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Impact and risk analysis for the Namoi subregion

Product 3-4 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

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

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

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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

The impact and risk analysis for the Namoi subregion is a regional overview of potential impacts on, and risks to, water resources and water-dependent ecological, economic and sociocultural assets due to coal resource development. Hydrological models estimate the changes in water-associated parameters and their uncertainties. These changes provide the input for identifying areas where impacts to ecosystems are likely. Where possible, a quantification of ecosystem impacts allows the ruling out of areas that are *very unlikely* (less than 5% chance) to experience change.

Results from regional-scale hydrological modelling indicate potential risks to about 1400 km^2 of ecosystems, 5500 km of streams, 2 springs and 624 water dependent assets. More detailed local information is required to determine the level of risk and potential impacts.

The Namoi subregion covers an area of 29,300 km^2; however, the total area investigated in this assessment, the assessment extent, is 35,660 km^2 as hydrological effects due to additional coal resource development may extended past the boundary of the subregion. The subregion is located in the Murray–Darling Basin in central NSW and the landscape is characterised by highlands in the east and south and a broad floodplain in the west. Drainage is dominated by the Namoi River and its tributaries and distributaries, the Mooki River, Coxs Creek, Pian Creek and Turragulla Creek. There are many ecologically important small lagoons, natural and artificial wetlands, and floodplain woodlands in the subregion.

Coal resources

Bioregional assessments (BAs) consider two potential coal resource development futures:

- *baseline coal resource development (baseline)*: a future that includes all coal mines and coal seam gas (CSG) fields that were commercially producing as of December 2012
  - in the Namoi subregion there are five open-cut coal mines: Boggabri Coal Mine, Rocglen Mine, Sunnyside Mine, Tarrawonga Mine and Werris Creek Mine; and one longwall mine: Narrabri North
- *coal resource development pathway (CRDP)*: a future that includes all modelled coal mines and CSG fields that are in the baseline as well as the additional coal resource development (those that were expected to begin commercial production after December 2012)
  - in the Namoi subregion ten additional coal resource developments represent the most likely future as of December 2015; eight are modelled: Boggabri Coal Expansion Project, Caroona Coal Project, Maules Creek Project, Narrabri South, Tarrawonga Coal Expansion Project, Vickery Coal Project, Watermark Coal Project and the Narrabri Gas Project. The remaining two mines, Vickery South Coal Project and the Gunnedah Precinct, did not have sufficient information for inclusion in the modelling. Analysis of the impacts of these two developments is restricted to commentary in Section 3.6 of this analysis. The eight mines that are included in the modelling form the basis for relating impacts to additional coal

resource developments. 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 Mine was included in 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, the company will continue to progress its Watermark Coal Project plans on the remainder of the licence and this is incorporated into the hydrological modelling.

The difference in results between modelled CRDP and baseline is the change that is primarily reported in a BA. This change is due to the additional coal resource development. Potential hydrological changes due to these coal resource developments are reported in companion products 2.6.1 (surface water) (Aryal et al., 2018) and 2.6.2 (groundwater) (Janardhanan et al., 2018) for the Namoi subregion; this product summarises the impacts on, and risks to, water resources and water-dependent ecological, economic and sociocultural assets.

Zone of potential hydrological change

The zone of potential hydrological change covers an area of 7014 km^2 (19.7% of the Namoi assessment extent). The zone is the union of the groundwater zone of potential hydrological change and the surface water zone of potential hydrological change:

- The *groundwater zone of potential hydrological change* is defined as the area with at least a 5% chance of exceeding 0.2 m of drawdown due to the modelled additional coal resource development in the regional watertable, which comprises the alluvial aquifer as well as weathered and fractured rock aquifers and covers an area of 2299 km^2 (about 6.5% of the Namoi assessment extent).
- The *surface water zone of potential hydrological change* contains those river reaches where a change in any one of nine surface water hydrological response variables exceeds a specified threshold due to modelled additional coal resource development. The thresholds incorporate at least a 5% chance of a 1% or greater change in a flow volume, or a 3 day or greater change in frequency. The surface water zone covers an area of 6430 km^2 (18% of the Namoi assessment extent) and represents 5521 km of stream length.

The zone was used to rule out potential impacts on ecosystems and water-dependent assets within the Namoi assessment extent. Water resources and water-dependent assets outside the zone are *very unlikely* to be impacted.

Note that the drawdown in the confined parts of the Pilliga Sandstone was modelled and does not exceed 0.2 m more than 2 km outside of the zone of potential hydrological change. There are no extraction bores or springs within this area so defining the zone based upon the drawdown at the regional watertable is appropriate.

Potential hydrological changes

Groundwater

Results from regional groundwater modelling show drawdown due to modelled additional coal resource development of greater than 0.2 m is *very likely* (greater than 95% chance) for an area of 156 km^2. It is *very unlikely* (less than 5% chance) that more than 2299 km^2 will experience drawdowns of this magnitude due to modelled additional coal resource development. It is *very unlikely* that drawdown due to coal mining extends more than about 10 km from any coal mine. Results for 2 m and 5 m drawdown extents suggest it is:

- *very likely* that an area of at least 117 km^2 exceeds 2 m of drawdown and *very unlikely* that more than 853 km^2 exceeds 2 m of drawdown
- *very likely* that an area of at least 99 km^2 exceeds 5 m of drawdown and *very unlikely* that more than 520 km^2 exceeds 5 m of drawdown.

The range of potential drawdown outcomes reflects the uncertainty in the key input parameters for the various aquifers (e.g. hydraulic conductivity and storage); different parameters and assumptions that are considered plausible based on the current state of knowledge can lead to quite different predicted outcomes.

These numbers are additional to the 116 km^2 in the mine pit exclusion zone, where the modelled drawdowns are considered unreliable due to steep hydraulic gradients at the pit face. The modelled estimates of drawdown within the mine pits, while significant, are considered unreliable for use in the receptor impact modelling and are not included when evaluating potential impacts on landscape classes and ecological assets.

Surface water

Within the zone, potential changes to surface water due to additional coal resource development were assessed using three hydrological response variables that represent zero-flow, high-flow and annual flow characteristics of streamflow. Changes in these variables represent the dominant hydrological drivers.

Changes in stream flow are very likely in Back Creek, Merrygowen Creek, Bollol Creek, Maules Creek, Driggle Draggle Creek and two unnamed creeks near Lake Goran. Most of the creeks have catchment areas much less than 100 km2 and effects are localised. The much larger Namoi River is largely insensitive to these changes in inflows because of the volume of flow.

Generally, the predicted changes in streamflow are small relative to the rainfall-related interannual variability, especially for annual flow and high-flow days. The streams likely to see the largest increases in the number of zero-flow days are Back, Merrygowen and Bollol creeks, as well as an unnamed creek. These creeks drain the Maules Creek, Boggabri expansion, Tarrawonga expansion and Watermark coal developments, respectively. The increase in zero-flow days in these creeks may represent a change that is greater than the interannual variability under the baseline, which serves to indicate the degree of hydrological change.

Water quality

The risk to regional stream water salinity due to additional coal resource development will depend 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. Modelling predicts a possible reduction in baseflow and this may lead to a reduction in stream salinity.

In all the streams identified from the regional-scale modelling with potentially large changes in flow regime, the impact on local stream salinity will depend on the relative reductions in catchment runoff and baseflow over time.

Reductions in catchment runoff are more likely to affect runoff peaks, while baseflow reductions have a more noticeable effect on low flows. In streams, such as Back Creek, Merrygowen Creek and Ballol Creek, Tulla Mullen Creek and Mooki River near Maules Creek, located near Boggabri, Tarrawonga, Vickery and Watermark coal mines respectively, where modelling results suggest 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 in these water bodies. 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. The magnitude and extent of water quality changes cannot be determined without specifically representing 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.

Impacts on, and risks to, ecosystems

The impact and risk analysis investigates how hydrological changes due to additional coal resource development may affect ecosystems at a landscape scale. Twenty-nine landscape classes, aggregated to six landscape groups, represent the ecosystems in the Namoi subregion. Landscape groups and some classes within other landscape groups ‘ruled out’ of the ecological modelling include:

- the ‘Dryland remnant vegetation’ landscape group, as it comprises non-water-dependent vegetation communities for the purposes of the BAs
- the ‘Human-modified’ landscape group, which comprises highly modified agricultural and urban landscapes; some impacts and risks are considered under economic assets
- The 'Non-GAB springs' landscape class as the 15 springs in this landscape class are assumed to draw their water from the regional watertable and none of the springs are located within the zone of potential hydrological change.

Potential impacts of hydrological changes on ecosystems in the zone of potential hydrological change are assessed using qualitative mathematical models and receptor impact models. These models use indicators of the ecosystem condition, such as the probability of presence of a particular species, or projected foliage cover of the canopy vegetation, to assess the impacts of hydrological changes. Eight receptor impact models quantify potential ecological changes in the

‘Floodplain or lowland riverine’ and ‘Non-floodplain or upland riverine’ landscape groups and the Pilliga riverine (upland and lowland) ecosystems within these two landscape groups (Table 16). The results identify assessment units (parts of ecosystems and landscape classes) that are potentially ‘at minimal risk of ecological and hydrological changes’, ‘at some risk of ecological and hydrological changes’, or ‘more at risk of ecological and hydrological changes’ (thresholds used are described in Section 3.4.3.3).

‘Floodplain or lowland riverine’ landscape group

The lowland riverine landscape classes in this group include ecosystems adjacent to the Namoi River and its major tributaries. Receptor impact modelling considered modelled hydrological changes and the responses of corresponding receptor impact variables, which are projected foliage cover, presence of tadpoles and assemblages of macroinvertebrates in the edge habitat.

Potential ecosystem impacts estimated from the receptor impact modelling showed changes in one or more of the receptor impact variables at a confined set of locations across the distribution of the associated landscape class. For example, modelling predicted the largest declines in the average number of families of aquatic macroinvertebrates due to additional coal resource development (ranging from 16 to 17 families at the 5th percentile and 4 to 3 families at the 50th percentile) in the Maules Creek and Bollol Creek.

Thresholds indicative of a relative measure of risk across a given landscape class from a combination of the receptor impact model results provided an assessment of potential ecosystem impacts. The greatest concentration of ‘more at risk of ecological and hydrological changes’ and ‘at some risk of ecological and hydrological changes’ assessment units are located along the Namoi River and its tributaries, Maules Creek, Back Creek and Bollol Creek. Of the 1425 assessment units included in one or more of the receptor impact models, 51 show ‘at minimal risk of ecological and hydrological changes’ and 29 ‘more at risk of ecological and hydrological changes’, with most of these risk categories being related to the potential impacts on lowland riverine and floodplain wetland landscape classes. A more detailed and local consideration of risk needs to consider the specific values at the location that the community are seeking to protect (e.g. particular assets), and bring in other lines of evidence that include the magnitude of the hydrological change and the qualitative mathematical models.

‘Non-floodplain or upland riverine’ landscape group

The receptor impact model for the upland riverine landscape classes modelled the relationship between cease-to-flow hydrological response variables (zero-flow days and maximum zero-flow spells) and two receptor impact variables: average number of families of aquatic macroinvertebrates in edge habitat and the probability of presence of tadpoles from the *Limnodynastes* genus. There were no detectable differences in mean changes in either average number of families of aquatic macroinvertebrates or the probability of presence of tadpoles across the upland riverine landscape classes between the baseline and modelled CRDP futures across the different percentile simulation periods (2042 and 2102).

The receptor impact model for the ‘Upland riparian forest GDE’ landscape class was based on the relationship between the effect of changes in groundwater drawdown and the frequency of overbank flows on projected foliage cover in the riparian trees. There were only a small number of assessment units where projected foliage cover predictions indicated a decline at the 5th percentile, and no assessment units at the 50th percentile for either simulation period. The limited change in this receptor impact variable is consistent with the associated hydrological response variables, where very small parts of the ‘Upland riparian forest GDE’ landscape class were exposed to changes in additional groundwater drawdown or change in frequency of overbank flows.

Pilliga riverine (upland and lowland)

The experts considered the Pilliga region, which encompasses both the Pilliga and Pilliga Outwash Interim Biogeographic Regionalisation for Australia (IBRA) subregions, as a separate entity for the purposes of the ecological modelling due to its distinctive biophysical attributes. Potential ecological impacts were a reflection of the modelled changes in groundwater and surface water, and the corresponding receptor impact variables, which were average number of families of aquatic macroinvertebrates and projected foliage cover of riparian vegetation. Predicted declines in both of these ecosystem indicators showed that potential changes were confined to assessment units along Bohena Creek and were equivalent to the ‘at some risk of ecological and hydrological changes’ category across the Pilliga riverine landscape class based on the risk thresholds defined for other receptor impact models.

There were 8 water-dependent landscape classes intersecting the Pilliga region that did not have an associated receptor impact model and hence ecosystem impacts remain undefined. These include the two Great Artesian Basin (GAB) springs that intersect the Pilliga region. 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.

Impacts on, and risks to, water-dependent assets

Ecological assets

Assessment of the potential impacts on ecological assets includes multiple lines of evidence: overlay analysis, qualitative mathematical models derived from expert elicitation and predictions of receptor impact variables as ecosystem indicators.

The Namoi subregion has 1690 water-dependent ecological assets in the assessment extent. Of these, 624 are in the zone of potential hydrological change and are subject to potential hydrological changes due to additional coal resource development. Water-dependent ecological assets in the zone associated with ‘Habitat (potential species distribution)’ asset class in the ‘Vegetation’ subgroup include (Table 34):

- 15 species listed under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) such as:
    - koala (*Phascolarctos cinereus*)
    - swift parrot (*Lathamus discolor*)
    - regent honeyeater (*Anthochaera phyrgia*)

- 7 assets listed on the Collaborative Australian Protected Area Database (CAPAD)
- the Pilliga Important Bird Area
- 6 EPBC Act-listed threatened ecological communities.

Out of the 624 ecological assets, 135 are ‘more at risk of hydrological changes’ because all or part of the area where these assets occur is within one or more of the potentially impacted landscape groups and there is a greater than 50% chance of the modelled hydrological change exceeding the defined threshold (Section 3.5.2.2). These ‘more at risk of hydrological changes’ assets include:

- 76 assets in the ‘Surface water feature’ subgroup, none of which are listed in *A directory of important wetlands in Australia* (DIWA)
- 12 assets in the ‘Groundwater feature (subsurface)’ group including
  - Cadna-owie Hooray Equivalent Great Artesian Basin recharge area
  - Gunnedah Basin Groundwater Management Zone
  - Lower Namoi Alluvium Groundwater Management Zone
  - Great Artesian Basin Groundwater Management Zone
- 47 assets in the ‘Vegetation’ subgroup including
  - the Pilliga Important Bird Area, contiguous with the Pilliga Nature Reserve and forming the largest intact native forests west of the Great Dividing Range
  - the habitat of 5 threatened ecological communities and of 11 listed species in the EPBC Act.

Economic assets

There are 168 economic assets in the Namoi assessment extent. Of these, there are 47 assets in the ‘Groundwater management zone or area’ subgroup and 39 in the ‘Surface water management zone or area’ subgroup that are potentially impacted by hydrological changes due to additional coal resource development.

Of the 8953 bores in the assessment extent, 2555 bores were identified within the zone of potential hydrological change, and 2051 of these are *very unlikely* to be impacted due to additional coal resource development as they are in the surface water zone. There are 133 bores (excluding the 25 bores in the mine pit exclusion zone) where there is a greater than 5% chance of more than 2 m additional drawdown.

In relation to surface water availability, maximum reductions in annual flow in the Namoi Regulated River water source area are less than 1% and unlikely to lead to reductions in water availability, although total reductions can be as high as 4.2 GL/year.

There are reductions in water availability in the Mooki River, Maules Creek, Driggle Draggle Creek, Bollol Creek, Merrygowan Creek, Tulla Mullen Creek and one unnamed creek near the Lake Goran, but these are all less than 1% of the total water availability in each unregulated water source under the baseline.

Cease-to-pump rules apply to some water sourced 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/day at Tourable Gauge and 11 ML/day at Boggabri Gauge.

There is a 5% chance of additional 12 cease-to-pump days per year for Bundock Creek from the additional coal resource developments in the medium term. Additional cease-to-pump days for Bohena Creek, and the Mooki River at Breeza are generally less and limited to a maximum of 9 days with a 5% chance at the Bohena Creek and a maximum of 6 days (5% chance) for the Mooki River at Breeza.

Sociocultural assets

There are 31 water-dependent sociocultural assets in the assessment extent, including 22 heritage sites and 9 Indigenous assets. Fourteen of these are in the zone of potential hydrological change, and therefore are potentially impacted. The impact of potential hydrological changes on these assets requires a quantitative understanding of the nature of their water dependency. Some examples of these assets include the Boggabri Lagoon and the Burburgate Carved Tree, and built infrastructure such as the Wee Waa and Gunnedah courthouses, and heritage-listed buildings, cemeteries and graves (see Table 49 and Figure 50 of Section 3.5). 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.

Future monitoring

Post-assessment monitoring is important to test and validate (or not) the risk predictions of the assessment. At the highest level, monitoring effort should reflect the risk predictions and focus the effort where the changes are the largest and incorporate those areas where modelling limitations did not allow a risk quantification. However, it is important to place some monitoring effort at locations with no predictions and lower risk predictions to act as a reference and confirm the range of potential impacts and identify unexpected outcomes.

The BA for the Namoi subregion has identified that potential hydrological or ecosystem impacts due to additional coal resource development are likely in areas concentrated around the main proposed coal resource development locations. Groundwater monitoring would be expected to be a focus for the following water sources as they have the largest number of bores with a greater than 5% chance of more than 2 m drawdown, In order they are: Gunnedah-Oxley Basin, Murray Darling Basin, Upper Namoi Zone 4 Namoi Valley, Upper Namoi Zone 7 Yarraman Creek, Upper Namoi Zone 8 Mooki Valley, Southern Recharge and Upper Namoi Zone 3 Mooki Valley.

There are 3629 km of streams that are potentially impacted in the not modelled areas, which means that the ecological impacts in those same locations remains unquantified and future work may need to address these constraints. For the modelled streams, future surface water monitoring should focus on streams that pass near the additional coal resource developments, and particularly for Back, Merrygowan, Bollol and Driggle Draggle creeks, given the changes in flow regime modelled to occur there.

Gaps and opportunities

The BA for the Namoi subregion incorporated the best available information within the constraints and timing of the Programme. For example, at the time of modelling sufficient information was not available for two additional coal resource developments: the Gunnedah Precinct and Vickery South Coal Project. The Gunnedah Precinct has the potential for cumulative impacts with the baseline Sunnyside Mine (currently in care and maintenance). The Vickery South Coal Project has the potential for cumulative impacts with the Vickery Coal Mine (an additional coal resource development), as well as the Rocglen Mine (a baseline development). Therefore, considering alternative coal resource development pathways is an important future consideration.

The assessment is regional and cumulative, and provides an important framework for local-scale environmental impact assessments of new coal resource developments and the local geological, hydrogeological and hydrological modelling that supports them. The results do not replace the need for detailed site-specific studies, nor should they be used to supplant the results of detailed studies that may be required under state legislation. There are opportunities to tailor the regional-scale BA modelling results for more local analyses (e.g. combining detailed local geological information with the groundwater emulators developed through BA, where appropriate).

Some of the broader knowledge gaps identified that can improve the understanding the potential impacts of coal resource development include:

- Spatially explicit data on the thickness of the stratigraphic layers and a more detailed understanding of fault locations and depths would improve the geological model and may provide an improved precision to the groundwater modelling. Including faults into the current modelling is unlikely to change the spatial extent of the zone of potential hydrological change at regional resolution of 1 km^2, however, local-scale accuracy and precision is likely to improve.
- Improved mapping of depth to groundwater, and its spatial and temporal variation, not only has potential to constrain hydrological change predictions, it 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.
- 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 modelling (and consequently some of the receptor impact modelling).
- An improved ecohydrological understanding of water-dependent vegetation communities and their water requirements.
- A collection of background data for benchmarking that includes (i) ecological data (e.g. high resolution vegetation mapping) for identifying current conditions and assessing changes in ecosystems and ecosystem indicators, (ii) improved instream water quality monitoring data

and separate agricultural, infrastructure and coal resource development impacts on water quality, and (iii) groundwater quality monitoring data.

- Increased investigation of subsurface ecosystem changes, in particular, the hyporheic zone, is highly relevant for the many non-permanent streams in the Namoi subregion and increased investigation of subterranean ecosystems and their response to changes in groundwater.
- Identifying water-dependent assets valued by the 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, for example, a wetland may have both ecological and Indigenous value.
- Putting future changes due to additional coal resource development in the context of a changing climate and changing demands for water, and particularly from agriculture in the Namoi subregion.

In many areas it was not possible to develop receptor impact models and therefore investigate potential risk to ecosystems. In these areas, a simple spatial overlay of landscape classes corresponding to the zone of potential hydrological change identifies the locations (and parts of ecosystems) where additional work may be needed to quantify the risk. For example, expanding the surface water modelling to further areas would increase the coverage of risk to ecosystems. It would be prudent to clarify if the non-modelled areas do not experience any increased surface water-related risk to ecosystems, before focusing solely on areas identified as higher risk from receptor impact modelling.

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au. Users can explore detailed results for the Namoi subregion using a map-based interface in the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/NAM.

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Surface water hydrology	CSIRO: Neil Viney and Yongqiang Zhang (Discipline Leaders), Santosh Aryal, Mat Gilfedder, Fazlul Karim, Lingtao Li, Dave McJannet, Jorge Luis Peña-Arancibia, Tom Van Niel, Jai Vaze, Bill Wang, Ang Yang

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This technical product was reviewed by several groups:

- Technical Assurance Reference Group: Chaired by Peter Baker (Principal Science Advisor, Department of the Environment and Energy), this group comprises officials from the NSW, Queensland, South Australian and Victorian governments.

Introduction

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) was established to provide advice to the federal Minister for the Environment on potential water-related impacts of coal seam gas (CSG) and large coal mining developments (IESC, 2015).

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

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

The Bioregional Assessment Programme

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

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

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

- the Sydney Basin bioregion
- the Gippsland Basin bioregion.

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

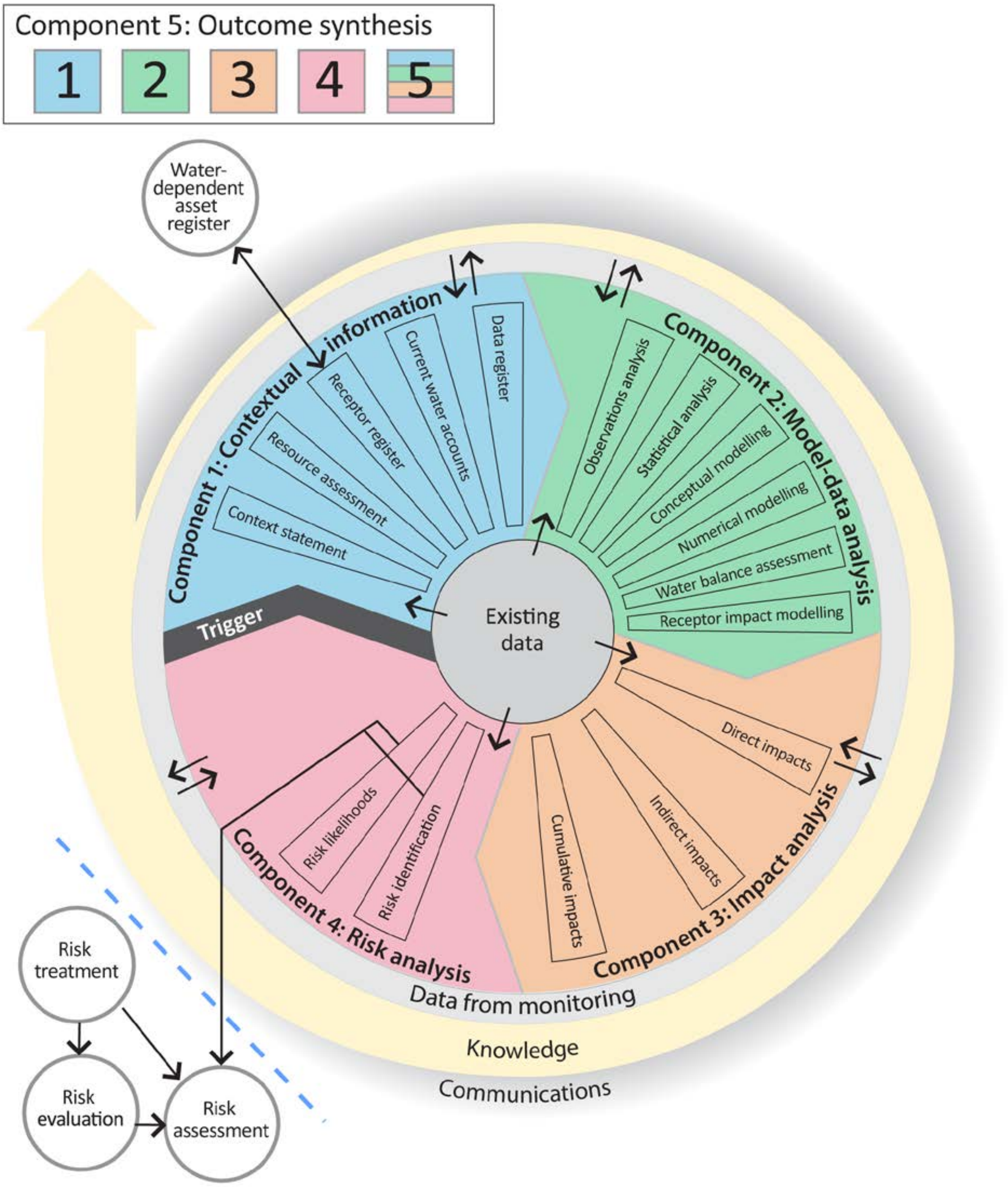

Figure 1 Schematic diagram of the bioregional assessment methodology

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

Methodologies

The overall scientific and intellectual basis of the BAs is provided in the BA methodology (Barrett et al., 2013). Additional guidance is required, however, about how to apply the BA methodology to a range of subregions and bioregions. To this end, the teams undertaking the BAs have developed and documented detailed scientific submethodologies (Table 1), in the first instance, to support the consistency of their work across the BAs and, secondly, to open the approach to scrutiny, criticism and improvement through review and publication. In some instances, methodologies applied in a particular BA may differ from what is documented in the submethodologies.

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

Table 1 Methodologies

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

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

Technical products

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

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

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

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

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

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

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

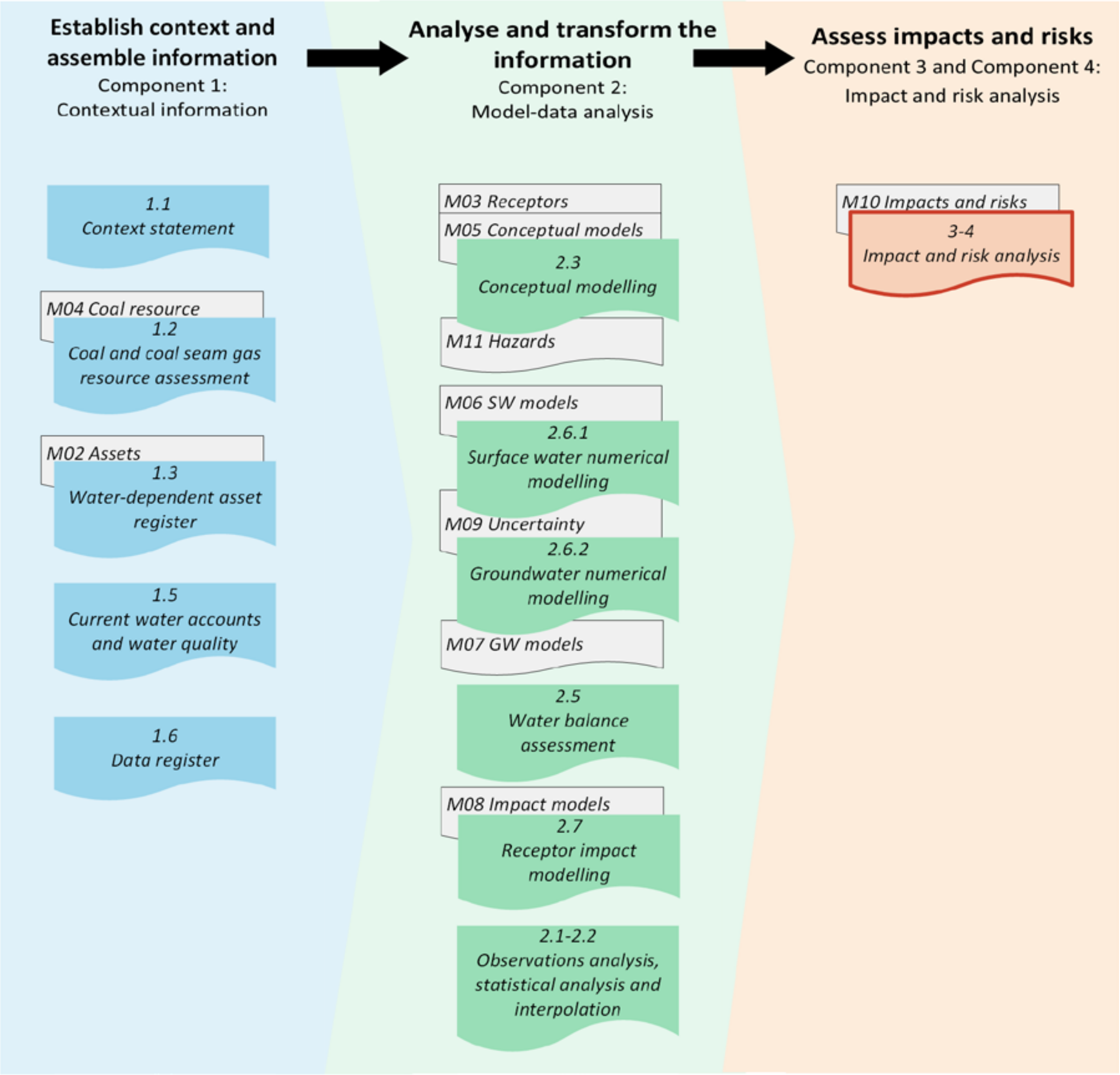

Figure 2 Technical products and submethodologies associated with each component of a bioregional assessment

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

Table 2 Technical products delivered for the Namoi subregion

For each subregion in the Northern Inland Catchments Bioregional Assessment, technical products are delivered online at http://www.bioregionalassessments.gov.au, as indicated in the 'Type' columna. Other products – such as datasets, metadata, data visualisation and factsheets – are provided online. There is no product 1.4. Originally this product was going to describe the receptor register and application of landscape classes as per Section 3.5 of the BA methodology, but this information is now included in product 2.3 (conceptual modelling) and used in product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling). There is no product 2.4. Originally this product was going to include two- and three-dimensional representations as per Section 4.2 of the BA methodology, but these are instead included in products such as product 2.3 (conceptual modelling), product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling).

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

[a] The types of products are as follows:

- 'PDF' indicates a PDF document that is developed by the Northern Inland Catchments Bioregional Assessment using the structure, standards and format specified by the Programme.
- 'HTML' indicates the same content as in the PDF document, but delivered as webpages.
- 'Register' indicates controlled lists that are delivered using a variety of formats as appropriate.

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

About this technical product

The following notes are relevant only for this technical product.

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

References

Barrett DJ, Couch CA, Metcalfe DJ, Lytton L, Adhikary DP and Schmidt RK (2013) Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment. Department of the Environment, Australia. Viewed 28 June 2018, http://data.bioregionalassessments.gov.au/submethodology/bioregional-assessment-methodology.

IESC (2015) Information guidelines for the Independent Expert Scientific Committee advice on coal seam gas and large coal mining development proposals. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Australia. Viewed 28 June 2018, http://www.iesc.environment.gov.au/publications/information-guidelines-independent-expert-scientific-committee-advice-coal-seam-gas.

3 Impact analysis for the Namoi subregion

The impact and risk analysis is the key output of a bioregional assessment (BA). This product presents potential impacts of coal resource development on water resources and water-dependent assets in the Namoi subregion. Risks are analysed by assessing the magnitude and likelihood of these potential impacts.

The impact and risk analysis (Component 3 and Component 4) builds on the contextual information (Component 1) and knowledge from the model-data analysis (Component 2).

In the impact and risk analysis:

- A zone of potential hydrological change is determined using both the surface water and groundwater numerical hydrological modelling results (from product 2.6.1 (surface water numerical modelling) and product 2.6.2 (groundwater numerical modelling)).
- The zone of potential hydrological change is overlain with the extent of the landscape classes (product 2.3 (conceptual modelling)) and water-dependent assets (product 1.3 (description of water-dependent asset register)) to identify those ecosystems and assets that might be subject to hydrological change.
- Potential impacts to ecological assets are considered via:
  - qualitative mathematical models, which predict (at a high level) how components of specific ecosystems (represented by landscape classes) might respond to changes in hydrology
  - quantitative receptor impact models (where applicable), which numerically translate the changes in hydrology into predicted changes in components of ecosystems.
- Potential impacts to economic and sociocultural assets are considered via changes to water availability and accessibility.

The product then describes potential impacts for those coal resource developments that cannot be modelled and concludes with key findings, knowledge gaps, how to use the assessment and how to build on this assessment.

3.1 Overview

Summary

The Bioregional Assessment Programme provides transparent scientific information to better understand the potential impacts of coal seam gas (CSG) and coal mining developments on water resources and water-dependent assets such as wetlands and groundwater bores. A bioregional assessment (BA) is a regional-scale analysis of the ecology, hydrology, geology and hydrogeology of a bioregion to quantify the likelihood and scale of potential impacts and risks on water resources and water dependent assets, improving the available information for future regulatory approvals and government decision making at both national and state levels.

The Namoi subregion, situated in the Murray-Darling Basin, covers approximately 29,300 km^2 and is home to approximately 27,000 people with the main centres Gunnedah and Narrabri located along the Namoi River. Agriculture is a major land use, covering 70% of the subregion, and irrigation is a significant part of the agricultural production in the subregion. The Namoi alluvium, located in the Liverpool Plains, supports a highly valuable agricultural development, which includes cropping of cotton and grains, with the less arable soils being under livestock grazing.

The Liverpool Plains also contain endangered native grasslands. Its riparian vegetation is dominated by river she-oaks and willows, and river red gum communities are found along the major streams. The Pilliga contains 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 is the largest reserve in the region. A wide range of aquatic habitats, including large areas of anabranch and billabong wetlands downstream of Narrabri, add to the ecological significance of the Namoi subregion.

There are five currently operating coal mines and 10 additional coal mine developments are planned. The potential water-mediated impacts and risks to the environment associated with these future coal resource development are of concern for this Assessment, which considers two potential futures: the baseline and the coal resource development pathway (CRDP). Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Additional drawdown is the maximum difference in drawdown (*dmax*) between the CRDP and baseline, due to additional coal resource development. The interaction of groundwater drawdown and surface water changes identifies the areas with hydrological changes for assessments of impact and risk to assets. This is the zone of potential hydrological change.

BAs focus solely on water-mediated impacts related to water quantity, groundwater level or water resource availability. The design of a BA is specifically aimed to analyse the cumulative impacts of coal resource developments. The modelled baseline and CRDP may each consider a suite of developments, the potential impacts of which may overlap to varying degrees in both time and space.

The BA defines a set of landscape classes as ecosystems to deal with the complex landscapes that encompass a wide range of ecological systems and their interaction with human activities. Because of this complexity, a direct analysis of each and every point, or water-dependent asset, in the landscape across the subregion is not currently possible. Abstraction and a systems-level classification can manage the challenges of the dimensionality of the task. The assessment of impacts on and risks to water-dependent ecological assets relies heavily on the landscape classification.

The risk analysis approach used in BAs differs from the traditional deterministic hydrological modelling. The quantitative representation of the predictive uncertainty through probability distributions allows the consideration of the likelihood of impacts or effects of a specified magnitude and underpins the impact and risk analysis.

A BA identifies areas of the subregion that additional coal resource development is unlikely to impact. Potential impacts are ruled out where possible, both spatially and in terms of specific groundwater or surface water effects, so as to identify where potential impacts have a higher probability of occurring.

3.1.1 Namoi subregion

The Namoi subregion is situated in the Murray-Darling Basin and is part of the Northern Inland Catchments bioregion (248,000 km^2). The subregion covers 29,300 km^2 and is home to approximately 27,000 people, with the main centres, Gunnedah and Narrabri, located along the Namoi River. Drainage into the Namoi subregion is mainly from the eastern highlands to the north-west and west onto a broad floodplain. The four major geographic zones: Liverpool Plains, Pilliga, Pilliga Outwash and Castlereagh-Barwon, distinguished by similarity in climate, soils and land capability, are relevant for this Assessment (see, for example, companion product 2.3 for the Namoi subregion (Herr et al., 2018)).

The major stream in the subregion, the Namoi River, joins the Barwon River near Walgett in the west. Its major feeders, Pian Creek, Baradine Creek and Gunidgera Creek, drain the broad floodplain of the Castlereagh-Barwon area, whereas Bohena Creek emanates from the Pilliga Forest, and Coxs Creek and the Mooki River are located in the Liverpool Plains in east (Figure 3). The flow in the Namoi River is regulated through two storage dams outside the subregion, and several weirs also barrage the Peel River and Dungowan Creek (see companion product 1.1 for the Namoi subregion (Welsh et al., 2014)).

The alluvial plains across this subregion consist of alternating beds and lenses of gravel, sand and silt-clay sediments up to 150 m thick. The Namoi alluvium, located in the Liverpool Plains, supports a highly valuable agricultural development, which includes cropping of cotton and grains, with the less arable soils being under livestock grazing. Agriculture covers 70% of the subregion and irrigation is a significant part of the agricultural production in the subregion. Historical groundwater use has impacted on streamflow in the Namoi River and its tributaries. The Lower Namoi River has changed from a substantially gaining river prior to irrigation development to a largely losing river and long-term groundwater level declines at the western end of the valley, where usage is low, are most likely related to extraction higher in the valley.

A wide range of aquatic habitats, including large areas of anabranch and billabong wetlands downstream of Narrabri, add to the ecological significance of the Namoi subregion. The Liverpool Plains contain endangered native grasslands. River she-oaks and willows dominate the riparian vegetation, and river red gum communities grow along the major streams. The state forest of the Pilliga is 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 is the largest reserve in the region. The asset register for the Namoi subregion (Bioregional Assessment Programme, 2017, Dataset 1; companion product 1.3 for the Namoi subregion (O'Grady et al., 2015)) contains many ecological assets and includes the potential spatial habitat distribution of species listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and wetlands, river reaches and groundwater-fed springs (see Section 3.5). Lake Goran is listed in *A directory of important wetlands* (Environment Australia, 2001) and there are two Important Bird Areas listed (see companion product 1.3 for the Namoi subregion (O'Grady et al., 2015)).

From a geological perspective, the Gunnedah Basin contains the main coal-bearing sequences that are the target of historical, current and future coal and gas extraction. To the central and western parts of the subregion, the Surat Basin sedimentary rocks overlie the Gunnedah Basin. The Pilliga Sandstone and its outcrop in the central part of the Namoi subregion mark the boundary of the Great Artesian Basin (CSIRO, 2012). Coal mining targets the Gunnedah Basin where the coal seams come closer to the surface. The major coal mine developments occur in the Liverpool Plains and the coal seam gas (CSG) exploration is focused on the northern end of the Liverpool Plains, the Pilliga north of Coonabarabran and the eastern part of the Pilliga Outwash. There are five currently operating coal mines and nine additional coal mine developments are planned. A tenth development (Caroona), which was part of the coal resource development pathway (CRDP) (based on 2012 information), is now unlikely to go ahead as the NSW Government bought back the exploration licences to guarantee the future of farming land (NSW Premier and Cabinet, 2016). The only existing CSG exploration, the Narrabri Gas Project, is targeting the deeper coal seams of the Gunnedah Basin that underlie the Pilliga Sandstone (see companion product 2.3 for the Namoi subregion (Herr et al., 2018) and Santos (2017)).

In summary, there are six existing coal resource developments and ten additional coal resource developments (including one CSG development) in the Namoi subregion CRDP. The Caroona development, while unlikely to proceed, is included in the CRDP and 14 developments form part of the hydrological modelling and modelling for the impact and risk analysis (see companion product 2.3 (Herr et al., 2018)).

Changes to the surface water and groundwater hydrology from the modelled additional coal resource development are documented in companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018) for the Namoi subregion. Results from the modelling define a zone of potential hydrological change, outside of which impacts upon water-dependent landscape classes and assets due to additional coal resource development are deemed *very unlikely* (less than 5% chance). It is the risk to and potential impacts on water-dependent landscape classes and assets within this zone that is the focus of this product.

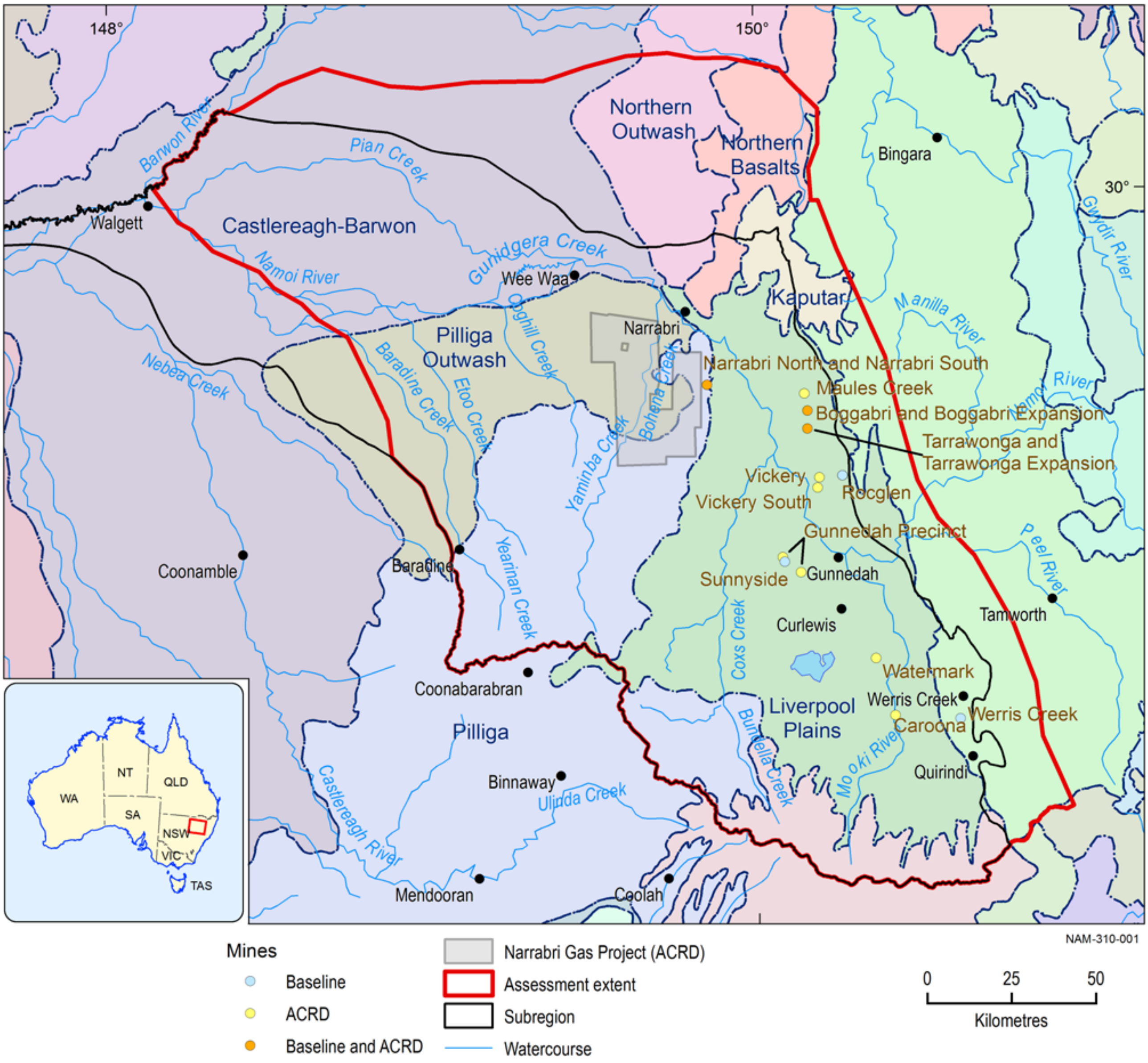

Figure 3 Major streams in the main geographic zones of the Namoi subregion and their relationship to the Namoi subregion coal resource developments (see also companion product 2.3 (Herr et al., 2018))

Data: Department of Sustainability, Environment, Water, Population and Communities (Dataset 2)

3.1.2 Scope and context

The objective of the Bioregional Assessment Programme is to understand and predict regional-scale cumulative impacts on water resources and water-dependent assets from coal resource developments in some of Australia’s major coal-bearing basins. The assessments distinguish areas where water resources and water-dependent assets are *very unlikely* to be impacted (with a less than 5% chance) from those where water resources and water-dependent assets are potentially impacted. Given the regional-scale focus, the modelling does not account for local-scale details (e.g. the presence of local aquitards; stream condition). Areas identified in a bioregional assessment (BA) as at risk of potentially significant impacts serve as ‘red flags’ for directing further local investigation. Governments, industry and the community can then focus on areas that are potentially impacted when making regulatory, water management and planning decisions. In some cases, the risk of adverse impacts may be substantially diminished or negligible when local-scale factors are considered.

The impact and risk analysis considers only biophysical consequences, such as changes in hydrology or ecology; fully evaluating consequences requires value judgments and non-scientific information that is beyond the scope of BAs. A full risk assessment (with risk evaluation and risk treatment) is not conducted as part of BAs.

The purpose of the following sections is to highlight design choices that have steered the direction of this BA and culminated in the impact and risk analysis. Further details about the design choices are provided in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018).

3.1.2.1 Choice of modelled futures

A BA is a regional analysis that compares two futures of coal resource development. In the Bioregional Assessment Programme, use of the term ‘coal resource development’ specifically includes coal mining (both open-cut and underground) as well as CSG extraction. However, other forms of coal-related development activity, such as underground coal gasification and microbial enhancement of gas resources, are not within the scope of the assessment.

The two futures considered in a BA are:

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

The difference in results between CRDP and baseline is the change that is primarily reported in a BA. This change is due to the *additional coal resource development* – all coal mines and CSG fields, including expansions of baseline operations that are expected to begin commercial production after December 2012. Figure 3 shows the location of the coal resource developments and companion product 2.3 (Herr et al., 2018) provides details of the timelines for these developments.

Thus, the primary focus of a BA is on the potential impacts on water resources and water-dependent assets that are attributable to additional coal resource development. In the Namoi subregion, these include nine coal mine developments (including Caroona, which as of 2017 is not going ahead) and one CSG development. In this Assessment, the baseline includes six existing coal mines (see companion product 2.3 (Herr et al., 2018)).

Although the difference in potential impacts between these two futures is the focus of the assessment, the potential impacts under the baseline are important for regional context. For instance, the potential implications to groundwater-dependent assets of an additional 2 m of drawdown may depend on whether the drawdown under the baseline is 0.05, 0.5 or even 50 m. Potentially important impacts due to coal resource development under the baseline may also occur in parts of the subregion where additional coal resource developments have no further effect. The assessment gives less attention to these. The year in which maximum drawdown occurs under each future is unlikely to coincide and simply adding the drawdown results in a worst-case scenario that is unlikely to eventuate. Maximum drawdown occurs when the drawdown difference is at its maximum between the baseline and a ‘no-development’ scenario, and between the CRDP and the baseline scenario. These maximum drawdowns could (and in fact are likely to) occur at different times.

The CRDP is the most likely future, based on the analysis and expert judgment of the Assessment team in consultation with coal and gas industry representatives, state agencies and the Commonwealth Government. Based on information available at the time, the CRDP for the Namoi subregion was finalised in 2015 (see companion product 2.3 (Herr et al., 2018) for the Namoi subregion) to allow the hydrological numerical modelling to commence. Developments in the CRDP may ultimately be implemented in different ways (e.g. changes to timing) or circumstances of coal resource developments may even change (e.g. a proponent may withdraw for some reason). For example, the Caroona development is now not going ahead, even though it is included in the CRDP. This reflects the dynamic nature of resource investment decision making, which may ultimately respond to diverse economic, political or social factors. Consequently, the CRDP is a representation of an indicative future. It highlights potential changes for water resources and water-dependent assets where assessment of local conditions will improve future understanding. Equally as important, the CRDP plays a role in identifying where changes will not occur and thus flagging where potential impacts to water resources and water-dependent assets are *very unlikely*.

The modelling held factors such as climate change or land use (e.g. agriculture) constant between the two futures. Although the future climate and/or land use may differ from those assumed in BAs, the effect of this choice is likely to be small because the focus of BAs is on reporting the impacts of additional coal resource development, i.e. the difference in results between the CRDP and baseline. Where potential hydrological or ecological changes due to the additional coal resource development are identified it will be important to consider those changes in conjunction with local information and in the context of other water related changes that may occur in the Namoi subregion (e.g. irrigation or water extraction for human consumption) as that could also influence the ecological trajectory. This could be part of a more complete regional assessment of cumulative impacts beyond BA.

3.1.2.2 Focus on water quantity and availability

BAs focus solely on water-mediated impacts, and specifically those related to water quantity, groundwater level or water resource availability. The scope of the BAs determined that potential water quality impacts are limited to salinity. Some broader water quality hazards are identified through the dedicated hazard analysis but the scientific analysis is restricted to salinity and is only addressed qualitatively. BAs are also concerned with those surface water and groundwater effects that may accumulate, either over extended time frames or as a result of multiple coal resource developments. These typically correspond to changes in surface water and groundwater that occur over long periods of time, sometimes decadal, and which may create the potential for flow-on effects through the wider hydrological system.

Many activities related to coal resource development may cause local or on-site changes to surface water or groundwater. These are not considered in BAs because regulatory site-based risk management and mitigation procedures address these issues, and because they are unlikely to create potential cumulative impacts. The assessment identifies impacts and risks associated with water quality attributes other than salinity that potentially happen as a result of coal resource development, but does not analyse these further.

3.1.2.3 Assessment of regional-scale cumulative developments

BAs analyse the cumulative impacts of coal resource developments at a regional scale, and do not focus specifically on individual mines or CSG operations. The baseline and CRDP for the Namoi subregion each comprise a suite of developments, which are distributed across the assessment extent at variable distances from each other and have variable, but often overlapping, periods of operation. Thus there is potential for the impacts to accumulate to varying degrees in both space and time.

Regional-scale models predict the cumulative hydrological changes and potential impacts of those developments on landscape classes and water-dependent assets from multiple developments over time. The area of potential impact is more extensive and extends greater distances downstream of developments than what occurs from site-scale, single mine models. In some cases the spatial or temporal alignment of certain coal resource developments can allow for attribution of potential effects to individual developments, but that occurs because of that alignment rather than by design.

Results of the impact and risk analysis reported in this product do not replace the need for the detailed site- or project-specific investigations that existing state and Commonwealth legislation require. The hydrological and ecological systems modelling in a BA is appropriate for assessing the potential impacts on and risks to water resources and water-dependent assets at the regional scale, whereas the modelling undertaken for a mining proponent’s development, as part of an environmental assessment, occurs at a much finer scale and makes use of local information to more accurately represent the local situation. Therefore, results from these detailed mine-specific studies may differ from BA results. Employing a BA to invalidate existing site-specific modelling or impact assessments would be a fallacy; instead, BA results are useful in identifying broad areas where risk to assets and ecosystems from future coal resource developments are likely.

3.1.2.4 Focus on predictive uncertainty

BAs consider parameter uncertainty as fully as possible when predicting hydrological outcomes (i.e. changes to surface water or groundwater) and ecological outcomes (i.e. changes to ecologically relevant receptor impact variables). For example, groundwater models were run many thousands of times using a wide range of plausible input parameters for the critical hydraulic properties, such as the hydraulic conductivity and storage coefficients of all modelled hydrogeological layers. This differs from the traditional deterministic approach used more routinely for groundwater and surface water modelling.

While models are constrained to data, the density of reliable observation data is sparse, so results may not represent local conditions well. However, they do consistently represent the risk and uncertainty at all sites through probability distributions of possible hydrological changes, where the area, depth, timing and assumed pumping rates of each development largely determine the spatial variation, and lack of detail about the physical environment at any given point in the assessment extent define the uncertainty.

Given the wide range of plausible input parameters used in the regional modelling, the hydrological changes due to additional coal resource development at any given location within the assessment extent are likely to lie within the distribution of modelled changes. This assumption is likely to be tested near open-cut mines where potentially steep hydraulic gradients at the mine pit interface are poorly resolved in the regional groundwater models. These areas are excluded from the regional analysis for this reason. Where the BA regional-scale analysis identifies an area as ‘at risk’ of large hydrological changes and potentially significant impacts on ecological, economic and/or sociocultural values, local-scale information may be necessary to constrain the predictive uncertainty to something more representative of local conditions, and more appropriate for informing the local management response. For example, the presence of a local aquitard that is not a feature of regional groundwater model may reduce potential near-surface hydrological and ecological impacts inferred using the regional model. This should be taken into account in any conditions or management response.

The quantitative representation of the predictive uncertainty through probability distributions allows BAs to consider the likelihood of impacts with a specified magnitude and underpins the impact and risk analysis. Sources of uncertainty that cannot be quantified were considered qualitatively.

3.1.2.5 Integrating ecological complexity with a landscape classification

Subregions are complex landscapes with a wide range of ecological systems that interact with human activities. The systems can be discrete, overlapping or integrated. Because of this complexity, a direct analysis of each and every point, or water-dependent asset, in the landscape across the subregion is not currently possible. Abstraction and a systems-level classification can manage the challenges of the dimensionality of the task.

The BA defines a set of landscape classes as ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. The spatial coverage of landscape classes across the subregion is exhaustive and non-overlapping, and there is expected to be less heterogeneity in the response within a landscape class than between landscape classes. This reduces the complexity for each subregion and is appropriate for a regional-scale assessment. The landscape classification characterises the landscape and focuses on the key processes, functions and interactions for the individual landscape classes. The landscape classification for the Namoi subregion builds on existing well-accepted classifications and is described in detail in companion product 2.3 for the Namoi subregion (Herr et al., 2018). The landscape classification allows effort to be focused on those landscape classes that are water dependent.

The assessment of impacts on and risks to water-dependent ecological assets relies heavily on the landscape classification. Potential impacts to individual assets are assessed via the landscape classes where they are located. For each of those landscape classes, the assessment is based on the qualitative mathematical models for those landscape classes and the indicators of hydrological change or ecosystem change that experts have identified as important for that landscape class.

3.1.2.6 Ruling out potential impacts

An important outcome of the multiple components of the BA is to identify areas of the subregion that additional coal resource development is unlikely to impact. The Assessment team rules out potential impacts where possible, both spatially and in terms of specific groundwater or surface water effects, so as to concentrate on where potential impacts have a higher probability of occurring. This process starts with the identification of a preliminary assessment extent (PAE) for a subregion or bioregion that is a conservative spatial boundary, encompassing areas of potential impact based on the most likely coal resource developments within the subregion or bioregion. The PAE is where assessment effort is focused, including in the collation of water-dependent assets, the creation of landscape classes to summarise key surface ecosystems, and the construction of numerical surface water and groundwater models.

Results of the hydrological modelling provide the details to finalise the ‘assessment extent’ used in the impact and risk analysis. No changes to the Namoi PAE were necessary, and the assessment extent for the Namoi subregion is the same as the PAE identified in companion product 1.3 for the Namoi subregion (O’Grady et al., 2015).

Results of the hydrological modelling also define the zone of potential hydrological change (Section 3.3.1). Potential impacts on water-dependent landscape classes and assets are ruled out if they are wholly outside the zone of potential hydrological change. Thus, the zone identifies landscape classes that should be investigated further through qualitative mathematical modelling and receptor impact modelling and, as required, through use of local information to better define the risk and appropriate management response. Equally important, this logical and consistently applied process rules out landscape classes or water-dependent assets where potential impacts due to additional coal resource development are *very unlikely* (less than 5% chance) to occur.

3.1.3 Structure of this report

This product presents information about the impact and risk analysis for the Namoi subregion and is the key output of the BAs. The structure is as follows:

- Section 3.1 describes the scope of the BA conducted for the Namoi subregion and provides context to the critical philosophical and operational choices.
- Section 3.2 describes the methods for assessing impacts and risks in the Namoi subregion that are additional to those in the receptor impact modelling (companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)). It includes details of the databases, tools and geoprocessing that support the impact and risk analysis, and the approach to aggregating potential impacts to landscape classes and assets. The approach is consistent with that outlined in the companion submethodology M10 (as listed in Table 1) for the analysis of risk and cumulative impacts (Henderson et al., 2018).
- Section 3.3 provides a closer look at the spatial extent of hydrological changes within the zone of potential hydrological change, using a subset of the hydrological response variables defined in companion submethodology M06 (as listed in Table 1) for surface water

modelling (Viney, 2016). The reported surface water hydrological response variables represent changes in low flows, high flows and annual flow due to additional coal resource development. While not explicitly modelled, the potential for additional coal resource development to impact water quality is reported in this section.

- Section 3.4 considers the impacts on and risks to landscape classes within the zone of potential hydrologic change due to additional coal resource development. An aggregated, system-level analysis of potential impacts is possible at the scale of the landscape class. A 'rule-out' process identifies landscape classes that are *very unlikely* to be impacted due to hydrological changes. The impacts on and risks to landscape classes are assessed either quantitatively using the receptor impact models described in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) or more qualitatively using the qualitative mathematical models developed through expert elicitation (Ickowicz et al., 2018). Potential hydrological changes for those landscape classes focus on those identified as important through the expert elicitation.
- Section 3.5 considers the risk and impacts due to additional coal resource development at the asset level. The focus is on those water-dependent assets in the asset register for the Namoi subregion (Bioregional Assessment Programme, 2017, Dataset 1; companion product 1.3 for the Namoi subregion (O'Grady et al., 2015)) that are in the zone of potential hydrological change. The analysis is predominantly at the asset group level, rather than for each individual asset. It includes ecological, economic and sociocultural assets.
- Section 3.6 assesses the potential hydrological changes and impacts on landscape classes and assets from the additional coal resource developments that were not modelled.
- Section 3.7 concludes with key findings and knowledge gaps, including commentary on how to validate and build on this assessment in the future.

Companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) summarises the overarching methodology and development of the Namoi subregion qualitative mathematical models and receptor impact models used to make predictions about the potential impacts on ecosystems reported in Section 3.4. As such, it serves as an appendix to this product.

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3.2 Methods

Summary

The impact and risk analysis (Component 3 and Component 4) follows the overarching methodology described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018).

Results from the groundwater and surface water modelling, including estimates of the predictive uncertainty, define the zone of potential hydrological change due to additional coal resource development. These probabilistic estimates of hydrological change that arise from the additional coal resource development provide the basis for analysing the impacts and risks on water resources. The estimates also form the basis for analysing the risk to landscape classes and water-dependent assets.

The impact and risk analysis uses a spatial overlay of the zone of potential hydrological change to assess the potential impacts on and risks to landscape classes and water-dependent assets due to additional coal resource development. The potential for impacts on landscapes and water-dependent assets that do not intersect the zone of potential hydrological change is deemed *very unlikely* (less than 5% chance) and they are ruled out of further analysis. Within this zone, the potential impact of hydrological changes on landscape classes and assets is based on indicators of hydrological change (hydrological response variables) and ecosystem change (receptor impact variables).

This section also summarises the databases, tools and geoprocessing that support the impact and risk analysis.

3.2.1 Impact and risk analysis

The *Methodology for bioregional assessments of the impacts of coal seam gas and coal mining development on water resources* (the bioregional assessment (BA) methodology) (Barrett et al., 2013) states:

> The central purpose of BAs is to analyse the impacts and risks associated with changes to water-dependent assets that arise in response to current and future pathways of CSG and coal mining development.

The impact and risk analysis for the Namoi subregion (Component 3 and Component 4) follows the overarching logic described in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018), and is summarised diagrammatically in Figure 4. It builds on the contextual information (Component 1) and knowledge developed through identification of conceptual models of causal pathways, numerical groundwater modelling and data analysis (Component 2) (as listed in Table 2).

The impact analysis quantifies the magnitude or extent of the potential hydrological or ecosystem changes due to coal resource development. This includes considering:

- *direct impacts*: a change in water resources and water-dependent assets resulting from coal seam gas (CSG) and coal mining developments without intervening agents or pathways
- *indirect impacts*: a change in water resources and water-dependent assets resulting from CSG and coal mining developments with one or more intervening agents or pathways
- *cumulative impacts*: the total change in water resources and water-dependent assets resulting from CSG and coal mining developments when all past, present and reasonably foreseeable actions that are likely to impact on water resources are considered.

The risk analysis is related, however, it considers not only the magnitude or extent of the potential impact, but also the likelihood of that impact eventuating. This is often framed as ‘consequence multiplied by the likelihood’. A dedicated uncertainty analysis underpins the quantification of the likelihood and allows probabilistic statements about certain events or impacts occurring. Within BAs, the uncertainty analysis stochastically propagates uncertainties in underlying hydrological parameters through hydrological models to produce distributions of potential surface water and groundwater changes. These in turn are inputs into receptor impact models to produce distributions of receptor impact variables, which serve as indicators of potential ecosystem impacts.

BAs identify risks through a hazard analysis and analyse those risks by estimating the magnitude and likelihood of specific impacts. The risk assessment, risk evaluation and the risk treatment that occur as part of the broader risk management (see, for instance, ISO 31000:2009 *Risk management – principles and guidelines* (ISO, 2009)) are beyond the scope of BAs because they require careful consideration of a number of non-scientific matters and value judgements; these are roles of proponents and government regulators in the first instance, often in response to specific community values.

This product describes the predicted hydrological changes, and then the potential impacts of those changes on landscape classes and water-dependent assets, which contain ecological, economic and sociocultural values. These regional-scale results do not replace the need for detailed site or project specific studies, nor should they be used to pre-empt the results of detailed studies that may be required under NSW legislation. Where the regional analysis identifies potential impacts, local-scale information can improve the risk evaluation.

BAs present the likelihood of certain impacts occurring, for example, the percent chance of exceeding 0.2 m of drawdown in a particular aquifer and location (see Section 3.2.3). The information that is generated and that underpins statements like this is available for others to access at www.bioregionalassessments.gov.au and use in their own targeted risk assessments. Users can choose thresholds of impact that may threaten the specific values they are trying to protect and calculate the corresponding likelihood of occurrence. More details about hydrological changes and potential impacts in the Namoi subregion are available at www.bioregionalassessments.gov.au/explorer/NAM.

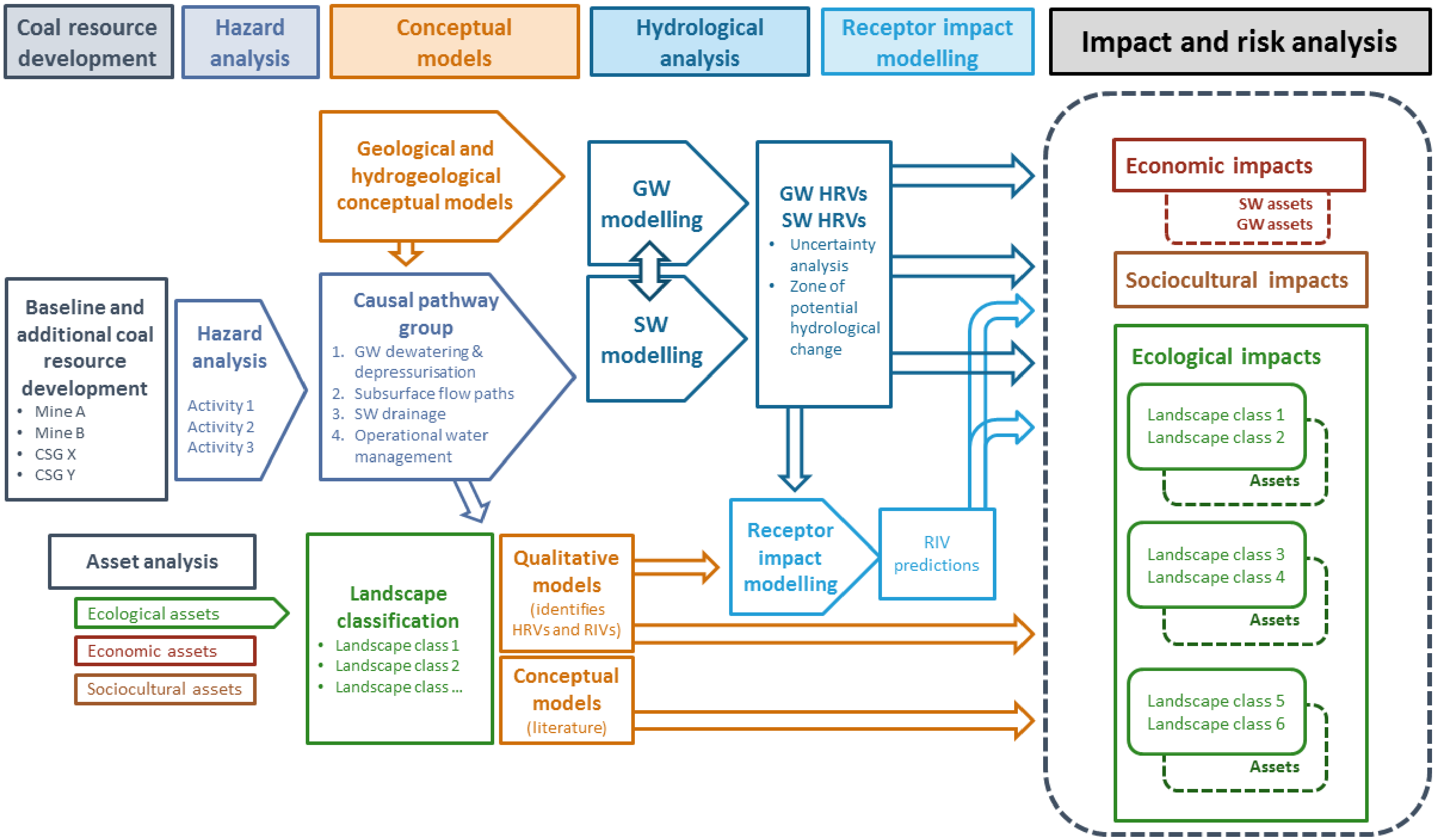

Figure 4 Overarching methodology for impact and risk analysis in bioregional assessments

CSG = coal seam gas, GW = groundwater, HRV = hydrological response variable, RIV = receptor impact variable, SW = surface water

3.2.2 Causal pathways

The conceptual model of causal pathways (as described in companion submethodology M05 (as listed in Table 1) for developing a conceptual model of causal pathways (Henderson et al., 2016)), and the hazard analysis that underpins them, describe the logical chain of events – either planned or unplanned – that link coal resource development and potential impacts on water and water-dependent assets. These causal pathways provide the logical and transparent foundation for the impact and risk analysis. They have been identified through a systematic and exhaustive process, and while there is subsequent prioritisation of those pathways according to the likelihood, severity and detectability of potential impacts, there is a need to ensure that all causal pathways are addressed for the impact and risk analysis to meet the necessary quality criteria. This does not mean that all causal pathways need to be assessed in the same way, only that they are all addressed in some way. Many causal pathways are represented directly in the quantitative numerical groundwater and surface water modelling, while others cannot be modelled for scale or complexity reasons and are addressed qualitatively through a narrative using the current conceptual understanding and knowledge base. There are causal pathways that are more local and addressed adequately by existing site-based management, and others that must be considered knowledge gaps (e.g. because the means of disposal for co-produced water is unknown) and some that are on balance considered implausible.

The causal pathways developed for the Namoi subregion have leveraged existing resources and knowledge of geological, surface water and groundwater conceptual models and are available in companion product 2.3 for the Namoi subregion (Herr et al., 2018).

A systematic hazard analysis, using the Impact Modes and Effects Analysis method (described in companion submethodology M11 (as listed in Table 1) for hazard analysis (Ford et al., 2016)), identified the activities that occur as part of coal resource development in the Namoi subregion and that might result in a change in the quality or quantity of surface water or groundwater. The many individual ‘hazards’ themselves are not represented in the hydrological models, instead they are grouped into four causal pathway groups that reflect the main hydrological pathways via which the effects of a hazard propagate away from its origin and which are broadly represented in the BA hydrological models. They are:

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

Figure 5 and Figure 6 illustrate the regional, three-dimensional overview of the regional settings and form the basis for these causal pathway groups. Further details about causal pathway groups, their hazards and effects are in companion product 2.3 for the Namoi subregion (Herr et al., 2018).

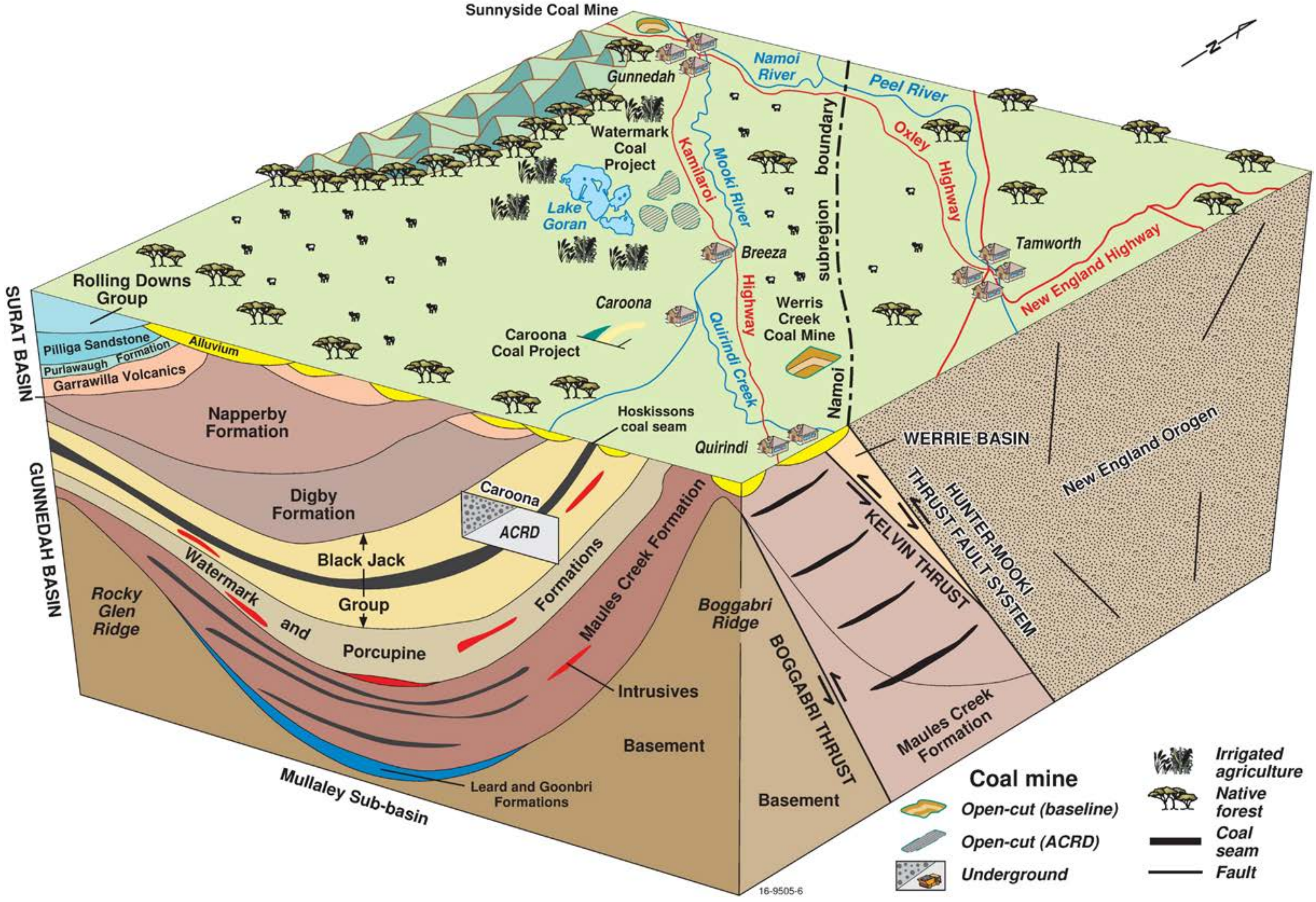

Figure 5 Schematic diagram of the south-east of the Namoi subregion from Quirindi to Gunnedah showing underlying geology relative to coal resource development

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

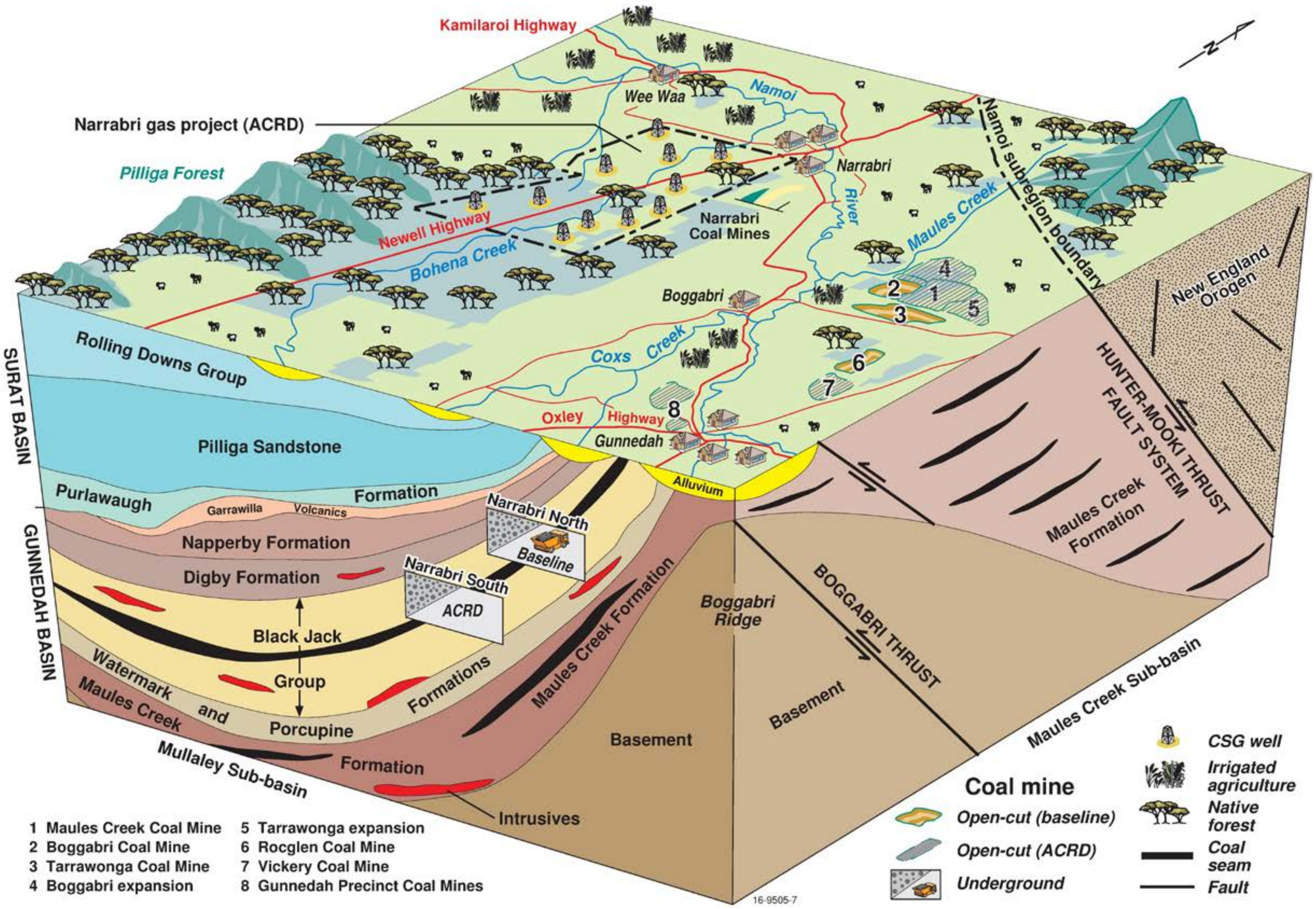

Figure 6 Schematic east–west diagram of the Namoi subregion from Gunnedah to Wee Waa showing underlying geology relative to coal resource development

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

3.2.2.1 Modelled hydrological changes

The hydrological models represent causal pathways through their conceptualisation and parameterisation of changes in surface water drainage, dewatering of the mines, changes in hydraulic properties above longwall mines and discharges of mine water off site. The models integrate the hydrological changes from the different causal pathways into the predicted hydrological response across the model domain over time.

Hydrological numerical modelling (companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018) for the Namoi subregion) describes the effects of surface water interception and aquifer depressurisation associated with coal resource development. The numerical modelling produces spatially explicit, probabilistic estimates of changes to the hydrology.

Groundwater modelling simulates the change in groundwater fluxes and stores associated with the coal resource development pathway (CRDP) within the model boundaries. The surface water modelling provides probabilistic estimates for a range of hydrological response variables, including changes in flow and volume, in the major streams of the Namoi subregion due to the coal resource development.

The variables estimated by the hydrological modelling form the basis for assessing the changes to landscape classes, and the classification of different types of ecosystems within BAs. Variables that characterise the hydrological dependence of landscape classes within the zone of potential hydrological change were identified and refined through two expert workshops held in August 2016 and December 2016 (see companion product 2.7 (Ickowicz et al., 2018)). These variables were subsequently mapped to hydrological response variables that were able to be modelled. For example, where the ecological experts identified overbank flow as important to a landscape class, this was modelled by considering the number of events that exceed the flow corresponding to a return period of 3 years for the reference period 1983 to 2012.

3.2.2.2 Hydrological changes addressed otherwise

Some hazards and potential hydrological changes were not modelled. For example, changes in water quality due to coal resource development activities are out of scope of BAs, except the potential effects on stream salinity. Changes in stream salinity were not modelled, but are considered qualitatively in Section 3.3.4. Some identified hazards are relevant to the local conditions, and site-based management addresses these.

Companion product 2.3 (Herr et al., 2018) identifies the hazards and their hydrological effects. Table 13 in Herr et al. (2018) shows the causal pathway groups and associated hydrological effects. Figure 35 and Figure 37 in Herr et al. (2018) show the individual hazards the hydrological modelling covers, while Figure 36 and Figure 38 show the individual hazards that are addressed more qualitatively through a narrative. Many other hazards fall within the site-based risk management and therefore are not considered part of this Assessment. These are grouped in Table 14 and Table 15 in Herr et al. (2018).

3.2.3 Hydrological analysis

The hydrological analysis encompasses the surface water and groundwater modelling reported in companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018), respectively, for the Namoi subregion. The Namoi surface water and groundwater models quantify potential changes in hydrology from multiple coal resource developments and enable an assessment of the cumulative impacts of coal resource development at a regional scale. For streamflow, nine hydrological response variables, which incorporate changes in groundwater fluxes from the groundwater model, allow an assessment of the effects on low-, average- and high-flow characteristics of the time-series data. For groundwater, a single hydrological response variable quantifies the maximum additional drawdown attributable to the modelled additional coal resource development.

Companion submethodology M06 for surface water modelling (Viney, 2016) and companion submethodology M07 for groundwater modelling (Crosbie et al., 2016) (as listed in Table 1) define thresholds for each hydrological response variable. A modelled change at or above the threshold identifies the level of hydrological change due to additional coal resource development that needs to be considered further. Preliminary zones of potential hydrological change for surface water (companion product 2.6.1 (Aryal et al., 2018)) and for groundwater (companion product 2.6.2 (Janardhanan et al., 2018)) identify the areas beyond which impact is considered *very unlikely*.

For surface water, a model node is included in the zone of potential hydrological change if it registered a change above the threshold in at least one of the nine hydrological response variables. The Namoi link-node mapping shows where results from surface water model nodes define upstream and downstream links in the stream network (see companion product 2.6.1 (Aryal et al., 2018)), and it identifies which stream reaches are within the surface water zone of potential hydrological change (see Figure 37 in Aryal et al. (2018)).

For groundwater, a maximum drawdown of 0.2 m due to additional coal resource development is used as a threshold. If 5% or more of the model simulations predict a drawdown of greater than 0.2 m, the model node is included in the groundwater zone of potential hydrological change (see Figure 10 in Section 3.3). If less than 5% of the model simulations predict a drawdown of greater than 0.2 m, then hydrological impact is assessed as *very unlikely*.

The zones of potential hydrological change for surface water and groundwater modelling, identified in companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018), form the basis for a combined zone of potential hydrological change that is spatially explicit and at a 1 km pixel resolution, and this resolution is aligned with the shape of assessment units. Assessment units are the basis of the subsequent assessment (see Section 3.2.5 for details). This resolution recognises the input data resolutions in the hydrological modelling and allows for an assessment at the bioregional level. Section 3.3 outlines the process of this zone development for the Namoi subregion. The additional processing steps needed to incorporate stream reaches that are not explicit in the AWRA-R link-node network are also available in Section 3.3. This includes those landscape classes that have an inherent surface water dependency and intersect with these stream reaches. This overcomes the spatial limitation of representing streams as line features, which do not include riparian and floodplain areas. The zone of potential hydrological change underpins the ‘rule-out’ overlay analysis of landscape classes and assets (Section 3.2.4).

3.2.3.1 Representing predictive uncertainty

The models used in the assessment produce a large number of predictions of groundwater drawdown and streamflow characteristics 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 7). This approach allows an assessment of the likelihood of exceeding a given magnitude of change, and underpins the assessment of risk.

Groundwater models, for example, require information about physical properties such as the thickness of geological layers, how porous aquifers are, and whether faults are present. As the exact values of these properties are not always known, the modellers used a credible range of values, which are based on various sources of data (commonly point-scale) combined with expert knowledge. Incorporation of this credible range included running the model 3500 times using a different set of plausible values for those physical properties each time. Historical observations, such as groundwater level and changes in water movement and volume from across the subregion, help to constrain and validate the model runs subsequently.

The complete set of model runs produces a range or distribution of predictions (Figure 7) that is consistent with the available regional observations and the understanding of the modelled system. The range conveys the confidence in model results, with a wide range indicating that the expected outcome is less certain, while a narrow range provides a stronger evidence base for decision making. The distributions created from these model runs are expressed as probabilities that drawdown or a change in streamflow will 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 5th, 50th or 95th percentile results, corresponding to a 95%, 50% or 5% chance of exceeding thresholds. Figure 8 illustrates this predictive uncertainty spatially.

Throughout this product, the term '*very likely*' describes where there is a greater than 95% chance of something occurring, and '*very unlikely*' is used where there is a less than 5% chance.

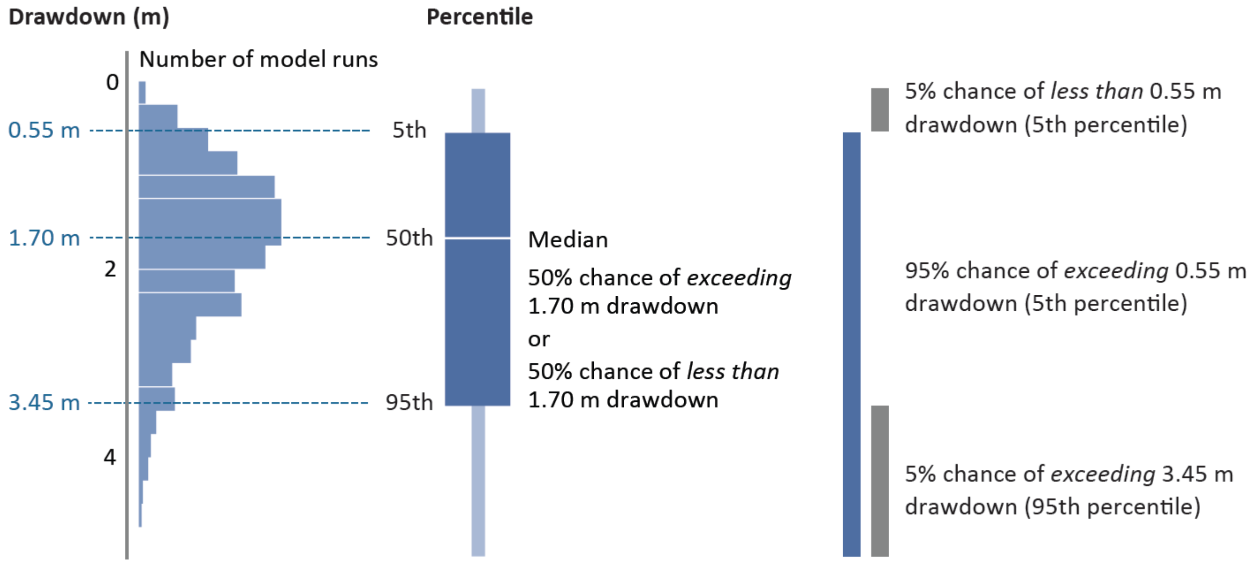

Figure 7 Illustrative example of probabilistic drawdown results using percentiles and percent chance

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

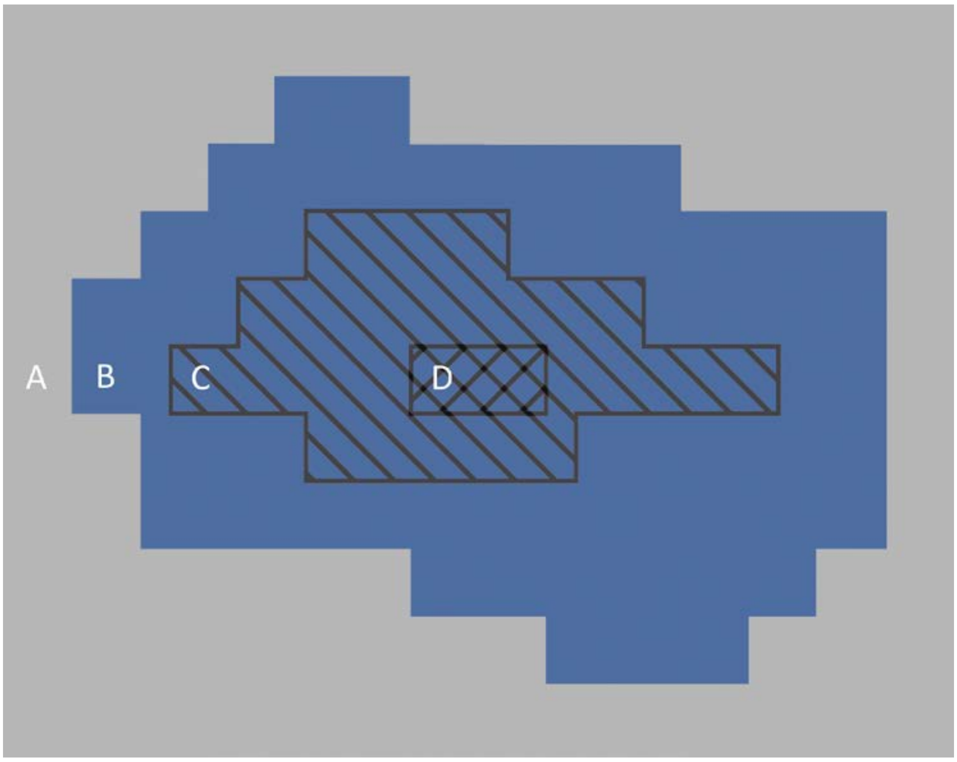

Figure 8 Illustrative example of key areas in the landscape defined by probabilistic results

The assessment extent was divided into smaller square assessment units (see Section 3.2.5) and the probability distribution (Figure 7) was calculated for each. In this product results are reported with respect to the following key areas:
A. outside the zone of potential hydrological change, where hydrological changes (and hence impacts) are *very unlikely* (defined by maps showing the 95th percentile)
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 95th percentile). Further work is required to determine whether the hydrological changes in the zone translate into impacts for water-dependent assets and landscapes
C. 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 50th percentile)
D. 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 5th percentile).

Percentile estimates of drawdown enable the reader to choose their own drawdown thresholds. For example, an ecologist may be interested in potential hydrological changes in an area of floodplain remnant vegetation where their conceptual ecological model indicates that herbaceous species are affected by 1 to 2 m of drawdown and floodplain trees are affected by 10 to 20 m of drawdown. The ecologist can use the 5th, 50th and 95th percentile estimates of drawdown for the relevant landscape class or asset to assess the likelihood and extent of potential impacts on and risks to that ecosystem due to coal resource development.

In contrast, the percent chance of exceeding important threshold values enables the reader to choose their level of certainty. A regulator may be interested in the likelihood of a groundwater bore exceeding defined regulatory thresholds. The regulator can then determine the number of bores where there is a 20% chance of exceeding 5 m drawdown.

3.2.4 Assessing potential impacts for landscape classes and assets

The approach for assessing potential impacts on landscape classes and water-dependent assets is discussed in companion submethodology M10 (as listed in Table 1) for analysing impacts and risks (Henderson et al., 2018). The principal focus of BAs is water-dependent assets that are nominated by the community. These assets may have a variety of values, including ecological, sociocultural and economic values.

The water-dependent asset register (Bioregional Assessment Programme, 2017, Dataset 1; companion product 1.3 for the Namoi subregion (O'Grady et al., 2015) provides a simple and authoritative listing of the assets within the assessment extent. The register is a compilation of assets identified in Local Land Services (formerly Catchment Management Authorities) databases and Commonwealth and state databases, and through the Namoi assets workshop. The Assessment team identified these assets for fitness for BA purpose, location within the assessment extent and water-dependency. Assets that satisfy the requirements form part of the impact and risk analysis.

Landscape classification discretises the heterogeneous landscape into a manageable number of landscape classes for impact and risk analysis. A landscape class is a surface ecosystem with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. There is expected to be less heterogeneity in the response within a landscape class than between landscape classes. They are used to reduce some of the complexity inherent in assessing impacts on a large number of water-dependent assets by focusing on the hydrological drivers and interactions relevant to a regional-scale assessment. The landscape classes provide a meaningful scale for understanding potential ecosystem impacts and communicating them through their more aggregated system-level view. The landscape classification for the Namoi subregion is located in companion product 2.3 (Herr et al., 2018), and companion submethodology M05 (as listed in Table 1) provides the methodology for developing a conceptual model of causal pathways (Henderson et al., 2016).

Assessing potential hydrological changes involves overlaying the extent of a landscape class or asset on the zone of potential hydrological change. For the landscape classes or assets that lie outside the zone, the magnitude of the hydrological changes is considered *very unlikely* to result in adverse impacts, and thus they can be ruled out in terms of further assessment. Section 3.4.2 identifies the ruled-out landscape classes in the Namoi subregion.

Where an asset or landscape class wholly or partially intersects the zone of potential hydrological change, there is the potential for impact. This does not mean there will be an impact but, rather based on the magnitude of the hydrological change, the possibility of an impact exists and further investigation is required. The nature of the water dependency of the landscape class can be important for informing the assessment. For example, if the water dependence of a landscape class relates to overbank flows to support seedling establishment, but the predicted hydrological changes in the nearby stream relate only to low-flow variables (i.e. flows within the bank), then it may be possible to rule out the landscape class from further consideration because it is *very unlikely* to be impacted.

Experts built eight receptor impact models and these represent two landscape groups in the Namoi subregion (Table 3), which formed the basis for quantifying the impact of the predicted hydrological changes on one or more receptor impact variables within the receptor impact model (see companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)). Expert elicitation provided meaningful hydrological response variables and receptor impact variables (Table 3, see also Table 5 in companion product 2.7 (Ickowicz et al., 2018)) during qualitative and receptor impact model building workshops and subsequent follow-up. While the groundwater and surface water models operate on different time steps, coupling of individual runs ensured dependence between the groundwater and surface water runs for the receptor impact modelling. The receptor impact variables serve as indicators of ecosystem response for the landscape class or ecosystem represented in the model. Within a landscape class at a specific location, local information, such as condition of the associated habitat, species diversity and abundance, presence of other stressors (e.g. agricultural or urban land uses) and recovery potential, will influence the perception of risk and whether risk management measures are required to minimise potential impacts.

A full description of the receptor impact modelling is provided in companion submethodology M08 (as listed in Table 1) for recept impact modelling (Hosack et al., 2018). This includes Table 4 in Section 2.7.1.2.6, which summarises some of the assumptions made for the receptor impact modelling, the implications of those assumptions for the results, and how those implications are acknowledged through the BA workflow and ultimately within this product. Examples of the main assumptions include the simplification of complex ecological systems, the segregation of the system into discrete classes that are assumed to respond similarly to hydrological changes, and the assumption that areas of landscapes classes remain constant over time (see Table 4 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) for the complete list of assumptions). The specific implications or flow-on effects of these assumptions are further explained in the respective sections for individual landscape classes in companion product 2.7 (Ickowicz et al., 2018). It is also important to note that the outputs from receptor impact modelling (which translate potential hydrological change into potential change in ecosystem indicators) are only one line of evidence used in this impact and risk analysis, and these outputs need to be considered in the context of the assumptions made and the availability and quality of local data.

Table 3 Receptor impact models and their variables

Landscape class group	Receptor impact model	Hydrological response variable	Receptor impact variable (RIV)
Floodplain or lowland riverine	Floodplain riparian forest	• Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) • The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods.	Projected foliage cover of dominant riparian trees (river red gum)
Floodplain or lowland riverine	Floodplain wetland (GDE and non-GDE)	• The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods.	Probability of presence of tadpoles from *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) in pools and riffles
Floodplain or lowland riverine	Permanent and temporary lowland streams (GDE and non-GDE)	• The number of zero-flow days per year, averaged over a 30-year period • The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period	Average number of families of aquatic macroinvertebrate in edge habitat
Floodplain or lowland riverine	Pilliga riverine (two models, one for each RIV)	• The number of zero-flow days per year, averaged over a 30-year period • The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period • Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012)	• Projected foliage cover • Average number of families of aquatic macroinvertebrates in instream pool habitat

Landscape class group	Receptor impact model	Hydrological response variable	Receptor impact variable (RIV)
Non-floodplain or upland riverine	Upland riparian forest GDE	• Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012) • The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods.	Projected foliage cover of riparian trees
Non-floodplain or upland riverine	Permanent and temporary upland streams (GDE and non-GDE) Upland riverine	• The number of zero-flow days per year, averaged over a 30-year period • The maximum length of spells (in days per year) with zero flow, averaged over a 30-year period	• Average number of families of aquatic macroinvertebrates in instream pool habitat • Probability of presence of tadpoles from *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)

Potential impacts are reported in Section 3.4 for landscape classes and in Section 3.5 for assets. Given the large number of assets, the focus of Section 3.5 is on identifying assets that are at ‘more at risk of hydrological changes’ within the zone of potential hydrological change. These are the assets that overlap with areas in the zone that have at least a 50% chance of a hydrological change greater than the threshold hydrological response variable values used to define the zone. Local information is necessary to improve upon the regional-scale risk predictions at any given site.

In addition, impact profiles for landscape classes and assets are available at www.bioregionalassessments.gov.au. Each profile summarises the hydrological changes and potential impacts that pertain to that landscape class or asset (e.g. increase in the number of low-flow days for landscape classes containing temporary or lowland streams in the zone of potential hydrological change). Users can aggregate and consider potential impacts for their own scale of interest.

Users can also explore the results for landscape classes and assets using a map-based interface at www.bioregionalassessments.gov.au/explorer/NAM/landscapes and www.bioregionalassessments.gov.au/explorer/NAM/assets.

3.2.5 Information management and processing

A very large number of multi-dimensional and multi-scaled datasets are used in the impact and risk analysis for each BA, including model outputs, and ecological, economic and sociocultural data from a wide range of sources. To manage these datasets and produce meaningful results, a consistent spatial framework is needed that permits rapid spatial and temporal analyses of impacts without compromising the resolution of the results. The datasets for this BA are organised into an *impact analysis database* (Bioregional Assessment Programme, Dataset 2) to enable efficient management. The purpose of this database is to produce result datasets that integrate the available modelling and other evidence across the assessment extent. These datasets are required to support three types of BA analyses: analysis of hydrological changes, impact profiles for landscape classes, and impact profiles for assets. The results of these analyses are summarised in this product, with more detailed information available at www.bioregionalassessments.gov.au. The impact analysis database is also available at data.gov.au.

The datasets used in the impact and risk analysis database (Bioregional Assessment Programme, Dataset 3) include the assets, landscape classes, modelling results (groundwater, surface water and receptor impact modelling), coal resource development 'footprints' and other relevant geographic datasets, such as the boundaries of the subregion, assessment extent and zone of potential hydrological change. All data in the impact and risk analysis database (and the results derived from it) meet the requirements for transparency.

The impact and risk analysis requires the geoprocessing of complex queries on very large spatial datasets. To overcome the computational load associated with this task a relational, rather than geospatial, approach was utilised. All dataset geometries are split against a universal grid of assessment units that exhaustively cover the assessment extent (Dataset 2). An assessment unit is a geographic area represented by a square (1 km^2) polygon with a unique identifier. Assessment units were used to partition asset and landscape class spatial data for impact analysis. The gridded data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

Normalising the database included calculating impact area, length and counts for individual features (e.g. stream reaches, individual assets, groups of assets or landscape classes) at the assessment unit level. Selecting the assessment units of interest and summing the pre-calculated values of area, length or count for the required dataset provides individual analysis result. This approach of front-loading the geospatial analysis through grid base attribution is fundamental to enabling the volume of calculations required to complete the assessment. The approach uses the source geometries in calculation and hence does not impact on the analysis calculations. In a few cases where source geometries created geospatial errors, resulted in the exclusion of these units. Removing invalid geometries did not, in any case, affect the analysis results more than a combined total area of one assessment unit (i.e. 1 km^2) per analysis calculation.

The surface water modelling generates results at points that are extrapolated to links (see Section 3.3.4), so there is a need to map streams to assessment units. For assessment units with only a single stream reach, the assessment unit stores the information associated with this stream segment. However, where the assessment unit contains multiple stream reaches (e.g. at the confluence of two streams), it is necessary to prioritise which stream reach informs the value of the assessment unit for representing the surface water modelling results. The general rules for prioritising a stream reach take into account:

- whether the modelled reaches show a hydrological change (i.e. a reach with a potential hydrological change takes priority over a reach predicted to have no significant change)
- whether the stream reach is represented in the model (i.e. modelled reaches take priority)

- the stream order of each reach (i.e. a higher order stream (e.g. main channel) takes priority over a lower order stream (e.g. tributary))
- reach length (i.e. where two streams in an assessment unit are of equally high stream order, priority is given to the longer of the two).

Some streams have insufficient hydrological information for assignment of hydrological variables. In this case, the BA identifies these streams and reports information based on area overlays only, that is, no receptor impact model exists in these areas.

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3.3 Potential hydrological changes

Summary

The baseline and the coal resource development pathway (CRDP) futures provide the basis for assessing the hydrological changes attributable to additional coal resource development in the Namoi subregion.

The groundwater zone of potential hydrological change is defined as the area with at least a 5% chance of drawdown exceeding 0.2 m in the regional watertable due to modelled additional coal resource development. It spans an area of 2299 km^2.

The surface water zone of potential hydrological change is defined as the area in which the change in any one of nine surface water hydrological response variables exceeds the specified thresholds. In addition to the modelled reaches, the surface water zone also includes non-modelled streams in the groundwater zone of potential hydrological change. A total stream length of 5521 km is included in the surface water zone.

The combined groundwater and surface water zone of potential hydrological change covers an area of 7014 km^2.

It is *very likely* that an area of at least 156 km^2 will experience 0.2 m of drawdown due to modelled additional coal resource development (additional drawdown); it is *very unlikely* that more than 2299 km^2 exceeds 0.2 m of additional drawdown. It is *very unlikely* that more than 853 km^2 exceeds 2 m of additional drawdown, and *very unlikely* that more than 520 km^2 exceeds 5 m of additional drawdown. These numbers include the 116 km^2 in the mine pit exclusion zone, where the modelled drawdowns are considered unreliable due to steep hydraulic gradients at the pit face.

The potential hydrological changes due to modelled additional coal resource development on surface water are assessed using the hydrological response variables: zero-flow days, high-flow days and annual flow. Large changes in flow regime are *very likely* in the Back Creek, Merrygowen Creek, Bollol Creek, Maules Creek, Driggle Draggle Creek and two unnamed creeks near Lake Goran. Most of the creeks have catchment areas much less than 100 km^2 and their effects are localised. The Namoi Regulated River, into which these creeks flow, is not very sensitive to changes in inflows from these creeks. Only the Namoi River and all of its potentially affected tributaries were modelled since the effects of small intermittent streams cannot be ascertained without a detailed finer resolution modelling. The modelled streams make up about 35% of the total stream length in the zone of potential hydrological change.

Results for the Namoi Regulated River show that widespread decreases in mean annual flow of greater than 5% is unlikely.

Generally, the predicted changes are small relative to the rainfall-related interannual variability, especially for annual flow and high-flow days. There is a chance that changes in zero-flow days could significantly change the zero-flow regime in streams near all the mining areas, with smaller intermittent streams close to Boggabri, Maules Creek, Tarrawonga and Watermark additional coal resource developments particularly at risk.

Any change in hydrology could result in changes in stream water quality; however, this was not modelled. A range of regulatory requirements are in place in NSW to minimise potential water quality impacts from coal resource development. Groundwater is typically more saline than surface runoff, which suggests that the predicted reductions in baseflow are more likely to lead to decreases in stream salinity. However, the actual effects depend very much on local conditions, and increases in stream salinity could occur.

Increases in baseflow, potentially leading to increases in alluvial aquifer and stream salinity, cannot be ruled out. However, the magnitude and extent of water quality changes cannot be determined without specifically representing water quality parameters in the modelling. This remains a knowledge gap.

Users can visualise more detailed results for hydrological changes using a map-based interface on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/NAM/hydrologicalchanges.

Potential hydrological changes due to additional coal resource development are based on hydrological response variables resulting from the surface water and groundwater modelling, reported in companion product 2.6.1 (Aryal et al., 2018) and companion product 2.6.2 (Janardhanan et al., 2018) for the Namoi subregion. These hydrological response variables represent the maximum difference in results between the coal resource development pathway (CRDP) and baseline for groundwater drawdown for a range of streamflow characteristics. They are also the basis for defining the zone of potential hydrological change – the focal extent for the impact and risk analysis (Section 3.3.1).

Potential impacts on groundwater and surface water within the zone of potential hydrological change are presented in Section 3.3.2 and Section 3.3.3, respectively. While changes in water quality were not part of the hydrological modelling, the potential for changes in water quality due to additional coal resource development in the Namoi subregion is considered in Section 3.3.4. All analyses are carried out on ‘assessment units’ which, in the Namoi subregion, consist of 1 km^2 (1 km x 1 km) grid cells that cover the entire assessment extent.

Additional hydrological response variables have been defined for input into the landscape class qualitative models and receptor impact models (companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)), and for quantifying potential impacts on economic assets. They represent key water dependencies in these systems and are based on average differences over 30-year and 90-year periods. Changes in these hydrological response variables are presented as part of the impact and risk analysis in Section 3.4 and Section 3.5.

3.3.1 Defining the zone of potential hydrological change

The zone of potential hydrological change is the area within the subregion where changes in hydrology due to additional coal resource development exceed defined thresholds for groundwater and surface water hydrological response variables. The impact and risk analysis presented in Section 3.4 and Section 3.5 focuses on landscape classes and assets that intersect this zone. Any landscape class or asset wholly outside of the zone of potential hydrological change is considered *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development.

The zone of potential hydrological change is defined as the union of the groundwater zone of potential hydrological change (Section 3.3.1.1) and the surface water zone of potential hydrological change (Section 3.3.1.2). It is presented in Section 3.3.2.

3.3.1.1 Groundwater

The groundwater zone of potential hydrological change is defined as the area around the coal resource development that has a greater than 5% chance of exceeding 0.2 m drawdown in the regional water table due to additional coal resource development. This 5% chance is determined based on the uncertainty analysis, described in Section 2.6.2.8 of companion product 2.6.2 for the Namoi subregion (Janardhanan et al., 2018). It means that, for each individual model cell within the groundwater zone, at least 5% (95th percentile) of groundwater model predictions exceeded 0.2 m of drawdown.

The deeper groundwater layers could be used as economic assets by extraction bores or ecological assets as the source water for springs. The drawdown in the confined parts of the Pilliga Sandstone does not exceed 0.2 m more than 2 km outside of the zone of potential hydrological change. There are no extraction bores or springs within this area so defining the zone based upon the drawdown at the regional watertable is appropriate.

The groundwater use and management for coal resource developments are regulated under state legislation and regulatory frameworks. The 0.2 m drawdown threshold adopted in bioregional assessments (BAs) is consistent with the most conservative minimal impact threshold in the *NSW Aquifer Interference Policy* (NSW Office of Water, 2012).

The 95th percentile of groundwater drawdown under the baseline and the CRDP are shown in Figure 9. The extent of this drawdown under the baseline is 407 km^2 (1.1% of the assessment extent). This increases to 2590 km^2 (7.3% of assessment extent) under the CRDP, which represents the combined extent of drawdown under baseline and due to additional coal resource development.

It is the area where the drawdown due to the additional coal resource development has at least a 5% chance of exceeding 0.2 m that forms the basis of the groundwater zone of potential hydrological change (Figure 10). The groundwater zone of potential hydrological change coincides approximately with a 10 km buffer around the mine footprints except in the Pilliga area. The combined effect of Narrabri mine and the Narrabri Gas Project results in an extensive area with a probability of greater than 5% of exceeding 0.2 m drawdown due to additional coal resource development. The groundwater zone of potential hydrological change covers an area of 2299 km^2, or 6.1% of the assessment extent.

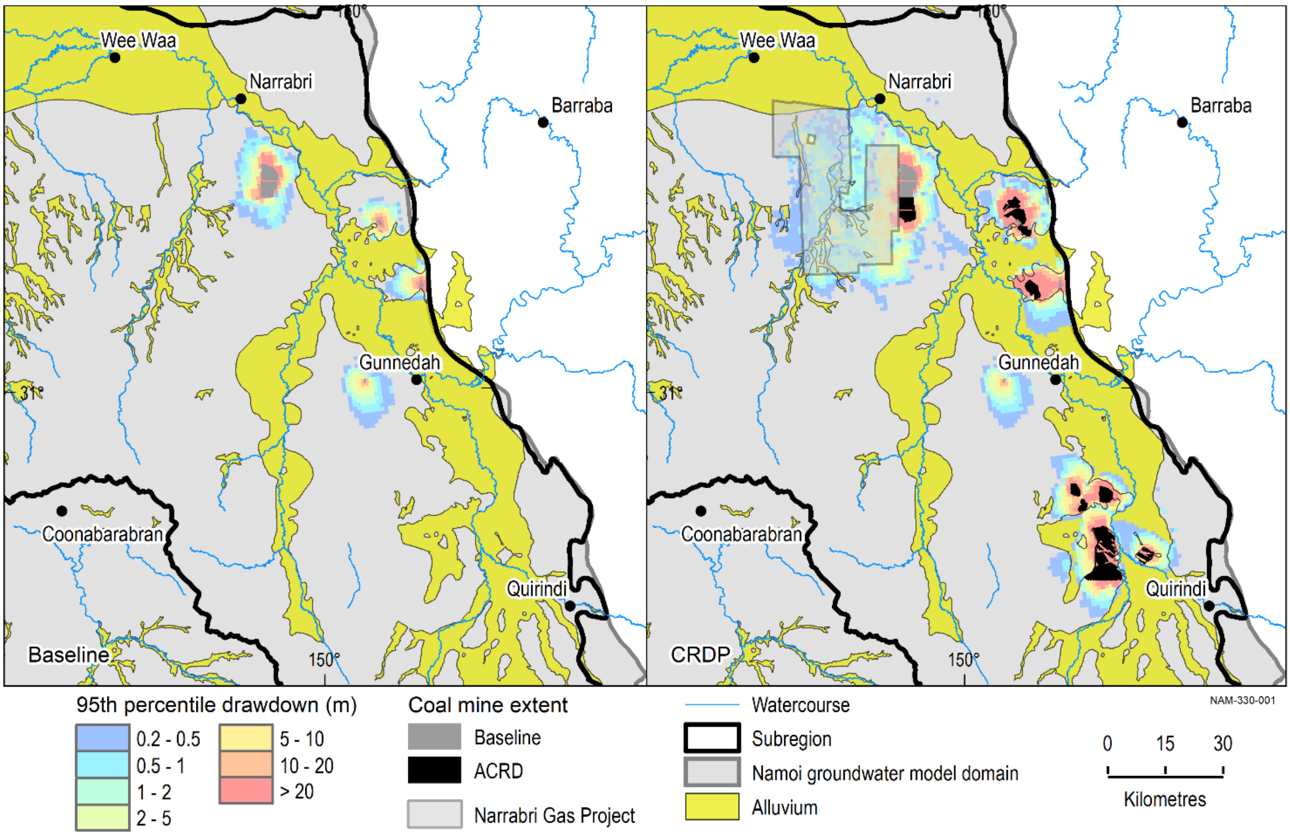

Figure 9 95th percentile of drawdown under (a) the baseline and (b) the coal resource development pathway

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

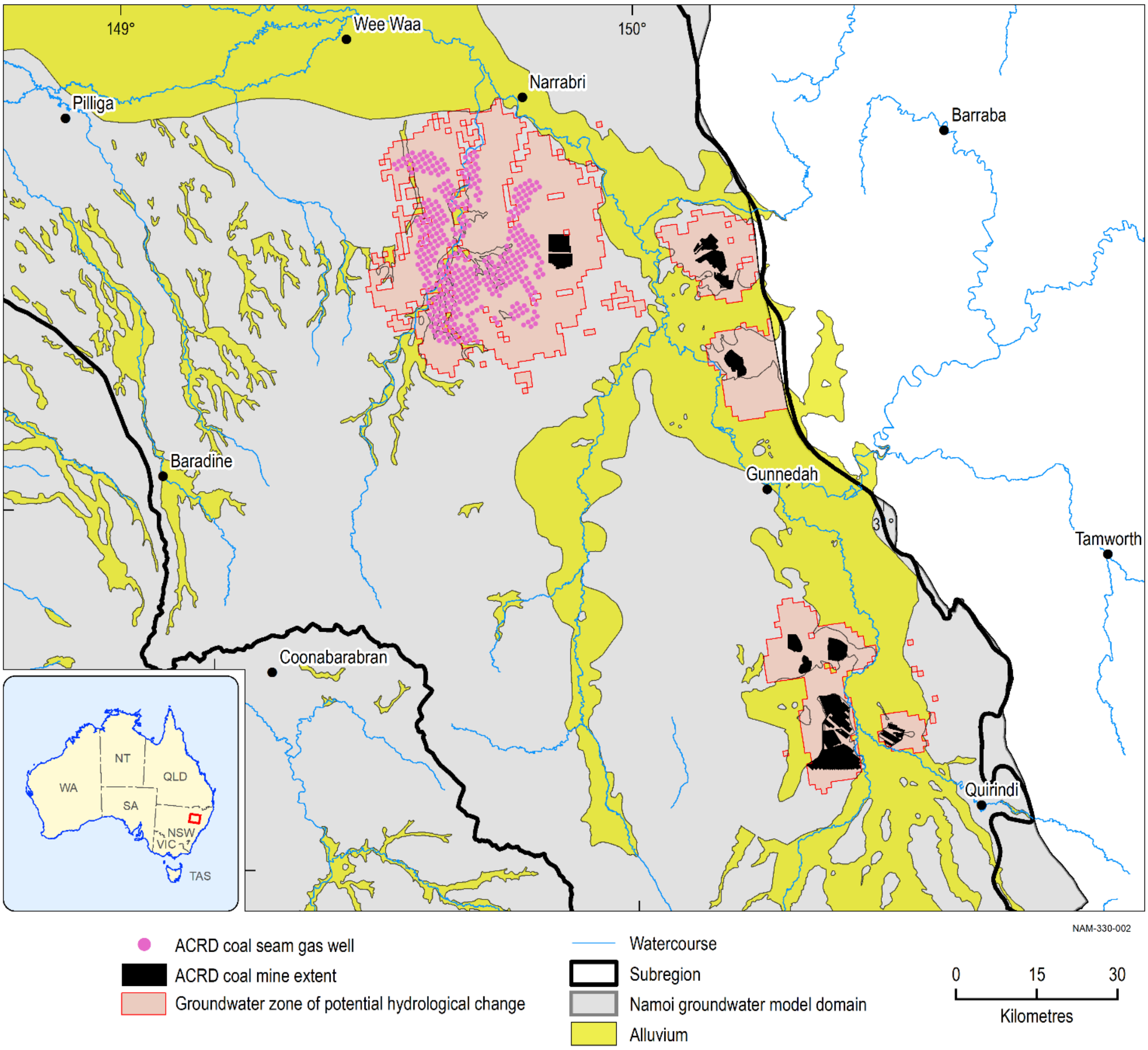

Figure 10 Groundwater zone of potential hydrological change

The groundwater zone of potential hydrological change is defined as a 5% chance of exceeding 0.2 m drawdown due to additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

3.3.1.2 Surface water

The threshold hydrological change adopted for each hydrological response variable for defining the zone of potential hydrological change is given in Table 4 (from companion submethodology M06 for surface water modelling (Viney, 2016)). Together, these nine hydrological response variables represent potential changes across the full flow regime. The low flows are represented by the daily flow rate at the 1st percentile (P01), zero-flow days (ZFD), low-flow days (LFD), low-flow spells (LFS) and length of longest low-flow spell (LLFS), while the high flows are represented by the daily flow rate at the 99th percentile (P99) and high-flow days (FD). Two remaining hydrological response variables represent changes in flow volume (AF) and interquartile variability (IQR). A location on the river is deemed to be in the zone if the change in at least one of the nine variables exceeds the given threshold. Probability estimates are derived from the predictions of 300 model replicates, each of which uses a unique set of model parameter values. A 5%

significance threshold implies that at least 15 of the 300 replicates have modelled changes that exceed the relevant change threshold. If fewer than 15 replicates have modelled changes that exceed the threshold at a particular location, then the change in that hydrological response variable at that location is considered *very unlikely* to impact water-dependent landscape classes and assets. Table 12 and Figure 27 in companion product 2.6.1 for the Namoi subregion (Aryal et al., 2018) identify the model nodes and links in the river modelling network where the hydrological change exceeds these thresholds.

Table 4 Surface water hydrological response variables and the thresholds used in defining the zone of potential hydrological change

Hydrological response variable	Units	Description	Threshold
AF	GL/year	Annual flow volume. 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).	≥5% chance of ≥1% change in AF
P99	ML/day	Daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in P99
IQR	ML/day	Interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in IQR
FD	days/year	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'.	≥5% chance of a change in FD ≥3 days in any year
P01	ML/day	Daily flow rate at the 1st percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of ≥1% change in P01 and change in runoff depth >0.0002 mm
ZFD	days/year	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).	≥5% chance of a change in ZFD ≥3 days in any year

Hydrological response variable	Units	Description	Threshold
LFD	days/year	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.	≥5% chance of a change in LFD ≥3 days in any year
LFS	number/year	Number of low-flow spells 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). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.	≥5% chance of a change in LFS ≥2 spells in any year
LLFS	days/year	Length of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).	≥5% chance of a change in LLFS ≥3 days in any year

The surface water zone of potential hydrological change includes reaches that make up the AWRA-R link-node network (see Figure 5 in companion product 2.6.1 for the Namoi subregion (Aryal et al., 2018)); however, the zone also includes reaches that were not modelled, but that could potentially be impacted due to additional coal resource development. They include perennial and temporary streams within the groundwater zone of potential hydrological change. It is assumed that within the groundwater zone of potential hydrological change, streams connected to regional groundwater could potentially be affected by additional coal resource development. Streams tagged as 'perennial' or 'temporary' in the modelled flow regime spatial layer for the Namoi subregion (Bioregional Assessment Programme, Dataset 3) are assumed to be connected to groundwater because the data do not allow separation of ephemeral streams (i.e. no groundwater connection) from intermittent ones (i.e. connected to groundwater). The temporary stream reaches in the modelled flow regime that intersect the surface water maximum footprint areas for open-cut mines for additional coal resource development (Bioregional Assessment Programme, Dataset 4) are included in this zone, as disruption to surface water drainage on coal mining sites can potentially affect them.

In the Namoi subregion, except for the Namoi River, all affected streams are temporary and assumed to have a varying degree of intermittency. These streams, when they pass through the groundwater zone of potential hydrological change, were extended further downstream of the zone to where they join a reach already in the surface water zone of potential hydrological change, and added to the network of potentially impacted streams. In all, about 5521 km of streams were identified as potentially impacted. These 5521 km of potentially impacted streams were used to select the 1 km x 1 km assessment units (Bioregional Assessment Programme, Dataset 5) that intersect the stream network (Bureau of Meteorology, Dataset 3) or contain surface water – dependent ecosystems (Bioregional Assessment Programme, Dataset 6), to define the surface water zone of potential hydrological change. These ecosystems include floodplain riparian forest/wetlands or floodplain riparian forest/wetland groundwater-dependent ecosystems (GDEs) within 1 km of the stream network. This selection was inspected and adjusted using a precautionary principle to ensure that the riparian vegetation that could potentially be impacted by changes in surface water hydrology is included in the zone. The surface water zone of potential hydrological change (Figure 11) shows the mine footprints that formed part of the surface water modelling.

The surface water zone of potential hydrological change covers an area of 6430 km^2 (about 22% of the assessment extent) and includes all streams intersecting the groundwater zone of potential hydrological change. It includes the whole of Namoi River downstream of the confluence with the Peel River, all of the Namoi River anabranches including Pian and Gunidgera creeks, Mooki River, the Back Creek, Merrygowen Creek, Bollol Creek, Driggle Draggle Creek and other smaller tributaries of the Namoi River. An unnamed creek that flows into Lake Goran is also part of the surface water zone of potential hydrological change.

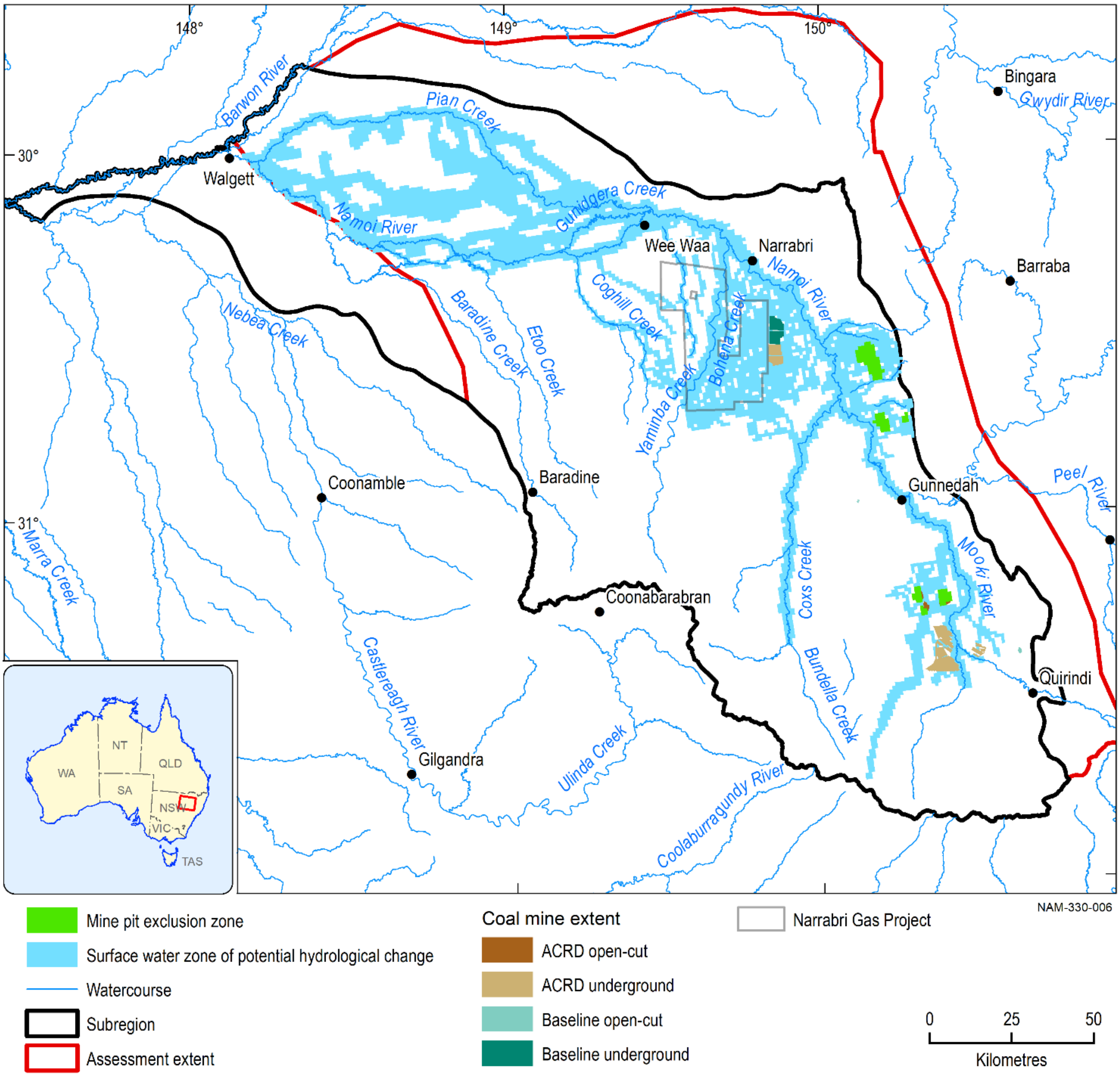

Figure 11 Surface water zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bureau of Meteorology (Dataset 3); Bioregional Assessment Programme (Dataset 5)

3.3.2 Zone of potential hydrological change

The zone of potential hydrological change (Figure 12) identifies the area potentially subject to hydrological changes due to additional coal resource development. It is derived from the union of the groundwater zone of potential hydrological change (Figure 10) and the surface water zone of potential hydrological change (Figure 11). The Namoi zone of potential hydrological change covers an area of 7014 km^2 (19.7% of assessment extent) in which 5521 km of stream length is potentially impacted (based on Geofabric stream network (Bureau of Meteorology, Dataset 3)). Four regions (Table 5) are defined for reporting purposes to provide greater detail around key coal resource development areas within the subregion.

The zone of potential hydrological change is the first filter applied to landscape classes and water-dependent assets in the Namoi subregion as part of an initial selection process for the impact and risk analysis. Landscape classes and assets that are completely outside the zone are *very unlikely* (less than 5% chance) to be impacted due to additional coal resource development and do not have qualitative landscape models or receptor impact models. Conversely, some landscape classes that intersect the zone have qualitative models and/or receptor impact models, which are used to assess the potential impact of the modelled hydrological changes on the ecosystems. Details of the qualitative models and receptor impact models are provided in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018). Results of the receptor impact modelling are presented in Section 3.4.

3.3.2.1 Mine pit exclusion zone

Figure 12 also shows the mine pit exclusion zone defined for the Namoi subregion. It is based on open-cut mine footprints under the CRDP within the zone of potential hydrological change. The mine pit exclusion zone identifies areas within the zone of potential hydrological change that are within, or in close proximity to, open-cut mine pits, and where:

- modelled drawdowns are highly uncertain due to the very steep hydraulic gradients at the mine pit interface
- changes in the drawdown are inevitable where the mine pit intersects the regional watertable and will extend to the pit floor
- 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
- impacts are predominantly site-scale, and addressed through existing development approval processes, and hence not the primary focus of BAs.

The modelled estimates of drawdown within the mine pits, while significant, are considered unreliable for use in the receptor impact modelling. The mine pit exclusion zone within the zone of potential hydrological change covers an area of 116 km^2.

3.3.2.2 Reporting areas

The Assessment team identified four discrete areas within the zone of potential hydrological change for reporting purposes (Figure 12). Table 5 identifies the additional coal resource developments within each reporting area. In the Namoi river basin, the four areas are connected by the surface water zone of potential hydrological change, which means that results reported for the Lower Namoi include changes from the Mid Namoi, Pilliga and Pilliga Outwash, and Upper Namoi. These reporting areas do not coincide with any reporting areas used by the state agencies.

Table 5 Reporting areas and modelled additional coal resource developments

Reporting area	Additional coal resource development
Lower Namoi	Nil; includes streams of the zone of potential hydrological change with Namoi River confluences downstream of the area adjacent to the Pilliga and Pilliga Outwash
Pilliga and Pilliga Outwash	Narrabri Coal Seam Gas Wells, Narrabri North and South underground mines
Mid Namoi	Boggabri Coal Expansion Project, Maules Creek Mine, Tarrawonga Coal Expansion Project
Upper Namoi	Watermark Coal Project, Caroona Coal Project

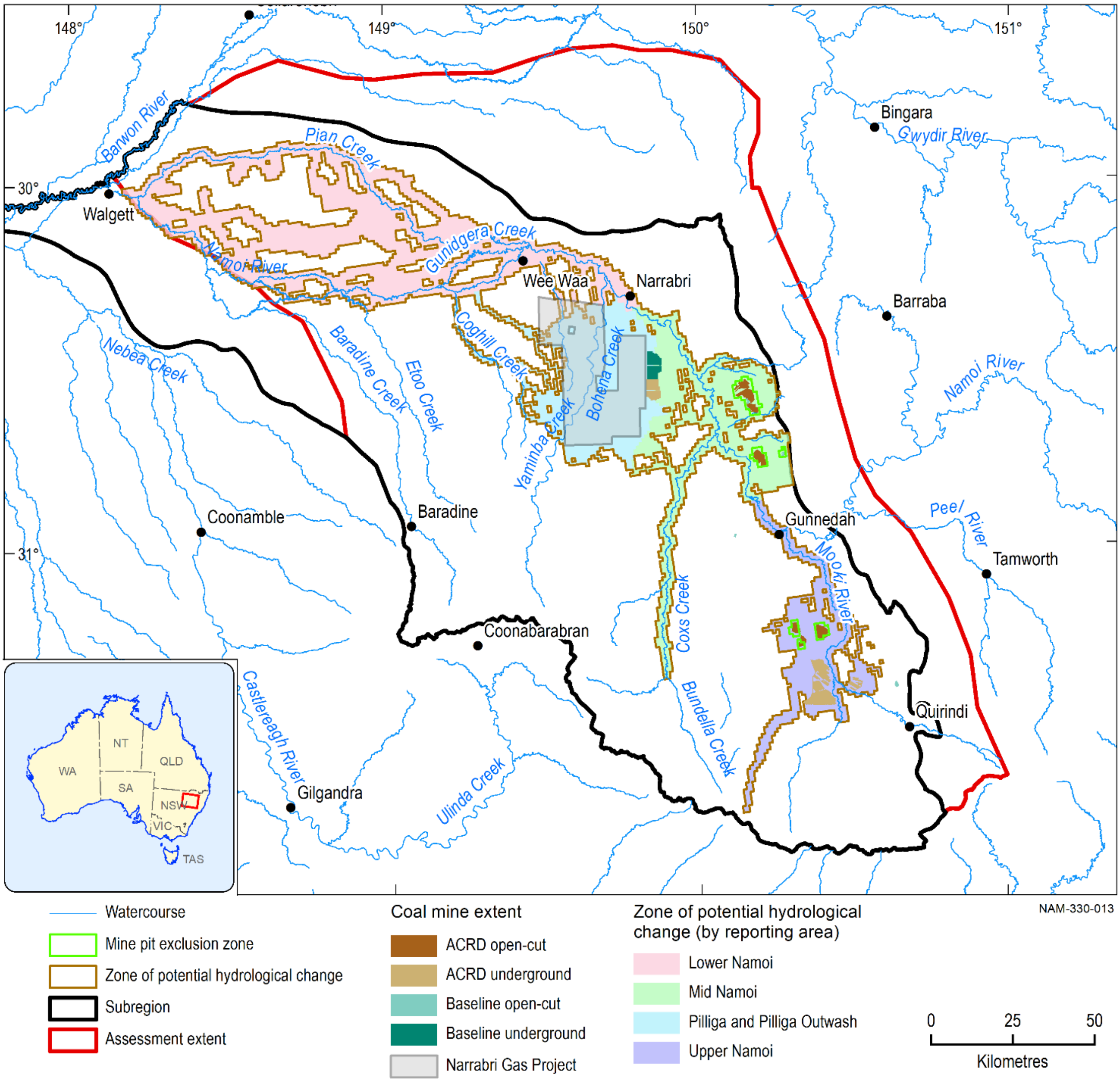

Figure 12 Zone of potential hydrological change

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

3.3.3 Potential groundwater changes

The hydrological response variable, *dmax*, which is the maximum difference in drawdown, obtained by choosing the maximum difference between two future groundwater model runs is used to summarise potential impacts on groundwater. These *dmax* values are presented for the baseline (difference from a 'no-development' model run) and due to additional coal resource development (difference between the CRDP and the baseline runs).

Drawdown greater than 0.2 m, greater than 2 m and greater than 5 m are the reporting thresholds to summarise groundwater modelling results across all BAs. These thresholds represent meaningful changes in the management of groundwater in NSW and Queensland. Minimum impact threshold provisions apply in most aquifers where an activity results in drawdowns greater than 2 m in NSW. For high-priority GDEs and culturally significant sites in the Great Artesian Basin (GAB), however, minimum impact thresholds can apply if drawdowns exceed 0.2 m.

Figure 13 shows the variation in depth of drawdown due to additional coal resource development. The main panel shows the 50th percentile (median), while the two smaller panels show extents for the 5th and 95th percentiles. Together, they illustrate the variability in model predictions due to parameter uncertainty. The areas where the additional drawdown is greater than 0.2 m, greater than 2 m and greater than 5 m for the 5th, 50th and 95th percentiles are summarised in Table 6. The area associated with the 5th percentile (156 km^2), for additional drawdown greater than 0.2 m, can be interpreted as representing the extent of drawdown when the model parameters reflect lower pumping rates and/or lower hydraulic conductivities. On the other hand, the area of drawdown associated with the 95th percentile (2299 km^2) includes the predictions based on higher pumping rates and relatively larger conductivity of geological layers. The influences of the different parameters can be complex and produce a range of drawdown responses; the interpretation given above is for general guidance only. Groundwater drawdown predictions indicate that drawdowns of greater than 5 m are *very likely* (greater than 95% chance; shown as the 5th percentile) due to the additional coal resource developments close to the coal mines (Figure 13).

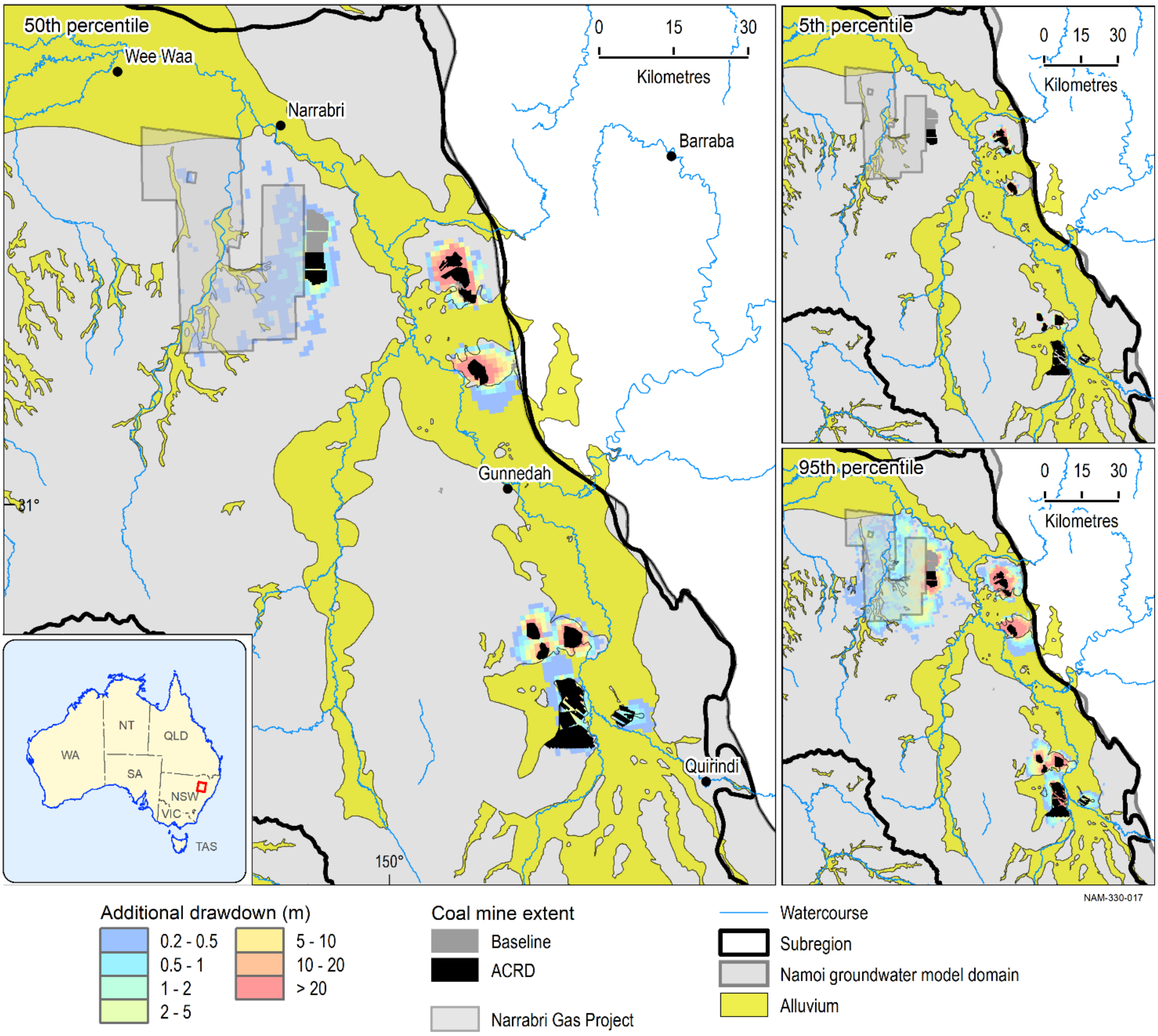

Figure 13 Drawdown due to additional coal resource development

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. The mine extents in the CRDP are the sum of those in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

The spatial distribution of drawdown under the baseline is shown in Figure 14, providing a visual comparison to the potential groundwater drawdown due to additional coal resource development in Figure 13. Table 7 summarises the drawdown information in terms of area (km^2) in the zone of potential hydrological change for each drawdown class in each reporting area. Under the baseline, the area with at least a 5% chance of drawdown greater than 0.2 m is 479 km^2 and the area with at least a 95% chance of drawdown greater than 0.2 m is 18 km^2.

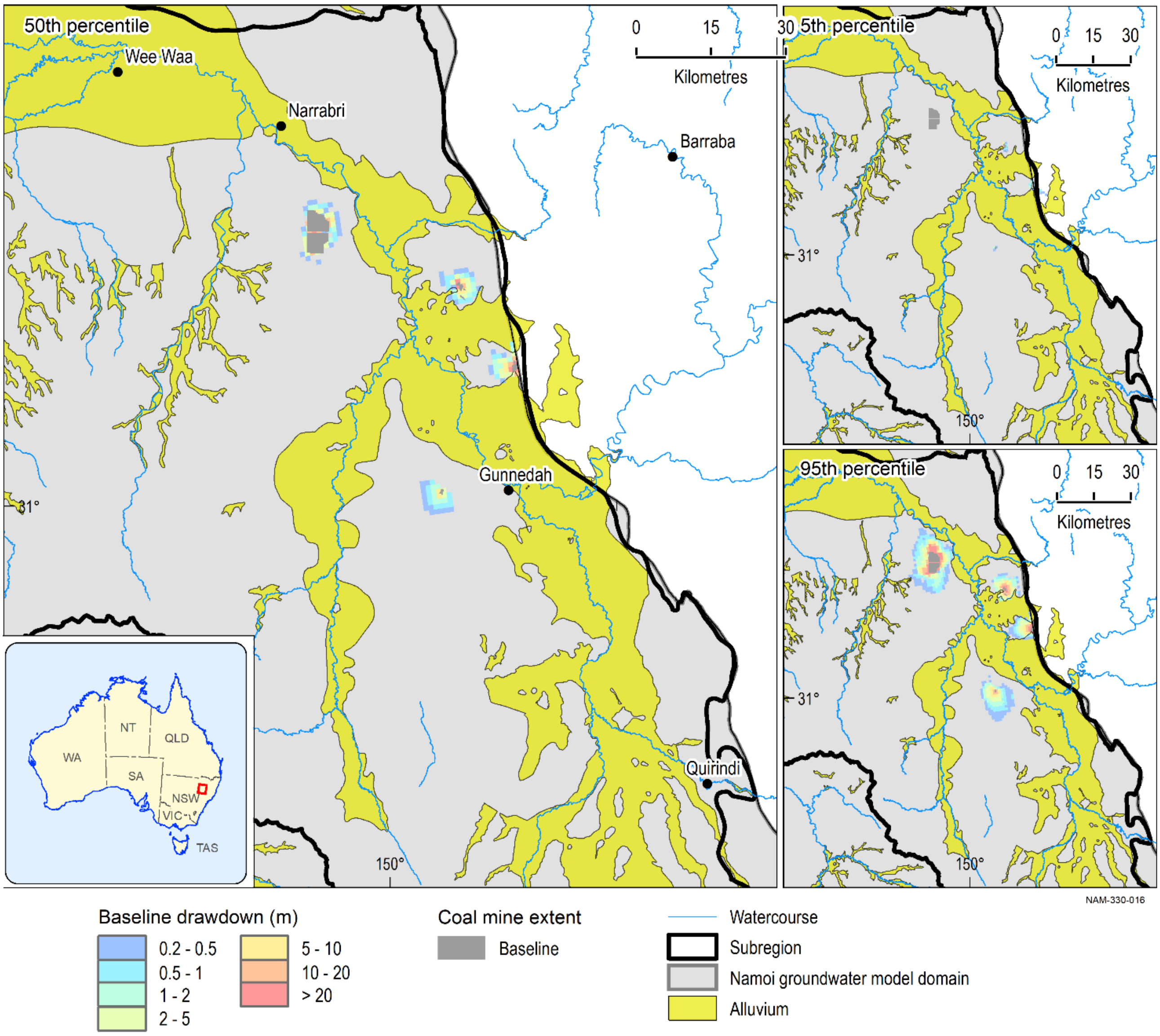

Figure 14 Drawdown due to baseline coal resource development

Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development.
Data: Bioregional Assessment Programme (Dataset 1)

Table 6 Surface area (km^2) and stream length (km) potentially exposed to varying levels of additional drawdown in the zone of potential hydrological change

Extent	Reporting area	Extent in zone of potential hydrological change	Extent with additional drawdown ≥0.2 m			Extent with additional drawdown ≥2 m			Extent with additional drawdown ≥5 m			Extent in mine pit exclusion zone
			5th	50th	95th	5th	50th	95th	5th	50th	95th	
Area (km^2)	Upper Namoi	998	52	205	442	42	108	234	36	78	165	34
	Mid Namoi	1531	104	255	631	75	168	309	63	127	245	82
	Pilliga and Pilliga Outwash	1589	–	68	1225	–	16	310	–	9	110	–
	Lower Namoi	2896	–	–	1	–	–	–	–	–	–	–
	Total	**7014**	**156**	**528**	**2299**	**117**	**292**	**853**	**99**	**214**	**520**	**116**
Stream length (km)	Upper Namoi	568	15	56	123	8	32	74	8	18	45	9
	Mid Namoi	1671	167	315	710	126	228	368	111	191	300	145
	Pilliga and Pilliga Outwash	1268	–	58	811	–	15	264	–	8	96	–
	Lower Namoi	2014	–	–	0	–	–	–	–	–	–	–
	Total	**5521**	**182**	**429**	**1644**	**134**	**276**	**707**	**119**	**217**	**440**	**154**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m additional drawdown for the 5th, 50th and 95th percentile estimates of the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. Drawdowns in the mine pit exclusion zones cannot be quantified with confidence.
‘–’ means ‘not applicable’.
Data: Bioregional Assessment Programme (Dataset 5)

Table 7 Surface area (km^2) and stream length (km) potentially exposed to varying levels of baseline drawdown in the zone of potential hydrological change

Extent	Reporting area	Extent in zone of potential hydrological change	Extent with baseline drawdown ≥0.2 m			Extent with baseline drawdown ≥2 m			Extent with baseline drawdown ≥5 m			Extent in mine pit exclusion zone
			5th	50th	95th	5th	50th	95th	5th	50th	95th	
Area (km^2)	Upper Namoi	998	–	–	–	–	–	–	–	–	–	34
	Mid Namoi	1531	18	115	290	2	51	133	2	30	88	82
	Pilliga and Pilliga Outwash	1589	–	30	189	–	20	72	-	14	49	–
	Lower Namoi	2896	–	–	–	–	–	–	–	–	–	–
	Total	**7014**	**18**	**145**	**479**	**2**	**71**	**205**	**2**	**44**	**137**	**116**
Stream length (km)	Upper Namoi	568	–	–	–	–	–	–	–	–	–	9
	Mid Namoi	1671	26	137	344	6	52	158	6	34	105	145
	Pilliga and Pilliga Outwash	1268	–	19	169	–	12	60	-	6	37	–
	Lower Namoi	2014	–	–	–	–	–	–	–	–	–	–
	Total	**5521**	**26**	**155**	**513**	**6**	**64**	**218**	**6**	**40**	**142**	**154**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown for the 5th, 50th and 95th percentile estimates of the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Drawdown in the mine pit exclusion zones cannot be quantified with confidence.
'–' means 'not applicable'.
Data: Bioregional Assessment Programme (Dataset 5)

Table 8 shows the area of the groundwater management zones of the alluvium that are within the groundwater zone of potential hydrological change. The alluvium zones that have the greatest area potentially impacted are the Upper Namoi Alluvium zones 4, 7 and 8 while the Lower Namoi Alluvium has less than 1 km^2 that is within the groundwater zone of potential hydrological change. An area of 287 km^2 of alluvium has a 5% chance of greater than 0.2 m additional drawdown. This represents around 8% of the Upper Namoi Alluvium and 0.01% of the Lower Namoi Alluvium.

Table 8 Area of alluvium within the groundwater zone of potential hydrological change

Groundwater management zone	Area in GW zone (km^2)	Percent of groundwater management zone in GW zone %
Lower Namoi Alluvium	0.87	0.01%
Upper Namoi Alluvium_03	13.76	2.48%
Upper Namoi Alluvium_04	135.75	15.97%
Upper Namoi Alluvium_05	1.70	0.59%
Upper Namoi Alluvium_06	0.06	0.01%
Upper Namoi Alluvium_07	90.65	64.39%
Upper Namoi Alluvium_08	44.35	14.08%
Upper Namoi Alluvium_11	0.26	0.15%

GW = groundwater

3.3.4 Potential surface water changes

The hydrological response variables generated from the Namoi surface water modelling results are listed in Table 4. In this product, three were chosen to represent changes in low-flow regime (zero-flow days, ZFD), high-flow regime (high-flow days, FD) and mean annual flow (annual flow, AF) due to additional coal resource development.

3.3.4.1 Zero-flow days

The maximum increases in the number of zero-flow days per year during the simulated 90-year period (2013 to 2102) due to additional coal resource development are shown in Figure 15. Streams shown as ‘potential hydrological change’ may experience increases in zero-flow days, but the extent of this increase could not be quantified from the modelling. In some cases, results from upstream or downstream model nodes cannot be reliably interpolated to these reaches due to changes in hydrology along the reach from tributary inflows or due to the impact of mines. These are shown in Figure 15 as ‘direct’ change that relates to streams that flow through or start within a mine area, or ‘indirect’ relating to streams that are within the potential additional drawdown area. An indication of the potential increases in zero-flow days in the ‘potential hydrological change’ reaches near mining operations can be inferred from stream reaches immediately upstream and/or downstream, where the potential increases in zero-flow days have been quantified.

Five stream reaches are *very likely* to have an increase in zero-flow days of more than 20 days per year. They are: Back, Merrygowen and Bollol creeks, Mooki River at Breeza and Mooki River upstream of its confluence with the Namoi River. These streams drain Maules Creek, Boggabri expansion, Tarrawonga expansion and Watermark coal developments respectively (see Aryal et al. (2018)). Only Bollol Creek is *very likely* to have an increase in zero-flow days of more than 80 days. For Back, Merrygowen and Bollol creeks there is a 5% chance of an additional 200 or more zero-flow days. All of these creeks may not actually flow for 200 days. This apparent anomalous increase in zero-flow days occurs because in particularly wet years modelling indicates that the river can flow for more than 200 days per year as reflected in the 5% chance of that happening. As BAs 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 cumulative exceedance plots of stream length with additional zero-flow days in Figure 16 and the underpinning data in Table 9 indicate that at the 95th percentile, there are 1678 km of streams that could experience 3 or more additional zero-flow days per year. At the 5th percentile, this could be as small as 91 km of streams. Note that there are another unquantified but ‘potentially impacted’ 3629 km of streams where zero-flow days may also increase, but were not modelled, or not able to be extrapolated to. The potentially impacted stream lengths are the same for all hydrological response variables and all percentiles as it was not determined how these streams are affected with respect to each of the hydrological response variables and percentiles individually.

Where changes have been quantified, more than 3 additional zero-flow days are *very likely* in 53 km of streams in the Upper Namoi and 37 km of streams in the Mid Namoi. No streams in the Pilliga Outwash are *very likely* to experience such change.

The potentially large changes in some of the small tributary streams of the Namoi River are relatively localised. The much larger Namoi River is largely insensitive to these changes in inflows because of the volume of flow. Note that flows in the regulated river can be augmented through releases from storage.

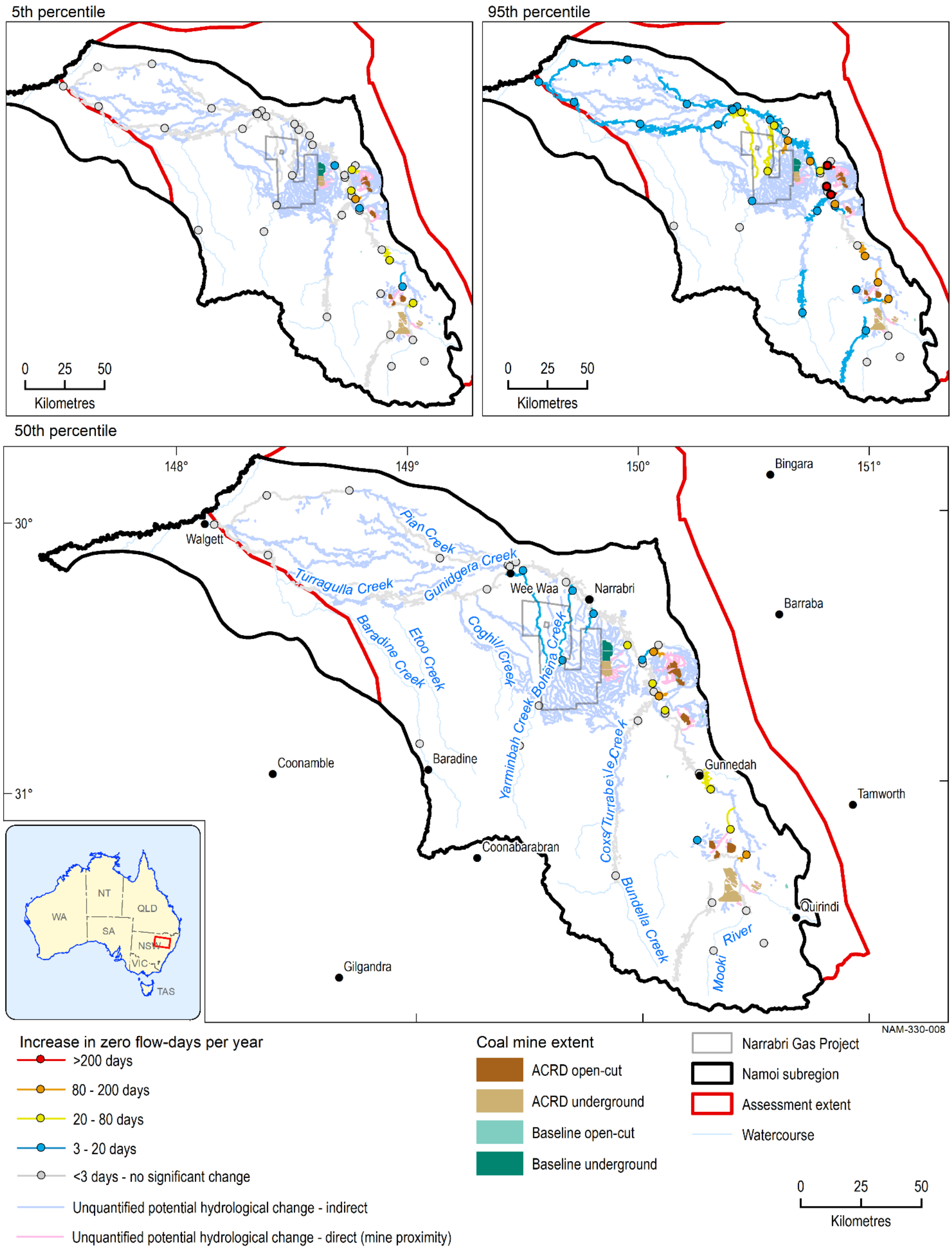

Figure 15 Increase in the number of zero-flow days due to additional coal resource development

The mine extents in the CRDP are the sum of those in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 2)

Table 9 Stream length (km) potentially exposed to varying increases in zero-flow days in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but not quantified (km)	Length with increases of ≥3 zero-flow days per year (km)			Length with increases of ≥20 zero-flow days per year (km)			Length with increases of ≥80 zero-flow days per year (km)			Length with increases of ≥200 zero-flow days per year (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Upper Namoi	568	257	53	53	219	53	53	53	0	8	53	0	0	0
Mid Namoi	1671	1167	37	54	381	31	37	54	15	31	37	0	0	31
Pilliga and Pilliga Outwash	1268	1165	0	97	103	0	0	97	0	0	20	0	0	0
Lower Namoi	2014	1040	0	71	975	0	0	71	0	0	0	0	0	0
Total	**5521**	**3629**	**91**	**276**	**1678**	**85**	**91**	**276**	**15**	**39**	**111**	**0**	**0**	**31**

Due to rounding, some totals reported here may not correspond exactly with the sum of the separate numbers.
Data: Bioregional Assessment Programme (Dataset 5)

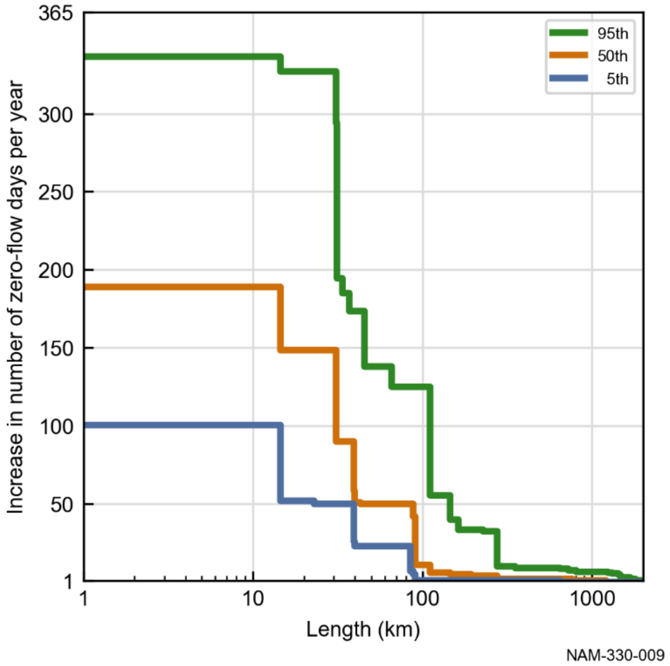

Figure 16 Cumulative exceedance plot of the increase in the number of zero-flow days due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

x-axis is in log scale.
Data: Bioregional Assessment Programme (Dataset 5)

To understand the significance of the modelled increases in zero-flow days, it is useful to look at them in the context of the natural interannual variability in zero-flow days. This is to see whether the predicted increases due to additional coal resource development are within the natural range of variability of the longer-term flow regime. The maximum increase in the number of zero-flow days due to additional coal resource development relative to the interannual variability in zero-flow days under the baseline has been adopted to put some context around the modelled changes. This ratio is shown for each surface water model node in Figure 17.

Table 10 provides the ratio ranges for ZFD, FD and AF adopted for each qualitative ratio class shown in Figure 17. Note that the changes shown in Figure 17 represent the maximum change due to additional coal resource development in a single year relative to the interannual variability across 90 years under the baseline. Thus, it is not a comparison of distributions, but an assessment of whether the change due to additional coal resource development, in the year of maximum difference between the CRDP and the baseline, is within the range of natural variability. If the maximum change is comparable to or greater than the interannual variability due to climate (e.g. an increase of 200 days relative to a baseline range of 20 to 50 days), then there is a greater risk of impact on the landscape classes and assets that rely on this water source.

Table 10 Ratio of increase in the number of zero-flow days (ZFD), high-flow days (FD) and annual flow volume (AF) due to additional coal resource development to the interannual variability in zero-flow days under the baseline

Qualitative ratio class	Ratio range
No significant change	ZFD <3 days FD ≥3 days AF ≥1%
Less than interannual variability	<0.5
Comparable to interannual variability	0.5–1.5
Greater than interannual variability	>1.5

FD = high-flow days – in previous products, this is referred to as ‘flood days’

At the 5th percentile (Figure 17, top left), only one of the nodes has the predicted changes in zero-flow days comparable to interannual variability. The Bollol Creek draining the Tarrawonga expansion is *very likely* to experience a change in zero-flow days that is comparable to or greater than the interannual variability under the baseline. The rest of the nodes with significant changes have less than the interannual variability.

At the 50th percentile (Figure 17), the changes at three model nodes, in all Namoi reporting areas in unregulated streams, are comparable to or exceed the baseline interannual variability, suggesting changes in flow regime associated with reduced runoff and/or weaker connections to regional groundwater. At the 95th percentile (Figure 17, top right), the increases in zero-flow days that are greater than interannual variability at three locations across the assessment extent – all in unregulated streams where augmenting river flows through dam releases is not possible – suggest the possibility of zero-flow regime changes. Also, at the 95th percentile, one location in the Namoi Regulated River, where augmentation of river flow through dam release is possible, has increases in zero-flow days that are greater than interannual variability. In total there are 13 nodes for which there is a 5% chance of increase in ZFD comparable to or greater than interannual variability.

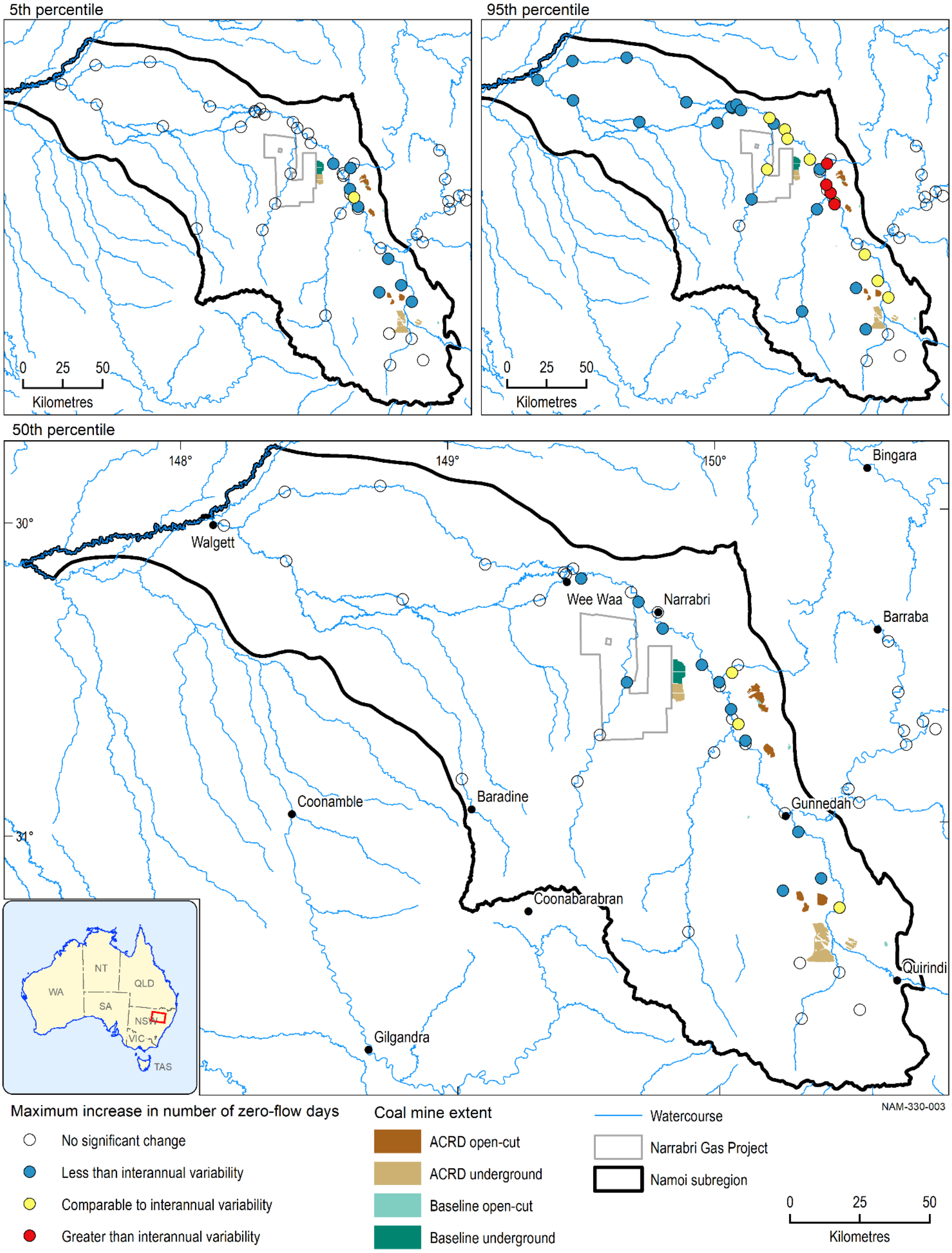

Figure 17 Ratio of change in zero-flow days due to additional coal resource development to the interannual variability in zero-flow days under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 7, Dataset 8)

3.3.4.2 High-flow days

Figure 18 shows the reduction in the number of high-flow days due to additional coal resource development in the Namoi subregion. Reduction of at least 3 high-flow days per year is *very likely* in six streams. They include Back, Merrygowen, Bollol and Driggle Draggle creeks draining Maules Creek, Boggabri expansion, Tarrawonga expansion and Vickery Creek coal developments. Two unnamed creeks impacted by the Watermark coal mine development are also affected. Among those, only the Back, Merrygowen and Bollol creeks are *very likely* to have a reduction in high-flow days of at least 10 days per year. None of the streams are *very likely* to have a reduction in high-flow days of more than 20 days per year, however, all of the above three creeks and one unnamed creek have a 5% chance of having a reduction in high-flow days of more than 50 days per year.

A cumulative exceedance plot of these reductions in high-flow days is shown in Figure 19, and the summary data, showing the length of potentially impacted streams, are presented in Table 11. The table lists the 5th, 50th and 95th percentiles of the stream length associated with reduction in high-flow days of different durations. It shows that reductions in high-flow days of at least 3 days per year are *very likely* in 34 km of stream in the Mid Namoi reporting area, which contains the Maules Creek, Boggabri expansion, Tarrawonga expansion and Vickery coal mine developments. At the 95th percentile, there are 31 km of streams that experience a reduction of more than 50 high-flow days per year. Most probabilities of reductions in high-flow days are found in the Mid Namoi, with just a 5% chance of a 3 to 10 day reduction in high-flows per year in 53 km of stream length of the Upper Namoi and 20 km of the Pilliga and Pilliga Outwash reporting areas.

Figure 20 shows the comparison of maximum change in high-flow days due to additional coal resource development and interannual variability in high-flow days under the baseline. At the 5th and 50th percentiles, all changes are either not significant or less than interannual variability. At the 95th percentile, there are four nodes which show reductions in high-flow days that are either similar to or greater than interannual variability. These four nodes, which drain catchments near Maules Creek, Boggabri expansion, Tarrawonga expansion and Watermark mine developments, could potentially experience reductions in high-flow days that take the high-flow regime outside the interannual variability previously seen under the baseline.

Generally, the impact of additional coal resource development on the reduction in high-flow days is not as great as it is on zero-flow days. In particular, the decrease in number of high-flow days in Maules Creek, Boggabri expansion, Tarrawonga expansion and Watermark mine developments are noticeably less than the increase in number of zero-flow days.

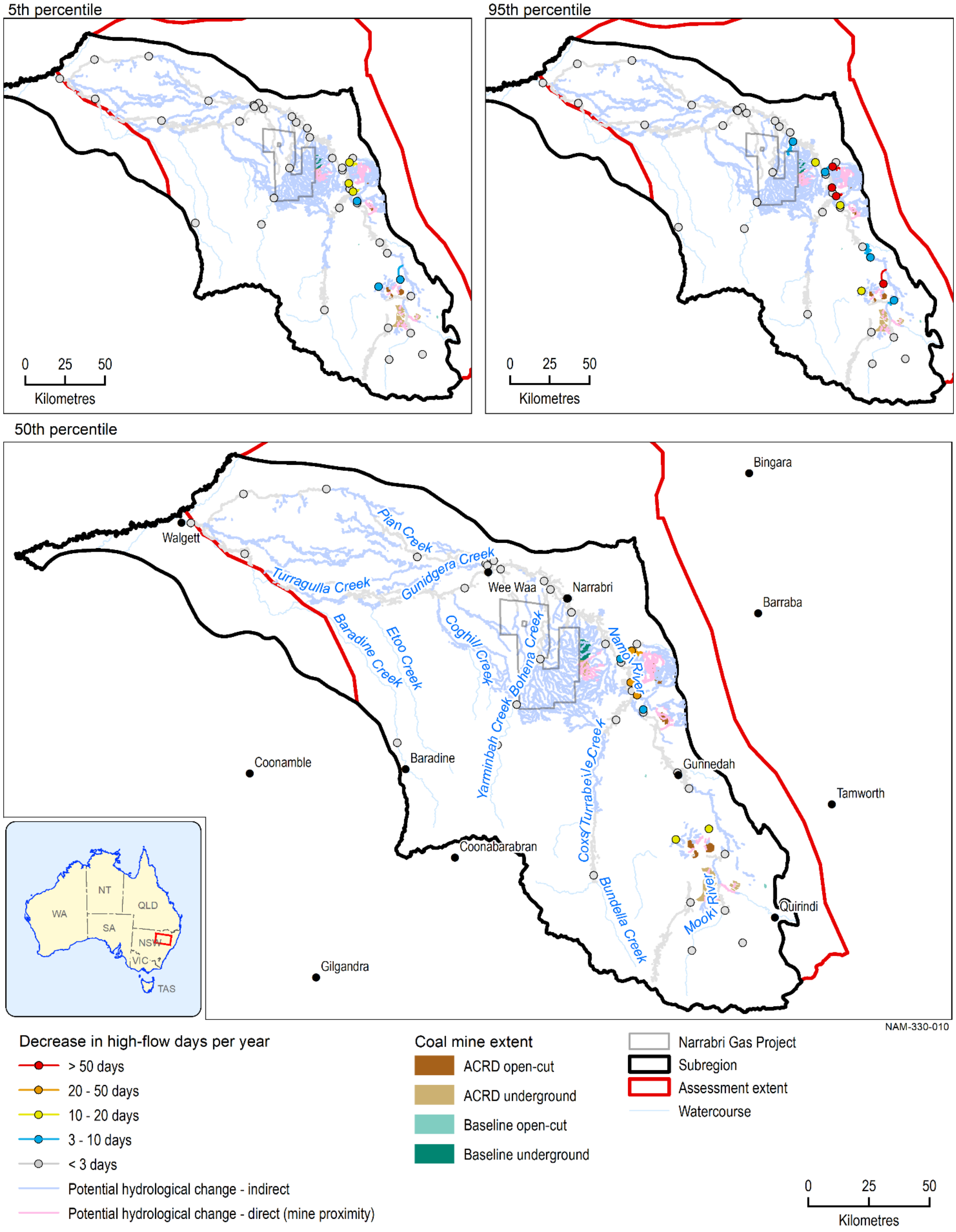

Figure 18 Decrease in the number of high-flow days due to additional coal resource development

Data: Bioregional Assessment Programme (Dataset 2)

Table 11 Stream length (km) potentially exposed to varying reductions in high-flow days in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but not quantified (km)	Length with ≥3 day reduction in high-flow days per year (km)			Length with ≥10 day reduction in high-flow days per year (km)			Length with ≥20 day reduction in high-flow days per year (km)			Length with ≥50 day reduction in high-flow days per year (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Upper Namoi	568	257	0	0	53	0	0	0	0	0	0	0	0	0
Mid Namoi	1671	1167	34	51	54	31	31	37	0	31	31	0	0	31
Pilliga and Pilliga Outwash	1268	1165	0	0	20	0	0	0	0	0	0	0	0	0
Lower Namoi	2014	1040	0	0	0	0	0	0	0	0	0	0	0	0
Total	**5521**	**3629**	**34**	**51**	**127**	**31**	**31**	**37**	**0**	**31**	**31**	**0**	**0**	**31**

Data: Bioregional Assessment Programme (Dataset 5)

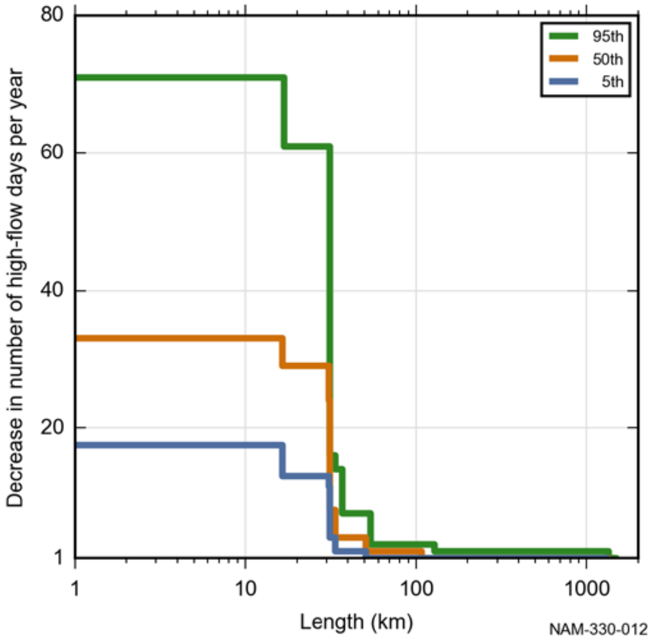

Figure 19 Cumulative exceedance plot of the reduction in the number of high-flow days due to additional coal resource development for the 5th (blue), 50th (orange) and 95th (green) percentiles

x-axis is in log scale.
Data: Bioregional Assessment Programme (Dataset 5)

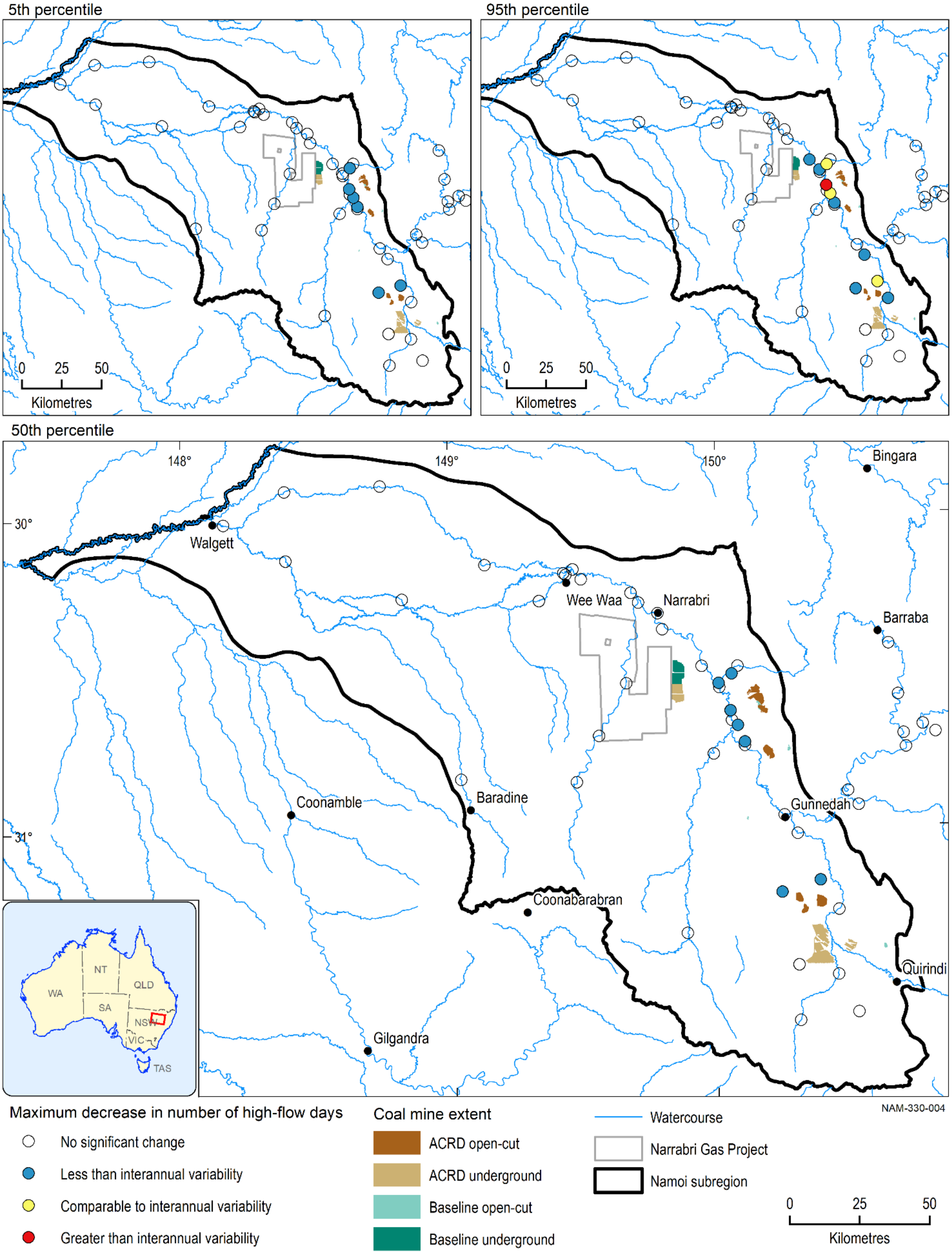

Figure 20 Ratio of change in high-flow days due to additional coal resource development to the interannual variability in high-flow days under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 7, Dataset 8)

3.3.4.3 Annual flow

The annual flow (AF) represents the maximum percentage change due to additional coal resource development in the annual flow volume in the year showing the maximum change over the simulated 90-year period (2013 to 2102). This is shown in Figure 21 for stream reaches in the surface water zone of potential hydrological change. A cumulative exceedance plot of the reduction in annual flow is shown in Figure 22, with summary data presented in Table 12

Decreases in mean annual flow of at least 1% are *very likely* in seven creeks covering 51 km of modelled streams. They include: Back and Maules creeks both draining the Maules Creek Coal Project; Merrygowen, Bollol and Driggle Draggle creeks draining Boggabri expansion, Tarrawonga expansion and Vickery coal developments, respectively. The remaining two creeks are unnamed creeks draining the Watermark coal mine development.

Decreases in mean annual flow of 5% to 20% are *very likely* in five of these seven creeks covering 19 km of modelled streams. They are: Back, Merrygowen and Driggle Draggle creeks and two unnamed creeks draining the Watermark coal mine development.

There is a 5% chance of reductions in annual flow of 20% to 50% at two stream nodes representing 17 km of the Merrygowen and Back creeks in the Mid Namoi.

Reductions in annual flow of more than 1% are almost entirely limited to the Mid Namoi reporting area, with just 20 km of streams in the Pilliga and Pilliga Outwash reporting area showing changes at the 5th percentile. These changes are localised as these relatively minor streams feed into the much larger Namoi River, which is largely insensitive to these changes in inflows.

The ratio of reduction in annual flow to the interannual variability seen under the baseline is shown in Figure 23. It shows that only at some nodes in the Mid Namoi is the change less than interannual variability. For most other nodes there are no significant changes.

Reductions in annual flow are similar for all three percentiles. This is because reduction in annual flow is driven primarily by direct interception of surface runoff by open cut mines. The probability of this reduction does not vary. Only a small component of the reduction in annual flow is driven by changes in baseflow due to reduced surface water – groundwater connectivity.

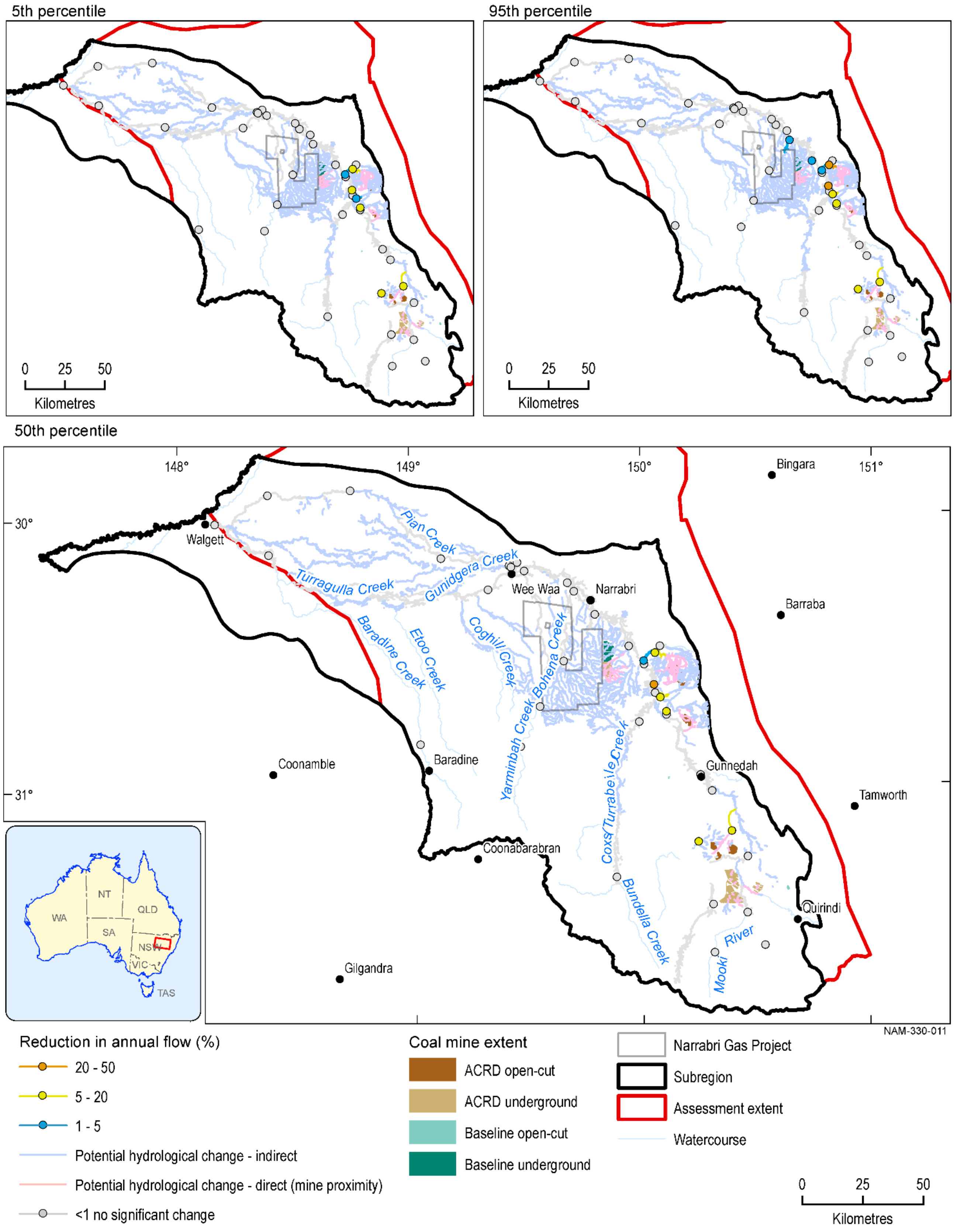

Figure 21 Reduction in annual flow due to additonal coal resource development

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 2)

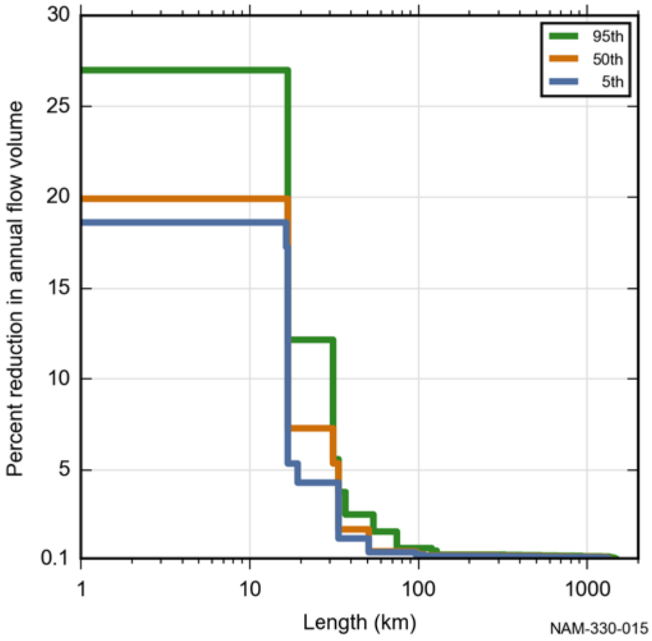

Figure 22 Cumulative exceedance plot of the percent reduction in annual flow due to additional coal resource development for 5th (blue), 50th (orange) and 95th (green) percentiles

x-axis is in log scale.
Data: Bioregional Assessment Programme (Dataset 5)

Table 12 Stream length (km) potentially exposed to varying reductions in annual flow in the zone of potential hydrological change

Reporting area	Length in zone of potential hydrological change (km)	Length potentially impacted but not quantified (km)	Length with ≥1% reduction annual flow (km)			Length with ≥5% reduction annual flow (km)			Length with ≥20% reduction annual flow (km)			Length with ≥50% reduction annual flow (km)		
			5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Upper Namoi	568	257	0	0	0	0	0	0	0	0	0	0	0	0
Mid Namoi	1671	1167	51	51	54	19	34	34	0	0	17	0	0	0
Pilliga and Pilliga Outwash	1268	1165	0	0	20	0	0	0	0	0	0	0	0	0
Lower Namoi	2014	1040	0	0	0	0	0	0	0	0	0	0	0	0
Total	**5521**	**3629**	**51**	**51**	**74**	**19**	**34**	**34**	**0**	**0**	**17**	**0**	**0**	**0**

Data: Bioregional Assessment Programme (Dataset 5)

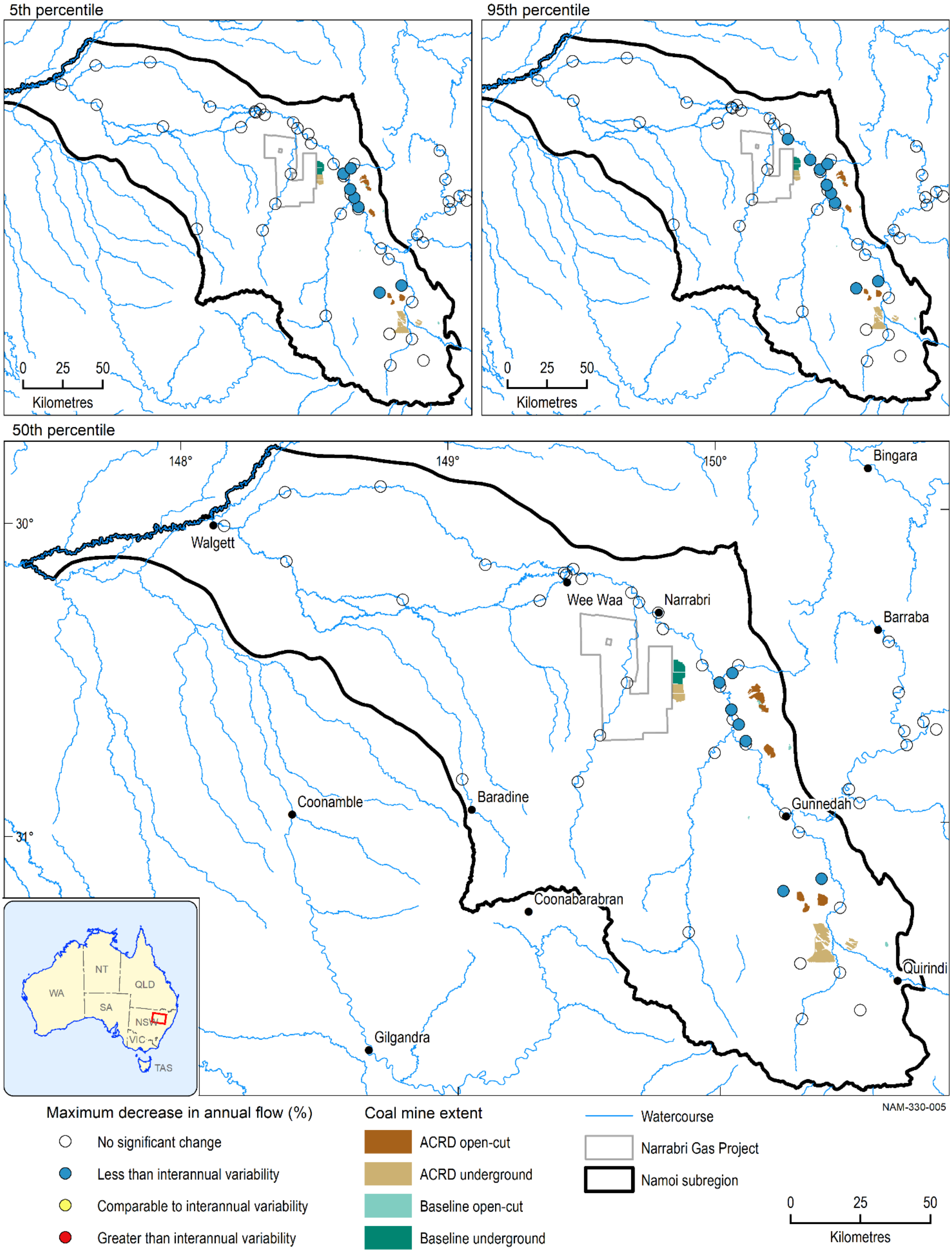

Figure 23 Ratio of change in annual flow due to additional coal resource development to the interannual variability in annual flow under the baseline

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 7, Dataset 8)

3.3.5 Potential water quality changes

Regional changes in surface water and groundwater flows due to additional coal resource development could potentially lead to changes in surface water and groundwater quality. While water quality was not modelled as part of this BA, the implications for water quality in the Namoi subregion are considered here in light of the modelled hydrological changes due to additional coal resource development.

Relevant factors for assessing the potential for changes in regional groundwater and surface water quality due to additional coal resource development in the Namoi subregion are:

- Coal resource developments in the subregion are required to manage discharges according to volumes, quality and discharge windows specified in environment protection licences (EPL), which are a condition of their approval to operate.
- There is one CSG development being modelled, the Narrabri Gas Project. However, potential water quality issues from use of hydraulic fracturing chemicals have not been considered here as there are no plans to use hydraulic fracturing in the Project (Santos, n.d.).
- None of the additional coal resource developments propose to re-inject co-produced water into depressurised aquifers.

The following sections identify the groundwater and surface water causal pathways that could potentially lead to regional impacts, and assess the risk of impact. The extent of influence and existing regulation and management practices are used to inform the assessment of risk.

3.3.5.1 Groundwater quality

Changes in groundwater quality due to coal resource development can occur as an indirect result of depressurisation and dewatering of aquifers and changes to subsurface physical pathways between aquifers, which enhance leakage between aquifers of different quality water. Changes in groundwater quality can also occur as a direct result of coal resource development and operational water management, such as when water is deliberately injected into an aquifer or coal seam to manage surplus water or counter the effects of groundwater depressurisation. Unless hydrologically isolated from their surroundings, the creation of coal stockpiles, rock dumps and tailings dams on coal mine sites can result in leaching of contaminants to groundwater. In all these cases, a hazard arises when the quality of the receiving water is changed such that it reduces its beneficial use value. BAs are concerned with the risk from non-accidental changes to water quality off site, which may be cumulative where mining operations are in close proximity.

Table 13 lists potential causes of changes in groundwater quality from coal resource development in the Namoi subregion and identifies the potential for off-site impacts. In NSW, a water supply work approval is needed under NSW’s *Water Management Act 2000* for a new bore. Construction of a bore must be undertaken by a licensed driller and drillers are expected to meet minimum requirements set out in guidelines outlined in the National Uniform Drillers Licensing Committee (NUDLC, 2012). These guidelines detail mandatory requirements and good industry practice for all aspects of the bore life cycle from bore design, bore siting, drilling fluids, casing, maximising bore efficiency, sealing and bore completion. While some leakage from older bores is considered likely, these bores are not part of the potential impact due to additional coal resource development and are not within the scope of this BA. Three of the four causal pathways in Table 13 could potentially have off-site impacts. In the remainder of this section, the likelihood of impacts is considered in the context of existing regulatory controls.

The potential impacts on watertable level, water pressure and groundwater quality from environmentally relevant activities, such as coal mining, are managed through the *NSW Aquifer Interference Policy* (NSW Office of Water, 2012). This policy requires that all water taken from an aquifer is properly accounted for; minimal impact considerations on the watertable, water pressure and water quality are addressed; and remedial measures are planned for in the event that actual impacts are greater than predicted. For aquifers in the Namoi subregion, no change in the beneficial use category of a groundwater source further than 40 m from the activity is permitted, unless studies can demonstrate that the change in groundwater quality will not affect the long-term viability of any water sharing plan, GDE, culturally significant site or water supply work. An increase of more than 1% per activity of the long-term average salinity is not permitted in a highly connected water source at the nearest point to the activity. As part of their groundwater monitoring and modelling plans, mining companies must demonstrate to the satisfaction of the NSW Department of Primary Industries Water that the proposed development is undertaken in accordance with the policy. Given this, the potential for significant changes in regional groundwater quality are likely to be low.

Table 13 Potential causes of changes in groundwater quality and potential for off-site impacts in the Namoi subregion

Causal pathway	Water quality concern	Scale	Off-site impacts in Namoi subregion
Groundwater pumping enabling coal extraction	Leakage between aquifers that diminishes the beneficial use value due to changes in water quality	Local to regional	Potential for off-site impacts from changes in the hydraulic gradients between connected aquifers of differing water quality
Failure of bore integrity	Leakage between aquifers that diminishes the beneficial use value due to changes in water quality	Local	Off-site impacts are unlikely. State regulation and best practice guidelines are in place to minimise potential impacts from bore construction and use.
Subsurface fracturing above longwall panels	Leakage between aquifers that diminishes the beneficial use value due to changes in water quality	Local to regional	Potential for off-site impacts from changes in the hydraulic gradients between connected aquifers of differing water quality
Leaching from stockpiles, rock dumps, tailings dams, storage dams	Leaching of contaminants into aquifers that reduce their beneficial use	Local to regional	Potential for off-site impacts, but regulatory controls in place to minimise risk

Changes in tensile and compression forces in the overburden above longwall panels following their collapse can lead to fracturing above longwall panels and hydraulic enhancement of the goaf, with the potential for freer movement of water between aquifers of potentially different water quality. Hydraulic enhancement was modelled in the Namoi groundwater model (companion product 2.6.2 for the Namoi subregion (Janardhanan et al., 2018)) and was shown to affect the extent of drawdown and surface water – groundwater exchanges, but implications for groundwater quality were not modelled. Sometimes groundwater assessments undertaken by mines represent changes in hydraulic properties above longwall panels in their modelling, but sometimes these changes are ignored because the scale of influence is deemed too local to affect larger-scale drawdown predictions. If hydraulic enhancement of the goaf is ignored, the hydraulic properties of the interburden may be overestimated to compensate for the lack of groundwater flowing into the mine. Invariably, the groundwater models do not represent changes in groundwater quality or surface water quality due to changes in hydraulic properties. The effect of coal resource development on the water quality of nearby aquifers and streams in the Namoi subregion remains largely a knowledge gap.

In relation to leaching of contaminants from mining-related contaminant sources, the Department of Industry Resources and Energy (DIRE), under NSW's *Mining Act 1992*, requires mines to have an approved mining operations plan (MOP). The MOP provides details of how the mining operation will be carried out, including details of management of stockpiles, rock dumps and tailings dams. Mining companies, as part of best practice management, are required to design storages that are secure and stable over their life and have a low risk of spills.

3.3.5.2 Surface water quality

Changes in surface water quality from coal resource development can occur as a result of disruptions to surface drainage from the removal of vegetation and disturbance of soil in construction of roads, site facilities, excavation of open-cut pits and landscaping of the site during production and rehabilitation. Disturbed soil due to mining activities and bare surfaces as a result of vegetation removal increase the risk of erosion, with potential to increase total suspended solids (TSS) in waterways. There is the potential for ecological imbalance in receiving waterways due to the mine water discharge into the stream network as part of operational water management, if the quality of the discharged water lowers the quality of the receiving water below its current beneficial use level. Groundwater pumping and subsurface fracturing and subsidence above longwall panels can lead to changes in surface flow and baseflow to streams and potentially affect the water quality of the stream.

Table 14 lists potential causes of changes in surface water quality due to coal resource development and identifies the potential for off-site impacts in the Namoi subregion, having regard to the likely scale of the effect and existing management. The 'Altering surface water system' causal pathway is considered unlikely to lead to noticeable off-site water quality impacts; the remaining three could potentially have off-site impacts on water quality.

Table 14 Potential causes of changes in surface water quality and potential for off-site impacts

Causal pathway	Water quality concern	Scale	Off-site impacts in Namoi subregion
Altering surface water system	Increased total suspended solids in waterways from soil eroded off mine site	Local	Off-site impacts are unlikely. Managed through regulatory requirements linked to mining operations plans.
Discharging extracted water into surface water system	Discharge water may diminish the beneficial use value due to changes in water quality	Local to regional	Potential for off-site impacts. Managed through environment protection licence conditions.
Groundwater pumping enabling coal extraction	Change in baseflow to downstream waterways may diminish the beneficial use value due to changes in water quality	Local to regional	Potential for off-site impacts. Managed through *NSW Aquifer Interference Policy (NSW Office of Water, 2012)*.
Subsurface fracturing and subsidence above longwall panels	Change in surface flow and baseflow to downstream waterways may diminish the beneficial use value due to changes in water quality	Local to regional	Potential for off-site impacts. Managed through *NSW Aquifer Interference Policy*.

Due to highly strict mine operating licencing conditions, the likelihood of off-site water quality impacts from altering the surface water system on the mine sites is considered low. There is a long history of soil erosion management in NSW, which has its origins in the agricultural sector, but has been extended to minimise the generation and mobilisation of sediments in all developments where disturbance of the soil occurs. NSW Resources and Energy (NRE) requires mines to provide details of how the mining operation proposes to minimise soil loss at all life stages of the mine and post-mining as part of an approved mining operations plan. Environmental protection licences, issued by NRE under NSW's *Protection of the Environment Operations Act 1997*, may also specify erosion control conditions. Furthermore, DIRE requires authorised mines to develop, implement and report on environmental monitoring programs. In annual environmental management reports (AEMR), the coal mining companies must publish their monitoring data in order to demonstrate that they are meeting their environmental objectives under their licence to operate.

3.3.5.2.1 Stream salinity

3.3.5.2.1.1 Discharges to regulated and unregulated rivers

There are many competing demands on water resources in the rivers of the Namoi subregion and water needs to be of a quality to support a diverse range of agricultural uses, town water supply and environment. Background salt levels are naturally high in some parts of the subregion such as the Coxs Creek and Mooki and Peel rivers, which are the major contributors of salts to the Namoi River. Salinity in these areas are thought to be caused by the presence of salt in underlying soil or bedrock released by weathering, salt deposited during past marine inundation of an area, or salt particles being carried over the land surface from the ocean (Mawhinney, 2011).

These coal mines are required to hold an environment protection licence (EPL), which specifies conditions attaching to the mine's licence to operate, including those relating to the management of mine water. Discharge of mine and CSG-related water to streams are authorised only if the quality of discharged water is the same or better than the quality of receiving waters. For example, in the Boggabri Coal Mine, water dams will be constructed to store contaminated water, including saline water, and water will be reused if the water quality is unsuitable to be discharged to Nagero Creek. Discharges may also be permitted during high-flow windows when the natural salinity of the river decreases and the river can accommodate extra salt from industrial discharges without exceeding salinity thresholds.

Table 15 shows that there are no flow thresholds stipulated for streams in the Namoi subregion above which mine water is allowed to be discharged. All mine projects have proposed to fully utilise the mine water for mine operation purposes or contain it within the mine site, except in the case of an extended wet season. Modelling studies carried out using historical rainfall conditions for the environmental impact assessments of respective mines suggest that there should be sufficient capacity to contain all mine water.

Table 15 Discharge arrangements of the different mine projects and effect of additional coal resource development (ACRD)

Mine development	Potentially affected stream	Baseline	Effect of ACRD
Boggabri Coal Expansion Project	Nagero Creek	Discharge to stream allowed if water quality is suitable	No change
Narrabri South Project (underground)	Tulla Mullen Creek	na	NA
Tarrawonga Coal Expansion Project	Goonbri Creek, Bollol Creek	Controlled discharge from licensed discharge point during extended wet period if water quality is suitable	No change
Caroona Coal Project[a]	Mooki River Quirindi Creek	na	No surface water discharge planned
Maules Creek Project	Back Creek	na	If needed, discharge to Back Creek if water quality is suitable
Watermark Coal Project	Unnamed Creek, Yarraman Creek	na	Sufficient capacity to contain mine water on site. If needed, water released off site during extended wet period if water quality is suitable.
Vickery Coal Project	Driggle Draggle Creek, Stratford Creek	na	Mostly used on site, or discharged off site if water quality is suitable
Narrabri Gas Project	Bohena Creek		Treated water used on site

[a]Caroona Coal Project was ceased and exploration licence cancelled. Not much information available at the time of writing (June 2017).

na = not applicable; NA = not available

In conclusion, due to a high level of regulation and monitoring of discharges of mine water to the surface drainage network in the Namoi subregion, the risk to stream water quality from this causal pathway is considered to be minimal.

3.3.5.2.1.2 Depressurisation, dewatering and hydraulic enhancement

The risk to regional stream water quality caused by changes in baseflow following depressurisation and dewatering of mines and/or changes in subsurface physical flow paths (e.g. from hydraulic enhancement of the goaf) will depend on the magnitude of the hydrological changes and the salinity of the groundwater relative to the salinity of the water in the stream into which it discharges. Modelling of the hydrological changes due to additional coal resource development in the Namoi subregion predicts a probable reduction in baseflows to Namoi subregion streams. If, as is usually the case, the salinity of the groundwater is higher than that of the stream into which it discharges, a reduction in baseflow would be expected to lead to a reduction in stream salinity.

Companion product 1.5 (Peña-Arancibia et al., 2016) for the Namoi subregion provides details on groundwater and surface water quality. In all the streams identified from the regional-scale modelling as at risk of potentially large changes in flow regime, the impact on local stream salinity will depend on the relative reductions in catchment runoff and baseflow over time. Reductions in catchment runoff are more likely to affect runoff peaks, while baseflow reductions have a more noticeable effect on low flows. The implications for stream salinity at any given time will depend on how the relative contributions from the quick and slower flow pathways change over time. In streams, such as Back Creek, Merrygowen Creek and Ballol Creek, Tulla Mullen Creek and Mooki River near the Maules Creek, located near Boggabri, Tarrawonga, Vickery and Watermark coal mines respectively, where modelling results suggest 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 the salinity of these water bodies.

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. The magnitude and extent of water quality changes cannot be determined without specifically representing water quality parameters in the modelling. This remains a knowledge gap.

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Dataset 6 Bioregional Assessment Programme (2017) Landscape classification of the Namoi preliminary assessment extent. Bioregional Assessment Derived Dataset. Viewed 25 May 2017, http://data.bioregionalassessments.gov.au/dataset/360c39e5-1225-401d-930b-f5462fdb8005.

Dataset 7 Bioregional Assessment Programme (2017) Namoi standard Hydrological Response Variables (HRVs). Bioregional Assessment Derived Dataset. Viewed 25 October 2017, http://data.bioregionalassessments.gov.au/dataset/189f4c7a-29e1-41f9-868d-b7f5184d829f.

Dataset 8 Bioregional Assessment Programme (2017) Namoi HRV ratios. Bioregional Assessment Derived Dataset. Viewed 05 December 2017, http://data.bioregionalassessments.gov.au/dataset/f86caa9b-bc0e-4fef-a5b0-68457f19d222.

3.4 Impacts on and risks to landscape classes

Summary

The diverse range of natural and human-modified ecosystems in the Namoi subregion were classified into 29 landscape classes, and then aggregated into six landscape groups based on the classification criteria and water dependency: 'Floodplain or lowland riverine', 'Non-floodplain or upland riverine', 'Rainforest', 'Springs', 'Dryland remnant vegetation' and 'Human-modified'.

Landscape classes that are unlikely to be impacted

Two landscape groups were 'ruled out' of the ecological modelling component of the assessment based on the criteria used in the initial landscape classification. Firstly, the 'Dryland remnant vegetation' landscape group can be ruled out because it comprises vegetation communities that are deemed to not be dependent on surface water or groundwater. Secondly, the 'Human-modified' landscape group (comprising six landscape classes) is excluded because it primarily comprises agricultural and urban landscapes that are highly modified by human activity. However some aspects of this group are considered elsewhere in the bioregional assessments (BAs) (i.e. economic assets).

Additionally, the 'Non-GAB springs' landscape class was excluded because none of the 15 springs found in the assessment extent are located within the zone of potential hydrological change.

Within the riverine lowland landscape classes, 'Permanent lowland stream GDE', 'Temporary lowland stream GDE' and 'Floodplain riparian forest', are *very unlikely* to be impacted, given no change in their relevant hydrological response variables for any of the simulation periods.

'Floodplain or lowland riverine' landscape group

The lowland riverine landscape classes in this group include the Namoi River and its major tributaries. The impacts on surface water were defined using increases in the cease-to-flow periods – defined using the variables mean annual zero-flow days (averaged over 30 years) (ZQD, subsequently referred to in this Section as 'zero-flow days') and mean annual maximum zero-flow spells. Approximately 16.9 km of the 'Permanent lowland stream' landscape class is exposed to a 50% chance of an increase of greater than 20 days in zero-flow days and an increase of greater than 10 days in maximum zero-flow spells over the 2013 to 2042 simulation period. Only approximately 10 km of 'Temporary lowland stream' is exposed to a similar magnitude of changes to 2042.

Hydrological responses of the riparian vegetation in these lowland riverine systems, classified almost exclusively as 'Floodplain riparian forest GDE', were defined by decreases in the

frequency of overbank flows (based on a pre-defined threshold of a 1 in 3 year flood event in the reference period) and maximum groundwater drawdown. Of the 72 km^2 of 'Floodplain riparian forest GDE' within the zone of potential hydrological change, only 0.5 km^2 has a 50% chance of a decrease of at least one overbank event every 20 years during the 2013 to 2042 simulation period. There is also a 50% chance of greater than 2 m groundwater drawdown in 0.6 km^2 due to additional coal resource development.

Hydrological responses in floodplain wetlands are also defined by decreases in the frequency of overbank flows. Any change in overbank flow events across the extent of floodplain wetlands is *very unlikely*, with 7.7 km^2 of 'Floodplain wetland' and 19.7 km^2 of 'Floodplain wetland GDE' having a 5% chance of experiencing one less event every 50 years during the 2013 to 2042 simulation period. However, no declines in the frequency of overbank flows for floodplain wetlands were detected for the 2073 to 2102 simulation period.

Potential ecosystem impacts estimated from the receptor impact modelling showed changes in one or more of the receptor impact variables at a confined set of locations across the distribution of the associated landscape class. For example, largest predicted declines in average number of families of aquatic macroinvertebrates due to additional coal resource development (ranging from approximately 16 to 17 families at the 5th percentile and approximately 4 to 3 families at the 50th percentile) were observed around Maules Creek and Bollol Creek. The receptor impact model results were combined to provide a combined assessment of potential ecosystem impacts based on thresholds indicative of a relative measure of risk across a given landscape class. The greatest concentration of 'more at risk of ecological and hydrological changes' and 'at some risk of ecological and hydrological changes' assessment units (see Section 3.4.3.3 for the definitions of these risk categories) is located along the Namoi River and its tributaries, Maules Creek, Back Creek and Bollol Creek. Of the 1425 assessment units included in one or more of the receptor impact models, 51 were predicted to have 'at minimal risk' and 29 'more at risk', with most of these risk categories being determined by potential impacts on lowland riverine landscape classes and floodplain wetland landscape classes. A more detailed and local consideration of risk needs to consider the specific values at the location that the community are seeking to protect (e.g. particular assets), and bring in other lines of evidence that include the magnitude of the hydrological change and the qualitative mathematical models.

‘Non-floodplain or upland riverine’ landscape group

Both the instream and riparian habitats were modelled in the ‘Non-floodplain or upland riverine’ landscape group. Impacts on the riverine system were defined using the same cease-to-flow variables as the lowland riverine classes. Only two upland riverine classes, ‘Temporary upland stream’ and ‘Temporary upland stream GDE’, are exposed to a 50% chance of increases in zero-flow days greater than 20 days (2.2 and 2.6 km, respectively) for both the 2013 to 2042 and 2073 to 2102 simulation periods. Patterns in the increase in maximum zero-flow spells (50% chance of increases in maximum zero-flow spells of greater than 10 days) affect the same landscape classes and stream lengths as increases in zero-flow spells for both simulation periods.

It is *very unlikely* that the riparian vegetation represented by the ‘Upland riparian forest GDE’ landscape class will be impacted for either hydrological response variables, maximum groundwater drawdown and frequency of overbank flow events. Areas predicted to have a 5% chance of drawdown of greater than 0.2 m intersect with only 0.1 km^2 of this landscape class. Only a small area (0.3 km^2) is at risk of a 5% chance of a change in one less overbank flow event every 50 years.

Pilliga riverine classes (upland and lowland)

The Pilliga region, which encompasses both the Pilliga and Pilliga Outwash Interim Biogeographic Regionalisation for Australia (IBRA) subregions, was considered as a separate entity for the purposes of the ecological modelling due to its distinctive biophysical attributes. Ecological impacts on the Pilliga riverine landscape classes (including predominantly temporary upland and lowland landscape classes) were defined based on changes in maximum groundwater drawdown, increases in zero-flow days and increases in maximum zero-flow spells. Groundwater drawdown due to additional coal resource development across the Pilliga riverine landscape classes is predicted to have the largest impact on the ‘Temporary upland stream’ landscape class with 14.8 km exposed to a 50% chance of greater than 2 m drawdown.

The surface water modelling for the Pilliga region shows that chances of increases in zero-flow days and maximum zero-flow spells are small (5%) and of a small extent. Only 0.3 km of ‘Temporary upland stream’ landscape class was exposed to a 5% chance of an increase in zero-flow days of greater than 20 days, while both upland (6.5 km) and lowland (85.6 km) classes were exposed to a 5% chance of an increase in zero-flow days of greater than 3 days for the 2013 to 2042 simulation period. For increases in maximum zero-flow spells, only 20 km of lowland and 0.3 km of upland riverine classes were exposed to a 5% chance of an increase in zero-flow days of greater than 3 days for the 2073 to 2102 simulation period. No changes in maximum zero-flow spells were predicted for the 2013 to 2042 simulation period. Only 6% of the total length of the Pilliga riverine landscape classes had surface water modelling data, thus hydrological impacts across most of the stream network in the Pilliga were not determined.

The potential ecosystem impacts on the Pilliga riverine landscape classes were assessed using the number of aquatic macroinvertebrate families and projected foliage cover as receptor impact variables. Declines in both of these variables were confined to assessment units along Bohena Creek and were equivalent to ‘at some risk’ level of risk across the Pilliga riverine landscape class based on the risk thresholds defined for other receptor impact models.

Potentially impacted landscape classes lacking quantitative ecological modelling

There were parts of some landscape classes for which there was limited or no surface water modelling. This is due to both the distribution of potential model nodes across the assessment extent and the limitations on interpolating model outputs across the stream network. It followed that receptor impacts that depended on surface water were also not available at the same locations; these locations have hydrological or ecological changes that cannot be quantified.

There were also several landscape classes where receptor impact modelling was not performed and where ecosystem impacts cannot be explicitly defined. These include the two ‘GAB springs’ that intersect the Pilliga region. 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.

The ‘Grassy woodland GDE’ landscape class is widespread in the Pilliga and given its likely dependence on groundwater at least in some locations may be impacted by additional groundwater drawdown. However, more detailed studies are required to identify the nature of this groundwater reliance.

3.4.1 Overview

This section describes the potential impacts on ecosystems that result from hydrological changes due to additional coal resource development. Ecosystems are represented by landscape classes, reflecting broad-scale patterns in geomorphology, soils, hydrology, and habitat and land use information for a diverse range of landscape features. The BA defines a set of landscape classes as ecosystems with characteristics that are expected to respond similarly to changes in groundwater and/or surface water due to coal resource development. The basis for the landscape groups and landscape classes is described in companion product 2.3 for the Namoi subregion (Herr et al., 2018). A schematic overview of the classification criteria and corresponding typology of landscape classes and landscape groups is shown in Figure 24. The landscape classes are organised into six landscape groups, which provide a basis to assess dependency on surface water and groundwater (Figure 24).

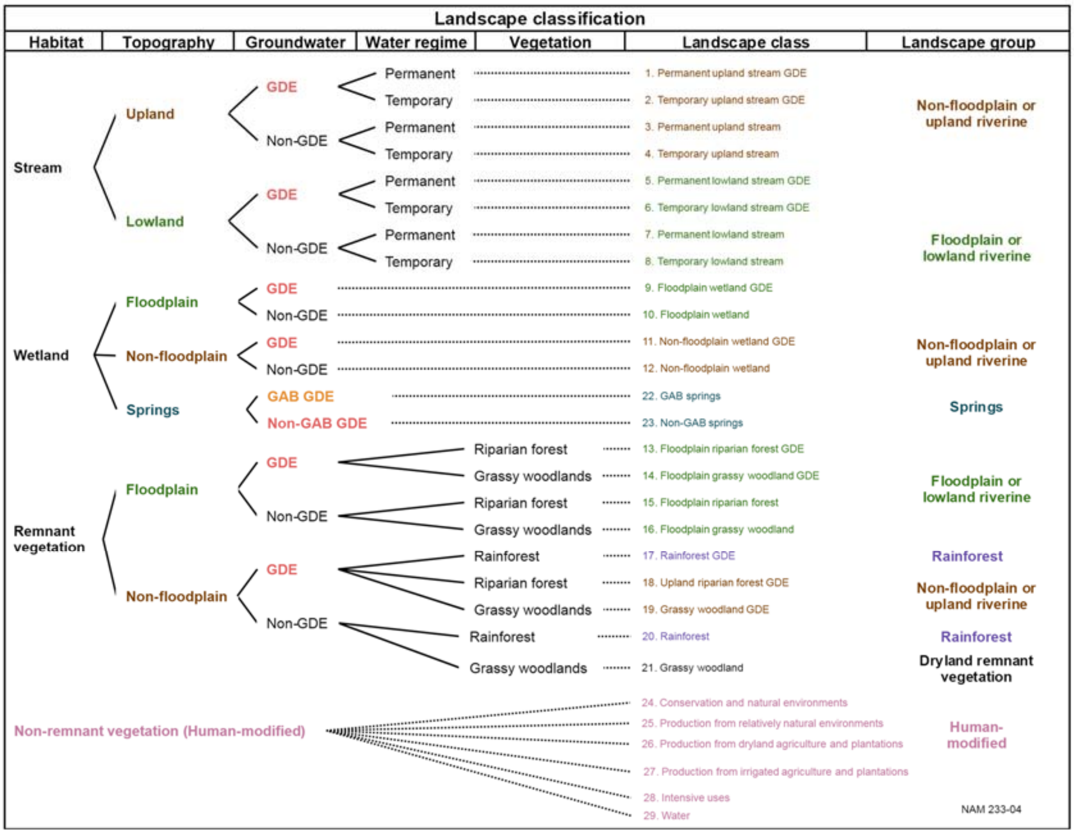

Figure 24 Schematic overview of the landscape classification for the Namoi assessment extent

The classification criteria are shown across the top row and the corresponding typology of landscape classes and groups is shown in the right-hand columns.
GAB = Great Artesian Basin, GDE = groundwater-dependent ecosystem
Source: companion product 2.3 for the Namoi subregion (Herr et al., 2018)

When developing ecological models for the Namoi subregion it was deemed necessary to develop a discrete model for defining potential ecological impacts for the Pilliga and Pilliga Outwash IBRA subregions (SEWPaC, 2012). The Pilliga and Pilliga Outwash IBRA subregions, simply termed the ‘Pilliga region’ here, represent a unique set of landscapes within the Namoi subregion. By comparison to the other landscapes across the Namoi subregion, the Pilliga region has many unique attributes in terms of its ecology, geomorphology, hydrogeology, soils and ecohydrology. Consistent with the structuring of the ecological models outlined in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018), the potential hydrological changes and ecosystem impacts are presented for both a separate Pilliga region of the zone of potential hydrological change and the remaining ‘non-Pilliga’ areas or reporting regions for the relevant landscape classes (see Section 3.3.2.2 for details on reporting regions).

A key consideration when identifying potential hydrological changes in landscape classes is that for some landscape elements there is limited or no surface water modelling. This is due to both the distribution of potential model nodes across the assessment extent and the limitations on interpolating model outputs across the stream network. Thus, changes in surface water hydrological response variables cannot be quantified for some parts of the zone of potential hydrological change. The extent of surface water modelling across the relevant stream-based landscape classes is presented when discussing hydrological and ecological impacts and was most limited for the upland riverine classes.

Results from regional-scale hydrological modelling indicate potential risks to about 1400 km^2 of water-dependent ecosystems that intersect the zone of potential hydrological change (Table 16). The hydrological modelling assumed and included environmental releases in line with NSW legislation requirements. Therefore, there were no impacts on streamflow in regulated rivers (see Table 12 in companion product 2.6.1 for the Namoi subregion (Aryal et al., 2018)) since any changes were accounted for by changes in dam releases. Details can be found in Section 2.6.1.4 of companion product 2.6.1. The zone of potential hydrological change contains all four riverine landscape classes within the 'Floodplain or lowland riverine' landscape group and includes 61% of the entire extent of this group within the assessment extent (Table 16 and Figure 25). Among these four riverine classes, the largest contribution is from the 'Temporary lowland stream' (2062.2 km) and 'Permanent lowland stream' (979.6 km) landscape classes (Table 16). All six of the non-riverine classes occur within the zone of potential hydrological change (Table 16). The largest non-riverine landscape classes by area are the 'Floodplain grassy woodland GDE' (421.7 km^2) and 'Floodplain grassy woodland' (121.3 km^2) (Table 16). Almost half of all the 'Floodplain riparian forest GDE' in the assessment extent (148.7 km^2) is included in the zone of potential hydrological change (Table 16). Most of the areas classified as 'Floodplain wetland' and 'Floodplain wetland GDE' in the assessment extent (30.1 and 151.8 km^2, respectively) form part of the zone of potential hydrological change (Table 16). A qualitative mathematical model was developed for the 'Floodplain or lowland riverine' landscape group, capturing components of the riverine and riparian systems as well as the adjacent floodplain and its wetlands and vegetation (see Section 2.7.3 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)) (Table 16). Given the expertise and resources available at the receptor impact modelling workshop for the Namoi subregion, it was decided that receptor impact models be developed for a subset of landscape classes in this group. The details of these models are outlined in Section 2.7.3 of companion product 2.7 (Ickowicz et al., 2018) and in Section 3.4.3.3 (Table 16).

Most riverine landscape classes within the 'Non-floodplain or upland riverine' landscape group in the zone of potential hydrological change are classified as 'Temporary upland stream' (745.1 km), reflecting the intermittent or ephemeral nature of many of the stream segments (Table 16). The remainder of the stream network is classified as 'Permanent upland stream' (92.6 km), 'Temporary upland stream GDE' (34.7 km) and 'Permanent upland stream GDE' (14.2 km) (Table 16). The 'Upland riparian forest GDE' landscape class makes up a very small area of the zone of potential hydrological change (2.9 km^2) along with a small area of 'Non-floodplain wetland' (13.1 km^2) and 'Non-floodplain wetland GDE' landscape classes (8.1 km^2) (Table 16). Three different components of this landscape group were considered for the qualitative modelling given the general lack of hydrological and spatial connectivity between the landscape classes across the zone of potential hydrological change. The upland riverine model included all upland riverine landscape classes and the adjacent riparian vegetation ('Upland riparian forest GDE'). Three receptor impact models were formulated based on this qualitative mathematical model and include the potential response of the riverine system through changes in macroinvertebrate assemblages, presence of tadpoles and changes in projected foliage cover in the riparian trees along the stream channel (Table 16). In addition to the upland riverine system, a qualitative mathematical model was developed for the non-floodplain wetlands in this landscape group (Table 16, further details are provided in Section 2.7.4 of companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)).

The Pilliga region within the zone of potential hydrological change contains both upland and lowland riverine reaches. ‘Temporary upland stream’ (530.4 km) and ‘Temporary lowland stream’ (624.6 km) landscape classes make up the majority of the riverine networks, reflecting the highly ephemeral and/or intermittent nature of the drainage network (Table 16 and Figure 25). Only a small fraction of the ‘Permanent lowland stream’ landscape class (14.3 km) intersects with the Pilliga region in the zone of potential hydrological change (Table 16). Given the unique characteristics of the Pilliga’s stream network (i.e. low relief, intermittent flow patterns), a qualitative model, in consultation with the local experts, was developed for both upland and lowland riverine classes – Pilliga riverine (Table 16; further details are provided in Section 2.7.3 and Section 2.7.4 of companion product 2.7 (Ickowicz et al., 2018)). This meant that both lowland and upland riverine landscape classes share a similar model that encompasses both the riverine and riparian systems. Two separate receptor impact models were formulated that use changes in projected foliage cover and assemblages of macroinvertebrates as receptor impact variables (Table 16).

The ‘Grassy woodland GDE’ landscape class makes up 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 634.5 km^2 of this landscape class across the entire zone of potential hydrological change of this landscape class is located outside of the Pilliga region (Table 16). This landscape class includes a collection of different vegetation communities and habitats, however, given the concentration of this landscape class in the Pilliga region of the zone of potential hydrological change, a qualitative model was developed by the workshop participants with a focus on the ecology of this region in mind (Table 16; further details are provided in Section 2.7.4 of companion product 2.7 (Ickowicz et al., 2018)). Given the limitations on resources at the receptor impact modelling workshop and the uncertainty surrounding the nature of groundwater dependency of vegetation in the Pilliga region, a receptor impact model was not formulated for this landscape class.

The ‘Rainforest’ landscape group occupies a limited area within the zone of potential hydrological change, with the ‘Rainforest’ landscape class intersecting 4.0 km^2 of the zone and the ‘Rainforest GDE’ landscape class intersecting only 0.3 km^2 (Table 16). A qualitative mathematical model was developed for this landscape group given the conservation values surrounding the vegetation types common to this group (further details are provided in Section 2.7.5 of companion product 2.7 (Ickowicz et al., 2018)).

Two springs are known to occur within the zone of potential hydrological change, which are classified as ‘GAB springs’ based on their association with underlying sandstone formations. These two springs are located on the eastern edge of the Pilliga Basin and are thought to be primarily recharge springs, given their location on the eastern fringes of the Great Artesian Basin (GAB) (Fensham and Fairfax, 2003). A qualitative mathematical model was formulated for a typical recharge GAB spring (Table 16, further details are provided in Section 2.7.6 of companion product 2.7 (Ickowicz et al., 2018)).

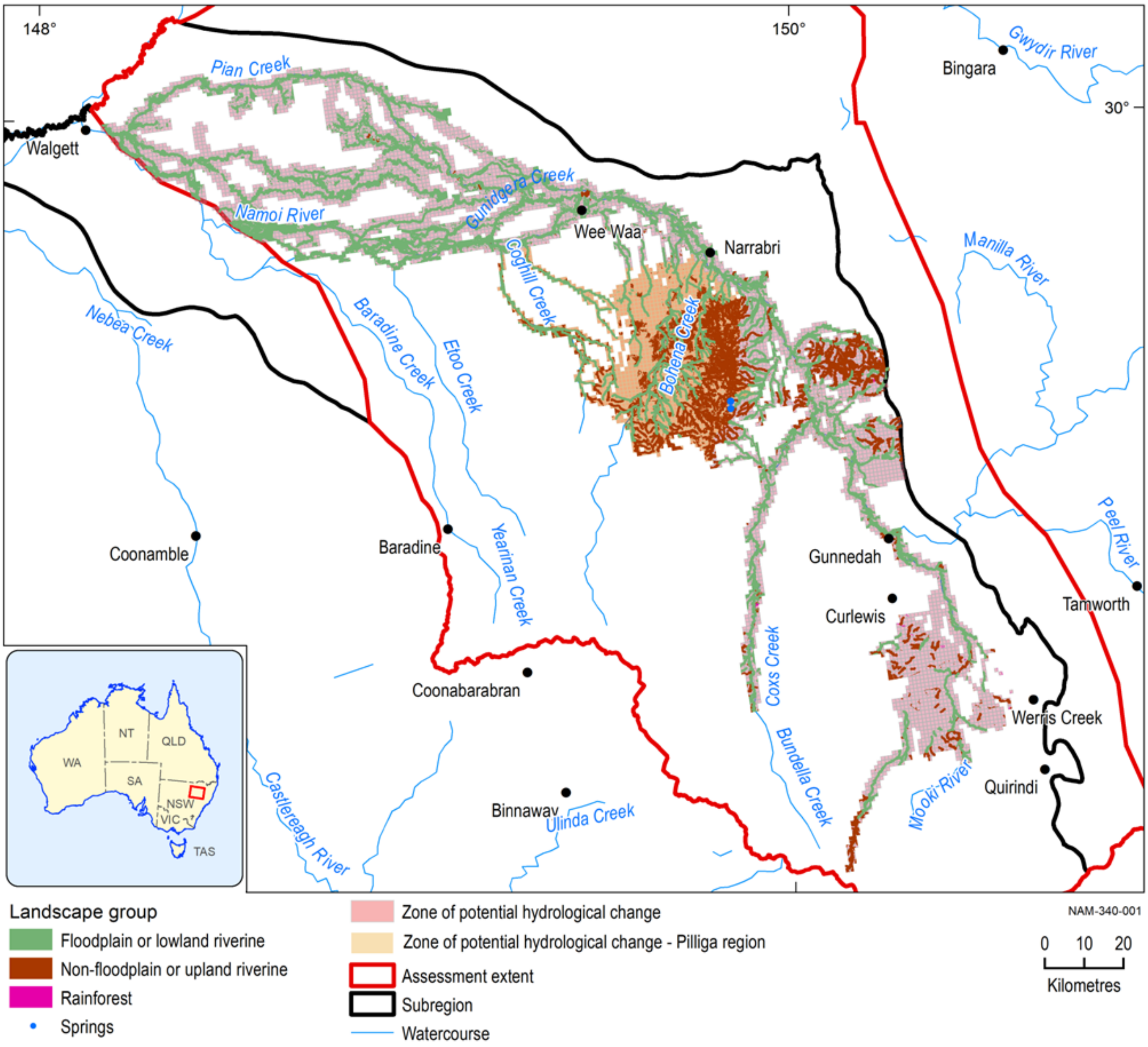

Figure 25 Location of the relevant landscape groups within the zone of potential hydrological change for the Namoi assessment extent

Data: Bioregional Assessment Programme (Dataset 2)

Table 16 Extent of all landscape classes in the assessment extent and zone of potential hydrological change

The relevant reporting region, qualitative model and receptor impact model are given for each landscape class.

Landscape group	Landscape class	Area in assessment extent (km²)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km²)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
Floodplain or lowland riverine	Floodplain riparian forest	1.5	na	na	0.2	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	1. Floodplain riparian forests - projected foliage cover
	Floodplain riparian forest GDE	148.7	na	na	72	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	1. Floodplain riparian forests - projected foliage cover
	Floodplain wetland	30.1	na	na	21.6	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	2. Floodplain wetland (GDE and non-GDE) - Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) in pools and riffles
	Floodplain wetland GDE	151.8	na	na	88	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	2. Floodplain wetland (GDE and non-GDE) - Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) in pools and riffles

Landscape group	Landscape class	Area in assessment extent (km²)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km²)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Permanent lowland stream	17.3	1,688.6	na	na	979.6	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	3. Permanent and temporary lowland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrate in edge habitat
	Permanent lowland stream GDE	na	456.8	na	na	240.8	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	3. Permanent and temporary lowland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrate in edge habitat
	Temporary lowland stream	1.5	8,053.3	na	na	2062.2	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	3. Permanent and temporary lowland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrate in edge habitat
	Temporary lowland stream GDE	8.3	509.3	na	na	84.3	na	Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	3. Permanent and temporary lowland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrate in edge habitat
	Floodplain grassy woodland	400.2	na		121.3	na		Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	No

Landscape group	Landscape class	Area in assessment extent (km^2)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km^2)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Floodplain grassy woodland GDE	1,445.4	na		421.7	na		Upper Namoi, Mid Namoi, Lower Namoi	Floodplain and lowland riverine	No
	Permanent lowland stream	17.3	1,688.6	na	na	14.3	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover 2. Pilliga riverine - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools
	Permanent lowland stream GDE	na	456.8	na	na	<0.1	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover 2. Pilliga riverine - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools
	Temporary lowland stream[a]	1.5	8,053.3	na	na	624.6	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover 2. Pilliga riverine - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools

Landscape group	Landscape class	Area in assessment extent (km^2)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km^2)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Temporary lowland stream GDE	8.3	509.3	na	2.4	86.9	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover 2. Pilliga riverine - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools
	Floodplain riparian forest	1.5	na	na	<0.1	na	na	Pilliga and Pilliga Outwash	No	No
	Floodplain riparian forest GDE	148.7	na	na	0.2	na	na	Pilliga and Pilliga Outwash	No	No
	Floodplain wetland	30.1	na	na	0.5	na	na	Pilliga and Pilliga Outwash	No	No
	Floodplain wetland GDE	151.8	na	na	1.6	na	na	Pilliga and Pilliga Outwash	No	No
	Floodplain grassy woodland	400.2	na	na	2.9	na	na	Pilliga and Pilliga Outwash	No	No
	Floodplain grassy woodland GDE	1,445.4	na	na	0.2	na	na	Pilliga and Pilliga Outwash	No	No
	Total area	**2204.8**	**na**	**na**	**752.2**	**na**	**na**			
	Total length	**na**	**10,708**	**na**	**na**	**4092.7**	**na**			

Landscape group	Landscape class	Area in assessment extent (km^2)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km^2)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
Non-floodplain or upland riverine	Upland riparian forest GDE	87.4	na	na	2.9	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Upland riparian forest - projected foliage cover
	Permanent upland stream	0.1	1,646.1	na	na	92.6	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Permanent and temporary upland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools; 2. Upland riverine - probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)

Landscape group	Landscape class	Area in assessment extent (km^2)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km^2)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Permanent upland stream GDE	1.1	227.4	na	0.1	14.2	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Permanent and temporary upland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools; 2. Upland riverine - probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)
	Temporary upland stream	na	16,512.8	na	na	745.1	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Permanent and temporary upland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools; 2. Upland riverine - probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)

Landscape group	Landscape class	Area in assessment extent (km²)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km²)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Temporary upland stream GDE	0.1	464	na	na	34.7	na	Upper Namoi, Mid Namoi, Lower Namoi	Upland riverine	1. Permanent and temporary upland streams (GDE and non-GDE) - average number of families of aquatic macroinvertebrates in instream pool habitat sampled using the NSW AUSRIVAS method for pools; 2. Upland riverine - probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*)
	Permanent upland stream	na	1,646.1	na	na	<0.1	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover
	Permanent upland stream GDE	na	227.4	na	na	<0.1	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover
	Temporary upland stream	na	16,512.8	na	na	530.4	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover
	Temporary upland stream GDE	na	464	na	na	11.5	na	Pilliga and Pilliga Outwash	Pilliga riverine (upland and lowland)	1. Pilliga riverine - projected foliage cover
		3,247.6	na	na	561.7	na	na	Pilliga	Grassy woodland GDE	No

Landscape group	Landscape class	Area in assessment extent (km²)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km²)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
	Grassy woodland GDE			na	72.8	na	na	Upper Namoi, Mid Namoi, Lower Namoi	Grassy woodland GDE	No
	Non-floodplain wetland	130.3	na	na	13.1	na	na	All	Non-floodplain wetland (GDE and non-GDE)	No
	Non-floodplain wetland GDE	23.5	na	na	8.1	na	na	All	Non-floodplain wetland (GDE and non-GDE)	No
	Total area	**3490.1**	**na**	**na**	**663**	**na**	**na**			
	Total length	**na**	**18,850.3**	**na**	**na**	**1428.5**	**na**			
Rainforest	Rainforest	na	153.1	na	na	4.0	na	All	Rainforests (GDE and non-GDE)	No
	Rainforest GDE	na	43.5	na	na	0.3	na	All	Rainforests (GDE and non-GDE)	No
	Total area	**na**	**196.6**	**na**	**na**	**4.3**	**na**			
Springs	GAB springs (number)	na	na	7	na	na	2	All	GAB springs	No
	Non-GAB springs (number)	na	na	15	na	na	0	All	GAB springs	No
	Total number	**na**	**na**	**22**	**2**	**na**	**2**			
Dryland remnant vegetation	Grassy woodland	8,623.7	na		1177.5	na	na	All	Not considered	Not considered
	Total area	**8,623.7**	**na**		**1177.5**	**na**	**na**			

Landscape group	Landscape class	Area in assessment extent (km²)	Length in assessment extent (km)	Number in assessment extent	Area in zone (km²)	Length in zone (km)	Number in assessment extent	Reporting region	Qualitative model	Receptor impact model
Human-modified	Conservation and natural environments	400.7	na	na	111.2	na	na	All	Not considered	Not considered
	Intensive uses	276	na	na	91.5	na	na	All	Not considered	Not considered
	Production from dryland agriculture and plantations	16,075.3	na	na	2814.5	na	na	All	Not considered	Not considered
	Production from irrigated agriculture and plantations	1,854.1	na	na	594.2	na	na	All	Not considered	Not considered
	Production from relatively natural environments	2,356.2	na	na	739	na	na	All	Not considered	Not considered
	Water	182.1	na	na	66.5	na	na	All	Not considered	Not considered
	Total area	**21,144.4**	**na**	**na**	**4416.9**	**na**	**na**			

[a] Values for the extent in assessment extent are the same regardless of reporting region.
GDE = groundwater-dependent ecosystem; na = not applicable
Data: Bioregional Assessment Programme (Dataset 1)

Receptor impact modelling converts the potentially abstract information about hydrological changes to quantities that can be more readily understood and interpreted. In particular, outcomes of the modelling relate more closely to their ecological values and beliefs and therefore support community discussion and decision making about acceptable levels of coal resource development (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). Receptor impact models are not intended to make site-specific predictions, but rather to quantify the range of possible responses of selected receptor impact variables to a given change in hydrology. It is beyond the scope of a BA to make precise predictions at exact locations.

Receptor impact variables represent biological components of the ecosystem that experts have chosen as indicators of ecosystem condition, and which are considered likely to be sensitive to changes in the hydrology of that system (see companion submethodology M08 (as listed in Table 1) for receptor impact modelling (Hosack et al., 2018)). Changes in hydrology are represented in the model by hydrological response variables, chosen to reflect particular water requirements of the ecosystem. The magnitude of change in the chosen receptor impact variables to changes in one or more hydrological response variables, captured through an expert elicitation process, is an indicator of the magnitude of risk to the ecosystem as a result of hydrological perturbation. For example, a prediction that the number of riffle-breeding frog species is likely to decrease in a particular reach where zero-flow days are predicted to increase does not necessarily mean that there are riffle-breeding frogs present and that they will be impacted. Rather, it means that given the magnitude of hydrological change predicted in that reach, there is a specific risk to the habitat requirements of riffle-breeding frogs, and more generally a risk to the ecosystems represented by the landscape class the riffle-breeding frog inhabits. The receptor impact modelling results are provided at a landscape scale and should not be interpreted as exactly representing the local conditions of a particular site. Predictions of receptor impact variables are ultimately one line of evidence, and any assessment of risk, particularly at a local scale, needs to be considered in conjunction with the broader hydrological changes that may be experienced and the qualitative mathematical models, which assist in describing potential knock-on effects to the ecosystems.

In the following sections, the results from receptor impact models should be treated as indicating the experts' pooled knowledge as to the likelihood and magnitude of ecological impacts in an ecosystem given a known hydrological change. Results also capture the uncertainties arising from lack of knowledge and the variability inherent in landscapes across short and long distances.

3.4.2 Landscape classes that are unlikely to be impacted

There are two landscape groups that are automatically ruled out of this component of the analysis. Firstly, the 'Dryland remnant vegetation' landscape group is 'ruled out' from potential impacts because it comprises vegetation communities that are deemed to be non-water dependent (for further information, see Section 2.3.3 of companion product 2.3 for the Namoi subregion (Herr et al., 2018)). Secondly, the 'Human-modified' landscape group (comprising six landscape classes) is excluded from this analysis because it primarily comprises agricultural and urban landscapes that are highly modified by human activity, and contains a set of ecohydological attributes distinct from the other landscape groups (for further information, see Section 2.3.3

of companion product 2.3 for the Namoi subregion (Herr et al., 2018)). Attributes of the water dependency of some aspects of these landscapes are considered elsewhere (see Section 3.5) (i.e. the impact of coal resource development on economic assets such as groundwater bores).

None of the 15 'Non-GAB springs' found in the assessment extent are located within the zone of potential hydrological change. Therefore, this landscape class can be ruled out as it is unlikely to be impacted due to additional coal resource development.

The remaining three landscape groups, and their respective landscape classes that intersect the 7014 km^2 zone of potential hydrological change, are considered dependent on groundwater and/or surface water regimes. These landscape groups, therefore, are potentially impacted due to additional coal resource development.

3.4.3 'Floodplain or lowland riverine' (non-Pilliga) landscape group

3.4.3.1 Description

The 'Floodplain or lowland riverine' landscape group occupies a land area of approximately 6% of the assessment extent and makes up around a quarter of the entire length of the stream network across the assessment extent. The landscape classification used by the Assessment team defined four 'lowland' riverine classes based on their topographical and geomorphological features (i.e. lowland), their water regime (i.e. permanent or temporary) and the likelihood of intersecting with known surface expression groundwater-dependent ecosystems (GDEs) (see Section 2.3.3 in companion product 2.3 for the Namoi subregion (Herr et al., 2018) for further details). The classification also captures a range of terrestrial features across the riparian – floodplain transition.

The lowland riverine landscape classes in this group include ecosystems adjacent to the Namoi River and its major tributaries and are low-gradient channels typically incised into alluvium with silt or sandy beds. There are limited riffles and fast water habitats in these streams and mostly pool habitat in those stream reaches with more temporary water regimes. In streams, such as Maules Creek, the channel is incised into sands and sand gravels with some riffles and cobble-bottomed stretches. Lowland stream systems in the Namoi subregion encompass a range of flow regimes. Riverine landscape classes classified as 'permanent' have surface flows greater than 80% of the time and are mostly found along the Namoi River and lower reaches of Mooki Creek and Peel River. Streams classified as 'temporary' have surface flows less than 80% of the time and cover a large collection of small tributaries to the Namoi River on the Liverpool Plains and Castlereagh-Barwon regions (Bioregional Assessment Programme, Dataset 1).

Floodplains can be defined broadly as a collection of landscape and ecological elements exposed to inundation or flooding along a river system (Rogers, 2011). The floodplain landscapes of the Namoi assessment extent are predominantly lowland-dryland systems incorporating a range of wetland types such as riparian forests, marshes, billabongs, tree swamps, anabranches and overflows (Rogers, 2011). The floodplain elements comprising the landscape classification include riparian forests, located within or directly adjacent to the stream channel; floodplain grassy woodlands that occupy the floodplain further away from the stream channel; and off-channel water bodies or wetlands that are interspersed along the floodplain (see Section 2.3.3 of companion product 2.3 (Herr et al., 2018) for further details). These features are also classified as ‘GDEs’ based on available GDE mapping (NSW Department of Primary Industries, Dataset 4), indicating a greater likelihood of additional water sources from the underlying alluvial aquifer. More details of this landscape group are provided in Section 2.7.3 of companion product 2.7 (Ickowicz et al., 2018).

The key hydrological determinants of ecosystem function identified by experts in the qualitative modelling workshops (companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)) have been interpreted as a set of hydrological response variables and receptor impact variables for each landscape class (Table 18). The assignment of hydrological response variables for landscape classes recognises the predominant ecohydrological linkages between water regime and ecosystem health and thus hydrological impacts on landscape classes are presented accordingly (Table 18). 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).

There are two landscape classes in the ‘Floodplain or lowland riverine’ landscape group (non-Pilliga region) where groundwater drawdown was assigned as a hydrological response variable: ‘Floodplain riparian forest’ and ‘Floodplain riparian forest GDE’. The corresponding receptor impact variable for riparian forests was identified as changes in projected foliage cover (Table 18). The frequency of overbank flows was identified as being an important driver of the riparian ecosystem (‘Floodplain riparian forest’ and ‘Floodplain riparian forest GDE’ landscape classes) as well as the off-channel water bodies or floodplain wetlands (‘Floodplain wetland’ and ‘Floodplain wetland GDE’ landscape classes; Table 18). The experts at the quantitative modelling workshop considered the presence of tadpoles in the genus *Limnodynastes* as the key receptor impact variable for floodplain wetlands. The cease-to-flow attributes of the surface water regime were considered as critical response variables for the riverine landscape classes and were assigned annual number of zero-flow days and annual maximum zero-flow spells (defined in Table 18). Assemblages of macroinvertebrates in the edge habitat were deemed to be appropriate receptor impact variables for gauging impacts on these cease-to-flow attributes of the flow regime (Table 18).

Table 17 Areas and/or lengths of landscape classes in the 'Floodplain or lowland riverine' landscape group within the entire assessment extent and the non-Pilliga region of the zone of potential hydrological change

The percentage of contribution of each landscape class to the total area of the zone of potential hydrological change is also given.

Landscape class	Area in assessment extent (km^2)	Area in the zone (km^2)	Percentage of total area in the zone (%)	Length in assessment extent (km)	Length in the zone (km)	Percentage of total length in zone (%)
Floodplain grassy woodland	400.2	121.3	1.7%	na[a]	na[a]	na[a]
Floodplain grassy woodland GDE	1,445.4	421.7	6%	na[a]	na[a]	na[a]
Floodplain riparian forest	1.5	0.2	<0.1%	na[a]	na[a]	na[a]
Floodplain riparian forest GDE	148.7	72	1%	na[a]	na[a]	na[a]
Floodplain wetland	30.1	21.6	0.3%	na[a]	na[a]	na[a]
Floodplain wetland GDE	151.8	88	1.3%	na[a]	na[a]	na[a]
Permanent lowland stream	17.3	13.4	0.2%	1,688.6	979.6	17.7%
Permanent lowland stream GDE	0	0	<0.1%	456.8	240.8	4.4%
Temporary lowland stream	1.5	1.5	<0.1%	8,053.3	2062.2	37.4%
Temporary lowland stream GDE	8.3	4.7	<0.1%	509.3	84.3	1.5%
Total – 'Floodplain or lowland riverine'	**2,204.8**	**744.4**	**10.6%**	**10,708**	**3366.9**	**61%**
Total – all landscape classes	**35,659.6**	**7013.9**	**100%**	**29,558.3**	**5521.2**	**100%**

[a] Extent of each landscape class is either an area of vegetation (km^2), length of stream network (km) or number of springs (number)
Data: Bioregional Assessments (Dataset 2)

3.4.3.2 Potential hydrological impacts

3.4.3.2.1 Groundwater

As a result of additional coal resource development, 0.6 km^2 of the 'Floodplain riparian forest GDE' landscape class are subject to a 50% chance of greater than 2 m drawdown and 0.8 km^2 are subject to greater than 0.2 m drawdown (Table 19). No impact from groundwater drawdown was predicted for the small portion of 'Floodplain riparian forest' (0.2 km^2) within the zone of potential hydrological change.

Table 18 Summary of the hydrological response variables and corresponding receptor impact variables used in the receptor impact models for the 'Floodplain or lowland riverine' landscape group, together with the corresponding qualitative model (signed digraph) that describes the ecosystem linkages among different components

The proportion of landscape classes with surface water modelling is also provided.

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class(es) with surface water modelling	Receptor impact variable
Floodplain riparian forest	Non-Pilliga	Floodplain and lowland riverine	• Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development. • The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.	68% comprising Floodplain riparian forest and Floodplain riparian forest GDE	Projected foliage cover of dominant riparian trees (including river red gum)
Floodplain riparian forest GDE	Non-Pilliga	Floodplain and lowland riverine	• Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development. • The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.	68% comprising Floodplain riparian forest and Floodplain riparian forest GDE	Projected foliage cover of dominant riparian trees (including river red gum)

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class(es) with surface water modelling	Receptor impact variable
Floodplain wetland	Non-Pilliga	Floodplain and lowland riverine	• The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.	63% comprising Floodplain wetland and Floodplain wetland GDE	Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*) in pools and riffles
Floodplain wetland GDE	Non-Pilliga	Floodplain and lowland riverine	• The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.	63% comprising Floodplain wetland and Floodplain wetland GDE	Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*) in pools and riffles
Permanent lowland stream GDE	Non-Pilliga	Floodplain and lowland riverine	• 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. • 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.	46% comprising Permanent lowland stream GDE, Temporary lowland stream GDE, Permanent lowland stream and Temporary lowland stream	Average number of families of aquatic macroinvertebrates in edge habitat

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class(es) with surface water modelling	Receptor impact variable
Temporary lowland stream GDE	Non-Pilliga	Floodplain and lowland riverine	• 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. • 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.	46% comprising Permanent lowland stream GDE, Temporary lowland stream GDE, Permanent lowland stream and Temporary lowland stream	Average number of families of aquatic macroinvertebrates in edge habitat
Permanent lowland stream	Non-Pilliga	Floodplain and lowland riverine	• 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. • 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.	46% comprising Permanent lowland stream GDE, Temporary lowland stream GDE, Permanent lowland stream and Temporary lowland stream	Average number of families of aquatic macroinvertebrates in edge habitat
Temporary lowland stream	Non-Pilliga	Floodplain and lowland riverine	• 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. • 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.	46% comprising Permanent lowland stream GDE, Temporary lowland stream GDE, Permanent lowland stream and Temporary lowland stream	Average number of families of aquatic macroinvertebrates in edge habitat
Floodplain grassy woodland GDE	Non-Pilliga	No	No	na	No
Floodplain grassy woodland	Non-Pilliga	No	No	na	No

[a]'Non-Pilliga' as used here refers to those parts of the zone of potential hydrological change that fall outside of the 'Pilliga region'.
See Section 2.7.3 of companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) for further details.
na = not applicable

Table 19 Area (km^2) of 'Floodplain riparian forest' and 'Floodplain riparian forest GDE' landscape classes (non-Pilliga) potentially exposed to varying levels of baseline drawdown and drawdown due to additional coal resource development in the zone of potential hydrological change

Scenario	Landscape class	Area in assessment extent (km^2)	Area in zone of potential hydrological change (km^2)	Area of drawdown ≥0.2 m (km^2)			Area of drawdown ≥2 m (km^2)			Area of drawdown ≥5 m (km^2)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Baseline	Floodplain riparian forest	1.5	0.2	0	0	0	0	0	0	0	0	0
	Floodplain riparian forest GDE	148.7	72	0	0	0.1	0	0	0	0	0	0
	Total	**150.2**	**72.2**	**0**	**0**	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**
Additional coal resource development	Floodplain riparian forest	1.5	0.2	0	0	0	0	0	0	0	0	0
	Floodplain riparian forest GDE	148.7	72	0.2	0.8	2.5	0	0.6	1	0	0.3	0.5
	Total	**150.2**	**72.2**	**0.2**	**0.8**	**2.5**	**0**	**0.6**	**1**	**0**	**0.3**	**0.5**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown and additional drawdown is shown for the 5th, 50th and 95th percentiles. Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Additional drawdown is the maximum difference in drawdown (*dmax*) due to additional coal resource development relative to the baseline. Areas within mine pit exclusion zones are excluded from further analysis.
Data: Bioregional Assessment Programme (Dataset 2)

3.4.3.2.2 Surface water

The extent of surface water modelling for the floodplain riparian forest landscape classes was quite high, with approximately 68% of the total area of these two landscape classes having model data (Table 18). Of the 72 km^2 of 'Floodplain riparian forest GDE' within the zone of potential hydrological change, only 0.5 km^2 is exposed to a 50% chance of a decrease of at least one overbank event per 20 years during the 2013 to 2042 simulation period (Table 20). However, it is *very unlikely* (less than 5% chance) that the frequency of overbank flows will decrease for the 2073 to 2102 simulation period for this landscape class (0.8 km^2; Table 20). Within the riverine lowland landscape classes, 'Permanent lowland stream GDE' and 'Temporary lowland stream GDE' are *very unlikely* to be impacted as no change in either of the hydrological response variables assigned to them was detected (see Section 3.4.3.2.2 for details). No changes in overbank flows were detected in the 'Floodplain riparian forest' landscape class for any simulation periods, which covers a very small area in the zone of potential hydrological change (0.2 km^2; Table 16).

Approximately 63% of the total extent of floodplain wetlands within the zone of potential hydrological change had surface water modelling results (Table 18). Any change in overbank flow events across the extent of floodplain wetlands is *very unlikely*, with 7.7 km^2 of 'Floodplain wetland' and 19.7 km^2 of 'Floodplain wetland GDE' having a 5% chance of experiencing one less event every 50 years during the 2013 to 2042 simulation period (Table 20). However, no declines in the frequency of overbank flows for floodplain wetlands were detected for the 2073 to 2102 simulation period (Table 20).

Surface water modelling data were available for approximately 46% of the total stream length classified as lowland riverine (Table 18). Only the two most common lowland riverine landscape classes are at risk from increases in the number of zero-flow days per year, 'Permanent lowland stream' and 'Temporary lowland stream'. The 'Permanent lowland stream' landscape class encompasses 979.6 km in the zone of potential hydrological change and includes the Namoi River and lower reaches of its major tributaries: Mooki River, Maules and Coxs creeks, and Peel River (Table 21). There is a 50% chance of an increase of 20 or more zero-flow days per year in 16.9 km of the stream network classified as 'Permanent lowland stream' during the 2013 to 2042 simulation period (Table 21 and Figure 26). For the 2073 to 2102 simulation period there are only 4.4 km of stream reaches in this class having a 50% chance of an increase of 20 or more zero-flow days per year and 48.9 km where there is a 50% chance of an increase of 3 or more days (Table 21 and Figure 27). Although a much larger portion of the stream network in the zone of potential hydrological change is classified as 'Temporary lowland stream' (2062.2 km) only 9.5 km are at risk of a 50% chance of an increase of 20 or more zero-flow days (for the 2013 to 2042 simulation period; Table 21 and Figure 26). This same amount of stream is at risk of a 50% chance of an increase of 20 or more zero-flow days for the 2073 to 2102 simulation period (Table 21 and Figure 27).

A similar pattern of change was observed for the change in annual maximum zero-flow spells across the 'Permanent lowland stream' and 'Temporary lowland stream' landscape classes. For the 2013 to 2042 simulation period, 16.9 km of 'Permanent lowland stream' are exposed to a 50% chance of an increase of 10 days or more in annual maximum zero-flow spells (Table 22 and Figure 28). This value decreases (2 km) for the 2073 to 2102 simulation period for the 'Permanent lowland stream' reaches (Table 22 and Figure 29). A total of 9.5 km of 'Temporary lowland stream' is at risk of a 50% chance of an increase of 10 days or more in the annual maximum zero-flow spells for the 2013 to 2042 simulation period (Table 22 and Figure 28) and remains similar (9.5 km) for the 2073 to 2102 simulation period (Table 22 and Figure 29). It is *very unlikely* that the 'Permanent lowland stream GDE' and 'Temporary lowland stream GDE' landscape classes will be impacted by an increase in the annual maximum zero-flow spells.

Table 20 Area (km^2) of landscape classes in the 'Floodplain or lowland riverine' (non-Pilliga) landscape group potentially exposed to a decrease in overbank flow events for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Area in assessment extent (km^2)	Area in zone of potential hydrological change (km^2)	Area with one fewer event every 50 years (km^2)			Area with one fewer event every 20 years (km^2)			Area with one fewer event every 10 years (km^2)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	Floodplain riparian forest GDE	148.7	72	0	0.5	31.7	0	0.5	1.6	0	0	0.5
	Floodplain riparian forest	1.5	0.2	0	0	0	0	0	0	0	0	0
	Floodplain wetland	30.1	21.6	0	0	7.7	0	0	0.1	0	0	0
	Floodplain wetland GDE	151.8	88	0	0	19.7	0	0	0.3	0	0	0
	Total	**332.1**	**181.8**	**0**	**0.5**	**59.1**	**0**	**0.5**	**2**	**0**	**0**	**0.5**
2102	Floodplain riparian forest GDE	148.7	72	0	0	0.8	0	0	0.5	0	0	0
	Floodplain riparian forest	1.5	0.2	0	0	0	0	0	0	0	0	0
	Floodplain wetland	30.1	21.6	0	0	0	0	0	0	0	0	0
	Floodplain wetland GDE	151.8	88	0	0	0	0	0	0	0	0	0
	Total	**332.1**	**181.8**	**0**	**0**	**0.8**	**0**	**0**	**0.5**	**0**	**0**	**0**

The area potentially exposed to one fewer overbank flow event every 50, 20 and 10 years compared to the baseline period is shown for the 5th, 50th and 95th percentiles. An overbank flow event is equivalent to a peak daily streamflow exceeding a reference value equivalent to a return period of 3 years as defined from modelled baseline flow in the reference period (1983 to 2012). Areas within mine pit exclusion zones are excluded from further analysis.

Data: Bioregional Assessment Programme (Dataset 2)

Table 21 Length (km) of landscape classes in the 'Floodplain or lowland riverine' (non-Pilliga) landscape group potentially exposed to an increase in zero-flow days for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3 days (km)			Length with increase ≥20 days (km)			Length with increase ≥80 days (km)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	Permanent lowland stream	1,688.6	979.6	16.9	19.3	65.3	14.5	16.9	21.1	0	0	16.6
	Permanent lowland stream GDE	456.8	240.8	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	8,053.3	2062.2	9.5	9.5	87.7	0	9.5	9.5	0	0	9.5
	Temporary lowland stream GDE	509.3	84.3	0	0	0.8	0	0	0	0	0	0
	Total	**10,708**	**3366.9**	**26.4**	**28.8**	**153.8**	**14.5**	**26.4**	**30.6**	**0**	**0**	**26.1**
2102	Permanent lowland stream	1,688.6	979.6	4.2	48.9	62.1	0	4.4	48.9	0	0	4.4
	Permanent lowland stream GDE	456.8	240.8	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	8,053.3	2062.2	9.5	19.3	66.2	0	9.5	19.3	0	0	9.5
	Temporary lowland stream GDE	509.3	84.3	0	0	0	0	0	0	0	0	0
	Total	**10,708**	**3366.9**	**13.7**	**68.2**	**128.3**	**0**	**13.9**	**68.2**	**0**	**0**	**13.9**

The length potentially exposed to ≥3, ≥20 and ≥80 days increase in zero-flow days compared to the baseline period is shown for the 5th, 50th and 95th percentiles.
Data: Bioregional Assessment Programme (Dataset 2)

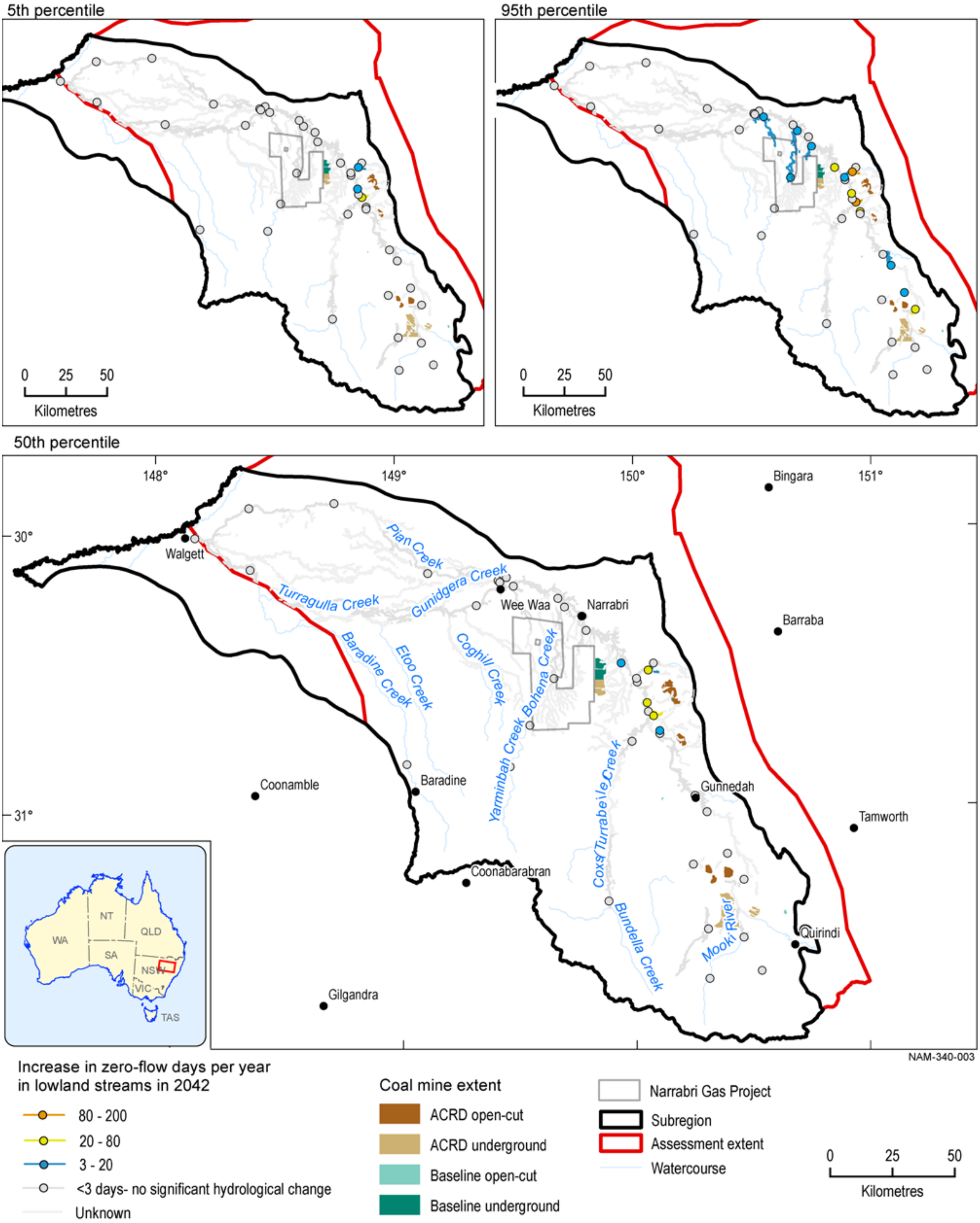

Figure 26 **Modelled increase in zero-flow days in lowland streams in 2042 in the zone of potential hydrological change**

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

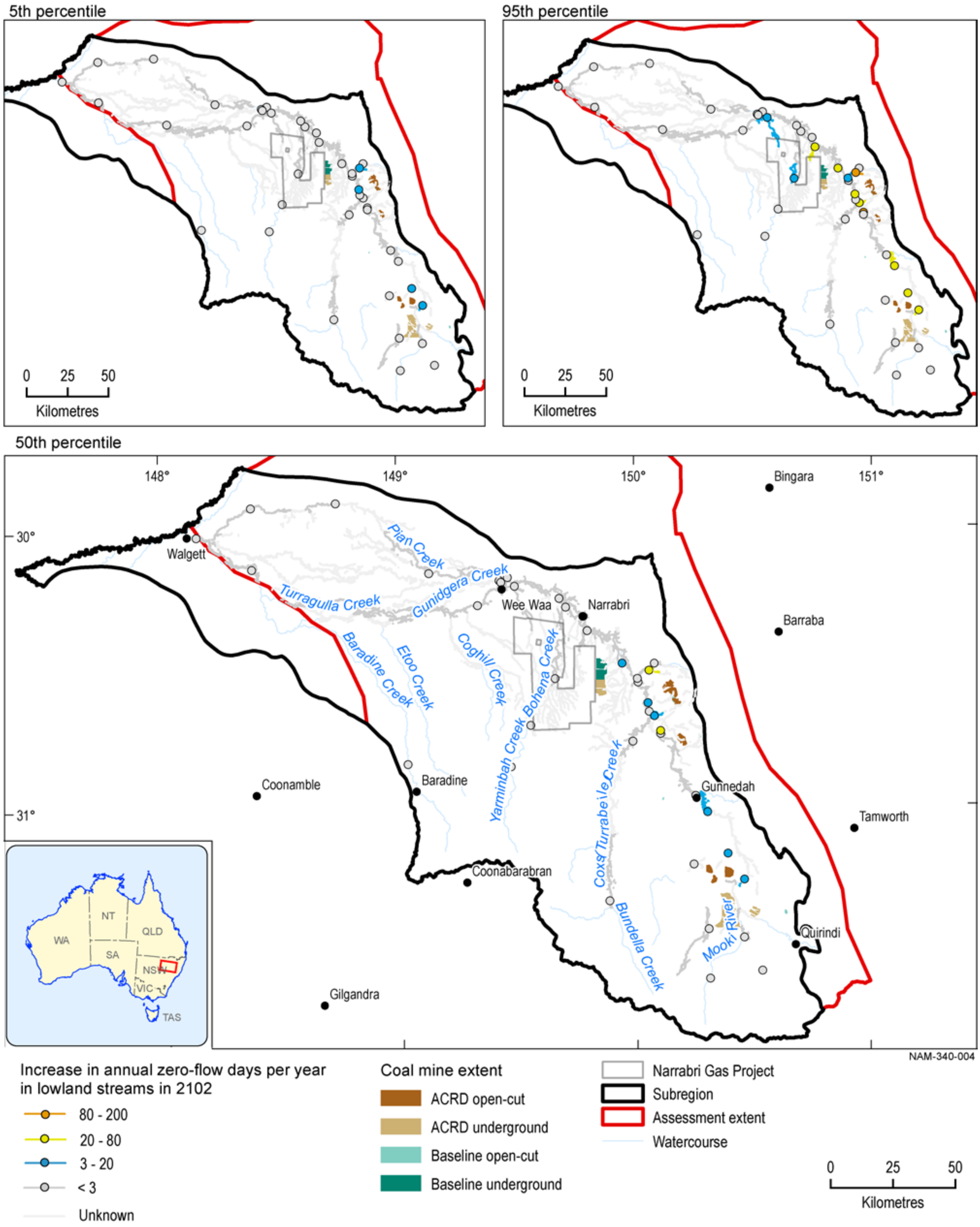

Figure 27 Modelled increase in zero-flow days in lowland streams in 2102 in the zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 2)

Table 22 Length (km) of riverine classes in the 'Floodplain or lowland riverine' (non-Pilliga) landscape group potentially exposed to an increase in annual maximum zero-flow spells for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3 days (km)			Length with increase ≥10 days (km)			Length with increase ≥40 days (km)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
2042	Permanent lowland stream	1,688.6	979.6	16.9	16.9	48.9	14.5	16.9	16.9	0	0	2.4
	Permanent lowland stream GDE	456.8	240.8	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	8,053.3	2062.2	9.5	9.5	19.3	0	9.5	9.5	0	0	9.5
	Temporary lowland stream GDE	509.3	84.3	0	0	0	0	0	0	0	0	0
	Total	**10,708**	**3366.9**	**26.4**	**26.4**	**68.2**	**14.5**	**26.4**	**26.4**	**0**	**0**	**11.9**
2102	Permanent lowland stream	1,688.6	979.6	2	6.6	48.9	0	2	21.1	0	0	2
	Permanent lowland stream GDE	456.8	240.8	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	8,053.3	2062.2	9.5	9.5	19.3	0	9.5	9.5	0	0	9.5
	Temporary lowland stream GDE	509.3	84.3	0	0	0	0	0	0	0	0	0
	Total	**10,708**	**3366.9**	**11.5**	**16.1**	**68.2**	**0**	**11.5**	**30.6**	**0**	**0**	**11.5**

The length potentially exposed to ≥3, ≥10 and ≥40 days increase in the length of the maximum zero-flow spell during the 30-year simulation period compared to the baseline period (1983 to 2012) is shown for the 5th, 50th and 95th percentiles.

Data: Bioregional Assessment Programme (Dataset 2)

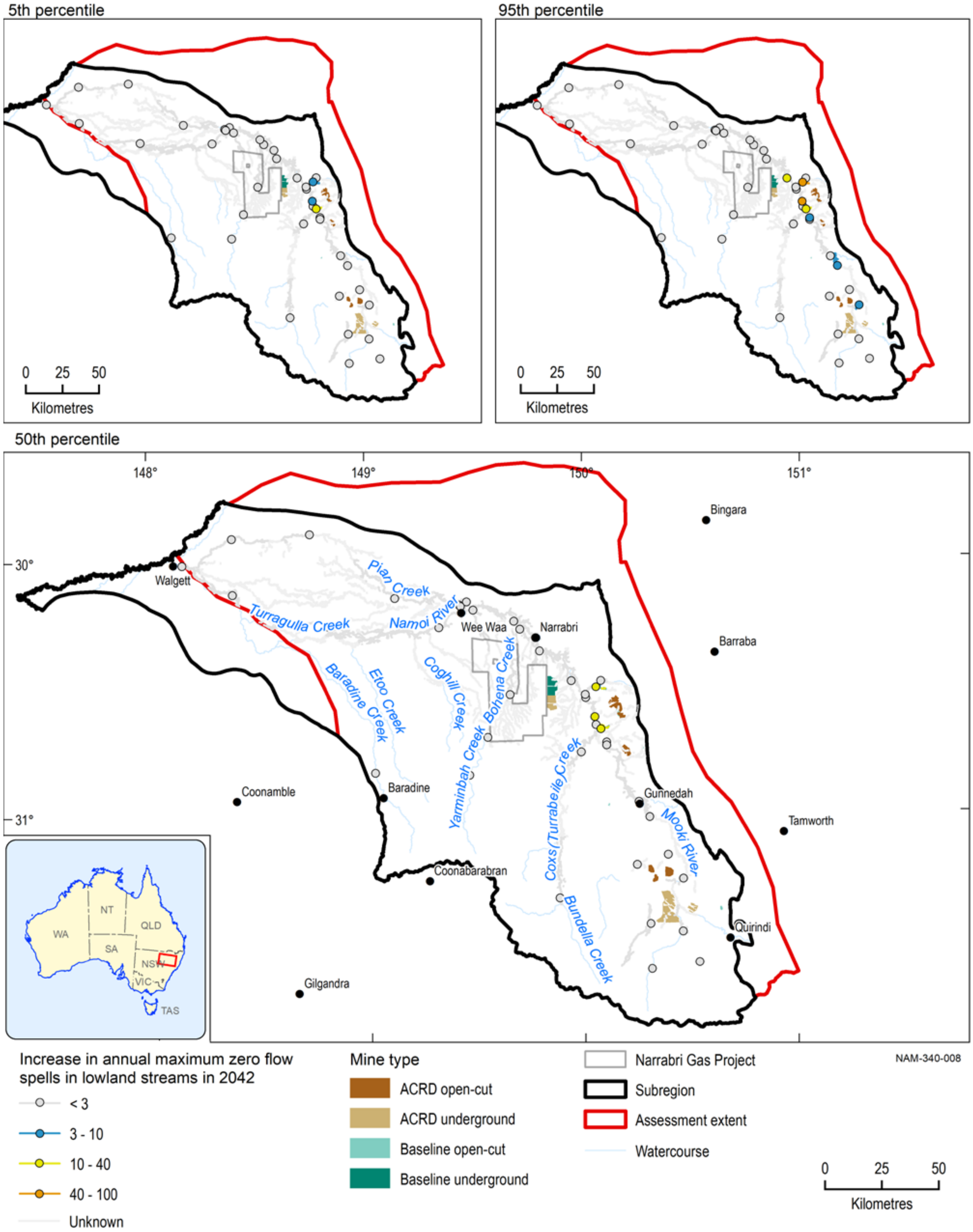

Figure 28 Modelled increase in annual maximum zero-flow spells in lowland streams in 2042 in the zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

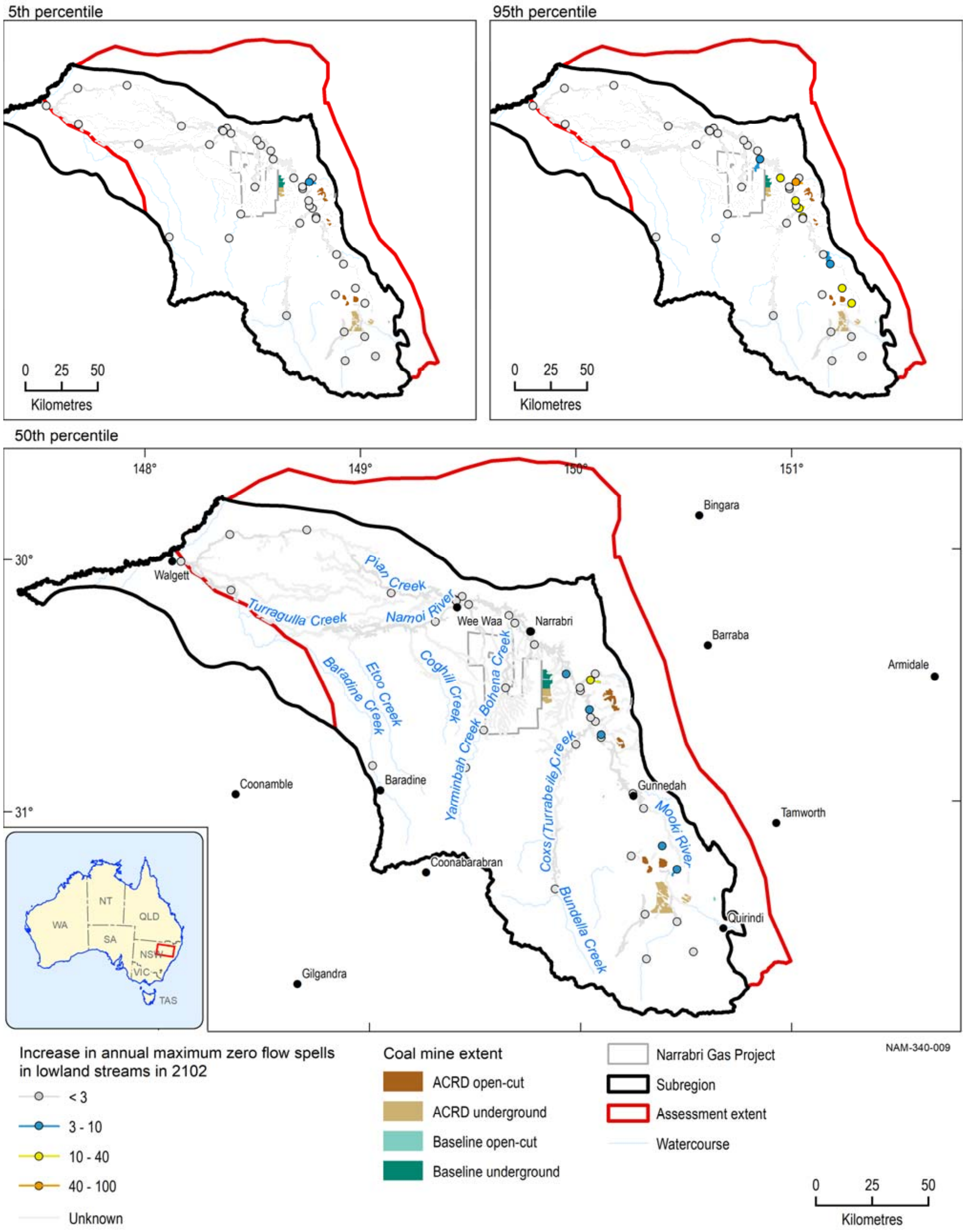

Figure 29 Modelled increase in annual maximum zero-flow spells in lowland streams in 2102 in the zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

3.4.3.3 Potential ecosystem impacts

The potential for ecosystem impacts on those areas classified as 'Floodplain or lowland riverine' within the zone of potential hydrological changes was estimated using three separate receptor impact models (see Table 18). To gauge an overall indication of ecosystem risk across this landscape group, the results of these receptor impact models were aggregated. This was done using the differences for each receptor impact variable (average number of families of aquatic macroinvertebrates, projected foliage cover of *E. camaldulensis* and the probability of presence of tadpoles from the *Limnodynastes* genus) between the CRDP and baseline futures that were derived for each assessment unit where model data were available. Three risk thresholds were defined for each receptor impact variable at the 95th percentile based on the spread of model results for each assessment unit for average number of families of aquatic macroinvertebrates, projected foliage cover and the probability of presence of tadpoles, respectively:

- 'at minimal risk of ecological and hydrological changes' – decreases less than 3, 0.10 and 0.05
- 'at some risk of ecological and hydrological changes' – decreases between 3 and 8, 0.10 and 0.2 and 0.05 and 0.15
- 'more at risk of ecological and hydrological changes' – decreases greater than 8, less than 0.2 and less than 0.15.

These thresholds were selected based on Figure 30, which presents the risk composite for the three receptor impact models based on the thresholds described above, whereby the highest level of risk determined from one or more receptor impact variables for any assessment defines the overall level of risk for that unit. The strength of this representation is in the comparison within the landscape class because it provides a measure of the relative risk and emphasises where attention should focus, and also where it should not. Where assessment units are assessed as 'more at risk' this corresponds to a level of hydrological change that may be commensurate with some ecosystem change. While receptor impact variables are chosen as indicators of ecosystem condition for a landscape class, a more detailed and local consideration of risk needs to consider the specific values at the location that community are seeking to protect (e.g. particular assets) because that will help identify meaningful thresholds. It is also necessary to bring in other lines of evidence that include the magnitude of the hydrological change and the qualitative mathematical models.

The greatest concentrations of 'more at risk' and 'at some risk' assessment units are located along the Namoi River and its tributaries, Maules Creek, Back Creek and Bollol Creek (Figure 30). Of the 1425 assessment units included in one or more of the impact models, 51 were predicted to have 'at minimal risk' and 29 'more at risk', with most of these risk categories being determined by potential impacts on lowland riverine landscape classes and floodplain wetland landscape classes. The existing condition of these stream reaches considered to be exposed to 'at some risk' or 'more at risk' is defined by the NSW river condition index (Healey et al., 2012). This mapping suggests that the combined instream value (based on distinctiveness, diversity, naturalness and vital habitat values) is high to very high in those potentially impacted reaches of the Namoi River and is low to medium along the tributaries (Department of Primary Industries, 2017). Assessments of riverine macroinvertebrate condition across the Namoi river basin indicate a poor to moderate condition in this part of the catchment (OEH, 2010a). The subsequent sections describe the specific results of each model that contribute to the observed location and magnitude of risks described here.

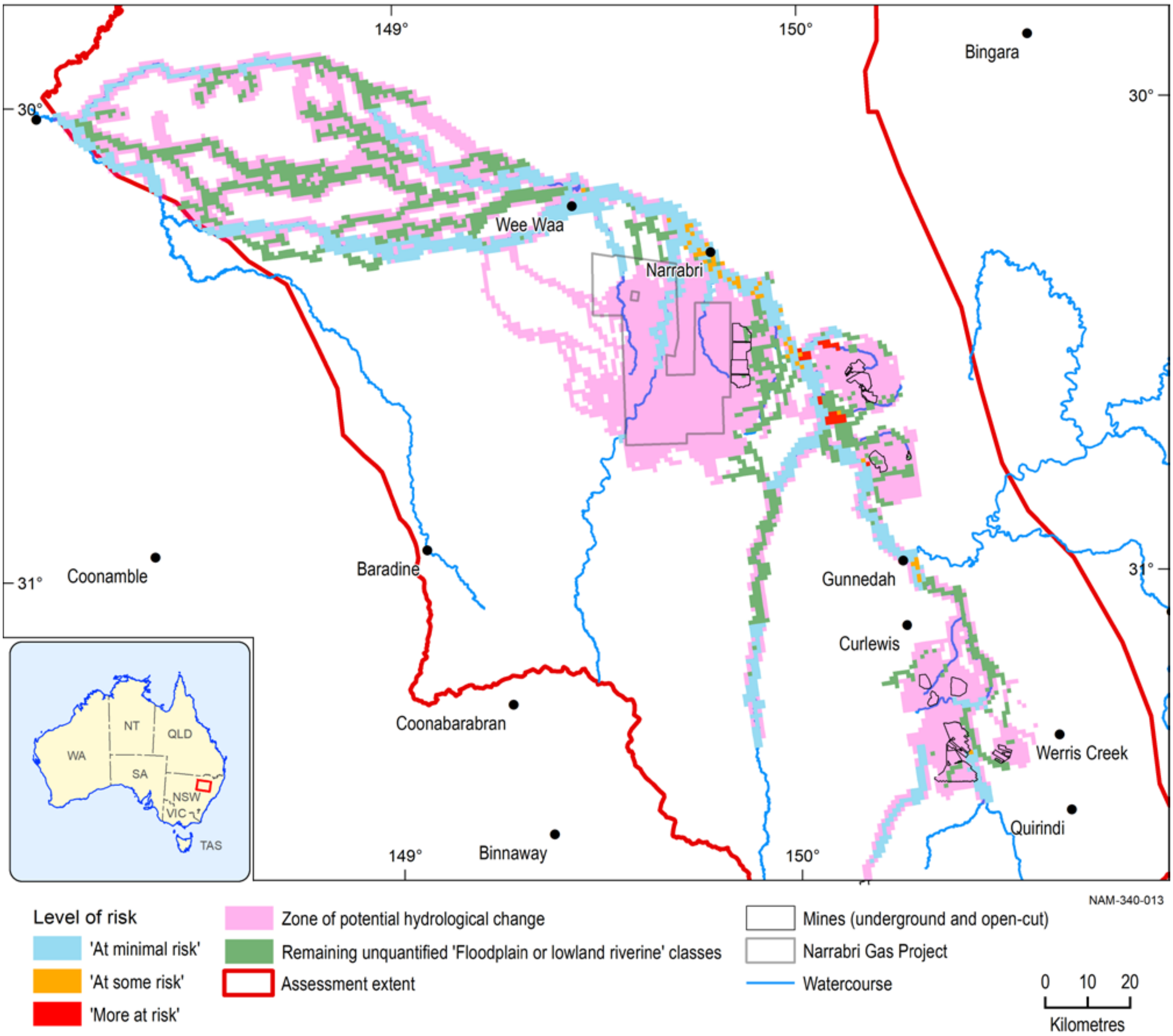

Figure 30 Composite risk map based on the results of receptor impact modelling across the 'Floodplain or lowland riverine' landscape group

The level of risk: 'at minimal risk of ecological and hydrological changes' ('at minimal risk'), 'at some risk of ecological and hydrological changes' ('at some risk') and 'more at risk of ecological and hydrological changes' ('more at risk') is presented for different assessment units where the receptor impacts are modelled for the different landscape classes. Remaining assessment units for the relevant classes in 'Floodplain or lowland riverine' group without receptor impact modelling and surface water modelling are also shown (green). Extent captures areas with 'at some risk' or 'more at risk' assessment units.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.3.3.1 Lowland riverine

The receptor impact model for lowland riverine landscape classes modelled the relationship between cease-to-flow hydrological response variables (zero-flow days and maximum zero-flow spells) and average number of families of aquatic macroinvertebrates in edge habitat (see Table 16).

There were no detectable differences in predicted mean changes, across all assessment units, in average number of families of aquatic macroinvertebrates across the lowland riverine landscape classes between baseline and CRDP futures across the different percentile simulation periods (2042 and 2102) (Figure 31a). This accords with the limited length (74.9 km of 'Permanent lowland stream' and 'Temporary lowland stream' landscape classes) of lowland streams predicted to have increases of greater than 50 days of zero-flow days and greater than 10 days of maximum zero-flow spells.

However, an assessment of the modelled changes in number of families of aquatic macroinvertebrates at a given assessment unit identified locations across the extent of the lowland riverine landscape classes that are at risk due to coal resource development (Figure 31b). Declines in predicted average number of families of aquatic macroinvertebrates due to additional coal resource development were similar between simulation periods and ranged from approximately –16 to –17 families at the 5th percentile to approximately –4 to –3 families at the 50th percentile (Figure 31b). An increase in predicted average number of families of aquatic macroinvertebrates was observed in the 95th percentile (Figure 31b).

The declines in stream discharge and attendant increases in the duration and frequency of cease-to-flow periods are likely to impact on aquatic invertebrates through changes in habitat condition and water quality and the physical extent and nature of the riverine habitat (Rolls et al., 2012). Abrupt changes in macroinvertebrate family richness may occur in the initial stages of drying in streams where drying is not common (Leigh and Datry, 2017). The magnitude and nature of the change in macroinvertebrate composition are likely to depend on whether changes in habitat are sustained enough to reduce resilience of taxa by removing potential refugia for different assemblages that can enable recovery after the cessation of the zero-flow period (Lake, 2003).

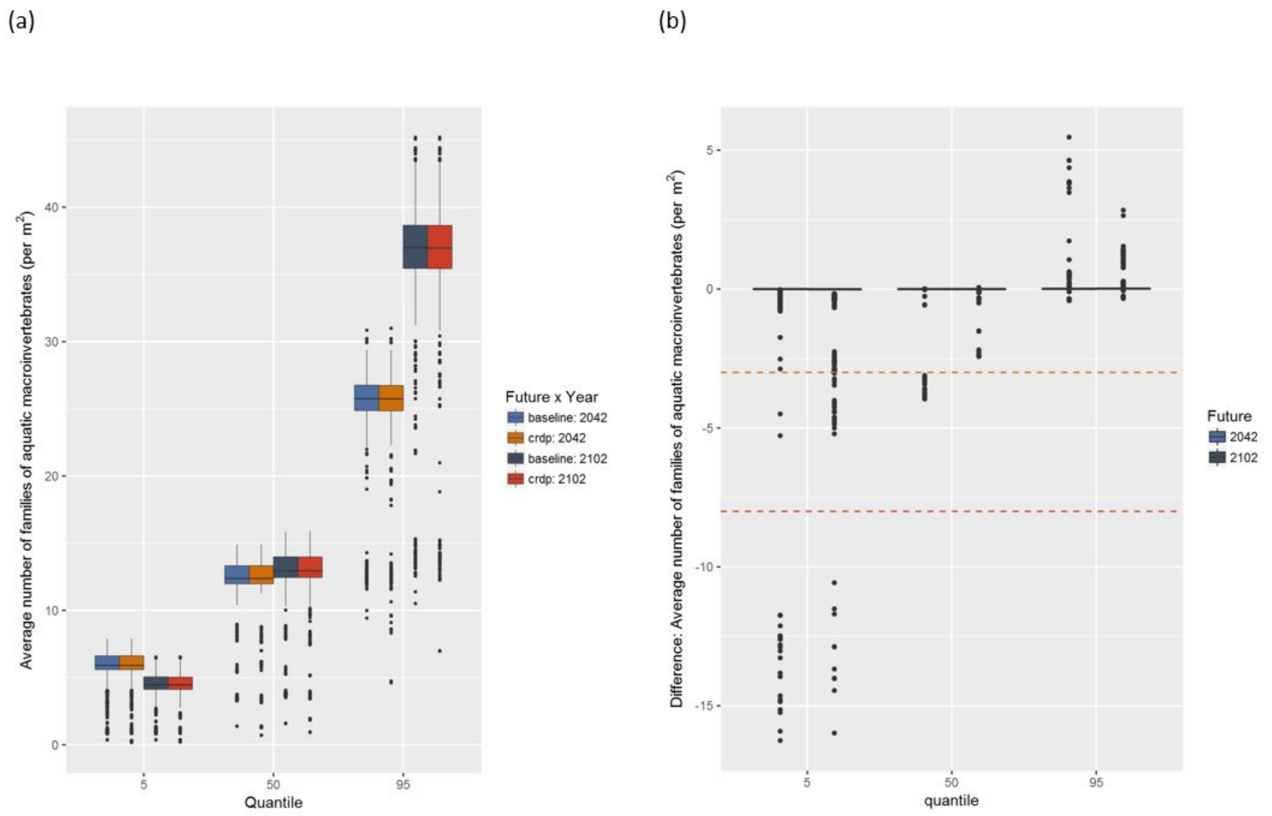

Figure 31 Modelled changes in predicted average number of families of aquatic macroinvertebrates across the lowland riverine landscape classes

(a) Box and whisker plots of modelled average number of families of aquatic macroinvertebrates in 2042 and 2102 in lowland streams under both baseline and coal resource development pathway (CRDP) futures. (b) Differences in predicted average number of families of aquatic macroinvertebrates between CRDP and baseline futures for each assessment unit containing lowland riverine landscape classes. The relevant thresholds used to delineate changes in the receptor impact variable associated with 'at some risk of ecological and hydrological changes' and 'more at risk of ecological and hydrological changes' are indicated by the orange and red dashed horizontal lines.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.3.3.2 Floodplain riparian forests

Ecological risk to the floodplain riparian forests, most commonly dominated by *E. camaldulensis*, was estimated using a receptor impact model using the response of projected foliage cover to changes in groundwater drawdown and overbank flows (see Table 18).

Similarly to lowland riverine landscape classes, no differences in projected foliage cover were detected across the extent of the riparian forests within the zone of potential hydrological change. Projected foliage cover at 2042 had a median value of 0.1 with a range of 0.02 (at the 5th percentile) to 0.38 (at the 95th percentile) (Figure 32a). Differences due to additional coal resource development within assessment units showed declines in projected foliage cover only at the 5th percentile in only a limited number of assessment units (Figure 32b), reflecting the limited area 'at some risk' to changes in groundwater drawdown and decreases in overbank flow events (Table 19 and Table 20).

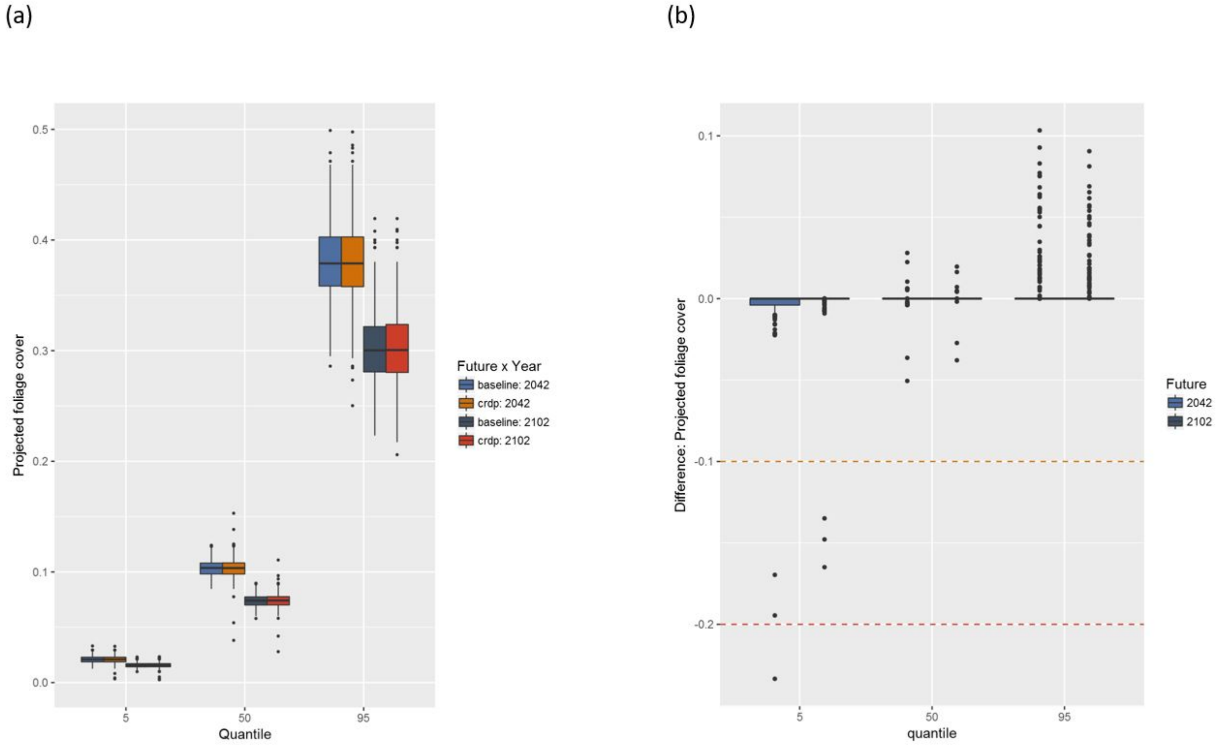

Figure 32 Modelled changes in projected foliage cover across floodplain riparian forests (‘Floodplain riparian forest GDE’ and ‘Floodplain riparian forest’ landscape classes)

(a) Box and whisker plots of projected foliage cover in 2042 and 2102 in floodplain riparian forests in under both baseline and coal resource development pathway (CRDP) futures. (b) Difference in projected foliage cover between CRDP and baseline futures for each assessment unit containing floodplain riparian forests. The relevant thresholds used to delineate changes in the receptor impact variable associated with ‘at some risk of ecological and hydrological changes’ and ‘more at risk of ecological and hydrological changes’ are indicated by the orange and red dashed horizontal lines.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.3.3.3 Floodplain wetlands

A receptor impact model for floodplain wetlands (‘Floodplain wetland’ and ‘Floodplain wetland GDE’ landscape classes) was formulated using overbank flow events as the hydrological response variable to predict changes in the probability of the presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) in pools and riffles (see Table 18).

Over the entire extent of floodplain wetlands in the zone of potential hydrological change, no differences in the probability of the presence of tadpoles were detected; median probabilities at 2042 were approximately 0.58 (ranging from 0.30 at the 5th percentile to 0.88 at the 95th percentile) (Figure 33a). At the level of the assessment unit, differences in the probability of the presence of tadpoles due to additional coal resource development were only evident at the 5th percentile with probabilities predicted to decrease up to 0.3 in the most severely impacted assessment unit (Figure 33b). Accordingly, declines in overbank flow events equivalent to one less flow event every 20 years were detected for 1.2 km^2 of floodplain wetlands adjacent to lowland streams.

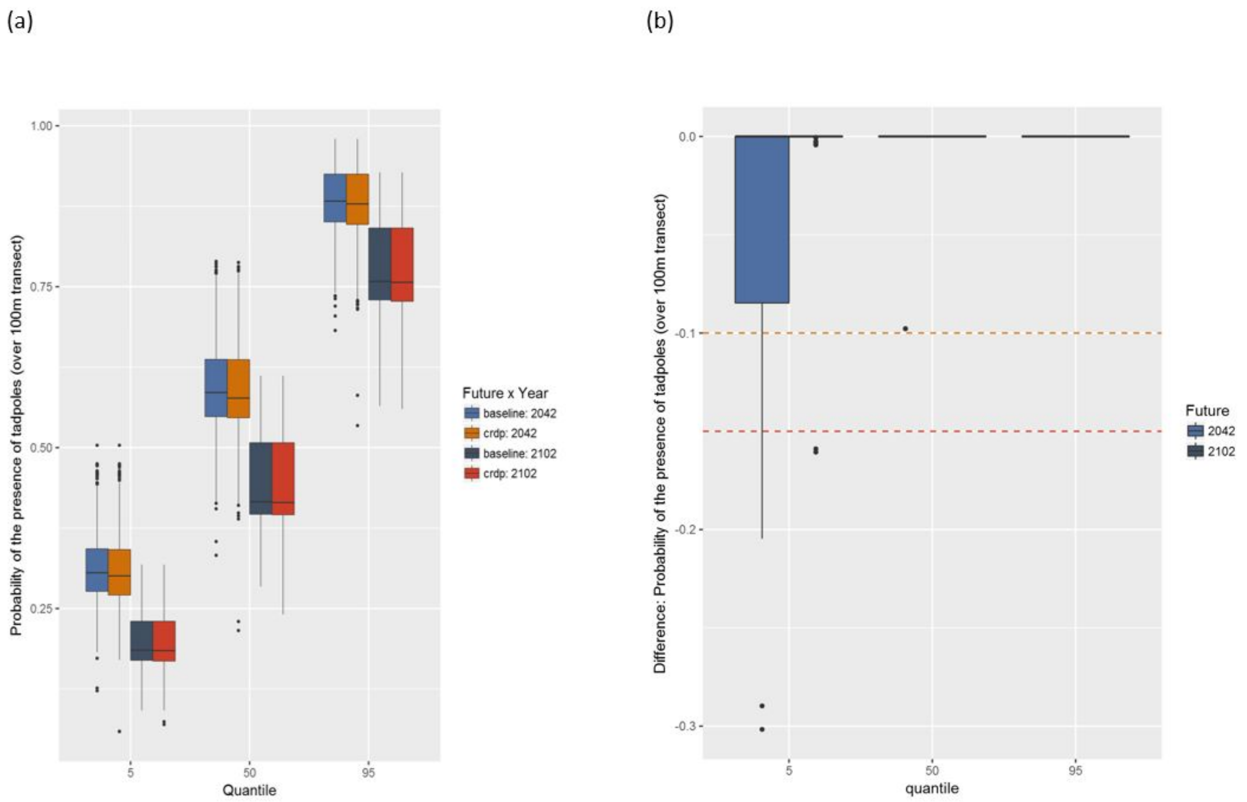

Figure 33 Modelled changes in probability of the presence of tadpoles across floodplain wetlands (‘Floodplain wetland GDE’ and ‘Floodplain wetland’ landscape classes)

(a) Box and whisker plots of probability of the presence of tadpoles in 2042 and 2102 in floodplain wetlands under both baseline and coal resource development pathway (CRDP) futures. (b) Difference in the probability of the presence of tadpoles cover between the CRDP and baseline futures for each assessment unit. The relevant thresholds used to delineate changes in the receptor impact variable associated with ‘at some risk of ecological and hydrological changes’ and ‘more at risk of ecological and hydrological changes’ are indicated by the orange and red dashed horizontal lines.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.4 ‘Non-floodplain or upland riverine’ (non-Pilliga) landscape group

3.4.4.1 Description

The ‘Non-floodplain or upland riverine’ landscape group, excluding the Pilliga region, encompasses those landscapes that are typically located away from the broader, floodplain and alluvium landscapes along the Liverpool Plains and Castlereagh-Barwon IBRA subregions (SEWPaC, 2012). Within the zone of potential hydrological change, the upland stream network consists of predominantly minor tributaries to Back Creek (eastern portion of the zone), minor tributaries to the Mooki River and Coxs Creek in the southern portion of the zone and forms most of the stream network in the eastern portion of the Pilliga region. Most of the stream network in the zone of potential hydrological change is classified as ‘Temporary upland stream’ reflecting the highly intermittent and/or ephemeral nature of surface water flow across much of the upland riverine network. The non-riverine landscape classes within this group include remnant vegetation in the riparian zone along the stream channel (‘Upland riparian forest GDE’ landscape class, less than 0.1% of the zone of potential hydrological change), groundwater-dependent vegetation across different landforms (‘Grassy woodland GDE’ landscape class, approximately 1% of the zone) and non-floodplain wetlands (‘Non-floodplain wetland’ and ‘Non-floodplain wetland GDE’ landscape classes, 0.2% and 0.1% of the zone, respectively (Table 23). Further background description of this landscape group is provided in Section 2.7.4 of companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018).

Table 23 Area (km²) and/or length (km) of landscape classes in the 'Non-floodplain or upland riverine' landscape group within the entire assessment extent and the non-Pilliga region of the zone of potential hydrological change

The percentage of each landscape class' contribution to the total area of the zone of potential hydrological change is also given.

Landscape class	Area in assessment extent (km²)	Area in zone of potential hydrological change (km²)	Percentage of total area in zone of potential hydrological change (%)	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Percentage of total length in zone of potential hydrological change (%)
Grassy woodland GDE	3,247.6	72.8	1%	na	na	na
Non-floodplain wetland	130.3	13.1	0.2%	na	na	na
Non-floodplain wetland GDE	23.5	8.1	0.1%	na	na	na
Upland riparian forest GDE	87.4	2.9	<0.1%	na	na	na
Permanent upland stream	0.1	0	0%	1,646.1	92.6	1.7%
Permanent upland stream GDE	1.1	0.1	<0.1%	227.4	14.2	0.3%
Temporary upland stream	0	0	0%	16,512.8	745.1	13.5%
Temporary upland stream GDE	0.1	0	0%	464	34.7	0.6%
Total – 'Non-floodplain or upland riverine' landscape classes	**3,490.1**	**97**	**1.4%**	**18,850.3**	**886.6**	**16.1%**
Total – All landscape classes	**35,659.6**	**7013.9**	**100%**	**29,558.3**	**5521.2**	**100%**

na = 'not available'

Data: Bioregional Assessments (Dataset 2)

3.4.4.2 *Potential hydrological impacts*

The key hydrological determinants of ecosystem function identified by experts in the qualitative modelling workshops (see Section 2.7.4 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)) have been interpreted as a set of hydrological response variables for each landscape class (Table 24). Hydrological response variables were assigned for two separate components of the upland riverine system based on recognised ecohydrological linkages between water regime and ecosystem health. Firstly, changes in the projected foliage cover in the riparian zone were modelled based on maximum groundwater drawdown and changes in the frequency of overbank flows (Table 24). Secondly, changes in assemblages of macroinvertebrates in instream pool habitats and changes in presence of tadpoles were modelled using attributes of zero flow, annual number of zero-flow days and annual maximum zero-flow spells (defined in Table 24).

3.4.4.2.1 Groundwater

Changes in maximum drawdown along upland streams identified as ‘Upland riparian forest GDE’ were very small with intersected areas exposed to 5% chance of drawdown greater than 0.2 m in the zone of potential hydrological change (Table 25).

Table 24 Summary of the hydrological response variables and corresponding receptor impact variables used in the receptor impact models for the 'Non-floodplain or upland riverine' landscape group, together with the corresponding qualitative model (signed digraph) that describes the ecosystem linkages among different components

The proportion of landscape classes with surface water modelling is also provided.

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class with surface water modelling (%)	Receptor impact variable
Upland riparian forest GDE	Non-Pilliga	Upland riverine	• Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development. • The mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.	100%	Projected foliage cover of riparian trees

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class with surface water modelling (%)	Receptor impact variable
Permanent upland stream GDE	Non-Pilliga	Upland riverine	• 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. • 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.	20% comprising Permanent upland stream GDE, Temporary upland stream GDE, Permanent upland stream, Temporary upland stream	• Average number of families of aquatic macroinvertebrates in instream pool habitat • Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*)
Temporary upland stream GDE	Non-Pilliga	Upland riverine	• 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. • 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.	20% comprising Permanent upland stream GDE, Temporary upland stream GDE, Permanent upland stream, Temporary upland stream	• Average number of families of aquatic macroinvertebrates in instream pool habitat • Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*)
Permanent upland stream	Non-Pilliga	Upland riverine	• 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. • 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.	20% comprising Permanent upland stream GDE, Temporary upland stream GDE, Permanent upland stream, Temporary upland stream	• Average number of families of aquatic macroinvertebrates in instream pool habitat • Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*)

Landscape class	Reporting region/basin[a]	Qualitative model	Hydrological response variable	Proportion of total landscape class with surface water modelling (%)	Receptor impact variable
Temporary upland stream	Non-Pilliga	Upland riverine	• 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. • 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.	20% comprising Permanent upland stream GDE, Temporary upland stream GDE, Permanent upland stream, Temporary upland stream	• Average number of families of aquatic macroinvertebrates in instream pool habitat • Probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii*, *L. salmini*, *L. interioris* and *L. terraereginae*)
Grassy woodland GDE	All	Grassy woodland GDE	No	na	No
Non-floodplain wetland GDE	All	Non-floodplain wetland	No	na	No
Non-floodplain wetland	All	Non-floodplain wetland	No	na	No

[a] 'Non-Pilliga' as used here refers to those parts of the zone of potential hydrological change that fall outside of the 'Pilliga region'. See Section 2.7.4 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) for further details.
na = not applicable

Table 25 Area (km²) of landscape classes in the 'Non-floodplain or upland riverine' landscape group (non-Pilliga) potentially exposed to varying levels of baseline drawdown and drawdown due to additional coal resource development in the zone of potential hydrological change

Scenario	Landscape class	Area in assessment extent (km²)	Area in zone of potential hydrological change (km²)	Area of drawdown ≥0.2 m (km²)			Area of drawdown ≥2 m (km²)			Area of drawdown ≥5 m (km²)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Baseline	Upland riparian forest GDE	87.4	2.9	0	0	0	0	0	0	0	0	0
	Total	**87.4**	**2.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Additional coal resource development	Upland riparian forest GDE	87.4	2.9	0	0	0.1	0	0	0	0	0	0
	Total	**87.4**	**2.9**	**0**	**0**	**0.1**	**0**	**0**	**0**	**0**	**0**	**0**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown and additional drawdown is shown for the 5th, 50th and 95th percentiles. Baseline drawdown is the maximum difference in drawdown (*dmax*) under the baseline relative to no coal resource development. Additional drawdown is the maximum difference in drawdown (*dmax*) due to additional coal resource development relative to the baseline. Areas within mine pit exclusion zones are excluded from further analysis.
Data: Bioregional Assessment Programme (Dataset 2)

3.4.4.2.2 Surface water

Only 20% of the upland riverine landscape classes had surface water modelling data available (Table 24). For those upland riverine classes where modelling data was available a total of 8.1 km are exposed to a 50% chance of increases in zero-flow days greater than 3 days during the 2013 to 2042 simulation period. Only two upland riverine landscape classes, 'Temporary upland stream' and 'Temporary upland stream GDE', are exposed to a 50% chance of increases in zero-flow days greater than 20 days (2.2 km and 2.6 km, respectively) for the 2013 to 2042 simulation period (Table 26). For the 2073 to 2102 simulation period, the increase in zero-flow days is similar, with the 'Temporary upland stream' and 'Temporary upland stream GDE' landscape classes exposed to a 50% chance of increases in zero-flow days greater than 20 days (2.2 and 2.6 km, respectively; Table 26). Further, there are 22.3 km of the upland riverine landscape classes exposed to a 50% chance of increases in zero-flow days greater than 3 days during this period (Table 26, Figure 34).

Both 'Temporary upland stream' and 'Temporary upland stream GDE' landscape classes are exposed to a 50% chance of annual maximum zero-flow spells increasing greater than 10 days during the 2013 to 2042 simulation period (2.2 and 2.6 km, respectively; Table 27). For the 2073 to 2102 simulation period, there are similar stream reaches having a 50% chance of annual maximum zero-flow spells increasing greater than 10 days for the 'Temporary upland stream' and 'Temporary upland stream GDE' (Table 27, Figure 35).

Only a very small area (0.3 km^2) of the 'Upland riparian forest GDE' landscape class has a 5% chance of one less overbank flow event every 50 years (during the 2013 to 2042 simulation period), indicating a very small potential impact on this landscape class based on the surface water modelling results (data not shown).

Table 26 Length (km) of landscape classes in the 'Non-floodplain or upland riverine' (non-Pilliga) landscape group potentially exposed to an increase in zero-flow days for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3 days (km)			Length with increase ≥20 days (km)			Length with increase ≥80 days (km)		
				5th	50th	95th	5th	50th	95th	50th	95th	95th
2042	Permanent upland stream	1,646.1	92.6	0	3.1	13.5	0	0	9.5	0	0	0
	Permanent upland stream GDE	227.4	14.2	0	0.2	2.6	0	0	0.2	0	0	0
	Temporary upland stream	16,512.8	745.1	2.2	2.2	5.9	0	2.2	2.4	0	0	2.2
	Temporary upland stream GDE	464	34.7	2.6	2.6	2.6	0	2.6	2.6	0	0	2.6
	Total	**18,850.3**	**886.6**	**4.8**	**8.1**	**24.6**	**0**	**4.8**	**14.7**	**0**	**0**	**4.8**
2102	Permanent upland stream	1,646.1	92.6	6.4	13.5	13.5	0	0	13.5	0	0	0
	Permanent upland stream GDE	227.4	14.2	0	1.4	2.4	0	0	1.4	0	0	0
	Temporary upland stream	16,512.8	745.1	2.4	4.8	5.9	0	2.2	4.8	0	0	2.2
	Temporary upland stream GDE	464	34.7	2.6	2.6	2.6	0	2.6	2.6	0	0	2.6
	Total	**18,850.3**	**886.6**	**11.4**	**22.3**	**24.4**	**0**	**4.8**	**22.3**	**0**	**0**	**4.8**

The length potentially exposed to ≥3, ≥20 and ≥80 days increase in zero-flow days for the 30-year simulation period compared to the baseline period (1983 to 2012) is shown for the 5th, 50th and 95th percentiles. Areas within mine pit exclusion zones are excluded from further analysis.
Data: Bioregional Assessment Programme (Dataset 2)

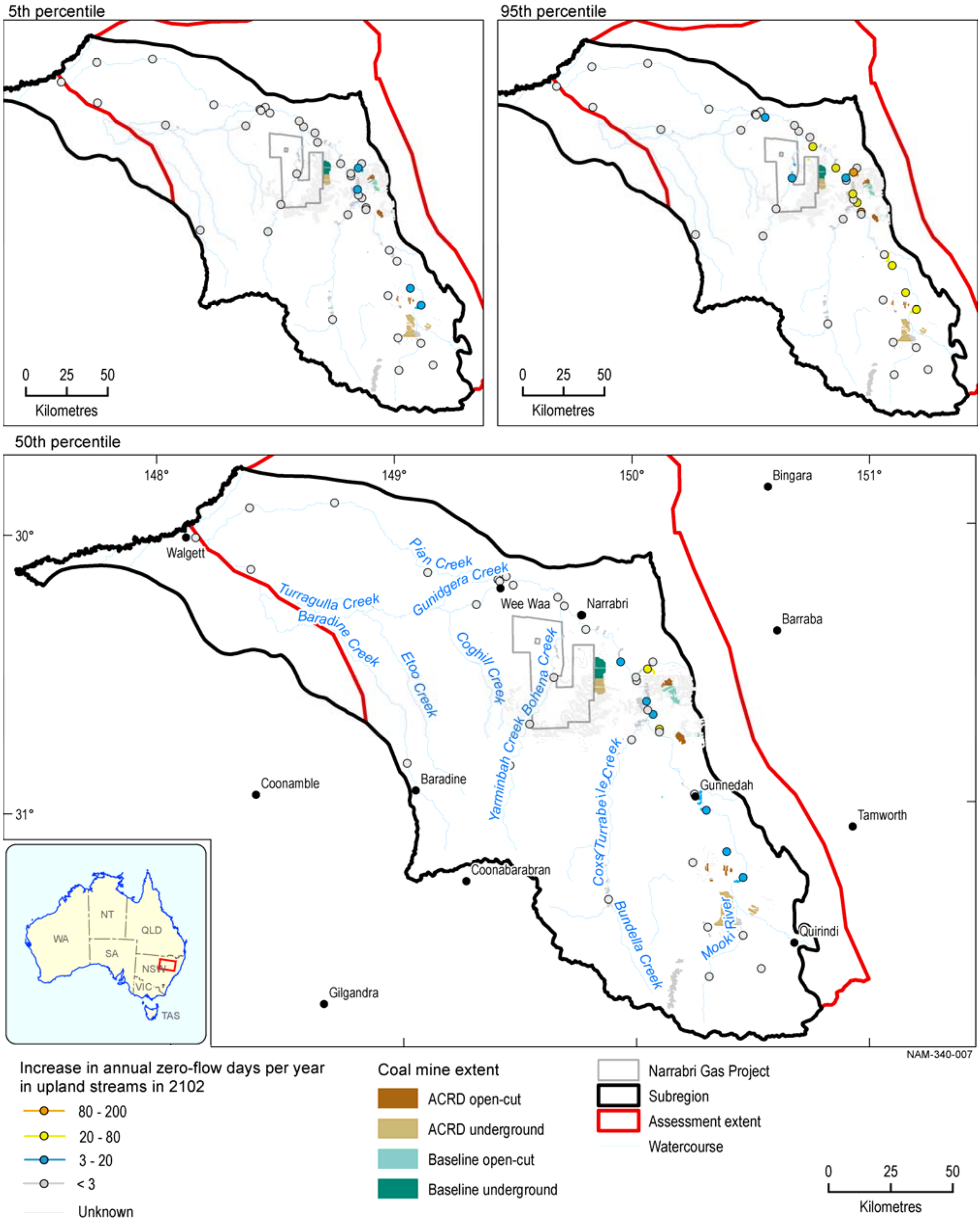

Figure 34 Modelled increase in annual zero-flow days in upland streams (non-Pilliga) in 2102 in the zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

Table 27 Length (km) of landscape classes in the 'Non-floodplain or upland riverine' (non-Pilliga) landscape group potentially exposed to an increase in annual maximum zero-flow spells for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change.

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3 days (km)			Length with increase ≥10 days (km)			Length with increase ≥40 days (km)		
				5th	50th	95th	5th	50th	95th	50th	95th	95th
2042	Permanent upland stream	1,646.1	92.6	0	0	13.5	0	0	3.1	0	0	0
	Permanent upland stream GDE	227.4	14.2	0	0	1.4	0	0	0.2	0	0	0
	Temporary upland stream	16,512.8	745.1	2.2	2.2	4.8	0	2.2	2.2	0	0	2.2
	Temporary upland stream GDE	464	34.7	2.6	2.6	2.6	0	2.6	2.6	0	0	2.6
	Total	**18,850.3**	**886.6**	**4.8**	**4.8**	**22.3**	**0**	**4.8**	**8.1**	**0**	**0**	**4.8**
2102	Permanent upland stream	1,646.1	92.6	0	9.5	13.5	0	0	9.5	0	0	0
	Permanent upland stream GDE	227.4	14.2	0	0.2	1.4	0	0	0.2	0	0	0
	Temporary upland stream	16,512.8	745.1	2.2	2.4	4.8	0	2.2	2.4	0	0	2.2
	Temporary upland stream GDE	464	34.7	2.6	2.6	2.6	0	2.6	2.6	0	0	2.6
	Total	**18,850.3**	**886.6**	**4.8**	**14.7**	**22.3**	**0**	**4.8**	**14.7**	**0**	**0**	**4.8**

The length potentially exposed to ≥3, ≥10 and ≥40 days increase in the length of the maximum zero-flow spell during the 30-year simulation period compared to the baseline period (1983 to 2012) is shown for the 5th, 50th and 95th percentiles. Areas within mine pit exclusion zones are excluded from further analysis.

Data: Bioregional Assessment Programme (Dataset 2)

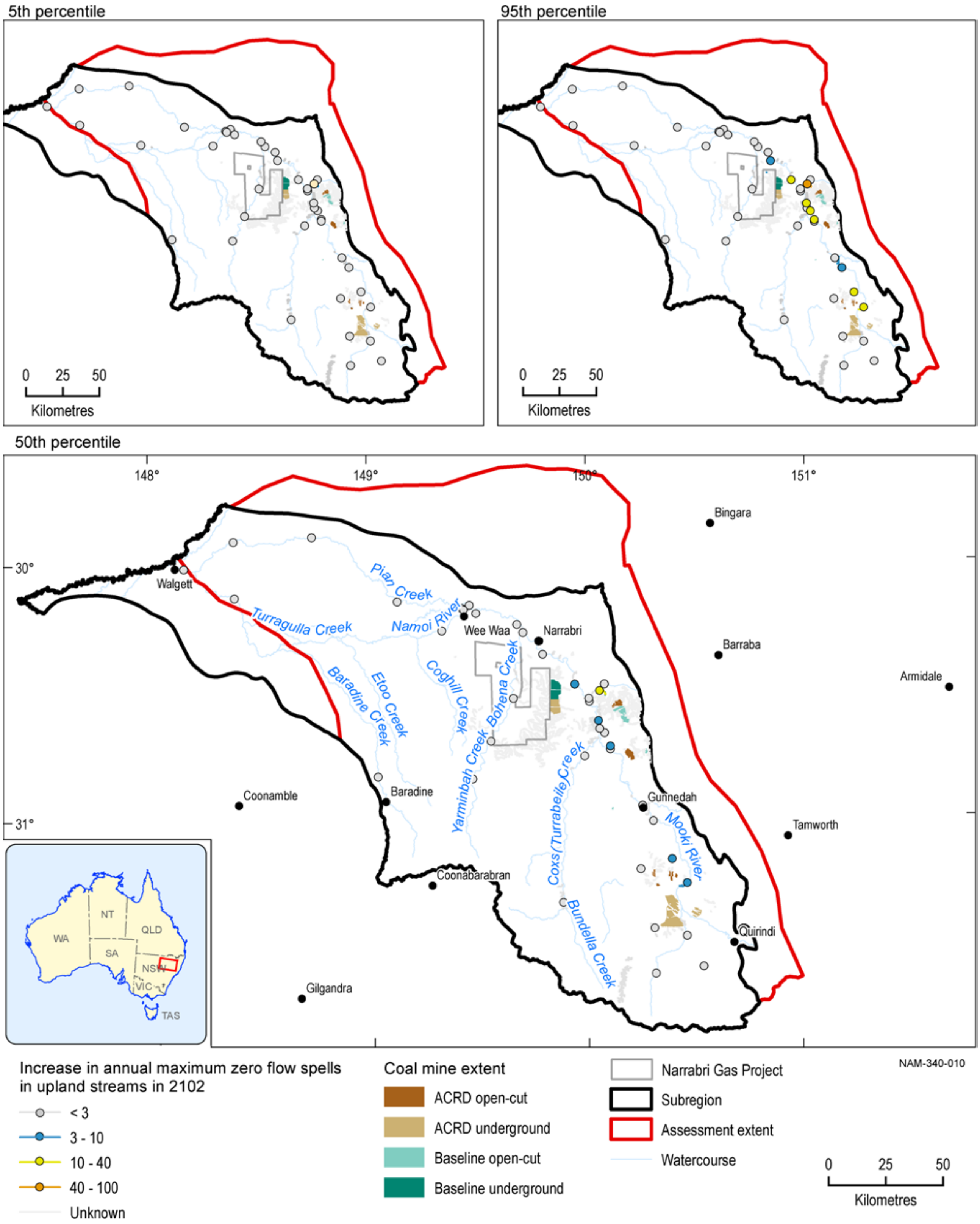

Figure 35 Modelled increase in annual maximum zero-flow spells in upland streams (non-Pilliga) in 2102 in the zone of potential hydrological change

The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

3.4.4.3 Potential ecosystem impacts

The potential for ecosystem impacts on those areas classified as ‘Non-floodplain or upland riverine’ within the zone of potential hydrological changes was estimated using three separate receptor impact models (see Table 24). To gauge an overall indication of ecosystem risk across this landscape group, the results of these receptor impact models were aggregated. This was done using the differences for each receptor impact variable (average number of families of aquatic macroinvertebrates, projected foliage cover of riparian vegetation dominated by *C. cunninghamiana* and the probability of presence of tadpoles from the *Limnodynastes* genus) between the CRDP and baseline futures that were derived for each assessment unit where model data were available. The risk thresholds used for defining risk and the associated terminology are identical to that applied to the receptor impact variables assigned to the landscape classes in the ‘Floodplain or lowland riverine’ landscape group (Section 3.4.3.3).

The composite of all receptor impact models is presented in Figure 36, whereby the highest level of risk determined from one or more receptor impact variables for any assessment defines the overall level of risk for that assessment unit. Only a small area on or adjacent to Maules Creek was identified as being ‘more at risk of ecological and hydrological changes’ (Figure 36), and therefore worthy of more emphasis in any subsequent follow up with local analyses and monitoring. These follow-up assessments should also consider other suitable locations where modelling data were unavailable. Analogous to the ‘Floodplain or lowland riverine’ landscape group, a more detailed and local consideration of risk needs to consider the specific values at the location that community are seeking to protect (e.g. particular assets), and bring in other lines of evidence that include the magnitude of the hydrological change and the qualitative mathematical models.

There was a considerable proportion (80%) of the potentially impacted landscape classes in this group where ecological impacts could not be quantified due to a lack of surface water modelling data (Table 24 and Figure 36). While much of these unquantified areas are upstream of the areas of coal resource development, this current analysis only applies to a limited extent of the upland riverine landscape classes. The subsequent sections describe the specific results of each model that contribute to the observed location and magnitude of risks described here.

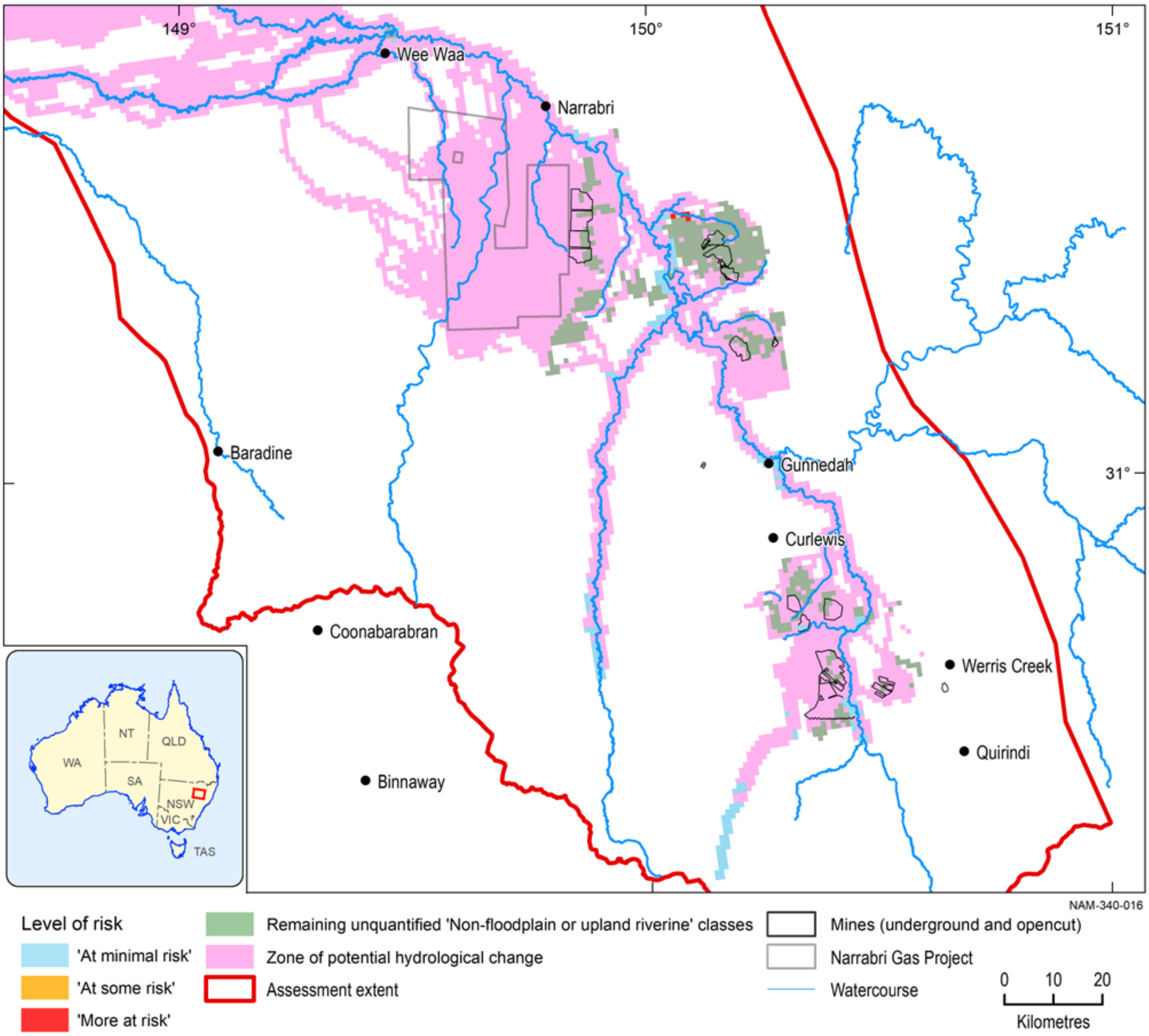

Figure 36 Composite risk map based on the results of receptor impact modelling across the 'Non-floodplain or upland' landscape group

The level of risk: 'at minimal risk of ecological and hydrological changes' ('at minimal risk'), 'at some risk of ecological and hydrological changes' ('at some risk') and 'more at risk of ecological and hydrological changes' ('more at risk') is presented for different assessment units where the receptor impacts are modelled for the different landscape classes. Remaining assessment units for the relevant landscape classes in the 'Non-floodplain or upland riverine' landscape group without receptor impact modelling and surface water modelling are also shown (green). Extent captures areas with 'at some risk' or 'more at risk' assessment units.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.4.3.1 Upland riverine

The receptor impact model for upland riverine landscape classes modelled the relationship between cease-to-flow hydrological response variables (zero-flow days and maximum zero-flow spells) and two receptor impact variables: average number of families of aquatic macroinvertebrates in edge habitat and the probability of presence of tadpoles from the *Limnodynastes* genus (*L. dumerilii, L. salmini, L. interioris* and *L. terraereginae*) (see Table 24).

There were no detectable differences in predicted mean changes in either average number of families of aquatic macroinvertebrates or the probability of presence of tadpoles across the upland riverine landscape classes between the baseline and CRDP futures across the different percentile simulation periods (2042 and 2102) (Figure 37a and c). However, an assessment of the modelled changes in the number of families of aquatic macroinvertebrates or the probability of presence of tadpoles at a given assessment unit identified locations across the extent of the lowland riverine landscape classes that are at risk due to coal resource development (Figure 37b and d). Declines in the average number of families of aquatic macroinvertebrates due to additional coal resource development were similar between simulation periods and ranged from approximately –12 families at the 5th percentile to approximately –3 families at the 50th percentile (Figure 37b). An increase in the average number of families of aquatic macroinvertebrates was observed at the 95th percentile (Figure 37b). Changes in the probability of tadpoles ranged from approximately –0.7 to –0.2 between the 5th and 50th percentile and was greater for the simulation period to 2042 (Figure 37d).

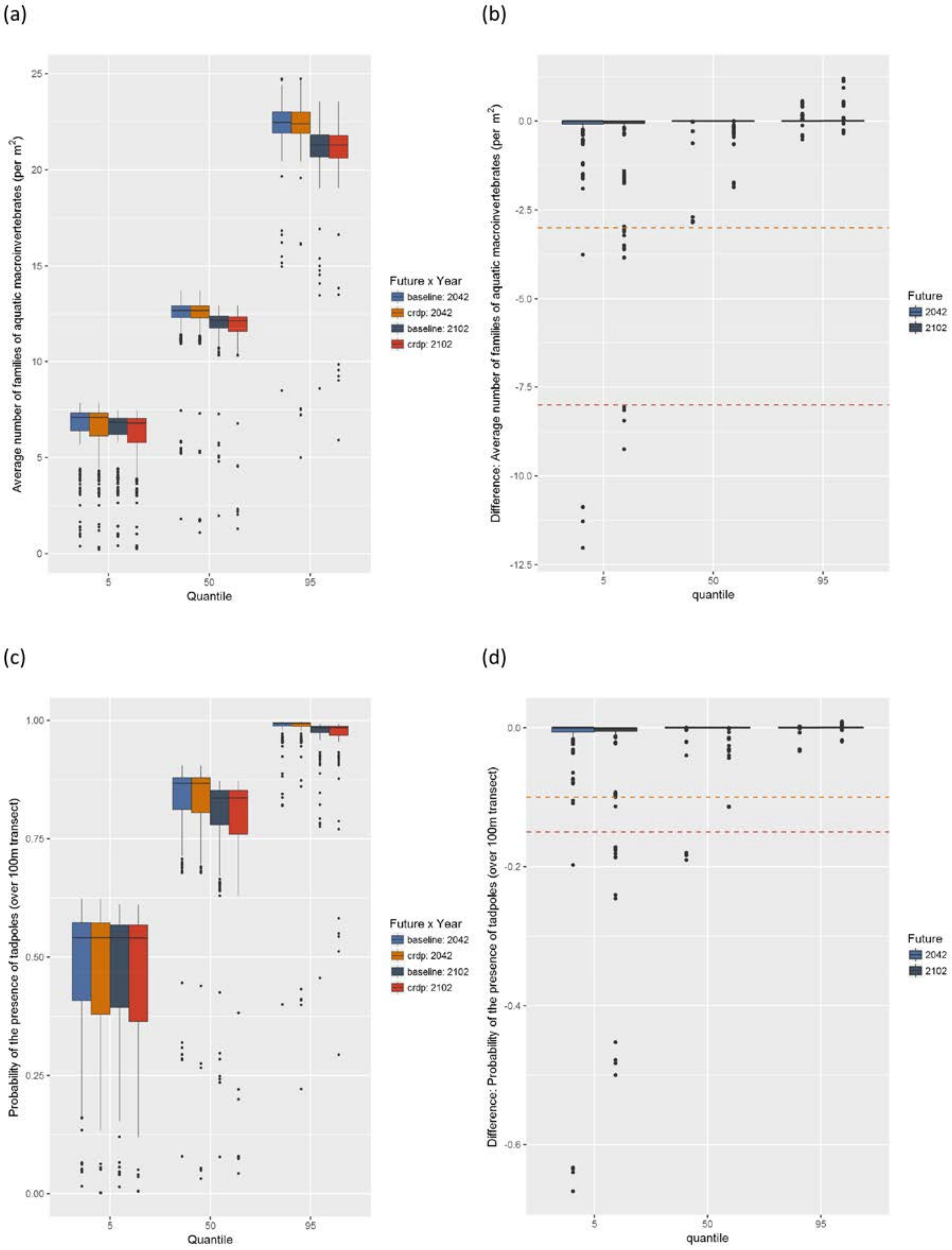

Figure 37 Box and whisker plots of two separate receptor impact models for upland riverine landscape classes in 2042 and 2102 under both baseline and coal resource development pathway (CRDP) futures

Box and whisker plots of modelled (a) average number of families of aquatic macroinvertebrates and (c) probability of the presence of tadpoles in 2042 and 2102 in upland riverine landscape classes under both baseline and coal resource development pathway (CRDP) futures. Differences in (b) average number of families of aquatic macroinvertebrates and (d) probability of the presence of tadpoles between CRDP and baseline futures for each assessment unit containing upland riverine landscape classes.
The relevant thresholds used to delineate changes in the receptor impact variable associated with ‘at some risk of ecological and hydrological changes’ and ‘more at risk of ecological and hydrological changes’ are indicated by the orange and red dashed horizontal lines.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.4.3.2 Upland riparian forest GDE

The receptor impact model for the 'Upland riparian forest GDE' landscape class was based on the relationship between the effect of changes in groundwater drawdown and the frequency of overbank flows on projected foliage cover in the riparian trees (dominated by *C. cunninghamiana*) (see Table 24).

Projected foliage cover estimates between the baseline and CRDP were similar across different model percentiles and ranged from 0.09 to 0.47 from the 5th to 95th percentiles, respectively (Figure 38a). No assessment units were predicted to experience declines in projected foliage cover with the additional coal resource development for either simulation period (Figure 38b). The limited change in this receptor impact variable is consistent with the associated hydrological response variables, where very small parts of the 'Upland riparian forest GDE' landscape class were exposed to changes in additional groundwater drawdown or the frequency of overbank flows.

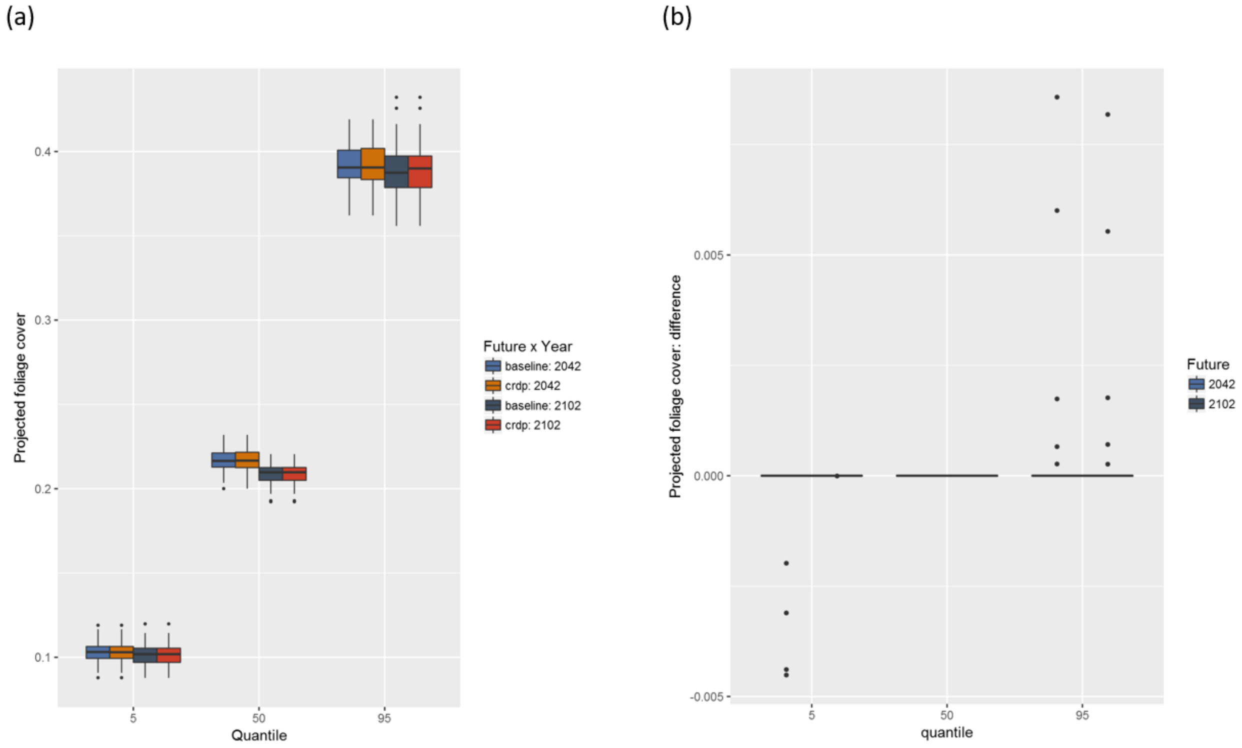

Figure 38 Modelled changes in projected foliage cover across the 'Upland riparian forest GDE' landscape class

(a) Box and whisker plots of projected foliage cover for 2042 and 2102 in upland riparian forests in under both baseline and coal resource development pathway (CRDP) futures. (b) Difference in projected foliage projected cover between CRDP and baseline futures for each assessment unit containing 'Upland riparian forest GDE' classes
Data: Bioregional Assessment Programme (Dataset 5)

3.4.5 Pilliga riverine (upland and lowland)

3.4.5.1 Description

As discussed in Section 3.4.1, the unique ecosystems within the Pilliga and Pilliga Outwash IBRA subregions were treated separately when developing ecological models. Given the relatively low relief and subtle changes between those streams classified as ‘lowland’ and ‘upland’ across much of the Pilliga region, the experts recommended evaluating impacts on these riverine landscape classes together for the purposes of eliciting models of their ecological changes under altered surface water and groundwater regimes. The stream network across most of the Pilliga region is predominantly infilled Quaternary sediments derived from the sandstone and deposited by dendritic streams draining north and west (Norriss, 1996). The sediments become finer towards the Namoi River valley where extensive clearing for agriculture has occurred. The eastern margins of the Pilliga region include the recharge beds of the GAB and palaeochannels of overlying alluvium, which can be incised into aquifer units such as the Pilliga Sandstone (see companion product 2.3 for the Namoi subregion (Herr et al., 2018)).

The riverine landscape classes within the Pilliga region all tend to be intermittent and/or ephemeral with only a small portion of the stream network classified as ‘Permanent lowland stream’ (14.3 km in the zone of potential hydrological change). Lowland streams (‘Temporary lowland stream’, ‘Temporary lowland stream GDE’ and a small portion of ‘Permanent lowland stream’) are mainly confined to the Pilliga Outwash portion of the Pilliga where the streams flow north onto the broad floodplains of the Castlereagh-Barwon Plains IBRA region (SEWPaC, 2012). Bohena Creek is one of the major streams flowing through the Pilliga, and flows north-east towards Narrabri and is classified predominately as ‘Temporary lowland stream GDE’ and ‘Temporary lowland stream’ (Figure 25). The ‘Temporary lowland stream’ (624.6 km in the zone) and ‘Temporary upland stream’ (530.4 km in the zone) landscape classes are by far the largest landscape classes within the zone of potential hydrological change of the Pilliga region (Table 28). The ‘Temporary upland stream GDE’ landscape class occupies only a small fraction of the stream network (11.5 km in the zone) (Table 28). Further description of the Pilliga landscape and associated landscape classes can be found in Section 2.7.3 and Section 2.7.4 of companion product 2.7 (Ickowicz et al., 2018)).

Table 28 Pilliga riverine landscape classes within the Pilliga region of the zone of potential hydrological change and their corresponding lengths and percentage contributions

Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Percentage of total length in zone of potential hydrological change (%)
Permanent lowland stream	1,688.6	14.3	0.3%
Permanent lowland stream GDE	456.8	0	0%
Temporary lowland stream	8,053.3	624.6	11.3%
Temporary lowland stream GDE	509.3	86.9	1.6%
Permanent upland stream	1646.1	0	0%
Permanent upland stream GDE	227.4	0	0%
Temporary upland stream	16,512.8	530.4	9.6%
Temporary upland stream GDE	464	11.5	0.2%
Total – Pilliga riverine landscape classes	**27,228**	**1267.7**	**23%**
Total – all landscape classes	**29,558.3**	**5521.2**	**100%**

Data: Bioregional Assessments (Dataset 2)

3.4.5.2 Potential hydrological impacts

The Pilliga riverine landscape classes (upland and lowland) of the Pilliga region were assigned three hydrological response variables based on their importance to the corresponding qualitative model for the Pilliga riverine landscape, which includes streams classified as both lowland and upland (Table 29). The relevant hydrological response variables are expressed as changes relative to a baseline reference period (1983 to 2012); mean increase in number of zero-flow days, mean increase in annual maximum no-flow spells and maximum decrease in groundwater drawdown (Table 29).

3.4.5.2.1 Groundwater

Most of the riverine streams in the Pilliga region of zone of potential hydrological change are ‘Temporary lowland stream’ (624.6 km) and ‘Temporary upland stream’ (530.4 km). Additional coal resource development is expected to have a larger impact on groundwater drawdown on the ‘Temporary upland stream’ landscape class with 14.8 km exposed to a 50% chance of greater than 2 m drawdown compared with 11.5 km of the stream network under a baseline future (Table 30 and Figure 39). For the lowland riverine landscape classes, there is a total of 33.5 km exposed to a 5% chance of greater than 2 m groundwater drawdown due to additional coal resource development compared to 0.4 km under the baseline future (Table 30 and Figure 39).

Table 29 Summary of the hydrological response variables and corresponding receptor impact variables used in the receptor impact models for the Pilliga[a] riverine landscape classes, together with the corresponding qualitative model (signed digraph) that describes the ecosystem linkages among different components

The proportion of landscape classes with surface water modelling is also provided.

Landscape class	Reporting region/basin	Qualitative model	Hydrological response variable	Proportion of total landscape classes with surface water modelling (%)	Receptor impact variable
Permanent lowland stream Temporary lowland stream Permanent lowland stream GDE Temporary lowland stream GDE Permanent lowland stream, Temporary upland stream Temporary upland stream GDE	Pilliga	Pilliga riverine (lowland and upland)	• 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. • 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. • Maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development.	6%	• Projected foliage cover • Average number of families of aquatic macroinvertebrates in instream pool habitat

[a] ‘Pilliga’ as used here refers to those parts of the zone of potential hydrological change that fall within the ‘Pilliga region’.
See Section 2.7.3 and Section 2.7.4 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018) for further details.

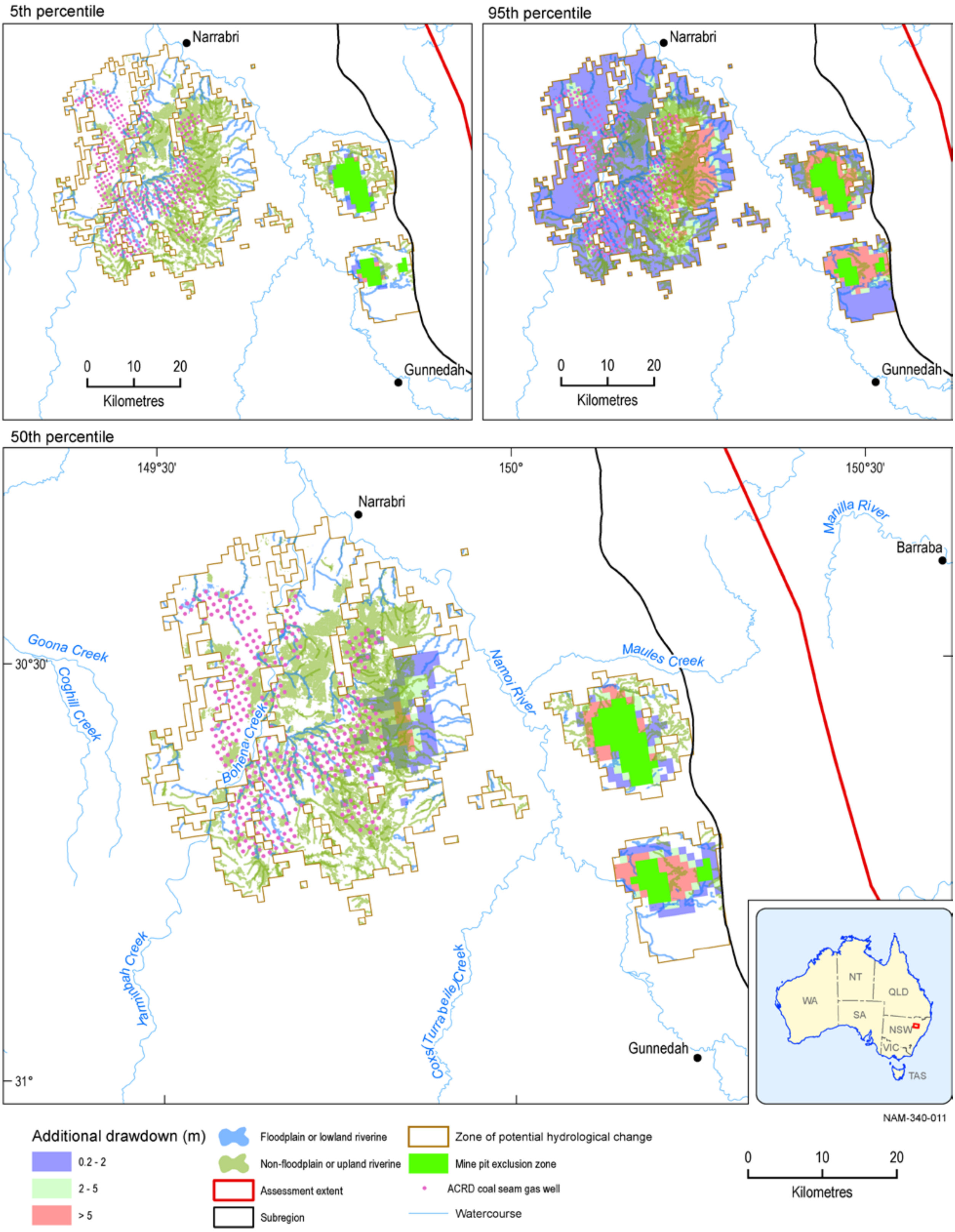

Figure 39 Additional drawdown in the Pilliga riverine landscape classes (upland and lowland) in the zone of potential hydrological change

Additional drawdown is the maximum difference in drawdown between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. The extent of the coal resource developments in the CRDP is the union of the extents in the baseline and the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

Table 30 Length (km) of landscape classes in the Pilliga riverine landscape classes potentially exposed to varying levels of baseline drawdown in the zone of potential hydrological change

Scenario	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length of drawdown ≥0.2 m (km)			Length of drawdown ≥2 m (km)			Length of drawdown ≥5 m (km)		
				5th	50th	95th	5th	50th	95th	5th	50th	95th
Baseline	Permanent lowland stream	1,688.6	14.3	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	8,053.3	624.6	0	0	25.5	0	0	0.4	0	0	0
	Temporary lowland stream GDE	509.3	86.9	0	0	0	0	0	0	0	0	0
	Temporary upland stream	16,512.8	530.4	0	18.6	143.1	0	11.5	59.5	0	6.3	36.7
	Temporary upland stream GDE	464	11.5	0	0	0	0	0	0	0	0	0
	Total	**27,228**	**1267.7**	**0**	**18.6**	**168.6**	**0**	**11.5**	**59.9**	**0**	**6.3**	**36.7**
Additional coal resource development	Permanent lowland stream	1,688.6	14.3	0	0	6.5	0	0	1.4	0	0	0
	Temporary lowland stream	8,053.3	624.6	0	0	333.3	0	0	31.8	0	0	0
	Temporary lowland stream GDE	509.3	86.9	0	0	14	0	0	0.3	0	0	0
	Temporary upland stream	16,512.8	530.4	0	58.4	448.7	0	14.8	230.3	0	7.7	95.9
	Temporary upland stream GDE	464	11.5	0	0	8.3	0	0	0	0	0	0
	Total	**27,228**	**1267.7**	**0**	**58.4**	**810.8**	**0**	**14.8**	**263.8**	**0**	**7.7**	**95.9**

The area potentially exposed to ≥0.2, ≥2 and ≥5 m baseline drawdown and additional drawdown is shown for the 5th, 50th and 95th percentiles. Baseline drawdown is the maximum difference in drawdown under the baseline relative to no coal resource development. Additional drawdown is the maximum difference in drawdown (*dmax*) due to additional coal resource development relative to the baseline. Areas within mine pit exclusion zones are excluded from further analysis.
Data: Bioregional Assessment Programme (Dataset 2).

3.4.5.2.2 Surface water

Only 6% of the lowland and upland riverine landscape classes in the Pilliga region had surface water modelling associated with them (Table 29). The surface water modelling for the Pilliga region shows a small chance (5%) of increase in zero-flow days (Table 31) for the zone of potential hydrological change. Only 0.3 km of ‘Temporary upland stream’ landscape class is exposed to a 5% chance of an increase in zero-flow days of greater than 20 days, while both upland (6.5 km) and lowland (85.6 km) landscape classes are exposed to a 5% chance of an increase in zero-flow spells of greater than 3 days for the 2013 to 2042 simulation period (Table 31).

For increases in maximum zero-flow spells, only 20 km of lowland and 0.3 km of upland riverine landscape classes are exposed to a 5% chance of an increase in length of zero-flow spells of greater than 3 days for the 2073 to 2102 simulation period (Table 32). No changes in maximum zero-flow spells were predicted for the 2013 to 2042 simulation period (Table 32).

Table 31 Length (km) of landscape classes in the Pilliga riverine landscape classes (upland and lowland) potentially exposed to an increase in zero-flow days for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3days (km)			Length with increase ≥20 days (km)			Length with increase ≥80 days (km)		
				5th	50th	95th	5th	50th	95th	50th	95th	95th
2042	Permanent lowland stream	1,688.6	14.3	0	0	5.3	0	0	0	0	0	0
	Permanent lowland stream GDE	8,053.3	624.6	0	0	63.8	0	0	0	0	0	0
	Temporary lowland stream	509.3	86.9	0	0	16.5	0	0	0	0	0	0
	Total	**10,251.2**	**725.8**	**0**	**0**	**85.6**	**0**	**0**	**0**	**0**	**0**	**0**
	Temporary upland stream	16,512.8	530.4	0	0	4.9	0	0	0.3	0	0	0
	Temporary upland stream GDE	464	11.5	0	0	1.6	0	0	0	0	0	0
	Total	**16,976.8**	**541.9**	**0**	**0**	**6.5**	**0**	**0**	**0.3**	**0**	**0**	**0**
2102	Permanent lowland stream	1,688.6	14.3	0	0	5.3	0	0	5.3	0	0	0
	Permanent lowland stream GDE	8,053.3	624.6	0	0	42.3	0	0	14.7	0	0	0
	Temporary lowland stream	509.3	86.9	0	0	4.2	0	0	0	0	0	0
	Total	**10,251.2**	**725.8**	**0**	**0**	**51.8**	**0**	**0**	**20**	**0**	**0**	**0**
	Temporary upland stream	16,512.8	530.4	0	0	4.9	0	0	0.3	0	0	0
	Temporary upland stream GDE	464	11.5	0	0	1.6	0	0	0	0	0	0
	Total	**16,976.8**	**541.9**	**0**	**0**	**6.5**	**0**	**0**	**0.3**	**0**	**0**	**0**

The length potentially exposed to ≥3, ≥20 and ≥80 days increase in zero-flow days from the baseline period (1983 to 2012) is shown for the 5th, 50th and 95th percentiles.
Data: Bioregional Assessment Programme (Dataset 2)

Table 32 Length (km) of landscape classes in the Pilliga riverine landscape classes (upland and lowland) potentially exposed to an increase in annual maximum zero-flow spells for two different simulation periods: 2042 and 2102, in the zone of potential hydrological change

Simulation period (end year)	Landscape class	Length in assessment extent (km)	Length in zone of potential hydrological change (km)	Length with increase ≥3days (km)			Length with increase ≥10 days (km)			Length with increase ≥40 days (km)		
				5th	50th	95th	5th	50th	95th	50th	95th	95th
2042	Permanent lowland stream	1,688.6	14.3	0	0	0	0	0	0	0	0	0
	Permanent lowland stream GDE	8,053.3	624.6	0	0	0	0	0	0	0	0	0
	Temporary lowland stream	509.3	86.9	0	0	0	0	0	0	0	0	0
	Total	**10,251.2**	**725.8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Temporary upland stream	16,512.8	530.4	0	0	0	0	0	0	0	0	0
	Temporary upland stream GDE	464	11.5	0	0	0	0	0	0	0	0	0
	Total	**16,976.8**	**541.9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2102	Permanent lowland stream	1,688.6	14.3	0	0	5.3	0	0	0	0	0	0
	Permanent lowland stream GDE	8,053.3	624.6	0	0	14.7	0	0	0	0	0	0
	Temporary lowland stream	509.3	86.9	0	0	0	0	0	0	0	0	0
	Total	**10,251.2**	**725.8**	**0**	**0**	**20**	**0**	**0**	**0**	**0**	**0**	**0**
	Temporary upland stream	16,512.8	530.4	0	0	0.3	0	0	0	0	0	0
	Temporary upland stream GDE	464	11.5	0	0	0	0	0	0	0	0	0
	Total	**16,976.8**	**541.9**	**0**	**0**	**0.3**	**0**	**0**	**0**	**0**	**0**	**0**

The length potentially exposed to ≥3, ≥10 and ≥40 days increase in the length of the maximum zero-flow spell during the 30-year simulation period compared to the baseline period (1983 to 2012) is shown for the 5th, 50th and 95th percentiles.
Data: Bioregional Assessment Programme (Dataset 2)

3.4.5.3 Potential ecosystem impacts

The potential for ecosystem impacts for relevant landscape classes within the Pilliga region in the zone of potential hydrological change was estimated using two separate receptor impact models applied to the riverine landscape classes (upland and lowland) (see Table 29). The receptor impact variables, average number of families of aquatic macroinvertebrates and projected foliage cover of riparian vegetation were modelled under the baseline and CRDP futures. These two models were combined across the relevant assessment units to define the aggregated risk where model inputs were available. The risk thresholds used for defining risk and their associated terminology are identical to that applied to the receptor impact variables assigned to the landscape classes in the 'Floodplain or lowland riverine' landscape group (see Section 3.4.3.3).

The Pilliga region has relatively few model nodes along the stream network, with only two nodes along Bohena Creek (classified as a 'Temporary lowland stream'). There is a large proportion (94%) of the entire length of the Pilliga riverine stream network that is not quantified under the surface water modelling approach used here (Figure 40 and Table 29). The risk composite across all modelled assessment units shows areas exposed to 'at some risk' along Bohena Creek and some adjacent assessment units intersecting tributaries (Figure 40). The subsequent sections describe the specific results of each model that contribute to the observed location and magnitude of risks described here.

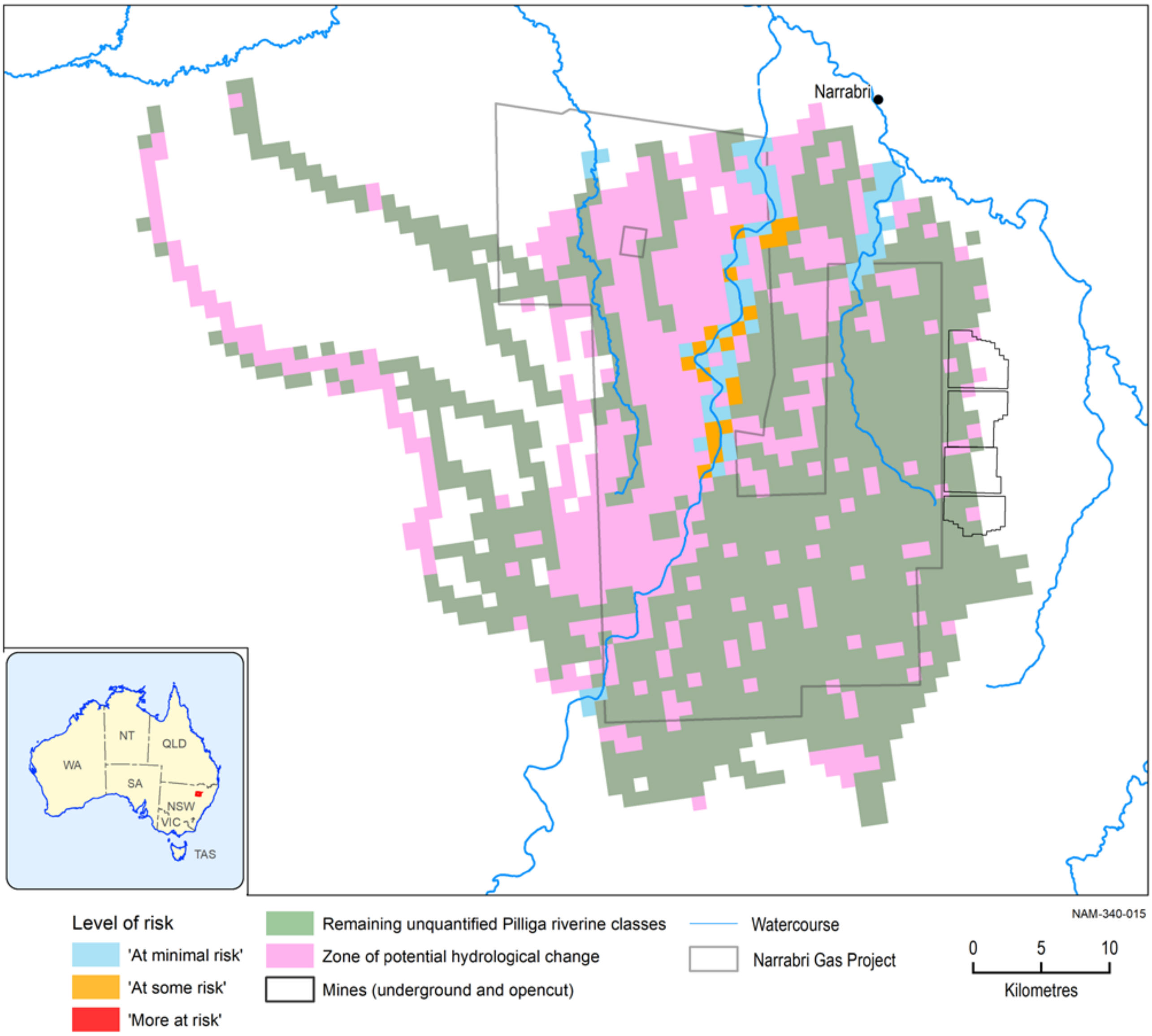

Figure 40 Composite risk map based on the results of receptor impact modelling across the Pilliga riverine landscape classes

The level of risk: 'at minimal risk of ecological and hydrological changes' ('at minimal risk'), 'at some risk of ecological and hydrological changes' ('at some risk') and 'more at risk of ecological and hydrological changes' ('more at risk') is presented for different assessment units where the receptor impacts are modelled for the different landscape classes. Remaining assessment units for the relevant classes in the Pilliga riverine without receptor impact modelling and surface water modelling are also shown (green). Extent captures areas with 'at some risk' or 'more at risk' assessment units.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.5.3.1 Pilliga riverine

There were no detectable differences in predicted mean changes in either projected foliage cover or average number of families of aquatic macroinvertebrates across the Pilliga riverine landscape classes between the baseline and CRDP futures across the different simulation periods (2042 and 2102) (Figure 41a and c). This is reflected in the very small amount of stream segments impacted by changes in surface water regime (Table 31 and Table 32) and the limited impacts from additional groundwater drawdown (Figure 39).

However, an assessment of the modelled changes due to coal resource development in the projected foliage cover and the number of families of aquatic macroinvertebrates identified a number of assessment units across the extent of the Pilliga riverine landscape classes that may experience some change (Figure 41b and d). At the 5th percentile declines in projected foliage cover were greater than 0.2 in two assessment units, with at least another five assessment units greater than 0.1 (Figure 41b). Changes in the average number of families of aquatic macroinvertebrates due to additional coal resource development were similar between simulation periods and were as low as –19 families for an assessment unit at the 5th percentile and as low as approximately –12 families for an assessment unit at the 50th percentile (Figure 41d). An increase in projected foliage cover and the average number of families of aquatic macroinvertebrates was observed at the 95th percentile (Figure 41b and d) and reflects the uncertainty in the predicted changes.

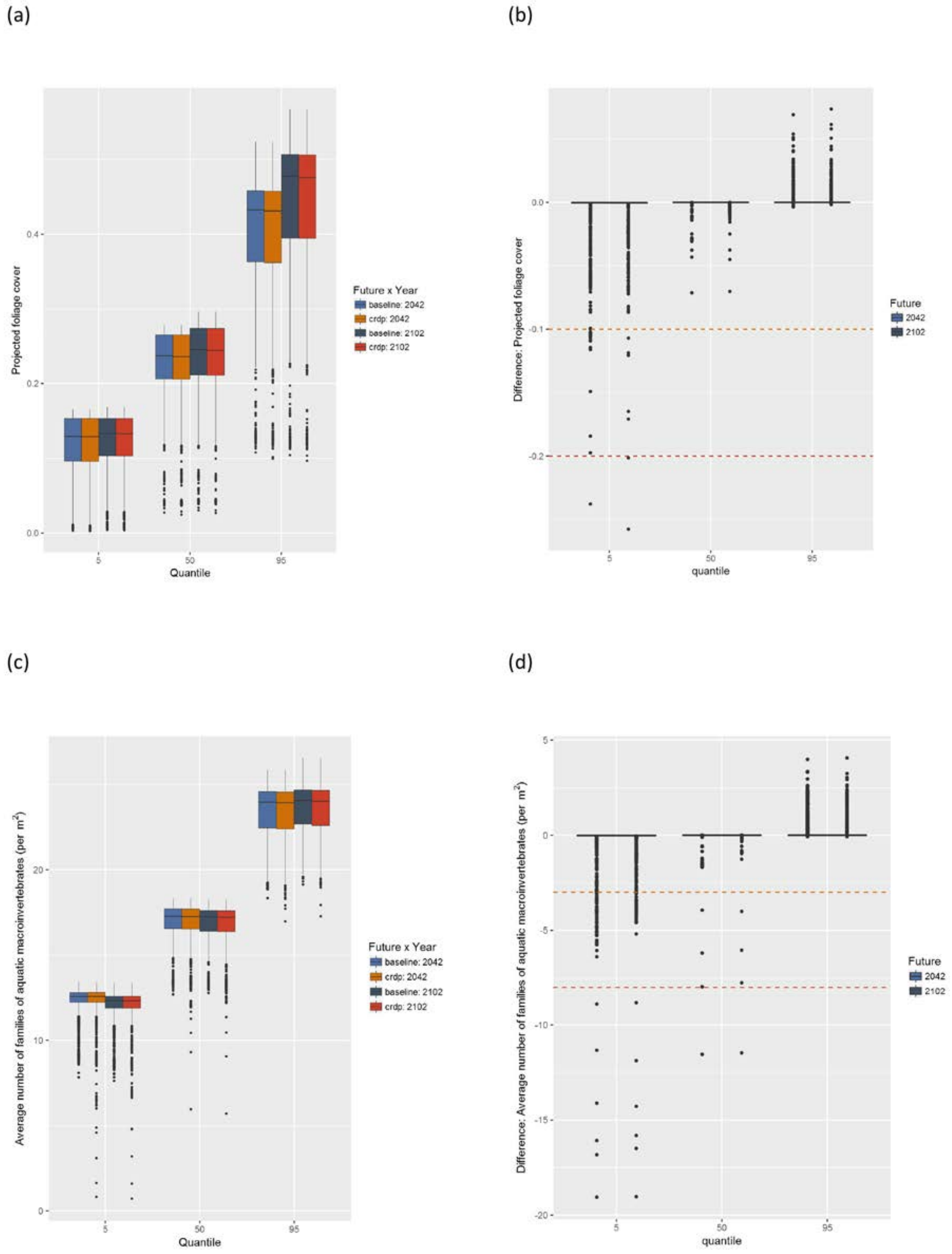

Figure 41 Box and whisker plots of two separate receptor impact models for Pilliga riverine landscape classes in 2042 and 2102 under both baseline and coal resource development pathway (CRDP) futures

Box and whisker plots of modelled (a) projected foliage cover and (c) average number of families of aquatic macroinvertebrates in Pilliga riverine landscape classes in 2042 and 2102 under both baseline and coal resource development pathway (CRDP) futures. Differences in (b) projected foliage cover and d) average number of families of aquatic macroinvertebrates between CRDP and baseline futures for each assessment unit containing Pilliga riverine landscape classes. The relevant thresholds used to delineate changes in the receptor impact variable associated with 'at some risk of ecological and hydrological changes' and 'more at risk of ecological and hydrological changes' are indicated by the orange and red dashed horizontal lines.
Data: Bioregional Assessment Programme (Dataset 5)

3.4.6 Potentially impacted landscape classes lacking quantitative ecological modelling

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 modelling identified maximum groundwater drawdown as the relevant hydrological response variable, although no quantitative modelling was done (Table 16 and see Section 2.7.5.2.2 in companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)). 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. Although the experts expressed some uncertainty around the likelihood of groundwater dependency in some of the vegetation types classified as ‘Grassy woodland GDE’, these results suggest further investigation into the nature of water dependency for this landscape class is required.

The ‘Rainforest’ landscape group occupies a limited area within the zone of potential hydrological change, with the ‘Rainforest’ landscape class intersecting with 4.1 km^2 of the zone and ‘Rainforest GDE’ only 0.3 km^2 (Table 16). The qualitative model formulated for the ‘Rainforest’ landscape group identified groundwater drawdown as the key hydrological response variable. However, the types of groundwater flow systems in areas where rainforest occurs in the Namoi assessment extent are unlikely to be impacted due to additional coal resource development. In the upland and outcropping landscape positions where rainforests tend to occur in the subregion, groundwater is usually expressed at the surface through localised flow paths (i.e. cracks and fissures) originating in the nearby recharge areas.

Two springs are known to occur within the zone of potential hydrological change. They are classified as ‘GAB springs’ given their association with underlying sandstone formations. These two springs are located on the eastern edge of the Pilliga Basin and are thought to be primarily recharge springs given their location on the eastern fringes of the GAB (Fensham and Fairfax, 2003). These two springs are identified as Eather and Hardy’s springs and are considered high-priority GDEs by the Namoi region state of the catchment report (OEH, 2010b). Field surveys of these two springs reported that they are located on sites proximal to the interface between Pilliga Sandstone and Purlawaugh Formation, which is a hydrogeologically likely place for springs to occur (Santos, 2017). This study also notes that the springs have poor ecological condition and have been highly modified or disturbed (i.e. site excavated and dammed) (Santos, 2017).

A qualitative model was formulated for a typical recharge GAB spring and identified changes in maximum groundwater drawdown as a key response variable for the ecosystem typically supported by GAB springs of this kind (Table 16, further details are provided in Section 2.7.6 of companion product 2.7 for the Namoi subregion (Ickowicz et al., 2018)). There is a 5% chance of greater than 0.2 m drawdown for both of the springs within the zone of potential hydrological change (data not shown). 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.

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Datasets

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3.5 Impacts on and risks to water-dependent assets

Summary

The potential impacts on and risks to water-dependent assets due to coal resource developments have been assessed. There are 624 ecological assets that are within or intersect with the zone of potential hydrological change. Of these assets, 20 are in the 'Groundwater feature (subsurface)' subgroup, 473 are in the 'Surface water feature' subgroup and 131 are in the 'Vegetation' subgroup. Of those assets listed in the 'Vegetation' subgroup there are 15 species and 6 threatened ecological communities that are listed under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

There are 86 economic assets in the zone of potential hydrological change, 47 of these are in the 'Groundwater management zone or area' subgroup and 39 are in the 'Surface water management zone or area' subgroup.

Within the assessment extent there are 31 groundwater sources, 9 of which have bores within the groundwater zone of potential hydrological change. There are only 504 bores within the groundwater zone of potential hydrological change that are potentially impacted due to additional coal resource development.

There are 14 sociocultural assets within the zone of potential hydrological change. Of these, 12 assets are heritage sites and 2 are Indigenous sites.

3.5.1 Overview

In this section, potential impacts due to additional coal resource development on ecological, economic and sociocultural assets are assessed. The ecological assets are divided into three subgroups: 'Surface water feature', 'Groundwater feature (subsurface)' and 'Vegetation'. The 'Vegetation' subgroup is further divided into two classes: 'Groundwater-dependent ecosystem' and 'Habitat (potential species distribution)' to improve clarity. Similarly, the economic assets are divided in two subgroups: 'Groundwater management zone or area' and 'Surface water management zone or area'. The intersection of sociocultural assets with the zone of potential hydrological change is then described, and the potential for impact assessed.

Given the large number of assets involved in the assessment, it is not possible to assess the risk to each individual asset in this section. The analysis undertaken here focuses on potential impacts on assets in terms of the association or spatial intersection with landscape classes experiencing varying levels of hydrological change. As detailed in Section 3.4, potential impacts on relevant water-dependent landscape classes are defined using the hydrological response variables associated with the quantitative receptor impact modelling. This subset of landscape classes is termed 'potentially impacted landscape classes'. The hydrological response variables are assigned to landscape classes based on these models and changes in these variables informs the assessment of where impacts to landscape classes are likely to occur. For assets that intersect any part of a potentially impacted landscape class, a more detailed assessment of the level of risk is presented. Thus, for any asset in the assessment extent (Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 1) the likely level of impact is based on its spatial extent overlapping:

- the zone of potential hydrological change
- a water-dependent landscape class (comprising all classes within 'Floodplain or lowland riverine', 'Non-floodplain or upland riverine', 'Rainforest' and 'Springs' landscape groups)
- a potentially impacted water-dependent landscape class. For those landscape classes with receptor impact modelling, changes in specific hydrological models can be mapped to a particular asset
- locations with relevant hydrological modelling and that surpass the 'more at risk of hydrological changes' threshold.

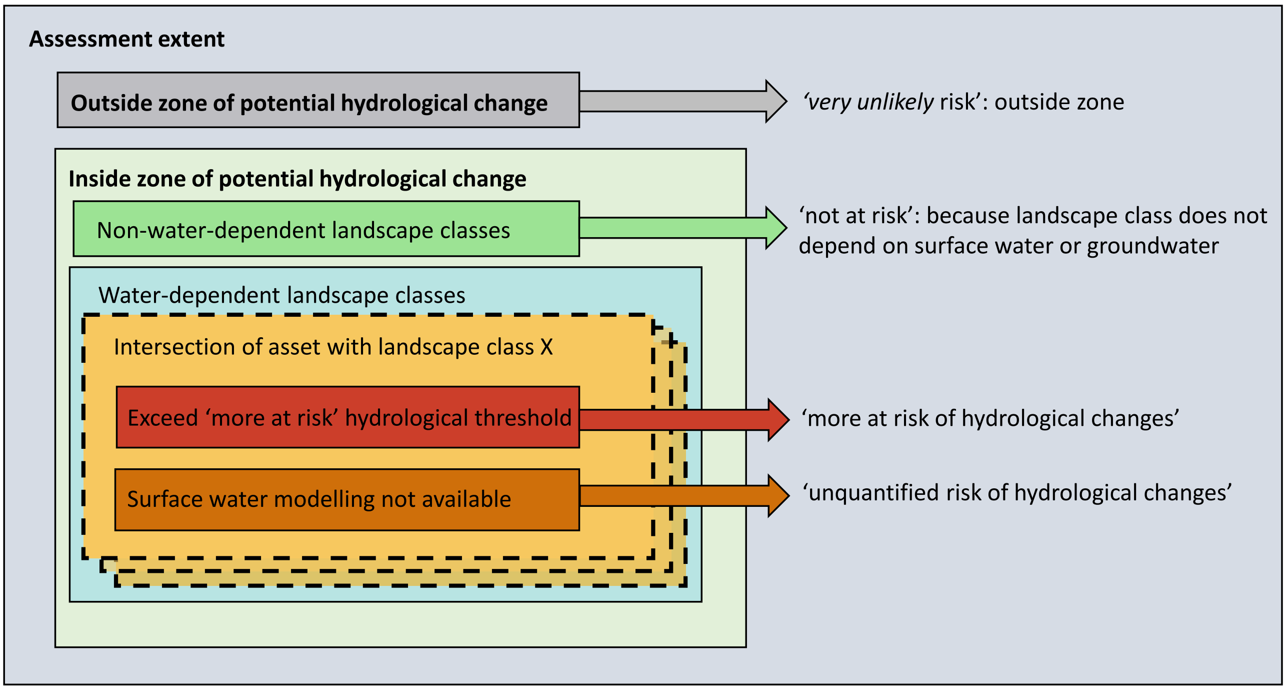

Figure 42 Overview of the different risk categories used to assess ecological assets

These distinctions are used to focus the discussion of assets into where impacts are most likely (Figure 42). An assessment of risk from changes in groundwater drawdown for assets that overlap the remaining water-dependent landscape classes (i.e. landscape classes that have qualitative modelling but no quantitative modelling) has also been carried out (Figure 42). Detailed potential impacts on individual assets can be visually explored on the BA Explorer, available at www.bioregionalassessments.gov.au/explorer/NAM/assets.

3.5.2 Ecological assets

3.5.2.1 Ecological assets in the zone of potential hydrological change

The assessment of impacts on water dependent ecological assets was based on those contained in the current water-dependent asset register (Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 1). The current asset register does not necessarily match the asset register referred to in the earlier product (companion product 1.3 for the Namoi subregion (O'Grady et al., 2015); Bioregional Assessment Programme, Dataset 2). The water-dependent assets register for the Namoi subregion contains 1690 ecological assets (Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 1). Of these, 624 assets intersect with the zone of potential hydrological change, including 20 in the 'Groundwater feature (subsurface)' subgroup, 473 in the 'Surface water feature' subgroup and 131 in the 'Vegetation' subgroup (Table 33).

Table 33 Ecological assets in the assessment extent and zone of potential hydrological change

Subgroup	Asset class	Water-dependent assets	Water-dependent assets in the zone
Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	33	20
	Subtotal	**33**	**20**
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
	Subtotal	**1142**	**473**
Vegetation	Groundwater-dependent ecosystem	442	102
	Habitat (potential species distribution)	73	29
	Subtotal	**515**	**131**
Total		**1690**	**624**

Data: Bioregional Assessment Programme (Dataset 1)

Six hundred and twenty-four ecological assets intersect with the zone of potential hydrological change (Table 33) and therefore have the potential to be impacted due to additional coal resource development. It is important to note that single assets may occur across a range of landscape classes.

Of the 131 assets in the 'Vegetation' subgroup, 102 are sourced from the *National atlas of groundwater dependent ecosystems* (GDE Atlas) (Bureau of Meteorology, 2012). The remaining 29 assets comprise 7 assets listed in the Collaborative Australian Protected Area Database (CAPAD), 1 Important Bird Area, 15 species listed under the EPBC Act and 6 threatened ecological communities, also listed under the EPBC Act (Table 34).

Table 34 Ecological assets associated with the 'Habitat (potential species distribution) asset class in the 'Vegetation' subgroup within the zone of potential hydrological change

Source	Water-dependent asset[a]
Collaborative Australian Protected Area Database	Brigalow Park Nature Reserve
	Lanes Mill Flora Reserve
	Leard Cca Zone 3 State Conservation Area
	Pilliga Cca Zone 1 National Park
	Pilliga Cca Zone 3 State Conservation Area
	Pilliga East Cca Zone 3 State Conservation Area
	Willala Ccs Zone 2 Aboriginal Area
Bird's Australia Important Bird Areas	Pilliga IBA
Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*	Australian Painted Snipe (*Rostratula australis*)
	Cattle Egret (*Ardea ibis*)
	Great Egret (*A. alba*)
	Malleefowl (*Leipoa ocellata*)
	Regent Honeyeater (*Anthochaera phrygia*)
	Satin Flycatcher (*Myiagra cyanoleuca*)
	Swift Parrot (*Lathamus discolor*)
	White-bellied Sea Eagle (*Haliaeetus leucogaster*)
	Koala (*Phascolarctos cinereus*)
	Potential Distribution of South-Eastern Long-Eared Bat (*Nyctophilus corbeni*)
	Spot-Tailed Quoll, Spotted Tail Quoll, Tiger Quoll (*Dasyurus maculatus maculatus*)
	Five-Clawed Worm-Skink, Long-Legged Worm-Skink (*Anomalopus mackayi*)
	Philotheca ericifolia
	Slender Darling-Pea, Slender Swainson, Murray Swainson-Pea (*Swainsonia murrayana*)
	Spiny Pepper-Cress (*Lepidium aschersonii*)
	Brigalow (*Acacia harpophylla* Dominant And Co-Dominant)
	Coolibah - Black Box Woodlands Of The Darling Riverine Plains And The Brigalow Belt South Bioregions
	Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands And Derived Native Grasslands Of South-Eastern Australia
	Natural Grasslands On Basalt And Fine-Textured Alluvial Plains Of Northern New South Wales And Southern Queensland
	Weeping Myall Woodlands
	White Box-Yellow Box-Blakely's Red Gum Grassy Woodland And Derived Native Grassland

[a]Punctuation and typography appear as used in the asset database.
Data: Bioregional Assessment Programme (Dataset 1)

All six nationally listed threatened ecological communities within the subregion intersect to some extent with the zone of potential hydrological change.

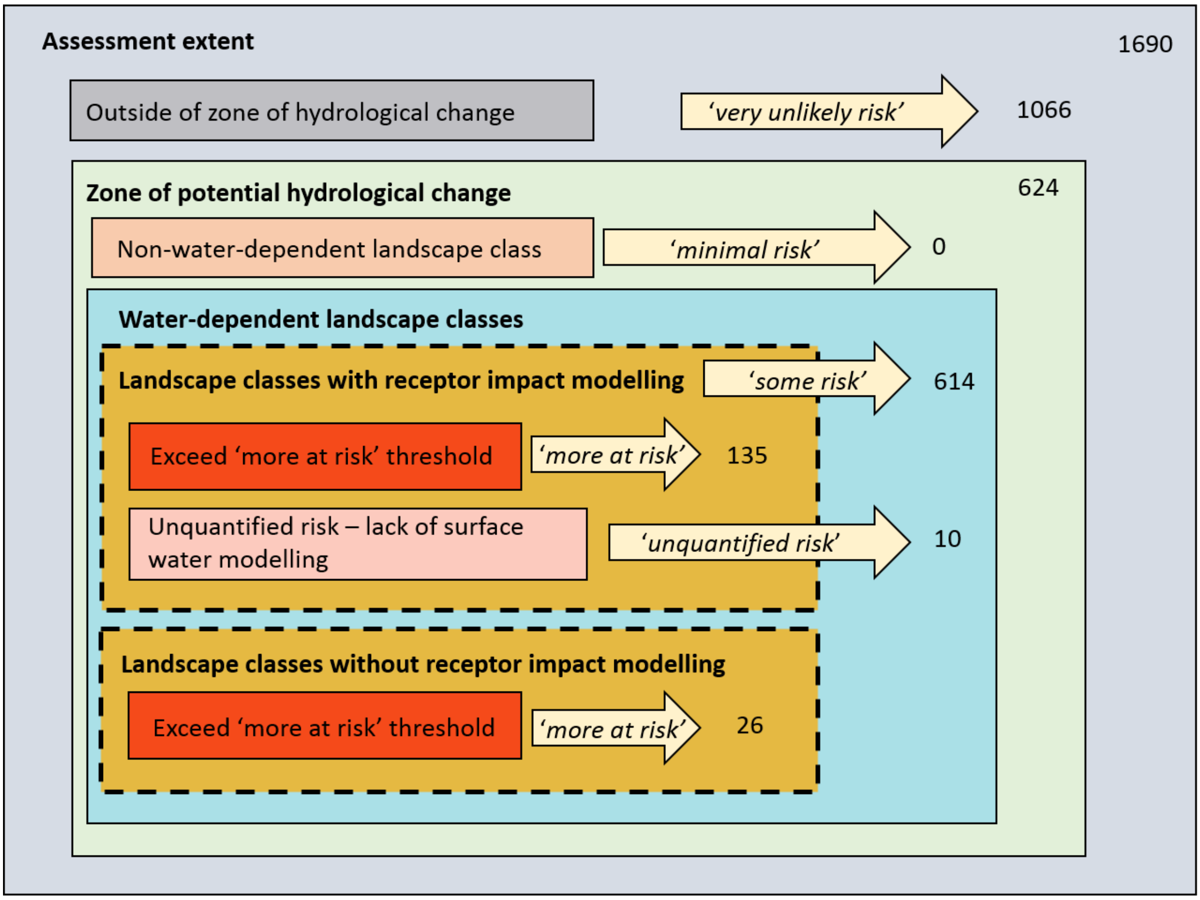

Figure 43 Number of ecological assets within different asset risk categories

Asset counts within a particular bounding box are unique but may occur across multiple landscape classes.
'some risk' = 'at some risk of hydrological changes'
'minimal risk' = 'at minimal risk of hydrological changes'
'more at risk' = 'more at risk of hydrological changes'

A total of 614 of the 624 assets in the zone of potential hydrological change are associated with 'potentially impacted landscape classes' where receptor impact modelling was carried out (Figure 43). These are discussed further in Section 3.5.2.3.

3.5.2.2 Ecological assets outside the zone of potential hydrological change

Of the total 1690 ecological assets within the assessment extent, 1066 do not intersect with the zone of potential hydrological change, thus it is *very unlikely* that these assets will be impacted due to additional coal resource development (Table 33 and Figure 43). These include 669 assets in the 'Surface water feature' subgroup, 13 assets in the 'Groundwater feature (subsurface)' subgroup and 384 assets in the 'Vegetation' subgroup.

Two assets, 'Segment of Barwon River with KEA values' (AID 5067) and 'Segment of Currabubula Creek with KEA values' (AID 5068) are listed in the Key Environmental Assets of the Murray–Darling Basin database and one asset, 'Barwon River and fringing wetlands' (AID 3339) is listed in the Environmental Assets Database. The remaining surface water assets that are *very unlikely* to be impacted were community nominated assets listed in the Water Asset Information Tool (WAIT) database (WAIT_Namoi (538 assets) and WAIT_Border Rivers-Gwydir (128 assets)).

In the 'Groundwater feature (subsurface)' subgroup, 13 assets from the WAIT_Border Rivers-Gwydir and the WAIT_Namoi databases are *very unlikely* to be impacted due to additional groundwater development. These all fall within the 'Aquifer, geological feature, alluvium or stratum' asset class.

In the 'Vegetation' subgroup, 384 assets fall outside the zone of potential hydrological change; thus, it is *very unlikely* that these will be impacted due to additional coal resource development. These include 340 assets classed as 'Groundwater-dependent ecosystem' sourced from the GDE Atlas and 44 assets classed as 'Habitat (potential species distributions)'. Of the latter, 36 assets are listed by CAPAD, 1 Important Bird Area (Bubdarra-Barraba IBA, AID 4687) and 7 species listed under the EPBC Act. These EPBC Act-listed species are *very unlikely* to be impacted due to additional coal resource development in the subregion, including four species that are listed as either endangered or critically endangered:

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

3.5.2.3 Assets associated with potentially impacted landscape classes

As discussed in Section 3.5.1, this product focuses the discussion of potentially impacted ecological assets by analysing the overlap between potentially impacted landscape classes (those classes where there is receptor impact modelling) and changes in their associated hydrological response variables. Where hydrological modelling is available for locations across the spatial extent of the landscape class, assets can be classified to be 'at some risk of ecological and hydrological changes' or 'more at risk of hydrological changes' due to additional coal resource development. While this approach uses hydrological information to infer impacts on assets, these locations also reflect potential changes in the corresponding receptor impact variable, which is consistent with assessing potential risks using multiple lines of evidence.

The threshold for identifying 'more at risk of hydrological changes' assets is defined as:

- at least a 50% chance of the modelled hydrological change exceeding a defined threshold for the hydrological response variable relevant for the landscape class (as defined in Section 3.4) to which the asset is associated.

Thresholds chosen to identify 'more at risk of hydrological changes' assets within impacted landscape class are:

- for ‘Floodplain riparian forest’, ‘Floodplain riparian forest GDE’ and ‘Upland riparian forest GDE’ landscape classes: change in drawdown due to additional coal resource development exceeding 2 m and/or one less overbank flow event every 20 years
- for ‘Floodplain wetland’ and ‘Floodplain wetland GDE’ landscape classes: one less overbank flow event every 20 years
- for all riverine landscape classes (upland and lowland): an increase in the frequency of events where the change in the number of zero-flow days (0.01 ML/day) exceeds 20 days per year and/or a change in the maximum annual zero-flow spell exceeds 10 days.

All assets associated with ‘potentially impacted landscape classes’ (614) show some change in their associated hydrological response variables and are deemed to be at ‘some risk of hydrological change’ (Figure 43). Ecological assets that solely intersect areas within a landscape class where surface water modelling was unavailable (see companion product 2.6.1 for the Namoi subregion (Aryal et al., 2018)) for the two potentially impacted landscape groups (‘Floodplain or lowland riverine’ and ‘Non-floodplain or upland riverine’) are also identified. The proportion of areas with surface water modelling varies between different landscape classes but can be as high as 94% (see Section 3.4 for further details). For these assets, it is not possible to quantify their risk level and are therefore termed ‘unquantified risk of hydrological change’. There are ten unique assets associated with the ‘unquantified risk of hydrological change’ category (Figure 43) in either the ‘Floodplain or lowland riverine’ landscape group or the ‘Non-floodplain or upland riverine’ group landscape.

In total, 135 unique assets are identified as ‘more at risk of hydrological changes’ (Figure 43). Of the 471 assets within the ‘Surface water feature’ subgroup that intersect with the zone of potential hydrological change, a total of 76 of these assets are deemed to be ‘more at risk of hydrological changes’. There are 69 surface water assets associated with the ‘Floodplain or lowland riverine’ and 46 surface water assets associated with the ‘Non-floodplain or upland riverine’ landscape groups that were deemed to be ‘more at risk of hydrological changes’ based on the thresholds described above. The breakdown of these assets is shown in Table 35. None of the assets identified as ‘more at risk of hydrological changes’ are listed in *A directory of important wetlands in Australia* (DIWA).

Table 35 Assets within the 'Surface water feature' subgroup and within the zone of potential hydrological change that are deemed as 'more at risk of hydrological changes' due to additional coal resource development, and their association with potentially hydrologically impacted landscape groups

Asset class	'Floodplain or lowland riverine' landscape group[a]	'Non-floodplain or upland riverine' landscape group[a]
Floodplain	3	2
Lake, reservoir, lagoon or estuary	2	0
River, stream reach, tributary, anabranch or bend	48	33
Wetland, wetland complex or swamp	16	11
Marsh, sedgeland, bog, spring or soak	0	0
Total	**69**	**46**

[a] The spatial extent of assets often intersects multiple landscape groups.
Data: Bioregional Assessment Programme (Dataset 1)

For the 'Floodplain or lowland riverine' landscape group, 11 'Groundwater feature (subsurface)' assets are potentially 'more at risk of hydrological changes' due to additional coal resource development (Table 36). There are 12 'Groundwater feature (subsurface)' assets associated with the 'Non-floodplain or upland riverine' landscape group that are potentially 'more at risk of hydrological changes' due to additional coal resource development (Table 36). These assets are:

- Cadna-owie Hooray Equivalent GAB recharge area (both landscape groups)
- Great Artesian Basin Groundwater Management Zone (both landscape groups)
- Gunnedah Basin Groundwater Management Zone (both landscape groups)
- Lower Namoi Alluvium Groundwater Management Zone (both landscape groups)
- Narrabri watertable aquifer (both landscape groups)
- Upper Namoi Alluvium Groundwater Management Zone (units 3, 4, 5, 8 and 11 in both landscape groups and 7 in only 'Non-floodplain or upland riverine' landscape group)
- Westbourne Formation (both landscape groups).

Table 36 Ecological assets within the 'Groundwater feature (subsurface)' group and within the zone of potential hydrological change that are deemed as 'more at risk of hydrological changes' due to additional coal resource development, and their association with potentially hydrologically impacted landscape groups

Group	Subgroup	Asset class	'Floodplain or lowland riverine' landscape group[a]	'Non-floodplain or upland riverine' landscape group[a]
Ecological	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	11	12

[a] The spatial extent of assets often intersects multiple landscape groups.
Data: Bioregional Assessment Programme (Dataset 1)

Within the 'Vegetation' subgroup a total of 47 assets are considered 'more at risk of hydrological changes' due to additional coal resource development. 29 and 20 assets intersecting 'Floodplain or lowland riverine' the 'Non-floodplain or upland riverine' landscape groups, respectively, in the asset class 'Groundwater dependent ecosystem' are considered 'more at risk of hydrological changes' (Table 37). Assets in the 'Habitat (potential species distribution)' asset class deemed to be ‘more at risk of hydrological changes’ due to additional coal resource development included 17 within ‘Floodplain or lowland riverine’ and 13 within the ‘Non-floodplain or upland riverine’ landscape groups (Table 37).

Table 37 Ecological assets within the ‘Vegetation’ subgroup and within the zone of potential hydrological change that are deemed as ‘more at risk of hydrological changes’ due to additional coal resource development, and their association with potentially hydrologically impacted landscape groups

Group	Subgroup	Asset class	‘Floodplain or lowland riverine’ landscape group[a]	‘Non-floodplain or upland riverine’ landscape group[a]
Ecological	**Vegetation**	Groundwater-dependent ecosystem	29	20
		Habitat (potential species distribution)	17	13
Total			**46**	**33**

[a] The spatial extent of assets often intersects multiple landscape groups.
Data: Bioregional Assessment Programme (Dataset 1)

One Important Bird Area, Pilliga IBA, was deemed to be potentially ‘more at risk of hydrological changes’ due to additional coal resource development.

This asset intersected with both the ‘Floodplain or lowland riverine’ and ‘Non-floodplain or upland riverine’ landscape groups and was deemed to be ‘more at risk of hydrological changes’ based on the increased probability of changes to surface water regimes (Figure 44).

While these assets have been identified as being ‘more at risk of hydrological changes’, the nature of water requirements of the flora and fauna of these reserves remains poorly understood. The Pilliga IBA is contiguous with the Pilliga Nature Reserve forming the largest intact native forests west of the Great Dividing Range and contains areas of low-to-moderate groundwater dependence, particularly along Bohena Creek.

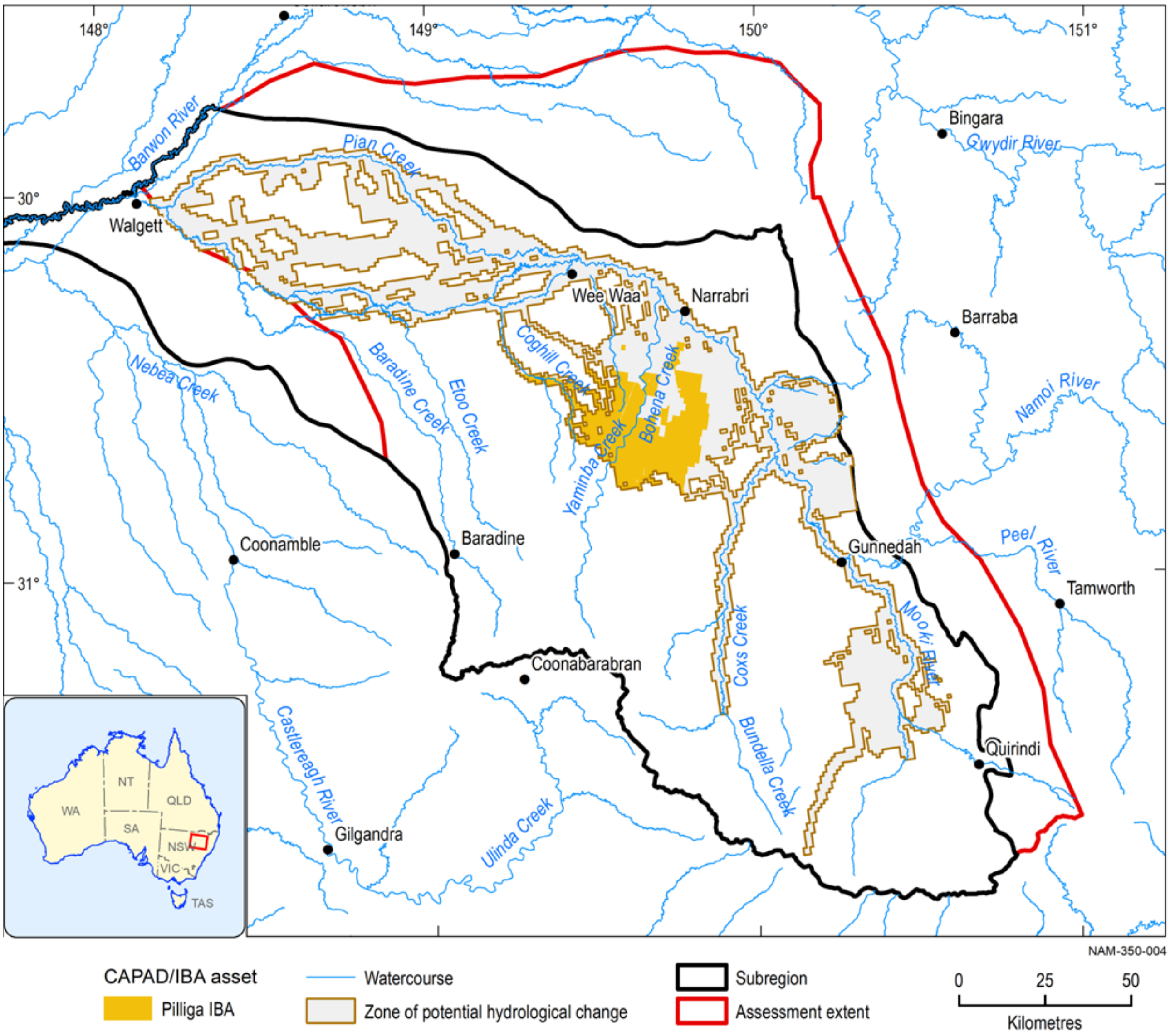

Figure 44 Distribution of Pilliga Important Bird Area (IBA) ('Vegetation' subgroup) deemed to be 'more at risk of hydrological changes'

CAPAD = Collaborative Australian Protected Area Database
Data: Bioregional Assessment Programme (Dataset 1)

Five assets listed as threatened ecological communities under the EPBC Act intersect with the zone of potential hydrological change and are considered to be 'more at risk of hydrological changes' due to additional coal resource development:

- Coolibah - Black Box Woodlands of the Darling Riverine Plains and the Brigalow Belt South Bioregions
- Grey Box (*Eucalyptus microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia
- Brigalow (*Acacia harpophylla* dominant and co-dominant)
- Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland
- White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland.

All five of these communities occur within landscape classes associated with the ‘Floodplain or lowland riverine’ landscape group. Three intersect with the ‘Non-floodplain or upland riverine’ landscape group: ‘Coolibah - Black Box Woodlands of the Darling Riverine Plains’, ‘Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland’ and ‘White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland’. The latter two threatened ecological communities listed here intersect with areas deemed ‘more at risk of hydrological changes’ for both surface water and groundwater hydrological response variables, while the remaining three are associated with increased chances of changes in surface water regimes (Figure 45).

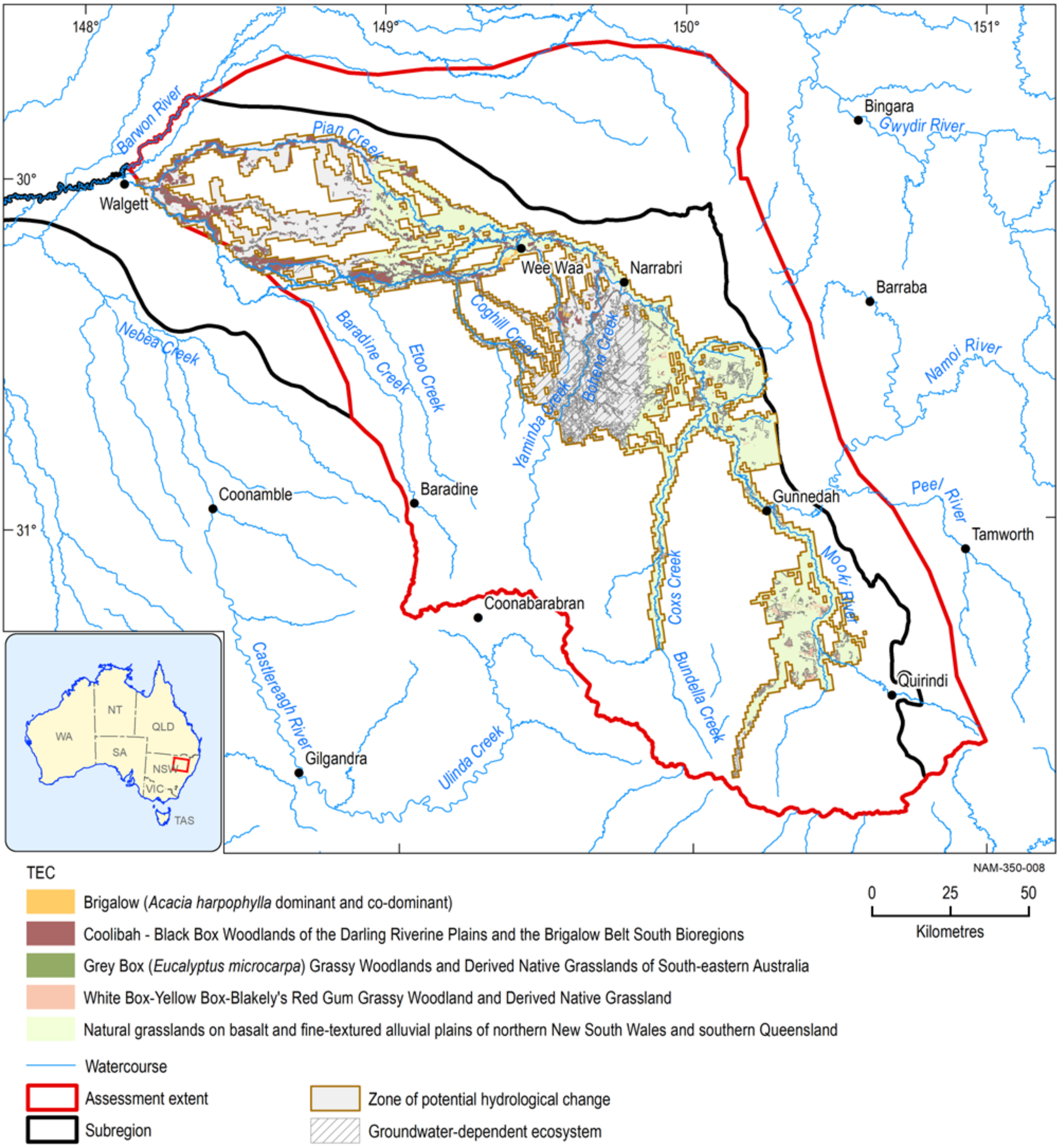

Figure 45 Distribution of assets in the 'Vegetation' subgroup classified as threatened ecological communities (TEC) and their intersection with assets classified as groundwater-dependent ecosystems

Data: Bioregional Assessment Programme (Dataset 1)

The water requirements for these communities are generally poorly understood. In NSW, Brigalow communities occur primarily on flat or gently undulating land characterised by heavy gilgaied clays that collect localised runoff (NPWS, 2002). There are no known studies of the groundwater dependence of *Acacia harpophylla*. Patterns of water use in *A. harpophylla* are tightly coupled to rainfall and the species can tolerate very low leaf water potentials (or very large soil water deficits, (Tunstall and Connor, 1981). Together these observations suggest that groundwater dependence of the dominants in these communities would be limited. There is scant knowledge on the water requirements of three of the threatened ecological communities: 'Grey Box (*Eucalyptus* *microcarpa*) Grassy Woodlands and Derived Native Grasslands of South-eastern Australia', 'Natural grasslands on basalt and fine-textured alluvial plains of northern New South Wales and southern Queensland' and 'White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland'.

There is greater understanding of the water regimes of the Coolibah – Black Box communities, although detailed studies of their water requirements are rare. These communities are associated with floodplains, and the distinction between forest and woodland is related to the degree of flooding, with forests occurring on more frequently flooded sites and woodlands in areas where flooding is less frequent (Roberts and Marston, 2011). Blackbox (*Eucalyptus largiflorens*) trees are well adapted to hot and dry conditions, and are able to access saline groundwater to maintain transpiration during these periods (Holland, 2002), but require flooding every 3 to 7 years to maintain health. These floods may play an important role in flushing salts from the soil profile and ensuring seedling survival following seedling establishment (Roberts and Marston, 2011). Coolibah trees, on the other hand, are less reliant on flooding. Flood regimes for these trees on the lower Gwydir floodplain are described as ranging from 1 in 10 through to 1 in 20, and these events appear to be beneficial through the flushing of salts from the soil profile. Coolibah are believed to be dependent on large-scale floods for large-scale regeneration. Coolibah trees have low transpiration rates and the capacity to access and use highly saline groundwater, which help them survive long dry periods (Roberts and Marston, 2011).

Species listed under the EPBC Act deemed 'more at risk of hydrological changes' due to additional coal resource development are listed in Table 38. These include six bird species, two mammals and three plant species.

Three water bird species were deemed 'more at risk of hydrological changes' due to additional coal resource development: the Australian painted snipe (*Rostratula australis*), the cattle egret (*Ardea ibis*) and the great egret (*Ardea alba*). Of these, the predicted distributions of the cattle egret and the great egret were associated with landscape classes where the thresholds for both surface water and groundwater hydrological response variables were surpassed. In contrast, the predicted distribution for the Australian painted snipe was associated with landscape classes where only the groundwater threshold was surpassed. As a general rule, the groundwater and surface water requirements of all the listed species are poorly understood. Great egrets have preference for permanent waterbodies, and breeding appears to be linked to flood events. Although there is little available information on the frequency of flooding required to maintain populations, Rogers and Ralph (2011) suggest that large floods should occur every 3 years and smaller floods every 2 years to maintain habitats. The water requirements of the Australian painted snipe and the cattle egret are less clear. Both species inhabit wetland types ranging from temporary to permanent wetlands, but appear to favour shallower systems, and inhabit a wider range of habitats.

For the remaining species listed in Table 38, impacts are likely to be mediated through changes in habitat. Species were listed as being potentially water dependent on the basis of their association with water-dependent habitats. All species listed in these habitats (Table 38) are 'more at risk of hydrological changes' from groundwater drawdown or changes in surface water regimes, which may impact on habitat through reduced canopy cover and health, in the short term, or a reduction in stand density over longer periods. However, understanding of these processes is limited at present. For koala, the groundwater-dependent river red gum (*Eucalyptus camaldulensis*) is a preferred food tree in the region and a range of eucalypt species such as *E. populnea*, *E. blakelyi*, and *E. largiflorens* are regarded as secondary food sources (NSW OEH, 2016a).

Changes in surface water regimes may similarly impact the habitat of the white-bellied sea eagle (*Haliaeetus leucogaster*), the koala (*Phascolarctos cinereus*), the long-eared bat (*Nyctophilus corbeni*) and the slender darling pea (*Swainsonia murrayana*), where these habitats overlap with impacted riverine landscape classes.

Table 38 Species listed under the Commonwealth's *Environment Protection and Biodiversity Act 1999* in the 'Habitat (potential species distribution)' subgroup deemed 'more at risk of hydrological changes' due to additional coal resource development, and their association with surface water and/or groundwater hydrological response variables identified by their intersection with water-dependent landscape groups

Animal class	Water-dependent assets[a]	Surface water	Groundwater
Birds	Australian Painted Snipe (*Rostratula australis*)	Yes	No
	Cattle Egret (*Ardea ibis*)	Yes	No
	Great Egret (*Ardea alba*)	Yes	Yes
	Satin Flycatcher (*Myiagra cyanoleuca*)	Yes	No
	Swift Parrot (*Lathamus discolor*)	No	Yes
	White-bellied Sea-Eagle (*Haliaeetus leucogaster*)	Yes	Yes
Mammals	Koala (*Phascolarctos cinereus*)	Yes	Yes
	Potential distribution of south-eastern long-eared bat (*Nyctophilus corbeni*)	Yes	Yes
Plants	*Philotheca ericifolia*	No	Yes
	Slender Darling-Pea, Slender Swainson, Murray Swainson-Pea (*Swainsonia murrayana*)	Yes	Yes
	Spiny peppercress (*Lepidium aschersonii*)	Yes	No

[a]Punctuation and typography appear as used in the asset database.
Data: Bioregional Assessment Programme (Dataset 1)

3.5.2.4 Assets associated with other water-dependent landscape classes

Within the 'Floodplain or lowland riverine' and the 'Non-floodplain or upland riverine' landscape groups, there were a number of landscape classes for which quantitative ecological models were not elicited. These include the 'Floodplain grassy woodland' and 'Floodplain grassy woodland GDE' landscape classes in the 'Floodplain or lowland riverine' landscape group and the 'Grassy woodland GDE', 'Non-floodplain wetland GDE' and 'Non-floodplain wetland' landscape classes in the 'Non-floodplain or upland riverine' landscape group that are potentially exposed to a 50% chance of groundwater drawdown of greater than 2 m. Similarly, no models were elicited for the 'Rainforest' or 'Springs' landscape groups. Table 39 summarises the number of assets that intersect with landscape classes that are potentially at risk from additional groundwater drawdown. In total, 64 unique assets deemed 'more at risk of hydrological change' were associated with these additional landscape classes. However, only 26 of these assets are additional to those already identified in Section 3.5.2.3 as being 'more at risk'. These additional assets identified as 'more at risk' include the EPBC Act-listed species Malleefowl (*Leipoa ocellata*) and 'Leard Cca Zone 3 State Conservation Area'.

Table 39 Number of assets associated with landscape classes for which quantitative models were not elicited but potentially exposed to a 50% chance of groundwater drawdown of greater than 2 m

Landscape group	Landscape class	Asset group	Asset class	Number of assets 'more at risk of hydrological changes'
Floodplain or lowland riverine[a]	Floodplain grassy woodland	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	2
	Floodplain grassy woodland	Surface water feature	Floodplain	1
	Floodplain grassy woodland	Surface water feature	River or stream reach, tributary, anabranch or bend	8
	Floodplain grassy woodland	Surface water feature	Wetland, wetland complex or swamp	0
	Floodplain grassy woodland	Vegetation	Groundwater-dependent ecosystem	7
	Floodplain grassy woodland	Vegetation	Habitat (potential species distribution)	9
	Floodplain grassy woodland GDE	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	0
	Floodplain grassy woodland GDE	Surface water feature	Floodplain	0
	Floodplain grassy woodland GDE	Surface water feature	River or stream reach, tributary, anabranch or bend	0
	Floodplain grassy woodland GDE	Surface water feature	Wetland, wetland complex or swamp	0
	Floodplain grassy woodland GDE	Vegetation	Groundwater-dependent ecosystem	0
	Floodplain grassy woodland GDE	Vegetation	Habitat (potential species distribution)	0
Non-floodplain or upland riverine[a]	Grassy woodland GDE	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	7
	Grassy woodland GDE	Surface water feature	Floodplain	1
	Grassy woodland GDE	Surface water feature	Lake, reservoir, lagoon or estuary	0
	Grassy woodland GDE	Surface water feature	Marsh, sedgeland, bog, spring or soak	0
	Grassy woodland GDE	Surface water feature	River or stream reach, tributary, anabranch or bend	20
	Grassy woodland GDE	Surface water feature	Wetland, wetland complex or swamp	1

Landscape group	Landscape class	Asset group	Asset class	Number of assets ‘more at risk of hydrological changes’
	Grassy woodland GDE	Vegetation	Groundwater-dependent ecosystem	16
	Grassy woodland GDE	Vegetation	Habitat (potential species distribution)	15
	Non-floodplain wetland	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	1
	Non-floodplain wetland	Surface water feature	Floodplain	0
	Non-floodplain wetland	Surface water feature	Lake, reservoir, lagoon or estuary	0
	Non-floodplain wetland	Surface water feature	River or stream reach, tributary, anabranch or bend	3
	Non-floodplain wetland	Surface water feature	Wetland, wetland complex or swamp	0
	Non-floodplain wetland	Vegetation	Groundwater-dependent ecosystem	2
	Non-floodplain wetland	Vegetation	Habitat (potential species distribution)	6
	Non-floodplain wetland GDE	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	2
	Non-floodplain wetland GDE	Surface water feature	Floodplain	1
	Non-floodplain wetland GDE	Surface water feature	Lake, reservoir, lagoon or estuary	0
	Non-floodplain wetland GDE	Surface water feature	River or stream reach, tributary, anabranch or bend	4
	Non-floodplain wetland GDE	Surface water feature	Wetland, wetland complex or swamp	1
	Non-floodplain wetland GDE	Vegetation	Groundwater-dependent ecosystem	3
	Non-floodplain wetland GDE	Vegetation	Habitat (potential species distribution)	9
Rainforest[a]	Rainforest	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	2
	Rainforest	Surface water feature	Floodplain	1
	Rainforest	Surface water feature	River or stream reach, tributary, anabranch or bend	9
	Rainforest	Vegetation	Groundwater-dependent ecosystem	4
	Rainforest	Vegetation	Habitat (potential species distribution)	12

Landscape group	Landscape class	Asset group	Asset class	Number of assets 'more at risk of hydrological changes'
Springs[a]	Springs	Groundwater feature (subsurface)	Aquifer, geological feature, alluvium or stratum	0
	Springs	Surface water feature	Floodplain	0
	Springs	Surface water feature	River or stream reach, tributary, anabranch or bend	0
	Springs	Vegetation	Groundwater-dependent ecosystem	0
	Springs	Vegetation	Habitat (potential species distribution)	0

[a]The spatial extent of assets often intersects multiple landscape groups.
GDE = groundwater-dependent ecosystem
Data: Bioregional Assessment Programme (Dataset 1)

3.5.3 Economic assets

The water resources in the surface water and groundwater systems are managed through water sharing plans in NSW. Water sharing plans are subordinate legislation under NSW's *Water Management Act 2000*. Table 40 lists the groundwater sources within the Namoi subregion that are covered by the six water sharing plans. Each water sharing plan specifies the water sources to which it applies.

Groundwater management in the Namoi subregion is undertaken through six water sharing plans of the NSW Government. These plans lie wholly or partially within the subregion. Figure 14 of companion product 1.5 for the Namoi subregion (Peña-Arancibia et al., 2016) shows the extent and overlap of the water sharing plan areas within the Namoi subregion. There are 22 groundwater sources defined by the NSW Government covered by these six water sharing plans in accordance with the Commonwealth's *Basin Plan 2012* (the Basin Plan) and 21 of those are within the Namoi subregion (Table 40) and there are 31 groundwater sources within the assessment extent. Two of these sources, the Surat and Southern Recharge groundwater sources, are not considered to be part of the Murray–Darling Basin.

Additional coal resource development can impact the economic assets when and where changes in groundwater and surface water hydrology increase the cost of water supply and access. The assessment of potential impact does not involve estimates of costs in monetary terms; instead economic assets within the zone of potential hydrological change are identified and the likelihood of changes to water access are assessed. Economic assets include the water resources themselves, the water supply works, which enable users to access water under a water access licence, or a basic water right.

Table 40 Groundwater management areas within the Namoi subregion

Groundwater source	Description of groundwater source[a]
Great Artesian Basin Surat Shallow	All groundwater above the Great Artesian Basin
Surat	Includes water contained in all rocks of Cretaceous and Jurassic age at a depth of more than 60 m below ground level within the Surat Groundwater Source boundaries (as mapped)[b].
Southern Recharge	Includes: (a) all rocks of Cretaceous, Jurassic and Tertiary age; and (b) all alluvial sediments, except water covered by a different water sharing plan[b].
Gunnedah-Oxley Basin MDB	Groundwater in: (a) all rocks of Permian, Triassic, Jurassic, Cretaceous and Tertiary age within the outcropped and buried areas; and (b) all alluvial sediments within the outcropped areas
Liverpool Ranges Basalt MDB	Groundwater in: (a) all basalt and sediments of Tertiary age; and (b) all alluvial sediments; and all other groundwater, excluding groundwater in the Gunnedah-Oxley Basin and the Sydney Basin
Warrumbungle Basalt	Groundwater in: (a) all basalt and sediments of Tertiary age; and (b) all alluvial sediments; and all other groundwater, excluding groundwater in the Gunnedah-Oxley Basin
Currabubula Alluvial	All groundwater, excluding groundwater in the Gunnedah-Oxley Basin
Quipolly Alluvial	All groundwater, excluding groundwater in the Gunnedah-Oxley Basin
Quirindi Alluvial	All groundwater, excluding groundwater in the Gunnedah-Oxley Basin
Lower Namoi	Groundwater in unconsolidated alluvium associated with the Namoi River and its tributaries including: (a) the Narrabri Formation; (b) the Gunnedah Formation; and (c) the Cubbaroo Formation; and all other groundwater, excluding groundwater in the Gunnedah-Oxley Basin
Upper Namoi – zones 1 to 11	Groundwater in unconsolidated alluvium associated with the Namoi River and its tributaries, including: (a) the Narrabri Formation; and (b) the Gunnedah Formation; and all other groundwater, excluding groundwater in the Gunnedah-Oxley Basin

[a] Descriptions come from Schedule 4 of the Commonwealth's *Basin Plan 2012* except for the Surat and Southern Recharge groundwater sources.
[b] Descriptions of the Surat and Southern Recharge groundwater sources come from the *Water Sharing Plan for the NSW Great Artesian Basin Groundwater Sources* (NSW Government, 2008).
MDB = Murray–Darling Basin
Source: companion product 1.5 for the Namoi subregion (Peña-Arancibia et al., 2016)

3.5.3.1 Assets in the zone of potential hydrological change

The water-dependent asset register for the Namoi subregion (O'Grady et al., 2015; Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 2) has 168 economic water-dependent assets comprising 10,418 elements; however, there are 39 economic assets in the zone of potential hydrological change within the surface water management zone. There are 80 economic assets in the assessment extent that are in the 'Groundwater management zone or area' economic asset subgroup comprising 8953 groundwater access entitlements (Table 41).

Table 41 Economic assets and elements in the Namoi assessment extent, zone of potential hydrological change and mine pit exclusion zone

Subgroup	Asset class	Number in assessment extent		Number in zone of potential hydrological change		Number in mine pit exclusion zone
		Assets	Elements	Assets	Elements	Elements
Groundwater management zone or area (surface area)	Water access right	26	1,936	14	737	7
	Basic water right (stock and domestic)	54	7,017	33	1818	18
	Subtotal	**80**	**8,953**	**47**	**2555**	**25**
Surface water management zone or area (surface area)	Water access right	35	1,457	18	1065	1
	Basic water right (stock and domestic)	53	8	21	0	0
	Subtotal	**88**	**1,465**	**39**	**1065**	**1**
Total		**168**	**10,418**	**86**	**3620**	**26**

Data: Bioregional Assessment Programme (Dataset 1, Dataset 2)

Figure 46 identifies the groundwater sources and bores and extraction points that intersect the zone of potential hydrological change, and hence are potentially impacted due to additional coal resource development. Table 42 lists the potentially impacted groundwater sources and the number of water rights holders (both access licence and basic rights) within the zone of potential hydrological change. Of the 31 groundwater sources in the Namoi assessment extent, there are 17 that have bores within the zone of potential hydrological change but only 9 that have bores within the groundwater zone of potential hydrological change. These 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, whereas the other 22 groundwater sources are *very unlikely* to be impacted due to additional coal resource development.

Of the 2555 bores identified as being within the zone of potential hydrological change there are only 504 within the groundwater zone of potential hydrological change and are therefore potentially impacted (excluding the 25 bores within the mine pit exclusion zone) (Table 41 and Table 42). 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.

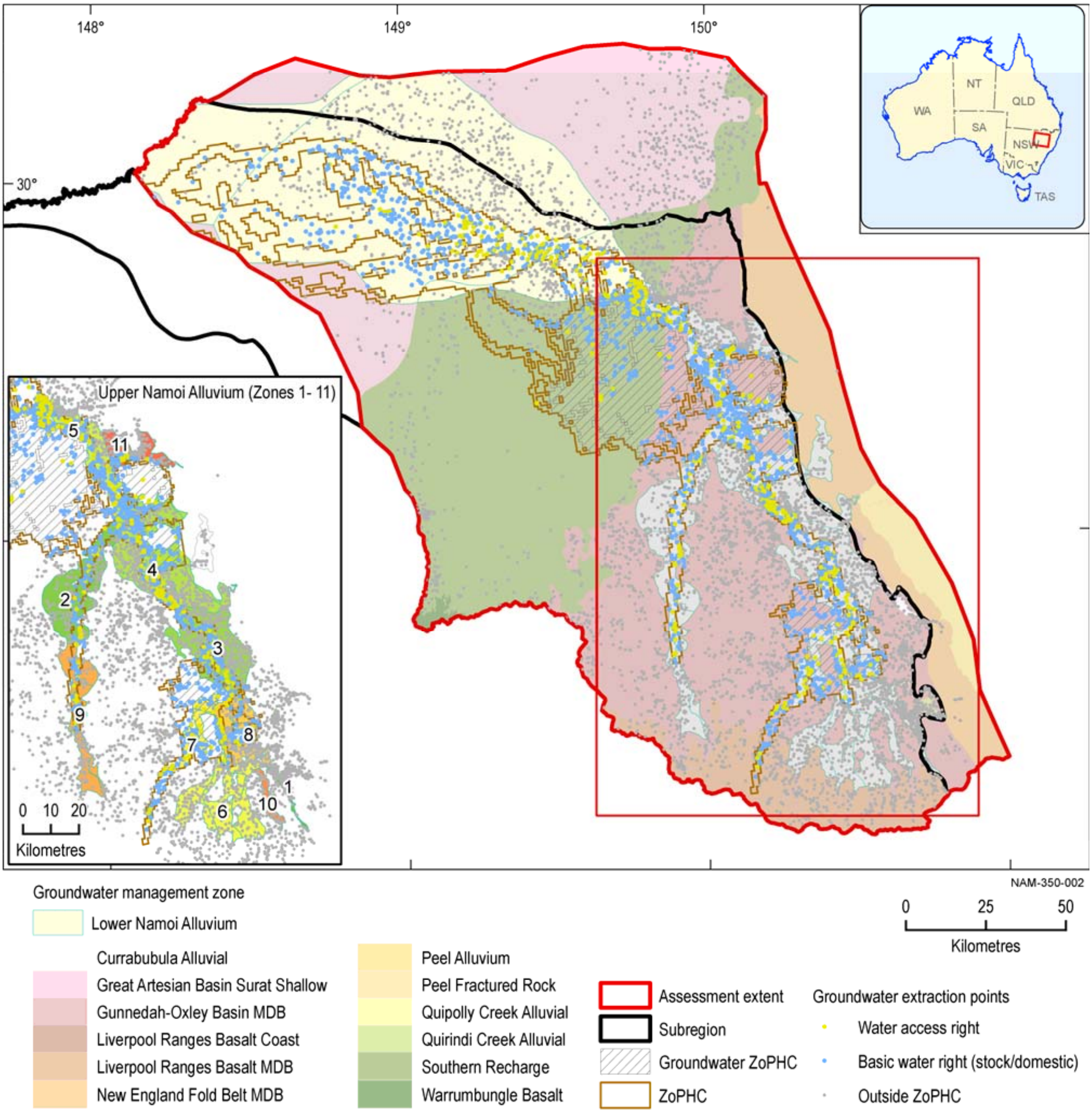

Figure 46 Groundwater source areas and bores in the zone of potential hydrological change

MDB = Murray–Darling Basin, ZoPHC = zone of potential hydrological change
Data: Bioregional Assessment Programme (Dataset 1)

Table 42 Number of bores in the assessment extent, zone of potential hydrological change, groundwater zone of potential hydrological change and in mine pit exclusion zone

Groundwater source	Water access licence				Basic access right				Combined			
	Assessment extent	Zone	GW zone	Mine pit exclusion zone	Assessment extent	Zone	GW zone	Mine pit exclusion zone	Assessment extent	Zone	GW zone	Mine pit exclusion zone
Currabubula Alluvial	9	0	0	0	16	0	0	0	25	0	0	0
Eastern Recharge	0	0	0	0	3	0	0	0	3	0	0	0
GAB Shallow Surat	7	0	0	0	98	2	0	0	105	2	0	0
Gunnedah-Oxley Basin MDB	204	40	15	6	2177	234	132	16	2381	274	147	22
Inland Groundwater Sources	0	0	0	0	7	0	0	0	7	0	0	0
Liverpool Ranges Basalt MDB	14	0	0	0	320	11	0	0	334	11	0	0
Lower Gwydir	0	0	0	0	3	1	0	0	3	1	0	0
Lower Namoi	477	231	1	0	1283	578	1	0	1760	809	2	0
NSW Murray-Darling Basin Fractured Rock	22	0	0	0	0	0	0	0	22	0	0	0
NSW Murray-Darling Basin Porous Rock	1	0	0	0	0	0	0	0	1	0	0	0
New England Fold Belt MDB	0	0	0	0	3	0	0	0	3	0	0	0
Peel Alluvium	1	1	1	0	0	0	0	0	1	1	1	0
Peel Valley Regulated, Unregulated, Alluvium And Fractured Rock	34	0	0	0	0	0	0	0	34	0	0	0
Quipolly Alluvial	13	0	0	0	19	0	0	0	32	0	0	0
Quirindi Alluvial	48	0	0	0	30	0	0	0	78	0	0	0
Southern Recharge	80	34	26	0	695	259	193	0	775	293	219	0
Surat	18	0	0	0	282	6	0	0	300	6	0	0
Upper and Lower Namoi	62	0	0	0	1	0	0	0	63	0	0	0
Upper Darling Alluvial	0	0	0	0	1	0	0	0	1	0	0	0
Upper Namoi Zone 1 Borambil Creek	55	0	0	0	64	0	0	0	119	0	0	0

Groundwater source	Water access licence				Basic access right				Combined			
	Assessment extent	Zone	GW zone	Mine pit exclusion zone	Assessment extent	Zone	GW zone	Mine pit exclusion zone	Assessment extent	Zone	GW zone	Mine pit exclusion zone
Upper Namoi Zone 2 Coxs Creek (Mullaley To Boggabri)	73	37	0	0	157	56	0	0	230	93	0	0
Upper Namoi Zone 3 Mooki Valley (Breeza To Gunnedah)	140	77	1	0	362	120	14	0	502	197	15	0
Upper Namoi Zone 4 Namoi Valley (Keepit Dam To Gins Leap)	277	148	12	1	526	242	35	2	803	390	47	3
Upper Namoi Zone 5 Namoi Valley (Gins Leap To Narrabri)	101	73	2	0	348	166	3	0	449	239	5	0
Upper Namoi Zone 6 Tributaries Of The Liverpool Range (South To Pine Ridge Road)	56	1	0	0	179	1	0	0	235	2	0	0
Upper Namoi Zone 7 Yarraman Creek (East Of Lake Goran To Mooki River)	23	21	15	0	33	32	19	0	56	53	34	0
Upper Namoi Zone 8 Mooki Valley (Quirindi - Pine Ridge Road To Breeza)	124	39	9	0	173	55	25	0	297	94	34	0
Upper Namoi Zone 9 Coxs Creek (Up-Stream Mullaley)	52	16	0	0	68	23	0	0	120	39	0	0
Upper Namoi Zone 10 Warrah Creek	6	0	0	0	27	0	0	0	33	0	0	0
Upper Namoi Zone 11 Maules Creek	39	19	0	0	141	32	0	0	180	51	0	0
Warrumbungle Basalt	0	0	0	0	1	0	0	0	1	0	0	0
Total	**1936**	**737**	**82**	**7**	**7017**	**1818**	**422**	**18**	**8953**	**2555**	**504**	**25**

GAB = Great Artesian Basin, GW = groundwater, MDB = Murray-Darling Basin
Data: Bioregional Assessment Programme (Dataset 1)

3.5.3.2 Bores where drawdown is greater than the minimum impact consideration

Environmental provisions relating to extractions from aquifers are intended to protect the long-term storage component of the aquifer. Extractions are based on reserving a proportion of recharge for the environment. Cease-to-pump rules are used to restrict pumping when levels drop below some specified level or water quality is deteriorating. The *NSW Aquifer Interference Policy* (NSW Office of Water, 2012), which was introduced in September 2012, is intended to protect groundwater resources from activities that potentially interfere with them. It requires that all water extracted from an aquifer must be accounted for, that the activity must address minimal impact considerations and planning must make provision for situations where actual impacts are greater than predicted.

Minimal impact thresholds are specified for highly productive and less productive groundwater sources and different aquifer types (alluvial, coastal sands, porous rock and fractured rock), but can generally be defined as less than 10% cumulative variation in watertable level, 40 m from any high-priority groundwater-dependent ecosystem (GDE) or culturally significant site, with a maximum decline of 2 m at any water supply work.

Table 43 lists the water sources that have bores within the zone of potential hydrological change with a greater than 5%, 50% and 95% chance of drawdowns exceeding 2 m due to additional coal resource development. Excluding the 25 bores within the mine pit exclusion zone, there are 118 bores with greater than 5% chance of exceeding 2 m additional drawdown, 14 bores with greater than 50% chance and 1 bore with greater than 95% chance of exceeding 2 m drawdown due to additional coal resource development. Of these 118 bores that may exceed the minimum impact threshold, at least 50 are owned by the mining companies (only Shenhua and Whitehaven provided information). The locations of these bores are shown in Figure 48 and a graphical representation is shown in Figure 47.

Of the nine groundwater sources that have bores within the zone of potential hydrological change there are seven that have bores with a greater than 5% chance of more than 2 m drawdown (Gunnedah-Oxley Basin MDB, Peel Alluvium, Southern Recharge and Upper Namoi zones 3, 4, 7 and 8). A cumulative distribution of the probability of exceeding 0.2, 2 and 5 m additional drawdown for each bore within these groundwater sources is shown in Figure 49 (the Peel Alluvium is not shown as it only has one bore with greater than 5% chance of exceeding 2 m drawdown).

Table 43 Number of bores where additional drawdown has greater than 5%, 50% and 95% chance of exceeding 2 m

Water source	Number of bores with additional drawdown ≥2 m											
	Water access licence				Basic access right				Combined			
	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%
Currabubula Alluvial	0	0	0	0	0	0	0	0	0	0	0	0
Eastern Recharge	0	0	0	0	0	0	0	0	0	0	0	0
GAB Shallow Surat	0	0	0	0	0	0	0	0	0	0	0	0
Gunnedah-Oxley Basin MDB	6	6	4	0	16	56	7	1	22	62	11	1
Inland Groundwater Sources	0	0	0	0	0	0	0	0	0	0	0	0
Liverpool Ranges Basalt MDB	0	0	0	0	0	0	0	0	0	0	0	0
Lower Gwydir	0	0	0	0	0	0	0	0	0	0	0	0
Lower Namoi	0	0	0	0	0	0	0	0	0	0	0	0
NSW Murray-Darling Basin Fractured Rock	0	0	0	0	0	0	0	0	0	0	0	0
NSW Murray-Darling Basin Porous Rock	0	0	0	0	0	0	0	0	0	0	0	0
New England Fold Belt MDB	0	0	0	0	0	0	0	0	0	0	0	0
Peel Alluvium	0	1	0	0	0	0	0	0	0	1	0	0
Peel Valley Regulated, Unregulated, Alluvium And Fractured Rock	0	0	0	0	0	0	0	0	0	0	0	0
Quipolly Alluvial	0	0	0	0	0	0	0	0	0	0	0	0
Quirindi Alluvial	0	0	0	0	0	0	0	0	0	0	0	0
Southern Recharge	0	6	0	0	0	26	0	0	0	32	0	0
Surat	0	0	0	0	0	0	0	0	0	0	0	0

Water source	Number of bores with additional drawdown ≥2 m											
	Water access licence				Basic access right				Combined			
	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%
Upper And Lower Namoi	0	0	0	0	0	0	0	0	0	0	0	0
Upper Darling Alluvial	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 1 Borambil Creek	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 2 Coxs Creek (Mullaley To Boggabri)	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 3 Mooki Valley (Breeza To Gunnedah)	0	0	0	0	0	1	0	0	0	1	0	0
Upper Namoi Zone 4 Namoi Valley (Keepit Dam To Gins Leap)	1	2	0	0	2	4	0	0	3	6	0	0
Upper Namoi Zone 5 Namoi Valley (Gins Leap To Narrabri)	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 6 Tributaries Of The Liverpool Range (South To Pine Ridge Road)	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 7 Yarraman Creek (East Of Lake Goran To Mooki River)	0	2	1	0	0	2	2	0	0	4	3	0
Upper Namoi Zone 8 Mooki Valley (Quirindi - Pine Ridge Road To Breeza)	0	3	0	0	0	9	0	0	0	12	0	0
Upper Namoi Zone 9 Coxs Creek (Up-Stream Mullaley)	0	0	0	0	0	0	0	0	0	0	0	0

Water source	Number of bores with additional drawdown ≥2 m											
	Water access licence				Basic access right				Combined			
	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%	Mine pit exclusion zone	5%	50%	95%
Upper Namoi Zone 10 Warrah Creek	0	0	0	0	0	0	0	0	0	0	0	0
Upper Namoi Zone 11 Maules Creek	0	0	0	0	0	0	0	0	0	0	0	0
Warrumbungle Basalt	0	0	0	0	0	0	0	0	0	0	0	0
Total	**7**	**20**	**5**	**0**	**18**	**98**	**9**	**1**	**25**	**118**	**14**	**1**

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development.
MDB = Murray-Darling Basin
Data: Bioregional Assessment Programme (Dataset 1)

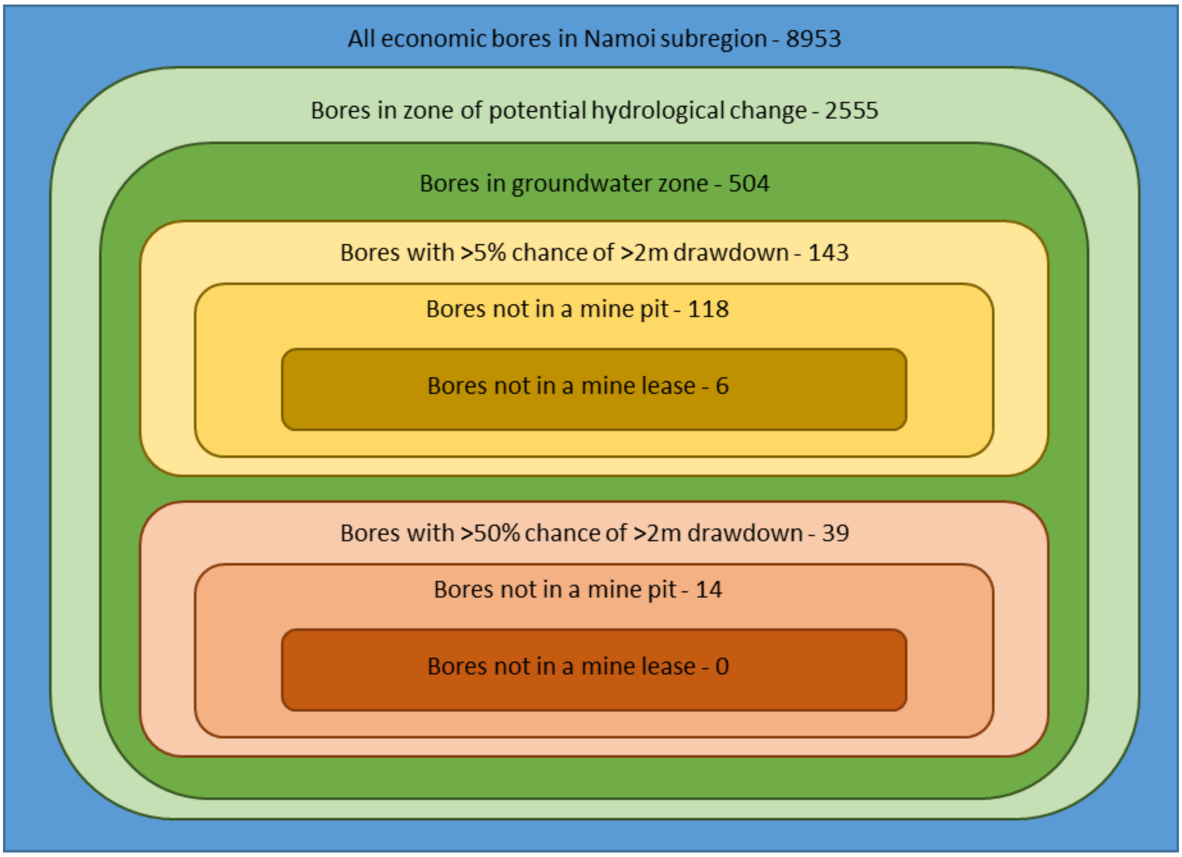

Figure 47 Summary showing the number of bores where minimum impact consideration thresholds have been exceeded

Data: Bioregional Assessment Programme (Dataset 1)

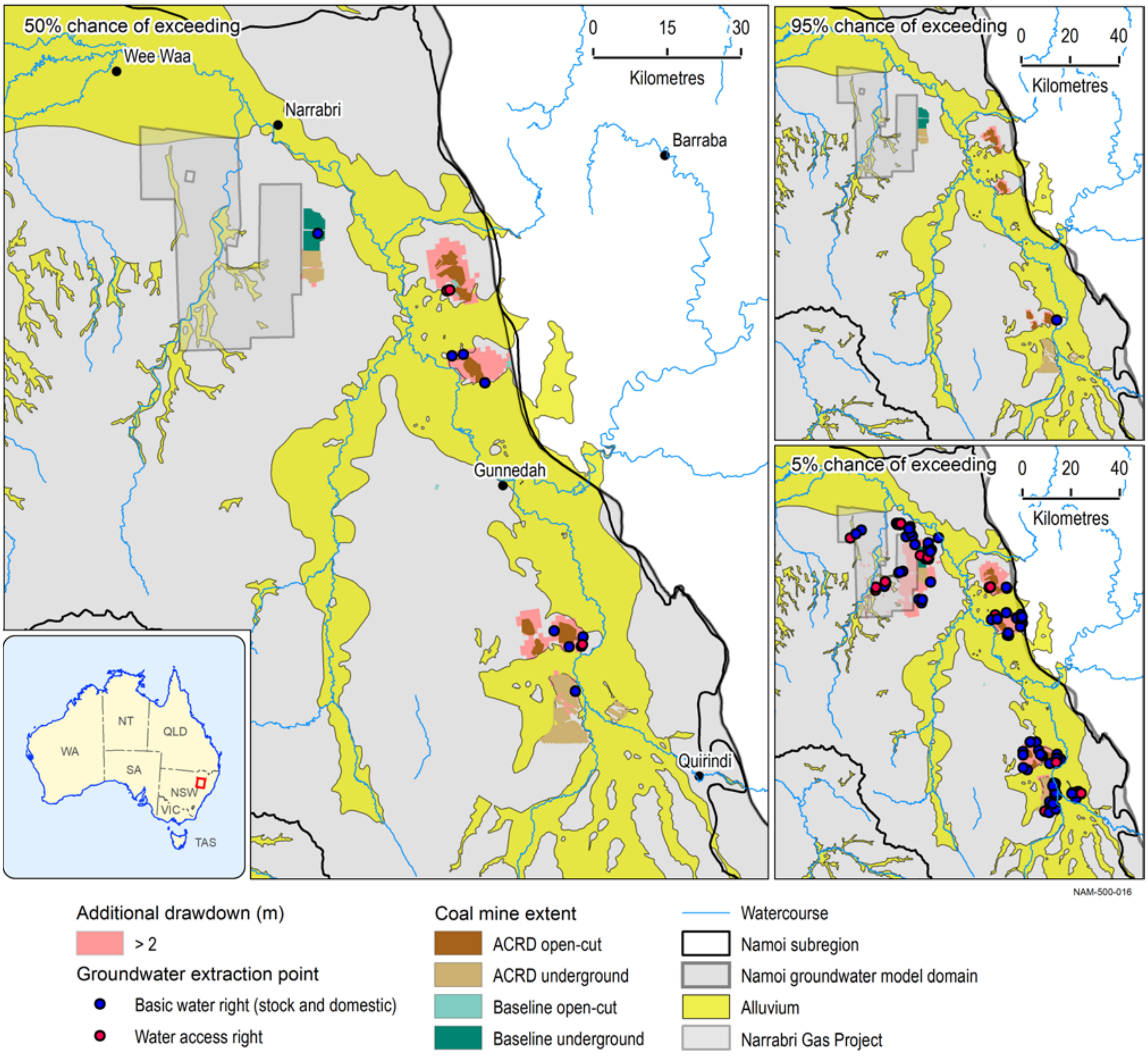

Figure 48 Bores where minimum impact considerations may apply due to additional coal resource development

The open symbols are where the bore is located on a mine lease, the closed symbols are where the bore is located outside of a mine lease. Bores known to be owned by a mining company have been excluded from this figure. The extent of the coal resource developments in the coal resource development pathway (CRDP) is the union of the extents in the baseline and in the additional coal resource development (ACRD).
Data: Bioregional Assessment Programme (Dataset 1)

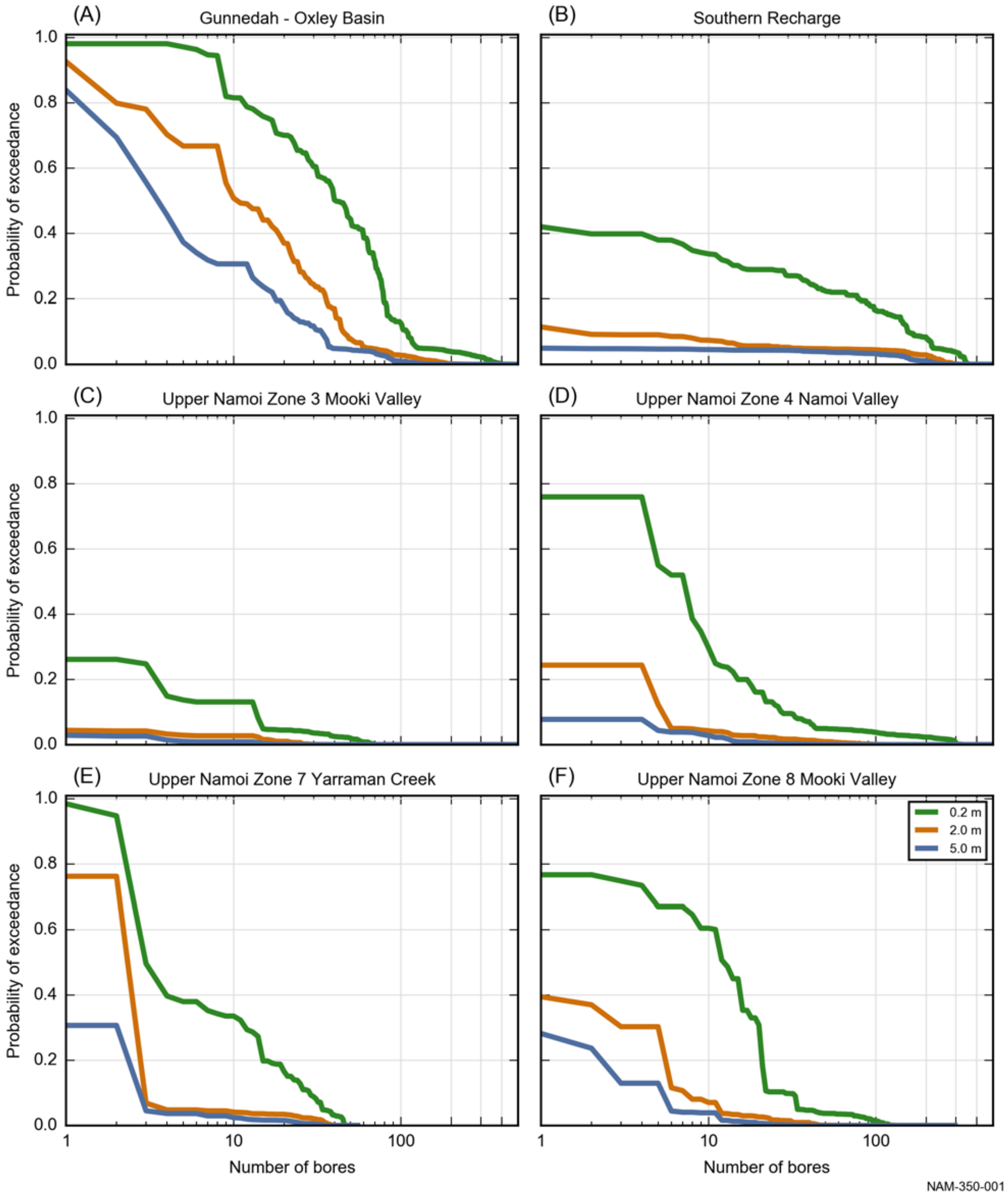

Figure 49 Probability of exceeding 0.2, 2 and 5 m additional drawdown for bores in (a) Gunnedah Oxley Basin, (b) Southern Recahrge, (c) Upper Namoi Zone 3, (d) Upper Namoi Zone 4, (e) Upper Namoi Zone 7 and (f) Upper Namoi Zone 8

Additional drawdown is the maximum difference in drawdown (*dmax*) between the coal resource development pathway (CRDP) and baseline, due to additional coal resource development. Bores within the mine pits are not plotted on this figure.
Data: Bioregional Assessment Programme (Dataset 1)

3.5.3.3 *Impact on surface water availability*

The change in annual flow (AF) is used here as an indicator of changes in surface water availability due to additional coal resource development.

The Namoi Regulated River water source comprises the Upper Namoi and Lower Namoi sources. The maximum percentage changes in annual flow due to additional coal resource development in the Namoi Regulated River is less than 1% for all periods compared to the baseline period flow during 1983 to 2012. The modelling results indicate none of the modelling nodes in the Namoi Regulated River including the Pian Creek anabranch exceeded the specified threshold for average annual flows. The Namoi River and the Peel River networks, up to their confluence at Carrol Gap, also did not exceed specified thresholds since there were no coal mine or coal seam gas (CSG) developments affecting those river stretches.

Table 44 summarises changes in annual flows for Namoi unregulated water sources. The most downstream node for the water source including that for the Bohena Creek, Coxs Creek and Mooki River has been used to assess the change in water availability. Five of the water sources do not show any changes in any periods. No nodes on Baradine and Bohena creeks exceeded the specified threshold for average annual flows. The specified thresholds at upstream nodes of the Mooki River, Quirindi and Coxs creeks were also not exceeded for annual flow. The reductions in annual flows that occur for all unregulated rivers are relatively small compared to the baseline value. In nearly all of the cases, the changes are bigger for the longer-term period of 2073 to 2102. Even in the creeks, which are just downstream of mine sites (e.g. Merrygowen and Driggle Draggle), the effect of additional coal resource development on annual flow is almost negligible.

Table 44 Change in water availability (annual flow) due to the additional coal resource development for Namoi unregulated water sources in the zone of potential hydrological change

The average annual baseline flow for the short-term period (1983 to 2012, 95th percentile) is provided as context. Only the water sources with modelled nodes within the subregion are shown.

Water source	Node	Baseline (GL/year)	Reduction due to additional coal resource development (GL/year)								
		Baseline period (1983–2012)	Short-term period (2013–2042)			Medium-term period (2043–2072)			Long-term period (2073–2102)		
		95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Bohena Creek	14 to 17	225.9	–	–	–	–	–	–	–	–	–
Coxs Creek	28, 29	480.8	–	–	–	–	–	–	–	–	–
Mooki River	33 to 39	435.9	0.1	0.3	1.4	0.2	0.8	2.1	0.2	0.3	1.0
Maules Creek	21, 22, 23	68.0	0	0.3	0.5	0	<0.1	0.3	0	<0.1	0.2
Driggle Draggle Creek	31	12.2	0	0	0.3	0	0.1	0.3	0	0	0.1
Bollol Creek	27	17.0	<0.1	<0.1	0.2	0	0	0	0	0	<0.1
Merrygowen Creek	25	2.6	0	0	0.3	0	0	0.1	0	0	<0.1
Tulla Mullen Creek	20	56.7	0	0	0.1	0	0.1	0.2	0	<0.1	0.2
Jacks Creek	19	24.2	–	–	–	–	–	–	–	–	–
Bundock Creek	9	55.1	–	–	–	–	–	–	–	–	–
Baradine Creek	6	97.4	–	–	–	–	–	–	–	–	–
Lake Goran unnamed creek	54	5.8	0	0	0	0	0	0.2	0	0	0.1

'–' refers to 'no change'

Data: Bioregional Assessment Programme (Dataset 3)

Unlike the Hunter subregion, the water sharing plans of the Lower Namoi Regulated River water source are not divided into different management zones. Table 45 summarises changes in annual flows for the Namoi Regulated River water source by reporting areas (see Section 3.3.2.2 in Section 3.3 for details on reporting areas). Nodes 32, 18, 14 and 1 are the downstream nodes of the Upper Namoi, Mid Namoi, Pilliga and Pilliga Outwash, and Lower Namoi reporting areas, respectively.

Table 45 Change in water availability (annual flow) due to additional coal resource development for reporting areas within the Namoi Regulated River water source

The average annual baseline flow for the short-term period (1983–2012, 95th percentile) is provided as context.

Reporting area	Node	Baseline (GL/y)	Reduction due to additional coal resource development (GL/y)								
		Short-term period (1983–2012)	Short-term period (2013–2042)			Medium-term period (2043–2072)			Long-term period (2073–2102)		
		95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Upper Namoi	32	1908	0.3	0.2	0	0.2	1.0	2.4	0.2	0.4	1.0
Middle Namoi	18	2046	0.2	0.9	0	0.7	1.2	4.2	0.1	0.5	1.0
Pilliga and Pilliga Outwash	14	226	0	0	<0.1	0	0	0	0	0	0
Lower Namoi	1	2162	0.2	0.9	1.7	0.2	0.7	1.7	0.2	0.3	0.4

Data: Bioregional Assessment Programme (Dataset 1, Dataset 3)

3.5.3.4 Impact on surface water reliability

3.5.3.4.1 Regulated river

The Namoi Regulated River between the Split Rock Dam wall and the Barwon River, of which the river stretch upstream of the junction of Namoi and Peel rivers is out of the subregion, is unaffected by additional coal resource development in terms of changes in percent annual flow. Therefore, licence holders with entitlements to water from the Namoi River are unlikely to be potentially impacted.

3.5.3.4.2 Unregulated river

The unregulated rivers that are within the Namoi subregion include a range of rivers and creeks. Twenty-six nodes in the unregulated rivers are modelled. As Table 44 shows, of the modelled unregulated rivers, annual flow is not affected materially for any of these rivers. The maximum 95th percentile change in the annual flow in unregulated water sources is negligible (0.3%).

To maintain the low flows in the streams, the Namoi Unregulated River Water Sharing Plan imposes cease-to-pump rules requiring users to stop taking water when the streamflow declines below a set minimum flow. In many of the water sources the existing conditions on some licences are more restrictive than the cease-to-pump rules (DPI, 2016).

Table 46 lists the water sources within the zone of potential hydrological change that surface water modelling found to have an above-threshold change in the number of zero-flow days (ZFD) or low-flow days (LFD) due to additional coal resource development. The table also details the cease-to-pump rules for each water source and specifies the flow threshold used to quantify the impact on cease-to-pump days due to additional coal resource development. Where cease to pump is triggered by ‘no visible flow’, the change in the average number of zero-flow days in each 30-year period has been used to quantify the change. Where cease to pump is based on the flow rate falling below a specified flow rate at a reference location, then the change is assessed using the specified threshold. Where the cease-to-pump trigger has not been specified for a water source, the assessment has been based on the change in the average number of zero-flow days.

Table 46 Cease-to-pump rules for water sources in the surface water zone of potential hydrological change that surface water modelling found to have a change in zero-flow or low-flow days due to additional coal resource development greater than the defined thresholds

Water source	Cease-to-pump condition	Flow threshold
Maules Creek	Must cease to pump when flow at node 23 <1 ML/day	≤1 ML/day
Bohena Creek	Pumping is not permitted from natural pools when the water level in the pools is lower than its full capacity[a]. This rule applies to both the on-river and off-river pool. For pump sites not within a natural pool, the cease-to-pump rule is when there is no visible flow at that pump site.	Use low flow for pump site in pool and zero flow otherwise.
Bundock Creek	Same as Bohena Creek	Same as Bohena Creek
Baradine Creek	Same as Bohena Creek	Same as Bohena Creek
Coxs Creek	*Lower Coxs Creek Management Zone:* must cease to pump when flow is equal to or below 15 ML/day at Tourable Gauge and 11 ML/day at Boggabri Gauge (node 28) *Mid Coxs Creek Management Zone*: users must cease to pump when flows are equal to or below 17.5 ML/day at Tambar Springs Gauge (node 29) and 15 ML/day at Tourable Gauge	≤11 ML/day and 17.5 ML/day at nodes 28 and 29, respectively
Mooki River	Cease to pump when flow at node 35 is 50 ML/day, commence to pump at 100 ML/day	≤50 ML/day

[a]Full capacity can be approximated by the pool water level at the point where there is no visible flow into and out of that pool.
Source: NSW's *Water Sharing Plan for the Namoi Unregulated and Alluvial Water Sources 2012*; DPI Water (no date)

Table 47 summarises the increase in the number of cease-to-pump days due to additional coal resource development at model nodes. Baseline cease-to-pump days for the baseline 2013 to 2042 period are provided for context. Under the baseline, cease-to-pump for Baradine Creek is possible given the median value is zero while the 95th percentile value is 218 days. Bundock Creek experiences large numbers of cease-to-flow days and the change due to the additional coal resource development is reasonably small at a maximum of 12 days (5% chance) during the 2043 to 2072 period. The cease-to-flow for Maules Creek under the baseline is likely but does not change much due to additional coal resource development. For the Bohena Creek there is a 5% chance that cease-to-flow during the 2043 to 2072 period may increase by 9 days. The Mooki River at Breeza (node 35) has a large number of cease-to-flow days under the baseline due to its larger threshold (≤50 ML/day). These baseline values do not seem to change much either, as larger flows do not seem to be affected for this node due to additional coal resources development (see companion product 2.6.1 for the Namoi subregion (Aryal et al., 2018)). Nodes 28 and 29 on Coxs Creek also have larger numbers of cease-to-flow days under the baseline, which do not change noticeably due to additional coal resource development.

Table 47 Increase in cease-to-pump days due to additional coal resource development (ACRD)

Node	Watercourse	Baseline cease-to-pump days			Increase in cease-to-pump days due to ACRD								
		Short-term period (2013–2042)			Short-term period (2013–2042)			Medium-term period (2043–2072)			Long-term period (2073–2102)		
		5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
6	Barradine Creek	0	0	218	0	0	0	0	0	0	0	0	0
9	Bundock Creek	127	250	322	0	0	7	0	1	12	0	1	5
14	Bohena Creek	0	117	256	0	0	4	0	0	9	0	0	4
23	Maules Creek	0	100	255	0	0	0	0	0	0	0	0	0
28	Coxs Creek at Boggabri	57	132	237	0	0	0	0	0	0	0	0	0
29	Coxs Creek at Tambar Springs	113	211	302	0	0	0	0	0	0	0	0	0
35	Mooki River at Breeza	170	249	282	0	0	2	0	1	6	0	1	3

Note that the baseline and additional coal resource development values are not additive.
Data: Bioregional Assessment Programme (Dataset 4)

3.5.4 Sociocultural assets

The water-dependent asset register for the Namoi subregion (O'Grady et al., 2015; Bioregional Assessment Programme, 2017; Bioregional Assessment Programme, Dataset 2) contains 31 sociocultural assets that are water dependent (Table 48). Of these, 14 assets intersect with the zone of potential hydrological change (Bioregional Assessment Programme, Dataset 1). Thus it is *very unlikely* that hydrological changes associated with coal resource development affect the remaining 17 sociocultural assets.

Table 48 Sociocultural assets in the Namoi assessment extent and zone of potential hydrological change

Asset class	Number of assets in the assessment extent	Number of assets intersecting with the zone of potential hydrological change
Heritage site	22	12
Indigenous site	9	2
Total	**31**	**14**

Data: Bioregional Assessment Programme (Dataset 1)

A sociocultural asset is defined as being water dependent if their location intersects the Namoi maximum flood extent or contains water-dependent features. This broad definition of water dependency makes it difficult to comment on the impact of any potential hydrological changes on these assets without having a quantitative understanding on the nature of their water dependency. This includes, for example, the Boggabri Lagoon and the Burburgate Carved Tree and, among others, built infrastructures such as the Wee Waa and Gunnedah courthouses, a Police residence heritage-listed building, cemeteries and graves – all located within the zone of potential hydrological change (Table 49). The Boggabri Lagoon and the Burburgate Carved Tree are both located close to the Namoi River within the human-modified landscape (Figure 50). 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.

Within the heritage sites, there is also the 'Tambar Springs palaeontological site' (approximately 290 ha). The Tambar Springs palaeontological site is situated in the agricultural area around Coxs Creek north of Tambah. It includes landscape classes associated with the Coxs Creek channel area, including 'Floodplain riparian forests GDE' and 'Grassy Woodland GDE'.

Table 49 Sociocultural assets within the zone of potential hydrological change

Asset class	Asset name
Heritage site	Burburgate Graves
	Collins Park Grandstand
	Gunnedah Courthouse
	Gunnedah General Cemetery
	Gunnedah Railway Station
	Narrabri Gaol (Former)
	Narrabri Post Office And Former Telegraph Office
	Narrabri Public School
	Police Residence
	Ruvigne Homestead Complex
	Tambar Springs Palaeontological Site
	Wee Waa Courthouse
Indigenous site	Burburgate Carved Tree
	Boggabri Lagoon (A21) Indigenous asset

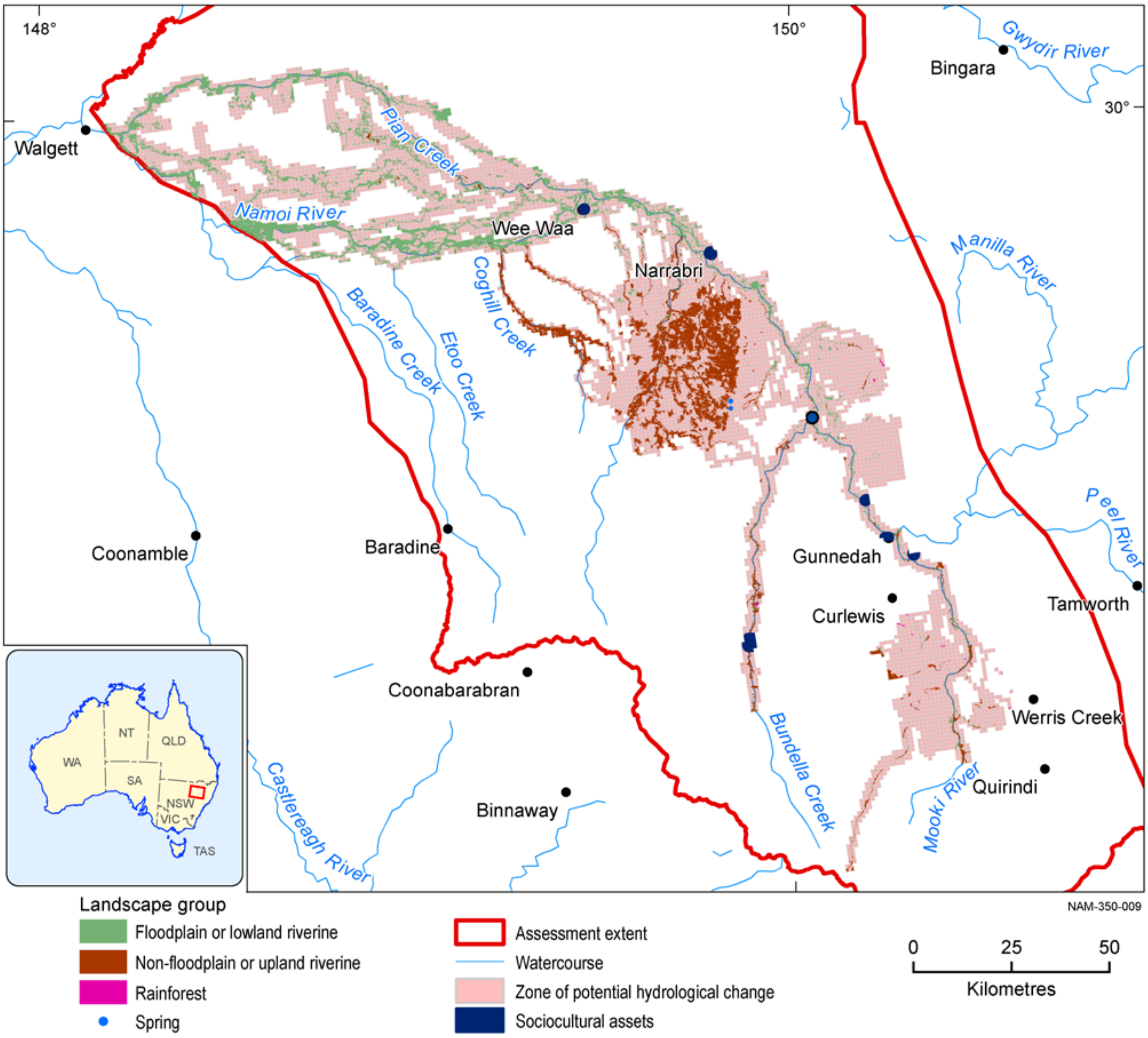

Figure 50 Sociocultural assets within the zone of potential hydrological change

3.5.5 Potential impacts on an individual asset

It is not possible to report potential impacts on each of the hundreds of individual assets within the zone of potential hydrological change. However, the information and data from the previous sections are available for future work trying to assess potential impacts on individual assets. Case studies to illustrate how multiple lines of available hydrological and ecological evidence may be useful in assessing potential impacts on individual assets are detailed in the impact and risk analyses of the Hunter and Galilee subregions (Herron et al., 2018, Lewis et al., 2018).

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3.6 Commentary for coal resource developments that are not modelled

Summary

There are two additional coal resource developments that were not modelled because sufficient information did not exist for them. These are the Gunnedah Precinct and Vickery South Coal Project. The Gunnedah Precinct has the potential for cumulative impacts with the baseline Sunnyside Mine (currently in care and maintenance). The Vickery South Coal Project has the potential for cumulative impacts with the Vickery Coal mine (an additional coal resource development), as well as the baseline Rocglen Mine.

3.6.1 Non-modelled additional coal resource developments

The companion product 2.3 for the Namoi subregion (Herr et al., 2018) identified two additional coal mines, the Gunnedah Precinct and the Vickery South Coal Project, in the coal resource development pathway (CRDP) that were not included in the hydrological modelling because there was insufficient information about their scope, size and water demand (Table 50).

Both proposed developments are situated within the zone of potential hydrological change as shown in Figure 12. Figure 51 shows the location of these mines relative to the 50th percentile of groundwater drawdown. Given the proximity of the Gunnedah Precinct and the Vickery South Coal Project to other coal resource developments, there is potential for cumulative impacts.

Table 50 Additional coal resource developments that were not modelled in the Namoi subregion based on companion product 2.3 (Herr et al., 2018)

Coal resource development	Reasons for not including in CRDP
Gunnedah Precinct	The Whitehaven Coal owned project area largely sits within an area previously mined (the Gunnedah Colliery). Future development of this area is possible, however there is currently insufficient information available about how the resource would be developed, and the timing/schedule/life span.
Vickery South Coal Project	Vickery South Coal Project has currently insufficient information available about how the Vickery South coal resource would be developed, and the timing/schedule/life span.

CRDP = coal resource development pathway

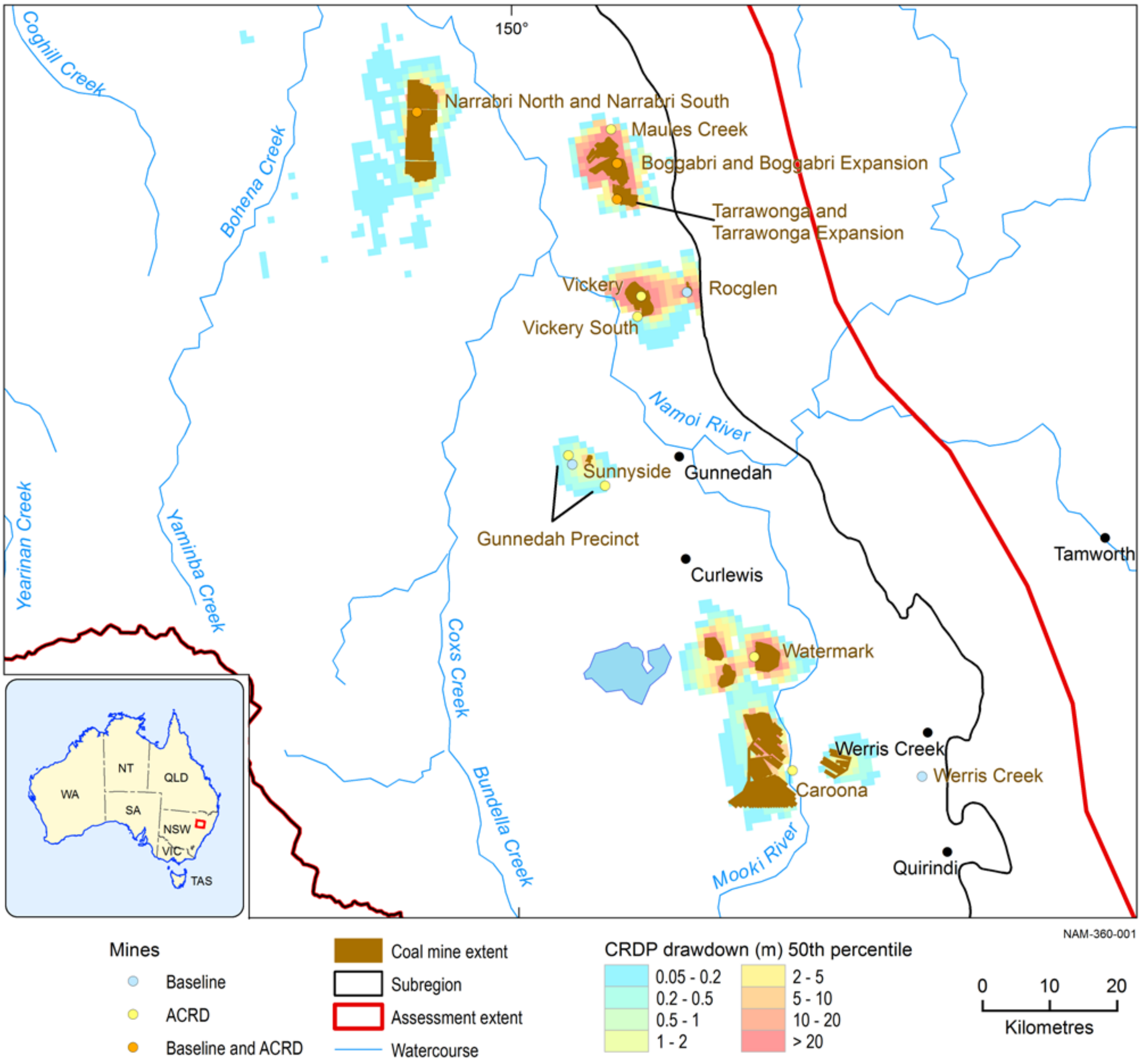

Figure 51 Location of the additional coal resource developments Gunndedah Precinct and Vikery South Coal Project that were not included in the hydrological modelling and in relation to the 50th percentile groundwater drawdown

Data: Bioregional Assessment Programme (Dataset 1)

3.6.2 Potential impacts of non-modelled additional coal resource developments

3.6.2.1 Gunnedah Precinct

The Gunnedah Precinct is a proposed open-cut development located near the Sunnyside Mine, which is now under care and maintenance. While the time frame for groundwater changes resulting from Sunnyside Mine to subside has not yet come to an end, the peak groundwater changes have passed. This means the future risk of cumulative impact from the Gunnedah Precinct on groundwater resources is reduced, assuming extraction of coal from Sunnyside Mine does not resume (there is development consent for this mine until 2020, see companion product 2.1-2.2 for the Namoi subregion (Aryal et al., 2018)).

Groundwater modelling identifies up to 2 m drawdown (Figure) in the vicinity of the Sunnyside Mine. The effect on groundwater drawdown of the Gunnedah Precinct is likely to be localised and cumulative because of its proximity to the existing Sunnyside Mine and is unlikely to extend to other mines. This is because the probability of exceeding 0.2 m drawdown is approximately 5% within a 10 km distance from any mine (companion product 2.6.2 for the Namoi subregion (Janardhanan et al., 2018)). There is also a potential for cumulative effects on local surface waters including streams, and any hydrological changes have the potential to intersect with the following landscape groups: 'Dryland remnant vegetation', 'Floodplain or lowland riverine', 'Human-modified', 'Non-floodplain or upland riverine', and 'Rainforest'. Impacts to specific ecological, sociocultural and economic assets were not considered in this product but the potential additional hydrological changes described should to be considered in relation to the assets in Section 3.5.

3.6.2.2 Vickery South Coal Project

The open-cut Vickery South Coal Project is an expansion of the future Vickery Coal Project (also an additional coal resource development) and so will have a cumulative impact, overlaying its changes to groundwater with drawdown already in progress from both Vickery and the existing Rocglen Mine (Figure 51). The location of this proposed development suggests the potential for changes to groundwater and surface waters (Figure 51), because the project area is within the alluvium associated with the Namoi River, Driggle Draggle Creek and Stratfort Creek (see companion product 2.1-2.2 for the Namoi subregion (Aryal et al., 2018)).

The hydrological changes associated with the development have the potential to intersect with the following landscape groups: 'Dryland remnant vegetation', 'Floodplain or lowland riverine', 'Human-modified', 'Non-floodplain or upland riverine' and 'Rainforest'. Impacts to specific ecological, sociocultural and economic assets were not considered in this product but the potential additional hydrological changes described should to be considered in relation to the assets in Section 3.5

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Datasets

Dataset 1 Bioregional Assessment Programme (2017) Namoi groundwater drawdown grids. Bioregional Assessment Derived Dataset. Viewed 22 May 2017, http://data.bioregionalassessments.gov.au/dataset/38b6fd6e-631c-4b3c-830b-0b449ad32d62.

3.7 Conclusion

Summary

Findings from this Assessment can help governments, industry and the community in providing better-informed regulatory water management and planning decisions. Assessment results flag where future efforts of regulators and proponents can be directed, and where further attention is not necessary.

Modelling of drawdown and surface water flow interception from eight additional coal resource development predicted changes in flow in a number of streams, where there was sufficient information for surface water modelling, with more low flows, and fewer high flows and overbank events. These changes in the streamflow lead to potential risks to the ‘Floodplain or lowland riverine’ and ‘Non-floodplain or upland riverine’ landscape groups.

Post-assessment monitoring is important to test and (in)validate the risk predictions of the assessment. At the highest level, monitoring efforts should reflect the risk predictions, and focus the effort where changes are potentially the largest and incorporate those areas where modelling limitations did not allow the risk to be quantified. However, it is important to place some monitoring effort at locations with lower risk predictions so as to confirm the range of potential impacts and identify unexpected outcomes.

Besides monitoring, there are a number of data-sparse areas where drawdown intersects with streams, and where the absence of surface water data made it impossible to construct and apply surface water models. These areas would benefit from consistent and regular data collection, which would improve the risk quantification of this Assessment. This includes surface water and ecological baseline data collection to establish an understanding of the environmental conditions.

Work on identifying and monitoring the hydrological conditions that relate to groundwater and subsurface flows and their limits that sustain subsurface biota would also improve this Assessment further, especially when co-located with hydrological monitoring areas that also collect data to improve the knowledge on surface water – groundwater interaction.

The assessment’s probabilistic approach used a wide array of parameterisations to represent the possibility of highly conductive, highly connected landscapes through to low-conductivity, poorly connected landscapes. These result sets are intended to span the hydrological changes that may occur, help ensure that the zone of potential hydrological change is conservative, and allow bioregional assessments (BAs) to make strong statements about non-impact for landscape classes or assets that are outside the zone. Better data will not necessarily improve the hydrological model predictions from the regional-scale model, but could potentially contribute to constraining model results for local-scale application.

Improved mapping of depth to groundwater, and its spatial and temporal variation, not only has potential to constrain hydrological change predictions, but it provides much needed context for the interpretation of the ecological impacts due to hydrological change.

Ecological risk is quantified using receptor impact models, and based on experts' understanding of the receptor impact variables over large areas and time frames relevant to the ecosystem's water requirement. As a consequence, predictions of receptor impact variables at specific locations reflect the response across the landscape class the experts would expect to occur given the hydrological conditions at that location. The usefulness of the receptor impact models is in identifying the risk to areas, based on the hydrological changes, and highlighting these areas that warrant priority for further investigation. These priority areas require consideration in conjunction with those where a lack of hydrological modelling prevented receptor impact modelling outputs.

BAs have been developed with the ability to be updated, for example, to incorporate new coal resource developments in the groundwater model. Existing datasets, such as the water-dependent asset register, remain relevant for future assessments.

The full suite of information, including information for individual assets, is available at www.bioregionalassessments.gov.au.

3.7.1 Key finding

Overall, hydrological modelling predicted a 2299 km^2 area under additional drawdown and 20% (7014 km^2) of the assessment extent is within the (combined surface and groundwater) zone of potential hydrological change as a result of the eight modelled additional coal resource developments in the Namoi subregion. This has the potential for cumulative impacts due to the location of a number of new developments in close proximity to each other as well as interaction with baseline coal resource development. As a result, there is overlap of groundwater drawdown from multiple developments. This drawdown and direct interception of overland flow potentially leads to more low flows, and fewer high flows and overbank events. There are 5521 km of streams in the zone of potential hydrological change and we were unable to interpolate to 3629 km of streams. For those areas with sufficient data, there is an increase in more than 3 zero-flow days per year predicted for 1678 km of streams. Predicted changes in the flow of the Namoi River are minimal. However, Back Creek, Merrygowen Creek and Bollol Creek are *very likely* to experience changes in their flow, particularly with respect to the change in the number of zero-flow days. The changes in the streamflow may lead to potential impacts on the water-dependent 'Floodplain or lowland riverine' and 'Non-floodplain or upland riverine' landscape groups. Where modelling was available some areas of Maules Creek, Back Creek and Bollol Creek within the 'Floodplain or lowland riverine' landscape group are 'more at risk of ecological and hydrological changes' than other streams in the assessment extent due to additional coal resource development. There are areas within the zone of potential hydrological change where the lack of surface water modelling prevented a quantification of the risk to ecosystems. These require more work to assess the potential for impact due to additional coal resource development to ecosystems and associated assets. There are also potential impacts on ecological assets that utilise the potentially impacted landscape groups, as well as groundwater economic assets. The alluvium zones that have the greatest area potentially impacted are the Upper Namoi Alluvium zones 4, 7 and 8 while the Lower Namoi Alluvium has less than 1 km^2 that is within the groundwater zone of potential hydrological change. The hydrological changes intersect with only a limited number of sociocultural assets from the asset register (Bioregional Assessment Programme, 2017; companion product 1.3 for the Namoi subregion (O’Grady et al., 2015); Bioregional Assessment Programme, Dataset 1).

3.7.2 Future monitoring

Post-assessment monitoring is important to test and (in)validate the risk predictions of the assessment. At the highest level, hydrological and ecological monitoring effort should reflect the risk predictions, and focus the effort where the changes are expected to be the largest and incorporate those areas where modelling limitations did not allow the risk to be quantified. However, it is also important to place some monitoring effort at locations with lower risk predictions so as to confirm the range of potential impacts and identify unexpected outcomes.

The BA for the Namoi subregion has identified that potential hydrological or ecosystem impacts due to additional coal resource development are likely in areas concentrated around the locations of the main proposed coal resource development. Groundwater monitoring effort should concentrate on the discrete drawdown zones identified in the hydrological modelling. The following water sources have the largest number of bores where the assessment identified a drawdown of more than 2 m and would be expected to be a focus of the groundwater monitoring. In order they are:

1. Gunnedah-Oxley Basin MDB
2. Upper Namoi Zone 4 Namoi Valley
3. Upper Namoi Zone 7 Yarraman Creek
4. Upper Namoi Zone 8 Mooki Valley
5. Southern Recharge
6. Upper Namoi Zone 3 Mooki Valley.

Future surface water monitoring should focus on streams that pass near the additional coal resource developments, and particularly Back Creek, Merrygowan Creek, Bollol Creek and Driggle Draggle Creek, given the changes in streamflow modelled to occur there.

Besides monitoring, there are a number of data-sparse areas that would benefit from consistent and regular data collection, which would improve the risk quantification of this assessment. This includes surface water and ecological baseline data collection to establish an understanding of the environmental conditions.

There are lengths of stream that are noted as potentially impacted because risk predictions are not made in some cases (e.g. because it is not sensible to interpolate from the stream model nodes used), and where establishing data collection points and monitoring may enable additional surface water modelling, which in turn may improve the clarity around potential hydrological changes from coal resource development.

This Assessment did not model or quantify water quality changes. Existing monitoring of instream water quality is patchy in terms of spatial and temporal coverage. Where water quality impacts of coal resource development are of concern, separating these changes from the location-specific background water quality, which may include impacts from agricultural activities and infrastructure, is necessary.

The availability of ecological data for benchmarking, including identifying current conditions, comparing and identifying changes in ecosystems and ecosystem indicators, is very limited, especially for dealing with regional-level changes. There is a lack of ecohydrological understanding around the many water-dependent vegetation communities' water requirements, and how these relate to specific hydrological response variables – a crucial requirement for assessing impacts related to hydrological changes.

The current Assessment has focused on ecosystems at the surface. This is because the understanding of the regional subsurface ecology is patchy at best and data suitable for identifying regional changes are unavailable. However, changes in groundwater and subsurface flows are likely to result in subsurface ecosystem changes and, in particular, this will relate to the hyporheic zone. The hyporheic zone is the transition zone between surface and the groundwater biota and contains the interstitial spaces that serve as refugia habitat for stream biota. It is this refugia from which they move into the streams after the drying period. This is highly relevant in the many non-permanent streams in the Namoi subregion. Work on identifying and monitoring the hydrological conditions and the limits that sustain these biota in the hyporheic zones would improve this Assessment, especially when co-located with hydrological monitoring areas.

Deeper-positioned subterranean ecosystems with their stygobiotoa respond to changes in groundwater. However, there is only limited local information available (see e.g. Korbel et al. (2013a, 2013b)), which is insufficient to provide an understanding of the hydrological determinants for stygobiota related habitat use and requirements. Groundwater biota sampling requires special sampling approaches to prevent bias in determining stygobiota composition and to achieve an unbiased picture of the subterranean ecosystems and their associated hydrological conditions (Korbel et al., 2017). This Assessment was unable to make any quantified statements related to impacts due to additional coal resource development on stygobiota. Establishing an understanding on the wider extent, compositions, structures, and hydrological habitat requirements of the stygobiota of the Namoi subregion is necessary when attempting to address risk from coal resource development. Monitoring stygobiota in association with changes in groundwater quality and quantity would be valuable in helping to address risks to this barely understood part of Australia's ecology.

3.7.3 Using this impact and risk analysis

Findings from BAs 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. This is emphasised through the rule-out process, which focuses attention on areas where hydrological changes are predicted. In doing so, it has identified areas, and consequently water resources and water-dependent assets, that are *very unlikely* (less than 5% chance) 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 level. It also provides important context to identify potential issues that may need to be addressed in local-scale environmental impact assessments of new coal resource developments. It should help project proponents to meet legislative requirements to describe the effects of underground water use on environmental values and to adopt strategies to avoid, mitigate or manage the predicted impacts. This Assessment does not investigate the broader social, economic or human health impacts of coal resource development, nor does it consider risks of fugitive gases, non-water-related impacts and the broader water quality implications.

BAs are not a substitute for careful assessment of proposed coal mine or coal seam gas (CSG) extraction projects under Australian or state environmental law. Such assessments may use finer-scale groundwater and surface water models and consider impacts on matters other than water resources. However, the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (a federal government statutory authority established in 2012 under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*) and relevant state regulators may use results from this Assessment in formulating their advice.

BAs have been developed with the ability to be updated, for example, to incorporate new coal resource developments in the groundwater model. Existing datasets, such as the water-dependent asset register, remain relevant for future assessments. 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 a subregion-scale re-assessment of potential impacts under an updated coal resource development pathway (CRDP). It may also be applicable for other types of resource development.

The full suite of information, including information for individual assets, is provided at www.bioregionalassessments.gov.au with more detailed results available for:

- potential hydrological changes at www.bioregionalassessments.gov.au/explorer/NAM/hydrologicalchanges
- potential impacts on landscapes at www.bioregionalassessments.gov.au/explorer/NAM/landscapes
- potential impacts on water-dependent assets at www.bioregionalassessments.gov.au/explorer/NAM/assets.

Access to underpinning datasets, including spatially explicit 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 Bioregional Assessment Programme's (the Programme) methodology is also documented in detailed scientific submethodologies (Table 1).

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.

3.7.4 Gaps, limitations and opportunities

This impact and risk analysis allows governments, industry and the community to focus on areas that are potentially impacted when making regulatory, water management and planning decisions. Due to the conservative nature of the modelling, the greatest confidence in results is for those areas that are *very unlikely* to be impacted (that is, outside the zone of potential hydrological change). Areas that identify impacts indicate where further work may be required to obtain better predictions of the potential magnitude of impacts to ecosystems and individual assets.

Each of the companion products identifies key knowledge gaps for the Namoi subregion. The following sections are a summary of the key knowledge gaps where further work could improve the understanding of the potential impacts of coal resource development.

3.7.4.1 Overall

The probabilistic approach to modelling undertaken in the assessment is ideally suited to deal with data and knowledge gaps. The Assessment team focused on integrating data and information that were quality-assured and relevant for this regional-scale analysis. However, this meant that some data and information about the Namoi subregion were not used to inform the modelling – for instance, because they were localised and ad hoc in their coverage; lacked reliable metadata to quality assure the data; not available to the Assessment team at the time of analysis; or because operational constraints prevented collating and scrutinising the data to the standards set out in the BA.

A wide array of parameterisations to represent the possibility of highly conductive, highly connected landscapes through to low-conductivity, poorly connected landscapes provided result sets that are intended to span the hydrological changes that may occur, help ensure that the zone of potential hydrological change is conservative, and allow BAs to make strong statements about non-impact for landscape classes or assets that are outside the zone. In flagging gaps and identifying opportunities for improvement in the following sections, it is important to be aware that more and better data will not necessarily improve the model predictions from the regional-scale model, but could potentially contribute to constraining model results for local-scale application.

This Assessment did not incorporate water quality into the modelling and this remains an area for further investigation.

3.7.4.2 Geological model

The geological model constructed to underpin the groundwater modelling, described in Section 2.1.2 of companion product 2.1-2.2 for the Namoi subregion (Aryal et al., 2018) is an improvement of the existing CDM Smith conceptualisation, with areas modified where more updated geological knowledge was available, most notably in the Surat Basin and the alluvium. However, it does not include faults, which can act as barriers or conduits to groundwater flow. A more detailed understanding of fault locations and depths would improve the geological model and provide an improved precision to the model results if included into the groundwater modelling. Including faults into the current modelling is unlikely to change the spatial extent of the zone of potential hydrological change at the current resolution of 1 km^2. However, probabilistic groundwater modelling accuracy and precision at the local scale is likely to benefit from fault inclusion if faults are present. Fault relevance for the modelling could also be determined, for example, through the analysis of well completion reports.

Further improvements to the geological model accuracy would be possible with additional spatially explicit data on the thickness of the stratigraphic layers, including well completion reports and structural mapping from the companies operating in the Namoi subregion that were not available to the Assessment team at the time. This would improve the accuracy of the modelling, particularly in the Maules Creek sub-basin.

3.7.4.3 Groundwater information

Groundwater data are often patchy and poorly documented, particularly for regional applications. This was an issue in the Namoi subregion, particularly for depth to watertable, recharge and contributions to baseflow from groundwater.

Groundwater data from state databases primarily include monitoring data for shallow groundwater systems and aquifers used for irrigation, stock and domestic purposes. These data are usually in the form of water level measurements and major ion analyses, which support knowledge of groundwater recharge processes and interactions between rivers and groundwater. However, it provides limited understanding of deeper groundwater systems. Local monitoring of the effect on groundwater levels by proponents of their mining activities is less relevant. Such data, rather than constraining the predictions, can bias the predictions if the historical stresses and local geological conditions of these monitoring data are not well understood and represented in the regional model. This has been factored into the assessment's uncertainty analysis and modelling. Future assessments would be assisted by improved information on deeper groundwater systems.

Depth to groundwater is a determinant for groundwater dependency of vegetation. For example, in areas where groundwater is sufficiently close to the landsurface for tree root access, the tree communities at these locations are using the groundwater (Anderson et al., 2016). Improved mapping of depth to groundwater, and its spatial and temporal variation, not only have potential to constrain hydrological change predictions, they provide 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.

The groundwater model results are relevant for a BA purpose and for the specific regional-scale resolution only. Using the model and its results for other purposes, especially at a more local-scale resolution is not advisable. Use for any other purpose requires a formal re-evaluation of the suitability of the conceptual model and model assumptions, in line with the *Australian groundwater modelling guidelines* (Barnett et al., 2012).

3.7.4.4 Integrated hydrological modelling

Interaction between the groundwater and surface water, the flux of water through the hyporheic zone, is important for estimating hydrological response variables, especially those relating to low- or no-flow conditions. The companion product 2.1-2.2 (Aryal et al., 2018) provides a regional overview and improved treatment of these interactions for the major streams at the subregion level. However, assessment of the impacts of hydrological changes from coal resource development on ecological assets, ecosystems and ecoclines (ecosystem boundary zones) generally requires a finer-scale approach in areas where local populations are under investigation. Hence, impact assessments need to develop integrated hydrological models that provide predictions suitable to the local ecological assets.

At the BA model scale, the depth of incision of the streambed below topography is a very influential parameter for the simulation of groundwater level in the regional watertable aquifer and the surface water – groundwater flux. Improvements in these parameters would enable an increased precision for results of the surface water hydrological modelling.

In the Namoi modelled stream network, the distribution of model nodes was too sparse to enable a comprehensive extrapolation to network reaches, resulting in many ‘potentially impacted’ reaches, where hydrological changes could not be quantified. A higher density of 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. A more extensive quantification of hydrological changes along the stream network would enable better spatial coverage of the results of the receptor impact modelling.

3.7.4.5 Assessing ecological impacts

Receptor impact modelling included experts’ input, which resulted in receptor impact models for specific landscape classes in the ‘Floodplain or lowland riverine’ and the ‘Non-floodplain or upland riverine’ landscape groups. Predictions of receptor impact variables from these models provide indicators of potential ecosystem risk for landscape classes in the Namoi subregion, but are constrained to those areas where surface water modelling could provide the hydrological response variables. Where there is limited or no surface water modelling, it is not possible to quantify the risk, though the underlying groundwater drawdown and the proximity to the coal resource development relative to other areas that are modelled are typically informative. In these areas, a simple spatial overlay of landscape classes over the zone of potential hydrological change identifies the locations (and parts of landscape classes) where additional work may be needed to quantify the risk.

The receptor impact modelling relied heavily on expert opinion. Thus, the number of experts and their expertise will influence the choice of ecosystem indicators used in the qualitative model development and the choice of receptor variables. It would be prudent to test the predictions against (regional) verifications of the ecological responses.

A receptor impact model quantifies the range or distribution of responses for a receptor impact variable given a specific change in hydrology. Predictions of receptor impact variables at specific locations (assessment units) then incorporate the hydrological uncertainty at that location and the uncertainty the experts have in the response across the landscape class or ecosystem for that change in hydrology. These are not predictions of the receptor impact variable at the specific location but rather predictions of the receptor impact variable response across the landscape class for the change in hydrology at the specific location. The predicted receptor impact variable may indicate where the hydrological change is of such a magnitude that it is commensurate with potential ecosystem change, even if the receptor impact variable is not found at that location. The usefulness of these models is in identifying the areas where the potential risk is greater and where further investigation should focus. These priority areas require consideration in conjunction with those where a lack of hydrological modelling prevented receptor impact modelling outputs.

Improving the knowledge of the existing qualitative models and the associated receptor impact models could improve the ecosystem response predictions. Revisiting the qualitative models for the landscape classes specifically and adjusting these for the purpose of prioritising future (ecological) research may be an effective way directing additional research resources (see e.g. Herr et al. (2016)).

Not all landscape classes have receptor impact modelling associated with them. For those landscape classes, the overlay with the zone of potential hydrological change identifies the areas or parts of landscape classes where there are potentially unquantified impacts that may warrant further investigation. For example, groundwater drawdown has the largest impact on the ‘Temporary upland stream’ landscape class in the Pilliga. While the surface water modelling in the Pilliga reporting area does not identify any changes in Bohena Creek for this landscape class, there are many other temporary upland streams where there is no surface water modelling output and thus, no receptor impact modelling for this landscape class. It would be prudent to clarify if the non-modelled streams experience any surface water-related changes before focusing solely on areas identified as higher risk from receptor impact modelling.

A similar argument holds for the assessment of ecological assets within the zone of hydrological change. The assessment identified assets ‘more at risk of hydrological changes’ based on hydrological modelling thresholds. This means that, while the assessment identified specific assets ‘more at risk’ based on their intersection with the hydrological modelling output, there are many locations where there is no quantified surface water change. This means the assets that are outside these areas, and are within the zone of potential hydrological change, do not have a quantified risk in this assessment. This will need consideration in dealing with these assets for the purpose of addressing priorities and impacts.

3.7.4.6 Sociocultural assets

Many sociocultural assets in the Namoi subregion from the Register of the National Estate are built infrastructure, such as historic buildings or bridges. The Programme does not have the expertise to comment on potential impacts of changes in hydrological regimes to built infrastructure.

At the time of this Assessment the locations of many of the Indigenous cultural assets of the Namoi subregion were not explicitly known. This prevented an assessment of potential water dependency. 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. The Programme does not have the expertise to comment on potential impacts on Indigenous assets. Thus, it is not clear what opportunity there might be to undertake a risk assessment of Indigenous assets in a culturally appropriate way.

3.7.4.7 Climate change and land use

The implications of climate change and changes in land use did not have any consideration in the modelling. A more complete picture of the potential impacts due to additional coal resource development could be obtained by considering these changes in the context of a warming climate and changing demands for water, particularly from agriculture in the Namoi subregion. Future work could include the role of interactions between coal resource development and agricultural land uses to identify the magnitude and influence of these interactions on changes in hydrology. This Assessment identified the risk to water-dependent landscape classes and assets from additional coal resource development, but how this information is used could differ if, for example, more area was set aside for strategic agricultural uses, or if the water demands of the urban populations changed.

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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.

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

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

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

analytic element model: a groundwater model in which the groundwater flow equations are solved based on the representation of internal boundary conditions, points, lines or polygons where constant groundwater level, constant flux or flux dependence on groundwater level is imposed (Bakker, 2013). The resulting groundwater flow equations can be evaluated at arbitrary points in space and time. The solution is therefore independent of a spatial discretisation of the model domain into grids, and a temporal discretisation into time steps, as is necessary for finite element or finite difference groundwater models.

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

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

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.

assessment unit: for the purposes of impact analysis, a geographic area that is used to partition the entire assessment extent into square polygons that do not overlap. The spatial resolution of the assessment units is closely related to that of the bioregional assessment groundwater modelling and is, typically, 1 x 1 km. Each assessment unit has a unique identifier. The partitioned data can be combined and recombined into any aggregation supported by the conceptual modelling, causal pathways and model data.

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

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

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

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

conceptual model: abstraction or simplification of reality

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

consequence: synonym of impact

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

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

dataset: a collection of data in files, in databases or delivered by services that comprise a related set of information. Datasets may be spatial (e.g. a shape file or geodatabase or a Web Feature Service) or aspatial (e.g. an Access database, a list of people or a model configuration file).

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) dmax: maximum difference in drawdown, obtained by choosing the maximum of the time series of differences between two futures. For example, to calculate the difference in drawdown between the coal resource development pathway (CRDP) and baseline, use the equations dmax = max (dCRDP(t) – dbaseline(t)) where d is drawdown, or dmax = max (hbaseline(t) – hCRDP(t)) where h is groundwater level and t is time.

dmaxRef: maximum difference in drawdown under the baseline future or under the coal resource development pathway future relative to the reference period (1983 to 2012). This is typically reported as the maximum change due to additional coal resource development.

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.

ecosystem function: the biological, geochemical and physical processes and components that take place or occur within an ecosystem. It refers to the structural components of an ecosystem (e.g. vegetation, water, soil, atmosphere and biota) and how they interact with each other, within ecosystems and across ecosystems.

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

ephemeral stream: a stream that flows only briefly during and following a period of rainfall, and has no baseflow component

EventsR3.0: the mean annual number of events with a peak daily flow exceeding the threshold (the peak daily flow in flood events with a return period of 3.0 years as defined from modelled baseline flow in the reference period (1983 to 2012)). This metric is designed to be approximately representative of the number of overbank flow events in future 30-year periods. This is typically reported as the maximum change due to additional coal resource development.

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

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

Geofabric: a nationally consistent series of interrelated spatial datasets defining hierarchically-nested river basins, stream segments, hydrological networks and associated cartography goaf: That part of a mine from which the coal has been partially or wholly removed; the waste left in old workings.

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

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

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

groundwater system: see water system

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

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

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

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

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

hydrological response variable: a hydrological characteristic of the system that potentially changes due to coal resource development (for example, drawdown or the annual flow volume)

impact: a change resulting from prior events, at any stage in a chain of events or a causal pathway. An impact might be equivalent to an effect (change in the quality and/or quantity of surface water or groundwater), or it might be a change resulting from those effects (for example, ecological changes that result from hydrological changes).

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

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

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

interquartile range (IQR): the interquartile range in daily flow (ML/day); that is, the difference between the daily flow rate at the 75th percentile and at the 25th percentile. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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

length of low-flow spell (LLFS): the length (days) of the longest low-flow spell each year. This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

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.

low-flow spells (LFS): the number of low-flow spells 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). A spell is defined as a period of contiguous days of flow below the 10th percentile threshold.

material: pertinent or relevant

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 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.

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.

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

P01: the daily flow rate at the 1st percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

P99: the daily flow rate at the 99th percentile (ML/day). This is typically reported as the maximum change due to additional coal resource development over the 90-year period (from 2013 to 2102).

percentile: a specific type of quantile where the range of a distribution or set of runs is divided into 100 contiguous intervals, each with probability 0.01. An individual percentile may be used to indicate the value below which a given percentage or proportion of observations in a group of observations fall. For example, the 95th percentile is the value below which 95% of the observations may be found.

preliminary assessment extent: the geographic area associated with a subregion or bioregion in which the potential water-related impact of coal resource development on assets is assessed. The PAE is estimated at the beginning of a bioregional assessment, and is updated to the ‘assessment extent’ on the basis of information from Component 1: Contextual information and Component 2: Model-data analysis.

probability distribution: the probability distribution of a random variable specifies the chance that the variable takes a value in any subset of the real numbers. It allows statements such as 'There is a probability of x that the variable is between a and b'.

receptor: a point in the landscape where water-related impacts on assets are assessed 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

return period: An event has a return period (or recurrence interval) of T years if its magnitude is equalled or exceeded once on average every T years. The reciprocal of the return period is the exceedance probability of the event, that is, the probability that the event is equalled or exceeded in any one year. For example, a flood with a return period of 10 years has a 0.1 or 10% chance of being exceeded in any one year and a flood with a return period of 50 years has a 0.02 or 2% chance of being exceeded in any one year. The actual number of years between floods of any given size varies a lot because of climatic variability.

riparian: An area or zone within or along the banks of a stream or adjacent to a watercourse or wetland; relating to a riverbank and its environment, particularly to the vegetation.

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.

severity: magnitude of an impact

source dataset: a pre-existing dataset sourced from outside the Bioregional Assessment Programme (including from Programme partner organisations) or a dataset created by the Programme based on analyses conducted by the Programme for use in the bioregional assessments (BAs)

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.

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

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.

transparency: a key requirement for the Bioregional Assessment Programme, achieved by providing the methods and unencumbered models, data and software to the public so that experts outside of the Assessment team can understand how a bioregional assessment was undertaken and update it using different models, data or software

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-dependent asset register: a simple and authoritative listing of the assets within the preliminary assessment extent (PAE) that are potentially subject to water-related impacts

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.

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

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).

Landscape classification

Definitions for landscape classes and landscape groups for the Namoi subregion are provided below. The register of terms and definitions for the landscape classification for each bioregion and subregion in the Bioregional Assessment Programme is available online at http://environment.data.gov.au/def/ba/landscape-classification.

- ‘Dryland remnant vegetation’ landscape group: Ecosystems not dependent on either surface water or groundwater
  - ‘Grassy woodland’ landscape class: The ‘Grassy woodland’ landscape class is characterised by woodland, with understories dominated by grasses. These communities are not associated with the floodplain landscapes or other groundwater-dependent ecosystems or wetlands. Water requirements are derived from localised rainfall and runoff. These landscape classes are not considered to be water dependent in the Bioregional Assessments Programme. Vegetation in this landscape class shows no evidence of extensive mechanical or chemical disturbance and is considered ‘remnant’.

- ‘Floodplain or lowland riverine’ landscape group: Ecosystems that are lowland alluvial plains
    - ‘Floodplain grassy woodland’ landscape class: The ‘Floodplain grassy woodland’ landscape class is characterised by ecosystems on recent alluvial systems and floodplains subject to periodic inundation. Vegetation is typically dominated by Eucalyptus or Acacia woodlands or open woodlands and may contain an understory dominated by grasses. There is no evidence of a groundwater dependence. This landscape class excludes floodplain palustrine and lacustrine wetlands.
    - ‘Floodplain grassy woodland GDE’ landscape class: The ‘Floodplain grassy woodland GDE’ landscape class is characterised by ecosystems on recent alluvial systems and floodplains subject to periodic inundation. Vegetation is typically dominated by Eucalyptus or Acacia woodlands or open woodlands and may contain an understory dominated by grasses. This landscape class is dependent on groundwater for some or all of its water requirements. This landscape class excludes floodplain palustrine and lacustrine wetlands.
    - ‘Floodplain riparian forest’ landscape class: The ‘Floodplain riparian forest’ landscape class is characterised by riparian forests on recent alluvial systems and floodplains subject to periodic inundation. Vegetation is typically dominated by *Eucalyptus camaldulensis* and *Casuarina cunninghamiana*. This landscape class is not dependent on groundwater and excludes floodplain palustrine and lacustrine wetlands.
    - ‘Floodplain riparian forest GDE’ landscape class: The ‘Floodplain riparian forest GDE’ landscape class is characterised by riparian forests on recent alluvial systems and floodplains subject to periodic inundation. Vegetation is typically dominated by *Eucalyptus camaldulensis* and *Casuarina cunninghamiana*. This landscape class is dependent on groundwater for some or all of its water requirements. This landscape class excludes floodplain palustrine and lacustrine wetlands.
    - ‘Floodplain wetland’ landscape class: The ‘Floodplain wetland’ landscape class is characterised by palustrine wetlands such as marshes, billabongs, anabranches and overflows. These ecosystems are not groundwater dependent and the water regime is dominated by surface water inputs.
    - ‘Floodplain wetland GDE’ landscape class: The ‘Floodplain wetland GDE’ landscape class is characterised by palustrine wetlands such as marshes, billabongs, anabranches and overflows. This landscape class is dependent on groundwater for some or all of its water requirements in addition to surface water inputs.
    - ‘Permanent lowland stream’ landscape class: The ‘Permanent lowland stream’ landscape class is characterised by permanent or near-permanent streams in the lower catchment not dependent on groundwater. The water regime is dominated by surface water inflows and the streams contain water for more than 80% of the time.
    - ‘Permanent lowland stream GDE’ landscape class: The ‘Permanent lowland stream GDE’ landscape class is characterised by permanent or near-permanent streams in the lower catchment that are dependent on groundwater. The water regime is characterised by both surface water and groundwater inflows and the streams contain water for more than 80% of the time.

  - 'Temporary lowland stream' landscape class: The 'Temporary lowland stream' landscape class is characterised by intermittent or ephemeral streams in the lower catchment not dependent on groundwater. The water regime is characterised by surface water and the streams contain water for less than 80% of the time.
  - 'Temporary lowland stream GDE' landscape class: The 'Temporary lowland stream GDE' landscape class is characterised by intermittent or ephemeral streams in the lower catchment. The water regime is characterised by surface water and groundwater inflows and the streams contain water for less than 80% of the time.
- 'Human-modified' landscape group: Land with significant human modification (i.e. evidence of extensive mechanical or chemical disturbance)
  - 'Conservation and natural environments' landscape class: The 'Conservation and natural environments' landscape class is characterised by land where the primary land use is typically natural conservation (e.g. nature reserve), managed resource protection (e.g. surface water supply) or minimal use (e.g. stock route). However, vegetation in this landscape class shows evidence of extensive mechanical or chemical disturbance and is considered 'non-remnant'.
  - 'Intensive uses' landscape class: The 'Intensive uses' landscape class is characterised by land uses that involve high levels of interference with natural processes. These land uses range from transport infrastructure (roads, railways), urban infrastructure (houses, factories), intensive horticulture (glasshouses), and animal husbandry (poultry farms).
  - 'Production from dryland agriculture and plantations' landscape class: The 'Production from dryland agriculture and plantations' landscape class is characterised by land used primarily for dryland primary production, including cropping, grazing and forest plantations. Native vegetation has been substantially modified and replaced by introduced species.
  - 'Production from irrigated agriculture and plantations' landscape class: The 'Production from irrigated agriculture and plantations' landscape class is characterised by land used primarily for irrigated agriculture, including perennial horticulture and irrigated cropping. Native vegetation has been substantially modified and replaced by introduced species.
  - 'Production from relatively natural environments' landscape class: Land in the 'Production from relatively natural environments' landscape class is characterised by land use that includes grazing native vegetation and production forests. Vegetation in this landscape class shows evidence of extensive mechanical or chemical disturbance and is classified as 'non-remnant'.
  - 'Water' landscape class: The 'Water' landscape class is characterised by water features important for natural resource management, agricultural production and as points of reference in the landscape. This landscape class includes both natural and artificial water bodies that are not otherwise defined in this classification.

- 'Non-floodplain or upland riverine' landscape group: Ecosystems that do not occur in floodplain environments
  - 'Grassy woodland GDE' landscape class: The 'Grassy woodland GDE' landscape class is characterised by eucalypt-dominated woodlands, shrublands and heathlands that may have grassy understories. These communities are not associated with floodplain landscapes. This landscape class is dependent on groundwater for some or all of its water requirements.
  - 'Non-floodplain wetland' landscape class: The 'Non-floodplain, wetland' landscape class is characterised by palustrine or lacustrine wetlands that occur off the floodplain environment. The water regime is typically temporary and dominated by rainfall or localised runoff. Wetlands in this landscape class are not considered to be groundwater dependent.
  - 'Non-floodplain wetland GDE' landscape class: The 'Non-floodplain wetland GDE' landscape class is characterised by palustrine or lacustrine wetlands that occur off the floodplain environments. These wetlands are dependent on groundwater for some or all of their water requirements.
  - 'Permanent upland stream' landscape class: The 'Permanent upland stream' landscape class is characterised by permanent or near-permanent streams in environments in the upper catchment. The water regime is dominated by surface water inputs and the streams contain water for more than 80% of the time. These streams are not considered to be groundwater dependent.
  - 'Permanent upland stream GDE' landscape class: The 'Permanent upland stream GDE' landscape class is characterised by permanent or near-permanent streams in environments in the upper catchment. The water regime is characterised by surface water and groundwater inputs and the streams contain water for more than 80% of the time. These streams are dependent on groundwater for some or all of their water requirements.
  - 'Temporary upland stream' landscape class: The 'Temporary upland stream' landscape class is characterised by intermittent or ephemeral streams in environments in the upper catchment. The water regime is dominated by surface water inputs and the streams contain water for less than 80% of the time. These streams are not considered to be groundwater dependent.
  - 'Temporary upland stream GDE' landscape class: The 'Temporary upland stream GDE' landscape class is characterised by intermittent or ephemeral streams in the upper catchment. The water regime is characterised by surface water and groundwater inputs and the streams contain water for less than 80% of the time. These streams are dependent on groundwater for some of their water requirements.
  - 'Upland riparian forest GDE' landscape class: The 'Upland riparian forest GDE' landscape class is characterised by riparian forests in the upper catchment. These may be associated with temporary or permanent upland streams. This landscape class is dependent on groundwater for some or all of it water requirements.

- ‘Rainforest’ landscape group:Forests with closed canopies dominated by non-eucalypt species
  - ‘Rainforest’ landscape class: The ‘Rainforest’ landscape class consists of forests with a closed canopy (>75%) generally dominated by non-eucalypt species with soft, horizontal leaves, although various eucalypt species may be present as emergents. Rainforests tend to be restricted to relatively fire-free areas of consistently higher moisture and nutrient levels than the surrounding sclerophyllous forests. These rainforests are not dependent on groundwater.
  - ‘Rainforest GDE’ landscape class: The ‘Rainforest GDE’ landscape class consists of forests with a closed canopy (>75%) generally dominated by non-eucalypt species with soft, horizontal leaves, although various eucalypt species may be present as emergents. Rainforests tend to be restricted to relatively fire-free areas of consistently higher moisture and nutrient levels than the surrounding sclerophyllous forests. These rainforests are dependent on groundwater for some or all of their water requirements.
- ‘Springs’ landscape group: Characterised by hydrogeological features by which groundwater discharges naturally to the land surface
  - ‘GAB springs’ landscape class: The ‘GAB springs’ landscape class is characterised by Great Artesian Basin (GAB) springs that occur where groundwater discharges to the surface either as subsurface flows from upslope sandstone bedrock or where artesian water under pressure is discharged to the land surface.
  - ‘Non-GAB springs’ landscape class: The ‘Non-GAB springs’ landscape class occurs where groundwater discharges to the surface either as subsurface flows from upslope bedrocks or where groundwater under pressure is discharged to the land surface. The source aquifers are not associated with the Great Artesian Basin (GAB).

4 Risk analysis for the Namoi subregion

Originally the risk analysis was intended to be reported independently of the impact analysis. Instead it has been combined with the impact analysis as product 3-4 to improve readability. For risk analysis see Section 3 of this product.

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