

## Advice to decision maker on coal mining project

### IESC 2019-102: Narrabri Underground Mine Stage 3 Extension Project (Narrabri Mine Extension) (State Ref No 9882) – Expansion

<b>Requesting agency</b>	Mining and Petroleum Gateway Panel on behalf of the Independent Planning Commission NSW
<b>Date of request</b>	15 February 2019
<b>Date request accepted</b>	27 February 2019
<b>Advice stage</b>	Gateway Application

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC) provides independent, expert, scientific advice to the Australian and state government regulators on the potential impacts of coal seam gas and large coal mining proposals on water resources. The advice is designed to ensure that decisions by regulators on coal seam gas or large coal mining developments are informed by the best available science.

The IESC was requested by the NSW Mining and Petroleum Gateway Panel to provide advice on Narrabri Coal Operations Pty Ltd's (NCOPL) Narrabri Underground Mine Stage 3 Extension Project in NSW. This document provides the IESC's advice in response to the requesting agency's questions. These questions are directed at matters specific to the project to be considered during the requesting agency's assessment process. This advice draws upon the available assessment documentation, data and methodologies, together with the expert deliberations of the IESC, and is assessed against the IESC Information Guidelines (IESC, 2018).

### Summary

The proposed Narrabri Underground Mine Stage 3 Extension Project (the project) is a longwall mining extension to the existing underground Narrabri Coal Mine, located in the Gunnedah Coalfields of NSW. The project will increase production from 11 million tonnes per annum (Mtpa) to up to 13 Mtpa of run-of-mine coal (a combination of thermal and pulverised coal injectate), and extend the mine life from July 2031 to 2045. The proposal also includes expansion and upgrades of existing surface infrastructure.

The project is located within the Namoi Water Management Area. The region has one of the highest levels of groundwater extraction in the Murray-Darling Basin (Department of Primary Industries, 2017). Surface water resources in the area include the Namoi River that is located approximately 6 km from the

proposed extension, and the ephemeral Kurrajong Creek located within the proposed development area. Known groundwater-dependent ecosystems (GDEs) adjacent to or within the project area include Mayfield, Hardys and Eather Springs. There are also approximately 40 farm dams located within the vicinity of the project.

The limited level of detail required for project documentation at the Gateway Application stage (New South Wales Government, 2013) accordingly limits the scope of the IESC's advice on the extent and likelihood of the proposed project's potential impacts to water resources. Consequently, this advice is only able to provide general guidance on the potential impacts, together with suggestions for additional information required if the proposal proceeds to the Environmental Impact Statement (EIS) stage.

Key potential impacts from this project are:

- groundwater drawdown that will potentially reduce availability of water for GDEs, such as springs, the Upper Namoi Alluvium and other water resources;
- surface water losses and altered stream-flow regimes (e.g. Kurrajong Creek) through surface fracturing, cracking and ponding along drainage lines above the proposed longwalls; and
- cumulative impacts created by the multiple competing demands for water in an already heavily used system.

The IESC has identified areas in which additional work is required to assess the materiality of impacts, as detailed in this advice. These are summarised below.

- Further model simulations are needed to examine a greater range of variability in parameters and predictions, including incorporation of pumping from licenced bores, refinement of boundary conditions and the parameters controlling recharge and evapotranspiration. This information is needed to improve the current understanding of potential extent and variability of drawdown impacts that could occur and to further support the proponent's assessment that impacts to both the Upper Namoi Alluvium and the Namoi River will be minimal, especially given the historical and current intensive use of these water resources.
- The groundwater model should be better integrated with the subsidence model to provide an improved understanding of impacts on surface water and alluvium.
- Maps are needed that illustrate the distribution of potential GDEs, particularly alluvial and riparian ones, superimposed on contours of estimated depths to the water table (in metres below ground level) both pre-mining and at maximum predicted drawdown. These maps should also show the locations of bores used to estimate the water table depths. These maps are needed to better understand potential impacts to GDEs.
- Surface water modelling informed by baseline stream gauging is required to assess water loss from surface waters due to groundwater drawdown and from cracking and ponding, under a range of climatic scenarios. Additional mitigation measures may be necessary, such as revising the mine layout to reduce subsidence-related strains and stresses experienced at the surface and retiring water licenses to account for the increased loss of surface water through cracking and ponding.
- Surface and groundwater quality monitoring is needed, including information on parameters measured and frequency of monitoring, on which to base site-specific water quality guidelines.
- An appropriate risk analysis (e.g. Serov et al. 2012) of the potential impacts of groundwater drawdown to GDEs is required, along with proposed mitigation strategies.

- A detailed assessment of potential risks to groundwater and surface water ecosystems of the Namoi catchment and a cumulative impact assessment will be required.

## Context

The Narrabri Mine (EPBC 2009/5003) is an existing underground coal mining operation located in the Gunnedah Coalfield, approximately 25 km south-east of Narrabri and approximately 60 km north-west of Gunnedah, NSW. The proposed project will expand the existing operation, targeting the Hoskissons Seam. The project will increase production from 11 Mtpa to up to 13 Mtpa of run-of-mine coal.

The IESC recognises that this project is at the Gateway Certificate Application stage. The Gateway process considers how a proposal will impact the agricultural values of the land on which it is to be located. The proposal must not significantly reduce the agricultural productivity of any Biophysical Strategic Agricultural Land (BSAL) based on considerations of the New South Wales Government (2013) in the following ways:

- any impacts on the land through surface area disturbance and subsidence;
- any impacts on soil fertility, effective rooting depth or soil drainage;
- increases in land surface microrelief, soil salinity, rock outcrop, slope and surface rockiness or significant changes to soil pH;
- any impacts on highly productive groundwater (within the meaning of the *Aquifer Interference Policy*),
- any fragmentation of agricultural land uses; and
- any reduction in the area of BSAL.

The IESC considers that the proposed project poses limited impacts to BSAL, where approximately 200 ha of Interim Protocol Verified and Potential BSAL have been identified within the application area. Of this, approximately 75 ha in total are located above proposed longwalls within agricultural and forested areas.

Acknowledging the requirements of the NSW Mining and Petroleum Gateway process outlined above, it is important to note that the supporting documentation is not required to focus on matters that do not directly relate to agricultural productivity (e.g. flora and fauna). All advice below is provided bearing this in mind and in anticipation of a full EIS at later stages of the development if the project proceeds.

## Response to questions

The IESC's advice, in response to the requesting agency's specific questions is provided below.

Question 1: It would be appreciated if the IESC could advise on the potential likelihood and significance of any impacts of the proposal on water resources, as well as advise on the appropriateness of the proposed mitigation measures.

1. The documentation provided to the IESC for this Gateway Certificate Application focuses on BSAL criteria and potential mitigation of impacts on BSAL. The likelihood or significance of potential impacts on water resources and their mitigation are not considered and this hampers the IESC's use of the current documentation to address this question except where issues are discussed in response to criteria i and iv above. Nonetheless, the IESC considers that there is a material risk of impacts on water resources given the current intensive use of groundwater in the region, the predicted extent of subsidence and groundwater drawdown by the proposal, and the proposed development's proximity

to significant water resources such as springs, groundwater-dependent vegetation, the Namoi River alluvium and the state-listed *Lowland Darling River Aquatic Community* (NSW DPI, 2007). These potential impacts are discussed below, along with some suggestions for subsequent groundwater and subsidence modelling and baseline assessment.

### Groundwaters

2. The IESC notes that the modelling provided by the proponent exceeds that required for the Gateway process and acknowledges the extensive model validation. However, the IESC also notes that the model will need to be further refined and developed to meet the Secretary's Environmental Assessment Requirements (SEARs) when issued, the IESC's Information Guidelines, and further issues covered in paragraphs 3 and 4 below. This further work will include a cumulative impact assessment incorporating the nearby Narrabri Gas Project, additional groundwater level data and the results of core permeability test work, among other updates. The IESC suggests that these should be fully addressed in the proposed EIS.
3. The current groundwater model predictions provided by the proponent (Hydro Simulations, 2019, p. 51) indicate that the impacts from the project will largely be within the minimal impact considerations of the *NSW Aquifer Interference Policy*, and will not result in any significant impacts to the highly productive Upper Namoi Alluvium or Great Artesian Basin (GAB). The IESC notes that impact predictions could change when the model is updated as planned. Consideration and discussion of the issues outlined below would further increase confidence in the groundwater impact assessment and associated modelling.
  - a. Further model refinements should attempt to incorporate pumping from licenced bores as this would provide a more complete understanding of the actual conditions in the groundwater system.
  - b. Discussion and justification of boundary conditions, and their sensitivities, applied in the groundwater model are needed, including for the large area of 'no-flow' in the eastern area of the groundwater model (Hydro Simulations, 2019, Figures 13 and 14, pp. 84-85) and the general head boundary condition applied in the north-west of the groundwater model (Hydro Simulations, 2019, Figure 13, p. 84).
  - c. The implementation of recharge in the model should be clearly explained. Currently, it is unclear whether the recharge applied in the transient modelling is a fixed rate defined as an arbitrary portion of average annual rainfall or whether the amount varies to accommodate temporal variability in rainfall. When the model is updated, an appropriate time series of rainfall record should be considered to represent the likely variability in recharge rates. Further, the modelled recharge rate should be justified and validated using independent methods such as chloride mass balance and water table fluctuation methods.
  - d. A maximum ET rate of 146 mm/year has been adopted (Hydro Simulations, 2019, p. 32), which appears to be unusually low for the local climate. The defensibility of the ET parameters will need to be further explored in future work, and evaluated in conjunction with recharge parameters in an uncertainty and sensitivity framework.
  - e. The specific storage values applied in the current model are noted by the proponent to have been updated, resulting in better model calibration results. However, these specific storage values require justification, including why values have increased and the sensitivity of the model's transmissivity and recharge values to these changes. Discussion that outlines the revised values from those used previously, the basis for the new values and the implications of these changes on the predicted magnitude and spatial extent of drawdown should be provided in the EIS.

- f. The influence of faults has not been discussed. The EIS should consider the behaviour of faults, as either barriers, conduits or both. Their potential impacts on the connectivity between groundwater and surface water also need to be considered.
  - g. The IESC commends the proponent for undertaking some sensitivity and uncertainty analysis at this early project stage. This analysis should be extended further in the EIS given the extensive utilisation and importance of groundwater in the region.
  - h. Future modelling should clearly identify whether the proposed project will cause drawdown in the Namoi Alluvium and, if so, quantify the volumes and timing of inter-aquifer leakage and discuss connectivity or impacts to the GAB.
  - i. The saturated extent of the alluvium should be included on maps of potential drawdown to aid interpretation of potential impacts. Additionally, the extent of drawdown in the Pamboola Formation which appears to directly underlie areas of alluvium to the east of the project (based on the proponent's conceptual models) should be shown to determine if there is potential for drawdown within that formation to impact the alluvium.
  - j. All maps of potential drawdown should show the full predicted extent of drawdown in each formation. A map of the maximum predicted extent of drawdown should be included, with the expected timing of this maximum drawdown clearly identified.
  - k. Groundwater quality data should be provided. Discussion on the potential for, and possible changes to, groundwater quality arising from groundwater interaction with the goaf and fractured strata, or leakage of mine-affected water into aquifers should also be provided.
  - l. Baseflow changes should be quantified for the reaches identified as RIV21 and RIV23-27 on Figure 13 (Hydro Simulations, 2019, p. 84) to inform a full ecological and surface water resource assessment of potential changes to these creeks.
  - m. All GDEs (including groundwater-dependent vegetation) should be clearly identified on maps of predicted drawdown and drawdown at each GDE quantified with the maps showing the depth to the water table (in metres below ground level) when modelling is updated.
  - n. Regional and site-specific data and information on surface-groundwater interactions and GDEs should be provided in the EIS.
4. Given the preliminary nature of the current modelling and the suggested improvements outlined in paragraph 3, the IESC notes that it is not currently clear if the project aligns with the Namoi Catchment Action Plan 2010–2020 targets and thresholds. These include the target that seeks an improvement in the ability of groundwater systems to support GDEs and designated beneficial uses by 2020 (Namoi CMA, 2010, p. 36) and the threshold for alluvial aquifers to never exceed historical maximum drawdown levels (Namoi CMA, 2010, p. 36). The IESC suggests that the proponent specifically considers these targets within their EIS.
  5. Given the nature of the Gateway Application process, limited information on planned mitigation measures was provided. If the project progresses, the 2013 monitoring program should be updated to reflect changes needed due to the proposed project and will need to be provided within the EIS. In particular, the spatial coverage of the groundwater monitoring network should be expanded where there are currently no monitoring bores to the west and south of the proposed project.
  6. The IESC also notes that the proponent currently may not hold sufficient licences for predicted take from some water sources under certain climatic conditions. The proponent should provide a plan for obtaining further licences and discuss options including operational changes that may be required if sufficient licence volumes cannot be obtained.

## *Subsidence*

7. Subsidence modelling should be better integrated with the groundwater model. Fracture networks may provide tortuous connection pathways between surface water and groundwater and may modify infiltration rates and water fluxes. Such connections have implications for:
  - a. surface waters, where part or all of creek flows could be re-routed into open cracks and below-surface pathways; and
  - b. groundwater-dependent vegetation, where stressed trees above extracted longwalls may indicate damage to tree roots.

The IESC suggests that the potential impacts of ground movements associated with subsidence, including near-surface fractures should be considered within the groundwater model for the EIS.

8. The proponent has undertaken a sensitivity analysis into the height of the fracture zone above the mined seam (Hydro Simulations, 2019, pp. 44-47). Several scenarios have been modelled that use different methods to calculate the height of the fracture zone above the mined seam. The two primary methods (Ditton Method and Tammetta Method) indicate that there is significant uncertainty about the height of the fracture zone, with a worst-case scenario being that the fracture zone breaks through to the surface. This has significant implications for groundwater behaviour between the mined seam and the surface as the extent of vertical and horizontal fracturing and ground movement changes the hydraulic properties. However, it is concerning that simulations undertaken by the proponent (using an equivalent porous media approach, Hydro Simulations, 2019, Table 23, p. 47) indicate similar groundwater response regardless of the assumed extent of the fracture zone. Further, the proponent suggests that model simulations of historical groundwater levels (Hydro Simulations, 2019, p. 46) are not sufficiently sensitive to assess which fracturing extent is more likely. The lack of model sensitivity to the assumed extent of fracture zone is concerning, and the reasons for this behaviour should be explored and discussed in the EIS. To provide better confidence that the model results are consistent with physical reasoning, it would be useful to include:
  - a. justification of the way in which vertical hydraulic conductivity is represented in the model, particularly in the top layers near and at the surface;
  - b. the provision of other model diagnostics, such as information on water fluxes and hydraulic heads, to discern differences in flow behaviour between scenarios; and
  - c. comparison between results of the current equivalent porous media (EPM) approach and alternative approaches such as discrete fracture networks (DFN) to better understand how the representation of fractures influences groundwater behaviour and surface water-groundwater connectivity.
9. The IESC notes that the subsidence predictions and associated impact parameters (i.e. tilt, curvature, strain and horizontal displacement) have been based on measured local data and empirical databases developed for other coalfields in NSW with similar mining geometries and geological conditions. At this site, the target coal seam varies from 143 to 367 m below ground, with no strong overlying 'bridging' geology. Confidence in the subsidence model could be improved by commissioning an independent review, as well as ensuring that the groundwater model complements the subsidence model.
10. The proposed Narrabri Extension is likely to result in a range of subsidence-related impacts to water resources. These include the following issues.
  - a. Final maximum panel subsidence predictions range from 2.55 m to 2.80 m (Ditton Geotechnical Services, 2019, p. 26), where predicted changes to Kurrajong Creek ponding and dams are

considered by the proponent to be minimal. The IESC believes that further information is required to confirm these predictions as it is unclear whether the risk assessment considered (i) incremental profile methods, (ii) climate variability and the influence of extreme weather events, in particular intense rainfall events and frequencies, or (iii) cracking (refer to 10b below).

- b. Surface cracking widths are predicted to range from 20 mm to 240 mm (Ditton Geotechnical Services, 2019, p. 31), although there are no reports on the depth of cracks at the existing mine (Whitehaven, 2017, p. 19). Whilst large cracks will be remediated, minor cracks (i.e. less than 50 mm wide) are not expected to require remediation as geomorphological processes would result in these cracks filling naturally over time (Soil Management Designs, 2019, p. 38). The IESC notes that:
  - i. cracks which are visibly closed at the surface (i.e. self-healed with sand, or remediated with gravel) are likely to provide preferential flow paths and remain hydraulically open in mixed vertisols (clay fraction 64 %, Greve et al., 2012); and
  - ii. modelling does not appear to consider water loss from cracking. The acquisition and retirement of water licences may be required to mitigate predicted losses.
- c. The rate of soil erosion is expected to increase significantly in areas with exposed dispersive/reactive soils and slopes. Erosion along the creek beds would be expected to develop above chain pillars between the panels and on the side where the gradients increase. The IESC notes that the extent of impact will be assessed by environmental consultants in the EIS (Ditton Geotechnical Services, 2019, p. 44).

#### *Surface waters*

11. No investigations have been undertaken to assess the likely impacts of subsidence and groundwater drawdown on surface waters. Without such analyses, it is not possible to comment on the likelihood and significance of impacts on surface water resources.

#### *Groundwater-dependent ecosystems (GDEs)*

12. A detailed assessment of potential impacts on GDEs is not provided because the Gateway Certificate Application process does not require assessments relating to flora and fauna at this stage of the development. However, the IESC considers that given the current pressures on groundwater from multiple users, the proposed project is likely to have potential impacts on the following GDEs:
  - a. groundwater-dependent vegetation, especially along creeklines and on the Namoi River alluvium in areas where groundwater drawdown is predicted;
  - b. nearby springs such as Hardys, Eather and Mayfield Springs where cumulative impacts associated with the Narrabri Gas Project are likely; and
  - c. the Namoi River in the vicinity of the project which is mapped as a potential GDE (GDE Atlas reference to add) and forms part of the state-listed *Lowland Darling River Aquatic Ecological Community* (NSW DPI, 2007). In particular, potential changes to groundwater–surface water interactions between the saturated alluvium and the Namoi River and its tributaries should be assessed because of the likely importance of upwelling groundwater supplying dissolved carbon and other crucial resources to the river’s food-web (e.g. Burrows et al. 2018) that includes this state-listed community.

Question 2: The IESC may also recommend further studies that should be undertaken if relevant.

13. The IESC recommends the following studies be completed as a component of any future assessments. The recommended studies and methods described are based on current understanding and should not be considered exhaustive. When undertaking further studies, the proponent should consider the information needs outlined in the IESC's Information Guidelines (IESC, 2018), and the current IESC Explanatory Notes on uncertainty analysis (Middlemis and Peeters, 2018), GDEs (Doody et al., 2019) and other topics as they become available.

#### *Water balance modelling*

14. The IESC notes that the project would involve the use of existing infrastructure with minor augmentations and extensions, including the progressive development of sumps, pumps, pipelines, water storages and other water management infrastructure. Given that there have been discharge incidents at the existing mine associated with high rainfall events (Environmental Resource Management Australia Pty Ltd, 2017, p. 14), a quantitative site-specific water balance is required which accommodates various sources of uncertainty (e.g. using the Water Accounting Framework for the Australian minerals industry, Minerals Council of Australia, 2014). This site-specific approach would describe:

- a. the total water supply and demand under a range of climatic and water demand scenarios to support the uncertainty analysis;
- b. the required water infrastructure, including infrastructure capacity, transfers and qualities;
- c. volumes and quality of water needed to be discharged (if any), under a range of rainfall scenarios; and
- d. potential impacts due to any water management actions.

15. Given the proposed increase in total coal rejects production, the EIS should provide the results of rejects geochemistry and consider implications of increased storage of rejects and potential changes to water quality should there be any uncontrolled releases.

#### *Surface and receiving waters*

16. The Trigger Action Response Plan (TARP) for the existing mine could not be located. However, surface water compliance criteria for the existing mine are stated as being based on the Catchment Action Plan for the Namoi River. Clarification is required as to whether baseline values for water quality (physical-chemical parameters and contaminants) have been established for the existing mine which gained approval in 2011.

17. A surface water assessment is needed which:

- a. includes baseline and event-based monitoring of water quality parameters over a sufficient time period to enable the derivation of appropriate site-specific water quality guideline values. The parameters monitored, frequency of monitoring and actual monitoring data are required;
- b. uses a risk-based approach to identify key surface waters that might be impacted (e.g. through direct and indirect discharges, subsidence fracturing, ponding or erosion), and considers how the proposal may alter the duration of low- and zero-flow days and potentially impact on instream biota. The proposed development area is drained by ephemeral streams whose flow regime is likely to be altered by subsidence and, potentially, groundwater drawdown. Altered flow regimes will affect the capacity of these ephemeral streams to provide habitat for aquatic species (review



in Stubbington et al., 2017) or support the important ecosystem services provided by these types of surface waters (Datry et al., 2018);

- c. identifies the existing (baseline) hydrological regime of all watercourses within the potential zone of hydrological impacts based on selected site-specific monitoring;
- d. uses appropriate surface water quantity and quality data consistent with the ANZG (2018) guidelines for aquatic ecosystem protection to inform impacts and risks; and
- e. informs appropriate mitigation strategies (e.g. timing and methods for re-establishing drainage lines to minimise erosion, and actions to be taken when there is a suspected exceedance of a guideline value).

#### *Groundwater-dependent ecosystems*

18. An assessment of the extent and condition of GDEs and groundwater-dependent flora and fauna is needed, followed by an appropriate risk assessment (e.g. Serov et al., 2012). These studies should consider the ecological water requirements for any groundwater-dependent species and their habitat. The locations of any shallow groundwater discharge points and other GDEs should be included, especially in areas where drawdown is predicted. A systematic approach to the assessment of GDEs (Doody et al. 2019) is recommended in which:
- a. the methods from, for example, the Australian GDE Toolbox (Richardson et al., 2011) and Eamus et al. (2015) are used to assess groundwater use by vegetation (especially during dry periods);
  - b. the hydrogeological conceptualisation is used to identify areas of shallow groundwater (less than 20 m below ground level) and potential areas of groundwater discharge;
  - c. vegetation type and extent, seasonal depths to groundwater and shallow groundwater drawdown maps are overlaid to identify areas of potential GDEs which should then be ground-truthed. These maps should be supported by monitoring data gathered near the regions occupied by ground-truthed GDEs, with the shallow groundwater monitoring locations also plotted on the maps; and
  - d. ecohydrological conceptualisations are used that integrate results from hydrogeological, hydrological, geomorphological and ecological investigations at spatial and temporal scales that are suitable for predicting potential impacts to GDEs and pathways of likely effects of the proposed development. The identified potential impact pathways should then be used to develop proposed mitigation strategies and to monitor the effectiveness of these strategies.

#### *Cumulative impacts*

19. A detailed assessment of potential risks to groundwater and surface water ecosystems of the Namoi catchment will be required in the EIS. As the region has one of the highest levels of groundwater extraction in the Murray-Darling Basin (Department of Primary Industries, 2017), a cumulative impact assessment will be required, taking into account overlap in groundwater drawdown with the Narrabri Gas Project, potentially other coal mines to the east of the project, and other water users.

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**Date of advice** 16 April 2019

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**Source documentation provided to the IESC for the** Ditton Geotechnical Services 2019. *Mine Subsidence Assessment in Support of a Gateway Certificate Application for the Narrabri Underground Mine Stage 3 Extension Project. Appendix C.* Prepared for Narrabri Coal Operations Pty Ltd.

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**formulation of  
this advice**

- Ecological Australia 2019. *Agricultural Impact Assessment for Gateway Application: Narrabri derground Mine Stage 3 Extension Project*. Prepared for Narrabri Coal Operations Pty Ltd.
- Hydro Simulations 2019. *Narrabri Underground Mine Stage 3 Extension Project: Gateway Application Preliminary Groundwater Assessment. Appendix D*. Prepared for Narrabri Coal Operations Pty Ltd.
- Soil Management Designs 2019. *Agricultural Impact Assessment for Gateway Application: Narrabri derground Mine Stage 3 Extension Project. Appendix B*. Prepared for Narrabri Coal Operations Pty Ltd.
- Whitehaven Coal 2019. *Narrabri Underground Mine Stage 3 Extension Project. Technical Overview*.

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**References  
cited within the  
IESC's advice**

- Andersen M, Barron O, Bond N, Burrows R, Eberhard S, Emelyanova I, Fensham R, Froend R, Kennard M, Marsh N, Pettit N, Rossini R, Rutledge R, Valdez D and Ward D 2016. *Research to inform the assessment of ecohydrological responses to coal seam gas extraction and coal mining*. Department of the Environment and Energy, Commonwealth of Australia.
- ANZG(2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian State and Territory Governments, Canberra ACT, Australia. Available at [www.waterquality.gov.au/anz-guidelines](http://www.waterquality.gov.au/anz-guidelines)
- Burrows, R, Rutledge, H, Valdez, D, Venarsky, M, Bond, N, Andersen, MS, Fry, B, Eberhard SM, and Kennard, M. 2018. Groundwater supports intermittent-stream food webs. *Freshwater Science* 37: 42–53.
- Datry Boulton AJ, Bonada N, Fritz K, Leigh C, Sauquet E, Tockner K, Hugueny B and Dahm CN 2018. Flow intermittence and ecosystem services in rivers of the Anthropocene. *Journal of Applied Ecology* 55: 353-364.
- Department of Primary Industries 2017. *Namoi Alluvium Water Resource Plan (GW14), Status and Issues Paper*. Available [online]: [http://www.water.nsw.gov.au/\\_data/assets/pdf\\_file/0020/701732/Status-and-Issues-Paper-Namoi-GW-WRP.pdf](http://www.water.nsw.gov.au/_data/assets/pdf_file/0020/701732/Status-and-Issues-Paper-Namoi-GW-WRP.pdf) accessed March 2019.
- Doody TM, Hancock PJ and Pritchard JL 2019. *Information Guidelines explanatory note: Assessing groundwater-dependent ecosystems*. Report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining through the Department of the Environment and Energy, Commonwealth of Australia. Available [online]: <http://iesc.environment.gov.au/publications/information-guidelines-explanatory-note-assessing-groundwater-dependent-ecosystems> accessed March 2019.
- Eamus D, Zolfaghar S, Villalobos-Vega R, Cleverly J and Huete A 2015. Groundwater-dependent ecosystems: recent insights from satellite and field-based studies. *Hydrology and Earth Systems Science* 19:4229-4256. Available [online]: <https://opus.lib.uts.edu.au/bitstream/10453/37864/1/hess-GDE%20review%20FINAL19-4229-2015.pdf> accessed March 2019.
- Environmental Resource Management Australia Pty Ltd 2017. *Narrabri Mine Conditions of Approval Independent Environmental Audit*. Prepared for Whitehaven Coal.
- Greve AK, Andersen MS and Acworth RI 2012. Monitoring the transition from preferential to matrix flow in cracking clay soil through changes in electrical anisotropy. *Geoderma* 179 – 180:46-52.
- IESC 2018. *Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals* [Online]. Available: <http://www.iesc.environment.gov.au/system/files/resources/012fa918-ee79-4131-9c8d-02c9b2de65cf/files/iesc-information-guidelines-may-2018.pdf> accessed March 2019.
- Middlemis H and Peeters LJM 2018. *Uncertainty analysis – Guidance for groundwater modelling within a risk management framework*. A report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia. Available [online]:

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- <http://iesc.environment.gov.au/publications/information-guidelines-explanatory-note-uncertainty-analysis> accessed March 2019.
- Minerals Council of Australia 2014. *Water accounting framework for the minerals industry – User guide*. Available [online]: <http://minerals.org.au/water-accounting-framework-australian-minerals-industry> accessed March 2019.
- Namoi Catchment Management Authority (CMA) 2010. *Namoi Catchment action plan 2010-2020*. Available [online]: [http://archive.ils.nsw.gov.au/\\_data/assets/pdf\\_file/0003/496362/archive\\_namoi-catchment-action-plan-2010-2020.pdf](http://archive.ils.nsw.gov.au/_data/assets/pdf_file/0003/496362/archive_namoi-catchment-action-plan-2010-2020.pdf) accessed March 2019.
- New South Wales Government 2013. *Strategic regional land use policy. Guideline for Gateway applicants*. Available [online]: <http://www.mpgp.nsw.gov.au/docs/Guideline%20for%20Gateway%20Applicants.pdf> accessed March 2019.
- NSW DPI 2007. *Endangered ecological communities in NSW Lowland Darling River aquatic ecological community*. Available [online]: [http://www.dpi.nsw.gov.au/\\_data/assets/pdf\\_file/0006/171573/Lowland-Darling-River-aquatic-ecological-community.pdf](http://www.dpi.nsw.gov.au/_data/assets/pdf_file/0006/171573/Lowland-Darling-River-aquatic-ecological-community.pdf) accessed March 2019.
- Richardson S, Irvine E, Froend R, Boon P, Barber S and Bonneville B 2011. *Australian groundwater-dependent ecosystem toolbox part 1: Assessment framework*. Waterlines report. National Water Commission, Canberra. Available [online]: <http://webarchive.nla.gov.au/gov/20160615084626/http://archive.nwc.gov.au/library/waterlines/69-70> accessed March 2019.
- Serov P, Kuginis L and Williams JP 2012. *Risk assessment guidelines for groundwater-dependent ecosystems, Volume 1 – The conceptual framework*. NSW Department of Primary Industries, Office of Water, Sydney. Available [online]: [http://archive.water.nsw.gov.au/\\_data/assets/pdf\\_file/0005/547682/gde\\_risk\\_assessment\\_guidelines\\_volume\\_1\\_final\\_accessible.pdf](http://archive.water.nsw.gov.au/_data/assets/pdf_file/0005/547682/gde_risk_assessment_guidelines_volume_1_final_accessible.pdf) accessed March 2019.
- Stubbing R, Bogan MT, Bonada N, Boulton AJ, Datry T, Leigh C and Vander Vorste R 2017. Chapter 4.3 The biota of intermittent rivers and ephemeral streams: aquatic invertebrates. In 'Intermittent Rivers and Ephemeral Streams: Ecology and Management'. (Eds. T. Datry, N. Bonada and A.J. Boulton), pp. 217-243. Academic Press, London.
- Whitehaven Coal 2017. *Narrabri Mine: Extraction Plan, Water Management Plan LW107 to LW110*. Available [online]: <http://www.whitehavencoal.com.au/narrabri-north-environmental-management/> accessed March 2019.
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