

## Advice to decision maker on coal mining project

### IESC 2019-109: Maxwell Underground Coal Mine Project (SSD 9526/ EPBC 2018/8287) – Expansion

<b>Requesting agency</b>	The Australian Government Department of the Environment and Energy and The New South Wales Department of Planning, Industry and Environment
--------------------------	--

<b>Date of request</b>	26 September 2019
------------------------	-------------------

<b>Date request accepted</b>	27 September 2019
------------------------------	-------------------

<b>Advice stage</b>	Assessment
---------------------	------------

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 Australian Government Department of the Environment and Energy and the New South Wales Department of Planning, Industry and Environment to provide advice on the Maxwell Ventures (Management) Pty Ltd's Maxwell Underground Coal Mine Project in New South Wales. This document provides the IESC's advice in response to the requesting agencies' questions. These questions are directed at matters specific to the project to be considered during the requesting agencies' 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 2018a).

### Summary

The proposed Maxwell project is an underground coal mine extension to be developed approximately 16 km south-southwest of Muswellbrook in the Hunter Valley, NSW. The proposed project is for underground mining of four coal seams using bord-and-pillar and longwall mining. Up to 8 million tonnes

of run-of-mine coal is proposed to be extracted annually over an operational life of 26 years. Voids from the existing Maxwell mine will be used for water storage.

The proposed project lies in a catchment which has previously been evaluated as degraded. Despite this, the areas of planned clearance and anticipated subsidence contain a total of 1,619 ha of ecological communities (White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland, Central Hunter Valley Eucalypt Forest and Woodland, Hunter Valley Weeping Myall (*Acacia pendula*) Woodland) listed as Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Additionally, habitat for native species is provided by remnant and regrowth vegetation, particularly riparian vegetation along Saddlers Creek and other waterways in the area.

Key potential impacts from this project are:

- groundwater drawdown, with predicted peak drawdown of the watertable of approximately 10 m and a recovery period over centuries;
- reduced flow and increased erosion and sedimentation in local watercourses, due to subsidence of up to 5.6 m and surface cracking between 25 and 300 mm wide predicted above the mining area;
- decreased groundwater and surface water quality should seepage occur from the rejects, tailings and brine in the East Void;
- decreased surface water quality from potential overflows of mine-affected water from the Rail Loop Dam and Access Rd Dam during flood events, or brine and other runoff from the Mine Entry Dam and Savoy Dam;
- impacts to riparian zone vegetation and EPBC Act-listed ecological communities, although their groundwater-dependence has not been determined; and
- cumulative impacts on surface and groundwater resources, water quality and ecological communities.

The IESC has identified several areas in which additional work is required to address key gaps in understanding of potential impacts, to enable a robust assessment. These are summarised below.

- Additional evidence is needed to determine whether EPBC Act-listed ecological communities and other terrestrial vegetation (e.g. riparian flora) within the zone of groundwater drawdown are groundwater-dependent. This should include maps of depth to groundwater under existing conditions and after predicted groundwater drawdown that are overlain with vegetation mapping.
- An ecohydrological conceptual model is required that illustrates potential impact pathways and likely ecological responses to predicted changes in surface and groundwater quantity and quality in the project area and downstream. This conceptual model should be used to guide a comprehensive risk assessment that incorporates likely cumulative impacts under various climatic scenarios.
- An analysis of the impacts of potential spills (e.g. during flood events) of mine-affected water from Access Road Dam and Rail Loop Dam should be provided.
- Quantitative estimates of all surface water losses resulting from subsidence should be provided. This should include analysis of the impacts on the flow regime, including increases in the duration and number of low- and zero-flow days as these changes may affect instream and riparian biota

(e.g. Swamp Oaks, *Casuarina glauca*) along Saddlers Creek and other waterways. Ponding may also adversely affect existing vegetation and recruitment (e.g. through waterlogging).

- The large discrepancy in the rate of seepage from spoil to the existing voids reported in the surface water (WRM 2019) and groundwater reports (HydroSimulations 2019) should be explained.
- To quantify confidence in groundwater modelling outputs, the proponent should provide an explanation of the differences between observed and predicted water levels in transient calibration hydrographs and the discrepancies between the current model and Gateway model and discuss how this impacts the plausible range of predicted impacts.

The IESC has identified areas where additional undertakings are required to monitor and mitigate potential impacts. These are summarised below.

- There are substantial uncertainties in subsidence prediction associated with multi-seam mining.
  - Subsidence monitoring should be designed and implemented to verify predictions, particularly along and across drainage lines. In addition to the proposed monitoring, the proponent should undertake shallow borehole monitoring of saturated alluvium underlying Saddlers Creek near its confluence with the Hunter River, as recommended by the groundwater model peer reviewer. These data could be integrated with riparian zone assessments and revegetation strategies.
  - The next update to the numerical groundwater model should include quantitative uncertainty analysis that takes into account the potential influence of subsidence on finer-scale variability in hydraulic properties.
  - Revegetation of riparian areas above the underground workings (ahead of mining) is needed. This should improve the resilience of stream ecosystems to subsidence impacts and help compensate for ecological impacts.
- The proponent should undertake an analysis to determine whether the normal fault located at Saddlers Creek materially affects groundwater flow and, if so, incorporate these findings into the updated groundwater model. Use of environmental water tracers (e.g. major ions, stable water isotopes) to identify possible inflows to the creek in the vicinity of the fault could be considered.
- Given uncertainties about the volumes of surface water lost through subsidence, the proponent should monitor to verify these losses. Depending on the volumes, the proponent may require additional water licences.
- An existing 3.5-m knickpoint on stream b2(1) should be stabilised in advance of mining to prevent it migrating upstream following subsidence, as recommended in the excellent report by Gippel (2019).
- The surface water quality monitoring program should be expanded to include metals, at least including molybdenum, selenium, antimony and arsenic as recommended in the geochemistry assessment (GEM 2019).
- Additional targeted ecological surveys should be undertaken to inform adaptive management as part of a risk-based approach guided by an appropriate ecohydrological conceptual model showing potential impact pathways and predicted ecological responses.

- Management plans should incorporate and justify triggers to define the circumstances in which geomorphic and erosional impacts would be (actively) remediated. Proposed groundwater mitigation measures need to be detailed in a trigger-action-response plan.
- The final landform design should address the recommendations listed in the geochemical assessment (GEM 2019, pp. 27–28).
- Assuming that the final void(s) of the existing mine will be used for the proposed project, the design and management should include:
  - a sensitivity analysis that tests assumptions in final-void modelling and tests whether there is a chance that final voids could overtop;
  - an assessment of the likely water quality in final void(s) and how it changes over time;
  - an analysis of the potential for high-density saline void water to cause density-driven flow to the wider groundwater system; and
  - if void(s) might overtop, a strategy to monitor and mitigate any adverse effects

### **Context**

The proposed Maxwell project is an underground coal mine extension to be developed approximately 16 km south-southwest of Muswellbrook in the Hunter Valley, NSW. The project involves underground mining of four coal seams; the shallowest seam to be mined using bord-and-pillar methods with the deeper three seams to be longwall-mined. Up to 8 Mt of run-of-mine coal (about 75% for coking) would be extracted each year, for an operational life of 26 years. Coal will be handled at the existing Maxwell infrastructure site with coal rejects, tailings and brine to be deposited within the existing open cut East Void.

The local region has been heavily modified through agriculture (grazing and irrigated cropping) and coal mining. The project area includes steep areas subject to substantial erosion along drainage lines. Despite these pressures, there remains valuable habitat for terrestrial and aquatic native species on and near the project area, particularly associated with Saddlers Creek and other waterways. The areas of planned clearance for the project and anticipated subsidence contain a total of 1,619 ha of ecological communities (White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland, Central Hunter Valley Eucalypt Forest and Woodland, Weeping Myall (*Acacia pendula*) Woodland) listed as Critically Endangered under the EPBC Act.

### **Response to questions**

The IESC's advice in response to the requesting agencies' specific questions is provided below. Note that the order of questions has been slightly re-arranged to improve the logical flow of advice.

1. The EIS has benefited from a qualitative environmental risk assessment, prepared following a workshop in November 2018. Participants included representatives from many of the organisations who prepared aspects of the EIS, including HydroSimulations and WRM Water and Environment, who developed the groundwater and surface water assessments respectively. The IESC suggests re-visiting the risk assessment following completion of the EIS, both to identify any changes in risk ratings and to propose more specific risk controls.

## General

Question 1: Do the groundwater, surface water and ecological assessments within the EIS provide adequate mapping and delineation of surface and groundwater resources?

### Groundwater

2. The proponent has undertaken a detailed assessment to characterise groundwater resources within the project area. The IESC commends the commissioning of studies focused on the height of fracturing and structural geology, electrical resistivity surveys and alluvial assessments specifically for the development of the EIS. However, there is high uncertainty in predicted impacts of subsidence on groundwater, as there are no published case studies relevant to above-seam fracturing for the multi-seam nature of the proposed project (see response to Questions 5 – 10 below).
3. Very limited groundwater quality monitoring data were provided, with no information on location or timing of groundwater bores sampled. Several exceedances of water quality guideline values for aquatic ecosystem protection for aluminium, copper and manganese were observed; however, it was unclear how exceedances would be addressed in future annual monitoring.

### Surface Water

4. The proponent provides an overview of the current condition of streams in the project area. The geomorphology report (Gippel 2019) provides a thorough assessment of watercourses that will be subject to subsidence.
5. The only two streamflow gauges relevant to local water resources are along Saddlers Creek. It is not clear what the catchment areas of these sites are, but they are assumed to range between 50 km<sup>2</sup> and 90 km<sup>2</sup>. While the site on the larger gauged catchment has a record length of 25 years, there is a “high level of uncertainty” in the data due to the paucity of rating data. Only around nine months of data are available for the smaller gauged catchment. A streamflow gauge is located on the Hunter River, but this has an upstream area of 13 400 km<sup>2</sup> and is only useful for providing contextual information on the larger catchment downstream of the mine site. Overall, estimates of surface water resources in the local catchments rely heavily on (largely unspecified) regional information and, as such, are highly uncertain (see Paragraph 144).
6. There are deficiencies in the surface water quality information presented in the EIS which should be addressed by the proponent. Surface water quality has implications for the impacts of potential spills from mine-water dams (Access Road Dam and Rail Loop) as well as aquatic and riparian biodiversity (e.g. in Saddlers Creek). An analysis of the impacts of potential spills (e.g. during flood events) of mine-affected water from Access Road Dam and Rail Loop Dam should be provided. Relevant deficiencies in the EIS include:
  - a. a lack of metal concentration data, other than major ions;
  - b. the limited monitoring locations for which data was provided, and that the monitoring locations were not clearly identified; and
  - c. the provision of water quality data only in summary form.

### Water-dependent ecosystems

7. An ecohydrological conceptual model is required that illustrates potential impact pathways and likely ecological responses to predicted changes in surface and groundwater quantity and quality in the project area and downstream. In particular, this conceptual model should include water-dependent ecosystems such as Saddlers and Saltwater creeks, associated riparian vegetation, threatened

ecological communities and stygofauna (see responses to Questions 11 and 12). Identification of impact pathways and their potential effects should be used to guide a comprehensive risk assessment that incorporates likely cumulative impacts from other land-uses in the project area against a backdrop of possible climatic scenarios. The outcomes of this risk assessment will guide appropriate monitoring and mitigation measures (see responses to Questions 13 and 14).

8. Water-dependent ecosystems have been assessed at a preliminary level. Aquatic ecology surveys were limited to seven sites, which were sampled on 28 – 30 May 2018 and 16 – 18 October 2018. The IESC notes that some of the smaller tributaries were dry during these surveys, which may have affected habitat quality assessment and species sightings.
  - a. The IESC notes that the condition of the ephemeral Saddlers Creek and Saltwater Creek above the proposed underground workings is poor: there is substantial erosion and sparse tree coverage.
  - b. However, more information is needed to assess impacts to the following species, among others, which have previously been recorded at the site (Atlas of Living Australia 2019): Platypus (*Ornithorhynchus anatinus*), Azure Kingfisher (*Alcedo azurea*), Eastern Snake-necked Turtle (*Chelodina longicollis*), amphibians such as the Green and Golden Bell Frog (*Litoria aurea*) and the Booroolong Frog (*Litoria booroolongensis*), and water birds (i.e. herons, egrets and ducks).
9. The proponent has provided adequate descriptions of the riparian habitat associated with Saddlers Creek. If the project is approved, additional targeted ecological surveys should be undertaken to facilitate adaptive management. These should include surveys for amphibian, turtle, fish and bird species, and should be timed to coincide with periods when these animals are most likely to be detected. Standard survey guidelines (e.g. Commonwealth of Australia 2010, 2011) should be used to establish a suitable baseline dataset for comparison with monitoring data collected during and after mining in the project area.
10. The proponent has adequately assessed impacts to wetlands. The IESC notes that no State-listed wetlands have been identified on, or adjacent to, the proposed project. The closest important wetland is approximately 50 km north-west of the proposed project area (Wappinguy Spring) (Hunter Eco 2019, p. 25).
11. Vegetation has been mapped in the project area. Additional information is required to evaluate the likelihood of on-site ecological communities being partly or fully dependent on groundwater, particularly the Critically Endangered ecological communities: White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland (Box gum grassy woodland), Central Hunter Valley Eucalypt Forest and Woodland, and Hunter Valley Weeping Myall (*Acacia pendula*) Woodland.
12. Mapping of the current and predicted watertables (e.g. at maximum drawdown, during greatest rate of change) overlain with vegetation mapping would be a useful initial step in assessing potential groundwater-dependence and likely ecological responses. Doody et al. (2019) provides guidance on determining groundwater-dependence, noting that in areas where the watertable is <10 m from the surface, vegetation is generally likely to be dependent on groundwater. The IESC also notes that there is potential for some direct impact on vegetation from subsidence (e.g. root shear, toppling). Due to the multi-seam operations, these impacts may be greater than those observed at other underground coal mines.

### Surface water

Question 2: In relation to surface hydrology and site water balance:

- a. has an appropriate model been selected and used by the proponent? Are the assumptions used in the model appropriate?
- b. is there sufficient data within the model to provide meaningful predictions?
- c. does the IESC consider that the decision makers can have confidence in the predictions provided by the model?

13. The models used to derive the flood estimates and to simulate site water management are appropriate (see Paragraphs 14 and 16). The modelling assumptions used to estimate the Probable Maximum Flood are not consistent with expectations (Paragraph 15); although while decision makers can have low confidence in the magnitude of these estimates, the IESC considers that this is not an issue of material concern. The site water balance modelling makes suitable use of regional and local data, although it includes seepage assumptions that are inconsistent with the groundwater modelling (Paragraph 16). The modelling of future void behaviour does not allow for changes to future climatic conditions (Paragraph 16). Overall, the IESC considers that decision makers can have a moderate level of confidence in site water balance simulations. No explicit modelling has been done to assess the potential losses to surface hydrology due to subsidence and thus it is not possible to provide comments on these aspects (see response to Question 4).

### Flooding

14. The Probable Maximum Flood (PMF) was estimated using a storage-routing model with parameters that the IESC assumes have been derived from regional (and not site-specific) information. Although the overall approach adopted is reasonable, there are two issues with the estimates.
- a. The catchment was assumed to be rather drier than conditions recommended in the national guidelines (Nathan and Weinmann 2019, Section 6.4), where the adopted initial and continuing losses were 15 mm and 3 mm/h, compared to the recommended values of 0 mm and 1 mm/h. (No discussion was provided on the selection of temporal patterns, storm duration or pre-burst rainfalls, which are all factors that can significantly influence the estimates).
  - b. There is considerable uncertainty associated with the adopted parameterisation and selected inputs, and it might be expected that simpler regional estimates of peak flow (as discussed in Nathan and Weinmann 2019, Section 6.2.4.1) could be equally relied upon.
15. Overall, it is considered that the PMF estimates are about half the expected magnitude, which implies a frequency of occurrence that is about 10 to 100 times greater than that typically associated with such extreme events. That said, the annual exceedance probability of the derived estimate is likely to be rarer than 1 in 5000, and thus represent flood conditions that are very much more extreme than any in the historic record. As such, the IESC does not consider the impact of the proposed mining works on current flood risks to be of material concern.

### Site water balance

16. The AWBM model is an appropriate model for assessing the site water balance. As discussed in Paragraph 5, there is a paucity of relevant gauging information and the model was parameterised using a combination of local and regional information collected for the Drayton South coal project. The relevance of this information to the current proposal in terms of spatial scale and hydrologic similarity is not explicitly discussed. However, the use of on-site data for calibration (January 2017 to

December 2018), including site rainfall data, is good practice and adds confidence to model predictions. Generally the adopted assumptions are appropriate, where the IESC notes that:

- a. the surface water assessment (WRM 2019, p. 78) estimates a very high rate of seepage from spoil to the existing voids of 6.1 ML/day yet groundwater modelling (Hydrosimulations 2019, p. 67) shows only 3 ML/year of seepage into void areas. This discrepancy – of a factor of approximately 700 – is not acknowledged or explained. The proponent should clarify this issue, as it undermines confidence in the model results.
- b. given the short period of available data with which to verify the model, the IESC supports the proponent’s proposal to update the site water balance annually with the most recent data (WRM 2019, p. 103).
- c. for predictive water balance modelling, the proponent used 129-year synthetic rainfall and evaporation (SILO) records (WRM 2019, p. 30). This overcame limitations in the record length and quality of observations from nearby weather stations. The proponent also shows that average monthly rainfall figures from the SILO series are within a few percent of those from the nearby Muswellbrook gauge (WRM 2019, p. 30).
- d. use of SILO data implicitly assumes that future average climatic conditions will be identical to the past and is inconsistent with the use of NARCLiM climate projections utilised in the groundwater assessment. The majority of global climate models project warmer and drier conditions for this region (e.g. CSIRO, 2012). It is prudent to assess the performance of the site water management system under these projected changes, where factors required to adjust historic climate series by simple scaling can be obtained from the NSW Climate Data Portal (NSW Government 2019a) or the Australian Climate Futures tool (CSIRO and BOM 2019).

Question 3: As outlined above, the EIS proposes an adaptive management approach to manage potential knickpoint formation and changes to stream channel alignment, including through ongoing monitoring and mitigation works. Does the IESC consider these proposed management measures to be technically robust and capable of avoiding significant impacts on these features?

17. The proponent proposes to manage erosion and associated impacts to water quality through regular monitoring and adaptive management (Gippel 2019, p. 98). The geomorphology assessment (Gippel 2019) provides a good baseline for detection of future impacts. Where ‘a significant increase is observed in the rate of knickpoint development or migration’, this would be remediated following professional assessment. Rock grade-control structures would likely be constructed, as these are commonly used and reliable; large wood structures may be a viable alternative (Gippel 2019, p. 98). The IESC supports these recommendations, and suggests that the effectiveness of the structures be monitored.
18. There is difficulty in predicting the precise locations where knickpoints will occur following subsidence so the proponent argues that hard engineering approaches (e.g. rock grade-control structures) are more appropriately used in response to impacts. The IESC agrees that it is appropriate in this environment to largely limit engineering interventions to where impacts are observed. The geomorphology assessment highlights one instance where remediation in advance of mining is necessary. Modelling of streamflow following subsidence suggests that there is a risk that stream b2(2) could cut through and join b2(1) higher in the catchment (Gippel 2019, pp. 84, 87). Gippel (2019, p. 87) recommends stabilisation of an existing 3.5-m knickpoint on stream b2(1) to prevent it migrating upstream. The IESC supports this recommendation.
19. As outlined in Gippel (2019, p. 94), the revegetation of riparian zones and mitigation of existing erosion would probably increase resilience and compensate for subsidence impacts. The IESC



supports this approach as it may limit the requirement for engineered interventions, particularly in areas where there is potential to undertake revegetation well in advance of mining.

20. The proponent does not plan to actively remediate ponding, unless deemed necessary for particular cases. Instead, they propose to allow ponds to naturally infill with sediment. Given the high sediment loads and the impacts associated with regrading stream profiles using heavy machinery, the IESC agrees that passive remediation of ponding is the preferred approach in this environment.
21. The proponent does not present specific triggers or timeframes for active mitigation of geomorphic and erosional impacts. This detailed information should be provided before any mining commences.

Question 4: The EIS identifies that the project is unlikely to result in significant impacts to surface water resources (volume and quality). Does the IESC agree that the assumptions and subsequent predictions regarding surface water losses (including from reduced baseflow):

- a. are appropriate;
- b. and can be considered conservative?

22. Estimates of surface water losses have not considered impacts of baseflow reductions or ponding in depressions, and therefore these estimates cannot be considered conservative.
23. The proponent's estimation of reductions in surface water flow volumes does not account for all potential losses. Additionally, results are not expressed in a way that shows the impacts on the flow regime, including increases in the number of low- and zero-flow days which may be ecologically relevant (see Paragraph 433).
24. The proponent describes losses of flow to Saddlers Creek and the Hunter River from three sources:
  - a. baseflow reduction due to groundwater drawdown: no change is predicted for Saddlers Creek and a very small loss of 0.55 ML/year is predicted from the Hunter River (HydroSimulations 2019, p. 90). These predicted impacts appear inconsistent with impacts discussed in Paragraph 344 as they are subject to the uncertainties discussed in Paragraph 2;
  - b. surface runoff reduction due to excision of the part of the catchment containing the Mine Entry Area: the mine entry area would remove 0.3% of the Saddlers Creek catchment during operations, but this area would be restored following closure and rehabilitation (WRM 2019, p. 93); and
  - c. surface runoff reduction due to ponding in depressions caused by subsidence. On the basis that sediment will gradually infill depressions as mining progresses, the proponent estimates the volume of ponding by assuming a depth of only 0.5 m compared to maximum predicted subsidence of 5.6 m. Moreover, while the total volume of ponding is estimated, the effects on seasonal low flow measures are not quantified.
25. The proponent should quantify total expected surface water flow losses. These losses may have implications for surface water licence requirements. To facilitate understanding of the likely ecological impacts of the reduction in flow, the effects of flow volume reduction on stream persistence and flow regime (e.g. timing, frequency and lengths of low- and zero-flow periods) should be assessed. The proponent should also investigate methods for monitoring surface runoff to verify the magnitude of surface runoff losses.
26. The potential for surface water to drain through cracks in streambeds is acknowledged in the EIS, but it is asserted that this will result in little impact.

- a. The subsidence report notes that surface cracking of between 25 and 50 mm is generally expected. However, cracks of up to 300 mm are predicted in some areas (MSEC 2019, pp. 39 – 40). Cracks this large could be conduits for substantial volumes of water into the subsurface.
- b. Gippel (2019, p. 93) argues that loss of surface flow into cracks will be rare, as there are few areas of exposed bedrock in the subsidence area. However, the IESC considers that there is also potential for cracking of bedrock beneath sediment-covered streambeds which could result in drainage of substantial volumes of surface water if streambed material has moderate or high permeability. This potential for underlying bedrock should be assessed by the proponent, especially where semi-permanent pools occur along Saddlers Creek and other watercourses in the project area.
- c. WRM (2019, p. 94) argues that streams in the subsidence area are ephemeral and that 'in times of heavy rainfall, the majority of the runoff would flow over the natural surface soil beds and would not be diverted into the dilated strata below'. However, there has not been any quantification of the likely rates of flow into streambed cracks (e.g. by undertaking recession analysis or tracer studies) and so it is not demonstrated that these cracks will not substantially reduce surface flow.
- d. It is possible that a component of surface water flows may not be returned to the surface. There is an unknown quantity of water lost via tortuous flow paths including fractures and bedding plane separations and shears in deeper strata overlying longwall panels (see PSM (2017) and associated peer reviews including Mackie (2017) for discussion of such processes). Whilst the IESC acknowledges the current site condition, the implications of this potential water loss for creeks and groundwater-dependent ecosystems during long-term operations and recovery of water levels after closure should be considered. Estimates of impacts should acknowledge uncertainty and include estimates of the likely upper and lower range of impacts.

#### Groundwater

Question 8: Are the statements in the Groundwater Assessment (Appendix B) under section 8.2 (EPBC Act Significant Impact on Water Resources Guidelines) reasonable conclusions based on the information provided in sections 4.6, 6.1 and 6.9 (as stated)?

27. The IESC does not have confidence in the impact conclusions provided within the groundwater assessment. The proponent's assessment against the Significant Impact on Water Resources Guidelines is based on the assessment of impacts to groundwater dependent ecosystems (GDEs), groundwater drawdown and depressurisation, and impacts to groundwater quality (described in HydroSimulations (2019) in sections 4.6, 6.1 and 6.9 respectively). The proponent's assessment of impacts to GDEs (Section 4.6) is discussed in response to Questions 11 and 12 below. The proponent's assessment of groundwater drawdown and quality (Section 6.1 and 6.9 respectively) is discussed below in Paragraphs 333–366 and Paragraph 377 respectively.
28. The key physical driver of concern is the extent to which mining causes surface cracking and near-surface ground movement, which has important consequences for the interactions between groundwater and surface waters and their dependent resources. The estimates of surface subsidence are likely underestimated within watercourses and near faults. Accordingly, the IESC has little confidence in the estimates of non-conventional subsidence at the local scale (and other associated ground movements) in areas that are most vulnerable to ecological decline.
29. The groundwater model developed by the proponent is focussed on simulating regional groundwater flows under the assumptions inherent in an equivalent porous media model. This type of model does

not directly incorporate the impacts of surface cracking and near-surface ground movement, and does not address finer scale variability within the upper most layers. This means the groundwater model does not adequately address what is likely to be the main impact pathway on baseflow in nearby watercourses, which has major implications for assessing likely impacts on aquatic biota and ecological processes.

30. The IESC (2018b) previously noted potential impacts to groundwater resources (and surface water drainage) are “likely to be severe and irreversible”, and that there were a number of sources of uncertainty within the preliminary groundwater model (IESC 2018b). With respect to Section 6.1, the IESC notes that there were several refinements to the model presented in the EIS. Further comments are outlined below.
- a. A sensitivity analysis has been undertaken to investigate the adequacy of model parameters, including to the high-risk areas of the Hunter River and Saddlers Creek. Results of the sensitivity analysis do not appear to considerably affect predicted drawdown within the alluvium (although a slightly larger area of Saddlers Creek and its alluvium could be impacted). Confidence in the sensitivity analysis could be improved by exploring the sensitivity across the full plausible range of parameter combinations, including model boundary condition parameters.
  - b. Confidence in the hydrogeological conceptualisation could be improved by doing additional monitoring, particularly where there is limited monitoring to the south and east of the proposed project. Additional monitoring equipment should be installed in these areas to confirm the maximum extent of groundwater drawdown and whether there was any interaction with drawdown from neighbouring mines in this area (i.e. cumulative impacts).
  - c. Differences between the observed and predicted water levels for the transient calibration hydrographs remain in the revised model (generally between 5 and 25 m; HydroSimulations 2019, App. I). The magnitude of these systematic differences does not appear to be justified nor has the implications of these differences on the simulated predictions been explored.
  - d. The proponent has mapped several faults trending north-west to south-east within the project area, with the major Randwick Park and East Graven faults occurring west of the proposed underground mining area. The IESC notes that Saddlers Creek appears to be located above a normal fault. Further information should be provided to determine whether this fault has a material effect on groundwater flow, particularly whether it may provide a conduit for groundwater drawdown. Environmental water tracers (e.g. major ions, stable water isotopes) may be useful in determining whether there is enhanced surface water loss interaction in this area.
  - e. The proponent has also committed to collect additional geological information of lithology, groundwater intersections and intersection structures (i.e. faults and dykes) to update the site geological model (HydroSimulations 2019, p. 118). The IESC notes that this information will be useful as part of model reviews proposed after the first three years of mining, and every five years thereafter (Malabar Coal 2019a).
  - f. The proponent used a resistivity survey to delineate the extent of the alluvium. This helpful approach provides additional evidence to complement borehole data.
  - g. Losses from surface and bedrock cracking do not appear to be estimated. Given that cracking is predicted to generally be between 25 and 100 mm (but could be greater than 300 mm in approximately 5% of cases) (MSEC 2019, pp. 39 – 40), losses could be substantial and should be quantified.

31. With respect to Section 6.9, little information is provided to quantify likely groundwater quality changes. The implications of this on void management are discussed in response to Question 4.

Question 5: Groundwater inflows within the Maxwell Underground workings are predicted to peak at 1,387 ML/year in Year 12 of the Project. The average annual inflows over the life of the Project are predicted to be in the order of 750 ML/year. Does the IESC consider that the decision makers can have confidence in these predictions?

32. The IESC does not have confidence in groundwater inflow predictions presented in the EIS to the stated inflows at ML/a accuracy. Appropriate use of inflow data from existing operations at neighbouring mines within the model domain as a history-matching (i.e. calibration) target would increase confidence in these predictions. As there are no published case studies relevant to above-seam fracturing for the multi-seam nature of the proposed project, reactivation of the goaf and workings could result in additional unpredicted subsidence and inflows from fracturing.

Question 6: The project is predicted to result in localised drawdown of up to 8 m is predicted in the Saddlers Creek alluvium and up to 4 m in the Saltwater Creek alluvium. Less than 0.5 m of drawdown is predicted in the Hunter River alluvium. Does the IESC consider that the decision makers can have confidence in these predictions?

33. The IESC does not have confidence in predicted drawdown within the alluvia of Saddlers Creek, Saltwater Creek or the Hunter River. The IESC's concerns regarding predictions of losses in surface flow are described in Paragraph 246.
34. The proponent predicts watertable drawdown to peak at approximately 10 m below pre-mining levels. The >2 m drawdown extent of the watertable is predicted to be largely within the mining area and not to extend into the Hunter River Alluvium under the cumulative impact scenario. Drawdown within the Saddlers Creek and Saltwater Creek alluvia is predicted to be 8 m and 2 m respectively (HydroSimulations 2019, pp. 87 – 88). Up to a 0.55 ML/a loss is predicted in the Hunter River (HydroSimulations 2019, p. 90).
- The IESC notes that the proponent also predicts that there will be no loss of baseflow in Saddlers Creek (HydroSimulations 2019, p. 90). It is unclear how there will be no loss in baseflow when an 8-m drawdown is predicted in the Saddlers Creek alluvium. This claim requires justification using site-specific data.
  - The IESC considers that GDEs may be impacted by drawdown of less than 2 m (see response to Question 11).

Question 7: Does the IESC consider that the EIS provides reasonable predictions in relation to:

- drawdown in privately-owned groundwater bores;
- groundwater quality changes, including long-term post mining changes; and
- impacts on groundwater dependent ecosystems (including stygofauna).

35. The IESC considers that the EIS provides reasonable predictions about drawdown in privately owned groundwater bores (Paragraph 366), but there is inadequate information to assess changes in groundwater quality (Paragraph 377), including long-term changes post mining. Impacts on GDEs require further assessment, as described below (Paragraph 388).

36. The IESC has greater confidence in predictions of groundwater drawdown in private bores than in predictions of groundwater inflows because the model has been calibrated against groundwater levels in areas subject to mining-induced drawdown. The uncertainty in subsidence described in

Paragraph 322 propagates to predictions of drawdown and therefore requires quantification, including in private bores.

37. The IESC does not have confidence in predicted changes to groundwater quality. The proponent does not describe potential changes to groundwater quality resulting from subsidence and the likely resulting changes in the chemistry of water infiltrating through the freshly exposed surfaces of fractured bedrock. Potential changes to groundwater quality in the Greta Coal Measures are discussed in response to Question 10.
- a. Improvements in water quality are predicted by the proponent along localised areas of the Hunter River and Saddlers Creek due to reduced leakage from the Permian coal measures (HydroSimulations 2019, p. 95). These improvements do not appear to be quantified.
  - b. The Permian coal measures are used for groundwater extraction, with no change predicted to the groundwater quality or its suitability for beneficial uses (HydroSimulations 2019, p. 96).
  - c. The IESC considers that the likely groundwater quality changes within the shallow aquifers require quantification to determine potential impacts to GDEs, as these changes may exceed the physiological tolerance of some species. There is considerable uncertainty in likely groundwater impacts post mining, as few data are available for expected water quality from spoil leachate and the effects of subsidence-induced cracking on groundwater quality are uncertain.
38. The IESC does not have confidence in predicted impacts to GDEs, including stygofauna (see Paragraph 45). In addition to uncertainty in groundwater drawdown predictions, there is uncertainty regarding the groundwater dependence of components of local ecosystems, particularly some of the tree species that form part of the threatened ecological communities. This issue is discussed in response to Questions 13 and 14 below.

Question 9: Does the IESC consider that the cumulative impacts of nearby mining operations on groundwater resources have been appropriately assessed?
---

39. Three predictive scenarios (null run, approved mines and approved mines plus project) have been modelled, including scenarios to investigate impacts for up to 1000 years after completion of the project. The groundwater report discusses several existing mines in the area, including the Mt Arthur, Drayton, Bengalla, Mangoola and Hunter Valley Operations (HVO) mines. The modeller considers that the Mt Arthur and Drayton mines are the most likely to cause cumulative impacts, whereas the other mines are unlikely to interact with groundwater intersected by the proposed project. The IESC also notes that any impact from the HVO mine to the south-east of the proposed project is likely to be restricted to deeper aquifers. Only the much larger Mt Arthur Mine appears to be incorporated into the modelling scenarios. The mines to the east are apparently not hydrogeologically connected due to geological structure. Additionally, the coal seams outcrop to the east, which helps to limit the extent of drawdown. The IESC therefore considers that additional mines to the east and south-east do not need to be considered further unless unexplained impacts are detected during monitoring (see recommendations in Paragraph 2).
40. However, mines to the north may require further investigation if mitigation triggers proposed as part of the groundwater management plan are exceeded. Further investigations should focus on:
- a. the Bengalla Mine, where predicted cumulative impacts undertaken for the project extended to the Hunter River (Hydro Simulations 2019, p. 42), especially in the early years of mining around 2016. These impacts have not been observed under the recent dry climatic conditions. Additionally, the proponent has discussed results of the bioregional assessment as context for their assessment (Hydro Simulations 2019, p. 42); and

- b. exploring the uncertainty and sensitivity of the model's boundary conditions to cumulative impacts from mines in the area.

Question 10: The EIS indicates that there is potential for seepage from the East Void to the Greta Coal Measures underlying the Liddell Ash Dam to the east, but that this seepage is unlikely to impact the beneficial use of groundwater within the Greta Coal Measures. Does the IESC consider that the assumptions and predictions regarding the management of seepage from final voids:

- a. accurately depict the relative impacts of the Project versus the existing Drayton Mine; and
- b. reflect an appropriate and conservative approach to the management of these impacts?

41. The proposed final landform includes the three remaining voids at the Maxwell Infrastructure area (previously known as Drayton Mine). Given that the voids from the existing project will be used by the proposed project and that there is insufficient water quality information from the Greta Coal Measures, it is not currently possible to answer these questions.

#### Groundwater Dependent Ecosystems

Question 11: Is there adequate information to quantify and assess the impacts of subsidence, surface water and groundwater impacts on listed threatened species and ecological communities?

Question 12: Does the IESC identify any GDEs or species likely to be impacted as a result of subsidence, surface water or groundwater impacts?

42. The inherent complexity of subsidence resulting from multi-seam mining and the lack of case-studies about the impacts of this type of mining in regions with comparable geology to the Hunter River catchment introduces some irreducible uncertainty in predictions of potential ecological responses, especially by EPBC Act- and State-listed threatened ecological communities. Where information is considered inadequate, this is highlighted in the following paragraphs.

43. As described in responses to Questions 3 and 4, the project will likely affect downstream water quantity and quality, including causing reductions in flow persistence and altering the flow regime, especially the timing, frequency and lengths of low- and zero-flow periods. These will affect aquatic and potentially riparian habitat, especially in Saddlers Creek, with repercussions for in-stream and riparian flora and fauna. Such changes to the flow regime in ephemeral streams often profoundly influence the biodiversity and community composition of native aquatic biota and alter rates of crucial ecological processes such as organic matter cycling (Datry et al. 2017), with repercussions for adjacent riparian and terrestrial communities. These changes affect the provision of ecosystem services by ephemeral streams (Datry et al. 2018), including those related to surface water-groundwater interactions. The IESC noted several deficiencies in ecological survey effort and timing (see response to Question 1) which may mean that some biota have been missed during surveys or estimates of their abundance are unreliable. Data from the Atlas of Living Australia (2019) show that a number of aquatic species have previously been recorded in this area but were not reported in the EIS.

44. There is uncertainty in the groundwater-dependence of some key tree species in the project area.

- a. Groundwater drawdown is not likely to affect Swamp Oaks along Saltwater Creek. However, along Saddlers Creek, Swamp Oaks are acknowledged in the EIS as riparian vegetation that are probably groundwater-dependent and may be affected by predicted drawdown in the alluvium. More information is needed on whether this drawdown will prevent recruitment by seedlings of this species (unable to access groundwater) and lead to local extinction of Swamp Oaks along Saddlers Creek, potentially affecting habitat for associated native biota.



b. The proponent asserts that listed woodland ecological communities occurring on site are unlikely to be dependent on groundwater. The area of predicted groundwater drawdown overlaps with much of the distribution of threatened ecological communities (including some that are Critically Endangered) in the project area. It is important for the proponent to be able to justify the assertion that this drawdown will not lead to reduced ecological condition or mortality of any component species of these communities. As described in response to Question 1, suitable depth-to-water mapping and interpretations of predicted rates and temporal patterns of drawdown would help address this risk. Other approaches for investigating potential groundwater-dependence of terrestrial GDEs are discussed in Doody et al. (2019).

45. Stygofauna have been identified in both the Hunter River and Saddlers Creek alluvia (Eco Logical 2019). Drawdown of up to 8 m is predicted in Saddlers Creek alluvium. The proponent does not consider that stygofauna will be significantly impacted because Saddlers Creek's alluvium is connected to the larger alluvium of the Hunter River and reductions in groundwater salinity are predicted (HydroSimulations 2019, p. 94). While this connectivity implies that unique species of stygofauna are unlikely to be lost, the groundwater drawdown caused by the project will result in an overall loss of habitat area. Further, given that rates of carbon processing in hyporheic and alluvial sediments of intermittent streams like Saddlers Creek can be high (Burrows et al. 2017), it is likely that groundwater drawdown in the alluvia will also affect this crucial ecosystem process, a risk that is not addressed by the proponent.

#### Avoidance, Mitigation and Monitoring

Question 13: Does the EIS provide reasonable strategies to effectively avoid, mitigate or reduce the likelihood, extent and significance of impacts to significant water-related resources?

Question 14: Would the IESC recommend any additional monitoring or management measures to address any residual impacts on water resources?

46. For discussion of these issues in relation to surface water and water-dependent ecosystems, refer to responses to Questions 3 and 4. These responses also discuss monitoring and management measures to address the impacts of subsidence on surface water resources. Additional groundwater modelling and monitoring requirements are provided in responses to Questions 5 – 8.

#### Remediation of subsidence impacts

47. A subsidence-effects monitoring program is proposed (i.e. for valley closure) (MSEC 2019, p. 44). Down-borehole monitoring does not appear to be proposed. The proponent should take geophysical logs of bores pre- and post-mining to verify the:

- a. depth of the surface fracturing zone and; and
- b. height of fracturing above each longwall.

This may require installation of additional bores if the existing monitoring bores are not constructed in a way that enables geophysical logs to be taken.

48. Infilling or grading of cracks is the main mitigation measure identified. Prior to any remediation, the proponent proposes to assess whether the remediation will be beneficial or if alternative methods of remediation (i.e. without machinery) are warranted. The proponent considers that minor cracks <50 mm are not expected to require remediation, as these are expected to infill naturally over time (Hunter Eco 2019, p. 98). Further justification is required to demonstrate this expectation. Response triggers should be developed for mitigation to be undertaken if these cracks do not infill within an appropriate timeframe. Cracks which are visibly closed at the surface (e.g. self-healed with sand, remediated with gravel) may also continue to allow preferential flow. For example, visibly closed

fractures in clayey soils can remain hydraulically active (vertisol clay fraction 64%, Greve et al., 2012). State soil mapping indicates that parts of the proposed project area are covered with vertisols (NSW Government 2019b).

49. Larger cracks (>50 mm) are proposed to be remediated through infilling with soil or suitable material. This is only proposed to take place where required but it is unclear on what basis this determination would be made. As noted in the IESC's previous advice (IESC 2018b), detection of cracks beneath alluvial sediments is likely to be difficult. The proponent has not explained how they propose to locate or remediate cracks that are obscured by alluvial sediment. Citing Commonwealth of Australia (2015), the proponent acknowledges that remediation methods for cracked rock bars have not been scientifically evaluated (Gippel 2019, p. 97). Further, grouting has not been proven successful in the short or long-term through independent hydrological studies and peer review.
50. Given this, the IESC considers that low confidence can be placed in successful remediation of surface or subsurface cracks. With the lack of documented success in grouting, the proponent should document, test and make public the results of their grouting to inform future mitigation practice in the region. This should involve a peer-reviewed test of the procedure.
51. The peer reviewer considers that the predicted effects of subsidence and vertical fracturing in the profile require additional monitoring (Malabar Coal 2019a, Att. 6, p. 6). The IESC agrees with this recommendation, including for additional shallow borehole monitoring at key locations along Saddlers Creek to determine the impact of any fracturing at the surface.
52. Sediment transport and associated turbidity is an acknowledged issue for local water quality. The proponent recognises that subsidence is likely to lead to increases in erosion in watercourses subject to subsidence. Of particular concern is formation of new knickpoints and the potential for a streambank to be cut through and change the course of a stream (stream avulsion). Suspended sediments (e.g. total suspended solids and turbidity) and sediment quality (sediment-bound contaminants) need to be monitored to assess potential adverse impacts.

#### Groundwater management plan

53. The proponent has committed to develop and implement a groundwater management plan that will include triggers for mitigation. Proposed groundwater mitigation measures include:
  - a. injection of water into the depressurised aquifers;
  - b. grouting and 'cut-off measures' (although it is not clear from the EIS what the 'cut-off measures' would be, or their likely effects);
  - c. obtaining additional water from other sources;
  - d. obtaining additional water licence allocations;
  - e. treatment of mine water for reuse within the water management system; and
  - f. make-good provisions for water supply bores.

The groundwater management plan should clearly set out triggers for corrective actions and describe these. As discussed in Paragraphs 49–50, the IESC has low confidence in the likely success of grouting. There is also scope to undertake further quantitative sensitivity analysis as part of the validation process.

54. Triggers for groundwater quality are only proposed to be developed for electrical conductivity (EC), pH and sulfate. It is unclear whether these will be based on reference (un-impacted sites) or what triggers will be used to assess other water quality parameters. For metals, a conservative approach



would be to use the 95% aquatic species protection guideline values (ANZG 2018). Should exceedances occur, specific mitigation measures should be proposed.

55. The proponent has committed to an annual groundwater report, and an assessment of groundwater predictions after the first three years of mining, and every five years thereafter (Malabar Coal 2019a). Monitoring and revision of the groundwater model is particularly important for this project as there is substantial uncertainty regarding the hydrogeological impacts of multi-seam mining. If monitoring indicates impacts substantially different from predictions, the IESC suggests that modelling should be revised and should include analysis of quantitative uncertainty. This revised modelling should be used to update plans for mitigation strategies if needed.

#### Groundwater-dependent ecosystems

56. The use of environmental DNA (eDNA) is recommended for the ongoing monitoring of stygofauna because it provides an opportunity to rapidly identify subterranean biota with finer taxonomic resolution than currently used in this EIS, at a potentially lower cost than traditional sampling approaches. Further information on the application of eDNA to groundwater-dependent ecosystems is provided by Doody et al. (2019).
57. The project will contribute to cumulative impacts on groundwater-dependent ecosystems and to water quality and quantity impacts on downstream surface water flows, including in the Hunter River. The proponent should contextualise the project's likely impacts by providing a summary of historical and current impacts to these ecological receptors and how they might be affected by additional potential impacts of the project.
58. As noted in Paragraph 191, riparian revegetation would probably enhance ecosystem resilience to help compensate for erosion and sedimentation impacts from the project. Resilience of water-dependent ecosystems to potential water losses could also be improved. The IESC strongly recommends that riparian revegetation should be undertaken in areas identified as showing evidence of heavy erosion, including Saddlers Creek and drainage lines that feed into Saltwater Creek (Eco Logical Australia 2019, p. 8).

#### Final landform and voids

59. The geochemistry assessment makes recommendations relevant to the final landform. It is important that these are followed.
- a. The establishment rock is not expected to require any specific handling for disposal. However, due to the risk of this material being sodic, the geochemistry assessment recommended that allowance is made to treat these materials (e.g. addition of gypsum) to ameliorate the sodicity, as required. No untreated sodic materials should be used for construction or site earthworks.
  - b. The geochemistry assessment also recommends that due to the expected presence of moderately saline, potentially acid-forming low-capacity (PAF-LC) material, the within-pit reject emplacement should be designed to prevent the reactive rejects from oxidising and the salts from migrating to the revegetation layer. Geochemical characterisation would be undertaken as part of managing coal handling and preparation plant emplacements.
60. Despite predicted equilibrium of void water levels relatively close to the surface, the proponent has not examined the effects of parameter uncertainty on predicted void levels. The proponent should provide analyses of the:
- a. likelihood of void spills under high-rainfall scenarios, including wetter-than-average periods;

- b. sensitivity of predictions to input groundwater parameters, particularly hydraulic conductivity; and
  - c. potential for high-density saline void water to cause density-driven flow to the wider groundwater system.
61. Given that water levels are currently expected to equilibrate to ~20 mbgl on the eastern side of the Maxwell Infrastructure area, there is potential for interaction with shallow groundwater and therefore release of contaminants to the wider environment. The proponent should assess the expected water quality in final voids. The geochemical assessment (GEM 2019) highlights that there is potential for elevated concentrations of arsenic, antimony and selenium in leach water. Evapo-concentration is likely to lead to very high salinity. There is considerable uncertainty in parameters used to calculate the final void level, and recommended sensitivity analysis (see Paragraph 600) may reveal potential for equilibrated water levels to be even closer to the surface.

<b>Date of advice</b>	19 November 2019
<b>Source documentation provided to the IESC for the formulation of this advice</b>	Malabar Coal Malabar Coal 2019a. Maxwell Project – Environmental impact statement. Cited appendices are listed below.
<b>References cited within the IESC’s advice</b>	<p>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. Available [online]: <a href="https://www.waterquality.gov.au/anz-guidelines">https://www.waterquality.gov.au/anz-guidelines</a>, accessed October 2019.</p> <p>Atlas of Living Australia 2019. <i>Explore your area, results for: Unnamed Road, Jerrys Plains NSW 2330</i> [Online]. Available: <a href="https://biocache.ala.org.au/explore/your-area#-32.4381 150.8500 12 ALL SPECIES">https://biocache.ala.org.au/explore/your-area#-32.4381 150.8500 12 ALL SPECIES</a>, accessed October 2019.</p> <p>Burrows R, Rutledge H, Bond N, Eberhard SM, Auhl A, Andersen MS, Valdez DG, Kennard M 2017. High rates of organic carbon processing in the hyporheic zone of intermittent streams. <i>Scientific Reports</i>, 7: Article 13198.</p> <p>Commonwealth of Australia 2010. Survey guidelines for Australia’s threatened frogs. Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT. Available: <a href="http://www.environment.gov.au">www.environment.gov.au</a>.</p> <p>Commonwealth of Australia 2011. Survey guidelines for Australia’s threatened fish. Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT. Available: <a href="http://www.environment.gov.au">www.environment.gov.au</a>.</p> <p>Commonwealth of Australia 2015. Management and monitoring of subsidence induced by longwall coal mining activity, prepared by Jacobs Group (Australia) for the Department of the Environment, Commonwealth of Australia, Canberra [Online]. Available: <a href="https://www.environment.gov.au/system/files/resources/8a22c56a-3c83-4812-aa2f-9d0bc40ac718/files/monitoring-management-subsidence-induced-longwall-coal-mining-activity.pdf">https://www.environment.gov.au/system/files/resources/8a22c56a-3c83-4812-aa2f-9d0bc40ac718/files/monitoring-management-subsidence-induced-longwall-coal-mining-activity.pdf</a>.</p> <p>Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BOM) 2019. “Climate Change in Australia” [Online]. Available:</p>

---

<https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/introduction-climate-futures/>. Accessed October 2019.

- Datry T, Bonada N. and Boulton AJ 2017. General introduction. In T. Datry, N. Bonada & A. J. Boulton (Eds.), "Intermittent Rivers and Ephemeral Streams: Ecology and Management", pp. 1-20. Amsterdam: Elsevier.
- Datry T, Boulton AJ, Bonada N, Fritz K, Leigh C, Sauquet E, Tockner K, Huguency B and Dahm CN 2018. Flow intermittence and ecosystem services in rivers of the Anthropocene. *Journal of Applied Ecology*, 55:353-364.
- 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 Development through the Department of the Environment and Energy, Commonwealth of Australia 2019. Available: <http://iesc.environment.gov.au/publications/information-guidelines-explanatory-note-assessing-groundwater-dependent-ecosystems>.
- Eco Logical Australia 2019. Maxwell Project: Aquatic Ecology and Stygofauna Assessment. Report prepared for Malabar Coal Ltd. Appendix F of EIS.
- IESC 2018a. *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>.
- IESC 2018b. *Advice to decision maker on coal mining project – IESC 2018-098: Maxwell Project – Expansion*. Advice dated 9 November 2018. [Online]. Available: <http://www.iesc.environment.gov.au/system/files/iesc-advice-maxwell-2018-098.pdf>
- Geo-Environmental Management (GEM) 2019. Environmental Geochemistry Assessment of the Maxwell Project. Report prepared for Malabar Coal Ltd. Appendix P of EIS
- Gippel CJ 2019. *Maxwell Project, Environmental Impact Statement, Technical Study Report, Geomorphology Assessment*. Fluvial Systems Pty Ltd, Stockton, Malabar Coal Ltd, Sydney, June. Appendix D of EIS.
- 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.
- Hunter Eco 2019. *Maxwell Project: Biodiversity Development Assessment Report*. Report prepared for Malabar Coal Ltd. Appendix E of EIS.
- Huynh T and Hobbs D 2019. Deriving site-specific guideline values for physico-chemical parameters and toxicants. 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. Available [online]: <http://www.iesc.environment.gov.au/system/files/resources/249ff82e-f853-499b-ac06-d90726f8a394/files/information-guidelines-explanatory-note-site-specific-guidelines-values.pdf>. Accessed October 2019.
- HydroSimulations 2019. *Maxwell Project: Groundwater Assessment in support of an EIS*. Report prepared for Malabar Coal Ltd. Appendix B of EIS.

- 
- Mine Subsidence Engineering Consultants (MSEC) 2019. *Maxwell Project – Subsidence Assessment. Subsidence predictions and impact assessments for the natural and built features due to multi-seam mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield seams in support of the environmental impact statement.* Report prepared for Malabar Coal Ltd. Appendix A of EIS.
- Mackie C 2017. *Height of fracturing at Dendrobium Mine - Peer review of Pells Sullivan Meynink Report.* Letter from Mackie Environmental Research Pty. Ltd. to the NSW Department of Planning and Environment. Dated 28 February 2017.
- Malabar Coal 2019b. Maxwell Project. Preliminary Rehabilitation and Mine Closure. Appendix U of EIS.
- Nathan R and Weinmann E 2019. Estimation of Very Rare to Extreme Floods, Book 8 in Australian Rainfall and Runoff - A Guide to Flood Estimation, Commonwealth of Australia.
- New South Wales (NSW) Government 2019a. "NSW Climate Data Portal", Office of Environment and Heritage. [online] Available: <https://climatedata.environment.nsw.gov.au/>. Accessed October 2019.
- New South Wales (NSW) Government 2019b. "Soil landscapes" from ESPADE, Office of Environment and Heritage. [online] Available: <https://www.environment.nsw.gov.au/topics/land-and-soil/information/soil-maps>. Accessed October 2019.
- Operational Risk Mentoring 2019. Maxwell Project. Environmental Risk Assessment. Report prepared for Malabar Coal Ltd. Appendix S of EIS.
- PSM 2017. *Height of Cracking – Dendrobium Area 3B, Dendrobium mine.* Report for Department of Planning and Environment, PSM3021-002R, March 2017.
- Whetton P, Hennessy K, Clarke J et al. 2012. Use of Representative Climate Futures in impact and adaptation assessment. *Climatic Change*, 115 (304): 433-442.
- WRM Water and Environment (WRM) 2019. *Surface Water Assessment: Maxwell Project.* Report prepared for Malabar Coal Ltd. Appendix C of EIS.
-