

Advice to decision maker on coal mining

IESC 2015-068: Further advice on impacts to swamps

Requesting agency	The Australian Government Department of the Environment and The New South Wales Department of Planning and Environment
Date of request	2 June 2015
Date request accepted	3 June 2015

Context

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC) was requested by the Australian Government Department of the Environment and the New South Wales Department of Planning and Environment to provide further advice on swamps in the context of underground mining in the Western and Southern Coalfields of New South Wales.

This advice draws upon aspects of information in the documentation provided as part of the request, together with the expert deliberations of the IESC. The documentation and information accessed by the IESC are listed in the source documentation at the end of this advice.

The ecological communities, Temperate Highland Peat Swamps on Sandstone (THPSS) and Coastal Upland Swamps in the Sydney Basin Bioregion listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), occur in the eastern part of the Sydney bioregion. THPSS occur in the Blue Mountains, Newnes Plateau and the Southern Highlands of New South Wales (with one additional swamp located at Jacksons Bog on the NSW-Victorian border). Coastal upland swamps occur in the Pittwater and Sydney Cataract areas, especially on the Woronora Plateau. These two communities are referred to hereafter as *listed swamps*. Mining in this region – the Sydney Basin – is ongoing and dates back to the 19th century. Historically, mining in this area used predominately bord and pillar methods. Now, the areas where mining and these listed swamps both occur are predominately mined through longwall mining methods.

The IESC has previously given advice on a number of coal mining projects where longwall mining has been proposed in areas where listed swamps occur. Specifically, the IESC has provided advice in relation to the Russell Vale (IESC 2014-057, 2014-058, 2015-065), Springvale (IESC 2015-054) and Angus Place (IESC 2015-053) mines.

Advice

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

There are significant gaps in knowledge of and an absence of baseline data on the interrelationships between local swamp geology, hydrology and ecology. The IESC considers that it is therefore not possible to confidently evaluate what the impact of mining subsidence will be on a given swamp. This uncertainty, combined with the lack of evidence for successful swamp remediation, leads to significantly high and potentially unmitigated risks to these swamps as a result of mining.

Question 1: What does the IESC consider are the key elements of a monitoring programme to detect any potential mining-induced impacts to swamps and dependent species? In particular:

a. What spatial and temporal coverage would the IESC consider to be appropriate for ecological, hydrological and geotechnical measures?

b. Can the IESC recommend any specific thresholds or trigger values for these measures?

Response – question 1a

1. The IESC considers that all swamps that may be affected by longwall mining should be monitored for ecological, hydrological and geotechnical parameters. The IESC considers that hydrological monitoring provides the most useful means for determining impacts within a timeframe suitable for regulatory and operational decision-making, because changes in hydrology can be relatively quick (generally in weeks/months; e.g. Ecoengineers (2014) and Krogh (2015)).
2. Hydrological monitoring must be complemented by ecological and geotechnical monitoring. Suitable measures, spatial and temporal coverage, and specific thresholds are described below. For both hydrological and ecological monitoring, the IESC considers that at least two years of baseline data should be obtained at both control and potentially impacted sites. The appropriate frequency of sampling a particular parameter will depend on its natural temporal variability and information content (e.g. sensitivity as early warning of potential impacts).
3. Proponents should clearly articulate monitoring objectives, specifying how potential hydrological and ecological responses will be detected by the monitoring programme. Ecological and geotechnical measurement will ensure that, over time, a better understanding is developed of the long-term relationship between ecology, hydrology and mining-induced change.
4. The IESC considers that at least three control swamps should be matched with each potentially impacted swamp, in line with the recommendations of Brownstein et al. (2014). Individual sites may serve as controls for multiple potentially impacted swamps. To reduce baseline variance between control and impact locations, control sites need to be as similar as practicable to the impact sites in terms of vegetation, geomorphology and hydrology (Brownstein et al., 2014, Commonwealth of Australia, 2014a, Downes et al., 2002) and size (Brownstein et al., 2015). The same type and duration of monitoring should be undertaken at both control and potentially impacted sites.
5. The use of control sites to understand natural variability should be complemented by mine-site specific rainfall and evaporation data to provide meteorological context for interpreting swamp hydrology.
6. To enable regulators and proponents to use the best data for management of listed swamps, all monitoring data should be required to be made promptly available to regulators. For example, weekly data updates while the swamp is being undermined should be considered. Data should be plotted progressively at both control and impact locations to show trends as they occur.

Response – question 1b

7. No. The IESC cannot recommend specific thresholds or trigger values. There are critical knowledge gaps in understanding of the relationship between mining subsidence, geology, hydrology and ecological response, which makes it difficult to determine suitable trigger values or thresholds. Trigger values should be developed based on an understanding of site specific natural variation informed by baseline monitoring and use of control sites.

Explanation

Hydrology

8. The use of hydrological measurements as the primary means of determining the presence of an impact to swamps is in line with the NSW offsets policy, under which ecological impacts to swamps are assumed to have occurred if shallow groundwater is affected (NSW Government, 2015). While direct monitoring of the ecology of listed swamps is valuable, the time-frame for detecting ecological responses to a mining-induced change in environment may be too long to inform effective responses by the regulator and proponent. However, changes in hydrology can be relatively quick, occurring within weeks/months (e.g. Ecoengineers (2014), (Krogh, 2015)).
9. Monitoring of shallow groundwater levels in swamps is likely to be the most important measure for determining potential impact to their hydrology. Other key indicators of impacts are soil moisture and, where the regional water table intersects a swamp, fluctuations in the regional water table and in surface water levels.
10. The IESC considers that each swamp that is potentially subject to impact and each control swamp should have installed, as a minimum:
 - a. a transect of piezometers (at least three; more would be appropriate in large swamps) installed along a line from the highest area of the swamp to the swamp outflow point
 - b. a second transect perpendicular to the first, located in the area where hydrological impact is most likely, such as directly above a longwall panel
 - c. a piezometer installed at the deepest point in the swamp's sediments and any other significant deep points to better understand potential mine-induced drainage ((Benson and Baird (2012) describe a method for measuring swamp sediment depth), and
 - d. the piezometers within the swamp should not be placed such that they are all overlying pillars between longwalls.
11. This configuration of at least two transects results in a minimum of five piezometers per swamp, with two transects of three piezometers each and one piezometer being part of both transects. The impacts on swamps from installation are likely to be low, since both piezometers and soil moisture measurement points in swamp sediments may be installed with hand augers. In some circumstances this approach may need to be varied, such as for hanging swamps where piezometer installation may present particular challenges.
12. The IESC considers that in addition to swamp control sites, piezometers within potentially impacted swamps should be paired with piezometers in control swamps to facilitate hydrograph comparison. This pairing would be done on the basis of hydrograph characteristics (e.g. similar recession curves following rainfall) and position within the swamp, such as location at the edge of the swamp.

13. The IESC considers that the following may be useful for identifying impacts to swamps after mining commences:
 - a. any instance where groundwater levels fall below that observed during the baseline monitoring period, unless the control site showed a similar decline in water levels
 - b. if a groundwater recession curve of water level following rainfall were to become steeper, compared with the baseline monitoring period, unless the control site showed a similar change, or
 - c. if a double mass plot of hydraulic head in impacted piezometers against control piezometers identifies a change in the relationship between the impact and control piezometers during and/or following mining.

Once baseline data are available, suitable thresholds may be developed in light of observed natural variability.

14. The regional water table in the vicinity of swamps should also be monitored. Except for hanging swamps, piezometers should be placed up-gradient and down-gradient from the swamp. For hanging swamps, the piezometers would be placed up-gradient from the swamp and screened in the hydrostratigraphic layer(s) that feed the swamp.

Outflow

15. Many listed swamps have a defined outflow watercourse. If water is lost from swamps due to mining, there is likely to be reduction in outflow at the base of swamps. This outflow, and any defined inflow watercourse, should be monitored for at least two years prior to mining and continue to be monitored post-mining until any changes have stabilised. Water flows should be monitored continuously with a data logger, ideally through installation of a V-notch weir. Where a weir cannot be installed, other options should be considered including developing a rating curve at an appropriate downstream location under a range of flow conditions, and revising it over time to reflect any changes to stream morphology.

Soil Moisture

16. Soil moisture in swamps has been found to decline following undermining (Krogh, 2015). It has been suggested that the reduction in soil moisture following mining may correlate with ecological change (Commonwealth of Australia, 2014a), though the characteristics of changes in soil moisture resulting from subsidence related impacts is still poorly understood. Soil moisture may be measured readily with probes and a datalogger and where changes exceed natural variability, may provide a useful indicator for further investigation. To characterise spatial variability in soil moisture, a monitoring point could be placed at each piezometer site within each monitored swamp with probes, linked to a datalogger, placed at the surface and at 20 cm intervals below the surface (as per Krogh, 2015). Indicators for further investigation may include:
 - a. the vertical profile of soil moisture changing, unless a similar change is observed in control sites
 - b. the rate of drying following rainfall increasing, compared with the baseline monitoring period, unless the control sites show a similar increase, or
 - c. as for potentiometric head, a double-mass plot, comparing impacted to control locations, shows a deviation in the relationship between the impact and control piezometers during and/or following mining.

Chemistry

17. Presently, there are few datasets available on chemistry in Australian listed swamps. Given the lack of existing data on swamp chemistry and of the relationship between changes to chemistry and subsequent ecological impacts, the IESC considers that swamp chemistry measurements could be used as indicators prompting closer investigation, but that more research and understanding of swamp chemistry and its variability and sensitivity to mine induced impacts is needed in order to inform regulators.
18. Measurement of some basic chemical parameters in piezometers and at swamp outflow points before, during and after mining may reveal impacts not observed through other hydrological monitoring. Parameters could include:
 - a. EC
 - b. pH
 - c. alkalinity
 - d. dissolved oxygen
 - e. redox potential (E_h)
 - f. filterable iron
 - g. filterable manganese

Ecology

19. The IESC considers that detailed annual swamp flora surveys should be undertaken using fixed transects across a hydrological gradient, consistent with the approach recommended by Brownstein et al. (2014). This approach requires random positioning of one transect per 200 m of swamp length, with 1 m² plots placed at set intervals along each transect, and annual monitoring. Spacing of transects and plots should be adapted to the specific site, based on the degree of heterogeneity (especially for small swamps). Monitoring intensity must be sufficient to robustly compare the control and potentially impacted sites. Within each plot, data should be collected on the percentage of canopy cover of shrub and understory species, the extent of live green vegetation cover and extent of non-vegetated area. The approach also incorporates fixed photographic points.
20. Field sampling methods, especially within listed swamps, should seek to minimise the physical impact of access and sampling. Remote sensing methods should be used where feasible, as they readily provide data over a broad area without site disturbance (e.g. Brownstein et al., 2014).
21. Brownstein et al. (2014) proposes monitoring changes in the distribution of water-plant functional groups and changes in vegetation structure and condition as indicators of vegetation responses to mining. This approach is consistent with research conducted by Johns et al. (2015) which identified that species variability in wetlands can make it difficult to identify differences based on hydrology that are applicable across all monitoring sites, especially for wetlands distributed over large geographical areas. Research showed that differences in relative frequencies of water-plant functional groups may be more consistent indicators of differences in hydrology and therefore applicable across a wider range of locations and wetland ecotypes than differences in vegetation growth forms.
22. On-site monitoring could be supplemented with seasonal (i.e. three-monthly) remote sensing, including seasonal aerial surveys as well as ground surveys to assess the extent of canopy

community composition and condition across the survey area. Unmanned aerial vehicle (UAV) platforms may be a viable alternative to traditional remote sensing approaches. Spatial resolution of 0.15 m or less is required for remote sensing (Brownstein et al., 2015). Fletcher and Erskine (2014) found that small UAV platforms are an effective and cost-efficient monitoring tool for capturing and analysing plant condition and presence at the individual shrub level in listed swamps, particularly where the required monitoring area is less than 100 ha.

23. Ground-truthing surveys could be undertaken to validate the aerial imagery (Commonwealth of Australia, 2014a) and collect additional information on the percentage of live vegetation, percentage of non-vegetated area and the percentage cover of exotic plant species. Brownstein et al. (2014) recommend using a minimum of five plots assigned to each community. These plots should be randomly located before entering the field site. The minimum distance between plots should not exceed 100 m and all plots should be at least 3 m within the swamp boundary.
24. Flora monitoring could be supplemented with frog and reptile monitoring. Both groups contain species that may be particularly vulnerable to changes in hydrology. For example, the Blue Mountains Water Skink (*Eulamprus leuraensis*) has been identified as a potential indicator of moisture availability in swamps (Commonwealth of Australia, 2014a). Monitoring would need to be undertaken in accordance with accepted protocols, such as Australian state government guidelines.

Geotechnical

25. As discussed below in response to Question 2, the IESC considers that there is a significant risk to listed swamps whenever the geotechnical thresholds outlined by the NSW Planning Assessment Commission (2010) are exceeded. These thresholds should be considered in mine planning and approval. For determining whether impacts to listed swamps have occurred, hydrological monitoring, as described above in paragraphs 8–15, is a more direct measurement of impacts that could affect ecology. Geotechnical measurement should be undertaken on a near real-time basis to enable rapid verification of predictions and clarify relationships between the magnitude of subsidence, hydrological and hydrogeological impact and ecological impact.

Question 2: Can the IESC recommend features of an appropriate longwall mine design to reduce the risk to swamps as a result of undermining? Features may include subcritical panel design and chain pillar width, for example.

Response

26. The IESC does not have sufficient expertise in mine engineering to assess specific designs or associated geotechnical risk and therefore has only made comments of a general nature in relation to the position of longwall panels away from overlying swamps. The most effective measure to reduce the risks to swamps would be to entirely avoid undermining swamps, either by adjusting the placement of longwalls or by reducing their length. Where swamps are undermined, the IESC considers that the only known effective way of reducing the risk to swamps, especially through cracking the bedrock beneath the swamps, is to ensure the magnitude of subsidence remains below thresholds described by the NSW Planning Assessment Commission (2010), including 0.5 mm/m tensile and 2 mm/m compressive strain.
27. Effective mitigation measures would be any measures that would maintain the magnitude of subsidence below the above thresholds. Several design options can reduce the magnitude of subsidence. Reductions in longwall panel width and increases in pillar width, for example, would reduce the expected magnitude of subsidence (Commonwealth of Australia, in press). Whatever design options are used, the primary objective should be to maintain the magnitude of

subsidence-related impacts below the above-listed thresholds to protect listed swamps, especially from surface cracking.

Explanation

28. The capacity for surface cracking to occur when thresholds outlined by the PAC are exceeded is supported by other literature. A report prepared on behalf of Centennial Coal states that “Fracturing of the uppermost bedrock has been observed in the past, as a result of longwall mining, where tensile strains have been greater than 0.5 mm/m or where compressive strains have been greater than 2 mm/m” (Mine Subsidence Engineering Consultants, 2014). Similarly, subsidence predictions for a BHP longwall mine in the Dendrobium area notes that, “[t]he fracturing of sandstone due to conventional subsidence movements has generally not been observed in the Southern Coalfield where the conventional tensile and compressive strains are less than 0.5 mm/m and 2 mm/m, respectively” (Mine Subsidence Engineering Consultants, 2012).
29. The IESC notes that different swamps may react differently to the same strains caused by subsidence. Firstly, the geological environment may be more or less vulnerable to impacts. Areas containing lineaments may experience greater than normal subsidence – this should be taken into account in subsidence predictions (e.g. NSW Department of Planning and Environment, 2015). Also, the strength of rock and thus its capacity to resist fracturing and cracking is likely to vary. As such, swamps may react differently to similar magnitudes of subsidence, dependent on site specific geological conditions. Swamps that are connected to a regional water table may be less vulnerable to hydrological and ecological impacts from subsidence-related surface cracking than those that depend on a perched water table, since impacts to the standing water level may not be permanent. Regional water tables often recover following longwall mining, although the timeframe varies from months to years (Commonwealth of Australia, 2014c).
30. If, in mining a longwall panel, hydrological impacts are detected, management protocols should ensure greater avoidance of impacts to swamps would be required for future longwall panels. This approach requires rapid assessment reporting protocols to be in place prior to mining, and for these processes to be clearly linked to agreed triggers/limits and associated management actions (including consideration of modification of mine design, e.g. reducing width for future longwall panels). The IESC notes that a similar management approach has been proposed by the NSW Planning Assessment Commission (NSW Planning Assessment Commission, 2015). Measures to achieve greater avoidance of impacts could include avoidance of swamps or (further) narrowing of longwall panels. Over time, monitoring data gathered in line with the above recommendations would help to derive region-specific relationships between predicted and actual subsidence, hydrological impacts on different types of swamp communities and ecological responses. In addition, the IESC considers that if the magnitude of subsidence is substantially more than predicted, the subsidence model should be investigated and amended before further mining is undertaken.

Question 3: Does the preliminary information described in the Rehabilitation Progress Report increase the IESC’s confidence in the effectiveness of remediation measures for mining related impacts on the swamps and dependent species? If not, can the IESC recommend what additional information should be provided to demonstrate the effectiveness and appropriateness of remediation measures?

Response

31. No. The preliminary information described in the Rehabilitation Progress Report does not increase confidence in the effectiveness of swamp remediation measures. The Rehabilitation Progress Report provides a pictorial report of remediation works undertaken at the East Wolgan Swamp. Remediation works are ongoing, and as such there is no suitable empirical evidence

presented in the Rehabilitation Progress Report that East Wolgan has or will be returned to its pre-impact condition. The IESC has very low confidence in the potential for successful long-term remediation of swamps impacted by subsidence and cracking and/or fracturing.

32. Information required to demonstrate the effectiveness and appropriateness of proposed remediation measures should include:
- a. previous projects, case studies or scientific literature that support the adequacy of each proposed measure in the project context and are based on reliable data.
 - b. for cracking and/or fracturing related impacts, evidence of:
 - i. site investigation techniques that can identify cracks and/or fractures in swamp bedrock, prior to significant damage to swamp substrates or vegetation. Investigative techniques should minimise disturbance to the site to the extent practicable whilst being sufficient to identify all major cracks and/or fractures/fracture networks.
 - ii. the effectiveness and suitability of remedial grouting, or other cracking and/or fracturing related remediation techniques (noting the major obstacles outlined in paragraph 33), including case studies that demonstrate the long-term successful performance of such measures.
 - c. a pre- and post-remediation monitoring programme suitable to assess the performance of mitigation measures, clearly showing hydrological and ecological conditions have been returned to pre-mining status.

Explanation

33. There are two major obstacles to grouting cracks and/or fractures beneath swamps:
- a. Firstly, it is difficult to identify cracks and/or fractures beneath swamps prior to obvious damage of peat substrates and vegetation. Low-impact site investigation using surface geophysical techniques has been proposed (Alpha Geoscience, 2011), but it is unclear whether these techniques are suitable in swamp contexts.
 - b. Secondly, gaining access to undertake remediation works is often difficult. This restricts vertical grouting, compounded by the likelihood of significant impacts to swamp ecology from drill rigs. Options for horizontal drilling and grout injection are not known to have been trialled for listed swamps (Commonwealth of Australia, 2014b); however, deep angled drilling has been used in remediating cracked stream beds of the Georges River (BHP Billiton, 2006).

Date of advice	24 July 2015
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Source documentation available to the IESC in the formulation of this advice	<p>BROWNSTEIN, G., JOHNS, C., MICK, R., FLETCHER, A. & ERSKINE, P. 2014. Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps. University of Queensland.</p> <p>CENTENNIAL COAL 2013. Temperate Highland Peat Swamps on Sandstone Monitoring and Management Plan for LW's 415 - 417: Springvale Mine. Centennial Coal.</p> <p>CENTENNIAL COAL 2014a. Response to Submissions - Springvale Mine</p>
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extension project - State Significant Development 5594 - Appendix 13 - Response to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report: Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques. Centennial Coal.

CENTENNIAL COAL 2014b. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 14 - Response to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report: Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques.

CENTENNIAL COAL 2014c. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 15 - Response to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report: Temperate Highland Peat Swamps on Sandstone: Longwall Mining Engineering Design – Subsidence Predictions, Buffer Distances and Mine Design Options.

CENTENNIAL COAL 2015. Temperate Highland Peat Swamps on Sandstone Monitoring and Management Plan LW 415 to 417 Annual Report Springvale Mine. Centennial Coal.

COMMONWEALTH OF AUSTRALIA 2014a. Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques. Canberra: Knowledge report, prepared by Jacobs SKM for the Department of the Environment.

COMMONWEALTH OF AUSTRALIA 2014b. Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques, Knowledge report. Canberra: Knowledge report, prepared by Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales for the Department of the Environment.

COMMONWEALTH OF AUSTRALIA 2014c. Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design-subsidence prediction, buffer distances and design options. Canberra: Knowledge report, prepared by Coffey Geotechnics for the Department of the Environment.

HYDROSIMULATIONS 2014. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 17 - Springvale and Angus Place Height of Fracturing Estimation.

MCHUGH, E. A. 2014. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 18 - The Geology of the Shrub Swamps within Angus Place, Springvale and the Springvale Mine Extension Project Areas.

RPS 2014. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 16 - Detailed Response to IESC Advice Water Issues.

SPRINGVALE COAL 2014. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Main Report. Centennial Coal.

THE BUSH DOCTOR (NSW) 2015. Work Progress Report: East Wolgan Swamp - Springvale Colliery: the rehabilitation of East Wolgan Swamp - northern soil pipe collapse. The Bush Doctor (NSW).

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

ALPHA GEOSCIENCE 2011. Ground penetrating radar and resistivity investigation of East Wolgan Swamp on the Newnes Plateau, North north East of Lithgow, NSW. Prepared for Centennial Coal.

BENSON, D. & BAIRD, I. R. C. 2012. Vegetation, fauna and groundwater interrelations in low nutrient temperate montane peat swamps in the upper Blue Mountains, New South Wales. *Cunninghamia*, 12, 267-307.

BHP BILLITON 2006. Georges River Report: Assessment of Georges River Remediation - Longwalls 5A 1-4.

BLUE MOUNTAINS CITY COUNCIL. 2010. *Soft engineering solutions for swamp remediation - A "how to" guide* [Online]. Available: <http://www.bmcc.nsw.gov.au/sustainableliving/environmentalinformatio n/livingcatchments/swampremediation>.

BROWNSTEIN, G., BLICK, R., JOHNS, C., BRICHER, P., FLETCHER, A. & ERSKINE, P. D. 2015. Optimising a Sampling Design for Endangered Wetland Plant Communities: Another Call for Adaptive Management in Monitoring. *Wetlands*, 35, 105-113.

BROWNSTEIN, G., JOHNS, C., MICK, R., FLETCHER, A. & ERSKINE, P. 2014. Flora monitoring methods for Newnes Plateau Shrub Swamps and Hanging Swamps. University of Queensland.

CENTENNIAL COAL 2014. Response to Submissions - Springvale Mine extension project - State Significant Development 5594 - Appendix 14 - Response to the Independent Expert Scientific Committee on Coal Seam Gas and Coal Mining Knowledge Report: Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques.

COMMONWEALTH OF AUSTRALIA 2014a. Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques. Canberra: Knowledge report, prepared by Jacobs SKM for the Department of the Environment.

COMMONWEALTH OF AUSTRALIA 2014b. Temperate Highland Peat Swamps on Sandstone: evaluation of mitigation and remediation techniques, Knowledge report. Canberra: Knowledge report, prepared by Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales for the Department of the Environment.

COMMONWEALTH OF AUSTRALIA 2014c. Temperate Highland Peat Swamps on Sandstone: longwall mining engineering design- subsidence prediction, buffer distances and design options. Canberra: Knowledge report, prepared by Coffey Geotechnics for the Department of the Environment.

COMMONWEALTH OF AUSTRALIA in press. Monitoring and management of subsidence induced by longwall coal mining activity. Canberra: prepared by Jacobs Group (Australia) with input from Mine Engineering Subsidence Consultants and Strata Control Technology for the Department of the Environment.

DOWNES, B. J., BARMUTA, L. A., FAIRWEATHER, P. G., FAITH, D. P., KEOGH, M. J., LAKE, P. S., MAPSTONE, B. & QUINN, G. 2002. *Monitoring Ecological Impacts: concepts and practices in flowing*

waters, Cambridge, Cambridge University Press.

ECOENGINEERS 2014. End of Panel Surface and Shallow Groundwater Impacts Assessment - Dendrobium Area 3B Longwall 9. Report for BHP Billiton Illawarra Coal.

FLETCHER, A. & ERSKINE, P. 2014. Monitoring surface condition of upland swamp subject to mining subsidence with very high-resolution imagery. Centre for Mined Land Rehabilitation.

JOHNS, C. V., BROWNSTEIN, G., FLETCHER, A., BLICK, R. A. J. & ERSKINE, P. D. 2015. Detecting the effects of water regime on wetland plant communities: Which plant indicator groups perform best? *Aquatic Botany*, 123, 54-63.

KROGH, M. 2015. Environmental Trust Grant 2011/RD/0028: Hydrology of Upland Swamps on the Woronora Plateau. Final report ed.: Science Division, NSW Office of Environment and Heritage.

MINE SUBSIDENCE ENGINEERING CONSULTANTS 2012. Report: Subsidence predictions and impact assessments - BHP Billiton Illawarra Coal: Dendrobium Area 3B - Longwalls 9 to 18. Report produced to support the SMP Application for submission to the Department of Trade and Investment Regional Infrastructure and Services,.

MINE SUBSIDENCE ENGINEERING CONSULTANTS 2014. Report: Subsidence predictions and impact assessments for Centennial Coal: Angus Place Colliery Development Continuity Modification. Report to support the Section 75W Modification for the Development of First Workings for the proposed Longwalls 1001 and 1003 for submission to the Department of Planning and Infrastructure.

NSW DEPARTMENT OF PLANNING AND ENVIRONMENT 2015. Preliminary Assessment Report: Springvale Mine Extension Project (SSD 5594). New South Wales Government.

NSW GOVERNMENT 2015. Policy Framework for Biodiversity Offsets for Upland Swamps and Associated Threatened Species Impacted by Longwall Mine Subsidence. New South Wales Government.

NSW PLANNING ASSESSMENT COMMISSION 2010. The PAC Review of the Bulli Seam Operations Project. Sydney.

NSW PLANNING ASSESSMENT COMMISSION 2015. Springvale Mine Extension Project: Review Report. Sydney: NSW Planning Assessment Commission.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY. 2011. *Resistivity Methods* [Online]. United States Environmental Protection Agency. Available:
http://www.epa.gov/esd/cmb/GeophysicsWebsite/pages/reference/methods/Surface_Geophysical_Methods/Electrical_Methods/Resistivity_Methods.htm.