Australian Government

BIOREGIONAL ASSESSMENTS

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

Description of the water-dependent asset register for the Gloucester subregion

Product 1.3 for the Gloucester subregion from the Northern Sydney Basin Bioregional Assessment

20 January 2015

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

The Bioregional Assessment Programme

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

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

Department of the Environment

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Authorship is listed in relative order of contribution.

Cover photograph

View of the Gloucester valley NSW with the Barrington River and associated riparian vegetation in the foreground and the township Gloucester in the distance looking south from the Kia Ora Lookout, 2013

Credit: Heinz Buettikofer, CSIRO

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Introduction

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

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

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

The Bioregional Assessment Programme

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

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

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

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

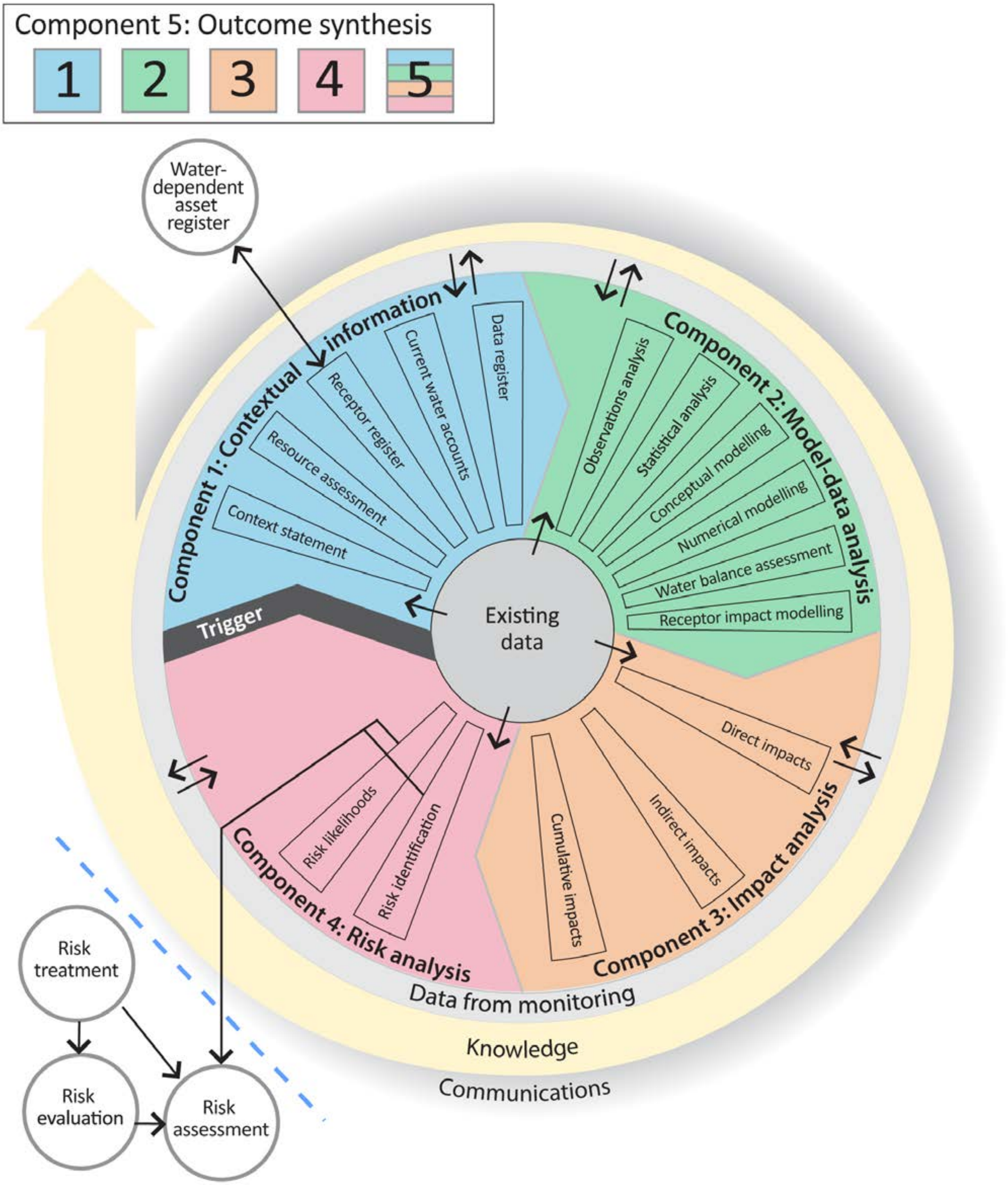


Figure 1 Schematic diagram of the bioregional assessment methodology

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

Methodologies

For transparency and to ensure consistency across all BAs, submethodologies have been developed to supplement the key approaches outlined in the *Methodology for bioregional assessments of the impact of coal seam gas and coal mining development on water resources* (Barrett et al., 2013). This series of submethodologies aligns with technical products as presented in Table 1. The submethodologies are not intended to be 'recipe books' nor to provide step-by-step instructions; rather they provide an overview of the approach to be taken. In some instances, methods applied for a particular BA may need to differ from what is proposed in the submethodologies – in this case an explanation will be supplied. Overall, the submethodologies are intended to provide a rigorously defined foundation describing how BAs are undertaken.

Table 1 Methodologies and associated technical products listed in Table 2

Code	Proposed title	Summary of content	Associated technical product
M01	*Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources*	A high-level description of the scientific and intellectual basis for a consistent approach to all bioregional assessments	All
M02	*Compiling water-dependent assets*	Describes the approach for determining water-dependent assets	1.3 Description of the water-dependent asset register
M03	*Assigning receptors and impact variables to water-dependent assets*	Describes the approach for determining receptors associated with water-dependent assets	1.4 Description of the receptor register
M04	*Developing a coal resource development pathway*	Specifies the information that needs to be collected and reported in product 1.2 (i.e. known coal and coal seam gas resources as well as current and potential resource developments). Describes the process for determining the coal resource development pathway (reported in product 2.3)	1.2 Coal and coal seam gas resource assessment 2.3 Conceptual modelling
M05	*Developing the conceptual model for causal pathways*	Describes the development of the conceptual model for causal pathways, which summarises how the 'system' operates and articulates the links between coal resource developments and impacts on receptors	2.3 Conceptual modelling
M06	*Surface water modelling*	Describes the approach taken for surface water modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative.	2.6.1 Surface water numerical modelling
M07	*Groundwater modelling*	Describes the approach taken for groundwater modelling across all of the bioregions and subregions. It covers the model(s) used, as well as whether modelling will be quantitative or qualitative. It also considers surface water – groundwater interactions, as well as how the groundwater modelling is constrained by geology.	2.6.2 Groundwater numerical modelling

Code	Proposed title	Summary of content	Associated technical product
M08	*Receptor impact modelling*	Describes how to develop the receptor impact models that are required to assess the potential impacts from coal seam gas and large coal mining on receptors. Conceptual, semi-quantitative and quantitative numerical models are described.	2.7 Receptor impact modelling
M09	*Propagating uncertainty through models*	Describes the approach to sensitivity analysis and quantifying uncertainty in the modelled hydrological response to coal and coal seam gas development	2.3 Conceptual modelling 2.6.1 Surface water numerical modelling 2.6.2 Groundwater numerical modelling 2.7 Receptor impact modelling
M10	*Risk and cumulative impacts on receptors*	Describes the process to identify and analyse risk	3 Impact analysis 4 Risk analysis
M11	*Hazard identification*	Describes the process to identify potential water-related hazards from coal and coal seam gas development	2 Model-data analysis 3 Impact analysis 4 Risk analysis
M12	*Fracture propagation and chemical concentrations*	Describes the likely extent of both vertical and horizontal fractures due to hydraulic stimulation and the likely concentration of chemicals after production of coal seam gas	2 Model-data analysis 3 Impact analysis 4 Risk analysis

Each submethodology is available online at <http://www.bioregionalassessments.gov.au>. Submethodologies might be added in the future.

Technical products

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

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

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

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

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

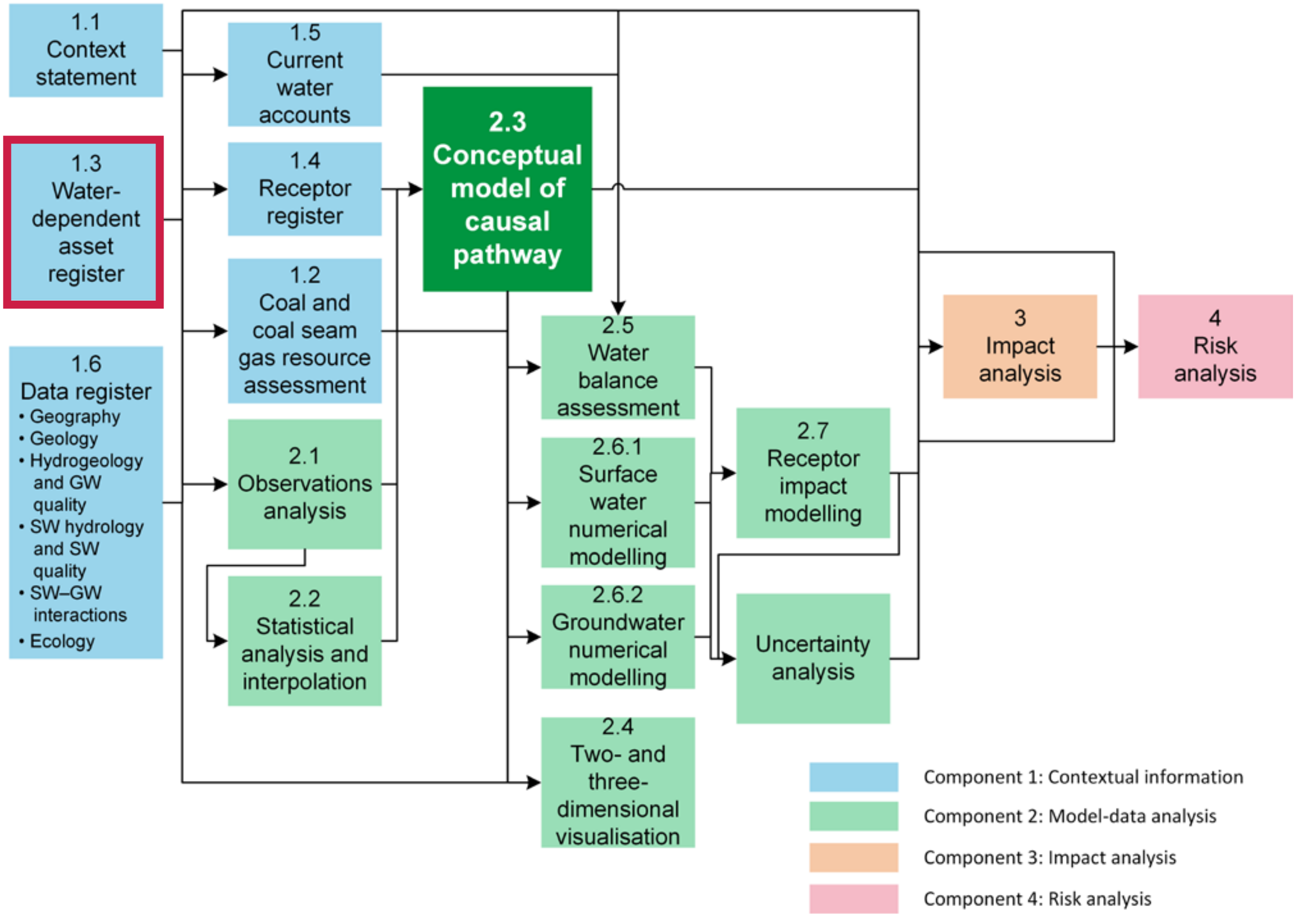


Figure 2 The simple decision tree indicates the flow of information through a bioregional assessment

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

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 the BAs for inclusion in this document used the Albers equal area with a central meridian of 140.0° East for the Lake Eyre Basin bioregion and its subregions, and 151.0° East for all other bioregions and subregions. The two standard parallels for all bioregions and subregions are –18.0° and –36.0°.

Table 2 Technical products being delivered as part of the Northern Sydney Basin Bioregional Assessment

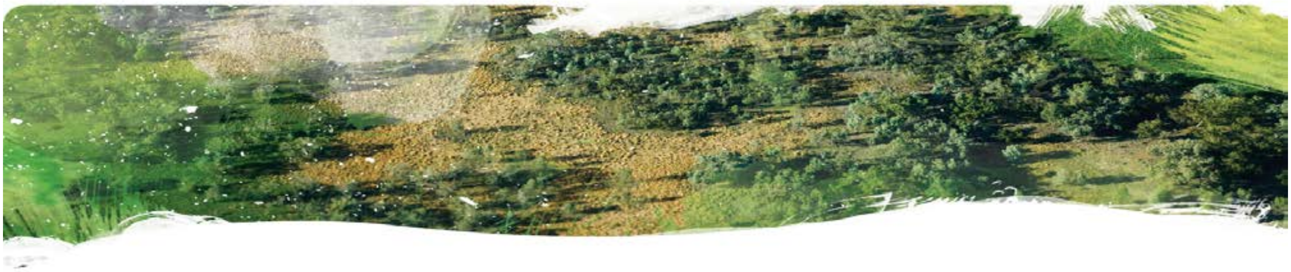
For each subregion in the Northern Sydney Basin Bioregional Assessment, technical products will be delivered as data, summaries and reports (PDFs) as indicated by ■ in the last column of Table 2. The red rectangle indicates the information covered in this technical product. A suite of other technical and communication products – such as maps, registers and factsheets – will also be developed through the bioregional assessments.

Component	Product code	Information	Section in the BA methodology[a]	Report
Component 1: Contextual information for the Gloucester subregion	1.1	Context statement	2.5.1.1, 3.2	■
	1.2	Coal and coal seam gas resource assessment	2.5.1.2, 3.3	■
	1.3	Description of the water-dependent asset register	2.5.1.3, 3.4	■
	1.4	Description of the receptor register	2.5.1.4, 3.5	■
	1.5	Current water accounts and water quality	2.5.1.5	■
	1.6	Data register	2.5.1.6	
Component 2: Model-data analysis for the Gloucester subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	■
	2.3	Conceptual modelling	2.5.2.3, 4.3	■
	2.4	Two- and three-dimensional representations	4.2	[b]
	2.5	Water balance assessment	2.5.2.4	■
	2.6.1	Surface water numerical modelling	4.4	■
	2.6.2	Groundwater numerical modelling	4.4	■
	2.7	Receptor impact modelling	2.5.2.6, 4.5	■
Component 3: Impact analysis for the Gloucester subregion	3	Impact analysis	5.2.1	■
Component 4: Risk analysis for the Gloucester subregion	4	Risk analysis	2.5.4, 5.3	■
Component 5: Outcome synthesis for the Northern Sydney Basin bioregion	5	Outcome synthesis	2.5.5	■

[a]Barrett et al. (2013)
[b]The two- and three-dimensional representations will be delivered in products such as 2.3, 2.6.1 and 2.6.2.

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 29 January 2015, <http://www.iesc.environment.gov.au/publications/methodology-bioregional-assessments-impacts-coal-seam-gas-and-coal-mining-development-water>.



1.3 Description of the water-dependent asset register for the Gloucester subregion

A water-dependent asset has a particular meaning for bioregional assessments; it is an asset potentially impacted by changes in groundwater and/or surface water due to coal or coal seam gas development. Some ecological assets solely depend on incident rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water.

This product describes water-dependent assets that have been identified in the bioregional assessment and are listed in the water-dependent asset register (available at <http://www.bioregionalassessments.gov.au>).

1.3.1 Methods

Summary

The water-dependent asset register is a list of water-dependent assets identified for use in the bioregional assessment (BA) of the Gloucester subregion. This section details the specific application to the Gloucester subregion of methods described in the companion submethodology M02 for identifying water-dependent assets (the Assets submethodology; Mount et al., 2014), outlining how the register was compiled. Key concepts and terminology are also explained.

The methods covered include: the process of collecting different groups of assets and determining their water dependency, the development and compilation of the water-dependent asset register, and the determination of the preliminary assessment extent (PAE) of the Gloucester subregion.

1.3.1.1 Background and context

This product presents information about the water-dependent asset register developed for the Gloucester subregion. Development of the register used methods and processes defined and outlined in the companion submethodology M02 (as listed in Table 1) for identifying water-dependent assets (Mount et al., 2014); their specific application to the Gloucester subregion is described in the following sections.

An *asset* is an entity having value to the community and, for BA purposes, is associated with a bioregion or subregion. A *bioregion* is a geographic land area within which coal seam gas (CSG) and/or coal mining developments are, or could, take place and for which BAs are conducted. A *subregion* is an identified area wholly contained within a bioregion that enables convenient presentation of outputs of a BA.

A *water-dependent asset* has a particular meaning for BAs; it is an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development. Some assets are solely dependent on incident rainfall and will not be considered as water dependent if evidence does not support a linkage to groundwater or surface water.

The *water-dependent asset register* is a simple and authoritative listing of the assets within the *preliminary assessment extent* (PAE) that are potentially subject to water-related impacts. A PAE is the geographic area associated with a bioregion or subregion in which the potential water-related impact of coal resource development on assets is assessed. The compiling of the asset register is the first step to identifying and analysing potentially impacted assets, which is the goal of the overall BA.

The asset source data are compiled into an *asset database*, including the spatial data, which are designated as *elements* (individual spatial features – points, lines and polygons e.g. components of a larger system) and *assets* (combinations of one or more elements). During the compilation process, assets are classified into three groups: (i) ecological, (ii) economic and (iii) sociocultural.

Many assets are obtained from state and national databases and a key group of assets is provided by natural resource management organisations (NRMs). Meetings are underway with Indigenous knowledge holders to discuss Indigenous cultural water-dependent assets.

The asset database is then used to generate the water-dependent asset register. A preliminary version of the asset register is presented to experts and organisations with local knowledge at organised workshops. Feedback is sought about whether the asset register is complete and correct; appropriate amendments are then made. It is at this stage – when assets have been selected using the PAE and the amended water-dependent assets have been recorded in the database – that the water-dependent asset register is complete for the purposes of producing product 1.3. Note, however, that the addition of new assets to the asset database, or a review of the status of existing assets in the database will mean that the asset register may be updated. As this has implications for other BA components, any updates must be documented and only be done with approval and tight version control. The product 1.3 will not be updated or republished but an updated version of the asset register (derived from the asset database) may be published at the same time as other products, for example, those associated with Component 3: impact analysis.

Following development of the asset register, the connection of the registered assets to coal resource development is assessed using the 'materiality' tests and, if potentially subject to water-related impacts, assigned *receptors* (after Barrett et al., 2013). A receptor is a point in the landscape where water-related impacts on assets are measured and/or estimated. This asset-receptor (or element–receptor) assignment can be either: (i) one-to-one, (ii) one-to-many, (iii) many-to-one or (iv) many-to-many. The approach to assigning receptors and impact variables to water-dependent assets is described in the pending companion submethodology M03 (as listed in Table 1).

1.3.1.2 Compiling assets and developing the water-dependent asset register

1.3.1.2.1 Ecological assets

The Hunter Central Rivers Catchment Management Authority (CMA) supplied asset data covering the entire CMA which includes the Gloucester subregion – note that from 1 January 2014, in NSW CMAs have transitioned into local land services (LLS) regions. However, as this CMA operated within the Gloucester subregion when it was defined in 2012, these data have continued to be used. These data (equivalent to 'elements') were loaded into the asset database – only 27 of these overlapped or were within the PAE; most in the ecological group of assets.

Additionally, data were obtained from a number of Australian Government sources (Table 3). Some of the elements sourced from the Australian Government duplicated elements provided by the Hunter Central Rivers CMA. Other sources, including the list of Australian Ramsar wetlands (Department of the Environment, 2014), were considered but found to not include any elements that were within or overlapped with the PAE.

Table 3 Australian Government data sources for assets in the Gloucester subregion

Data source[a]	Custodian	Website address
Collaborative Australian Protected Areas Database (CAPAD)	Department of the Environment	<http://www.environment.gov.au/topics/land/nrs/science-maps-and-data/capad>
Directory of Important Wetlands in Australia (DIWA)	Department of the Environment	<http://www.environment.gov.au/topics/water/water-our-environment/wetlands/australian-wetlands-database/directory-important>
Atlas of Groundwater Dependent Ecosystems including: • subsurface presence of groundwater data • surface expression of groundwater	Bureau of Meteorology	<http://www.bom.gov.au/water/groundwater/gde/>
Threatened ecological communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)	Department of the Environment	<http://www.environment.gov.au/biodiversity/threatened/communities>
Threatened species listed under the EPBC Act	Department of the Environment	<http://www.environment.gov.au/biodiversity/threatened/species>
Australian Heritage Database including: • *World Heritage List* (WHL) • *National Heritage List* (NHL) • *Commonwealth Heritage List* (CHL) • *Register of the National Estate* (RNE)	Department of the Environment	<http://www.environment.gov.au/topics/heritage/publications-and-resources/australian-heritage-database>

[a]Full descriptions and citations of data sources will be published in the metadata for each subregional asset database. Italics indicate the formal dataset name.

1.3.1.2.2 Economic assets

All economic assets are types of *water access entitlements*, either *water access rights* or *basic water rights*. In NSW, water access entitlements are known as 'water access licences'. Within the asset database, every water access entitlement is an element. Elements are grouped by type and also spatially to create assets. *Basic landholder rights* (i.e. a type of basic water right), including riparian rights, maintain the right of those adjacent to rivers, estuaries, lakes or aquifers underlying the land to extract water for domestic and stock use without a water access licence. Basic landholder rights are defined by the jurisdiction based on the location of the water source and include an estimated volume of use based on the number of landholders with adjacent water sources.

For the economic assets, the water access entitlement assets are divided into two classes:

- Basic water right (domestic and stock) – this is the right to take water for domestic and stock purposes only. A basic right for 'take of groundwater' requires approval for the works (bore) but does not require a licence for the extraction of groundwater. A basic right for 'take of surface water' does not require an approval for the works or approval for the extraction of surface water.
- Water access right – this right requires an approval for the works and a licence for the extraction of the water. The extraction of the water can be for a range of purposes including irrigation, commercial, industrial, farming, dewatering, mining, intensive agriculture etc.

Licensing data were sourced from the NSW Office of Water to determine economic assets (NSW Office of Water, 2013). These data are currently not publically available and were obtained by special request. Consistent with how water licensing information is published under the Commonwealth's *Water Act 2007*, this data will be published in an aggregated form. Data covered groundwater and surface water licences, and their corresponding works locations. Data about basic landholder rights were sourced online from the publically available water sharing plans (NSW Department of Primary Industries, 2014).

In collating the economic elements, it was considered important to ensure no current or active water access entitlements were excluded, even where there was doubt about the current status of the entitlement, for example, 'sleeper' licences. For example, basic water rights (stock and domestic) do not have to be renewed on a frequent basis leading to some uncertainty about their current use status. This meant that only surface and groundwater licences that were definitely 'abandoned', 'cancelled' or 'suspended' as at 20 November 2013 were marked as not 'current' or 'active' and therefore excluded for BA purposes. This also applied to any water access licences that did not have a corresponding works approval with location information. Where works (locations) information was present it was linked to the particular surface water or groundwater licences, and a count added to show how many works were associated with each licence. The volume of the licence was then equally split among the works to ensure that the licence volumes were not double-counted. A GIS layer was derived using the spatial coordinates provided with the licensed work approvals. This spatial layer was overlain with the PAE for the Gloucester subregion. The intersection of the two layers combined with the related attribute data gave a spatially explicit view of the active entitlements within the PAE, with a volume attributed to each works (surface water and groundwater).

The class of asset was aggregated using the NSW Office of Water 'purpose' field which records the purpose that water is used for. Any purpose that was listed as 'Domestic' and/or 'Stock' was included in the class 'Basic water right'. Where 'Stock' and/or 'Domestic' was listed with another licensed purpose, it was listed as a 'Water access right'. 'Water access right' was based on anything that had an extractive use purpose such as, for example, commercial, irrigation, farming, industrial, or dewatering.

The process assumed that each of the works associated with a water access right licence extracts an equal share of the volume. Each licence can have one or multiple works associated with it, where the works is the location where the water is extracted through a bore or pump. Therefore if there is one groundwater licence of 80 ML/year that has four works (bores) associated with it, then 20 ML/year is assigned to each of those works. It is not possible to validate this assumption within the resources of the BA. It is possible that the majority of extraction occurs at a single works location and is not evenly distributed across all works associated with the licence.

Groundwater works that were not classified as a basic water right or a water access right were classed as 'null'. These included test bores, bores installed for groundwater remediation, exploratory bores, exploratory research, monitoring bores and waste disposal bores. These elements are be 'flagged' in the asset database and are not included in the water-dependent asset register.

1.3.1.2.3 Sociocultural assets

Sociocultural data were sourced from a number of agencies and organisations including NSW and Australian government lists and registers of cultural heritage (Table 3). Typically, sociocultural assets that are landscape water features are included within the ecological asset classes to avoid repetition of assets.

Conversations have been held with Indigenous knowledge holders in the Gloucester subregion to gain an understanding of Indigenous cultural water-dependent assets. These discussions will continue over coming weeks and months.

Where possible and appropriate, and with the agreement of Indigenous knowledge holders, Indigenous water-related values will be incorporated into an updated water-dependent asset register or incorporated into later technical products.

1.3.1.3 Determining the preliminary assessment extent

The Gloucester subregion is defined by the geological Gloucester Basin (Roberts et al., 1991). As this is a geological mapping unit, there has been no consideration beyond the subregion boundary of groundwater and/or surface water connection.

Over the last ten years the regional hydrogeology of the Gloucester subregion has been characterised during commercial assessment of energy resources (there are no other sources) and no groundwater connectivity has been found beyond the Gloucester subregion (Parsons Brinckerhoff, 2012a, pp. xxv, 30, 31; SRK, 2010, p. 45). From a groundwater perspective it is a closed system with groundwater discharging to lower portions of the landscape and being evaporated through riparian vegetation (Parsons Brinckerhoff, 2012a, pp. 30-31). Hence, as there is no groundwater connection to assets beyond the boundary of the Gloucester subregion, no further consideration of groundwater connectivity is required.

By contrast, there are surface water connections beyond the boundary of the Gloucester subregion that need to be considered. The Gloucester subregion straddles the headwater of two surface water basins (Figure 3) and covers about 347.5 km^2 – of this, the north-flowing component (see ‘N’ in Figure 3) is 181.2 km^2 and 166.3 km^2 comprises the south-flowing component (see ‘S’ in Figure 3).

The Australian Hydrological Geospatial Fabric (Geofabric) – developed by the Bureau of Meteorology (2012) – was used to define a set of catchments that flow into and out of the northern and southern components of the Gloucester subregion (Figure 3). This process identified 13 subcatchments (Figure 3). Seven subcatchments define the north flowing rivers that comprise the Manning river basin, five subcatchments constitute the south flowing rivers that make-up the Karuah river basin, the remainder is the Wallamba River catchment. As the Wallamba River catchment (in which the town of Forster is located; see Figure 3) is not hydrologically connected to surface water flowing from the Gloucester subregion, it is not considered further. The names, areas and codes of the 13 subcatchments used herein are provided in Table 4.

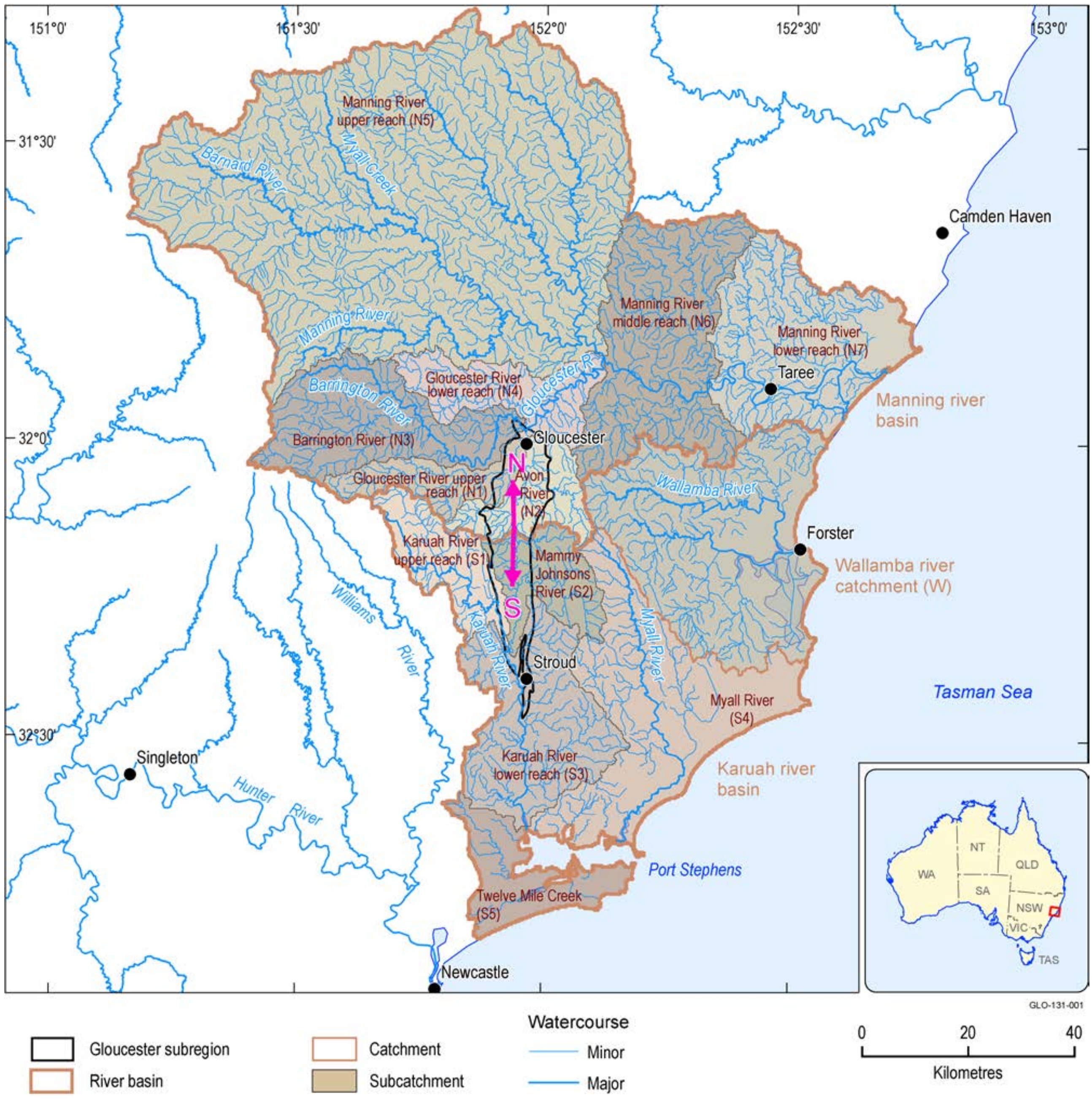


Figure 3 Location of the Gloucester subregion, within the Manning river basin and Karuah river basin

Some rivers from the Gloucester subregion flow north (denoted by the hot pink 'N' internal to the subregion boundary) into the Manning river basin, while others flow south (denoted by the hot pink 'S' internal to the subregion boundary) into the Karuah river basin. The codes for the subcatchments (developed and used here) are provided in brackets following the subcatchment name. Source data: The catchment boundaries and both the major and minor watercourses are from Geoscience Australia (2006).

Table 4 Details of subcatchments comprising the Manning and Karuah river basins and Wallamba river catchment as identified in Figure 3

Subcatchment name	Subcatchment code	Area (km^2)
Gloucester River upper reach	N1	253
Avon River	N2	289
Barrington River	N3	714
Gloucester River lower reach	N4	392
Manning River upper reach	N5	4493
Manning River middle reach	N6	1075
Manning River lower reach	N7	964
Karuah River upper reach	S1	339
Mammy Johnsons River	S2	319
Karuah River lower reach	S3	791
Myall River	S4	1155
Twelve Mile Creek	S5	356
Wallamba River	W	1411

The PAE is the geographic area associated with a bioregion or subregion in which the potential water-related impact of coal resource development on assets is assessed. It is the first step to identify the potentially impacted assets. Given that the Gloucester subregion is only connected externally via surface water, there is a need to know the relative proportions flowing from the subregion compared to those generated from other parts of the Manning and Karuah river basins – for example, in the Manning river basin to answer the question 'what proportion of the streamflow at Taree is generated from runoff originating in the northern flowing component of the Gloucester subregion?' As there is only limited streamflow gauging on the surface water network in the broader region within which the Gloucester subregion is located, there is insufficient observational data available to answer this question. Thus spatially explicit surface water modelling was undertaken; this modelling is documented in the remainder of this subsection.

Over the long-term, the relative proportion of the streamflow generated in a catchment relates to its area and more importantly to the spatial change in climate across the catchment (Budyko, 1974; Donohue et al., 2011). For a general introduction to the Budyko framework see Donohue et al., (2007; 2010); the following brief introduction is from McVicar et al. (2012). The Budyko framework is widely used; according to *Google Scholar* (a freely accessible web search engine that indexes the full text of scholarly literature across an array of publishing formats and disciplines; Google Scholar, 2014) using the search 'Budyko M.I. Climate and Life' shows that it has been cited in the international scientific literature over 1600 times. The Budyko framework addresses water quantity issues, and water quality, as represented by in-stream electrically conductivity, can be regarded as high quality throughout the subregion. So water quality issues are not considered when defining the PAE.

The catchment water balance describes the partitioning of the inward flux, or supply, of water (assumed here to be solely precipitation) into the outward fluxes of water and the within-catchment storage of water. With respect to streamflow, the water balance is:

$$Q = P - AET - DD - \frac{dS_w}{dt} \tag{1}$$

here Q, P, AET, and DD represent streamflow, precipitation, actual evapotranspiration and deep drainage, respectively (mm a^{-1}). S_w is soil water storage (mm). In unregulated catchments the partitioning of P into Q and AET predominantly depends on the processes that determine AET. In general, AET is limited by either the supply of: (i) water or (ii) energy (this can be termed atmospheric evaporative demand (AED) and is commonly represented as potential evapotranspiration (PET). This means that AET from a catchment can be described as being either 'water-limited' or 'energy-limited', respectively. This supply-demand limitation is a crucial over-arching framework for understanding catchment hydroclimatology; it does not account for changes in soil properties and assumes groundwater and surface water are in steady-state equilibrium with groundwater recharge and discharge being negligible.

Assuming steady state, Budyko (1974) described long-term catchment balances using the supply-demand framework (Figure 4). Formally, a water-limited environment occurs when the long-term catchment average AED for water exceeds the supply of water (i.e. P < PET) and the opposite is true for an energy-limited environment (i.e. P > PET). Over large catchments and long time-scales, Budyko showed that the evaporative index (ε, the ratio of AET to P) is dependent on the climatic dryness index (Φ, the ratio of PET to P) and closely follows a curvilinear relationship (the 'Budyko curve', shown in Figure 4). As water limitation increases (i.e. as one moves to the right in Figure 4), then AET approaches P and Q approaches 0. Conversely, as the water availability increases (i.e. as one moves to the left in Figure 4), AET approaches PET, with a larger fraction of P being partitioned into Q.

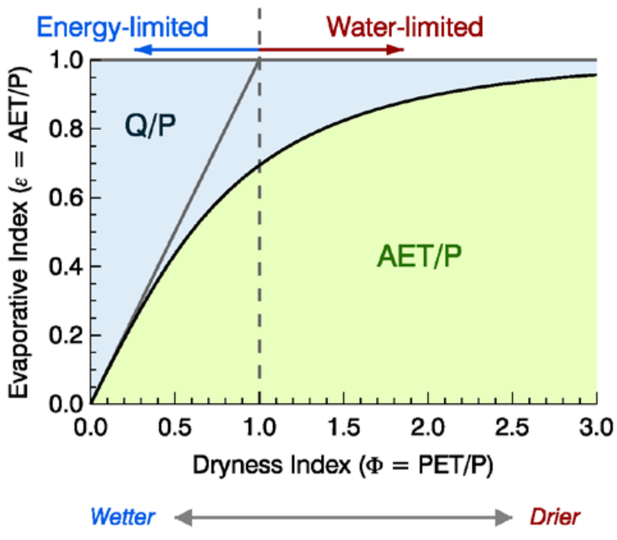


Figure 4 The Budyko curve and the supply–demand framework

The Budyko curve (black line) describes the relation between the long-term catchment averages of the evaporative index (ε = AET / P) and the dryness index (Φ = PET / P). The horizontal grey line represents the water-limit, where 100% of P becomes AET, and the diagonal grey line is the energy-limit, where 100% of AED (i.e., PET) is converted to AET. The green shaded area represents the fraction of P that becomes AET and the blue shaded area represents the fraction of P that becomes Q.

Using Choudhury's (1999) formulation of the Budyko curve, with (i) available energy being more commonly represented as PET (Donohue et al., 2012, whereas Choudhury originally used net radiation), (ii) n being the catchment properties parameter that alters the partitioning of P between modelled AET and R (runoff) and using a value of 1.9 here (Donohue et al., 2011) and (iii) assuming steady state conditions, then R is simply the difference between P and AET:

$$R = P - AET = P - \frac{P \cdot PET}{\left(P^n + PET^n\right)^{1/n}} . \quad (2)$$

Using readily available gridded meteorological datasets of P (Jones et al., 2009) and Penman's formulation of PET (Donohue et al., 2010), which is fully physically based using a dynamic wind speed (McVicar et al., 2008), Choudhury's formulation of the Budyko framework was used to model the climatological (1982 to 2010) partitioning of P in AET and R. Figure 5a and Figure 5b show the input meteorological grids used in Choudhury's formulation of the Budyko framework; the resultant modelled runoff is shown in Figure 5c. Note that in the introduction to the Budyko framework, in which the smallest spatial element considered is a subcatchment, Q is used, whereas for spatially explicit modelling using gridded meteorological data the term R is used. These are not identical in meaning and in the Budyko framework there is no routing within a catchment or down the river network. To define the PAE it is only the spatially explicit relative proportions of R that are required.

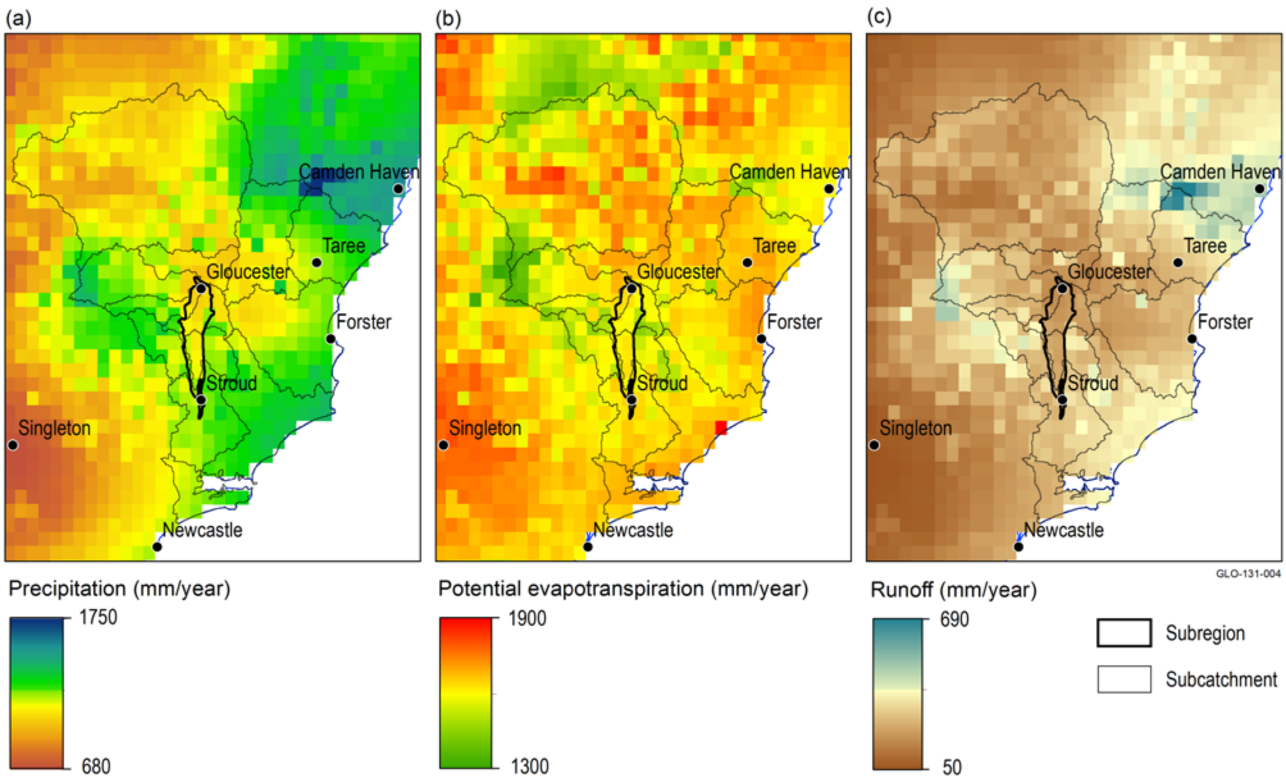


Figure 5 Spatial variation of 1982 to 2012 annual average inputs to (a and b) and output from (c) the modelling of annual average runoff for the Gloucester subregion and proximal basins

Parts (a) and (b) show annual average (1982 to 2012) precipitation and potential evapotranspiration, respectively. These are input to Choudhury's formulation of the Budyko framework to provide the modelled annual average (1982 to 2012) runoff which is shown in (c).

The input P and PET grids and the resultant R grid were then summarised by the 13 subcatchments (Figure 3 and Table 4), and were then expressed as a percentage of the totals determined for each of the Manning and Karuah river basins; see Table 5. This shows that the northern component of the Gloucester subregion (see Figure 3) contributes 2.16, 2.16 and 2.11 % of P, PET and R, respectively, to the Manning river basin totals of these long-term water balance components. The southern component of the Gloucester subregion (see Figure 3) contributes 5.22, 5.68 and 4.64% of P, PET and R, respectively, to the Karuah river basin totals of these long-term water balance components (Table 5).

Table 5 Annual average water balance components for the Manning and Karuah river basins

The annual average (1982 to 2010) water balance components are shown for precipitation, potential evapotranspiration (PET calculated with the Penman formulation) and Choudhury's modelled runoff for each of the subcatchments. Percentages are calculated relative to the respective river basin totals. Definitions for the subcatchment codes are provided in Table 4, and their locations are illustrated in Figure 3.

Subcatchments	Annual average precipitation (%)	Annual average potential evapotranspiration (%)	Annual average runoff (%)
Manning river basin			
N	2.16%	2.16%	2.11%
N1	3.28%	2.94%	3.74%
N2	3.55%	3.42%	3.69%
N3	9.27%	8.37%	10.58%
N4	4.55%	4.87%	4.04%
N5	52.24%	55.22%	48.11%
N6	13.80%	13.34%	14.35%
N7	13.31%	11.84%	15.48%
Karuah river basin			
S	5.22%	5.68%	4.64%
S1	11.18%	11.22%	11.10%
S2	10.16%	10.45%	9.79%
S3	26.12%	27.19%	24.66%
S4	41.09%	39.15%	43.57%
S5	11.46%	11.99%	10.89%

By considering the surface water subcatchment topology (i.e. their spatial relationships of inflow, outflow and tributaries) it is possible to accumulate the percentage contributions of the northern component of the Gloucester subregion (see Figure 3) down the Manning River to its outflow in the Tasman Sea (Table 6). In the following text, only results for R are discussed; the values for P and PET are provided for completeness in Table 6. Table 6 shows that the northern component of the Gloucester subregion contributes 57.18% of the R of N2 and, when considering the inflow from N1 to N2, this decreases to 28.40%. When considering the inclusive streamflow from N1 to N4, the contribution of the northern component of the Gloucester subregion reduces to 9.57%, and when the additional contribution of N5 is considered then the northern component of the Gloucester subregion only contributes 3.01% of the runoff from the area composed of N1, N2, N3, N4 and N5 (see Table 6 and, for locations, Figure 3). Based on expert opinion, at approximately 10% of the runoff there may be the ability to detect the impact of changes in runoff, but at less than 5% of the total runoff, even if the change did have an impact, this is considered to be smaller than the detection level. This suggests that any change to surface water flows beyond the confluence of N4 and N5 is small and hence defines the northern component of the Gloucester PAE to include the major river channel flowing in N4, as in N6 and N7 there will be negligible influence of changes in surface water generated from N due to the relatively large contribution from N5 (i.e. 48.11% from Table 5) to the entire Manning river basin.

Table 6 Accumulated percent contribution of water balance components from the northern component of the Gloucester subregion relative to selected parts of the Manning river basin

The annual average (1982 to 2012) water balance components are shown for precipitation, potential evapotranspiration (PET calculated with the Penman formulation) and Choudhury's modelled runoff. The percentage contributions of the northern component relative to the subcatchments, indicated by the denominator, are reported. Definitions for the subcatchment codes are provided in Table 4, and their locations are illustrated in Figure 3.

Subcatchment	Annual average precipitation (%)	Annual average potential evapotranspiration (%)	Annual average runoff (%)
N/N2	60.72%	63.36%	57.18%
N/(N1+N2)	31.58%	34.02%	28.40%
N/(N1+N2+N3)	13.39%	14.69%	11.72%
N/(N1+N2+N3+N4)	10.44%	11.04%	9.57%
N/(N1+N2+N3+N4+N5)	2.96%	2.89%	3.01%
N/(N1+N2+N3+N4+N5+N6)	2.49%	2.45%	2.50%
N/(N1+N2+N3+N4+N5+N6+N7)	2.16%	2.16%	2.11%

The southern component of the Gloucester subregion (see Figure 3) in the Karuah river basin was assessed in a similar manner to that used for the accumulated percentage contributions of the northern component of the Gloucester subregion. Table 7 shows that the southern component of the Gloucester subregion contributes 47.43% of the R of S2 and, when considering the inflow from S1 to S2, this decreases to 22.23%. When inflow from S3 is considered the contribution of the southern component of the Gloucester subregion reduces to 10.19% when the Karuah River flows into the western end of Port Stephens. When considering surface water flow into all of Port Stephens (i.e. S1+S2+S3+S4+S5, see Figure 3) the contribution of the southern component of the Gloucester subregion reduces to 4.64%. This suggests that any change to surface water flows to all of Port Stephens due to changes in the southern component of the Gloucester subregion will be negligible. This then means that not all of Port Stephens is considered in the PAE. The extension to the PAE of the Gloucester subregion is defined as the reach of the Karuah River that flows south from the southern component of the Gloucester subregion to the western end of Port Stephens (Figure 6).

Table 7 Accumulated percent contribution of water balance components from the southern component of the Gloucester subregion to selected parts of the Karuah river basin

The annual average (1982 to 2012) water balance components are shown for precipitation, potential evapotranspiration (PET calculated with the Penman formulation) and Choudhury's modelled runoff. The percentage contributions of the southern component relative to the subcatchments, indicated by the denominator, are reported. Definitions for the subcatchment codes are provided in Table 4, and their locations are illustrated in Figure 3.

Subcatchment	Annual average precipitation (%)	Annual average potential evapotranspiration (%)	Annual average runoff (%)
S/S2	51.39%	54.32%	47.43%
S/(S1+S2)	24.47%	26.19%	22.23%
S/(S1+S2+S3)	11.00%	11.62%	10.19%
S/(S1+S2+S3+S4+S5)	5.22%	5.68%	4.64%

The PAE of the Gloucester subregion is comprised of the union of the Gloucester subregion boundary and, to account for changes in surface water flows, 1 km buffer zones either side of the major rivers flowing from the northern component (to the outlet of N4) and from the southern component to Port Stephens (Figure 6). The Australian Bureau of Statistics (ABS, 2012, Table 4) reported an estimate of the total area of farm holdings and number of agricultural businesses for each local government area (LGA) as at 30 June 2011. For the Gloucester LGA the area is 129,354 ha held by 323 businesses, having an average size of approximately 400 ha. For Great Lakes LGA there is 67,885 ha held by 305 businesses, with an average area of approximately 222 ha. The average of these two areas (311 ha or 3.1 km^2) is, relative to all NSW (ABS, 2012), a small holding (due to the high rainfall and relative high population density of the subregion for a non-urban area), and it is assumed that water from rivers will be pumped a maximum of 1 km.

The Gloucester subregion covers about 347.5 km^2, with the area of the PAE being approximately 468.2 km^2. This means that accounting for possible surface water connections beyond the subregion requires the PAE to be 120.7 km^2 larger than the Gloucester subregion. It is in the PAE that geospatial referenced lists of water-dependent assets will be identified.

Figure 6 Location of the Gloucester preliminary assessment extent (PAE)

The PAE comprises the subregion and a 1 km buffer either side of the north-flowing Gloucester River until it joins the Manning River; a similar buffer is used for the south-flowing Karuah River until it reaches Port Stephens.

1.3.1.4 Assessing water dependence

Once the assets were compiled into the asset database and checked for inclusion in the PAE, it was the role of individual bioregion or subregion Assessment teams to assess the water dependence of assets. This meant identifying all assets in the asset list that may be potentially impacted by changes in the groundwater and/or surface water regime due to coal resource development. While the vast majority of the assets will be clearly 'water dependent' in the general sense of the phrase (e.g. bores, rivers and wetlands), there is a small group of assets that could be affected but are not as readily identified as being 'water dependent'. Examples of these assets could include historic buildings that may be potentially subject to added inundation or salinity impacts, or

Indigenous assets that may be more difficult to access due to changes in the water regime. This more particular meaning of 'water-dependence' has been defined to meet the specific requirements of the BA methodology which is focussed on 'assets potentially subject to water-related impacts' rather than only on 'impacts on water-dependent assets'.

Once water dependence was determined, and the decisions recorded in the asset database, a preliminary version of the water-dependent asset register was generated from the asset database. The preliminary version of the water-dependent asset register, with associated maps and data, was presented to experts and organisations with local knowledge at the Gloucester asset workshop in June 2014 for comment and feedback. More than 15 local representatives from relevant state and local governments and extractive industries attended (Table 8). They identified a number of shortfalls and subsequently provided data to amend the register – some of the issues raised and actions arising are presented in Table 9.

The characteristics of the three groups of water-dependent assets identified in the Gloucester subregion, and the reasons for their inclusion or exclusion from the water-dependent asset register, are described in sections 1.3.2 to 1.3.4.

The water-dependent asset register is a simple and authoritative listing of the names of the assets that will be included in other components of the BA; all the spatial and other data associated with each asset (including for each element) is stored in the asset database.

Table 8 Organisations represented at the asset workshop held in Gloucester on Tuesday 3 June 2014

Organisation	Number of participants
Gloucester Shire Council	3
Gloucester Water Study	1
Hunter Councils Environment Division	1
Great Lakes Council	3
Mid-Coast Water	2
NSW Office of Water	3
NSW Environment Protection Authority	1
Hunter Local Land Services	1
AGL (Gloucester Gas)	1
Gloucester Resources Limited (Rocky Hill)	1
Office of Water Science	2
CSIRO Land and Water Flagship	5
Bureau of Meteorology	1
Environmental Resources Information Network	1
	Total 26

Table 9 Summary of issues raised by representatives at the asset workshop and actions for the Assessment team of the Gloucester subregion

Description of issue	Action
Preliminary assessment extent (PAE)	
While the PAE was accepted by all, the working for this needs to be made fully available to the public.	This is included in the following section 1.3.1.2, and is provided at a purposeful level of detail so that the modelling approach is fully documented to inform stakeholders.
Economic assets	
Basic landholder rights data exists (landholders whose property is adjacent to a water source and are outside the NSW licensing system and can gain access to water for their basic rights) which will be useful for an economic asset.	A summary of basic landholder rights in the Gloucester subregion has been provided; this has now been included.
Missing bore depth and entitlement volumes for 10 entitlement licences.	These licences have been provided and included.
Requested check of volume and location of relevant town water supplies.	Assessment team confirmed these. Receptors are now located at the Gloucester and Stroud town water supply off-takes.
Sociocultural assets	
Concern over the perceived arbitrary nature of the list extracted from the *Register of the National Estate*.	An all-of-NSW dataset for heritage items described in local environmental plans (LEPs) has been provided. These LEPs are statutory planning instruments as described in the *Environmental Planning and Assessment Act 1979* (NSW). The LEP dataset was used when generating the final asset list.
It was suggested that the main sociocultural asset in the subregion were farms and could we model economic impact to such farms, especially during time of drought.	The BA economic assets include surface water licences and ground water licences. BA plans to model the potential impact of future CSG and coal extraction on water resources licences in the Gloucester subregion. Confirmed that the BA will be assessing the impact during an extended drought conditions and, to perform prospective understanding, will also account for climate change. Also confirmed that, as per the BA methodology, the Gloucester subregion BA is not performing economic modelling. However, given that future availability of water supplies will be modelled, with and without the coal resource development pathway, and that the farmers will understand what their livestock water requirements are in time of drought, that the carrying capacity of a farm could be modelled. However, as per the scope of the BA methodology, economic modelling will not be performed; assessing the water related impact on water dependent assets is the focus. In summary, a BA considers ecological, economic and sociocultural assets; some modelling of ecological assets is undertaken but economic or sociocultural modelling is out of scope. However, the modelling related to changes to the water regime undertaken by BAs can be used as input for economic modelling and sociocultural modelling performed external to the BA Programme.

Description of issue	Action
Concerns were raised that several water-dependent sociocultural assets on the Karuah River were not listed.	Locations of the 'Booral Wharf', 'Karuah River Washpool' (at Stroud Rd), and 'Allworth Community Swimming Pool/Baths' were provided. They are now processed and included in the water-dependent asset register. Note: while there were many other buildings listed in the LEP, there was some debate that these were not water dependent and should not be included in the preliminary register. However, given that the Assessment team possesses this data (see above) these buildings were considered.
Ecological assets	
Concerns were raised that the NSW threatened species list was not used when developing the asset database. While a list of species is available, species distribution maps are not associated with this list. Great Lakes Council suggested that both the platypus and Australian bass should be added to the water-dependent asset register. Spatially explicit text was provided, as follows: 'Platypus: The spatial location of this asset should be all waterways within the project area with a Stream Order of 2 and higher, but not below the tidal limit.' 'Australian bass: The spatial location of this asset should be all waterways within the project area with a Stream Order of 2 and higher, including areas below the tidal limit.'	Habitat for the Platypus and Australian Bass now in the asset database. Assessment team to be advised when the endangered ecological community (EEC) and threatened species models are published.
There was a concern that some of the 21 potential distributions of species habitat that are EPBC-listed were considered to have 'low' water- dependence. This low water-dependence status was determined by BA staff using the 'Profile' information from the NSW Department of Environment and Heritage Bionet website.	Based on a precautionary principle, involving all members of the workshop, it was decided that 3 of the 14 species initially deemed to have 'low' water-dependence would move into the 'moderate' class. These were the regent honeyeater, slaty red gum and swift parrot.
Biodiversity and habitat mapping for the Gloucester subregion is under development.	Assessment team to be informed of progress.
The workshop requested to split the current mapping of the 'Rainforest, (Lowland tropical Rainforest)' class, into four categories based on landscape position: **1.** mountainous gullies **2.** foothills **3.** riparian **4.** littoral The first two classes would not be water-dependent (on lateral flowing water that may be impacted by CSG and/or coal development) and would not require that impact models were built.	It is considered that all 'Rainforest, (Lowland tropical Rainforest) elements are water-dependent assets, and the receptor impact modelling, where carried out, will take into account the landscape position – in essence performing the landscape dependent masking that was agreed to at the workshop.
A 'Fisheries Biodiversity Hotspots' location dataset exists.	This dataset has been provided and incorporated into the asset database.
A macro-invertebrate dataset exists that will help identify key locations in the freshwater mussels in the Mammy Johnson River.	This dataset has been provided and incorporated into the asset database.

Description of issue	Action
General	
A question was raised as to what specific datasets were used in the preliminary water-dependent asset register?	The *Water Asset Information Tool* (WAIT) was used to generate a list of all datasets that was emailed to all workshop participants on Tuesday 17 June 2014.

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1.3.2 Ecological assets

Summary

The Gloucester subregion has 116 ecological assets made up from 3400 elements. They fall within five of the ten ecological asset classes: ‘River or stream reach, tributary, anabranch or bend’, ‘Wetland, wetland complex or swamp’, ‘Aquifer, geological feature, alluvium or stratum’, ‘Groundwater-dependent ecosystems’ and ‘Habitat (potential species distribution)’. Of the 116 assets, 64 have been included in the water-dependent asset register.

1.3.2.1 Description

The total number of ecological assets in the preliminary assessment extent (PAE) of the Gloucester subregion is 116 (made up from 3400 elements). They fall within five of the ten ecological asset classes (Table 10): ‘River or stream reach, tributary, anabranch or bend’, ‘Wetland, wetland complex or swamp’, ‘Aquifer, geological feature, alluvium or stratum’, ‘Groundwater-dependent ecosystems’ and ‘Habitat (potential species distribution)’. As described in the companion submethodology M02 (as listed in Table 1) for identifying water-dependent assets (Mount et al., 2014), an asset may be made up of one or many polygons termed ‘elements’, and the number of elements for each asset is indicated in the following tables.

Table 10 Classification of elements into ecological assets in the preliminary assessment extent (PAE) of the Gloucester subregion

Group	Subgroup	Class	Elements	Total assets
Ecological	Surface water feature	River or stream reach, tributary, anabranch or bend	24	24
		Lake, reservoir, lagoon or estuary	0	0
		Waterhole, pool, rockpool or billabong	0	0
		Wetland, wetland complex or swamp	140	1
		Marsh, sedgeland, bog, spring or soak	0	0
		Floodplain	0	0
Ecological	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	3	3
Ecological	Vegetation	Groundwater-dependent ecosystems	2426	45
		Riparian vegetation	0	0
		Habitat (potential species distribution)	807	43
		Total	3400	116

Landscape features such as aquifers, rivers and wetlands are obviously water dependent and are included in the water-dependent asset register (Table 11 to Table 13). The distribution of these is shown in Figure 7. As described in Section 1.3.2.2 below, data from the *Atlas of Groundwater Dependent Ecosystems* (Bureau of Meteorology, 2012) were not ‘fit for purpose’ for the bioregional assessment of the Gloucester subregion and have not been included in the water-dependent asset register (Table 14). However, more accurate mapping of groundwater-dependent ecosystems (GDEs) obtained from the NSW Office of Water will be used in the assessment to identify receptors for GDEs.

Table 11 Assets within the 'Aquifer geological feature, alluvium or stratum' class

Asset name[a]	Elements	In register
Hunter-Central Rivers Karuah Alluvium	1	Yes
Hunter-Central Rivers Manning Alluvium	1	Yes
Hunter-Central Rivers New England Fold Belt	1	Yes

[a]Punctuation and typography appear as used in the asset database.

Table 12 Assets within the 'River or stream reach, tributary, anabranch or bend' class

Asset name[a]	Elements	In register
Catchments 237, 243–247, 250–256, 298, 300, 308, 329–330, 344, 347, 356–357, 464	24	Yes
Hunter-Central Rivers Karuah River Estuary	1	Yes

[a]Punctuation and typography appear as used in the asset database.

Table 13 Assets within the 'Wetland wetland complex or swamp' class

Asset name[a]	Elements	In register
Port Stephens Estuary	140	Yes

[a]Punctuation and typography appear as used in the asset database.

Table 14 Assets within the 'Groundwater-dependent ecosystems' class

Asset name	Elements	In register
Barrington Moist Blue Gum-White Mahogany	25	No
Barrington River	7	No
Barrington Wet New England Blackbutt-Blue Gum	19	No
Central Mid Elevation Sydney Blue Gum	1	No
Coastal Flooded Gum	22	No
Dry Foothills Blackbutt-Turpentine	3	No
Dry Foothills Spotted Gum	239	No
Dry Grassy Blackbutt-Tallowwood	132	No
Dry Grassy Tallowwood-Grey Gum	41	No
Dry Heathy Blackbutt-Bloodwood	11	No
Dry Redgum-Bloodwood-Apple	79	No
Escarpment Redgum	168	No
Escarpment Tallowwood-Bloodwood	20	No

Asset name	Elements	In register
Foothills Grey Gum-Spotted Gum	6	No
Gloucester River	94	No
Gorge Grey Box	3	No
Grey Gum-Stringybark	2	No
Ironbark	180	No
Karuah River	24	No
Mangrove	6	No
Manning River	7	No
Moist Foothills Spotted Gum	59	No
Moist Open Escarpment White Mahogany	2	No
Open Coastal Brushbox	13	No
Open Shrubby Brushbox-Tallowwood	45	No
Open Silvertop Stringybark-Blue Gum	2	No
Paperbark	3	No
Rough-barked Apples	15	No
Smoothbarked Apple-Sydney Peppermint-Stringybark	31	No
South Coast Shrubby Grey Gum	494	No
South Coast Tallowwood-Blue Gum	304	No
Southern Wet Sydney Blue Gum	250	No
Stringybark-Apple	93	No
Swamp Mahogany	1	No
Sydney Peppermint-Stringybark	6	No
Wetland (5 assets in total)	5	No
Wet Coastal Tallowwood-Brushbox	5	No
Wet Flooded Gum-Tallowwood	1	No
Wet Foothills Blackbutt-Turpentine	5	No
Wet New England Blackbutt-Silvertop Stringybark	2	No
Wet Shrubby Brushbox-Tallowwood	1	No

[a]Punctuation and typography appear as used in the asset database.

Thirty-six of the 43 ecological assets that were classified as 'Habitat (potential species distribution)' were included in the water-dependent asset register on the basis that they were judged to be moderately or highly water dependent (Table 15). These included the Karuah National Park and the threatened ecological community 'Lowland Subtropical Rainforest on Basalt Alluvium in NE NSW and SE Qld' (Figure 7), as well as fish biodiversity hotspots and the oyster growing areas within the Karuah River. The justification for judging seven of the assets as having low water dependence, and excluding them from the water-dependent asset register, is provided in Table 16.

Table 15 Assets within the 'Habitat (potential species distribution)' class

Although examples of individual species are listed below, bioregional assessments consider the potential impact to the habitat of species not individual species per se.

Asset name[a]	Elements	In register
(Grevillea guthrieana)	1	Yes
Australasian Bittern (Botaurus poiciloptilus)	1	Yes
Black-eyed Susan (Tetratheca juncea)	6	No
Broad-headed Snake (Hoplocephalus bungaroides)	2	No
Brush-tailed Rock-wallaby (Petrogale penicillata)	1	No
Charmhaven Apple (Angophora inopina)	2	Yes
Eastern Bristlebird (Dasyornis brachypterus)	1	No
Giant Barred Frog (Mixophyes iteratus)	1	Yes
Grey-headed Flying-fox (Pteropus poliocephalus)	20	Yes
Hastings River Mouse (Pseudomys oralis)	1	Yes
Karuah National Park	1	Yes
Karuah River Oyster growing Area	1	Yes
Koala (Phascolarctos cinereus)	1	Yes
Leafless Tongue-orchid (Cryptostylis hunteriana)	1	Yes
Lowland Subtropical Rainforest on Basalt Alluvium in NE NSW and SE Qld (threatened ecological community)	77	Yes
New Holland Mouse (Pseudomys novaehollandiae)	1	No
Red Goshawk (Erythrotriorchis radiatus)	2	Yes
Regent Honeyeater (Anthochaera phrygia)	623	Yes
Slaty Red Gum (Eucalyptus glaucina)	1	Yes
Spot-tailed Quoll (Dasyurus maculatus maculatus)	1	No
Stuttering Frog (Mixophyes balbus)	1	Yes
Swift Parrot (Lathamus discolor)	15	Yes
Trailing Woodruff (Asperula asthenes)	3	Yes
White-flowered Wax Plant (Cynanchum elegans)	2	No
Known Platypus habitat in Catchment 244–247, 250, 252–253, 329–330, 347, 356 (11 assets in total)	33	Yes
Fish Biodiversity Hotspots 2–3, 21, 29, 30–31, 49, 108 (8 assets in total)	8	Yes

[a]Punctuation and typography appear as used in the asset database.

Table 16 Justification for judgement of low water dependence for seven assets

Common name	Scientific name	Justification
Black-eyed Susan	*Tetratheca juncea*	It generally prefers well-drained sites below 200 m elevation and annual rainfall between 1000 – 1200 mm. The preferred substrates are sandy skeletal soil on sandstone, sandy-loam soils, low nutrients; and clayey soil from conglomerates, pH neutral. 'Well-drained sites' suggests no dependence on groundwater.
Broad-headed snake	*Hoplocephalus bungaroides*	Nocturnal. Shelters in rock crevices and under flat sandstone rocks on exposed cliff edges during autumn, winter and spring. Moves from the sandstone rocks to shelters in hollows in large trees within 200 m of escarpments in summer. Feeds mostly on geckos and small skinks; will also eat frogs and small mammals occasionally. No specific mention of water dependency.
Brush-tailed rock-wallaby	*Petrogale penicillata*	Brush-tailed rock-wallaby habitat includes refuge habitat, feeding habitat, and routes in between. Refuge habitat includes rock faces or outcrops with large tumbled boulders, ledges and caves (often with vegetation cover) that provide shelter and some protection from predators. No specific mention of water dependency.
Eastern bristlebird	*Dasyornis brachypterus*	Habitat is characterised by dense, low vegetation including heath and open woodland with a heathy understorey; all of these vegetation types are fire prone. Age of habitat since fires (fire-age) is of paramount importance to this species. No specific mention of water dependency.
New Holland mouse, Pookila	*Pseudomys novaehollandiae*	Known to inhabit open heathlands, woodlands and forests with a heathland understorey and vegetated sand dunes. Distribution is patchy in time and space, with peaks in abundance during early to mid stages of vegetation succession typically induced by fire. No specific mention of water dependency.
Spot-tailed quoll	*Dasyurus maculatus maculatus*	Recorded across a range of habitat types, including rainforest, open forest, woodland, coastal heath and inland riparian forest, from the sub-alpine zone to the coastline. Mostly nocturnal, although will hunt during the day; spends most of the time on the ground, although also an excellent climber and may raid possum and glider dens and prey on roosting birds. Females occupy home ranges up to about 750 ha and males up to 3500 ha; usually traverse their ranges along densely vegetated creek lines. May utilise creek lines and riparian vegetation but no specific dependence.
White-flowered wax plant	*Cynanchum elegans*	Usually occurs on the edge of dry rainforest vegetation. Other associated vegetation types include littoral rainforest; coastal tea-tree – coastal banksia coastal scrub; forest red gum aligned open forest and woodland; spotted gum aligned open forest and woodland; and bracelet honeymyrtle scrub to open scrub. Associated vegetation types not indicative of groundwater dependent vegetation.

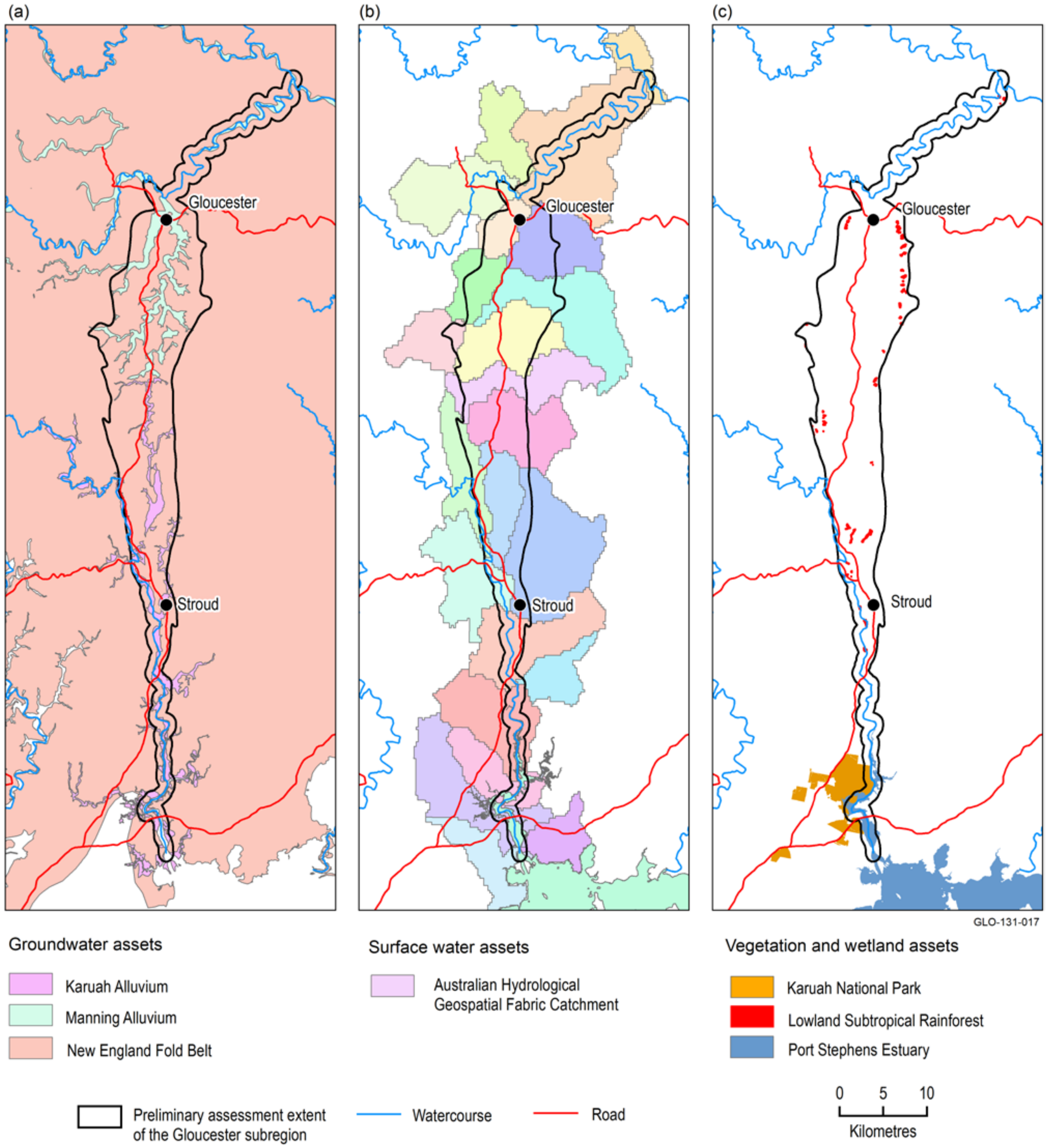

Figure 7 Location of ecological assets in the Gloucester subregion preliminary assessment extent (PAE)

(a) Groundwater assets, (b) Surface water assets and (c) Vegetation and wetland assets

1.3.2.2 Gaps

Nearly 40% of the assets initially identified within the PAE of the Gloucester subregion were GDEs from the *Atlas of Groundwater Dependent Ecosystems* (Bureau of Meteorology, 2012). The purpose of the *Atlas* is to facilitate consideration of GDEs and their water requirements in Australia in water management plans. The *Atlas* provides a broad overview of GDE location nationally but should only be considered a first step in aiding water resource planning and management. Further research is required, especially in high risk locations, to understand links between GDEs, their water requirements and their hydrogeological setting.

In the Gloucester subregion, the *Atlas* identified all perennial vegetation as potentially groundwater dependent, most of which is situated in areas of very deep groundwater where trees are unlikely to have access to groundwater. The *Atlas* is therefore not a suitable basis for identifying truly groundwater-dependent assets in the Gloucester subregion. This is likely to be the case in other high rainfall BAs, although the *Atlas* may be applied more successfully in drier BAs. Hence, the Assessment team judged that GDE polygons from the *Atlas* are not fit-for-purpose for the bioregional assessment of the Gloucester subregion unless they highlight 'known GDEs' which have been assessed in previous studies. This can be determined from the *Atlas* which highlights references to literature. More accurate mapping of GDEs, made available by the NSW Office of Water, is used for the BA in the Gloucester subregion (see companion product 2.1 for the Gloucester subregion).

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1.3.3 Economic assets

Summary

The water-dependent asset register for the Gloucester subregion has 20 economic water-dependent assets made up from 350 elements. There are 13 economic assets in the 'Surface water management zone or area' economic asset class made up of 269 surface water access entitlements and seven economic assets in the 'Groundwater management zone or area' economic asset class made up of 81 groundwater access entitlements.

1.3.3.1 Description

The total number of economic water-dependent assets in the preliminary assessment extent (PAE) of the Gloucester subregion is 20. There are 13 economic surface water assets and seven economic groundwater assets within the PAE of the Gloucester subregion. The assets are made up from 350 elements including 269 surface water access entitlements and 81 groundwater access entitlements with total share components (a specified share or volume of water that can be extracted within a specified water management area) of 19,880 and 263 ML/year, respectively. This data indicates a much stronger reliance on surface water than on groundwater in the PAE. Table 17 shows the breakdown of water access entitlements (i.e. elements) for surface water and groundwater in the PAE of the Gloucester subregion.

Table 17 Breakdown of water access entitlements for surface water and groundwater in the preliminary assessment extent (PAE) of the Gloucester subregion

	Surface water	Groundwater
Water access entitlements (Elements)	269	81
Total share component (ML/y)	19,880	263
Basic water right (stock and domestic)	63	45
Water access right	206	36

There are 13 economic surface water assets and seven economic groundwater assets within the PAE of the Gloucester subregion.

Table 18 shows the number of elements and assets for each category of economic asset within the Gloucester water-dependent asset register. The locations of the elements are shown in Figure 8 and the locations of the assets (i.e. the grouped elements) are shown in Figure 9. Where known, groundwater bore depth is recorded in the asset and receptor register. Depth is an important attribute associated with these elements and assets because the majority of the alluvium in the Gloucester subregion has a depth of 5 to 10 m, with the maximum being 15 to 20 m. This means that groundwater can be extracted from both the alluvial and fractured rock aquifers. The alluvial aquifers are characterised by high hydraulic conductivity, hence yield high water volume per metre of bore depth; yet many bores are used to extract water from the deeper strata, which are generally lower yielding. Changes in groundwater level (or hydraulic heads, when aquifers are confined) at the individual bore have the potential to be affected by reduction in water pressure in (depressurisation of) the deep strata due to coal seam gas (CSG) and/or coal mining operation. The level of impact (if any) on groundwater in the proximity of these bores will be dependent on the relative changes in groundwater levels compared to overall thickness of water bearing strata, yielding groundwater. This warrants the inclusion of 'depth' (where known) in Figure 8 and Figure 9.

Table 18 Elements and assets within each category of economic asset in the Gloucester water-dependent asset register

Group	Subgroup	Class	Number of elements	Number of assets
Economic	Groundwater management zone or area (surface area)	A groundwater feature used for water supply	0	0
		Water supply and monitoring infrastructure	0	0
		Water access right	36	2
		Basic water right (stock and domestic)	45	5
Economic	Surface water management zone or area (surface area)	A surface water feature used for water supply	0	0
		Water supply and monitoring infrastructure	0	0
		Water access right	206	5
		Basic water right (stock and domestic)	63	8

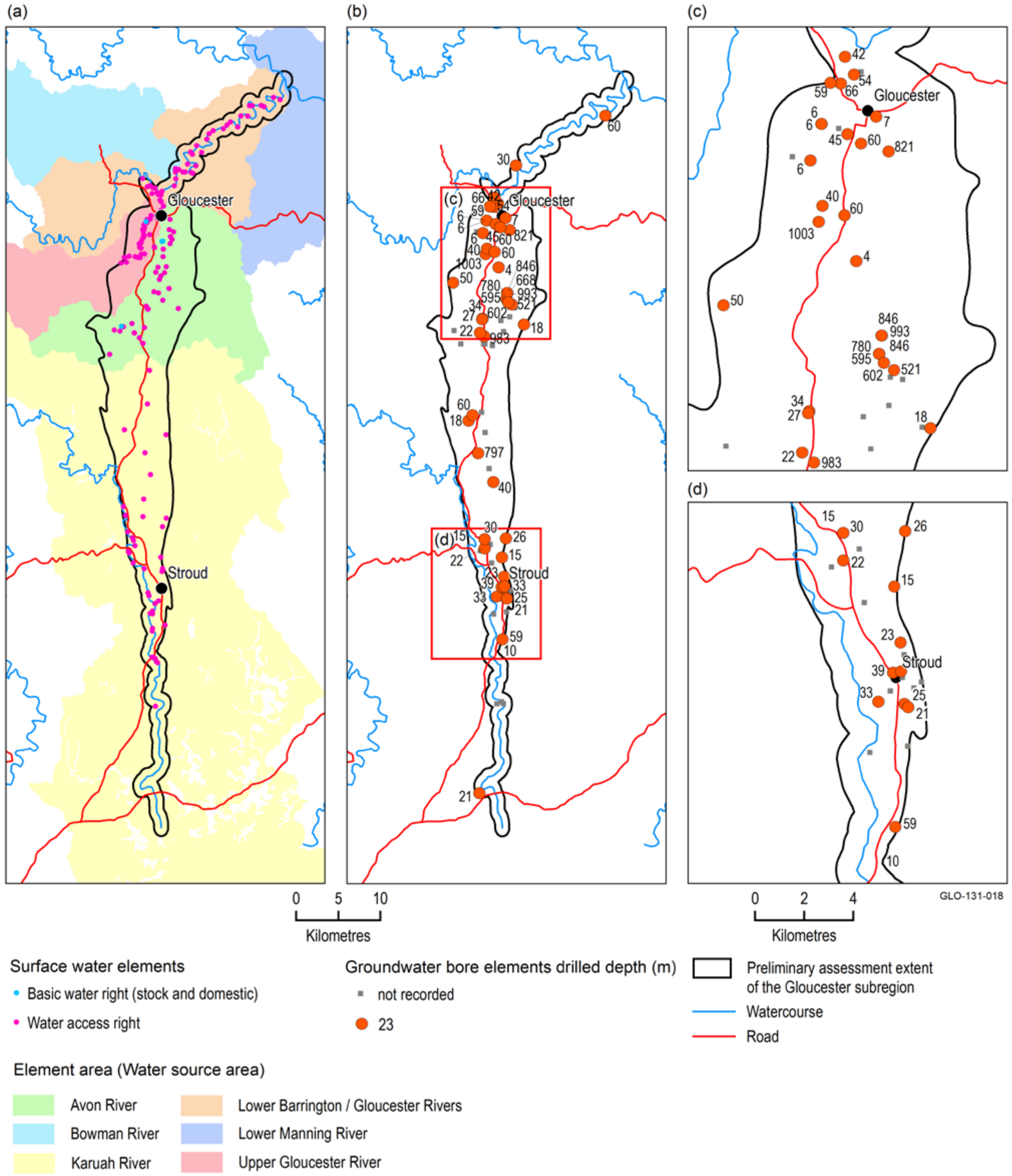

Figure 8 Location of economic elements within the preliminary assessment extent (PAE) of the Gloucester subregion

(a) Elements within different classes of the ‘Surface water management zone or area’ subgroup. (b) Elements (identified as groundwater bores) within the ‘Groundwater management zone or area’ subgroup. Parts (c) and (d) are zoomed in areas from (b) in the vicinity of the towns of Gloucester and Stroud, respectively. The scale bar under part (d) also applies to part (c).

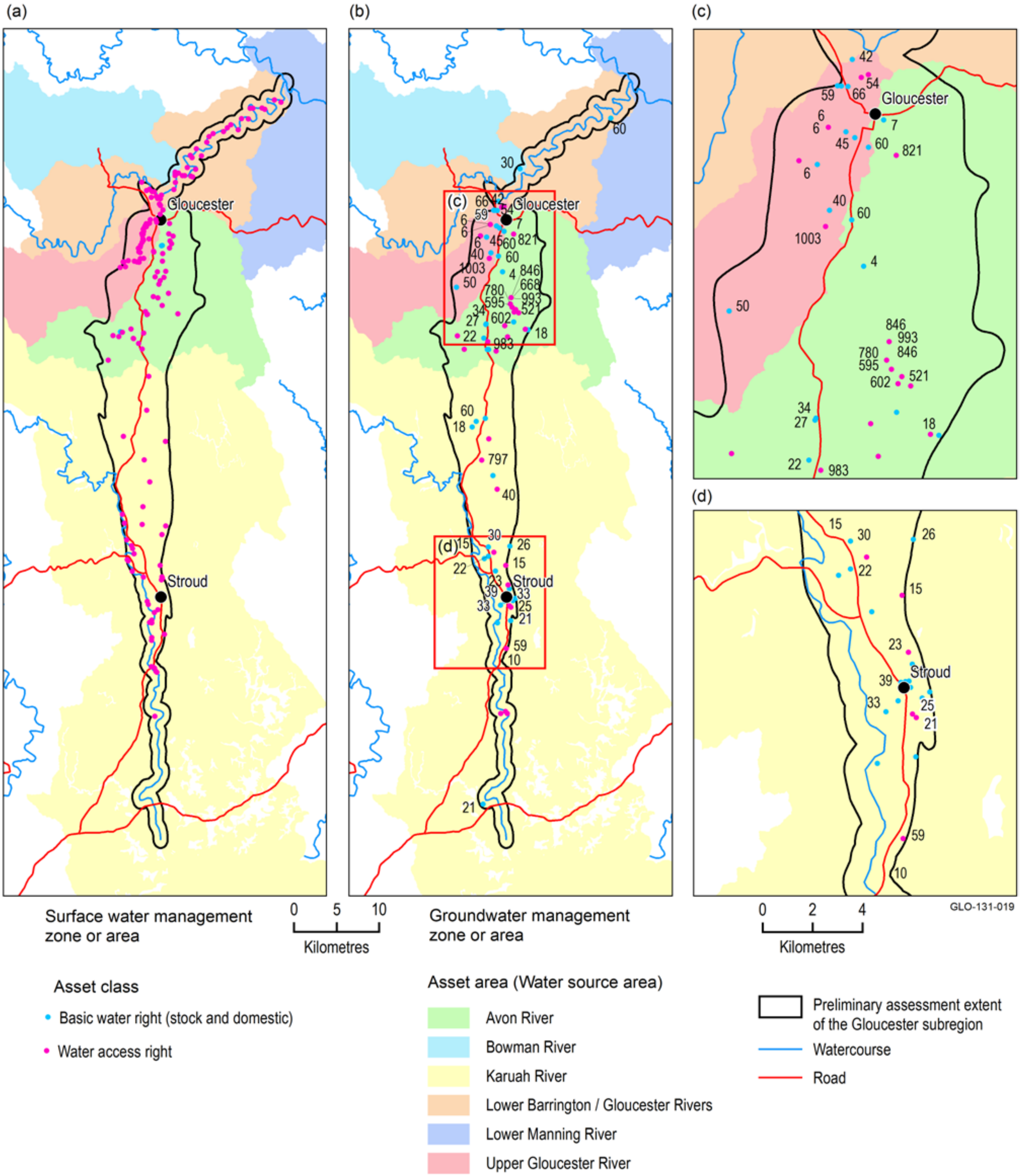

Figure 9 Location of classes of economic assets within the preliminary assessment extent (PAE) of the Gloucester subregion

(a) Economic assets within different classes of the ‘Surface water management zone or area’ subgroup. (b) Economic assets (identified as groundwater bores) within the ‘Groundwater management zone or area’ subgroup. Parts (c) and (d) are zoomed in areas from (b) in the vicinity of the towns of Gloucester and Stroud, respectively. The scale bar under part (d) also applies to part (c), and in parts (b) to (d) the black numbers refer to the depth (m) of the bore.

1.3.3.2 Gaps

The data in the *Surface Water Licences* dataset do not include details of the river reach where the offtake was located; instead data included the Water Source and Water Management Zone that is associated with the water sharing plan (WSP). A water source can be any set of rivers, aquifers or lakes and the like, which are defined by a gazetted WSP to be a water source. Therefore when the elements are aggregated into the asset, water licences are grouped together across the water source which is a large polygon that includes multiple reaches. This will need to be taken into account when assigning receptor locations.

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1.3.4 Sociocultural assets

Summary

Sociocultural assets were sourced from a number of locations including the Hunter-Central Rivers Catchment Management Authority (CMA), the *Australian Heritage* database, and the Gloucester asset workshop held in June 2014. A total of 69 sociocultural assets were identified; four were found to be water-dependent. Discussions have commenced with Indigenous knowledge holders in the Gloucester subregion about Indigenous cultural water-dependent assets.

1.3.4.1 Description

Initially 10 sociocultural assets that are landscape water features (comprising 9 catchments and 1 estuary) were identified by the Hunter-Central Rivers CMA. Following Mount et al. (2014), as these are all landscape water features having both ecological and sociocultural values, to avoid repetition of assets these are all included in the ecological asset classes, though the sociocultural information is retained for use in other bioregional assessment (BA) components such as the impact and risk analyses. Next, a search of the *Australian Heritage* database (Department of the Environment, 2014) uncovered 20 sociocultural assets comprising 20 elements. Finally, following the asset workshop held in Gloucester in June 2014, another 49 sociocultural assets (comprising 49 elements) were identified. Many (48 of 49) were obtained by spatially intersecting the PAE with the local environmental plans (LEPs - statutory planning instruments as described in the *Environmental Planning and Assessment Act 1979* (NSW)). The remaining single sociocultural asset (i.e., Allworth Community Swimming Pool/Baths located on lower Karuah River) was identified by the Great Lakes Council. Two other sociocultural assets provided post-workshop by the Great Lakes Council (i.e., Booral Wharf and Karuah River Washpool (at Stroud Rd)) were already recorded in the LEP.

Table 19 shows the breakdown of sociocultural elements and assets by subgroup and class. Many of the sociocultural assets were derived from geographically intersecting the *Australian Heritage* database and the LEPs with the preliminary assessment extent (PAE) of the Gloucester subregion and are buildings located in the towns of Gloucester and Stroud. Due to these buildings being located away from the river network, it is anticipated that there will be negligible change in water availability and/or water quality impacting these assets due to coal-related extractive industries.

Table 19 Classification of elements into sociocultural assets in the preliminary assessment extent (PAE) of the Gloucester subregion

Group	Subgroup	Class	Number of elements	Number of assets
Sociocultural	Cultural	Heritage site	66	66
		Indigenous site	0	0
	Social	Recreation area	3	3

Only four of the sociocultural assets were found to be water-dependent: (i) Port Stephens Estuary (which is the lower Karuah River), (ii) Booral Wharf, (iii) Karuah River Washpool (at Stroud Rd) and

(iv) Allworth Community Swimming Pool/Baths. Three are clearly water features (see (i), (iii) and (iv) above), while Booral Wharf is classified as 'historical ruins' (gazetted in November 1999 as part of the Great Lakes Council Environmental Heritage) and is deemed to be water dependent because a change in the flow regime has the potential to damage the structure.

Initial conversations have been held with Indigenous knowledge holders in the Gloucester subregion to gain an understanding of Indigenous cultural water-dependent assets. These discussions will continue over coming weeks and months. Where possible and appropriate, and with the agreement of Indigenous knowledge holders, Indigenous water-related values will be incorporated into an updated water-dependent asset register or incorporated into later technical products.

1.3.4.2 Gaps

For bioregional assessment purposes, no specific gaps in the knowledge base related to sociocultural assets in the Gloucester subregion have been identified.

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