Australian Government

BIOREGIONAL ASSESSMENTS

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

Current water accounts and water quality for the Hunter subregion

Product 1.5 for the Hunter subregion from the Northern Sydney Basin Bioregional Assessment

1 July 2016

A scientific collaboration between the Department of the Environment and Energy, 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 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 and Energy. The Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia are collaborating to undertake bioregional assessments. For more information, visit http://www.bioregionalassessments.gov.au.

Department of the Environment and Energy

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ISBN-PDF 978-1-925315-28-8

Citation

Zhang YQ, Rachakonda PK, Herron NF, Peña-Arancibia JL and Marvanek SP (2016) Current water accounts and water quality for the Hunter subregion. Product 1.5 for the Hunter subregion from the Northern Sydney Basin Bioregional Assessment. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia. http://data.bioregionalassessments.gov.au/product/NSB/HUN/1.5.

Authorship is listed in relative order of contribution.

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Cover photograph

Oblique view west of Muswellbrook showing Bengalla coal storage (left foreground) with irrigated agriculture and riparian vegetation either side of the Hunter River and Mount Arthur coal mine in the distance (right background), NSW, 2014

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Department of the Environment and Energy
Bureau of Meteorology
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v20170308

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Acknowledgements

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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 (IESC, 2015).

Bioregional assessments (BAs) are one of the key mechanisms to assist the IESC in developing this advice so that it is based on best available science and independent expert knowledge. Importantly, technical products from BAs are also expected to be made available to the public, providing the opportunity for all other interested parties, including government regulators, industry, community and the general public, to draw from a single set of accessible information. A BA is a scientific analysis, providing a baseline level of information on the ecology, hydrology, geology and hydrogeology of a bioregion with explicit assessment of the potential 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 and Energy, the Bureau of Meteorology, CSIRO and Geoscience Australia. Other technical expertise, such as from state governments or universities, is also drawn on as required. For example, natural resource management groups and catchment management authorities identify assets that the community values by providing the list of water-dependent assets, a key input.

The Technical Programme, part of the Bioregional Assessment Programme, will undertake BAs for the following bioregions and subregions (see http://www.bioregionalassessments.gov.au/assessments for a map and further information):

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

- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

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

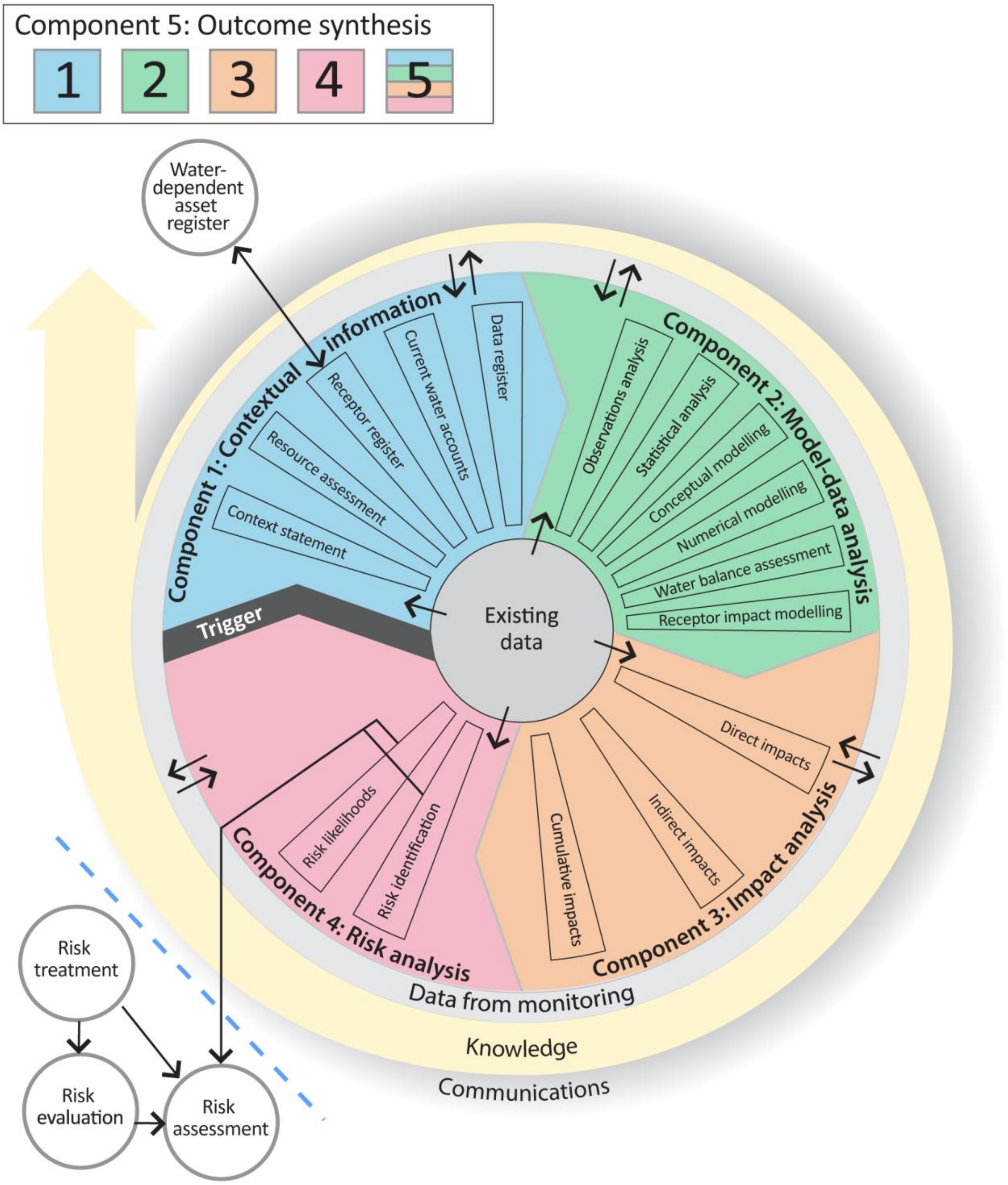

Figure 1 Schematic diagram of the bioregional assessment methodology

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

Methodologies

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1) to, in the first instance, support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies – in this case an explanation will be supplied in the technical products of that BA. Ultimately the Programme anticipates publishing a consolidated 'operational BA methodology' with fully worked examples based on the experience and lessons learned through applying the methods to 13 bioregions and subregions.

The relationship of the submethodologies to BA components and technical products is illustrated in Figure 2. While much scientific attention is given to assembling and transforming information, particularly through the development of the numerical, conceptual and receptor impact models, integration of the overall assessment is critical to achieving the aim of the BAs. To this end, each submethodology explains how it is related to other submethodologies and what inputs and outputs are required. They also define the technical products and provide guidance on the content to be included. When this full suite of submethodologies is implemented, a BA will result in a substantial body of collated and integrated information for a subregion or bioregion, including new information about the potential impacts of coal resource development on water and water-dependent assets.

Table 1 Methodologies

Each submethodology is available online at http://data.bioregionalassessments.gov.au/submethodology/XXX, where 'XXX' is replaced by the code in the first column. For example, the BA methodology is available at http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology and submethodology M02 is available at http://data.bioregionalassessments.gov.au/submethodology/M02. Submethodologies might be added in the future.

Code	Proposed title	Summary of content
bioregional-assessment-methodology	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets
M03	*Assigning receptors to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported about known coal and coal seam gas resources as well as current and potential resource developments
M05	*Developing the conceptual model of causal pathways*	Describes the development of the conceptual model of causal pathways, which summarises how the 'system' operates and articulates the potential links between coal resource development and changes to surface water or groundwater
M06	*Surface water modelling*	Describes the approach taken for surface water modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling
M08	*Receptor impact modelling*	Describes how to develop receptor impact models for assessing potential impact to assets due to hydrological changes that might arise from coal resource development
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantification of uncertainty in the modelled hydrological changes that might occur in response to coal resource development
M10	*Impacts and risks*	Describes the logical basis for analysing impact and risk
M11	*Systematic analysis of water-related hazards associated with coal resource development*	Describes the process to identify potential water-related hazards from coal resource development

Technical products

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

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

Technical products are delivered as reports (PDFs). Additional material is also provided, as specified by the BA methodology:

- unencumbered data syntheses and databases
- unencumbered tools, model code, procedures, routines and algorithms
- unencumbered forcing, boundary condition, parameter and initial condition datasets
- lineage of datasets (the origin of datasets and how they are changed as the BA progresses)
- gaps in data and modelling capability.

In this context, unencumbered material is material that can be published according to conditions in the licences or any applicable legislation. All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.

Technical products, and the additional material, are available online at http://www.bioregionalassessments.gov.au.

The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.

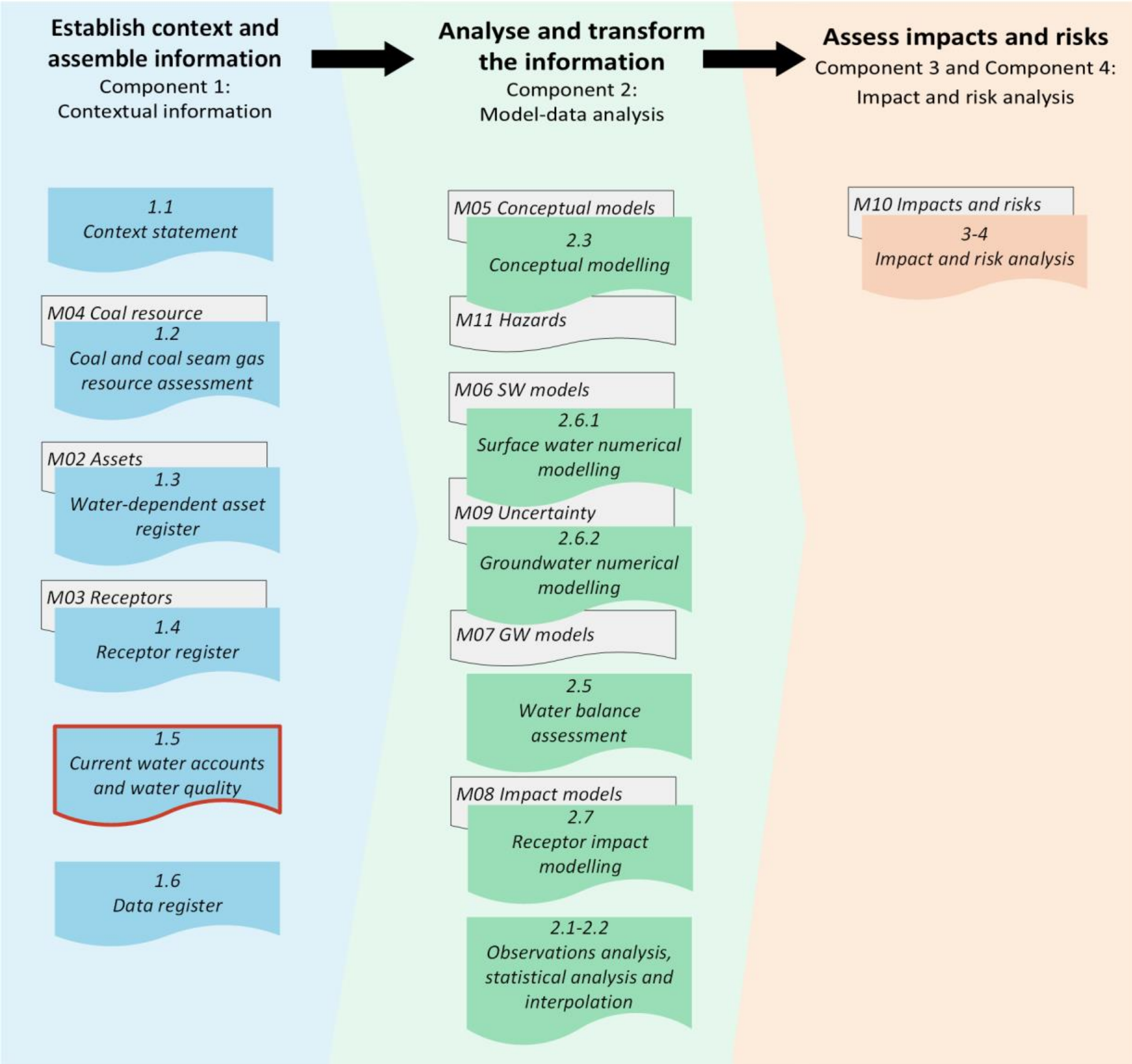

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

In each component (Figure 1) of a bioregional assessment, a number of technical products (coloured boxes, see also Table 2) are potentially created, depending on the availability of data and models. The light grey boxes indicate submethodologies (Table 1) that specify the approach used for each technical product. The red outline indicates this technical product. The BA methodology (Barrett et al., 2013) specifies the overall approach.

Table 2 Technical products delivered for the Hunter subregion

For each subregion in the Northern Sydney Basin Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' column[a]. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 2.4; originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

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

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

[b]*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (Barrett et al., 2013)

About this technical product

The following notes are relevant only for this technical product.

- All reasonable efforts were made to provide all material under a Creative Commons Attribution 3.0 Australia Licence.
- All maps created as part of this BA for inclusion in this product used the Albers equal area projection with a central meridian of 151.0° East for the Northern Sydney Basin bioregion and two standard parallels of –18.0° and –36.0°.
- Visit http://bioregionalassessments.gov.au to access metadata (including copyright, attribution and licensing information) for datasets cited or used to make figures in this product.
- In addition, the datasets are published online if they are unencumbered (able to be published according to conditions in the licence or any applicable legislation). The Bureau of Meteorology archives a copy of all datasets used in the BAs. This archive includes datasets that are too large to be stored online and datasets that are encumbered. The community can request a copy of these archived data at http://www.bioregionalassessments.gov.au.
- The citation details of datasets are correct to the best of the knowledge of the Bioregional Assessment Programme at the publication date of this product. Readers should use the hyperlinks provided to access the most up-to-date information about these data; where there are discrepancies, the information provided online should be considered correct. The dates used to identify Bioregional Assessment Source Datasets are the dataset's published date. Where the published date is not available, the last updated date or created date is used. For Bioregional Assessment Derived Datasets, the created date is used.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 15 September 2016, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

IESC (2015) Information guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Australia. Viewed 15 September 2016, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

1.5 Current water accounts and water quality

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

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

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

1.5.1 Current water accounts

Summary

This section summarises water accounts for the Hunter subregion. It includes information about major water storages and aquifers, streamflow and recharge, surface water and groundwater entitlements, surface water allocations and, where available, actual water use. The Hunter river basin includes regulated and unregulated sections. Unregulated sections include tributaries upstream of Lake Glenbawn, the Goulburn River and its tributaries in the west and smaller tributaries along the regulated sections; the regulated section is mainly regulated by releases from Glenbawn Dam and Glennies Creek Dam. The Macquarie-Tuggerah lakes basin includes three major rivers: Dora Creek, Wyong River and Ourimbah Creek.

There are five major storages used for water supply within the Hunter river basin, although only one of these is physically within the subregion. They have a combined storage capacity of 1254 GL. Since 1991, they have been on average at about 70 to 75% of capacity (~900 GL) at the end of the water year (30 June). There are three main aquifer types that are significant water sources in the Hunter: alluvial, coastal sands and fractured rock. Volumes stored in groundwater aquifers are generally not well known and are not reported here.

Gauging stations are mainly located along the river downstream of the major dams and on major tributaries. Between 2004–05 and 2011–12, mean annual inflow to the Hunter River from gauged tributaries was 1135 GL/year, comprising 560 GL/year from tributaries upstream of Greta and 575 GL/year from the Paterson and Williams rivers. In the Macquarie-Tuggerah lakes basin, mean annual inflow for 2004–05 to 2011–12 was 89 GL/year. The availability of annual mean recharge data for groundwater aquifers was too incomplete to provide a meaningful total.

Water use is managed through a system of water entitlements and water rights. Total surface water entitlements in the Hunter river basin are approximately 767 GL/year. Across all water sources, major water utilities hold the majority of entitlements, about 383 GL/year (50%). General security and unregulated river licences account for another 34% of the entitlement volume (~260 GL/year), with supplementary permits, high security licences, local water utilities and stock and domestic accounting for the remaining licences. Coal mines hold about 47 GL of general, high and supplementary water licences, including 55% of high security licences.

Water use data are not available for much of the subregion, except the Hunter Regulated River water source. Between 2010–11 and 2013–14, the average annual water extraction of 117 GL was 54% ofthe long-term average annual extraction limit (LTAAEL) of 217 GL/year. General security licensed take averaged about 38 GL/year, and use by major utilities averaged 29 GL/year. Annual mine water take varied from 5.6 to 15.7 GL (4 to 13% of all take) during this period. Newcastle was supplied with 63 to 71 GL/year over this same period.

In 2015, total groundwater entitlements for groundwater water sources that intersect or are contained within the subregion were estimated to be about 145 GL, with around 93 GL in

alluvial water sources in the Hunter river basin, 45 GL in the Tomago Tomaree Stockton coastal sand aquifers and a little over 6 GL in the Kulnura Mangrove Mountain groundwater sources. This volume encompasses a larger area than the subregion because some water source areas extend beyond the subregion boundary. An estimate of around 128.5 GL/year is obtained when licensed entitlements per bore within the Hunter subregion are summed. Basic water rights for domestic and stock use may account for an additional 7 GL/year.

A water account provides a summary of resource availability and use for a defined area through quantifying storage volumes, inflows and outflows within a management framework. This section summarises water accounts in the Hunter subregion based on data from 1991 to 2014.

Surface water accounts information is provided for two major river basins within the Hunter subregion: the Hunter river basin and the Macquarie-Tuggerah lakes basin. Due to their relatively small areas and/or relative lack of water resource development, the small areas of the Hunter subregion within the Namoi and Karuah river basins are not included.

Groundwater accounts information is provided for groundwater source areas that are within or intersect the subregion and draws on bore data from across the subregion and water sharing plan (WSP) information, where plans exist.

1.5.1.1 Surface water

The Hunter river basin is a large river basin in coastal NSW with a contributing area of 21,437 km^2, including a significant area in the north and east which falls outside the Hunter subregion boundary. The Hunter River rises in the Liverpool Ranges, and flows generally south and then west into Lake Glenbawn, created by the construction of Glenbawn Dam. Downstream of the dam, the Hunter River maintains a south-west direction to its junction with the Goulburn River before turning eastward towards Newcastle and the sea (Figure 3). Its five main tributaries, in terms of runoff contributions, include the Williams, Paterson and Goulburn rivers, Wollombi Brook and Glennies Creek.

Downstream of Glenbawn, Glennies Creek and Lostock dams, streamflow to and along the Hunter River is regulated by dam releases (Figure 3). Flow regulation means that streamflow is influenced by releases of water from the major storages. Elsewhere, streamflow is unregulated and the flow regime is primarily a response to rainfall.

The Macquarie-Tuggerah lakes basin contributes to the Lake Macquarie and Tuggerah Lakes systems of the NSW Central Coast, south-east of the Hunter river basin (Figure 3). The Macquarie-Tuggerah lakes basin covers an area of 1836 km^2. In the north it contains a number of east-flowing streams, which rise in the Sugarloaf Ranges. To the south, the basin is bounded by the catchment divide with the Hawkesbury river basin. The Macquarie-Tuggerah lakes basin comprises the catchments of three main river systems: Dora Creek, Wyong River and Ourimbah Creek. Dora Creek flows into Lake Macquarie at the township of Dora Creek. To the south, the Wyong River and Ourimbah Creek catchments drain into Tuggerah Lake. These rivers are largely unregulated.

In a surface water account, water availability is defined in terms of water held in storages, including engineered storages and natural storages (e.g. the river itself) and/or volumes of water that are permitted to be extracted for consumptive use within a water management framework. Inflows are catchment runoff contributions to river flow, usually measured at tributary outlets or inflows to large storages. Outflows refer to river flows that exit the water accounting area, which in the Hunter subregion are mostly outflows to coastal lakes, estuaries and the sea, and actual extractions for use. The remainder of this section summarises for the Hunter river and Macquarie-Tuggerah lakes basins:

- water volumes held in surface water storages
- gauged surface water inflows and outflows
- surface water entitlements and allocations to extract water
- take and use of surface water.

Data for storages, inflows and allocations were available for different periods: water storage volumes were available for 1991 to 2012; stream gauging data for 2004–05 to 2011–12; allocations for 2004–05 to 2013–14; and water use for 2010–11 to 2013–14. The water accounts are thus indicative of recent climate conditions and water use practices.

A summary of data gaps relating to surface water accounts is provided at the end of the section.

Figure 3 Surface drainage network, dams and current streamflow gauges within the Hunter subregion

Regulated sections of the river network include Hunter River downstream of Glenbawn Dam, Glennies Creek downstream of Glennies Creek Dam and Paterson River downstream of Lostock Dam.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 2, Dataset 3, Dataset 4)

1.5.1.1.1 Water storage in the Hunter river basin

There are five major storages used for water supply within the Hunter river basin, although only one of these (Grahamstown Dam) is physically within the subregion. They have a combined accessible storage capacity of 1254 GL: Glenbawn (749 GL), Glennies Creek (282 GL), Grahamstown Dam (182 GL), Lostock (19.7 GL) and Chichester (21.5 GL) (Bureau of Meteorology, 2015). Water held in the Glenbawn reservoir is used for flood mitigation, hydro-electric power, irrigation, water supply and conservation. Glenbawn Dam was commissioned in 1947 to secure water for irrigation, industry and town water supply, and for flood mitigation. Construction of a 300 GL reservoir was completed in 1958. In 1987, the dam wall was raised by 22 metres, increasing its storage capacity to 749 GL (plus a potential capacity of 120 GL for flood mitigation). Glennies Creek Dam was built in the 1980s to supplement supplies from Glenbawn Dam. Grahamstown Dam is an off-river storage of which about 50% of inflow is pumped from the Williams River. Its primary purpose is to maintain a sufficient volume buffer to maintain water supply in drought. It is Newcastle’s largest drinking water supply reservoir. On average it supplies about 40% of Newcastle’s drinking water requirements, and a much higher percentage during drought (Hunter Water, 2015b). Chichester Dam on the Williams River is the second largest of Newcastle’s water supply storages, and also services the urban areas around Maitland and Cessnock. Lostock Dam on the Paterson River was built for water conservation and supports irrigation, stock and domestic, town water and environmental water uses.

Lake Liddell (150 GL) and Lake Plashett (67 GL) are two other important storages within the subregion that supply water to electricity generators. Lake Liddell is located near Muswellbrook and supplies cooling water for the Liddell Power Station. Lake Plashett is used as a storage reservoir for Bayswater Power Station. There are other small storages that are used for such things as mine water management and agricultural uses, but their volumes are not reported here.

Table 3 summarises storage volumes at 30 June for the subregion’s five main storages between 1991 and 2012. The day 30 June is the last day of the water year and used in water accounting to quantify closing storage volumes. On average Glenbawn, Glennies Creek and Grahamstown storages close the water year with 70 to 75% of accessible capacity, while Chichester and Lostock storages are typically at 100% of accessible capacity. Glenbawn and Glennies Creek storages recorded their lowest 30 June storage volumes in 2006–07 during the Millennium Drought with 239 GL and 96 GL, respectively, representing approximately 33% of accessible capacity. At Grahamstown, in the same year the 30 June volume was 92% of capacity, whereas 1993–94 was when 30 June volumes were at their lowest (i.e. 64% of capacity, based on capacity priority to augmentation). All three storages were at capacity at the end of 2011–12 following good rainfall in 2007–08 and 2010–11. At Lostock, there is little variation in the 30 June storage volumes over time.

Figure 4 shows the time series of storage volumes at 30 June at Glenbawn, Glennies Creek and Grahamstown storages. Storage volumes at Glenbawn Dam and Glennies Creek Dam exhibit a similar pattern with falling storage volumes from 1991 to 1997 (inflows less than outflows), a period of recovery to 2000 (inflows greater than outflows), before falling again to their lowest volumes in 2006–07. These storage changes largely reflect interannual variations in rainfall. The decline in storage volumes after 2000 can be attributed to the Millennium Drought when precipitation was well below the long-term mean (van Dijk et al., 2013). In contrast, the Grahamstown Dam storage volumes exhibit less variability and a different pattern. Prior to 2005, it had a mean 30 June storage volume of 113 GL, varying from 83 GL in 1993–94 to 133 GL in 2000–01. Following augmentation works in 2005, its storage capacity increased by 50%, leading to higher stored volumes in 2006 and beyond.

Table 3 Storage volumes at 30 June for the five main water supply dams in the Hunter river basin between 1990–91 and 2011–12

	Glenbawn (748.8 GL)[a]	Glennies Creek (282.3 GL)[a]	Grahamstown (182.4 GL)[a]	Chichester (21.5 GL)[a]	Lostock (19.7 GL)[a]
	Volume (GL)	Volume (GL)	Volume (GL)	Volume (GL)	Volume (GL)
1990–91	685.5	256.1	98.6	NA	16.6
1991–92	648.4	239.6	116.1	NA	20.3
1992–93	631.7	232.4	99.0	NA	20.3
1993–94	600.4	211.6	82.7	NA	19.8
1994–95	471.3	188.0	114.4	NA	20.4
1995–96	484.8	174.0	110.9	NA	20.3
1996–97	478.4	162.0	113.1	NA	20.3
1997–98	386.2	125.0	120.5	NA	20.4
1998–99	648.9	165.7	124.0	NA	20.4
1999–00	750.8[b]	222.2	118.2	NA	20.0
2000–01	754.5[b]	276.9	132.8	NA	20.4
2001–02	694.0	250.2	127.6	NA	20.1
2002–03	530.1	192.5	119.5	NA	20.0
2003–04	456.7	154.7	100.8	NA	19.1
2004–05	390.7	140.7	130.6	NA	20.3
2005–06	286.8	109.2	101.3	NA	NA
2006–07	239.1	95.5	167.7	21.6[b]	NA
2007–08	401.6	171.8	182.4	21.5	NA
2008–09	543.7	223.4	180.7	21.5	NA
2009–10	501.4	198.6	147.1	21.5	NA
2010–11	718.3	249.2	181.7	21.5	NA
2011–12	747.6	280.7	177.1	21.6[b]	NA
Mean	547.8	196.4	129.4	21.5	19.9

[a]accessible storage capacity
[b]storage volume greater than storage capacity indicates spilling
NA = data not available
Data: Bureau of Meteorology (Dataset 5)

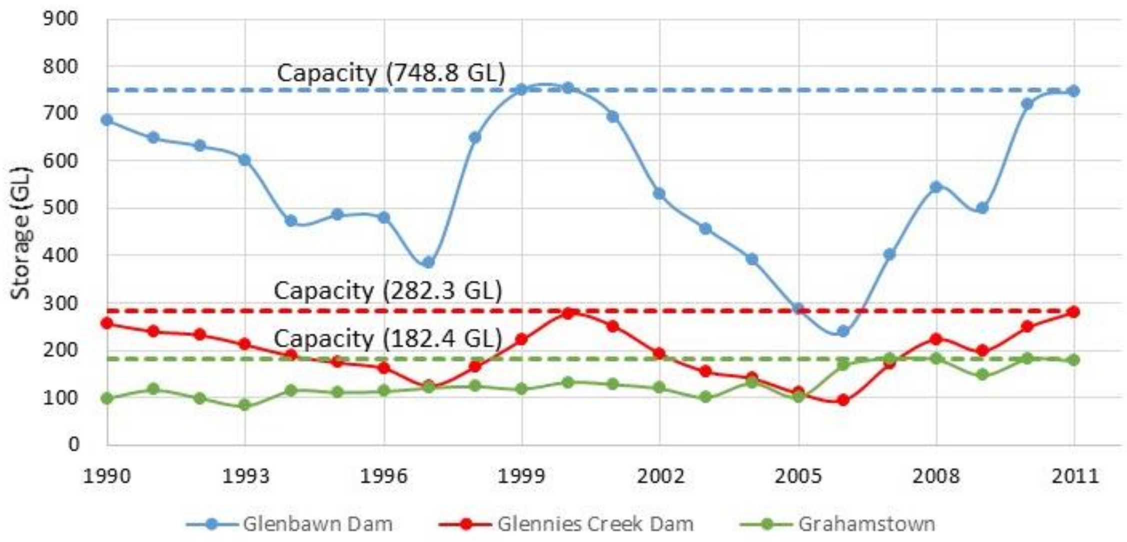

Figure 4 Water storage volumes on 30 June for the three largest dams in the Hunter river basin between 1990 and 2011

Dashed lines indicate available storage capacity for the three dams with the same colour schemes.
Data: Bureau of Meteorology (Dataset 5)

1.5.1.1.2 Water storage in the Macquarie-Tuggerah lakes basin

Mardi Dam is the major dam in the the Macquarie-Tuggerah lakes basin, which is an off-river storage dam located near the Wyong River with a capacity of 6.5 GL. The Mardi storage acts as a balancing storage for Mangrove Dam (190 GL (Bureau of Meteorology, 2015)), which sits outside the Macquarie-Tuggerah lakes basin and the subregion. They are managed as part of the Central Coast water supply system, servicing residents in Gosford City and Wyong Shire council areas. A two-way pipeline links Mardi Dam to Mangrove Creek Dam. During high river streamflow conditions, water is harvested from the Wyong River and Ourimbah Creek to the Mardi Dam and transferred to the Mangrove Creek Dam for storage. During drier periods, when Mardi Dam has exhausted its stores, water stored in Mangrove Creek Dam can be transferred back again to meet user demand.

1.5.1.1.3 Gauged inflows and outflows in the Hunter river basin

Inflows to the Hunter subregion include water released from the major storages and natural inflows from unregulated tributaries. The locations of operating streamflow gauges are shown in Figure 3. Many minor tributaries have never been gauged or have had gauging stations that are now closed.

Table 4 summarises stream inflows, dam outflows and the difference between inflows and outflows for Glenbawn and Glennies Creek dams from 1990–91 to 2011–12 based on the NSW Office of Water Integrated Quantity and Quality Model (IQQM) calibrations (Simons et al., 1996; NSW Office of Water, Dataset 6).

Table 4 Modelled annual inflows and outflows for Glenbawn and Glennies Creek dams, using IQQM model calibrations for the Hunter subregion

	Glenbawn Dam			Glennies Creek Dam		
	Inflows (GL/y)	Outflows (GL/y)	Difference (GL/y)	Inflows (GL/y)	Outflows (GL/y)	Difference (GL/y)
1990–91	261.9	269	–7.1	26.7	34.1	–7.4
1991–92	78	84.1	–6.1	20	44.9	–24.9
1992–93	73.7	90.6	–16.9	22	38.8	–16.8
1993–94	70.3	103.9	–33.6	22.4	40.3	–17.9
1994–95	58.1	141	–82.9	42.2	57.3	–15.1
1995–96	121.4	93.4	28	38.8	34.5	4.3
1996–97	107.5	86.9	20.6	25.6	33.8	–8.2
1997–98	54.4	201.1	–146.7	31.6	46.4	–14.8
1998–99	313.8	39.9	273.9	75.7	27.2	48.5
1999–00	157	51	106	86.7	25.9	60.8
2000–01	288.1	149.8	138.3	81.6	24	57.6
2001–02	148.8	216	–67.2	13.7	34.9	–21.2
2002–03	62.9	109.3	–46.4	23.3	62.6	–39.3
2003–04	83.1	124.6	–41.5	15.9	42.4	–26.5
2004–05	83	163.1	–80.1	21.5	37.8	–16.3
2005–06	73.1	173.6	–100.5	12.2	35.3	–23.1
2006–07	63.2	194.2	–131	31.2	16.8	14.4
2007–08	192.3	24.3	168	87.7	16.1	71.6
2008–09	204.3	77.7	126.6	70.2	29.9	40.3
2009–10	81.4	127.8	–46.4	21.5	50	–28.5
2010–11	285.8	75.7	210.1	68.2	21.6	46.6
2011–12	172.1	61	111.1	56.2	18.1	38.1
Mean	137.9	120.8	17.1	40.7	35.1	5.6

IQQM = Integrated Quantity and Quality Model; values based on 2004 Water Sharing Plan with 2012 conditions
Data: NSW Office of Water (Dataset 6)

Annual inflows between 2005 and 2012 for tributaries to the Hunter are summarised in Table 5. Major contributors to annual inflows include the Goulburn River (gauging station number 210031), the upper Hunter River (210018), Wollombi Brook (210004), Paterson River (210079) and Williams River (210010). Annual inflows varied considerably from very low totals during the dry years of the Millennium Drought to the higher yields in 2010–11 and 2011–12 when good rainfall ended the drought. The total mean annual flow across these gauging stations for 2004–05 to 2011–12 was 1135 GL/year.

Erratum: 2 March 2017

Subsequent to the publication of this product on 1 July 2016, an error was discovered. This change has been enacted and is highlighted in grey.

[original]

Table 4 Modelled annual inflows and outflows for Glenbawn and Glennies Creek dams, using IQQM model calibrations for the Hunter subregion

IQQM = Integrated Quantity and Quality Model
Data: NSW Office of Water (Dataset 6)

[revised]

Table 4 Modelled annual inflows and outflows for Glenbawn and Glennies Creek dams, using IQQM model calibrations for the Hunter subregion

IQQM = Integrated Quantity and Quality Model; values based on 2004 Water Sharing Plan with 2012 conditions
Data: NSW Office of Water (Dataset 6)

Table 5 Annual inflows for Hunter river basin tributary streams

Gauging station name	Gauging station number	Mean annual streamflow (GL/y)								
		2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	Mean
Wybong Creek at Wybong	210040	0.3	0.4	16.8	21.7	25.8	3.7	29.7	42.1	17.6
Goulburn River at Sandy Hollow	210031	11.1	23.0	273.5	91.2	76.9	22.7	434.4	293.8	153.3
Pages River at Gundy Recorder	210052	16.7	17.5	13.5	52.2	38.2	10.1	83.2	69.5	37.6
Kingdon Ponds Creek at Nr. Parkville	210093	0.5	0.0	3.1	11.7	4.4	1.1	8.9	10.5	5.0
Rouchel Brook at Rouchel Brook	210014	13.8	NA	NA	78.1	65.8	15.2	101.7	81.6	59.4[a]
Hunter at Moonan Dam Site	210018	65.3	56.9	35.5	140.3	162.2	58.5	233.4	128.0	110.0
Bayswater Creek at Liddell	210110	NA	0.1	0.1	NA	4.6	0.1	8.2	21.6	5.8[a]
Glennies Creek at Middle Falbrook	210044	32.7	30.3	84.8	61.0	65.1	NA	62.9	127.4	66.3[a]
Wollombi Brook at Warkworth	210004	NA	NA	NA	125.1	74.2	4.8	92.1	230.5	105.3[a]
Paterson River at Gostwyck	210079	153.9	71.8	201.1	461.9	373.7	100.1	348.8	386.0	262.2
Williams River at Glen Martin	210010	199.1	117.2	261.5	559.1	433.4	131.9	321.0	479.5	312.8
Total inflows		**493.4**[a]	**317.2**[a]	**889.9**[a]	**1602.3**	**1324.3**	**348.2**[a]	**1724.3**	**1870.5**	**1135.3**[a]

[a]data missing
NA = data not available
Data: Bioregional Assessment Programme(Dataset 7)

The Hunter River gauging station at Greta is the most downstream gauging location on the Hunter River before the river becomes subject to tidal influences. Mean annual outflow at Greta for the same period was 697 GL/year (Table 6). Note that Paterson River and Williams River join the Hunter downstream of Greta, so the 575 GL/year of inflows from these tributaries are not reflected in the Greta flow volumes.

Table 6 Annual outflow for Hunter river basin at Greta

Gauging station name	Gauging station number	Mean annual streamflow (GL/y)								
		2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	Mean
Hunter at Greta	210064	102.6	92.1	1616.8	862.6	855.7	77.5	944.6	987.2	696.8

Data: Bioregional Assessment Programme (Dataset 7)

1.5.1.1.4 Gauged inflows in the Macquarie-Tuggerah lakes basin

Inflows to the Macquarie-Tuggerah lakes basin are recorded at four gauging stations on Ourimbah Creek, Jigadee Creek, Wyong River and its tributary Jilliby Creek (Figure 3). Annual streamflow for these gauging stations is presented in Table 7. There existed a large interannual variability in the annual inflow for 2004–2005 to 2011–2012. Mean annual inflow for 2004–05 to 2011–12 was 89 GL/year.

Table 7 Mean annual streamflow for gauging stations within the Macquarie-Tuggerah lakes basin for the Hunter subregion

Gauging station name	Gauging station number	Mean annual streamflow (GL/y)								
		2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11	2011–12	Mean
Ourimbah Creek at U/S Weir	211013	5.5	3.3	22.0	33.4	NA	3.9	16.0	27.4	15.9[a]
Wyong River at Gracemere	211009	11.1	6.5	50.3	91.3	28.2	8.3	37.9	86.5	40.0
Jilliby Creek at U/S Wyong River	211010	4.4	NA	16.4	43.0	7.5	4.5	18.7	34.4	18.4[a]
Jigadee Creek at Avondale	211008	6.2	6.0	NA	NA	7.9	NA	14.9	37.1	14.4[a]
Total inflows		**27.2**	**15.7**[a]	**88.8**[a]	**167.6**[a]	**43.6**	**16.7**[a]	**87.5**	**185.3**	**88.8**[a]

[a]data missing
NA = data not available; U/S = upstream
Data: Bioregional Assessment Programme (Dataset 7)

1.5.1.1.5 Surface water entitlements and allocations

Across most water resources in NSW, a system of water licences and allocations is used to manage the take of water from water sources. Management of water resources is provided for under NSW's *Water Management Act 2000* via WSPs, and is intended to ensure that water resources are shared sustainably between multiple users, including the environment. It largely supersedes NSW's *Water Act 1912*, which is being progressively phased out as new WSPs are developed, but still applies in areas without plans and some provisions are still in force. Licensed entitlements provide an indication of economic demand on a water resource and may be constrained by a long-term average annual extraction limit (LTAAEL) or diversion limit on the resource. The maximum permissible take under a licence is typically greater than what is actually taken in any given year.

Allocations are used to limit extractions held under entitlement from the regulated river in response to the availability of water in the water supply storages. In times of good water availability, allocations for all classes of licence will be 100% (or more), meaning that the licensee is entitled to extract the maximum permitted under the licence. When water availability is low, a licence holder may be permitted to extract a volume less than the full entitlement. Thus annual allocations provide an indication of the stress on water resources over time.

Supplementary water licences are issued in regulated reaches, which permit licence holders to access storm flows that cannot be controlled in storages and is not required to meet environmental flow or other high priority right holder demands. Supplementary water is essentially surplus to the regulated requirements and is available opportunistically (i.e. when a period of supplementary access is announced by DPI Water).

At July 2015, total surface water entitlements, including supplementary entitlements, in the Hunter subregion amounted to approximately 767 GL/year, or not more than 579 GL/year when the long-term annual average extraction limits on take from the Hunter Regulated River water source (217 GL/year) and by the Hunter Water Corporation (HWC) across all its water sources (79.5 GL/year) are taken into account. This total includes most of the water source areas covered by the WSP areas shown in Figure 5. It does not include licensed entitlements for four of the five water sources in the Central Coast unregulated water source WSP area: Tuggerah Lakes and Brisbane Water water source areas, because the volumes are negligible (34 and 234 ML/year, respectively); and Mooney Mooney Creek and Mangrove Creek water sources, because they are outside and drain away from the subregion. Table 8 summarises surface water entitlements by water source for Hunter regulated and unregulated water sources, Wybong River, Jilliby Jilliby Creek, Ourimbah Creek and Wyong River water sources. Some of the Hunter river basin water sources extend beyond the subregion boundary (Figure 5), so licensed volumes within the Hunter subregion will be less than the total reported in Table 8. Companion product 1.3 for the Hunter subregion (Macfarlane et al., 2016) provides an estimate of 385 GL/year surface water access rights within the subregion itself.

The Hunter Regulated River water source is one of the most heavily allocated with close to 246 GL/year of licensed entitlements. However, the *Water Sharing Plan for the Hunter Regulated River Water Source 2003* sets a long-term average annual extraction limit (LTAAEL) of 217 GL/year on extractions, including extractions under supplementary water licences (estimated from modelling to be 49 GL/year on average). Thus the current volume of licensed entitlements exceeds the LTAAEL, indicating a fully allocated system. Acquiring a perpetual water use licence and/or an annual allocation water can only occur through the water market.

The Williams River and Newcastle water sources also have large volumes of water held under entitlement (total of 348 GL/year), but this volume greatly over-estimates what is strictly available for extraction. The HWC holds a 239 GL/year entitlement to water in the Williams River water source, plus another 100 GL/year from the Newcastle water source, for water supply to the Newcastle region. However, the LTAAEL from all their water sources (which also includes 60 GL/year entitlement to water in the Tomago sandbeds) is 79.5 GL/year, which has been determined from a population-based estimate of water requirements for the water supply region. The high entitlement volume ensures that HWC has maximum flexibility in refilling storages after droughts. In Table 8, the Williams River water source volume of 87.82 GL/year given in parentheses assumes an LTAAEL of 79.5 GL/year for HWC, while the 247.32 GL/year includes their total entitlement volume of 239 GL/year. The Newcastle water source volume has not been adjusted, although some of the 79.5 GL/year attributed to the Williams River water source would come from it.

In the smaller Macquarie-Tuggerah lakes basin, licensed entitlements total about 50 GL/year.

Water licences are typically issued for a specified purpose. Table 9 summarises water entitlements by licence type/purpose for all water sources, as well as just the Hunter Regulated River water source, with the same caveats applying as for Table 8. Urban and industrial uses dominate water use in the Hunter subregion. This is reflected in the volumes licensed to major utilities, for urban water supply and power generation and to local water utilities, which amount to about 57% of licensed entitlements (including supplementary water). General security licences account for about 18% of licences on issue with another 16% licensed to users in the unregulated water sources. High security licences represent a relatively small component of the entitlement pool, but about 55% of these are held by mining companies. Mining companies also hold about 26% of general security licences and a small proportion (4%) of supplementary licences (NSW Department of Primary Industries, 2014), in all about 47 GL/year of entitlements. Agricultural water uses would account for much of the general security water licences.

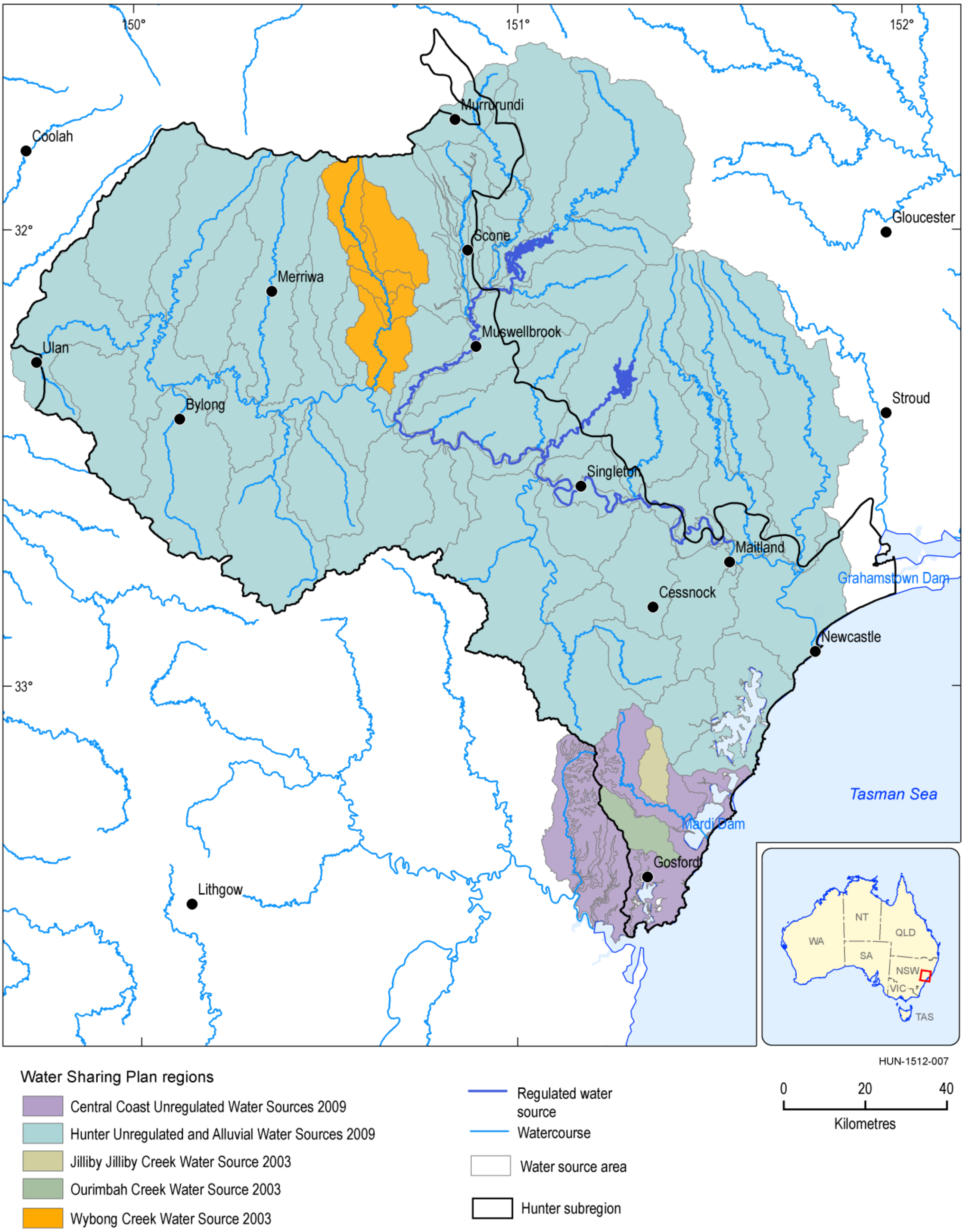

Figure 5 Water sharing plan regions and associated water source areas in the Hunter subregion.

Data: NSW Office of Water (Dataset 8); Bioregional Assessment Programme (Dataset 4)

Table 8 Surface water licences and entitlement volumes at July 2015, grouped by water source area in the Hunter river basin and Macquarie-Tuggerah lakes basin in descending order of licensed volume

A water entitlement is a right conferred by law to hold or take water from a water resource.

Basin	Water source area	Licences	Licensed volume (GL/y)
Hunter River	Williams River	187	247.32 (87.82)[a]
	Hunter Regulated River	1434	245.84 (217.0) [a]
	Newcastle	8	100.48
	Lower Goulburn River	83	14.07
	Hunter River Tidal Pool	106	11.56
	Paterson River Tidal Pool	108	10.97
	Paterson Regulated River	151	10.63
	Jerrys	24	9.81
	Wybong Creek	120	8.19
	Lower Wollombi Brook	116	6.73
	Black Creek	180	6.41
	Pages River	115	6.15
	Merriwa River	53	4.45
	Upper Hunter River	73	4.03
	Paterson/Allyn Rivers	109	3.92
	Halls Creek	55	3.25
	Martindale Creek	33	2.96
	Upper Wollombi Brook	88	2.62
	Isis River	35	2.07
	Widden Brook	4	2.01
	Upper Goulburn River	15	1.78
	Glendon Brook	51	1.58
	Baerami Creek	11	1.56
	Krui River	15	1.45
	Wallis Creek Tidal Pool	19	1.41
	Dart Brook	62	1.32
	Singleton	27	1.18
	Rouchel Brook	28	1.1
	Muswellbrook	43	0.73
	Luskintyre	17	0.57
	Wallis Creek	22	0.47
	Glennies	12	0.45

Basin	Water source area	Licences	Licensed volume (GL/y)
	Bow River	4	0.2
	Upper Paterson	7	0.2
	Wollar Creek	9	0.1
	Bylong River	2	0.09
	Doyles Creek	1	0.02
	Munmurra River	1	0.01
Macquarie-Tuggerah Lakes	Wyong River	108	39.22
	Ourimbah	92	7.17
	North Lake Macquarie	7	1.21
	Jilliby Jilliby Creek	27	1.04
	Dora Creek	19	0.8
	South Lake Macquarie	8	0.3
	Total	**3689**	**767.43 (579.09)**

[a] the numbers in parentheses reflect permissible take when long-term average annual extraction limits on Hunter Water Corporation are taken into account
Licence numbers and entitlement volumes are current at July 2015.
Data: NSW Office of Water (Dataset 9)

Table 9 Surface water entitlement volumes grouped by purpose in the Hunter river basin and Macquarie-Tuggerah lakes basin (rounded to nearest GL)

Purpose	All water sources		Hunter Regulated River water source	
	Volume (GL/y)	Percentage (%)	Volume (GL/y)	Percentage (%)
Major utility	383	49.9%	36	14.6%
Regulated river (general security)	137	17.8%	127	51.4%
Unregulated river	123	16.0%	0	0%
Supplementary water	49	6.4%	49	19.8%
Regulated river (high security)	22	2.9%	22	8.9%
Local water utility	51	6.6%	11	4.5%
Domestic and stock	3	0.4%	2	0.8%
Total	**768**	**100.0%**	**247**	**100.0%**

Data: NSW Office of Water (Dataset 9)

Figure 6 summarises annual allocations in the Hunter Regulated River water source from 2004–05 to 2011–12 (similar water allocations were made for the Paterson Regulated River water source also (NSW Office of Water, Dataset 11)). Allocations are differentiated by category of water access licence: ‘Major utility’ refers to major town water supply and power generation licence holders (e.g. Hunter Water Corporation; Macquarie Generation); ‘Local water utility’ refers to smaller town water supply providers (e.g. local councils); ‘General security’ and ‘High security’ licences pertain to regulated river reaches, with high security licence holders having greater surety of a full allocation in dry years than those holding a general allocation licence. It can be seen that during this period, 'Domestic and stock', 'Local water utility' and 'Major utility' licence holders were allocated 100% of their entitlements (NSW Office of Water, Dataset 10). 'High security' and 'General security' licence holders received 100% of entitlements each water year except for 2006–07 when high security allocations fell to 92%, and general security allocations to 35%, of entitlements due to the severest drought in the last 20 years. At this time Glenbawn Dam and Glennies Creek Dam were at 32 and 34% of their capacity, respectively, their lowest levels in the 20 year period (Table 3 and Figure 4).

Annual allocations to supplementary water are more variable because these allocations are made in response to high streamflow, when the available water cannot be captured in storages and is deemed to exceed any immediate water needs and specific environmental requirements. Supplementary water allocations were low (<30% of the long-term average annual volume of 49 GL/year) between 2004 and 2007, but in four of the five subsequent water years, supplementary water allocations greatly exceeded the modelled estimate of the long-term average annual volume.

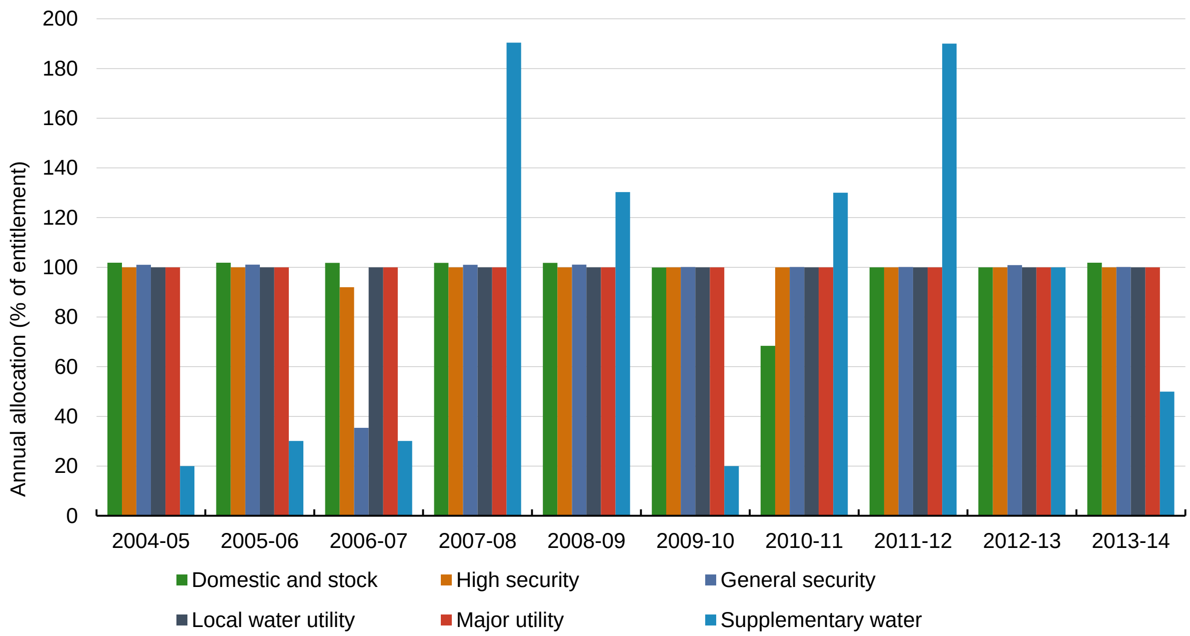

Figure 6 Annual allocations in the Hunter Regulated River water source (% of entitlement) for main licence types

Data: NSW Office of Water (Dataset 10)

1.5.1.1.6 Water use in the Hunter Regulated River water source

Comprehensive water use data are not available for the Hunter subregion as a whole, but there is good information available for the Hunter Regulated River and Paterson Regulated River water sources and for the Hunter Water Corporation. Since most of the Paterson River water source is outside the subregion and water use is relatively low at about 2.4 GL/year on average between 2010–11 and 2014–15 (WaterNSW, 2011, 2012, 2013, 2014, 2015), the data presented here are for the more intensively used Hunter Regulated River water source. Hunter Water Corporation water sources are both within and outside the subregion, but most of the users of the water they supply are within the subregion. Between 2007–08 and 2014–15, HWC has diverted on average 67.8 GL/year to its customers (includes losses and use by HWC) (Hunter Water 2015a; 2011).

In NSW the majority of licensed extractions in regulated water sources and some highly committed groundwater systems are metered, following the introduction of requirements for metering in these water sources in the 1980s; in unregulated water sources, the level of metering has tended to be low. Following the National Water Initiative in 2004, all Australian governments agreed to new standards for water meters and meter data collection and a national framework for non-urban water metering. NSW has developed a policy for water extraction monitoring (NSW Department of Water and Energy, 2007) that sets out the objectives for meeting the new standard, including having 90% of water extracted in each WSP area subject to active monitoring. NSW's *Water Act 1912* now requires a licensee to purchase, install and maintain a water meter or other monitoring equipment (e.g. electricity consumption meter; pump revolution meter; pump operating hours monitor) on extractions for commercial purposes – under NSW's *Water Management Act 2000*, this responsibility resides with the water supply works approval holder. WaterNSW (formerly the State Water Corporation) has the responsibility for monitoring water extraction in the regulated system, while DPI Water is responsible for monitoring in the unregulated and groundwater systems.

Figure 7 summarises actual surface water use (GL) for the Hunter Regulated River water source between 2010–2011 and 2013–14. On average over these four years, 117 GL was extracted from this water source per year, representing 54% of the long-term average diversion limit (217 GL, Table 8) – this average does not include dilution flows (in 2011–12, there were almost 62 GL of water released for dilution purposes). Take varied from 115 to 124 GL, always well below the volume of licensed entitlements for the water source.

Data on take from the unregulated water sources of the Hunter river basin are not available, but can be inferred, in part, from patterns of take from the Hunter Regulated River water source.

In the Hunter Regulated River water source, most surface water is taken under general security, major utility and supplementary water licences, consistent with their share of the water entitlement pool. However, there can be considerable variation in take from year to year. Supplementary take varied from 16 GL in 2013–14 to 57 GL in 2011–12, whereas general security take exhibited the opposite pattern with the highest volume of take (55 GL) in 2013–14 and the lowest volume of take (14 GL) in 2011–12. Supplementary take in 2011–12 was in excess of the licensed entitlement volume of 49 GL/year (Table 9) due to a very high allocation (190%) of supplementary water take (Figure 5). Use by major utilities appears to be less variable, ranging from 24 to 32 GL over the four-year period. This is likely due to less sensitivity to changes in climate and a more constant demand for the power generation sector. Water supply to Newcastle, primarily from Chichester and Grahamstown water storages, over this period ranged from about 63 to 71 GL (Hunter Water, 2015b) or 26 to 29% of Williams River water source licensed entitlements (247 GL, Table 8).

Figure 8 summarises surface water use as a percentage of water allocation (i.e. actual water take divided by water allocation volume) for the Hunter Regulated River water source for the same four-year period. Major water utilities averaged close to 80% of allocations, with a range of 64 to 89%. Opportunistic take of water under supplementary licences varied between about 60 and 70%

of allocation. Take under general security licences was more variable, varying between 10 and 43% of allocation over the four years, with a mean close to 30%. This variability is typical for general security licences, which tend to be held for agicultural uses. Crop water requirements vary considerably with climate, with extractions tending to be low when there is sufficient rainfall to meet crop water demands and higher during dry periods.

In absolute terms, extractions from the Hunter Regulated River water source under domestic and stock, local water utility and high security licences are small by comparison to other licence types (Figure 7). This is consistent with these licence types comprising about 14% of the licensed entitlement volume. However, Figure 8 shows that over the four years, take by local water utilities was relatively high at between 52 and 66% of allocation. Extractions under high security licences and for domestic and stock use tend to be well below licensed allocations during this period. High security licensed use varied between 21 and 32% of entitlements, but this proportion would be expected to be considerably higher during extended dry periods, when allocations of general security water are reduced.

Water take by the mining sector between 2010–11 and 2013–14 ranged from 5.6 GL (12% of entitlement) to 15.6 GL (33% of entitlement) across high, general and supplementary licences. As a proportion of total take by all users in the Hunter Regulated River water source, this represents 4.8 to 13.3% of take. In 2005–06, mine water take exceeded 18 GL (38% of entitlement) and was as low as 4.5 GL (10% of entitlement) in 2007–08 (NSW Department of Primary Industries, 2014).

The four years of use data available suggest that the levels of extraction from this key water source are generally below the licensed entitlements. Use by the mining sector is relatively small, but based on entitlements held, the mining industry is able to extract more water than they are currently using. Water theft may occur, but the volume of water extracted without a licence for uses other than stock and domestic are not known.

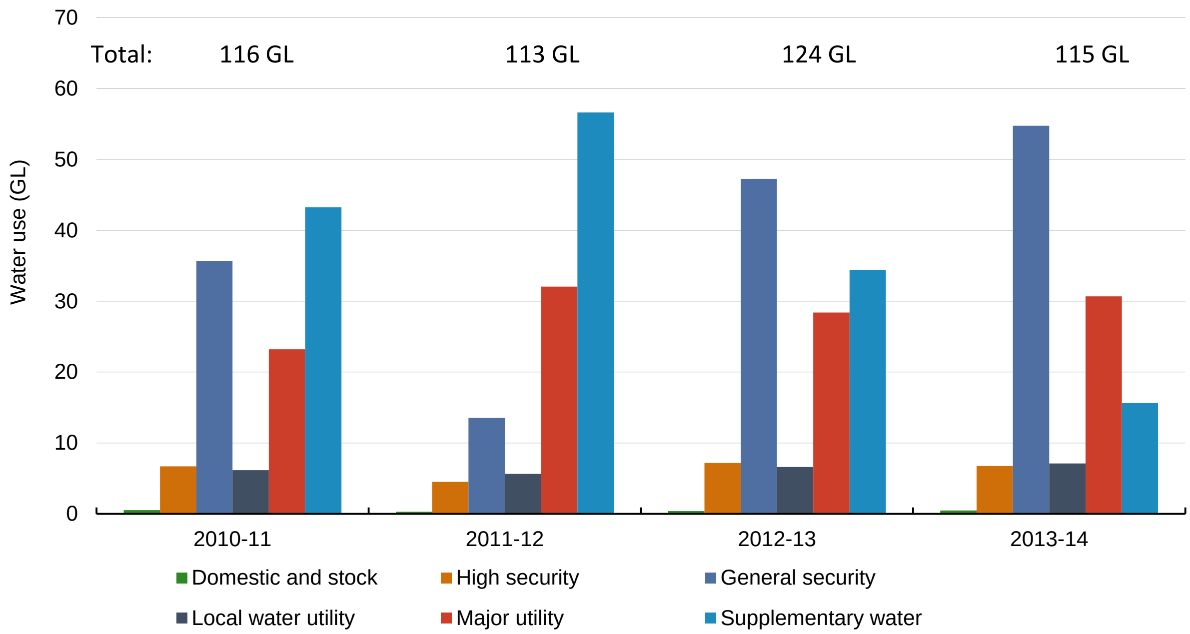

Figure 7 Water use (GL) by surface water licence type for the Hunter Regulated River water source

Number above each year is the total water use for each year.
Data: WaterNSW (Dataset 12)

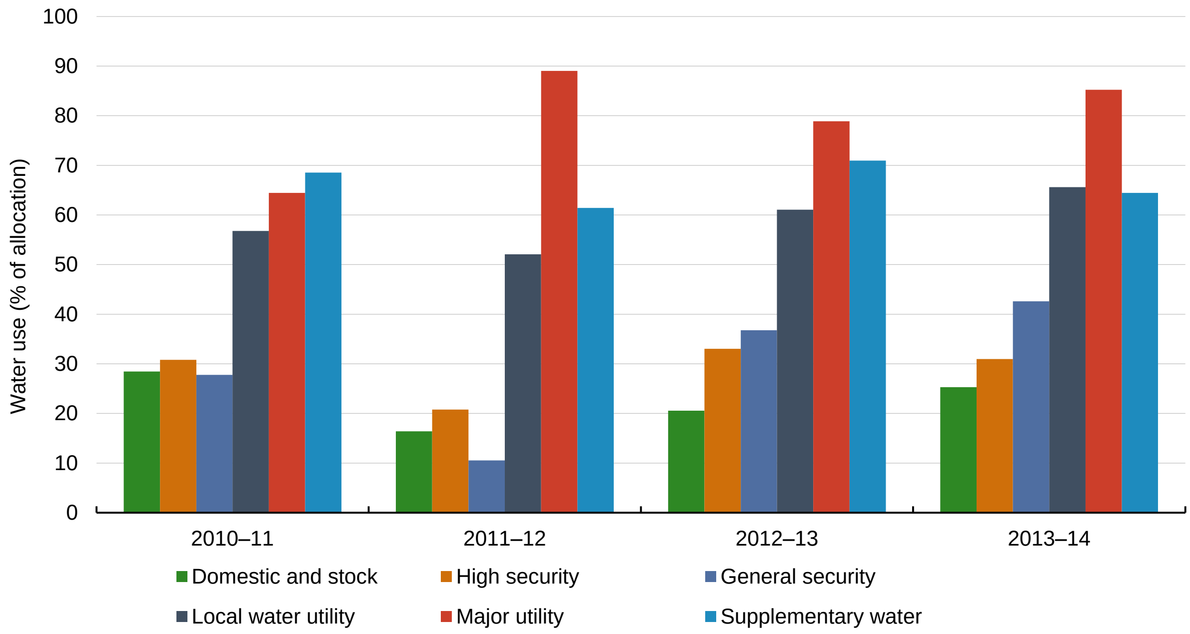

Figure 8 Water use as a percentage of allocation by surface water licence type for the Hunter Regulated River water source

Data: WaterNSW (Dataset 12)

1.5.1.1.7 Gaps

There are a number of data gaps which make doing a surface water account for the Hunter subregion challenging. These gaps are summarised as follows:

- Storages: there are many small storages (e.g. farm dams; mine water storages) across the Hunter subregion for which storage volumes have not been reported. The availability of data on the storage capacities of farm dams across the subregion is not known. Mine water management plans typically report the storage capacities of storages on their sites and this information could be collated to provide a total storage capacity for mining sites.
- Inflows: only observations from recorded gauges were used to estimate river inflows. There are ungauged tributary inflows which are not included in the estimate of inflows. These residual contributions can be roughly estimated based on flow differences between upstream and downstream gauges on the Hunter River. Modelled estimates are possible using a landscape water balance model, such as AWRA-L, or other rainfall-runoff models.
- Exchanges with groundwater can be difficult to measure and these fluxes are often estimated. River flows include a groundwater component (baseflow) and, in losing reaches, losses to groundwater. Baseflow estimation methods and numerical groundwater modelling are used to quantify these components. Impacts on baseflow from drawdown as a result of mining are unknown, but will be estimated through this BA.
- Actual water use data are not available for the entire subregion. Lack of comprehensive metering of take means that getting accurate values of water use across the region is not currently possible. Estimates can be made based on licensed volumes, patterns of use in metered areas and assumptions about basic water rights use.

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1.5.1.2 Groundwater

Groundwater is an important resource in the Hunter subregion. This section provides an account of groundwater availability and use, in the context of how groundwater resources are managed. Groundwater use is not always monitored, so the reported use volumes are an estimate based on information available.

1.5.1.2.1 Current water accounts

A water account provides a summary of resource availability for a defined area through quantifying storage volumes, inflows and outflows within a management framework. For groundwater, aquifer storage capacity and actual storage volumes are often not known or difficult to quantify, so extraction limits or entitlements on issue for a groundwater source can be used as a surrogate for the water available for use. Inflows in a groundwater context refer to aquifer recharge. Outflows refer to natural discharges (e.g. to rivers and springs) and extractions for human use. The groundwater accounts presented here use: extraction limits, if prescribed, or entitlements on issue to define the water available for use; recharge estimates from NSW Department of Water and Energy (2009) for inflows, where available; and estimates of extraction for human use for outflows, where available. Natural discharges (e.g. via baseflow, springs) are not reported because measured data are not generally available. Estimates of baseflow from the literature and based on digital filtering baseflow separation are reported in sections 1.1.5 and 1.1.6 of companion product 1.1 Context statement for the Hunter subregion (McVicar et al., 2015) and Section 2.3.2 from companion product 2.3 for the Hunter subregion (Dawes et al., 2016), which range from 20 to 63% of streamflow.

Water licence datasets, including licence type, entitlement volume (if applicable) and location of the bore (if recorded), for the Hunter subregion were obtained from NSW Office of Water (Dataset 1) and used in the compilation of the asset database for the Hunter subregion (Bioregional Assessment Programme, Dataset 2). NSW requires that all bores have a work approval and are registered, regardless of the intended purpose. Under NSW's *Water Management Act 2000* (the Water Management Act), a water access licence is required to extract water for all consumptive purposes except basic landholder rights (for example, for stock and domestic purposes).

A water access licence entitles the licence holder to:

- specified shares in the available water within a particular water management area
- take water at specified times, rates or circumstances from specified areas or locations.

Following the introduction of a water extraction monitoring policy in 2009 (NSW Department of Water and Energy, 2009; see Section 1.5.1.1.6), bores licensed for extraction for commercial purposes within a water allocation scheme under NSW's *Water Act 1912* (the Water Act) must have a meter and an annual extraction limit. Under the Water Management Act, requirements for metering are specified through water sharing plans (WSPs). Older plans, such as the *Water Sharing Plan for the Kulnura Mangrove Mountain Groundwater Sources 2003*, make no provisions for metering of groundwater extractions. Newer plans can at the direction of the Minister require metering equipment to be installed or for the licensee to maintain a logbook of extractions. The *Draft Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources*

2015 is an example of this. In the Hunter subregion in 2015, metering of groundwater extractions was minimal and it is difficult to quantify actual groundwater extraction volumes. However, as new water allocation schemes and groundwater sharing plans are rolled out, it is expected that metered extraction data will become more readily available and better estimates of groundwater extraction volumes will be possible.

Groundwater availability

Aquifers in the Hunter subregion can be broadly classed into three hydrogeological types: alluvial, coastal sands, and fractured (including porous) rock aquifers. The alluvial and coastal sands aquifers are relatively localised hydrostratigraphic units, occurring along the main river valleys and close to the coastline. The alluvial deposits tend not to be deeper than about 20 m, while the coastal sands aquifers average about 20 m, but can be up to 50 m deep. The deeper, more extensive aquifer systems occur within fractured and porous rock across the subregion. Figure 9 shows the distribution of groundwater bores across the Hunter subregion classified according to the aquifer type from which each bore accesses water. Not all bore data include screening depth or stratigraphy that enable them to be mapped to their water source, so they have been classified based on the following assumptions: (i) any bore overlying mapped alluvium and shallower than 20 m is an alluvial bore; (ii) a bore overlying a coastal sands aquifer is a coastal sands bore; and (iii) all other bores are in fractured or porous rock aquifers (classed here as fractured rock aquifers). The assumptions may not hold in all cases, so the classification is indicative, rather than definitive. It can be seen that alluvial bores are concentrated along the Hunter River valley around Maitland, Singleton, between Muswellbrook and Scone and between Muswellbrook and the junction with the Goulburn River, with smaller concentrations around Bylong and the lower Goulburn River. There is a high density of bores north of Newcastle that tap water stored within the Tomago Tomaree Stockton Sandbeds, an important coastal aquifer for Newcastle water supply. The distribution of deeper bores is more widespread, except within the conservation areas to the south of the subregion.

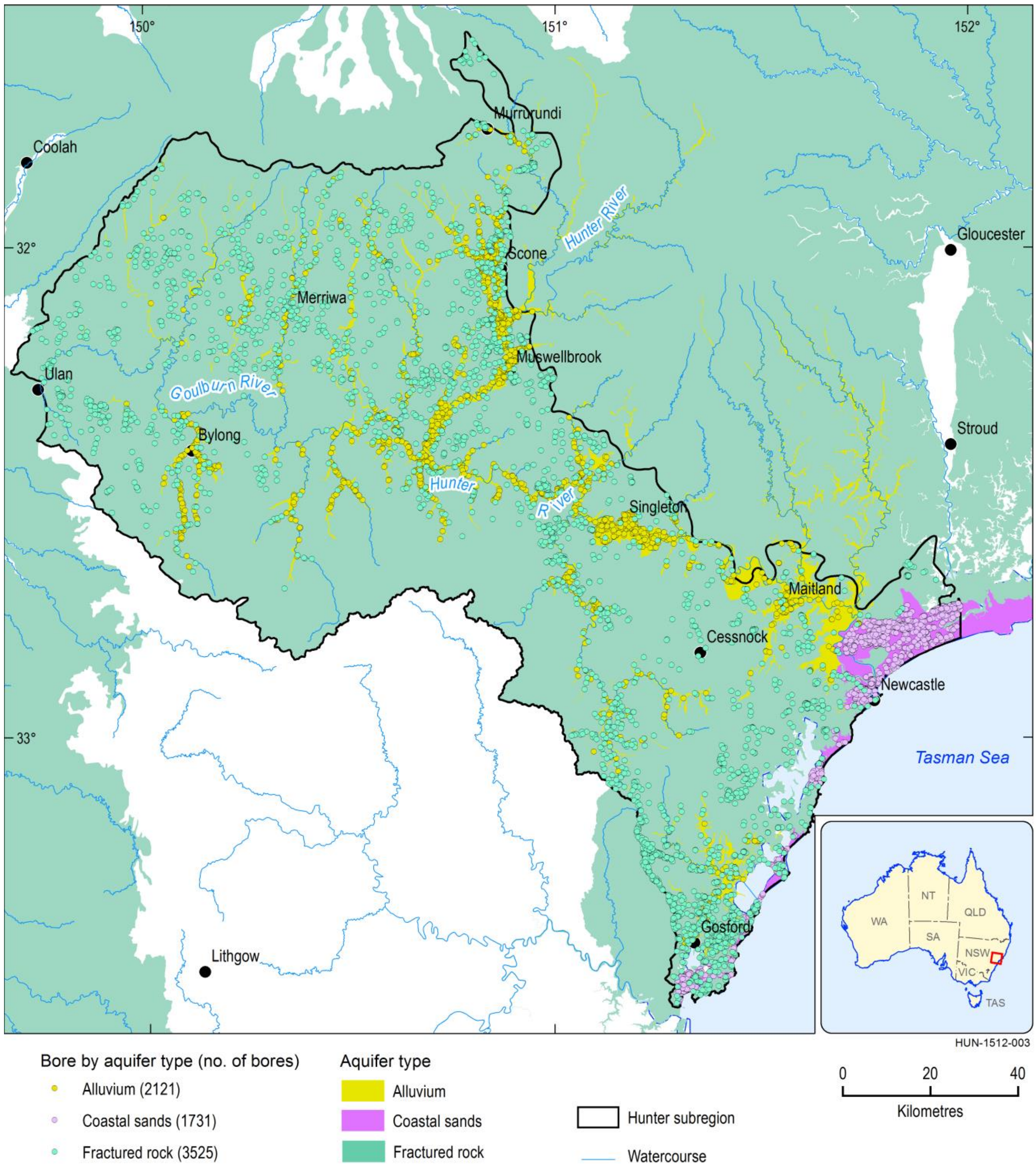

Figure 9 Hunter subregion bores classified by hydrogeological aquifer type

Data: Bioregional Assessment Programme (Dataset 2)

It is difficult to quantify the volumes of water physically stored within the different aquifers. Instead the definition of groundwater availability adopted here is based on the volumes defined as available for consumptive use within NSW's groundwater management framework.

Water sharing plans, established under the Water Management Act, define rules for sharing water between the environmental needs of the aquifer and water users, and also between different types of water use such as town supply, rural domestic supply, stock watering, industry and irrigation (NSW Department of Primary Industries, 2015). While not all groundwater sources in the Hunter subregion are currently covered by WSPs, progress is being made towards achieving complete coverage. As at September 2015, there were four groundwater-specific WSPs in place that intersect all or part of the Hunter subregion; there are another two WSPs that deal with the management of surface water and groundwater within the alluvial aquifers to which they apply, but exclude fractured rock aquifers; and there is a fifth groundwater-specific WSP, which is at a draft stage (on public exhibition from 8 February 2016), that will intersect the Hunter subregion (Table 10). Figure 10 shows the extent of the six plans that have commenced. The overlap of the Hunter subregion with the NSW Murray Darling Basin fractured and porous rock WSP area is relatively small and licensed entitlement volumes for these resources are not reported here.

Table 10 Water sharing plans that apply to groundwater resources in the Hunter subregion

Water sharing plan	Aquifer type	Status
Hunter Unregulated River and Alluvial Water Sources	Alluvial	Commenced 1 August 2009
Wybong Creek Water Source	Alluvial	Commenced 1 July 2004 Suspended 18 August 2006
Tomago Tomaree Stockton Groundwater Sources	Coastal sands	Commenced 1 July 2004
Kulnura Mangrove Mountain Groundwater Sources	Fractured rock	Commenced 1 July 2004
NSW Murray Darling Basin Fractured Rock Groundwater Sources	Fractured rock	Commenced 16 January 2012
NSW Murray Darling Basin Porous Rock Groundwater Sources	Fractured rock	Commenced 16 January 2012
North Coast Fractured and Porous Rock Groundwater Sources (draft)	Fractured rock	Public exhibition 8 February to 20 March 2016

Source: DPI Water (2015a)

Most of the alluvial groundwater in the Hunter subregion is managed under the Hunter Unregulated and Alluvial Water Sources WSP (NSW Government, 2009). The alluvial aquifers are considered to be highly connected to surface water, and are generally managed conjunctively with the surface water source they are associated with. Alluvial groundwater availability, defined in terms of licensed entitlements to extract water, is defined for each unregulated water source area and for the Hunter Regulated River water source (Figure 10) and summarised in Table 11 for those water source areas that intersect the subregion. The licensed entitlement volume from all these water sources is estimated to be 93.3 GL/year as at 24 March 2015. Some of these water source areas extend outside the subregion and the values provided in Table 11 reflect the entire water source. For example, there are no groundwater licence holders in that part of the Williams River water source that intersects the subregion; and in the Pages River water source, the 4 licence holders within the subregion are entitled to 0.12 GL/year, with the remaining 7.28 GL/year of entitlement licensed to users outside the subregion. The surface water entitlements for these water sources are summarised in Table 8.

On 5 February 2016, DPI Water placed an embargo (with exemptions) on further applications for commercial water licences for groundwater within the Hunter water shortage zone (refer to Map 1 in DPI Water (2016)), an area which covers almost the entire Hunter subregion. The embargo reflects an assessment that the groundwater sources within this zone are unlikely to have sufficient water to meet the requirements of licensees within this zone. The embargo does not apply to groundwater within the WSP areas of the Hunter Unregulated River and Alluvial water sources, Hunter Regulated River water source, Kulnura Mangrove Mountain groundwater sources or the Tomago Tomaree Stockton groundwater sources.

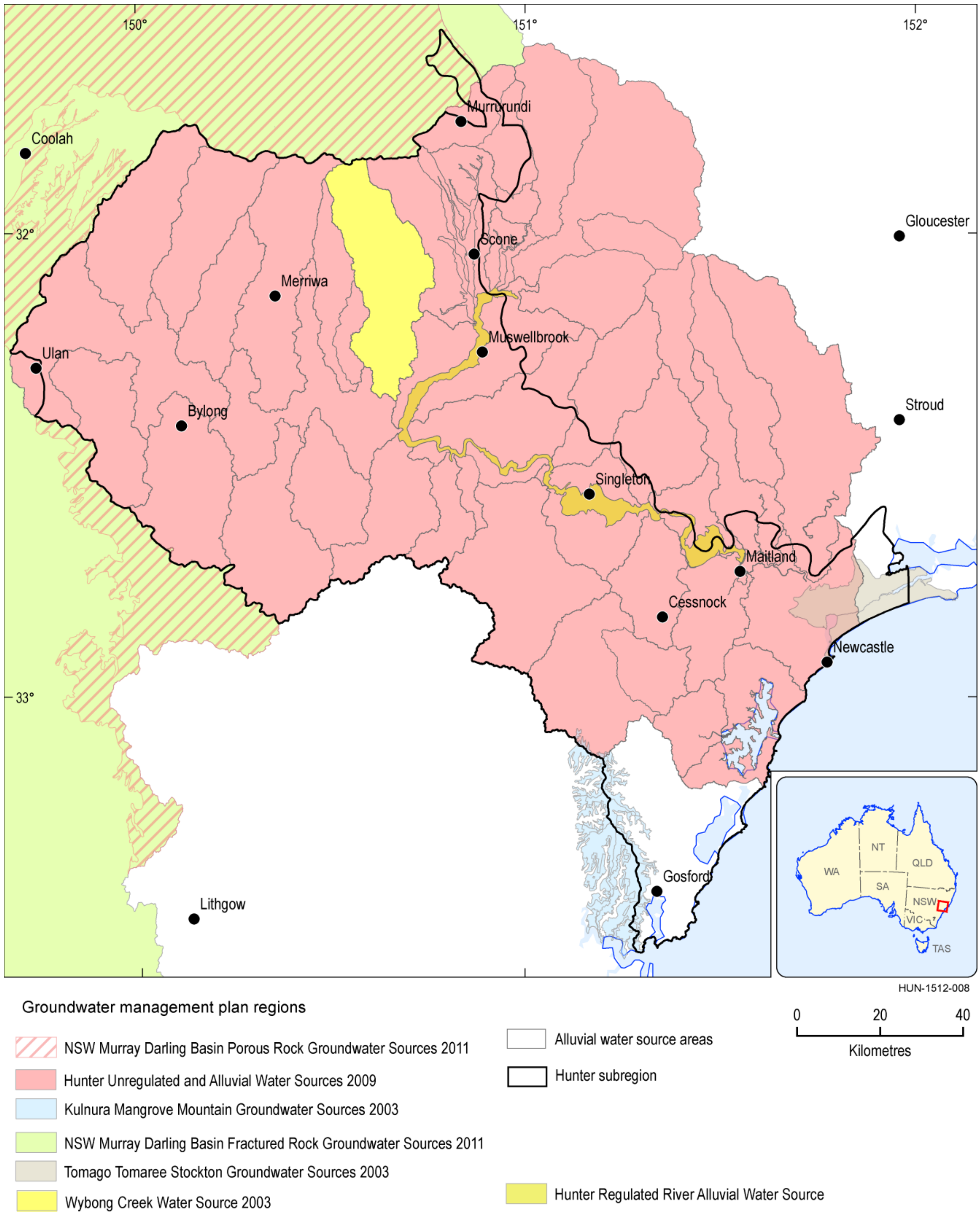

Figure 10 Water sharing plans for managing groundwater resources in the Hunter subregion

Data: NSW Office of Water (Dataset 3, Dataset 4)

Table 11 Groundwater entitlements at 24 March 2015 and estimated rainfall recharge by water source

Listed in descending order of total licensed entitlements. The boundaries of the areas covered by these water sharing plans extend beyond the Hunter subregion.

Water sharing plan	Water source	Number of licences[c]	Licensed entitlement (GL/y)	Estimated rainfall recharge (GL/y)[d]
Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009	Hunter Regulated River Alluvial	220	29.05	NA
	Dart Brook[a]	Not supplied	28.07	8.93
	Bylong River	29	7.71	2.58
	Pages River[a]	4	7.4	3.3
	Lower Wollombi	41	3.7	5.57
	Lower Goulburn River	27	3.09	2.8
	Baerami Creek	16	2.52	1.15
	Wybong Creek[b]	25	2.24	NA
	Merriwa River	12	1.9	2.52
	Martindale Creek	21	1.58	0.31
	Jerrys[a]	9	1.24	NA
	Widden Brook	6	1.2	1.9
	Muswellbrook[a]	14	1.17	NA
	Wollar Creek	3	0.78	0.85
	Halls Creek	11	0.69	NA
	Doyles Creek	5	0.29	0.13
	Singleton	2	0.23	NA
	Upper Goulburn River	2	0.1	3.83
	Newcastle[a]	1	0.09	NA
	Upper Wollombi Brook	4	0.07	3.13
	Williams River[a]	0	0.07	NA
	Glendon Brook[a]	3	0.06	NA
	Munmurra River	2	0.02	0.36
	Glennies[a]	1	0.01	NA
	Luskintyre[a]	3	0.01	NA
	Bow River	1	<0.01	0.4
	Wallis Creek	1	<0.01	NA
	Total	**463**	**93.31**	

[a]Only a portion of the water source falls within the Hunter subregion.
[b]This water source was set to be merged in 2015 with the water sharing plan for the Hunter Unregulated and Alluvial water sources.
[c]Includes only licences in the subregion (current February 2016)
[d]NSW Department of Water and Energy (2009)
NA = data not available
Data: NSW Office of Water (Dataset 1)

The accessible aquifer volume for the Tomago Sandbeds is 60 GL from a maximum storage volume of about 100 GL (Hunter Water Corporation, 2011). Under the WSP for the Tomago Tomaree Stockton Groundwater Sources 2003, long-term average annual extraction limits (LTAAEL) have been set at 25 GL/year for Tomago, 6 GL/year for Tomaree and 14 GL/year for Stockton sandbeds (NSW Government, 2003).

The WSP for the Kulnura Mangrove Mountain Groundwater Sources provides LTAAEL for eight water sources within the plan area. In total, this has been set at 6.29 GL/year (NSW Department of Primary Industries, 2013).

Based on the aforementioned licensed entitlement volumes and LTAAEL for the main groundwater source areas in the Hunter subregion, the groundwater available for extraction is about 145 GL/year, with an unspecified volume permitted from fractured and porous rock aquifers under basic water rights.

To obtain an estimate of the total volume of water licensed to be extracted from groundwater within the Hunter subregion, the water entitlement volumes for every bore in the Hunter assets database (Bioregional Assessment Programme, Dataset 2) were summed. A total of 128.46 GL of groundwater is potentially available for extraction each year. This estimate includes bores in porous and fractured rock aquifers not covered by current WSPs, so cannot be directly related to the licensed entitlement volumes by water source area in Table 11 and preceding paragraphs. Again, this total does not include basic water rights for domestic and stock use (around 2389 bores in Bioregional Assessment Programme, Dataset 2), for which the volume of take is not specified but generally assumed to be 2 ML/year per bore (Realica-Turner, *In prep.*), translating to not more than about 4.8 GL/year across all domestic and stock bores.

Recharge

Recharge is the addition of water to a groundwater system. It usually comes from rainfall and surface water bodies, such as rivers and lakes, but can also come from adjacent groundwater systems. Long-term mean annual rainfall recharge is often used as the basis for defining LTAAEL for groundwater sources and is an important term of a groundwater account. Rainfall recharge rates are reported in report cards (NSW Department of Water and Energy, 2009) for some of the water source areas covered by the Hunter Unregulated and Alluvial Water Sources WSP, and have been provided in Table 11. However, in a recently released report on macro WSPs to assist community consultations (DPI Water, 2015b), DPI Water provides recharge estimation principles, as a basis for water sharing in groundwater sources in NSW that take account of factors other than just rainfall recharge. In coastal NSW, the long-term mean annual rainfall recharge remains the basis for water sharing in fractured rock, porous rock and coastal sands aquifers. The broad approach to calculating mean annual recharge is to multiply mean annual rainfall by an infiltration factor. For coastal sands, the infiltration factor is 30%, coastal alluvials 10%, coastal porous rock up to 6% and fractured rock 4%, although these can be varied based on more local information.

Rainfall recharge is not the basis for water sharing in coastal upland alluvial aquifers, such as those covered by the Hunter Unregulated and Alluvial Water Sources WSP. These alluvial aquifers are managed conjunctively with the surface water system and the LTAAEL is based on current entitlements.

Estimates of recharge across the Hunter subregion have been generated specifically for the purposes of the Hunter subregion Bioregional Assessment. One output of the landscape water balance model (AWRA-L), is a gridded surface of deep drainage, which can be equated to recharge (see companion product 2.6.1 for the Hunter subregion (Zhang et al., 2016)). The chloride mass balance method (Anderson, 1945) has been used to estimate a recharge surface for the Hunter subregion (see Section 2.1.3 of companion product 2.1-2.2 for the Hunter subregion (Herron et al., 2016)).

Groundwater use

Figure 11 shows the distribution of bores across the Hunter subregion, classed by purpose (Bioregional Assessment Programme, Dataset 2; NSW Office of Water, Dataset 5). Bores for irrigation water use are concentrated along the main rivers; town water supply bores are localised, but with a high number in the populated areas along the coast; domestic and stock bores are scattered across the subregion and mining bores occur at various locations across the subregion.

Table 12 shows the licensed entitlement volumes grouped by purpose (basic water rights under the Water Act are not included). Of the 128.46 GL/year of licensed groundwater entitlements, mining has the highest share with 51.08 GL/year (40%), followed by irrigation bores with an estimated volume of 46.17 ML/year (36%). Most of the remainder support town water supply, domestic and stock uses or have an unspecified use.

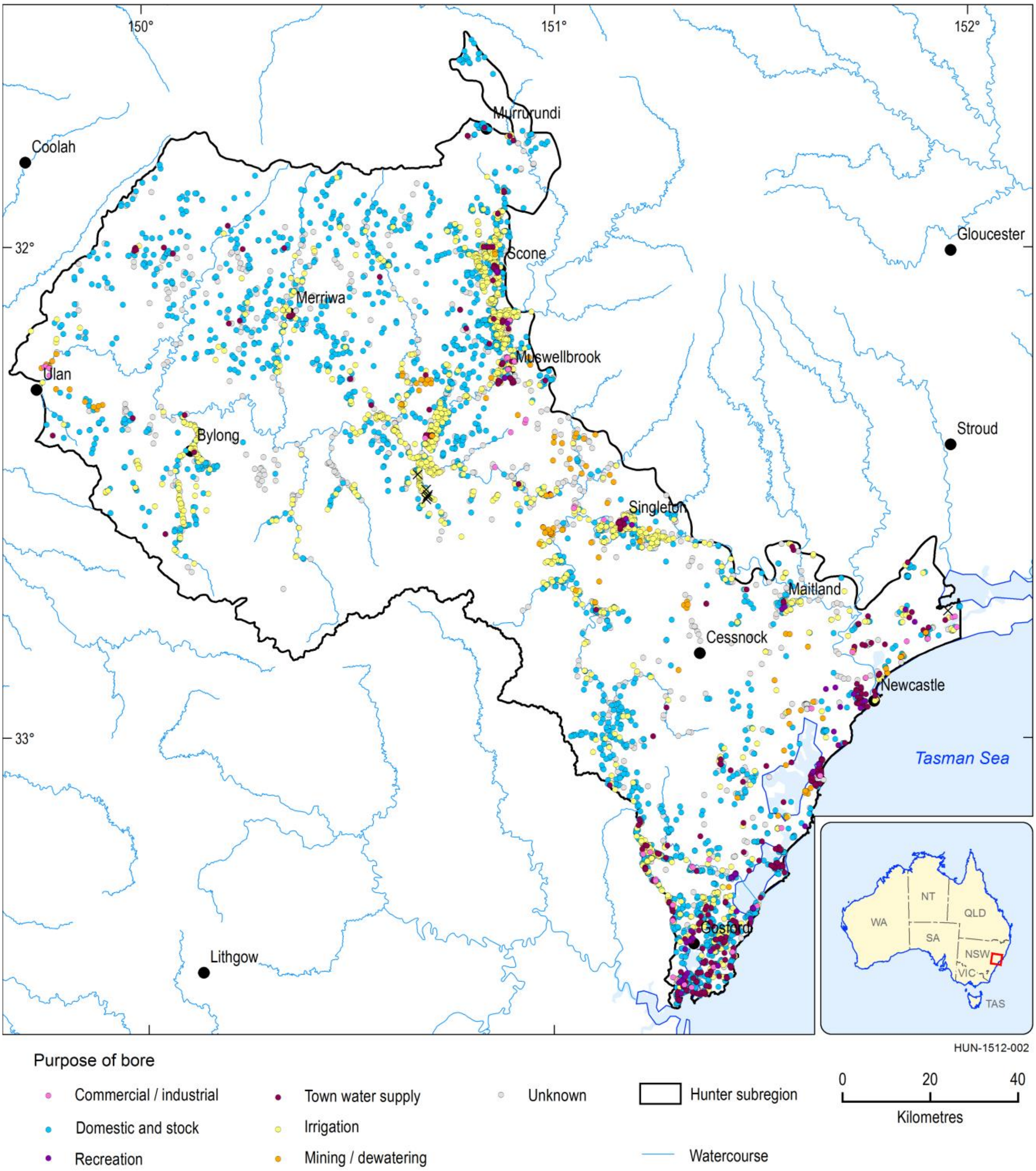

Figure 11 Distribution of purpose of bores in the Hunter subregion as per the National Groundwater Information System (NGIS) database

Data: Bioregional Assessment Programme (Dataset 2); NSW Office of Water (Dataset 5)

Very little metered data are available to quantify actual extraction volumes. The licensed entitlement volumes represent the maximum permissible take from a groundwater source, rather than the actual take in any given year. Estimates of use based on these volumes will likely over-estimate actual use in any given year, as rates of extraction tend to be lower than the permissible take (S Realica-Turner (DPI Water), 2015, pers. comm.).

In addition to use under licensed entitlement, there are many groundwater bores that supply water for domestic and stock use under a basic water right, for which an annual volume of take is not specified. As previously stated, estimates of take for domestic and stock use are assumed to be 2 ML/year per bore, or not more than 4.8 GL/year across all domestic and stock bores.

Table 12 Groundwater entitlements by licensed purpose for the Hunter subregion

Purpose	Percentage of number of bores	Licensed entitlement (GL/y)
Mining and dewatering[a]	2.2%	51.08
Irrigation	21.6%	46.17
Unknown	22.2%	16.32
Town water supply[b]	6.8%	7.04
Domestic and stock	45.3%	6.75[d]
Recreational	0.9%	0.86
Industrial[c] and Commercial	1.0%	0.24
Total	**100%**	**128.46**

[a]may also include exploration
[b]may also include industrial
[c]may also include mining
[d]does not include basic water rights
Data: Bioregional Assessment Programme (Dataset 2)

1.5.1.2.2 Gaps

The storage capacity and volume of water stored in some aquifers are often unknown, which means quantifying the available groundwater store is difficult. From a water accounting perspective, availability is better defined in terms of the LTAAEL or the volume held under water access and basic water rights. Typically, the viable, high-demand groundwater resources in NSW have had WSPs developed for them (e.g. alluvial aquifers in the Hunter River; Tomago Tomaree Stockton coastal sands aquifers) to manage the resources within sustainable extraction limits. In fractured and porous rock aquifers where water availability is often poorly quantified, current levels of entitlements may not be sustainable. The embargo on new groundwater access licences in the Hunter subregion since 5 February 2016 reflects the mismatch between availability and existing licensed entitlement volumes. A water sharing plan for the North Coast Fractured and Porous Rock Groundwater Sources is under development.

Catchment recharge estimates are not available for all of the Hunter subregion, however, DPI Water has defined a broad approach for calculating mean annual rainfall recharge (DPI Water, 2015b), which could be applied to the subregion. Estimates of recharge across the subregion using chloride mass balance methods and landscape water balance modelling have been undertaken, which goes some way to addressing the current data gap.

Information on stratigraphy and screened intervals was not available for any of the bores located in the Hunter subregion. This information would provide a more reliable basis for estimating groundwater use by aquifer type.

For bores with water licences, if actual usage data were to become available this would assist in the provision of a more accurate representation of the distribution of groundwater use for some bores within the Hunter subregion. The uncertainty arising from not having accurate groundwater extractions data will be included in the uncertainty analyses undertaken as part of the bioregional assessment (BA) modelling.

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1.5.2 Water quality

Summary

Poor water quality due to high salt concentrations has been a considerable issue in parts of the Hunter river basin. This is largely a consequence of geological conditions, but may have been exacerbated in the Hunter River by discharges of saline groundwater from mining operations and rising groundwater levels from past land clearing. The Hunter River Salinity Trading Scheme (HRSTS) was introduced in 1995 to minimise the impact of saline water discharges from industry.

This section reports stream salinity from monitoring throughout the Hunter river basin, with particular focus on three gauging stations on the Hunter Regulated River (Denman, Glennies Creek and Singleton). Salinity levels are typically fresh in the north-east of the river basin, which has important water supply catchments. Higher salinities occur in Wybong and Goulburn rivers and around Lake Liddell. Along the Hunter Regulated River, mean electrical conductivities between 1995 and 2013 varied from around 600 µS/cm at Denman to 750 µS/cm at Glennies Creek to 640 µS/cm at Singleton. All sites exhibit high variability, particularly at low flows when baseflow discharges dominate the streamflow response.

The groundwater quality data available for the Hunter subregion were generally poor and difficult to draw firm conclusions from. Analysis of the available salinity data indicated that salinity in the coastal sands aquifer was on average lower than in alluvial and fractured rock aquifers. The results are not statistically significant as they are based on five samples only. There are large ranges in salinity in the alluvial (21 to 14,500 µS/cm) and fractured rock aquifers (29 to 48,600 µS/cm) but major errors were found in the dataset that undermine confidence in these ranges. For most samples, the hydrostratigraphic unit from which they were obtained was not known. Possibilities for beneficial use of water are provided based on median electrical conductivity values.

Some trace element data are presented for groundwater, but it is difficult to provide meaningful interpretation given the limited number of samples for some elements and lack of information about the water sources sampled and origins of the trace elements.

1.5.2.1 Surface water

This section summarises surface water quality information in the Hunter river basin only. No water quality information was available for the Macquarie-Tuggerah lakes basin.

Surface water quality can be affected by most changes in land cover or land use. The removal of vegetation and creation of bare areas (e.g. for agriculture, roads, quarries, urban development) can lead to soil erosion and changes in suspended sediments, turbidity, phosphorus (P) and nitrogen (N) within waterways. The use of fertilisers and pesticides in agriculture can contribute to elevated N, P and other pollutant levels in runoff. Point-source runoff from intensive animal production and industrial discharge of waste directly to streams impact stream water quality. Stratification of water stored in large reservoirs can alter water temperatures. Draining of lowlying land to reduce water-logging can lead to the development of acid sulfate soils and highly acidic discharges to streams, affecting stream pH.

Coal resource development can impact water quality through changes to runoff following vegetation removal (e.g. areas cleared of vegetation, service roads, and site processing facilities), discharge of mine waters into waterways and leaking of hydrocarbons. Changes in streamflow from coal mining induced groundwater drawdown may also impact surface water quality. Salinity, turbidity, suspended solids, pH, heavy metal and hydrocarbon concentrations are all potentially affected. Key aims of mine water management are containment of runoff on-site and restrictions on mine water discharges to periods when off-site impacts are minimised.

Salinity is measured by the ability of soluble salts to transmit an electric current (electrical conductivity or EC) quantified in microsiemens per centimetre (µS/cm). The focus of this section is EC data because salinity is a significant water quality issue for the region. Coal mines in the Hunter subregion have been identified as potentially significant exporters of salt because the salinity of groundwater pumped from aquifers intercepted by mining excavations can significantly exceed that of the rivers to which it is discharged.

Since 2007, DPI Water has been routinely monitoring ambient water quality across the Hunter river basin as part of the State Water Quality Assessment and Monitoring Program (SWAMP). Monthly monitoring of temperature, dissolved oxygen (DO), EC, pH, turbidity, total nitrogen (TN) and total phosphorus (TP) is undertaken at nine stream gauging locations in the Hunter river basin. DPI Water does not undertake any monitoring in the Macquarie-Tuggerah lakes basin, but is supplied with water quality data (including EC, pH, turbidity, TP, ortho-P and total oxidised N) collected by Wyong Council at one of its monitoring sites (gauging station number 211009, Wyong River at Gracemere).

Water quality data are collected or held by other organisations. Section 1.5.2.1.3 provides details of some of the water quality variables that have been collected in the Hunter subregion by different agencies. Analyses of these data are not presented here because the number and frequency of samples and details about the data collection programme are not sufficient to provide meaningful assessments of water quality for these parameters.

1.5.2.1.1 Stream salinities across the Hunter subregion

The salinity of water in the Hunter River and its tributaries varies considerably, with some of the tributaries having very good quality water and others having relatively high salt concentrations. The dominant source of salts in the Hunter river basin are the Permian sedimentary rocks, which were deposited by a series of marine transgressions and therefore have a high salt content. Where the main corridor of the Hunter River valley has eroded into these Permian rocks, surface and groundwater discharges to the Hunter River have contributed to naturally high salinity levels.

Other lesser sources of river salinity in the Hunter river basin (Environment Protection Authority, 2013) include rainfall, atmospheric deposition, runoff and infiltration.

Recent changes in land cover and use in the river basin may have contributed to rising groundwater levels in some areas and an increase in the discharge of salt to streams (Environment Protection Authority, 2013). These anthropogenic land use changes include coal resource development (e.g. areas cleared of vegetation, service roads, and site processing facilities), power generation and agriculture. In particular, there has been concern in the community about the impact of mine water discharges on stream salinities in the Hunter River and implications for other users of river water. Crops vary considerably in their tolerance to saline water, but most crops can use water which has an EC value of up to about 700 µS/cm without loss of yield. However, for grapevines, an important commodity in the Hunter subregion, the threshold beyond which yields start to decline is about 1000 µS/cm; yields for lucerne start to decline at about 1300 µS/cm (NSW Department of Primary Industries, 2014a).

The Hunter River Salinity Trading Scheme (HRSTS) was introduced in 1995 to manage saline discharges from industry in the Hunter Regulated River downstream of Glenbawn Dam to Singleton. Under the scheme, industries are permitted to discharge industrial water to the river in a way that maintains the salinity of the river within acceptable limits. Thus, when the river is in low flow, no discharge is allowed; when the river is in high flow, limited discharge is allowed; and when the river is in flood, unlimited discharge is allowed. The total volume of salt permitted to be discharged by those in HRSTS is capped at 1000 salt discharge credits. Credits can be traded among licence holders. This gives each licence holder the flexibility to increase or decrease their allowable discharge from time to time. The impacts of HRSTS on stream salinities are not the focus of this section. A recent report by the Environment Protection Authority (2013) suggested that the scheme has had little impact on stream salinities.

The section provides:

- details of salinity data available in the Hunter river basin from continuous monitoring at gauging stations (Bioregional Assessment Programme, Dataset 1)
- an overview of stream salinities across the Hunter subregion
- a more detailed look at salinities in the regulated Hunter River through analysis of salinity data from three sites along the Hunter River (Denman, Glennies Creek, Singleton).

There are 23 gauging stations which have more than 10 years of river salinity data in the Hunter river basin. Table 13 summarises the gauging stations and dates where EC levels are recorded at 15-minute intervals by DPI Water. The locations of these monitoring stations are shown in Figure 12.

Table 13 Gauging stations and period for which electrical conductivity data are available for the Hunter subregion

Bold font indicates reference gauging stations used for monitoring impacts of the Hunter River Salinity Trading Scheme.

Gauging station number	Gauging station name	Electrical conductivity data	
		Start date	End date[a]
210002	Hunter River at Muswellbrook Bridge	21 Feb 1992	26 Aug 2013
210004	Wollombi Brook at Warkworth	31 Jan 1992	29 May 2013
210015	Hunter River at Glenbawn	30 Apr 1996	10 Jul 2013
210016	Goulburn River at Kerrabee	27 Jul 2002	14 Aug 2013
210021	Paterson River D/S Lostock Dam	24 Apr 1997	28 Aug 2013
210031	Goulburn River at Sandy Hollow	3 Feb 1992	27 Aug 2013
210039	Hunter River at Belltrees	4 Aug 1999	11 Jul 2013
210040	Wybong Creek at Wybong	7 Jul 1993	26 Aug 2013
210044	Glennies Creek at Middle Falbrook	11 Feb 1993	16 Nov 2012
210055	**Hunter River at Denman**	**13 Feb 1993**	**27 Aug 2013**
210056	Hunter River at Aberdeen	21 Mar 1998	10 Jul 2013
210064	Hunter River at Greta	1 Feb 1992	16 Aug 2013
210076	Aniene Creek at Liddell	1 Apr 1993	25 Jan 2013
210079	Paterson River at Gostwyck	6 Jul 2002	12 July 2013
210083	Hunter River at Liddell	16 Feb 1991	30 Aug 2013
210084	Glennies The Rocks No.2	15 May 1997	10 Dec 2012
210110	Bayswater at Liddell	20 Jan 1994	10 Dec 2012
210114	Carrow Brook	29 Sep 1999	15 Nov 2012
210123	U/S Glennies Creek Dam	13 Aug 1999	4 Mar 2006
210127	**Hunter River U/S Glennies Creek**	**25 Jun 1993**	**17 Apr 2013**
210128	Hunter River at Mason Dieu	27 Jul 1993	22 Nov 2000
210129	**Hunter River U/S Singleton**	**9 Feb 1993**	**2 Jul 2013**
210134	Hunter River at Long Point	29 Oct 1993	3 Jul 2013

[a]End dates are not always indicative of end of records, but of cut-off dates for inclusion in published datasets.
D/S = downstream of; U/S = upstream of
Data: Bioregional Assessment Programme (Dataset 1)

Figure 12 Surface drainage network, dams and surface water quality gauges within the Hunter subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4, Dataset 5)

Figure 13 shows the spatial distribution of median daily EC at the 23 gauges. For the Hunter River's northern tributaries, which feed into Glenbawn, Glennies Creek and Lostock storages, water quality is good and suitable for all uses, with median daily EC less than 400 µS/cm. Along the regulated section of the Hunter River median river salinities are higher, but within the 400 to 800 µS/cm range, which means the water is fit for most uses. Water entering the Hunter River from the Goulburn River in the western part of the river basin tends to be of lower quality with potentially some limitations on its use. Median salinities at gauging stations 210016 and 210031 on the Goulburn River are between 800 and 1200 µS/cm, and at gauging station 210040 on Wybong Creek, a tributary to the Goulburn River, in the 1200 to 2000 µS/cm salinity range. Streamflow in Wybong Creek is relatively low, but the Goulburn River contributes a significant volume to the Hunter River and would contribute to the increase in Hunter River salinities between Muswellbrook and Singleton. The highest stream salinities are recorded at two gauges (210076 and 210110) in the vicinity of Lake Liddell, with median daily ECs exceeding 2000 µS/cm.

Figure 13 Spatial distribution of daily electrical conductivity (EC) median at the 23 surface water quality gauges within the Hunter subregion

Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4, Dataset 5, Dataset 6)

1.5.2.1.2 Salinity in the Hunter Regulated River

Salinity along the regulated part of the Hunter River is of particular interest because some of its tributaries have elevated stream salinities, it is a highly utilised water source, a receiving water body for discharges from industry and the focus of the Hunter River Salinity Trading Scheme (HRSTS). Prior to its introduction, irrigators were becoming increasingly concerned that saline discharges from the mining industry were increasing salinity in the river to a level unsuitable for irrigation.

Denman (210055), Glennies Creek (210127) and Singleton (210129) stream gauging stations are used as the reference sites along the Hunter River to monitor salinity levels relative to water quality objectives (NSW Department of Primary Industries, 2014b). The locations of these three reference gauging stations are shown in Figure 12. The flow ranges and salinity objectives for the three are summarised in Table 14.

Table 14 Hunter River streamflow categories and electrical conductivity thresholds for the Hunter River Salinity Trading Scheme (HRSTS)

Sector	Sector reference point	Low streamflow		High streamflow		Flood streamflow	
		Range (ML/d)	EC threshold (µS/cm)	Range (ML/d)	EC threshold (µS/cm)	Range (ML/d)	EC threshold (µS/cm)
Upper	Denman (210055)	0–1,000	Not applicable	1,000–4,000	900	>4,000	600
Middle	Glennies Creek (210127)	0–1,800	Not applicable	1,800–6,000	900	>6,000	900
Lower	Singleton (210129)	0–2,000	Not applicable	2,000–10,000	900	>10,000	900

EC = electrical conductivity
Source: derived from NSW Department of Primary Industries (2014b)

Figure 14 to Figure 16 show time series of EC between 1995 and 2013 at Denman, Glennies Creek and Singleton, respectively. In all three salinity time series, a strong seasonal signal is evident with perhaps a longer three- to five-year cycle as well. At the three locations, salinities between 2001 and 2007 were on average lower and less variable than at other times in the record. This change corresponds to a dry period when flows in the river were dependent mainly on releases of relatively fresh water. In June 2007, a major storm occurred (often referred to as the Pasha Bulker event) which led to flood flows in the Hunter River. The sudden spike in river salinity after this event reflects the flushing of accumulated salts in the tributary streams, following an extended dry period. The pattern of on average higher, more variable salinity since June 2007 is consistent with a wetter period flow regime, when tributary inflows dominate Hunter River flows and dam releases are minimal.

At Denman (Figure 14), salinity levels have not exceeded 1200 µS/cm at any time during the period of record. Between 1995 and 2000, they averaged around 540 µS/cm. The period between 2000 and 2006 was characterised by on average lower salinity (465 µS/cm), and was followed by an increase in salinity from about 2007 to levels that are on average higher (621 µS/cm) than during the earlier periods of record.

At Glennies Creek (Figure 15), the salinity pattern is similar to that at Denman, but with higher mean salinity (750 µS/cm). Salinities have exceeded 1200 µS/cm on a number of occasions since 2007 and have regularly exceeded 900 µS/cm since 2007.

At Singleton (Figure 16), the stream salinity pattern is similar to Denman, but on average higher than at Denman and lower than at Glennies Creek (642 µS/cm). Stream salinities regularly exceed 900 µS/cm but have only exceeded 1200 µS/cm on one occasion. Salinities are lower than at Glennies Creek gauging station, most likely due to inflows from Wollombi Brook downstream of Glennies Creek.

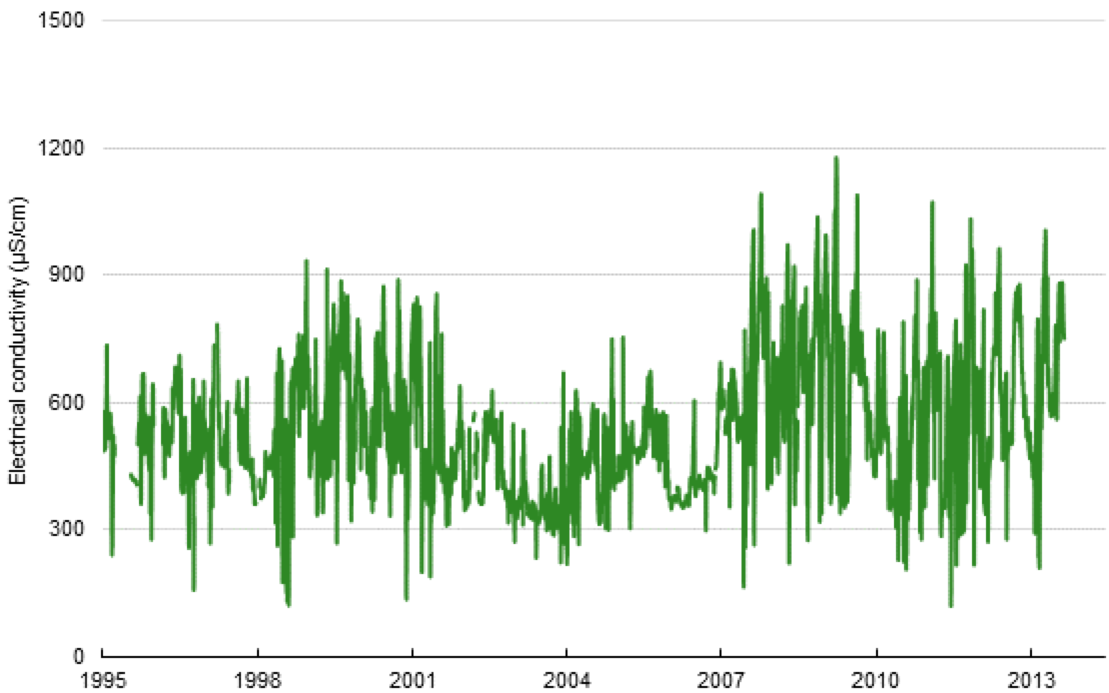

Figure 14 Time series of daily electrical conductivity of the Hunter River at Denman (210055)

Data: Bioregional Assessment Programme (Dataset 1)

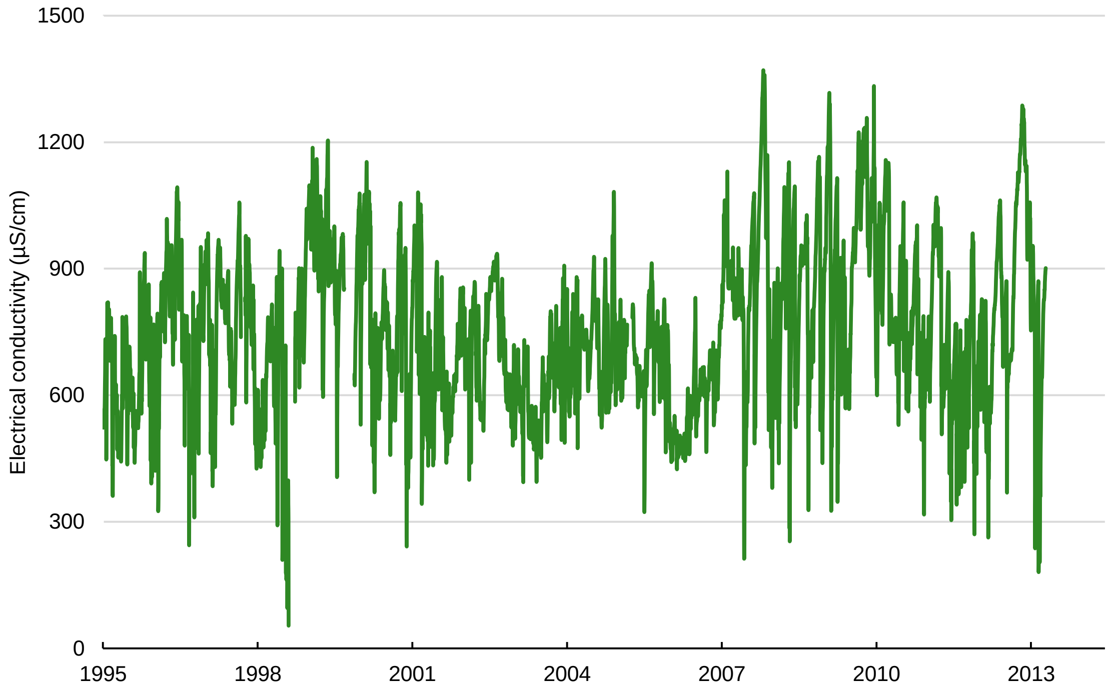

Figure 15 Time series of daily electrical conductivity of the Hunter River at Glennies Creek (210127)

Data: Bioregional Assessment Programme (Dataset 1)

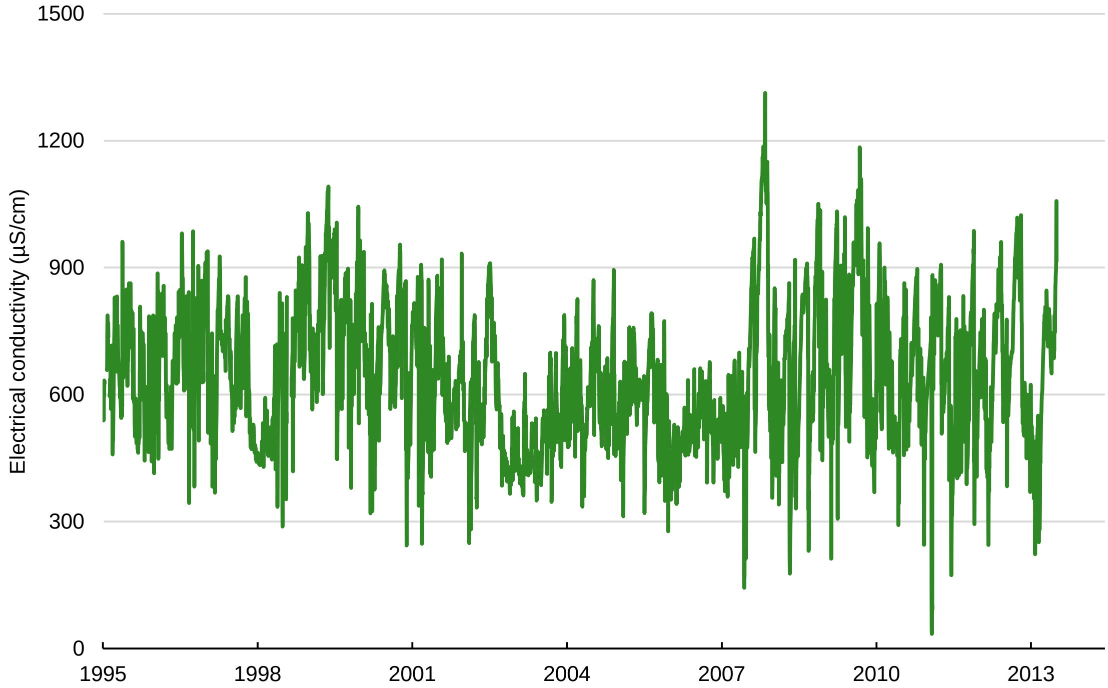

Figure 16 Time series of daily electrical conductivity of the Hunter River at Singleton (210129)

Data: Bioregional Assessment Programme (Dataset 1)

In Figure 17, the daily salinity data from the three reference sites are plotted as exceedance curves, which describe the proportion of observations that exceed different salinities. At Denman, salinity levels exceeded 600 µS/cm for 30% of observations in the period 1995 to 2013, and exceeded 900 µS/cm for 2% of EC observations in that period. Salinities exceeded 900 µS/cm at Glennies Creek for 20% of observations and at Singleton for 6% of observations.

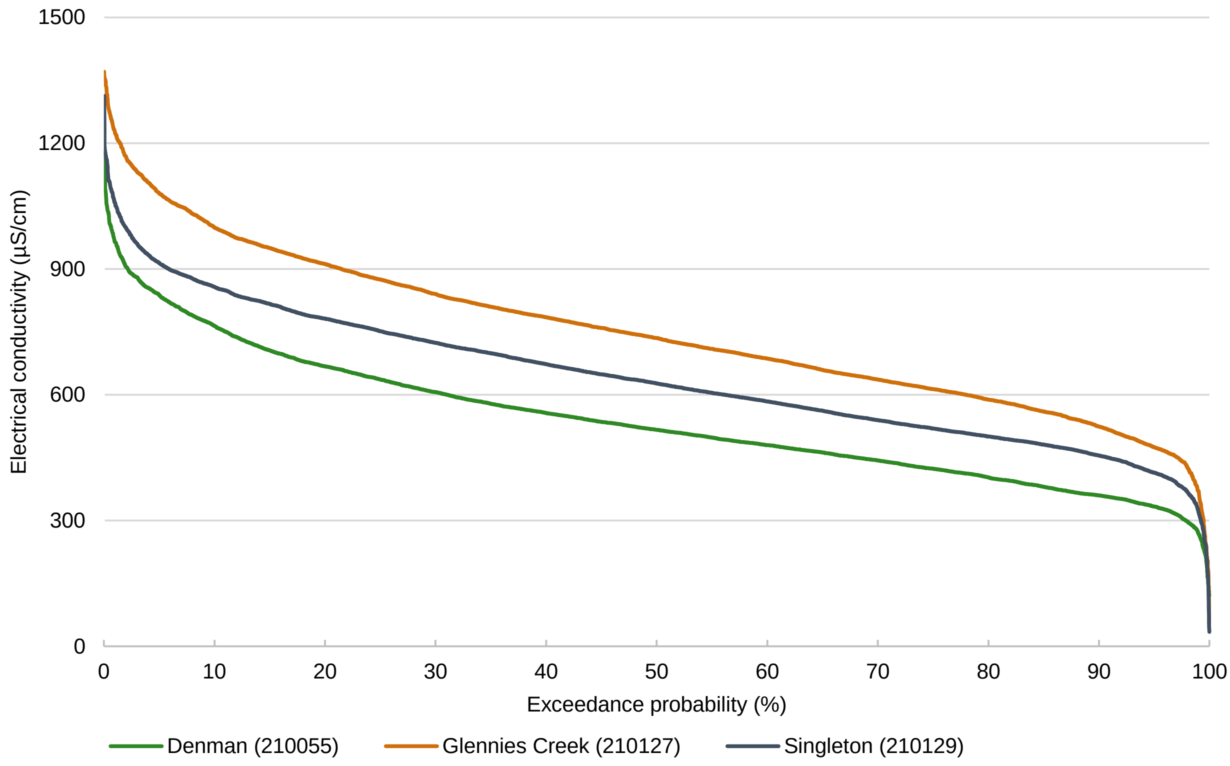

Figure 17 Electrical conductivity (µS/cm) exceedance curves at the three reference sites

Data: Bioregional Assessment Programme (Dataset 1)

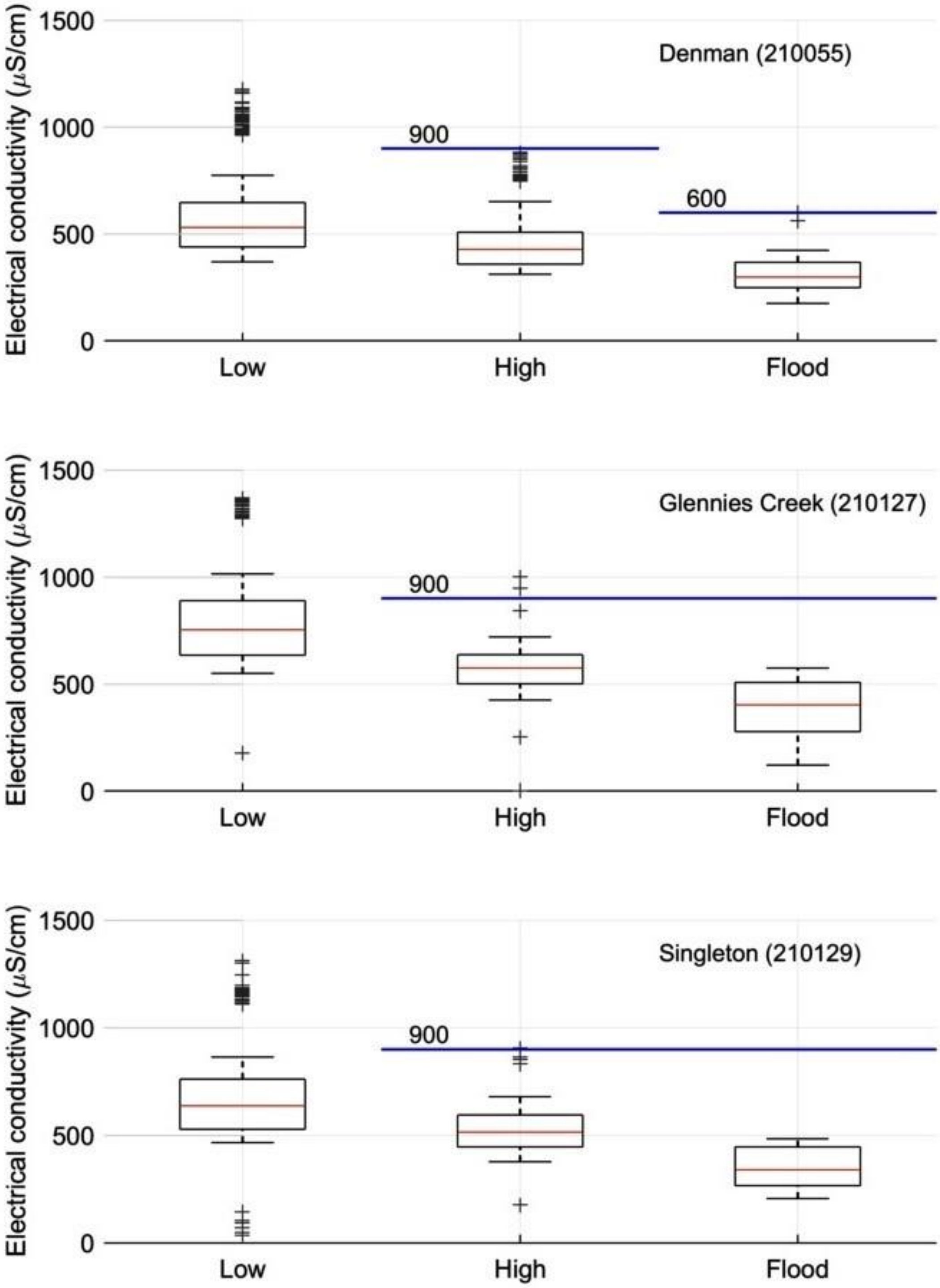

Figure 18 Summary of electrical conductivity of the Hunter River for the three streamflow categories (Table 14) for the three reference sites between 1995 and 2013

For each box, bottom, middle and top are the 25th, 50th and 75th percentiles, respectively, and the bottom and top whiskers are the 10th and 90th percentiles, respectively. Outliers are indicated with a black cross.
Data: Bioregional Assessment Programme (Dataset 1)

Figure 18 summarises the salinity data by streamflow category (Table 14) at the three reference sites. Presented this way, the pattern of decreasing salinity levels with increasing streamflow is evident, reflecting the change from the more saline, baseflow-dominated regime at low flows to the less saline, quickflow-dominated response at higher flows. At Denman during low flows, the range of recorded salinities is mostly between 450 and 650 µS/cm. At high streamflow and flood flows, the salinity targets of 900 µS/cm and 600 µS/cm, respectively, were not exceeded during the period of record. Downstream at the Glennies Creek and Singleton gauging stations, low flow salinities are almost always higher than 500 µS/cm, but tend to be around 500 to 600 µS/cm at high streamflow. At Glennies Creek there are two recorded occasions when salinity levels exceeded the target threshold of 900 µS/cm under high streamflow conditions, whereas at Singleton, stream salinities never exceeded the target threshold.

1.5.2.1.3 Other water quality data

As previously stated, DPI Water undertakes monthly monitoring of temperature, DO, EC, pH, turbidity, TN and TP at nine gauging stations within the Hunter river basin.

The Bureau of Meteorology is mandated to collect water information from organisations across Australia, which are named in the Water Regulations 2008, with a view to establishing a national water information system. Water quality data is one of the categories of data the Bureau of Meteorology collects. The Bureau of Meteorology surveyed water data collection agencies around Australia to establish what water information agencies collect or have historically collected and could provide to it. Results of the survey indicated that a range of water quality data are or have been collected in the Hunter subregion, although not all of the data have been supplied to the Bureau of Meteorology (Table 15) (C Price (Bureau of Meteorology), 2015, pers. comm.).

Table 15 shows that there are a number of sources of information about surface water quality in the Hunter subregion. Some of these measurements would be to monitor water quality for drinking water and safe swimming conditions (e.g. Gosford City Council). Other water quality parameters, such as TP, TN, total suspended solids (TSS) and temperature, are collected to ensure safe levels for aquatic habitat. The types of data collected provide some indication of the water quality concerns in the subregion. Except for EC, the water quality parameters collected do not specifically reflect issues arising from mining development.

Table 15 Surface water quality parameters collected by water data organisations for the Hunter subregion

Agency	Water quality variables	Details
DPI Water	EC, temperature, pH	Ongoing, continuous monitoring (Bioregional Assessment Programme, Dataset 1)
	DO, turbidity, TN and TP	Since 2007, monthly readings at 9 gauging stations in the Hunter Data not supplied to the Bureau of Meteorology
NSW Office of Environment and Heritage	EC, temperature, pH, TP, Turbidity	Historic (1994–2006): 130 samples in Hunter subregion across 52 sites across ~60 dates (NSW Office of Environment and Heritage, Dataset 7)
WaterNSW (formerly State Water Corporation)	EC, temperature	Send their data to NSW DPI Water (might be part of Bioregional Assessment Programme, Dataset 1)
Hunter Water Corporation	EC, temperature, pH, TSS, TP, TN,	Not sent to Bureau of Meteorology
Hunter Local Land Services (formerly Hunter-Central Rivers Catchment Management Authority)	EC, TDS	Black Creek and Glendon Brook (2007–2009) Discrete Non-ongoing (Hunter Local Land Services, Dataset 8)
Gosford City Council	EC, temperature, pH, TSS, TP, TN, Turbidity, DO, OP, TKN, NOx, Ammonia N, BOD, Chlorophyll a, Enterococci, Coliforms	Lab analyses reports (PDF) (2008–2009) Discrete (Gosford City Council, Dataset 9)
Wyong Shire Council	EC, temperature, pH, TSS, TP, TN Turbidity	Weekly (discrete) (2008–2014) for Ourimbah Creek and Wyong River water pump stations (Wyong Shire Council, Dataset 10)

EC = electrical conductivity; TSS = total suspended solids; TP = total phosphorus; TN = total nitrogen; TDS = total dissolved solids; DO = dissolved oxygen; OP = ortho-phosphorus; TKN = total Kjeldahl nitrogen; NOx = nitrogen oxides

Water quality data are often collected by mining companies, as part of environmental assessment and monitoring requirements to obtain and meet conditions of a mining licence. This information was not sought or obtained as part of the Assessment. Water quality data are often collected by local councils, universities, local land services and other organisations, particularly where water is being used for drinking water supply or for recreational purposes and particular standards are required to be maintained. A search for these data was also not undertaken. Project-specific water quality data can be very difficult to interpret, due to issues of sampling frequency, length of monitoring, lack of accompanying flow data and lack of information about the objectives of sampling. The data can take a lot of time to sift through and understand and will often not be sufficient to build a regional view of water quality.

1.5.2.1.4 Gaps

Electrical conductivity data are not available for all tributaries of the Hunter River. At the 23 long-term observation sites where data are available, there are gaps in the EC record.

Electrical conductivity and other water quality data were not available for the Macquarie-Tuggerah lakes basin. Unlike at stream gauging locations in the Hunter river basin, DPI Water does not routinely collect data for the Macquarie-Tuggerah lakes basin but does receive data from Wyong Council monitoring on the Wyong River at Gracemere. Water quality issues tend to relate to quality of water for town water supply and for aquatic habitats in the coastal lakes. TN, TP and TSS are important factors in the health of seagrass beds.

The summary of Hunter subregion water quality data provided here is not exhaustive. Other water quality data are likely to be held by universities, mining companies, environmental consulting groups and other private organisations. While some of the mining data might be useful at a local scale for understanding water quality around mining sites, other data are expected to reflect community concern about coastal lake water quality issues arising from agricultural and urban runoff. As previously stated, project-specific water quality data can be difficult to interpret due to short-term, sparse records and/or lack of supporting information. The data can take a lot of time to sift through and understand and will often not be sufficient to build a regional view of water quality.

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1.5.2.2 Groundwater

This section presents information about groundwater quality in the Hunter subregion. Salinity is the major water quality issue in the Hunter subregion and more data are available for salinity than for other contaminants, hence the main focus of this section is groundwater salinity. While some information about select trace elements is presented, there is an insufficient number of samples for many of the elements and a lack of supporting information (e.g. aquifer depth, location of sample, purpose of sampling) to permit meaningful interpretation for BA purposes. Salinity and trace elements are not explicitly modelled for the Assessment in the Hunter subregion, but an understanding of the sources of contaminants and the hydrologic connectivity between saline aquifers, water supply aquifers and the river network would help to assess the impacts of mining development on water-dependent assets. Information about the major ion composition of groundwater in seven groundwater provinces in the Hunter subregion is reported in companion product 1.1 for the Hunter subregion (McVicar et al., 2015), together with a description of the hydrogeological units and conceptual understanding of hydrodynamics in the Hunter subregion.

1.5.2.2.1 Data

Groundwater chemistry data were compiled from the NSW water quality database (NSW Office of Water, Dataset 1). For the Hunter subregion, 7712 samples from 1278 bores were available, of which 7273 samples (94%) included salinity (electrical conductivity) measurements, but only a small number of samples included trace element measurements. This NSW groundwater database contains data from bores drilled in the early 1900s through to the present day. This is likely to mean that over the period of record, measurements have been made using different sample collection methodologies and analysis methods with implications for the consistency of data quality through time. Analysis of the salinity data revealed values that exceed the physical limits for salinities expressed in microsiemens per centimetre (µS/cm), suggesting that the dataset contains records using a mix of units. Since these extreme values all occurred prior to 1985, only samples collected after 1985 are summarised here. It is possible that there are still spurious records within the subsample used (i.e. values that are physically possible, but unusually low (e.g. 21) which could be in dS/m; or unusually high (e.g. 48,600) which could be in µS/m), and the assessment of water quality should be viewed as indicative. Where multiple records were available for individual bores, the data have been averaged. Groundwater salinities tend not to be as variable as streamflow salinities over time, so averages provide a useful indication of water quality.

None of the bores in Dataset 1 (NSW Office of Water, Dataset 1) are attributed to specific hydrogeological units. To summarise the groundwater chemistry data by aquifer type, each bore was assigned to a hydrogeological unit using the approach described in Section 1.5.1.2. The approach has limitations and some bores may be incorrectly assigned as a result. Location and drilled depth of bore were obtained from the NSW groundwater bore database collected for inclusion into the National Groundwater Information System (NGIS) (NSW Office of Water, Dataset 2).

To assist in the interpretation of water quality, the groundwater chemistry data have been classified according to suitability for a range of potential uses: human consumption, stock consumption and long-term irrigation (defined as up to 100 years). Threshold values were obtained from the Australian Drinking Water Guidelines (ADWG) (NHMRC and NRMMC, 2011) and the National Water Quality Management Strategy (NWQMS) (ANZECC/ARMCANZ, 2000).

Water quality data are often collected by mining companies as part of environmental assessment and monitoring requirements to obtain and meet conditions of a mining licence. This information was not sought nor obtained as part of the project.

1.5.2.2.2 Salinity

Salinity of groundwater is often expressed in terms of electrical conductivity (EC) in microsiemens per centimetre (µS/cm). To assist with the interpretation of values, sea water is typically around 55,000 µS/cm and water for human consumption not more than about 1,500 µS/cm. The µS/cm post-1985 salinity data for the Hunter subregion have been summarised by aquifer type in Table 16, including number of samples, mean, range and percentage of samples that exceed the different use categories in the guidelines (human consumption, irrigation and stock watering). Classification of bores into alluvial, coastal sands and fractured and porous rock aquifers was based on the method described in Section 1.5.1.2. While the coastal sands aquifers have the lowest salinities, the statistics are based on only five samples, so results are not statistically significant. The alluvial aquifers are on average fresher than the fractured rock aquifers, and water is almost always of a quality suitable for irrigation and stock use, although many crop species are sensitive to water salinities below the 8,000 µS/cm threshold and stock can be sensitive to salinities below the 20,000 µS/cm threshold. For example, yields from grapevines, an important crop in the Hunter subregion, start to decline when salinities exceed about 1000 µS/cm, and for lucerne when salinities exceed about 1300 µS/cm (NSW Department of Primary Industries, 2014). Similarly, beef and dairy cattle and horses, which are important stock in the Hunter subregion, can be sensitive to water salinities in the 6000 to 8000 µS/cm range. The maximum value for groundwater salinity of 48,600 µS/cm is high and may be a spurious value or be in different units, but high salinities are certainly associated with water contained within the Permian coal-bearing units and this water has very limited uses.

Table 16 Electrical conductivity (µS/cm) in the Hunter subregion compared to water guidelines

Aquifer	Number of samples	Minimum (µS/cm)	Maximum (µS/cm)	Mean (µS/cm)	Percentage of samples exceeding ADWG[a] threshold of 1,500 µS/cm (%)	Percentage of samples exceeding irrigation[b] threshold of 8,000 µS/cm (%)	Percentage of samples exceeding stock[c] threshold of 20,000 µS/cm (%)
Alluvial	1005	21	14,500	2,092	44%	2%	0%
Coastal sands	5	301	3,450	1,048	20%	0%	0%
Fractured rock	1458	29	48,600	4,777	62%	18%	4%

[a]Based on Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011) and approximate conversion from total dissolved solids (TDS) to electrical conductivity (EC) using conversion factor 0.64. TDS greater than 900 mg/L (~1476 µS/cm) is considered poor quality drinking water.
[b]Based on Table 4.2.5 in the National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[c]Based on National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000) and approximate conversion from TDS to EC. TDS greater than 13,000 mg/L (EC of ~20,000 µS/cm) is the maximum concentration when a decline in health of all stock would be expected (ANZECC/ARMCANZ, 2000, Table 4.3.1)
Data: NSW Office of Water (Dataset 1)

The EC data have been mapped by alluvial, coastal sands and fractured rock aquifer types in Figure 19, Figure 20 and Figure 21, respectively. No strong spatial patterns are evident from the mapped data. There appears to be more saline groundwater within the alluvial aquifers around Singleton, north of Muswellbrook and in the lower Goulburn. EC data for the coastal aquifers in Figure 20 are localised, and indicate that the groundwater aquifer north of Newcastle contains relatively fresh water. Some localised areas of higher groundwater salinity levels are evident in the fractured rock aquifers.

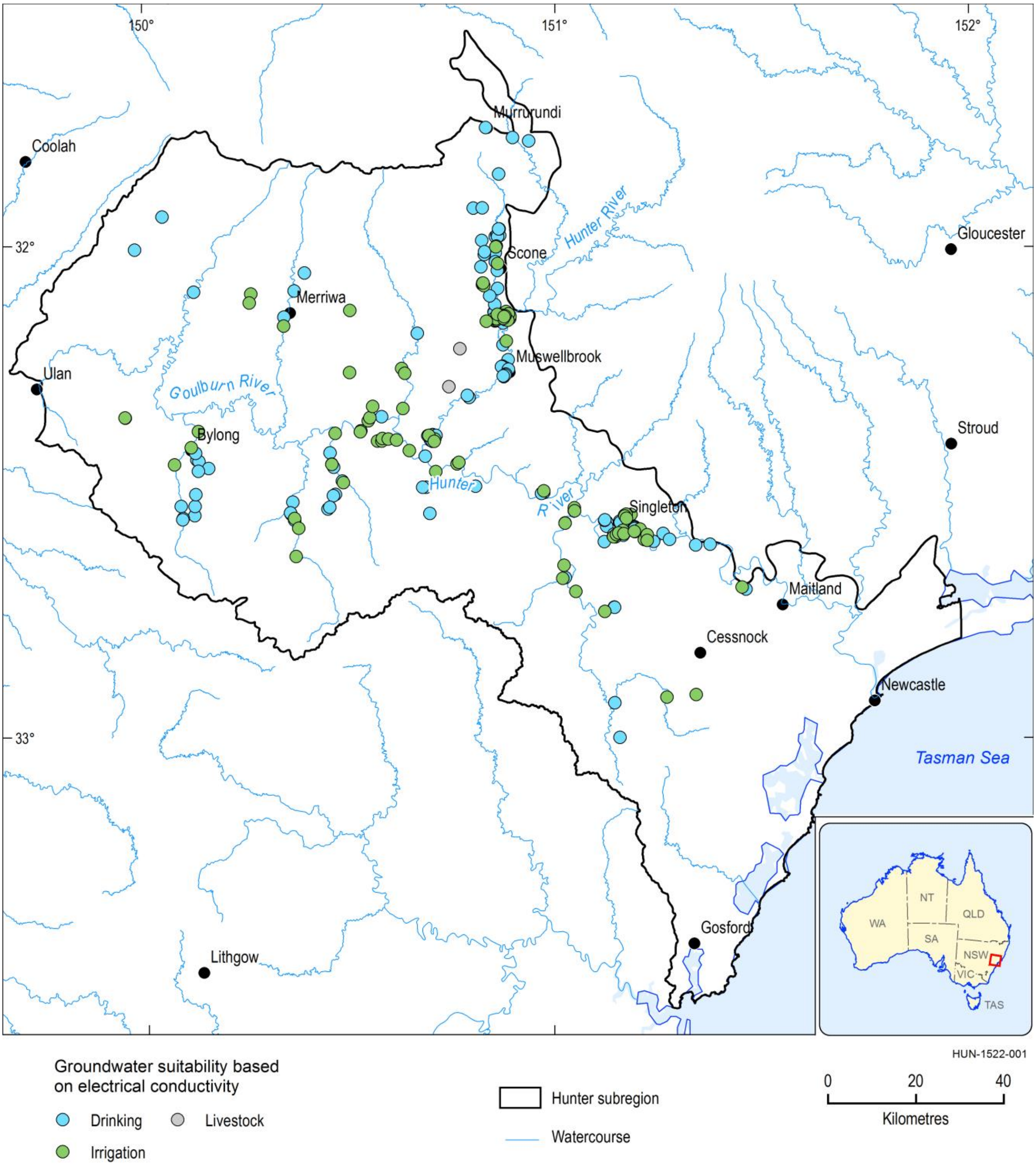

Figure 19 Distribution of electrical conductivity from alluvial bores in the Hunter subregion (samples post-1985)

Data: NSW Office of Water (Dataset 1, Dataset 2)

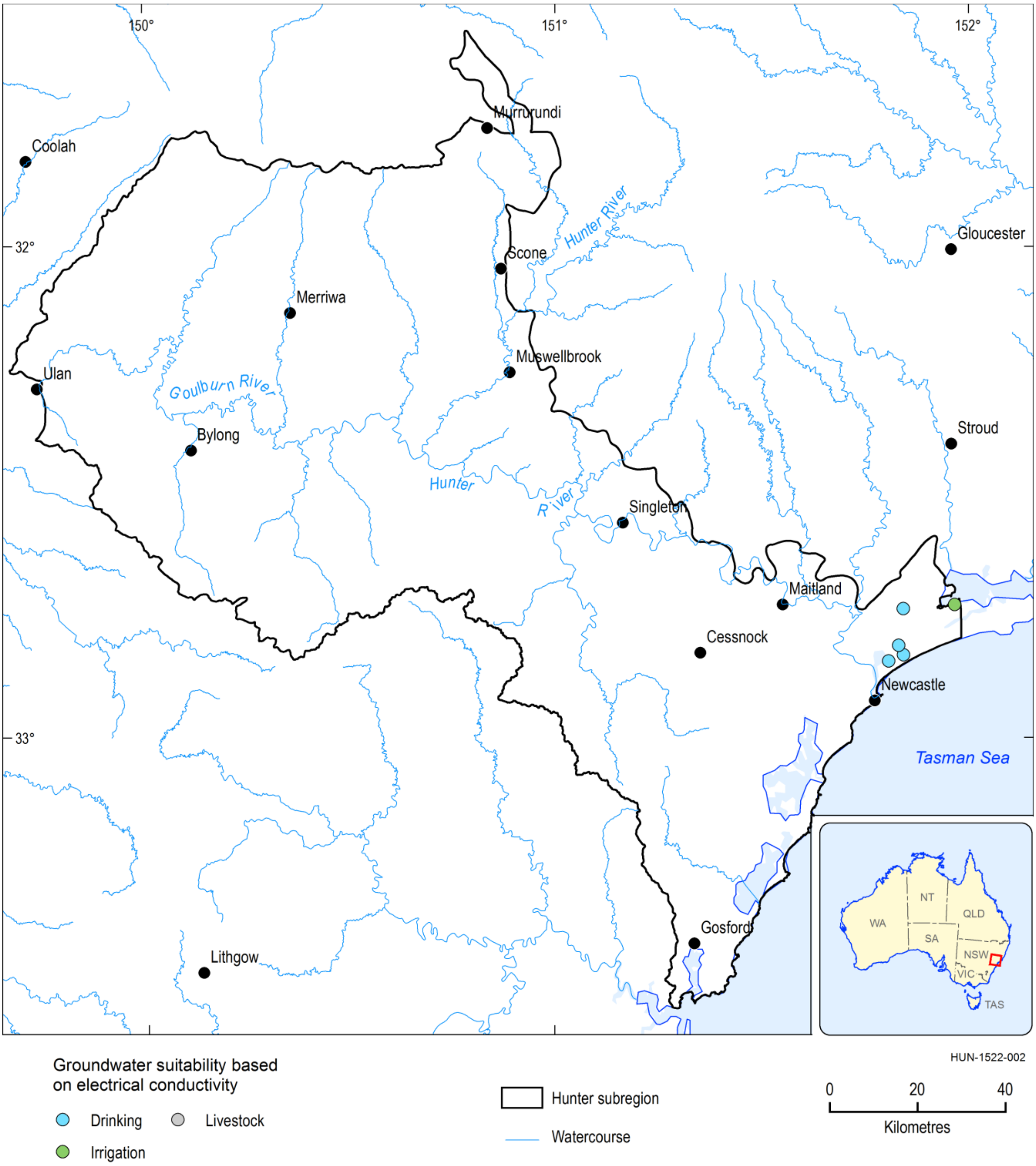

Figure 20 Distribution of electrical conductivity from coastal sands bores in the Hunter subregion (samples post-1985)

Data: NSW Office of Water (Dataset 1, Dataset 2)

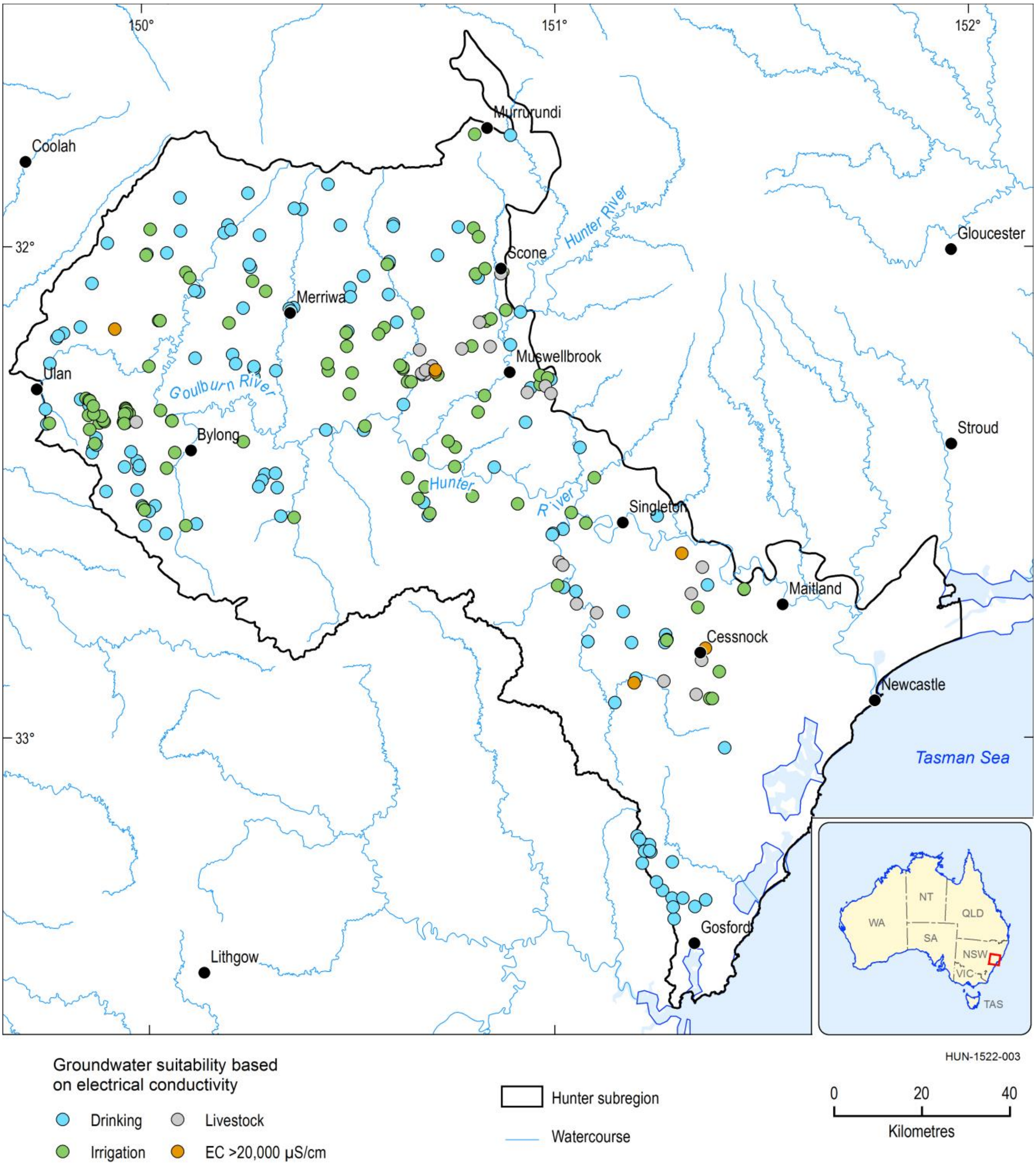

Figure 21 Distribution of electrical conductivity from fractured rock bores in the Hunter subregion (samples post-1985)

Data: NSW Office of Water (Dataset 1, Dataset 2)

1.5.2.2.3 Trace elements

Trace element data as recorded by NSW Office of Water (Dataset 1) for the Hunter subregion have been summarised by aquifer type in Table 17 to Table 19, including the number of samples, range and number of samples that exceed the different use categories in the guidelines (human consumption, irrigation and stock watering). Classification of bores into alluvial, coastal sands and fractured rock aquifers was based on the method described in Section 1.5.1.2. Data from the NSW Office of Water (Dataset 1) contains groundwater chemistry records from 1903 to 2013.

There are limited state agency data on trace elements in coastal sands aquifers (Table 18). Exceedances for the trace elements have been calculated using thresholds for human consumption from the ADWG (NHMRC and NRMMC, 2011) and for stock watering and irrigation water from the NWQMS (ANZECC/ARMCANZ, 2000). Trace element threshold values and number of bores exceeding the guidelines in the Hunter subregion groundwater bores are summarised in Table 17 to Table 19. Over 40% of samples from Hunter subregion alluvial and fractured rock bores exceed drinking water guidelines for iron, lead, manganese and nickel, but is generally suitable for stock watering.

For the Hunter subregion, 7712 samples from 1278 bores were available, of which 847 (420 alluvial, 55 coastal sands and 372 fractured rock) bores (~66%) have one to two trace element measurements and 173 (109 alluvial and 64 fractured rock) bores (~14%) have more than ten trace element measurements.

It is difficult to provide meaningful interpretation of these trace element data, particularly for the purpose of assessing the impacts of coal resource developments on water quality, given the limited number of samples, lack of information about which water sources have been sampled and what the sources of the trace elements are.

Table 17 Number of analyses and exceedances for trace elements in alluvial aquifers of the Hunter subregion

	Number of samples	Min (mg/L)	Max (mg/L)	ADWG trigger[a] (mg/L)	Number of samples exceeding trigger	Irrigation trigger[b] (mg/L)	Number of samples exceeding trigger	Stock trigger[c] (mg/L)	Number of samples exceeding trigger
Aluminium (Al)	12	0.01	2.7	0.2[d]	3	5	0	5	0
Boron (B)	144	0.01	0.8	4	0	0.5	6	5	0
Cobalt (Co)	4	0.05	0.05	NA	NA	0.05	0	1	0
Copper (Cu)	7	0.01	0.05	2	0	1	0	1	0
Fluorine (F)	291	0.01	217	1.5	13	1	22	2	10
Iron (Fe)	197	0.01	63	0.3[d]	97	0.2	104	NS	-
Lead (Pb)	7	0.02	0.1	0.01	7	2	0	0.1	0
Manganese (Mn)	25	0.02	1.3	0.1[d]	16	0.2	12	NS	-
Molybdenum (Mo)	4	0.05	0.05	0.05	0	0.01	4	NS	-
Nickel (Ni)	4	0.05	0.05	0.02	4	0.2	0	1	0
Nitrate (NO_3)	512	0.01	160	50	2	NS	-	NS	-
Zinc (Zn)	61	0.01	2.2	3[d]	0	2	1	2	1

[a]Table 3.4.1 in Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011)
[b]Table 4.2.10 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[c]Table 4.3.2 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[d]aesthetic water quality trigger (not health related)
NS = not specified
Data: NSW Office of Water (Dataset 1)

Table 18 Number of analyses and exceedances for trace elements in coastal sands aquifers of the Hunter subregion

	Number of samples	Min (mg/L)	Max (mg/L)	ADWG trigger[a] (mg/L)	Number of samples exceeding trigger	Irrigation trigger[b] (mg/L)	Number of samples exceeding trigger	Stock trigger[c] (mg/L)	Number of samples exceeding trigger
Boron (B)	7	0.07	0.9	4	0	0.5	1	5	0
Fluorine (F)	10	0.11	0.95	1.5	0	1	0	2	0
Iron (Fe)	11	0.1	12	0.3[d]	7	0.2	10	NS	-
Manganese (Mn)	1	0.06	0.06	0.1[d]	0	0.2	0	NS	-
Nitrate (NO_3)	10	0.01	4.2	50	0	NS	-	NS	-
Zinc (Zn)	1	1	1	3[d]	0	2	0	2	0

[a]Table 3.4.1 in Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011)
[b]Table 4.2.10 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[c]Table 4.3.2 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[d]aesthetic water quality trigger (not health related)
NS = not specified
Data: NSW Office of Water (Dataset 1)

Table 19 Number of analyses and exceedances for trace elements in fractured rock aquifers of the Hunter subregion

	Number of samples	Min (mg/L)	Max (mg/L)	ADWG trigger[a] (mg/L)	Number of samples exceeding trigger	Irrigation trigger[b] (mg/L)	Number of samples exceeding trigger	Stock trigger[c] (mg/L)	Number of samples exceeding trigger
Aluminium (Al)	23	0.01	1.2	0.2[d]	3	5	0	5	0
Boron (B)	80	0.01	2.4	4	0	0.5	3	5	0
Cobalt (Co)	2	0.05	0.05	NS	-	0.05	0	1	0
Copper (Cu)	5	0.02	0.1	2	0	1	0	1	0
Fluorine (F)	100	0.02	8.7	1.5	17	1	25	2	7
Iron (Fe)	93	0.01	71.3	0.3[d]	45	0.2	53	NS	-
Lead (Pb)	2	0.1	0.1	0.01	2	2	0	0.1	0
Manganese (Mn)	19	0.02	1.5	0.1[d]	13	0.2	10	NS	-
Molybdenum (Mo)	2	0.05	0.05	0.05	0	0.01	2	NS	-
Nickel (Ni)	2	0.05	0.05	0.02	2	0.2	0	1	0
Nitrate (NO_3)	235	0.01	46	50	0	NS	-	NS	-
Zinc (Zn)	19	0.01	9.5	3[d]	1	2	1	2	1

[a]Table 3.4.1 in Australian Drinking Water Guidelines (NHMRC and NRMMC, 2011)
[b]Table 4.2.10 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[c]Table 4.3.2 in National Water Quality Management Strategy (ANZECC/ARMCANZ, 2000)
[d]aesthetic water quality trigger (not health related)
NS = not specified
Data: NSW Office of Water (Dataset 1)

1.5.2.2.4 Gaps

The quality of the hydrochemistry data available for this assessment is difficult to determine, as analytical uncertainties are not reported in the dataset. The dataset includes chemical analyses from disparate points in time, sometimes decades apart, which will have differing levels of accuracy and precision. Additionally, bore screening intervals and stratigraphic unit information are not assigned in the database. Assigning these bores to stratigraphic units using the approach described in Section 1.5.1.2 may not accurately reflect the actual stratigraphic unit from which water is extracted. Useful further work could include cross checking the stratigraphic position assigned to bores with limited stratigraphic information.

A number of potentially harmful trace elements have not been included in this product due to scarcity or absence of data. Some elements have only one or two sample points, while others (arsenic, beryllium, cadmium, chromium, mercury, molybdenum, nickel, silver, selenium, uranium and vanadium) have no data.

There is also a scarcity of information about the concentrations of a range of organic compounds in groundwater, such as polycyclic aromatic hydrocarbons, as hydrocarbons are not routinely measured in groundwater in the Hunter subregion. Further work defining the range and distribution of trace element concentrations in the subregion is required to fully understand the potential hazards they pose.

Water quality data from mining companies and other organisations might enhance the regional picture of water quality.

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