

GUJARAT NRE NO.1 COLLIERY MAJOR EXPANSION PART 3A APPLICATION GROUNDWATER ANALYSIS

NSW Department of Planning and Infrastructure

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19 June 2013

NSW Department of Planning and Infrastructure Mining and Industry Projects GPO Box 39 Sydney NSW 2001

Attention: Howard Reed

Dear Howard

RE: Gujarat NRE No.1 Colliery Major Expansion

Part 3A Application Groundwater Analysis

Coffey Projects Pty Ltd (Coffey) is pleased to provide the NSW Department of Planning and Infrastructure with our report on Groundwater Analysis for the Gujarat NRE No.1 Colliery Major Expansion Part 3A Application.

We draw your attention to the enclosed sheet entitled "Important Information about your Coffey Report" which should be read in conjunction with this report. Should you have any questions regarding this report please contact the undersigned.

For and on behalf of Coffey Projects Pty Ltd

Paul Tammett

Paul Tammetta Associate Subsurface Hydrologist

Distribution: Original held by Coffey Projects Pty Ltd 1 electronic copy to NSW Department of Planning and Infrastructure

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1 INTRODUCTION

This report presents the results of a review of the groundwater component of the Gujarat NRE No.1 Colliery Major Expansion Part 3A Application. The review (and associated separate analysis of data presented in the application) was conducted by Paul Tammetta of Coffey for the NSW Department of Planning and Infrastructure (DPI). The scope of the review comprised the following:

- Review of the data and hydrogeological conceptual model used by the proponent in assessing impacts on the groundwater system.
- Review of the methods employed in assessing impacts on the groundwater system. Numerical groundwater flow modelling used for impact assessment was also reviewed.
- Where necessary, undertaking separate analyses of the data used by the proponent, and other data, for the purpose of identifying risks posed by the proposed development to drainage courses and swamps. The potential migration of goaf salts to the surface environment is also discussed.
- Development of recommendations to provide more certainty to predictions of impacts, and reduce the risks to the environment.

The subject of the review is the following document, however data are also drawn from other documents (not subjects of the review) in the data analysis phase:

• GeoTerra Pty Ltd. 2012. NRE No.1 Colliery Major Expansion Groundwater Assessment. Report GUJ1-GWR1C, prepared for Gujarat NRE Coking Coal Pty Ltd. November.

2 BACKGROUND

2.1 Proposed Development

Gujarat NRE Coking Coal Pty Ltd (Gujarat) proposes to mine 11 longwall panels to the southeast of Lake Cataract (Wonga East) and seven longwall panels to the west of Lake Cataract (Wonga West). At Wonga East, three panels of 105m width are to be located southeast of Mt Ousley Road, and 8 panels of 150m width are to be located to the northwest of this road, as shown in Figure 1a. At Wonga West, two panels of 155m width are to be located immediately northeast of Lizard Creek, and five panels with an average width of about 385m are to be located immediately southwest of Lizard Creek, immediately north of Wallandoola Creek, as shown in Figure 1b. All proposed panels will mine the Wongawilli coal seam.

LW4, and part of LW5, has been completed in Wonga East, with a mined height of 3.1m for LW4 (Geoterra, 2012a). SG (2012) reports a mined height of 3.2m for this panel. Mining is currently occurring in LW5, with face advance for all panels in Wonga East to be from west to east. LW8 and LW9 underlie Cataract Creek, which is perennial (Geoterra, 2012b). The average maximum subsidence along the LW4 centreline was measured as 1.33m (SG, 2013). This is about twice the amount predicted for a single seam operation using the database of Holla and Barclay (2000) for the Southern Coalfield.

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Figure 1a. Proposed Development in Wonga East.

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Bulli Seam full extraction

Creek reach with reported cessation of flow during extended dry periods, but no reported creek bed cracking (Geoterra, 2012b)

Figure 1b. Proposed Development in Wonga West.

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2.2 Previous Mining

The proposed development underlies previous workings in the Balgownie and Bulli coal seams. The stratigraphic order of the seams (from top to bottom) is the Bulli Seam, Balgownie Seam, and Wongwailli Seam.

All previous mining has a component of partial extraction (development drives or room and pillar operations). This review focuses on full extraction mining, where overlying ground deformation occurs. With multi-seam mining, as is the case here, existing pillars in partial extraction workings may crush, and this has been taken into account.

Full extraction Bulli Seam workings comprise room and pillar mining with pillar extraction in Wonga East, and longwalling in Wonga West. The locations of full extraction Bulli Seam blocks and panels are shown in Figures 1a and 1b. An historic photo of mine workers in a mine heading in a room and pillar operation in the Southern Coalfield (Figure 3.11 of GML, 2004) suggests a 1.9m mining height for these operations. The Bulli seam is 2m to 4.7m thick in this area (Geoterra, 2012a).

Full extraction Balgownie Seam workings comprise 11 longwalls in Wonga East as shown in Figure 1a. The seam thickness is reported as approximately 1.35m (Geoterra, 2012a), with the acknowledgement that the mined height was probably greater. Panel widths ranged between 144m and 186m. The northwestern panels are split by a structural feature. The average maximum subsidence caused by these panels, for locations under Bulli seam full extraction blocks, was measured as 1.1m (SG, 2012). The average vertical subsidence for these panels under Bulli seam full extraction blocks is about 80% of the extracted thickness (SG, 2012), implying a mined height of around 1.5m. SE (2012), in an analysis for pillar run potential, adopted a mined height of 1.8m for these panels, citing practical mining considerations.

Previous workings in Wonga West comprise longwalling with a variety of panel widths. No information was found for mined heights for the panels overlying the proposed development. Mined heights are available for LW501 and LW502 (Singh and Jakeman, 1999; 2001).

2.3 Stakeholder Concerns

Submissions from stakeholders list various groundwater-related concerns that revolve around the following issues:

- The ability of Lake Cataract to maintain its water collection and storage capability (this includes associated tributaries).
- The ability of undermined upland swamps to maintain their ecology.

The first issue also has associated ecological issues in the event that the water transmission capabilities of tributary water courses are compromised by the proposed mining.

3 REPORT REVIEW

In this review, no distinction is made between Appendix D of Geoterra (2012a), which presents the groundwater modelling of GA (2012) and the body of Geoterra (2012a). The initial part of the report provides a detailed discussion of relevant legislation pertaining to groundwater-related aspects of the development.

3.1 Data

The review of data used by the proponent focuses on the following three data streams, which are required for the development of a hydrogeological conceptual model.

- Hydraulic heads in the subsurface media.
- Hydraulic properties of the subsurface media.
- Hydraulic controls on groundwater flow in the media (comprising the geometry of the hydrogeological units, rainfall recharge, stream baseflow, structural impediments / enhancements to groundwater flow, and various other aspects).

3.1.1 Hydraulic Heads

The hydraulic head monitoring network comprises 40 measuring devices (8 standpipe piezometers and 32 vibrating wire piezometers) distributed throughout the depth profile at 11 locations. This is considered a reasonable number for the size of the mining lease. However, none of the locations have provided drawdown measurements close to a panel, during mining of LW4 and/or LW5. Drawdown information is important for model calibration for a model where large stresses, causing large changes in hydraulic heads, will be simulated,.

Monitoring locations P501 and P502 in Wonga West overlie historical Bulli seam longwalls LW501 and LW502. Hydraulic heads from these piezometers are presented and interpreted to indicate vertical fracturing extending to less than 153m above the Bulli Seam. These monitoring locations are WB17 and WB18 respectively, from Singh and Jakeman (2001). These data (augmented with microseismic data) were interpreted in Tammetta (2012) as indicating a height of desaturation of 92m, due to the short panel width (110m) and moderate mined height (2.6m). This result is not applicable to wider longwall panels since the height of desaturation is a function of panel width, mined height, and overburden thickness (Tammetta, 2012).

The pressure head profile for GW1 is presented and interpreted to indicate a restriction to downward flow in the upper Bulgo Sandstone. This is not considered to be the case. This pattern is observed elsewhere in the southern coalfield, and worldwide, where claystone does not exist at the base of the profile. The pressure head profile indicates the presence of an inverted water table at about 170m depth, representing the height of desaturation above the Bulli workings at that location. The profile shape resembles a half tear-drop, commonly seen above collapsed workings prior to, or at, equilibration throughout the profile. The base of the tear represents a significant downward gradient, with vertical flow dependent on the vertical hydraulic conductivity, not the lateral conductivity measured by the packer tests. These data are analysed separately by the reviewer later in this report.

Device depths at NRE D listed in Table 5 of Geoterra (2012a) are inconsistent with depths shown in Figure 20 of Geoterra (2012a) and inconsistent with depths shown in the NRE D log in Figure 3 of

Appendix B. For the separate analysis undertaken below, device depths from Figure 20 and Appendix B (consistent with each other) have been used.

The report interprets hydraulic heads at NRE A, GW1, and Cataract Creek to indicate that Cataract Creek loses channel water to the subsurface. This is not considered to be the case. The hydraulic head field exhibits large vertical hydraulic head gradients, so that hydraulic heads from the uppermost devices at those monitoring locations are not representative of the water table. These data are analysed separately by the reviewer later in this report.

The hydraulic head surface of Drawing 8 ("Standing Water Levels" for the Upper Hawkesbury Sandstone) appears to suffer from the effect of vertical hydraulic head gradients, and is not useful for indicating lateral hydraulic head gradients. In an environment of significant vertical gradients, hydraulic head surfaces, to be of use, must be compiled using measurements from a group of devices that is located in a vertical interval (of not more than 20m thickness but preferably 15m or less, depending on the magnitude of the vertical hydraulic head gradient) which is a specified distance above or below a key depositional marker horizon (such as the Bald Hill Claystone).

3.1.2 Hydraulic Properties

The site-specific hydraulic conductivity database accrued by the proponent comprises six short duration pump tests at six locations, and 65 packer tests at eight locations. This is considered reasonable. The results have been interpreted taking into account the effect of depth on conductivity.

Packer testing from bore GW1 shows decreasing hydraulic conductivity versus depth. From three tests (out of 22) at this location, the report interprets that the Stanwell Park Claystone has lower lateral conductivity than adjacent strata. Although these three test results are consistent, they lie within the typical variation in conductivity for a fractured rock unit at a given depth (typically about 1 decade around the geometric mean, as displayed over the rest of the profile for GW1). The interpretation in the report is therefore considered tenuous on statistical grounds, and because of results from other areas in the Southern Coalfield.

A discussion of storativity of the subsurface media is not provided. Although this information is less prevalent than hydraulic conductivity information, and more difficult to measure, a discussion on literature estimates would have served as a precursor for numerical simulation.

3.1.3 Hydraulic Controls

The report provides a reasonable summary of the geology and distribution of sedimentary rock layers. Structure contours for key horizons (such as the Wongawilli Seam floor) are not provided, however these are assumed to have been made available by the proponent to the consultant for use in numerical simulation. Structural features are discussed. Discussion of the hydraulic behaviour of the subsurface media is provided for individual hydrogeological units. The discussion is mostly of a qualitative nature.

Previous mining is adequately discussed.

3.1.3.1 Water Course Baseflows

Recharge to the groundwater system from rainfall is a fundamental control. In a numerical model, recharge is positively correlated with hydraulic conductivity, meaning that without quality a-priori information to constrain one, it is not possible to reliably estimate the other. Given the large uncertainty

in numerical models, quality a-prior information is required to constrain both. Baseflow analysis provides a useful indicator of rainfall recharge to the groundwater system.

Geoterra (2012b) presents "pool depth" measurements for four locations in Cataract Creek from 2010. Flow monitoring at locations CC3 and CC4 on Cataract Creek (see Figure 11 and Table 16 of Geoterra, 2012b) is said to have commenced using either temporary box notch weirs, or the flow velocity / cross section method, both of which provide direct flow measurements. It is also stated that pool depth measurements will be converted to flow rates once rating tables are developed for the monitoring sites. Geoterra (2012b) also presents pool depth measurements for three locations on Cataract River from April 2012. Pool heights are also measured at several monitoring points in Lizard and Wallandoola Creeks.

WRM (2012) presents high frequency flow monitoring data for Lizard Creek for the period October 2009 to August 2012 for monitoring location LC3. Data from February 2011 onward appear well suited to a baseflow analysis, however an analysis does not appear to have been conducted.

WRM (2012) identifies publicly available stream flow monitoring data for two gauges located within the area of interest (Bellambi Creek and Loddon River), simultaneously covering the period 1991 to 1995. WRM (2012) calibrated a numerical surface water model of the mine area using flow data from these gauges. Calibrated baseflow indices for these gauges were around 0.3. Average long-term daily flow calculated by the calibrated model for various creeks are (Geoterra, 2012b):

- 11.7 ML/day for Cataract Creek at its confluence with Cataract Reservoir. The proportion of baseflow for the calibration period is about 30% for both of the calibration gauges. Using this baseflow index gives an average calculated long-term baseflow of about 3.5 ML/day.
- 17.0 ML/day for Lizard Creek at its confluence with the Cataract River downstream of lake Cataract, with an average daily baseflow of about 5 ML/day.
- 33 ML/day for Wallandoola Creek, with an average daily baseflow of about 10 ML/day.

These flow observations and numerical estimates form a reasonably-sized transient dataset for calibration of baseflow in the numerical groundwater flow model. The groundwater model uses qualitative results from the WRM (2012) analysis to estimate a groundwater recharge rate of 2% of rainfall, with 4% for areas of coincident Bulli and Balgownie full extraction workings in Wonga East. These rates appear reasonable, but discussion of a quantitative basis for these rates should be provided.

3.1.3.2 Flow Variation

Various streams are interpreted to be gaining, losing, or both, according to drilling information and site observations, which are not provided. Knowledge of the position of the water table is normally required to make these judgements, however the hydraulic head field displays significant vertical gradients, meaning that shallow measuring devices may not be measuring the hydraulic head at the water table. In this situation, use of measurements from the uppermost devices as surrogates for the water table may underestimate the height of the water table.

Flow in Wallandoola Creek is reported to be permanent in the valley fill swamps, down to the upper part of waterfall W1 where creek bed cracking allows channel flow to cease during extended dry periods (Geoterra, 2012b). Channel flow resumes downstream of waterfall W1.

Flow in Lizard Creek is reported to be permanent in the valley fill swamps, down to site LC3, where creek bed cracking allows channel flow to cease during extended dry periods (Geoterra, 2012b), with permanent flow resuming about 200m upstream of waterfall L1, down to site LC5. Between sites LC5 and LC6, channel flow can cease during extended dry periods, however no streambed cracking is reported. Permanent flow is resumed downstream of site LC6.

The locations where creek bed cracking has been observed in Wallandoola and Lizard Creeks coincides with the edges of the southwest Bulli seam longwall block in Wonga West (see Figure 1b). Geoterra (2012b) interprets that the previous Bulli seam longwall mining has caused "conventional and non-conventional" impacts (as defined in NSW PAC, 2010) on stream flow and / or water quality in these creeks.

Flow in Cataract Creek has been observed to be perennial (Geoterra, 2012b). Geoterra (2012b) reports that no adverse impacts on stream flow or water quality have occurred. However, unlike Wonga West, the creek is underlain only by pillar extraction workings (except for a reach over the ends of Balgownie LW9 and LW10, and a short reach over LW11 – see Figure 1a) which create smaller collapsed zones than longwall mining.

3.1.3.3 Groundwater Inflows to Mine Voids

Information regarding water pumped out of mine voids is vague. In discussing the historic 200 and 300 series Bulli seam longwalls, the report states that voids in the Wonga West area, located to the west of Cataract Reservoir, are "essentially dry". This is inferred to mean that the voids are maintained dewatered, since it is subsequently stated that water is being pumped out of mine voids "to the west of Cataract Reservoir". Pumping rates would have been useful, if available. Void water level information (and void geometries), and void injection rates (if applicable) would assist in converting pumping rates into groundwater inflows. Void water level information may be irrelevant since it appears that the voids have minimal standing water.

Quantitative information is provided for water extracted from the Wonga East workings (27 Cut Through) from 2010. These data presumably apply for drained workings, and are useful as a calibration target (taking into account evaporation and coal moisture losses). As before, any injection into the void would be required to process the data.

3.1.4 Hydrogeological Conceptual Model

The hydrogeological conceptual model is discussed without illustration and confounds the discussion of groundwater sources and sinks with discussion of modelling mechanisms.

The following aspects of the adopted hydrogeological conceptual model are considered to be tenuous:

- That the "deeper" Hawkesbury Sandstone is hydraulically separate from overlying and underlying units at Wonga West (presumably because of the presence of the Bald Hill Claystone (for the underlying units)).
- That the height of fracturing allowing desaturation (due to proposed mining) is assumed to extend only up to the mid to upper Bulgo Sandstone (the Bald Hill Claystone is assumed to be unaffected, except for a localised area in Wonga East).

The first aspect is circumvented in the numerical simulation since all model layers communicate hydraulically with adjacent layers via the vertical hydraulic conductivity parameter. The second aspect is a crucial one for the conceptual model; it is analysed separately by the reviewer later in this report.

The assumption of surface tensile fracturing occurring to a depth of 20m is reasonable. 15m is a widely used estimate for single seam longwalling; the depth for multiple seam mining is likely to be larger.

3.2 Impact Assessment Method

The impact assessment relies heavily on the results of numerical simulation. The review of the assessment method therefore focuses on the development and use of the numerical model. The electronic version of the model was not available, and an understanding of the functioning of the model has relied on the report only. It is recognised that there may have been time and budgetary constraints applied to the impact assessment which are not known to the reviewer.

The assessment has used FEFLOW, a finite-element numerical groundwater flow model produced by DHI-WASY. It assumes laminar flow in its governing equation for saturated conditions. The use of this model is appropriate for the problem at hand. Models of this type are useful for predicting changes in the hydraulic head field outside collapsed zones, and for estimating changes in baseflow to, or leakage from, surface water bodies through changes in hydraulic head in the subsurface media, but are inappropriate where severe trauma occurs near the body. These types of model are not appropriate for assessing hydraulic conductivity changes at the base of individual swamps. The use of a numerical model for a problem of this nature (prediction of depressurisation due to underground mining) is predicated on stringent calibration.

The purpose of the numerical simulation is reported as being to "assess the relative changes in the groundwater regime and recharge to surface water bodies due to the proposed mining". Later in the report the aim is stated as being "to assess the influence that the proposed extraction of Wonga East, Wonga West, and VMains may have on current conditions". Model output presented later comprises hydraulic head drawdown, changes in flow exchange with surface water features, and groundwater inflow to the mine void.

The model does not attempt to simulate discrete structural features. The capacity for these structures to create high conductivity pathways through deformation cannot be modelled soundly with models of the type used here. These analyses would generally require a discrete feature approach with geotechnical simulation of deformation, perhaps in a probabilistic way.

3.2.1 Model Architecture

The number of model layers is more than satisfactory, and would have been a solid platform for replication of vertical hydraulic gradients. Layer geometries are detailed and are reported to have been developed from elevation data for topography, Bulli seam, and Wongawilli seam structure contours. These data were presumably supplied by the proponent as digital structure contour surfaces interpolated from resource drilling.

Model domain extremities are reasonable however the northern and western extremities in the Wonga West area would have benefited from extension further north and west, since mine voids (strong hydraulic controls) are further away in these areas. The extremities are reported to be catchment boundaries. It is sound practice to extend model extremities to discharge boundaries which are a reasonable distance from the proposed stresses, so that the pre-mining hydraulic head field is set up by

rainfall recharge and groundwater discharge at discharge boundaries, and modelled stresses have negligible effect at the domain extremities. For an area such as this, a combination of distant line sinks / mine voids would be advantageous. This would also allow more distant water course baseflows to be calibrated.

Potential lateral flow out of the model domain is not discussed. The potential for fluxes of this nature to be significant, compared to discharge to surrounding mine voids in the model domain, will most likely be in the upper model layers.

Lake Cataract is simulated as a constant head boundary, meaning that leakage will be controlled by the hydraulic conductivity of the layers in which the boundary is set (the lake may intersect several units due to layer dips and outcropping). While this is acceptable, it may cause problems during the detailed calibration which will be required (this is further discussed below), and it may be prudent to simulate the lake using a variable head boundary that controls flux (such as the river package in MODFLOW SURFACT), otherwise lake fluxes will be more volatile, and may cause difficulty, during calibration.

3.2.2 Model Parameters

Hydraulic conductivity in the model is reported to be based on packer testing undertaken for this project, and from model calibration results for the Metropolitan Mine (operated by Helensburgh Coal).

The report specifies the uncertainties inherent in hydraulic conductivity above subsided strata, and the difficulty in simulating conductivity change (from virgin conditions) caused by multiple seam mining. Where significant uncertainties in parameters and boundary conditions exist, the use of numerical simulation becomes questionable. For the model results to be considered by external parties, the uncertainty must be reduced by additional a-priori information. The model is considered uncalibrated at present (this is further discussed below), and model results are not considered to be reliable. However, information on hydraulic conductivity from the site itself, and other sources, is presented in the separate analysis by the reviewer below, to assist in reducing uncertainty and constraining model parameters during the required recalibration.

The goaf zone immediately above the mined floor has extreme conductivity, and values selected for model simulation are considered very low.

3.2.3 Model Calibration

Model calibration is discussed in a deficient manner. It is not stated which parameters were selected for calibration, and which were adopted without variation.

It appears that the model has been calibrated in steady state mode only, using only hydraulic head targets. Transient calibration, to a calibration target data set including (in addition to hydraulic head time series measurements) water course baseflow estimates and measured void discharges, has not been undertaken. This is considered a significant deficiency. A calibrated hydraulic head surface is presented in Figure 19 of Appendix D. The contoured quantity is called "resultant heads" and it is not known if it is the calibrated water table or the hydraulic head surface for some key depositional horizon. A correlation of observed and calibrated hydraulic heads is provided in Figure 20 of Appendix D, however no performance measure is provided.

A steady state calibration (where it is normally difficult to sustain vertical hydraulic head gradients, since the hydraulic head field equilibrates to an infinite time), coupled with the presentation of one calibrated hydraulic head surface, implies that calibrated vertical hydraulic head gradients are negligible. If this is

the case, it is in disagreement to observations and represents a further deficiency. If pre-mining pressure heads, at depth, in the model are overestimated (negligible hydraulic head gradient), this underestimates drawdown in upper layers and the associated leakage from surface water bodies caused by this drawdown. It also leads to an unrepresentative evolution of the hydraulic head field from imposed stresses.

No water balances for the model domain, at any time instant, are provided, precluding an assessment of boundary conditions and hydrogeological units that feature heavily in the flow system.

3.2.4 Swamps

Impact assessment for swamps was undertaken by BR (2012). The method comprised an initial risk assessment according to regulatory agency subsidence criteria, followed by a comparative analysis (with past mining) and review of flow accumulation and predicted strains (tensile and compressive) for site-specific swamps. Based on a risk assessment using predicted strains for the proposed development, and observed strains at other locations, and focusing on interpreted "special significance" swamps, BR (2012) concluded:

- Swamps CRUS1 to CRUS3, LCUS1, LCUS6, LCUS27, WCUS1, and valley infill sections of WCUS4 showed no significant risk factors that would indicate susceptibility to impact.
- Swamps CCUS1, CCUS4, CCUS5, CCUS10, WCUS4, and WCUS11 may be subject to strains that would result in fracturing of the bedrock below these swamps.
- Swamp WCUS7 is likely to be subject to tensile strains sufficient to result in fracturing of bedrock below this swamp.
- There is some potential for fracturing of the bedrock below the headwater section of LCUS8, however it is likely to be limited in extent and degree.

Based on additional assessments for each swamp, the overall conclusion in BR (2012) is that there is a significant likelihood of negative environmental consequences for swamps CCUS1 and CCUS5.

Regarding the presence of peat in the substrate of site specific swamps, Geoterra (2012a) describes swamp Lcus4 in Wonga West as having up to 1.5m of peat. BR (2012) reports that only some swamps within the study area generate peat, but they are not identified. The thickness of swamp substrate from rudimentary logs shown in Figure 11 of Geoterra (2012a) is an average of around 1m.

The impact assessment adopts the following two assumptions, which are considered tenuous:

- That changes in hydraulic parameters (deformation) of swamp bedrock is estimated to have no effect on groundwater levels in the bedrock, in excess of typical climatic variability.
- That connective cracking to deeper strata is not predicted, and therefore free drainage of swamps into deeper strata (the mine void) is not anticipated.

An analysis of these aspects has been undertaken separately by the reviewer below.

4 SEPARATE ANALYSIS

In the analyses that follow, mapping information has been sourced from the following:

- Wongawilli and Bulli seam floors, and topography: NSW DPI (from NRE Gujarat). The supplied structure contours for the Bulli and Balgownie seam floors are noted to be exactly 42m apart for all nodes in the digitial elevation model.
- Bulli seam pillar extraction mining in Wonga East: Plan 2e, Cardno (2012).
- Balgownie seam longwalling: Plan 2e, Cardno (2012).
- Proposed NRE Gujarat WW longwalls: Drawing 1, Geoterra (2012a)
- Georeferenced computer files of existing and proposed workings supplied by the proponent via NSW DPI.

The reaches of Cataract and Lizard Creeks were digitised from Drawing 1 in Geoterra (2012a), assuming the coordinate axes are the MGA. Wherever digitising was undertaken on figures with unlabelled coordinate axes, the coordinate system was assumed to be the MGA. The reach for Wallandoola Creek was taken from georeferenced mapping files provided by Geoscience Australia (via web service) for its 1:250000 scale map series.

4.1 Hydraulic Conductivity

An analysis of measured hydraulic conductivity in the Southern Coalfield has been undertaken for the purpose of providing (if needed) a basis for constraints in the hydraulic conductivity field for model calibration, and a basis for the recommended probabilistic numerical analysis of potential leakage from Lake Cataract.

Hydraulic conductivity measurements from packer tests for strata in the Southern Coalfield are shown in Figure 2. Decreasing permeability with depth is a conspicuous feature of the strata. Structural features such as dykes or faults may reduce or enhance the normal hydraulic characteristics of the strata. Superimposed on the distribution are the packer tests for the NRE lease. Results for GW1 and NE3 are broadly similar to other data. Results from other bores show significant variation.

Results in Reid (1996) for strata impacted by mining are from packer tests undertaken in strata directly overlying the mined seam, where caving has occurred from full extraction (from boreholes adjacent to Avon Reservoir and at Wongawilli Colliery). Mining occurred in either the Bulli or Wongawilli Seams, and the Bulli Seam would be at an average depth of about 320m (with respect to the impacted strata packer test results) on Figure 2. Panel widths are thought to have been about 250m or less. The effect of mining on overburden hydraulic conductivity is seen as a trend centred around 0.15m/day at the surface, with conductivity increasing slightly with depth, and probably indicates a significant loss of confining pressure in the tested strata.



Figure 2. Hydraulic conductivity measurements from packer tests for strata in the Southern Coalfield, and from the NRE Gujarat No.1 Mine Lease.

At a mine site in Kentucky, USA, changes in hydraulic conductivity were measured in detail (Hutcheson et al, 2000). At that location, overburden strata comprise about 250m of interbedded coal seams, shale, limestone, and massive sandstone of Middle Carboniferous age. The panel width was 213m at a depth of about 250m, with a mined seam thickness of 2.3m. Two major sandstone sequences of about 30m thickness each, occur within overlying strata. Hutcheson et al (2000) report measured pre-mining and post-mining hydraulic conductivities over a single longwall (LW7). Results are shown in Figure 3. These results are similar to those of Reid (1996), also indicating that the normal relationship of decreasing permeability with depth for undisturbed strata is significantly affected by longwall mining.



Figure 3. Measured pre- and post-mining hydraulic conductivity at a site in Kentucky (data from Hutcheson et al. 2000).

At a coal mine in Illinois, USA (Booth and Spande, 1992), hydraulic conductivity was measured from packer tests for pre- and post-mining scenarios over the centre of a longwall at a depth of 221m (panel width 183m, and mined seam thickness 2.7m). Rock strata comprise mostly Permian age coal measures. Changes in hydraulic conductivity are shown in Figure 4. Below the Mount Carmel Sandstone Member, post-mining hydraulic conductivities are about 100 times greater than pre-mining.

Booth et al (1998) recorded an average increase of one to two orders of magnitude in hydraulic conductivity from pre-mining to post-mining conditions, assessed from packer tests in a sandstone layer approximately 170m above a longwall in the USA. Confined storativities assessed from long-term pump tests increased by a factor of around 10 (from the 10⁻⁴ range to the 10⁻³ range), resulting from the increased compressibility available from increased void volume due to separation of bedding planes and dilation of fractures and joints.



Figure 4. Measured pre- and post-mining hydraulic conductivity at a site in Illinois (data from Booth and Spande, 1992).

These observations are for single seam mining, however the measured post-mining hydraulic conductivities are controlled by the resultant stress. Resultant stress above the panel cannot decrease to below zero MPa for any amount of multi-seam mining. The measurements over single seam operations above suggest that stress in the measured strata is very low, with conductivities being comparable to those for undisturbed strata at the surface (where stress approaches zero). Therefore, single seam data are considered useful in guiding potential hydraulic conductivity change over multi-seam operations.

4.2 Height of the Desaturated Zone above Full Extraction Workings

An analysis of the height of desaturation above full extraction workings has been undertaken for the purpose of comparing results with the assumption used in numerical simulation in Geoterra (2012a) that the height of fracturing allowing desaturation (due to proposed mining) extends only up to the middle to upper Bulgo Sandstone. This is a crucial aspect of the hydrogeological conceptual model.

Tammetta (2012) conducted an analysis of the height of complete groundwater drainage above subsided longwall panels (referred to as H) for continuously-sheared panels in single seam operations. The analysis used a data base of hydraulic head measurements made with multiple devices down the depth profile at each of 18 sites worldwide (including seven from Australia, of which two are from the southern coalfield, one from the western coalfield, and four are from the Hunter Coalfield of the Sydney Basin). Direct measurements from an additional site from the Southern Coalfield, comprising multiple devices at two locations (one over centre panel) drilled at the request of the NSW Dams Safety Committee, are also available and strongly support the findings, however these data do not appear to

be available in the public domain. In the analysis by Tammetta (2012), H was shown to be relatively independent of most parameters except the geometry of the mined void and the overburden thickness. An empirical equation linking H (in metres) over centre panel to these parameters was developed and is given by:

$H = 1438 \ln(4.315 \times 10^{-5} u + 0.9818) + 26$

where $u = w t^{1.4} d^{0.2}$, w is the mined width (equal to the panel width plus the adjacent heading widths), d is the overburden thickness, and t is the mined height. All dimensions are in metres. The equation applies to a variety of strata types, and strata lithology plays only a minor role. H was also shown to be equivalent to the height above the mined seam where a large change in downward movement of rock strata above a subsided longwall panel occurs, as measured by extensometer arrays. That is, H is equal to the top of the zone of large downward movement. The desaturated zone and the zone of large downward movement to as the collapsed zone.

The height of desaturation above full extraction for the following special situations is shown to be consistently smaller than estimates made for continuously-sheared panels (Tammetta, 2012):

- Above chain pillars of continuously sheared panels (with either a panel on one side only or panels on both sides).
- Above the centreline of room and pillar panels with pillar extraction being undertaken.
- Above the centreline of continuously sheared panels, underneath flowing rivers or saturated highpermeability alluvium.

The reasons for this are discussed in Tammetta (2012). Of special interest for the current project is the estimation of H for Bulli Seam pillar extraction workings in Wonga East.

Tammetta (2012) presents a conceptual model of ground deformation above a subsided longwall panel from a groundwater perspective. The model consists of a collapsed zone and a disturbed zone, as shown in Figure 5.

The Collapsed Zone is parabolic in cross-section, and reaches from the mined seam to a maximum height equal to H over centre panel. This zone is severely disturbed and is completely drained of groundwater during caving. It is subsequently unable to maintain a positive pressure head. It will behave as a drain while the mine is kept dewatered. Within this zone, the matrix of rock blocks may continue draining for extended periods however the defects will immediately transport this water downward to the mine. Groundwater flow will not be laminar, and Darcy's equation is unlikely to be obeyed.

The Disturbed Zone overlies the Collapsed Zone. Positive groundwater pressure heads are maintained over most of the zone. Limited data for long-term groundwater behaviour in this zone suggest that hydraulic heads remain relatively stable, except for immediate lowering associated with drainage of lower strata and minor increases in void space after caving. Groundwater flow will be laminar, and Darcy's equation is likely to be obeyed. Desaturation in the disturbed zone occurs above the chain pillars. Here, H is smaller than over centre panel, and may reduce to zero if the pillar is flanked by one panel only. H above the pillars is likely to be more strongly dependent on d than for centre panel, and will probably also be dependent on the pillar width.



Figure 5. Conceptual model for ground deformation above a caved longwall panel (after Tammetta, 2012).

4.2.1 Hydraulic Heads and Previous Mining

The first stage of the analysis of the collapsed zone comprised testing the interrelationship between estimated collapsed zone heights for previous workings (using the results of Tammetta, 2012) and the hydraulic head information collected by the proponent. Monitoring site GW1 is located over Bulli seam pillar extraction workings and just off the edge of Balgownie LW7. For the Balgownie panel, GW1 is in a location similar to that over chain pillars with a mined panel on one side only, and its u parameter is so small that the height of desaturation contributed by Balgownie LW7 at nest GW1 is conservatively assumed to be nil (refer to Tammetta, 2012).

The height of desaturation at GW1 is thus assumed to be due only to Bulli pillar extraction. From the GW1 pressure head profile H is assessed to be 225m (overburden thickness) minus 170m (base of saturation), giving 55m. This fits the distribution in Figure 4 of Tammetta (2012), and is shown in Figure 6. GW1 is slightly off the centreline of the Bulli block so H is less than the maximum.



Figure 6. Height of desaturation estimated from the pressure head profile at GW1 for pillar extraction workings at GW1.

This result provides added reliability for estimating H for other Bulli workings and the Balgownie longwalls in Wonga East, along a cross section from NRE A to NRE B, through GW1, as shown in Figure 7. The figure shows the calculated collapsed zone heights for the Bulli and Balgownie full extraction workings seperately, and the summed height. The cross-section cuts the parabolic cone formed by Balgownie LW7 along an off-centre line, so that the maximum H is not shown on the cross section. In addition, truncation of Balgownie LW7 at the fault (see Figure 1a) further reduces H for the Balgownie LW7 block in the section (this block is northwest of the fault, with width 180m and "length" 145m, with the rest of Balgownie LW7 being continued on the other side of the fault). For this short panel, H is estimated assuming a "width" (w) of 145m.

The collapsed zone heights for both seams were summed arithmetically, based on the logic discussed in Appendix A (which also includes a discussion of potential pillar crushing). It is recognised that the total H may in fact be larger than a simple arithmetic sum of the individual H, however insufficient hydraulic head data are available to test this. Surface subsidence measurements for Wongawilli LW4 at Wonga East are reported to be in excess of typical observations in the southern Coalfield (SG, 2013; Holla and Barclay, 2000), suggesting that surface subsidence is not a simple arithmetic accumulation for multiple seam mining.







The interrelationship between the summed H from all workings and the measured hydraulic heads was assessed along the cross section. Figure 8a shows the interpreted hydraulic head distribution (broadly representative of early 2012) and the calculated collapsed zone height. The curvature in the hydraulic head contours resulting from the control exerted by the collapsed zones is considered most reasonable and is observed at other locations in the Southern Coalfield, as is the vertical hydraulic head gradient. The interrelationship is therefore considered strong, with hydraulic heads representative of the collapsed zones as calculated here.

The vertical hydraulic head gradient steepens considerably in the vicinity of the collapsed zones, typical of this situation. The hydraulic heads at NRE A, in conjunction with the reported response of deeper devices there to rainfall events (Geoterra, 2012a), may represent a subvertical feature of reasonable width, oriented at some angle to the section, which has increased hydraulic conductivity along its plane (compared to adjacent strata), but not normal to its plane.

The water table was estimated at each location by upward extrapolation of the pressure head profiles to zero pressure. The water table along the section is interpreted to be higher than the water level in Cataract Creek, indicating a gaining stream. A stream of such short length would not be expected to be perennial (as reported) unless a sustained baseflow input was available. This accords with observations made during a site visit on 10 April 2013 where Cataract Creek was visually estimated to be flowing (following several dry days) at a rate significantly in excess of 2 L/s.



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Figure 8a. Interpreted hydraulic head distribution (broadly representative of early 2012) along the cross section.

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4.2.1.1 Pressure Head Profiles

An analysis of measured hydraulic heads has been undertaken for the purpose of demonstrating the significant vertical hydraulic head gradient over the workings. Figure 8b shows the vertical pressure head profiles (broadly representative of early 2012) for the monitoring locations. Excluding NRE A, the average vertical pressure head gradient is 0.45 downward, equivalent to a downward vertical hydraulic head gradient of 0.55, which is significantly higher than lateral gradients. GW1 indicates that downward hydraulic head gradients increase significantly as the workings are approached. These aspects of the hydraulic head field are of significant importance.





4.2.2 Predicted Height of the Collapsed Zone

The results of the assessment by Tammetta (2012) have been used to estimate the height of the collapsed zone for previous and proposed mining in the mine lease. Longwall and pillar extraction block widths are taken from mapping information as listed above. Overburden thicknesses are taken from digital elevation models provided by the proponent. The Balgownie seam floor is assumed to

overlie the Wongawilli seam roof by about 19m in the lease area (Geoterra, 2012a), or a floor to floor interval of about 30m. The following assumptions are made regarding mined heights:

- t = 1.9m for Bulli seam pillar extraction in Wonga East.
- t = 1.8m for Balgownie seam longwalls (SE, 2012).
- t = 2.6m for Bulli seam longwalls in Wonga West (from LW501 and LW502, Singh and Jakeman, 1999; 2001).
- t = 3.1m for proposed Wongawilli seam panels in Wonga West and Wonga East (from a reported t of 3.1m for LW4 in Wonga East, Geoterra, 2012a).

H above pillar extraction blocks for a single seam is assumed to be 50% of H calculated for a dimensionally equivalent continuously sheared longwall panel.

The assessment method comprises calculation of collapsed zones heights for each seam, then simple summation of these heights to develop an isopach of the combined collapsed zone thickness. To this isopach is added 20m (the estimate for the thickness of the surface tensile cracking zone), to create an isopach that represents a combined collapsed zone / surface tensile zone thickness, referred to as the potential drainage thickness (if the collapsed and surface tensile zones connect, the profile is assumed to fully drain, with resultant groundwater pressure heads of zero or less). The potential drainage thickness is then subtracted from the Wongawilli seam overburden thickness. Negative values indicate the protrusion of the potential drainage thickness above ground surface, and indicate the condition where the collapsed and surface tensile zones have connected, allowing complete drainage of the overlying profile and surface water features into the mined void.

In the figures presented below, contours of protrusion generally apply to the panel (or block) centres (the height of desaturation over centre panel was applied along the whole width of a panel in obtaining the contours, to simplify spatial data processing).

4.2.2.1 Wonga East

Figure 9 shows the protrusion of the interpreted potential drainage thickness above ground surface for Wonga East. Outlines of significant swamps are also shown. Complete drainage is calculated to occur over parts of LW3 to LW8.

A serious risk to Cataract Creek is present in the area where Cataract Creek, Balgownie LW11, a Bulli pillar extraction block, and Wongawilli panels LW7 and LW8 coincide (see Figures 9 and 1a). The interpretation indicates that the collapsed zone and surface tensile fracturing zones will connect in this area, and lead to creek drainage into the mined void. The calculated baseflow of Cataract Creek is 11.7 ML/day (see above), which is 6% of the average water volume generated by Lake Cataract between 2006 and 2012 (from the SCA water balance reports web page, sighted 14 May 2012: http://www.sca.nsw.gov.au/publications/publications/sca-water-balance).



P400 301600 301800 302000 302200 302400 302600 302800 303000 303200 303400 303600 303800 304000 304200 304400 304600 3048
Figure 9. Protrusion of the calculated potential drainage thickness above ground surface for
Wonga East.

The ground elevation at the point of serious risk is estimated to be about 310mAHD from supplied topographic information, however the channel invert is likely to be a few metres lower. The base of the surface tensile zone is assumed to be around 290mAHD or lower, but dipping down towards the west along LW7 and LW8. The full supply level for Lake Cataract is 289.5mAHD (from NSW Department of Environment and Heritage web page, sighted 13 May 2012:

http://www.environment.nsw.gov.au/heritageapp/ViewHeritageItemDetails.aspx?ID=5051469). LW7 and LW8 fall short of the lake, according to an uncontrolled mapping file used for the lake, however the presence of LW9 and LW10 extending to underneath the lake (with the associated surface tensile cracking zones) adds another dimension to the risk, with continued integrity of the ground over the chain pillars between LW9 and LW8 being required to prevent water at around, or above, the full supply level draining to the workings at the zone of serious risk, if Cataract Creek is breached.

Where H intersects a water course, then the baseflow in the water course will be lost. The nature of connections observed elsewhere (for example at South Wambo Creek at the Wambo Mine) is such that the compromised ground may consume significant flows, allowing little (if any) water to survive the journey across the compromised ground during times of peak flow.

The western end of LW10, and possibly LW9, in Wonga East underlies Lake Cataract. Assuming single seam mining conditions, the approximate height of the collapsed zone is 140m. The overburden thickness is about 280m here, leaving a vertical thickness of 120m between the collapsed zone and the

base of the surface tensile fracturing zone. However, the surface tensile fracturing zone extends along the entire panel, to the high risk zone at Cataract Creek. Where a panel underlies a surface water body, the effective base of the body becomes the base of the surface tensile fractured zone, and the effective extension of the body (for a specified water level elevation for the water body) may occur to the point where the base of the surface tensile fractured zone intersects the specified water level elevation (assuming the ground slopes up from the body, and surface tensile cracks are in reasonable communication with each other). This provides additional risk at the high risk area.

Using Figure 4 of BR (2012), most of swamp CCUS6 is located over a zone of interpreted protrusion, and is at risk of permanent ecosystem change.

4.2.2.2 Wonga West

Figure 10 shows the protrusion of the interpreted potential drainage thickness above ground surface for Wonga West. Outlines of significant swamps are also shown. Complete drainage is calculated to occur over the proposed wide panels (LW1 to LW5) wherever they underlie Bulli seam workings. The zone of complete drainage comes to within about 100m of Lizard Creek at the northern end of LW2, and to within 100m of Wallandoola Creek at the southern ends of LW4 and LW5 (see Figures 10 and 1b). The interpretation indicates that the collapsed zone and surface tensile fracturing zone will connect in these areas, which may lead to creek drainage into the mined void.

The calculated baseflow of Wallandoola and Lizard Creeks is 33 and 17.0 ML/day respectively (see above). These creeks do not flow into Lake Cataract, however these calculated average flows are collectively about 25% of the average water volume generated by Lake Cataract between 2006 and 2012 (from the SCA water balance reports web page, sighted 14 May 2012: http://www.sca.nsw.gov.au/publications/publications/sca-water-balance).

Any swamp overlying a Wongawilli seam panel that underlies a Bulli seam panel will also overlie a zone of interpreted protrusion. Using Figure 5 of BR (2012), the largest four of these swamps are LCUS9, LCUS18, LCUS25, and WCUS4.



Figure 10. Protrusion of the calculated potential drainage thickness above ground surface for Wonga West

4.3 Swamps

An analysis of the potential impacts on swamps has been undertaken for the purpose of comparing results with the following assumptions used in the impact assessment:

- That deformation of swamp bedrock is estimated to have no effect on groundwater levels in the bedrock, in excess of typical climatic variability.
- That connective cracking to deeper strata is not predicted, and therefore free drainage of swamps into the mine void is not anticipated.

4.3.1 Potential Impact Mechanisms

Upland swamps require the following essential conditions for existence:

- Impeded drainage at the floor of the substrate (a floor of low permeability clay or localised lowpermeability rock). Vertical drainage of water from the swamp substrate must be minimal.
- Waterlogged substrate and lower average temperatures.

To maintain waterlogged conditions, a swamp requires a location with high soil water credit (rainfall minus evaporation). If peat is present, it requires a quasi-continual, uninterrupted supply of water to avoid drying out. Much of the water supply comes from surface runoff or springflow. Groundwater accession to the substrate may also occur as a secondary recharge process. For a continual water supply to be available, the runoff behaviour must be advantageous for swamp development. Runoff patterns are dependent on regional topography and sedimentation. Sediment chokes can trap low-flow runoff. The best exponents of these swamps occur on Mesozoic sandstones, at altitude, in the western and southern areas of the Sydney Basin.

Hydraulic conductivity measurements for Hawkesbury Sandstone show a variation of about ± 1 log cycle around the geometric mean at a fixed depth. A surface outcrop layer, therefore, may show a random layout of zones ranging from very low to very high conductivity. This, together with advantageous surface runoff conditions, creates the regional spatial pattern typical for these swamps.

There are three key threatening processes to swamps from longwall mining, as follows:

- Breach of the sealing layer under the swamp substrate (by surface tensile fracturing or intersection with the collapsed zone).
- Reduction or elimination of the substrate water supply (for example, if runoff is diverted by distant subsidence troughs or consumed by distant surface cracking).
- Fouling of the substrate water supply (for example, where surface discharge of low pH / high sulphate goaf water reports to a swamp).

A much rarer form of impact might be underground mine fires which may heat surficial media by a few degrees or more and compromise the flora and fauna habitat. No such situation is known to have occurred in the Southern Coalfield, however goaf fires have been reported in old mine workings at Lithgow, but it is understood that, since the time the fires were first discovered, swamps have not been observed above these workings.

4.3.2 Observed Impacts on the Swamp Sealing Layer

Wherever a swamp is undermined by a longwall panel, surface tensile cracking will compromise the sealing capacity of the rock supporting the swamp substrate. This effect is illustrated by most available monitoring records, that cover a sufficient time period, in the public domain. Wherever surface subsidence occurs, cracking is also likely to occur, to accommodate the tilts and strains to which the ground is subject. Mills (2012) reports that, based on an analysis of surface subsidence data from the Newcastle Coalfield (Tobin, 1998), the zone in the subsurface which is above a height of about three times the panel width generally shows no ground movement (full bridging), which suggests surface tensile fractures may not develop in this situation.

Detailed groundwater monitoring records for rock immediately underlying (and supporting) the swamp substrate are available for undermined swamps at Angus Place and Dendrobium collieries from public domain documents (environmental assessments and annual environmental reports available on the mine websites). Figure 11 illustrates swamp and longwall layouts, and monitoring locations, at Angus Place and Dendrobium mines.



Figure 11. Undermined swamps at Dendrobium and Angus Place collieries.

The assessment has been undertaken by first finding a relationship that equates monitored groundwater levels to rainfall and evaporation, and then using groundwater monitoring hydrographs for the rock sealing layer to identify variations in the hydraulic head of the sealing rock layer that are not due to climatic factors. Most swamp monitoring hydrographs for mines in the Sydney Basin have records that are too short to be able to unambiguously identify mine effects (with many piezometers installed after effects have occurred), however hydrographs for the following monitoring piezometers are exceptions and are the subject of this analysis:

- Piezometer 12_01 at Swamp 12 at Dendrobium Colliery (Figure 12a). The screen interval is not known but is believed to occur in the Hawkesbury Sandstone immediately under the swamp substrate.
- Piezometer WW1 at West Wolgan swamp at Angus Place Colliery (Figure 12b). The screen interval is reported to be located in the Banks Wall Sandstone to a depth of 2.5m below ground level.



Piezometer 12_01 was undermined in late June 2011. Fortnightly rainfall at Darkes Forest and fortnightly average pan evaporation from the Australian Bureau of Meteorology (ABM) gridded dataset (for this location) was used to construct a running cumulative residual (R) of the difference between fortnightly rainfall and evaporation (the water deficit). R is calculated by first finding the time series of fortnightly rainfall minus fortnightly pan evaporation, referred to as the fortnightly water deficit. The average of the time series of the fortnightly water deficit is then found. A second time series is then created, comprising the fortnightly deficit minus the average, creating a time series of deficit residuals. These deficit residuals are then cumulatively added to create R. R for Swamp 12 is shown in Figure 12a. R tracks the groundwater levels reasonably well. The data show that the water level drop in June 2011 was due to undermining, because climate behaviour would have maintained higher water levels. The nature of the impact comprises a fall of water level to below the base of the piezometer, with

Coffey Projects GEOTLCOV24840AA-AB 19 June 2013 recharge events exhibiting much higher peaks and shorter duration. Krogh (2012) describes the impact as showing very abrupt recession of water levels compared to pre-mining conditions. The lowering of the hydraulic head in the sealing layer is caused by increased void space created by surface tensile fracturing. Associated increases in hydraulic conductivity cause the smaller recession times following recharge events.



Mine.

The impact at piezometer WW1 at Angus Place Mine is interpreted using an R comprising rainfall from Katoomba and average pan evaporation from the ABM gridded data set for this location. The hydrograph for piezometer WW1 is shown in Figure 12b. Undermining by LW940 in late 2008 appears to have had negligible impact. However, passage of the adjacent LW950, in mid July 2009, caused WW1 water levels to fall further than would have been expected from natural processes. Water levels following passage of LW950 do not match the rainfall deficit. Water level falls in mid-2011 occur a few months after passage of LW960, and do not appear to have been caused by natural processes.

Krogh (2012) presents the hydrographs for piezometers 15b_H1 to 15b_H3 for Swamp 15b at Dendrobium Mine (Figure 13). 15b_H1 lies over the centreline of LW8, while the others lie over chain pillars between LW7 and LW8. The piezometer screens are understood to be located in the rock sealing layer. Krogh (2012) interprets clear impact at 15b_H2 and 15b_H3 (during passage of the LW7 face adjacent to these locations in October 2011) in contrast to the hydrograph for 15b_H1 which was not undermined.



4.3.2.1 Summary

Using the method of plotting R and hydrographs, a list of impacted swamps and mining geometry can be compiled. Table 1 lists other sites that have been studied, and the interpretation at each site. The data are interpreted to indicate the following:

- Clear impacts on the swamp sealing layer occurred for ground surfaces as high as 86m above the top of the collapsed zone. Results indicate that where the collapsed zone does not intersect the surface tensile fractured zone, the surface zone alone is the cause of cracking in the sealing layer.
- The responses at WE1 and WE2 (East Wolgan Swamp), and at WW1 and WW2 (West Wolgan Swamp), suggest that the most severe impact occurs at the fringes of a panel (in the tensional zone), to a minimum distance of half the panel width (0.5w) past the edge of the panel (that is, a distance of 1 panel width from the centre of the panel).
- LW930 passed alongside WW1 and WW2 in late June 2006. The groundwater level response appears to be due to drought conditions and suggests no impact from mining at distances of 1.6w (WW1) and 1.5w (WW2) from LW930.
- From all results in Table 1, the angle of influence for impacts (defined as the angle whose tangent is the lateral distance to an impact at the surface, divided by the overburden thickness) is a maximum of approximately 45° (WE1 and LW411 Springvale). These impacts are characterised by deformation of the rock underneath the swamp. Impacts were not interpreted to occur at two locations where the angle was approximately 50° (WW1 and LW930) and 45° (WW2 and LW930). These results agree closely with field observations discussed in Ouyang and Elsworth (1993) where

an angle of influence of 42° was interpreted from a large database of dewatering information for water supply wells.

4.3.3 Potential Impacts on the Swamp Substrate

Once a swamp rock sealing layer is invaded by surface tensile cracks, there are a number of possible fates for the swamp ecological community, which may take significant amounts of time to become manifest. The ecology of a swamp is directly dependent on the moisture content of the substrate (this aspect defines the swamp). The fate of the moisture content is dependent on several factors. For example, if a low conductivity clay layer exists between the substrate and the cracked sealing layer, and the clay is not cracked during deformation, drainage of the swamp substrate may be impeded, and ecological impacts may be masked for some time. If the substrate is peat, and no clay layer exists between the peat and the cracked sealing layer, immediate drainage results, since peat usually has high lateral and vertical hydraulic conductivity. If the pre-mining water budget for the swamp is in excess (perennial drainage from the swamp via some water course), then post-mining substrate drainage may be mitigated (but at the expense of discharge to the water course).

In discussing time frames of impact on the swamp substrate and associated ecosystem, resulting from a compromised sealing layer due to longwall mining, NSW SC (2005) reports that changes in vegetation may not occur immediately. With time, impacted areas may experience changes in the original vegetation community, with species being favoured that prefer the new conditions. NSW SC report that the timeframe of these changes is likely to be long-term. While subsidence may be detected in the short term, displacement of susceptible species by those suited to altered conditions is likely to extend over years to decades as the vegetation equilibrates to the new hydrological regime (NSW SC, 2005).

It is likely that if a swamp is located where the collapsed zone and surface tensile zone intersect, the swamp substrate is likely to be completely drained, and permanent change to the swamp ecosystem will result.

4.4 Goaf Salts

The analysis of the height of the collapsed zone, and the areas where this zone connects with the surface tensile zone, identify areas where migration of high salinity water from the goafs can easily exit the surface, depending on the geometry of the mine workings and the post mining hydraulic head field (especially the equilibrium void water levels). The lowest point of the connected workings that intersects the ground surface will be the point where there is the highest risk of discharge of impacted groundwater. Where the top of the collapsed zone reaches to above the base of discharge boundaries (such as Cataract Creek), there will be the potential for impacted groundwater to travel towards the discharge point.

Underground void water levels will recover (from rainfall recharge) to the first point of drainage, therefore the potential for increases in salt concentration is mitigated. However, these processes may take in the order of decades to centuries.

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Table 1. Interpretat	ion of groundwater monitor	ng hydrographs for mining un	der, or adjacent to, swamps at An	gus Place and Dendrobium Coal Mines

Site	Date Undermined (and Longwall Panel)	Position* (panel widths from centre panel)	Panel width (m)	Mined height (m)#	Overburden thickness (m)	Angle of influence (Degrees)	Height of collapsed zone (m above mined seam) ^	Top of Collapsed Zone (mbgl)	Interpretation
KC1	Late May 2008 (LW940)	0.4	260	3.7	295	Over panel	289	6	Clear impact
	Late June 2006 (LW930)	1.6	255	3.7	365	50	295	70	No mining impact.
WW1	Early Nov 2007 (LW940)	0.5	260	3.7	365	Over panel	300	65	No clear impact until passage of LW950 (next panel south)
	Mid July 2009 (LW950)	0.8	270	3.7	375	30	312	63	Impact
	Late June 2006 (LW930)	1.5	255	3.7	365	45	295	70	No mining impact
WW2	Late Oct 2007 (LW940)	0.3	260	3.7	361	Over panel	299	62	No clear impact until passage of LW950 (next panel south)
	Mid July 2009 (LW950)	0.9	270	3.7	375	35	312	63	Impact
14/14/2	Mid Jun 2006 (LW930)	0.6	260	3.7	355	25	298	57	No pre-impact water level data available.
00003	Late Oct 2007 (LW940	0.5	260	3.7	355	Over panel	298	57	No pre-impact water level data available.
WW4	Early May 2006 (LW930)	0	260	3.7	352	Over panel	298	54	No pre-impact water level data available.
WE1	Late Jul 2006 (LW411 Springvale)	1	310	3.2	347	45	290	57	Impact masked by drought effect.
	Early Apr 2010 (LW960)	0.5	295	3.7	350	Over panel	333	17	Reduced number of spikes after LW960, despite LDP04 discharges affecting groundwater levels.
WE2	Early Aug 2006 (LW411 Springvale)	0.9	310	3.2	342	40	289	53	Clear impact (water periodically above ground pre-impact)
	Early Apr 2010 (LW960)	0.6	295	3.7	345	30	333	12	Reduced number of spikes after LW960, despite LDP04 discharges affecting groundwater levels.
12_01	Mid Jun 2011 (LW7)	0	240	3.6	330	Over panel	264	66	Clear impact
15b_H2	Mid Oct 2011 (LW7)	0.6	240	3.6	322	30	263	59	Clear impact
LC3_02	Mid Aug 2010 (LW6)	0.7	240	3.4	332	25	246	86	Clear impact
NS1	Early Feb 2009 (LW950)	0.3	260	3.7	346	Over panel	297	49	Impact masked by very last discharges at LDP06. Following water levels show impact.
NS2	Early Feb 2009 (LW950)	0	280	3.7	346	Over panel	317	29	Impact masked by very last discharges at LDP06. Following water levels show impact.
NS4	Early March 2004 (LW27)	0.5	280	3.7	307	Over panel	311	-4	No pre-impact water level data available.

* In units of panel width, from panel centre. Distance of 0.5 is at panel edge. Distance > 0.5 is off-panel.
^ Calculated using the equation in Tammetta (2012).
Estimate only.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Water Courses

Interpretation of risk areas for water courses is based on examining the calculated zones of protrusion, and taking into account the potential for the cumulative collapsed height to be larger than a simple summation of collapsed zone heights for individual seams (see Appendix A). This is done in a qualitative way (and based on past experience) by conservatively assuming the protruded area sizes represent minimum sizes.

5.1.1 Cataract Creek

A serious risk of cracking from the mined seam up to creek base is assessed for Cataract Creek, in the area shown in Figure 14a. According to calculations by the proponent, and Upper Nepean water supply water balances viewed online, Cataract Creek supplies about 6% of the total water generated by Lake Cataract. The author knows of no post-mining hydraulic head measurements over multiple longwall-mined coal seams. Unfortunately, reduction of risk using historical observations will not be possible until a world-wide database of direct hydraulic head measurements down the profile at (at least) about 10 locations over multiple mined seams world-wide is available. The risk to Cataract Creek is therefore considered immitigable.

Where surface tensile cracking does not connect to the collapsed zone, the surface tensile cracking may cause channel water to fall below the creek bed (entering the zone of increased storage in the surface cracking zone), reappearing downgradient where the surface tensile cracking zone is not of sufficient capacity to carry the flow. Most of the flow might be maintained, with an initial loss to storage created by the tensile cracking zone. The most well-known example of this type of impact is that suffered by the bed of Cataract River downstream of Broughtons Pass Weir in 1994, due to mining of longwall panels. NSW SC (2005) reports that water re-emerging downstream of the impacted zone was deoxygenated and contaminated with iron deposits, with absence of aquatic life. In 1998, a Mining Wardens Court Hearing concluded that 80% of the drying of the Cataract River was due to longwall mining operations, with the balance attributed to reduced flows regulated by Sydney Water (NSW SC, 2005). Further information on this impact is provided in NSW SC (2005).



301800 302000 302200 302400 302600 302800 303000 303200 303400 303600 30380 Figure 14a. Interpreted risk zone for Cataract Creek.

5.1.2 Lizard and Wallandoola Creeks

A serious risk of cracking from the mined seam up to the creek base is assessed for Wallandoola and Lizard Creeks, in the areas shown in Figure 14b. These creeks do not flow into Lake Cataract, however according to calculations by the proponent, and Upper Nepean water supply water balances viewed online, Lizard and Wallandoola Creeks have a combined average flow equal to about 25% of the total water generated by Lake Cataract.



5.2 Swamps

Where a swamp overlies a zone of protrusion, the swamp is likely to suffer a change in habitat (with elimination of the swamp habitat). This is interpreted to be the case at least for the following, but possibly other swamps also:

- Most of swamp CCUS6 at Wonga East (using Figure 4 of BR, 2012) (see Figure 14a).
- Any swamp overlying a Wongawilli seam panel that underlies a Bulli seam panel at Wonga West. The largest four of these swamps at Wonga West are LCUS9, LCUS18, LCUS25, and WCUS4 (using Figure 5 of BR, 2012) (see Figure 14b).

This list is not exhaustive and other swamps may be similarly at risk.

Because of the typical distribution of swamps, and their large number over a typical mined area, stakeholders may wish to consider a probabilistic approach to impact assessment and potential cost to

society. GE (2009) conducted a socio-economic assessment of the proposed Bulli Seam Operations (at Appin and West Cliff collieries). Based on questionnaires posed to the public (for the Bulli Seam Operations), and results from a similar assessment for the Metropolitan Colliery, the community value associated with impacted swamps was estimated to be \$2M per ha. If this cost is assumed to apply to a swamp with 100% probability of irreversible ecosystem change (elimination of the swamp habitat), then values may be developed for other probabilities of elimination, for mining outside zones of protrusion, and applied to the summed swamp areas in the entire proposed panel footprint. Typical peer-reviewed subsidence parameters estimated in the course of an environmental impact assessment, combined with a relationship between these parameters and observed impacts, may be one of several approaches to estimating probabilistic costs.

This approach mitigates the uncertainty involved in attempting to predict the potential ecological change for each individual swamp. Instead, the approach adopts some percentage, based on available historical observations in the Western and Southern Coalfields, as a best estimate of the proportion of the total swamp habitat likely to be eliminated over a proposed mine area (for example, in the Wonga West area as a whole). The monetary value associated with the adopted probability for an area can then be used in a cost-benefit analysis of the return (monetary, aesthetic, etc.) to society provided by the following two competing processes:

- Continued swamp survival.
- Longwall mining.

The method does not preclude the option of individual analysis of larger, more significant swamps, if required.

5.3 Numerical Groundwater Flow Simulation

Using a calibrated model, numerical simulation is appropriate for calculating the reduced baseflow to, or increased seepage from, water courses and Lake Cataract, resulting from drawdown in hydraulic heads underneath these features, caused by mining. Common algorithms employed for these simulations assume no catastrophic deformation (however some, such as FEFLOW, can incorporate time-varying hydraulic parameters). The models can calculate drawdowns resulting from imposed hydraulic head boundary conditions (that may vary with time) within cells or elements.

5.3.1 Model Calibration

The current model is considered uncalibrated and model results cannot be used for impact assessment. If the proponent wishes to assess impacts using model results, the model will require simultaneous transient calibration to measured hydraulic heads (throughout the depth profile), estimated baseflow to water courses, and measured void discharges, as has been undertaken for other mines in the Southern Coalfield. Sufficient data are available for this to be undertaken, and to significantly reduce uncertainty and improve the reliability of model results. In conjunction with hydraulic heads, simultaneous calibration of surface discharges and deep discharges is a vital way of attempting to calibrate the crucial vertical hydraulic conductivity distribution of the subsurface, and the degree of insulation afforded by this distribution between shallow and deep flow processes.

To obtain a starting heads distribution, for the transient calibration period, that will not destabilise at commencement of simulation (severe departures over the initial period from incompatible parameters), a pre-calibration transient model is likely to be required.

A model water balance will need to be provided for the calibration period.

5.3.2 Assessment of Groundwater Exchange with Lake Cataract

Potential leakage induced from Lake Cataract will require a probabilistic assessment using the transiently calibrated model, as has been undertaken for other mines in the Southern Coalfield. This will require the probabilistic variation of key parameters (using random realisations of the parameter fields). Simple variation of the conductivity value for large model conductivity zones is not acceptable, since the geometric mean is then compromised. It is suggested that hydraulic conductivity, the single most important dictator of flux in models of this nature, be used as the perturbed quantity, by using the local and regional packer test databases to generate geometric means and standard deviations over various depth intervals, and then generating random realisations for input to the model mesh.

5.3.3 Time Constraints for the Proponent

It is understood that the proponent is under time constraints to ensure continued operation, and that the required numerical simulation cannot be completed prior to submission of its preferred project report (PPR). This should not cause difficulties since the processes that are the focus of the numerical simulation take many years to develop and attenuate.

Figure 15 shows typical model-calculated mine inflows and lake seepages (induced by the mining), for a groundwater system slightly modified from an actual mining situation in the Southern Coalfield, with mining occurring at a depth of about 300m. Mining and goaf pumping continue for 18 years (at which point goaf pumping ceases), however the peak seepage induced from the lake is not achieved for 35 years. This response is due to the anisotropic nature of the media between the goaf and the surface water body, and the distance between them.



Figure 15. Model-calculated mine inflows and lake seepage for a typical longwall mining situation in the Southern Coalfield. The duration of induced lake seepage is far in excess of goaf inflows.

A reasonable course of action would be that stakeholders allow an extension of three months for assessment of groundwater impacts, at which point the proponent must provide the groundwater impact assessment according to the recommendations given above (assuming the calibration is successful). The proponent can be allowed to continue operations between the submission date for the PPR and three months from notification being given to the proponent to undertake the recommendations above, subject to a condition that the proponent provides results within the allotted time frame, from a successfully calibrated model. The effects being modelled are long-term, and an extension of a few months, particularly at the beginning of mining, will make minimal difference.

5.4 Monitoring

To assist with model calibration, drawdown information should be sourced from:

- If available, groundwater monitoring data collected during mining of the Balgownie seam longwalls.
- Installation and monitoring of a multiple device installation located on the northern edge of LW6 somewhere near the start (but not at the start), based on the position of the working face at the end of April 2013. The most important information will come from mid range strata such as the Bulgo Sandstone and adjacent units.

For the purpose of swamp impact assessment, the proponent may wish to install a multiple device installation over the centre of a mined longwall to compare subsequent monitoring data to the calculations made for the height of the accumulated collapsed zone in the separate analysis above. Given the equivalence between the height of desaturation and the top of the zone of large downward movement, a multiple point borehole extensometer array could also be installed, but over an unmined panel.

With the present state of knowledge, it is unlikely that sufficient field measurements could be obtained by the proponent, prior to completion of the groundwater impact assessment, to justify an assessment attempting to reduce the risk to Cataract, Wallandoola, and Lizard Creeks from impacts caused by the proposed development.

5.5 Goaf Salts

High salinity water from the goafs might easily exit the surface wherever the collapsed zone intersects the surface tensile cracking zone, depending on the geometry of the mine workings and the post mining hydraulic head field (especially the equilibrium void water levels). The lowest point of the connected workings that intersects the ground surface will be the point where there is the highest risk of discharge of impacted groundwater. Where the top of the collapsed zone reaches to above the base of discharge boundaries (such as Cataract Creek), there will be the potential for impacted groundwater to travel towards the discharge point.

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For and on behalf of Coffey Projects Pty Ltd

Paul Tammett

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Important information about your Coffey Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give

preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.



Important information about your Coffey Report

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

Data should not be separated from the report*

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way.

Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment.

Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

* For further information on this aspect reference should be made to "Guidelines for the Provision of Geotechnical information in Construction Contracts" published by the Institution of Engineers Australia, National headquarters, Canberra, 1987.

Appendix A

Logic for Accumulation of Collapsed Zone Heights

Accumulation of Individual Collapsed Zone heights

Collapsed zone heights for full extraction workings in single seam operations have been estimated using the results of Tammetta (2012). In a multiple seam mining situation, the total height of the collapsed zone is assessed by considering two extremes.

In the first extreme, two identical seams are separated exactly by H, so that H for the lower seam touches the floor of the upper seam (assuming identical panel widths and mined heights, and a small variation in the $d^{0.2}$ term). In this situation the total height of the collapsed zone above the lower seam is 2H (arithmetic accrual).

In the second extreme, the two seams are adjacent. If, theoretically, they were to be mined simultaneously, then H due to both seams would be about 2.5H (assuming a mined height of 3.1m per seam). If each seam was mined at different times, the total H could be less than 2.5H (but not less than 2H).

The assessment in the report assumes a linear accrual. However, in identifying areas of risk to water courses, the interpretation takes into account the potential for the cumulative collapsed height to be larger than an arithmetic accrual of collapsed zones for individual seams, but only in a qualitative way (and based on past experience) due to an absence of direct measurements for these situations.

Pillar Crushing

Crushing of remnant pillars due to proposed mining is likely to increase collapsed zone heights. However, in an assessment of the potential for the extraction of the proposed Wongawilli panels to induce catastrophic pillar failure between Balgownie Seam panels 6 and 7, SE (2012) concludes that it is unlikely to induce this type of failure in the Balgownie and Bulli Seams. For calculating H, this information is used to support the assumption that pillars in the Balgownie and Bulli Seams remain largely intact following mining of the Wongawilli Seam.

SE (2012) also concludes that, based on surface subsidence measurements for the Balgownie longwalls (above the maximum subsidence predictions for the Southern Coalfield), pillars in the Bulli seam overlying these panels are likely to have failed. This has been taken into account in designation of full extraction blocks for the Bulli Seam.