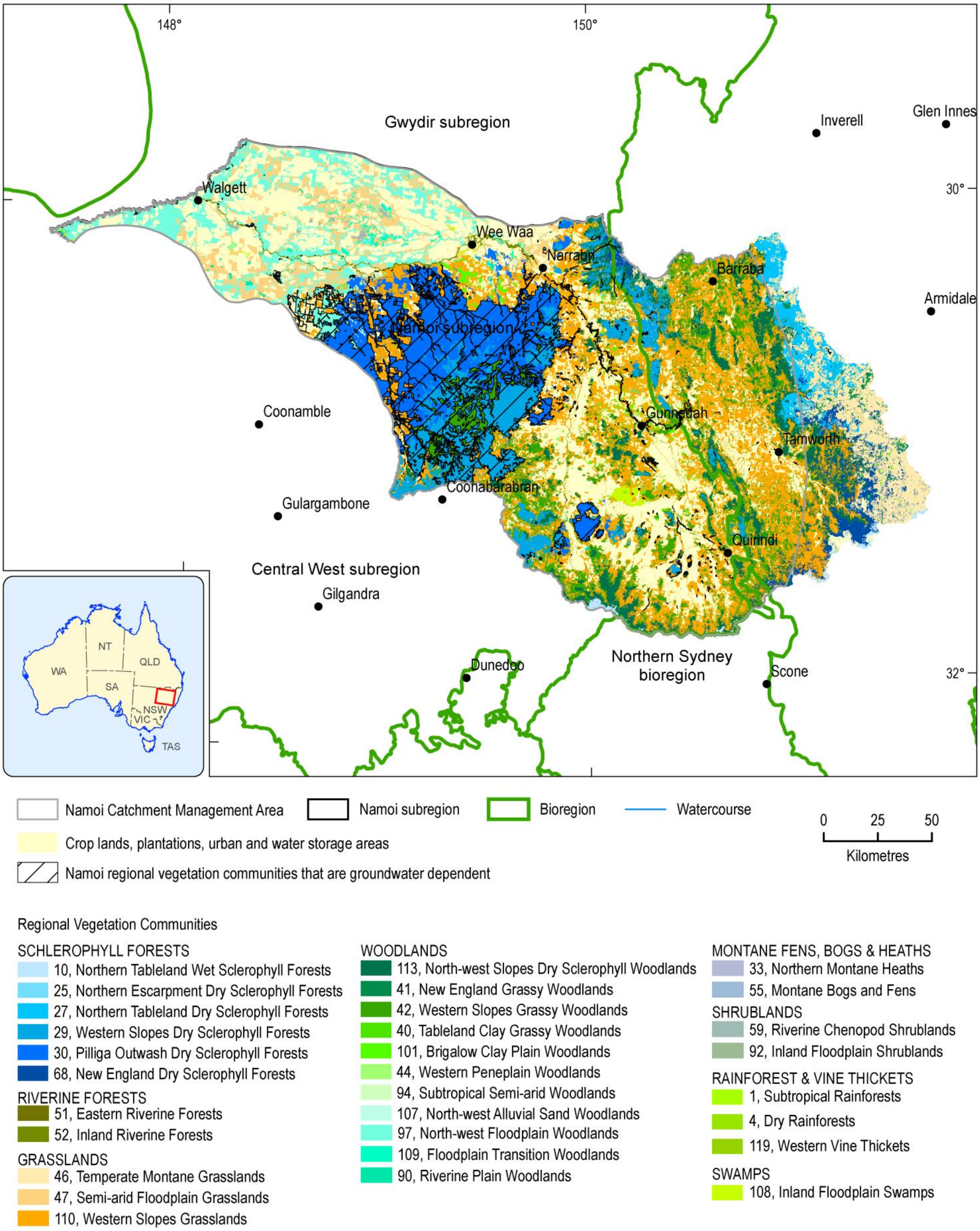

Figure 50 Groundwater-dependent ecosystems of the Namoi and their relationship with regional vegetation communities

1.1.7.6 Assets

Within the framework for bioregional assessments of coal seam gas and coal mining development, assets are explicitly defined as 'those characteristics (ecological, economic, or cultural) of the bioregion to which can be ascribed a defined value (whether quantitative, semi quantitative or qualitative) and which can be clearly linked, either directly or indirectly, to a dependency on water quality or quantity and be impacted by coal resource development' (SEWPaC, 2012). Throughout formulation of the Namoi Catchment Action Plan (Namoi CMA, 2013a), expert workshops were used to define assets within the river basin as part of the process for understanding the resilience of the social, economic and environmental institutions and values within the Namoi. Where available, conceptual models of the processes that regulate the function of these assets were presented. These provide a general overview of the main processes involved in the functioning of the assets but were generally not quantitative or semi quantitative and it was not clear that these were used in any qualitative modelling (Dambacher et al., 2007) to assess future risks or trends. As part of the Bioregional Assessment programme a comprehensive list of water dependent assets will be compiled and stored in an asset register.

In accordance with the philosophy adopted in the Namoi Catchment Action Plan (Namoi CMA, 2013a) and adopting the format of Eco Logical Australia risk assessment for assets of the Namoi CMA (Eco Logical Australia, 2011) assets were divided into themes of Biodiversity, Land and Water. Previous studies have identified many assets within each of these categories. Here we summarise this previous work and in particular Supplementary Document 1, associated with the Namoi Catchment Action Plan (Namoi CMA, 2012). However, this does not represent a comprehensive list of assets that might be considered as part of the bioregional assessments process. This is an overview of assets relevant to each of the asset classes, and a useful classification of assets that may help to reduce the complexity of addressing a vast list of assets and identifying useful receptors. Although it is convenient to divide the assets into themes, for most assets there will be strong relationships and interconnectivity among assets from all themes.

1.1.7.6.1 Land assets

Expert workshops were used as the basis for forming definitions of landscape assets, during formulation of the Namoi Catchment Action Plan. It was decided that land management units (LMUs) were an appropriate scale for the assets under consideration (Namoi CMA, 2012). These landscape assets are summarised in Table 19. More detailed descriptions of land management units are presented in Table 13, and detailed descriptions of each asset given in Namoi CMA (2012).

Table 19 Landscape assets of the Namoi river basin

Asset type	State	Trend	Primary threats	Conceptual model
Liverpool Plains red earths	Good	Stable	Sheet erosion/overgrazing	nil
Duri hills	Good	Stable	Sheet erosion	nil
Recent western floodplains	Good	Improving	Wind erosion	nil
High western floodplains	Good	Improving	Wind erosion, soil carbon decline soil structural decline	nil
Central black earth floodplains	Good	Improving	Soil salinity associated with Agriculture and shallow saline groundwater	nil
Colluvial black earths	Good	Improving	Soil salinity and sheet erosion	nil
Central mixed soil floodplains	Good	Improving	Organic carbon decline and sheet erosion	nil
Flat Pilliga outwash	Fair	Stable	Soil Structural decline	nil
Peel floodplain	Not reported	N/A	N/A	N/A
*Basaltic swamps and hills	Not reported	N/A	N/A	N/A
*Steep basaltic swamps	Not reported	N/A	N/A	N/A
Other soils general	Poor	Decreasing	Wetting and drying cycle changing due to climate change, inappropriate land use, invasive species	nil

The Riparian corridor and Upland Bogs and swamps land management units are listed as Water related assets
* Significant for river basin hydrology-major recharge source

1.1.7.6.2 Water assets

The Namoi CMA ran two expert workshops with groundwater, surface water, riparian vegetation and biodiversity experts to identify assets within the water theme.

Table 20 Water assets of the Namoi river basin

Asset type	State	Trend	Primary threats	Conceptual model
Groundwater availability	Not reported	Declining	Extraction rates recharge rates policy, climate change	Yes
Groundwater recharge	Not reported	Unknown	Land use, climate change changed hydrology	Yes
Optimal level of groundwater quality	Variable	Down	Extraction rates, recharge rates climate change, bed and bank incision, pollution from chemical and salt	Yes
Surface water quantity	Poor	Declining	Extraction, climate change, declining rainfall, afforestation, land use change, urbanisation	Yes
Surface water availability environment	Stable	Increasing (possibly)	Not reported	No
Surface water available to people	Not reported	Declining	Climate change, policy, declines in quality, changed land management, extraction rates	Yes
Floodplain flows	Not reported	Declining	Extraction, afforestation, changes in rainfall pattern, land use change, urbanisation, development of infrastructure, changes to river geomorphology	Yes
In stream flows	Not reported	Declining	Water extraction, afforestation, climate change, changes in rainfall pattern, land use change, urbanisation	Yes
Local flows	Not reported	Declining	Draining, grazing, damming, extraction, drying climate	Yes
Hydrological connectivity	Variable	Declining	Incision of streams, declining rainfall, changed flow regimes, aquifer drawdown, extraction	Yes
River geomorphology	Not reported	Declining	Changed flow regimes, increased runoff and floods, removal of in stream structures, reduced riparian vegetation, gravel and sand extraction	Yes
Aquatic species	Not reported	Declining	Species extinctions, reduced genetic stock	Yes
Riparian buffers	Poor	Stable	Clearing, invasive species, degradation of geomorphology, change in hydrological regime, climate change	Yes
Riparian vegetation	Not reported	Declining	Water regulation, vegetation age, poor quality of vegetation lack of recruitment, loss of geomorphological integrity	Yes
Optimal level of surface water quality	Not reported	Declining	Land use change, agricultural practises leading to diffuse pollution, point source pollution, in stream erosion, salinity)	Yes

Source data: Namoi CMA (2012)

1.1.7.6.3 Biodiversity assets

Biodiversity in the Namoi Catchment Action Plan is defined as 'the variety of life forms, the different plants, animals and micro-organisms, the genes they contain and the ecosystems they form'. Again, expert workshops were conducted to identify assets within the biodiversity theme's known thresholds and to develop conceptual models that provide an understanding of key ecosystem resilience parameters. The workshops identified assets and considered appropriate conceptual models for each.

Table 21 Biodiversity assets of the Namoi river basin

Asset type	State	Trend	Primary threats	Conceptual model
Local scale connectivity	Not reported	Declining	Tree decline, clearing	Yes
Regional landscape connectivity	Not reported	Declining	Tree decline	Yes
Total native woody cover	Not Reported	Declining	Utility clearing, mining and development, agricultural practices, disturbance events, approved clearing, natural attrition, illegal clearing climate change	Yes
Species populations	High Risk	Declining or stable	Habitat disturbance, habitat loss, feral animals, invasive weeds, climate change	Yes
Large area of conserved habitat	Not reported	Stable	Not reported	nil
Intact native vegetation communities	Very Poor	Declining-stable	Habitat disturbance, invasive species, fragmentation	Yes
Waterways connected	Not reported	Declining-stable	Climate change, water regulation, grazing, vegetation removal, weeds, introduced fish species, intensification of agriculture and urban development	Yes
Waterways unconnected	Poor	Declining	Climate change, draining, grazing, vegetation removal weeds, intensification of agriculture and urban development	Yes
Groundwater-dependent ecosystems	Poor	Unknown or declining	Climate change, groundwater extraction declining groundwater quality, grazing, vegetation clearing, weeds, intensification of agriculture and urban developments	Yes

Source data: Namoi CMA (2012)

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