Australian Government

BIOREGIONAL ASSESSMENTS

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

Conceptual modelling for the Maranoa-Balonne-Condamine subregion

Product 2.3 for the Maranoa-Balonne-Condamine subregion from the Northern Inland Catchments Bioregional Assessment

26 May 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.

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Condamine river weir on Darling Downs in Queensland, 2005

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Executive summary

In bioregional assessments (BAs), conceptual models are developed to describe the *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets in the Maranoa-Balonne-Condamine subregion. A BA considers the difference in results between two potential futures:

- *baseline coal resource development* (baseline): a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012. For the Maranoa-Balonne-Condamine subregion, however, 'baseline' includes all CSG developments in the subregion that are reported in the 2014 annual report for the Surat cumulative management area
- *coal resource development pathway* (CRDP): a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is due to the *additional coal resource development* (ACRD) – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012.

Methods

This product details the conceptual model of causal pathways of the Maranoa-Balonne-Condamine subregion, following the method described in in companion submethodology M05 on the development of conceptual models of causal pathways. It identifies:

- the key system components, processes and interactions, which essentially define pathways over and through which water can move
- the ecosystems in the subregion in terms of landscape classes and their dependence on water
- the potential hydrological changes that may occur due to coal resource development in the subregion by describing and documenting the baseline and CRDP, including a summary of water management for coal resource developments
- hazards from coal resource development using the Impact Modes and Effects Analysis (IMEA) hazard analysis approach
- causal pathways from coal resource development through to hydrological changes, both for baseline and CRDP.

The conceptual model of causal pathways for the Maranoa-Balonne-Condamine subregion leverages existing state-based resources and knowledge of geological, surface water, groundwater and ecological conceptual models. Notably, the geological and groundwater conceptual models are consistent with the Office of Groundwater Impact Assessment (OGIA) regional groundwater model developed in 2012. The OGIA model was revised for BAs to also simulate water-related impacts of coal mine development in the regional groundwater systems. The Assessment team refined the landscape classification and high-level conceptualisation of the causal pathways following discussions at the 'Conceptual modelling of causal pathways' workshop held in July 2015.

Summary of key system components, processes and interactions

The spatial extent of the water flows and pathways is limited to the preliminary assessment extent (PAE) of the Maranoa-Balonne-Condamine subregion. The PAE is the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The PAE includes mapped outcrop areas of the Hutton, Clematis and Precipice sandstone aquifers and along the Dawson, Moonie and Weir rivers that are outside the subregion boundary. Coal mine and CSG operations in the subregion target the Walloon Coal Measures of the Surat and Clarence-Moreton geological basins, which has the potential to directly affect the regional groundwater and surface water systems. Hydrological changes to the groundwater system associated with coal resource development can propagate through the alluvium and other aquifers to indirectly affect surface water – groundwater interactions in the aquifer outcrop and subcrop areas.

Important groundwater systems in the subregion are the surficial alluvial, basalt and Great Artesian Basin (GAB) sandstone aquifers. The Condamine Alluvium and Main Range Volcanic aquifers are important water sources for irrigation, stock and domestic and town water supplies. The GAB aquifers of the Surat Basin that underlie most of the subregion are part of one of the largest groundwater systems in the world and are a major water source for stock and domestic and town water supplies. River basins in the PAE are the Border, Condamine-Balonne (including the Maranoa River), Fitzroy and Moonie rivers. Most river systems are temporary, with the exception of parts of the Dawson River, which receive baseflow contributions from rejected GAB recharge in the aquifer outcrop areas. The temporary nature of the surface water systems means that the management, treatment and disposal of water associated with coal resource development can affect surface water quality and surface water – groundwater interactions.

Ecosystems

The ecosystems in the Maranoa-Balonne-Condamine subregion are classified in terms of landscape classes and their dependence on water. Landscape classification is used to characterise the diverse range of water-dependent assets into a smaller number of classes for further analysis. Where appropriate, the approach has built on and integrated with existing classification systems. This classification identified 34 landscape classes, which are aggregated into 5 landscape groups based on broad-scale distinctions in their water dependency and association with GAB or non-GAB GDEs (groundwater-dependent ecosystems), floodplain/non-floodplain or upland/lowland environments and remnant/human-modified habitat types:

- 'Floodplain or lowland riverine (including non-GAB GDEs)'
- 'GAB GDEs (riverine, springs, floodplain or non-floodplain)'
- 'Non-floodplain or upland riverine (including non-GAB GDEs)'

- ‘Dryland remnant vegetation’
- ‘Human modified’.

The BA team finalised the landscape classification following discussion with stakeholders at the ‘Conceptual modelling of causal pathways’ workshop held in July 2015.

Most of the PAE (72%) is classed under the ‘Human-modified’ landscape group that includes agricultural, urban and other intensive land uses. In the remainder of the PAE most of the landscape falls into the ‘Dryland remnant vegetation’ landscape class (20%) and the landscape groups ‘Floodplain or lowland riverine (including non-GAB GDEs)’ (5%), ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ (2%) and ‘GAB GDEs (riverine, springs, floodplain or non-floodplain)’ (1%). The ‘Dryland remnant vegetation’ landscape class is not considered to be water dependent. The stream network is classed as ‘Floodplain or lowland riverine (including non-GAB GDEs)’ (48%), ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ (39%) and ‘GAB GDEs (riverine, springs, floodplain or non-floodplain)’ (13%). Most springs and spring complexes in the PAE of the Maranoa-Balonne-Condamine subregion (86%) are associated with GAB aquifers. Aspects of water dependency and the vegetation communities associated with each landscape group are discussed.

Baseline and coal resource development pathway

The CRDP for the Maranoa-Balonne-Condamine subregion includes five baseline open-cut coal mines, five baseline CSG fields and two additional open-cut coal mines. The CRDP is based on information available as of July 2015 and was finalised after feedback provided at the CRDP workshop held in December 2014. The five baseline coal mines are: Cameby Downs Mine, Commodore Mine, Kogan Creek Mine, New Acland Coal Mine Stage 2 and Wilkie Creek Mine (which ceased operations in December 2013). The two proposed coal mines are: New Acland Coal Mine Stage 3 and The Range. To ensure consistency with OGIA reporting, the baseline includes all CSG projects in the Maranoa-Balonne-Condamine subregion that are reported in the 2014 annual report for the Surat cumulative management area. The five baseline CSG projects are: Australia Pacific LNG Project, Queensland Curtis LNG Project, Santos Gladstone LNG and Santos Gladstone LNG Gas Field Development projects, Surat Gas Project and Ironbark Project.

Water affected by open-cut coal mines in the subregion is typically treated for discharge off site and for use in mine-related activities such as dust suppression and coal washing. Water management for CSG operations is consistent with the Queensland Government’s Coal Seam Gas Water Management Policy. This policy aims to strategically manage co-produced water by prioritising its beneficial use by new and existing users as well as water-dependent industries; it proposes treatment and disposal of co-produced water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values. Reverse osmosis is the preferred water treatment technology of the four major CSG operators in the subregion (Arrow Energy Pty Ltd, Origin Energy Limited, QGC Pty Limited and Santos Ltd).

Hazard analysis

A dedicated hazard analysis, IMEA, is used to systematically identify activities that may initiate *hazards*, defined as events, or chains of events that might result in an *effect* (change in the quality or quantity of surface water or groundwater). A large number of hazards are identified; some of these are beyond the scope of BA and others are adequately addressed by site-based risk management processes and regulation. The main hazards considered for BA in the Maranoa-Balonne-Condamine subregion associated with CSG operations are potential impacts on aquifers, impacts associated with storage, processing and disposal of treated water: raised groundwater levels, soil salt mobilisation and leaching from storage ponds. Hazards associated with open-cut coal mines include the potential to link, or cause leakage between, aquifers, deliberate pit wall dewatering, subsidence and enhanced aquifer interconnectivity caused by post-closure water filling the pit.

Causal pathways

Hazards associated with CSG operations and open-cut coal mines that are considered to be in scope for BA in the Maranoa-Balonne-Condamine subregion are grouped into four main causal pathway groups:

- ‘Subsurface depressurisation and dewatering’
- ‘Subsurface physical flow paths’
- ‘Surface water drainage’
- ‘Operational water management’.

The ‘Subsurface depressurisation and dewatering’ causal pathway group associated with the CRDP has the potential to directly affect the regional groundwater system, and indirectly affect surface water – groundwater interactions in aquifer outcrop areas.

The ‘Subsurface physical flow paths’ causal pathway group involves physical modification of the rock mass or geological architecture by creating new physical paths that water may potentially infiltrate and flow along. This hazard may occur due to hydraulic fracturing of coal seams or when the integrity of wells drilled for groundwater or gas extraction is compromised. The cracking that occurs in the rock mass above underground longwall panels may also subsequently cause enhanced hydraulic connection. The extent of these changes is likely to be restricted to aquifer or aquifer outcrop areas within tenements, but can also affect connected watercourses within and downstream of tenements. Incomplete knowledge of the location of subterranean faults and fractures of the geological layers means that uncertainty exists in the precise spatial extent of groundwater level decline due to subsurface depressurisation and dewatering. However, the uncertainty analysis reported in companion product 2.6.2 (groundwater numerical modelling) for the Maranoa-Balonne-Condamine subregion allows a probabilistic estimate of maximum groundwater level decline.

The ‘Surface water drainage’ causal pathway group contains the most frequent hazards associated with CSG operations and open-cut coal mines. Intercepting surface water runoff, altering surface water system and subsidence of land surface can change, or disrupt, surface water drainage in the PAE. Effects on surface water direction, volume and quality can have medium-term (5 to 10 years) to long-term (10 to 100 years) cumulative effects on watercourses within and downstream of tenements.

The ‘Operational water management’ causal pathway group involves the modification of water management systems and may have cumulative effects on surface water catchments and stream networks, surface water – groundwater interactions and groundwater conditions. Effects are likely to be in the medium to long term and include watercourses in aquifer outcrop areas that are within and downstream of tenements.

Gaps

The combination of limited water quality and quantity data availability and use of a groundwater model that is focused on the deeper regional aquifer, limits the value of developing a coupled surface water – groundwater numerical model in the Maranoa-Balonne-Condamine subregion at this time.

Further work

The causal pathways described in this product guide how the modelling (product 2.6.2 (groundwater numerical modelling)) is conducted and how product 3-4 (impact and risk analysis) is framed for the Maranoa-Balonne-Condamine subregion.

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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.

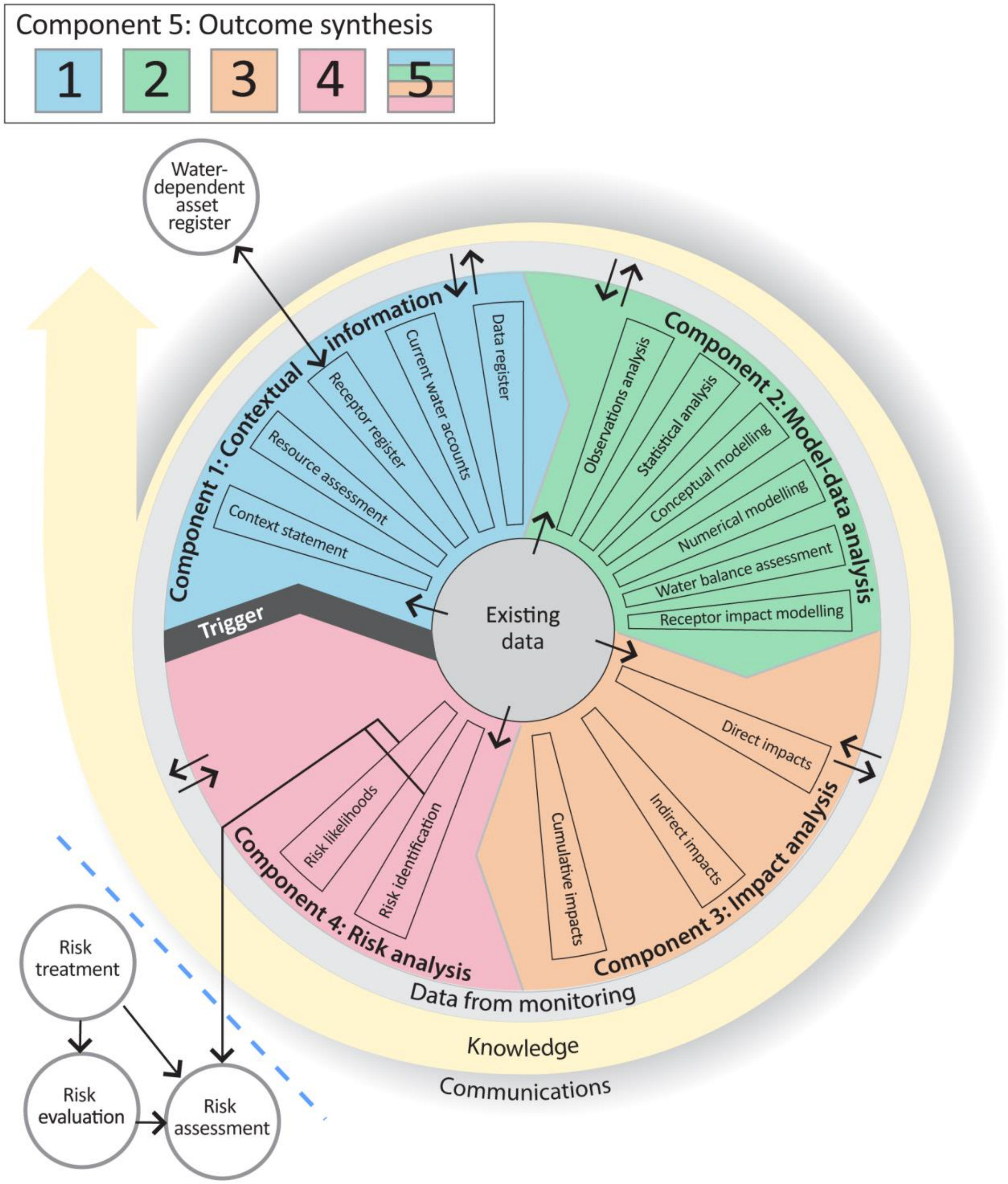

Figure 1 Schematic diagram of the bioregional assessment methodology

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.

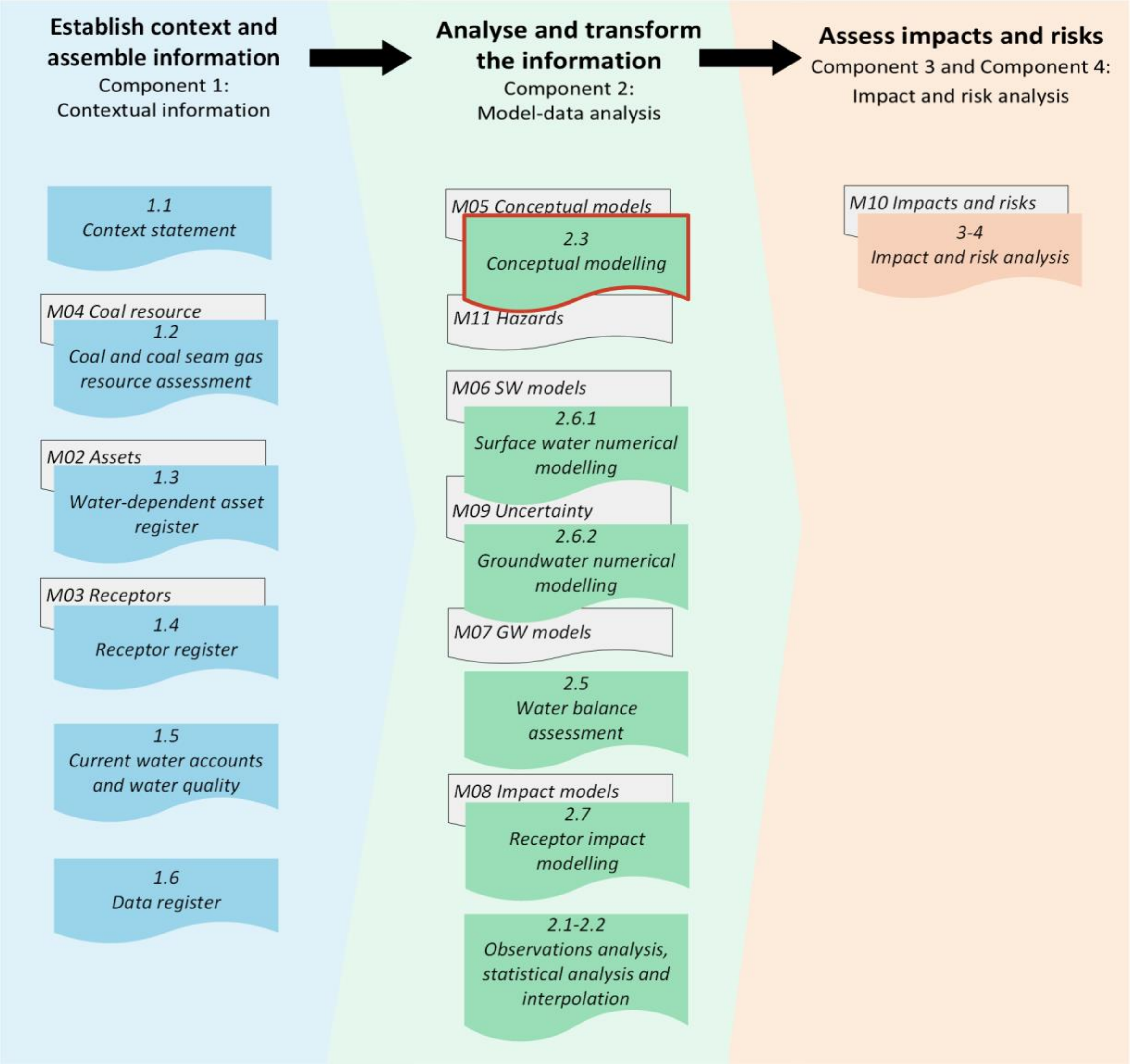

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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 Maranoa-Balonne-Condamine subregion

For each subregion in the Northern Inland Catchments 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 1.4. Originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in products 2.6.1 (surface water modelling) and 2.6.2 (groundwater modelling). 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) 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 Maranoa-Balonne-Condamine 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
	1.5	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 Maranoa-Balonne-Condamine subregion	2.1-2.2	Observations analysis, statistical analysis and interpolation	2.5.2.1, 2.5.2.2	Not produced
	2.3	Conceptual modelling	2.5.2.3, 4.3	PDF, HTML
	2.5	Water balance assessment	2.5.2.4	Not produced
	2.6.1	Surface water numerical modelling	4.4	Not produced
	2.6.2	Groundwater numerical modelling	4.4	PDF, HTML
	2.7	Receptor impact modelling	2.5.2.6, 4.5	Not produced
Component 3 and Component 4: Impact and risk analysis for the Maranoa-Balonne-Condamine subregion	3-4	Impact and risk analysis	5.2.1, 2.5.4, 5.3	PDF, HTML
Component 5: Outcome synthesis for the Maranoa-Balonne-Condamine 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 Inland Catchments 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.
- 'Not produced' indicates that the product was not developed. A webpage explains why and points to relevant submethodologies (Table 1).

[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 Inland Catchments 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.

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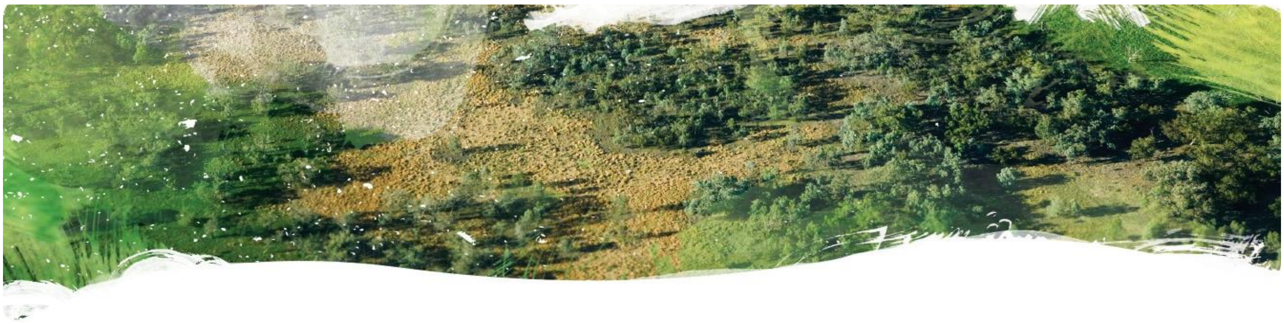

2.3 Conceptual modelling for the Maranoa-Balonne-Condamine subregion

This product firstly summarises key system components, processes and interactions for the geology, hydrogeology and surface water in the Maranoa-Balonne-Condamine subregion. It describes its ecosystems using a landscape classification.

The product then characterises the two potential futures considered in bioregional assessments:

- baseline coal resource development (baseline): a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012
- coal resource development pathway (CRDP): a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is the change that is primarily reported in a bioregional assessment. This change is due to the additional coal resource development (ACRD) – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012.

The Impact Modes and Effects Analysis method is then used to identify hazards, defined as events, or chains of events, that might result in an effect (change in the quality or quantity of surface water or groundwater).

Next are presented causal pathways, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. Causal pathways, for both baseline and CRDP, are identified by considering coal resource development activities, impact causes, impact modes and the resulting water-related effects. This product describes the causal pathways from the coal resource development to the hydrological changes

(represented by hydrological response variables); product 3-4 (impact and risk analysis) describes the subsequent causal pathways from the hydrological changes to the impacts (represented by the receptor impact variables, which are linked to the landscape classes and assets).

The product concludes by describing the causal pathways for the baseline and CRDP, which guide how the modelling (product 2.6.2 (groundwater numerical modelling)) is conducted, and how product 3-4 (impact and risk analysis) is framed.

2.3.1 Methods

Summary

The conceptual model of causal pathways characterises the *causal pathway*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. This section details the specific application to the Maranoa-Balonne-Condamine subregion of methods described in the companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016).

Key concepts and terminology are also explained, and the overall steps are summarised: (i) synthesis of the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion; (ii) landscape classification; (iii) definition of the baseline coal resource development (baseline) and the coal resource development pathway (CRDP); (iv) hazard analysis; and (v) description of the resulting causal pathways from the coal resource development to hydrological change, for the baseline and CRDP.

The approach taken in the Maranoa-Balonne-Condamine subregion has leveraged existing state-based resources and knowledge of geological, surface water, groundwater and ecological conceptual models. Notably, the Office of Groundwater Impact Assessment (OGIA) regional groundwater flow model was revised for the bioregional assessment (BA) to also simulate water-related impacts of coal mine development in the regional groundwater systems. The causal pathways were finalised following discussion with stakeholders at the ‘Conceptual modelling of causal pathways’ workshop held in July 2015.

2.3.1.1 Background and context

This product presents information about the conceptual model of causal pathways for the Maranoa-Balonne-Condamine subregion, which was developed using methods outlined in the companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). The application to the Maranoa-Balonne-Condamine subregion is described in Section 2.3.1.2, with more specific details in the individual sections that follow.

Conceptual models are abstractions or simplifications of reality. A number of conceptual models are developed for a BA, including conceptual models for geology, groundwater and surface water, which underpin the numerical modelling.

Another type of conceptual model is a conceptual model of causal pathways, which characterises the *causal pathway*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water resources and water-dependent assets. The conceptual model of causal pathways brings together a number of conceptual models developed in a BA, and might be expressed in a variety of ways, with narrative, pictorial graphics, and influence diagrams all important.

The causal pathways play a critical role in focusing the BA on the most plausible and important *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality or quantity of surface water or groundwater). The causal pathways associated with these hazards underpin the construction of groundwater and surface water models, and frame the assessment of the *severity* and *likelihood* of impacts to water-dependent assets. A *water-dependent asset* 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 that will be impacted by coal resource development.

The construction of causal pathways requires the Assessment team to first synthesise and summarise the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion (as presented in Section 2.3.2). Emphasising gaps and uncertainties is as important as summarising what is known about how various systems work.

Section 2.3.3 presents the development of a *landscape classification*, which aims to systematically simplify a complex system that contains a large number of assets identified by the community. The landscape classification describes the main biophysical and human ecosystems, and provides a high-level conceptualisation of the subregion at the surface. Most assets are related to one or more *landscape classes*, which are defined for BA purposes as ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Landscape classes are present on the landscape across the entire subregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of *ecosystem assets*, which are ecosystems that may provide benefits to humanity (Bureau of Meteorology, 2013; United Nations et al., 2014).

Section 2.3.4 then defines two potential futures (Figure 3) namely the:

- *baseline coal resource development* (baseline), a future that includes all coal mines and CSG fields that are commercially producing as of December 2012
- *coal resource development pathway* (CRDP), a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012.

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the *additional coal resource development* (ACRD) – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012. To ensure consistency with Office of Groundwater Impact Assessment (OGIA) reporting, the baseline in the Maranoa-Balonne-Condamine subregion includes all CSG projects that are reported in the 2014 annual report for the Surat cumulative management area.

Figure 4 illustrates this fundamental comparison of these futures, with the baseline in the top half of the figure and the CRDP in the bottom half of the figure. It emphasises that in order to assess potential impact on assets, it is important to compare the changes of two types of variables at specific points in space and time:

- *hydrological response variables*, the hydrological characteristics of the system that potentially change due to coal resource development (for example, drawdown (Figure 3) or the annual streamflow volume)
- *receptor impact variables*, the characteristics of the system that, according to the conceptual modelling, potentially change due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums).

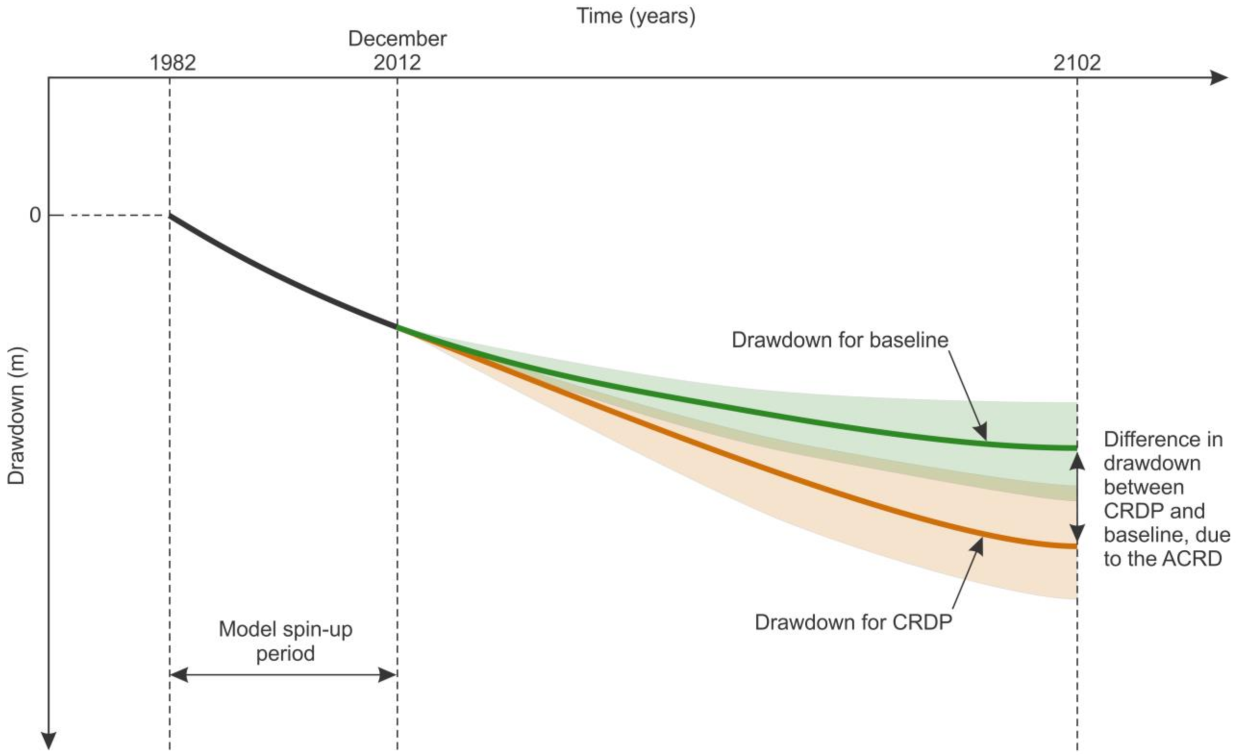

Figure 3 Generic example of drawdown at a specific location over time for the baseline coal resource development (baseline) and coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development (ACRD)

The lighter shades indicate the uncertainty in results. Model spin-up period is a warm-up period for the models.

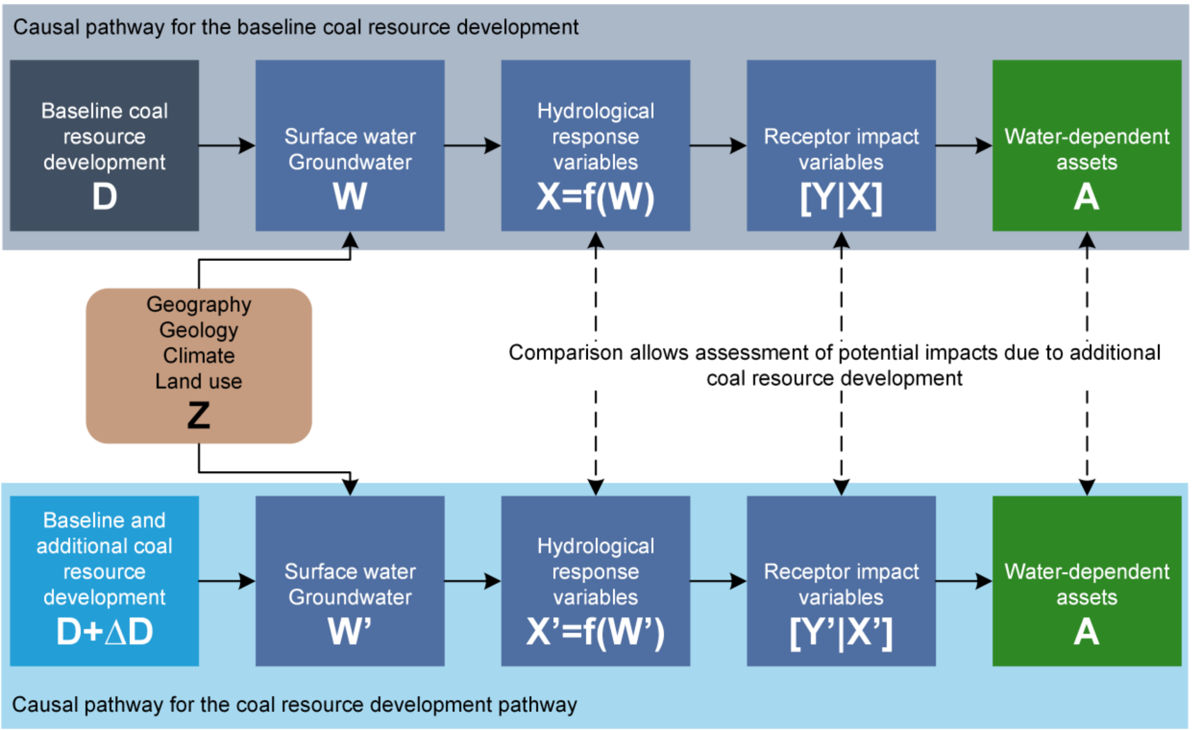

Figure 4 The difference in results between the coal resource development pathway (CRDP) and the baseline coal resource development (baseline) provides the potential impacts due to the additional coal resource development (ACRD)

Section 2.3.5 details the hazard analysis, using the Impact Modes and Effects Analysis (IMEA) method, as described in companion submethodology M11 (as listed in Table 1) for hazard analysis (Ford et al., 2016), and illustrated in Figure 5. Potential causal pathways for both baseline and CRDP are identified by considering:

- *activities* – planned events associated with a CSG operation or coal mine. For example, activities during the exploration and appraisal life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages
- *impact causes* – activities (or aspects of an activity) that initiate a hazardous chain of events
- *impact modes* – the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events
- *effects* – changes in the quantity or quality of surface water or groundwater. An effect is a specific type of an *impact* (any change resulting from prior events).

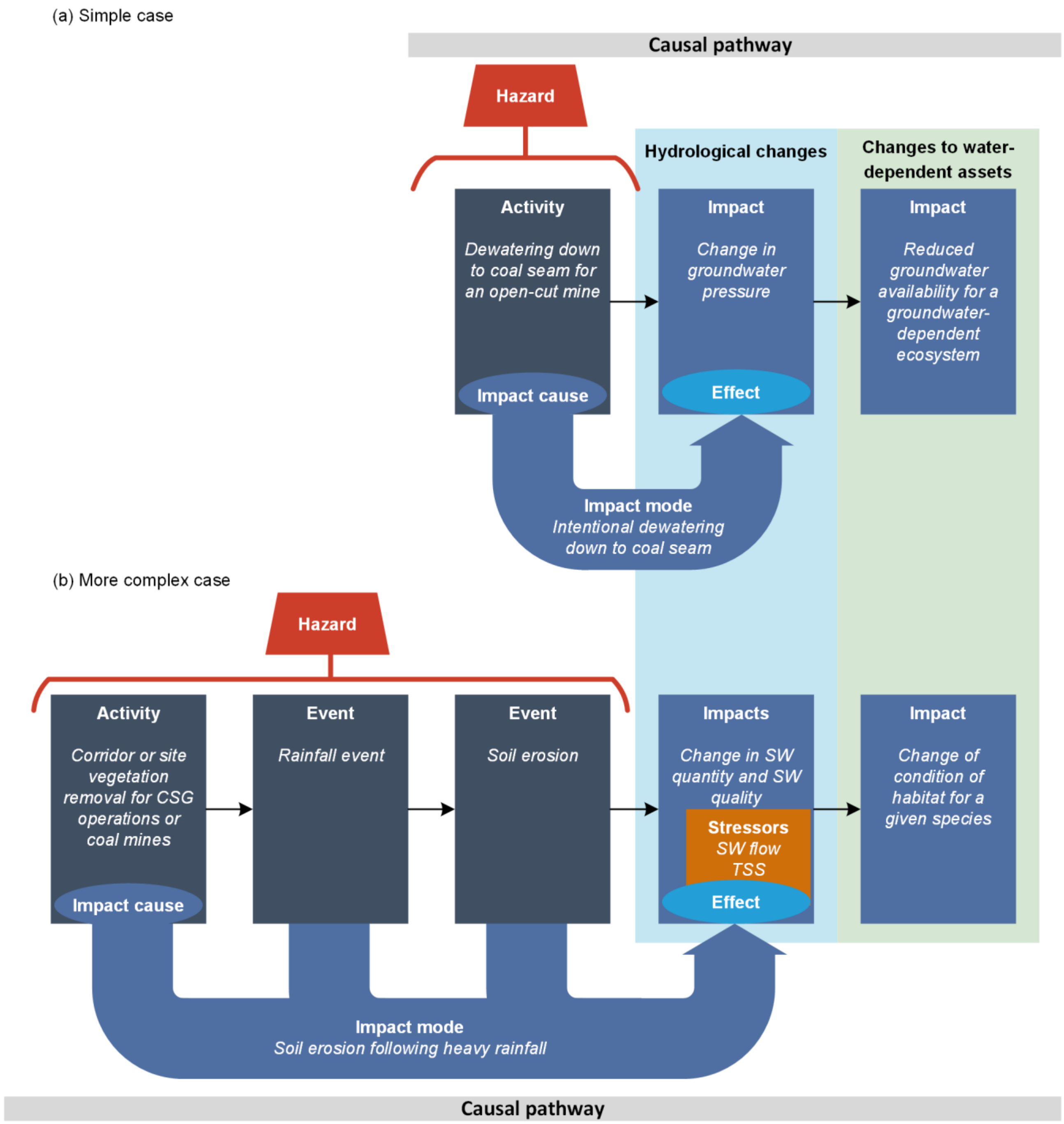

Figure 5 Hazard analysis using the Impact Modes and Effects Analysis

The italicised text is an example of a specified element in the Impact Modes and Effects Analysis. (a) In the simple case, an activity related to coal resource development directly causes a hydrological change which in turn causes an ecological change. The hazard is just the initial activity that directly leads to the effect (change in the quality or quantity of surface water or groundwater). (b) In the more complex case, an activity related to coal resource development initiates a chain of events. This chain of events, along with the stressor(s) (for example, surface water (SW) flow and total suspended solids (TSS)), cause a hydrological change which in turn causes an ecological change. The hazard is the initial activity plus the subsequent chain of events that lead to the effect.

This product only specifies the causal pathways from coal resource development to hydrological response variables (see Figure 4). For BAs undertaking receptor impact modelling, the subsequent causal pathways (from hydrological response variables to impacts on landscape classes and water-dependent assets) are reported in the companion product 2.7 (receptor impact modelling). These causal pathways are reported for only those landscape classes with potential hydrological changes, as reported in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). Note, however, that companion product 2.6.1 (surface water numerical modelling) and product 2.7 (receptor impact modelling) are not produced for the Maranoa-Balonne-Condamine subregion, as explained in Section 2.3.1.2.

2.3.1.2 Developing causal pathways

The approach taken in the Maranoa-Balonne-Condamine subregion has leveraged existing state-based resources and knowledge of geological, surface water and groundwater conceptual models. The geological and groundwater conceptual models are consistent with the Office of Groundwater Impact Assessment (OGIA) regional groundwater model, which is 'a regional groundwater flow model for making predictions of groundwater impacts from the petroleum and gas activities and for developing the … Spring Impact Management Strategy' (QWC, 2012). The groundwater numerical modelling approach undertaken in the Maranoa-Balonne-Condamine subregion is detailed in companion product 2.6.2 (groundwater numerical modelling) (Janardhanan et al., 2016). The OGIA model is re-run annually based on the latest available industry development plans. As such, it has the best available representation of operational and planned CSG development in the subregion for cumulative groundwater impact assessment.

The OGIA model was revised for the BA to also simulate water-related impacts of coal mine development in the Maranoa-Balonne-Condamine subregion. However, the OGIA model may not on its own be suitable for assessing impacts on groundwater-dependent ecosystems or surface water – groundwater interactions. Licensed surface water and groundwater entitlement volumes are available. However, volumetric measurements of surface water or groundwater use and identification of the source of groundwater were identified as knowledge gaps in companion product 1.5 for the Maranoa-Balonne-Condamine subregion (Cassel et al., 2015). This report also identified that long-term, consistent water quality data measurements of surface water and groundwater systems in the Maranoa-Balonne-Condamine subregion were not available. For these reasons, the Assessment team has not developed a coupled surface water and groundwater numerical model of the Maranoa-Balonne-Condamine subregion.

The implications of this approach are that several companion products are not required for the BA in the Maranoa-Balonne-Condamine subregion, as described below. Companion product 2.1-2.2 (observations analysis, statistical analysis and interpolation) is not required because the Assessment team did not develop a surface water numerical model and the observations analysis, statistical analysis and interpolation in the development of the OGIA model is well documented (GHD, 2012; QWC, 2012). Companion product 2.5 (water balance assessment) is not produced. Instead the water balance and analysis of the surface water – groundwater interactions are documented in companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (Janardhanan et al., 2016). Product 2.7 (receptor impact modelling) is not produced because the Assessment team cannot use surface water numerical modelling to estimate hydrological changes or quantify all hydrological response variables necessary for this product.

The 'Conceptual modelling of causal pathways' workshop was held in Brisbane in July 2015. The key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion were summarised and potential causal pathways were discussed with stakeholders at this workshop. The Assessment team refined the landscape classification of the main biophysical and human ecosystems that captures the high-level conceptualisation of the subregion at the surface through consultation with stakeholders at the workshop and separate meetings with experts from the Queensland Government. Discussion of the potential causal pathways considered the coal resource developments included in the groundwater modelling, hazards, impact causes, impact modes, activities and the resulting water-related effects identified by the IMEA. Discussion with stakeholders focused on knowledge gaps and uncertainties identified by the Assessment team.

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2.3.2 Summary of key system components, processes and interactions

Summary

This section summarises the connections in the hydrological cycle of the Maranoa-Balonne-Condamine subregion. The spatial extent of the water flows and pathways is limited to the subregion preliminary assessment extent (PAE). The PAE extends beyond the northern and eastern subregion boundaries to include areas of the Hutton, Clematis and Precipice sandstone aquifers and shallower aquifers that may be affected by coal seam gas (CSG)-related groundwater extraction within the subregion and 5 to 7 km from the Dawson, Moonie and Weir rivers outside of the subregion boundary to encompass potential downstream surface water impacts.

Coal mining and CSG development in the Maranoa-Balonne-Condamine subregion targets the Walloon Coal Measures of the Surat and Clarence-Moreton geological basins. Important groundwater systems in the subregion are alluvial aquifers associated with major rivers (and antecedent systems), basalt aquifers associated with the Main Range Volcanics and aquifers of the Surat Basin within the Great Artesian Basin (GAB). The Condamine Alluvium and Main Range Volcanic aquifers are important water sources for irrigation, stock and domestic and town water supplies. The Condamine Alluvium is the most important and highly developed alluvial groundwater system in the subregion.

Coal resource development in the Maranoa-Balonne-Condamine subregion has the potential to directly affect the regional groundwater and surface water systems. Hydrological changes to the groundwater system can propagate through the alluvium and other aquifers to indirectly affect surface water – groundwater interactions in the aquifer outcrop and subcrop areas. Connectivity by direct linkages due to faulting and fracturing enhances the effects of groundwater level changes due to extraction. However, the role of faults and fractures as conduits or barriers to flow, their location in three dimensions, and their propensity to change their nature due to water pressure changes are all poorly known in the Maranoa-Balonne-Condamine subregion.

River basins in the PAE of the Maranoa-Balonne-Condamine subregion are the Border, Condamine-Balonne (including the Maranoa River), Fitzroy and Moonie rivers. Most river systems are temporary, with the exception of parts of the Dawson River, which receives baseflow contributions from rejected GAB recharge in the aquifer outcrop areas. The ephemeral nature of the surface water systems means that the management, treatment and disposal of water can affect surface water – groundwater interactions.

2.3.2.1 Scope and overview

The purpose of this section is to collate and summarise the connections in the hydrological cycle of the Maranoa-Balonne-Condamine subregion (see companion product 1.1 for the Maranoa-

Balonne-Condamine subregion (Welsh et al., 2014)), and to describe how these hydrological connections may be affected by coal mining and CSG development.

The spatial extent of the water flows and pathways is limited to the subregion PAE as defined in companion product 1.3 for the Maranoa-Balonne-Condamine subregion (Mitchell et al., 2015) (Figure 6). The PAE extends beyond the northern and eastern subregion boundaries to include areas of the Hutton, Clematis and Precipice sandstone aquifers and shallower aquifers that may be affected by CSG-related groundwater extraction within the subregion and 5 to 7 km from the Dawson, Moonie and Weir rivers outside of the subregion boundary to encompass potential downstream surface water impacts. This covers a surface area of about 130,300 km^2 and is underlain by the geological Surat Basin.

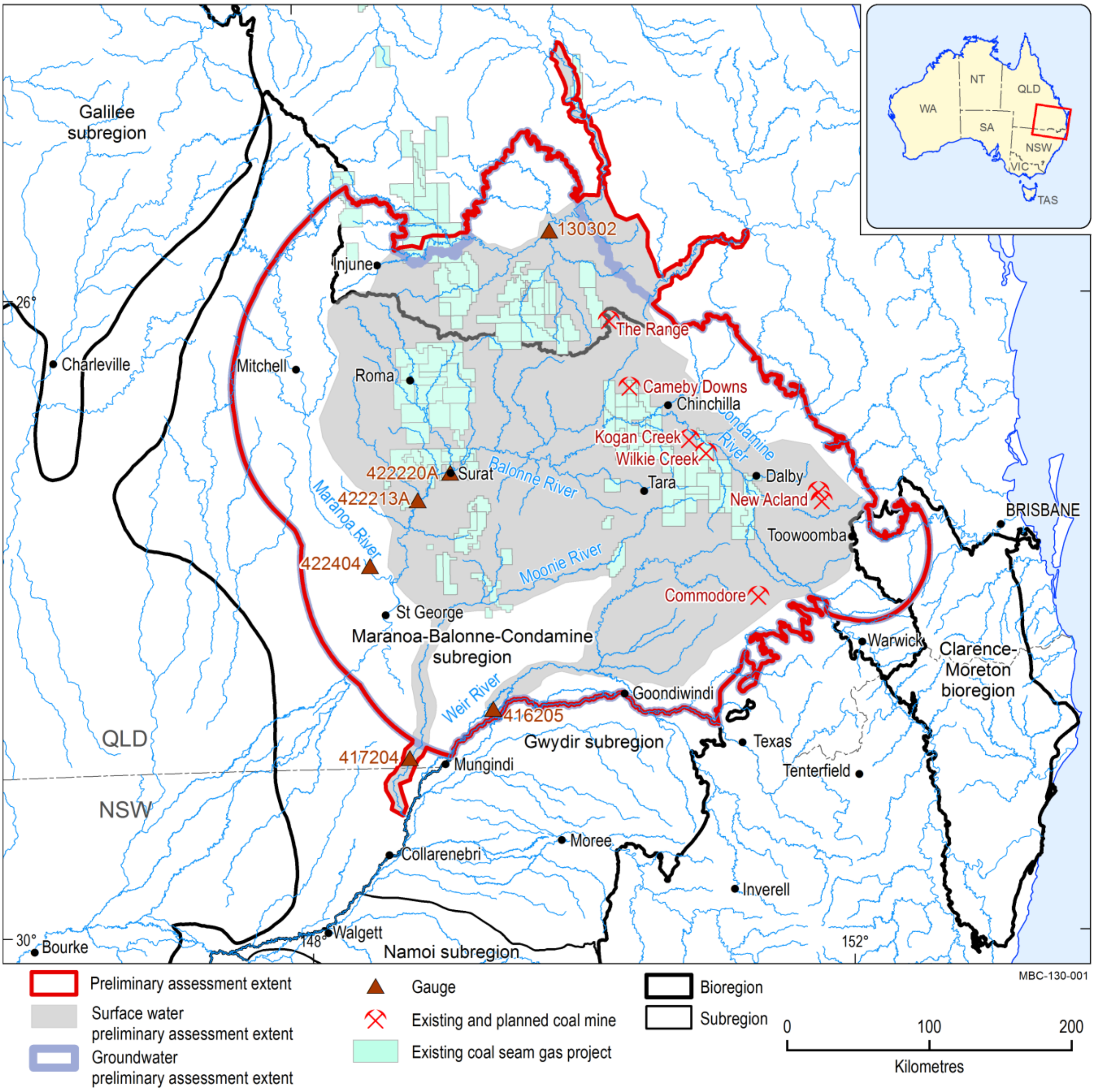

Figure 6 Preliminary assessment extent (PAE) of the Maranoa-Balonne-Condamine subregion

Data: Bioregional Assessment Programme (Dataset 1), Department of Natural Resources and Mines (Dataset 2, Dataset 3)

The Maranoa-Balonne-Condamine subregion contains three main geological environments (from youngest to oldest) encompassing the following individual groundwater systems:

- alluvial aquifers associated with major rivers (i.e. the Condamine, Balonne, Dumaresq and Macintyre rivers) and antecedent systems that form paleochannel infill and broad alluvial cover over much of the subregion
- fractured rock aquifers within the Main Range Volcanics
- sedimentary rocks of the geological Surat Basin that comprise aquifers of the Great Artesian Basin (GAB).

Groundwater flows in the alluvial groundwater systems, with the exception of the Condamine Alluvium, are generally topographically driven. Areas of potential inter-formational flow from alluvial aquifers into GAB units exist across parts of the subregion, where water levels in the alluvium are higher than in the underlying units of the GAB. Groundwater flow in intake beds (Kellett et al., 2003) and in the upper units of the GAB is to the south and south-west. Most surface watercourses in the Maranoa-Balonne-Condamine PAE are temporary and are likely to be losing-disconnected with respect to groundwater flows for most of the year. An exception is the Dawson River in the northern part of the PAE, which receives groundwater flow from the surrounding GAB intake beds (mainly Hutton Sandstone). These groundwater inflows sustain almost continuous flow throughout the year.

Surface water – groundwater interactions in the Office of Groundwater Impact Assessment (OGIA) regional groundwater model (described in the groundwater numerical modelling (companion product 2.6.2 (Janardhanan et al., 2016))) are simulated using the MODFLOW Drain and River packages. The OGIA model assumes that all surface watercourses act as groundwater discharge boundaries, meaning that groundwater only flows from the aquifer into the watercourse and that groundwater does not recharge the aquifer from the watercourse (GHD, 2012). This conceptualisation is consistent with previous studies of groundwater fluxes in the subregion (Hillier, 2010) and is a conservative approach, which means that recharge from surface watercourses cannot affect predicted groundwater level drawdown due to coal resource development.

CSG operations reduce groundwater levels in the Walloon Coal Measures through water extraction during exploration and production to allow gas to flow and be collected in CSG wells. Hydrological changes to the target aquifer can propagate through connected aquifers to indirectly affect surface water – groundwater interactions in the aquifer outcrop and subcrop areas in the PAE. This has the potential to reduce groundwater levels affecting water-dependent assets, including groundwater-dependent vegetation, watercourse springs, spring complexes and economic bores. There may also be the possibility that a leaky well permits the transfer of water between layers and to the surface. For open-cut mining operations, local mine site dewatering is required so that coal can be mined and the mine is not flooded by incoming groundwater flows. This will induce water to flow toward the pit locally, and again will affect groundwater levels. In such cases, increased hydraulic gradients away from the surface watercourse could decrease baseflow contributions to the stream or increase the rate of infiltration from the stream bed. The management of extracted water from coal mining and CSG development (described in Section

2.3.4) may reduce or increase water flows in surface water and groundwater flow systems, potentially affecting water quality and flows.

2.3.2.2 Geology and hydrogeology

The coal mining and CSG operations, and the water-related impacts, are contained entirely within the Maranoa-Balonne-Condamine PAE. This section describes the important parts of the geological and hydrogeological systems that may be affected by coal mining and CSG operations in the Maranoa-Balonne-Condamine subregion.

2.3.2.2.1 Geology

A detailed description of the geology of the Maranoa-Balonne-Condamine subregion is provided in the context statement (companion product 1.1 (Welsh et al., 2014)). The Maranoa-Balonne-Condamine subregion includes parts of three geological basins:

- Surat Basin: a Jurassic-Cretaceous aged sedimentary basin that outcrops and subcrops over the majority of the subregion, apart from a portion of the easternmost flank of the subregion
- Clarence-Moreton Basin: a Triassic-Cretaceous aged sedimentary basin, present within the eastern portion of the subregion, and laterally connected to the Surat Basin across the Kumbarilla Ridge
- Bowen Basin: a Permian-Triassic aged sedimentary basin that is unconformably overlain and completely obscured by the Surat Basin in the Maranoa-Balonne-Condamine subregion.

The Surat and Clarence-Moreton geological basins are extensively overlain by a relatively thin veneer of younger Cenozoic units comprising unconsolidated alluvial deposits associated with both existing and paleo drainage lines. Additionally, volcanic rocks of the Main Range Volcanics, predominantly basalt, are present along the eastern margin of the subregion and form a discontinuous south-east oriented band extending from south-east of Toowoomba to north-east of Dalby. Portions of the Main Range Volcanics are overlain by younger alluvial sediments in some areas. The coal-bearing units considered within the subregion occur within the Walloon Coal Measures, which is a laterally continuous unit occurring within both the Surat and Clarence-Moreton basins. Figure 7 is a simplified cross-section of the subregion showing the relationship between the geological basins.

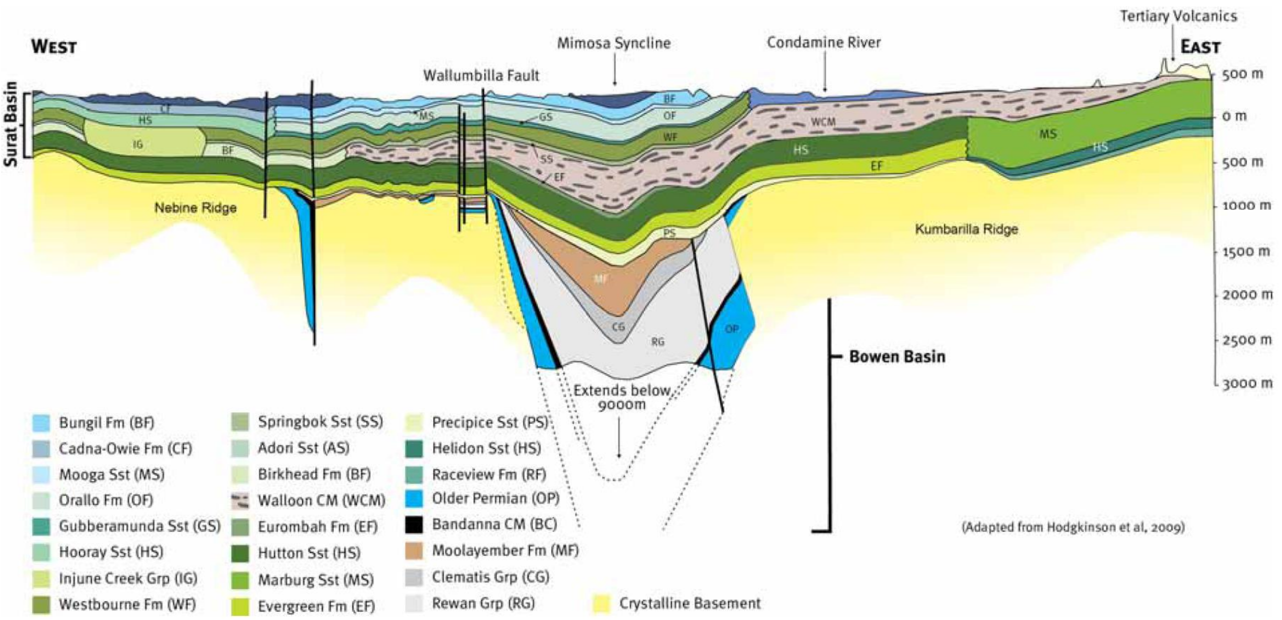

Figure 7 Schematic geologic cross-section of the Surat and Bowen basins

The Helidon Sandstone is a superseded stratigraphic name. It has been replaced by the Woogaroo Subgroup.
CM = Coal Measures, Fm = Formation, Grp = Group, Sst = Sandstone
Source: Esterle et al. (2013) as modified from Hodgkinson et al. (2009) and QWC (2012)

Surficial geology affects important water flow pathways, including groundwater discharge, deep soil drainage and groundwater recharge. Groundwater discharge occurs when a hydraulic gradient exists from an unconfined aquifer into a watercourse or the atmosphere, via the unsaturated zone. Groundwater recharge occurs via different mechanisms, including diffuse rainfall recharge and surface water recharge. Diffuse rainfall recharge occurs where stratigraphic units are exposed at the surface, termed ‘aquifer outcrop areas’ or ‘intake beds’ in the GAB. High spatial variability in recharge and discharge rates are due to the variable hydraulic properties of the sediments and rocks. Figure 8 shows a simplified representation of surface geology in the Maranoa-Balonne-Condamine subregion. Much of the subregion is covered by thin alluvial deposits, with Main Range Volcanics to the east and Kumbarilla beds to the north of the subregion. Figure 8 also shows the location of the cross-sections used to visualise the deeper aquifers in the vicinity of the two additional coal resource development (ACRD) open-cut coal mines, New Acland Coal Mine and The Range (discussed in Section 2.3.5).

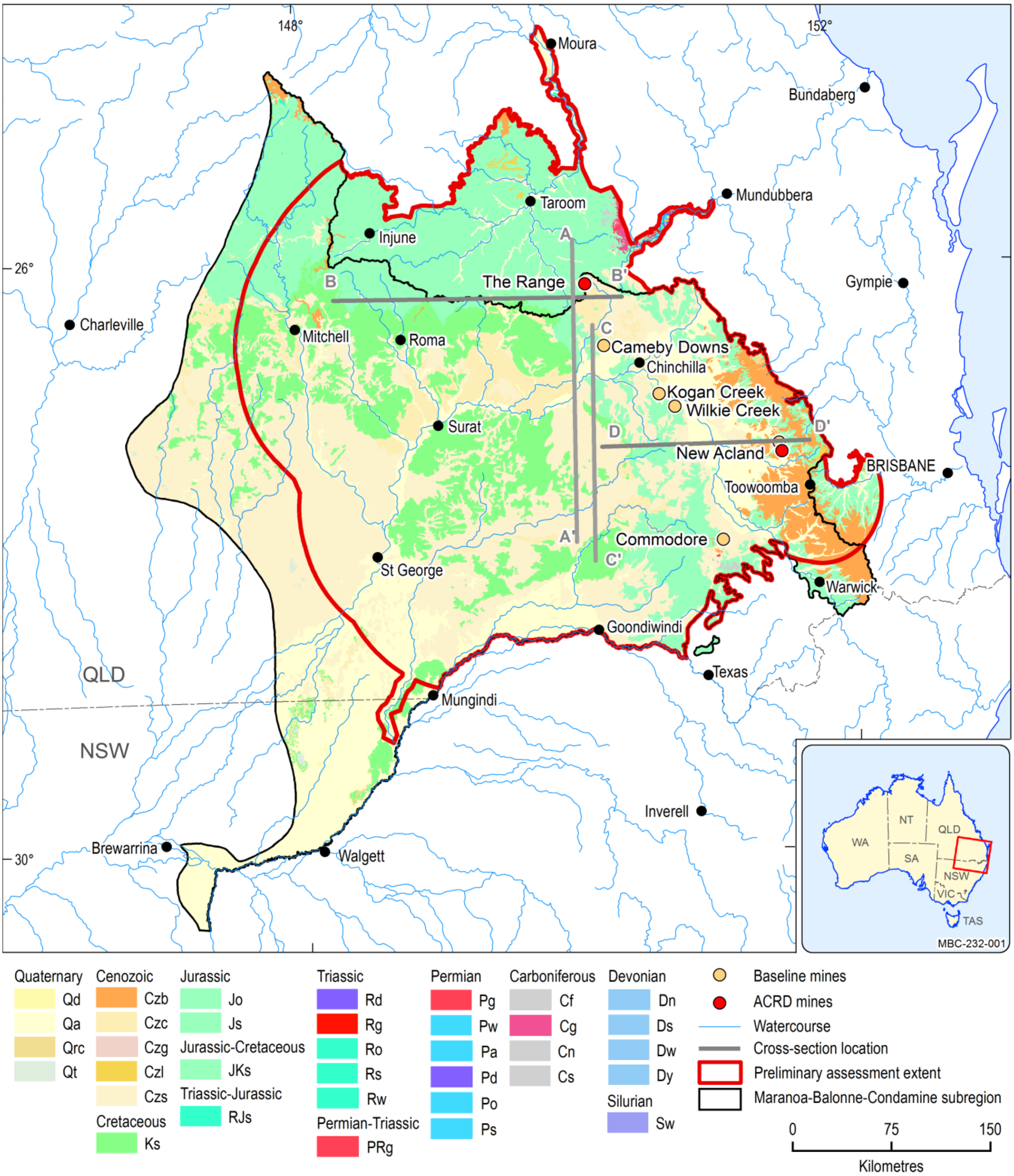

Figure 8 A simplified surface geology map showing the relative locations of coal resource developments

Included are cross-section locations discussed in Section 2.3.5.
Geological names for each rock unit are described by Geoscience Australia (2016).
Data: Geoscience Australia (Dataset 4)

2.3.2.2.2 Hydrogeology

The major aquifers of the Maranoa-Balonne-Condamine subregion are associated with the:

- antecedent systems that form paleochannel infill and broad alluvial cover over much of the subregion
- fractured rock aquifers within the Main Range Volcanics
- sedimentary rocks of the GAB
- major rivers (i.e. the Condamine, Balonne, Dumaresq and Macintyre rivers).

A detailed description of the key aquifer systems is in Section 1.1.4 of companion product 1.1 for the Maranoa-Balonne-Condamine subregion (Welsh et al., 2014). The temporal sequence of geological units and relative groundwater flow potential are identified in a summary of hydrostratigraphic relationships (Figure 9) (Ransley and Smerdon, 2012).

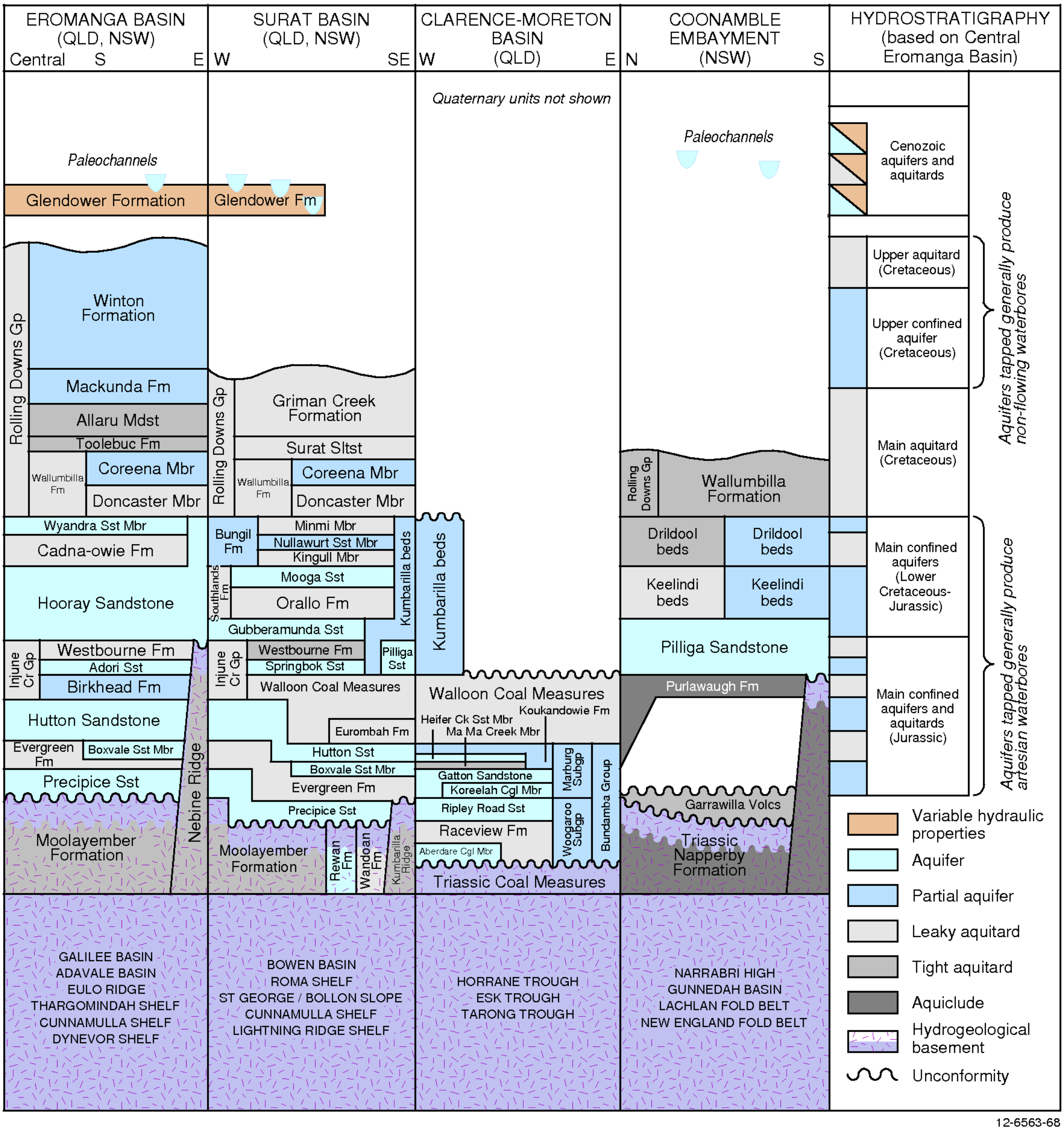

Figure 9 Hydrostratigraphic relationships in the Clarence-Moreton Basin, Surat Basin, Coonamble Embayment and adjoining Eromanga Basin of the Great Artesian Basin

Gp = Group, Fm = Formation, Mbr = Member, Sltst = Siltstone, Sst = Sandstone
Source: Ransley and Smerdon (2012)

2.3.2.2.3 Alluvial aquifers

Alluvial systems play an important role for the agriculture and ecologically significant areas in the subregion. From a whole-of-catchment perspective, alluvial depositional and aquifer systems follow a generalised pattern identified as ‘Upper’, ‘Mid’ and ‘Lower’ catchment alluvial development (Figure 10). The landscape classification described in Section 2.3.3 classifies catchments as either ‘upland’ or ‘lowland’, where ‘upland’ refers to the upper catchment and ‘lowland’ refers to the mid and lower parts of a catchment.

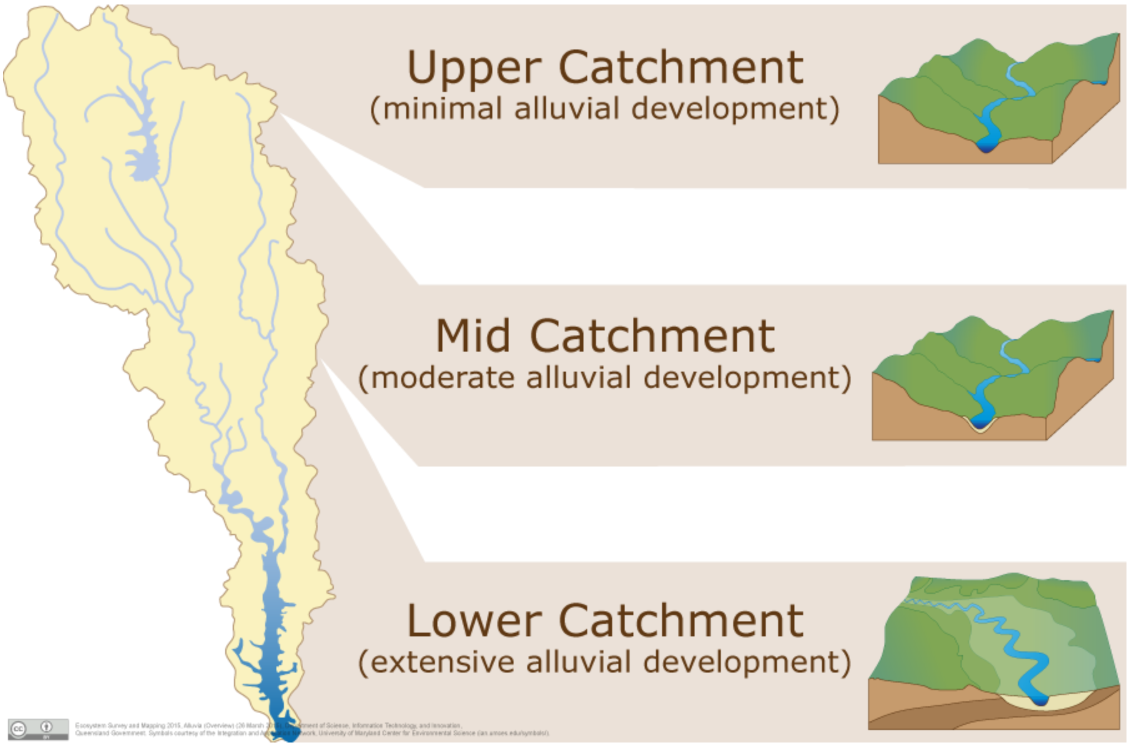

Figure 10 Schematic of ‘Upper Catchment’, ‘Mid Catchment’ and ‘Lower Catchment’

Source: DEHP (2013)

Upper catchment – upland

Alluvial sediments in the topographically higher upper catchment (upland) are relatively thin (typically less than 15 m thick) and are composed mostly of unconsolidated coarse-grained sediments such as boulders, gravel and sand (DEHP, 2013). The upper Condamine tributaries draining from the basaltic Toowoomba Plateau produce highly-weathered bedrock-derived soils. The tributaries coming from the Taroom Hills to the north result in sandstone-derived sediments. Due to the coarse-grained nature of the alluvial sediments of the upper catchment, groundwater is stored and transmitted rapidly through intergranular voids between boulders, gravel and sand. In the subregion, drainage from fractured rocks of the Main Range Volcanics may result in springs feeding the tributaries of the alluvial streams. Groundwater quality in areas associated with the tributaries of the Main Range Volcanics tends to be of low salinity and is magnesium bicarbonate dominated (Welsh et al., 2014).

Mid and lower catchment – lowland

Alluvial aquifers in the mid and lower catchment tend to be significantly wider and deeper than those in the upper catchment, reaching up to 150 m thickness in the Condamine Alluvium near Dalby (Welsh et al, 2014). Typically, the alluvial sediments in the lower catchment are fining-upward sequences of unconsolidated and, less commonly, semi-consolidated sediments. Within these alluvial sequences, gravel- and sand-rich layers occur near the base, overlain by thick deposits of finer floodplain silts and clays which have been deposited in a low-energy floodplain environment. Groundwater in the lower Condamine Alluvium shows increased salinity, when compared to the magnesium bicarbonate-dominated upstream areas, with records from 3,000 to 14,000 mg/L total dissolved solids (TDS) (Welsh et al, 2014). The alluvial aquifers of the Maranoa-

Balonne-Condamine subregion are represented by the 'Cenozoic aquifers and aquitards' shown in Figure 9.

Average alluvial aquifer thickness is in the order of 20 to 30 m for the Condamine river basin. The Border Rivers river basin straddles the New South Wales – Queensland border. The Queensland Border Rivers Alluvium groundwater management area relates to the alluvial sediments associated with the Dumaresq River, which are confined to a paleochannel that extends from Mingoola to Keetah. These 'alluvial sediments are generally greater than 30 metres below surface and are up to 50 metres thick and do not outcrop' (DRNM, 2015). In Queensland, these alluvial sediments are not formally recognised stratigraphic units, although they may be considered stratigraphically equivalent to the Gunnedah and Narrabri formations, which occur further to the south. In New South Wales, alluvial aquifer thicknesses can be up to 70 m for the Gunnedah Formation, separated by a semi-permeable layer of 2 to 15 m from the Narrabri Formation, which ranges in thickness from 10 to 30 m (CSIRO, 2007). Aquifer thickness in the Maranoa-Balonne river basin can exceed 180 m (Exon, 1976). Little information is available for the Moonie river basin aquifers; they are possibly up to 100 m thick, but are regularly accessed with bores screened between 10 to 35 m depth for stock and domestic use (CSIRO, 2008).

2.3.2.2.4 Fractured rock aquifers

The Main Range Volcanics host the fractured rock aquifers of the subregion (Figure 8). These systems are primarily located along the eastern margin of the Condamine river basin. The basalts of these aquifers are covered, in part, with alluvium from this river basin. Average aquifer thicknesses are in the order of 28 m (Skelt et al., 2004). These volcanic rocks do not consist of a single homogeneous basalt flow or one single aquifer. Rather, the basalt sequence consists of many overlapping basalt flows with a maximum thickness of approximately 10 m each (Brodie and Green, 2002), which are stacked together and commonly separated by lower permeability layers including the clay-rich weathering profiles that developed between periods of volcanic activity.

These different zones of varying permeability affect the capacity of different basalt flows to store and transmit groundwater. At the top and the base of the basalt flows, zones consisting of broken vesicles commonly occur, and these provide considerable primary pore space that can contain and transmit groundwater. At the edge of the basalt flows, at the interface of the higher permeability basalts and the lower permeability overlying alluvial aquifers, groundwater discharges to the surface as springs, and these may feed streams (Brodie and Green, 2002).

2.3.2.2.5 Great Artesian Basin aquifers

The entire Maranoa-Balonne-Condamine subregion falls within the boundary of the geological Surat Basin, which forms part of the wider GAB. The variably confined layers of complex sandstone aquifers in the GAB are separated and confined by fine-grained mudstone and siltstone aquitards (Figure 9) (Ransley and Smerdon, 2012). The intake beds for the GAB outcrop areas cover much of the subregion in the north and the east where the alluvial cover is absent. North of Mitchell, in the northernmost extension of the subregion, there are outcrops of the entire Mesozoic sequence of the GAB. The Walloon Coal Measures in the Surat Basin are laterally continuous with the Birkhead Formation of the Eromanga Basin.

Groundwater gradients between the Surat Basin and the overlying alluvium indicate the potential for upwards leakage to alluvial deposits in parts of the subregion. The intense weathering of exposed GAB rocks prior to deposition of overlying alluvium resulted in a basin-wide saprolite layer of low permeability in the basal portion (Kellett and Stewart, 2013). This is considered to reduce connectivity with overlying systems except in some places where the saprolite has been removed by erosion. Kellett and Stewart (2013) identifies those areas of potential interaction between the alluvium and the GAB aquifers.

Regional conceptualisation

The OGIA model has simplified the hydrostratigraphy of the subregion by grouping stratigraphic units into major aquifers, aquitards and productive coal measures (Figure 11). These simplified hydrostratigraphic layers are based on similarities in aquifer properties that are appropriate for the regional scale groundwater model.

The Walloon Coal Measures comprises a varied sequence of sedimentary rocks, with permeability ranging from high to low, where the coal seams are the main water-bearing layers in a sequence of predominantly low permeability mudstones, siltstones and fine-grained sandstones (QWC, 2012). The OGIA model is conceptualised as 19 layers to represent all major aquifers, aquitards and productive coal measures. QWC (2012) state that ‘The Walloon Coal Measures is represented in the model by three layers:

- an upper layer representing generally low permeability mudstone (Layer 9)
- a composite middle layer representing all coal seams from the top of the uppermost productive seam to the base of the lowermost productive seam and the inter-bedded sediments (Layer 10); and
- a lower layer representing a low permeability formation of dominantly mudstone (Layer 11).

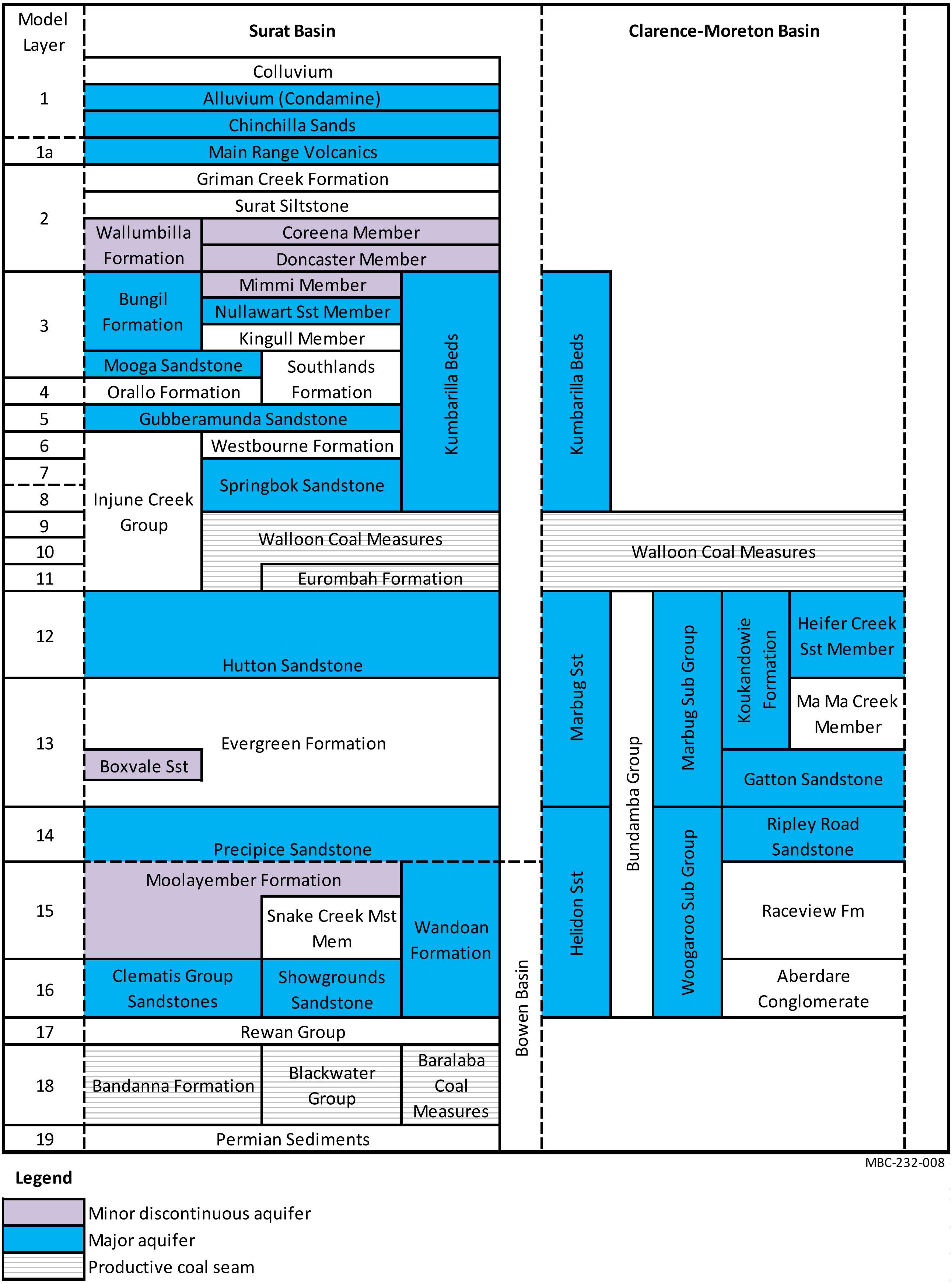

Figure 11 Stratigraphy of the Surat, Bowen and Clarence-Moreton basins and the corresponding model layers in the Office of Groundwater Impact Assessment (OGIA) model

Fm = Formation, Mem = Member, Mst = Mudstone, Sst = Sandstone
Source: GHD (2012)

Regional groundwater flow

The potentiometric surface of the main confined aquifers (Gubberamunda and Mooga sandstones) shows that regional groundwater flow in the Maranoa-Balonne-Condamine subregion is from the intake beds in the northern and eastern areas of the subregion, flowing to the south-west (Figure 12) (Ransley and Smerdon, 2012). Groundwater flow within the Kumbarilla beds immediately south-west of The Range and west of New Acland Coal Mine is generally down the regional formation dip to the south-west towards the Taroom Trough. However, there is some debate surrounding groundwater flow directions in parts of the Hutton Sandstone in the Surat Basin in Queensland. Based on drill stem pressure test data of petroleum wells combined with water bore head measurements, Hodgkinson and Grigorescu (2012) indicated the potential for a significant component of northward groundwater flow from Chinchilla toward Taroom. This finding is counter intuitive, as expected groundwater flow directions are down dip, toward the south-west, and away from the Hutton Sandstone intake beds.

Ransley and Smerdon (2012) found that the watertable in the north of the Surat Basin lies in the GAB aquifer outcrop areas (intake beds) and aquitards along the western slopes of the Great Dividing Range. Detailed mapping reveals an area of flow loss to river baseflow from GAB aquifer outcrop areas where the Dawson River forms a deeply incised valley that cuts into the Hutton and Precipice sandstones (Figure 13). The interchange between aquifers and the Dawson River potentially accounts for some but not all of the northward flow directions proposed by Hodgkinson and Grigorescu (2012). It is likely that a localised component of northward groundwater flow occurs within the Hutton Sandstone near the Dawson River. The estimated groundwater flow loss from the GAB intake beds (mainly Hutton Sandstone) to the Dawson River is 8623 ML/year (Ransley and Smerdon, 2012).

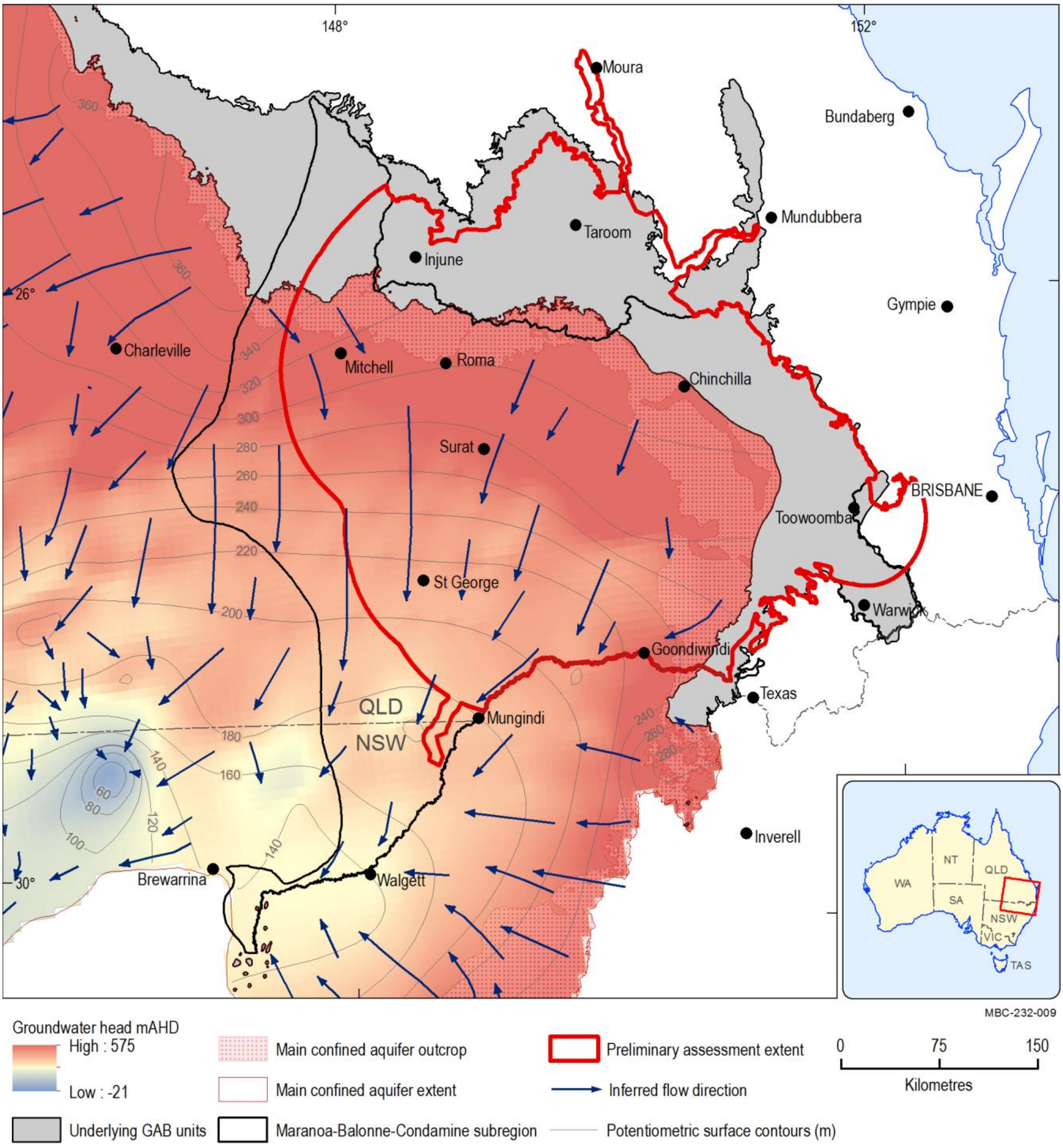

Figure 12 Potentiometric surface of the main confined aquifers, showing regional groundwater flow directions in the Maranoa-Balonne-Condamine subregion

GAB = Great Artesian Basin, Main confined aquifers = Gubberamunda and Mooga sandstones.
Data: Bioregional Assessment Programme (Dataset 5); Geoscience Australia (Dataset 6, Dataset 7)

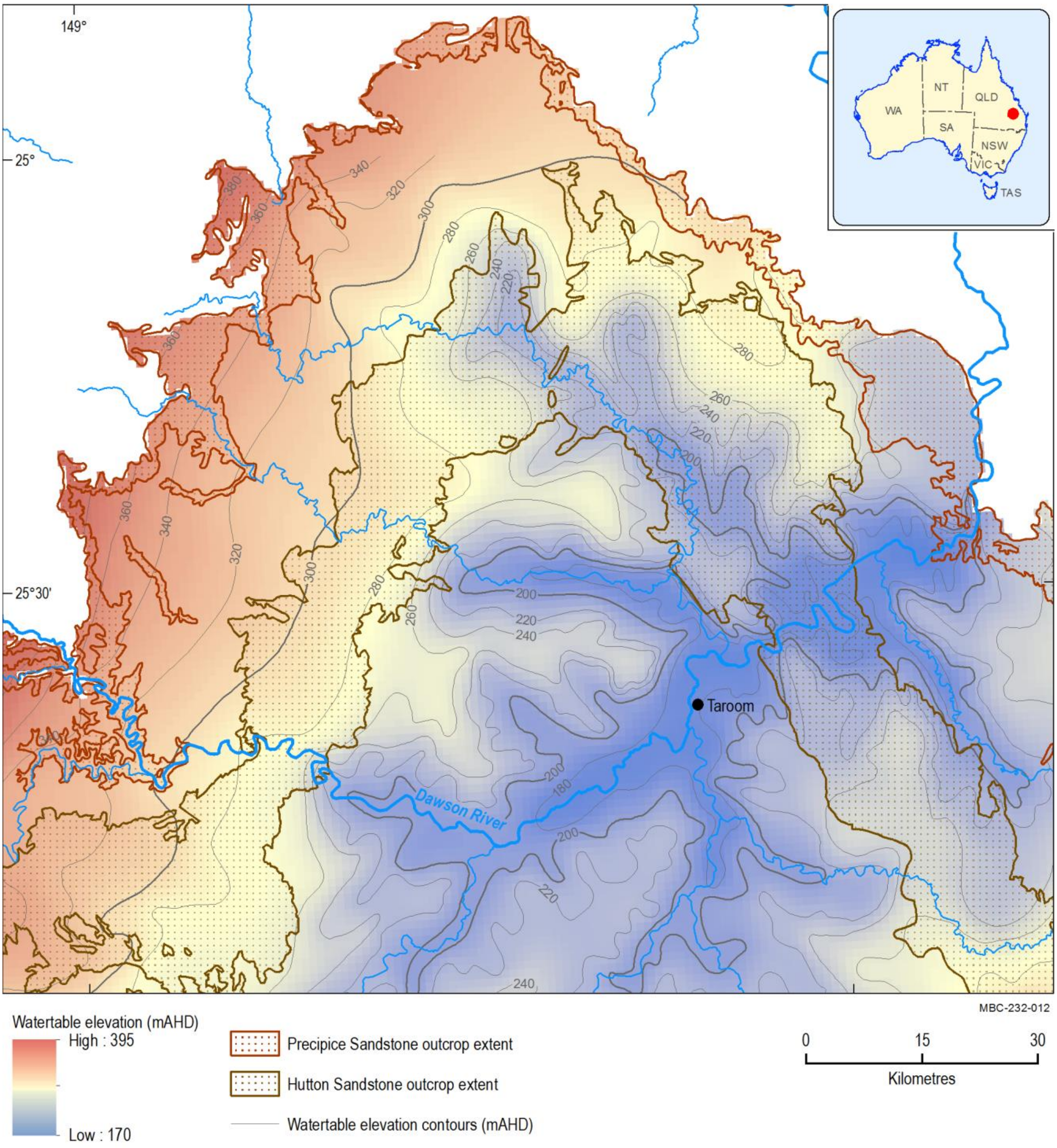

Figure 13 Watertable elevation and mapped GAB aquifer outcrops relative to the Dawson River

Data: Geoscience Australia (Dataset 8, Dataset 9, Dataset 10)

2.3.2.3 Surface water

The Maranoa-Balonne-Condamine subregion includes the river basins of the Condamine-Balonne River (including the Maranoa River) and Moonie River, and the portion of the Border river basin that is located in Queensland (see the context statement (companion product 1.1 for the Maranoa-Balonne-Condamine subregion (Welsh et al., 2014))).

Most rivers in the Maranoa-Balonne-Condamine subregion are temporary, with ephemeral or intermittent surface water flow that varies between seasons and years. Apart from a few wet months (October to April), most watercourses (except the Dawson River), have zero or close to zero flows. Therefore, any potential discharge from developments to these rivers could have a significant effect on the instream and riparian environments. Disposal into surface waters is not a preferred option under Queensland's *Environmental Protection Act 1994* (DEHP, 2012). As there will be little or no natural streamflow for most days of the year, the quality of released water also remains potentially unchanged (undiluted) at downstream locations in these temporary streams. However during the dry season, it is likely that concentration of dissolved salts may rise due to evapoconcentration. Water management of CSG operations and coal mines in the subregion is described in Section 2.3.4.

2.3.2.4 Water balance

The subregion is bounded by the natural catchment boundaries of the main rivers within it, thus there is no noticeable surface water inflow to the subregion, with the exception of inflow from the headwaters of the Macintyre River. The long-term mean annual rainfall and potential evapotranspiration across the Maranoa-Balonne-Condamine subregion are 580 mm and 2145 mm, respectively (Welsh et al, 2014) indicating a large annual water deficit. The long-term mean annual rainfall and modelled runoff of the Condamine-Balonne river basin are 514 mm and 19 mm, respectively (runoff ratio 3.7%, Scenario A) (CSIRO, 2008).

The long-term average natural surface water flows estimated using the water balance techniques of Budyko (1974), as described in McVicar et al. (2015), are visualised in Figure 14. It shows that streamflow in the Barwon, Dawson and Burnett rivers is much greater than in their individual tributaries, thus potentially providing greater dilution effects than their tributaries once the impact of CSG and coal mining development reach these rivers.

The Budyko estimate of mean annual flow for the Condamine-Culgoa River system at the Maranoa-Balonne-Condamine subregion boundary is 2540 GL (30 mm) for the period 1982–2010 (Figure 14), which is larger than the long term modelled runoff. The mismatch between the Budyko and rainfall-runoff analyses can be partially explained by the losses due to consumptive use, which are accounted for in the rainfall-runoff modelling but not in the Budyko analysis. The difference in calculation period used in the long term modelling and Budyko analysis may also explain the discrepancy. This suggests that over 60% of runoff does not reach the catchment outlet due to losses or consumptive use. A preliminary determination of observed flow based on published data (DNRM, n.d.) at a comparable site (422205A Balonne – Minor River at Hastings) shows an average annual runoff of 9.2 mm (range 0.5 to 60 mm) for the same period, which is lower than both the modelled flow and flow from the Budyko analysis.

The long-term mean annual rainfall and modelled runoff for the Moonie river basin are 528 mm and 17 mm respectively (runoff ratio 3.2%) (CSIRO, 2008). However the mean annual runoff for the basin based on Budyko analysis is approximately 23.5 mm. Similarly, the long-term mean annual rainfall and modelled runoff for the entire Border Rivers river basin are 680 mm and 32 mm respectively (runoff ratio 4.7%) (CSIRO, 2007). For comparison, the Budyko runoff for the Barwon River near Mungindi to the south of the PAE is 51.0 mm. This is consistent with the losses due to consumptive use observed in this other river basins.

Dilution, evaporation, seepage, chemical transformation or a combination of these make it difficult to predict how far the impact of any effluent water could travel along the watercourse. Influential factors include quality and quantity of the release (or spill), existing flow in the receiving waters and prevailing weather conditions.

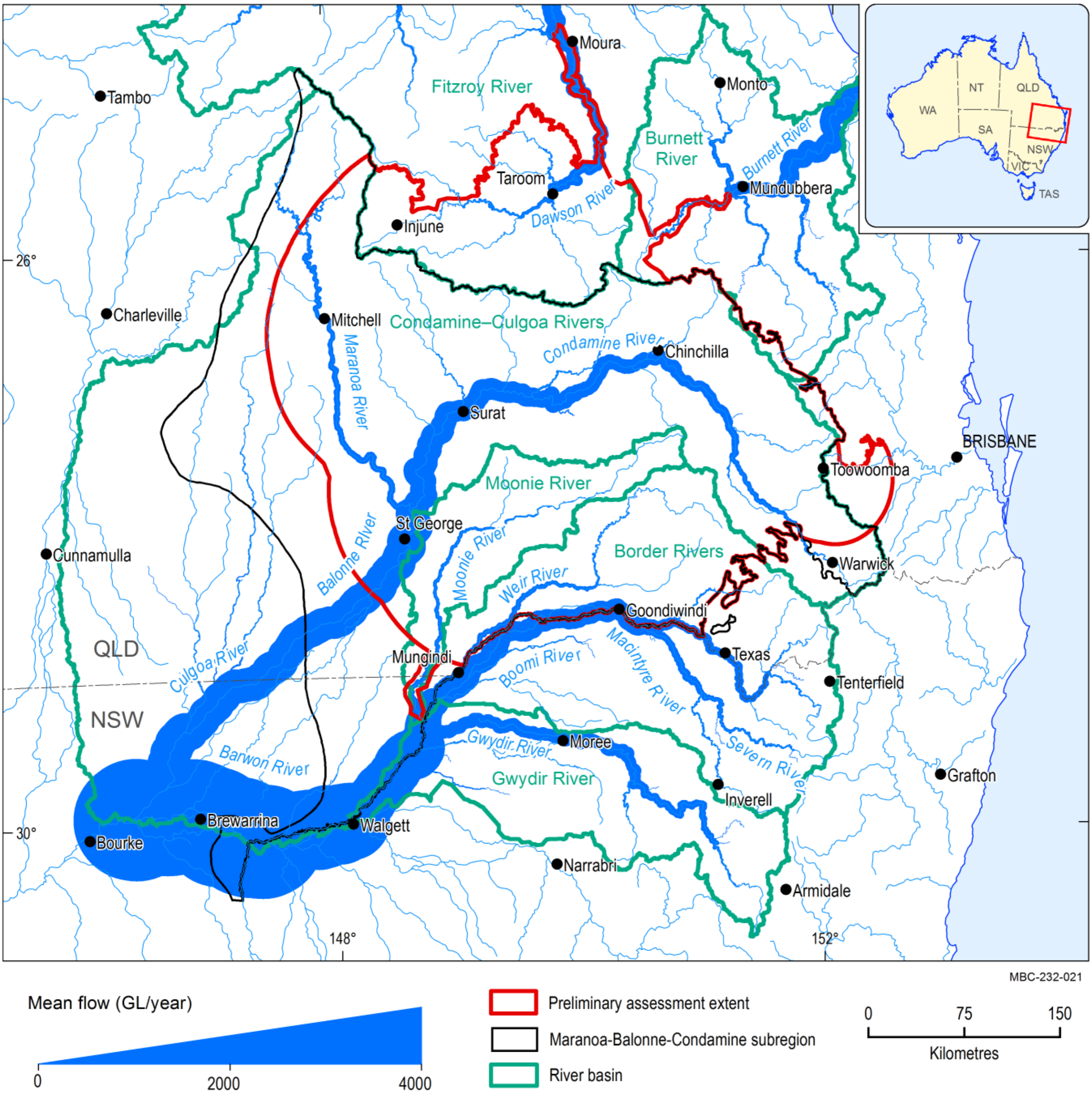

Figure 14 Surface water flows for river basins in the Maranoa-Balonne-Condamine preliminary assessment extent

Long-term natural annual flow is estimated using the water balance technique of Budyko (1974), as described by McVicar et al. (2015). This technique does not take into account human impoundments (dams / weirs) or diversion from rivers. It models long-term natural stream flow from a hydroclimatic perspective.
Data: Bioregional Assessment Programme (Dataset 11)

Groundwater recharge generally occurs along outcrop regions to the north and east along the Great Dividing Range, predominately via direct rainfall infiltration into outcrop or indirect leakage from streams or overlying units (QWC, 2012). Direct rainfall or diffuse recharge rates are generally low (less than 2.5 mm/year). However, they can be up to 30 mm/year during high intensity rainfall and localised recharge from stream or aquifer leakage (Kellett et al., 2003). Recharge rates are shown in ‘mm/year’ in Figure 15. Modelled long-term average net recharge values are estimated in steady-state model calibration by allowing recharge rates to vary between 1 and 30 mm/year, except in the Main Range Volcanics aquifers, which are allowed to vary between 20 and 30 mm/year (as described in Table 3 in Section 2.6.2.4 of companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (groundwater numerical modelling; Janardhanan et al., 2016)).

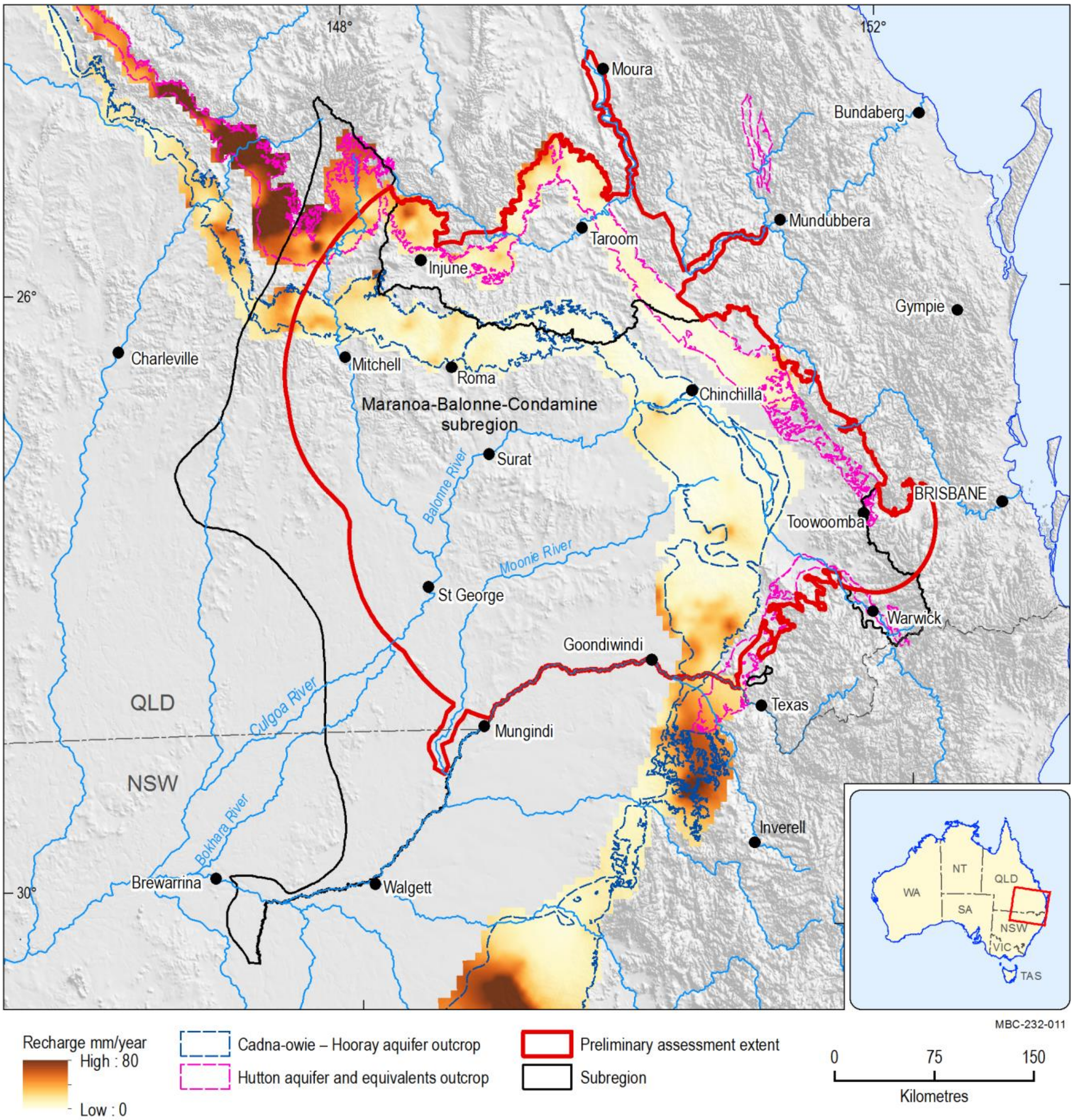

Figure 15 Recharge in the Great Artesian Basin intake beds of the Cadna-Owie – Hooray aquifers and the Hutton Aquifer and equivalents

Data: Geoscience Australia (Dataset 6, Dataset 12)

Ransley and Smerdon (2012) conceptualised the water balance for the Surat Basin in Figure 16. From their calculations, inputs to the Jurassic aquifers consists of 237.5 GL/year recharge from rainfall in the intake beds (Ransley and Smerdon 2012). However, net recharge in the intake beds is lower due to 12.5 GL/year flow losses to the Dawson River valley and Mulgildie Basin (mostly Hutton Sandstone). Ransley and Smerdon (2012) also identified other losses from net recharge.

Water outputs from the Surat Basin include 126.5 GL/year bore abstractions, small spring discharges (~0.2 GL/year), losses via evapotranspiration (56 GL/year), diffuse upward leakage (93 GL/year) and limited groundwater throughflow to the Eromanga Basin. The drop in aquifer pressure resulting from the decline in storage is not uniform across the Surat Basin. Pressure drops in the Gubberamunda Sandstone aquifer are very high in the south-west of the Surat Basin, exceeding 100 m in the area between St George and Cunnamulla where groundwater usage is highest (Ransley and Smerdon, 2012).

Ransley and Smerdon (2012) surmised that potential impacts of coal seam gas production in the intake beds of the northern Surat Basin are as yet not fully understood. Their synopsis was that, although the target formation for gas and water production is the Walloon Coal Measures, leakage is likely generated in the Springbok Sandstone, Hutton Sandstone and Gubberamunda Sandstone aquifers. The magnitude of induced drawdown depends on the degree of hydraulic connection between the Walloon Coal Measures and these sandstone aquifers (Ransley and Smerdon, 2012).

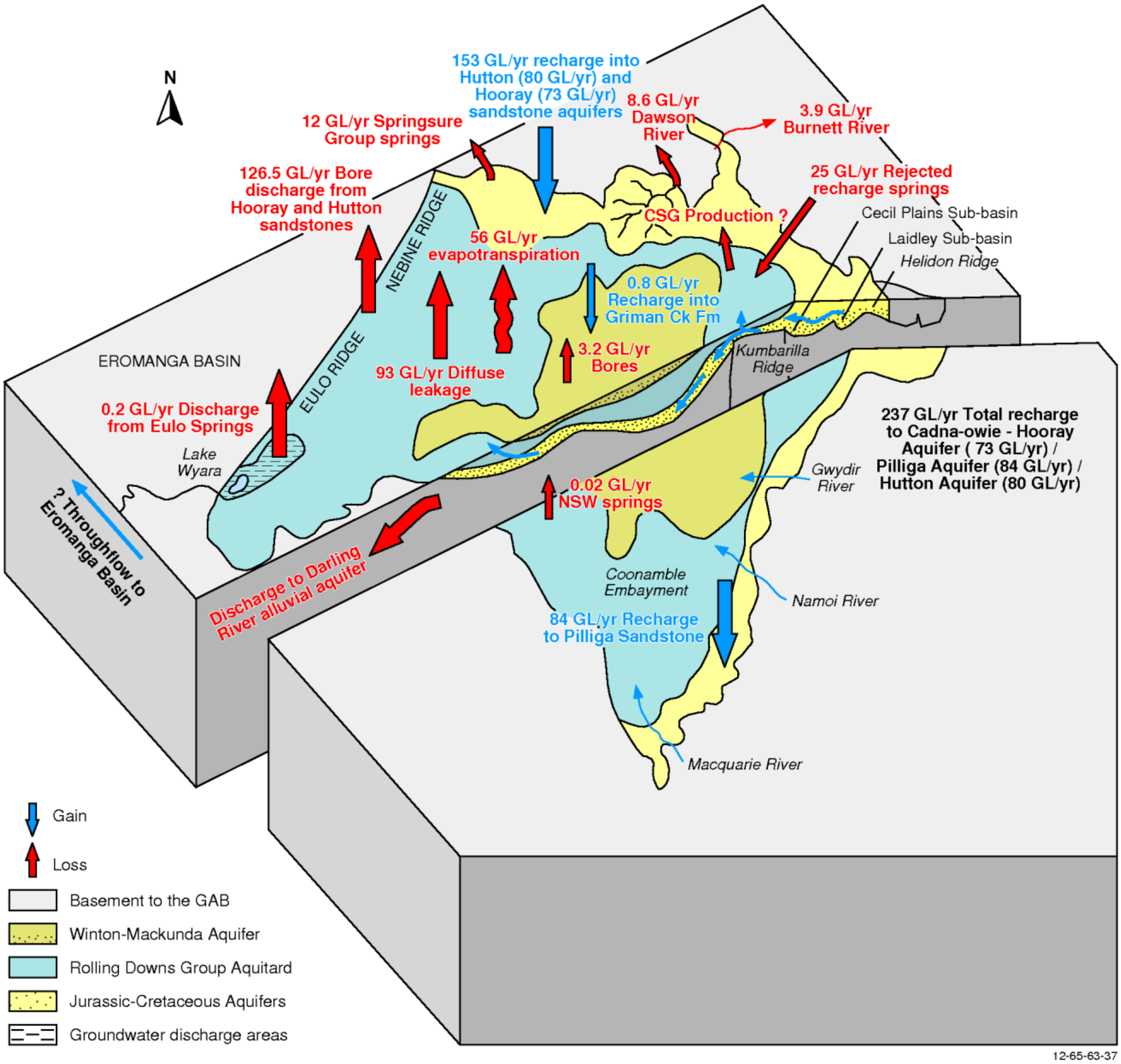

Figure 16 Hydrogeological framework and groundwater balance of the Surat Basin

CR = Creek, Fm = Formation, GAB = Great Artesian Basin
Source: Ransley and Smerdon (2012)

As indicated in Welsh et al. (2014), recharge to the Condamine River alluvium is via rainfall infiltration throughout the Condamine river basin, flood recharge in the lower areas, lateral flow from adjacent upstream aquifers and upward leakage from the basalts of the Main Range Volcanics (CSIRO, 2008). Non-flood streambed leakage from the Condamine River is considered to be the largest source of recharge to the alluvium (Huxley, 1982), with additional contributions from irrigation water via deep drainage.

A subsequent Queensland Department of Environment and Resource Management (DERM) water-balance study considered Condamine River streambed recharge estimates, concluding that the most likely values are those calculated by Lane (1979) who reported stream loss values ranging from 38.5 to 115 ML/year/km (KCB, 2010).

In the vicinity of The Range Project, recharge is estimated to be in the order of 2 to 4 mm/year for the Hutton Sandstone and generally less than 3 mm/year in the Kumbarilla beds. Recharge to the Kumbarilla beds near the New Acland Coal Mine is estimated to be approximately 1 to 2 mm/year (Ransley and Smerdon, 2012).

2.3.2.5 Gaps

The knowledge gaps described here relate to limited surface water quality and quantity data that lead to limited modelling ability of surface water processes. Although future coal resource development may eventually affect water quality and quantity of major rivers and creeks, it is the lower order streams that are more likely to be directly affected. Currently there are no streamflow and water quality gauging stations in any of the lower order streams, thus limiting the ability to model the streamflow and water quality of these streams. Some water quality measuring stations exist in the major rivers and tributaries for limited monitoring of nutrients, electrical conductivities, dissolved oxygen, pH and other constituents critical to the survival of native fish and other species. Healthy Waters Management Plans that address water quality requirements of both the Queensland Environmental Protection Act legislation and the Commonwealth Basin Plan (MDBA, 2012) are currently being developed. The plans assess risks to water quality, and identify water quality targets based on local data (including electrical conductivity, nutrients, turbidity, pH) to inform regulatory conditions on Environmentally Relevant Activities such as CSG and coal mines. These plans will improve the monitoring and assessment of threats to surface water quality in the subregion.

The role of faults and fractures as conduits or barriers to flow, their location in three dimensions, and their propensity to change their nature due to water pressure changes are all poorly known in the Maranoa-Balonne-Condamine subregion.

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2.3.3 Ecosystems

Summary

Landscape classification is used to characterise the diverse range of water-dependent assets into a smaller number of classes for further analysis. It is based on key landscape properties related to patterns in geology, geomorphology, hydrology and ecology, as well as the associated land use patterns associated with human-modified ecosystems. The process of devising and implementing a landscape classification for the Maranoa-Balonne-Condamine preliminary assessment extent (PAE) used predominantly existing classes within data associated with aquatic and groundwater-dependent ecosystems (GDEs), remnant vegetation and land use mapping. Where appropriate, the approach (outlined in this section) has built on and integrated with existing classification systems. This section describes the classifiers or attributes by which landscape features are categorised and their corresponding rule sets for spatial data, which are represented as polygons (e.g. wetlands), polylines (stream network) and points (e.g. springs).

Most of the PAE (72%) is classed under the ‘Human-modified’ landscape group that includes agricultural, urban and other intensive land uses. For the remaining parts of the landscape, most (20%) fall into the ‘Dryland remnant vegetation’ landscape class that is not considered to be water dependent. The ‘Floodplain or lowland riverine (including non-GAB GDEs)’ landscape group covers approximately 5% of the PAE and includes almost half of the watercourses. Approximately 2% of the PAE and almost 40% of the watercourses are included in the ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ landscape group. The ‘Great Artesian Basin (GAB) GDEs (riverine, springs, floodplain, non-floodplain)’ landscape group includes approximately 1% of the PAE and 13% of the watercourses. Aspects of water dependency and the vegetation communities associated with each landscape group are discussed.

2.3.3.1 Landscape classification

2.3.3.1.1 Methodology

The Maranoa-Balonne-Condamine preliminary assessment extent (PAE) contains a diverse range of assets that span ecological, sociocultural and economic values. Landscape classification is used to characterise the nature of water dependency among a diverse range of assets, based on key landscape properties associated with geology, geomorphology, hydrology and vegetation (natural and human-modified ecosystems). The primary objective of the landscape classification is to conceptualise the main biophysical and human systems at the land surface and describe their hydrological connectivity. Hydrological connectivity describes how different biophysical factors, such as flow regime, influence the spatial and temporal patterns of connection between elements of the water cycle, including surface water and/or groundwater systems (Pringle, 2001). For example, surface water connectivity can be longitudinal along the river channel itself, lateral during overbank flows and, vertical where surface water is in contact with underlying groundwater (Stanford and Ward, 1993; Boulton et al., 2014). Assets are grouped based on functional criteria depending on their association with a particular landscape class. This section describes the methodology and datasets used to classify the landscape in the Maranoa-Balonne-Condamine PAE, following methods outlined in the companion submethodology M03 (as listed in Table 1) for assigning receptors to water-dependent assets (O'Grady et al., 2015).

Many different classification approaches and methodologies have been developed to provide consistent and functionally relevant representations of ecosystems such as the Australian National Aquatic Ecosystem (ANAE) Classification Framework (Aquatic Ecosystems Task Group, 2012a). Where appropriate, the approach outlined in this section is integrated with and builds on these existing classification systems. The landscape classification for the Maranoa-Balonne-Condamine PAE predominantly uses existing classes within data associated with aquatic ecosystems, GDEs, remnant vegetation and land use mapping. The landscape classification uses data layers consisting of polygons (e.g. remnant vegetation, terrestrial/surface GDEs; subsurface GDEs or wetlands), polylines (stream network) and points (springs and spring complexes). The Assessment team describes 34 landscape classes, which are aggregated into five landscape groups with similar habitats, topography, water dependency and water regime. This initial classification helps to place the landscape classes within a common biophysical system that aids in formulating conceptual models and patterns in water dependency across the landscape.

Classification of remnant and human-modified landscape elements

The approach was formulated in close collaboration with experts who have extensive experience with the landscapes of the PAE and have contributed to the development of similar classification systems such as the ANAE (Aquatic Ecosystems Task Group, 2012b). The classification uses broad geomorphological, soil, hydrological and habitat information to derive classes of water-dependent, remnant and human-modified landscape features to produce landscape classes that capture key distinctions using the following rule sets (Table 3):

- broad habitat type (remnant/non-remnant)
- geomorphology (floodplain/non-floodplain)
- groundwater source (Great Artesian Basin (GAB)/non-GAB/non-groundwater dependent)
- wetland (wetland/non-wetland)
- water regime (near-permanent/temporary/null).

Table 3 Landscape classification rule sets used for the landscape elements (polygons)

Classification	Class	Relevant dataset citation	Dataset (field)	Rule
Broad habitat type	Remnant	Queensland Herbarium (Dataset 1)	Qld_RE_13 (RE)	If 'RE' NOT 'non-rem'; 'Broad habitat' = 'Remnant'
	Non-remnant	Queensland Herbarium (Dataset 1)	Qld_RE_13 (RE)	If 'RE' = 'non-rem'; 'Broad habitat' = 'Non-remnant'
Geomorphology	Floodplain	Queensland Herbarium (Dataset 1)	Qld_RE_pre (Landzone)	If 'LAND ZONE' = '3'; 'Topography ' = 'Floodplain'
	Non-floodplain	Queensland Herbarium (Dataset 1)	Qld_RE_pre (Landzone)	If 'LAND ZONE' NOT '3'; 'Topography ' = 'Non-floodplain'
Groundwater source	Great Artesian Basin	Department of Science, Information Technology, Innovation and the Arts (DSITIA) (Dataset 2)	Surface_GDE, (C_Model) Terrestrial_GDE (C_Model)	If GDE area AND 'C_Model' = 'Unweathered sandstone'; 'Water source' = 'GAB GDE'
	Non-Great Artesian Basin	DSITIA (Dataset 2)	Surface_GDE, (C_Model) Terrestrial_GDE (C_Model)	If GDE area AND NOT 'C_Model' = 'Unweathered sandstone'; 'Water source' = 'non-GAB GDE
	Non-groundwater	DSITIA (Dataset 2)	Surface_GDE, (C_Model) Terrestrial_GDE (C_Model)	If NOT GDE area = 'non GDE'
Wetland	Wetland	DSITIA (Dataset 3)	Qld Wetlands (WETCLASS)	If 'WETCLASS' NOT '-' OR; 'Landform' = 'Wetland'
	Non-wetland	DSITIA (Dataset 3)	Qld Wetlands (WETCLASS)	If 'WETCLASS' = '-'; 'Landform' = 'Non-wetland'
Water regime	Near-permanent	DSITIA (Dataset 3)	Qld Wetlands (WTRREGIME)	If 'WTRREGIME' = 'WR3'; 'Water regime' = 'Near-permanent'
	Temporary	DSITIA (Dataset 3)	Qld Wetlands (WTRREGIME)	If 'WTRREGIME' NOT 'WR3'; 'Water regime' = 'Intermittent, ephemeral or uncertain'
	Null	DSITIA (Dataset 3)	Qld Wetlands (WETCLASS)	If 'WETCLASS' = '-'; 'Water regime' = ' '

Vegetation is classed as either 'remnant', if it is mapped in the current Queensland remnant vegetation mapping (Queensland Herbarium, Dataset 1), or 'non-remnant' if it is defined using the Queensland pre-clearing vegetation mapping (Queensland Herbarium, Dataset 1). This classifier delineates between 'human-modified' landscapes and those that are relatively intact. This distinction has important consequences for defining where important habitats and biota may occur when considering assets and their likely distribution. Ecological assets, such as potential species and community distributions, will often be confined to those areas that have been mapped as ‘remnant’ and assist in focusing the analysis of potential impacts on assets within the landscape.

The PAE is also divided into floodplain and non-floodplain areas based on the *Land Zones of Queensland* (Wilson and Taylor, 2012), where Land Zone 3 is defined as recent Quaternary alluvial systems (Queensland Herbarium, Dataset 1). This helps to broadly characterise which landscape features, such as wetlands, might be influenced by flooding regimes that are more likely to support water-dependent vegetation and habitats.

All wetland types (palustrine, lacustrine or riverine) are classed as wetlands and given the water regime described in the Queensland wetlands dataset (DSITIA, Dataset 3). This means that only those elements classed as ‘wetland’ receive a ‘water regime’ class. These two classifiers are necessary for identifying typically water-dependent features and their associated water regimes. The distribution and persistence of aquatic ecosystems is influenced largely by water regime and is a key attribute for differentiating and characterising habitats and ecosystems.

The distinction between GDEs based on their likely groundwater source (GAB *versus* non-GAB) is done using the Queensland GDE mapping and classification (DSITIA, Dataset 2). GAB GDEs associated with unweathered sandstones (excluding springs) tend to occur on sandstone outcrop areas or sandstone ridges that are important GAB recharge areas. Expression of groundwater around these outcrop areas occurs along foot slopes and channels due to fractures and weathered zones in these otherwise low-permeability rocks. Those remaining GDEs falling into the ‘non-GAB’ class include GDEs associated with floodplain alluvia (floodplain, non-GAB GDE) or non-floodplain landscapes including permeable rock or basalt systems and inland sand ridges (non-floodplain, non-GAB GDE).

Land use mapping data (ABARES, Dataset 4) are used to classify all landscape elements identified as ‘non-remnant’ into six land use types (Table 4) that comprise the human-modified group of landscape classes:

- conservation and natural environments
- intensive uses
- modified water bodies
- production from dryland agriculture and plantations
- production from irrigated agriculture and plantations
- production from relatively natural environments.

Table 4 Landscape classification rule sets used for the human-modified landscape polygons

Classification	Class	Relevant dataset citation	Dataset (field)	Rule
Human-modified	Conservation and natural environments	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'Conservation and natural environments'; 'Modified' = 'Conservation and natural environments'
	Intensive uses	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'intensive uses'; 'Modified' = 'intensive uses'
	Modified water bodies	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'Water'; 'Modified' = 'Modified water bodies'
	Production from dryland agriculture and plantations	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'Production from dryland agriculture and plantations'; 'Modified' = 'Production from dryland agriculture and plantations'
	Production from irrigated agriculture and plantations	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'Production from irrigated agriculture and plantations'; 'Modified' = 'Production from irrigated agriculture and plantations'
	Production from relatively natural environments	ABARES (Dataset 4)	ALUM_v7(Primary_V7)	If 'Primary_V7' = 'Production from relatively natural environments'; 'Modified' = 'Production from relatively natural environments'

The landscape classification (Bioregional Assessment Programme, Dataset 5) covers the entire PAE and includes all remnant and non-remnant vegetation polygons. Landscape classes are defined using the five classifiers described in Table 3 with their nomenclature reflecting key water-dependency attributes. For example, a landscape element classified as 'remnant', 'floodplain', 'non-GAB GDE', 'non-wetland' and 'null' has the landscape class of 'Floodplain, non-GAB GDE'. In other words, this element is remnant vegetation that is a GDE associated with a non-GAB floodplain aquifer, but is not classed as a wetland.

Classification of the stream network

Streams in the PAE are classified based on their catchment position, water regime and association with GDEs. Catchment position (i.e. upland *versus* lowland) exerts a strong influence on stream geomorphology, flow patterns and associated biota. Water regime is critical in determining habitat suitability for stream biota and is influenced by the geomorphology and hydrology of the stream channel and riparian zone. Rivers and streams can also receive significant baseflow inputs from local and regional groundwater systems and act as recharge sources to support GDEs. Differentiating between GDEs associated with GAB flow paths and aquifers and other non-GAB GDEs is also considered to be important given the regional-scale hydrological connectivity between GAB aquifers and coal measures under development. The level of human modification was not explicitly included in the classification system of the stream network and is therefore confined to the landscape classes included in the polygon data layers (see detail provided earlier in this section). The influence of different landscape classes adjacent to the in stream or riverine landscape classes is critical, yet difficult to distinguish based on the available data on the stream network.

The Assessment team classified the entire stream network in the Maranoa-Balonne-Condamine PAE to provide a consistent classification of the riverine landscapes (Bioregional Assessment Programme, Dataset 5). Two classifiers (catchment position and water regime) from the ANAE (Aquatic Ecosystems Task Group, 2012b) rule sets are used to classify the stream network (Table 5). The stream network data are based on the Geofabric v2 cartographic mapping of river channels derived from 1:250,000 topographic maps (Bureau of Meteorology, Dataset 6). The Geofabric is a purpose-built geographic information system (GIS) that maps Australian rivers and streams and identifies how stream features are hydrologically connected. The water regime of these stream networks is also defined (near-permanent or temporary) using associated attributes in the Geofabric dataset (Bureau of Meteorology, Dataset 6) (see Table 5 for details). Mapping of valley bottom flatness (MrVBF) (CSIRO, Dataset 7) is used to classify streams as either upland or lowland following methods outlined in Brooks et al. (2014) (Table 5). The presence of GDEs associated with individual stream segments is classified as GAB, non-GAB or non-GDE using the Queensland GDE data (DSITIA, Dataset 2). Spatial analysis is used to identify surface expression of GDEs contained in the Queensland eastern Murray-Darling Basin mapping (polylines; DSITIA, Dataset 2) that intersects with the stream network.

Table 5 Landscape classification rule sets used for the stream network polylines

Classification	Class	Relevant dataset citation	Dataset (field)	Rule
Catchment position	Upland	Bureau of Meteorology (Dataset 6), CSIRO (Dataset 7)	Geofabric and MrVBF	If ‘MrVBF ‘< ‘2.5’; ‘Catchment position‘ = ‘upland’
	Lowland	Bureau of Meteorology (Dataset 6), CSIRO (Dataset 7)	Geofabric and MrVBF	If ‘MrVBF ‘≥ ‘2.5’; ‘Catchment position‘ = ‘lowland’
Water regime	Temporary	Bureau of Meteorology (Dataset 6)	Geofabric (Water regime)	If ‘Water regime’ = ‘non perennial’; ‘Water regime’ = ‘temporary’
	Near-permanent	Bureau of Meteorology (Dataset 6)	Geofabric (Water regime)	If ‘Water regime’ = ‘perennial’; ‘Water regime’ = ‘near-permanent’
Groundwater source	Great Artesian Basin	DSITIA (Dataset 2)	Surface_GDE (lines), (C_Model)	If GDE area AND ‘C_Model’ = ‘Unweathered sandstone’; ‘Water source’ = ‘GAB GDE’
	Non-Great Artesian Basin	DSITIA (Dataset 2)	Surface_GDE (lines), (C_Model)	If GDE area AND NOT ‘C_Model’ = ‘Unweathered sandstone’; ‘Water source’ = ‘non-GAB GDE’
	Non-groundwater	DSITIA (Dataset 2)	Surface_GDE (lines), (C_Model)	If NOT GDE area = ‘non-GDE’

Classification of springs

The springs and spring complexes contained in the asset database for the Maranoa-Balonne-Condamine subregion (Bioregional Assessment Programme, Dataset 8) are classified based on groundwater source: GAB or non-GAB. Information on source aquifer is derived from the most recent database for spring vents in this region (OGIA, Dataset 9). GAB springs tend to be associated with sandstone aquifers such as Springbok and Precipice sandstones, whereas non-GAB springs have source aquifers in basalt aquifers associated with the Main Range Volcanics or other non-GAB sediments (Table 6).

Table 6 Landscape classification rule sets used for springs and spring complexes

Classification	Class	Relevant dataset citation	Dataset (field)	Rule
Groundwater source	Great Artesian Basin	Bioregional Assessment Programme (Dataset 8), Office of Groundwater Impact Assessment (Dataset 9)	Spring vents and source aquifer (‘Source aquifer’)	If NOT ‘Source aquifer‘ = ’ Main Range volcanics’ OR ‘tertiary volcanics’ OR ’Cainozoic sediments’; ‘Groundwater source‘ = ‘GAB’
	Non-Great Artesian Basin	Bioregional Assessment Programme (Dataset 8), Office of Groundwater Impact Assessment (Dataset 9)	Spring vents and source aquifer (‘Source aquifer’)	If ‘Source aquifer‘ = ’ Main Range volcanics’ OR ‘tertiary volcanics’ OR ’Cainozoic sediments’; ‘Groundwater source‘ = ‘non-GAB’

The datasets used for this classification approach are derived from on-ground mapping and other approaches (e.g. remote sensing) done at different spatial resolutions. Thus, the precision and accuracy of different elements comprising the landscape class varies depending on the source data. Furthermore, integrating these data sources into a consistent and complete landscape classification of the PAE inevitably produces some mismatches in the element boundaries – an issue that was minimised by giving preference to those spatial data layers with the greatest level of accuracy and confidence when producing a union of the final landscape elements. Thus, the potential for misclassification is most likely within datasets mapped at lower resolution such as the land use mapping (ABARES, Dataset 4), whereas the wetland mapping boundaries (DSITIA, Dataset 3), a layer given priority over the land use data, remained intact and were reclassified according to the landscape classification rule set discussed above.

The logic of the landscape classification rule sets used in the Maranoa-Balonne-Condamine subregion is shown in Figure 17.

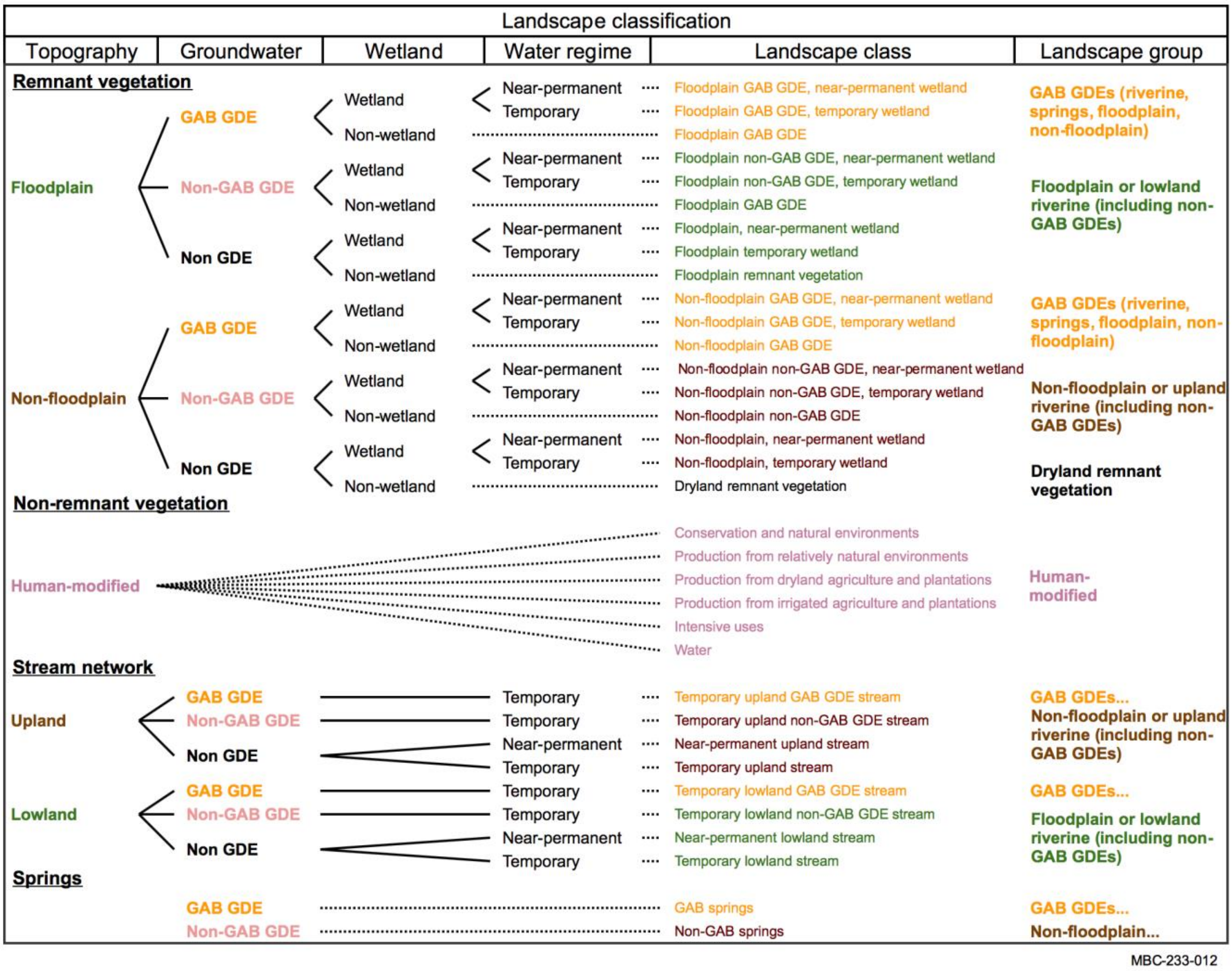

Figure 17 Schematic of the landscape classification based on six key criteria

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem, GAB GDEs… = GAB GDEs (riverine, springs, floodplain, non-floodplain), Non-floodplain… = Non-floodplain or upland riverine (including or non-GAB GDEs)

2.3.3.1.2 Landscape classification

The approach detailed in Section 2.3.3.1 identified 34 landscape classes, which are aggregated into five landscape groups based on broad-scale distinctions in their water dependency and association with GAB or non-GAB GDEs, floodplain/non-floodplain or upland/lowland environments and remnant/human-modified habitat types (Table 7). Most of the PAE (72.2%) is classified in the ‘Human-modified’ landscape group, which includes agricultural, urban and other intensive land uses (Table 7).

The distribution of remnant vegetation in the five landscape groups is shown in Figure 18. Among those areas mapped under the Queensland regional ecosystems (classed as remnant vegetation) (Table 7), the largest proportion (19.8%) are classed as ‘Dryland remnant vegetation’ (Table 7). ‘Dryland remnant vegetation’ are not considered water dependent (i.e. solely dependent on incident rainfall) because they do not intersect floodplain, wetland or GDE features. The ‘Floodplain or lowland riverine (including non-GAB GDEs)’ landscape group covers approximately 5% of the PAE. Of the remaining non-floodplain landscapes, the ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ landscape group covers 2.2% of the PAE and the ‘GAB GDEs (riverine, springs, floodplain or non-floodplain)’ landscape group covers 1.3% of the PAE (Table 7).

Table 7 Land area and percentage of total area in each landscape class in the Maranoa-Balonne-Condamine preliminary assessment extent (PAE)

Landscape group	Landscape class	Landscape class area (ha)	Percentage of total PAE (%)
Floodplain or lowland riverine (including non-GAB GDEs)	Floodplain remnant vegetation	208,592	1.61%
	Floodplain, near-permanent wetland	14,746	0.11%
	Floodplain, non-GAB GDE	245,461	1.89%
	Floodplain, non-GAB GDE, near-permanent wetland	6,100	0.05%
	Floodplain, non-GAB GDE, temporary wetland	44,209	0.34%
	Floodplain, temporary wetland	67,541	0.52%
	Total	**586,649**	**4.51%**
GAB GDEs (riverine, springs, floodplain or non-floodplain)	Floodplain, GAB GDE	28,955	0.22%
	Floodplain, GAB GDE, near-permanent wetland	31	<0.01%
	Floodplain, GAB GDE, temporary wetland	869	0.01%
	Non-floodplain, GAB GDE	144,575	1.11%
	Non-floodplain, GAB GDE, near-permanent wetland	1	<0.01%
	Non-floodplain, GAB GDE, temporary wetland	160	<0.01%
	Total	**174,591**	**1.34%**
Non-floodplain or upland (including non-GAB GDEs)	Non-floodplain, non-GAB GDE	255,106	1.96%
	Non-floodplain, non-GAB GDE, near-permanent wetland	293	0.03%
	Non-floodplain, non-GAB GDE, temporary wetland	3,282	<0.01%
	Non-floodplain, near-permanent wetland	4,655	0.04%
	Non-floodplain, temporary wetland	19,522	0.15%
	Total	**282,858**	**2.18%**
Dryland remnant vegetation	Dryland remnant vegetation	2,570,840	19.78%
	Total	**2,570,840**	**19.78%**
Human-modified	Conservation and natural environments	55,381	0.43%
	Intensive uses	78,760	0.61%
	Production from dryland agriculture and plantations	1,899,220	14.61%

Landscape group	Landscape class	Landscape class area (ha)	Percentage of total PAE (%)
	Production from irrigated agriculture and plantations	347,633	2.68%
	Production from relatively natural environments	6,983,287	53.74%
	Water	16,381	0.13%
	Total	**9,380,662**	**72.18%**
All	**Total**	**12,995,600**	**99.99%**

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 5)

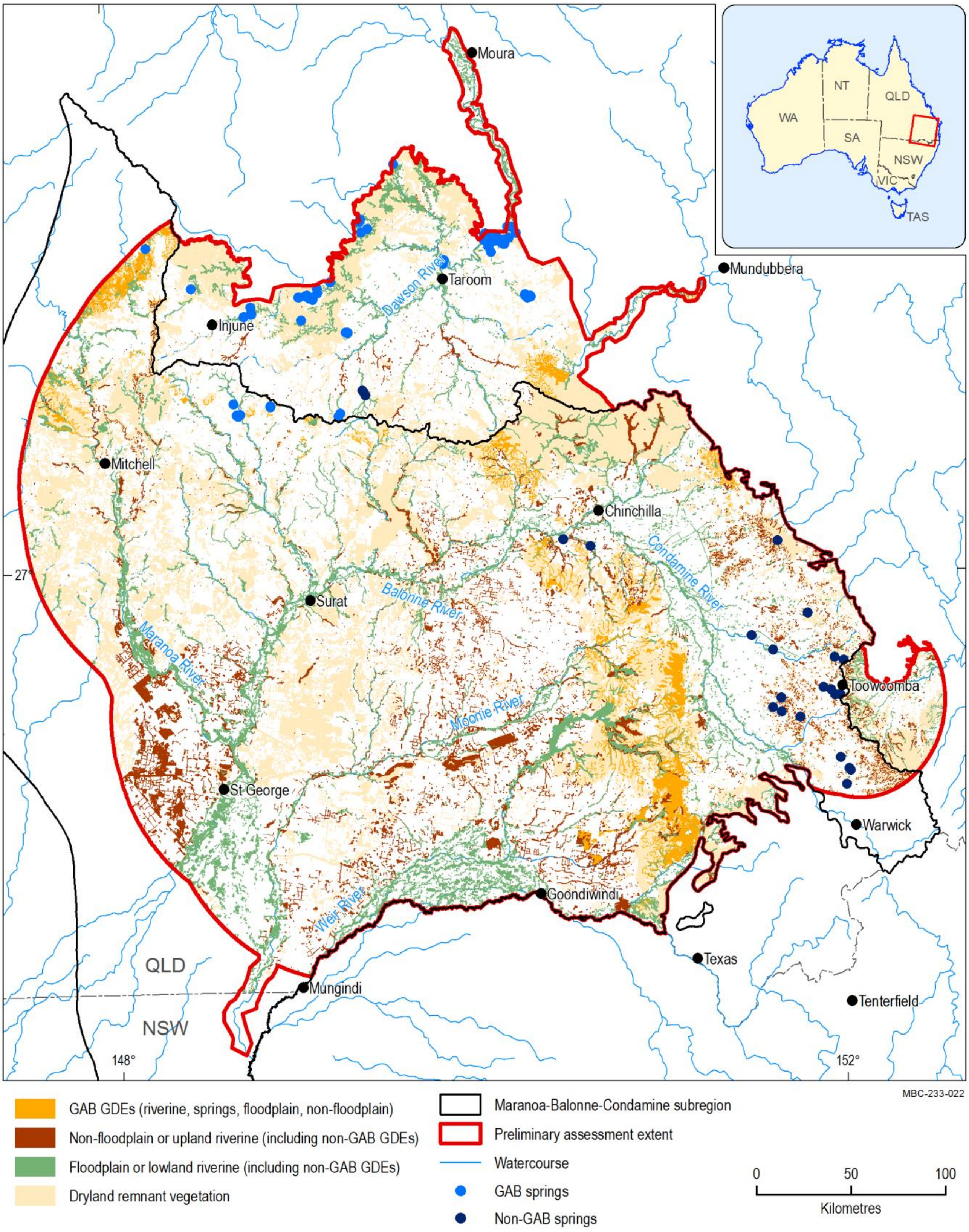

Figure 18 Location of remnant vegetation and springs in the Maranoa-Balonne-Condamine preliminary assessment extent classified by landscape group

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 5)

‘Temporary lowland streams’ (47%) in the ‘Floodplain or lowland riverine (including non-GAB GDEs)’ landscape group and ‘Temporary upland streams’ (36%) in the ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ landscape group are the most common landscape classes in the stream network. Figure 18 shows the distribution of streams in each landscape group in the Maranoa-Balonne-Condamine PAE. Streams that contain GDEs are less widespread, with streams that contain GAB GDEs covering 15% and streams that contain non-GAB GDEs covering 6% of the stream network in the PAE (Table 8). Figure 19 shows the distribution of catchments within the Maranoa-Balonne-Condamine PAE classed as either ‘upland’ or ‘lowland’. Those stream segments classified as ‘upland’ tend to be found along the eastern and northern portions of the PAE (particularly in the Fitzroy River and Burnett River basins) and are associated with the Main Range Volcanics and sandstone outcropping areas and other elevated portions of the Maranoa-Balonne-Condamine PAE (Figure 19). ‘Lowland’ streams are predominately in the Condamine-Culgoa, Moonie and Border river basins (Figure 19).

Table 8 Length of stream network in each landscape class in the Maranoa-Balonne-Condamine preliminary assessment extent (PAE)

Landscape group	Landscape class	Total length (km)	Percentage of total length (%)
Floodplain or lowland riverine (including non-GAB GDEs)	Near-permanent, lowland stream	170	0.28%
	Temporary, lowland non-GAB GDE stream	268	0.44%
	Temporary, lowland stream	28,716	47.11%
	Total	**29,154**	**47.83%**
GAB GDEs (riverine, springs, floodplain or non-floodplain)	Temporary, lowland GAB GDE stream	3,586	5.88%
	Temporary, upland GAB GDE stream	4,183	6.86%
	Total	**7,769**	**12.74%**
Non-floodplain or upland riverine (including non-GAB GDEs)	Temporary, upland non-GAB GDE stream	2,119	3.48%
	Near-permanent, upland stream	159	0.26%
	Temporary, upland stream	21,757	35.69%
	Total	**24,035**	**39.43%**
All	**Total**	**60,958**	**100%**

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 5)

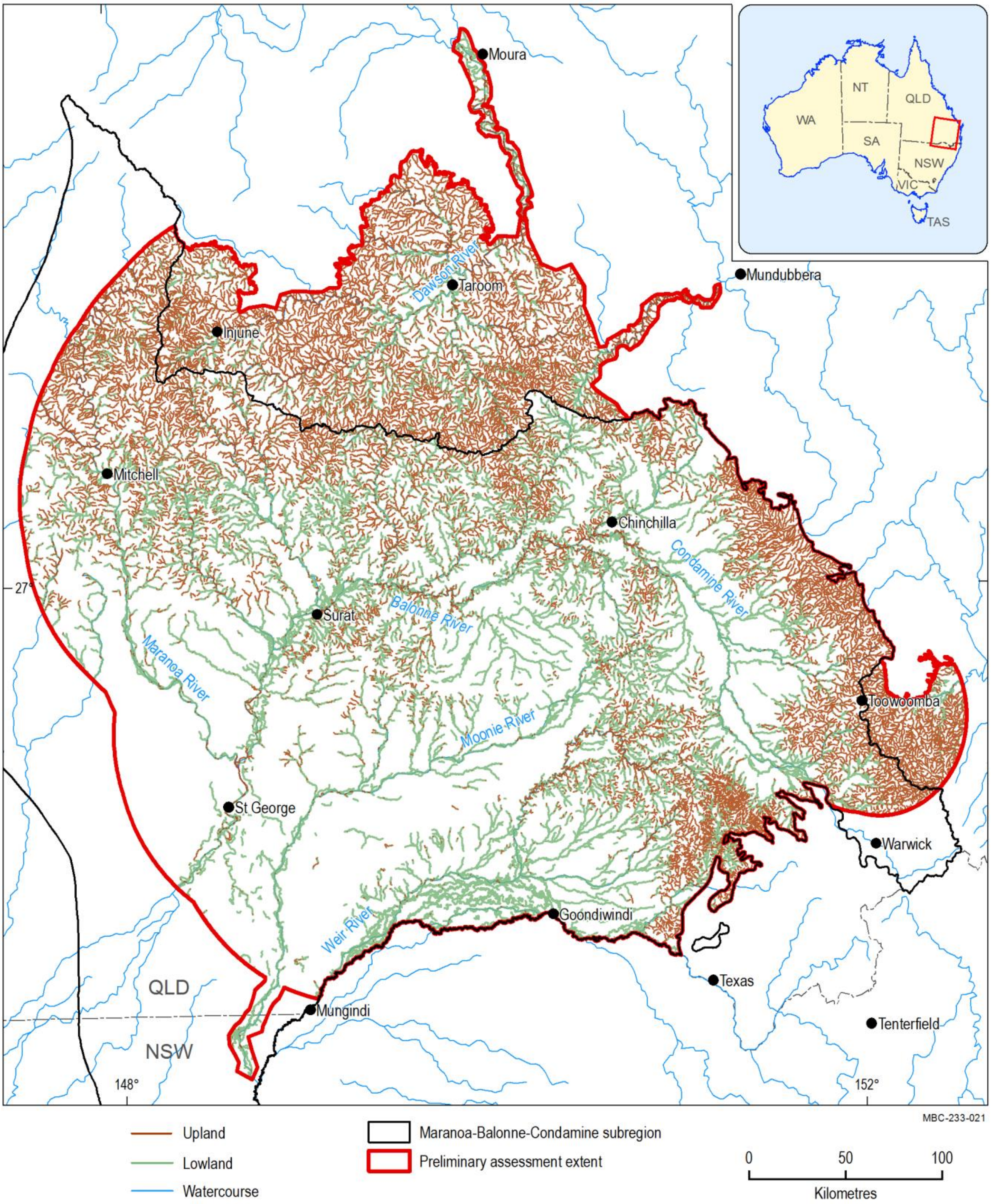

Figure 19 Location of watercourses classified as upland or lowland in the Maranoa-Balonne-Condamine subregion

Dataset: Bioregional Assessment Programme (Dataset 5)

Most springs and spring complexes in the Maranoa-Balonne-Condamine PAE (86%) are associated with GAB aquifers (Table 9). Figure 18 shows that most of the GAB springs are located in the north of the PAE. Non-GAB springs are associated with Cenozoic or Main Range Volcanics aquifers, which are located along the eastern boundary of the PAE (Figure 18).

Table 9 Springs in each landscape class in the Maranoa-Balonne-Condamine preliminary assessment extent

Landscape group	Landscape class	Total count	Percentage of total springs (%)
GAB GDEs (riverine, springs, floodplain or non-floodplain)	GAB springs	153	86.44%
Non-floodplain or upland riverine (including non-GAB GDEs)	Non-GAB springs	24	13.56%
All	**Total**	**177**	**100%**

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem

Floodplain or lowland riverine (including non-Great Artesian Basin groundwater-dependent ecosystems)

Floodplains can be broadly defined as a collection of landscape and ecological elements exposed to inundation or flooding along a river system (Rogers, 2011). The floodplain landscapes of the Maranoa-Balonne-Condamine PAE are predominantly lowland-dryland systems incorporating a range of wetland types such as riparian forests, marshes, billabongs, tree swamps, anabranches and overflows (Rogers, 2011). Floodplains are underlain by alluvial aquifers, which are formed from deposited sediments such as gravel, sand, silt and/or clay within river channels or on floodplains. Water is stored and transmitted to varying degrees through inter-granular voids meaning that alluvial aquifers are generally unconfined, shallow and have localised flow systems (DSITI, 2015). Groundwater expressed at the surface supports GDEs occupying drainage lines, riverine water bodies, and lacustrine and palustrine wetlands. Ecosystems associated with the subsurface expression of groundwater include fringing riverine communities and woodlands occupying the back plain environment.

Figure 20 is an example of the distribution of landscape classes along a typical floodplain area, showing part of the Condamine Alluvium near Dalby. The river channel is fringed by the riparian zone, which is predominantly classed as ‘Floodplain, non-GAB GDE’ with smaller areas of the ‘Floodplain, non-GAB GDE, near-permanent wetland’, ‘Floodplain, non-GAB GDE, temporary wetland’, ‘Floodplain, near-permanent wetland’ and ‘Floodplain, temporary wetland’ landscape classes. Adjacent to the riparian zone is the back plain environment, representing the transition between the frequently flooded river channel and the upland environment. The back plain environment contains floodplain woodlands and various types of wetlands with varying degrees of groundwater dependency (Holloway et al., 2013). The back plain environment of the Condamine Alluvium is predominantly classed as ‘Floodplain remnant vegetation’. Important woodland species in the back plain environment include black box (*Eucalyptus largiflorens*), coolibah (*Eucalyptus coolabah*), river coobah (*Acacia stenophylla*) and other *Eucalyptus* spp., shrubs and grasses.

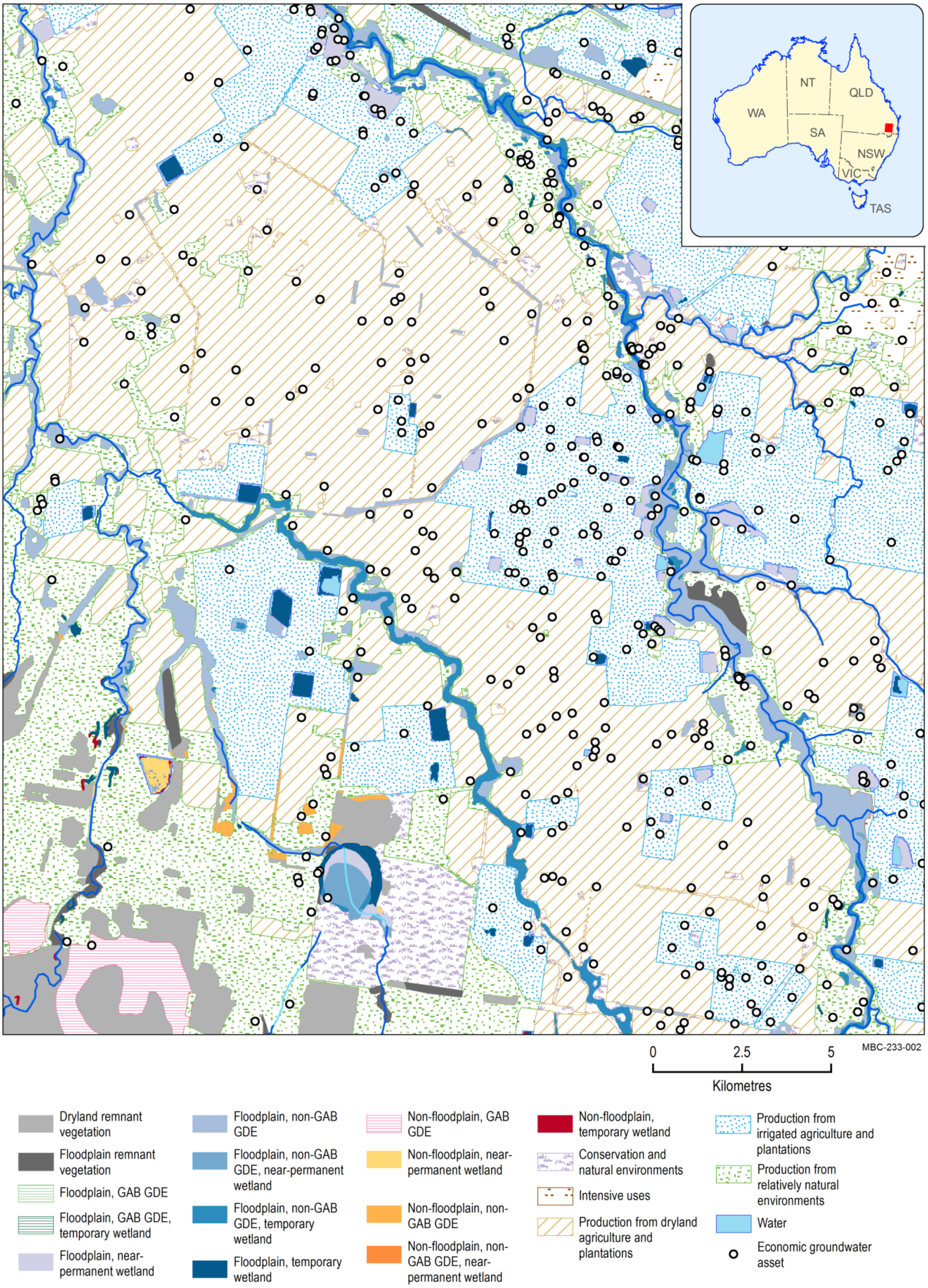

Figure 20 Distribution of landscape classes in the Condamine Alluvium near Dalby

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 5)

Another typical floodplain environment is along the Balonne River in the western portion of the PAE, which is shown conceptually in Figure 21 and spatially in Figure 22. The conceptual model shows that inundation from flooding defines the riparian zone, with groundwater movement being predominantly downward from the surface to the alluvial aquifers. Floodplain trees are able to access groundwater in the alluvial aquifers. Figure 22 shows that the ‘Floodplain near-permanent wetland’ and ‘Floodplain near-permanent wetland, non-GAB GDE’ landscape classes are located adjacent to major river channels and are analogous to riparian forests. River red gum (*Eucalyptus camaldulensis*), co-occurring *Eucalyptus* and she-oak (*Casuarina cunninghamiana*) species and, in some cases, Gallery rainforest communities, are the dominant vegetation communities in ‘Floodplain, near-permanent wetland’ landscape class areas (Figure 22). The back plain environment of the Balonne River contains the ‘Floodplain remnant vegetation’, ‘Floodplain non-GAB GDEs’ and ‘Floodplain, temporary wetland’ classes that have a temporary water regime and reduced flooding frequency, duration and depth in comparison to the riparian zone (Figure 22). The ‘Floodplain, non-GAB GDEs’ landscape class tends to be interspersed along the riparian and back plain environments and groundwater use is influenced by groundwater depth and salinity (Holloway et al., 2013; Roberts and Marston, 2011). Several listed ecological communities are associated with the ‘Floodplain or lowland riverine (including non-GAB GDEs)’ landscape group. This includes the ‘Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions Threatened Ecological Community’ listed under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and threatened regional ecosystems listed under Queensland’s *Vegetation Management Act 1999*; ‘Gallery rainforest (notophyll vine forest) on alluvial plains Endangered Regional Ecosystem’ (as dominant component) and ‘*Eucalyptus camaldulensis* fringing open forest Endangered Regional Ecosystem’ (as dominant component) (Table 10).

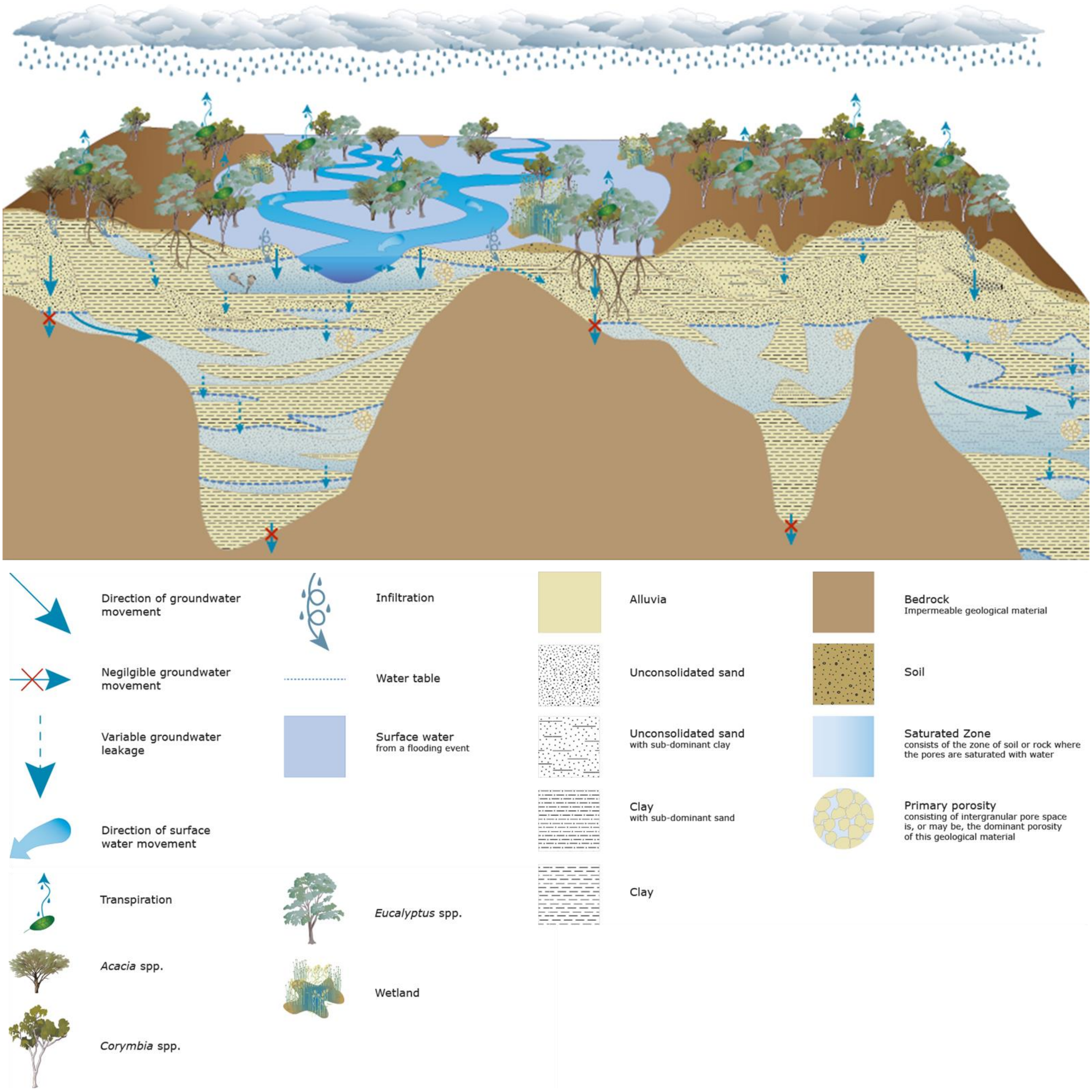

Figure 21 Pictorial conceptual model of a typical floodplain landscape with substantial alluvial development

The light blue and brown areas on the land surface delineate the frequently inundated riparian zone and the less frequently flooded back plain environment. The arrows indicate the direction of water movement, with the dashed arrow line indicating variable groundwater leakage and the crossed (red) arrow line, indicating negligible groundwater movement. The blue dashed horizontal line indicates the position of the water table within the cross-section.
Source: DEHP (2015a)

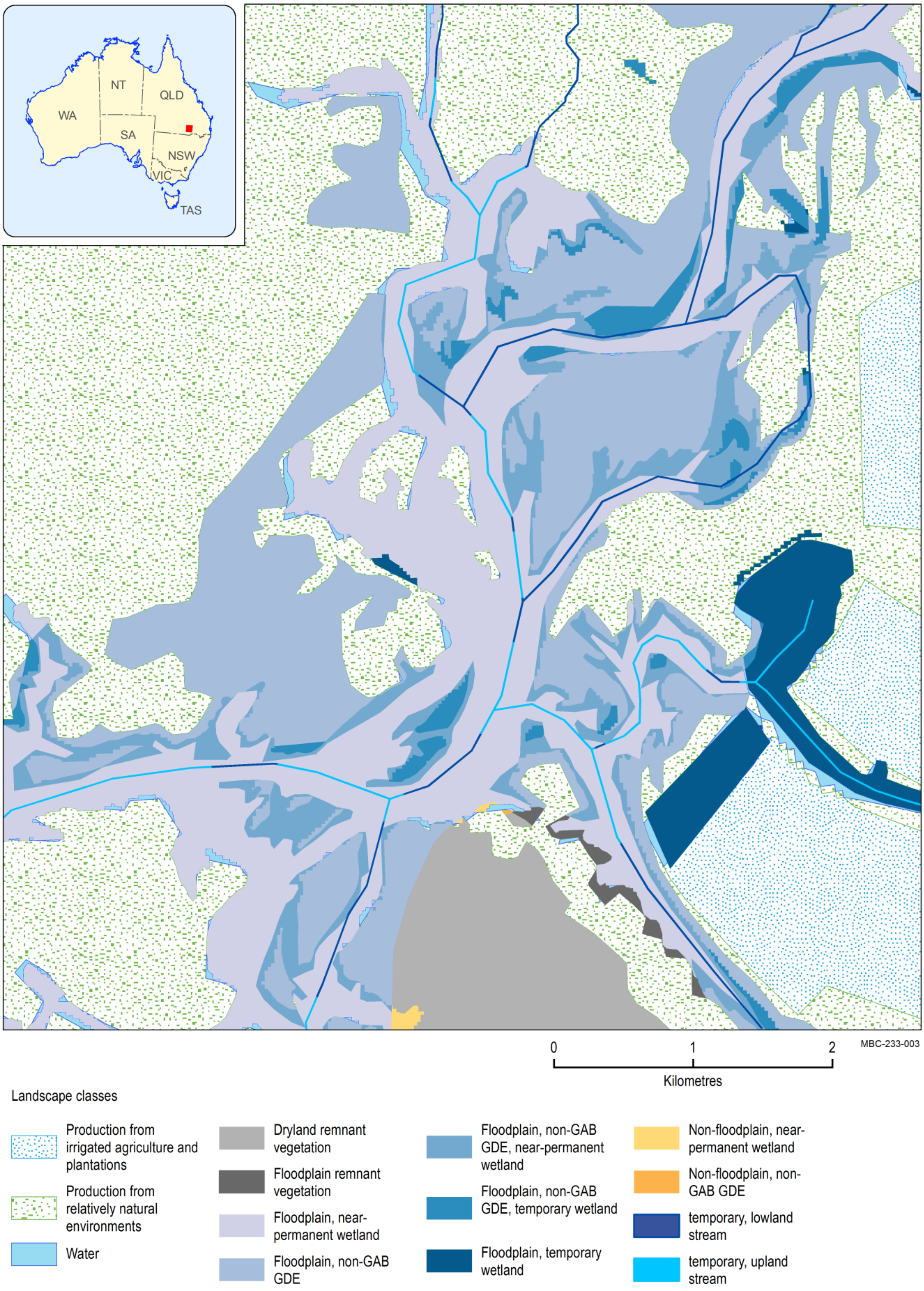

Figure 22 Location of floodplain landscape classes along a reach of the Balonne River

GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 5)

Table 10 Location, associated communities, threatened ecological communities, water dependency and nature of water dependency for each landscape group

Landscape group	Location	Associated communities	Listed ecological communities	Nature of dependency	Water sources and water regime (spatial[a], temporal[b])
Floodplain or lowland riverine (including non-GAB GDEs)	Land zone 3 – Quaternary alluvial systems	• Riparian forests dominated by river red gum. • *Casuarina cunninghamiana* is also common. • Floodplain woodlands including coolibah, black box and poplar box • Gallery rainforest on alluvium • Swamp Tea-tree	• Swamp Tea-tree (*Melaleuca irbyana*) Forest of South-east Queensland Threatened Ecological Community • Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions Threatened Ecological Community • Gallery rainforest (notophyll vine forest) on alluvial plains Endangered Regional Ecosystem (as dominant component) • *Eucalyptus camaldulensis* fringing open forest Endangered Regional Ecosystem (as dominant component) • *Melaleuca irbyana* low open forest on sedimentary rocks Endangered Regional Ecosystem (as dominant component)	• associated with near-permanent and temporary lowland streams • floodplain wetlands are characterised by size, water regime and emergent vegetation • flooding pulses enable growth and recruitment • river red gum flooding required every 1 to 4 years (Roberts and Marston, 2011). • black box/coolibah/River Cooba – flooding required every 3 to 7 years (Roberts and Marston, 2011). • streamside water not critical water source (Thorburn and Walker, 1994). • groundwater – intermittent and aseasonal and where salinity levels are tolerable (Holloway et al. 2013)	Surface water (regional, episodic) and groundwater (landscape, aseasonal/intermittent)

Landscape group	Location	Associated communities	Listed ecological communities	Nature of dependency	Water sources and water regime (spatial[a], temporal[b])
GAB GDEs (riverine, springs, floodplain, non-floodplain)	• unweathered sandstone outcrop areas • GAB springs found mainly in the north of the PAE across various landforms.	• *Eucalyptus* and *Corymbia* woodlands • *Eucalyptus*, *Callitris*, *Angophora* communities • semi-evergreen vine thicket • other unique spring communities.	• The community of native species dependent on natural discharge of groundwater from the Great Artesian Basin Threatened Ecological Community • Gallery rainforest (notophyll vine forest) on alluvial plains Endangered Regional Ecosystem (as dominant component) • Semi-evergreen vine thicket on alluvial plains Endangered Regional Ecosystem (as dominant component)	• GAB GDEs – aseasonal and intermittent • for outcropping areas, groundwater may discharge along foot slopes and channels • spring discharge sites can be permanent or intermittent (Fensham and Fairfax, 2003) • surface discharge is caused by faults or fractures in overlying sediments, contact between confining sediments and outcropping of bedrock, outcropping of water-bearing sediments near the GAB margins	• springs – groundwater (regional, near-permanent) • GDEs – groundwater (local-regional, intermittent).

Landscape group	Location	Associated communities	Listed ecological communities	Nature of dependency	Water sources and water regime (spatial[a], temporal[b])
Non-floodplain or upland riverine (including non-GAB GDEs)	- Gilgai wetlands - most commonly found in association with Brigalow communities on shrink-swell and cracking clay soils - inland sand ridges GDE – common in the western region of the Maranoa-Balonne-Condamine - permeable geologies GDE – confined to the Main Range Volcanics in the east	- Gilgai communities including grasses and sedges: - shrubs (e.g. *Eremophila* spp.) - trees including *Melaleuca bracteata*, belah (*Casuarina cristata*) and Eucalypts (*Eucalyptus tereticornis*; *Eucalyptus camaldulensis* and *Eucalyptus populnea*) - inland sand ridges: *Eucalyptus* spp. (*Eucalyptus intertexta, Eucalyptus largiflorens*) and *Corymbia tesselaris* - basalt/permeable geologies GDE: *Eucalyptus* and *Casuarina* spp. and grass *(Pennisetum* spp.) layer.	- Brigalow (*Acacia harpophylla* dominant and co-dominant) Threatened Ecological Community - Brigalow associated Queensland regional ecosystems - White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland Threatened Ecological Community	- episodic to intermittent surface water source - variation in infiltration in response to swelling of clays promotes accumulation of water (Chertkov, 2005) - inland sand ridges - perched and unconfined aquifer, localised flow paths (Holloway et al., 2013) - permeable geologies – groundwater transmission and discharge dependent on contact zones (local flow paths) (DISITI, 2015).	- surface water (local, intermittent) - groundwater (local, intermittent)
Dryland remnant vegetation	Upland areas (excluding floodplain; Land Zone 3)	Various woodland, shrubland and grassland communities not associated with floodplain, GDE or wetlands	Brigalow (*Acacia harpophylla* dominant and co-dominant) Threatened Ecological Community and several of the associated Queensland regional ecosystems[c]	Reliant on locally stored soil water	Rainfall and runoff, (localised, temporary)

Landscape group	Location	Associated communities	Listed ecological communities	Nature of dependency	Water sources and water regime (spatial[a], temporal[b])
Human-modified	Irrigated agriculture concentrated around Condamine Alluvium and other floodplain systems	Herbaceous pasture and crop species. Plantation tree species. Some small areas of remnant native vegetation.	Listed ecological communities are not associated with the human-modified landscape group.	• variable ranging from incident rainfall – dryland cropping and grazing to irrigated agriculture reliant on shallow and deep aquifers • potential for groundwater dependency of plantations and deep-rooted perennial crops • flooding may help to replenish subsoil moisture for farm systems on floodplains.	Rainfall (local, intermittent); surface water (local-regional, temporary-near-permanent); groundwater (local-regional, temporary-near-permanent)

[a] Spatial scale of the flow system and its predominant pattern, refers to local (10^0 to 10^4 m^2), landscape (10^4 to 10^8 m^2) or regional (10^8 to 10^{10} m^2) scales.

[b] Temporal scale of the water regime, refers to the timing and frequency of the reliance on a particular water source.

[c] This EPBC-listed community and the Queensland regional ecosystems associated with Brigalow are common.

GDE = groundwater-dependent ecosystem, GAB = Great Artesian Basin

Great Artesian Basin groundwater-dependent ecosystems (riverine, springs, floodplain, non-floodplain)

This landscape group represents landscape classes that are hydrologically connected to GAB aquifers. GAB springs are surface expressions of groundwater sourced from aquifers contained in the Triassic, Jurassic and Cretaceous sedimentary sequences associated with the GAB (Habermehl, 1982). Spring ecosystems contain many locally endemic species and plant communities and have significant ecological, economic and cultural values (Fensham and Fairfax, 2003). Of the 94 GAB spring wetlands surveyed in a recent assessment of the Surat cumulative management area (Fensham et al., 2012), most (58) were listed under the EPBC Act as a threatened ecological community, while 34 springs were listed both as a threatened ecological community and for individual species found in the springs (Table 10). Three springs were listed for individual species found in the springs (Fensham et al., 2012).

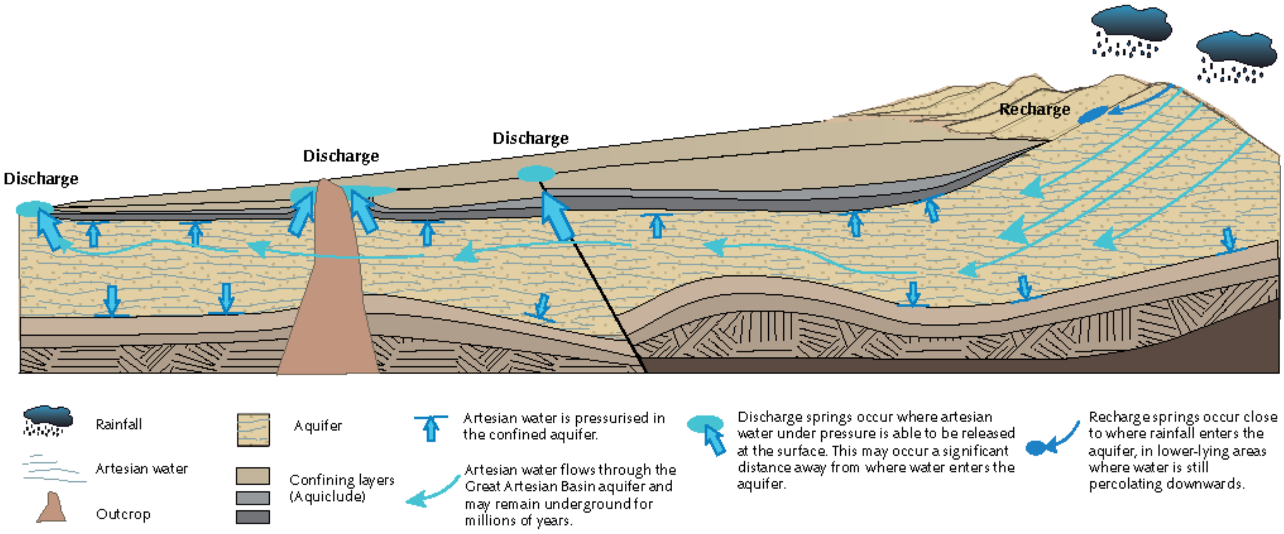

Figure 23 Pictorial representation of the hydrogeological characteristics of recharge and discharge springs associated with the Great Artesian Basin aquifers

Source: DEHP (2013a)

Apart from ecosystems associated with spring vents, other GDEs associated with GAB aquifers are located in areas where GAB sedimentary layers outcrop at or near the surface in the eastern and northern parts of the PAE. The GAB aquifer outcrop areas are predominantly GAB recharge areas, where rainwater percolates into the GAB aquifers between confining layers (Figure 23). However, fractures, inter-granular pores and weathered zones can cause groundwater to discharge locally at or near the surface in these areas (DSITIA, 2015). This is referred to as ‘rejected recharge’. These features describe the ‘Non-floodplain GAB GDE’ landscape class, which can also include near-permanent and temporary wetlands where groundwater is expressed at the surface (Figure 22). The plant communities of these GDEs tend to be dominated by *Eucalyptus, Corymbia* and *Angophora* spp. (Table 10).

Non-floodplain or upland riverine (including non-GAB GDEs)

The landscape classes in the ‘Non-floodplain or upland riverine (including non-GAB GDEs)’ landscape group include upland streams and wetlands that are not associated with floodplains or GAB GDEs. Non-floodplain, temporary wetlands on low permeability, shrink-swell cracking clays sometimes form gilgai (meaning ‘small waterhole’ wetlands) (DEHP, 2013b). These temporary wetlands are essentially small depressions within the Cenozoic clay deposits that are interspersed with mounds and depressions over relatively small distances (approximately 2 m; Chertkov, 2005). Spatial variation in infiltration occurs as these clays swell when wet, causing cracks to close and water to pool on the surface (Chertkov, 2005).

The most common vegetation associated with non-floodplain wetlands is Brigalow (*Acacia harpophylla*) and belah (*Casuarina cristata*) (Table 10). Flora associated with the wet areas include grasses, aquatic herbs, sedges and rushes (DEHP, 2013b). These wetlands are ecologically important components of the Brigalow Belt in southern Queensland and support threatened EPBC Act-listed species such as the yakka skink (*Egernia rugosa*). The Brigalow threatened ecological community listed under the EPBC Act ('Brigalow (*Acacia harpophylla* dominant and co-dominant)') occurs in areas classified as dryland remnant vegetation as well as areas thought to be water dependent (e.g. ‘Floodplain remnant’ landscape class).The nature of wet and dry phases within these wetlands is determined by localised runoff from rainfall, which means that their dependency on flow systems at larger scales is likely to be negligible (Table 10).

Non-GAB GDEs includes the GDEs associated with inland sand ridges (Figure 24) and permeable rock or basalt aquifers (Figure 25). Inland sand ridges occur outside the most elevated portion of the floodplain or alluvial land zones and are classed as ‘Non-floodplain, non-GAB GDEs’. They are more common in the western region of the PAE (Figure 22). Inland sand ridges support *Corymbia* and *Eucalyptus* species with varying reliance on perched aquifers within the sandy profile (Holloway et al., 2013).

In permeable rocks, groundwater is transmitted and stored through fractures, inter-granular spaces or weathered zones and is typically discharged to the surface at contact zones between two rock types (Figure 25) (DSITI, 2015). Associated plant communities tend to be open woodlands, dominated by *Eucalyptus* spp. and often contain shrub and grass (*Pennisetum* spp.) layers (Table 10). Aquifers in permeable rocks may also support ecosystems within the aquifer itself, which is sometimes indicated by the presence of stygofauna (DEHP, 2015c). These basalt aquifer landscape features are located in the eastern portion of the PAE, in the more elevated areas of the Main Range Volcanics of the Condamine-Balonne river basin. These GDEs are characterised by localised flow systems that have intermittent/aseasonal connectivity (Figure 25 and Table 10) (DSITI, 2015).

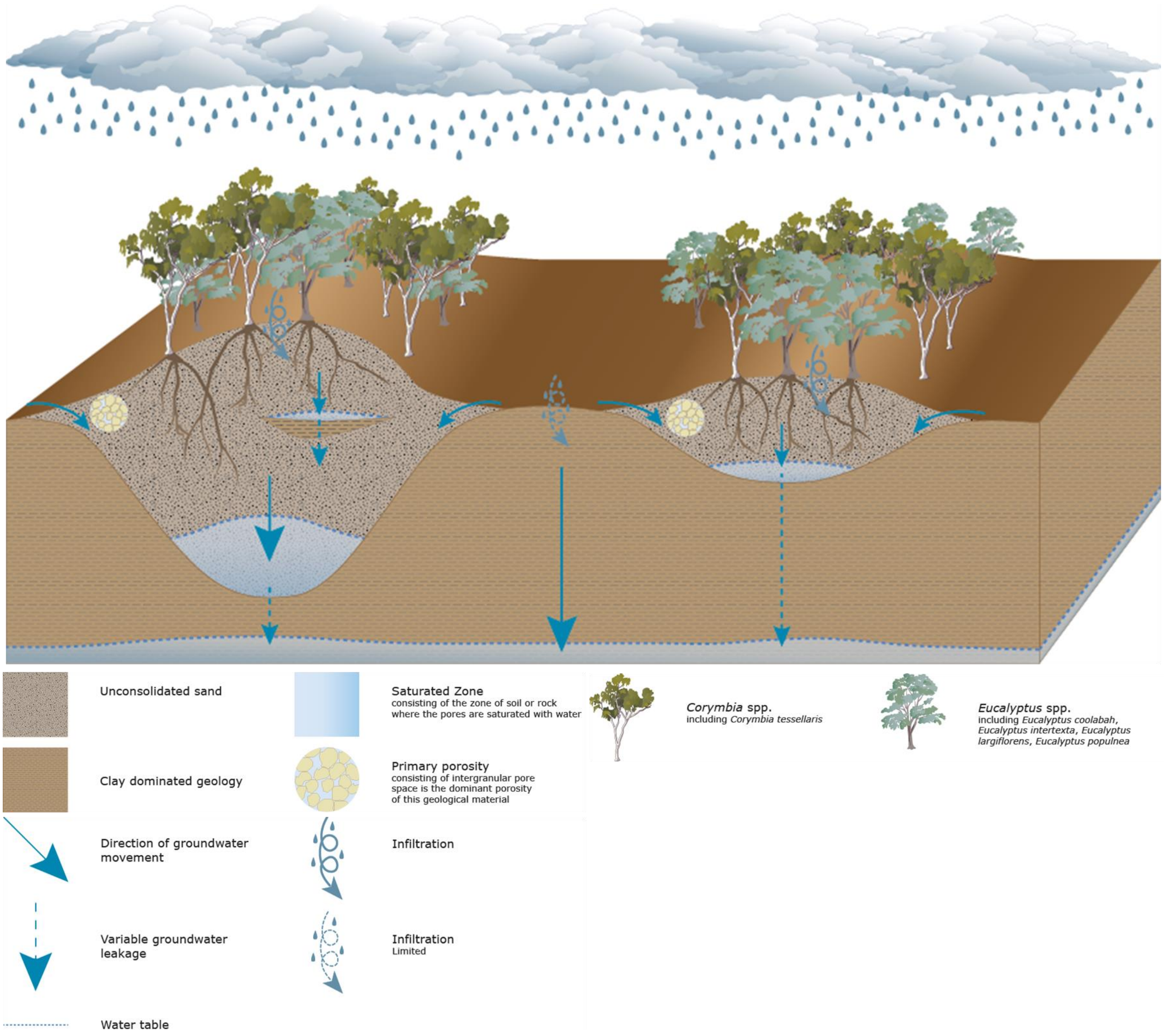

Figure 24 Pictorial conceptual model of groundwater-dependent ecosystems associated with inland sand ridges

Source: DEHP (2015b)

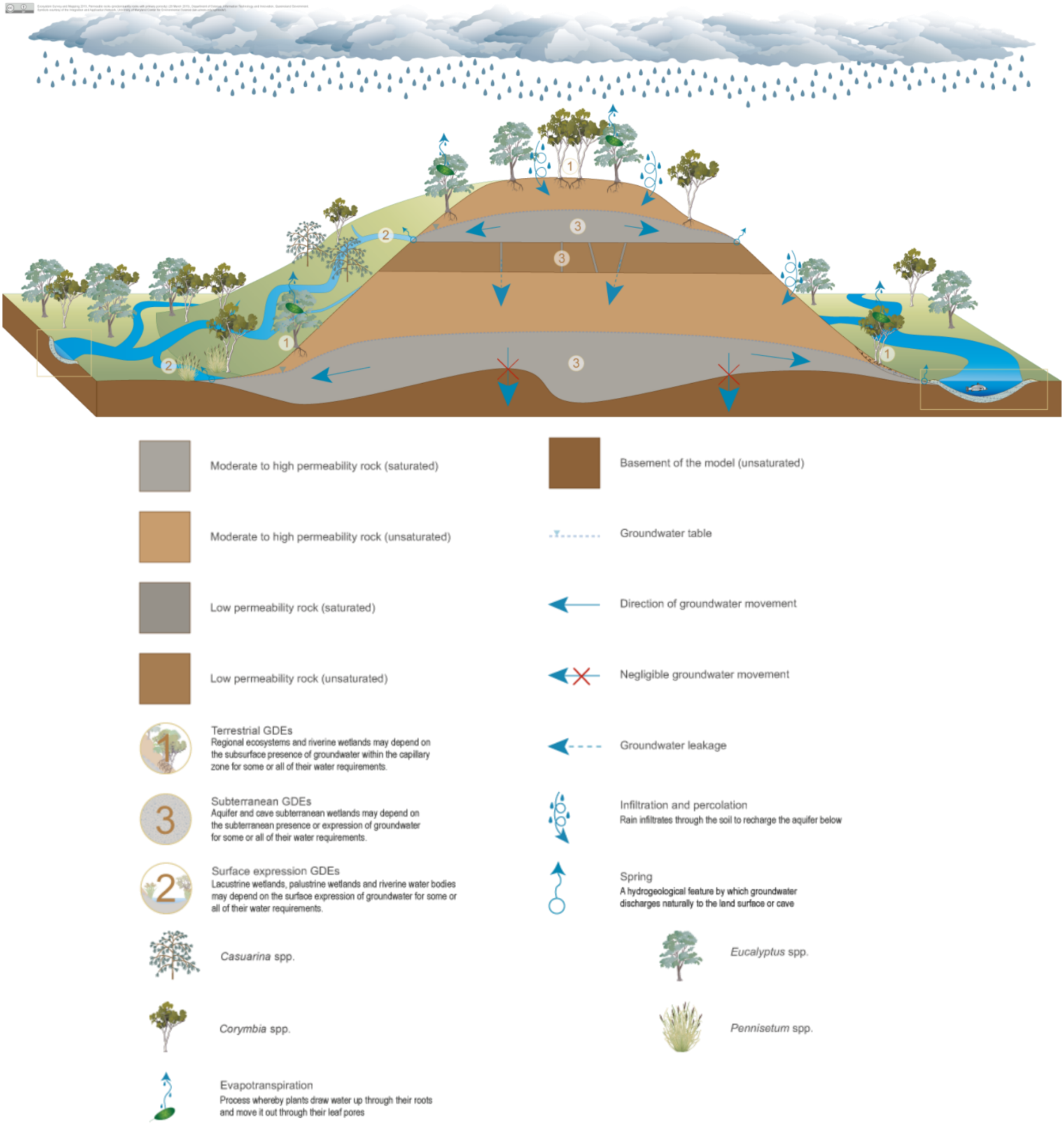

Figure 25 Pictorial conceptual models of groundwater-dependent ecosystems associated with permeable rock (basalt)

Source: DEHP (2015c)

Dryland remnant vegetation

This landscape group represents a large component of those landscapes classified as ‘remnant’ in the Queensland regional ecosystem mapping (Queensland Herbarium, Dataset 1). The term ‘dryland’ implies that this landscape class is reliant on incident rainfall and local runoff and does not include features in the landscape identified as wetlands, GDEs or springs. The associated communities are highly variable and cover many different types of woodland, shrubland and grassland (Table 10). The Brigalow threatened ecological community listed under the EPBC Act ('Brigalow (*Acacia harpophylla* dominant and co-dominant)') occurs across some areas classified as

'Dryland remnant vegetation' as well as being distributed across those landscape classes thought to be water dependent (e.g. 'Floodplain remnant' landscape class).

Human-modified landscapes

Most of the PAE (72.2%) is dominated by human-modified landscapes used for agricultural production, mining and urban development (Table 7). The water dependency of the landscape classes derived from this landscape group ranges from a heavy dependence on groundwater and surface water extracted from nearby aquifers and streams (e.g. intensive uses and production from irrigated agriculture and plantations), through to dryland cropping and grazing reliant on incident rainfall and local surface water runoff (e.g. production from dryland agriculture and plantations). The distribution of landscape classes on the Condamine Alluvium near Dalby shows that most of the landscape classes are in the 'Human-modified' landscape group (Figure 20). Deeper-rooted vegetation, including remnant vegetation and plantations may tap into groundwater within certain landscapes. Intensive areas, such as townships, often have a strong reliance on groundwater and surface water via bores and river offtakes. Figure 26 shows the location of human-modified land uses around a natural wetland conceptually, including dryland cropping, grazing, irrigated agriculture and mining.

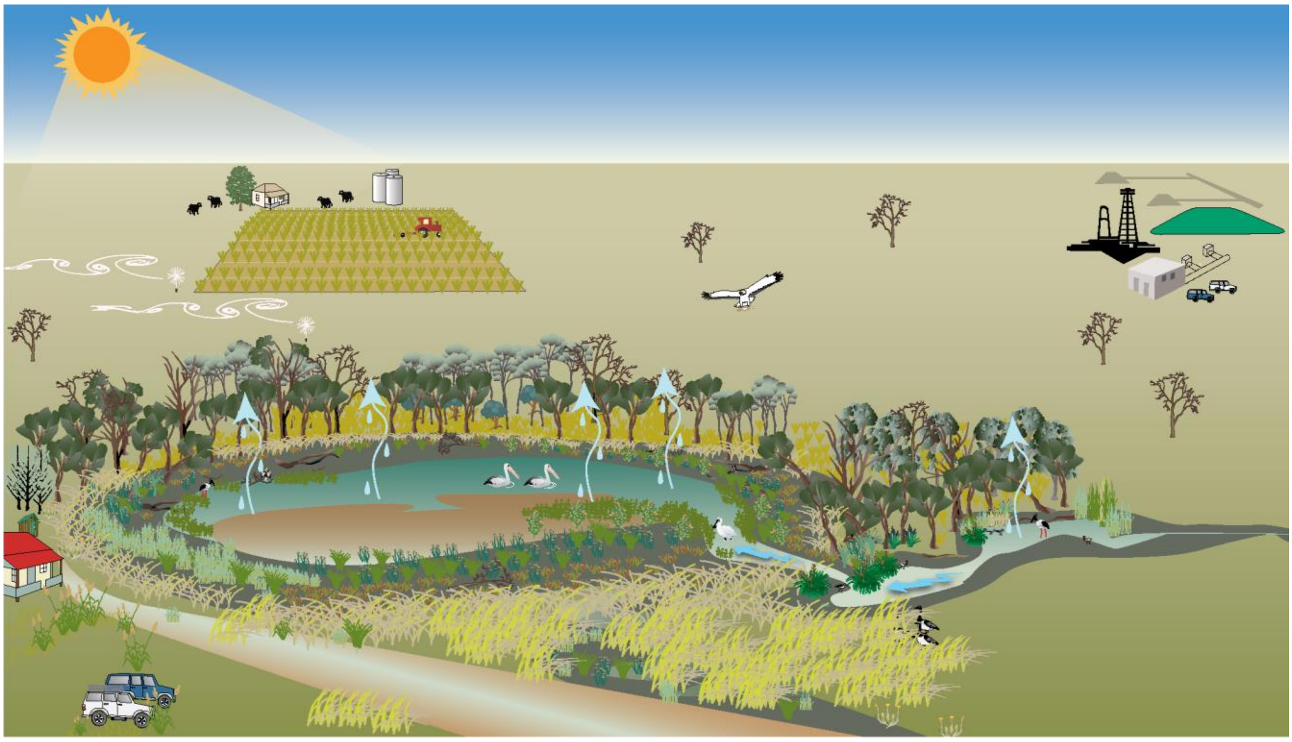

Figure 26 Pictorial conceptual model of a human-modified landscape including different land uses such as dryland cropping and mining

Source: Adapted from DEHP (2012)

2.3.3.2 Gaps

At the time of writing this product, Queensland GDE mapping data for the Dawson river basin was not available for the northern part of the PAE. The relevant GDE data, the landscape classification and associated receptor register will be updated and revised datasets will be registered and incorporated in subsequent products for the bioregional assessment (e.g. those associated with Component 3: Impact analysis).

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2.3.4 Baseline and coal resource development pathway

Summary

The Maranoa-Balonne-Condamine subregion coal resource development pathway (CRDP) includes five baseline coal resource development (baseline) open-cut coal mines, five baseline coal seam gas (CSG) developments and two open-cut coal mine project proposals. The five baseline coal mines are: Cameby Downs Mine, Commodore Mine, Kogan Creek Mine, New Acland Stage 2 Mine and Wilkie Creek Mine (which ceased operations in December 2013). The two proposed coal mines in the coal resource development pathway (CRDP) are: New Acland Coal Mine Stage 3 and The Range. The five CSG developments included in the baseline are: Australia Pacific LNG Project, Santos Gladstone LNG Project, Queensland Curtis LNG Project, Surat Gas Project and Ironbark Project. No other CSG project proposals are considered sufficiently mature to warrant inclusion in the CRDP.

Strategies for managing the affected water from the open-cut mining operations in the subregion typically include water treatment for discharge off-site and use in mine-related activities such as dust suppression and coal washing. With respect to CSG, the Queensland Government has developed the *Coal Seam Gas Water Management Policy* (DEHP, 2012), which aims to strategically manage co-produced water by prioritising its beneficial use by new and existing users as well as water-dependent industries. The strategy further proposes treatment and disposal of co-produced water in a way that firstly avoids, and then minimises and mitigates on environmental values. Reverse osmosis (RO) is the preferred water treatment technology of the four major CSG operators (Arrow Energy Pty Ltd, Origin Energy Limited, QGC Pty Limited and Santos Ltd).

2.3.4.1 Developing the coal resource development pathway

The coal resource development pathway (CRDP) is informed by companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014) and based on the judgment of the Assessment team. The Assessment team used all publicly available evidence and followed the approach outlined in companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014) to evaluate the potential for each coal resource development to proceed to future commercial production. The CRDP is based on information available as of July 2015 and was finalised after feedback provided at the CRDP workshop that was held in December 2014 in Toowoomba. Representatives from the Commonwealth Office of Water Science, state government departments and agencies, regional councils, and industry attended the workshop.

In bioregional assessments (BA) the CRDP includes all baseline plus any additional coal resource developments (ACRD) continuing into the future. The baseline is defined as a future that includes all coal mines and CSG fields that are commercially producing as of December 2012. The ACRD is defined as all coal mines and coal seam gas (CSG) fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012. However, to ensure consistency with the groundwater modelling approach for the subregion, the definition of baseline includes all CSG developments in the Maranoa-Balonne-Condamine subregion that are reported in the 2014 Annual Report for the Surat cumulative management area (OGIA, 2014), which was prepared using the Office of Groundwater Impact Assessment (OGIA) numerical groundwater model (QWC, 2012). Groundwater modelling for the Maranoa-Balonne-Condamine subregion is described in more detail in companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (Janardhanan et al., 2016).

Five baseline coal mines, five baseline CSG fields and two coal mine project proposals are included in the CRDP for the Maranoa-Balonne-Condamine subregion. The location of each coal resource development in the Maranoa-Balonne-Condamine subregion is shown in Figure 27. Table 11 summarises baseline and additional coal resource developments included in the CRDP for the Maranoa-Balonne-Condamine subregion.

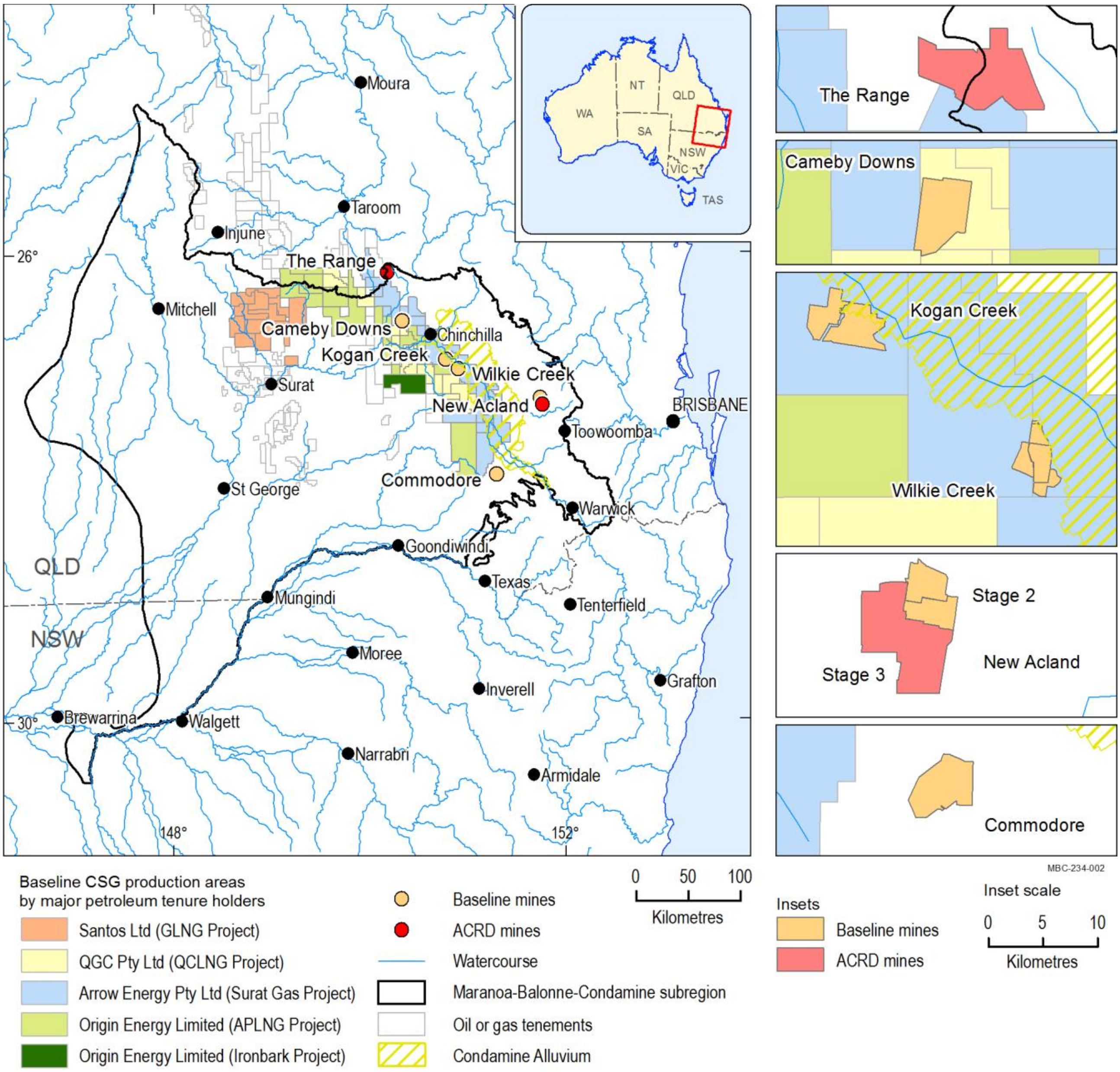

Figure 27 Baseline and additional coal resource developments included in the coal resource development pathway in the Maranoa-Balonne-Condamine subregion

Some of the coal seam gas (CSG) tenures are located outside the subregion, but are included in the coal resource development pathway (CRDP) as they contain gas fields located partially within the subregion boundaries.

All petroleum tenures shown are part of the baseline.

The maximum extent of the coal resource developments in CRDP is equal to the union of extents for baseline and additional coal resource development (ACRD). The mines in the CRDP are the sum of those in the baseline and in the ACRD.

Data: Bioregional Assessment Programme (Dataset 1), Department of Natural Resources and Mines (Dataset 2)

Table 11 Summary of baseline and additional coal resource developments (ACRD) included in the coal resource development pathway. The existing operations and proposed developments in the coal resource development pathway (CRDP) are the sum of those in the baseline and the ACRD

The primary activity in bioregional assessments (BAs) is the comparison of two potential futures: (i) *the baseline coal resource development (baseline)*, a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012; and (ii) *the coal resource development pathway (CRDP)*, a future that includes all coal mines and CSG fields that are in the baseline as well as those that are expected to begin commercial production after December 2012. The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development (ACRD) – all coal mines and CSG fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012.

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Cameby Downs Mine	Open-cut coal mine	Owned and operated by Syntech Resources Pty Ltd, managed by Yancoal Australia Ltd	Yes – model	Yes – model	2010	Expected mine life: 45 years	ML 50233	688 Mt	Operating mine
Commodore Mine	Open-cut coal mine	Majority owned by InterGen Australia Pty Ltd and Marubeni Corporation, mining services provided by Downer EDI Limited	Yes – model	Yes – model	2002	Expected mine life: 30 years	ML 50151	177 Mt	Operating mine

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Kogan Creek Mine	Open-cut coal mine	Abadare Collieries Pty Ltd (subsidiary of CS Energy Ltd)	Yes – model	Yes – model	2007	Contracted operation until 2018	ML 50074	400 Mt	Operating mine. Life of mine unclear, operated by Golding Contractors
New Acland Coal Mine Stage 2	Open-cut coal mine	New Hope Group	Yes – model	Yes – model	2002	Reserves to be depleted by 2017	ML 50170, ML 50216	64 Mt product coal	Operating mine
Wilkie Creek Mine	Open-cut coal mine	Peabody Energy Inc.	Yes – model	Yes – model	1994	2013	ML 5908, ML 50208, ML 50214, ML 50215, ML 50276, ML 55004	NA	Mine operational 1994–2003, but mine has since been sold (as of July 2015). The transaction is expected to be finalised in the third quarter of 2015. This could indicate that the mine may be re-opened and expanded at some point in the future.

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
New Acland Coal Mine Stage 3	Open-cut coal mine (5,069 ha lease area, including 957 ha of proposed pits)	New Hope Group	No	Yes – model	Construction start: 2015	Production: 2017–2029 (12 years)	ML 50170, ML 50216	441 Mt	• EIS approved • note further EIS information has become available since companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014) was written (see DSD, 2014) • operating life planned to approx 2029. Plans available for progressing mining are noted in companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014).
The Range	Open-cut coal mine (5,226 ha lease area, including 1,845 ha of proposed pits)	Stanmore Coal Limited	No	Yes – model	Construction start: 2014; production start: 2016	Mine life: 26 years	MLA 55001	287 Mt (approximately 157 Mt of ROM coal is proposed to be extracted)	• EIS approved by Queensland Government (Stanmore Coal, 2013), waiting for Commonwealth approvals (Stanmore Coal, 2015)

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Australia Pacific LNG Project	Coal seam gas wells (6,100 km^2 area with 6,500 wells at 800 m (minimum) spacing)	Australia Pacific LNG Pty Limited	Yes – model	Yes – model	Construction start: 2011	30 years; forecast end: 2035	PL 209, PL 215, PL 226, PL 265, PL 266, PL 267, 272, 297, PL 404, PL 408; ATP 606, ATP 663, ATP 692, ATP 972, ATP 973	9846 PJ (as of 31 December 2014)	• gas fields in production • included in the OGIA numerical groundwater model • gas supply for two LNG trains with a capacity of 4.5 Mt/y each • project construction more than 90% complete (as of 31 March 2015) • first gas delivered to Curtis Island in February 2015 • first LNG delivery scheduled for mid-2015.
Santos Gladstone LNG Project + GLNG Gas Field Development) Project	Coal seam gas wells (64,140 ha area with up to 600 wells)	Santos GLNG Pty Ltd	Yes – model	Yes – model	Construction start: 2011	Well life: 5–15 years; project life: 30 years; forecast end: 2045	PL 3, PL 6, PL 7, PL 8, PL 9, PL 13, PL 93, PL 309, PL 310, PL 314, PL 315, PL 10, PL 11; ATP 336, ATP 631	3,041 PJ (as of 31 December 2014)	• gas fields in production, including extension to approved GLNG Project within already approved and additional tenements • included in the OGIA numerical groundwater model • gas supply for two LNG trains with a combined capacity of 7.8 Mt/y • construction of project about 95% complete (as of 30 June 2015) • first LNG production expected end of third quarter 2015.

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Queensland Curtis LNG Project	Coal seam gas wells	QGC Pty Limited (BG Group)	Yes – model	Yes – model	Construction start: 2010; first gas to Curtis Island: 2013	Well life: 15–20 years; project life: 20–50 years	PL 179, PL 180, PL 201, PL 211, PL 212, PL 228, PL 229, PL 247, PL 257, PL 262, PL 273, PL 274, PL 275, PL 276, PL 277, PL 278, PL 279, PL 442, PL 443, PL 474, PL 458, PL 459, PL 461, PL 466, PL 472; ATP 574, ATP 621, ATP 632, ATP 648	10,067 PJ (as of 31 December 2014)	• gas fields in production • included in the OGIA numerical groundwater model • gas supply for two LNG trains with a combined capacity of 8.5 Mt/y • first gas for LNG production delivered December 2013 • first train commenced LNG production December 2014, second train in May 2015 • LNG plateau production anticipated by mid-2016.

Name of existing operation or proposed development	Coal mine or coal seam gas (CSG) operation	Company	Included in baseline?	Included in CRDP?	Start of mining operations or estimated project start	Projected mine life or estimated project life	Tenement(s)	Total coal resources (Mt)[a] (for coal mines) or 2P[b] gas reserves (for CSG) (PJ)	Comments
Surat Gas Project	Coal seam gas wells	Arrow Energy Pty Ltd	Yes – model	Yes – model	2014	Well life: 15–20 years; project life; 35 years	PL 194, PL 198, PL 230, PL 238, PL 252, PL 258, PL 260; ATP 676, ATP 683, ATP 746, ATP 474, ATP 747, ATP 810	7,490 PJ (as of 31 December 2014)	• gas fields in production • included in the OGIA numerical groundwater model • no financial commitment as of July 2015 • Arrow Energy looking at multiple opportunities, including collaboration with one or more of the existing LNG projects, to develop its gas resource • likely markets are the three other CSG to LNG projects currently under construction.
Ironbark Project	Coal seam gas wells	Origin Energy Limited	Yes – model	Yes – model	2016	Up to 40 years	ATP 788	259 PJ (as of 31 December 2014)	• included in the OGIA numerical groundwater model • EIS in preparation • project currently consists of a number of pilot production, appraisal and monitoring wells to evaluate the gas resource.

[a] Indicates the different resource classes that may combine to form the total resource tonnage – typically these are reported in accordance with the Joint Ore Reserves Committee (JORC) Code. For example, the different JORC resource classes of measured, indicated and inferred resources could be shown (or whichever combination of resource classes is applicable for each project).

[b] Proved plus probable reserves

ROM = run-of-mine, OGIA = Office of Groundwater Impact Assessment, LNG = liquified natural gas, ATP = authority to prospect, PL = petroleum lease, ML = mining lease, NA = not available

2.3.4.1.1 Baseline coal resource developments

Baseline coal mines

Five coal mines are included in the baseline in the Maranoa-Balonne-Condamine subregion, four of which are still in operation as of 16 July 2015. The operational mines are open-cut developments and include the Cameby Downs Mine, Commodore Mine, Kogan Creek Mine and New Acland Coal Mine Stage 2. Additionally, there is one open-cut mine, Wilkie Creek Mine, which ceased operation in December 2013.

All five mines are located in the eastern part of the Maranoa-Balonne-Condamine subregion (Figure 27). The Commodore Mine and New Acland Stage 2 Coal Mine extract coal from the Walloon Coal Measures of the Clarence-Moreton Basin, whereas the Cameby Downs, Kogan Creek, and Wilkie Creek mines target seams of the Walloon Coal Measures in the Surat Basin. The mines were described in detail in companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014) and key details are summarised in Table 11. This section provides a brief summary of this information.

Cameby Downs Mine

The Cameby Downs Mine is currently owned and operated by Syntech Resources Pty Ltd and managed by Yancoal Australia Ltd. The mine commenced coal production in 2010 (Yancoal, 2015). The capacity of the project’s Stage 1 is limited by environmental approvals to up to 2.3 Mt/year of run-of-mine (ROM) coal (Yancoal, 2015) extracted from the Juandah Coal Measures, which translates to about 1.8 Mt/year of thermal coal (Yancoal, 2015). Resources at the mine comprise 208 Mt measured, 247 Mt indicated and 233 Mt inferred and proved plus probable (2P) reserves of 440 Mt (proved 189 Mt and probable 251 Mt). On-site facilities at the mine include coal handling and preparation plants.

Commodore Mine

The Commodore Mine is an open-cut mine majority owned by InterGen Australia Pty Ltd and Marubeni Corporation with Downer EDI Limited providing mining services. The mine commenced production in 2002 supplying about 3.5 Mt/year of raw coal to the Millmerran power station (Weeden et al., 2007, InterGen, 2015). The coal is extracted from the Kooroongarra, Commodore and Bottom Rider seams of the Walloon Coal Measures. Overburden and waste from mining activities are stored to later backfill pits and develop the final landform, with progressive rehabilitation already underway (InterGen, 2015).

Kogan Creek Mine

Kogan Creek Mine is an open-cut mine owned by Aberdare Collieries Pty Ltd, a subsidiary of CS Energy Ltd which is owned by the Queensland Government. The total coal resource (measured and indicated) reported at the mine is 400 Mt (CS Energy, 2013). Production commenced in 2007 at a rate of 2.8 Mt/year of thermal ROM coal extracted from the M, N, and O seams of the Juandah Coal Measures. The voids resulting from the open-cut mining operations are backfilled using spoil dumps in preparation for land rehabilitation (CS Energy, 2013).

New Acland Coal Mine Stage 2

The New Acland Coal Mine Stage 2 is currently operated by New Hope Group. The project's Stage 2 consists of a 64 Mt coal resource within the Acland-Sabine, Waipanna, and Balgowan sequences of the Walloon Coal Measures (EPA, 2006). Mining commenced in 2002 and was estimated to occur at a rate of 4 Mt/year of product coal for a ROM coal production rate of up to 7.5 Mt/year with reserves being forecasted to be depleted by 2017 (Queensland Government EPA, 2006). However, product coal production has been quoted to be about 5 Mt/year by New Hope Group (New Hope Group, 2012a, 2014a).

Approximately 10% of the New Acland mining lease area is mined at any one time, while agricultural activities continue on remaining land. Land rehabilitation is ongoing to ensure the land is returned to a commercially viable agricultural state (EPA, 2006; New Hope Group, 2013). On-site facilities include two coal handling and preparation plants.

Wilkie Creek Mine

The Wilkie Creek Mine commenced coal mining operations in 1994 and was acquired by Peabody Energy Inc. (Peabody Energy) in 2002 (MiningLink, 2015). The mine produced approximately 2.3 Mt/year of thermal coal from the Tarcoola, Braemar, and Kogan coal seams (MiningLink, 2015). Areas that were disturbed during coal mining were progressively rehabilitated after they had been mined out (MiningLink, 2015).

In 2009, Peabody Energy announced plans for the Wilkie Creek Expansion Project, which involved coal mining in new areas of the lease and thus an extension of the life of the mine (WDRC, 2011a). This project, however, did not eventuate and in December 2013 the mine ceased coal production (Peabody Energy, 2013). As of July 2015 the Wilkie Creek Mine has been sold to Exergen Pty Ltd with the deal expected to be closed in the third quarter of 2015 (MiningLink, 2015).

Baseline coal seam gas developments

Based on the OGIA numerical groundwater model (see Section 2.3.4.1), CSG operations included in the baseline are predominantly the large-scale gas field developments supporting the three liquefied natural gas (LNG) projects on Curtis Island near Gladstone: Australia Pacific LNG (APLNG) Project, Queensland Curtis LNG (QCLNG) Project and Santos Gladstone LNG (GLNG) Project in combination with the Santos GLNG Gas Field Development Project. In addition, the Surat Gas Project, whose gas resource may be developed to support the other LNG projects, as well as the smaller-scale Ironbark Project, are part of the baseline. The footprint of the baseline gas field developments in the subregion is indicated in Figure 27.

Since gas field development is a progressive process, the tenements presented in Figure 27 will not all be developed and produced at the same time, but the process will occur in stages. Some of the tenements contain producing gas fields, some of which have been in production since before construction of the LNG projects commenced (such as the Talinga, Berwyndale, Kenya, Argyle, Kogan, Tipton and Daandine gas fields (for details see companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014)), some tenements have pilot testing, some have appraisal activity and some have exploration activities. The timing of gas field commencement and cessation used in the groundwater model follows that used in the 2014 annual report for the OGIA numerical groundwater model, which is described in more detail in companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (Janardhanan et al., 2016).

The baseline CSG developments are described in detail in companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014). This section provides a brief summary of that information with key details summarised in Table 11. However, as the projects progress, specific details and figures quoted are likely to be subject to change as current understanding and conditions evolve.

Australia Pacific LNG Project

Australia Pacific LNG Pty Limited (APLNG) is a joint venture between Origin Energy Limited (37.5% ownership), ConocoPhillips Company (37.5%), and China Petroleum & Chemical Corporation (25%). The APLNG Project comprises the development of CSG fields, the gas from which is to be transported to Curtis Island via a newly constructed pipeline to be processed for export (Origin Energy, 2013). Two LNG trains are being built on Curtis Island (Origin Energy, 2013) with capacities of 4.5 Mt/year each. Two additional trains are proposed to be built later in the project which would bring the total capacity to 18 Mt/year (APLNG, 2010). Construction of the APLNG Project was reported to be more than 90% complete by 31 March 2015 (Origin Energy, 2015). The project is expected to run for 30 years and will include the development of up to 10,000 CSG wells (to service four LNG trains; 5,000 wells are needed for the first two LNG trains) at a rate of up to 600 wells per year (APLNG, 2010). The gas for the project (11.5 Mt/year to supply two LNG trains) is to be mostly supplied by further developing APLNG's gas fields, with the remainder being sourced from APLNG's existing operations (outside the Walloon gas fields), exploration areas and equity in tenures operated by other gas producers (APLNG, 2010). Construction of the gas fields commenced in 2011 and the first gas was delivered to Curtis Island in February 2015 (Origin Energy, 2015). During Phase 1, which covers the initial five years of the project, a total of 1100 production wells are expected to be drilled (Origin Energy, 2013). By March 2015, 1069 development wells (including 121 wells at Spring Gully in the Bowen Basin, outside the Maranoa-Balonne-Condamine subregion) had been drilled to serve the APLNG Project.

Santos Gladstone LNG and Santos Gladstone LNG Gas Field Development projects

The GLNG Project is a joint venture between Santos Ltd (Santos) (30%), Petroliam Nasional Berhad (27.5%), TOTAL S.A. (27.5%) and Korea Gas Corporation (15%) with Santos acting as operator (Santos, 2015a). The project includes the development of CSG resources in the Bowen and Surat basins in south-east Queensland, construction of an underground gas pipeline to Gladstone and two LNG trains with a total capacity of 7.8 Mt/year on Curtis Island. The nominal project life is 30 years, though the project may remain operational beyond that point. Construction of the project is about 95% complete (as of 30 June 2015, Santos, 2015b) and the first LNG production was shipped on schedule in October 2015. For the Santos GLNG Project, Santos' existing CSG fields at Fairview and Roma are being further developed, while the Arcadia Valley gas field is a new development (Santos, 2009). Only the Roma gas fields are located in the Maranoa-Balonne-Condamine subregion.

A total of 2650 wells are planned for the Santos GLNG Project. An additional 6100 wells are estimated as part of the Santos GLNG Gas Field Development Project, a continuation of the Santos GLNG Project. This means up to 8750 wells will be drilled at Roma, Fairview, and Arcadia. By 30 June 2015, 478 CSG wells were online of which 120 are located at Roma (Santos, 2015b). The producing life of a well is estimated to be 5 to 15 years, so that wells will be replaced over time with new wells drilled in different locations to continue sufficient supply of CSG. The schedule of well development will be dictated by field performance and the drilling programme will be adjusted accordingly. The specific locations of exploration and development wells and associated infrastructure are determined incrementally based on the outcome of ongoing exploration programmes (Santos, 2009).

Queensland Curtis LNG Project

The QCLNG Project is owned and operated by QGC Pty Limited (QGC) and involves expansion of QGC's existing CSG operations and development of new gas fields in the Surat Basin in southern Queensland. The gas is transported via an underground pipeline to Curtis Island where it is converted to LNG for export (QGC, 2009). The LNG facility comprises two trains which are designed to produce a combined 8.5 Mt/year of LNG (QG, 2009). In order to meet this demand, 1414 TJ/day of gas are required (707 TJ/day per train). Construction of the QCLNG Project commenced in 2010 (QGC, 2012). The first gas for LNG production was delivered to Curtis Island in December 2013 (Hough, 2013); LNG production commenced in December 2014 from the first train, while the second LNG train began commercial operation in May 2015 (Kovacs, 2015). By July 2015, more than 1.5 Mt of LNG had already been shipped with LNG plateau production anticipated by mid-2016 (Kovacs, 2015). Although the minimum project life is expected to be 20 years, the approval conditions allow development over a 50-year period up to 2060 (QGC, 2013). Development of the gas fields is set to occur as a continuous process with some development occurring simultaneously. It is estimated that 6000 CSG production wells are to be drilled over the life of the project, with individual well life estimated to range from 15 to 20 years or longer. By mid-2014 more than 2350 wells had been drilled for the QCLNG Project (GasFields Commission Queensland, 2015). The remaining wells will be phased in over the life of the project to supplement declining wells (QGC, 2009); starting in 2015, 300 wells a year are forecasted to be drilled to keep production levels steady (GasFields Commission Queensland, 2015). Approximately 5000 wells are expected to be in production at any one stage (QGC, 2013).

Surat Gas Project

The Surat Gas Project is owned and operated by Arrow Energy Pty Ltd (Arrow Energy). The project includes expansion of production at Arrow Energy's existing CSG fields Stratheden, Kogan North, Daandine and Tipton West and development of other Arrow Energy tenures in the Surat Basin. To optimise production over the life of the project, development of the resources will be staged and will be concurrent in several areas as Arrow Energy incrementally expands its current operations and develops new gas fields (Arrow Energy, 2012). Sustained gas production is forecasted at 1215 TJ/day for which more than 1500 wells are estimated to be required in the first five years to achieve this (Arrow Energy, 2012). A maximum of 6500 wells are to be drilled throughout the project life (Department of the Environment, 2013), which is estimated to be 35 years. Well production rates are expected to be sustainable for about nine years before they start to decline;

the total well life is estimated to be between 15 and 20 years (Arrow Energy, 2012). New wells will continue to be drilled at an average rate of 400 per year (Arrow Energy, 2013a) to maintain the required production when the initial wells start to decline and are eventually phased out and replaced.

Ironbark Project

Origin Energy's Ironbark Project currently consists of a number of pilot CSG wells, appraisal wells and monitoring wells. The Duke 2 and Duke 3 pilots, which have five operating wells each, began production in July 2012 and May 2013 respectively and successfully completed pilot production by December 2014. Six wells have been drilled as part of a third production pilot, Duke 7 (Origin Energy, 2014, pers. comm.). The 2P reserves were 259 PJ as of 31 December 2014. An environmental impact statement (EIS) for the Ironbark Project is in preparation (as of July 2015). Though still in the pilot testing phase with no EIS having been submitted, the Ironbark Project is included in the baseline rather than the CRDP to be consistent with the OGIA numerical groundwater model used to predict groundwater interactions in the subregion and beyond (QWC, 2012; OGIA, 2014) (see companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (groundwater numerical modelling; Janardhanan et al., 2016).

2.3.4.1.2 Additional coal resource development

The decision over the inclusion of ACRD in the CRDP is informed by companion product 1.2 (*coal and coal seam gas resource assessment)* and based on the judgement of the Assessment team, which was guided by companion submethodology M04 (as listed in Table 1) for developing a coal resource development pathway (Lewis, 2014). The Assessment team utilised all publicly available evidence and, where possible, verified details and information with relevant companies to evaluate the potential for individual coal resource developments to proceed to future commercial production. Based on the research of the Assessment team, two coal mining project proposals are included in the CRDP for the Maranoa-Balonne-Condamine subregion: the New Acland Coal Mine Stage 3, which is an extension to the existing New Acland Coal Mine, and The Range, which is a new (greenfield) mine. The mines are planned as open-cut developments. These are the only two coal mine project proposals in the subregion for which EIS have been submitted and, in the case of the New Acland Coal Mine Stage 3, approved by the State. Table 12 gives the reasons for including or not including coal resource developments that were considered in companion product 1.2 for the Maranoa-Balonne-Condamine subregion (Sander et al., 2014) in the CRDP for the Maranoa-Balonne-Condamine subregion. Several potential projects are at the stage of early or preliminary exploration (i.e. Wandoan Coal Project, Dalby West), and some are at the stage of performing baseline or concept studies (i.e. Columboola Project, Cornwall, Tin Hut Creek). These projects are not included in the CRDP as their progression to commercial operation is too uncertain, particularly in light of falling commodity prices in the 2014–15 financial year. Other project proposals are less advanced in terms of their assessment, planning and regulatory approval status. Consequently, most of the identified coal resources listed in Table 12 are considered (on the basis of evidence available as of July 2015) to have low potential to progress to future commercial production and were not included in the CRDP. However, it is possible that some of these coal resources may be re-evaluated for future development.

There are no CSG project proposals for the Maranoa-Balonne-Condamine subregion, in addition to the baseline CSG developments, that are sufficiently advanced to warrant inclusion in the CRDP. To be included in the CRDP the project should have progressed from the initial exploration stage and be at least in the stage of demonstrating its producibility, for example, through pilot production. An initial advice statement should be available; anything prior to this is too speculative to be included in the CRDP in the light of currently fluctuating oil and gas prices. The Ironbark Project, which is not a commercial operation yet but is currently at pilot production stage with an EIS in preparation, has been included in the baseline to ensure consistency with the OGIA numerical groundwater model (QWC, 2012; OGIA, 2014).

Table 12 Coal resource developments considered for inclusion in the coal resource development pathway (CRDP)

Coal resource development	Company	Included in CRDP?	Reasons for including or not including in CRDP
New Acland Coal Mine Stage 3	New Acland Coal Pty Ltd	Yes – modelled	The New Acland Coal Mine Stage 3 has been proposed by the New Hope Group as an expansion of the existing New Acland open-cut mine. The environmental impact statement was first submitted in 2014 with additional information provided in August 2014 (DSD, 2014) and approval granted in December 2014. The project is to start construction in 2015 with progressive pit development from 2017 to 2029 generally from north to south across each of the three new pits (Manning Vale West, Manning Vale East and Willeroo) (New Hope Group, 2014b). The Stage 3 project involves the extension and operation of the existing New Acland Coal Mine to increase production from 4.8 –7.5 Mt/y of thermal coal (New Hope Group, 2012b, 2014b). The pits will be progressively backfilled using spoil dumps (New Hope Group, 2014b).
The Range	Stanmore Coal Limited	Yes – modelled	Stanmore Coal Limited has proposed a new open-cut coal mine, The Range, which is to extract coal from the Pelham Seam within the Taroom Coal Measures that occurs through much of The Range area (WDRC, 2011b). The EIS was approved by the Queensland Government in February 2013 and is now being progressed through Commonwealth approvals (Stanmore Coal, 2013, 2015). Construction was to begin in 2014 and production is to begin in 2016 continuing for a period of 26 years (Stanmore Coal, 2012). The mine is expected to produce 6–6.7 Mt/y of ROM coal for an average product coal of 5 Mt/y with the potential for up to 7 Mt/y; a total of 157 Mt of coal is forecasted to be produced (DEHP, 2013). The project consists of three open-cut pits (two of them being developed initially with the third being developed in the final years) and requires clearing of approximately 187.22 ha (DEHP, 2013). Approximately 8 million cubic metres of topsoil will be removed during the life of the project which will be used for progressive rehabilitation.

Coal resource development	Company	Included in CRDP?	Reasons for including or not including in CRDP
Western Surat Gas Project	Senex Energy Limited	No	A project proposal of significant size is Senex Energy Limited's Western Surat Gas Project, which includes Senex Energy's Don Juan tenements (ATP 593P and ATP 771P) and three additional permits (ATP 767, ATP 795, ATP 889) (Senex Energy, 2015a). The proposal includes the drilling of up to 1000 wells over a period of approximately 30 years for a targeted production throughput rate of 35 TJ/day (Senex Energy, 2015b). Senex Energy expects to commence pilot production no later than the end of 2017 with early appraisal results to inform the larger scale investment decision. An EIS is expected to be submitted in mid-2016 (Senex Energy, 2015c). As the Western Surat Gas Project is currently only a proposed action in the early stages of planning and no pilot production has commenced and no IAS has been submitted, the project is not included in the CRDP.
ambreCTL Project ('Felton')	Ambre Energy Limited (Ambre Energy)	No	On basis of assessment of available evidence, continuation does not appear to be going ahead. There is no clear direction available from Ambre Energy Limited and no evidence of a current program via Queensland Government. No feedback was obtainable after phoning and emailing Ambre Energy. No further activity is indicated publicly. No EIS is evident. Queensland Government website states that Ambre Energy's previous project at the same site, 'Felton Mine and Dimethyl Ether Pilot Plant Project' was withdrawn on 15 March 2011 and replaced by the 'ambreCTL Project'. However no further information is listed by Queensland Government on ambreCTL Project. Local opposition for this project has been made public via Friends of Felton and media (DEHP, 2014a).
Back Creek	Allegiance Coal Limited	No	Allegiance Coal Limited has progressed to preparation of a mineral development license (MDL) application. However, the project is pre-EIS and thus not included in the CRDP (Allegiance Coal, 2011).
Bottle Tree	Cockatoo Coal Limited	No	The project's status is pre-EIS and it has only indicated and inferred resources, thus it is not included in the ACRD (Cockatoo Coal, 2015).
Bringalily	Blackwood Corporation Ltd	No	Any potential development proposals for the Bringalily coal deposit are pre-EIS and thus not included in the CRDP.
Bushranger (Coal)	Cockatoo Coal Limited	No	The project's status is pre-EIS and it has only indicated and inferred resources, thus it is not included in the CRDP (Cockatoo Coal, 2015).
Cameby Downs Expansion Project	Yancoal Australia Ltd	No	Queensland Government website states: '...on 8 October 2013, the proponent withdrew the referral for the project. Yancoal had until 31 March 2014 to submit the EIS to the department for assessment. However, the EIS was not submitted by that date. Consequently, the final Terms of Reference for the EIS have ceased to have effect (DEHP, 2014b).
Columboola Project	MetroCoal Limited and SinoCoal Resources Pty Ltd	No	MetroCoal Limited (N Villa, 2014, pers. comms.) confirmed that desktop studies and concept studies have commenced and are continuing. However, due to CSG activity considerations in the area this project will not be permitted to commence before 2023.
Cornwall	Aquila Resources Ltd	No	Aquila Resources (JHH, 2014, pers. comms.) confirmed that the project Cornwall status remains at pre-EIS but in July 2014 the mineral development licence (MDL) was granted and a conceptual study will be performed. However no EIS or further plans are reportable.
Dalby West	MetroCoal Limited	No	MetroCoal Limited (N Villa, 2014, pers. comms.) confirmed that only early exploration stages have commenced, but as the tenure is overlapped by CSG activity, coal mining will not be accessible for 15 years

Coal resource development	Company	Included in CRDP?	Reasons for including or not including in CRDP
Davies Road	Cockatoo Coal Limited	No	The project’s status is pre-EIS and it has only indicated and inferred resources, thus it is not included in the CRDP (Cockatoo Coal, 2015).
Glen Wilga	CS Energy Ltd	No	The project has measured coal resources, but is pre-EIS and thus not included in the CRDP (WDRC, 2014).
Haystack Road	CS Energy Ltd	No	The project’s status is pre-EIS and it has only indicated resources, thus it is not included in the CRDP (WDRC, 2014).
Horse Creek	Sekitan Resources Pty Ltd	No	In addition to their recent acquisition of the Wilkie Creek Mine (see Wilkie Creek Mine extension below) from Peabody Energy in 2015, Sekitan Resources Pty Ltd, a wholly owned subsidiary of Exergen Pty Ltd, acquired the mining lease for Horse Creek near Chinchilla (The Chronicle, 2015). However, the project is pre-EIS and thus not included in the CRDP.
Injune	Cockatoo Coal Limited	No	The project’s status is pre-EIS and thus it is not included in the CRDP.
Krugers	Cockatoo Coal Limited	No	The project’s status is pre-EIS and it has only indicated and inferred resources, thus it is not included in the CRDP (Cockatoo Coal, 2015).
Lochbar	NA	No	Any potential development proposals for the Lochbar coal deposit are pre-EIS and thus not included in the CRDP.
Ownaview	Cockatoo Coal Limited and Mitsui	No	The project’s status is pre-EIS and it has only inferred resources, thus it is not included in the CRDP (WDRC, 2014).
Pittsworth	NA	No	Any potential development proposals for the Pittsworth coal deposit are pre-EIS and thus not included in the CRDP.
Rywung	Yancoal Australia Ltd	No	The project has measured coal resources, but is pre-EIS and thus not included in the CRDP (WDRC, 2014).
Sefton Park	Yancoal Australia Ltd	No	The project has measured coal resources, but is pre-EIS and thus not included in the CRDP (WDRC, 2014).
Surat Coal (Carbon Energy)	Carbon Energy Limited	No	Underground coal gasification (UCG) project. UCG projects are out of scope and thus not included in the CRDP.
Tin Hut Creek	Cockatoo Coal Limited	No	Cockatoo Coal (R Punt, 2014, pers. comms.) advised that baseline studies have commenced, although this remains at pre-EIS status.
Wandoan Coal Project (MDL 420)	Moreton Resources Limited	No	Moreton Resources views the Wandoan Coal Project as a long-term strategic asset. Moreton Resources will seek to advance its understanding of the total potential of this asset in 2016 (Moreton Resources Limited, 2015).
Wilkie Creek Mine extension	Sekitan Resources Pty Ltd	No	The sale of the previously described Wilkie Creek Mine (current status: closed) in July 2015 to Sekitan Resources Pty Ltd, a wholly owned subsidiary of Exergen Pty Ltd, indicates ongoing commercial interest in this mine and a potential re-commencement of mining activities on the existing leases. However, in the absence of detailed plans or information and the deal not being finalised yet (expected in the third quarter of 2015), the Wilkie Creek Mine extension is not included in the CRDP.

ATP = authority to prospect, CRDP = coal resource development pathway, EIS = environmental impact statement, IAS = initial advice statement

Baseline and additional coal resource development timelines

The coal resource developments in the Maranoa-Balonne-Condamine subregion are forecast to be developed and operated over many years and even decades. To visualise this, a timeline was constructed using references presented earlier in this product (Figure 28). The timeline shows baseline and ACRD and highlights that many of the projects described in the subregion will be operational at the same time, emphasising the need for a model that captures the potential cumulative impacts.

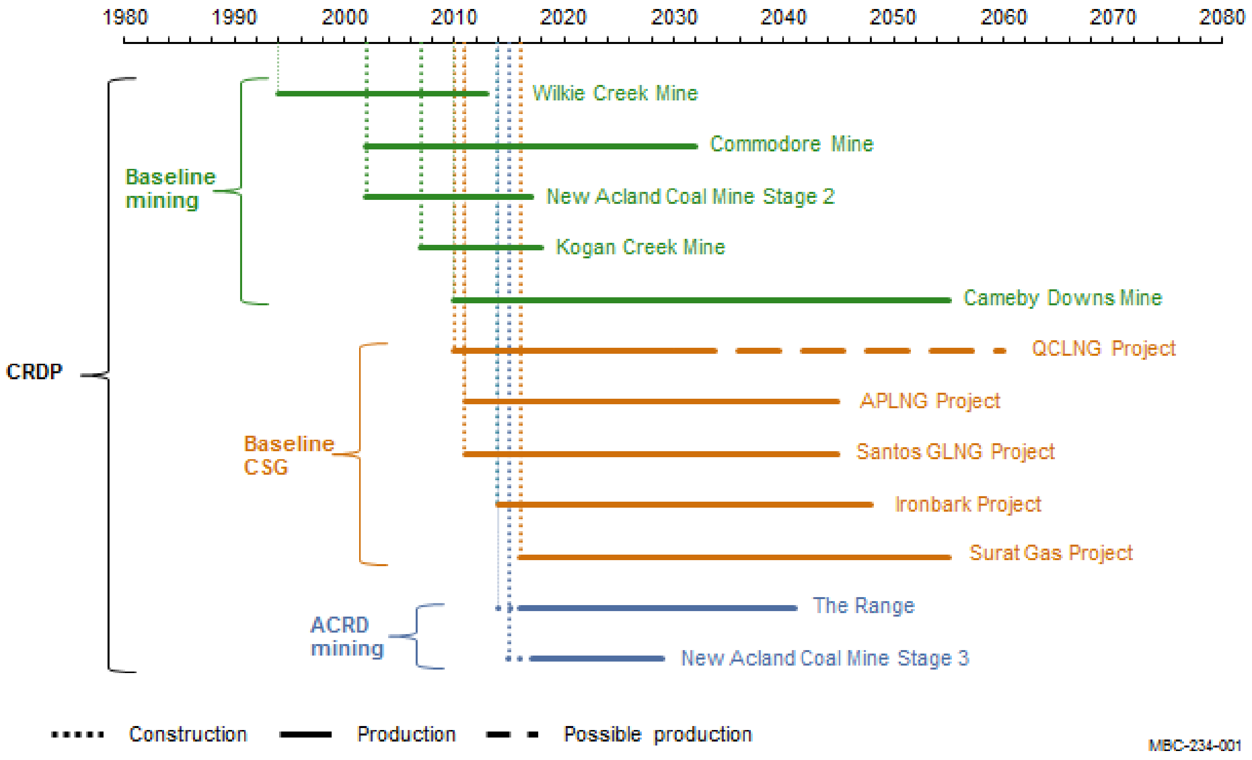

Figure 28 Timeline of coal resource developments in the baseline and additional coal resource developments in the Maranoa-Balonne-Condamine subregion constructed using publicly available information

For the baseline coal seam gas (CSG) projects, construction and production occurs concurrently due to the staged development process.
The coal resource developments in the CRDP are equal to the sum of those in the baseline and ACRD.
Baseline = baseline coal resource development, a future that includes all coal mines and coal seam gas (CSG) fields that were commercially producing under an operations plan approved as of December 2012. For the Maranoa-Balonne-Condamine subregion, however, 'baseline' includes all CSG developments in the subregion that are reported in the 2014 Annual Report for the Surat cumulative management area
CRDP = coal resource development pathway, a future that includes all coal mines and coal seam gas (CSG) fields that are in the baseline as well as those that are expected to begin commercial production after December 2012
ACRD = additional coal resource development, all coal mines and coal seam gas fields, including expansion of baseline operations, that are expected to begin commercial production after December 2012
APLNG Project = Australia Pacific LNG Project, LNG = Liquefied Natural Gas, QCLNG Project = Queensland Curtis LNG Project, Santos GLNG Project = Santos Gladstone LNG Project + GLNG Gas Field Development Project.

2.3.4.2 Water management for the coal resource developments

This section describes the water management strategies employed for the coal resource developments in the Maranoa-Balonne-Condamine subregion. The purpose of this description is to inform the 'Conceptual modelling of causal pathways' described in Section 2.3.5. For other BAs that undertake surface water numerical modelling, additional detail on water management strategies is provided in companion product 2.1-2.2 (observations analysis, statistical analysis and interpolation); this additional detail is required to develop the surface water numerical model. However, companion product 2.1-2.2 (observations analysis, statistical analysis and interpolation) is not required for the Maranoa-Balonne-Condamine subregion because the Assessment team did not develop a surface water numerical model. More detail about water management strategies used to develop the OGIA regional groundwater model is provided in GHD (2012), QWC (2012) and WaterMark Numerical Computing (2012).

The management of co-produced CSG water and mine-affected water is addressed under Queensland’s *Environmental Protection Act 1994* (DEHP, 2012). The impacts of the extraction of water during such operations on groundwater supplies are managed under Queensland’s *Water Act 2000* (DEHP, 2012).

Other legislation that controls the potential reuse of CSG co-produced or mine-affected water include Queensland’s *Water Supply (Safety and Reliability) Act 2008* (Water Supply Act) and Queensland’s *Waste Reduction and Recycling Act 2011* (DEHP, 2012).

2.3.4.2.1 Water management for coal mine developments

Different stages in the life of a mine, such as construction, production and rehabilitation, may affect water at the mine site and surrounding areas in different ways. As a result, water of varying quantity and quality is produced and managed accordingly. Water from upstream or unaffected areas is usually diverted around the mine site and released to natural watercourses. For this reason it is important to consider upstream ecological impacts. Runoff from the affected areas within a mine is typically sediment laden and contains other impurities. After a suitable treatment, this water is often used on site for various purposes such as for coal washing and dust suppression. Some of the affected waters are treated further to achieve the quality required by the relevant state environmental protection agency for release to natural watercourses. Water management strategies for all open-cut coal mines included in the CRDP are summarised in Table 13.

Table 13 Water management strategies for open-cut coal mines included in the coal resource development pathway in the Maranoa-Balonne-Condamine subregion

Development	Water sources	Water type	Comments
Cameby Downs Mine	Water demand	All	Estimated water demand is 1500 ML/y, which is used in the coal handling and preparation plant (CHPP) and for dust suppression in haul roads and stockpiles required (Psi-Delta, 2010). Preferred water sources, in order of preference, are mine-affected water, recycled process water, surface water runoff and make-up water from QGC's Glen Eden Pond (Yancoal, 2015).
	Mine-affected water	Other impurities	Managed to avoid discharge to receiving water. Supplied from pit dewatering (including groundwater inflows). Collected in dams and in-pit water storage. Recycled process water recovered from the CHPP and reject streams.
	Surface water runoff from disturbed sites	Sediment laden	Surface water runoff captured and stored within the mine water management system is used in CHPP and for dust suppression in haul road and stockpiles. If suitable, surface water runoff is released in receiving watercourses in accordance with the conditions of the environmental authority.
	External water supply	Clean	Cameby Downs Mine holds a beneficial use approval (BUA) to source up to 1460 ML/y of water from QGC's Glen Eden Pond to the Cameby Downs Mine for use in the CHPP or for dust suppression until 2029. Cameby Downs Mine also has an internal water reticulation system and sewage treatment plant.
	Surface water runoff from undisturbed sites	Clean	Surface water runoff is diverted around mining operation with up-catchment diversions banks, channels and flood levees. Columboola Creek is diverted around the open-cut extent of the lease area following the Australian Coal Association Research Program stream diversion design criteria (Hardie et al., 2002). Flood levees are planned with sufficient flood protection from Columboola Creek and an unnamed creek (Yancoal, 2015).
Commodore Mine	Water demand	All	Approximately 150 ML of water is required each year, which is primarily used for dust suppression at the site as the coal is not washed (Psi-Delta, 2010). No surface water or groundwater resources are accessed for mine water needs.
	Mine-affected water	Other impurities	To prevent dust emissions and spillage into the creek during conveyor transport to the nearby power station, the conveyors across creeks are fully enclosed (InterGen, 2014).
	Surface water runoff from disturbed sites	Sediment laden	Overland flow is collected and stored in sediment dams, which can be supplemented with recycled water.
	External water supply	Clean	If the overland flow is not sufficient in any one year, the mine also has access to recycled water via the nearby power station (Psi-Delta, 2010).
	Surface water runoff from undisturbed sites	Clean	No further information was found as of July 2015.

Development	Water sources	Water type	Comments
Kogan Creek Mine	Water demand	All	Water demand at the Kogan Creek Mine is about 180 ML/y, which is primarily used for dust suppression (Psi-Delta, 2010; WDRC, 2012) as the coal is not washed at this mine.
	Mine-affected water	Other impurities	No further information was found as of July 2015.
	Recycled process water	Other impurities	No further information was found as of July 2015.
	Surface water runoff from disturbed sites	Sediment laden	No further information was found as of July 2015.
	External water supply	Clean	The water supply is predominantly from groundwater bores, although overland flow is also captured (Psi-Delta, 2010).
	Surface water runoff from undisturbed sites	Clean	No further information was found as of July 2015.
New Acland Coal Mine Stage 2 and Stage 3	Water demand	All	Water demand at the New Acland Coal Mine Stage 2 is 1370 ML/y, which is used for coal washing and dust suppression (Psi-Delta, 2010). Estimated water usage for the New Acland Coal Mine Stage 3 is 3300 ML/y (New Hope Group, 2014b).
	Mine-affected water	Other impurities	Water is sourced from overland flow as part of the mine's zero discharge requirements in environmental dams that are used to capture water that collects in the mine pits and is used for dust suppression activities tailing dams. Water is collected in process water dams, which are used to supply process water to the CHPPs and aid in the management and segregation of clean and dirty water at the site.
	Surface water runoff from disturbed sites	Sediment laden	Surface water runoff from disturbed and mine-affected areas will be captured and treated in sediment and environmental dams before potential release off-site or use in mine-related activities (New Hope Group, 2014b). This water is used in mine-related activities, including dust suppression in haul road and stockpile. If suitable, it can be released as part of the controlled release strategy, which supports proactive management of water during periods of extended rainfall (New Hope Group, 2014b). The strategy was developed to minimise potential impacts on water quality, aquatic ecology and existing users downstream. The maximum release rate is based on the salinity of the released water and the flow in the receiving waters. Controlled releases are to be made to Lagoon Creek and the mine itself (New Hope Group, 2014b).

Development	Water sources	Water type	Comments
	External water supply	Clean	The Toowoomba Regional Council Wetella Wastewater Reclamation Facility (WWRF) (New Hope Group, 2014b) has a contracted supply of up to 5550 ML/y to the year 2055. The recycled water will be supplied via a 45 km pipeline that was constructed in 2009 (New Hope Group, 2014b). New Hope Group currently has a licensed groundwater capacity of up to 1412 ML/y (New Hope Group, 2014b), although water from groundwater bores is only intended to be used in emergencies (i.e. when there are problems with the recycled water supply). A small amount of additional water (up to 150 ML/y) may be sourced from the Oakey Reverse Osmosis Water treatment plant (New Hope Group, 2014b). Potable water will be sourced from aquifers via groundwater bores and treated on site by a reverse osmosis treatment plant (New Hope Group, 2014b).
	Surface water runoff from undisturbed sites	Clean	Surface water runoff from undisturbed areas will be diverted away and released directly into adjacent waterways (New Hope Group, 2014b).
Wilkie Creek Mine	Water demand	All	Water demand at the Wilkie Creek Mine was approximately 735 ML/y (Psi-Delta, 2010), which was used for coal washing and dust suppression (Psi-Delta, 2010). Additional water was sourced from pit dewatering and groundwater entitlements.
	Mine-affected water	Other impurities	As part of the zero discharge requirements, overland flow from the mine was captured and used to meet mine water needs.
	Surface water runoff from disturbed sites	Sediment laden	As part of the zero discharge requirements, overland flow from the mine was captured and used to meet mine water needs.
	External water supply	Clean	No further information was found as of July 2015.
	Surface water runoff from undisturbed sites	Clean	No further information was found as of July 2015.
The Range	Water demand	All	Water requirements of 1350 ML/y up to 2868 ML/y have been estimated for The Range coal mine (DEHP, 2013) which will predominantly be used for dust suppression and coal washing, though only about 40% of the produced run-of-mine (ROM) coal is expected to be washed (DEHP, 2013).
	Mine-affected water	Other impurities	Capture, storage and reuse of mine water (i.e. groundwater inflows and runoff water from disturbed areas, including un-rehabilitated waste rock dumps, the open-pit and mine infrastructure areas) for which four mine water dams are to be constructed progressively (staged over the life of the mine). A sediment control system, including sediment dams, to treat water diverted from rehabilitated waste rock dump areas prior to being released to the environment.
	Surface water runoff from disturbed sites	Sediment laden	As part of the zero discharge requirements, overland flow from the mine will be captured and used to meet mine water needs.

Development	Water sources	Water type	Comments
	External water supply	Clean	Water supply options considered include a branch pipeline from the proposed SunWater Nathan to Dalby pipeline; or from an off-take agreement with a coal seam gas producer (DEHP, 2013). The preferred option for the project was identified to be a connection to SunWater's proposed Wolleebee Creek to Glebe Weir pipeline. Water collected and stored at the mine site will also be used (DEHP, 2013). External water supply will be stored in a raw water dam.
	Surface water runoff from undisturbed sites	Clean	A network of drains and bunds to divert clean water around disturbance areas

2.3.4.2.2 Water management for coal seam gas developments

The management of co-produced water during CSG production is expected to require a number of approaches or solutions, which may vary throughout the life of the operation and across geographical areas. The Queensland Government implemented the *Coal Seam Gas Water Management Policy* (DEHP, 2012) to (i) articulate the government's position on the management and use of CSG water, (ii) guide the CSG operators in co-produced water management, and (iii) ensure community understanding about the preferred approaches for co-produced water management. It aims to encourage the beneficial use of CSG co-produced water in a way that protects the environment and maximises its productive use as a valuable resource. To achieve this objective, the policy proposes the following hierarchy in the management and use of co-produced water:

- Priority 1: CSG water is used for a purpose that is beneficial to one or more of the following:
  - the environment or new water users
  - existing or new water-dependent industries.
- Priority 2: after feasible beneficial use options have been considered, treating and disposing CSG water in a way that firstly avoids, and then minimises and mitigates impacts on environmental values.

According to the policy, the beneficial use may include injection into depleted aquifers, substitution for an existing entitlement, supplementary water for existing irrigation schemes, new irrigation use, livestock watering, urban and industrial water supplies, coal washing and dust suppression, and release to the environment in a manner that improves local environmental values (DEHP, 2012). In determining the most appropriate beneficial use the CSG operators should consider the options in the following order:

1. Consider the uses closest to the region of extraction
2. Provide water to existing water users in the region of extraction
3. Provide water to new water-dependent industries or users in the region of extraction.

The four major CSG operators in the Maranoa-Balonne-Condamine subregion have developed water management plans in accordance with Queensland Government's *Coal Seam Gas Water Management Policy* (DEHP, 2012). RO is the preferred water treatment method by all operators, which means that beneficial use or disposal of CSG co-produced water will be preceded by RO treatment.

In all but exceptional circumstances, evaporation dams, which were common practice in CSG water management in Queensland until 2010, will not be approved as an option for managing co-produced water (DEHP, 2012). Evaporation dams will only be considered as a reasonable water disposal option during exploration activities or production testing.

Water management strategies for each baseline CSG development in the Maranoa-Balonne-Condamine subregion are summarised in Table 14.

Table 14 Water management strategies for coal seam gas operations included in the coal resource development pathway in the Maranoa-Balonne-Condamine subregion

Project	Strategy	Description
Australia Pacific LNG (APLNG) Project	Overall	The Australia Pacific LNG (APLNG) Project EIS identified 80 water management options (APLNG, 2011a, 2011b, 2011c) that were grouped into six broad categories. Forecast peak water production volume from the combined Talinga and Condabri development areas is 48 ML/day, with peak production occurring in the first two years (APLNG, 2014). This water will be managed in an integrated manner and supplied via a water distribution pipeline along Fairymeadow Road near Miles. Treated water will be used for irrigation of commercial crops and for project activities (construction, potable water supplies and emergency supply for industrial users (APLNG, 2014). This includes a total contracted supply of 43 ML/day with a total dedicated storage of 5105 ML.
	Existing	Identified options include evaporation ponds and stream discharge. A contingent release to the Condamine River is planned with the mean predicted river release volume of 3 ML/day over 24 days in the initial years (APLNG, 2014). The contingent release will occur mainly in the high rainfall years and the release will be made to flowing river conditions (i.e. releases during no flow or low-flow conditions are expected to be infrequent). In the event of an emergency situation, contingent release of treated water to the Condamine River will also be considered (APLNG, 2014).
	Industrial supply	Supply of treated/untreated water to industry, including proposed and existing mines and power stations
	Potable water supply	Supply of treated water to townships such as Dalby, Miles, Chinchilla and Condamine via existing distribution networks
	Agricultural supply	Supply of treated CSG water to landholders and agriculture ventures owned and operated by APLNG in the region
	Reinjection	Different reinjection options have been explored guided by government legislation and APLNG’s sustainability principles. Feasibility studies at the Spring Gully (outside the Maranoa-Balonne-Condamine subregion), Talinga, Condabri and Combabula gas fields have assessed the technical and economic viability of aquifer injection to offset the impacts of groundwater depressurisation in the Precipice and Hutton Sandstone (APLNG, 2012).
	Other	Innovative technologies such as solar ponds and algae production, and large-scale options such as construction water and ocean disposal.

Project	Strategy	Description
Santos Gladstone LNG (GLNG) Project and Santos Gladstone LNG Gas Field Development projects	Overall	CSG water management options considered by Santos for the Santos GLNG Project (Santos, 2013) include beneficial uses, such as injection, irrigation, and dust suppression, and disposal options, such as release to rivers. Forecast peak production for the Santos GLNG Project life is 48 ML/day (Santos, 2013). The produced water will be managed in an integrated manner. The management options considered by Santos comprise injection, beneficial use (irrigation, dust suppression) and discharge to surface waters.
	Existing	Release of treated CSG water into Dawson River is planned at the Fairview gas field. The Dawson River release scheme aims to restore part of the pre-development baseflows in the river system between the discharge location and Glebe Weir (Santos, 2013).
	Industrial supply	Minor use for dust suppression is planned at all the fields.
	Agricultural supply	Irrigation projects are planned for beneficial use of produced water from the Roma, Fairview and Arcadia Valley gas fields at the Mount Hope and Fairview Irrigation Projects (Santos, 2013). The Fairview gas field is outside the Maranoa-Balonne-Condamine subregion. The Mount Hope Irrigation Project is a partnership between Santos and a private landholder and will irrigate 130 ha of forage crops. The Fairview Irrigation Project will irrigate forage crops and locally adapted native tree species.
	Reinjection	Injection into the Gubberamunda Sandstone has been found to be feasible at the Roma field, but infeasible at the Fairview site. Santos plans to inject 9–20 ML/day in the initial years of production from the Roma gas field (Santos, 2013). Reinjection from the Fairview gas field was not ecologically feasible as it would cause ephemeral catchments to become permanently flowing systems. Early results from the Arcadia Valley field (outside the Maranoa-Balonne-Condamine subregion) indicated that the aquifers are not suitable for injection (Santos, 2013).
Queensland Curtis LNG (QCLNG) Project	Overall	The QCLNG Project will use the Chinchilla and Dawson Valley beneficial use schemes to manage CSG water (QGC, 2014). The Chinchilla Beneficial Use Scheme will pump water from the Southern and Central gas fields to two water treatment plants (Windibri and Kenya Water Treatment Plants) from where the treated water will be transported via a 20 km pipeline to Chinchilla Weir. Similarly, the Dawson Valley Beneficial Use Scheme will pump water from the Northern Gas Fields to the Northern Water Treatment Plant from where the treated water will be transported via a 120 km pipeline from Woleebee Creek to Glebe Weir for distribution to customers along the pipeline route. The QGC Water Management Plan envisages 97% of the treated CSG produced water to become available for beneficial use. Beneficial use of up to 185 ML/day would be achieved through two schemes proposed by QGC.

Project	Strategy	Description
	Agriculture, industry, and urban water supply	The Chinchilla Beneficial Use Scheme is authorised to supply up to 85 ML/day of treated water for irrigation and stock watering and to supplement town water supply. The Kenya Water Treatment Plant, which supplies the Chinchilla Beneficial Water Use Scheme, has a maximum treatment capacity of 112 ML/day, with 22 in-field storage ponds with capacity ranging from 104–5158 ML. The Dawson Valley Beneficial Use Scheme is authorised to supply up to 100 ML/day of water for agricultural, industry and urban water supply. The Northern Water Treatment Plant at Woleebee Creek is constructed to treat a peak flow rate of 72 ML/day, with two in-field storage ponds planned.
	Discharge to watercourse	The beneficial use schemes will discharge treated CSG water to watercourses (i.e. Condamine River and Dawson River).
Surat Gas Project	Overall	Arrow Energy seeks to maximise the beneficial use of CSG water, minimise the environmental impacts associated with CSG water use and disposal, and mitigate impacts of groundwater depressurisation. (Arrow Energy 2013b). The preferred management option for CSG water is beneficial use through substitution of existing groundwater allocations in the area for agricultural, industrial and urban use (Arrow Energy, 2013c).
	Agriculture	Substituting CSG water for current irrigation extraction under existing allocations, supply to new irrigation projects and other agricultural uses, including provisions for livestock watering Irrigation trials have been conducted at Theten, outside Dalby and further beneficial use applications are being considered in the Dalby Expansion Project area.
	Industrial	Power station cooling, coal washing, and use by Arrow Energy for construction and operational uses
	Domestic and urban	Potential supply of treated water to towns such as Moranbah and Dalby
	Injection	Injection feasibility studies were conducted in 2010 and deep injection trials are planned in the Dalby expansion project area. Injection trials in the Precipice Sandstone Aquifer and other shallow and deep aquifers in the Dalby Expansion Project area are planned. However, this is contingent on the finalisation of the regulatory framework for CSG water reinjection (Arrow Energy, 2013b).
	Discharge to watercourse	This is considered as a contingency measure when beneficial use options are not feasible.
	Ocean outfall	Disposal of CSG water to sea is also recognised as a possible option for some operational areas.
Ironbark Project	Overall	CSG water management options proposed for the Ironbark Project are beneficial use, reinjection and controlled discharge (Origin Energy, 2011). The transfer of untreated CSG produced water to treatment plants at adjoining APLNG tenures for treatment prior to beneficial use or controlled discharge is also being considered.

CSG = coal seam gas, LNG = liquefied natural gas, EIS = environmental impact statement

2.3.4.3 Gaps

Knowledge gaps and uncertainties are as follows for the Maranoa-Balonne-Condamine subregion:

- As coal resource development projects progress, specific details and figures quoted (e.g. water demand of a mine, well numbers of CSG developments, projected timelines) are likely to be subject to change as current understanding and conditions evolve.
- Projects that are currently included in the CRDP can, if economic, political, or other conditions change, still be abandoned before the projects are operational. However, at the time of writing, the CRDP includes all projects that are expected to begin commercial production after December 2012, or are CSG developments in the subregion that are reported in the 2014 Annual Report for the Surat Cumulative Management Area.
- For the majority of the baseline coal mine developments in the Maranoa-Balonne-Condamine subregion, no specific water management plans are available at the time of writing (July 2015).

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2.3.5 Conceptual model of causal pathways

Summary

This section describes the causal pathways by which open-cut coal mines and coal seam gas (CSG) operations impact water quantity and quality, and affect water-dependent assets in the Maranoa-Balonne-Condamine preliminary assessment extent (PAE). The coal resource development pathway (CRDP) includes five baseline CSG operations, five baseline open-cut coal mines and two additional open-cut coal mines (New Acland Coal Mine Stage 3 and The Range).

A hazard analysis systematically identifies activities that occur as part of coal resource development in the Maranoa-Balonne-Condamine subregion and which may initiate *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality or quantity of surface water or groundwater). A large number of hazards are identified; some of these are beyond the scope of bioregional assessments (BAs), such as accidents, and others are adequately addressed by site-based risk management processes and regulation. Hazards associated with CSG operations and open-cut coal mines that are considered to be in scope for BA in the Maranoa-Balonne-Condamine subregion are grouped into four main causal pathway groups: (i) ‘Subsurface depressurisation and dewatering’; (ii) ‘Subsurface physical flow paths’; (iii) ‘Surface water drainage’; and (iv) ‘Operational water management’.

‘Subsurface depressurisation and dewatering’ causal pathway group associated with the CRDP has the potential to directly affect the regional groundwater system, and indirectly affect surface water – groundwater interactions and depth to the watertable. For the ‘Subsurface physical flow paths’ causal pathway group, subsurface physical flow paths can be affected by hydraulic fracturing, changes to well integrity and surface water – groundwater interactions associated with coal resource development. The extent of these changes is likely to be restricted to aquifer or aquifer outcrop areas within tenements, but can affect connected watercourses within and downstream of tenements. Incomplete knowledge of the location of subterranean faults and fractures of the geological layers means that uncertainty exists in the precise spatial extent of groundwater level decline due to CSG operations.

‘Surface water drainage’ is the most common causal pathway group for CSG operations and open-cut coal mines. Subsidence, diverting site drain lines, rainwater and runoff diversion, levee bunds and creek crossings can change, or disrupt, surface water drainage. Effects on surface water direction, volume and quality can have medium-term (5 to 10 years) to long-term (10 to 100 years) cumulative effects on watercourses within and downstream of tenements. The ‘Operational water management’ causal pathway group involves the modification of water management systems and may have cumulative effects on surface water catchments and stream networks, surface water – groundwater interactions and groundwater conditions. Effects are likely to be in the medium to long term and include the alluvium and watercourses in aquifer outcrop areas that are within and downstream of tenements. The availability of long-term, consistent water quality and water quantity data measurements of surface water and groundwater systems limits the value of developing a

coupled surface water-groundwater numerical model in the Maranoa-Balonne-Condamine subregion at this time.

2.3.5.1 Methodology

Conceptual models of causal pathways are a specific type of conceptual model that characterises the *causal pathways*, the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets.

These conceptual models bring together the existing understanding and conceptual models of the key system components, processes and interactions for the geology, hydrogeology, surface water, and surface ecosystems, and consider the most plausible and important impacts and their spatial and temporal context. The conceptual modelling draws heavily on information from companion products from Component 1: Contextual information, which is summarised in Section 2.3.2, Section 2.3.3 and Section 2.3.4.

The causal pathways underpin the construction of groundwater and surface water models, and frame the assessment of the impacts on and risks to water and water-dependent assets. The approach taken in the Maranoa-Balonne-Condamine subregion has leveraged existing state-based resources and knowledge of geological, surface water and groundwater conceptual models. The Assessment team summarised the key system components, processes and interactions for the geology, hydrogeology and surface water of the subregion at the ‘Conceptual modelling of causal pathways’ workshop held in Brisbane in July 2015. The focus of the workshop was to improve the landscape classification (described in Section 2.3.3) and description of the conceptual model of causal pathways. Discussion with representatives at the workshop focused on knowledge gaps and uncertainties identified by the Assessment team.

In a BA, the identification and definition of causal pathways are supported by a formal hazard analysis, known as Impact Modes and Effects Analysis (IMEA) as outlined in companion submethodology M11 (Ford et al., 2016) and illustrated in Figure 5. IMEA is a variant of the established hazard analysis tool, Failure Modes and Effects Analysis (FMEA). The causal pathways are based on the outcomes of this hazard analysis and current understanding of the way ecosystems and landscape classes in the subregion work and interact. The IMEA rigorously and systematically identifies potential *hazards*, defined as events, or chains of events, that might result in an *effect* (change in the quality or quantity of surface water or groundwater). Only hazards identified through the IMEA process are considered further in the BA. Additionally, the IMEA considers all the possible ways in which activities may lead to effects or impacts, before assessing the severity, likelihood and detectability of such impacts under current controls through structured scoring.

Key to an IMEA is identifying *activities*, planned events associated with a CSG operation or coal mine. Activities are grouped into *components*, which are grouped into *life-cycle stages*. It is important to assign activities to their appropriate life-cycle stage because the scale and duration of similar activities can be different for each life-cycle stage, which is reflected in the scores for severity and/or likelihood of the impacts resulting from these activities.

Activities for CSG operations are separated into five life-cycle stages and four components:

- life-cycle stages: (i) exploration and appraisal, (ii) construction, (iii) production, (iv) decommissioning, and (v) work-over
- components: (i) wells, (ii) processing facilities, (iii) pipelines, and (iv) roads and infrastructure.

Activities for open-cut coal mines are separated into five life-cycle stages and three components:

- life-cycle stages: (i) exploration and appraisal, (ii) development, (iii) production, (iv) closure, and (v) rehabilitation
- components: (i) open pit, (ii) surface facilities, and (iii) infrastructure.

An *impact cause* is an activity (or aspect of an activity) that initiates a hazardous chain of events. An activity can have undesirable effects (such as water and gas extraction that unintentionally reduces groundwater pressure to unacceptable levels for other beneficial uses) or desirable effects (such as reinjection of co-produced water to restore groundwater pressure in a depleted aquifer to some desired level).

An *impact mode* is the manner in which a hazardous chain of events could result in an effect. There might be multiple impact modes for each activity or chain of events. The impact modes may arise through various mechanisms, including anthropogenic activities that are planned and expected to occur as part of operations; unplanned events due to human error or infrastructure failure; or through combination with external factors (e.g. heavy rainfall or floods).

Examples are illustrated in Figure 5:

- An example for open-cut coal mines (Figure 5(a)) is initiated with the activity ‘dewatering down to coal seam for an open-cut mine’, which is the impact cause. The impact mode (‘intentional dewatering down to coal seam’) leads to the effect (‘change in groundwater quantity (drawdown)’), which in turn may result in an ecological impact, ‘reduced groundwater availability for a groundwater-dependent ecosystem’.
- An example for CSG operations (Figure 5(b)) is initiated with the activity ‘corridor or site vegetation removal for CSG operations or coal mine’, which is the impact cause. Subsequent events (‘rainfall event’ and ‘soil erosion’) then combine to form the impact mode (‘soil erosion following heavy rainfall’) that leads to multiple effects (‘change in surface water quantity and surface water quality’) and associated stressors (‘surface water flow’ and ‘total suspended solids (TSS)’). In turn, this may cause an ecological impact, ‘change of condition of habitat for a given species’.

Participants in IMEA workshops were invited to identify all plausible hazards and impact modes on an activity-by-activity basis, together with the potential hydrological effects on groundwater and/or surface water. Each hazard is scored with respect to the severity, likelihood and time to detection. The IMEA elicits an interval (upper and lower score) for each hazard that all workshop participants agree upon:

- The *severity score* describes the magnitude of the impact resulting from a hazard, which is scored so that an increase (or decrease) in score indicates an increase (or decrease) in the magnitude of the impact.

- The *likelihood score* describes the annual probability of a hazard occurring, which is scored so that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the probability of occurrence.
- The *detection score* describes the expected time to discover a hazard, scored in such a way that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the expected time (measured in days) to discover it.

Two overarching hazard ranking scores are calculated:

- *hazard score*, the sum of the severity score and likelihood score
- *hazard priority number*, the sum of severity score, likelihood score and detection score.

It is important to emphasise that despite the use of severity scores and likelihood scores, the hazard ranking scores do not provide an absolute or even relative measure of risk. IMEA provides a relative rank of hazards. The value of this analysis lies in the systematic and thorough identification of hazards and in their ranking relative to each other. Hazards with higher scores do not imply that the risks associated with those potential hazards are in some way significant or apply equally across the subregion at all times, only that it is important that these hazards (along with many others) are considered for inclusion in the BA.

There is considerable structure and hierarchy within these lists of IMEA hazards (Bioregional Assessment Programme, Dataset 1) with the finer-level hazards aggregating to successively coarser resolutions. For example, there are a range of activities as part of CSG operations that may require the removal of site vegetation (the impact cause), including the creation of pipeline networks, storage ponds, site processing plants, water treatment plants, ground-based geophysics and the construction of access roads; these may all potentially result in changes to surface water quality from soil erosion following heavy rainfall (impact mode).

The hazards identified by the IMEA represent a conceptual model of the chain of events that begins with an activity and ends with a potential impact on groundwater or surface water; causal pathways include these chains of events and also extend to resulting ecological impacts (see Figure 5). Causal pathways are considered for CSG operations and open-cut coal mines separately, for both the baseline coal resource development (baseline) and the coal resource development pathway (CRDP). A full suite of generic causal pathways for hazards due to coal mines and CSG operations is presented in figures in an appendix in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016). These figures identify activities, impact causes and impact modes as well as those aspects of surface water and groundwater that might be affected. The causal pathways in the submethodology are generally applicable to all subregions or bioregions; Section 2.3.5 presents specific results for the Maranoa-Balonne-Condamine subregion.

Hazards are grouped for the Maranoa-Balonne-Condamine subregion if they have the same causal pathways, even if those hazards occur because of different activities, at different life-cycle stages, or at different intensities. This smaller set of causal pathway groups provides a useful starting point for summarising and representing the causal pathways associated with coal resource development (e.g. through influence diagrams) and focusing on those causal pathways that are in scope for BA.

The spatial footprint for the identified hazards and causal pathways identified is a core focus of the conceptual modelling, and is arrived at on the basis of existing knowledge, scientific logic and preliminary hydrological modelling results. An important aspect of this is using those same sources to identify which landscape classes and assets may be affected by a potential hydrological change that arises from those causal pathways, and (equally importantly) which landscape classes and assets will *not* be affected. Throughout the BA, areas of the PAE that will not be affected are progressively ruled out in order to focus efforts of the Assessment team and ultimately the impact and risk analysis.

2.3.5.2 Hazard analysis

A hazard analysis was conducted for the Maranoa-Balonne-Condamine subregion (Bioregional Assessment Programme, Dataset 1) based on the existing and proposed CSG operations and coal mines and their water management (outlined in Section 2.3.4.1 and Section 2.3.4.2, respectively). The hazard analysis for the Maranoa-Balonne-Condamine subregion was completed during a one-day workshop in May 2015 with experts from CSIRO, Geoscience Australia and the Department of the Environment. Specific coal resource expertise from these agencies beyond the Assessment team was included. Additional hazard analysis workshops for other subregions, some of which had stronger external representation, have assisted in confirming the comprehensiveness of the hazards identified for the Maranoa-Balonne-Condamine subregion.

The hazard analysis for the Maranoa-Balonne-Condamine subregion scored a total of 196 activities associated with CSG operations and 123 activities associated with open-cut coal mines. All decisions were recorded; however, some activities were left unscored if they were considered not applicable to the Maranoa-Balonne-Condamine subregion or if that activity was not expected to occur at the time of the assessment.

2.3.5.2.1 Coal seam gas operations

The hazard analysis identifies impacts on aquifers as the highest ranked hazards associated with CSG operations in the Maranoa-Balonne-Condamine subregion. The hazard analysis identifies the following potential impacts to aquifers including:

- injection of treated water into the aquifer
- hydrostatic depressurisation of the aquifer (target coal seam and non-target aquifers)
- fault-mediated depressurisation caused by faults opening or closing due to CSG operations
- aquitard-mediated depressurisation (i.e. an aquitard is absent or the integrity of the aquitard is compromised in some parts of the subregion)
- connection of previously disconnected aquifers by hydraulic fracturing, incomplete casing of wellheads or incomplete seal integrity.

After impacts on aquifers, the potential impacts associated with storage, processing and disposal of treated water: raised groundwater levels, soil salt mobilisation and leaching from storage ponds were all identified as potentially important in this context.

Figure 29 plots the 30 highest ranked hazards (and associated activities and impact modes), ranked by midpoint of the hazard priority number. This figure shows the range of hazard score and hazard priority number for each of these potential hazards.

'Disruption to natural surface drainage' was the most common impact mode in the 30 highest ranked hazards. This impact mode appears 21 times in the IMEA for CSG operations in the Maranoa-Balonne-Condamine subregion, and 7 times in the 30 highest ranked hazards. This is because many of the activities associated with CSG operations (such as site vegetation removal and diverting site drain lines) lead to this impact mode. This impact mode is considered hazardous as it may lead to impacts on surface water volume, direction and quality; in extreme cases, impacts on groundwater quantity were identified as a possible outcome.

The following complete the list of the 30 highest ranked hazards that might potentially impact on water-dependent assets in the Maranoa-Balonne-Condamine subregion for CSG operations:

- gas leakage into groundwater caused by incomplete or compromised cement casing
- leaching from storage ponds (untreated co-produced water and hypersaline brine ponds)
- soil erosion following heavy rainfall, with total suspended solids (TSS), total dissolved solids and surface water flow as the associated stressors.

Details of the hazard analysis are available at Bioregional Assessment Programme (Dataset 1).

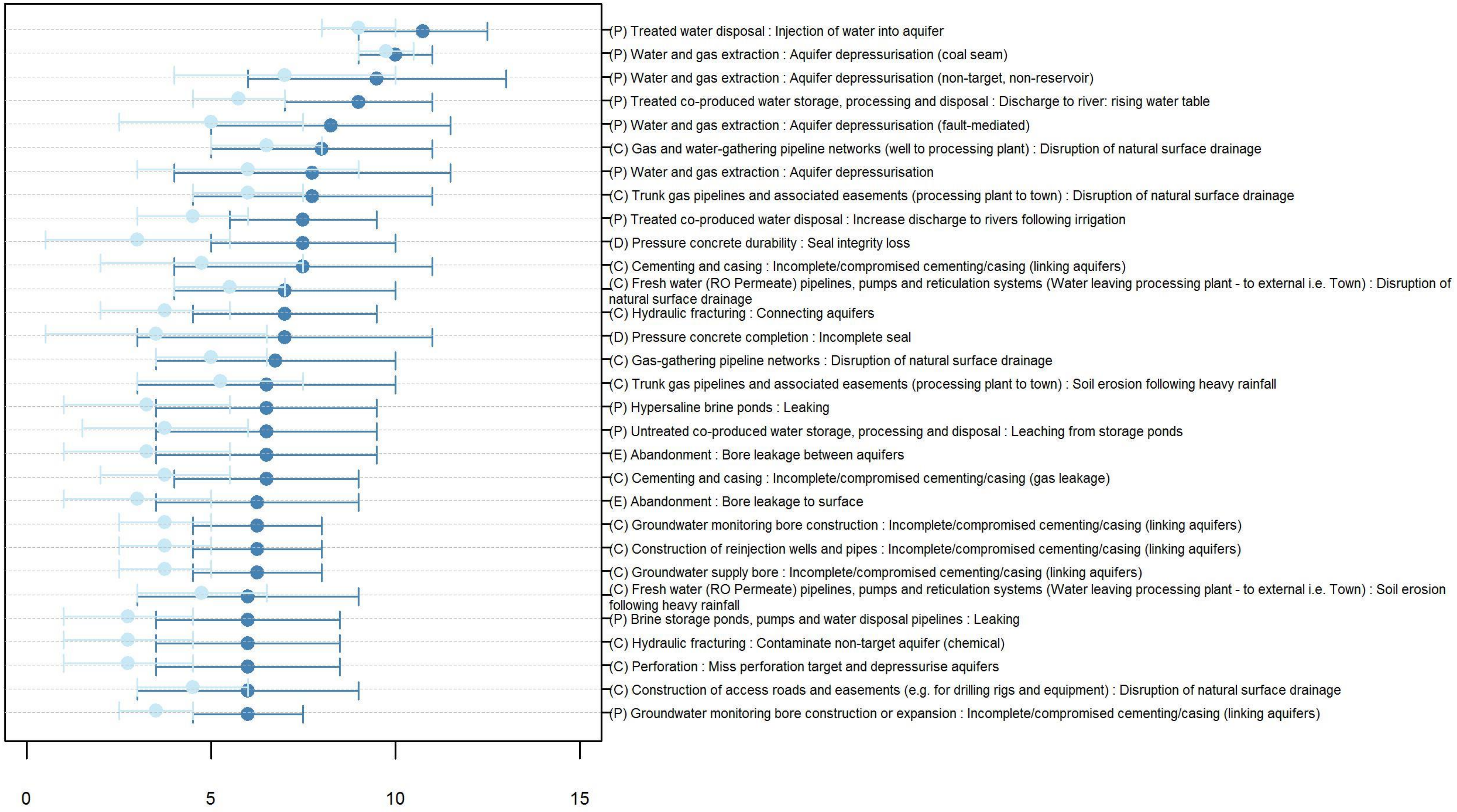

Figure 29 Highest ranked hazards (and their associated activities and impact modes) for coal seam gas operations, ranked by midpoint of the hazard priority number

The x-axis shows the hazard priority number and hazard score for potential hazards. The intervals between the highest and lowest hazard priority number are shown in dark blue; the intervals for hazard score are shown in light blue. The same hazard may appear multiple times, as it may arise from a number of different life-cycle stages and activities. Hazards are listed with the syntax [Life-cycle stage][Activity]:[Impact mode], where life-cycle stages are indicated by (E) for exploration and appraisal, (C) for construction, (P) for production and (D) for decommissioning.
Typology and punctuation are consistent with Dataset 1.
Data: Bioregional Assessment Programme (Dataset 1)

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

2.3.5.2.2 Open-cut coal mines

Activities that lead to disruption of, and changes to, natural surface drainage and runoff associated with open-cut coal mines in the Maranoa-Balonne-Condamine subregion are associated with nine of the 30 highest ranked hazards. These potential impacts occur because open-cut coal mines may potentially divert rivers and creeks, and divert the natural direction of rainfall-runoff by the construction, or expansion, of the pit and associated mine infrastructure and work areas, and by re-contouring landforms and discharges.

The potential impacts of leaching is associated with eight of the 30 highest ranked hazards, including leaching from:

- in-pit waste rock dumps and backfill
- waste rock dumps outside of the pit
- coal stockpiles (in and out of the pit)
- run-of-mine (ROM) plants
- tailings decant water dams.

The following are identified as having the potential to link, or cause leakage between, aquifers:

- incomplete or compromised cementing of groundwater supply and monitoring bores
- mine expansion too close to a water body
- abandoned exploration and appraisal bores.

These – together with deliberate pit wall dewatering, subsidence and enhanced aquifer interconnectivity caused by post-closure water filling the pit – are identified as potentially important hazards. The remaining 30 highest ranked hazards include:

- soil erosion caused by heavy rainfall or failure to successfully rehabilitate abandoned mines
- artificial groundwater recharge (following pit abandonment)
- groundwater and surface water contamination via drill cutting disposal.

Figure 30 plots the 30 highest ranked hazards (and their associated activities and impact modes), ranked by midpoint of their hazard priority number. The figure shows the range of hazard scores and hazard priority numbers for each of these hazards.

Details of the hazard analysis are available at Bioregional Assessment Programme (Dataset 1).

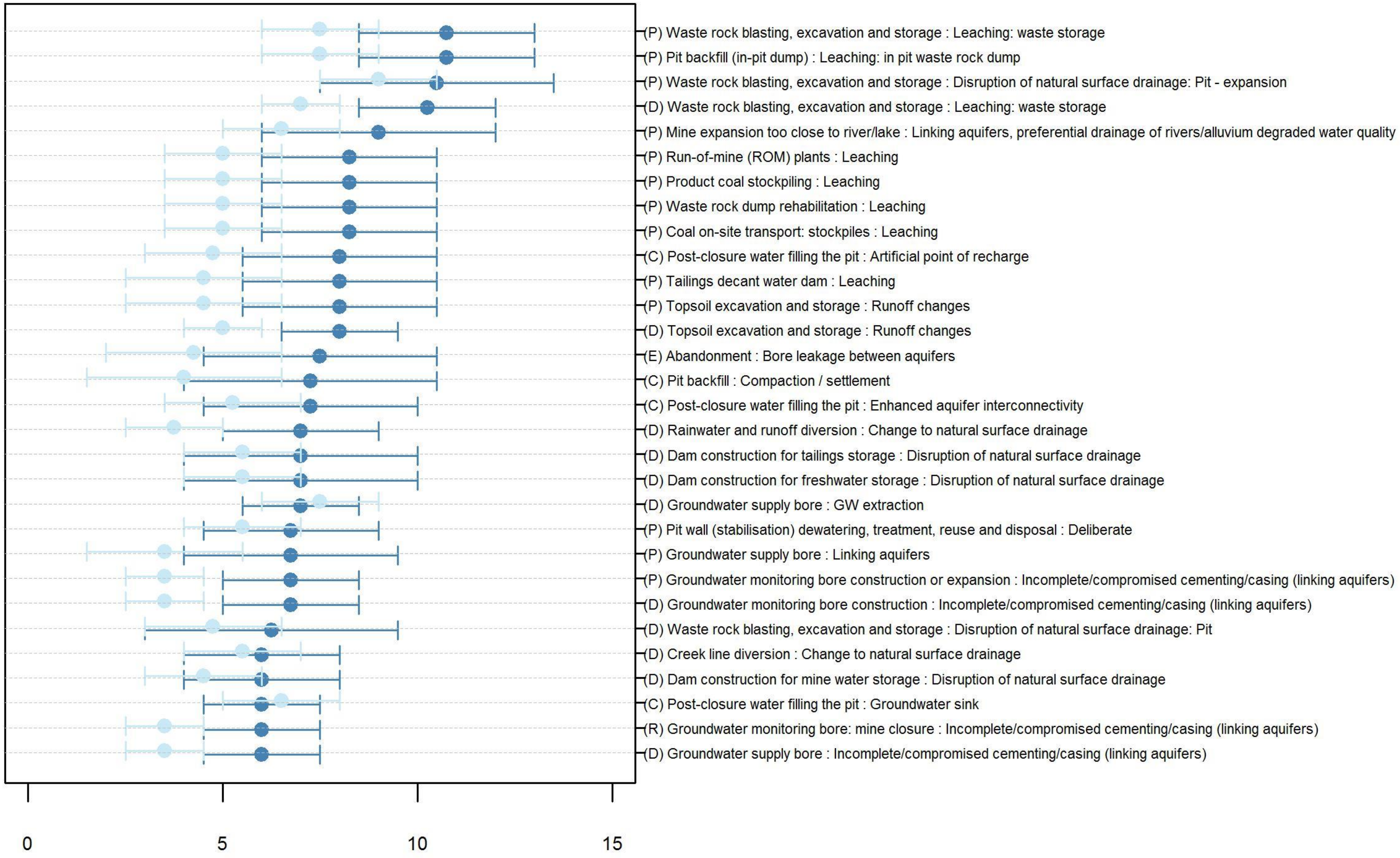

Figure 30 Highest ranked hazards (and their associated activities and impact modes) for open-cut mines, ranked by midpoint of the hazard priority number

The x-axis shows the hazard priority number and hazard score for potential hazards. The intervals between the highest and lowest hazard priority number are shown in dark blue; the intervals for hazard score are shown in light blue. The same hazard may appear multiple times, as it may arise from a number of different life-cycle stages and activities. Hazards are listed with the syntax [Life-cycle stage][Activity]:[Impact mode], where life-cycle stages are indicated by (E) for exploration and appraisal, (D) for development, (P) for production, (C) for closure and (R) for rehabilitation. Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 3).
Data: Bioregional Assessment Programme (Dataset 3)

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

The hazard analysis also indicates the possibility of cumulative impacts associated with vegetation removal and diversion of site drainage lines around CSG plants, mines and pipeline corridors. Individually these hazards are not deemed to be relatively important, but they are in the top five ranked impact causes for activities associated with open-cut mines and CSG operations. These hazards are deliberate and associated with many activities, and are therefore likely to contribute to other stressors in the environment.

2.3.5.2.3 Hazard handling and scope

A full list of hazards has been generated for both coal mines and CSG operations, as described in Section 2.3.5.2.1 and Section 2.3.5.2.2. This section describes the scope of subsequent work, which addresses only a subset of the full list of hazards.

The hazards of primary focus from a BA perspective are those that extend beyond the development site and that may have cumulative impacts, as these are consistent with the regional focus of BA, and are where BA will add value beyond site-specific environmental impact statements (EIS). Ultimately, however, BAs need to be able to address all identified hazards by considering the scope, modelling, other literature or narratives, and specifying where science gaps may exist.

BAs are constrained by considering only impacts that can happen via water, and so hazards such as dust, fire or noise are deemed out of scope and are addressed by site-based risk management unless there is a water-mediated pathway.

In general, leading practice is assumed and accidents are deemed to be covered adequately by site-based risk management procedures and are beyond the scope of BA; for example, the failure of a pipeline is covered by site-based risk management. However, for the Maranoa-Balonne-Condamine subregion, hazards associated with the ‘exploration and appraisal’ and ‘construction’ phases of CSG operations are considered in scope -- even those hazards associated with human error and accidents. These hazards are deemed in scope because activities in this phase (such as hydraulic fracturing and drilling) occur at sufficient scale and frequency to require further consideration in this BA.

Hazards that pertain to the development site and with no off-site impacts are important to acknowledge but will typically be addressed by site-based risk management procedures.

For CSG operations, the following hazards are considered out of scope for further analysis as part of the BA of the Maranoa-Balonne-Condamine subregion because they are deemed to be covered by site-based risk management and regulation:

- abandonment practice
- hazards addressed by site management, no water-mediated pathway (dust, fire or noise)
- containment failure due to construction or design
- disruption of surface drainage network for site-based infrastructure, plant and facilities, roads, creek crossings
- equipment/infrastructure failure (e.g. pipeline failures)
- leaching/leaking from storage ponds and stockpiles

- spillages and disposals (diesel, mud, cuttings, fluid recovery)
- vegetation clearance and subsequent soil erosion following heavy rainfall.

Figure 31 and Table 15 describe all hazards associated with CSG operations that are considered to be in scope in the Maranoa-Balonne-Condamine subregion. The hydrological effect of an activity such as 'water and gas extraction' depends on the impact cause and impact mode. For example, 'depressurisation' (impact cause) that causes 'subsidence' (impact mode) affects 'surface water direction' (hydrological effect) and 'aquitard leaks' (impact cause) that cause 'non-target, non-reservoir aquifer depressurisation' (impact mode) affects 'groundwater pressure' (hydrological effect) (Figure 31).

Hydrological effects associated with CSG operations that are considered to be in scope in the Maranoa-Balonne-Condamine subregion are shown in Figure 31 and listed below:

- surface water quality
- surface water direction
- surface water flow
- groundwater quality
- aquifer properties
- groundwater composition
- groundwater flow (reduction)
- groundwater level
- groundwater pressure.

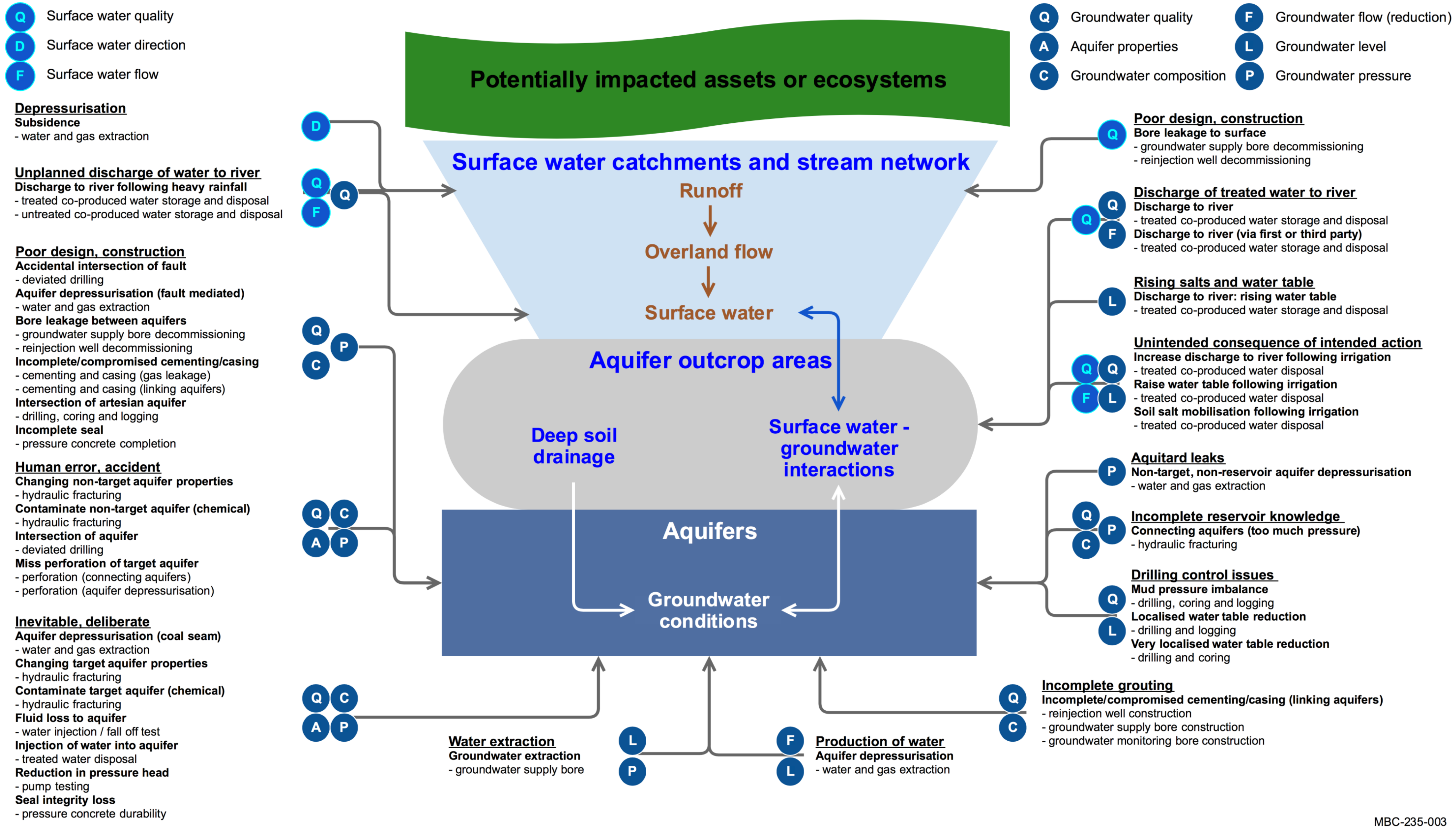

Figure 31 Hazards (impact causes, impact modes and activities) and associated effects identified for the life-cycle stages of coal seam gas operations that are considered to be in scope in the Maranoa-Balonne-Condamine subregion

Impact causes are underlined, impact modes are bold and activities are bullet points. Arrows indicate the spatial context for each hazard: aquifers, aquifer outcrop areas, watercourses, catchments.
GDEs = groundwater-dependent ecosystems, groundwater composition = mixing groundwaters of different composition (in terms of natural dissolved solids)
Typology and punctuation are consistent with the hazard analysis dataset (Bioregional Assessment Programme, Dataset)

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

Table 15 Hazards identified for the life-cycle stages of coal seam gas operations that are considered to be in scope in the Maranoa-Balonne-Condamine subregion and their associated hydrological effects, spatial context, temporal context, and potentially impacted assets or ecosystems

This table lists each hazard (with its spatial and temporal context) in a chain of logic from hydrological effects to potentially impacted assets or ecosystems. The spatial context includes target and non-target aquifers, aquifer outcrop areas, coal resource development tenements and watercourses. Within the relevant spatial and temporal context, assets and ecosystems are described using landscape classification rule sets (GAB GDEs, non-GAB GDEs), landscape class group (e.g. 'Floodplain or lowland riverine (including non-GAB GDEs)') or asset type (e.g. economic = economic groundwater asset).

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	Hydrological effects	Spatial context	Temporal context[b]	Potentially impacted assets or ecosystems
Aquitard leaks: (P) Aquifer depressurisation (non-target, non-reservoir) – water and gas extraction	Change in GW pressure	Aquifers intersected by CSG wells within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Depressurisation: (P) Subsidence – water and gas extraction	SW direction	Watercourses within and downstream of tenements	Long term	All
Discharge of treated water to river: (P) Discharge to river (via first or third party) – treated co-produced water storage, processing and disposal	SW quality, SW flow, GW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Discharge of treated water to river: (P) Discharge to river – treated co-produced water storage, processing and disposal	SW quality, SW flow, GW quality	Aquifer outcrops within tenements (GAB and alluvial)	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Drilling control issues: (E, C) Mud pressure imbalance – drilling, coring and logging	GW quality	Aquifers intersected by CSG wells within tenements	Short term	GAB GDEs, non-GAB GDEs and economic
Drilling control issues: (E, C) Localised watertable reduction – drilling and logging	GW level	Aquifers intersected by CSG wells within tenements	Short term	GAB GDEs, non-GAB GDEs and economic
Drilling control issues: (E, C) Very localised watertable reduction – drilling and coring	GW level	Aquifers intersected by CSG wells within tenements	Short term	GAB GDEs, non-GAB GDEs and economic

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	**Hydrological effects**	**Spatial context**	**Temporal context[b]**	**Potentially impacted assets or ecosystems**
Human error, accident: (C) Changing non-target aquifer properties – hydraulic fracturing	Aquifer properties	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Human error, accident: (C) Contaminate non-target aquifer (chemical) – hydraulic fracturing	GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Human error, accident: (C) Intersection of aquifer – deviated drilling	GW quality, GW pressure	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Human error, accident: (C) Miss perforation of target aquifer – perforation (connecting aquifers)	GW composition, GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Human error, accident: (C) Miss perforation of target aquifer – perforation (aquifer depressurisation)	GW pressure, GW quality	Target aquifer	Long term	GAB GDEs, non-GAB GDEs and economic
Incomplete grouting: (C, P) Incomplete/compromised cementing/casing (linking aquifers) – reinjection well construction	GW composition, GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Incomplete grouting: (C) Incomplete/compromised cementing/casing (linking aquifers) – groundwater monitoring bore construction	GW composition, GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Incomplete grouting: (C) Incomplete/compromised cementing/casing (linking aquifers) – groundwater supply bore construction	GW composition, GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	Hydrological effects	Spatial context	Temporal context[b]	Potentially impacted assets or ecosystems
Incomplete reservoir knowledge: (C) Connecting aquifers (too much pressure) – hydraulic fracturing	GW composition, GW quality, GW pressure	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (P) Aquifer depressurisation (coal seam) – water and gas extraction	GW pressure	Target aquifer	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (C) Changing target aquifer properties – hydraulic fracturing	Aquifer properties	Target aquifer within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (C) Contaminate target aquifer (chemical) – hydraulic fracturing	GW quality	Target aquifer within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (C) Fluid loss to aquifer – water injection / fall off test	GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (P) Injection of water into aquifer – treated water disposal	GW composition, GW pressure	Aquifers targeted by reinjection wells	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (E) Reduction in pressure head – pump testing	GW pressure	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (D) Seal integrity loss – pressure concrete durability	GW quality	Aquifers intersected by CSG wells within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (C) Accidental intersection of fault – deviated drilling	GW quality	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	Hydrological effects	Spatial context	Temporal context[b]	Potentially impacted assets or ecosystems
Poor design, construction: (P) Aquifer depressurisation (fault-mediated) – water and gas extraction	GW pressure	Aquifers intersected by CSG wells and faults	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (C) Incomplete/compromised cementing/casing – cementing and casing (gas leakage)	GW quality	Aquifers intersected by CSG wells within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (C) Incomplete/compromised cementing/casing – cementing and casing (linking aquifers)	GW quality	Aquifers intersected by CSG wells within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (E, C) Intersection of artesian aquifer – drilling, coring and logging	GW pressure	Aquifers intersected by CSG wells	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (D) Bore leakage between aquifers – groundwater supply bore decommissioning	GW composition, GW quality, GW pressure	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (D) Bore leakage between aquifers – reinjection well decommissioning	GW composition, GW quality, GW pressure	Aquifers intersected by reinjection wells	Long term	GAB GDEs, non-GAB GDEs and economic
Poor design, construction: (D) Bore leakage to surface – groundwater supply bore decommissioning	SW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Poor design, construction: (D) Bore leakage to surface – reinjection well decommissioning	SW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	Hydrological effects	Spatial context	Temporal context[b]	Potentially impacted assets or ecosystems
Poor design, construction: (D) Incomplete seal – pressure concrete completion	GW quality, GW pressure	Aquifers within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Production of water: (P) Aquifer depressurisation – water and gas extraction	GW flow (reduction), GW level	Aquifers intersected by CSG wells	Long term	GAB GDEs, non-GAB GDEs and economic
Rising salts and watertable: (P) Discharge to river: rising watertable – treated co-produced water storage, processing and disposal	GW level	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Unintended consequence of intended action: (P) Increase discharge to rivers following irrigation – treated co-produced water disposal	SW flow, SW quality	Watercourses	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Unintended consequence of intended action: (P) Raise watertable following irrigation – treated co-produced water storage and disposal	GW level, GW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Unintended consequence of intended action: (P) Soil salt mobilisation following irrigation – treated co-produced water storage and disposal	SW quality, GW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Unplanned discharge of water to river: (P) Discharge to river following heavy rainfall – treated co-produced water storage and disposal	SW quality, SW flow, GW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)

Hazard **(with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')**	**Hydrological effects**	**Spatial context**	**Temporal context[b]**	**Potentially impacted assets or ecosystems**
Unplanned discharge of water to river: (P) Discharge to river following heavy rainfall – untreated co-produced water storage and disposal	SW quality, SW flow, GW quality	Alluvium and watercourses in aquifer outcrop areas within tenements	Short term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Water extraction: (P) Groundwater extraction – groundwater supply bore	GW level, GW pressure	Aquifers intersected by groundwater supply bores within tenements	Long term	GAB GDEs, non-GAB GDEs and economic

[a] Life-cycle stage of coal seam gas operations where C = construction, D = decommissioning, E = exploration and appraisal, P = production

[b] short term = less than 5 years, medium term = 5 to 10 years, long term = 10 to 100 years

CSG = coal seam gas, GAB = Great Artesian Basin, GDEs = groundwater-dependent ecosystems, GW = groundwater, SW = surface water, GW composition = mixing groundwaters of different composition (in terms of natural dissolved solids)

Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1)

Data: Bioregional Assessment Programme (Dataset 1)

For open-cut coal mines, the following hazards are considered out of scope in the Maranoa-Balonne-Condamine subregion because they are deemed to be covered by site-based risk management and regulation and do not have cumulative effects on water in the subregion:

- addressed by site management, no water-mediated pathway (dust, fire or noise)
- bore and well construction (integrity, leakage)
- disruption of surface drainage network for site-based infrastructure, plant and facilities, roads, creek crossings
- equipment/infrastructure failure (e.g. pipeline failures, plant failures)
- leaching/leaking from storage ponds and stockpiles
- loss of containment (due to construction or design, slope failure)
- re-contouring, compaction and settlement following backfill
- spillages and disposals (diesel, mud, cuttings, fluid recovery)
- vegetation clearance and subsequent soil erosion following heavy rainfall.

Of those hazards that are in scope, some will be addressed by the BA numerical modelling, while others (e.g. water quality hazards) will be assessed qualitatively, using the logic and rule-sets described in the conceptual model of causal pathways. The hazard priority number or hazard scores indicate the relative importance of the hazard. Hazards with low scores are of lower priority.

Figure 32 and Table 16 describe all hazards associated with coal mining developments that are considered to be in scope in the Maranoa-Balonne-Condamine subregion. The hydrological effect of an activity such as ‘water management structures’ depends on the impact cause and impact mode. For example, the hydrological effect of ‘poor handling / management’ (impact cause) can cause ‘excessive runoff during closure’ (impact mode) that affects ‘surface water quality and groundwater quality’ (hydrological effects) and ‘diverting site drain line’ (impact cause) can cause ‘disruption of natural surface drainage’ (impact mode) that affects ‘surface water volume / quantity, surface water quality and groundwater quantity / volume’ (hydrological effect). Hydrological effects associated with coal mines that are considered to be in scope in the Maranoa-Balonne-Condamine subregion are shown on Figure 32 and listed below:

- surface water quality
- surface water direction
- surface water flow
- surface water volume
- change to zero flow days
- groundwater quality
- groundwater direction
- groundwater flow (reduction)
- groundwater quantity/volume
- groundwater pressure.

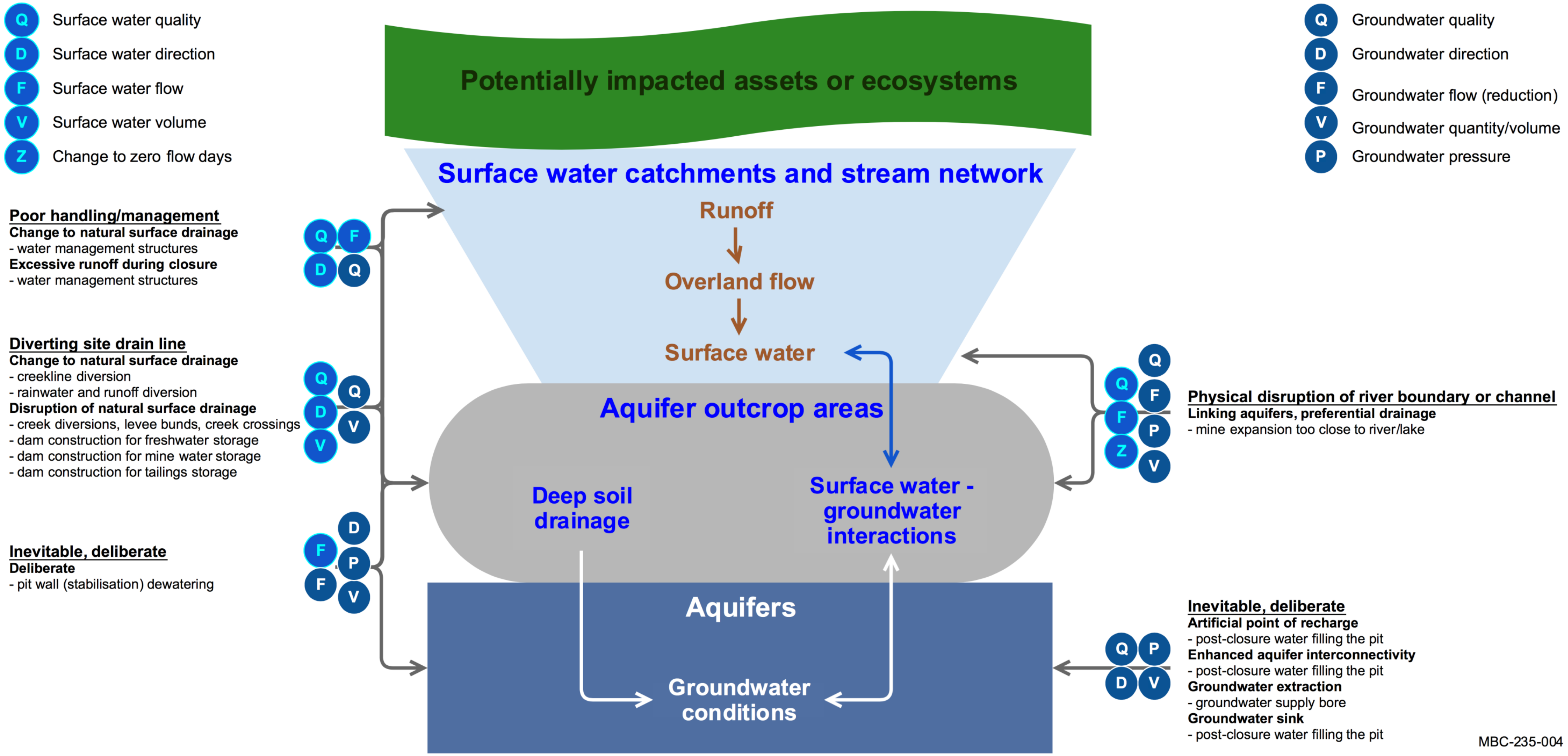

Figure 32 Hazards (impact causes, impact modes and activities) and associated effects identified for the life-cycle stages of open-cut coal mines that are considered to be in scope in the Maranoa-Balonne-Condamine subregion

Impact causes are underlined, impact modes are bold and activities are bullet points. Arrows indicate the spatial context for each hazard: aquifers, aquifer outcrop areas, watercourses, catchments.
GDEs = groundwater-dependent ecosystems
Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

Table 16 Hazards identified for the life-cycle stages of open-cut coal mines that are considered to be in scope in the Maranoa-Balonne-Condamine subregion and their associated hydrological effects, spatial context, temporal context, and potentially impacted assets or ecosystems

This table lists each hazard (with its spatial and temporal context) in a chain of logic from hydrological effects to potentially impacted assets or ecosystems. The spatial context includes target and non-target aquifers, aquifer outcrop areas, coal resource development tenements and watercourses. Within the relevant spatial and temporal context, assets and ecosystems are described using landscape classification rule sets (GAB GDEs, non-GAB GDEs), landscape class group (e.g. 'Floodplain or lowland riverine (including non-GAB GDEs)') or asset type (e.g. economic = economic groundwater asset).

Hazard (with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')	Hydrological effects	Spatial context	Temporal context[b]	Potentially impacted assets or ecosystems
Diverting site drain line: (D) Change to natural surface drainage – creekline diversion	SW directional characteristics, SW volume/quantity, SW quality	Watercourses within and downstream of tenements	Medium to long term	All watercourses
Diverting site drain line: (D) Change to natural surface drainage – rainwater and runoff diversion	SW volume/quantity, SW quality, GW quantity/volume	Watercourses within and downstream of tenements	Medium to long term	All watercourses
Diverting site drain line: (D) Disruption of natural surface drainage - creek diversions, levee bunds, creek crossings	SW directional characteristics, SW volume/quantity, SW quality	Watercourses within and downstream of tenements	Medium to long term	All watercourses
Diverting site drain line: (D) Disruption of natural surface drainage - dam construction for freshwater storage	SW volume/quantity, SW quality, GW quantity/volume	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Diverting site drain line: (D) Disruption of natural surface drainage - dam construction for mine water storage	SW volume/quantity, SW quality, GW quantity/volume	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Diverting site drain line: (D) Disruption of natural surface drainage - dam construction for tailings storage	SW volume/quantity, SW quality, GW quantity/volume	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Inevitable, deliberate: (C) Artificial point of recharge - post-closure water filling the pit	GW quantity/volume, GW quality	Aquifer outcrops within tenements (GAB and alluvial)	Long term	GAB GDEs, non-GAB GDEs and economic

Hazard **(with syntax 'Impact cause: (life-cycle stage[a]) impact mode – activity')**	**Hydrological effects**	**Spatial context**	**Temporal context[b]**	**Potentially impacted assets or ecosystems**
Inevitable, deliberate: (P) Deliberate - pit wall (stabilisation) dewatering	GW flow, GW direction, GW quantity/volume, GW pressure, SW flow	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Inevitable, deliberate: (C) Enhanced aquifer interconnectivity - post-closure water filling the pit	GW quality	Aquifer outcrops within tenements (GAB and alluvial)	Medium to long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (D) Groundwater extraction - groundwater supply bore (GW pressure)	GW pressure	Aquifers intersected by groundwater supply bores within tenements	Long term	GAB GDEs, non-GAB GDEs and economic
Inevitable, deliberate: (C) Groundwater sink - post-closure water filling the pit	GW quantity/volume, GW direction	Aquifer outcrops within tenements (GAB and alluvial)	Medium to long term	GAB GDEs, non-GAB GDEs and economic
Physical disruption of river boundary or channel: (P) linking aquifers, preferential drainage - mine expansion too close to river/lake	SW flow, GW quantity/volume, GW pressure, GW quality, change to zero-flow days	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)
Poor handling/management: (C) Change to natural surface drainage - water management structures (dams, levee bunds and diversions)	SW directional characteristics, SW flow, SW quality	Watercourses within and downstream of tenements	Medium to long term	All watercourses
Poor handling/management: (C) Excessive runoff during closure - water management structures (dams, levee bunds and diversions)	GW quality, SW quality	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements	Medium to long term	Floodplain or lowland riverine (including non-GAB GDEs) GAB GDEs (riverine, springs, floodplain or non-floodplain)

[a] Life-cycle stage of coal mine where C = mine closure, D = development, E = exploration and appraisal, P = production, R = rehabilitation

[b] Medium term = 5 to 10 years, long term = 10 to 100 years

GAB = Great Artesian Basin, GDEs = groundwater-dependent ecosystems, GW = groundwater, SW = surface water. Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).

Data: Bioregional Assessment Programme (Dataset 1)

2.3.5.3 Causal pathways

CSG and coal mining development in the Maranoa-Balonne-Condamine subregion targets the Walloon Coal Measures of the geological Surat and Clarence-Moreton basins. The main Great Artesian Basin (GAB) aquifers in the subregion, listed from shallowest to deepest, are the Bungil Formation, Mooga Sandstone, Gubberamunda Sandstone, Springbok Sandstone, Hutton Sandstone, Marburg Sandstone and Precipice Sandstone. The deeper sandstone aquifers of the Clematis Group and equivalent formations of the Bowen Basin are also recognised as GAB aquifers. Major aquitards in the subregion listed from shallowest to deepest are the Griman Creek, Wallumbilla, Orallo, Westbourne, Birkhead, Evergreen formations and Rewan Group (and their stratigraphic equivalents). Other than the GAB aquifers, the major aquifer systems in the subregion are the Cenozoic alluvial aquifers and the volcanic basalt aquifers along the eastern margin of the subregion. The Condamine Alluvium is the most significant and highly-developed alluvial groundwater system in the subregion. It is heavily used for groundwater supply predominantly for irrigation, but also for town water supply, domestic, stock, watering and industrial uses to a lesser extent. Significant aquifers are contained in the Main Range Volcanics in the east of the subregion and Cenozoic basalts that occur in the north of the subregion overlying the Bowen Basin. These basalt aquifers are used for irrigation, stock and domestic and town water supplies.

Coal resource development in the Maranoa-Balonne-Condamine subregion has the potential to directly affect the regional groundwater and surface water systems. Hydrological changes to the groundwater system can propagate through the alluvium and other aquifers to indirectly affect surface water – groundwater interactions in the aquifer outcrop and subcrop areas. Deep soil drainage and surface water – groundwater interactions in aquifer outcrop areas can also be affected by coal resource development, potentially affecting groundwater quality, aquifer properties, groundwater composition, flow (reduction), level and pressure. Potential changes to groundwater conditions include groundwater quality, aquifer properties, groundwater composition, flow (reduction), level and pressure in affected aquifers.

River basins in the subregion are the Border, Condamine-Balonne (including the Maranoa River), Fitzroy and Moonie rivers. Most river systems in the subregion are temporary. An exception is parts of the Dawson River, which receives baseflow contributions from rejected GAB recharge in the aquifer outcrop areas. Potential effects of changes to surface water – groundwater interactions associated with the management, treatment and disposal of water include changes baseflow to ephemeral watercourses following aquifer reinjection or changed surface water – groundwater interactions around mine pits. Potential effects of coal resource development in the Maranoa-Balonne-Condamine subregion on runoff and overland flow in surface water catchments and streams are changes to surface water quality, direction, flow, volume and zero-flow days, including changes to the magnitude, duration and variability of surface water flows.

2.3.5.3.1 Coal seam gas operations and open-cut coal mines

Hazards associated with CSG operations and open-cut coal mines that are considered to be in scope for BA in the Maranoa-Balonne-Condamine subregion are aggregated into four main causal pathway groups. These four causal pathway groups represent a conceptual model of the chain of events that begins with an activity and ends with a potential impact on a groundwater- or surface water-dependent asset. Four main causal pathway groups are identified in the Maranoa-Balonne-Condamine subregion:

- ‘Subsurface depressurisation and dewatering’
- ‘Subsurface physical flow paths’
- ‘Surface water drainage’
- ‘Operational water management’.

Subsurface depressurisation and dewatering

Groundwater extraction leads to hydrostatic depressurisation of the target coal seam and connected aquifer layers. Hydrological effects arising from this group of hazards depend on the local environment of the individual well (groundwater supply bore, CSG exploration or production bore or mine dewatering bore). If there are no faults or fractures nearby then the head changes caused by depressurisation must be passed to other layers diffusively according to hydrological conductivity, layer structure and the presence of aquitards. These affect the magnitude of head change, the spatial extent of head change and the time it takes for maximum head change to occur. Therefore, there is no general rule for how depressurisation of the target aquifer will affect connected aquifers. Where a fault or fracture does exist then pressure change can be transmitted more readily. However, this depends on the geometry of the geological compartments defined by the faults or fractures. Furthermore, it may be possible that prolonged depressurisation will reactivate a fault pathway, and thus create a pathway that was not active prior to the aquifer depressurisation.

Water is removed from most mines to allow the safe extraction of coal, and this decrease in local groundwater level creates a gradient toward the pit, and induces flow into it. The primary sources of this water are the geological layers in which the mine is sited, down to the layer being mined. The spatial extent of the influence area of the pit dewatering is a function of the depth of mining, the local hydraulic properties of conductivity and storativity, and the time elapsed. For example, a particular asset may be so distant from an open-cut mine that, within the life of the mine, drawdown will not affect it. However, in the years following mine closure, the spread of the drawdown cone may affect it. This can only be quantified with targeted monitoring and numerical groundwater modelling. Groundwater level monitoring can directly measure drawdown changes over time, whereas numerical groundwater modelling provides predictive estimates of drawdown changes to inform future planning. Mine pit dewatering can also affect alluvial aquifers, which can also affect the volume and timing of groundwater that is discharged as baseflow to connected watercourses. If the dewatering of an open-cut mine allows a drawdown cone to intersect with an alluvial aquifer supporting a stream, then potentially the water that would naturally discharge to the stream is instead drawn away from the alluvium toward the open-cut mining pit. Changes to surface water – groundwater interactions and depth to the water table can affect GDEs, including terrestrial vegetation and aquatic ecosystems.

The spatial context, hazards (impact modes and activities) and hydrological effects associated with the ‘Subsurface depressurisation and dewatering’ causal pathway group following water and gas extraction are shown in Figure 33. The cumulative effects of aquifer depressurisation associated with baseline CSG operations and dewatering associated with the five baseline and two additional coal mines is likely to be widespread, affecting target and non-target aquifers within the tenements and potentially affecting connected aquifers, surface water systems and GDEs outside the tenements. The groundwater numerical modelling (companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (Janardhanan et al., 2016)) describes the cumulative effects of aquifer depressurisation caused by the difference between results for the CRDP and the baseline (due to the additional coal resource development (ACRD)) for only those developments that can be modelled in the Maranoa-Balonne-Condamine subregion.

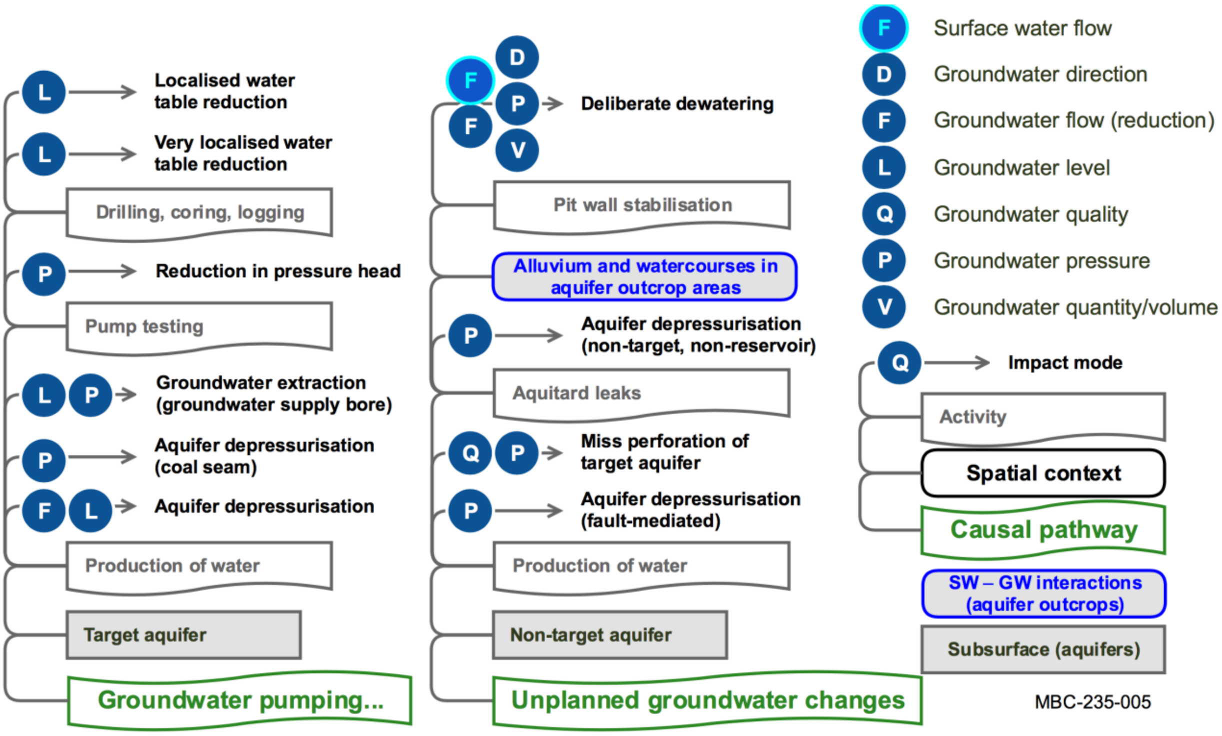

Figure 33 'Subsurface depressurisation and dewatering' causal pathway group arising from coal seam gas operations and open-cut coal mines

Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1). 'Groundwater pumping…' refers to 'groundwater pumping enabling coal seam gas extraction' and 'groundwater pumping enabling open-cut coal mining' causal pathways

Subsurface physical flow paths

Preferential flow paths can be affected by hydraulic fracturing (including deviated drilling and changes to non-target aquifers), well integrity (including incomplete and/or compromised cementing/casing, miss perforation of target aquifers) and surface water – groundwater interactions (including changes to aquifer interconnectivity, mine expansion too close to a river or lake, preferential drainage and recharge associated with post-closure water filling the pit). The spatial context, hazards (impact modes and activities) and hydrological effects associated with the 'Subsurface physical flow paths' causal pathway group are shown in Figure 34. Potential effects are likely to be localised, that is, they are restricted within less than 1 km of the preferential flow path, but will continue until remedial actions are taken. Potential effects include the escape of gas from the coal seams to the overlying geological layers and ultimately to the atmosphere. Inter-aquifer mixing can potentially compromise aquifer water quality. Effects on surface water systems are thought to be minimal due to the limited extent of impacts associated with changes to preferential flow paths and will be restricted to aquifer outcrop areas within tenement areas.

Hydraulic fracturing is designed to alter connectivity within target layers but may potentially alter inter-aquifer connectivity and introduce additional preferential flow paths. Aquifer stimulation involves high pressure injection of water (and other materials including chemical compounds and sand) to induce changes in aquifer properties to aid the release and flow of gas from the coal seams towards the well. The intended impact of changing aquifer properties is expected to be limited to the coal seams with a smaller risk of impacting neighbouring aquifers or aquitards. The lateral extent to which aquifer properties are changed diminishes with distance from the well and is therefore dependent on the number of wells where this process is implemented. The water quality of the fractured aquifer and neighbouring aquifers can be compromised, but is subject to management controls (such as compliance with standards and regulations) and monitoring. At the end of hydraulic fracturing, water is pumped out, which is discussed for the 'Subsurface depressurisation and dewatering' causal pathway group. Potential effects of disposal of co-produced water removed after hydraulic fracturing are discussed for the 'Operational water management' causal pathway group.

Well construction may lead to enhanced connection between aquifer layers (Stuckey and Mulvey, 2013), and allow the mixing of waters from previously disconnected layers of different quality and chemical properties, or of any fluid introduced down the well. CSG wells are drilled vertically from the surface to the coal seam and within the coal seam by directional or deviated drilling. Maintaining well integrity throughout construction, operation and decommissioning phases is crucial to ensuring sustainable gas production and avoiding adverse environmental impacts. Incomplete and/or compromised casing and seals could introduce preferential flow paths. Miss perforation of the target aquifer can create a connection between previously disconnected aquifers. Preferential flow paths have the potential to connect any two or more consecutive or non-consecutive geological layers up to the land surface through failure of well integrity or via faults affected by fracture stimulation.

Open-cut coal mines can have a localised effect on preferential flow paths in surrounding aquifers, affecting surface water – groundwater interactions. This includes changes to hydraulic gradients in the alluvial aquifer and connected aquifers associated with mine pit dewatering and preferential drainage and recharge associated with post-closure water filling the pit. An important component of streamflow is baseflow, where groundwater discharges to the stream from the alluvial aquifer. Changes to hydraulic gradients can change the timing and volume of baseflow contributions to streams, which can affect the stream ecosystem within and downstream of tenements. Changes to baseflow contributions will be restricted to the aquifer outcrop areas, where direct interactions between watercourses and unconfined aquifers are possible. The locations of watercourses in aquifer outcrop areas in the Maranoa-Balonne-Condamine subregion are shown in Figure 35. The locations of catchments and watercourses potentially affected by the CRDP in the subregion are shown in Figure 36.

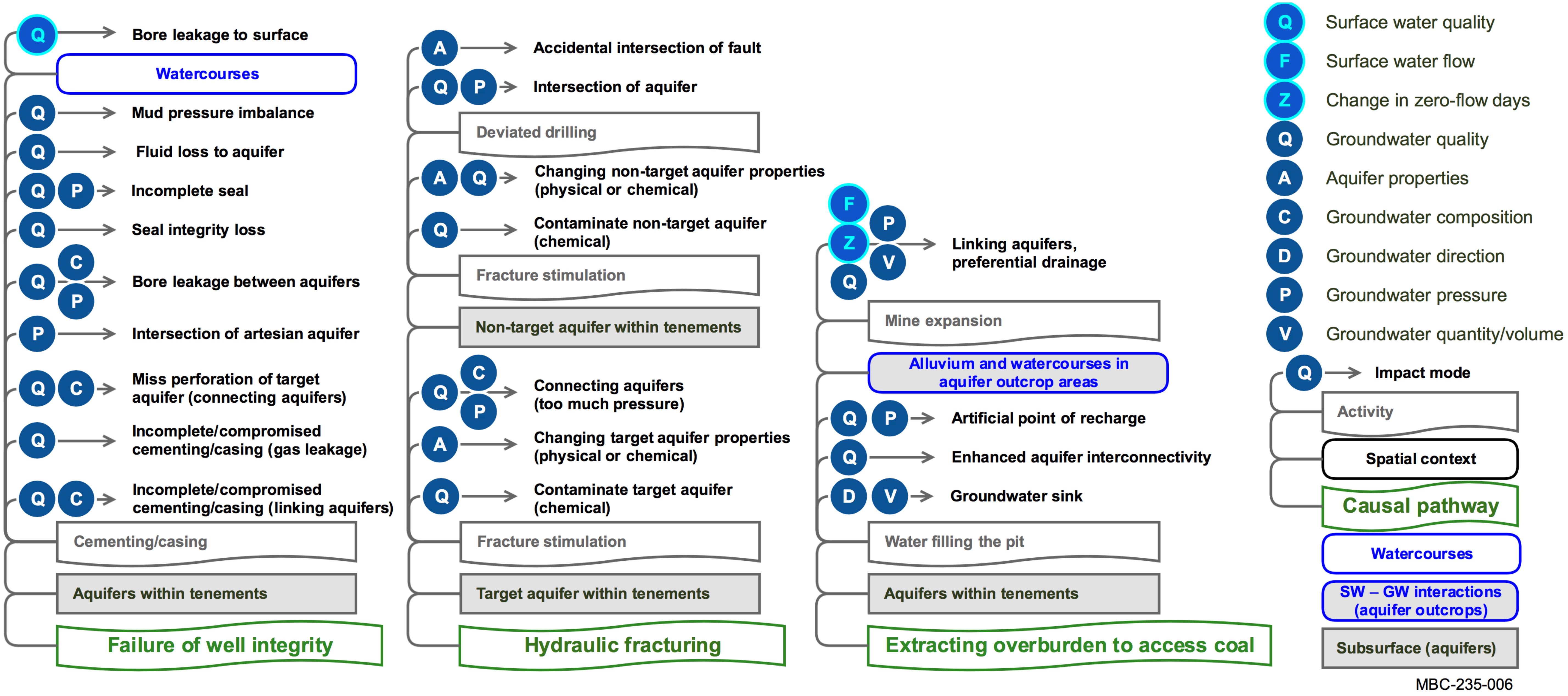

Figure 34 'Subsurface physical flow paths' causal pathway group arising from coal seam gas operations and open-cut coal mines

SW = surface water, GW = groundwater, groundwater composition = mixing groundwaters of different composition (in terms of natural dissolved solids)
Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).

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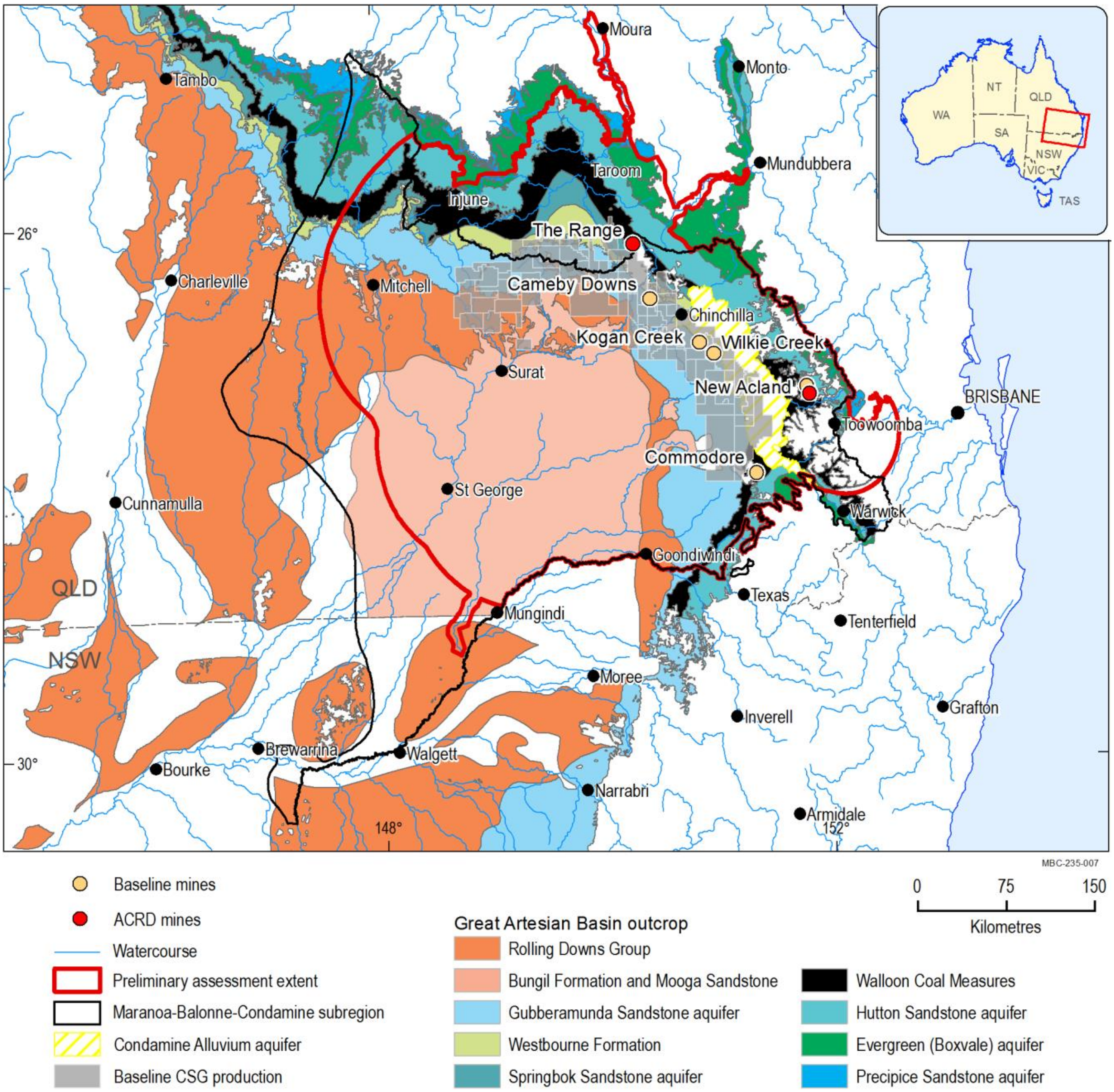

Figure 35 Aquifer outcrop areas and watercourses in the Maranoa-Balonne-Condamine subregion

The mines in the coal resource development pathway (CRDP) are the sum of those in the baseline and in the ACRD.
ACRD = additional coal resource development, CSG = coal seam gas, GAB outcrop = Great Artesian Basin aquifer outcrop areas
Data: Geoscience Australia (Dataset 2), Office of Groundwater Impact Assessment (Dataset 3, Dataset 4)

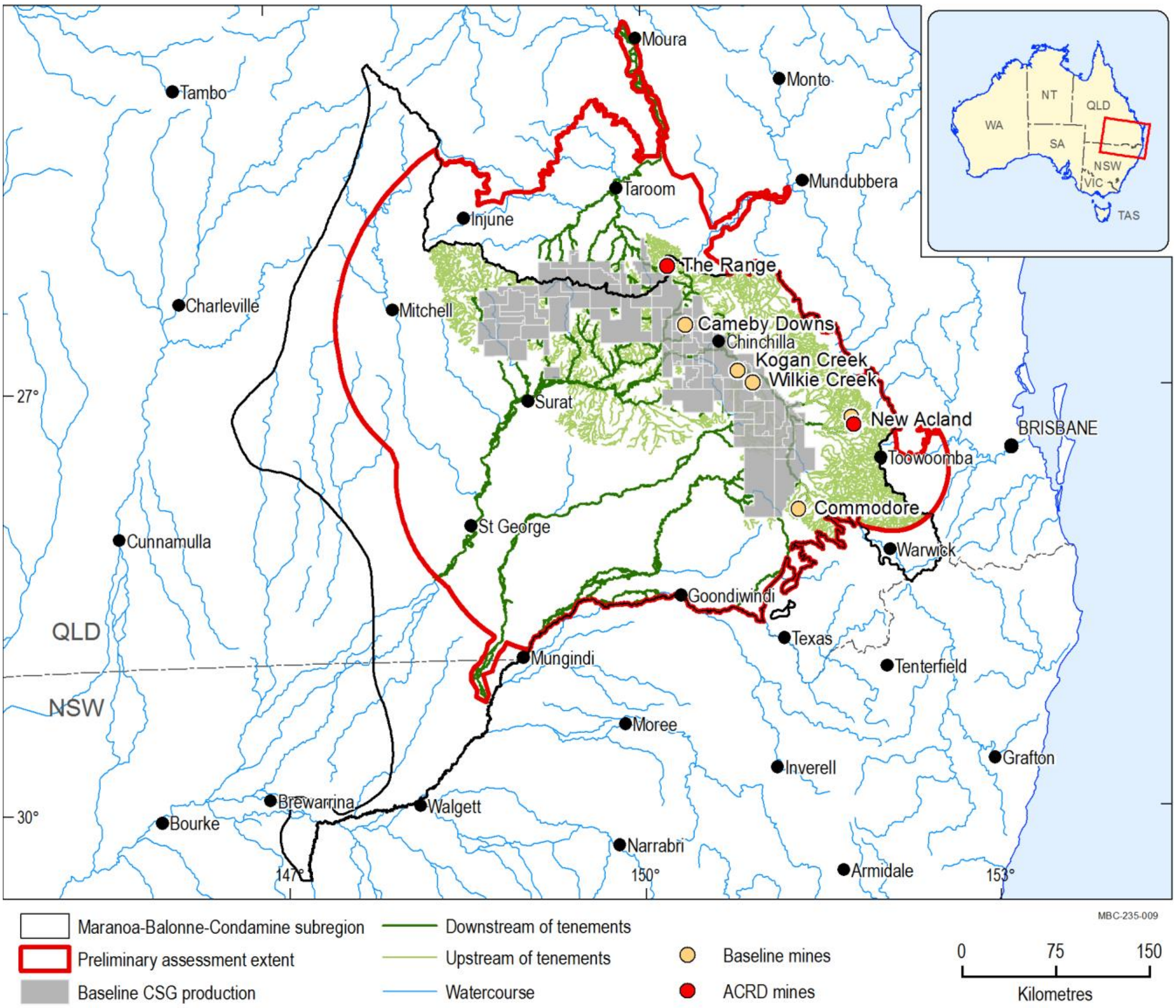

Figure 36 Location of watercourses potentially affected by the coal resource development pathway in the Maranoa-Balonne-Condamine subregion

The mines in the coal resource development pathway (CRDP) are the sum of those in the baseline and in the additional coal resource development (ACRD).
CSG = coal seam gas
Data: Bioregional Assessment Programme (Dataset 5)

Surface water drainage

Disruption of the surface drainage network may lead to a loss, or redirection, of runoff that can have long-term cumulative effects on downstream watercourses. The physical infrastructure of CSG operations, including land clearing, land levelling, the construction of hard packed areas such as roads and tracks, pipelines and plant for collection and transport of gas can all disrupt natural surface flows and pathways by redirecting and concentrating flows. Water flow and landscape topography co-evolve in natural systems such that the areas of most concentrated flow tend to be the most resistant to erosion. Changes in flow regime and catastrophic events can alter flows and pathways either temporarily before returning to the previous state, or semi-permanently until the next event. In the same way, anthropogenic structures and earth works associated with CSG exploration and production may divert and concentrate surface flow. This may lead to erosion of the land surface, stream banks or streambeds, and alter water quality in streams if new material is mobilised and washed into them. Geomorphological changes may create chemical or hydraulic barriers to migration of aquatic organisms that can affect upstream watercourses such as changes to the pH or dissolved oxygen concentrations (chemical) and stream velocity or turbulence (hydraulic).

Open-cut mines may also alter the surface water pathways, through diverting site drain lines and on-site water retention. While the total amount of runoff in a surface water catchment might be reduced by only a few percent, creek line diversions change where water enters the stream network. For example, a mine may alter runoff pathways such that a single upland stream that contributes only a few percent of overall catchment streamflow is diverted around the mine to a watercourse further downstream. This has implications for the local stream environment and downstream reaches where the contribution at this point may be more significant. It can lead to flow being more concentrated, so that erosion risk is greater, or reduce the flow contributions to a water-dependent asset. It may also change surface water – groundwater interactions in the alluvium and watercourses in aquifer outcrop areas. The relative effect will be greater the closer an open-cut mine is to the stream. On-site water retention minimises the chances of any runoff from the mining operations or infrastructure being contaminated and released to the surface water catchment or watercourse. Therefore, any runoff that is naturally generated within the mining operations area is lost to streamflow and the environment. After mining ceases mine-site rehabilitation occurs and, at some stage following this activity, some proportion of the rehabilitated land area will again become connected to the wider surface water catchment.

The spatial context, hazards (impact modes and activities) and hydrological effects associated with the ‘Surface water drainage’ causal pathway group are shown in Figure 37. The cumulative effects on natural surface drainage in the subregion are likely to have medium to long term cumulative effects on watercourses within, upstream and downstream of tenements.

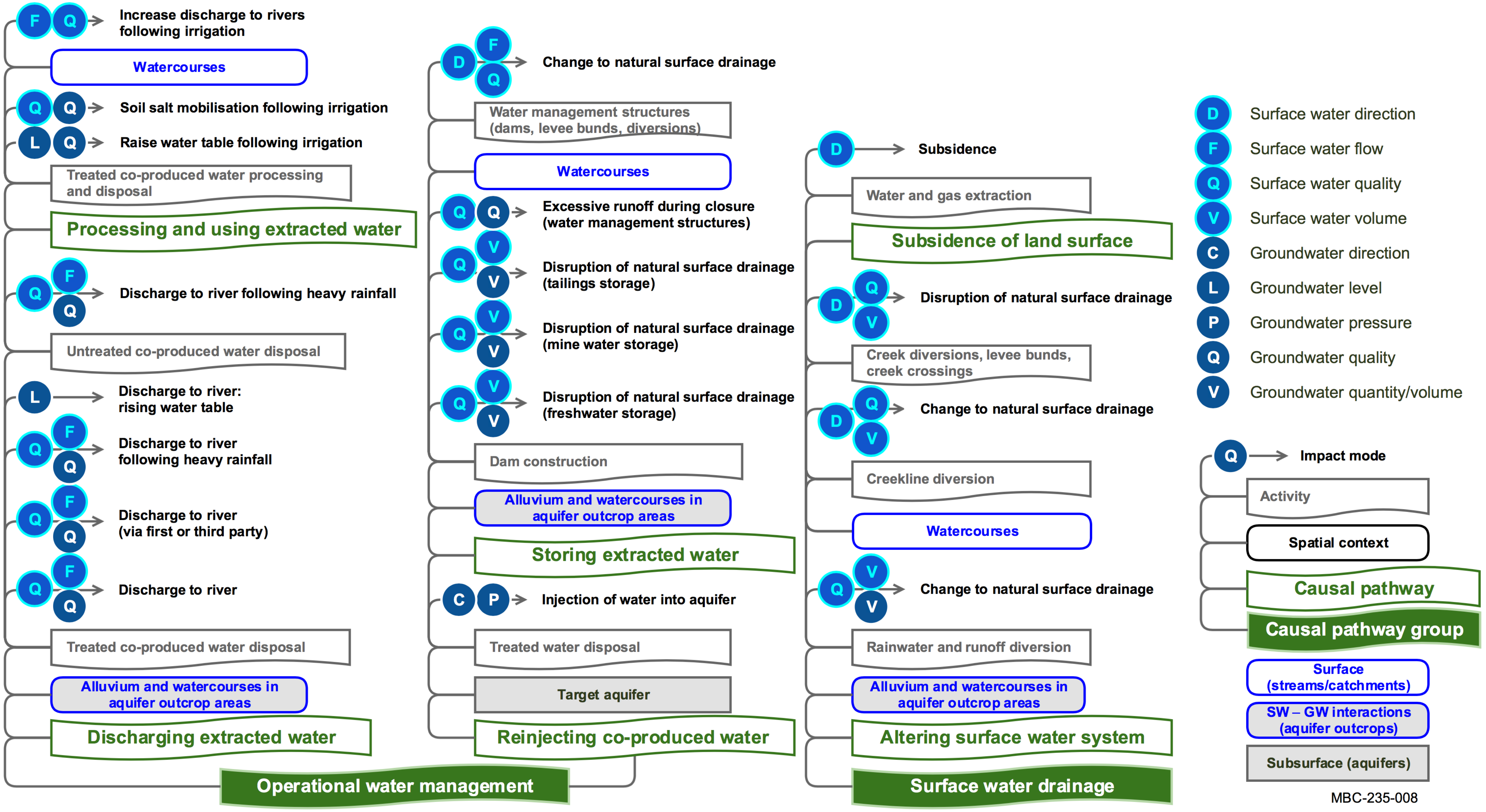

Figure 37 'Surface water drainage' and 'Operational water management' causal pathway groups arising from coal seam gas operations and open-cut coal mines

GW = groundwater, SW = surface water
Typology and punctuation are consistent with the hazard analysis (Bioregional Assessment Programme, Dataset 1).

This figure has been optimised for printing on A3 paper (297 mm x 420 mm).

Operational water management

CSG operations remove water from the coal seam to release gas during the production stage. If the produced water is of poor quality it may require dilution with fresh water, or treatment to remove salts, gas and other contaminants sourced from the coal seam. Open-cut coal mines produce water of varying quantity and quality at different stages in the life of a mine. Operation water management includes activities related to sourcing water for on-site operations, storing extracted water, discharging extracted water into the surface water system, processing and using extracted water and reinjecting co-produced water into the aquifer.

Priorities for co-produced water disposal in the subregion are purposes that are beneficial to the environment, new water users, existing or new water-dependent industries. '…after feasible beneficial use options have been considered, treating and disposing CSG water in a way that firstly avoids, and then minimises and mitigates impacts on environmental values' (DEHP, 2012). In addition, Healthy Waters Management Plans that address water quality requirements of both the Queensland's *Environmental Protection Act 1994* legislation and the Commonwealth's *Basin Plan 2012* (MDBA, 2012) are currently being developed. The plans assess risks to water quality and identify water quality targets based on local data (including electrical conductivity, nutrients, turbidity, pH). The water quality targets are designed to assist in informing regulatory conditions on environmentally relevant activities such as CSG operations and coal mines.

Beneficial uses include water for site management such as dust suppression or washing, discharge to rivers for conveyance to beneficial uses and reinjection to depleted aquifers. Co-produced water that is disposed of locally via irrigation or release to rivers can affect water quality and quantity. Discharge of co-produced water to rivers and for irrigation can affect watertable levels and soil salt mobilisation along watercourses and near irrigation areas. Aquifer reinjection can increase groundwater pressures and change the volume and timing of groundwater discharge to springs and watercourses in aquifer outcrop areas. Reinjection can also change aquifer composition, with the extent of water quality changes being limited by local hydraulic properties (conductivity and storativity) and time.

Water management structures (dams, levee bunds and diversions) associated with open-cut coal mines can change natural surface drainage or cause excessive runoff during closure that has a cumulative effect on surface water and groundwater systems in the subregion. Upstream impacts that change watercourse geomorphology or create barriers to the migration of aquatic organisms are also possible. The location of watercourses potentially affected by the CRDP in the subregion are shown in Figure 36.

The spatial context, hazards (impact modes and activities) and hydrological effects associated with the 'Operational water management' causal pathway group are shown in Figure 37. Water management structures are likely to have medium- to long-term effects on surface water quality, direction and flow. 'Discharge to river' (impact mode) is likely to have episodic- to short-term effects on surface water flow and quality in the alluvium and watercourses in aquifer outcrop areas in the subregion. Changes to groundwater level and quality and surface water quality associated with 'discharge to river' and irrigation that raises the watertable and mobilises salt is likely to be episodic to short term and localised. Effects are likely to be in the medium to long term and include the alluvium and watercourses in aquifer outcrop areas that are within, upstream and downstream of tenements.

2.3.5.3.2 Causal pathways for the coal resource development pathway

This section describes the potential cumulative effects of the CRDP in the Maranoa-Balonne-Condamine subregion, which includes five baseline CSG operations, five baseline open-cut coal mines and two additional open-cut coal mines (New Acland Coal Mine Stage 3 and The Range). Coal resource development has the potential to affect aquifers, catchments and watercourses via the four main causal pathway groups discussed previously:

- ‘Subsurface depressurisation and dewatering’
- ‘Subsurface physical flow paths’
- ‘Surface water drainage’
- ‘Operational water management’.

‘Subsurface depressurisation and dewatering’ associated with the five baseline CSG operations, five baseline open-cut coal mines and two additional open-cut coal mines have the potential to directly affect the regional groundwater system, and indirectly affect surface water – groundwater interactions in aquifer outcrop areas. Cross-sections A to A’ in Figure 38 and B to B’ in Figure 39 (cross-section locations are shown in Section 2.3.2, Figure 8) illustrate the location and stratigraphy of aquifers near The Range coal mine. These cross-sections show that the cumulative effect of the baseline and additional coal resource developments near The Range is likely to extend beyond the tenements, potentially affecting connected aquifers and surface water systems. This may include a small portion of Quaternary alluvium associated with Dogwood Creek along the southern boundary. The cumulative effect of subsurface dewatering and depressurisation has the potential to affect groundwater discharge to springs and watercourse springs along the Dawson River (shown in Figure 39). Watertable level contours in the vicinity of The Range (Figure 40) indicate a groundwater flow divide within the proposed mine footprint that corresponds to the surface water divide and subregion boundary. This means that local-scale changes to groundwater flow directions associated with dewatering or operational water management could occur to both the east and west of the mine. Cross-section A to A’ (Figure 38) shows that the Walloon Coal Measures dip in a south-westerly direction away from The Range coal mine, which indicates the potential for interactions with surficial Quaternary and Cenozoic alluvial systems near the mine and with the Springbok Sandstone further to the south. This is consistent with the location of the Springbok Sandstone to the west of the mine shown in cross-section B to B’ (Figure 39).

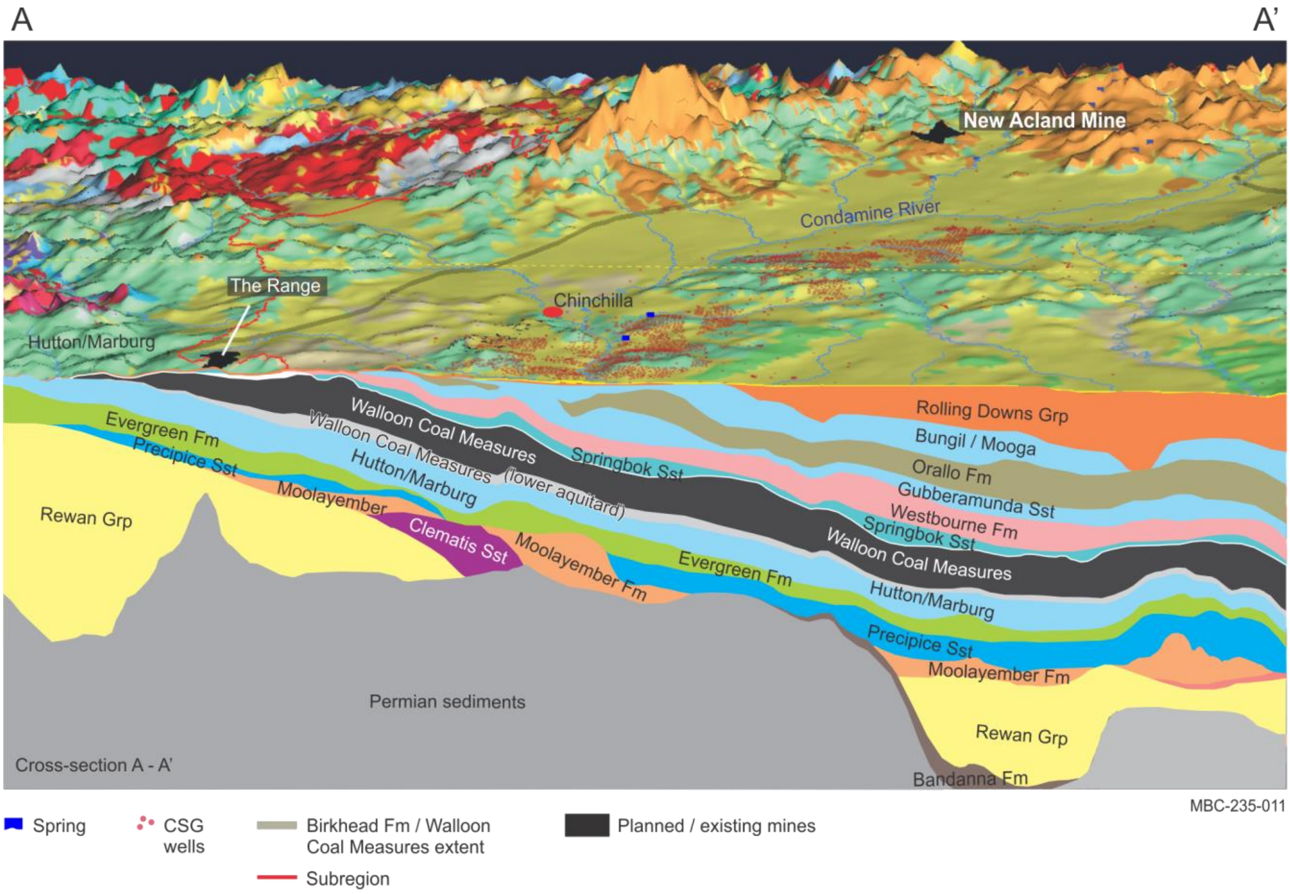

Figure 38 Cross-section A to A', facing east, shows The Range coal mine relative to surface geology and underlying Office of Groundwater Impact Assessment (OGIA) groundwater model layers

Also shown is the location of the New Acland Mine.
CSG = coal seam gas, Fm = Formation, WCM = Walloon Coal Measures
Data: Bioregional Assessment Programme (Dataset 6), Geoscience Australia (Dataset 7), Department of Natural Resources and Mines (Dataset 8, Dataset 12), Office of Groundwater Impact Assessment (Dataset 11)

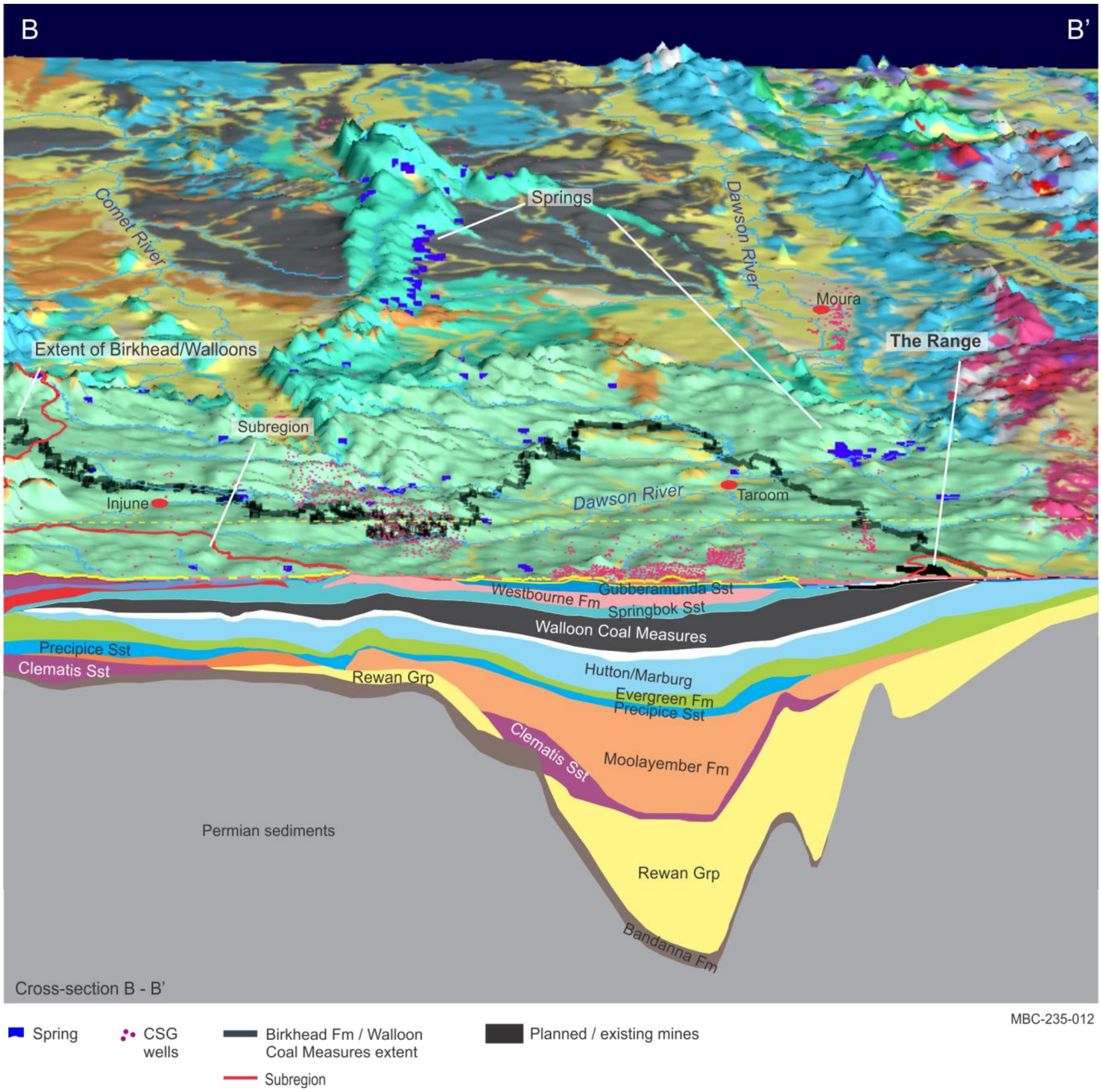

Figure 39 Cross-section B to B’, facing north, shows The Range coal mine relative to surface geology and underlying Office of Groundwater Impact Assessment (OGIA) groundwater model layers

CSG = coal seam gas, Fm = Formation, Sst = Sandstone
Data: Bioregional Assessment Programme (Dataset 6), Geoscience Australia (Dataset 7), Department of Natural Resources and Mines (Dataset 8, Dataset 12), Office of Groundwater Impact Assessment (Dataset 11)

Deep soil drainage and surface water – groundwater interactions in aquifer outcrop areas can also be affected by coal mining. Figure 40 shows the relationship of The Range coal mine footprint relative to the surface geology mapping.

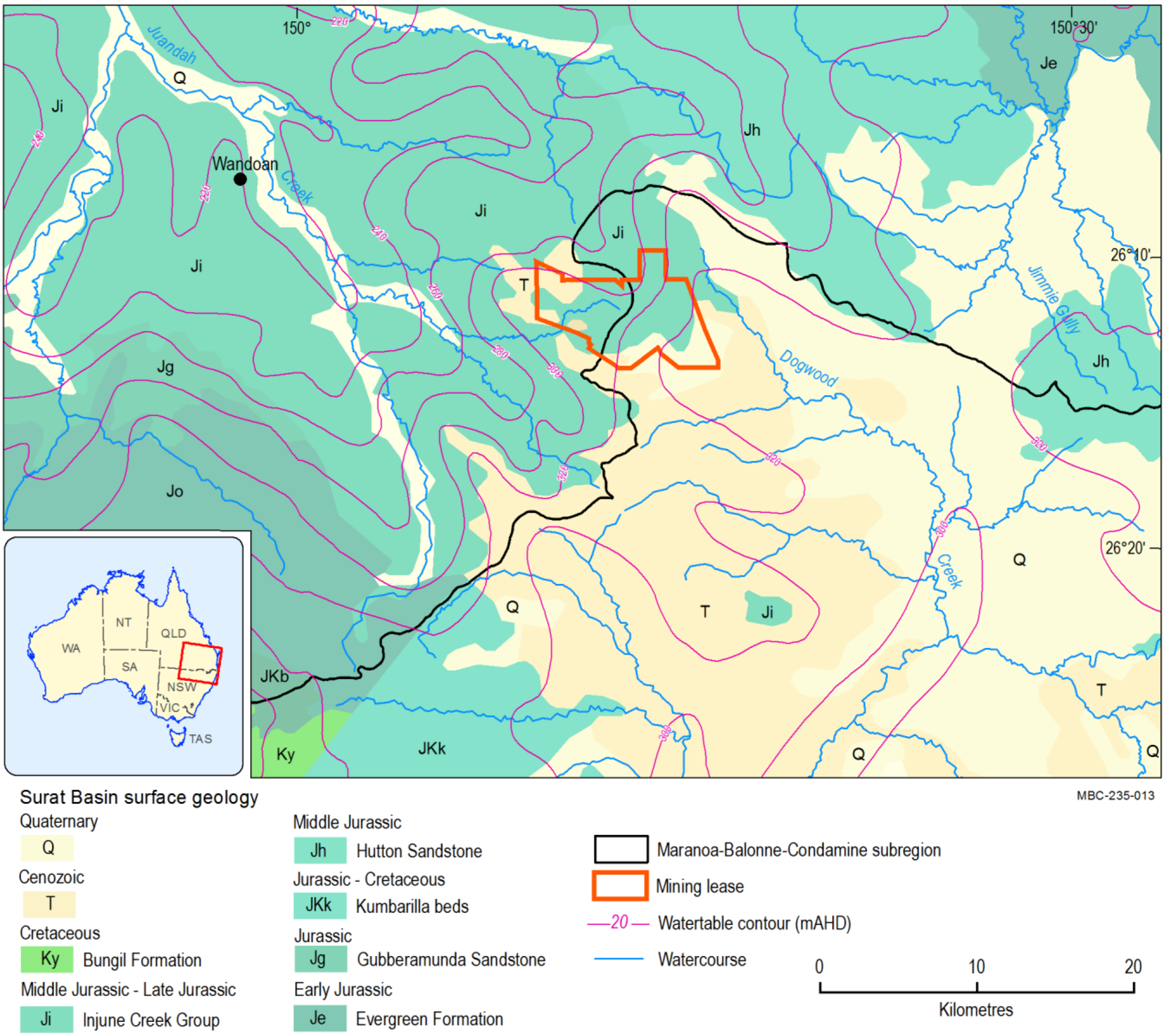

Figure 40 Location of The Range coal mine footprint boundary relative to surface geology, watertable contours and watercourses

Data: Geoscience Australia (Dataset 9), Department of Natural Resources and Mines (Dataset 10, Dataset 12)

Expansion of New Acland Coal Mine for Stage 3 has the potential to directly affect the regional groundwater system, and indirectly affect surface water-groundwater interactions in connected aquifer outcrop areas. The New Acland Coal Mine is located in the north-eastern surficial extent of the Walloon Coal Measures, surrounded by the Main Range Volcanics and up gradient of the Condamine Alluvium as shown in cross-section C to C’ (Figure 41) and D to D’ (Figure 42). The Condamine Alluvium and Main Range Volcanic aquifers are important water sources for irrigation, stock and domestic and town water supplies.

Surface water flows from elevated areas around the New Acland Coal Mine in a westerly direction to the flatter landscape of the Condamine Alluvium. Groundwater flow is also from east to west along the westward-dipping geological layers (see Section 2.3.2, Figure 8). The footprint of the New Acland Coal Mine Stage 3 overlies outcropping Walloon Coal Measures as well as Main Range Volcanics and Cenozoic units (Figure 43). Disturbance caused by the mine has the potential to affect Lagoon Creek, a tributary to Oakey Creek that flows through the mine footprint. Disturbance to the Cenozoic cover has the potential to affect Cain Creek to the north, and Doctor Creek to the south of the mine.

Three spring complexes that are associated with the Main Range Volcanics aquifer are located within 20 km of the New Acland Coal Mine. Two of the spring complexes are down gradient from the mine, including the non-GAB Bowenville Springs complex. The cumulative effect of subsurface dewatering and depressurisation in the Walloon Coal Measures for mining and CSG operations has the potential to indirectly affect groundwater discharge to springs and watercourse springs that flow towards the Condamine Alluvium.

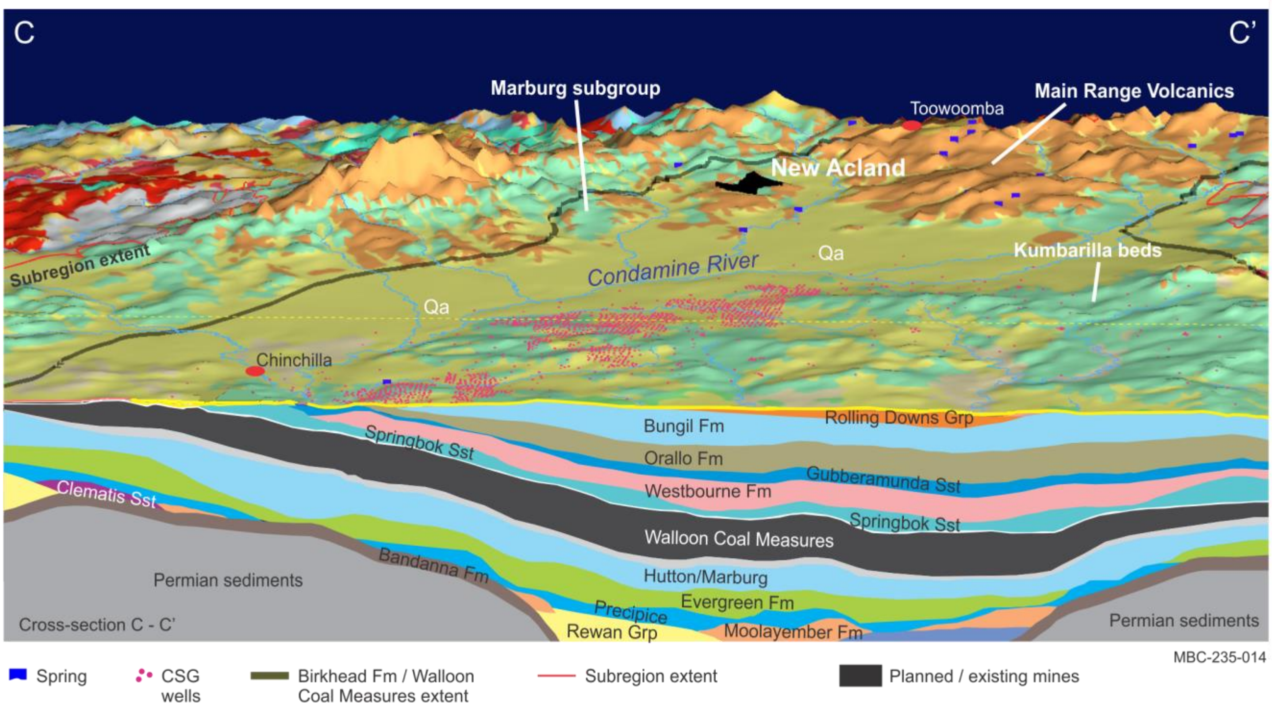

Figure 41 Cross-section C to C’, facing east, shows New Acland Coal Mine, surface geology and underlying Office of Groundwater Impact Assessment (OGIA) groundwater model layers

Note the surficial extent of the Birkhead Formation/Walloon Coal Measures near the New Acland Coal Mine
CSG = coal seam gas, Fm = Formation, Grp = Group, Qa = Quaternary deposits, Sst = Sandstone
Data: Bioregional Assessment Programme (Dataset 6), Geoscience Australia (Dataset 7), Department of Natural Resources and Mines (Dataset 8, Dataset 12), Office of Groundwater Impact Assessment (Dataset 11)

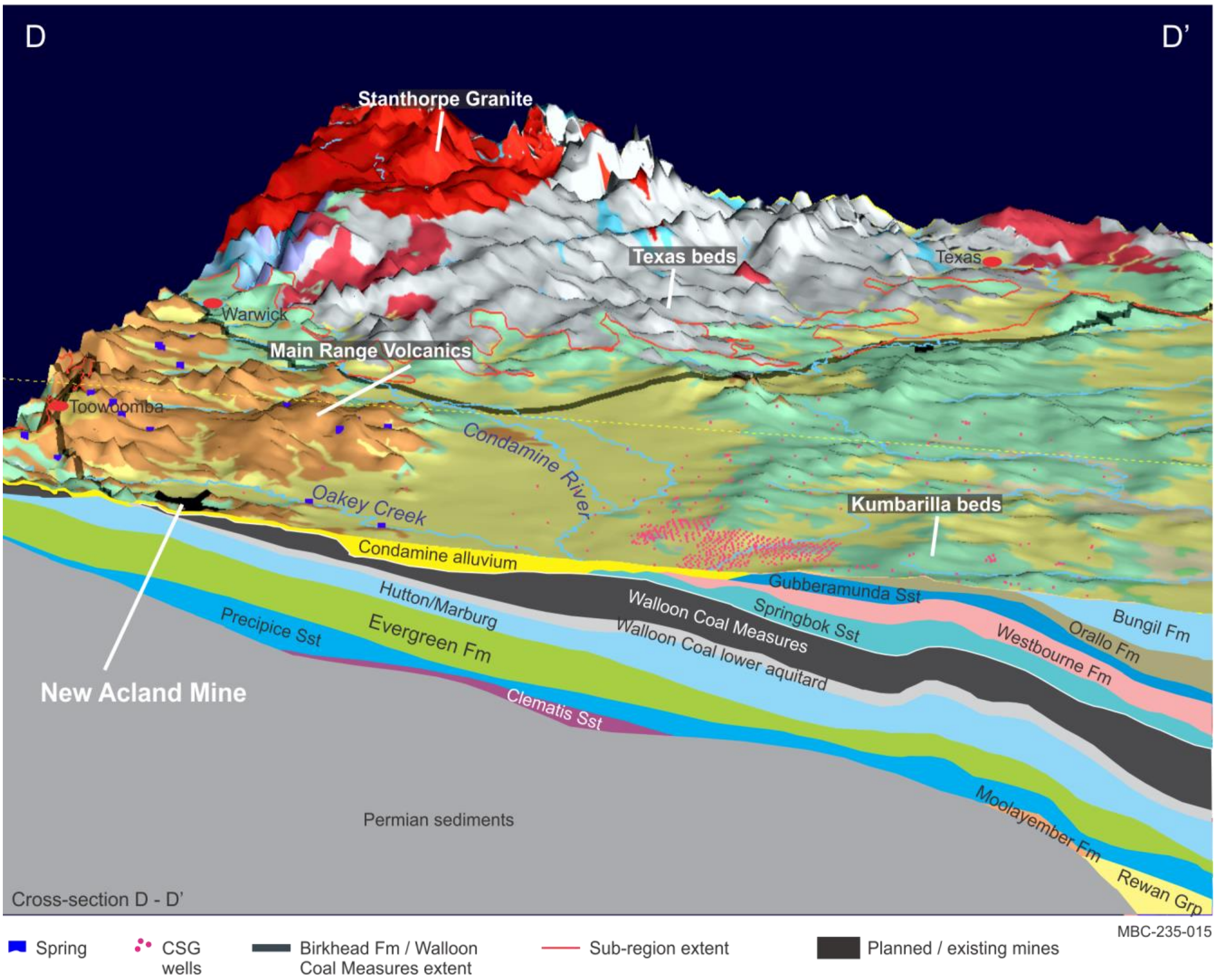

Figure 42 Cross-section D to D’, facing south, shows the New Acland Coal Mine relative to surface geology and underlying Office of Groundwater Impact Assessment (OGIA) groundwater model layers

CSG = coal seam gas, Fm = Formation, Grp = Group, Sst = Sandstone
Data: Bioregional Assessment Programme (Dataset 6), Geoscience Australia (Dataset 7), Department of Natural Resources and Mines (Dataset 8, Dataset 12), Office of Groundwater Impact Assessment (Dataset 11)

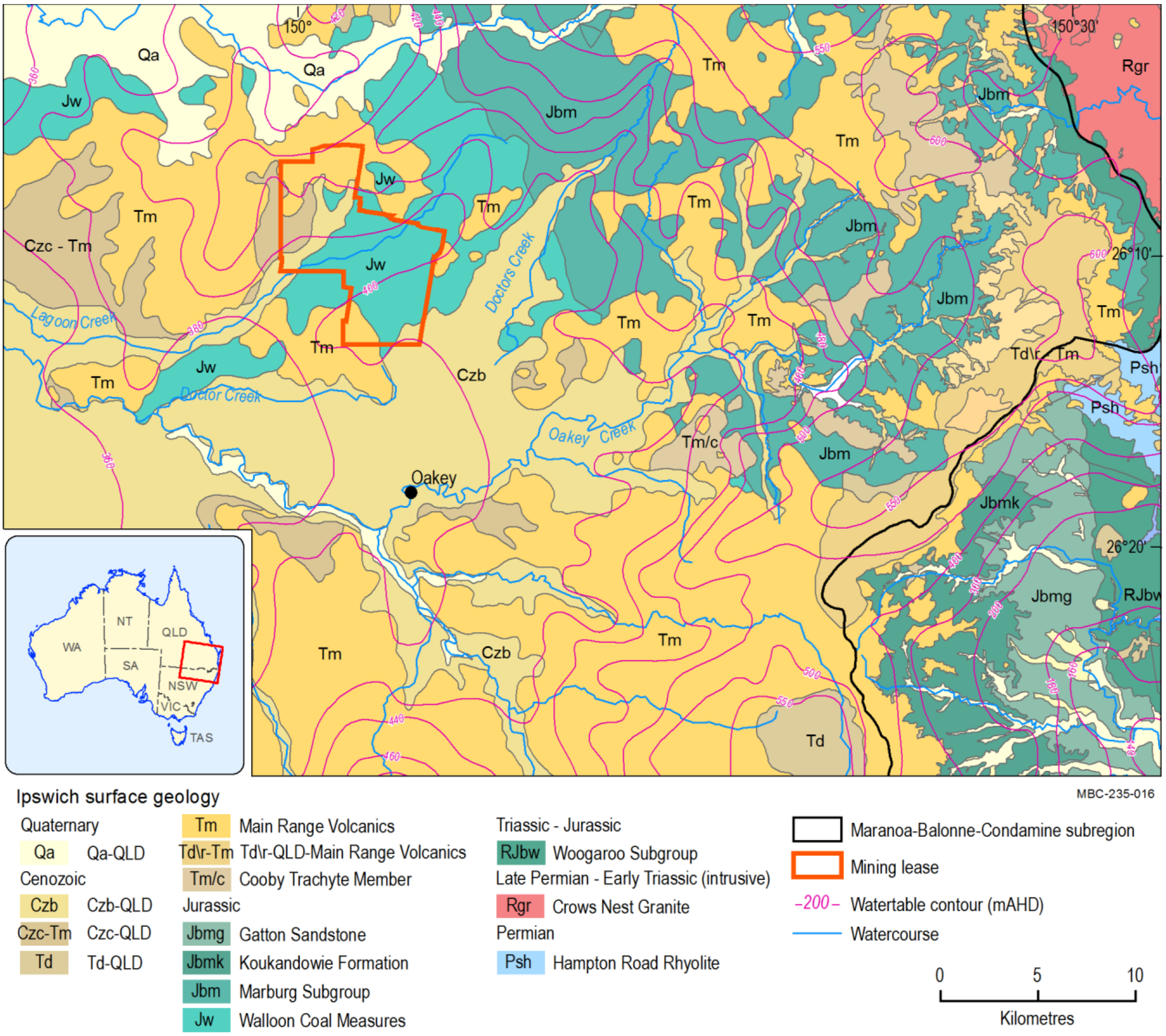

Figure 43 Location of the New Acland Coal Mine Stage 3 footprint relative to surface geology, watertable contours and watercourses

Data: Geoscience Australia (Dataset 9), Department of Natural Resources and Mines (Dataset 10, Dataset 12)

Table 17 summarises the main causal pathway groups linking coal resource development to potentially affected parts of the Maranoa-Balonne-Condamine subregion. The table shows that open-cut coal mines and CSG operations that affect ‘subsurface depressurisation and dewatering’ (thus reducing groundwater pressures) can have widespread effects in connected aquifers, and indirectly affect surface water – groundwater interactions in aquifer outcrop areas. Changes to ‘Subsurface physical flow paths’ are likely to be localised within an aquifer or aquifer outcrop area within tenements, but can affect watercourses within and downstream of tenements. The area affected by ‘surface water drainage’ depends on the development location and can potentially affect watercourses within and downstream of tenements. Similarly, the area affected by ‘Operational water management’ depends on the location and geological setting of water management structures and disposal infrastructure. This causal pathway group can potentially affect the alluvium and watercourses in aquifer outcrop areas within and downstream of tenements.

Table 17 Causal pathway groups arising from open-cut coal mines and coal seam gas operations for baseline coal resource development (baseline) and coal resource development pathway (CRDP)

Both the baseline and the CRDP include open-cut coal mines and coal seam gas operations, and therefore the causal pathway groups are the same for both.

Type of coal resource development	Causal pathway group	Baseline coal resource development	Coal resource development pathway	Spatial context
Open-cut coal mines	Subsurface depressurisation and dewatering	Yes	Yes	Aquifers
	Subsurface physical flow paths	Yes	Yes	Aquifers within tenements Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements
	Surface water drainage	Yes	Yes	Watercourses within and downstream of tenements
	Operational water management	Yes	Yes	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements
Coal seam gas operations	Subsurface depressurisation and dewatering	Yes	Yes	Aquifers
	Subsurface physical flow paths	Yes	Yes	Aquifers within tenements Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements
	Surface water drainage	Yes	Yes	Watercourses within and downstream of tenements
	Operational water management	Yes	Yes	Alluvium and watercourses in aquifer outcrop areas within and downstream of tenements

2.3.5.4 Gaps

Knowledge of the location of subterranean faults and fractures of the geological layers that can affect flow paths is the greatest knowledge gap. This means it is more difficult to identify where even the largest faults can affect the 'Subsurface depressurisation and dewatering' and 'Subsurface physical flow paths' causal pathway groups. For example, the location of faults in the subregion and their nature, location and extent of smaller potential pathways between adjacent layers is not known at a regional scale. This means that uncertainty exists in the precise spatial extent of groundwater level decline due to CSG operations. However, the uncertainty analysis undertaken for the numerical groundwater modelling does allow a probabilistic estimate of maximum groundwater level decline, as described in the groundwater numerical modelling (companion product 2.6.2 for the Maranoa-Balonne-Condamine subregion (Janardhanan et al., 2016)).

The availability of long-term, consistent water quality and water quantity data measurements of surface water and groundwater systems limits the value of developing a coupled surface water-groundwater numerical model in the Maranoa-Balonne-Condamine subregion for BA at this time. Data availability issues will be addressed through the assessment of risks to water quality and identification of water quality targets based on local data (including electrical conductivity, nutrients, turbidity, pH) in the development of the Healthy Waters Management Plans under Queensland's *Environmental Protection Act 1994* legislation and the Commonwealth's *Basin Plan 2012* (MDBA, 2012). The water quality targets developed for the plans will assist in informing regulatory conditions on environmentally relevant activities such as CSG operations and coal mines.

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Datasets

Dataset 1 Bioregional Assessment Programme (2015) Impact Modes and Effects Analysis for the MBC subregion. Bioregional Assessment Source Dataset. Viewed 25 February 2016, http://data.bioregionalassessments.gov.au/dataset/e338c1b2-359f-428a-959f-a4f65900ca04.

Dataset 2 Geoscience Australia (2015) Great Artesian Basin - Hydrogeology and Extent Boundary. Bioregional Assessment Source Dataset. Viewed 10 February 2016, http://data.bioregionalassessments.gov.au/dataset/020957ea-4877-4009-872c-3cacfb6f8ded.

Dataset 3 Office of Groundwater Impact Assessment (2012) MBC Surat UWIR Bungil-Mooga extent. Bioregional Assessment Source Dataset. Viewed 16 February 2016, http://data.bioregionalassessments.gov.au/dataset/31d47938-f033-481b-9804-bd033f0a8f09.

Dataset 4 Office of Groundwater Impact Assessment (2012) MBC Surat UWIR Condamine alluvium extent. Bioregional Assessment Source Dataset. Viewed 01 March 2016, http://data.bioregionalassessments.gov.au/dataset/687347f8-90ed-444a-aa4e-560bbd79561d.

Dataset 5 Bioregional Assessment Programme (2015) MBC Potentially affected watercourses. Bioregional Assessment Derived Dataset. Viewed 19 February 2016, http://data.bioregionalassessments.gov.au/dataset/2d1b8127-b602-4e60-b6ab-d7d505702e0d.

Dataset 6 Bioregional Assessment Programme (2015) MBC Groundwater model. Bioregional Assessment Derived Dataset. Viewed 10 February 2016, http://data.bioregionalassessments.gov.au/dataset/6fe25546-a6ca-44fc-a101-51b1758e2890.

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Dataset 8 Department of Natural Resources and Mines (2014) Queensland Coal Seam Gas well locations - 14/08/2014. Bioregional Assessment Source Dataset. Viewed 18 February 2016, http://data.bioregionalassessments.gov.au/dataset/88028a0b-7c1e-4b70-8217-abc2c536e6c4.

Dataset 9 Geoscience Australia (2013) Water table elevation of the Great Artesian Basin (GABWRA). Bioregional Assessment Source Dataset. Viewed 29 February 2016, http://data.bioregionalassessments.gov.au/dataset/08f01dba-ec93-4c00-8e29-2b25a1948a33.

Dataset 10 Geological Survey of Queensland, Department of Natural Resources and Mines (2012) QLD Geological Digital Data - QLD Geology, Structural Framework, November 2012. Bioregional Assessment Source Dataset. Viewed 01 March 2016, http://data.bioregionalassessments.gov.au/dataset/a841bdfd-376c-4c7b-afd4-e92aba991f06.

Dataset 11 Office of Groundwater Impact Assessment (2015) Spring vents assessed for the Surat Underground Water Impact Report 2012. Bioregional Assessment Source Dataset. Viewed 27 August 2015, http://data.bioregionalassessments.gov.au/dataset/6d2b59fc-e312-4c89-9f10-e1f1b20a7a6d.

Dataset 12 Department of Natural Resources and Mines (2014) QLD Mining Lease 20140516. Bioregional Assessment Source Dataset. Viewed 26 February 2016, http://data.bioregionalassessments.gov.au/dataset/bb75dd72-ff3a-43bd-b160-9722e323a492.

Glossary

The register of terms and definitions used in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/glossary (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

activity: for the purposes of Impact Modes and Effects Analysis (IMEA), a planned event associated with a coal seam gas (CSG) operation or coal mine. For example, activities during the production life-cycle stage in a CSG operation include drilling and coring, ground-based geophysics and surface core testing. Activities are grouped into components, which are grouped into life-cycle stages.

additional coal resource development: all coal mines and coal seam gas (CSG) fields, including expansions of baseline operations, that are expected to begin commercial production after December 2012

aquitard: a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

asset: an entity that has value to the community and, for bioregional assessment purposes, is associated with a subregion or bioregion. Technically, an asset is a store of value and may be managed and/or used to maintain and/or produce further value. Each asset will have many values associated with it and they can be measured from a range of perspectives; for example, the values of a wetland can be measured from ecological, sociocultural and economic perspectives.

baseline coal resource development: a future that includes all coal mines and coal seam gas (CSG) fields that are commercially producing as of December 2012

bioregion: a geographic land area within which coal seam gas (CSG) and/or coal mining developments are taking place, or could take place, and for which bioregional assessments (BAs) are conducted

bioregional assessment: 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 coal mining development on water resources. The central purpose of bioregional assessments is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of coal seam gas and coal mining development.

bore: a narrow, artificially constructed hole or cavity used to intercept, collect or store water from an aquifer, or to passively observe or collect groundwater information. Also known as a borehole or piezometer.

causal pathway: for the purposes of bioregional assessments, the logical chain of events either planned or unplanned that link coal resource development and potential impacts on water and water-dependent assets

coal resource development pathway: a future that includes all coal mines and coal seam gas (CSG) fields that are in the baseline as well as those that are expected to begin commercial production after December 2012

component: for the purposes of Impact Modes and Effects Analysis (IMEA), a group of activities associated with a coal seam gas (CSG) operation or coal mine. For example, components during the development life-cycle stage of a coal mine include developing the mine infrastructure, the open pit, surface facilities and underground facilities. Components are grouped into life-cycle stages.

conceptual model: abstraction or simplification of reality

connectivity: a descriptive measure of the interaction between water bodies (groundwater and/or surface water)

consequence: synonym of impact

context: the circumstances that form the setting for an event, statement or idea

cumulative impact: for the purposes of bioregional assessments, the total change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered

current controls: the methods or actions currently planned, or in place, to detect hazards when they occur or to reduce the likelihood and/or consequences of these hazards should they occur

dataset: a collection of data in files, databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file). In the BA Repository, datasets are guaranteed to have a metadata record in the Metadata Catalogue and to have their components (files, database interface) delivered via the Data Store. In semantic web terms, a BA dataset is defined as a subclass of DCAT Dataset and PROMS Entity and is described in the BA Ontology as a scope note in term record.

detection score: for the purposes of Impact Modes and Effects Analysis (IMEA), the expected time to discover a hazard, scored in such a way that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the expected time (measured in days) to discover it

direct impact: for the purposes of bioregional assessments, a change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments without intervening agents or pathways

discharge: water that moves from a groundwater body to the ground surface or surface water body (e.g. a river or lake) diversion: see extraction

ecosystem: a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit. Note: Ecosystems include those that are human-influenced such as rural and urban ecosystems (i.e. humans are regarded as part of nature).

effect: for the purposes of Impact Modes and Effects Analysis (IMEA), change in the quantity or quality of surface water or groundwater. An effect is a specific type of an impact (any change resulting from prior events).

extraction: the removal of water for use from waterways or aquifers (including storages) by pumping or gravity channels

formation: rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time

Geofabric: a nationally consistent series of interrelated spatial datasets defining hierarchically-nested river basins, stream segments, hydrological networks and associated cartography

groundwater: water occurring naturally below ground level (whether in an aquifer or other low permeability material), or water occurring at a place below ground that has been pumped, diverted or released to that place for storage there. This does not include water held in underground tanks, pipes or other works.

groundwater-dependent ecosystem: ecosystems that rely on groundwater - typically the natural discharge of groundwater - for their existence and health

groundwater recharge: replenishment of groundwater by natural infiltration of surface water (precipitation, runoff), or artificially via infiltration lakes or injection

groundwater system: see water system

hazard: an event, or chain of events, that might result in an effect (change in the quality or quantity of surface water or groundwater)

hazard priority number: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of severity score, likelihood score and detection score.

hazard score: for the purposes of Impact Modes and Effects Analysis (IMEA), one of two ranking systems that indicate the relative importance of a hazard. It is the sum of the severity score and likelihood score.

hydrogeology: the study of groundwater, including flow in aquifers, groundwater resource evaluation, and the chemistry of interactions between water and rock

hydrological response variable: a hydrological characteristic of the system that potentially changes due to coal resource development (for example, drawdown or the annual streamflow volume) impact: a change resulting from prior events, at any stage in a chain of events or a causal pathway. An impact might be equivalent to an effect (change in the quality or quantity of surface water or groundwater), or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

impact cause: an activity (or aspect of an activity) that initiates a hazardous chain of events

impact mode: the manner in which a hazardous chain of events (initiated by an impact cause) could result in an effect (change in the quality or quantity of surface water or groundwater). There might be multiple impact modes for each activity or chain of events.

Impact Modes and Effects Analysis: a systematic hazard identification and prioritisation technique based on Failure Modes and Effects Analysis

indirect impact: for the purposes of bioregional assessments, a change in water resources and water-dependent assets resulting from coal seam gas and coal mining developments with one or more intervening agents or pathways

inflow: surface water runoff and deep drainage to groundwater (groundwater recharge) and transfers into the water system (both surface water and groundwater) for a defined area

landscape class: for bioregional assessment (BA) purposes, an ecosystem with characteristics that are expected to respond similarly to changes in the groundwater and/or surface water due to coal resource development. They are present on the landscape across the entire BA subregion or bioregion and their spatial coverage is exhaustive and non-overlapping. Conceptually, landscape classes can be considered as types of ecosystem assets.

life-cycle stage: one of five stages of operations in coal resource development considered as part of the Impact Modes and Effects Analysis(IMEA). For coal seam gas(CSG) operations these are exploration and appraisal, construction, production, work-over and decommissioning. For coal mines these are exploration and appraisal, development, production, closure and rehabilitation. Each life-cycle stage is further divided into components, which are further divided into activities.

likelihood: probability that something might happen

likelihood score: for the purposes of Impact Modes and Effects Analysis (IMEA), the annual probability of a hazard occurring, which is scored so that a one-unit increase (or decrease) in score indicates a ten-fold increase (or decrease) in the probability of occurrence

permeability: the measure of the ability of a rock, soil or sediment to yield or transmit a fluid. The magnitude of permeability depends largely on the porosity and the interconnectivity of pores and spaces in the ground.

preliminary assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed

receptor: a point in the landscape where water-related impacts on assets are assessed receptor impact variable: the characteristics of the system that, according to the conceptual modelling, potentially change due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)

receptor register: a simple and authoritative list of receptors in a specific bioregional assessment

recharge: see groundwater recharge

risk: the effect of uncertainty on objectives

runoff: rainfall that does not infiltrate the ground or evaporate to the atmosphere. This water flows down a slope and enters surface water systems.

saturated zone: the part of the ground in which all the voids in the rocks or soil are filled with water. The watertable is the top of the saturated zone in an unconfined aquifer.

severity: magnitude of an impact

severity score: for the purposes of Impact Modes and Effects Analysis (IMEA), the magnitude of the impact resulting from a hazard, which is scored so that an increase (or decrease) in score indicates an increase (or decrease) in the magnitude of the impact

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme. This includes data sourced from the Programme partner organisations.

spring: a naturally occurring discharge of groundwater flowing out of the ground, often forming a small stream or pool of water. Typically, it represents the point at which the watertable intersects ground level.

stratigraphy: stratified (layered) rocks

stressor: chemical or biological agent, environmental condition or external stimulus that might contribute to an impact mode

subcrop: 1 - A subsurface outcrop, e.g. where a formation intersects a subsurface plane such as an unconformity. 2 - In mining, any near-surface development of a rock or orebody, usually beneath superficial material.

subregion: an identified area wholly contained within a bioregion that enables convenient presentation of outputs of a bioregional assessment (BA)

surface water: water that flows over land and in watercourses or artificial channels and can be captured, stored and supplemented from dams and reservoirs

uncertainty: the state, even partial, of deficiency of information related to understanding or knowledge of an event, its consequence, or likelihood. For the purposes of bioregional assessments, uncertainty includes: the variation caused by natural fluctuations or heterogeneity; the incomplete knowledge or understanding of the system under consideration; and the simplification or abstraction of the system in the conceptual and numerical models

unsaturated zone: the zone in soils and rocks occurring above the watertable, where there is some air within the pore spaces water-dependent asset: an asset potentially impacted, either positively or negatively, by changes in the groundwater and/or surface water regime due to coal resource development

water system: a system that is hydrologically connected and described at the level desired for management purposes (e.g. subcatchment, catchment, basin or drainage division, or groundwater management unit, subaquifer, aquifer, groundwater basin)

water use: the volume of water diverted from a stream, extracted from groundwater, or transferred to another area for use It is not representative of 'on-farm' or 'town' use; rather it represents the volume taken from the environment

watertable: the upper surface of a body of groundwater occurring in an unconfined aquifer. At the watertable, pore water pressure equals atmospheric pressure.

well: typically a narrow diameter hole drilled into the earth for the purposes of exploring, evaluating or recovering various natural resources, such as hydrocarbons (oil and gas) or water. As part of the drilling and construction process the well can be encased by materials such as steel and cement, or it may be uncased. Wells are sometimes known as a ‘wellbore’.

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