Australian Government

BIOREGIONAL ASSESSMENTS

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

Assessing impacts of coal resource development on water resources in the Hunter subregion: key findings

Product 5: Outcome synthesis for the Hunter subregion from the Northern Sydney Basin Bioregional Assessment

2018

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

Hunter assessment at a glance

This bioregional assessment considered the potential cumulative impacts on water and water-dependent assets due to 22 additional coal resource developments in the Hunter subregion in NSW (Figure 1). The assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets, identifying where potential changes in water resources and ecosystems may occur, and ruling out areas where impacts are *very unlikely*. Governments, industry and the community can then focus on the areas that are potentially impacted and apply local-scale modelling when making regulatory, water management and planning decisions.

HEADLINE FINDING

Regional-scale modelling indicates potential risks to Wyong River, Loders Creek, Saddlers Creek and Wollars Creek. Using more detailed local information significantly reduced modelled risk to the Wyong River. Other streams were not modelled using local data.

Groundwater: An area of 1879 km^2 potentially experiences cumulative groundwater impacts due to baseline and additional coal resource developments. *See page 11*

Surface water: Regional-scale modelling indicates potentially large changes in flow regime in Wyong River, Loders Creek, Saddlers Creek and Wollars Creek. *See page 15*

Ecosystem impacts: The zone of potential hydrological change includes 102 km^2 of groundwater-dependent ecosystems – predominantly rainforests, forested wetlands, and wet and dry sclerophyll forests. *See page 18*

Asset impacts: Reductions in water availability in the Hunter River at Greta are *very likely* to exceed 5 GL per year, but are *very unlikely* to exceed 12 GL per year, over the period from 2013 to 2042. *See page 24*

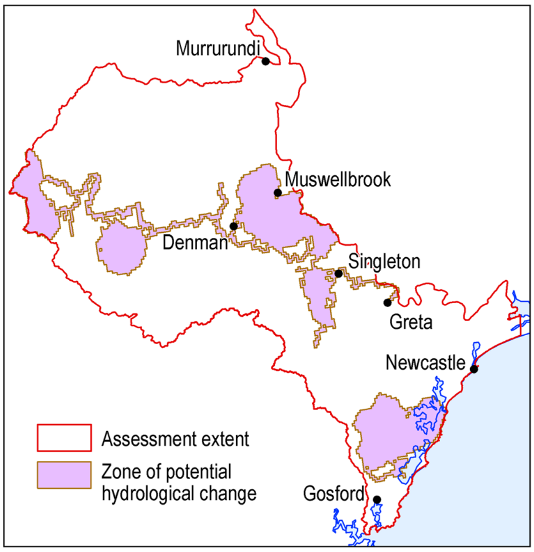

Figure 1 The zone of potential hydrological change

The pink zone (defined further in Box 4) was developed to show where efforts to identify potential impacts should be focused. Impacts are ruled out in areas outside this zone, which combines:

- the area with at least a 5% chance of exceeding 0.2 m drawdown due to additional coal resource development
- the area with at least a 5% chance of exceeding changes in specified surface water characteristics that arise due to additional coal resource development.

Data: Bioregional Assessment Programme (Dataset 1)

BASELINE COAL RESOURCE DEVELOPMENTS (BOX 1)

42 x mines, 0 x CSG

ADDITIONAL COAL RESOURCE DEVELOPMENTS (BOX 1)

22 x mines, 0 x CSG

Throughout this synthesis, the term ‘*very likely*’ is used where modelling predicts a greater than 95% chance of something occurring, and ‘*very unlikely*’ is used where modelling predicts a less than 5% chance (Box 5).

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COVER PHOTOGRAPH

© Google earth (2015), Sinclair Knight Merz Imagery date 16 December 2008. Position 32°17’58’’ S, 150°48’51’’ E, elevation 136 m, eye altitude 1.59 km

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Executive summary

About the subregion *see page 3*

The Hunter subregion is part of the Northern Sydney Basin bioregion and includes the major coastal cities of Newcastle and Gosford-Wyong (Figure 2). It is known for its coal mining, power generation, equine and viticulture industries. It includes two Ramsar-listed wetlands and contains part of the Greater Blue Mountains World Heritage Area. The total area investigated for this assessment (the **assessment extent**) is the same as the subregion extent, which covers 17,045 km^2.

Potential hydrological changes *see page 11*

Regional-scale hydrological modelling identified changes in groundwater and streamflow due to coal resource development for two futures (Box 1). The **baseline** future comprises 42 mines (22 open-cut and 20 underground) that were operating in December 2012. The **coal resource development pathway** (Box 1) was the most likely future for the subregion (as of September 2015) and includes the baseline developments plus 22 **additional coal resource developments**: 4 new open-cut mines, 2 new underground mines and 16 expansions to existing operations. Surface water and/or groundwater modelling were not undertaken for a small number of these developments. No coal seam gas (CSG) developments exist or are proposed in the subregion.

Additional coal resource development could lead to 19% of the assessment extent experiencing hydrological changes that exceed defined thresholds (Box 4). Outside this **zone of potential hydrological change**, hydrological changes are not significant, and hence impacts are *very unlikely* (less than 5% chance).

Modelling indicates potentially large changes in flow regime in Wyong River, Loders Creek, Saddlers Creek, Wollar Creek and a number of ephemeral creeks (Figure 12). Fourteen percent, or 2441 km^2, of the assessment extent has at least a 5% chance of greater than 0.2 m drawdown in the regional watertable due to additional coal resource development. Modelling of the Wyong River using local-scale data indicates that large changes in the flow regime are unlikely in that river.

Potential impacts *see pages 18 and 24*

The two Ramsar-listed wetlands are outside the zone of potential hydrological change and so are *very unlikely* to be impacted.

Potentially impacted ecosystems in the zone include 102 km^2 of groundwater-dependent ecosystems (GDEs) (predominantly rainforests, forested wetlands, and wet and dry sclerophyll forests), and 634 km of perennial and 518 km of intermittent streams.

Modelled changes in ecologically important flows indicate a higher risk to the condition of riverine forested wetlands along the Goulburn River compared to other riverine forested wetlands in the subregion.

Changes in water availability in the Hunter Regulated River at Greta are *very likely* (greater than 95% chance) to exceed 5 GL per year, but *very unlikely* to exceed 12 GL per year, over the period 2013 to 2042.

Drawdowns exceeding 2 m due to additional coal resource development are *very likely* for 13 bores. The number of water supply bores where drawdown exceeds 2 m is *very unlikely* to be more than 170. Under the *NSW Aquifer Interference Policy*, 'make good' provisions could apply to licensed water holders affected by drawdowns of greater than 2 m. More detailed site-specific studies are needed to review the predicted changes in areas where regional-scale modelling indicates a high probability of large drawdowns.

Almost 140 km^2 of the Greater Blue Mountains World Heritage Area is within the zone but most is not predicted to be impacted because it supports vegetation that does not depend on groundwater. About 1.5 km^2 of forested wetland in this World Heritage Area could be affected by drawdown due to additional coal resource development.

Box 1 Investigating two futures

Results are reported for two potential futures:

- **baseline coal resource development (baseline):** a future that includes all coal mines that were commercially producing as of December 2012
- **coal resource development pathway:** a future that includes all coal mines that are in the baseline as well as the **additional coal resource development** (those developments that were expected to begin commercial production after December 2012, including expansions of baseline operations).

The difference in results between the coal resource development pathway and baseline is the change that is primarily reported in a bioregional assessment. This change is due to additional coal resource development.

The coal resource development pathway for the Hunter subregion was based on information available as of September 2015. However, coal resource developments may change over time or be withdrawn (e.g. in February 2017, the NSW Planning and Assessment Commission rejected the Drayton South Coal Project for the fourth time), or timing of developments may change. Factors such as climate change or land use were held constant between the two futures. Although actual climate or land use may differ, the effect on results is expected to be minimal as the assessment focused on the difference in the results between the coal resource development pathway and baseline.

Explore this assessment

Bioregional assessments are independent scientific assessments of the potential cumulative impacts of CSG and coal mining developments on water resources and water-dependent assets such as rivers, wetlands and groundwater systems. These regional-scale assessments focus on 13 areas across Queensland, NSW, Victoria and SA where coal resource development is taking place, or could take place.

The assessments rule out areas where impacts on water resources and water-dependent assets are *very unlikely* (a less than 5% chance). The zone of potential hydrological change (Box 4) identifies where potential impacts cannot be ruled out. Because the models were developed for regional-scale assessments, they do not represent local-scale features, such as local aquitards. Thus results from bioregional assessments flag potentially impacted areas where governments, industry and the community may need to focus their attention and apply local-scale modelling when making regulatory, water management and planning decisions. This may result in substantially lower risks than those predicted by the regional data and models used in bioregional assessments.

The assessments investigate:

- the characteristics of the subregion, including water resources, assets, and coal and CSG resources (Component 1)
- how future coal resource development could affect surface water and groundwater (Component 2)
- how hydrological changes could impact on water-dependent ecosystems and assets (Component 3 and Component 4).

The full suite of impacts on water quality is not assessed, but the potential for changes in stream salinity is considered in light of the modelled hydrological changes, salinity hazard mapping and existing regulation and management.

The assessment of the **Hunter subregion,** which is part of the Northern Sydney Basin Bioregional Assessment, is reported in 12 technical products (Box 2), which are summarised in this synthesis.

FIND MORE INFORMATION

www.bioregionalassessments.gov.au includes all technical products as well as information about all datasets used or created, most of which can be downloaded from data.gov.au. Additional resources are listed in this synthesis, and include methodologies, maps, models and lists of water-dependent assets, ecosystems and potential hazards. Users can visualise where potential impacts might occur using a map-based interface in the BA Explorer, at www.bioregionalassessments.gov.au/explorer/HUN. References, further reading and datasets are listed at the end of this synthesis.

Box 2 Technical products for the Hunter subregion

Component 1: Contextual information

1.1 Context statement
1.2 Coal and coal seam gas resource assessment
1.3 Description of the water-dependent asset register
1.5 Current water accounts and water quality
1.6 Data register

Component 2: Model-data analysis

2.1-2.2 Observations analysis, statistical analysis and interpolation
2.3 Conceptual modelling
2.5 Water balance assessment
2.6.1 Surface water numerical modelling
2.6.2 Groundwater numerical modelling
2.7 Receptor impact modelling

Component 3 and Component 4: Impact and risk analysis

3-4 Impact and risk analysis

The pages of this synthesis follow this colour guide when describing the assessment outputs. Product 1.4 (receptor register) and product 2.4 (two- and three-dimensional visualisations) were not produced for any bioregional assessment as evolution of the methods rendered them obsolete.

CONTENTS OF THIS SYNTHESIS

About the subregion

In the Hunter subregion (Figure 2), the **assessment extent** (the total area investigated) is the same as the subregion extent, which covers 17,045 km^2. It includes a large part of the Hunter river basin and all of the Macquarie-Tuggerah lakes basin in NSW. Major population centres include Newcastle and Gosford-Wyong along the coast, with smaller urban areas inland, including Maitland, Cessnock, Singleton and Muswellbrook.

The dominant land use along the subregion coast is urban, while grazing, production forestry and nature conservation dominate the hinterland areas of Gosford and Wyong. Mining, irrigated agriculture, viticulture and horse breeding are economically important land uses in the Hunter river basin. Water users include the urban, power generation and coal mining sectors; agriculture; and the environment. Environmental water and access to water for consumptive use are managed through water sharing plans that specify extraction limits and water access rights to surface water and groundwater sources.

The Hunter subregion is of great ecological significance because it corresponds to a break in the Great Dividing Range that provides a link between coastal and inland NSW, and includes an overlap between tropical and temperate climate zones. It includes the Ramsar-listed Kooragang Nature Reserve and Hunter Wetland Centre Australia, 17 important wetlands, 6 threatened ecological communities, 7 Important Bird Areas, and 105 nationally listed flora and fauna species.

This assessment focused on water-dependent ecosystems and assets in the subregion that are potentially impacted by changes in groundwater or surface water regime due to coal resource development.

Ecosystems in the assessment extent were categorised through a landscape classification (Box 6), based on the subregion's geology, geomorphology (physical features), hydrogeology (the way water moves through porous rocks), land use and ecology. See 'What are the potential impacts of additional coal resource development on these ecosystems?' (page 18) for more information.

The community nominated assets that they consider important due to their ecological, economic or sociocultural values (Bioregional Assessment Programme, 2017; Macfarlane et al., 2016). These include ecosystems such as stream vegetation that provides habitat for frogs, groundwater used for agriculture, and sites of cultural significance. See 'What are the potential impacts of additional coal resource development on water-dependent assets?' (page 24) for more information.

Coal resource development

Key finding 1: The coal resource development pathway (Box 1) was deemed the most likely future for the subregion as of September 2015. It includes 42 coal mines that were in commercial production in December 2012, and 22 additional coal resource developments: 4 new open-cut mines, 2 new underground mines and 16 expansions to existing operations.

Coal mining has been occurring in the Hunter subregion since around 1800. In December 2012, there were 22 open-cut mines and 20 underground mines operating.

When the coal resource development pathway was finalised in September 2015, the additional coal resource developments included 22 proposals for new or expanded operations; ten other potential coal resource developments were considered too exploratory or unlikely to proceed and were not included in the additional coal resource development. There is no CSG production in the Hunter subregion, nor any proposals for CSG development in the future, although a couple of gas companies hold petroleum exploration licences in the subregion.

This assessment focused on the potential cumulative impact between 2013 and 2102 of additional coal resource developments. The timeline of construction and production for each coal resource development is shown in Figure 3. This figure also shows which developments were included in the quantitative modelling for the subregion. Some additional coal resource developments were not modelled at all (Austar underground, West Muswellbrook and Wambo), or were modelled using just the groundwater model (Chain Valley underground and Mandalong) or just the surface water model (Mount Arthur open-cut, Wilpinjong). More details can be found in the impact and risk analysis (Section 3.6 of Herron et al. (2018c)). Reasons for not modelling mines included insufficient data, scale of the proposed modifications, or mining under coastal lakes. Potential impacts from those non-modelled mines where hydrological changes are possible are discussed in Section 3.6 of Herron et al. (2018c).

The subregion straddles three of the five coalfields that make up the geological Sydney Basin (Figure 2). The Hunter and Newcastle coalfields contain the Greta Coal Measures, the Wittingham (Hunter Coalfield) and Tomago (Newcastle Coalfield) Coal Measures, and the Newcastle Coal Measures. The coal of economic interest in the Western Coalfield is in the Illawarra Coal Measures. Operations in the Newcastle Coalfield are predominantly underground, whereas the Hunter and Western coalfields contain a greater mix of underground and open-cut operations.

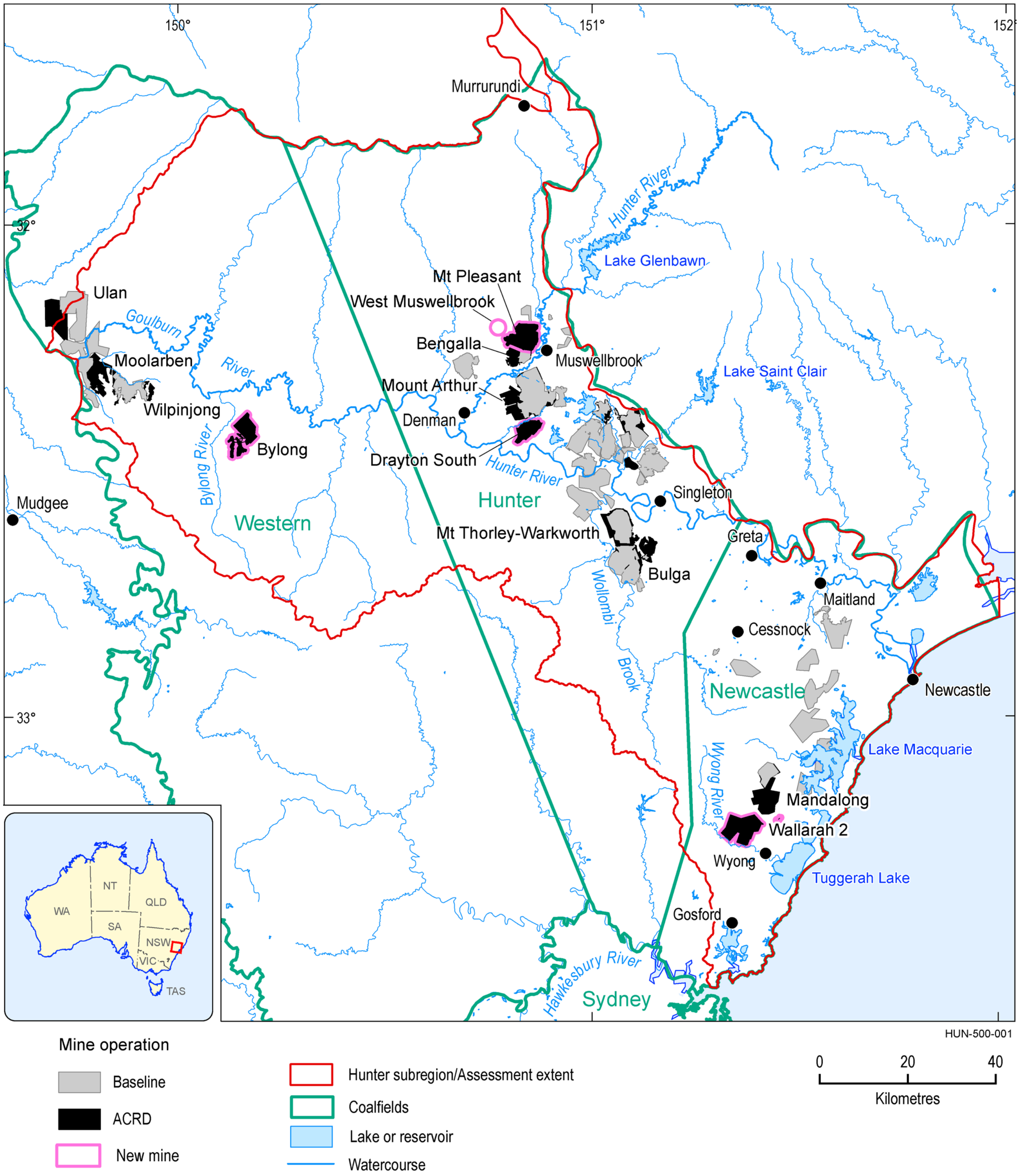

Figure 2 Mines in the coal resource development pathway in the three coalfields (Western, Hunter and Newcastle)

In the Hunter subregion, the assessment extent is the same as the subregion extent. Mines in the coal resource development pathway (CRDP) include baseline and additional coal resource developments (ACRD). Only mines referred to in the text are labelled.
Data: Bioregional Assessment Programme (Dataset 2, Dataset 3, Dataset 4)

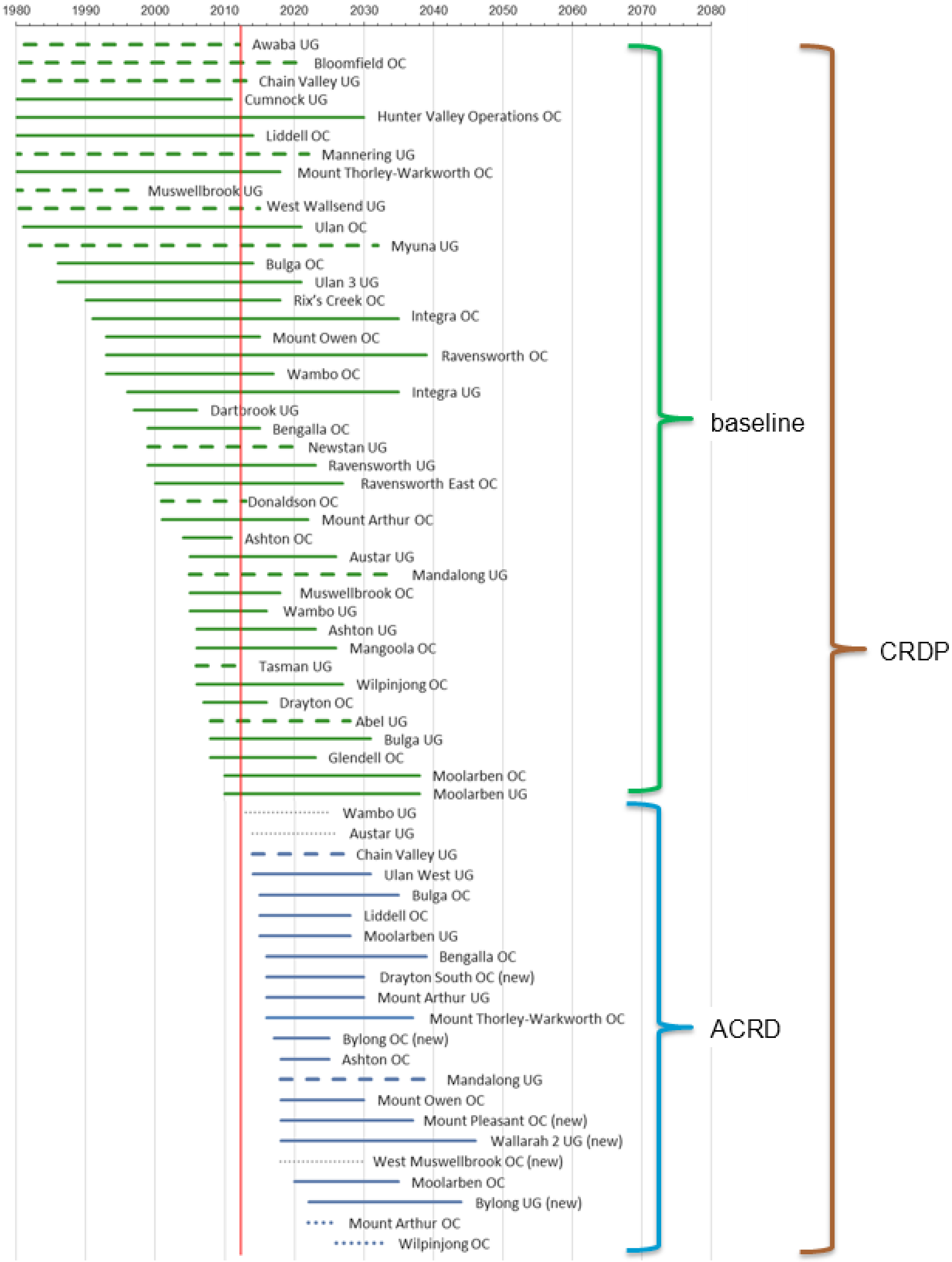

Figure 3 Timeline for coal resource developments in the coal resource development pathway

green = baseline as at December 2012, blue = additional coal resource development as of September 2015, red line = December 2012, light grey = not modelled, blue or green dashes = groundwater model only, blue dots = surface water model only, OC = open-cut, UG = underground
The dates reflect the expected period of coal extraction and may not coincide precisely with the dates used for mine pumping in the modelling. Mines in the coal resource development pathway include baseline and additional coal resource developments (ACRD).
Data: Bioregional Assessment Programme (Dataset 5)

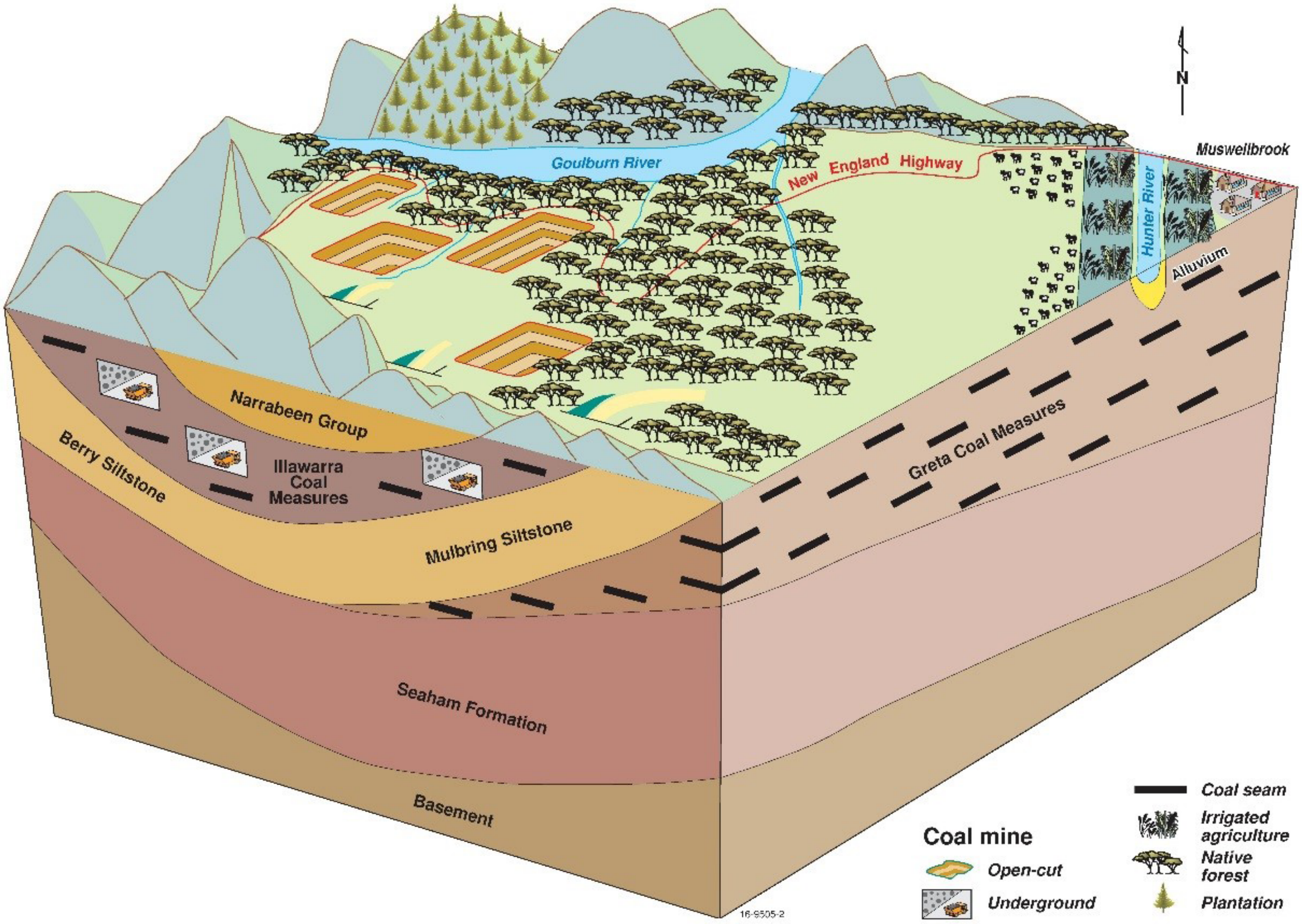

Figure 4 Regional geological model representing the Western Coalfield (west) to Hunter coalfield (east) in the Goulburn river basin in the west of the subregion

This section through the Goulburn river basin, just north of the Goulburn River, represents the area from Mudgee to Muswellbrook. The Berry Siltstone (Mulbring Siltstone in the Hunter Coalfield) is near the surface and provides an aquitard that moves water laterally and feeds surface springs and streams. Coal seams of the Illawarra Coal Measures are also near the surface in the west and subject to both open-cut and underground coal mine operations. In the east, the Greta Coal Measures become thicker and nearer to the land surface.
This block diagram is not to scale, but is representative based on the geological model.

Three regional-scale block diagrams illustrate coal resource development in the three major coalfields of the Hunter subregion: Western Coalfield (Figure 4), Hunter Coalfield (Figure 5) and Newcastle Coalfield (Figure 6).

More information about the coal and CSG resources, mines and proposed developments can be found in the coal and CSG resource assessment (Hodgkinson et al., 2015).

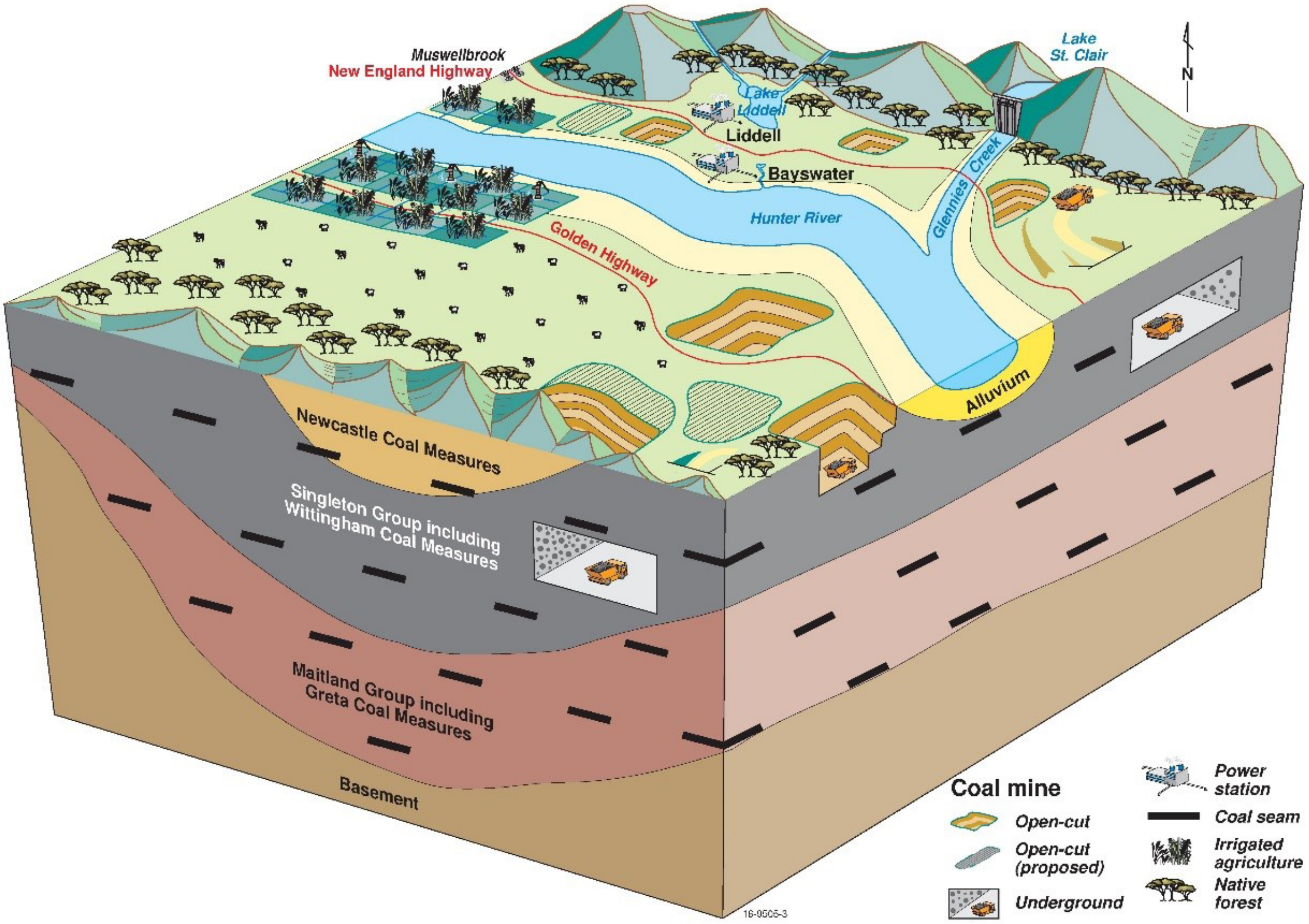

Figure 5 Regional geological model representing the Hunter Coalfield (shown in Figure 2) in the centre of the subregion

This area contains a high density of coal mine operations along the Hunter River, most of which target the Wittingham Coal Measures. The surface Hawkesbury Sandstone layers are absent when mapped at this scale, and the Wittingham Coal Measures are the thickest individual unit underlying the area, most of which is close to the surface.
This block diagram is not to scale, but is representative based on the geological model.

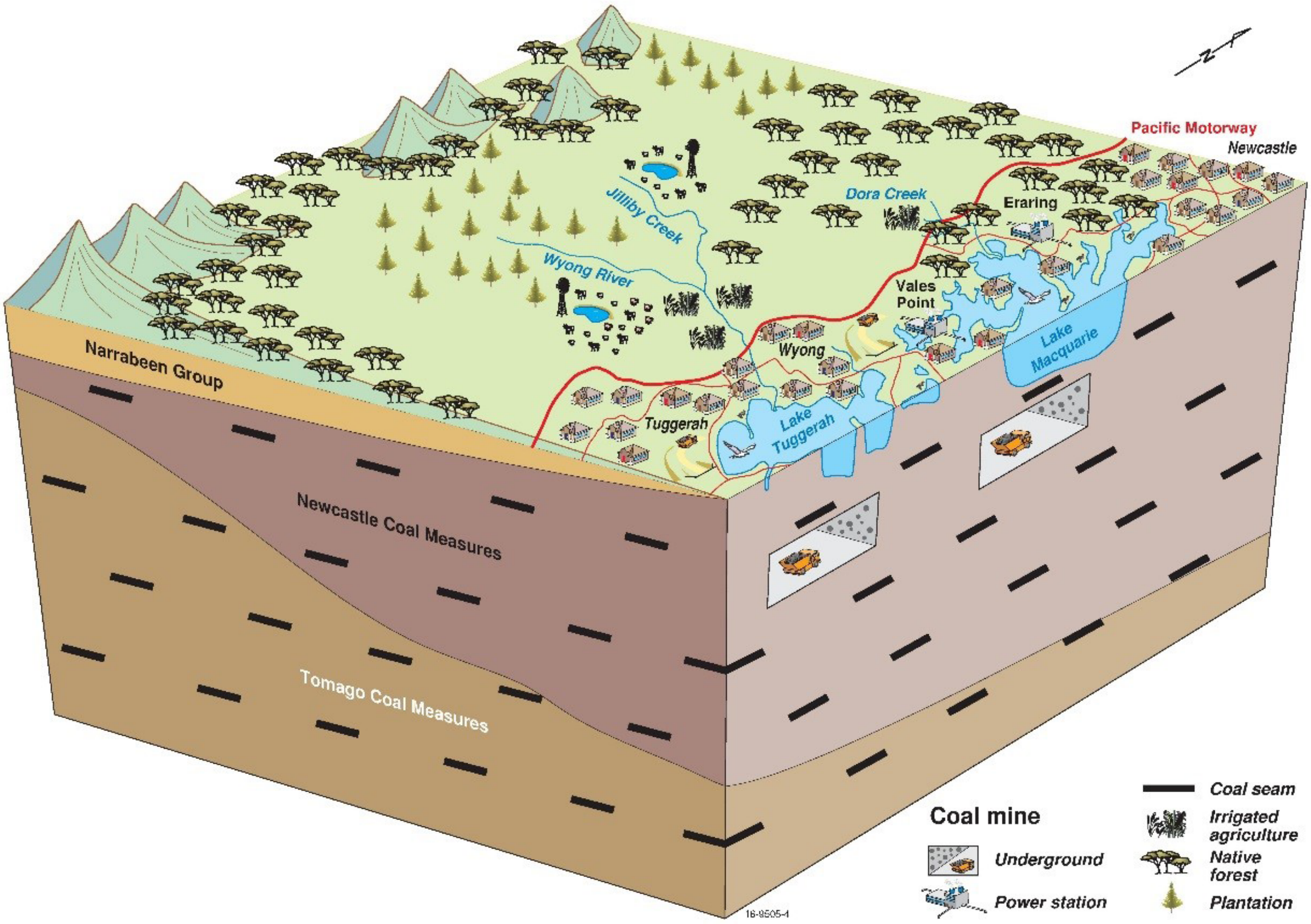

Figure 6 Regional geological model representing the Newcastle Coalfield (shown in Figure 2) on the coastline

This area contains predominantly underground mines near the coastal lake systems south of Newcastle. The Hawkesbury Sandstone (not shown) and Narrabeen Group form the uplands between river floodplains, with the Newcastle Coal Measures thickening towards the coast and the deeper Tomago Coal Measures thickening away from the coast.
This block diagram is not to scale, but is representative based on the geological model.

FIND MORE INFORMATION

Context statement, product 1.1 (McVicar et al., 2015)

Coal and coal seam gas resource assessment, product 1.2 (Hodgkinson et al., 2015)

Description of the water-dependent asset register, product 1.3 (Macfarlane et al., 2016)

Water-dependent asset register (Bioregional Assessment Programme, 2017)

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Compiling water-dependent assets, submethodology M02 (Mount et al., 2015)

Developing a coal resource development pathway, submethodology M04 (Lewis, 2014)

How could coal resource development result in hydrological changes?

The assessment identified potential hazards (Dataset 6) associated with coal mines that could result in hydrological changes, such as aquifer depressuriation due to groundwater extraction. In the Hunter subregion, waste rock blasting, excavation and storage, subsidence and subsurface fracturing from longwall mining and mine dewatering were identified as key hazards. Hazards in scope were further assessed by first estimating relevant hydrological changes through surface water and groundwater modelling and then identifying potential impacts on, and risks to, water-dependent ecosystems and assets (described in the following sections).

After the potential hazards were identified, the chain of events that commonly arise from coal resource development activities were analysed and categorised into four causal pathway groups (letters correspond to those in Figure 7):

A. **'Subsurface depressurisation and dewatering'** is triggered by extraction of groundwater to enable CSG extraction and dewatering of open-cut mine pits. This potentially directly affects the groundwater system, and indirectly affects surface water – groundwater interactions. Potential effects are likely to be in the short term (less than 5 years) for groundwater pressure changes, to long term (10 to 100s of years) for changes in groundwater movement or quality.

B. **'Subsurface physical flow paths'** are initiated by activities that cause physical changes to the rock mass or geological layers, resulting in new physical paths that water may potentially gain access to and flow along. Potential effects are in the medium (5 to 10 years) to long term and are likely to be restricted to aquifer or aquifer outcrop areas, but can also affect connected watercourses within and downstream of mines.

C. **'Surface water drainage'** starts with activities that physically disrupt the surface and near-surface materials (vegetation, topsoil, weathered rock). Medium- to long-term cumulative effects are possible for watercourses within and downstream of development. Activities may include construction of diversion walls and drains, interception of runoff, realignment of streams, and groundwater extraction for underground coal mining leading to subsidence of land surface.

D. **'Operational water management'** is triggered by modification of surface water systems to allow storage, disposal, processing and use of extracted water. Potential effects are likely to be in the medium to long term and include impacts on watercourses within and downstream of operations.

Many activities related to coal resource development may cause local or on-site changes to surface water or groundwater. These are not considered explicitly in bioregional assessments because they are assumed to be adequately managed by site-based risk management and mitigation procedures, and are unlikely to result in cumulative impacts.

Mine water use in NSW is regulated. Mines are required to prepare mine water management plans that identify environmental impacts and provide options for minimising impacts, hold licences for water extractions and discharges, and adhere to licence conditions intended to protect the environment on site and off site (see Section 2.3.4 in the conceptual modelling (Dawes et al., 2018)).

Although most of the regulatory framework is geared towards site-specific controls, the Hunter River Salinity Trading Scheme was introduced to manage the cumulative impacts on river salinity from discharges of water to the river from coal mines and power generators. Coal resource development can lead to changes in other water quality parameters in streams and aquifers, but these changes were not part of the scope of the bioregional assessments and their impacts have not been considered.

FIND MORE INFORMATION

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Herron et al., 2018d)

Developing the conceptual model for causal pathways, submethodology M05 (Henderson et al., 2016)

Systematic analysis of water-related hazards associated with coal resource development, submethodology M11 (Ford et al., 2017)

Impact Modes and Effects Analysis for the Hunter subregion (Dataset 6)

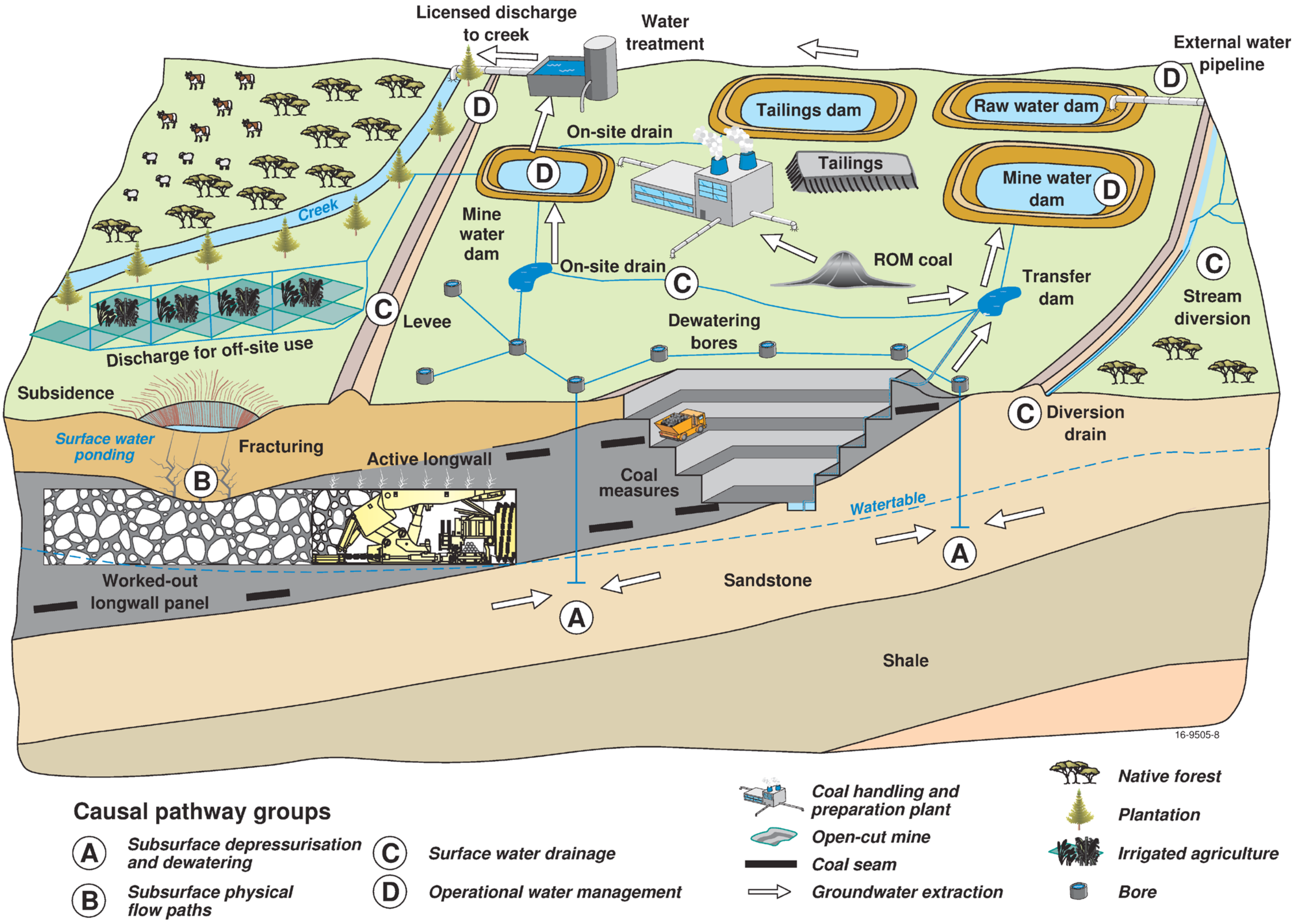

Figure 7 Conceptual diagram of the causal pathway groups associated with underground and open-cut coal mines for the Hunter subregion

This schematic diagram is not drawn to scale. ROM = run of mine

Box 3 Calculating groundwater drawdown

Drawdown is a lowering of the groundwater level, caused, for example, by pumping. The groundwater model modelled drawdown under the coal resource development pathway and drawdown under the baseline (**baseline drawdown**). The difference in drawdown between the coal resource development pathway and baseline (referred to as **additional drawdown**) is due to additional coal resource development. In a confined aquifer, drawdown relates to a change in water pressure and does not necessarily translate to changes in depth to the watertable.

The maximum drawdown over the course of the groundwater model simulation (from 2013 to 2102) is reported for each 1 km^2 grid cell individually, and is expected to occur at different times across the area assessed. It is not expected that the year of maximum baseline drawdown coincides with the year of maximum additional drawdown. Therefore, simply adding the two figures will result in a drawdown amount that is not expected to eventuate.

A mine pit exclusion zone was used to identify where the modelled estimates of drawdown were considered unreliable for use in the receptor impact modelling. It covers an area of 435 km^2 within the zone of potential hydrological change in the Hunter subregion. Drawdown is not reported inside this area.

What are the potential hydrological changes?

Potential hydrological changes due to additional coal resource development were modelled using regional-scale surface water and groundwater models. Potential impacts due to additional coal resource development are limited to the zone of potential hydrological change (Figure 1 and Box 4).

Key finding 2: The zone of potential hydrological change covers an area of 3213 km^2 (19% of the assessment extent) and includes 1228 km of streams (8% of streams in the assessment extent).

Groundwater

Key finding 3: The area with at least a 5% chance of at least 0.2 m of drawdown is 2441 km^2 for additional coal resource development (Figure 8) and 4307 km^2 for the baseline (Figure 9). The area of overlap (1879 km^2) potentially experiences cumulative groundwater impacts due to baseline and additional coal resource developments.

Results from regional-scale groundwater modelling indicate that drawdown (Box 3) of greater than 0.2 m due to the additional coal resource development in the subregion is *very likely* to occur at distances of up to 5 km from mine sites and *very unlikely* to occur at distances exceeding 20 km.

Groundwater model results indicate that additional drawdown greater than 5 m is *very likely* at Bylong, Mandalong, Ulan and Mount Arthur mine sites (Figure 17 and Figure 19 in Herron et al. (2018c)). Additional drawdown exceeding 5 m has at least a 50% chance of occurring at the Wallarah 2, Drayton South and Moolarben mine sites. Incorporating local-scale hydrogeological information into the analysis for the Wallarah mine 2 (which was carried out for only this mine) substantially reduced the risk of drawdown exceeding 5 m due to additional coal resource development (see Section 3.3 and Section 3.7 in Herron et al., 2018c).

The year of maximum groundwater change varies throughout the Hunter subregion. It most likely occurs during the decades after mining activity ceases, and occurs later with increasing distance from mine tenements.

Around West Muswellbrook, Wambo and Wilpinjong mines, which were not represented in the groundwater model, the modelled drawdowns could be underpredicted.

Box 4 The zone of potential hydrological change

A **zone of potential hydrological change** (Figure 1) was defined to rule out potential impacts. It was derived by combining the **groundwater zone of potential hydrological change** with the **surface water zone of potential hydrological change** (see Figure 15 and Figure 16 in Herron et al. (2018c)).

The groundwater zone is the area with at least a 5% chance of greater than 0.2 m drawdown (Box 3) due to additional coal resource development. This threshold is consistent with the most conservative minimal impact thresholds in NSW state regulations (which apply to Great Artesian Basin aquifers). Although this threshold does not apply in the Hunter subregion, it was applied here for consistency with other subregions in the Bioregional Assessment Programme. The groundwater zone was defined by changes in the regional watertable from which most ecological assets source water.

The surface water zone includes the streams with a change exceeding the defined threshold in at least one of nine surface water **hydrological response variables (see Table 6 of Herron et al. (2018c)).** The hydrological response variables represent different characteristics of the flow regime that could change due to coal resource development – for example, the annual flow volume or number of low-flow days. Changes in these variables could lead to impacts in ecosystems.

The zone of potential hydrological change defined where the impact and risk analysis focused (Herron et al., 2018c). Where the regional-scale modelling identified areas as potentially at risk of impacts, local-scale information is needed to better resolve the assessment of impact and risk to inform the management response.

Not all mines in the CRDP were included in the surface water and/or groundwater modelling (Figure 3). The potential hydrological changes from these developments are considered in the impact and risk analysis (Herron et al., 2018c). The inclusion of modelled hydrological changes from these developments would likely expand the zone of potential hydrological change in some areas and/or increase already modelled changes.

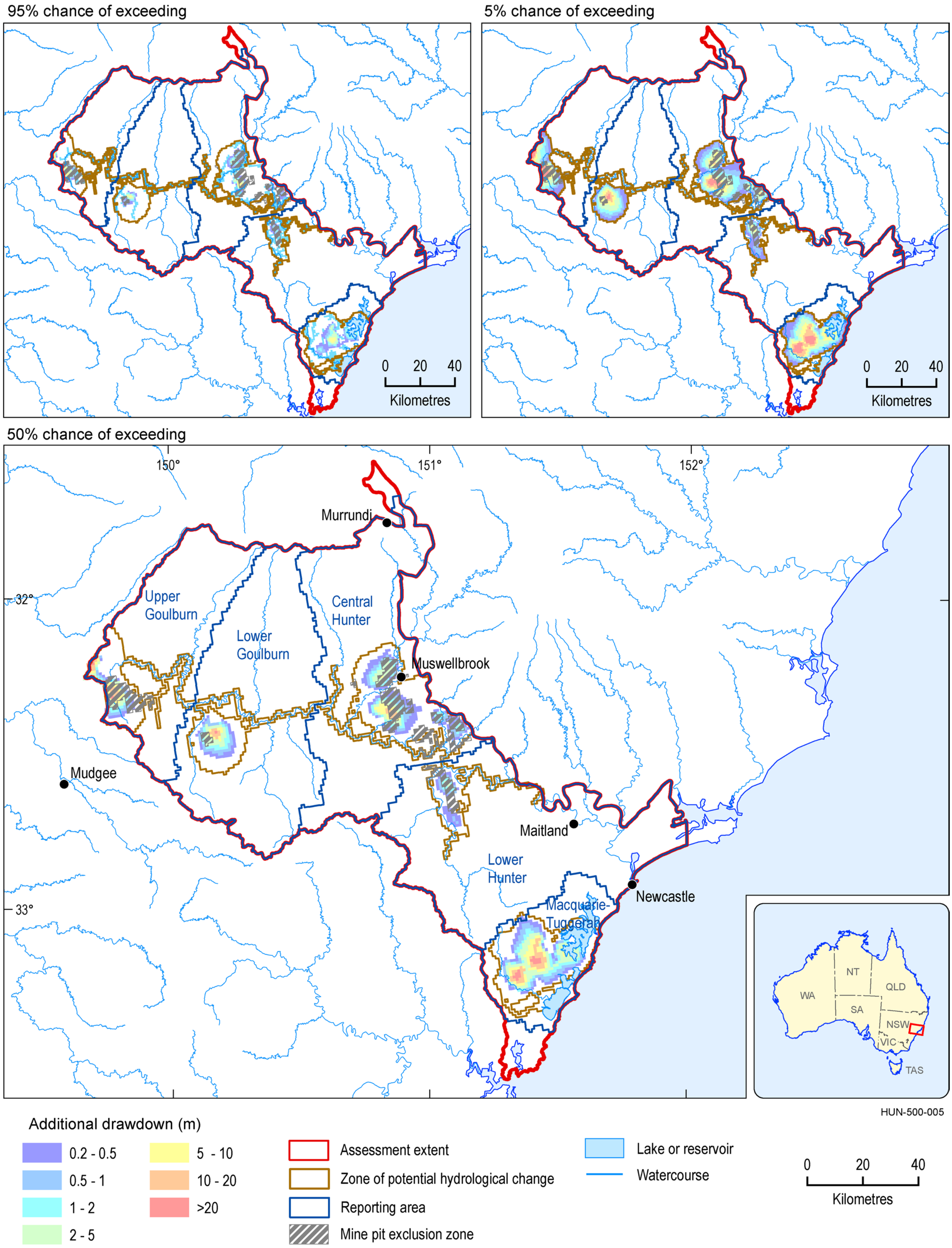

Figure 8 Additional drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

Additional drawdown is the maximum difference in drawdown between the coal resource development pathway and baseline, due to additional coal resource development (Box 3). Results are shown as percent chance of exceeding drawdown thresholds (Box 5). These appear in the impact and risk analysis (Herron et al., 2018c) as percentiles.

Data: Bioregional Assessment Programme (Dataset 1, Dataset 7, Dataset 8)

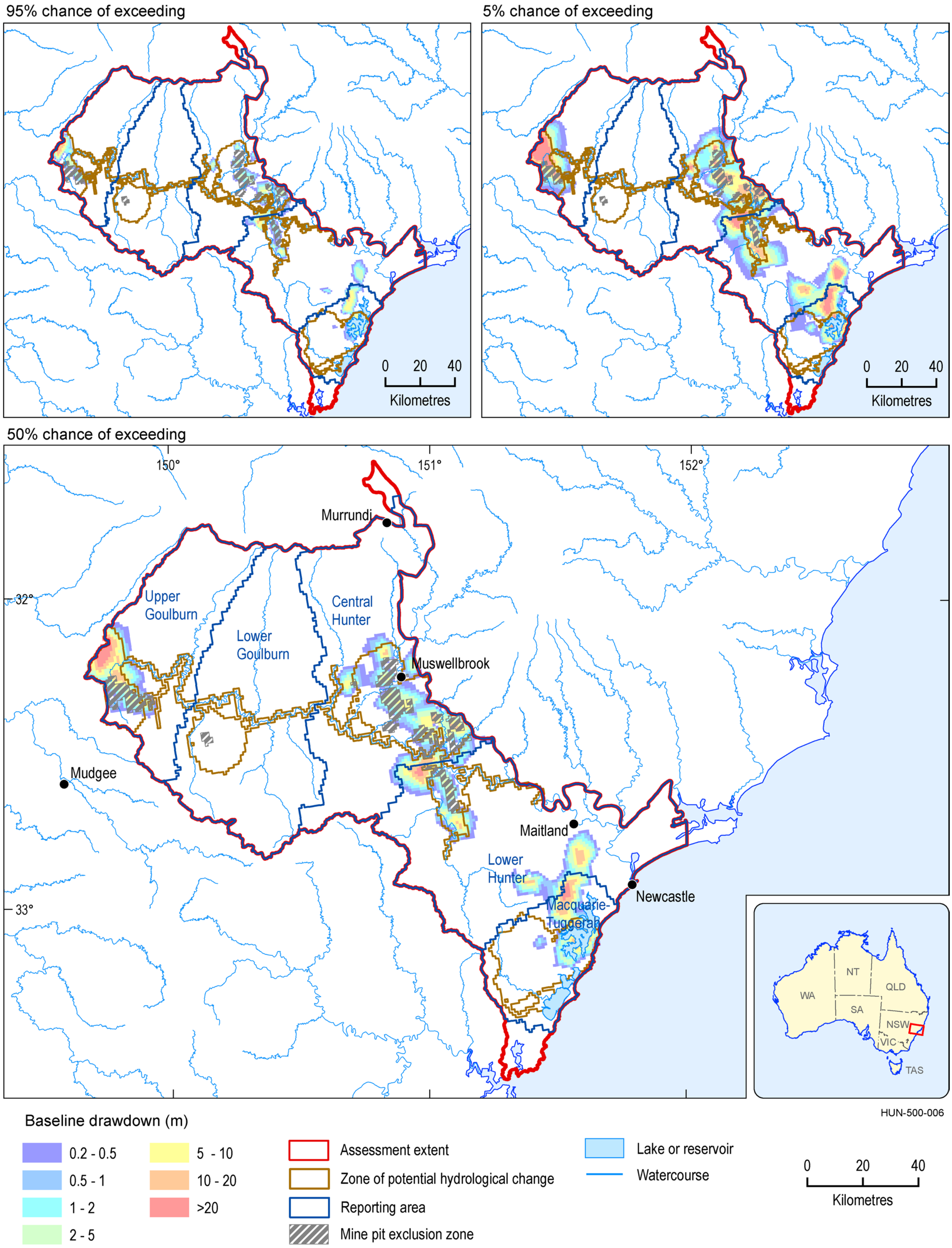

Figure 9 Baseline drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

Baseline drawdown is the maximum difference in drawdown under the baseline relative to no coal resource development (Box 3). Results are shown as percent chance of exceeding drawdown thresholds (Box 5). These appear in the impact and risk analysis (Herron et al., 2018c) as percentiles.
Data: Bioregional Assessment Programme (Dataset 1, Dataset 7, Dataset 8)

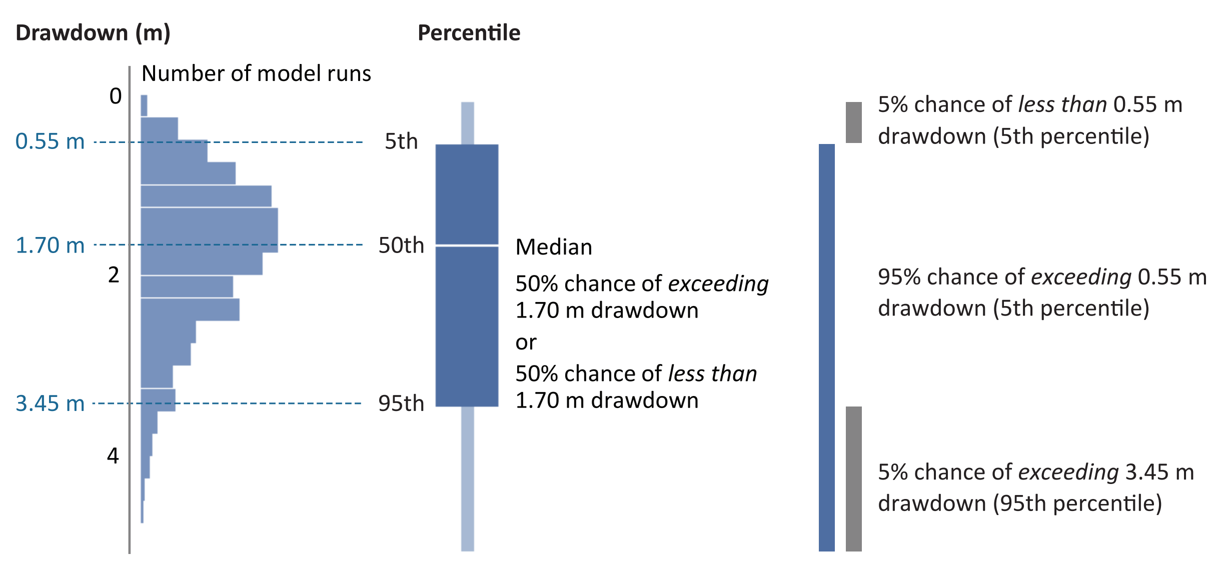

Figure 10 Illustrative example of probabilistic drawdown results using percentiles and percent chance

The chart on the left shows the distribution of results for drawdown in one assessment unit, obtained from an ensemble of thousands of model runs that use many sets of parameters. These generic results are for illustrative purposes only.

Box 5 Understanding probabilities

The models used in the assessment produced a large number of predictions of hydrological response variables rather than a single number. This results in a range or distribution of predictions, which are typically reported as probabilities – the percent chance of something occurring (Figure 10). This approach allows an assessment of the likelihood of exceeding a given magnitude of change, and underpins the assessment of risk.

Hydrological models require information about physical properties, such as the thickness of geological layers and how porous aquifers are. It is unknown how these properties vary across the entire assessment extent (both at surface and at depth), and therefore the hydrological models were run thousands of times using different sets of values from credible ranges of those physical properties each time. The model runs were optimised to reproduce historical observations, such as groundwater level and changes in water movement and volume.

A narrow range of predictions indicates more agreement between the model runs, which enables decision makers to anticipate potential impacts more precisely. A wider range indicates less agreement between the model runs and hence more uncertainty in the outcome.

The distributions created from these model runs are expressed as probabilities that hydrological response variables (such as drawdown) exceed relevant thresholds, as there is no single 'best' estimate of change.

In this assessment, the estimates of drawdown or streamflow change are shown as a 95%, 50% or 5% chance of exceeding thresholds. Throughout this synthesis, the term '*very likely*' is used to describe where there is a greater than 95% chance that the model results exceed thresholds, and '*very unlikely*' is used where there is a less than 5% chance. While models are based on the best available information, if the range of parameters used is not realistic, or if the modelled system does not reflect reality sufficiently, these modelled probabilities might vary from the changes that occur in reality. These regional-level models provide evidence to rule out potential cumulative impacts due to additional coal resource development in the future.

The assessment extent was divided into smaller square assessment units and the probability distribution (Figure 10) was calculated for each. In this synthesis, results are reported with respect to the following key areas (Figure 11):

A. outside the zone of potential hydrological change, where hydrological changes (and hence impacts) are *very unlikely* (defined by maps showing the 5% chance)

B. inside the zone of potential hydrological change, comprising the assessment units with at least a 5% chance of exceeding the threshold (defined by maps showing the 5% chance). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and ecosystems

C. assessment units with at least a 50% chance of exceeding the threshold (i.e. the assessment units where the median is greater than the threshold; defined by maps showing the 50% chance)

D. assessment units with at least a 95% chance of exceeding the threshold (i.e. the assessment units where hydrological changes are *very likely*; defined by maps showing the 95% chance).

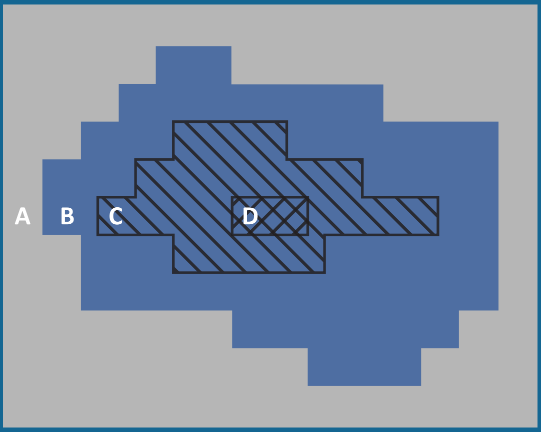

Figure 11 Key areas for reporting probabilistic results

Surface water

The potential changes due to additional coal resource development on surface water flow regimes were assessed using three hydrological response variables:

- maximum change in the annual number of low-flow days (i.e. days with flow less than the 10th percentile of simulated flows between 2013 and 2102 under the baseline) (Figure 12)
- maximum change in the annual number of high-flow days (i.e. days with flow greater than the 90th percentile of simulated flows between 2013 and 2102 under the baseline)
- maximum change in the annual flow over the 90-year simulation period (2013 to 2102).

Changes in other hydrological response variables can be viewed on the BA Explorer at www.bioregionalassessments.gov.au/explorer/HUN/hydrologicalchanges.

Key finding 4: Results from regional-scale modelling indicate that large changes in flow regime are possible in Wyong River, Loders Creek, Saddlers Creek, Wollar Creek and a number of ephemeral creeks as a result of additional coal resource development.

In general, hydrological changes are greater in the small tributaries of the Hunter River (shown in Figure 12) than along the river itself. The largest hydrological changes occur in Loders Creek and a nearby unnamed creek, which drain the Bulga and Mount Thorley–Warkworth mines and enter the Hunter River just upstream of Singleton, as well as in Dry Creek and an unnamed creek near Muswellbrook, which drain the Bengalla and Mount Pleasant mines. These small streams are *very likely* to experience large changes in flow regime due to additional coal resource development – such as increases in low-flow days of at least 20 days per year, decreases in high-flow days of at least 10 days per year, and at least 20% (50% in some cases) decreases in mean annual flow volume.

Dry Creek and the two unnamed creeks are small, hence potential hydrological changes are mostly restricted to the creeks themselves. The Hunter Regulated River, into which they flow, is not very sensitive to changes in inflows from these creeks. Changes in flow in Wollar Creek, Saddlers Creek and Loders Creek have a hydrological effect on the Goulburn and Hunter rivers into which they flow.

The larger Wyong River is a perennial stream, and model estimates vary from a high probability (95% chance) of small changes (e.g. increases in the number of low-flow days per year between 3 and 20 days) to a small probability (5% chance) of large changes (e.g. more than 200 additional low-flow days) in flow regime due to additional coal resource development. The larger changes are outside the range of variability seen under the baseline, which is more likely to move the system outside the range of conditions previously encountered.

Local-scale information can be used to refine the regional-scale estimates in areas identified as at risk. An example of the use of local hydrogeological information to constrain regional model estimates in the Wyong river basin is provided in Section 3.3.3.1 of Herron et al. (2018c) and is summarised here.

Hydrogeological information from the environmental impact statement for the proposed Wallarah 2 development (Mackie Environmental Research, 2013) was used to identify the subset of groundwater modelling simulations with parameter values consistent with local hydraulic measurements. Measured median hydraulic conductivities in this area are about two orders of magnitude less than the median of the parameter values used for all of the simulations. The drawdown and changes in surface water were recalculated for this subset of simulations. The small chance of 200 additional low-flow days per year based on the regional analysis becomes a small chance of at least 7 additional low-flow days when the baseflows from the locally relevant subset of groundwater modelling simulations are fed into the surface water model.

The additional coal resource developments at Mandalong Southern Extension, West Muswellbrook, Wambo and Wilpinjong mines were not represented in the surface water and/or groundwater models. Therefore, surface water hydrological changes cannot be ruled out in the following locations:

- Dora, Mannering, Moran, Stockton, Wallarah and Wyee creeks around the Mandalong underground mine
- Wybong, Dartbrook and other nearby creeks around the proposed West Muswellbrook open-cut mines
- the Goulburn River and Wollar Creek near Wilpinjong open-cut mine expansions
- possibly around proposed expansions of the Wambo underground mine.

Low-flow days

The impact due to additional coal resource development is generally greater on low flows than on high flows. There are streams near all the additional coal resource developments in the Hunter subregion that are modelled to have a 50% chance of at least 20 additional low-flow days per year (i.e. below the 10th percentile simulated flow under the baseline between 2013 and 2102) due to the additional coal resource development (Figure 12). Increases of more than 80 low-flow days per year are *very likely* in the unnamed creek draining the Mount Pleasant and Bengalla developments. There is a 5% chance that the increase in low-flow days in the two unnamed creeks, Loders Creek, Saddlers Creek, Dry Creek and the Wyong River could exceed 200 days per year due to additional coal resource development. These larger changes are outside the range of variability experienced under the baseline, which is more likely to move the system outside the range of conditions previously encountered (Figure 23 in Herron et al. (2018c)). The assessment found that the combination of runoff interception and changes in baseflow caused by groundwater drawdown contributed to increases in low-flow days.

High-flow days

Reductions in high-flow days of at least 3 days per year are *very likely* along lower Wollar Creek, which drains the Moolarben and Wilpinjong mine developments, and in Dry Creek, Loders Creek, Saddlers Creek and Wyong River. There is at least a 50% chance that the Wyong River experiences reductions in high-flow days of at least 3 days per year, but is *very unlikely* to experience reductions greater than 20 days per year. It is *very unlikely* that the Hunter Regulated River and most of the Goulburn River experience reductions of more than 10 high-flow days per year. Changes in high-flow characteristics tend to be dominated by interception of runoff.

Annual flow

Results for the Hunter Regulated River show that decreases in mean annual flow of between 1% and 2% are *very likely*, and decreases of more than about 2% upstream of the junction with Loders Creek, or 3% to 4% downstream of this point to Greta, are *very unlikely*.

Decreases in mean annual flow of at least 5% are *very likely* in the smaller Dry Creek, Wollar Creek, Saddlers Creek, Loders Creek and the two unnamed creeks draining the Mount Pleasant and Mount Thorley–Warkworth mine sites.

There is at least a 50% chance that these changes are comparable to the interannual variability of annual flow under the baseline in Dry Creek, Loders Creek and one of the unnamed creeks. Such a change would move the system outside the range of conditions previously encountered. More detail is available in Figure 27 of Herron et al. (2018c).

Water quality

Water quality was not modelled in this assessment, but the implications for stream salinity in the Hunter subregion were considered in light of the modelled hydrological changes due to additional coal resource development, salinity hazard mapping and existing regulatory controls (see Section 3.3.5 of Herron et al. (2018c)). Some of the streams identified as at risk of potentially large hydrological changes, such as Loders Creek and Saddlers Creek, are naturally highly saline, and this would be expected to influence the management response to the predicted hydrological changes.

Salinity of the Hunter Regulated River is managed through the Hunter River Salinity Trading Scheme. Under the scheme, annual discharges by mines to the river are managed to maintain stream salinity at an acceptable level for other users. Modelling results suggest there will be minimal impact on the number of high-flow days when discharge is permitted under the scheme.

Changes in stream salinity cannot be ruled out. Groundwater is typically more saline than surface runoff. This suggests that reductions in baseflow are more likely to lead to decreases in stream salinity, while reductions in catchment runoff could lead to increases in salinity. The actual effects depend very much on local conditions and relative changes in surface water and groundwater components of the streamflow.

FIND MORE INFORMATION

Explore the hydrological changes in more detail on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/HUN/hydrologicalchanges

Observations analysis, statistical analysis and interpolation, product 2.1-2.2 (Herron et al., 2018b)

Water balance assessment, product 2.5 (Herron et al., 2018a)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Herron et al., 2018d)

Impact and risk analysis, product 3-4 (Herron et al., 2018c)

Surface water modelling, submethodology M06 (Viney, 2016)

Groundwater modelling, submethodology M07 (Crosbie et al., 2016)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

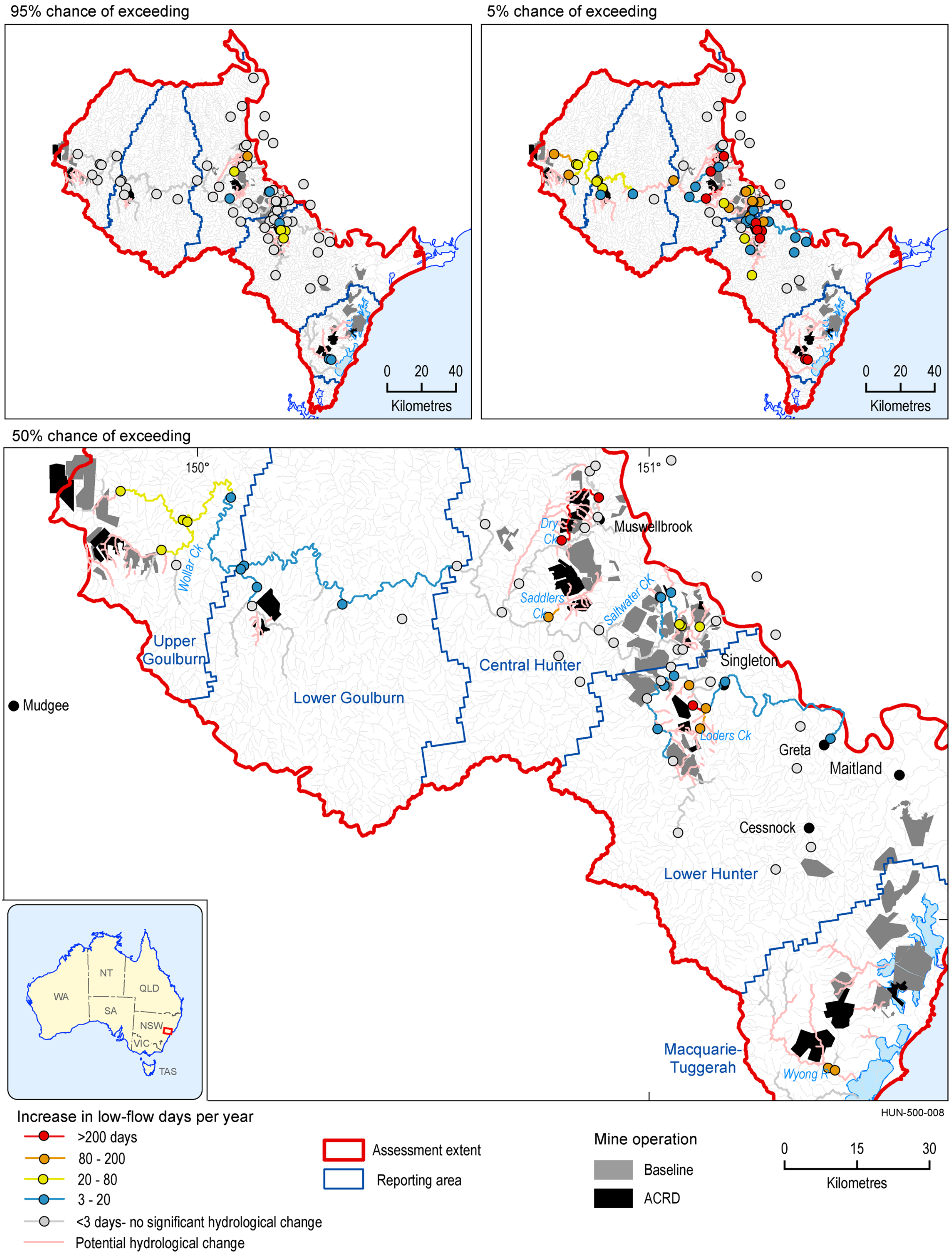

Figure 12 Maximum increase in the number of low-flow days due to additional coal resource development (95%, 50% and 5% chance of exceeding given values of change)

Mines in the coal resource development pathway (CRDP) include baseline and additional coal resource developments (ACRD). The difference in low-flow days between the CRDP and baseline is due to ACRD. Results are shown as percent chance of exceeding given values of change (Box 5). These appear in Herron et al. (2018c) as percentiles.
Data: Bioregional Assessment Programme (Dataset 12)

What are the potential impacts of additional coal resource development on ecosystems?

The impact and risk analysis (Herron et al., 2018c) investigated how hydrological changes due to additional coal resource development may affect ecosystems. These ecosystems were classified into 26 landscape classes and 5 landscape groups (Box 6, Table 1).

The impact and risk analysis (Box 7) focused on landscape classes that intersect the zone of potential hydrological change (Box 4). Any ecosystem or asset wholly outside of this zone is considered *very unlikely* to be impacted due to additional coal resource development.

For potentially impacted ecosystems within the zone, **receptor impact models** (Box 8) were used to translate predicted changes in hydrology into a distribution of ecological outcomes that may arise from those changes. These models used indicators of the health of the ecosystem, such as taxa richness or canopy cover of vegetation, to infer the potential ecological impacts of hydrological changes.

Ecosystems

Which ecosystems are *very unlikely* to be impacted?

Ecosystems outside the zone of potential hydrological change are *very unlikely* to be impacted, including 1232 km of perennial streams, 1450 km of intermittent streams and 8840 km of ephemeral streams.

Within the zone, most (3012 km^2) of the ecosystems are classified as non-groundwater-dependent vegetation (51%) and economic land uses (43%), such as irrigated and dryland agriculture, production forestry, mining and industrial uses. These are ruled out as they are predominantly rainfall dependent and therefore not the focus of bioregional assessments.

1347 km of ephemeral streams in the zone are unlikely to be impacted because, by definition, ephemeral streams are not connected to groundwater, and none of these 1347 km of streams are disrupted by changes in surface water drainage.

Box 6 Understanding the landscape classification

The natural and human-modified ecosystems in the subregion were classified into 26 landscape classes (Table 1 and Section 2.3.3 in Dawes et al. (2018)) to enable a systematic and comprehensive analysis of potential impacts on, and risks to, the water-dependent assets nominated by the community. These landscape classes were aggregated into five landscape groups, based on their likely shared response to hydrological changes. The landscape classification was based on the subregion's geology, geomorphology, hydrogeology, land use and ecology. Definitions for landscape classes and landscape groups for the Hunter subregion are available online at environment.data.gov.au/def/ba/landscape-classification/hunter-subregion.

Box 7 Analysing impact and risk

Potential impacts to water-dependent ecosystems and assets were assessed by overlaying their location on the zone of potential hydrological change (Box 4) to identify the hydrological changes that a particular asset or ecosystem might experience.

- **Outside this zone**, ecosystems and assets are ***very unlikely*** **to be impacted** by hydrological changes due to additional coal resource development.
- **Inside this zone**, ecosystems and assets are **potentially impacted**.

Within the zone, not all water-dependent ecosystems or assets will be affected by hydrological changes, as this depends on their reliance on groundwater or surface water. Hydrological changes due to additional coal resource development may be large, but within the range of natural seasonal and climatic variability, and so may not affect water-dependent ecosystems or assets. Alternatively, small changes may affect sensitive ecosystems that have a strong reliance on groundwater or surface water.

For ecological assets, the assessment considered the potential impact to the habitat of species, not potential impacts to the species themselves.

Ecosystems that fall within the mine pit exclusion zone are likely to be directly impacted, but as estimates of drawdown are unreliable, the degree of impact is not possible to quantify. Similarly, the surface water modelling close to mine pits cannot quantify the degree of impact on some streams.

Seagrasses, which occur in coastal lakes within the zone of potential hydrological change, are particularly sensitive to changes in water levels which can be caused by subsidence above underground mines. However, in NSW, mines are required to prepare subsidence management plans that detail how they will minimise impacts from subsidence as a condition of approval.
In the Macquarie and Tuggerah coastal lake systems, subsidence exclusion zones have been delineated, in which there are restrictions on underground mining practices. As a result, the risk from subsidence was considered to be low (for more details see Section 3.4 in Herron et al. (2018c)).

Which ecosystems are potentially impacted?

Ecosystems that intersect the zone of potential hydrological change (Box 4) are potentially at risk of impact due to additional coal resource development (Table 1, Figure 13).

Of the 14,659 km of rivers and streams in the Hunter subregion, 3137 km (21%) are in the zone of potential hydrological change. This includes 634 km of perennial streams, 518 km of intermittent streams, and 1985 km of ephemeral streams (Table 1). Of the 1985 km of ephemeral streams, 638 km are potentially disrupted by changes in surface water drainage. The remaining 1347 km of ephemeral streams are unlikely to be impacted.

Key finding 5: There are 102 km^2 of ecosystems identified as potentially groundwater dependent in the zone of potential hydrological change, including rainforests (60% of the total in the assessment extent), forested wetlands (38%), and wet and dry sclerophyll forests (18%) (Table 1 and Figure 13).

Box 8 Receptor impact models

Receptor impact models translate predicted changes in hydrology into ecological outcomes that may arise from those changes. Applying receptor impact models across ecosystems assists in identifying where changes in hydrology may result in ecosystem changes, and consequently where additional local-scale information and further investigation may be warranted.

To assess potential ecological outcomes, experts identified receptor impact variables, characteristics that serve as indicators of the ecological condition of an ecosystem, and which are also likely to respond to hydrological changes as well as being within the expertise of the available experts. These variables were specifically chosen to be representative of a landscape class in the Hunter subregion.

One or more hydrological response variable(s) that affect each indicator were identified with ecological experts. Receptor impact models (statistical models) were then developed to represent the relationship between each indicator and its important hydrological response variables. Details are found in Hosack et al. (2018a) and Dataset 13.

For **riverine forests** in **forested wetlands** in the Hunter subregion, one ecological indicator (bolded) was chosen to predict changes that are sensitive to the following hydrological response variables:

- **projected foliage cover:** overbench flow, overbank flow, groundwater drawdown.

For **perennial streams**, two indicators (bolded) were chosen to predict changes that are sensitive to the following hydrological response variables:

- **abundance of riffle-dwelling Hydropsychidae (caddisfly) larvae:** zero-flow days (averaged over 30 years) and the mean maximum spell duration of zero-flow days
- **the probability of presence of riffle-breeding frogs:** zero-flow days (averaged over 30 years) and the mean maximum spell duration of zero-flow days.

For **intermittent streams**, two indicators (bolded) were chosen to predict changes that are sensitive to the following hydrological response variables:

- **hyporheic invertebrate taxa richness:** zero-flow days (averaged over 30 years) and the mean maximum spell duration of zero-flow days
- **the probability of presence of riffle-breeding frogs:** zero-flow days (averaged over 30 years) and the mean maximum spell duration of zero-flow days.

Hydrological models were used to quantify changes in the hydrological response variable(s). Predictions of an ecological indicator at a specific location were made by applying the receptor impact model for that indicator to the predicted hydrological response variable(s) at that location.

Receptor impact models were used to predict changes in the indicator for a landscape class that result from the changes in hydrological response variables. The changes in the indicator reflect the magnitude of potential ecological impacts for that ecosystem. The indicators provide a measure of the risk to the ecosystem, rather than a prediction about (for example) caddisfly and frog populations *per se*.

Importantly, receptor impact models were not used in isolation but were applied along with other lines of available evidence, including expert advice, hydrological modelling results and other existing data and knowledge, to assess potential ecological impacts.

Small to no changes in the number of zero-flow days (averaged over 30 years) modelled for most perennial and intermittent streams suggest generally low risk to instream habitat. Exceptions are the perennial Wyong River and the intermittent Saddlers and Loders creeks, where potentially large flow regime changes are predicted to affect instream ecosystems. Impacts on instream habitat cannot be ruled out in a number of intermittent streams that were not modelled, but which flow close to additional coal resource developments.

Groundwater-dependent ecosystems in the zone of potential hydrological change represent 28% of the total area of groundwater-dependent ecosystems within the assessment extent (Table 1).

Forested wetlands

Key finding 6: Modelled changes in ecologically important flows indicate a higher risk to the condition of riverine forested wetlands along the Goulburn River compared to other riverine forested wetlands in the subregion.

A receptor impact model (Hosack et al., 2018a) was used to predict whether changes in groundwater drawdown and frequency of overbench and overbank flows result in changes in projected foliage cover of riverine forests (in the 'Forested wetland' landscape class) along unregulated rivers of the Hunter river. The model was not appropriate for quantifying impacts on coastal forested wetlands, nor riverine forests along the regulated river.

Most of the riverine forests on unregulated streams in the Hunter river basin are *very unlikely* to experience groundwater drawdown of more than 0.2 m, and it is *very unlikely* that more than 0.1 km^2 will experience drawdown exceeding 2 m. Changes in overbench and overbank flows are mainly predicted along the Goulburn and Hunter rivers. Due to flow regulation, the modelled changes in overbench and overbank flows along the Hunter River, and hence the risk to Hunter River forested wetlands, are difficult to determine.

The median result suggests little likelihood of changes in projected foliage cover in most of the riverine forested wetlands. Details can be found in Section 3.4.4.3.2 of Herron et al. (2018c). To better resolve the risk to riverine forests along the Goulburn River, local information is needed to constrain the predictions of hydrological change and put these potential changes in the context of other factors influencing ecosystem condition.

Impacts to coastal forested wetlands in the modelled drawdown zone from the proposed Wallarah 2 mine and Mandalong expansion were not modelled and cannot be ruled out.

Perennial streams

Key finding 7: Modelled flow regime changes in the perennial Wyong River and the intermittent Saddlers and Loders creeks indicate a higher risk to instream habitat compared to other modelled streams in the subregion.

Receptor impact models (Hosack et al., 2018a) were developed to predict the risk to instream habitats of perennial streams due to additional coal resource development. Experts identified perennial stream ecosystems as sensitive to increases in the long-term average number of zero-flow days (see Box 8). Potentially large changes in the number of zero-flow days were modelled in the Wyong River.

The Wyong River is the only modelled perennial stream where increases in the mean annual number of zero-flow days (averaged over 30 years) due to additional coal resource development were modelled to exceed 3 days (95% chance of exceeding), with median estimates suggesting increases of between 20 and 80 days per year. There is a 5% chance of an increase of more than 200 zero-flow days per year (averaged over 30 years), although this impact becomes much less when local-scale hydraulic data is incorporated into the model (see 'Surface water' on page 15).

Two receptor impact models were used to quantify the risk from these hydrological changes in terms of numbers of caddisfly larvae and the probability of presence of riffle-breeding frogs (see Box 8), two components of the ecosystem that rely on permanent flow for their persistence. Details can be found in Section 3.4.3.3.1 of the impact and risk analysis (Herron et al., 2018c). Local information is needed to better resolve the level of risk, including better definition of the magnitude and likelihood of the hydrological changes and the implications of these potential changes given local considerations.

Surface water modelling was not undertaken for the perennial Dora Creek. Similar hydrological changes to those modelled for the Wyong River might be expected given its similar geography and magnitude of modelled groundwater drawdown. This suggests a risk of impacts on instream habitats in Dora Creek also.

No significant changes in zero-flow days (averaged over 30 years) are predicted in perennial streams of the Hunter river basin, hence instream ecosystems that are adapted to current flow regimes are *very unlikely* to be impacted in this basin.

Table 1 Area (km^2) or length (km) of all landscape classes in the assessment extent and the zone of potential hydrological change

Landscape group	Landscape class	Extent in assessment extent	Extent in the zone
Riverine (km)	Permanent or perennial	1,866	634
	Lowly to moderately intermittent Moderately to highly intermittent[a]	1,968	518
	Highly intermittent or ephemeral	10,825	1985
GDE (km^2)	Rainforest	40.2	23.9
	Wet sclerophyll forest	14.2	4.5
	Dry sclerophyll forest	91.1	14.6
	Freshwater wetland	35.5	1.1
	Forested wetland	150.8	57.8
	Grassy woodland	12.6	0.2
	Heathland	14.0	0.2
	Semi-arid woodland	0.6	<0.1
	Spring	na	na
Coastal lakes and estuaries (km^2)	Lakes	172	76.2
	Lagoons	9	3.8
	Seagrass	39	15.6
	Saline wetlands	30	1.5
	Creeks	<1	<0.1
	Barrier river	13	0.4
	Drowned valleys	<1	na
Non-GDE vegetation (km^2)	Non-GDE vegetation	10,414	1633
Economic land use (km^2)	Dryland agriculture	3,819	768
	Irrigated agriculture	252	106
	Intensive use	1,068	322
	Plantation or production forestry	726	133
	Water	142	50

[a] The ‘Lowly to moderately intermittent’ and ‘Moderately to highly intermittent’ landscape classes were collapsed into a single ‘Intermittent’ landscape class for analysis (Hosack et al., 2018a).

GDE = groundwater-dependent ecosystem, na = not applicable

Data: Bioregional Assessment Programme (Dataset 12)

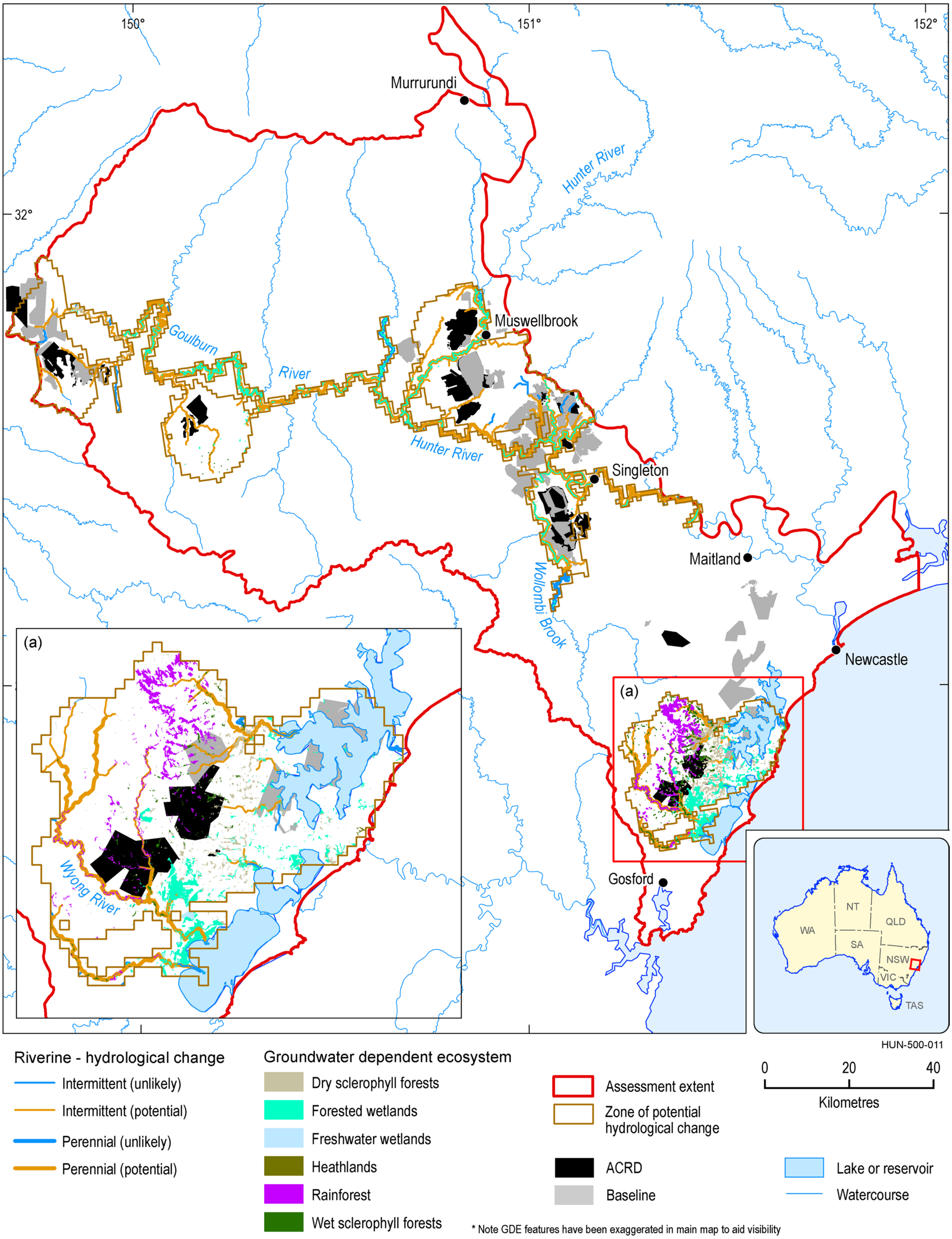

Figure 13 Landscape classes within the zone of potential hydrological change

Landscape classes are shown for the 'GDE' landscape group and the 'Riverine' landscape group. Groundwater-dependent ecosystems (GDEs) are exaggerated (not to scale) for clarity. Riverine hydrological changes are either 'unlikely' (outside the zone of potential hydrological change) or 'potential' inside the zone. Mines in the coal resource development pathway (CRDP) includes baseline and additional coal resource developments (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

Intermittent streams

Two ecological indicators of instream habitat were chosen (Box 8) which potentially change in response to changes in the number of zero-flow days (averaged over 30 years). Results of regional-scale hydrological modelling indicate a 50% chance of changes in zero-flow days (averaged over 30 years) in Saddlers Creek exceeding 20 days per year, and exceeding 3 days per year in Loders Creek and in an unnamed creek in the Bayswater Creek catchment. There is a 5% chance that increases in zero-flow days (averaged over 30 years) in Saddlers and Loders creeks exceed 80 days per year. Conversely, there is also a 5% chance of no significant change in zero-flow days (averaged over 30 years) in these creeks. There are other intermittent streams near mines where hydrological changes were not quantified, but where impacts may be expected.

Saddlers Creek (at least a 50% chance) and Loders Creek (at least a 5% chance) have the potential to experience changes in the two chosen ecological indicators (Box 8) as a result of the reductions in zero-flow days (averaged over 30 years) due to additional coal resource development. Hence, it is possible that the instream habitat of these streams may be impacted. Details can be found in Section 3.4.3.3.2 of Herron et al. (2018c).

Again, these results identify areas where further investigation is warranted, rather than being site-specific predictions about ecological changes per se. Local factors, such as presence of faults or aquitards, geomorphic condition and quality of the water, will influence the extent to which risks identified from regional-scale modelling warrant further attention.

Changes in the two chosen ecological indicators (Box 8) due to additional coal resource development are *very unlikely* in the upper Goulburn River, Wollar Creek and Saltwater Creek. Hence, it is unlikely that the instream habitat of these streams would be impacted.

The lack of groundwater modelling of the Wilpinjong additional coal resource development means that streamflow changes in Wollar Creek and the Goulburn River may be underpredicted, with potentially larger impacts than those presented here.

FIND MORE INFORMATION

Explore potential impacts on ecosystems in more detail on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/HUN/landscapes.

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Receptor impact modelling, product 2.7 (Hosack et al., 2018a)

Impact and risk analysis, product 3-4 (Herron et al., 2018c)

Receptor impact modelling, submethodology M08 (Hosack et al., 2018b)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

Impact and risk analysis database (Dataset 1)

Landscape classification (Dataset 9)

Receptor impact models (Dataset 13)

Results from applying receptor impact models (Dataset 14)

What are the potential impacts of additional coal resource development on water-dependent assets?

The impact and risk analysis (Herron et al., 2018c) investigated how hydrological changes due to additional coal resource development may affect water-dependent assets, such as bores, wetlands or heritage sites.

More than 2200 water-dependent assets listed in the asset register (Dataset 10; Bioregional Assessment Programme, 2017; Macfarlane et al., 2016) were analysed for the subregion (Table 2). They include:

- **1652 ecological assets**, encompassing
  - the Ramsar-listed Kooragang Nature Reserve and Shortland Wetland
  - 17 wetlands including Lake Macquarie, Tuggerah Lake and Colongra Swamp
  - 6 threatened ecological communities
  - 7 Important Bird Areas
  - potential habitats of 105 flora and fauna species listed in the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
- **249 economic assets**, including water source areas such as the Hunter Regulated River water source and associated water rights
- **307 sociocultural assets**, including 275 heritage sites, 9 Indigenous sites and 23 recreation areas.

Potential impacts on most water-dependent assets were assessed by overlaying their extent on the zone of potential hydrological change (Figure 8). The assessment took a precautionary approach: it identified potential impacts if an asset or any part of it is within the zone.

Ecological changes were not predicted for assets, because receptor impact models (Box 8) were developed for landscape groups and not individual assets. However, an example of a more detailed analysis of a specific asset ('potential distribution of Malleefowl (*Leipoa ocellata*)') is provided in Herron et al. (2018c) to illustrate the type of approach that could be undertaken to assess impacts at a finer level of detail.

The greatest confidence in regional hydrological modelling results is in those areas that are *very unlikely* to be impacted. Where potential impacts have been identified, further local-scale modelling may be required to determine the likelihood and magnitude of impacts.

Ecological assets

Which ecological assets are *very unlikely* to be impacted?

Of the 1652 ecological water-dependent assets in the Hunter assessment extent, 921 water-dependent assets, or 56%, are outside the zone of potential hydrological change and thus are *very unlikely* to be impacted by hydrological changes.

Key finding 8: The two Ramsar-listed wetlands, Kooragang Nature Reserve and Shortland Wetland, are outside the zone of potential hydrological change, and are *very unlikely* to be impacted due to additional coal resource development.

Other assets outside the zone and *very unlikely* to be impacted include:

- the Brisbane Water and Hunter Estuary important bird areas
- potential habitats of 16 species listed under the EPBC Act or NSW's *Threatened Species Conservation Act*, including 11 plant species, 3 bird species, the Booroolong frog and the beady pipefish
- Ginger Beer, Parnell, Wappinguy and Wild Bull springs
- 48 parks and reserves, including Brisbane Water National Park, Camerons Gorge Nature Reserve, Hunter Wetlands National Park and Karuah National Park.

The critically endangered Wollemi Pine, which has a potential species distribution of 137 km^2 in the zone, is considered unlikely to be impacted because it is a rainforest species and not dependent on groundwater.

See Section 3.5.2 of Herron et al. (2018c) for more details.

Which ecological assets are potentially impacted?

Groundwater-dependent ecosystems and potential habitats of species make up nearly 90% of the ecological assets found in the zone of potential hydrological change.

Potentially impacted EPBC Act-listed species include iconic species, such as the regent honeyeater, swift parrot and koala.

Table 2 Water-dependent assets in the assessment extent and the zone of potential hydrological change

Asset group	Asset subgroup	Asset class	Number of water-dependent assets	Number of water-dependent assets in the zone
Ecological	Surface water feature	Floodplain	9	2
		Lake, reservoir, lagoon or estuary	100	33
		River or stream reach, tributary, anabranch or bend	66	29
		Wetland, wetland complex or swamp	30	8
	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	24	12
	Vegetation	Groundwater-dependent ecosystems	587	270
		Habitat (potential species distribution)	836	377
	Subtotal		**1652**	**731**
Economic	Groundwater management zone or area (surface area)	Groundwater feature used for water supply, water supply and monitoring infrastructure, water access right or basic water right (stock and domestic)	141	58
	Surface water management zone or area (surface area)	Surface water feature used for water supply, water supply and monitoring infrastructure, water access right or basic water right (stock and domestic)	108	65
	Subtotal		**249**	**123**
Sociocultural			307	67
	Subtotal		**307**	**67**
Total			**2208**	**921**

Economic asset numbers are not individual bores but water access entitlements that could include one or multiple bores or water rights.
Potential impacts on water-dependent assets were assessed by overlaying their extent on the zone of potential hydrological change.
Data: Bioregional Assessment Programme (Dataset 10), Bioregional Assessment Programme (2017)

Three state-listed species (green-thighed frog, red-crowned toadlet and wallum froglet) all have extensive potential habitats within the zone. Some species – including migratory species, such as the black-faced monarch, cattle egret, fork-tailed swift, great egret and satin flycatcher – have very large potential habitat distributions that cover most, or all, of the zone and are found in a variety of landscape classes beyond the potentially impacted classes. All potentially impacted potential habitats of species had less than 50% of their area that lies within the assessment extent also within the zone of potential hydrological change.

Three Important Bird Areas in the zone overlap with potentially impacted groundwater-dependent ecosystems:

- 1.5 km^2 of the 134 km^2 of the Greater Blue Mountains Important Bird Area in the zone is associated with forested wetlands.
- 5.0 km^2 of the 112 km^2 of the Lake Macquarie Important Bird Area in the zone is associated with wet and dry sclerophyll forests and 3.8 km^2 with forested wetlands.
- 10.1 km^2 of the 395 km^2 of the Mudgee-Wollar Important Bird Area in the zone is associated with forested wetlands and 1 km^2 with wet and dry sclerophyll forests.

Five areas in the Collaborative Australian Protected Area Database overlap with potentially impacted groundwater-dependent ecosystems, including 3.6 km^2 of the 54 km^2 of the Hinterland Spotted Gum Endangered Ecological Community, which is associated with 1.3 km^2 of wet and dry sclerophyll forests and 1.5 km^2 of forested wetlands.

Economic assets

Economic water-dependent assets are made up of surface water and groundwater sources and their associated water access licences and basic water rights, and water supply infrastructure.

Which economic assets are *very unlikely* to be impacted?

Fifteen unregulated and alluvial water sources are outside the zone of potential hydrological change and are *very unlikely* to be impacted.

Four groundwater sources, namely the Liverpool Ranges Basalt Coast groundwater source and the Stockton, Tomaree and Tomago water sources, do not intersect the zone and are therefore also *very unlikely* to be impacted.

Mardi Dam and Grahamstown Dam are outside the zone and natural inflows are unlikely to be impacted. However, Mardi Dam is filled by pumping water from Wyong River and Ourimbah Creek, so the extent to which additional coal resource development impacts streamflow in Wyong River, water supply to Mardi Dam could be affected.

See Section 3.5.3 of Herron et al.(2018c) for more details.

Which economic assets are potentially impacted?

Following the rule-out process, five groundwater sources and 19 unregulated and alluvial water sources were identified as being potentially impacted by additional coal resource development.

There are 3831 water supply bores and surface water extraction points in the zone that are potentially impacted (Figure 14).

Impacts on economic assets were assessed in terms of changes in water availability, reliability of supply and potential for invoking ‘make good’ provisions under the *NSW Aquifer Interference Policy* (NSW Office of Water, 2012).

Key finding 9: Changes in mean annual water availability in the Hunter Regulated River at Greta are *very likely* to exceed 5 GL per year (less than 1% of mean annual flow), but *very unlikely* to exceed 12 GL per year (approximately 1.6% of mean annual flow) over the period from 2013 to 2042.

This reduction in water availability is indicated by the change in mean annual flow. Flow reductions in the regulated river can be managed through increasing the volume of water released from Glenbawn and Glennies Creek dams to meet environmental water requirements, which could have an impact on available water determinations for consumptive users.

In the Singleton, Muswellbrook, Jerrys and Wyong River water source areas, reductions of 0.2 to 2.9 GL per year are *very likely*, and it is *very unlikely* that these reductions will exceed 3 to 6 GL per year.

Change in the the number of cease-to-pump days per year due to additional coal resource development was used as an indicator of impacts on reliability of supply. ‘Cease-to-pump’ rules attach to most water sources in NSW to ensure sufficient water is retained in unregulated rivers to meet environmental requirements. Potentially significant changes are possible for the Wyong River and some creeks in the Singleton, Jerrys and Muswellbrook water source areas. In all these water source areas, the modelled results show a highly varied response. In the Wyong River, this ranges from a 5% chance that there is no impact on cease-to-pump days, a 50% chance of 8 additional cease-to-pump days and a 95% chance of fewer than 145 additional cease-to-pump days (Section 3.5.3.3.2 in Herron et al. (2018c)). Incorporating local-scale hydrogeological information into the analysis for the Wyong river basin (which was carried out in only this basin) reduced the magnitude of this change substantially.

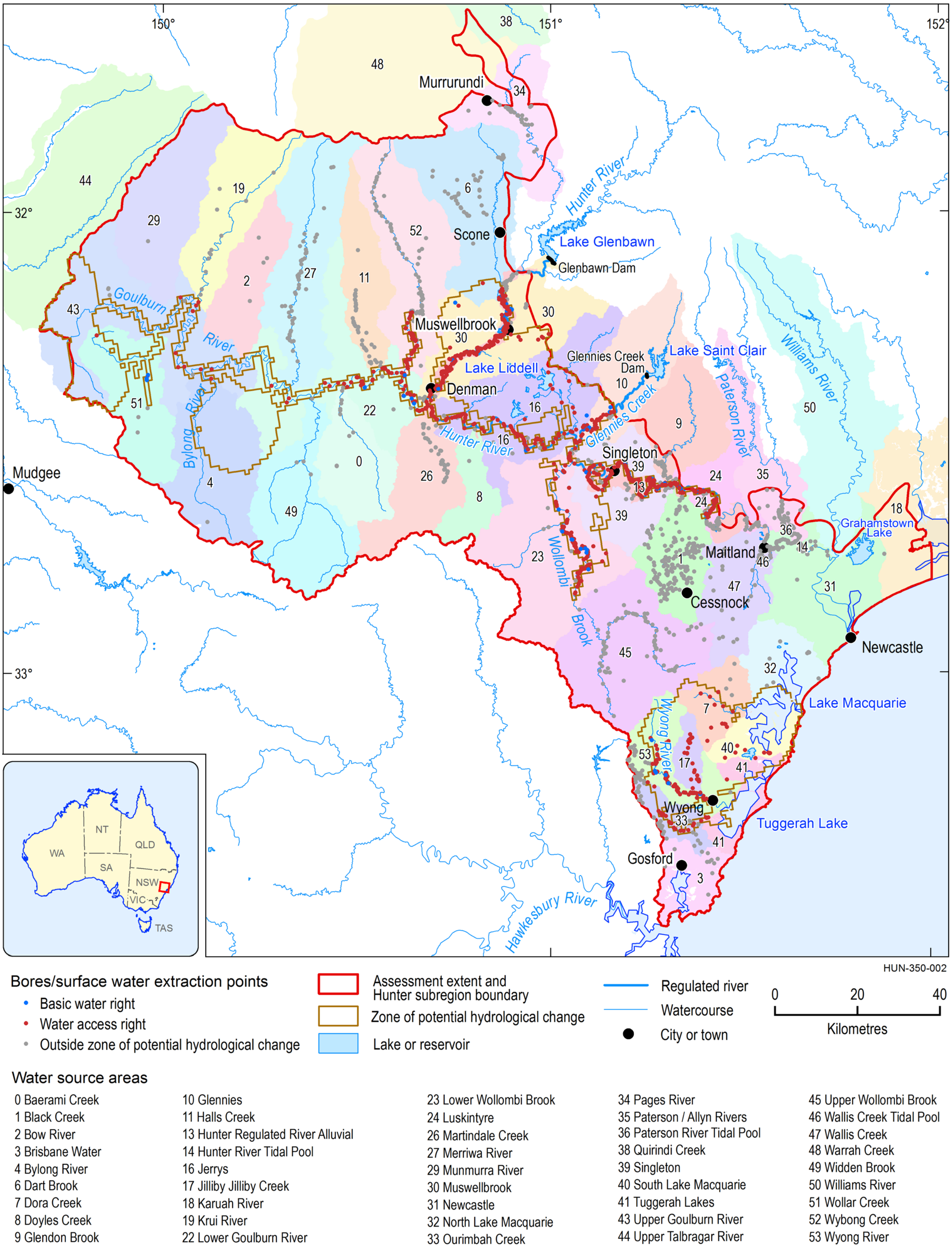

Figure 14 Surface water source areas and extraction points in the zone of potential hydrological change

Data: Bioregional Assessment Programme (Dataset 7, Dataset 8, Dataset 11)

Bores where 'make good' provisions might apply

Key finding 10: It is *very likely* that groundwater drawdowns due to additional coal resource development will exceed 2 m at 13 water supply bores. The number of water supply bores where drawdown exceeds 2 m is *very unlikely* to be more than 170.

The *NSW Aquifer Interference Policy* specifies minimal impact thresholds for highly productive and less productive groundwater sources in NSW. Generally, if drawdown from activities that interfere with aquifers exceeds 2 m, then 'make good' provisions should apply, unless it can be demonstrated to the Minister's satisfaction that the variation will not prevent the long-term viability of GDEs or culturally significant sites nearby.

Of the 13 bores where it is *very likely* that groundwater drawdown will exceed 2 m, 7 are water access licences, 3 are basic water rights, and 3 fall in the mine pit exclusion zone. All 13 bores are on mining leases.

Of the 170 bores where drawdown greater than 2 m is possible, 50 are within the mine pit exclusion zone where drawdown estimates are uncertain but highly likely, and a further 109 are on mine lease areas. It is *very unlikely* that more than 11 non-mining use water supply bores in the Sydney Basin – North Coast groundwater source (7) and Jilliby Jilliby Creek (2), Tuggerah Lakes (1) and South Macquarie Lake (1) water sources would exceed the 'make good' provisions threshold; there is a 50% chance that there are fewer than five.

Sociocultural assets

Which sociocultural assets are *very unlikely* to be impacted?

Of the 307 sociocultural assets in the Hunter assessment extent, 240 are outside the zone of potential hydrological change and it is thus *very unlikely* that they will be affected by hydrological changes due to additional coal resource development.

Key finding 11: Almost 140 km^2 of the 10,000 km^2 of the Greater Blue Mountains World Heritage Area are in the zone of potential hydrological change, of which 99% is native vegetation in non-groundwater-dependent ecosystems, and therefore not sensitive to changes in groundwater and not expected to be impacted.

About 1.5 km^2 of the Greater Blue Mountains World Heritage Area within the zone coincides with potentially impacted forested wetlands.

Which sociocultural assets are potentially impacted?

There are 67 water-dependent sociocultural assets within the zone of potential hydrological change; 45 of these are built infrastructure and 22 are reserves or national parks. The Bioregional Assessment Programme does not have the expertise to comment on potential impacts of changes in hydrological regimes on built infrastructure. The reserves and national parks overlap with 13 km^2 of potentially impacted groundwater-dependent ecosystems and 84 km of potentially impacted permanent or perennial streams.

See Section 3.5.4 of Herron et al. (2018c) for more details.

FIND MORE INFORMATION

Explore potential impacts on water-dependent assets in more detail on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/HUN/assets

Description of the water-dependent asset register, product 1.3 (Macfarlane et al., 2016)

Water-dependent asset register (Bioregional Assessment Programme, 2017)

Impact and risk analysis, product 3-4 (Herron et al., 2018c)

Compiling water-dependent assets, submethodology M02 (Mount et al., 2015)

Impacts and risks, submethodology M10 (Henderson et al., 2018)

Asset database (Dataset 10)

Impact and risk analysis database (Dataset 1)

How to use this assessment

Findings from bioregional assessments can help governments, industry and the community provide better-informed regulatory, water management and planning decisions.

Assessment results flag where future efforts of regulators and proponents can be directed, and where further attention is not necessary. This is achieved through the ‘**rule-out**’ process, which focuses on areas where hydrological changes may occur. This process identified areas, and consequently water resources and water-dependent assets, that are *very unlikely* to experience hydrological change or impact due to additional coal resource development.

This assessment predicts the likelihood of exceeding levels of potential hydrological change at a **regional scale**. It also provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal resource developments. It should help project proponents to meet legislative requirements to identify the environmental values that may be affected by coal resource development, and to adopt strategies to avoid, mitigate or manage potential impacts. These assessments do not investigate the social, economic or human health impacts of coal resource development, nor do they consider risks of fugitive gases and impacts unrelated to water.

Bioregional assessments are not a substitute for careful assessment of proposed coal mine or CSG extraction projects under Australian or state environmental law. Such assessments may use finer-scale groundwater and surface water models and consider impacts on matters other than water resources. However, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (a federal government statutory authority established in 2012 under the EPBC Act) can use these assessment results to formulate their advice. Local data can be used to constrain results of the regional-scale modelling to better inform the management response.

Data access

The full suite of information is provided at www.bioregionalassessments.gov.au, including all technical products as well as information about all datasets used or created, most of which can be downloaded from data.gov.au. These underpinning datasets, including shapefiles of geographic data and modelling results, can assist decision makers at all levels to review the work undertaken to date, and to extend or update the assessment if new models or data become available.

The Programme’s rigorous commitment to data access is consistent with the Australian Government’s principles of providing publicly accessible, transparent and responsibly managed public sector information.

Building on this assessment

Bioregional assessments can be updated – for example, incorporating new coal resource developments in the groundwater or surface water modelling. Existing lists such as the water-dependent asset register (Macfarlane et al., 2016; Bioregional Assessment Programme, 2017; Dataset 10) will remain relevant for future assessments. If new coal resource developments emerge in the future or more data become available to represent some of the non-modelled mines in the CRDP, the data, information, analytical results and models from this assessment provide a comprehensive basis for re-assessment of potential impacts under an updated CRDP. It may also be applicable for other types of resource development. Guidance about how to apply the Programme's methodology is documented in detailed scientific submethodologies, listed in the references on page 32.

Extending this bioregional assessment should focus on improving confidence in assessing impacts in the landscape through more mapping of groundwater depths, vegetation communities and their water requirements, and identification of groundwater-dependent ecosystems.

Surface water and groundwater monitoring

Monitoring is important to evaluate the risk predictions of this bioregional assessment. Monitoring efforts should reflect the risk predictions, with the greatest effort directed to areas where the changes are predicted to be the largest and local-scale information supports the regional-scale assessment of risk. Monitoring in locations with lower risk predictions can help to confirm the range of potential impacts and identify unexpected outcomes. In the Hunter subregion, monitoring of groundwater levels in the five discrete drawdown zones due to additional coal resource development is recommended. Suggested priorities, based on potentially impacted bores, are the Sydney Basin – North Coast, Jilliby Jilliby Creek, Tuggerah Lakes and South Lake Macquarie water sources. In addition, groundwater level monitoring the area west of the proposed West Muswellbrook Project, where the drawdown area is likely to extend beyond the drawdown area due to only baseline mines, is recommended, starting before its development.

Priorities for streamflow and groundwater monitoring, based on streams identified as potentially at risk from large changes in flow regime, are Wyong River and Dora Creek, but also possibly Loders Creek, Saddlers Creek and Wollar Creek. Streamflow and groundwater monitoring could be of value in Mannering, Morans, Stockton, Wallarah and Wyee creeks given potential changes in flow regime that may arise from the proposed Mandalong Southern Extension Project. Monitoring of the Goulburn and Hunter rivers should continue, given potential changes in baseflow.

Additional streamflow monitoring in the Wybong Creek would help to assess potential impacts from the proposed West Muswellbrook Project. Measurements and monitoring of key water quality parameters at hydrological monitoring sites can contribute to better understanding of surface water – groundwater interactions.

Assessing impacts on ecosystems

It is recommended that monitoring of changes in select indicators of ecosystem condition in potentially at risk streams and groundwater-dependent ecosystems accompany any monitoring of hydrological changes. The expert elicitations conducted in the bioregional assessment have identified potential indicators and associated impact variables that could be used for this purpose. The large uncertainties reflected in the receptor impact models from the expert elicitations can be reduced by collecting data on measurable ecosystem components that are sensitive to changes in hydrology. How frogs, hyporheic invertebrate populations, Hydropsychidae larvae and/or tree canopies respond to changes in water availability and flow regime in different environments – and the extent to which changes in these ecosystem components propagate through to other components of the ecosystems they occupy – require greater understanding. Any alternative methods of assessing the condition of water-dependent ecosystems adopted by relevant state agencies should also be targeted at these potentially at risk ecosystems.

Water dependencies of some of the different ecosystems are not well understood and may be site specific. The landscape classification approach represents a generalisation and a loss of site specificity. The impacts on coastal swamp forests within the 'Forested wetland' landscape class were not assessed and are a gap in this bioregional assessment. Similarly, the qualitative model developed for the 'Rainforest' landscape class was premised on rainforests that occupy low-order stream and gully habitats. Most rainforest communities are unlikely to be impacted, because if they are dependent on groundwater at all, it is local groundwater sources. Riparian rainforests on the Wyong River are potentially impacted by additional coal resource development, but impacts were not quantified. Experts were uncertain about aspects of freshwater wetland hydrology, including interactions with the regional watertable.

Both the mapping of vegetation and the nature of the water dependence of some identified groundwater-dependent ecosystems are a significant source of uncertainty. Assessment of impacts on water-dependent assets would be improved by review of vegetation mapping and ongoing research to identify groundwater-dependent ecosystems and determine the degree of groundwater dependency in the subregion. This will improve understanding of the interactions between changes in groundwater availability and the condition of groundwater-dependent terrestrial vegetation.

Actual water requirements of different plant communities during different life stages is only approximately known. Future assessments would be assisted by more work to identify suitable bioindicators of ecosystem condition, or alternative methods of assessing the condition of water-dependent ecosystems.

A summary of the assumptions and limitations of the qualitative and receptor impact models that emerged during the expert elicitation workshops is provided in the receptor impact modelling for the Hunter subregion (see Section 2.7.6 in Hosack et al. (2018a)). Knowledge gaps and research opportunities are identified for some models. A more comprehensive listing of the gaps and opportunities that have emerged during the assessment is provided in Section 3.7 of Herron et al. (2018c).

Groundwater modelling data

Sparsely distributed and poorly documented data was an issue in the Hunter subregion, particularly for depth to watertable, recharge and contributions to baseflow from groundwater. Improved mapping of depth to groundwater, and its spatial and temporal variation, has potential to constrain hydrological change predictions and enhance the context for the interpretation of the ecological impacts due to hydrological change. Interactions between changes in groundwater availability and the condition and persistence of terrestrial groundwater-dependent vegetation remain uncertain due, in part, to sparse mapping of groundwater depths outside of alluvial layers.

The greatest potential to reduce predictive uncertainty in the groundwater modelling lies in improved characterisation of hydraulic properties of the sedimentary rocks, especially the porosity and storage parameters. Historical groundwater levels are controlled by a dynamic interaction between recharge, the geomorphology of rivers and the hydraulic properties of aquifers. A calibration to groundwater levels will only constrain the hydraulic properties if the recharge and river geomorphology are well known at a regional scale.

Although the locations of major faults are known, the extent to which they act as conduits of water between geological layers over different depths is not well understood and is thus a knowledge gap.

Indigenous assets

Consultation with Indigenous communities to determine Indigenous assets was not undertaken for the subregion. However, a report is available that outlines an approach to engage with Indigenous communities and collect information on Indigenous water assets in the subregions and bioregions within NSW (NSW DPI, 2016).

There were nine Indigenous assets from the Register of the National Estate within the water-dependent asset register for the Hunter subregion (Macfarlane et al., 2016; Bioregional Assessment Programme, 2017; Dataset 10). Identifying water-dependent assets valued by local Indigenous communities would provide a more comprehensive account of sociocultural assets, even if many of those assets are already in the water-dependent asset register through other sources, such as a wetland that may have both ecological and Indigenous value.

Climate change and land use

In comparing results under two different futures in this assessment, factors such as climate change or land use are held constant. Future assessment iterations could look to include these and other stressors to more fully predict cumulative impacts on a landscape scale.

FIND MORE INFORMATION

See sections titled ‘Gaps’ in:

Description of water-dependent asset register, product 1.3 (Macfarlane et al., 2016)

Current water accounts and water quality, product 1.5 (Zhang et al., 2016)

Conceptual modelling, product 2.3 (Dawes et al., 2018)

Surface water numerical modelling, product 2.6.1 (Zhang et al., 2018)

Groundwater numerical modelling, product 2.6.2 (Herron et al., 2018d)

Impact and risk analysis, product 3-4 (Herron et al., 2018c)

See www.bioregionalassessments.gov.au for links to information about all datasets used or created, most of which can be downloaded from data.gov.au.

References and further reading

The information presented in this product for the Hunter subregion is based on the analysis and interpretation of existing data and knowledge, enhanced by new scientific studies of the geology, groundwater, surface water and ecology. All technical products developed for the Hunter subregion are listed here. Also listed are the submethodologies that describe the key approaches used to undertake the assessments.

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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.

Definitions for landscape groups and landscape classes in the landscape classification for the Hunter subregion are available at http://environment.data.gov.au/def/ba/landscape-classification/hunter-subregion.

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

additional drawdown: the maximum difference in drawdown (dmax) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development

annual flow (AF): the volume of water that discharges past a specific point in a stream in a year, commonly measured in GL/year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

aquifer: rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit quantities of water to bores and springs

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. The assessment extent is created by revising the preliminary assessment extent on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis. In the Hunter subregion, the assessment extent is the same as the subregion extent.

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

baseflow: the portion of streamflow that comes from shallow and deep subsurface flow, and is an important part of the groundwater system

baseflow index: the ratio of baseflow to total streamflow over a long period of time (years)

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

baseline drawdown: the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development

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 resources 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

conceptual model: abstraction or simplification of reality

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 depressurisation: in the context of coal seam gas operations, depressurisation is the process whereby the hydrostatic (water) pressure within a coal seam is reduced (through pumping) such that natural gas desorbs from within the coal matrix, enabling the gas (and associated water) to flow to surface

dewatering: the process of controlling groundwater flow within and around mining operations that occur below the watertable. In such operations, mine dewatering plans are important to provide more efficient work conditions, improve stability and safety, and enhance economic viability of operations. There are various dewatering methods, such as direct pumping of water from within a mine, installation of dewatering wells around the mine perimeter, and pit slope drains.

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

drawdown: a lowering of the groundwater level (caused, for example, by pumping). In the bioregional assessment (BA) context this is reported as the difference in groundwater level between two potential futures considered in BAs: baseline coal resource development (baseline) and the coal resource development pathway (CRDP). The difference in drawdown between CRDP and baseline is due to the additional coal resource development (ACRD). Drawdown under the baseline is relative to drawdown with no coal resource development; likewise, drawdown under the CRDP is relative to drawdown with no coal resource development.

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.

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

groundwater: water occurring naturally below ground level (whether stored in or flowing through aquifers or within low-permeability aquitards), 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

groundwater zone of potential hydrological change: outside this extent, groundwater drawdown (and hence potential impacts) is very unlikely (less than 5% chance). It is the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers.

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

high-flow days (FD): the number of high-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for high-flow days is the 90th percentile from the simulated 90-year period. In some early products, this was referred to as 'flood days'.

Hunter subregion: Along the coast, the Hunter subregion extends north from the northern edge of Broken Bay on the New South Wales Central Coast to just north of Newcastle. The subregion is bordered in the west and north–west by the Great Dividing Range and in the north by the towns of Scone and Muswellbrook. The Hunter River is the major river in the subregion, rising in the Barrington Tops and Liverpool Ranges and draining south−west to Lake Glenbawn before heading east where it enters the Tasman Sea at Newcastle. The subregion also includes smaller catchments along the central coast, including the Macquarie and Tuggerah lakes catchments.

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 flow 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 and/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).

landscape class: for bioregional assessment (BA) purposes, an ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. Note that there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. 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.

landscape group: for the purposes of bioregional assessments (BAs), a set of landscape classes grouped together based on common ecohydrological characteristics that are relevant for analysis purposes

likelihood: probability that something might happen

low-flow days (LFD): the number of low-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102). The threshold for low-flow days is the 10th percentile from the simulated 90-year period.

maximum zero-flow spell (ZME): the maximum length of spells (in days per year) with zero flow, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

mine pit exclusion zone: areas in the zone of potential hydrological change that are within or near open-cut mine pits, and where (i) modelled drawdowns are highly uncertain due to the very steep hydraulic gradients at the mine pit interface; (ii) changes in the drawdown are inevitable where the mine pit intersects the regional watertable; (iii) other factors, such as physical removal of a wetland or creek, may have a larger impact on a landscape class than the predicted decrease in groundwater level; and (iv) impacts are predominantly site-scale, assumed to be adequately addressed through existing development approval processes, and hence not the primary focus of bioregional assessments. The modelled estimates of drawdown in the mine pit exclusion zone are considered unreliable for use in the receptor impact modelling.

model node: a point in the landscape where hydrological changes (and their uncertainty) are assessed. Hydrological changes at points other than model nodes are obtained by interpolation.

overbank flow: flood condition where water flows beyond and sub-parallel to the main channel of a river, but within the bounding floodplain

overbench flow: high-flow condition where a river channel is partially or completely filled for a period of weeks to months. All habitats within the river channel will be wet including boulders, logs and lateral benches, and the entire length of the channel is connected with relatively deep water, allowing movement of biota freely along the river.

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.

receptor impact model: a function that translates hydrological changes into the distribution or range of potential ecosystem outcomes that may arise from those changes. Within bioregional assessments, hydrological changes are described by hydrological response variables, ecosystem outcomes are described by receptor impact variables, and a receptor impact model determines the relationship between a particular receptor impact variable and one or more hydrological response variables. Receptor impact models are relevant to specific landscape classes, and play a crucial role in quantifying potential impacts for ecological water-dependent assets that are within the landscape class. In the broader scientific literature receptor impact models are often known as ‘ecological response functions’.

receptor impact variable: a characteristic of the system that, according to the conceptual modelling, potentially changes due to changes in hydrological response variables (for example, condition of the breeding habitat for a given species, or biomass of river red gums)

recharge: see groundwater recharge

regional watertable: the upper groundwater level within the unconfined, near-surface aquifer (not perched), where pore water pressure is equal to atmospheric pressure. For bioregional assessment (BA) purposes, the regional watertable is developed by combining, at the subregion or bioregion scale, the watertable from all the near-surface geological units (or layers) in which it occurs, so that impacts to water-dependent assets and ecosystems can be assessed. As the regional watertable is not a contiguous geological layer, water may not move freely through it.

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.

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.

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

subsidence: localised lowering of the land surface. It occurs when underground voids or cavities collapse, or when soil or geological formations (including coal seams, sandstone and other sedimentary strata) compact due to reduction in moisture content and pressure within the ground.

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

surface water zone of potential hydrological change: outside this extent, changes in surface water hydrological response variables due to additional coal resource development (and hence potential impacts) are very unlikely (less than 5% chance). The area contains those river reaches where a change in any one of nine surface water hydrological response variables exceeds the specified thresholds. For the four flux-based hydrological response variables (annual flow (AF), daily flow rate at the 99th percentile (P99), interquartile range (IQR) and daily flow rate at the 1st percentile (P01)), the threshold is a 5% chance of a 1% change in the variable. That is, if 5% or more of model runs show a maximum change in results under coal resource development pathway (CRDP) of 1% relative to baseline. For four of the frequency-based hydrological response variables (high-flow days (FD), low-flow days (LFD), length of longest low-flow spell (LLFS) and zero-flow days (ZFD)), the threshold is a 5% chance of a change of 3 days per year. For the final frequency-based hydrological response variable (low-flow spells (LFS)), the threshold is a 5% chance of a change of 2 spells per year.

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.

very likely: greater than 95% chance

very unlikely: less than 5% chance

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)

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’.

zero-flow days (ZFD): the number of zero-flow days per year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

zero-flow days (averaged over 30 years) (ZQD): the number of zero-flow days per year, averaged over a 30-year period. This is typically reported as the maximum change due to additional coal resource development.

zone of potential hydrological change: outside this extent, hydrological changes (and hence potential impacts) are *very unlikely* (less than 5% chance). Each bioregional assessment defines the zone of potential hydrological change using probabilities of exceeding thresholds for relevant hydrological response variables. The zone of potential hydrological change is the union of the groundwater zone of potential hydrological change (the area with a greater than 5% chance of exceeding 0.2 m of drawdown due to additional coal resource development in the relevant aquifers) and the surface water zone of potential hydrological change (the area with a greater than 5% chance of exceeding changes in relevant surface water hydrological response variables due to additional coal resource development).

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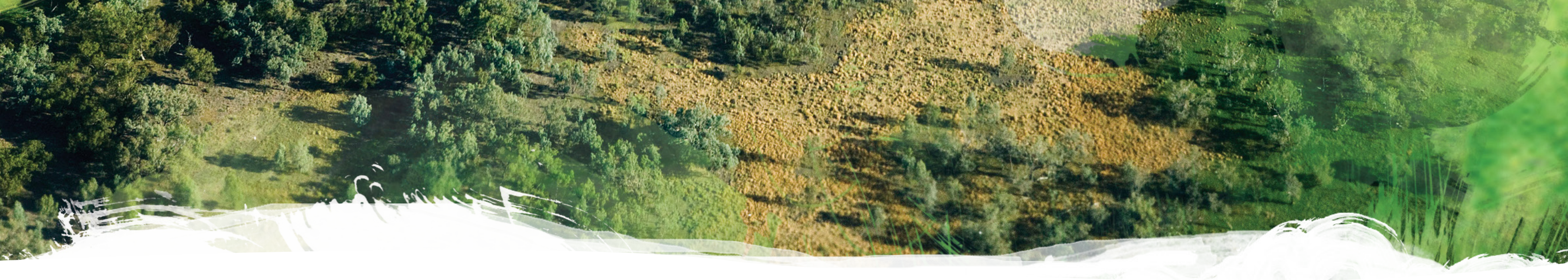

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