

Advice to decision maker on coal mining project

IESC 2019-105: Dendrobium Mine – Plan for the future: Coal for steelmaking (EPBC 2017/7855 and SSD 8194) – Expansion

Requesting agency	The Australian Government Department of the Environment and Energy and The New South Wales Department of Planning, Industry and Environment
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Advice stage	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 Illawarra Coal Holdings Pty Ltd's 'Dendrobium Mine – Plan for the future: Coal for steelmaking 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, 2018).

Summary

'Dendrobium Mine – Plan for the future: Coal for steelmaking' is a proposed expansion of the operational Dendrobium Underground Mine located 8 km west of Wollongong in the Southern Coalfield of New South Wales. The project is located in the Metropolitan Special Area, a restricted-access area designed to protect Sydney's drinking water supply catchments. The expansion would allow access to Areas 5 and 6 to mine coal from the Bulli and Wongawilli Seams respectively. Mining would continue at an approximate rate of 5.2 million tonnes per annum run-of-mine in total with Area 5 to be mined between 2024 and 2038 and Area 6 between 2043 and 2048.

The project will increase the area affected by subsidence, including undermining 26 Coastal Upland Swamps of the Sydney Basin Bioregion (listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)) and several first, second and third order streams. This will result in considerable changes to surface water flows and water regimes within the impacted stream reaches and swamps. The project will also contribute to groundwater drawdown in the Hawkesbury Sandstone aquifers. However, no impacts are predicted to the small number of water supply bores from the proposed project.

Existing infrastructure such as coal handling, water management and train-loading facilities will be utilised with some minor additions required to the water management system. Discharges of mine-affected water are likely to increase considerably; however, these will continue to be managed under the mine's existing environment protection licence EPL3421 (EPA 2018) with discharges occurring to Allens Creek in Unanderra.

Key potential impacts from this project are:

- surface impacts from subsidence, including vertical subsidence, cracking and fracturing of streambeds and swamp bases, and diversion of surface water underground;
- permanent changes to the flow regimes of numerous first-, second- and third-order stream reaches that will considerably decrease streamflows and increase the number of low- and no-flow days under all rainfall scenarios;
- major changes to water regimes and drying severity in swamps. Twenty six swamps will be directly undermined and impacted by subsidence with an additional 20 potentially impacted as these are located partially or wholly within 600 m of planned longwall panels;
- irreversible changes will occur in EPBC-listed swamps, instream and riparian environments (including major changes in important ecological processes such as organic matter decomposition and microbial activity in the hyporheic zones) and water-dependent flora and fauna, such as the state-listed Giant Dragonfly (*Petalura gigantea*), resulting from the above mentioned changes to flows and water regimes in streams and swamps.
- adverse impacts on water quality of inflows to water supply storages associated with the expected changes in the upland environment. Such water quality impacts are likely to include changes in turbidity, nutrient loads and pathogens;
- groundwater drawdown within the Hawkesbury Sandstone aquifers; and
- potential long-term unquantified impacts to groundwater levels and quality post-mining.

The IESC notes that the surface water assessments have been completed to a high standard and that the subsidence assessments have been completed to a good standard, particularly with respect to the use of existing observations of impacts at other areas of the Dendrobium Mine.

However, information and a quantitative analysis needs to be provided on options for variations to the proposed mine plan, such as setbacks from swamps, or variations to longwall width (or other aspects of mine design and geometry) as these appear to be the only viable options, which could be used to reduce the predicted impacts. There is a lack of evidence for there being any other mitigation options that would protect upland swamps and high order streams from irreversible decline.

Noting this, the IESC has identified key areas in which additional work is required to better inform the key potential impacts, as detailed in this advice. This work would be particularly relevant to assessing the possible benefits of a revised mine plan. These are summarised below.

- Given the evidence for irreversible impacts on upland swamps elsewhere in the Southern Coalfield then further information and evidence to support the likely success of proposed remediation measures for swamps and streams (e.g. grouting and flow dispersion structures) is needed. To the IESC's knowledge there are no peer-reviewed publicly available reports to indicate that any such remediation attempts have been successful.
- The irreversible impacts associated with near surface cracking and near surface ground movement requires further investigation, including additional monitoring, field investigations and analyses. For example, the limitations of using an equivalent porous medium (EPM) modelling approach in a highly disturbed or fractured area should be addressed.
- Further information regarding the groundwater impact predictive scenarios (HydroSimulations 2019, pp. 91 – 92) and sensitivity analysis (HydroSimulations 2019, pp. 104 – 108) should also be provided to allow comparison of predicted results from a revised mine plan.
- The characterisation of geological structures and lineaments requires further consideration. This is needed to fully understand potential impacts to water assets in the region, and to allow the development of appropriate trigger-action response plans (TARPs).
- The potential impacts from localised changes on ecological components of water resources also require further investigation and discussion to enable the development of appropriate monitoring, management and mitigation measures. The additional work should also consider how the predicted changes to water regimes will alter water quality.
- The potential for increased risk of bushfire impacts on individual swamps that have dried, and at the landscape scale given 26 swamps will be directly undermined and are at higher risk of drying, requires further consideration. Bushfires and the drying of swamps can increase the likelihood of erosion which can affect catchment yields and water quality.

Context

The proposed project is an extension to the existing operational Dendrobium Mine. The project is located in a coal mining region which has been actively worked since the 1800s. This project, however, is also located within the catchments of Lake Avon and Lake Cordeaux which supply drinking water to the Illawarra and parts of Sydney. Previous mining at Dendrobium Mine has resulted in a reduction to surface water flows into Lake Avon and Lake Cordeaux. Subsidence movements arising from this project are likely to further increase the volume of water lost from the surface water system due to streambed cracking.

A number of EPBC Act-listed Coastal Upland Swamps of the Sydney Basin Bioregion exist within the project area. Under the proposed mine plan 26 swamps will be directly undermined and hence impacted by subsidence with a high likelihood of changes to the swamp water regime. A further 20 swamps are located partially or wholly within 600 m of a proposed longwall panel and hence may also be impacted by subsidence-related changes in water regime.

Response to questions

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

General

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

1. Sufficient information has been provided to delineate the majority of surface and groundwater resources that will be permanently altered by the proposed mine plan.

2. The proponent has undertaken a detailed assessment to characterise groundwater resources within the project area. The IESC notes that the groundwater assessment builds on previous site models, using site-specific data and geological mapping, and data from the Illawarra Coal bore database. The IESC notes that:
 - a. confidence in the hydrogeological conceptualisation could be improved by undertaking additional monitoring (see response to question 2); and
 - b. fault investigations are on-going at the site, where detailed mapping of Areas 5 and 6 would occur as the development extends into these areas.
3. Surface water resources, including EPBC Act-listed Coastal Upland Swamps of the Sydney Basin Bioregion, are clearly identified and mapped in the EIS. Stream features such as waterfalls greater than 5 m in height and with a pool at the base of the step, and pools larger than 100 m³ in volume have also been identified and mapped in the project area. However:
 - a. not all 26 swamps in Areas 5 and 6 are currently being monitored, potentially limiting swamp-specific information on their current condition. Baseline surveys (of suitable spatial and temporal extent – see response to question 12) of all swamps should be completed before any longwall approaches within 400 m of a swamp (i.e. before impacts due to ground movement occurs at the swamp).
4. The installation of six flow gauging sites within the proposed expansion area is commended. Ongoing monitoring needs to be supported by periodic review of the rating curves. The current monitoring of groundwater levels adjacent to swamps also provides useful baseline data. Additional gauges will need to be installed and monitored to include control sites that are not impacted by the project.

Groundwater

Question 2: To what extent can decision makers have confidence in the predictions of potential impacts on groundwater resources provided in the EIS, including in regard to groundwater inflows, potential impacts on private bores and any impacts to the nearby water reservoirs through groundwater depressurisation, connective cracking, geological structures and/or changes in the specific storage of underlying strata.

5. The key physical driver of concern is the extent to which mining-induced ground movement causes surface cracking and near-surface ground movement, which has important consequences for the interactions between groundwater and surface waters and their resources. The estimates of surface subsidence are largely based on the use of an empirical method (Incremental Profile Method (IPM)) and numerical modelling (UDEEC). While this method might be appropriate to estimate subsidence at the longwall scale, it is noted that the model materially underestimates observations of local ground movement 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.
6. 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 model does not adequately incorporate the impacts of surface cracking and near-surface ground movement. This means the groundwater model does not address what is likely to be the main impact pathway on baseflow in nearby watercourses, and this has implications for assessing likely impacts on aquatic biota and ecological function. Accordingly, the IESC has a low level of confidence in the proponent's estimates of mining impacts on surface water-groundwater interactions.
7. 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 (PSM 2017) and associated

peer reviews including Mackie (2017) for a discussion of such processes). Accordingly, it is possible that a component of surface water flows may not be returned to the upland swamps and streams. The implications of this potential water loss for creeks and groundwater-dependent ecosystems during long-term operations and recovery of water levels after closure need to be considered in a manner that bounds the likely upper and lower range of impacts.

8. The IESC also has limited confidence in the current groundwater model predictions provided by the proponent (HydroSimulations, 2019, pp. 93 – 103, 105 – 108) given the risk of potential impacts to groundwater assets (see response to question 3). The IESC notes that impact predictions could change when the model is updated as part of an assessment of a revised mine plan. Consideration and discussion of the issues outlined below would further increase confidence in the groundwater impact assessment and associated modelling.
 - a. The location of all monitoring bores that contributed to the model should be clearly displayed. The IESC notes that there are no multi-level piezometers above the coal seams in Area 6. In relation to Areas 5 and 6, monitoring is limited north of the proposed mine areas, and between the proposed mining areas and Lake Avon and Lake Cordeaux.
 - b. The groundwater model has not adequately simulated the dynamic changes in hydraulic properties associated with mining-induced ground movement under streams. Results from the sensitivity analysis (HydroSimulations 2019, pp. 104 – 108) should be clearly displayed or compared. Additional matters related to the hydraulic parameters used in the model follow.
 - i. The Bald Hill Claystone ($K_h: 1.0 \times 10^{-5}$ m/day) and Stanwell Park Claystone ($K_h: 3.0 \times 10^{-5}$ m/day; $K_v: 6 \times 10^{-6}$ m/day) are traditionally considered to act as regional aquitards and limit the vertical flow of water between the Hawkesbury Sandstone and the Bulgo and Scarborough sandstones of the Narrabeen Group (Herron et al. 2018). However, it is not clear whether the hydraulic parameters used within the model are consistent with all available information. For example, the Bald Hill Claystone has similar hydraulic conductivity to adjacent strata (HydroSimulations 2019, Figures 4-2 – 4-8, pp. 145 - 151) and thus may not be an effective regional aquitard, particularly where ground movement due to mining occurs.
 - ii. Specific storage (S_s) is assumed to be constant in the modelled deformation zones (e.g. surface cracking or underlying strata). However, an increase of S_s that has been observed in these deformed zones (David et al. 2017) indicates that drawdown from overlying aquifers and losses from surface water may not be modelled in a realistic manner by assuming a constant S_s .
 - c. Surface cracking was simulated by assuming a depth of fracturing that was 10 times the longwall cutting height, with the model allowing for increased hydraulic conductivity but not storage. Whilst the depth of cracking may be considered a conservatively high assumption, there is a lack of evidence for the depth of surface cracking, or site data to justify the factors selected for increased horizontal and vertical hydraulic conductivity.
 - d. It is commendable that a comprehensive data set on tritium has been provided, along with estimates of modern water at depth. Multiple lines of evidence have improved confidence in the conceptual model of flow paths. However, a quantitative comparison of the tritium results with groundwater modelling fluxes layer by layer has not been undertaken to help confirm model predictions. It would also be worthwhile to consider a broader suite of suitable water tracers as suggested by the proponent to compare with the tritium results, stable isotope tracers (David et al. 2015) and added tracer tests (Parsons Brinkerhoff 2015). Tracer studies have indicated there is hydraulic connection between the surface and the seam to varying degrees over timeframes

greater than two years. In some areas, tracers indicate seepage losses from surface zones over years and decades.

- e. There appear to be some inconsistencies between the stratigraphic and modelled typical thicknesses of strata, notably for the Bulgo Sandstone (typically 95 m, modelled as upper and lower units each 40 – 60 m thick) (HydroSimulations 2019, pp. 23, 71) and the Wongawilli seam (the model assumes 4.2 m of the Wongawilli seam will be mined from the floor of the seam, which is 7 – 10 m thick but modelled as 4 – 10 m thick) (HydroSimulations 2019, pp. 25, 71). The materiality of these inconsistencies on modelling results is unclear.
9. The IESC notes that the regional groundwater model did not attempt to predict local scale impacts relevant to high order streams and swamps. While the impacts on swamps have been estimated using the VADOSE/W model (and validated using monitoring data from Area 3), the impacts to surface water streams (excluding swamp areas) are based on the results from the groundwater modelling. Accordingly, decision makers can have reasonable confidence in the estimates of mining impacts on swamps, but the estimates of impacts on high order streams can be given less confidence as the surface water modelling has relied upon the results provided by the groundwater model.
 10. The proponent has conducted a literature review of geological structures for the local area. For a revised mine plan, the characterisation of geological faults requires further consideration.
 - a. As cross sections used to develop the groundwater model appears to be incomplete in representation of faults and strata thicknesses these need to be revised to be consistent with physical processes of deposition and movement.
 - b. The location of bores used to develop cross sections is unclear. Without this information, it is not possible to validate the cross sections provided.
 - c. A detailed topographic analysis of swamp location and linear structural features should be undertaken. This would help identify which swamps in Areas 5 and 6 are most at risk from anomalous ground movement.
 - d. It is also unclear whether the potentially significant Elouera Fault has been included in the groundwater model. The IESC also notes that aspects of the geological structure review do not appear to be included in the groundwater model, including:
 - i. a significant zone of disturbance described as the Potential Bulli Fault (PSM 2019, pp. 4, 13);
 - ii. three regional faults inferred within Areas 5 and 6 (PSM 2019, p. 12); and
 - iii. faults inferred in drawing 5 (PSM 2019).
 - e. Based on the above desktop analysis, further site specific investigations (e.g. geophysics) may be warranted.

Groundwater

Question 3: Are the assumptions and the range of scenarios applied in the groundwater modelling reasonable and is there sufficient data within the model to provide meaningful predictions, including worst-case impacts on groundwater resources?

11. Limitations of the equivalent porous medium model are discussed in response to question 2. Five predictive groundwater impact scenarios have been modelled to investigate different levels of development. The IESC considers that the scenarios applied to investigate potential impacts appear appropriate as they include a null case of no mining, historical mining only, impacts from other

proposed and approved mines in the area, currently approved Dendrobium areas combined with other proposed and approved mines, and all proposed and approved Dendrobium areas as well as other proposed and approved mines.

12. Changes to water quality do not appear to be discussed. In particular, the IESC considers that potential long-term changes to surface water quality as groundwater levels recover post-mining, as well as the mechanisms which cause water quality changes to occur, should be considered.

Surface water

Question 4: To what extent can decision makers have confidence in the predictions of potential impacts on surface water resources provided in the EIS, including in regard to potential stream flow losses, water quality, changes to stream geomorphology and impacts on upland swamps.

13. The proponent has undertaken a detailed assessment of potential surface water impacts for the EIS. The assessment has been completed to a good standard, including an iterative peer review process. Therefore, decision makers can have reasonable confidence in the impact predictions, some of which are considerable (under the 10th percentile (dry) rainfall conditions) and are discussed below in paragraphs 16 – 18. The IESC notes the following factors that can affect confidence in predicted impacts that decision makers should consider.
- a. The spatial scales relevant to the sites of high environmental value are small and are likely to be influenced by local conditions that may differ from the gauged catchments used to inform the predicted impacts.
 - b. The assessment of water quality changes has focussed on the potential for changes to occur within the reservoirs. The IESC notes that given the volume of the reservoirs, considerable dilution of mining-related changes to water quality is probable. However, mining-related water quality changes have the potential to cause localised impacts, particularly to flora and fauna within and adjacent to streams. Such impacts (e.g. from diversion of surface flows into fractures and re-emergence downstream) have been observed at other mines in the Southern Coalfield. These potential impacts and the subsequent effects on ecological components and processes (e.g. organic matter decomposition) of water resources have not been thoroughly investigated and discussed.
 - c. There is a lack of clarity in the assessment of potential cumulative impacts to surface water flows. While potential flow reductions and changes to flow regimes have been clearly identified and quantified, it remains unclear what the cumulative impacts to creeks such as Donalds Castle Creek will be given that the flow regimes of some creeks have been previously impacted by multiple longwall panels.
 - d. The subsidence predictions of potential impacts to streams and swamps predicts conventional subsidence-related movements at the longwall scale. Surface cracking and non-conventional ground movements also need to be considered.
 - e. A quantitative comparison of predicted subsidence impacts in Areas 3A and 3B with predictions for Areas 5 and 6 at swamps has not been provided. Historic performance of predicted and observed impacts as discussed in the Longwall Panel 13 End-of-Panel Report for the existing mine should also be provided to improve confidence in the current modelling (e.g. impacts to catchment yields, shallow water levels, baseflow losses, soil moisture, water quality parameters and aquatic ecology).
 - f. There is a lack of information on whether the previously observed impacts to swamps, including more rapid drying (steeper groundwater level recession curves) (HEC 2019, Figures 20 – 22, pp. 63 – 64), are worsening with time.

- g. Likely changes to stream morphology within the project area are not explicitly considered, with the exception of an analysis of the potential for increased erosion and scouring within swamps.
- h. The assessment of impacts to streams and swamps tends to consider each stream or swamp independently. However, these elements are part of a broader landscape of connected ecohydrological systems. How the changes to one component of the system may affect other components needs to be considered.

Surface water

Question 5: Are the assumptions used in the modelling reasonable and is there sufficient data within the model to provide meaningful predictions, including worst-case impacts on surface water resources?

- 14. There are several aspects to the adopted modelling approach which provide a good level of confidence in the predictions. In terms of hydroclimatology, the predictions are based on over one hundred years of historic climate data which provides a robust indication of variability. CSIRO's online Climate Futures Tool provides a reasonable basis for projecting surface water estimates under a warming climate (noting that these could be further informed by more accurate regional climate model projections (Giorgi et al. 2009)). Using groundwater modelling parameterisation provides a practical means of estimating deep drainage, though in this case little confidence can be given to the groundwater model results due to the reason discussed in response to question 2, and the assumed 50% increase in recharge above the longwall panels (HydroSimulations 2019, p. 76). The use of the VADOSE/W model to estimate vertical and lateral drainage fluxes (in combination with monitored data from Area 3) is commendable, and provides confidence in the estimated impacts on swamps.
- 15. It is stated that the parameters of the AWBM model – the key tool used to simulate streamflows from rainfall and evaporation – were based on experience with similar projects. However, no mention was made of the number or quality of the prior calibration/validation results used, nor is any comment provided on the extent to which model simulations are consistent with more locally gauged data. Accordingly, it is not possible to provide independent comment on the degree of confidence in the absolute estimates of baseline catchment runoff. However, if it is assumed that the AWBM simulations are reasonably consistent with observed streamflow conditions, then this provides a reasonable basis to assess relative differences in streamflows under the “with project” and “without project” scenarios.
- 16. The IESC notes that predicted impacts to flow regimes of higher-order stream reaches (i.e. first-, second- and some third-order reaches) are considerable in Area 5 but are generally much lower in Area 6, including:
 - a. multiple sub-catchments in Area 5 will have large increases in no-flow conditions (HEC 2019, Figures 39 – 52, pp. 91 – 100). Under median rainfall conditions, sub-catchments in Area 5 which commonly experience no-flow conditions approximately 5% of the time could cease flowing between 50-75% of the time. Under 10th percentile (dry) rainfall conditions, flow regimes in streams draining several catchments in Area 5 will change from not flowing 5-10% of the time to not flowing 100% of the time. Even under 90th percentile (wet) rainfall conditions streams draining Area 5 sub-catchments could cease to flow up to approximately 50% of the time.
- 17. The surface water assessments are focused on overall measures relevant to catchment yield (i.e. streamflow volumes indicative of water resource availability). The potential impacts of these predicted changes on ecologically important flow components in higher order streams at the project site, and in turn flora, fauna and ecological processes that depend on such flow behaviour, have not been fully considered and discussed. The predicted changes are likely to result in changes to the frequency and occurrence of seasonal low and high flow spells, pool persistence, and pool water quality, and it is unclear how these impact on ecological function and processes. This is especially important because these pools are likely to be critical refuges for aquatic biota during low-flow and no-flow periods. The

potential ecological impacts of the changed flow regime need to be further investigated as it is likely that much of the aquatic and riparian flora and fauna will be eliminated or reduced in abundance and species richness by these considerable changes.

18. The predicted changes to streamflow at swamp outlets in Area 5 range from approximately 5-28% reductions under median rainfall conditions while in Area 6 reductions will be approximately 3-8% (HEC 2019, Table 34, pp. 85 – 90). Even under the 90th percentile (wet) rainfall conditions, the impacts may result in streamflow reductions of up to 16%. The changes to streamflow and recession curves for the different swamp types are considerable under the 10th percentile (dry) rainfall condition and include:
 - a. most modelled swamps in Area 5 under 10th percentile (dry) rainfall conditions will cease to have streamflow at their outlets while swamps in Area 6 will have flows reduced by 52-86% (HEC 2019, Table 34, pp. 85 – 90). This modelling could be considered to correspond to a potential worst-case situation in that it represents very dry conditions, but it is based on a historical record in which equally dry or worse conditions have occurred for 10% of the record;
 - b. two swamp types (based approximately on swamp width) will dry out under the 10th percentile (dry) rainfall conditions “with-project” scenario, with the other two types predicted to have less than 0.25 m depth of groundwater remaining. This drying is not predicted in the “without project” scenario (HEC 2019, Figures 26 – 37, pp. 73 – 79); and
 - c. the IESC notes that the adopted approach is reliant on the estimates from the groundwater model which may not accurately reflect the enhanced losses due to surface cracking and ground movement. The predictions are subject to the concerns expressed in response to question 2.
19. The irreversible impacts of the predicted hydrologic changes on swamp biota and ecological processes are not fully discussed. A better understanding of the resilience of the swamp ecosystems i.e. their ability to recover following partial or short-term drying, is needed to assess the magnitude of impacts to swamps.
 - a. Recovery of swamps once they have been dry for an extended time is unlikely. The likely response of the aquatic biota and processes (both physical and ecological), and the possibility of hysteresis (Davis et al. 2010), under potential restoration scenarios needs to be considered.
 - b. Time-series geophysical surveys should be considered to understand the depth of drying and fracturing and to help evaluate offsets.
 - c. Given the Area 6 swamps are most likely to support the Giant Dragonfly, additional monitoring and evaluation of change and potential swamp recovery is needed in Area 6.

Surface water

Question 6: Where setbacks are proposed from surface water features (such as water reservoirs, and most third order streams), are these setbacks reasonable and likely to avoid significant impacts on these features?

20. The proponent has incorporated the following setbacks into the mine design:
 - a. no secondary extraction within 1000 m of the Avon Dam and Cordeaux Dam walls;
 - b. no mining within 300 m of the full supply levels of Avon Dam and Cordeaux Dam;
 - c. no predicted valley closure of more than 200 mm for any named watercourse (equates to an approximate setback of 400 m); and

- d. no mining within 50 m (mining on one side) or 100 m (mining on both sides) of identified waterfalls (height greater than 5 m with a pool at the step base) and pools (volume of greater than 100 m³).
21. It is noted that the above setbacks do not ameliorate the adverse impacts on the ecologically important water regime in higher order streams and upland swamps.
22. The above setbacks are stated to be based on observations and experience within the Southern Coalfield (MSEC 2019, pp. 27 – 29) and appear to be reasonable to protect reservoirs based on the provided data. The setbacks are likely to reduce the potential for impacts to the features protected by the setback, although the setbacks have not been designed to eliminate all potential for impacts (e.g. the valley closure criteria is stated to reduce the chance of impact to less than 10%). Additionally, unexpected impacts have occurred during previous mining in the area, such as non-conventional anomalous subsidence movements which are inherently unpredictable; thus, the application of setbacks or further changes to the mine design cannot ensure a zero potential of impacts to features.
23. The IESC are aware of the longstanding and ongoing debate regarding the potential for loss of stored water from water supply dams as a result of underground coal mining activities (Advisian 2016). Mining activities are subject to a range of offset conditions to reduce the potential for such impacts, though the effectiveness of such provisions are subject to some uncertainty. With the changes introduced by the recent Dam Safety Regulation 2019 it is noted that dam owners are obliged to reduce dam safety risks 'so far as reasonably practicable', and accordingly it would be expected that the potential for loss of stored water and threats to the structural integrity of the dams are being considered by the responsible agency.

Catchment impacts

Question 7: To what extent can decision makers have confidence in the predictions of potential losses to water supply volumes within the Metropolitan Special Area of Sydney's drinking water catchment, including potential reductions in flows reporting to the reservoirs as a result of impacts to streams and groundwater depressurisation of underlying strata?

24. The proponent has estimated losses from streams and reservoirs based on the outputs of both groundwater and surface water modelling. While the estimated losses are small relative to the volume of reservoir inflows under median rainfall conditions, it is likely that these losses are proportionally more significant under the 10th percentile (dry) rainfall conditions. This requires further discussion considering that most of the sub-catchments within Area 5 are predicted to cease flowing under the 10th percentile (dry) rainfall conditions (see paragraphs 16 – 18).
25. It is expected that future hydroclimatic conditions will increase the frequency of bushfire risk (Hasson et al. 2009; Lucas et al. 2007), and these can adversely impact on streamflow volumes (Zhou et al. 2015; Nolan et al. 2015) and water quality (Wilkinson et al. 2011; Heath et al. 2015) for some years after fires occur. It is noted, however, that the impacts on yields is dependent on a number of factors, and that bushfires do not necessarily reduce streamflows (Heath et al. 2014). While the prime hydroclimatic drivers influencing this threat are independent of mining activities in the region, it is reasonable to consider that any drying out of upland areas and associated possible changes in vegetation cover (as noted in the response to question 4) can be expected to exacerbate such risks. The nature of the projections associated with a warming climate represent additional threats to the volume and quality of inflows to the downstream water supply storages, and as such these can only add to, not ameliorate, any adverse impacts arising from mining operations.
26. The proponent proposes to measure the reduction in surface water flows entering the reservoirs and compensate the water supplier for these losses. The IESC notes that this will require upgrading the current monitoring network and is likely to require collection of considerable site-specific pre-impact flow data to enable accurate calculation of losses attributable to the project.

Water dependent ecosystems

Question 8: Have the impacts of the project on surface water and groundwater dependent ecosystems (i.e. stygofauna and upland swamps) been adequately described and assessed?

27. Impact predictions in terms of groundwater depressurisation, flow reduction and alterations to flow regimes have been clearly identified in the EIS. However, the effects of these changes on surface water and groundwater-dependent ecosystems have not been adequately described and fully assessed. These are described in more detail below.
28. As discussed in paragraphs 16 – 18, the potential changes to surface flows and water regimes of streams and swamps, including under median percentile rainfall conditions, are likely to be considerable and persistent. Discussion and analysis of how these changes could impact the biota and ecological processes in swamp, instream and riparian ecosystems are inadequate and further work is required as outlined in the response to question 12. This additional work should include development of ecohydrological models at both the swamp/reach and catchment scale that consider connectivity between individual swamps, stream reaches and groundwater. Additional analysis is also required of how potential localised changes to water quality resulting from the project (e.g. increases in iron concentrations and changes to dissolved oxygen from diversion of surface flows) could affect water-dependent ecosystems. Notable impacts include:
- a. reduced water availability within 26 swamps which will be directly undermined, and an additional 20 swamps that are located (partially or wholly) within 600 m of longwall panels. These swamps are likely to be impacted (see paragraph 18), which will also impact:
 - i. Giant Dragonfly habitat identified within Area 6 swamps. It is possible that several other swamps in Area 5 and Area 6 also provide foraging habitat for the Giant Dragonfly; and
 - ii. Stygofauna and their habitats within the shallow perched aquifers, though it is noted that no site-specific stygofauna studies were undertaken.
 - b. minor and localised impacts on riparian habitat are predicted but do not appear to be quantified. For example, there may be some die-back of fringing aquatic vegetation following flow diversions and drainage of pools or from strata gas emissions (Cardno 2019, p. 47). Changes to vegetation may impact the protected Broad-headed Snake (*Hoplocephalus bungaroides*), Littlejohn's Tree Frog (*Litoria littlejohni*), Giant Burrowing Frog (*Heleioporus australiacus*), Red-crowned Toadlet (*Pseudophryne australis*), Giant Dragonfly and Koala (*Phascolarctos cinereus*). The IESC also notes that species not protected are also likely to be impacted by the project.
29. Changes to swamp flow regimes may result in drying of several modelled swamp types particularly under the 10th percentile (dry) rainfall conditions. Drying of swamps will affect microbial activity and the rate of organic matter decomposition, changing the rate of peat deposition. None of these potential impacts have been clearly and adequately discussed. Further discussion of these impacts is needed to understand the potential for long-term changes to swamp ecology and catchment water quality.
30. Key Fish Habitat (types 1 and 2) has also been identified within the lower catchment areas of the project. The IESC considers that the project has the potential to impact Key Fish Habitat through flow reductions, including for protected species such as the Macquarie Perch.

Additional information

Question 9: Are there any significant impacts or risks to water resources that have not been adequately identified and/or assessed, particularly in regard to Sydney's drinking water supply, including consideration of faults or other geological structures?

31. The IESC notes that reductions to Sydney's drinking water supply is predicted to be relatively small, where yields to Lake Avon and Pheasants Nest Weir are predicted to be reduced by 0.55% and 0.39% respectively in median years. These impacts are unlikely to be of material concern even in drought years or under expected future climate projections.
32. Noting the predicted impacts to the larger area, the IESC considers that the primary impacts from the proposed project will be to water-dependent ecosystems on-site (see paragraph 27).
33. Consideration of geological structures and faults is discussed in paragraph 10 and potential loss to surface water catchments is provided in the response to Question 7.

Additional information

Question 10: Given that there will always be some uncertainty in modelling predictions, what further modelling, sensitivity analysis or data (if any) should be considered prior to a planning decision on the project to improve confidence in the predictions and ensure any significant impacts or risks to water resources are considered by decision makers?

34. The IESC notes that the current mine plan will have irreversible impacts to water resources (swamps and higher order streams of important environmental value), which are unlikely to be remediated through mitigation measures (refer to response to questions 11 and 12). Further modelling is unlikely to significantly change these predictions, but could be used to assess the benefits of a revised mine plan.
35. The IESC notes that the landscape scale subsidence modelling was completed to a high standard and used numerical subsidence modelling as a check on predictions obtained from the empirical approach. However, the IESC notes that there are concerns for the non-conventional subsidence and localised ground movement. Further use could have been made of the numerical model to examine a range of potential impact scenarios. This would have assisted in gaining an insight to potential worst-case scenarios which would be helpful in the project environment given some previous occurrences of unexpected impacts and the likelihood of unpredictable non-conventional anomalous movements.
36. Potential impacts from surface cracking and near-surface fracturing may be underestimated due to the use of a continuum model and water movement via tortuous flow paths (see response to question 2). Areas of concern to improve confidence in the groundwater impact assessment and associated modelling are discussed in paragraph 8. In addition, the IESC notes that there is a lack of baseline data which is required to evaluate the risks to receptors, where the IESC agrees with the proponent's commitments to:
 - a. further review the monitoring network, including consideration of the Independent Expert Panel for Mining in the Catchment (2018) recommendations regarding the period of baseline data required (e.g. the installation of additional monitoring sites in Area 5 and Area 6 to facilitate the recording of sufficient baseline data); and
 - b. undertake additional packer and permeability testing and pore pressure analysis for hydraulic properties of the Hawkesbury Sandstone, Bald Hill Claystone and upper Bulgo Sandstone. The IESC considers that this should be undertaken pre and post mining and notes that other testing methods could complement and extend traditional methods (e.g. see McMillan et al. 2019).
37. Groundwater triggers do not appear to be proposed. TARPs need to be developed to protect water-dependent ecosystems under any revised mine plan (see response to question 12).

Mitigation, monitoring and management

Question 11: Are there any changes to the mine location, design and layout that should be considered to reduce significant impacts to water resources, including longwall width, height of extraction and setbacks?

38. In the subsidence assessment, two potential mine layout options were shown (MSEC 2019, pp. 29 – 34). One represented a minimum case which included a swamp setback (MSEC 2019, Figure 3.17, p. 30) which would not directly undermine 26 swamps. The minimum option would decrease the magnitude of predicted vertical subsidence and valley closure (which can cause fracturing of the swamp base) at swamps, and would decrease the direct impacts on predicted vertical subsidence and valley closure at swamps. This option was not discussed in detail and there was no explicit explanation of potential reductions in impacts at swamps or why the option was not considered further.
- a. Further information on the ‘minimum scenario’ should be provided so that the scenario, or a variant of the scenario, can be considered to reduce the predicted considerable impacts to swamps and streams. Parameters that should be considered in the analysis include setbacks from swamps, or variations to longwall width (or other aspects of mine design and geometry) to reduce potential impacts of undermining.

Mitigation, monitoring and management

Question 12: Are there any additional mitigation, monitoring and management or offsetting measures that should be considered by decision makers to address the residual impacts of the project on water resources in conditions of consent, particularly any conditions to inform adaptive management to address areas of scientific uncertainty.

Adaptive management

39. Noting the predicted irreversible impacts from the proposed project as identified in the key impacts section of this advice, the ‘minimum case’ mine plan (MSEC 2019, Figure 3.17, p. 30) could be adopted as a first step in the long-term risk-based management plan, before proceeding with full scale operations. As part of expansion operations, adaptive management should utilise site-specific and regional baseline data to avoid impacts to important environmental assets by making innovative changes to the mine plan. Expansion operations should be based on site-specific triggers and consider alternative mining methods.
40. Proposed monitoring and management plans were not discussed in detail in the EIS. Recommendations on the contents of these plans were included in several of the specialist impact reports. These recommendations should be incorporated during development/updating of the monitoring and management plans. Prior to the project commencing, the plans should be provided to the regulators for review to ensure that proposed monitoring and management strategies will be suitable and that there is adequate scope for monitoring and mitigation activities to be refined as more data becomes available.
41. The IESC notes that for streams and swamps, proposed management and remediation measures are focused on the use of various types of grouting or installation of structures such as coir logs to promote ponding and water dispersion. Noting CoA (2014 and 2015), further evidence, including independent peer review, needs to be provided to show that these techniques have been successful in similar stream and swamp environments, preferably from the same region. The data needs to illustrate both a short-term improvement and a sustained longer term recovery (including durability/effectiveness of remediation materials), and could include:
- a. use of water level behaviour at control sites to show recovery of water levels and the ability to maintain saturated conditions in the swamp under suitable rainfall conditions. This includes an improvement in recession curves following remediation;
- b. soil moisture data to show the recovery and maintenance of soil moisture over extended periods and a reduction in rates of drying;

- c. use of monitoring at control sites to assess whether changes in swamp outflow data or streamflows are showing a recovery in surface water flows for given climatic conditions;
 - d. ecological survey results showing a recovery in swamp or riparian ecological characteristics such as species composition, species persistence, and maintenance of natural rates of crucial ecosystem processes such as organic matter decomposition and nutrient cycling; and
 - e. time-series geophysical surveys of the swamps and environmental water tracer studies to understand water loss dynamics below the swamp and changes to these following remediation to determine if future recovery is possible.
42. Potential adaptive management measures have not been considered in detail in the EIS. If adaptive management is proposed, which the IESC recommends, then the management plans and associated TARPs need to be clearly articulated and provided to the regulator as part of the management program, as outlined in paragraph 39 above. TARPs would be most useful if they utilised conceptual models and site-specific data; defining trigger values for groundwater, surface water and subsidence plus ecological observations in swamp, riparian and aquatic environments.
- a. The IESC notes that trigger timeframes proposed for the existing mine may not be adequate to implement mitigation measures to protect water-dependent ecosystems in the long term. For example, ecosystem functionality and species composition/distribution triggers are generally based on different levels that relate to a specified decline in an attribute between 2 – 4 years (South 32 2018, App. A, p. 77 – 91). Further justification of how species have responded to mitigation measures is required to increase confidence in the management strategies.
 - b. Adaptive management options and TARPs should also be developed for swamps and head water streams which are not to be directly undermined but which are located close enough to a panel that impacts may occur (e.g. within 400 – 600 m). This, when combined with monitoring, would potentially allow unexpected impacts to be detected early, mitigated, and possibly allowing a reduction in the final level of impact.
43. As outlined in paragraph 24 above, the flow gauging network will need to be upgraded to enable more accurate monitoring of flow losses and changes to flow regimes. This will also be important for the development and implementation of TARPs based on flow changes.
44. Water quality data from streams unaffected by mining at the project site show exceedances of the ANZG (2018) guideline values for a number of analytes. The IESC suggests that site-specific guideline values should be developed for analytes where exceedances are known to occur as suggested by ANZG (2018) and Huynh and Hobbs (2019). These guideline values should be based on data that is not affected by mining; thus, sampling to enable this needs to occur prior to any potential mining impact.
45. The project is predicted to have a considerable water surplus, with the proponent considering options for beneficial reuse within the Illawarra Region. Beneficial reuse options could help reduce the demand for water on the water provider, potentially reducing the impact of flow losses and thus should be encouraged where suitable.

Offsets

46. Direct water licence offsets are proposed for groundwater impacts. The proponent states that they hold sufficient licences to account for peak predicted take within the Nepean Sandstone Management (Zone 2) water source, and has committed to obtain sufficient licences for the project in consultation with DI Water (South 32 2019, Att. 8, p. 8-6; South 32 2019, Att. 7, p. 7-7). The IESC notes that:

- a. it is not clearly stated if these entitlements are also used as part of the existing approved mining areas; and
 - b. not all licences currently obtained by the proponent are within the appropriate aquifers.
47. The proponent is proposing to offset losses to reservoirs via monetary measures. The IESC considers that additional monitoring is required to accurately calculate these losses as discussed previously in paragraph 24.
48. The IESC also notes that potential subsidence-related impacts to swamps are proposed by the proponent to be offset consistent with government policies. The IESC considers that further clarification is required, as many swamps contain endemic species and the impacts relate to an extensive area that is greater than the sum of its individual assets. Clarification is required on which swamps are proposed to be offset, and how their attributes compare to swamps that are likely to be impacted.

Date of advice	14 October 2019
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Source documentation provided to the IESC for the formulation of this advice	<p>AXYS Consulting 2019. <i>Illawarra Coal Holdings Pty Ltd. Dendrobium Mine. Plan for the Future: Coal for Steelmaking. Risk Assessment Report</i>. Report prepared for South 32. Appendix M of EIS.</p> <p>Cardno 2019. <i>Dendrobium Mine – Plan for the Future: Coal for Steelmaking. Aquatic Ecology Assessment</i>. Report prepared for South 32. Appendix E of EIS.</p> <p>HEC (Hydro Engineering and Consulting Pty Ltd) 2019. <i>Dendrobium Mine. Plan for the future. Surface Water Assessment</i>. Report prepared for South 32. Appendix C of EIS.</p> <p>HydroSimulations 2019. <i>Dendrobium Mine – Plan for the future: Coal for steelmaking. Groundwater Assessment</i>. Report prepared for South 32. Appendix B of EIS.</p> <p>MSEC 2019. <i>Illawarra Coal: Dendrobium Mine – Plan for the future: Coal for steelmaking. Subsidence predictions and impact assessments for the natural and built features in support of the environmental impact statement application</i>. Report prepared for South 32. Appendix A of EIS.</p> <p>Niche Environment and Heritage 2019. <i>Dendrobium Mine – Plan for the future: Coal for Steelmaking. Biodiversity Assessment Report</i>. Report prepared for South 32. Appendix D of EIS.</p> <p>PSM Consult Pty Ltd 2019. <i>Dendrobium Mine. Plan for the Future: Coal for Steelmaking. Geological structures review</i>. Report prepared for South 32. Appendix P of EIS.</p> <p>South 32 2019. <i>Dendrobium Mine – Plan for the future: Coal for steelmaking – Environmental impact statement</i>.</p>
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