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 Namoi subregion: key findings

Product 5: Outcome synthesis for the Namoi subregion
from the Northern Inland Catchments Bioregional Assessment

2018

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

Namoi assessment at a glance

This bioregional assessment considered the potential cumulative impacts on water and water-dependent assets due to ten future additional coal resource developments in the Namoi subregion of NSW (Figure 1). Eight of these ten coal resource developments have sufficient information to be modelled; potential impacts from non-modelled mines are inferred from their location. The assessment is a regional overview of potential impacts on, and risks to, water-dependent ecological, economic and sociocultural assets. It identified where potential changes in water resources and ecosystems may occur, ruling out areas where impacts are *very unlikely* (less than 5% chance). 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

Results from regional-scale hydrological modelling indicate potential risks to 1415 km² of ecosystems, 1892 km of streams, 2 springs and 724 water-dependent assets.

More detailed local information is required to determine the level of risk and potential impacts, including quantifying potential hydrological changes in an additional 3629 km of streams within the zone that could not be modelled.

Groundwater: It is *very unlikely* (less than 5% chance) that more than 2299 km² will experience drawdown in the regional watertable of greater than 0.2 m due to additional coal resource development. Of this, 287 km² is in the alluvium. Modelling shows 0.01% of the lower Namoi alluvium, 8% of the upper Namoi allivium, and none of the main aquifers of the Great Artesian Basin could experience impacts. *See page 11*

Surface water: Regional-scale modelling indicates that changes in the streamflow of the Namoi River are minimal. However, Back, Merrygowen and Bollol creeks are *very likely* (greater than 95% chance) to experience changes in their streamflow, particularly in the number of zero-flow days. *See page 15*

Ecosystem impacts: Of the ecosystems in the subregion, floodplains or lowland riverine ecosystems near Maules, Back and Bollol creeks are most likely to experience impacts resulting from changes in hydrology. *See page 19*

Asset impacts: 161 ecological assets are found in areas that are 'more at risk of hydrological changes' (Box 10). In the zone of potential hydrological change, risk could not be quantified for 10 unique ecological assets due to data limitations. *See page 24*

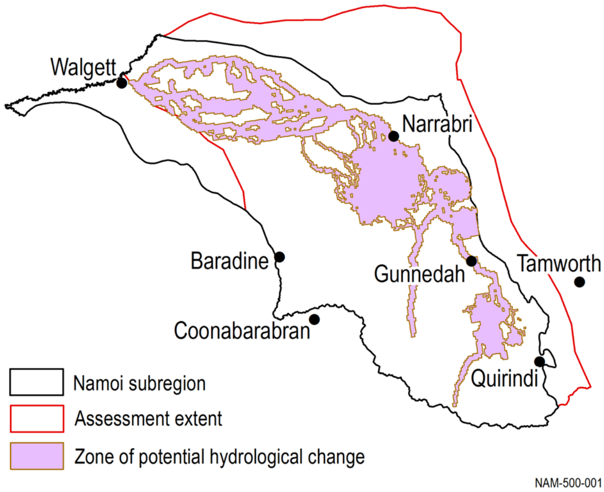

Figure 1 The zone of potential hydrological change

The pink zone (defined further in Box 4) defines the area in the Namoi subregion, outside of which impacts are ruled out. The assessment of potential impacts therefore focused inside 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 thresholds in specified surface water changes that arise due to additional coal resource development.

Data: Bioregional Assessment Programme (Dataset 1)

BASELINE COAL RESOURCE DEVELOPMENTS (BOX 1)

6 x mines

ADDITIONAL COAL RESOURCE DEVELOPMENTS (BOX 1)

9 x mines

1 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.

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CITATION

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COVER PHOTOGRAPH

Gulligal Lagoon, which is located about halfway between Gunnedah and Boggabri on the western side of the Namoi River, NSW, 2005. Credit: Neal Foster

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Executive summary

About the subregion *see page 3*

This synthesis presents key findings from the bioregional assessment of the Namoi subregion, part of the Northern Inland Catchments bioregion.

Located in the Murray–Darling Basin in central NSW, the subregion lies in the Namoi river basin, which includes the Namoi, Peel and Manilla rivers. Its largest towns are Gunnedah, Narrabri and Walgett.

The subregion covers 29,300 km^2; however, the total area investigated, the assessment extent, is 35,660 km^2 (Figure 2).

This assessment considered two futures: the baseline and the coal resource development pathway (Box 1). The **baseline** future comprises six existing coal mines: five open-cut and one longwall. The ten **additional coal resource developments** comprise three expansions to coal mines, six new coal mines and one coal seam gas (CSG) development. Eight of these additional coal resource developments had sufficient information for hydrological modelling.

Potential hydrological changes *see page 11*

Regional-scale hydrological modelling identified potential changes in groundwater and streamflow due to these eight additional coal resource developments. To rule out impacts on water-dependent ecosystems and assets, a **zone of potential hydrological change** (Figure 1) identified areas where hydrological modelling predicted changes. The zone comprises 20% of the assessment extent, covers 7014 km^2, and includes 5521 km of streams.

Within the zone, 2299 km^2 have at least a 5% chance of more than 0.2 m of drawdown due to additional coal resource development (Figure 9). Of this, 287 km^2 are in the alluvium, representing around 8% of the upper Namoi alluvium and 0.01% of the lower Namoi alluvium.

Modelling identified 1678 km of streams with at least a 5% chance of an increase of more than 3 zero-flow days per year. Reductions in number of high-flow days, and reductions in total streamflow, occur for much shorter lengths of streams.

Within the zone, 66% of the total 5521 km of streams are potentially impacted but unquantified because of mine proximity or due to extrapolation difficulties. The assessment cannot rule out potential changes in these streams.

Potential impacts *see pages 19 and 24*

Water-related ecological changes are most likely in floodplains or lowland riverine ecosystems. Potential ecosystem impacts are mostly limited to short sections of streams and their associated floodplains immediately downstream of additional coal resource developments. Two of the 22 springs in the assessment extent potentially experience hydrological changes due to additional coal resource development.

Of the 1690 ecological assets in the assessment extent, 624 are in the zone of potential hydrological change. Of these, 161 are found in areas that are relatively 'more at risk of hydrological changes' (Box 10), and the risk for 10 assets remains unquantified.

Impacts on surface water availability in rivers are likely to be minor. Of the 8953 bores in the assessment extent, 8424 are *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development. Outside the mine pit exclusion zone (Box 3), there are 118 bores with a greater than 5% chance of more than 2 m additional drawdown.

The greatest confidence in hydrological modelling results is in those areas where impacts are *very unlikely*. Where potential impacts are identified, further local-scale modelling may help with clarifying impacts to ecosystems.

Box 1 Investigating two potential 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 (CRDP):** a future that includes all coal mines and coal seam gas fields that are in the baseline as well as the **additional coal resource development**, those coal mines and coal seam gas fields expected to begin commercial production after December 2012, including expansions of baseline operations.

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

The CRDP for the Namoi subregion was based on information available as of December 2015. However, coal resource developments may change over time or be withdrawn, 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 CRDP and baseline, minimising the impacts of changes that occur in both futures.

Explore this assessment

Bioregional assessments are independent scientific assessments of the potential cumulative impacts of coal seam gas (CSG) and coal mining developments on water resources and water-dependent assets such as bores or potential habitats of species. 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* (with a less than 5% chance). The zone of potential hydrological change (Box 4) identifies where potential impacts cannot be ruled out. Governments, industry and the community can then focus on areas that are potentially impacted and undertake local-scale analyses where required for regulatory, water management and planning decisions.

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 assessments consider potential changes in water quantity and some impacts related to salinity but they do not assess a full suite of impacts on water quality.

The assessment of the **Namoi subregion**, part of the Northern Inland Catchments Bioregional Assessment, is reported in 12 technical products (Box 2), which this synthesis summarises.

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/NAM. References, further reading and datasets are listed at the end of this synthesis.

Box 2 Technical products for the Namoi 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

The Namoi subregion, within the Northern Inland Catchments bioregion, covers approximately 29,300 km^2 in the Murray–Darling Basin in NSW (Figure 2).

The subregion is home to about 27,000 people, with the main centres of Gunnedah and Narrabri located along the Namoi River. Agricultural land covers 77% of the subregion, with irrigated agriculture a large component. The Namoi alluvium supports highly valuable agricultural development that includes cropping of cotton and grains, and livestock grazing on the less arable soils.

The **assessment extent** (the total area investigated in this assessment) is about 35,660 km^2 (Figure 2).

The main near-surface aquifers in the Namoi subregion are associated with the alluvial sediments along the Namoi River and its larger tributaries, the Mooki and Peel rivers, and the Coxs and Pian creeks (Figure 2 and Figure 3). Other aquifers occur within the Great Artesian Basin (GAB) and the Gunnedah Basin.

The Namoi River is the subregion's main surface water resource. It drains about 42,000 km^2 from its headwaters in the Great Dividing Range. Except for the perennial Namoi River, all streams are temporary.

The Liverpool Plains contain endangered native grasslands and riparian vegetation with dominant river sheoaks and willows, and river red gum communities along the larger streams. A wide range of aquatic habitats, including large areas of anabranch and billabong wetlands downstream of Narrabri, add to the ecological importance of the Namoi subregion.

To study potential impacts on these ecosystems, the assessment developed a landscape classification to categorise the main natural and human-modified ecosystems in the assessment extent (Box 7), 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 ecosystems?' (page 19) for more information.

The assessment also investigated potential impacts on assets based on their ecological, economic or sociocultural values (O'Grady et al., 2015). These include ecosystems such as the state forest of the Pilliga (the largest remaining area of dry sclerophyll forest west of the Great Dividing Range in NSW) and the Pilliga Nature Reserve in the upper catchment of Bohena Creek (the largest reserve in the region). See 'What are the potential impacts of additional coal resource development on water-dependent assets?' (page 24) for more information.

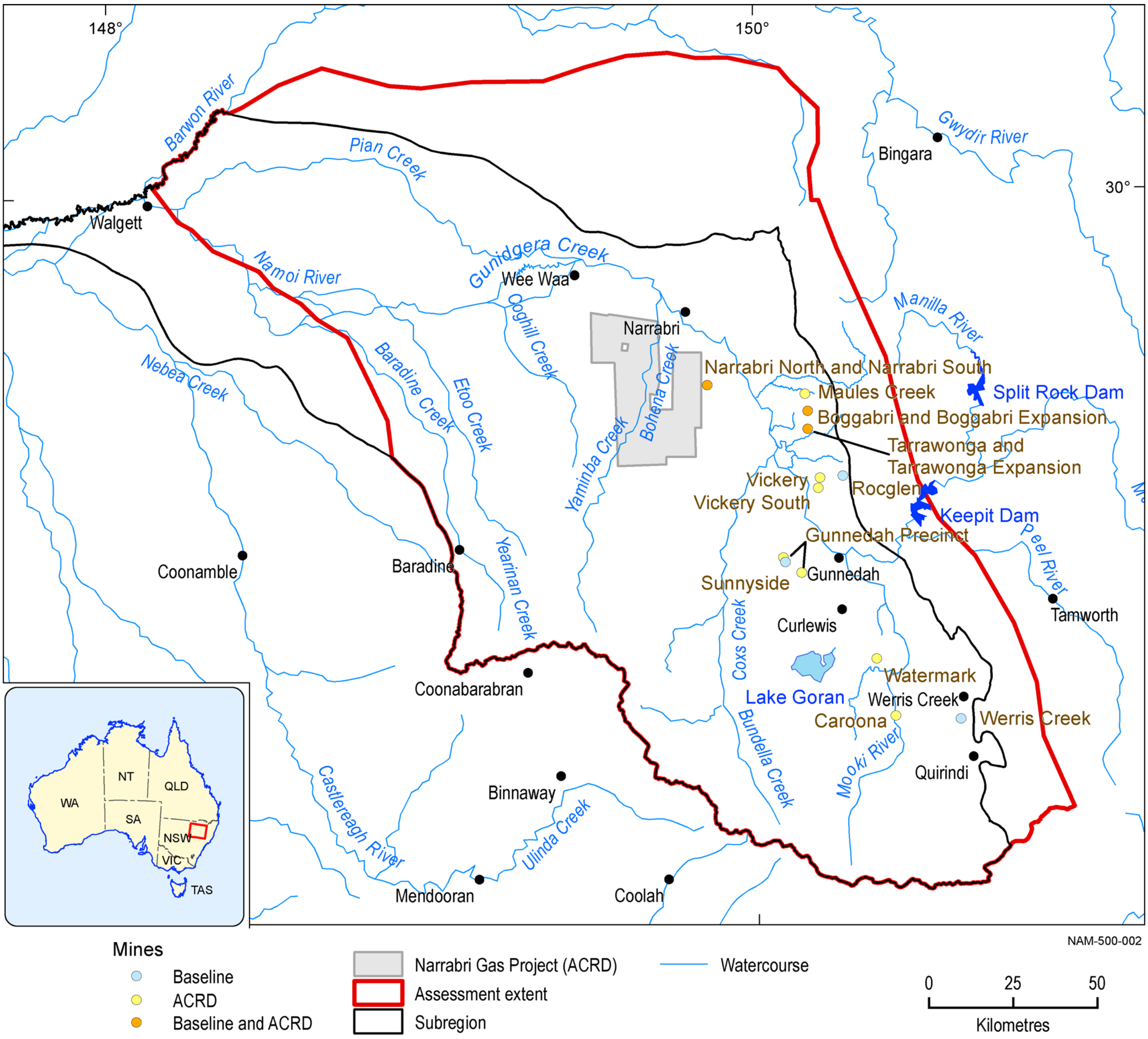


Figure 2 Coal mines and coal seam gas tenements in the coal resource development pathway and the major modelled streams

The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline coal resource development (baseline) and the additional coal resource development. Three developments are both baseline mines and additional coal resource developments (ACRD): Boggabri, Tarrawonga and Narrabri North are baseline mines, while Boggabri expansion, Tarrawonga expansion and Narrabri South are additional coal resource developments (ACRDs). The Vickery South Coal Project and the Gunnedah Precinct, both ACRDs, did not have sufficient information for hydrological modelling.
Data: Geoscience Australia (Dataset 2), Santos (Dataset 3)

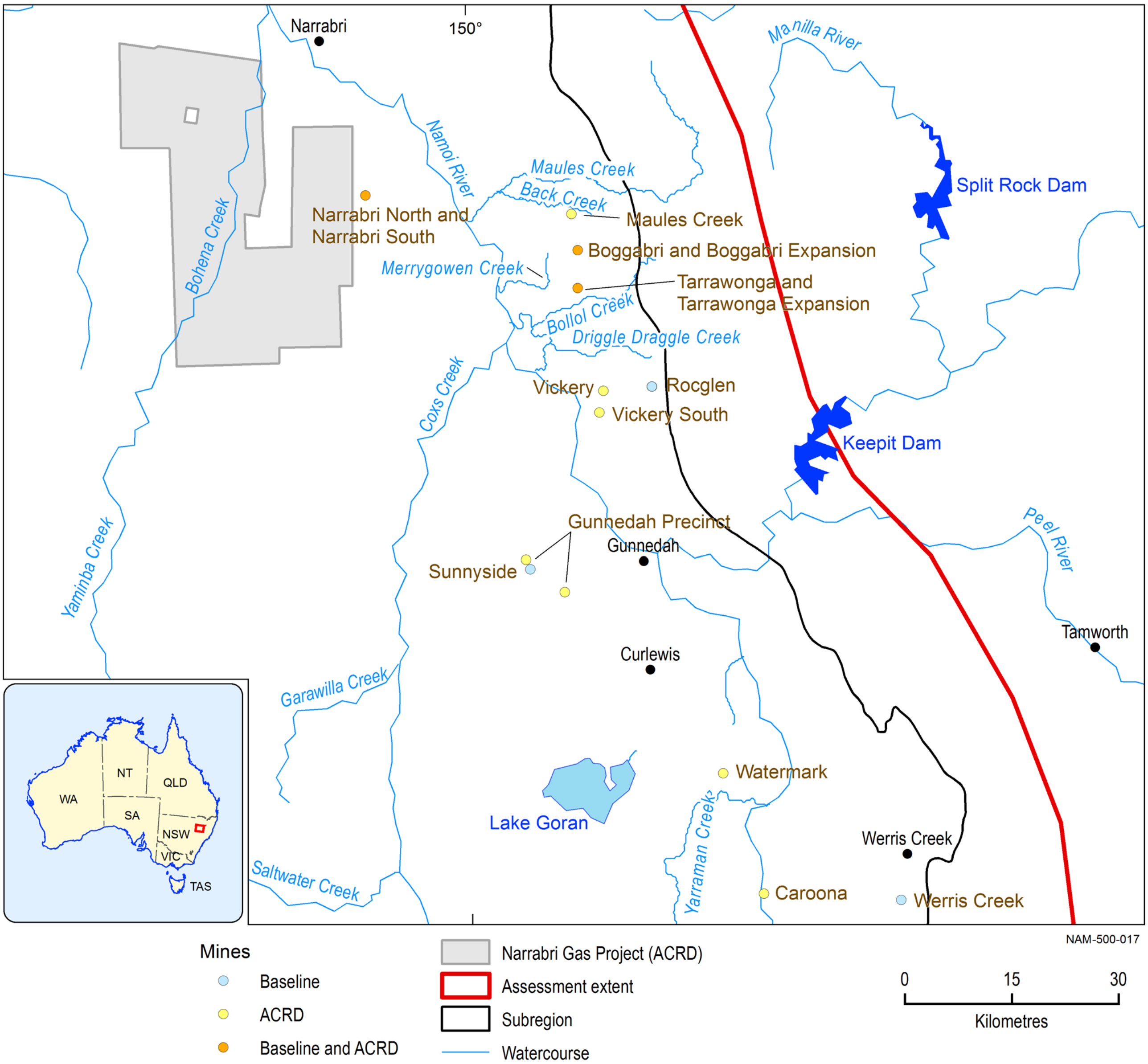


Figure 3 Close-up of part of the Namoi subregion, showing named watercourses in the vicinity of baseline and additional coal resource developments

The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline coal resource development (baseline) and the additional coal resource development (ACRD).

Data: Geoscience Australia (Dataset 2), Santos (Dataset 3)

Coal resource development

Key finding 1: The coal resource development pathway (Box 1) defines the most likely future for the subregion as of December 2015. It includes six baseline coal mines and ten additional coal resource developments: expansions to three open-cut mines, three new open-cut mines, two new underground mines, one underground/open-cut mine and one coal seam gas development.

When the CRDP was finalised in December 2015, it included ten additional coal resource developments that were proposals for new or expanded operations (Figure 2 and Figure 3). Of these, the hydrological modelling incorporated eight additional coal resource developments:

- expansions to two open-cut mines: Boggabri Coal Expansion Project and Tarrawonga Coal Expansion Project
- three new open-cut mines: Maules Creek Mine, Watermark Coal Project and Vickery Coal Project
- two underground mines: Caroona Coal Project and Narrabri South
- one CSG development: Narrabri Gas Project.

The remaining two mines, Vickery South Coal Project (open-cut) and the Gunnedah Precinct (underground and open-cut), did not have sufficient information to model. The impact and risk analysis provides a commentary on these two developments (Section 3.6 in Herr et al. (2018a)). The assumed timeline of construction and production for each additional coal resource development is shown in Figure 4.

The NSW Government bought back BHP's Caroona coal exploration licences on the Liverpool Plains in August 2016. This occurred after the finalisation and modelling of the CRDP; thus, the Caroona Coal Project remained part of the modelling even though it is no longer proceeding. As of July 2017, the Shenhua exploration licence for the Watermark Coal Project was reduced by 51.4% to exclude the Liverpool Plains. However, this did not change the operational mining area and therefore the hydrological modelling of the Watermark Coal Project remains relevant.

The coal resources under development in the Namoi subregion are primarily in the Gunnedah Basin, with the main economic coal seams located in the Black Jack Group and the Maules Creek Formation. Two regional-scale block diagrams illustrate the geology associated with baseline and additional coal resource developments (Figure 5 and Figure 6). The Werris Creek Mine is located in the Werrie Basin, adjacent to the eastern side of the Gunnedah Basin. The target coal seams for the Werris Creek Mine are in the Willow Tree Formation (Figure 7). The Hunter-Mooki Thrust Fault System isolates the groundwater in the Werrie Basin from the Gunnedah Basin. For this reason, groundwater modelling did not include the Werris Creek mine.

More information about the coal and CSG resources, mines and proposed developments are in the coal and CSG resource assessment (Northey et al., 2014).

Figure 4 Timelines for modelled coal resource developments in the coal resource development pathway

These timelines were used for the hydrological modelling. The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline and the additional coal resource development. Two additional coal resource developments (Vickery South Coal Project and Gunnedah Precinct) could not be modelled due to insufficient data, hence they are not shown on this timeline.

FIND MORE INFORMATION

Context statement, product 1.1 (Welsh et al., 2014)

Coal and coal seam gas resource assessment, product 1.2 (Northey et al., 2014)

Description of the water-dependent asset register, product 1.3 (O'Grady et al., 2015)

Conceptual modelling, product 2.3 (Herr et al., 2018b)

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

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

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

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

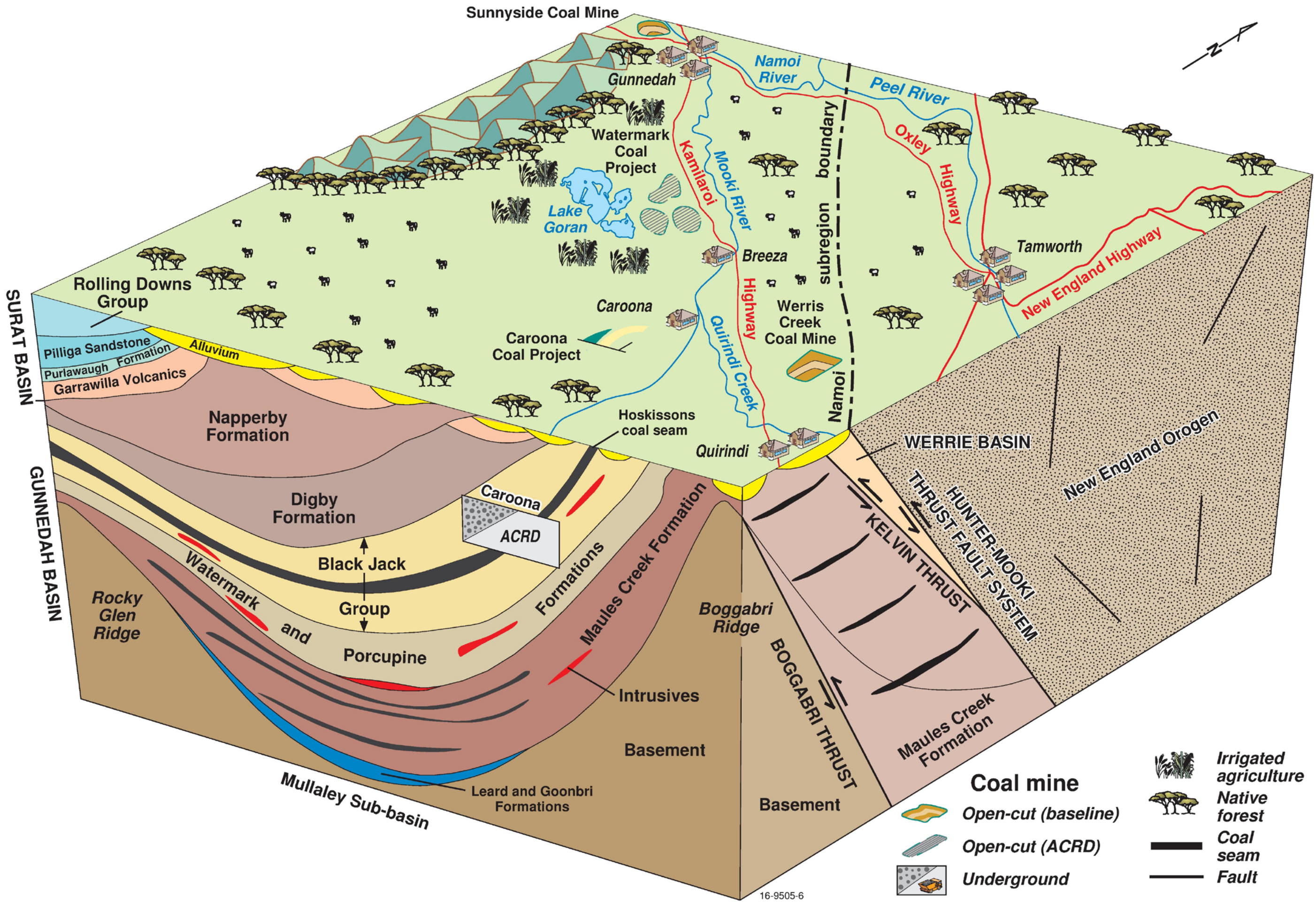


Figure 5 Schematic diagram of the south-east Namoi subregion from Quirindi to Gunnedah showing underlying geology relative to coal resource development

The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline and the additional coal resource developments (ACRD).

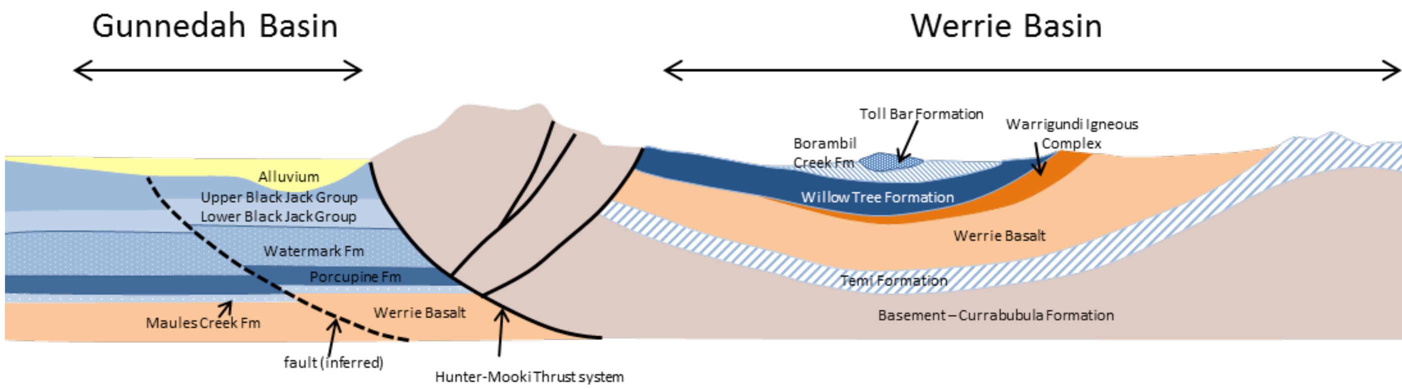


Figure 7 Cross-section of the Werrie Basin

The location of the cross-section is shown as an orange line in the inset map. Fm = formation
Source: derived from Pratt (1996)

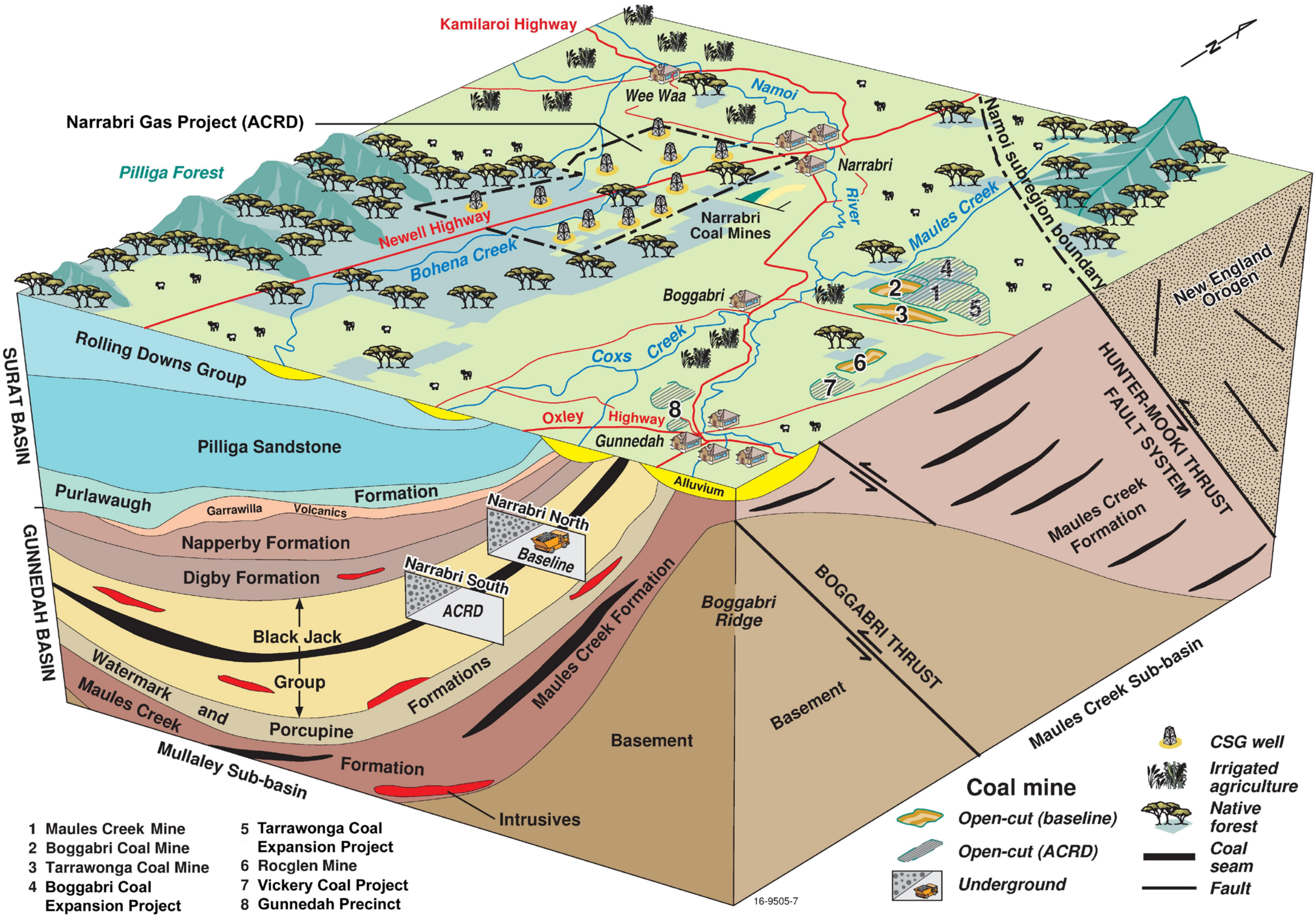
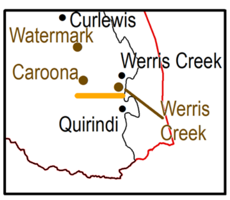


Figure 6 Schematic east–west diagram of the Namoi subregion from Gunnedah to Wee Waa showing underlying geology relative to coal resource development

The coal resource developments in the coal resource development pathway (CRDP) are the sum of those in the baseline and the additional coal resource development (ACRD). CSG = coal seam gas



How could coal resource development result in hydrological changes?

The assessment identified potential hazards (Dataset 4) associated with coal resource development that could result in hydrological changes, such as aquifer depressurisation due to groundwater extraction. A **hazard** is a chain of events that begins with a coal resource development activity and results in hydrological changes. Causal pathways extend the chain of events to the potential impacts on ecosystems and assets resulting from these hydrological changes.

Hazards in scope were assessed by estimating relevant hydrological changes through hydrological modelling where possible, and then identifying potential impacts on, and risks to, water-dependent ecosystems and assets (described in the following sections).

In the BA context, four causal pathway groups summarise the causal pathways that commonly arise from coal resource development activities:

A. **'Subsurface depressurisation and dewatering'** is triggered by extraction of groundwater to enable CSG extraction and dewatering of underground and open-cut mine pits. This potentially directly affects both local and regional groundwater systems, 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 CSG production or 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, based on the licence conditions as summarised in the relevant environmental impact assessments, and are unlikely to result in cumulative impacts.

FIND MORE INFORMATION

Conceptual modelling, product 2.3 (Herr et al., 2018b)

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

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

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., 2016)

Hazard analysis (Impact Modes and Effects Analysis) (Dataset 4)

What are the potential hydrological changes?

Key finding 2: The zone of potential hydrological change (Figure 1 and Box 4) covers an area of 7014 km², including 5521 km of streams. This represents about 20% of the area in the entire Namoi assessment extent.

Outside this zone, potential changes to water quantity and availability due to additional coal resource development are *very unlikely*.

Groundwater

Key finding 3: It is *very unlikely* that baseline drawdown due to coal mining extends more than about 10 km from any mine (Figure 8). Additional drawdown due to the Narrabri Gas Project is estimated to extend over a much larger area but is generally lower in magnitude compared to drawdown due to the mines (Figure 9).

Results are reported for the regional watertable, which comprises the alluvial aquifer as well as weathered and fractured rock aquifers. The year when maximum change is attained varies throughout the subregion. It is most likely to be during the decades after mining activity ceases, and occurs later with increasing distance from mine tenements (Janardhanan et al., 2018).

Key finding 4: The area with at least a 5% chance of greater than 0.2 m drawdown due to baseline development is 479 km²; baseline coal mines are sufficiently separated so that there is no overlap of drawdown with neighbouring baseline mines (Figure 8).

The area with the same chance of this drawdown due to additional coal resource development is 2299 km² (Figure 9) of which 287 km² is alluvium, representing 8% of the upper Namoi alluvium and 0.01% of the lower Namoi alluvium (Table 8 in Herr et al. (2018a)).

Drawdown due to additional coal resource development covers a much larger area compared to baseline drawdown, although, as for baseline mines, drawdown due to additional mines is *very unlikely* to extend more than about 10 km from the mine. In some cases, however, drawdown does overlap due to multiple developments that are nearby. These areas have potential cumulative impacts:

- Drawdown due to Narrabri South overlaps with drawdown due to the baseline Narrabri North Mine, as well as that due to the Narrabri Gas Project.
- East of these developments, drawdown due to the Maules Creek Mine overlaps with drawdown due to the baseline Boggabri Coal Mine, the Boggabri Coal Expansion Project, the baseline Tarrawonga Mine and the Tarrawonga Coal Expansion Project.
- South of these mines, drawdown due to the Vickery Coal Project overlaps with drawdown due to the baseline Rocglen Mine.
- Modelling also suggested potential overlap between the Watermark Coal Project and the now-abandoned Caroona Coal Project.

It is *very likely* that 156 km² will experience at least 0.2 m of drawdown due to additional coal resource development, but *very unlikely* that this will extend beyond 2299 km². An area of 99 km² is *very likely* to experience at least 5 m of drawdown due to additional coal resource development, but it is *very unlikely* that more than 520 km² will experience more than 5 m of drawdown (Table 6 in Herr et al. (2018a)).

Box 3 Calculating groundwater drawdown

Drawdown is a lowering of the groundwater level that is a result of, for example, pumping. The groundwater model predicted 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 futures (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 km² grid cell, and occurs 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 an amount of drawdown that is not likely to eventuate.

Close to open-cut mines, confidence in the results of the groundwater model is very low because of the very steep hydraulic gradients at the mine pit interface. As a result, a **mine pit exclusion zone** was defined. Groundwater drawdown within this 116 km² zone was not used in the assessment of ecological impacts.

The modelling included coal seam gas depressurisation and mine dewatering, but it did not differentiate the individual effects of these variables on drawdown.

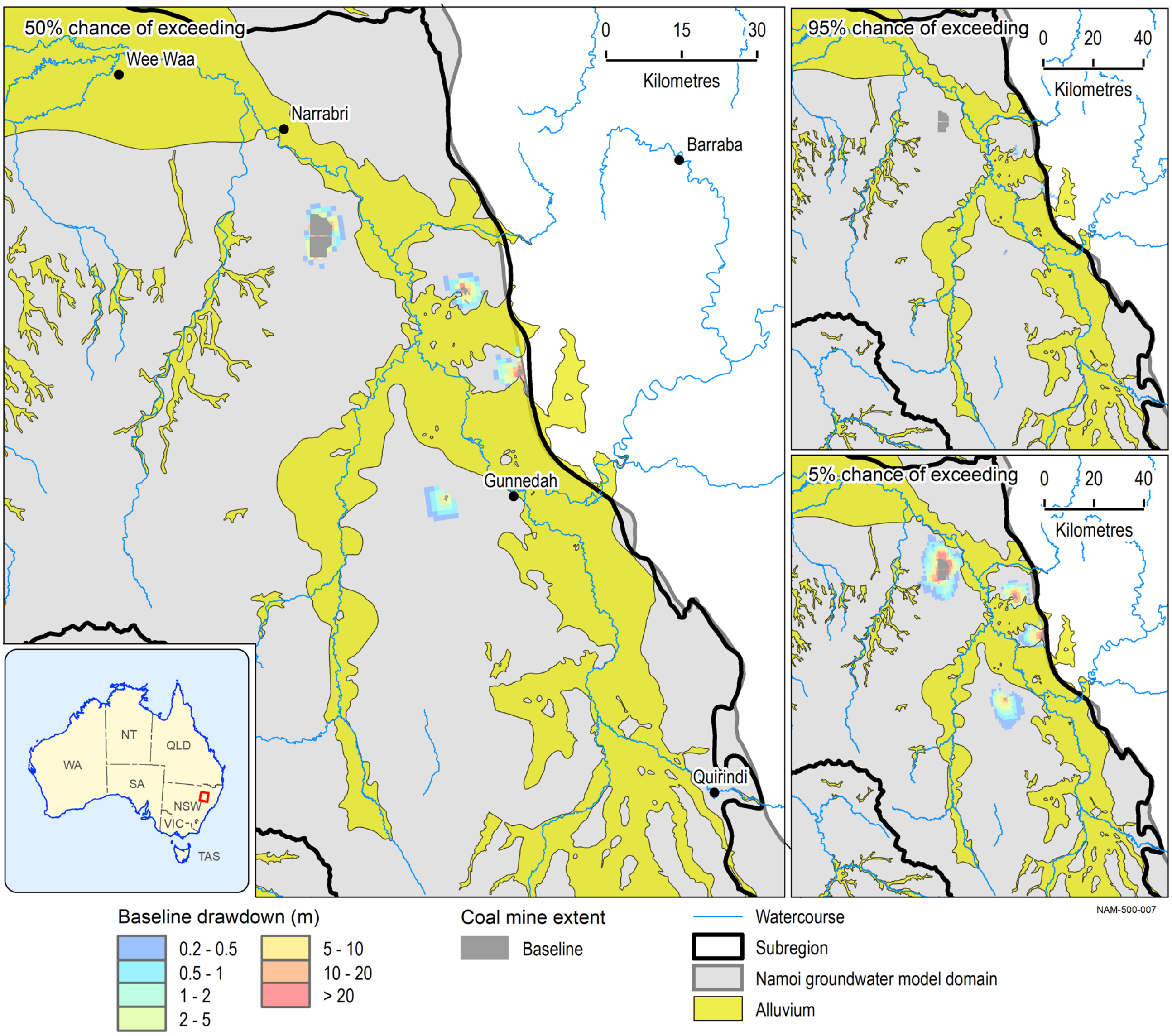


Figure 8 Baseline drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

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 Herr et al. (2018a) as percentiles. Areas reported for drawdown exclude the mine pit exclusion zones.
Data: Bioregional Assessment Programme (Dataset 5)

Box 4 The zone of potential hydrological change

A **zone of potential hydrological change** (Figure 1) was defined to rule out potential impacts in areas outside the zone. It is a combination of the **groundwater zone of potential hydrological change** and the **surface water zone of potential hydrological change** (see Section 3.3.1 in Herr et al. (2018a)). These zones were defined using **hydrological response variables**, the hydrological characteristics of the system that potentially change due to coal resource development – for example, groundwater drawdown or the number of low-flow days.

The groundwater zone is the area with at least a 5% chance of greater than 0.2 m drawdown in the near-surface aquifer (Box 3) due to additional coal resource development.

The surface water zone contains those river reaches where there is at least a 5% chance that a change in any one of nine surface water hydrological response variables exceeds specified thresholds (see Table 4 in Herr et al. (2018a)). The surface water zone also includes those streams that flow through the groundwater zone of potential hydrological change where there was insufficient data to enable surface water modelling.

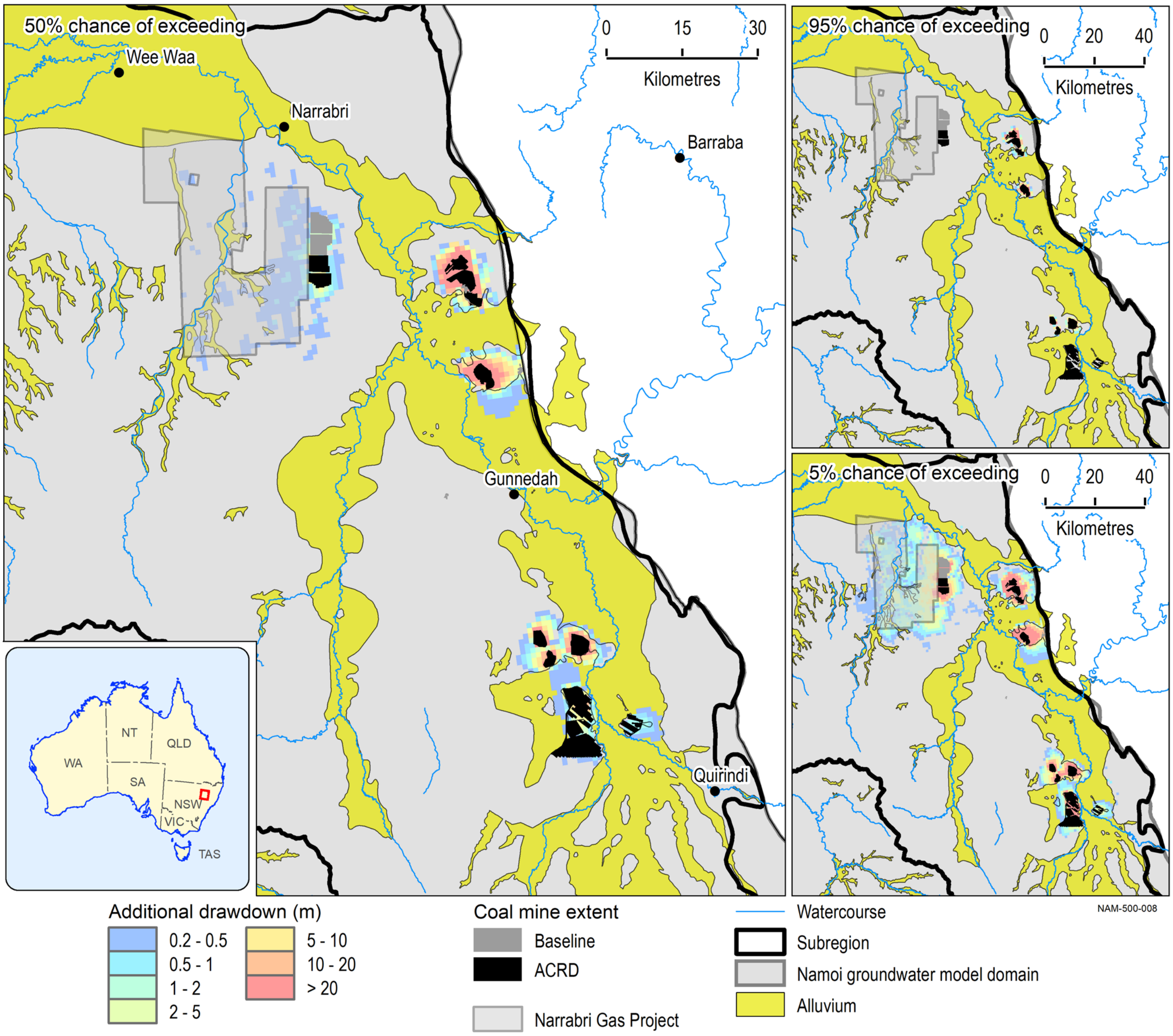


Figure 9 Additional drawdown (m) in the regional watertable (95%, 50% and 5% chance of exceeding given values of drawdown)

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 Herr et al. (2018a) as percentiles. Areas reported for drawdown exclude the mine pit exclusion zones.

Data: Bioregional Assessment Programme (Dataset 5)

Water-dependent ecosystems and ecological assets outside of this zone are *very unlikely* to experience any hydrological change due to additional coal resource development. Within the zone, potential impacts may need to be considered further. This assessment used regional-scale receptor impact models (Box 8) to translate predicted changes in hydrology within the zone into a distribution of ecological outcomes that may arise from those changes. Finer-scale assessments may help to account for local conditions.

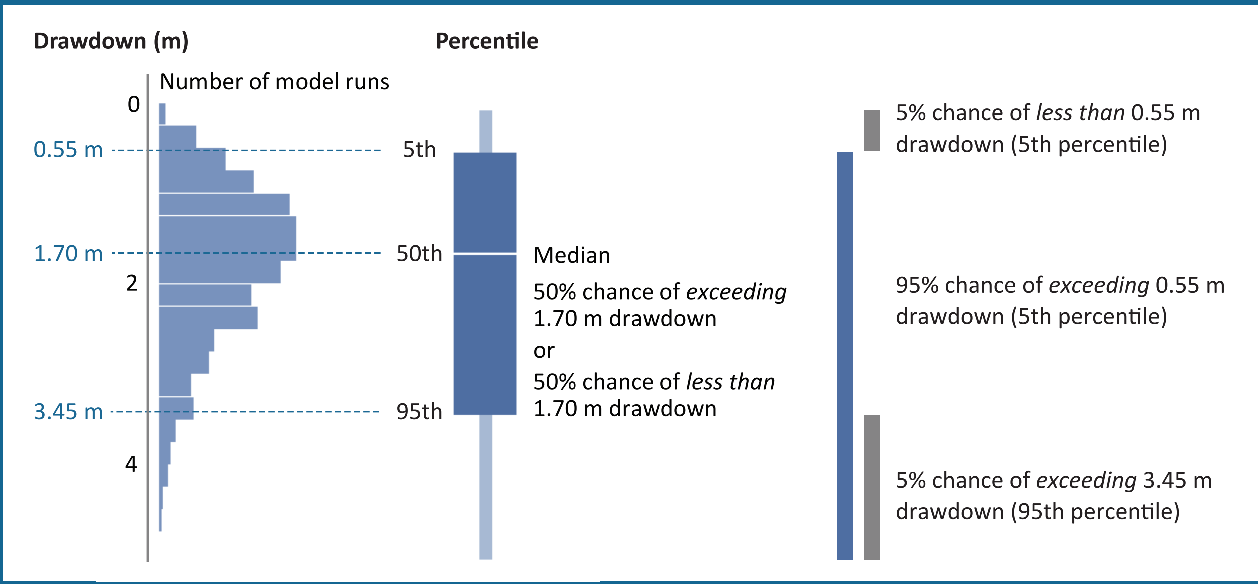


Figure 10 Illustrative example of probabilistic drawdown results using percentiles and percent chance

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 groundwater drawdown and changes in streamflow 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. Because it is unknown how these properties vary across the entire assessment extent (both at surface and at depth), 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 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 a range of 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).

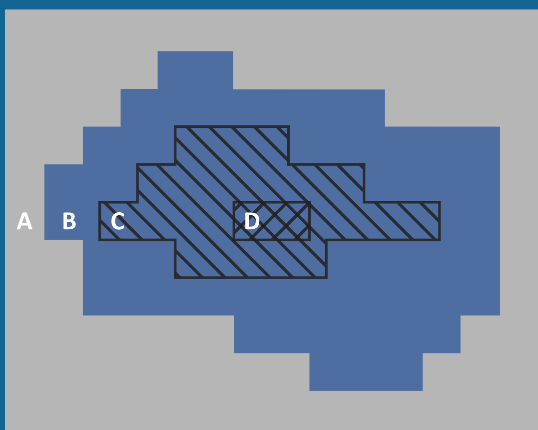


Figure 11 Key areas for reporting probabilistic results

Surface water

The zone of potential hydrological change in the Namoi subregion includes 5521 km of stream network. Of this, 3629 km (or 66%) are potentially impacted but not quantified, either because of their proximity to the mines or due to difficulties in extrapolating results (Aryal et al., 2018a). Potential changes in these streams cannot be ruled out.

The zone was defined by ten **hydrological response variables** (Box 4). This synthesis summarises the maximum modelled changes in three hydrological response variables that were used to characterise flows for the impact and risk analysis:

- **zero-flow days**, which are sensitive to both the interception of surface runoff and the cumulative impact of groundwater drawdown on baseflow over time
- **high-flow days**, which are more sensitive to interception of surface runoff (Aryal et al., 2018a)
- **annual flow**, which is also more sensitive to interception of surface runoff.

Changes in other hydrological response variables are available on the BA Explorer at www.bioregionalassessments.gov.au/explorer/NAM/hydrologicalchanges.

Key finding 5: Regional-scale modelling indicated that changes in the streamflow of the Namoi River are minimal. However, from the streams where hydrological modelling was possible, Back Creek, Merrygowen Creek and Bollol Creek (Figure 3 and Figure 12) are *very likely* to experience changes in their streamflow, particularly in the number of zero-flow days.

Most of these creeks have catchment areas much less than 100 km^2 and effects are localised.

Zero-flow days

Surface water modelling quantified the annual change in the number of zero-flow days due to additional coal resource development for 1892 km of the 5521 km of streams in the zone of potential hydrological change.

The modelling indicated that it is *very unlikely* that more than 1678 km of the modelled streams will experience more than an additional 3 zero-flow days per year (see Table 9 in Herr et al. (2018a)). There is a 5% chance that 276 km of modelled streams in the zone will experience 20 or more additional zero-flow days per year, and a 5% chance that 31 km of these streams will experience 200 or more additional zero-flow days per year in the year in which maximum change occurs (see Table 9 in Herr et al. (2018a)).

The streams with the largest increases in the number of zero-flow days (Figure 12) are Back, Merrygowen and Bollol creeks, which drain the Maules Creek Mine, Boggabri Coal Expansion Project and Tarrawonga Coal Expansion Project, respectively (see Figure 3 for the locations of these creeks and developments).

Not all of these creeks actually flow for 200 days every year. This apparent anomalous increase in zero-flow days occurs because modelling indicated that the river can flow for more than 200 days per year in particularly wet years. As bioregional assessments report the maximum change in zero-flow days due to additional coal resource development, the reporting is biased towards a wet year when these maximum changes can occur.

The increase in zero-flow days in these creeks may represent a change that is greater than the interannual variability under the baseline (Figure 13), which is more likely to move the system outside the range of conditions previously encountered. Changes in many other streams are similar to, or less than, the interannual variability under the baseline.

High-flow days

Additional coal resource development is more likely to affect zero flows than high flows, reflected by the shorter length of streams likely to experience changes in high-flow days (Figure 18 and Table 11 in Herr et al. (2018a)).

It is *very unlikely* that more than 127 km of modelled streams will experience decreases of more than 3 high-flow days per year. There is a 5% chance that 37 km of these streams might experience a reduction of 10 or more high-flow days per year. There is a 5% chance that 31 km of these streams might experience a reduction of 50 or more high-flow days per year.

Reduction in high-flow days of at least 3 days per year is *very likely* in six streams:

- Back, Merrygowen, Bollol and Driggle Draggle creeks, which drain the Maules Creek Mine, Boggabri Coal Expansion Project, Tarrawonga Coal Expansion Project and Vickery Coal Project, respectively
- two unnamed creeks impacted by the Watermark Coal Project.

Among these six, Back, Merrygowen and Bollol creeks are *very likely* to have a reduction in high-flow days of at least 10 to 20 days per year.

The modelled decreases in the number of high-flow days are less than the interannual variability under the baseline in most locations and for most probabilities of change (Figure 17 in Herr et al. (2018a)). The streams that drain catchments near the Maules Creek Mine, Boggabri Coal Expansion Project, Tarrawonga Coal Expansion Project and Watermark Coal Project could potentially experience reductions in high-flow days comparable to, or greater than, the interannual variability under the baseline, which is more likely to move the system outside the range of conditions previously encountered.

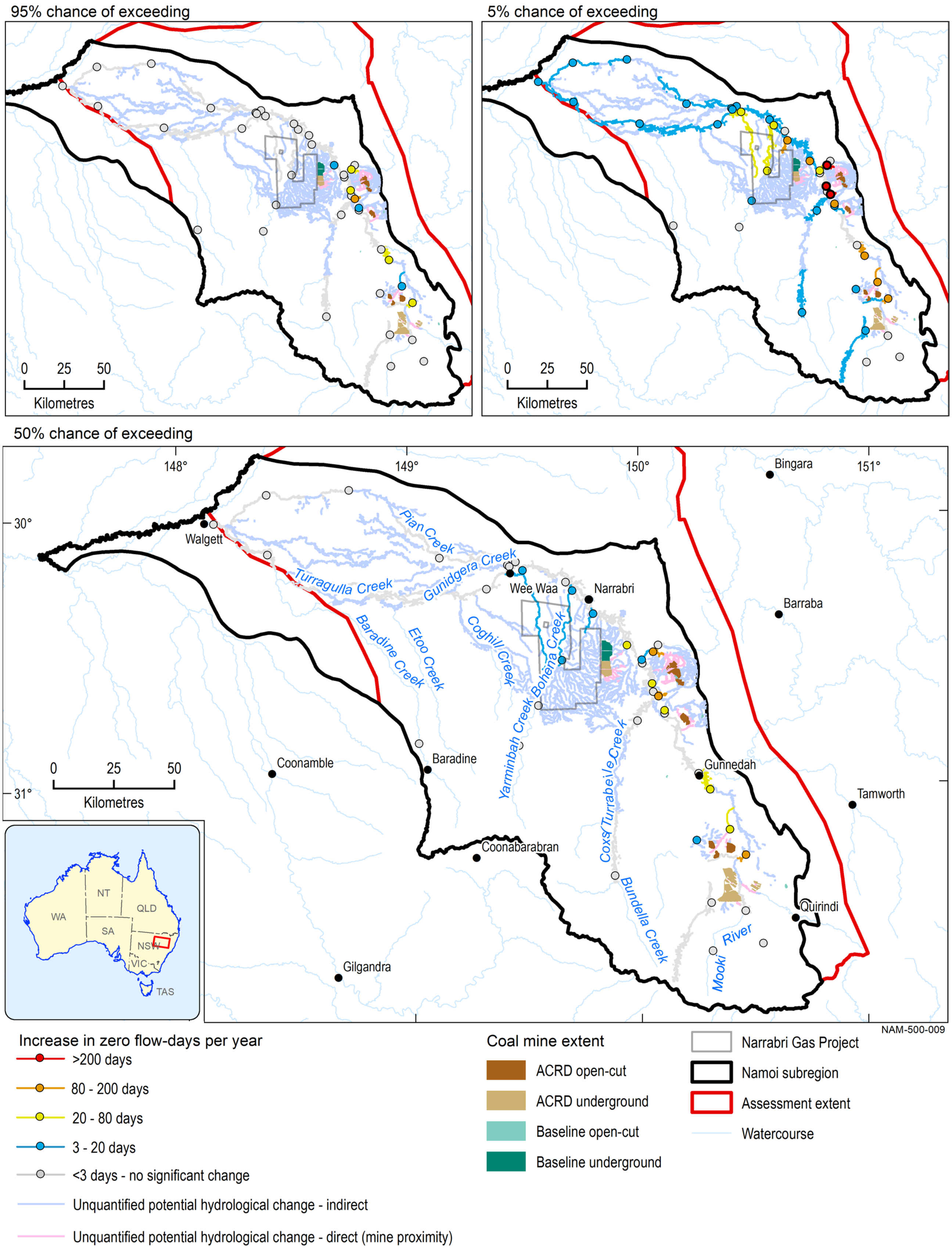


Figure 12 Increase in the number of zero-flow days due to additional coal resource development

The coal resource development pathway includes baseline and additional coal resource developments (ACRD). The difference in zero-flow days between the coal resource development pathway and baseline is due to additional coal resource development. See Figure 3 for the location of the streams with the largest increases in the number of zero-flow days: Back, Merrygowen and Bollol creeks. Results are shown as percent chance (Box 5). These appear in Herr et al. (2018a) as percentiles. ‘Unquantified hydrological change – direct (mine proximity)’ indicates streams that flow through or start within a mine area. ‘Unquantified hydrological change – indirect’ indicates streams within a potential additional drawdown area.
Data: Bioregional Assessment Programme (Dataset 1)

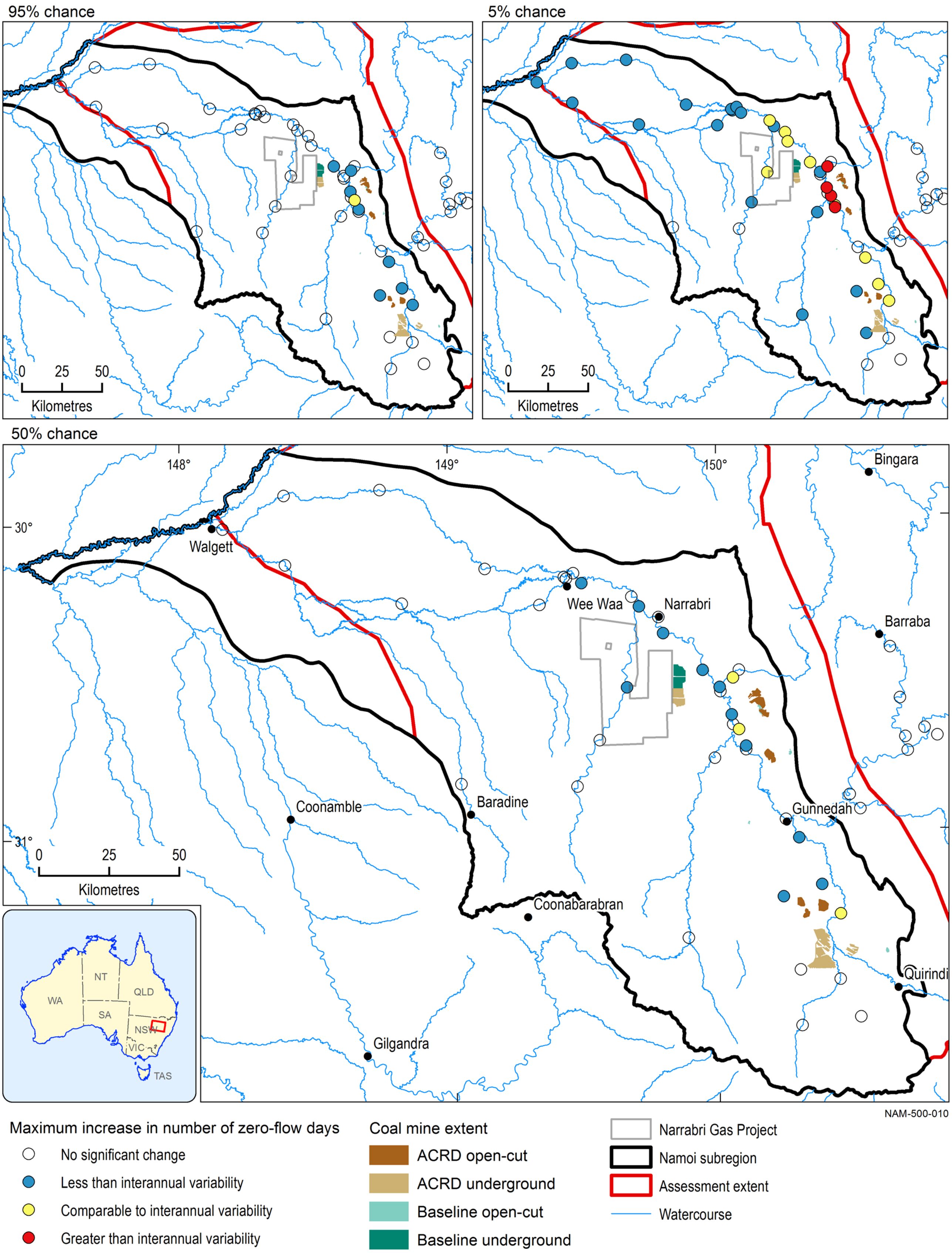


Figure 13 Ratio of maximum increase in the number of zero-flow days per year due to additional coal resource development to the interannual variability in number of zero-flow days under the baseline (95%, 50% and 5% chance)

Streams are labelled in Figure 12. The coal resource development pathway includes baseline and additional coal resource developments (ACRD). The difference in zero-flow days between the coal resource development pathway and baseline is due to additional coal resource development. Results are shown as percent chance (Box 5). These appear in Herr et al. (2018a) as percentiles.
Data: Bioregional Assessment Programme (Dataset 1)

Annual flow

Modelling predicted it is *very unlikely* that more than 74 km of modelled streams will experience decreases of more than 1% in annual flow. There is a 5% chance that 34 km might experience reductions of more than 5% in annual flow, and a 5% chance that 17 km may experience reductions of 20% to 50%.

Immediately downstream of mine sites, 51 km of streams are *very likely* to experience reductions in annual flow of more than 1%, and 19 km of streams are *very likely* to experience reductions of 5% to 20%. Generally, the large modelled decreases in annual flow are restricted to streams draining small catchments immediately downstream of open-cut mines. See Figure 21 and Table 12 in Herr et al. (2018a) for more information.

Reduction in mean annual flow of at least 5% is *very likely* in five streams:

- Back, Merrygowen and Driggle Draggle creeks, which drain the Maules Creek Mine, Boggabri Coal Expansion Project and Vickery Coal Project, respectively
- two unnamed creeks impacted by the Watermark Coal Project.

Among these five, only Back Creek, Merrygowen Creek and an unnamed creek are *very likely* to have a reduction in mean annual flow of 10% to 20%.

Reported decreases in annual flow are smaller than interannual variability under the baseline in all locations and for all probabilities of change (Figure 23 in Herr et al. (2018a)).

Water quality

The risk to regional stream water salinity due to additional coal resource development depends on the magnitude of the hydrological changes and the salinity of the groundwater relative to the salinity of the stream into which the water is discharged. In all the streams identified from the regional-scale modelling with potentially large changes in flow, the impact on local stream salinity depends on the relative reductions in catchment runoff and baseflow over time. Where modelling predicts a possible reduction in baseflow, this could lead to a reduction in stream salinity (Peña-Arancibia et al., 2016).

Reductions in catchment runoff are more likely to affect runoff peaks, while baseflow reductions have a more noticeable effect on low flows. In streams where modelling suggested increasing numbers of zero-flow days, it is likely that channel pools will be subject to longer periods of salt concentration by evaporation and less efficient flushing. These are conditions that favour increasing salinity of these water bodies. Creeks with increased numbers of modelled zero-flow days include:

- Back Creek (near Boggabri Coal Expansion Project)
- Merrygowen Creek and Ballol Creek (near Tarrawonga Coal Expansion Project)
- Mooki River near Watermark Coal Project.

Increases in baseflow, potentially leading to increases in alluvial aquifer and stream salinity, cannot be ruled out; however, this is not an outcome that has been reported in the literature and remains an area for further investigation. Estimating the magnitude and extent of water quality changes would require specific representation of water quality parameters in the modelling. This remains a knowledge gap.

Regulatory requirements are in place in NSW that aim to minimise potential salinity impacts due to coal resource development. See Section 3.3.4 of Herr et al. (2018a) for more detail.

FIND MORE INFORMATION

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

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

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

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

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

Impact and risk analysis, product 3-4 (Herr et al., 2018a)

Surface water modelling, submethodology M06 (Viney, 2016)

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

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

Surface water uncertainty analysis (Dataset 6)

Summary of surface water results (Dataset 7)

Surface water model (Dataset 8)

Regional watertable (Dataset 1)

Groundwater model uncertainty analysis (Dataset 5)

Summary of groundwater drawdown by assessment unit (Dataset 1)

Groundwater model results (Dataset 5)

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

The impact and risk analysis (Box 6) used multiple lines of evidence to investigate how hydrological changes due to additional coal resource development may affect ecosystems in the assessment extent.

Six landscape groups represent these ecosystems (Box 7; Table 1 in Section 2.3.3 in Herr et al. (2018b)):

- 'Floodplain or lowland riverine'
- 'Non-floodplain or upland riverine'
- 'Dryland remnant vegetation'
- 'Rainforest'
- 'Human-modified'
- 'Springs'.

Potential impacts on ecosystems were assessed by overlaying their extent on the zone of potential hydrological change (Box 4).

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 the presence of tadpoles, to infer the potential ecological impacts of hydrological changes.

The relative risk to ecosystems is reported using categories defined in Box 9.

More detail on each ecosystem, including information on water dependency, sensitivity to change and potential ecosystem relevance of hydrological changes, is contained in Section 3.4 of the impact and risk analysis (Herr et al., 2018a).

Box 6 Analysing impact and risk

Potential impacts to water-dependent ecosystems and assets were assessed by multiple lines of evidence that included:

- water dependence
- hydrological response variables from hydrological modelling
- the overlay of the zone of potential hydrological change (Box 4) on the extent of ecosystems and assets
- qualitative mathematical models derived from consultation with experts
- quantitative receptor impact models and additional discussion of outputs with experts (Box 8), primarily developed for ecosystems not assets.

Impacts to all assets and ecosystems were assessed (as a minimum) by overlaying the extent of ecosystems and assets on the zone in order 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.
- **Within this zone**, ecosystems and assets are **potentially impacted**, unless there is clear evidence to rule out impact. This evidence might come from hydrological modelling, regional-scale qualitative mathematical models and/or receptor impact models applied to some ecosystems. The impact depends on the ecosystem's or asset's reliance on groundwater and/or surface water, the magnitude and likelihood of the change, and the extent of the ecosystem or asset exposed to the change.

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

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

Box 7 Understanding the landscape classification

Twenty-nine landscape classes represent the natural and human-modified ecosystems in the Namoi subregion (Figure 24 and Table 16 in Herr et al. (2018a)). They enable a systematic and comprehensive analysis of potential impacts on, and risks to, the water-dependent assets nominated by the community. The landscape classification was based on the subregion's geology, geomorphology, hydrogeology, land use and ecology. These landscape classes were aggregated into six landscape groups, based on their likely response to hydrological changes. Definitions for landscape classes and landscape groups for the Namoi subregion are available online at environment.data.gov.au/def/ba/landscape-classification/namoi-subregion.

Ecosystems

Which ecosystems are *very unlikely* to be impacted?

Key finding 6: Potential impacts due to additional coal resource development are *very unlikely* for 20 springs in the assessment extent that are outside the zone of potential hydrological change. Two springs, on the eastern fringes of the Great Artesian Basin within the zone, may experience an unquantified impact. Further local-scale investigations are required to determine the magnitude of any potential impacts.

Of the 15 non-GAB springs found in the assessment extent, none occur within the zone of potential hydrological change (Box 4). Therefore, impacts on these ecosystems can be ruled out as they are *very unlikely* to experience hydrological changes due to additional coal resource development since it is assumed that the regional watertable is the source of these springs. Five of the seven GAB springs are outside the area where there may be additional groundwater drawdown in the GAB. The two remaining springs in the zone need further investigation to determine their connection to the GAB, as discussed further on page 23.

Ecosystems where potential impacts were ruled out include:

- dryland remnant vegetation, because this comprises vegetation communities that are deemed to not be dependent on surface water or groundwater for the purposes of this bioregional assessment
- human-modified ecosystems, because these primarily comprise agricultural and urban ecosystems that are highly modified by human activity (some aspects are covered in potential impacts on economic assets, see page 26 of this synthesis)
- rainforests, because the 4.4 km^2 area that they occupy in the zone relies on groundwater systems that are unlikely to be impacted due to additional coal resource development (Section 3.4.6 of Herr et al. (2018a)).

Which ecosystems are potentially impacted?

The 'Floodplain or lowland riverine', 'Non-floodplain or upland riverine', and 'Springs' landscape groups, and their respective landscape classes that intersect the 7014 km^2 zone, are considered dependent on groundwater or surface water and potentially impacted due to additional coal resource development. This includes an area of 1415 km^2 (Table 1).

Receptor impact models (Box 8) identified areas at greater relative risk (Box 9) for potentially impacted floodplain and lowland riverine ecosystems; non-floodplain and upland riverine ecosystems; and upland and lowland Pilliga riverine ecosystems. The receptor impact models developed for these three ecosystems rely on the same hydrological response variables: changes in overbank flooding and in cease-to-flow attributes (such as zero-flow days and zero-flow spells; see Section 3.4 of Herr et al. (2018a)). Thus the potential ecological relevance of these hydrological changes is the

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 allows a better understanding of how changed hydrological conditions may impact water-dependent assets within those ecosystems at specified points in time.

To assess potential ecological outcomes:

1. Experts first choose **receptor impact variables**, characteristics that serve as indicators of the ecological condition of an ecosystem. These are specifically chosen to be representative of a landscape group or class. The Namoi subregion used three indicators:
   - probability of the presence of tadpoles in pools and riffles
   - average number of aquatic macroinvertebrate families in edge habitat
   - projected foliage cover of vegetation.

   For each indicator, experts also identified one or more hydrological response variables, chosen because the indicator is sensitive to changes in those hydrological response variables.
2. Hydrological models were used to quantify changes in the hydrological response variable(s).
3. Receptor impact models (Ickowicz et al., 2018) were used to predict changes in the indicator for a landscape group or class that result from the changes in hydrological response variable(s). For the Namoi subregion, nine receptor impact models were developed (as listed in Table 16 in Section 3.4 of Herr et al. (2018a)).

The changes in the indicator reflect the magnitude of potential ecological impacts for that ecosystem. Short-term (2013 to 2042) and long-term (2073 to 2102) periods were assessed.

same for the three ecosystems (Section 2.7.3 in Ickowicz et al. (2018)), for example:

- Overbank flooding maintains the health of floodplain vegetation through provision of freshwater, leaching of soil salinity and regeneration of floodplain species. Therefore, fewer overbank events limit nutrient supply and essential wetland habitat for frogs and fish in riverine ecosystems.
- More zero-flow days and zero-flow spells are likely to put additional stress on in-stream organisms in times when their survival depends on isolated pools or the water level and quality of the hyporheic zone.
- Greater groundwater drawdown may reduce baseflow contributions and increase intermittency in streams, and may make access to water more difficult for floodplain and riparian vegetation.

Floodplain and lowland riverine ecosystems

Relative to the entire assessment extent, 34% of the area and 38% of the stream length of floodplain and lowland ecosystems are in the zone of potential hydrological change (Figure 14).

Key finding 7: Some areas of floodplain or lowland riverine ecosystems – including those near Maules, Back and Bollol creeks and adjacent parts of the Namoi River, all near additional coal resource developments – are 'more at risk of ecological and hydrological changes' due to additional coal resource development than other areas in the assessment extent.

Parts of these ecosystems are 'more at risk of ecological and hydrological changes' due to potential alterations in the hydrological regime. For example, about 17 km of permanent lowland stream ecosystems have a 50% chance of an additional 20 zero-flow days (averaged over 30 years) and an increase of more than 10 days in maximum zero-flow spells over the short-term period (2013 to 2042) (Section 3.4.3 in Herr et al. (2018a)). There are 10 km of temporary lowland stream ecosystems that are exposed to a similar magnitude of changes (Section 3.4.3 in Herr et al. (2018a)).

About 0.5 km^2 of the riparian vegetation of these lowland riverine ecosystems has a 50% chance of a decrease of at least one overbank event per 20 years during the short-term period (2013 to 2042) (Section 3.4.3 in Herr et al. (2018a)). There is also a 50% chance of greater than 2 m groundwater drawdown for an area of 0.6 km^2 due to additional coal resource development (Section 3.4.3 in Herr et al. (2018a)).

An area of 7.7 km^2 of floodplain wetland ecosystems and an area of 19.7 km^2 of floodplain wetland groundwater-dependent ecosystems have a 5% chance of experiencing a decline of at least one overbank flow every 50 years during the 2013 to 2042 short-term period (Section 3.4.3 in Herr et al. (2018a)).

Table 1 Extent of each landscape group in the assessment extent and the zone of potential hydrological change

Landscape group[a]	Area, length or number	Extent in assessment extent	Extent in zone of potential hydrological change
Floodplain or lowland riverine	Area (km^2)	2,205	752
	Stream network length (km)	10,708	4093
Non-floodplain or upland riverine	Area (km^2)	3,490	663
	Stream network length (km)	18,850	1429
Rainforest	Area (km^2)	197	4
Springs	Number	22	2
Dryland remnant vegetation	Area (km^2)	8,624	1178
Human-modified	Area (km^2)	21,144	4417

[a]Definitions for landscape classes and landscape groups for the Namoi subregion are available online at environment.data.gov.au/def/ba/landscape-classification/namoi-subregion.
Data: Bioregional Assessment Programme (Dataset 1)

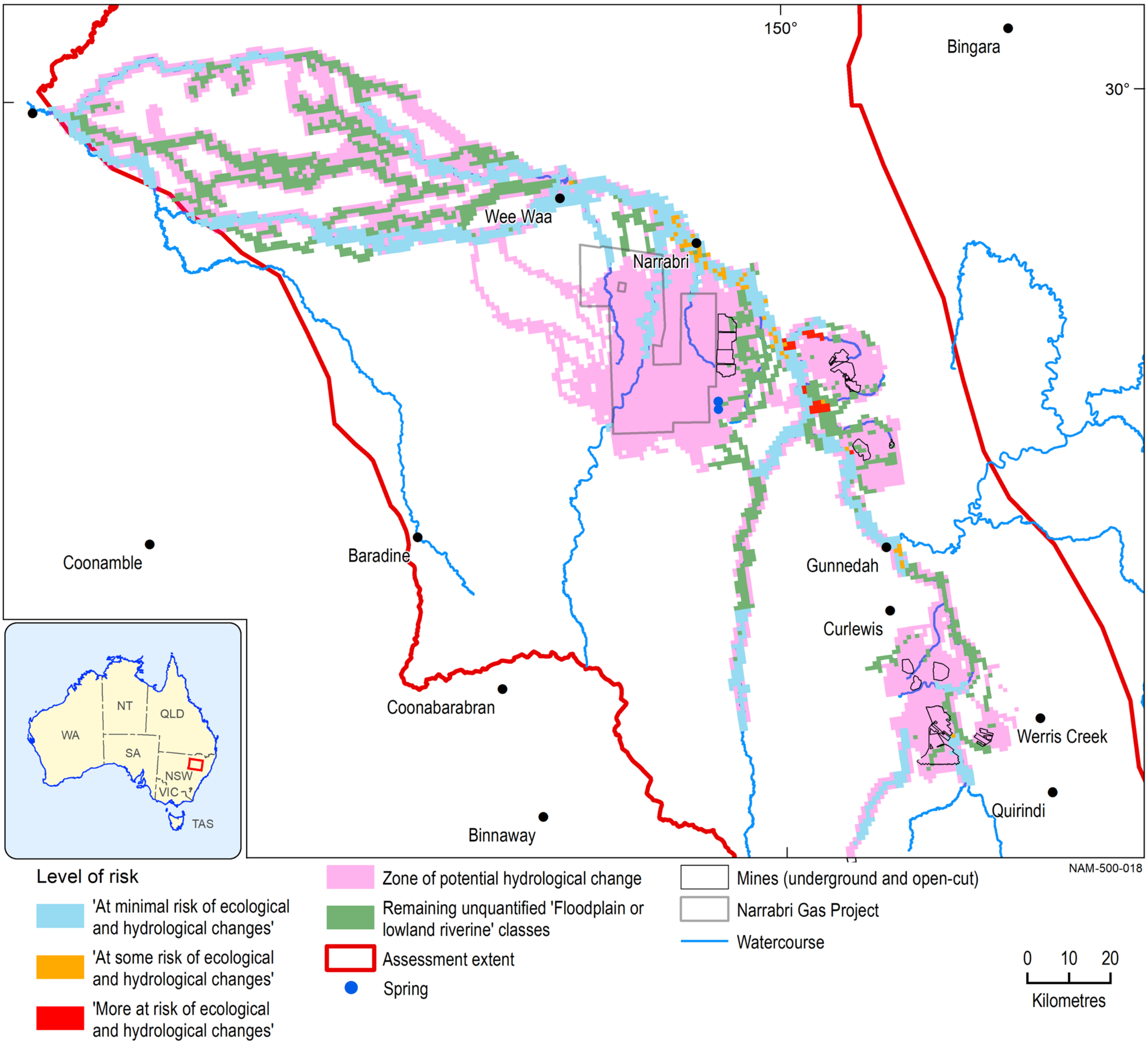


Figure 14 Composite risk map for the 'Floodplain or lowland riverine' landscape group

Assessment units in the 'Floodplain or lowland riverine' landscape group are coloured according to their risk of ecological and hydrological changes relative to other assessment units in that landscape group. Three risk categories (defined in Box 9) are shown on this map: 'at minimal risk of ecological and hydrological changes' (blue); 'at some risk of ecological and hydrological changes' (orange); and 'more at risk of ecological and hydrological changes' (red). Assessment units without receptor impact modelling and surface water modelling are shown in green. Two springs within the zone are shown.
Data: Bioregional Assessment Programme (Dataset 1)

Box 9 Categorising risk for ecosystems

Parts of some ecosystems were deemed at greater risk of ecological and hydrological changes relative to other parts of that ecosystem. Three categories were defined: 'more at risk of ecological and hydrological changes', 'at some risk of ecological and hydrological changes' and 'at minimal risk of ecological and hydrological changes'. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

Assessment units that overlap with a landscape group or class are categorised based on the degree that modelled ecological changes exceed thresholds of risk. These subregion-specific thresholds are based on expert opinion and defined using receptor impact variables listed in Box 8 (see Section 3.4 of Herr et al. (2018a) for more details on the thresholds).

Non-floodplain and upland riverine ecosystems

Approximately 1% of the area and 16% of the stream length of the zone of potential hydrological change are occupied by non-floodplain and upland riverine ecosystems. Approximately 5 km of stream length of upland riverine ecosystems have a 50% chance of increases in zero-flow days (averaged over 30 years) greater than 20 days for both simulation periods (2013 to 2042 and 2073 to 2102, see Section 3.4.3 in Herr et al. (2018a)). A similar length of streams among the upland riverine ecosystems has a 50% chance of annual maximum zero-flow spells, increasing to greater than 10 days in both simulation periods.

A 4 km^2 area on or adjacent to Maules Creek is 'more at risk of ecological and hydrological changes' (Figure 36 in Section 3.4.4 in Herr et al. (2018a)); this area may require further investigation with local analyses and monitoring.

Upland and lowland Pilliga riverine ecosystems

Receptor impact modelling considered the Pilliga region as a separate entity due to its distinctive biophysical attributes. Temporary upland stream ecosystems in this subregion have 14.8 km exposed to a 50% chance of greater than 2 m drawdown due to additional coal resource development. Surface water modelling predicted that increases in zero-flow days (averaged over 30 years) and length of longest maximum zero-flow spells are not likely in the zone of potential hydrological change within the Pilliga, with only 0.3 km of stream with a 5% chance of greater than 20 additional zero-flow days (averaged over 30 years) in 2013 to 2042 and a similar length with a 5% chance of increases in the length of longest low-flow spells of greater than 3 days. However, the assessment of changes in surface water is limited as the Pilliga region has relatively few model nodes along the stream network, with only two nodes along Bohena Creek. A large proportion (94%) of the entire length of the Pilliga stream network was not quantified in the surface water model used here. Predicted declines were confined to the assessment units along Bohena Creek.

Several locations on or near Bohena Creek are 'at some risk of ecological and hydrological changes' (Figure 40 in Section 3.4.4 in Herr et al. (2018a)).

Grassy woodland groundwater-dependent ecosystems

The 'Grassy woodland GDE' landscape class within the zone of potential hydrological change comprises most of the non-riverine landscapes in the Pilliga region (561.7 km^2), and only a small portion (72.8 km^2) of the total 634.7 km^2 of this landscape class is located outside of the Pilliga region. The qualitative model indicates that this ecosystem is potentially sensitive to changes in groundwater, and the groundwater modelling indicates that 13.9 km^2 of this landscape class are exposed to a 50% chance of greater than 2 m drawdown due to additional coal resource development. This drawdown may reduce the water availability and in turn cause water stress to and decline in groundwater-dependent vegetation during dry periods. However, the experts expressed some uncertainty around the likelihood of groundwater dependency in some of the vegetation types classified as 'Grassy woodland GDE', thus a receptor impact model was not built to quantify potential ecosystem impacts (Section 3.4.6 of Herr et al. (2018a)).

Great Artesian Basin springs

Two of seven GAB springs are located on the eastern edge of the Pilliga region, within the zone of potential hydrological change (Figure 14). It is unclear whether these springs source their water from the regional watertable used to define the zone, so it is not known whether they are potentially impacted. The classification as GAB springs is based on their association with underlying sandstone formations; their connection to the GAB requires further investigation. Find out more in Section 3.4.6 of the impact and risk analysis (Herr et al., 2018a).

FIND MORE INFORMATION

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

Conceptual modelling, product 2.3 (Herr et al., 2018b)

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

Impact and risk analysis, product 3-4 (Herr et al., 2018a)

Assigning receptors to water-dependent assets, submethodology M03 (O'Grady et al., 2016)

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

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

Landscape classification (Dataset 9)

Impact and risk analysis database (Dataset 1)

Receptor impact model (Dataset 10)

Results from applying receptor impact models (Dataset 11)

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

The impact and risk analysis (Box 6) used multiple lines of evidence to investigate how hydrological changes due to additional coal resource development may affect water-dependent assets, such as bores, heritage sites or habitats of species.

A total of 1889 water-dependent assets listed in the asset register (Table 2; Bioregional Assessment Programme, 2017; Dataset 12; O'Grady et al., 2015) were analysed for the subregion, including:

- **1690 ecological assets**, including
  - 15 species and 6 ecological communities listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)
  - Lake Goran (listed as a nationally important wetland)
  - Important Bird Areas
  - a number of important alluvial aquifers, groundwater management zones and groundwater-fed springs
- **168 economic assets**, comprising 10,418 elements that are grouped into 88 surface water and 80 groundwater management units
- **31 sociocultural assets**, comprising 22 heritage sites and 9 Indigenous sites.

Potential impacts on assets were assessed by overlaying their extent on the zone of potential hydrological change (Box 4, Box 6). The assessment took a precautionary approach: it identified potential impacts if an asset or any part of it is within the zone of potential hydrological change.

Assets with areas that exceed thresholds of hydrological changes are identified as 'more at risk of hydrological changes' relative to other assets (defined in Box 10).

Ecological changes were not predicted for assets, because receptor impact models (Box 8) were developed for landscape classes, not individual assets. Section 3.5.5 of the impact and risk analysis (Herr et al., 2018a) provides an example of assessing potential impacts on assets.

Ecological assets

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

Key finding 8: Of the 1690 ecological water-dependent assets in the Namoi assessment extent, 1066 (or 63%) are outside the zone of potential hydrological change and are *very unlikely* to be impacted, including:

- the Bubdarra-Barraba Important Bird Area
- the potential habitats of seven species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

These seven EPBC Act-listed species include:

- the critically endangered leek orchid (*Prasphyllum* sp., Wybong)
- the endangered Australasian bittern (*Botaurus poiciloptilus*)
- the endangered Booroolong frog (*Litoria booroolongensis*)
- the endangered Tarengo leek orchid (*Prasophyllum petilum*)
- the vulnerable red goshawk (*Erythrotriorchis radiatus*)
- the vulnerable Belson's panic (*Homophilis belsoni*)
- the migratory black-faced monarch (*Monarcha melanopsis*).

See Section 3.5.2 of the impact and risk analysis (Herr et al., 2018a) for more details.

Box 10 Categorising risk for assets

Parts of some assets were deemed 'more at risk of hydrological changes' relative to other parts of that asset. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

Assessment units that overlap with an asset are categorised as 'more at risk' based on the degree that modelled hydrological changes exceed thresholds of risk. These subregion-specific thresholds are based on expert opinion and defined using hydrological response variables (see Section 3.5 of Herr et al. (2018a) for more details on the thresholds).

Which ecological assets are potentially impacted?

Key finding 9: Of the 1690 ecological assets in the assessment extent, 624 are in the zone of potential hydrological change.

Of these assets in the zone, 161 are found in areas that are 'more at risk of hydrological changes' relative to other areas. For 10 assets in the zone, risk could not be quantified because surface water modelling was not available.

Of the 624 ecological assets in the zone, 20 are in the 'Groundwater feature' subgroup, 473 are in the 'Surface water feature' subgroup and 131 are in the 'Vegetation' subgroup. Those assets of interest in the 'Vegetation' subgroup include:

- 102 assets from the *National atlas of groundwater dependent ecosystems* (GDE Atlas)
- 7 assets listed in the Collaborative Australian Protected Area Database (CAPAD)
- 1 Important Bird Area
- 15 species listed under the EPBC Act
- 6 threatened ecological communities, also listed under the EPBC Act (Table 34 in Herr et al. (2018a)).

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	34	14
		Lake, reservoir, lagoon or estuary	31	21
		Marsh, sedgeland, bog, spring or soak	21	2
		River or stream reach, tributary, anabranch or bend	767	230
		Waterhole, pool, rockpool or billabong	10	0
		Wetland, wetland complex or swamp	279	206
	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	33	20
	Vegetation	Groundwater-dependent ecosystem	442	102
		Habitat (potential species distribution)	73	29
	Subtotal		**1690**	**624**
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)	80	47
	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)	88	39
	Subtotal		**168**	**86**
Sociocultural	Heritage site		22	12
	Indigenous site		9	2
	Subtotal		**31**	**14**
Total			**1889**	**724**

Economic asset numbers are not individual bores but water access entitlements that could include one or multiple bores or water rights.
Data: Bioregional Assessment Programme (2017, Dataset 12)

Ecological assets were considered to be ‘more at risk of hydrological changes’ if any of their spatial extent intersected with areas exposed to larger changes in groundwater and/or surface water regimes as defined by thresholds of change in their hydrological response variables.

A total of 161 ecological assets were deemed to be ‘more at risk of hydrological changes’ (Box 10), including:

- 76 surface water features
- Cadna-owie Hooray Equivalent Great Artesian Basin recharge area
- Great Artesian Basin Groundwater Management Zone
- Gunnedah Basin Groundwater Management Zone
- Lower Namoi Alluvium Groundwater Management Zone
- Narrabri watertable aquifer
- Upper Namoi Alluvium Groundwater Management Zone
- Westbourne Formation
- the Pilliga Imortant Bird Area
- the potential habitats of 5 threatened ecological communities and 11 threatened species listed under the EPBC Act.

The 11 threatened species listed under the EPBC Act include the koala, an iconic animal for the Namoi subregion. It is ‘more at risk of hydrological changes’ because habitat with the preferred food tree, the river red gum, accesses groundwater and changes to surface water regimes may increase the reliance on groundwater.

The largest proportion (by area) of assets is associated with two ecosystems: ‘floodplain or lowland riverine’ and ‘non-floodplain or upland riverine’. The percentage of areas with surface water modelling varies between different landscape classes but can be as high as 94% (see Section 3.4 in Herr et al. (2018a) for further detail). A total of 10 ecological assets intersect parts of the stream network where surface water modelling was not available and thus it is not possible to quantify their risk level.

Economic assets

Economic water-dependent assets comprise surface water and groundwater sources, their associated water access licences and basic water rights, and water supply infrastructure.

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

Outside the zone of potential hydrological change are 48 assets from the ‘Surface water management zone or area’ asset subgroup and 8 assets from the ‘Groundwater management zone or area’ asset subgroup.

Impacts on surface water economic assets were assessed in terms of water availability, reliability of supply, environmental water releases and potential for greater than 5% chance of more than 2 m additional drawdown. Water availability for Bohena Creek, Coxs Creek, Bundock Creek and Baradine Creek unregulated water sources is not impacted due to additional coal resource development.

The deeper groundwater layers could be used as economic assets by extraction bores or ecological assets as the source water for springs. The zone of potential hydrological change in the deeper Pilliga Sandstone extends no farther than 2 km beyond the zone of potential hydrological change defined by the overlying regional watertable, and there are no extraction bores or springs in this 2 km fringe, so identifying potentially impacted bores using the zone defined by the regional watertable is appropriate.

Of the 31 groundwater sources in the Namoi assessment extent, 17 are *very unlikely* to experience impact due to additional coal resource development. Of the 2555 bores identified as being within the zone of potential hydrological change, 504 are within the groundwater zone of potential hydrological change (Box 4) and are therefore potentially impacted (Table 42 in Section 3.5.3 of Herr et al. (2018a)). It is *very unlikely* that the 2051 bores solely within the surface water zone of potential hydrological change will be impacted due to additional coal resource development.

Which economic assets are potentially impacted?

Surface water economic assets

Key finding 10: Maximum reductions in annual flow in the Namoi Regulated River due to additional coal resource development are less than 1% and unlikely to lead to reductions in water availability.

Additional reductions in annual flows in all unregulated water sources are less than 1% of the annual flow under the baseline.

Additional increases in cease-to-pump days are less than 12 days per year at all locations.

Potential reductions in water availability were identified in the following unregulated water sources: Mooki River, Maules Creek, Driggle Draggle Creek, Bollol Creek, Merrygowan Creek, Tulla Mullen Creek and Lake

Goran unnamed creek, but these are all less than 1% of the total water availability in each unregulated water source under the baseline (Table 44 in Herr et al. (2018a)).

Reductions in water availability are also possible in the Namoi Regulated River water source. These are all much less than 1% of the total water availability under the baseline, although total reductions can be as high as 4.2 GL per year (Table 45 in Herr et al. (2018a)).

Cease-to-pump rules apply for most water sources in NSW to ensure sufficient water is retained in unregulated rivers to meet environmental requirements. For example, in the Lower Coxs Creek Management Zone, users must cease to pump when flow is equal to or below 15 ML per day at Tourable Gauge and 11 ML per day at Boggabri Gauge (Table 46 in Herr et al. (2018a)).

Under the baseline for the short-term period from 2013 to 2042, surface water modelling indicated no changes in cease-to-pump days for Baradine Creek, Maules Creek or Coxs Creek at Boggabri. Increases in the number of cease-to-pump days for Bundock, Bohena, Coxs Creek at Tambar Springs, and the Mooki River at Breeza are possible, but these are limited to an additional 12 cease-to-pump days per year at most (Table 47 in Herr et al. (2018a)). Bohena Creek has a 5% chance that cease-to-pump days during the 2043 to 2072 long-term period may increase by 9 days. The Mooki River at Breeza (node 35) has a large number of cease-to-pump days under the baseline due to its larger threshold (≤50 ML/day). Two locations on Coxs Creek (hydrological model nodes 28 and 29) also have larger cease-to-pump days under the baseline, which do not change noticeably due to additional coal resource development.

Groundwater economic assets

Nine groundwater sources (Gunnedah-Oxley Basin MDB; Lower Namoi; Peel Alluvium; Southern Recharge; and Upper Namoi zones 3, 4, 5, 7 and 8) are potentially impacted due to additional coal resource development (Figure 46 in Herr et al. (2018a)). All groundwater sources (except for Lower Namoi and Upper Namoi Zone 5) have bores with a greater than 5% chance of more than 2 m additional drawdown (see Table 43 and Figure 49 in Section 3.5.5 in Herr et al. (2018a)).

Key finding 11: Of the 8953 bores in the assessment extent, 8424 are *very unlikely* to be impacted due to additional coal resource development.

Outside the mine pit exclusion zone, there are 118 bores with a greater than 5% chance of more than 2 m additional drawdown, 14 with greater than 50% chance and 1 bore with greater than 95% chance (Figure 15).

Sociocultural assets

The water-dependent asset register for the Namoi subregion (Table 2; O'Grady et al., 2015; Bioregional Assessment Programme, 2017; Dataset 12) contains 31 sociocultural assets, including 22 heritage sites and 9 Indigenous assets (Table 48 in Section 3.5.4 in Herr et al. (2018a)).

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

Seventeen sociocultural water-dependent assets are outside the zone of potential hydrological change. It is *very unlikely* that hydrological changes due to additional coal resource development will affect these (Table 48 in Section 3.5.4 in Herr et al. (2018a)).

Which sociocultural assets are potentially impacted?

Fourteen of the 31 sociocultural water-dependent assets identified in the assessment extent are in the zone of potential hydrological change, and are therefore potentially impacted. Of these, 12 assets are heritage sites and 2 are Indigenous sites.

Assessment of the impact of potential hydrological changes on assets requires a quantitative understanding of the nature of their water dependency which is not within the scope of this bioregional assessment. Assets in the zone include:

- the Indigenous assets, Boggabri Lagoon and the Burburgate Carved Tree
- built infrastructure, such as the Wee Waa and Gunnedah courthouses
- heritage-listed buildings, cemeteries and graves.

Further details are available in Table 49 and Figure 50 in Section 3.5 in the impact and risk analysis (Herr et al., 2018a).

The Bioregional Assessment Programme does not have the expertise to comment on potential impacts of changes in hydrological regimes on the value of Indigenous assets and built infrastructure. Evaluating potential impacts on these sites would require further local-scale assessment.

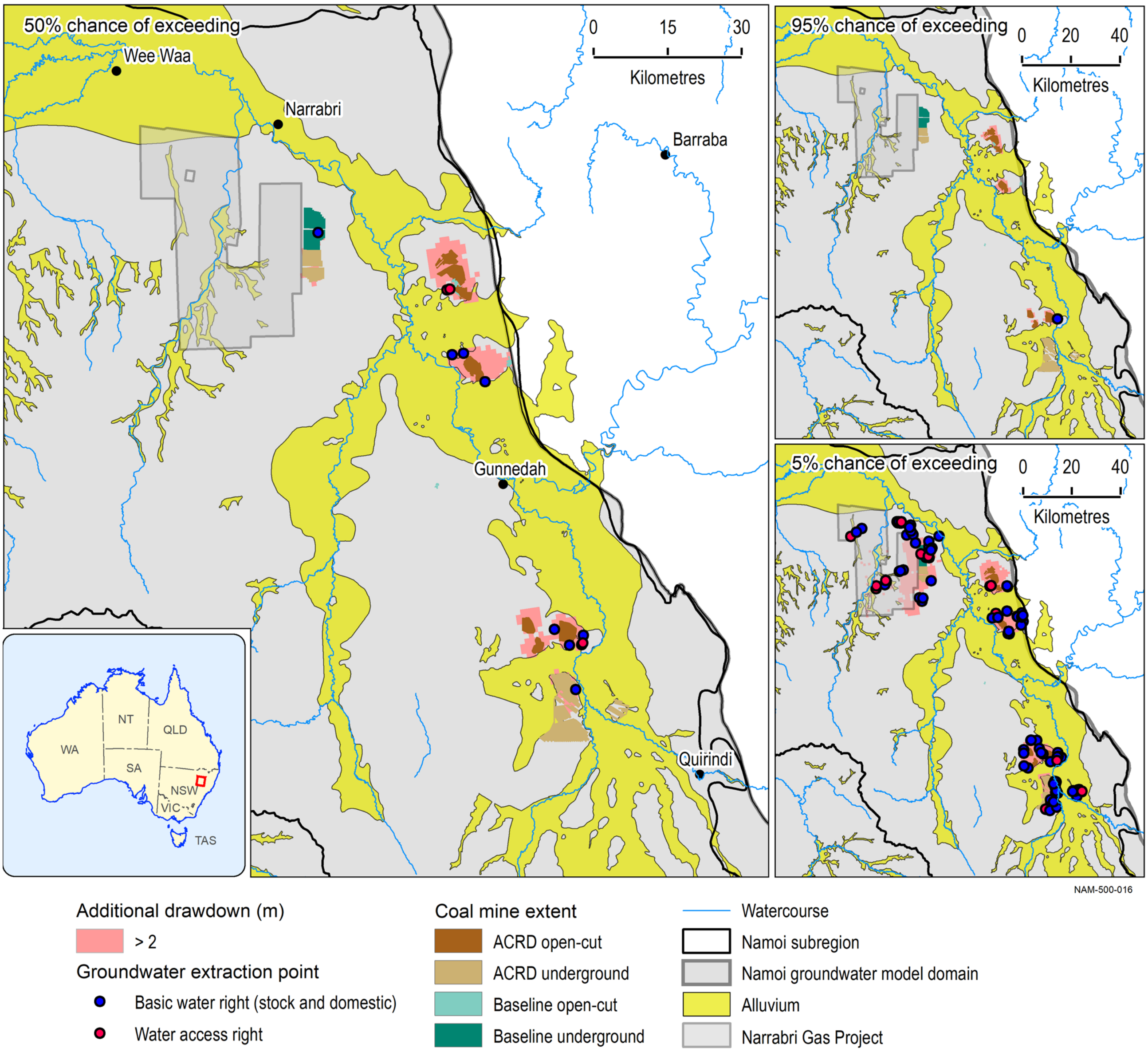


Figure 15 Bores with greater than 95%, 50% and 5% chance of more than 2 m of drawdown due to additional coal resource development

The coal resource development pathway includes baseline and additional coal resource developments (ACRD).
Data: Bioregional Assessment Programme (Dataset 5, Dataset 13)

FIND MORE INFORMATION

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

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

Water-dependent asset register, list for product 1.3 (Bioregional Assessment Programme, 2017)

Impact and risk analysis, product 3-4 (Herr et al., 2018a)

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

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

Landscape classification (Dataset 9)

Asset database (Dataset 12)

Spatial overlay of hydrological changes in the regional watertable databases (Dataset 1)

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 may not be necessary. This is achieved through the rule-out process, which directs focus onto areas where hydrological changes are predicted. This process has 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** and also considers cumulative changes from coal resource developments. It 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 describe the environmental values that coal resource development may affect, and to adopt strategies to avoid, mitigate or manage the predicted impacts, including those that overlap with those arising from other future coal resource developments. These assessments did not investigate the social, financial or human health impacts of coal resource development, nor did they consider risks of fugitive gases and non-water-related impacts.

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 as well as interactions with neighbouring developments.

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (a federal government statutory authority established in 2012 under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*) can use these assessment results to help formulate their advice on proponent's proposals for coal resource development projects, and on addressing cumulative impacts with other developments.

Data access

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Access to underpinning datasets, including geographic data and modelling results, can assist decision makers at all levels to review the work undertaken to date; to explore the results using different thresholds; and to extend or update the assessment if new models or data become available. Additional guidance about how to apply the Programme's methodology is also documented in 11 detailed scientific submethodologies (as listed in 'References and further reading' on page 32).

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

If new coal resource developments emerge in the future, the data, information, analytical results and models from this assessment would provide a comprehensive basis for bioregion-scale re-assessment of potential impacts under an updated coal resource development pathway. For example, new coal resource developments could be incorporated in the groundwater model. Components such as the water-dependent asset register (Bioregional Assessment Programme, 2017; Dataset 12) remain relevant for future assessments. The information and approach may also be applicable for other types of resource development, such as agriculture or shale gas.

Informing local-scale assessments

There are opportunities to tailor the bioregional assessment modelling results for more local analyses (e.g. local-scale environmental impact assessments of new coal resource developments) by combining more detailed local geological and hydrogeological information with the groundwater model emulators developed through bioregional assessments.

Causal pathways

There are limited long-term consistent surface water quality and quantity data for the Namoi subregion, which are required for developing models that can predict water quality into the future. There is a lack of detailed understanding of the interaction between the surface water and groundwater systems, particularly at the local level.

The lack of knowledge about the location of subterranean faults means it is difficult to incorporate their effects on groundwater in the 'Subsurface depressurisation and dewatering' and 'Subsurface physical flow paths' causal pathway groups directly. However, the uncertainty analysis undertaken for the numerical groundwater modelling enables a probabilistic estimate of maximum groundwater level decline, as described in the groundwater numerical modelling (Janardhanan et al., 2018) for the subregion.

The geological model underpinning the groundwater modelling did not include fault locations and depths. Inclusion of faults would increase the precision of groundwater modelling but, given the regional scale of this assessment, it would not change the extent of the zone of potential hydrological change. However, probabilistic groundwater modelling accuracy and precision at the local scale is likely to benefit from fault inclusion.

Hydrological modelling

A higher density of surface water model nodes and gauging information, located immediately upstream of major stream confluences and upstream and downstream of mine operations, would allow the point-scale information to be interpolated to a greater proportion of the stream network and improve the extent of surface water modelling, as well as a more extensive assessment of relative risks to water-dependent assets and ecosystems.

Improved mapping of depth to groundwater, and its spatial and temporal variation, not only has potential to constrain hydrological change predictions, it also provides much needed context for the interpretation of the ecological impacts due to hydrological change. Interactions between changes in groundwater availability and the health and persistence of terrestrial groundwater-dependent vegetation remain uncertain due, in part, to sparse mapping of groundwater depths outside of alluvial layers.

Quantifying the interaction between groundwater and surface water, the flux of water through the hyporheic zone (the zone beneath a streambed where groundwater and surface water mix), is important for estimating the hydrological response, especially those relating to low- or no-flow conditions. A finer-scale understanding and representation of this interaction may improve the assessment of impact, particularly where local populations are under investigation.

Ecology

The separation between groundwater-dependent and surface water – dependent wetlands may not always be accurate. In many areas there is little knowledge of surface water – groundwater interactions. There is also a data gap in the understanding of water thresholds for ecosystems associated with springs and other water-dependent ecological assets.

There is limited knowledge on the actual water requirements of different plant communities. Future work could include the identification of suitable indicators of ecosystem condition and alternative methods of assessing the condition of water-dependent ecosystems, which would improve the quantification of risk.

Improving the qualitative models and receptor impact models would better predict the ecological changes in ecosystems in response to hydrological changes. Revisiting the qualitative models and adjusting these specifically for the purpose of prioritising future (ecological) research may be an effective way of directing additional research resources (see, for example, Herr et al. (2016)).

Climate change and land use

In comparing results under two different futures in this assessment, factors such as climate change or land use were held constant. Future assessment iterations could look to include these and other stressors to more fully predict cumulative impacts at a regional scale. This would particularly be informative for the Namoi subregion, due to the extensive agriculture in this subregion.

Indigenous assets

The Bioregional Assessment Programme does not have the expertise to comment on potential impacts on Indigenous assets.

Cultural sensitivities often attach to Indigenous assets, and the Indigenous communities may prefer that details of their location and value are retained with their Elders or within their communities. 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 (DPI, 2016).

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.

Future monitoring

At the highest level, monitoring efforts should reflect the risk predictions, and focus the effort where the changes are expected to be the largest or where there was an inability to quantify the risk. However, it is important to place some monitoring effort at locations with no or lower risk predictions so as to confirm the range of potential impacts and identify unexpected outcomes.

Existing monitoring of instream water quality is sparse in terms of spatial and temporal coverage. Where water quality impacts of coal resource development is of concern, it is necessary to separate these changes from the location-specific background water quality, which may include impacts from agricultural activities and infrastructure. An improved monitoring approach with improved spatial and temporal data for surface water and groundwater may be appropriate.

Given the many temporary streams in the subregion, biological sampling along with measuring changes in the hyporheic zone and in groundwater quality and quantity would fill a crucial gap in the understanding of the hyporheic biota (the organisms found beneath a streambed where groundwater and surface water mix) and subterranean biota (the organisms found underground, mostly in groundwater between sediment particles and rocks).

Establishing an understanding on the wider extent, compositions, structures and hydrological habitat requirements of the subterranean biota of the Namoi subregion is necessary when attempting to address risk from developments. Monitoring subterranean biota will help address risks to this barely understood part of Australia’s ecology.

FIND MORE INFORMATION
See sections titled ‘Gaps’ in:

Description of water-dependent asset register, product 1.3 (O’Grady et al., 2015)

Current water accounts and water quality, product 1.5 (Peña-Arancibia et al., 2016)

Conceptual modelling, product 2.3 (Herr et al., 2018b)

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

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

Impact and risk analysis, product 3-4 (Herr et al., 2018a)

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 Namoi 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 Namoi 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 (note that terms and definitions are respectively listed under the 'Name' and 'Description' columns in this register). This register is a list of terms, which are the preferred descriptors for concepts. Other properties are included for each term, including licence information, source of definition and date of approval. Semantic relationships (such as hierarchical relationships) are formalised for some terms, as well as linkages to other terms in related vocabularies.

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.

at minimal risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered 'at minimal risk of ecological and hydrological changes' relative to other assessment units if modelled hydrological changes result in ecological changes that do not exceed the lower thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

at some risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered 'at some risk of ecological and hydrological changes' relative to other assessment units if modelled hydrological changes result in ecological changes that exceed the lower thresholds of risk but do not exceed the upper thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

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 geological formation: stratigraphic unit with distinct rock types, which is able to mapped at surface or in the subsurface, and which formed at 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'.

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.

more at risk of ecological and hydrological changes: assessment units that overlap a landscape class are considered 'more at risk of ecological and hydrological changes' relative to other assessment units if modelled hydrological changes result in ecological changes that exceed the upper thresholds of risk. These bioregion-specific thresholds are based on expert opinion and are defined using receptor impact variables. Categorisation assists the rule-out process and in identifying where further local-scale assessment is warranted.

more at risk of hydrological changes: assessment units that overlap an asset are considered 'more at risk of hydrological changes' relative to other assessment units if modelled hydrological changes exceed bioregion-specific thresholds of risk. These thresholds are based on expert opinion and are defined using hydrological response variables. Categorisation assists the rule-out process and identifying where further local-scale assessment is warranted.

Namoi subregion: The Namoi subregion is located within the Murray–Darling Basin in central New South Wales. The subregion lies within the Namoi river basin, which includes the Namoi, Peel and Manilla rivers. However, the subregion being assessed is smaller than the Namoi river basin because the eastern part of the river basin does not overlie a coal-bearing geological basin. The largest towns in the subregion are Gunnedah, Narrabri and Walgett. The main surface water resource of the Namoi subregion is the Namoi River. There are three large dams that supply water to the subregion, of which Keepit Dam is the main water storage. More than half of the water released from Keepit Dam and river inflow may be extracted for use for agriculture, towns and households. Of this, the great majority is used for agricultural irrigation. The landscape has been considerably altered since European settlement for agriculture. Significant volumes of groundwater are also used for agriculture (cropping). Across the subregion there are a number of water-dependent ecological communities, and plant and animal species that are listed as threatened under either Commonwealth or New South Wales legislation. The subregion also contains Lake Goran, a wetland of national importance, and sites of international importance for bird conservation.

Northern Inland Catchments bioregion: The Northern Inland Catchments bioregion is located west of the Great Dividing Range in eastern Australia and includes parts of the northern Murray–Darling Basin in northern New South Wales and southern Queensland. The Northern Inland Catchments bioregion adjoins the Clarence-Moreton bioregion in the north-east, and the Northern Sydney Basin bioregion in the south. The bioregion was selected for assessment because of the likely coal seam gas and coal mining development and the potential for water dependent impacts on the environment and other water-using industries such as agriculture. The Northern Inland Catchments bioregion includes four subregions: the Maranoa-Balonne-Condamine, Gwydir, Namoi and Central West subregions. The subregion boundaries follow river basin boundaries, but only include areas that have the types of rocks known to contain coal and coal seam gas. Some water resources outside the Northern Inland Catchments bioregion that may potentially be impacted as a result of coal and coal seam gas development in the Northern Inland Catchments bioregion will also be considered in the assessment.

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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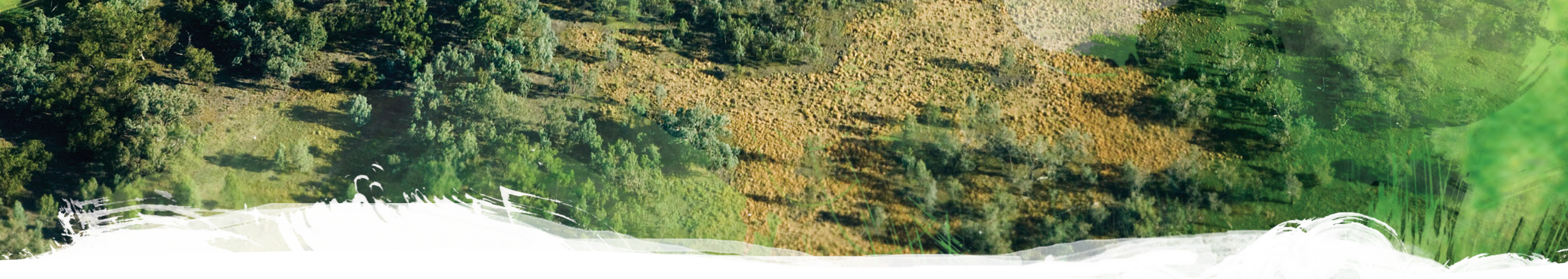

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