Wallarah 2 Coal Project

Review of the Mackie Environmental Research Modelling Report, field evidence and stakeholders comments

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1.0 Introduction

In July 2010 Kalf and Associates Pty Ltd was requested to conduct a peer review concerning the adequacy of the groundwater studies produced by Mackie Environmental Research in October 2009 for the Wallarah 2 Coal Project (W2CP) Environmental Assessment. The instructions were issued on behalf of the proponent of the W2CP.

The review was required to consider:

1. the suitability of the database (hydrological, geological, geophysical, geotechnical, etc) for hydrogeological assessments;
2. the conceptual hydrogeological model developed for the project having regard for interdisciplinary findings (geological, geotechnical, hydrogeological, etc);
3. computer simulation and impact prediction of proposed long wall mining;
4. strategies for longer-term monitoring of groundwater systems; and
5. the relevance and significance of issues raised by stakeholders in submissions to the Department of Planning in response to the exhibition of the Environmental Assessment.

This review report first provides some general comments about the Mackie report and the material to be covered, and then proceeds to address points 1 to 5 above followed by conclusions and considerations. Three Appendices A to C have been included that give more detailed analysis and/or discussion about field case evidence with summaries and comments that appear in the main body of the report. A fourth Appendix D covers the Mackie monitoring and verification recommendations as set out in his EA report (Mackie 2009).

For the preparation of this document Dr Frans Kalf (Kalf and Associates Pty Ltd) was provided with a copy of Dr Colin Mackie's October 2009 report. Also supplied were copies of Wyong Shire Council consultant's review report (Pells, Sullivan and Meynick 2010 - referred hereafter as the PSM review),a review by the New South Wales Office of Water (NOW 2010 - referred hereafter as the NOW review) and a review document authored by the Department of Environment, Climate Change and Water (DECCW 2010).

In addition, interviews were held with Dr Mackie in the KA office on the 13 July 2010. A site visit to the W2CP Tuggerah office was also conducted on the 21 July 2010 where discussions were held with Mr. Keith Bartlett and Mr. John Edwards - Wallarah 2 project geologists. During that visit exploratory drill core was also examined at that office on the same day. High-resolution photographs were later requested for all exploratory bores in the alluvium along the major creeks.

Several papers and documents were also obtained and researched and referred to herein. These references are listed at the end of this report.

On the 8th October I met with Dr Mackie. He presented modifications and results of his updated model. On the 13 October 2010 I received a letter from Dr Mackie confirming his presentation discussion in my office and giving further details of the model modifications, computer results, figures/graphs and supporting geotechnical modelling data.

In this review I have used both Mackie documents (2009, 2010) as listed in the references at the end of this report. The original Mackie report (2009) has been referred to herein as the EA Mackie report while the other document is referred to as the Mackie update report. The various stakeholders comments examined were of course based on the original report (Mackie 2009) and have not had the opportunity of revision based on the updated model modifications. I have however examined the original stakeholders comments and where it is evident that these comments would not have been altered significantly by the Mackie model update I have proceeded to provide my assessment about those review comments.

2.0 The Mackie Modelling Report - General Comments

The EA Mackie report overall is quite detailed and presented and documented in a professional manner in my opinion. The report covers the calibrated groundwater steady-state condition, admittedly using limited monitoring water levels. However, the use of a large database of core and packer test permeability[1] and well known hydrogeological principle of undisturbed water levels in a hard rock environment have produced a very plausible modelled regional pre-mine watertable / potentiometric surface[2].

The adopted parameters and conceptual model adopted for predicting impact due to mining have been examined herein in some detail and compared to some relevant existing data from disturbed (due to coal mining) and undisturbed strata bore sites in the Southern Coalfield of NSW and also from results of mining under the Cataract Reservoir in the same area. In addition the hydrogeological studies at Cooranbong, the Wyee State Mine, and drilling for the Gosford/Wyong emergency water supply on the central coast of NSW have also been assessed.

Much of the criticism by stakeholders leveled at the Mackie assessment and model is misplaced and primarily due to misunderstandings about issues concerning the model itself; calibration; the geological strata and, in particular, lack of acknowledgement or understanding about the anisotropic[3] nature of the permeability distribution that would occur in the Narrabeen stratigraphy disturbed by mining. Some statements in one of the stakeholder's reviews are quite misleading.

2.1 Suitability of the database for hydrogeological assessments

Geological and monitoring data base

A large drilling database has been collected by the W2CP mining company Kores Australia over some years comprising some 382 bores within initial 2-kilometer grid spacing and a finer 500m spacing within the coarser grid in several regions of the site area. Most holes were cored to full depth through the so-called Narrabeen sedimentary geological strata down to the Fassifern coal seam at depth. Thirty of these holes were scanned using an acoustic scanner to detect any joints and to determine stress directions.

The Mackie report has noted that the drilling of suitable groundwater monitoring holes has been hindered for some years because of lack of access to proposed drilling sites within the mining

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[1] In this report, for convenience, the term permeability has been used instead of hydraulic conductivity. Hydraulic conductivity is the more correct term used in hydrogeology since it includes the fluid properties density and viscosity in the definition as well as the properties of the matrix or fractures of the strata. If reference is made therefore to the strata matrix or fractures system alone the term intrinsic permeability is implied.

[2] Potentiometric surface - sometimes referred to as the piezometric surface, that is the total hydraulic head in the rock formation.

[3] Anisotropic - with significant different horizontal and vertical permeability in the strata profile as opposed to isotropic having the same horizontal and vertical permeability. It also refers to fracture frequency directional differences in geological and geotechnical engineering studies. (Harrison and Hudson 2000).

area. It appears this occurred after the hand over of the site from BHP-Billiton to Sydney Gas and before the handover to Kores. However, Kores has recently purchased a property in the Dooralong Valley (Jilliby Jilliby creek alluvial flats) where a line of five multi-level piezometers was constructed in March 2010, that has been monitored since that time. In addition, there are a number of older bores spread over the proposed mining area where some records from about 1998 to 2001 are available. The location and details of these boreholes is given in the EA Mackie report.

Although the extent of monitoring data is limited, the area has not been subjected to previous mining, and hence the groundwater system in the region has remained relatively unchanged except for limited fluctuation of the watertable at shallow depth due to weather variability over the intervening period. This is evident from the early bore water level records available (Mackie 2009) that show very little water level variation particularly at depth. This would very likely still be the case in these bores up to the present time.

In hydrogeology, the groundwater system in the area can be said to be in a pre-mine 'steady state' condition if there has not been any major disturbance to such a system. This provides the starting conditions for a mine impact assessment model. A groundwater principle of hydrogeology can then be used to assist in calibrating this starting set of water levels. This principle has been proven in practically all geological hard rock environments namely: that the watertable or regional groundwater head (potentiometric surface) is a subdued replica of the surrounding topography. Variations caused by elevation differences in the topography in gullies and along creeks and rivers will therefore be mirrored in the regional watertable. Under these conditions the watertable in lower lying areas is situated some meters below the ground surface due to evapotranspiration[4] and above ground if artesian[5] conditions occur due to adjacent elevated terrain. This principle can greatly assist in this task even without a large array of monitoring bores, which is quite often the case in mining sites in my experience.

Groundwater modelling of the mining together with data on strata permeability can then be readily superimposed on this 'steady state' set of ground water heads over the region. This is standard practice. This was the principle applied to modelling undertaken by Dr Mackie with the earlier existing bore data (and more recent water level data) used to calibrate the heads at several locations. The results are given in his Figure 8 and in my opinion is a reasonable fit to the existing water level data and therefore a very plausible distribution of the pre-mine potentiometric surface over the region.

[4] The combined processes of evaporation from the soil and trees and other foliage.

[5] Artesian - where the head of groundwater lies above ground level and causes groundwater to flow out of a bore.

Pressure losses created by mining in and around the extracted coal seam panels[6] will locally change this 'steady-state' regime. Thus groundwater monitoring of the pressures and water table and stream flow will therefore become relevant once mining begins. It will be during this period that so called transient state simulation/calibration will therefore become relevant.

It is agreed that before mining begins, it would be desirable therefore to install more additional monitoring sites to obtain the pre-mine database of water levels for such transient analysis. It is understood that it will be some 3 years before actual mining begins during the construction of the mine decline and mine site facilities. Hence there will be ample time for such a monitoring network to be established provided of course that access can be gained from Council and local landholders. Further discussion on monitoring is given in that section in this report.

Geotechnical Database

A large geotechnical database has been assembled for the project. Not all of this material will be reviewed here except that which is relevant to the groundwater issues at the site.

The first of this data concerns the alleged presence of a geological fault that has been claimed to lie along the orientation of Jilliby Jilliby creek in the vicinity of its confluence with Little Jilliby Jilliby creek extending some distance upstream along the main creek channel from this point. Discussion with Kores geologists Mr. Keith Bartlett and Mr. John Edwards has indicated that all of the geological and geotechnical data including a number of 2D seismic survey profiles extending upstream across the main creek has not identified any such fault. The direction (SSE) along which the Jilliby Jilliby Creek drains the area is very likely controlled by the strike (the orientation of outcrop) of the underlying surrounding hard rocks beneath the creeks alluvial flats, according to these geologists. Mr. Keith Bartlett (2007) prepared a file note concerning this issue.

As well as analyses of rock properties, packer[7] tests were carried out on 31 of the exploration bores within the project area. Laboratory permeability and elastic storage was also determined using numerous core samples.

Strata Control Technology (SCT) at the Wallarah 2 mine site Hue Hue area has conducted Geotechnical modelling of fracture and bedding shear/delamination development during panel

[6] Panels - Rectangular shaped slabs of excavated coal from the coal seam. These panels are separated by so called chain pillars or thinner intervening unexcavated coal that lie between each panel.

[7] packer tests - tests to determine the horizontal permeability of the rock formation (see later footnotes for a more detailed description of the procedure).

removal using the FLAC2D computer code. A discussion of the implications of this modelling on groundwater flow in the disturbed Narrabeen strata due to mining is provided herein at the end of Appendix A.

It is evident that the geotechnical data is extensive at this site and adequate to include in any groundwater model impact assessment.

2.2 The conceptual hydrogeological model

The conceptual model used in the Mackie report is one that is acknowledged worldwide where coal mining occurs overlain by a relatively thick sequence of interbedded sandstone, shale, siltstone and claystone strata.

It is relevant at this point therefore to first present the evidence and conceptual models presented by Booth (2002), Reynolds (1977), Forster (1995) and additional evidence of more recent mining impacts beneath the Cataract Reservoir in the Southern Coalfield NSW, and the NSW Central Coast Wyee State Mine as validation of the conceptual model.

The Justice Reynolds report (Reynolds 1977) presents the results of a Commission of Inquiry that deals with mining under the large storage reservoirs overlying the Southern Coalfield of NSW (A detailed discussion and analysis is given in Appendix A).

The successful longwall mining under the Cataract Reservoir is reported in more detail in Appendix B while Forster (1995) describes the findings at the Wyee Coal mine (Appendix C).

Conceptual model of mining zones

It is known from Australian and overseas experience that the mined out coal seams can cause the development of essentially three zones within the geological strata profile. These zones that extend from those seam(s) are often gradational in their development in the geological profile:

Zone 1: a deep intensely fractured highly permeable zone that corresponds to a caved zone (typically 2 to 8 times the height of the workings) and a fractured zone with bed separation above this (typically 30 to 40 times the thickness of the workings). Groundwater in this zone drains to the mine in the short term.

Zone 2: an intermediate zone, developed in the shale-dominated interval that subsides coherently with less fracturing, maintaining its overall low vertical permeability characteristics.

Zone 3: a near-surface fractured zone in which aquifers are affected by *in situ* fracturing but not generally drainage into the mine from which they are separated by the intermediate constrained layer (Aquitard zone). In zone 3 both tensional fractures may occur at shallower depths with compression of fractures in a central zone beneath the workings.

Booth (2002) quotes a number of researchers (papers dated 1981, 1984, 1986, 1987, 1989, and 2000) that have noted the presence of Zone 2 at Longwall mining sites. He notes that " ***the successful operation of longwall mines under lakes and the sea convincingly demonstrates that a confining zone normally exists and that highly permeable fractures directly connecting the mine to the surface generally do not exist".*** This has been the experience at Longwall mine sites in Australia, particularly in NSW (see Appendix A, B and C)

Reynolds Inquiry Findings

During the period 1974 to 1977, Justice Reynolds as Commissioner (at the time a Judge of the Court of Appeal) conducted an inquiry into the impacts of mining under large storage reservoirs overlying the Southern Coalfield of New South Wales (NSW). The inquiry was initiated because of a long dispute at the time between the NSW Water Board and Department of Mines, to allow mining beneath the water storages. The investigation was comprehensive and involved taking evidence and opinions from local and overseas experts with overseas visits and inspections of coal mining areas in the UK (6 sites), Belgium, West Germany, Italy, France, Canada, 6 sites in the USA and also mines in Japan. While his report deals specifically with underground coal mining impacts to stored waters it is nevertheless therefore also relevant to impacts on surface water stream flow and surface farm dams with respect to groundwater flow towards the mine.

Reynolds (1977) outlines a number of overseas mines examined and he states that they have not had significant or measurable groundwater inrushes[8]. He notes that (at the time) sixteen collieries in the UK were producing 13 million tonnes of coal a year from beneath the sea. Similar examples of successful undersea mining were visited in Canada and Japan with other sites in Chile, Taiwan, Spain and the USSR known to be successful.

Reynolds acknowledges that the conditions at these overseas mines are not entirely the same as those in the Southern Coalfield and that geology at each overseas site is also different. However,

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[8] inrushes - mining term that describes large groundwater inflows into underground mines that either cause major disruption to the mining process or flows that are too great to pump out quickly.

he concludes the discussion on overseas experience in relation to the NSW Southern Coalfield conditions with:

"***There can be no simple comparison. However, the total experience of sub-aqueous mining is not, as has been claimed by some witnesses irrelevant to the present Inquiry and opinions which are based upon a total rejection of the relevance of widespread successful sub-aqueous mining become suspect. What experience has shown is that, by the application of a suitable system of mining of controlled intensity, which has regard to the specific geology and, in particular, to the depth of cover, whether it be under the sea or under fresh water, extraction may take place without water entering the mine. The large variety of stratigraphic sequences which are involved in successful sub-aqueous mining indicates that, given a reasonable admixture of argillaceous*** **[**i.e. shales, claystone**]** ***and arenaceous*** **[**sandstone**]** ***beds, depth of cover is the important factor. The Board's submission that the dominant feature leading to successful sub-aqueous mining is*** **[**only related to**]** ***specific geology is not acceptable. It is only one of a complex of considerations***."

Reynolds goes on to describe in detail the NSW experience. He notes that coal mining under the sea and in estuarine water bodies has been undertaken quite extensively in an area near Newcastle extending about 11 kilometres along the sea coast.

In the Southern Coalfield of NSW he notes the absence of substantial groundwater inflow with most water entering the mine near or at the portal[9] zones. Many of the mines can be described as "dry" with seepage that cannot be readily measured.

Of particular relevance later during the Inquiry were specific hydraulic [packer][10] tests conducted on two boreholes drilled in 1975 at the Kemira Colliery. One bore was constructed where the 300m plus depth of strata above the coal seam remained undisturbed with no mining of the underlying seam and another bore in the same area where a panel had been removed in the underlying seam. This afforded a comparison to be made between the permeability of the rock strata at both sites under both sets of conditions.

Reynolds (1977) concludes from these tests: ***"The findings at Kemira indicate that the problems related to partial extraction and permeability cannot be dealt with or solved by the application of a***

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[9] portal - the tunnel or decline entrance to the mine.

[10] Packer testing involves lowering in a borehole a special hollow rod with openings and inflatable packers at either end of the open section. After packer inflation water is forced under pressure into the formation through the rod openings and a measurement taken of the amount of water that enters into the formation over the length of the rod openings. This is a measure of the transmissivity of the fractures and/or rock matrix over the injection length. Dividing the transmissivity by the injection length yields the average permeability of the injection length of the rock strata. That is $K_h = T/L$ where T is the transmissivity; L is the rod opening length and K_h is the horizontal permeability (hydraulic conductivity) of the strata injected.

simple proposition that three zones will be created in the overburden of which the central is tightly constrained and impervious. However, they do not destroy a view which is based upon experience of sub-aqueous mining that, if the cover is sufficient in relation to the mining method employed, poorly permeable zones in a generally central zone will not be so affected by fracturing, joint opening, joint slippage, bed separation or bed slippage as to lose their retarding qualities."

A detailed discussion and analysis of the permeability distribution conducted as part of this review of the Kemira packer test results at these two bores sites is presented in Appendix A. The analysis indicates that while the results indicate that horizontal permeability in the strata would be significantly affected by mining, the effective vertical permeability is not. Field evidence indicates that the horizontal permeability within the mining zone increases up to a factor of about 100 caused by fracturing of the disturbed strata. Dr Mackie in his update report has included this increase (in a scaling range up to 150 times) in horizontal permeability due to mining in a manner consistent with the geotechnical fracture modelling conducted by STC (2010)

Longwall Mining beneath the Cataract Reservoir

Details of the impact of longwall mining beneath the Cataract Reservoir at depths between 320m and 430m is presented in Appendix B which is an extract from the publication by Holla and Barclay (2000) from an investigation conducted and reported by Reid in 1995. The report concludes that :

"All of the investigations into groundwater monitoring, injection tests and water inflow into the mine indicated no evidence of any significant changes in the hydraulic connectivity from the reservoir to the mine workings."

"The results of [measured] ***in situ strains have been interpreted to mean that the mining has resulted in small deformations at the floor of the reservoir and this has increased confidence in the ability of the strata to remain relatively impermeable.***

"The results of various investigations undertaken by the colliery indicated that surface and sub-surface strata disturbance due to mining of the six panels had no detrimental effects on the integrity of the reservoir. On this basis, the next series of panels were designed with changed pillar and panel geometries. Up to the end of 1999, a total of 14 more panels were successfully extracted with panel width varying between 100 m and 150 m and pillar width between 60 m and 65 m."

Longwall Mining at the Wyee State Mine Central Coast NSW

Forster notes (page 4) that ***" it is important to note that the permeability changes measured (if they are not due to packer sealing problems) are predominantly changes in the horizontal permeability, due mostly to opening of bedding planes. Most changes in the vertical permeability cannot be measured*** [except by piezometric response]***since the vertical fractures which caused these changes are normally not intersected by the boreholes."***

With regard to piezometric pressures he notes (page 5): ***" in the upper strata of this borehole the piezometric levels showed very little variation prior to undermining. <u>After mining, the strata above 47 m maintained pre-mining levels</u> and appeared to form an unconfined surface aquifer showing a steadily increasing hydrostatic pressure with depth. The piezometric head in the strata between 47 and 60m fell by about 20m due to undermining then recovered gradually with time to the new pre-mining levels."***

2.3 Computer simulation and impact prediction of proposed longwall mining

The Mackie report uses a computer program known as Modflow-Surfact (MS) to determine the mining impacts on the groundwater system in the region. This program is a more advanced variant of the well-known Modflow program developed by the United States Geological Survey used worldwide for modelling groundwater systems. Modflow-Surfact is a three-dimensional layered model that can handle both saturated and unsaturated conditions, surface stream flow, in varying degrees of complexity, surface and sub-surface mining including also a number of additional simulation options. This code has been used for determining the regional impact of coal seam extraction on water levels and streams at numerous sites in NSW and elsewhere in projects that have received approval from the NSW Department of Planning (DoP).

Dr Mackie has set up the model for a pre-mine steady-state simulation as a precursor for simulating progressive coal seam extraction over the life of the mine including post mine water level recovery. This approach is standard practice. Steady-state simulation of the regional water levels is an acceptable approach as a starting head condition for such a model. The steady-state simulation used a limited set of borehole calibrated water level data, together with a large array of cored samples, core and packer permeability testing to assign horizontal as well as vertical permeability to the sequence of strata overlying the coal seam. In addition the approach used an widely accepted hydrogeological principle that regional water levels in hard rock terrain are determined essentially by topography, that is, that the regional watertable/potentiometric surface is a muted replica of the topography. Net rainfall appears to have been applied to the model rather than gross rainfall with an applied evapotranspiration function.

As indicated this has yielded in my opinion a plausible pre-mine water level over the region for the model (Figure 8 in the Mackie report). Additional pre-mine, insitu fracturing has also been allowed for in the Mackie updated model by extending the increased horizontal fracturing above the constrained zone to near surface.

The model, at present, uses both the drain function to simulate ephemeral streams or the "River" package in the MS computer code for simulating river and creek flow. This is accepted practice as it allows the leakage from main creek channels (that use the ‘River’ package) to be determined in a direct manner. I do not agree with NOW review (discussed later herein) that this approach is too simplified to make such a determination.

The model has adopted a very conservative, completely drained, caving and highly fracture zone 220m above the mined out parts of the seam and also includes in the updated model increased horizontal permeability of the strata in the constrained zone to near surface that lies above it. The analysis of data from the Kemira bore constructed and hydraulically tested during the Commission of Inquiry, and at another mine site, unequivocally shows that this horizontal permeability through the constrained zone can be affected by longwall panel removal. For example this has also been the experience of Forster (1995 -see also Appendix C) for the mined out panels at the Wyee State Coal Mine. However, it is clear from these studies that the effective vertical permeability in the profile would not be significantly affected in the disturbed strata due to longwall mining.

The Mackie updated report indicates that the inclusion of increased horizontal permeability in the upper profile due to mining has some moderate effect on the groundwater flow distribution due to the redistribution of hydraulic gradient but there is essentially no effect on the vertical flow towards or into the mine indicated (Mackie 2010).

The harmonic[11] vertical permeability magnitude in the range 10^{-5} to 10^{-6} m/day adopted in the model I agree is suitable given that the vertical permeability is controlled by the intervening layers of lower permeability between the bedding fractures, separation and shear structures.

[11] harmonic - see Appendix A

The Mackie report has assessed the shallow subsidence effect on the alluvial groundwater system indicating a temporary drop of about the same magnitude as the subsidence (1.3m). A very conservative net recharge to the alluvial flats has been used and hence the recovery time may be shorter than indicated. However, the water level variation would be within the range of natural variation of water levels due to rainfall variability and much less than declines experienced during drought periods.

While dual-porosity modelling has so far not been attempted at these types of mine sites this option should also be explored as additional data is gathered during the early stages of mining at the Wallarah 2 mine site to determine the applicability of such an approach. Such modelling is currently feasible using the Modflow-Surfact code.

The report refers to ***"Constraints to regional <u>finite element</u> modelling"*** in section E8 when it uses a finite difference computer code. Presumably this is a typographical error.

2.4 Strategies for longer term monitoring of groundwater systems

The Mackie report has outlined a comprehensive monitoring and verification-of-impacts program and mitigation in Sections 9.1 and 9.2 of his report. A copy of this for convenience is given herein in Appendix D. I concur with this monitoring program but would also include the following:

Two pre-mining monitoring bores to be centered and separated above each of the initial 125m and 150m wide panels. These bores should be cored and logged (including fracture frequency) in the normal manner and packer tested from the near surface to full depth. Following seam panel extraction these bores may be damaged at depth and therefore replacement bores should be constructed in the near vicinity to the original bore sites and packer tests repeated from the surface to the caving zone. The bores should be logged (including fracture frequency) and then packer tested to determine the increases in horizontal permeability. The new bores should also be completed with multi-depth piezometers to assess strata vertical connectivity.

This process should be repeated with at least one monitoring bore and replacement bore centered within the panel adjacent to the Jilliby Jilliby creek alluvium before mining extends beneath the creeks alluvial flats and after panel extraction.

Dr Mackie in discussion has indicated that the above drilling and testing programme and several other additional bores would be drilled, logged for fracture distribution and hydraulically tested during the initial phases of the mining project. Dr Mackie also indicated that it may be useful to optimise the location of other additional bores with any proposals put forward by SCT in the future.

With regard to possible remediation, farm dams should also be included in the assessment.

2.5 Relevance and significance of issues raised by stakeholders

The Pells Sullivan Meynink Review

Wyong Shire Council commissioned this report as part of the Earth Systems review and it deals with the geotechnical, hydrogeological and hydrological impact of the proposed mining.
Dr P Pells reviewed the groundwater aspects and in particular the EA Mackie modelling description and results. Dr Pells' review (Pells 2010) is referred to hereafter as the PSM review.

1. On page 21 the PSM review makes the following statement: ***"Mackie have used the computer program, modflow, which is widely used for this kind of work that is not a true three-dimensional model. It attempts to take three-dimensional factors into account through a "smearing" process in vertical, one-dimensional columns. However, if the input parameters are appropriate it is considered that modflow is a reasonable model to use to provide guidelines as to likely impacts on the groundwater regime. However, many of these impacts could be calculated using simple, one-dimensional hand calculations, and to some extent the apparent sophistication of modflow can deflect the reader from a proper appreciation of the limitations of such computer modelling."***

   This paragraph seems to reveal a degree of misunderstanding about the theoretical basis of the Modflow-Surfact computer code used and its applications to groundwater flow problems. Modflow and in particular Modflow-Surfact, a more advanced variably saturated computer code variant, is a three-dimensional layered model that can model to any 3D resolution required depending on data availability, computer memory and resources.

   The word ***"smearing"*** is also inappropriate. All numerical models whether finite difference or finite element[12] involve some form of averaging of rock properties at the finite difference cell or element scale. The important point is that such a model applied to stratified layers that occur in association with coal seams, should be representative of the higher permeability zones of the strata layers in the horizontal direction and the lower

[12] Two different methods that subdivide the strata of porous medium into cells or so called elements to solve a set of simultaneous equations of groundwater flow applied to each cell or element.

permeability zones in the vertical direction. In the vertical direction, the lower or lowest permeability of a particular layer or layers in a stratified sequence in disturbed strata due to mining ultimately determines the groundwater flow rate in that direction. Flow patterns that are initially vertical and become horizontal or vice versa over a given time period cannot, in any way, be accounted for using the "one-dimensional hand calculations" suggested in the PSM review.

The notion therefore that one could determine, for example the three-dimensional regional drawdown distribution in a multi-layered variable strata thickness sequence of variable horizontal and vertical permeability and saturated-unsaturated conditions under a variety of boundary conditions using a one-dimensional column manual approach, is invalid.

Determining the vertical leakage using such a one-dimensional column, as apparently used in the PSM review, using packer permeability results would also be wrong because it takes no account that the vertical permeability can be several orders of magnitude less than the horizontal values particularly for disturbed strata as discussed in detail in Appendix A.

2. The report goes on page 19 to compare the Ulan mining site with the Wallarah proposed site indicating that the field results and assumed model results at these two sites: ***" are so diametrically opposed to those of Wallarah 2 that they warrant quoting in this review."*** There does appear to be elements of the dramatic and scare value here in my opinion given that the geological environment of the two sites influenced by mining are not quite comparable. In this context the emphasis on the Ulan site looses some of its puff when the report notes: ***" Even if the Ulan situation is not a compete*** [sic->complete] ***analogy for Wallarah........"***, followed by: ***".. it would seem reasonable that Mackie should seek to integrate the findings from Ulan into the Wallarah 2 studies.*** It seems to me that if the ***"Ulan situation is not a complete analogy for Wallarah"*** ,as admitted in the PSM review, then there would be no valid reason to "***integrate***" the Ulan findings into the Wallarah analysis.

It is better to compare the Wallarah site with some of those coal mine sites in the Southern Coalfield of NSW as has been done in this report. Such a comparison together with many other studies indicates the presence of a retarding zone to vertical flow (i.e. an aquitard zone) between the surface and the coal seam. This is validated by the limited inflows into mines in the Southern Coal Field overlain by a large water storage (e.g.

Cataract Reservoir - see Appendix B, Longwall mining under Cataract Reservoir). However, the PSM review fails to provide evidence for the Southern Coalfield only giving a reference Pells-1993 for further details. This document is not listed in Pell's report reference list.

3. On page 19 the PSM review notes that: ***"the permeability values for most of the strata above the extracted longwalls, and within the confined*** [sic -> Constrained] ***zone, are equal to the substance permeabilities of a rock; therefore Mackie have adopted permeability that is between 10 times and 100 times lower than those measured in the Cooranbong study and in the Wyong groundwater study."*** The term "***substance permeabilities***" is taken to mean the natural insitu, that is, the pre-mine horizontal permeability of the strata. Examining the Mackie adopted model horizontal permeability values indicates that they are in the range 1.8×10^{-5} m/day to 3.4×10^{-5} m/day while the Cooranbong measured values are in the range (Forster 1997) 2.6×10^{-4} m/day in shallower (56 to 62m) Patonga Claystone with remaining deeper strata profile in the range 4.8×10^{-5} m/day to 1.7×10^{-6} m/day. That is apart from the shallow Patonga Claystone permeability value the remaining deeper Narrabeen Group strata at Cooranbong have permeabilities that are about the same or 10 times less than the values adopted by Mackie for the model pre-mine horizontal permeability.

4. Later in the PSM review on page 23 it is not so clear from that report, that the ***"substance permeabilities"*** (that were interpreted herein as horizontal *K* values) would be distinctly different from the vertical permeability values of the strata when it is stated that: ***" the vertical permeability values adopted by the Mackie report for Wallarah 2 model are between 100 to 1000 times lower than values suggested by field testing".*** Apart from the fact that packer tests do not measure vertical permeability, the comment indicates that the PSM review makes no particular distinction between the horizontal permeability *Kh* values, that are those essentially measured using packer tests in the field, and vertical permeability *Kv* of the strata particularly after mining disturbance. As discussed in Appendix A the vertical permeability values are of distinctly different magnitudes because packer tests tend to measure the most permeable parts of the strata in a horizontal direction while vertical groundwater flow is controlled by the layer of lowest permeability in the strata profile.

   For example at the Kemira colliery test bores, the vertical permeability in the disturbed strata is calculated to have a harmonic average value of 5×10^{-7} m/day for a permeability ratio *Kh/Kv* of 1000 or 5×10^{-6} m/day if such a ratio is 100. (Table A1. Appendix A). The higher value is of the same order of magnitude used in the Mackie modelling report.

Thus given a substantial cover of interbedded sandstones, shales, siltstones and claystone the constrained zone severely retards water leakage from the surface towards the mine. The New South Wales Office of Water (NOW) agree with the conclusion about such retarding qualities in their review of the Mackie model report (page 2) ***:" the risk of subsidence-induced inter-connectivity between alluvial groundwater systems and the mine workings may be regarded as minimal".***

The analysis in Appendix A from the two Kemiri bores in the Southern Coalfield indicates that the horizontal permeability of the Narrabeen strata are however affected to varying degrees by mining throughout the profile with horizontal permeability in the constrained zone increasing by up to 2 orders of magnitude (100 times) but as indicated with little change if any in the effective vertical permeability.

5. The PSM review on page 18 notes that the Mackie report has ***" ignored the information given in respect to the natural permeability of the strata above the coal seam and has ignored similar data from the report by Coffeys Partners International (1998) for the Wyong Groundwater Study".*** I have examined the Coffey report in detail and tabulated the packer tests derived (horizontal) permeability values. The arithmetic average for these set of results excluding those for the coal seam is 4.8 x 10^{-4} m/day. However, the majority of the values have a magnitude of 10^{-5} m/day and therefore not surprising the set of values yields a median permeability value of 10^{-5} m/day[13]. The reason for the occurrence of many values of 10^{-5} m/day is because the tests in the Coffey report could not apparently resolve permeability values less than about 4.3 x 10^{-4} m/day. The report notes that:***" For determining the mean K values in m/day cited.. a nominal value of 10^{-5} m/day was ascribed to those values having a K*** [permeability] ***of <*** [less than] ***4.32 x 10^{-4} m/day."***

   Clearly the horizontal permeability magnitude is similar to the Kemira bore K7 pre-mine horizontal permeability test values (Arithmetic average = 7 x 10^{-5} m/day; Median = 4.3 x 10^{-5} m/day) and those in the Cooranbong investigation (Arithmetic Average = 8.5 x 10^{-5} m/day, Median = 7.7 x 10^{-5} m/day). Since the strata permeability is anisotropic the vertical permeability is likely to be 100 to 1000 smaller than the horizontal for disturbed strata for the reasons outlined in detail in Appendix A. For disturbed strata due to mining it could be expected that the harmonic average vertical permeability would lie in the range adopted by the Mackie model.

[13] The arithmetic average in this case is incorrectly weighted toward the few larger values in the set. The median gives a better measure of the most common values.

6. On page 22 the PSM review notes that ***" The Mackie assumption as to the absence of fractures within the bulk of the Narrabeen sequence is also in contradiction to findings of a paper by Cook (2009)."*** It is agreed that there is high fracture and porosity in certain areas in the upper Terrigal formation, many kilometres south of the mining site where this formation is a much thicker, but not in ***"the bulk"*** of the Narrabeen strata sequence as suggested particularly within the mining lease. This can be seen from the range of bores depths that have had some limited success and failure. Most of these bores yield only small supplies of variable quality water sourced from irregularly distributed fractures in predominately lower lying topographic sites at depths less than 50m. For example the NOW registered bore details listed by Mackie (2010) have a median depth of about 30m and a median bore yield of about 0.8 L/sec. Some bores have failed to produce a useful supply. There is only one deep bore recorded of 131m that yields only 0.2 L/sec.

   The PSM review indicates that Cook (2009) has reported an ***"aggregate"*** yield of 15 L/sec[14] from bores constructed as part of the Gosford/Wyong emergency water supply. This yield is obtained from borefields in the uppermost Terrigal Formation in the strata sequence. The closest bores (Bangalow and Ourimbah creek borefields) are located some 11 kilometres south in a straight line from the southern boundary of the Wallarah 2 lease area.

   More importantly, is that the Terrigal formation does not underlie the eastern part of the proposed mine site area and nor does it underlie the major creeks across the mining lease such as Jilliby Jilliby (Dooralong Valley) and lower part of Little Jilliby Creek (Figure 1 below on page 20). The uppermost formation underlying most of the coal lease and the creeks is the Patonga Claystone formation, the strata that Cook refers to as ***"unprospective".*** Later in the same paper Cook states: ***"The underlying Patonga Claystone was assessed to have low potential for the discovery of useful flows of groundwater for the purpose. In addition, the quality of groundwater is generally poor with common high salinity levels."*** That is, the Patonga formation is of low permeability, and has very limited groundwater potential for the same reasons that the intervening strata down to the coal seam have virtually no groundwater potential as well as having a high groundwater salt content. The Terrigal formation comprising mainly sandstone only occurs along the elevated terrain in the western part of the mining lease with a groundwater potential that would be far less favourable.

[14] It is to be noted that the horizontal permeability of the Terrigal formation at these localised fracture bore sites zones is in the range 0.9 to 35 m/day, some many thousands of times greater than the bulk of the Narrabeen strata that underlie the mine site.

Figure 1 The *"unprospective"* Patonga Claystone formation underlying the majority of the mine site area and the major creeks (Taken from Mackie 2009 Figure 4)

Figure E4 verifies this in the EA Mackie report showing interpreted horizontal permeability profile for bore B250W300 that penetrates this formation at an elevated site. The profile shows no major difference between the Terrigal Formation horizontal permeability and the underlying Patonga formation. Any water bearing strata in the Terrigal formation would tend to be perched and hydraulically isolated from mine influence at a height of more than 500m above the seam (Figure 1). Therefore it would not be affected by panel extraction. These are the findings in a similar strata profile in the Southern Coalfield of NSW (Merrick 2009) where elevated groundwater circulation systems in the Hawkesbury Sandstone are perched water-bearing strata unaffected by mining.

Hence the reference to the Gosford/Wyong water supply site by the PSM review and the implication that the apparently localised highly fractured nature of that rock formation at these distant bore site locations would apply over the mine site is quite misleading.

7. The PSM review (page 21) also refers to a study done by Coffey and Partners in 1980 by MacGregor who inspected ***"by helicopter, boat and by foot"*** exposures of rock along cliff lines in the South Coast to assess the fracture and joint frequency and distribution of the Narrabeen strata. While of interest, to suggest that these de-stressed and weathered rock exposures would reflect the actual geological structures that would occur deep within the bulk of the rock mass away from the exposed cliff faces is invalid.

8. On page 24 the PSM review states: ***" Both the Mackie reports and the MSEC report seeks to dismiss the substantial evidence from the Southern and Western coalfields to the effect that the zone of near surface cracking is created within the rock strata that is substantially deeper than 10 to 20 m and has had major impacts on certain streams and rivers such as the Cataract river and the Waratah Rivulet. Evidence of cracking being deeper than 10 to 20 m included the emission of substantial quantities of methane into the bed of the Cataract river. This certainly came from depths greater than 20 m."***

Vertical cracking near the surface can occur but these fractures are due to surface subsidence tensile forces that are known and agreed to occur at relatively shallow depths, but not at all mining sites. Holla and Barclay (2000) indicate that at the Cataract River the gorge floor cracked at several locations but that surface cracking already existed prior to mining due to pre-existing regional stress field created during the formation of the gorge (or at least were in a stressed state for this to readily occur). The cracks were shown to be unconnected to the mine with an estimate that surface cracking ***" might extend approximately 10m to 20m below the surface. There was surface water leakage to the shallow water table under the river and this leakage could be controlled by***

the [vertical] ***permeability of the Hawkesbury Sandstone. Monitoring of piezometers installed in the river indicated that the regional water table had not moved as a result of mining.***

Box notch weir was installed to monitor flow along the river due to a controlled release of 5 ML per day over the Broughtons Pass Weir. The study indicated that there were surface water losses attributable to the mining and natural causes amounting to 1.5 ML per day. These water losses, however, contributed to subsurface flow within the shallow groundwater system, which was connected to the Nepean River flow. There were no total losses to the river flow system, as all the water eventually flowed into the Nepean River. " (Holla and Barclay 2000 pages 95-96).

Methane outflow at the ground surface is not necessarily immediately sourced directly from the coal seam but may be present in the upper layers of the Narrabeen strata as verified by Cook (2009) who found methane and carbon dioxide de-gassing present in the uppermost Terrigal formation during water supply pumping tests. Gas mobility is also much greater than water having a much greater hydraulic conductivity in the same strata than water due to differences in density and viscosity.

Finally, the fracture simulations conducted by SCT/MSEC (2010) (See Appendix A, Figure A2) show that shallow vertical fractures with slightly higher vertical permeability only occur sporadically in the Hue Hue area W2CP profile within 10m to 15m from the surface.

The Now Review

1. The report notes:***" surface flows are strongly dependent on shallow alluvial groundwater, which provide hydraulic support and salinity buffering to the surface flows."*** The meaning of this statement is not entirely clear. Presumably the so-called ***"hydraulic support"*** means perhaps that groundwater in the alluvium can flow back to the creek or river during low flow periods thereby maintaining baseflow in the stream. The phrase ***"salinity buffering to the surface flows"*** also possibly means that flow from the alluvium to the stream would maintain surface water quality. However, it is known that the salinity of groundwater in the alluvium is generally of poor quality with slightly brackish groundwater at and near the surface increasing to brackish and then saline groundwater at depth. Hence it seems likely that there would be higher salinity water entering the streams during low stream flow periods, which would be the opposite result to what would be a desirable outcome. Hence the ***"hydraulic support"*** and ***"salinity buffering"*** would therefore seem to be a disadvantage for maintaining good stream flow water quality at

Wallarah 2 mine site.

In this context a further statement (page 5 para 4) the NOW review notes that the water quality of both alluvial and hard rock groundwater are similar and that this therefore indicates: ***" a slow upward leakage of <u>brackish</u> groundwater from deeper hard rock aquitards in inland areas. This information would support Now's view of the greater interaction of groundwater discharging from hard rocks into the alluvium and providing hydraulic support to, and providing some level of base flow contribution to surface water sources. "***. This again is a curious conclusion as noted previously since it would seem of much greater benefit if brackish water is actually prevented from entering the stream channel.

Irrespective of the water quality pre-mine condition, the overriding issue is that the groundwater water levels in the alluvium, in the longer term overall, are unlikely to be substantially influenced by mining. First, because there would not be any significant measurable groundwater volume in the alluvium that will drain to the mine (as acknowledged by NOW), and secondly once a given volume fills some shallow fracturing below the base of the alluvium, natural recharge to the alluvium will allow the groundwater to recover over time.

As indicated previously the EA Mackie report indicates that the temporary drop in water level in the alluvium would be the similar to the magnitude of subsidence (up to 1.3m). It has to be kept in mind that this drop would be well within the range of the water table elevation variation due to seasonal rainfall variability and far less than water level decline during extended drought periods.

2. NOW have stated (page 2) that: ***" Now considers that the MODFLOW-SURFACT model developed for the proposal to be deficient for robust predictions of groundwater interactions in the post-subsidence conditions. NOW has significant reservations as to the adequacy of the model, as it is uncalibrated to its transient and steady state modelled outputs, and is based on a simplified conceptual framework of groundwater interactions between the alluviums connected to the Wyong River and Jilliby Jilliby creek and tributaries".***

   Firstly let me make it clear that I do not agree that the Modflow-Surfact model per se is deficient for the purpose of assessing the post-subsidence conditions at sub-surface coal mining sites. This computer code is used worldwide for groundwater assessments and impacts and in particular has been used in NSW for a number of sub-surface coal mining projects that have been approved by the Department of Planning of NSW (DoP) on the basis of the modelled results and advice tendered on the basis of those results. The computer code has accepted routines (of varying complexity) for assessing aquifer stream interactions that have also been part of the model studies approved by the DoP.

The Mackie update report has also indicated that sensitivity studies between the creek line and the host alluvium were conducted as described in Appendix F of the EA report.

3. There appears to be some misunderstanding regarding the purpose of and aim of the model calibration process in the NOW review. The pre-mine steady state case has actually been calibrated at Wallarah as discussed previously and which I consider to be a plausible result suitable for predicting regional mining impacts. Some sensitivity analysis was also conducted during this simulation as discussed in the Mackie report for rainfall input. The more important parameter database used for this calibration is very extensive, comprising a large number of packer tests and laboratory horizontal and vertical permeability test on core samples.

   It needs to be understood that transient calibration is suitable where there has been substantial stress (e.g. previous mining, pumping) applied to the groundwater system. However, this has not been the case at Wallarah. The groundwater system remains; pre-mine, in an essentially steady state condition. There are of course water level variations due to weather variability (i.e. rainfall affecting shallow piezometers). However, to undertake calibration of these changes would not be critical at this stage to making an assessment about the impact of mining. Vertical permeability would be by far the most sensitive parameter compared to slight differences in pre-mine water levels. Storativity is well known from experience in this type of environment and specific storage has been independently determined from Lab tests as described in the Mackie report.

   Once mining begins of course transient calibration will become important part of the model validation process. There will be ample time to establish a more detailed monitoring network once approval is given for access, given that it will be some 3 years before proper mining of the panels begins. Such monitoring has of course already begun during March 2010 at a particular set of multi-piezometers across the alluvial flats of Jilliby Jilliby creek.

4. The NOW review makes the following comment: ***" Water level monitoring commenced in 1998 and ceased in 2001 and the hydrographs presented showed no real movement in levels over this period raising questions related to the accuracy of instrumentation. "*** That there is very little water level variation in piezometers at depth is very often evident at many pre-mining sites in relatively low permeable strata. This has also been observed in the Southern Coalfield piezometers. Hence I would not agree that it raises " ***questions related to the accuracy of instrumentation".*** Only shallow piezometers would tend to show water level changes due to rainfall, as has been observed in the new piezometers across the Jilliby Jilliby creek alluvial flats.

5. The concern in the NOW review about surface cracking of rock strata and its influence on surface water flows needs to be put into perspective. The geological conditions at the surface or near surface that exist at Wallarah are different than the Southern Coalfield (SC). In the SC the main creeks and rivers channels are predominantly in direct contact with mainly quartz sandstone strata whilst at Wallarah there is alluvial cover overlying (Patonga) claystone strata along the main channels. Thus these channels are not in direct contact with the same underlying rock strata that occur in the SC and hence the mechanism that has lead to some temporary loss and re-emergence of surface flow downstream in the SC sandstones would not occur in this manner. In addition SCT rock fracture analysis (see results in Appendix A) would indicate limited rock fracturing at the stratigraphic rock surface at Wallarah 2 (MSEC/SCT 2010).

   The findings of Forster (1995) are also relevant: ***" testing carried out during the study did not detect any surface effects due to mining. Because the overburden is topped by a layer of weathered rock and soil to a depth of 10 to 15 m in this area, the induced surface strains would have been absorbed by this material without any noticeable effects. If a layer of soil and/or weathered rock covers the ground surface then strain effects will often not be evident in this zone. This assumption is supported by the observation at Cooranbong, where the surface shows little sign of disruption despite having been subjected to tensile strains probably in excess of 8 mm/metre."***

   Reid in 1995, referenced in Holla and Barclay (2000) notes with regard to possible fracturing at the base of the Cataract Reservoir : ***"The results of*** [measured] ***in situ strains have been interpreted to mean that the mining has resulted in small deformations at the floor of the reservoir and this has increased confidence in the ability of the strata to remain relatively impermeable."***

6. In minor tributary gullies underlain by the Terrigal formation elsewhere,(e.g. Little Jilliby creek) the Mackie report has noted: " ***it is possible that surface cracking of hard rock strata in elevated areas may initiate localised redirection*** [temporary loss and re-emergence downstream] ***of surface flows in some drainages leading to fresh water rock hydrochemical interactions ...."*** but that ***" the Terrigal formation hosting these drainages is not known to have historically generated natural iron springs and the potential is therefore considered to be low "*** (i.e. compared to the Southern Coalfield experience.). As noted previously, my assessment is that most of the elevated water bearing strata in the Terrigal formation with a overburden of 400 to more than 500m above the coal seam would not be affected significantly by the mine.

7. NOW on page 2 and 5 are in agreement with the conclusion that there would be virtually no inflow to the Wallarah 2 mine from the surface: ***:" the risk of subsidence-induced inter-connectivity between alluvial groundwater systems and the mine workings may be regarded as minimal".*** And later in the same document ***" the knowledge to date on the extent of goaf[15] fracturing is such that NOW concurs that direct connective cracking between the mine working goaf and that of tension cracking on the land surface is a low likelihood given the depth of mining proposed."***

8. The review notes that: ***"NOW recommends a Planing Assessment Commission to be convened, which includes expertise related to surface hydrology under extractive stress, and surface-groundwater connectivity and interdependence. This should consider NOW's comments provided in Attachment A, and the risks associated with reduced availability of access to surface flows in the event that subsurface redirection of surface and/or alluvial groundwaters occurs."***

   It is of interest to note that a similar expert panel who initially reviewed the project, without the use of a model, indicated that there would be no significant impact on the groundwater or surface water regime at Wallarah, as noted in the Mackie report :
   " Both the WACJV and DPI agree that there are dense, almost impermeable rock strata between the shallow alluvial aquifer and deeper hard rock aquifers of the region. Subsidence cracks in the hard rocks at the base of the alluvium are likely to be limited in number and depth to quickly fill with both groundwater and sediment. Accordingly, the panel concludes that, even if cracks do occur at the base of the alluvium, they are unlikely to allow significant mixing of water from the hard rock aquifers and the alluvial aquifers.";

   "The panel therefore considers that community concerns about the potential for the Wallarah 2 proposal to significantly impact the shallow alluvial groundwater resources of

[15] Goaf - the opening created due to rock collapse immediately above the mined out coal seam.

the Wyong Valleys are unfounded."

9. Issues regarding the scope and timing of additional monitoring before panel mining commences are covered in the main body of the Mackie report (see Appendix D for a copy of those recommendations) with some additions outlined in the next section.

The DECCW Review

This review covers a range of issues. Only comments related to groundwater and the Mackie model and those relevant issues that have not been discussed in previous sections of this report are covered here.

1. The review often describes impacts in a general way but does not always refer to documented evidence on these issues (see examples described later)
2. There are on page 8 several references made to Booth about impacts at underground coalmines that are made without reference to specific site conditions. It is known that these examples are from certain overseas coalmine sites. Thus no direct comparison can be made between the Wallarah 2 site coal strata and the impacts referred to.
3. The reference to papers by Madden and Merrick and Madden and Ross in the recent Sydney Basin conference are not particularly relevant because these studies were confined to the deeper parts of the mined profile where there is acknowledged collapse of the strata above the mined out seams. This effect was covered and included in the EA Mackie model. The references by Madden et al. do not discuss the conditions in the more important constrained zone or at shallow depth.
4. The reference to Booth's comment in the review in the next paragraph that ***" aquifers in the deep fractured zone typically drain to the mine"*** therefore is not disputed, since this is precisely what has been simulated in the Mackie model.
5. In the following paragraph, on the same page, the review quotes additional statements made by the overseas keynote speaker Booth regarding mining impacts at shallow depth. Unfortunately the meaning that is conveyed by Booth is that these impacts *always occur* rather than that they *may occur* depending site conditions, overburden depth, geology, strata permeability and so on, which probably is what Booth meant to say. For example, in Booth's later statement he notes with regard to degree of head loss and water level recovery, that this ***"..varies substantially with topographic (upland or valley) setting, hydraulic characteristics of the aquifer, extent and intensity of deformation, and thickness of the overburden above the mine".*** It is not possible therefore to make a definite inference as to the relevance of the conditions described compared to those that exist at the Wallarah 2 project site.

6. The reference (page 10 para 3) to the Aurecon consultants document regarding the East Wolgan swamp in the review cannot be commented on as the report does not appear to be in the public domain and I have not been able to obtain a copy of that report. But again the question arises whether this site can be directly compared to Wallarah 2 conditions with respect to overburden thickness, and other geological and hydrological factors including weather variability that may also have been an influencing factor at the East Wolgan swamp site.

7. The report mentions the Tahmoor, Dendrobium and Baal Bone coal mining sites but no specific references are given, and no description as to the exact circumstances or conditions at these sites for a meaningful comparison to be made. Statements such as ***" Where it has been measured elsewhere in NSW"*** with water level decline magnitudes quoted of ***"between 3m to 6m"*** are meaningless without report references about the site conditions, mining extent, depth of measurement, where and when these measurements were made and so on.

3.0 Conclusions and Considerations

- The Mackie report overall is quite detailed and presented and documented in a very professional manner in my opinion. The report covers both the calibrated groundwater steady-state using admittedly limited monitoring water levels; however, the use of a large database of core and packer test permeability and well known hydrogeological principle of undisturbed water levels in a hard rock environment have produced a very plausible modeled regional pre-mine water levels.

- The conceptual model used by Mackie Environmental Research for simulating longwall mining uses the acknowledged structural behavior of sedimentary strata overlying longwall coal seam extraction. This includes a caving zone overlain by a major fracture zone; a constrained zone of low vertical permeability above that and finally a surface zone. Updates to the computer model (Mackie 2010) include scaled higher horizontal permeability due to mining in the constrained zone to near surface levels in lower lying areas above the mine footprint. The model also simulates the impact on streams and rivers and determines leakage in a suitable manner in my opinion including sensitivity of permeability between the creek lines and the underlying alluvium.

- Bore permeability testing carried out during the Commission of Inquiry into mining under stored water in the Southern Coalfield of NSW indicates that the permeability in the strata profile, similar to strata at Wallarah 2, is highly anisotropic once the profile is disturbed by longwall mining. This anisotropy is due to the predominate horizontal fracturing, bedding shear and delamination (strata separation) at depth during mining, within the constrained zone. This causes in turn a much higher horizontal permeability in this zone with a retained lower effective vertical permeability, due to the resistance to vertical flow of the intervening layers between these structures. A geotechnical fracture model prepared for the Wallarah 2 project validates this aspect. There is also evidence of essentially limited inflow to sub-surface mines in the Southern Coalfield and mines in the Central Coast of NSW and elsewhere. The updated Mackie model has incorporated these disturbed horizontal permeability distributions.

- The New South Wales Office of Water are in agreement with the conclusion that there would be virtually no inflow to the Wallarah 2 mine from the surface: ***:" the risk of subsidence-induced inter-connectivity between alluvial groundwater systems and the mine workings may be regarded as minimal".*** And later in the same document ***" the knowledge to date on the extent of goaf[16] fracturing is such that NOW concurs that direct connective cracking between the mine working goaf and that of tension cracking on the land surface is a low likelihood given the depth of mining proposed."***
.
- While there is currently limited monitoring, due to a number of reasons, there will be sufficient time to install additional monitoring piezometers, provided access is approved, given that it will be some 3 years during construction of the mine decline and site facilities before actual longwall mining commences. The reported notion that the mine should not go ahead because of limited data and monitoring is not considered to be a valid reason for withholding approval to proceed.

- Dr Pells' review (PSM review) appears to misunderstand the basis and features of the Modflow-Surfact model used in Dr Mackie's analysis. The model is a three-dimensional layered model, does not "smear" the strata model parameters and can if required model to any vertical resolution required including variable saturation.

- The PSM review makes reference to the Ulan mine indicating that the results should be integrated into the modelling of the Wallarah 2 coal project. However, given that the PSM review then admits ***"Ulan situation is not a complete analogy for Wallarah"***, there clearly would be no valid reason to include such findings into the Wallarah analysis.

[16] Goaf - the opening created due to rock collapse immediately above the mined out coal seam.

- The PSM review makes no distinction between the horizontal and vertical permeability of the Narrabeen strata either in a pre-mine or post-mine state. The report therefore fails to acknowledge or understand that the strata is not isotropic but anisotropic and therefore that fracturing during mining is essentially horizontal with leakage from the surface severely restricted because of the effective low vertical permeability controlling such vertical flow. Therefore the PSM review is wrong to assert that the ***" vertical permeability values adopted by Mackie for the Wallarah 2 model are between 100 to 1000 times lower than the values suggested by field testing".*** Apart from the fact that field testing does not determine vertical permeability, the values adopted for vertical permeability in Mackie report are actually of a similar magnitude or likely to be even higher than interpreted from the field tests if there is an understanding about the anisotropic permeability of the Narrabeen Group of interbedded strata under deformation. This is supported by other studies referred to in the PSM review.

- The PSM review makes reference to studies and drilling and testing for the Gosford/Wyong emergency water supply indicating highly permeable zones in the Terrigal Formation implying this is also likely the case at the Wallarah 2 site. The statements are misleading given that most of the site area and main creek channels at Wallarah 2 are underlain by the Patonga Claystone and deeper rock strata that have low permeability and very limited to virtually no groundwater potential with a high salt water content. The investigator of the Gosford/Wyong water supply has noted that the Patonga Claystone formation is ***"unprospective".***

- The New South Wales Office of Water (NOW) review indicates that the main concern is the perceived interruption or influence of shallow mine subsidence cracking on the baseflow in creeks. NOW contend that the alluvial groundwater hydraulically ***"supports"*** and ***"buffers"*** low surface flow in these creeks (even though they are likely to be brackish) and that the Mackie model is not ***"robust"*** enough to make predictions about the effects of these perceived changes. I do not agree with the NOW review that the Mackie Modflow-Surfact model is not ***"robust"*** enough, that is, is not capable of determining the impact, if any, on the shallow alluvial groundwater system.

  The experience by Forster (1995) indicates: ***" testing carried out during the*** [Wyee State Coal mine] ***study did not detect any surface effects due to mining. Because the overburden is topped by a layer of weathered rock and soil to a depth of 10 to 15 m in this area, the induced surface strains would have been absorbed by this material without any noticeable effects. If a layer of soil and/or weathered rock covers the ground surface then strain effects will often not be evident in this zone. This assumption is supported by the observation at***

Cooranbong, where the surface shows little sign of disruption despite having been subjected to tensile strains probably in excess of 8 mm/metre."

Also Reid in 1995 referenced in Holla and Barclay (2000) notes with regard to possible fracturing at the base of the Cataract Reservoir with Longwall mining beneath it : ***"The results of*** [measured] ***in situ strains have been interpreted to mean that the mining has resulted in small deformations at the floor of the reservoir and this has increased confidence in the ability of the strata to remain relatively impermeable."***

- With regard to the likely variation in water level in the alluvium due to subsidence, the Mackie report indicates that the temporary drop in water level in the alluvium would be similar to the magnitude of subsidence (up to 1.3m). It has to be kept in mind that this drop would be well within the range of the water table elevation variation due to seasonal rainfall variability and much less than watertable decline that would be created during extended drought periods

- The review related to groundwater conducted by DECCW and the impacts they say might be created by the Wallarah 2 coal mine are of interest, but are too general and unspecific to enable a satisfactory comparison to be made with those that are likely to occur at Wallarah 2 mine site. Many of the issues raised have already been addressed in the EA Mackie and update reports and field experience at other mine sites as set out in this report.

- My critical review of the modelling and observations contained in the EA report; Mackie "update report" and my study of earlier and more recent computer model results, including field evidence and groundwater impacts caused by coal mine subsidence elsewhere, result in me agreeing with Dr Mackie about the predicted minimal impacts on groundwater due to mining at the W2CP. That is, the likely impacts on shallow groundwater and surface water environments are considered to be low and highly unlikely to affect the water resources of the alluvial lands situated within the Dooralong and Yarramalong valleys.

- I concur with the monitoring and verification program as set out in the Mackie report. (See Appendix D) but would also include the following:

  Two pre-mining monitoring bores to be centered and separated above each of the initial 125m and 150m wide panels. These bores should be cored and logged (including fracture frequency) in the normal manner and packer tested from the near surface to full depth. Following seam panel extraction these bores may be damaged at depth and therefore replacement bores should be constructed in the near vicinity to the original bore sites and packer tests repeated from the surface down to the caving zone. The bores should be cored and logged (including fracture frequency) and then packer tested to determine the increase in horizontal permeability. The new bores should also be completed with multi-depth piezometers to assess strata vertical connectivity.

This process should be repeated with at least one monitoring bore and replacement bore centered within the panel immediately adjacent to the Jilliby Jilliby creek alluvium before mining extends beneath the creek alluvial flats.

Discussion with Dr Mackie indicates the above suggested drilling and testing programme will most likely include additional bores for assessment during the earlier stages of mining. Dr Mackie also indicated that it may be useful to optimise the location of other additional bores with any proposals put forward by SCT in the future.

With regard to possible remediation, farm dams should also be included in the assessment.

4.0 References

Bartlett K. 2007 Structural Control of the Location and Orientation of Jilliby Creek.*File Note 21 June.*

Booth C. J. 2002. The effects of longwall coal mining on overlying aquifers. *In Younger P.L. and Robins N.S. (eds) 2002 Mine Water Hydrogeology and Geochemistry. Geol. Soc, London, Special Publications, 198, 17-45.*

Coffey Partners International Pty Ltd. 1998. Wyong Groundwater Study. *Report for Coal Operations Australia Pty Ltd. No Z302/2-BZ, December*

Cook L. 2009. Groundwater Investigations- Emergency Town Water Supply Gosford-Wyong Councils Water Authority Joint Water Supply Scheme. *Groundwater in the Sydney Basin Symposium, Sydney, NSW. Australia 4-5 August pp 36-48. IAH NSW. ISBN 978 0 646 51709 4*

Department of Environment, Climate Change and Water. 2010. Comments on the Wallarah Coal Project Assessment- only sections dealing with Groundwater Issues and Mackie model. Received by DoP 21 Jun 2010.

Harrison J.P. and J. A. Hudson 2000 Engineering Rock Mechanics Part 2 Illustrative worked examples. *Pergamon .*

Holla L., E. Barclay 2000 Mine subsidence in the Southern Coalfield, NSW, Australia. *Mineral Resources New South Wales ISBN 0 7313 9225 6*

Mackie Environmental Research 2009. Wallarah 2 Coal Project. Groundwater Management Studies. Volume 2 Appendix B, *Environmental Assessment. October*

Mackie Environmental Research 2010. Wallarah 2 Coal Project. Letter report describing modifications made to the Mackie model including computer results. October.

Merrick N.P.2009 Comparative modelling of longwall mining effects using Standard-MODFLOW and MODFLOW-SURFACT in the Southern Coalfield, New South Wales, Australia. *Groundwater in the Sydney Basin Symposium, Sydney, NSW. Australia 4-5 August. pp 236-245. Figure 4. IAH NSW. ISBN 978 0 646 51709 4*

NSW Office of Water 2010 Letter review MP07_0160- Wallarah 2 underground coal project. Attachment A and B. *Letter to P Freeman Director Major Projects Assessments DoP from F Hancock.17 June.*

Pells P. 2010 Review of groundwater issues and Mackie groundwater model. *Pells Sullivan Meynink geotechnical consultants letter report to Earth Systems. Wallarah 2 Coal Project 27 May Ref: PSM1105.TR1 Rev B.*

Forster 1995. Impact of underground mining on the hydrogeological regime, Central Coast NSW. *Pacific Power.*

Forster 1997 Cooranbong Colliery life extension project- Overburden strata groundwater study. *Pacific Power International.*

Reynolds R. G. (1977) Coal mining under stored water. *Department of Mineral Resources Library*

Strata Control Technology (SCT) and Mine Subsidence Engineering Consultants (MSEC) 2010. Subsidence Impact Assessment . Vol 2 Appendix A. W2CP Environmental Assessment.

Appendix A

Justice Reynolds Inquiry into mining under stored water Southern Coalfield of NSW 1974 to 1977 and simulated rock fracturing and vertical permeability at Wallarah 2 Hue Hue Area

Kemira Bores Nos 6 and 7

During the Reynolds Inquiry two boreholes were drilled in the Southern Coal Field region in 1975. One borehole was positioned above a mined out panel whilst a second hole some distance away was drilled through the same formation in unmined area of the site. The objective was to determine the changes, in particular the permeability *K* of the penetrated strata that might have occurred in borehole 6 due to removal of the panel in comparison with the permeability of the undisturbed strata penetrated in borehole 7.

The bores are situated at the Kemira colliery near the Cordeaux Reservoir and were drilled to depths of 273m (Kemira borehole No 6 designated here as K6) and 383m (Kemira borehole No 7 designated here as K7). Borehole K6 was situated immediately above the 117m wide panel extracted whilst K7 was situated about 1.9kms from the borehole K6. Both bores penetrated the Narrabeen strata sequence essentially the same as one another and similar Narrabeen strata (but not exactly the same) as the Wallarah 2 Coal project.

During drilling in both bores, core was extracted as well as packer permeability testing[17]. In the case of K6 the hole was cored from 91.44m to 272.96m a point about 63m above the Bulli coal seam. K7 was cored from 136.37m to 382.93m (the floor of the Bulli coal seam). Bore K6 was cased to a depth of 116.4m to seal off groundwater (within the Hawkesbury Sandstone) above this depth whilst bore K7 was cased to a depth of 136.7m for the same reason.

The report notes that the fracture log (from core) in K7 showed ***" a complete absence of fracturing induced by mining"*** (Reynolds 1977 page 61 para. 2). However in the K6 fracture log showed ***" substantial cracking over the length of the cored section"*** (Reynolds 1977 page 59 para. 6).

The complete and published hydraulic packer test results for the two bores are given in Table 5 and 6, page 61 in Reynolds (1977). An examination of these tables indicates that the constrained zone in borehole K6 based on the boundary of very high permeability immediately above the seam and much lower permeability above this zone lies in the depth range 123m to 242m. A

[17] Packer testing involves lowering a special hollow rod with openings and inflatable packers at either end of the open section. After packer inflation water is forced under pressure into the formation through the rod openings and a measurement taken of the amount of water that enters into the formation over the length of the rod openings. This is a measure of the transmissivity of the fractures and/or rock matrix over the injection length. Dividing the transmissivity by the injection length yields the average permeability of the injection length of the rock strata. That is $Kh = T/L$ where T is the transmissivity; L is the rod opening length and K_h is the horizontal permeability (hydraulic conductivity) of the strata injected.

comparable depth range in borehole K7 is 138m to 249m approximately. Table A1 below presents the drilling depths, tested interval lengths, horizontal and estimated vertical permeability and interval depths divided by the vertical permeability and the respective harmonic, arithmetic mean and median.

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Table A1 Constrained Zone Harmonic and Arithmetic average permeability - Bores K6 and K7 - Kemira colliery Southern Coalfield of NSW

(Table prepared by KA for this review)

Bore K6	Harmonic Average	Constrained Zone				KA July 2010
Depth (m)	Interval z	Kh (cm/sec)	Kh m/day	Kv=Kh/1000 m/day	z/Kv constrained zone	
123.51	6.75	1.70E-05	1.47E-02	1.47E-05	4.60E+05	
132.66	9.15	4.30E-06	3.72E-03	3.72E-06	2.46E+06	
138.76	6.1	1.70E-06	1.47E-03	1.47E-06	4.15E+06	
147.91	9.15	1.30E-05	1.12E-02	1.12E-05	8.15E+05	
157.06	9.15	8.60E-07	7.43E-04	7.43E-07	1.23E+07	
166.21	9.15	6.00E-07	5.18E-04	5.18E-07	1.77E+07	
175.36	9.15	5.00E-07	4.32E-04	4.32E-07	2.12E+07	
184.51	9.15	2.00E-06	1.73E-03	1.73E-06	5.30E+06	
193.66	9.15	1.00E-06	8.64E-04	8.64E-07	1.06E+07	
202.81	9.15	2.00E-06	1.73E-03	1.73E-06	5.30E+06	
211.96	9.15	2.60E-05	2.25E-02	2.25E-05	4.07E+05	
221.11	9.15	6.40E-08	5.53E-05	5.53E-08	1.65E+08	
229.91	8.83	1.70E-05	1.47E-02	1.47E-05	6.01E+05	
236.31	6.1	5.30E-07	4.58E-04	4.58E-07	1.33E+07	
242.15	6.1	2.60E-06	2.25E-03	2.25E-06	2.72E+06	
	125.38			**5.02721E-07**	**2.63E+08**	sum z/Kv
				Harm mean no interval	**4.77E-07**	Harmonic mean Z/Sum(z/Kv)

	Arithmetic Average	Constrained Zone				
Depth (m)		Interval z	Kh m/day		Kh*z	
123.51		6.75	1.47E-02		9.91E-02	
132.66		9.15	3.72E-03		3.40E-02	
138.76		6.1	1.47E-03		8.96E-03	
147.91		9.15	1.12E-02		1.03E-01	
157.06		9.15	7.43E-04		6.80E-03	
166.21		9.15	5.18E-04		4.74E-03	
175.36		9.15	4.32E-04		3.95E-03	
184.51		9.15	1.73E-03		1.58E-02	
193.66		9.15	8.64E-04		7.91E-03	
202.81		9.15	1.73E-03		1.58E-02	
211.96		9.15	2.25E-02		2.06E-01	
221.11		9.15	5.53E-05		5.06E-04	
229.91		8.83	1.47E-02		1.30E-01	
236.31		6.1	4.58E-04		2.79E-03	
242.15		6.1	2.25E-03		1.37E-02	
		125.38	**5.14E-03**	Arithmetic Av no interval	6.52E-01	Sum (Kh*z)
			1.73E-03	Median	**5.20E-03**	Arithmetic Average Z/Sum(Kh*z)

Bore K7	Arithmetic Average	"Pot. Constrained Zone"				
Depth (m)		Interval z	Kh m/day		Kh*z	
137.89-165.44		27.55	8.64E-06		2.38E-04	
172.23		6.4	4.32E-05		2.76E-04	
181.38		9.15	6.91E-05		6.32E-04	
190.53		8.85	9.50E-06		8.41E-05	
199.68		9.15	1.12E-05		1.03E-04	
208.83		9.15	1.56E-05		1.42E-04	
214.93		6.1	7.17E-05		4.37E-04	
224.08		9.15	1.47E-04		1.34E-03	
233.23		9.15	3.89E-04		3.56E-03	
239.33		6.1	7.08E-05		4.32E-04	
248.48		9.15	1.47E-05		1.34E-04	
		109.9	**7.73E-05**	Arithmetic Av no interval	7.38E-03	Sum (Kh*z)
			4.32E-05	Median	**6.72E-05**	Arithmetic Av Z/Sum(Kh*z)

The test results above need to be put into perspective with regard to vertical *Kv* and horizontal permeability *Kh* of the strata

Packer tests are tests that inject water laterally under pressure into borehole strata over some given interval length. In the case of the bore holes K6 and K7 the injected interval varied between 6m and about 9m. The injected interval would likely have had layers with relatively much higher permeability than the interbedded layers with much lower permeability. Hence the packer test results only tend to reflect the higher permeability of the strata layers in a horizontal direction. Such tests do not directly measure the vertical permeability of a stratified rock sequence.

Reynolds (1977) in a sub note in his tables (of which Table A1 above is an extract) indicates that permeability is : ***"Calculated on the assumption that tested interval is isotropic*** (the same in both horizontal and vertical direction as opposed to anisotropic). ***This is untrue according to the pressure data. It is calculated that*** $Kh > 1000\,Kv$ (that is the vertical permeability is estimated to be 1000 times less than the horizontal permeability) ***hence the actual leakage coefficients*** (and therefore horizontal permeability) ***for*** ['] ***impervious***['] ***beds should be multiplied by*** 10^{-3} ***to get the correct order."***

Another way of stating the above is that the ratio of the higher horizontal permeability of the strata divided by the vertical permeability particularly for disturbed strata is equal to 1000. In Table A1 above the fifth column shows the calculated vertical permeability for disturbed strata in K6 based on this reported ratio.

The test results indicate in Borehole K7 (using the test interval lengths) a calculated average horizontal permeability of 6.7×10^{-5} m/day and median of 4.3×10^{-5} m/day whilst in borehole K6 the average horizontal permeability is calculated to be about 5.2×10^{-3} m/day and median of 1.7×10^{-3} m/day. That is, in the disturbed strata in borehole K6 the horizontal permeability is some two orders of magnitude (100 times) greater than the undisturbed strata in borehole K7. This result is therefore in agreement with the observed appearance of cracking throughout the fracture log of bore K6 compared to borehole K7 as noted previously.

Referring back now to Tables A1, the average of the calculated vertical permeability values cannot be the arithmetic average or median value since the flow of groundwater in a vertical direction is controlled by the layer of lowest permeability in the strata profile[18].

The average that should be used for this purpose is the harmonic mean using in this case the tested intervals adopted for thickness[19]. The harmonic mean, takes into account the lowest

[18] This can be visualised easily in the extreme by an imagined steel plate sandwiched between the horizontal strata. Clearly with a plate vertical permeability of essentially zero there would be no vertical flow through the strata. The vertical permeability of all the other layers above or below this plate would have no effect on the result.

permeability in the strata as the controlling value. For borehole K6 with disturbed strata the average harmonic permeability is calculated to be 4.8 x 10^{-7} m/day. It is not surprising then that the often stated constrained zone exists in a coal measure stratigraphic profile and that, while not 'impervious', tends to severely impede surface leakage towards underground extracted coal seams. Note that if the horizontal permeability to vertical permeability ratio had been 100 then the respective harmonic average permeability value for K6 would be 4.8 x 10^{-6} m/day.

Reynolds (1977) concludes from the Kemira borehole tests:

" The findings at Kemira indicate that the problems related to partial extraction and permeability cannot be dealt with or solved by the application of a simple proposition that three zones will be created in the overburden of which the central is tightly constrained and impervious. However, they do not destroy a view which is based upon experience of sub-aqueous mining that, if the cover is sufficient in relation to the mining method employed, poorly permeable zones in a generally central zone will not be so affected by fracturing, joint opening, joint slippage, bed separation or bed slippage as to lose their retarding qualities."

The vertical permeability of the strata sequence within the "constrained" zone used in the Mackie model can be calculated to be, using the harmonic mean, as 2.63 x 10^{-6} m/day. That is, this vertical permeability value is about one order of magnitude greater than the disturbed strata calculated value in borehole K6 (4.8 x 10^{-7} m/day). If the ratio is 100 instead of 1000 then the harmonic vertical permeability of 4.8 x 10^{-6} m/day is the same order of magnitude as the harmonic vertical permeability used in the Mackie model.

The K7 average horizontal permeability (6.7 x 10^{-5} m/day) is of the same order of magnitude as the adopted Mackie average horizontal permeability (3 x 10^{-5} m/day). The results from Kamira suggest that for disturbed strata horizontal permeability increases by a factor of at least 100 (i.e. average 3 x 10^{-3} m/day) within the mining constrained zone. Mackie (2010) in his updated report has introduced such an increase in a scaling manner, (from 10 to 150 times) so as to also take account of the variability of such horizontal permeability changes over the areal extent of the mined out panels and vertically within the strata rock profile.

The description to follow of fracture modelling of proposed coal seam extraction at Wallarah 2 provides further evidence about the validity of the results and analysis given above at the Kemira

[19] While the use of the tested interval is not strictly the thickness of the lower permeable layers, using a uniform thickness fraction of those intervals does not appreciably change the calculated vertical permeability value. There is insufficient data to differentiate the actual layer thicknesses. Such differentiation is however unlikely to change the order of magnitude of the result.

Colliery at boreholes K6 and K7.

Simulated fracture development at the Hue Hue Area - Wallarah 2 Coal Project

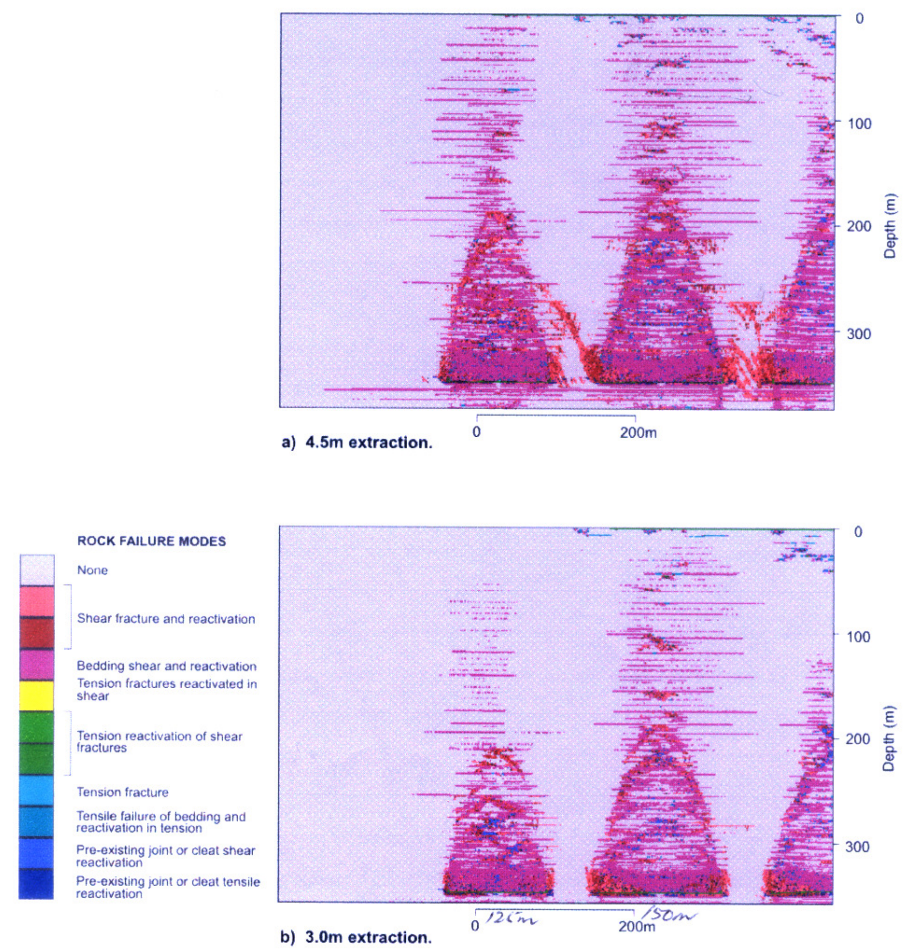

Figure A1 SCT modeled 125m and 150m panel rock fracture development for the Hue Hue 3.0m and 4.5m coal extraction

Strata Control Technology (SCT)/ MSEC (2010) provide a fracture simulation for the actual stratigraphic profile at the proposed Wallarah 2 mine (Figure A1). These results are part of the ongoing geotechnical investigation at the mine site and illustrate well the extent and form of the fracturing that could be expected within the geological profile.

The SCT model has included simulating the bedding parting/shear and tension fracturing using the two-dimensional explicit finite difference model program (FLAC2D). The model simulates ultimate fracture development profile within the represented Narrabeen Group of sediments in the area of first stage mining (designated as the Hue Hue subsidence area) in response to panel removal. Simulations included two panel widths, 125m and 150m for a constant overburden thickness of 350m. For each simulated case a coal seam of 3m and 4.5m within the 6m thick seam were used.

The results show the presence of a zone of rock collapse immediately above the seam; a severely fractured and sheared 'parabolic' zone above that and then mostly irregular horizontal fracturing and bedding separation (colored red) within the upper part of the sequence with some isolated shearing.

The extent and degree of fracturing/shearing can be seen to be related to both panel width and the thickness of the coal seam extracted. However, it will be evident that there are horizontal "gaps" of essential undisturbed or weakly fractured strata between the upper horizontal fracture zones. These "gaps" indicate that permeability distribution (horizontal compared to vertical) would be highly anisotropic[20].

Figure A2 (see below) shows the vertical hydraulic conductivity (permeability) of the above profile from the same report. This shows numerous layers in the upper parts of the profile that retain or are close to their pre-mine insitu vertical permeability (values on the left side of the graph).

The limited depth of slightly increased vertical fracturing and vertical permeability at the ground surface due to panel extraction in the Figures A1 and A2 is also worth noting. However, the shallow vertical connectivity does not extend very far below the surface because the slightly higher shallow vertical permeability decreases rapidly below about 10m -15m (Figure A2).

These results validate the analysis given for the Kemira bores that whilst horizontal permeability can be substantially affected within the mining zone vertical permeability is not, resulting in limited leakage to extracted coal seams. This limited leakage is supported by observations of relatively low flow magnitude in the majority of coalmines in NSW and overseas where there is a substantial thickness of interbedded argillaceous (siltstone, shale, claystone) rock types.

Increased horizontal fracturing in disturbed strata has been shown to have only moderate local effect on the groundwater flow distribution and hydraulic gradient (Mackie 2010). This so because

[20] Anisotropic - with significant different horizontal and vertical permeability in the strata profile as opposed to isotropic having the same horizontal and vertical permeability.

of the isolated nature of this fracturing, its variable distribution above individual panels and the evident lack of strong connection of these fracture zones between panels and outside the mining footprint (Figure A1).

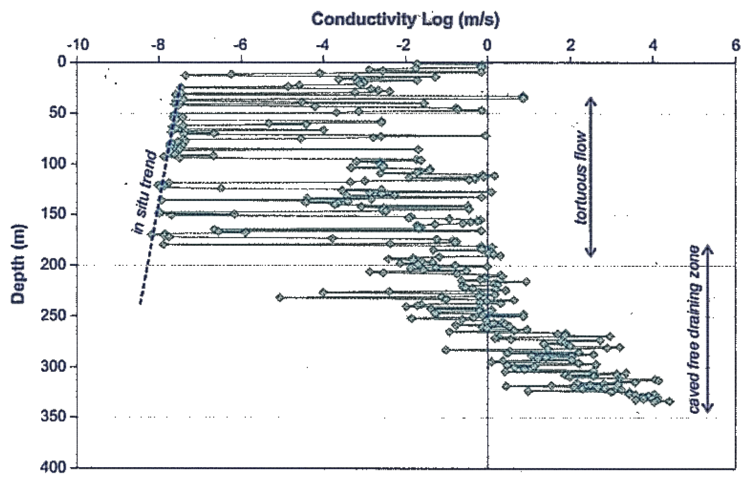

Figure A2 Overburden vertical hydraulic conductivity (permeability) for the Hue Hue 4.0m case. (from Figure 2.28 .SCT/MSEC 2010). Numerous layers have variable horizontal permeability with some zones having values that are at or close to their pre-mine insitu values, above the caving zone, thus severely limiting vertical drainage.

Appendix B

Longwall mining under the Cataract Reservoir
Southern Coalfield of NSW

Longwall mining under Cataract Reservoir

The Kemira bore test results are instructive, but they do not involve the actual observations of a more severe set of boundary conditions where the seam extraction in the Southern Coal Field is overlain by a substantial depth of water in a reservoir. The following are extracts from such a case study reported by Holla and Barclay (2000 -page p88-90):

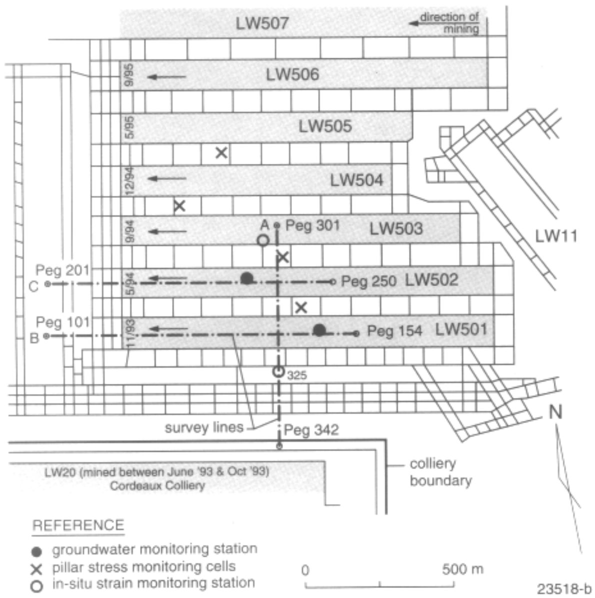

Figure B1 Longwall layout under Cataract Resevoir

"The first case of extensive longwall mining under the stored water of a major water supplied dam (Cataract Reservoir) commenced in 1993 with the approval to mining panels of narrow face width given by the Chief Inspector of coal mines on the recommendations of the Dams Safety Committee. The initial six panels were 110 m wide and interpanel chain pillars were 66 m wide. Mining depth was between 320 m and 430 m and the extracted Bulli seam was 2.5 m thick. The layout of the first six panels is shown in figure 9.1 [Figure B1] ***along with the location of subsidence survey lines. The topography over the longwall panels varied in elevation from between 270 m and 360 m AHD, with a Full Supply Level of lake Cataract at 290m. A comprehensive programme of monitoring was undertaken as part of the conditions of the approval, including the following:***

- ***surface subsidence monitoring;***
- ***Groundwater monitoring;***
- ***pillar stress monitoring; and***
- ***In situ strain monitoring.***

"Groundwater monitoring involved measuring the head of water in piezometers installed over the centre of panels [Figure B1] ***within the overburden approximately at the following horizons (Reid 1995).***

- ***85 m above the Bulli seam (325 m below the surface) within the Scarborough Sandstone over panel 501***
- ***100m and 85 m above the Bulli seam (225 m below the surface) within the Bulgo Sandstone over both panels 501 and 502***
- ***240 m above the Bulli seam (170 m below the surface) within the Bulgo Sandstone over panel 502***
- ***305 m above the Bulli seam (hundred and 5 m below the surface) within the Hawkesbury Sandstone over panel 502***

The following general observations were made from the results monitored over five years during monitoring [Reid in 1995- referenced in Holla and Barclay 2000].

- ***The groundwater head in the deepest piezometer was zero. This has been interpreted as the loss of groundwater head in the sandstones below the Stanwell Park Claystone possibly by the propagation of vertical cracks to at least 85 m above the seam.***
- ***There were variations in groundwater heads in piezometers installed within the Bulgo Sandstone (the middle unit). However, the head generally re-established almost to the pre-mining levels after mining moved away.***
- ***The groundwater in the Hawkesbury Sandstone above the very low permeability Bald Hill Claystone, appeared unaffected by mining***

Bed separation or stress changes within the strata are considered the likely mechanisms to account for the variations in the Bulgo Sandstone. The maintenance of some pressure during mining, and the recovery of head relatively soon after mining, suggests that <u>there has not been the development of extensive vertical fractures in the middle level.</u>

Monitoring of water pumped into and out of the mine continued during mining. There had been no recorded case of excessive inflows into the mine that had required unusual amounts of water to be pumped out. Generally, more water was pumped into the workings under the stored water for dust suppression etc. than was pumped out.

Static head tests and injection fall-off tests were also conducted in a borehole above panel 502 after the extraction had occurred. The tests indicated that there was a rapid reduction in head near the base of the Bulgo Sandstone. Above this, and below the Hawkesbury Sandstone, the static head generally increased, and the measured [horizontal] ***permeability was generally low, being of the order of*** 10^{-8} ***m/sec*** [or 8.64 x 10^{-4} m/day].

All of the investigations into groundwater monitoring, injection tests and water inflow into the mine indicated no evidence of any significant changes in the hydraulic connectivity from the reservoir to the mine workings."

"The results of [measured] ***in situ strains have been interpreted to mean that the mining has resulted in small deformations at the floor of the reservoir and this has increased confidence in the ability of the strata to remain relatively impermeable.***

The results of various investigations undertaken by the colliery indicated that surface and sub-surface strata disturbance due to mining of the six panels had no detrimental effects on the integrity of the reservoir. On this basis, the next series of panels were designed with changed pillar and panel geometries. Up to the end of 1999, a total of 14 more panels were successfully extracted with panel width varying between 100 m and 150 m and pillar width between 60 m and 65 m."

Appendix C

Longwall mining at the Wyee State Mine
Central Coast NSW

Forster (1995) describes the hydrogeological conditions at the longwall mined out seam at the Wyee State Mine Central coast of NSW. This example is of particular interest because:

- The area is underlain by the Narrabeen strata with an overburden depth above the seam in the range of only 155m and 185m (the minimum overburden depth at Wallarah 2 is some 350m).

- The extracted 2m seam amounted to a panel 170m wide and 700m long known as the North 3D Panel lying immediately adjacent to the North 3C panel 175m wide and 700m long wide creating an effective supercritical panel some 355m wide.

- Packer tests were performed and piezometer pressure measured before and after undermining

The investigation yielded the following results:

Pre-mining (horizontal) permeability was found to be ***"less than 10^{-8} m/sec*** [8.64 x 10^{-5} m/day] ***except in the upper 20 to 25m where the permeability was 10^{-7} m/day to 10^{-8} m/day*** [8.64 x 10^{-4} m/day to 8.64 x 10^{-5} m/day]."

One borehole (D3) over the 3D panel showed the greatest change in horizontal permeability by two to four orders of magnitude. Only two sections of the borehole did not show any increase in permeability; between depths of 80 and 86m and above 32m.

Forster notes (page 4) that ***" it is important to note that the permeability changes measured (if they are not due to packer sealing problems) are predominantly changes in the horizontal permeability, due mostly to opening of bedding planes. Most changes in the vertical permeability cannot be measured*** [except by piezometric response] ***since the vertical fractures which caused these changes are normally not intersected by the boreholes."***

With regard to piezometric pressures he notes (page 5): ***" in the upper strata of this borehole the piezometric levels showed very little variation prior to undermining. <u>After mining, the strata above 47 m maintained pre-mining levels</u> and appeared to form an unconfined surface aquifer showing a steadily increasing hydrostatic pressure with depth. The piezometric head in the strata between 47 and 60 m fell by about 20 m due to undermining then recovered gradually with time to the new pre-mining levels."***

and later ***" the pressure differential measured through the strata suggest that the low vertical permeability of the strata unit was not increased significantly by mining."***

also ***" a constrained zone forms an effective barrier to vertical drainage in the overburden strata after undermining. This is particularly important when considering the minimum depth of cover necessary for mining under the surface water bodies or tidal waters....... more importantly, the testing has shown that these rocks have very low vertical permeability which, in the constrained zone, are not increased significantly by mining."***

With regard to surface cracking: ***" testing carried out during the study did not detect any surface effects due to mining. Because the overburden is topped by a layer of weathered rock and soil to a depth of 10 to 15 m in this area, the induced surface strains would have been absorbed by this material without any noticeable effects. If a layer of soil and/or weathered rock covers the ground surface then strain effects will often not be evident in this zone. This assumption is supported by the observation at Cooranbong, where the surface shows little sign of disruption despite having been subjected to tensile strains probably in excess of 8 mm/metre."***

Appendix D

Mackie proposed monitoring and verification

"As previously noted, groundwaters are not currently monitored by W2CP due to restricted access to existing (or potentially new) locations. The monitoring network should be re-instated for the purpose of assessing local and regional impacts relating to proposed underground operations. Such impacts are broadly defined as:

- **physical depressurisation of the shallow coal measures rock strata and potential indirect impacts on alluvial aquifer systems associated with the Dooralong and Yarramalong valleys;**
- **and changes to shallow groundwater storage induced by subsidence.**

An accelerated decline in formation pressures in shallow strata underlying the valley alluvium could signal a change in seepage rates. Future impacts assessment criteria should therefore address the pressure regime within shallow strata near and beneath the alluvial lands. Leakage can be estimated by interpolation of the pressure/water table hydraulic gradients and calculation of the leakage flux from measured rock permeabilities. This estimate can also be reconciled with the volume of mine water pumped from proposed underground operations. In order to establish both the strata hydraulic gradients and the rock mass permeabilities it will be necessary to expand the groundwater monitoring network. The following recommendations are provided.

Depressurisation monitoring should include:

- **Construction of at least 20 standpipe piezometers to augment measurement of pressures/water levels in shallow alluvium and underlying strata to a depth of 50 m. As a minimum, the design should allow for isolation of bottom hole strata from mid hole and alluvial strata utilising combined standpipe and pore pressure transducer completions;**
- **Installation of vertical arrays of pore pressure transducers distributed within the Narrabeen Group of rocks (overburden) at a minimum of 8 locations;**
- **Strata hydraulic conductivity measurement on rock core obtained at some of the above noted locations. Such measurement should comprise testing for matrix permeability and insitu testing for permeability over the piezometric intervals;**
- **Quarterly monitoring of water levels in all existing piezometers and in new piezometers;**
- **Daily monitoring of water levels by installed auto recorders in selected existing piezometers and in new piezometers in order to discriminate between oscillatory groundwater movements attributed to rainfall recharge, and longer term pressure losses related to mining.**

Mine water seepage monitoring should include:

- **Measurement of all water pumped underground and all mine water pumped to surface on a daily basis. Measurement should be undertaken using calibrated flow meters or other suitable gauging apparatus;**
- **Routine monitoring of ROM coal moisture content delivered from the working face in order to more accurately determine the underground water balance;**
- **Routine monitoring of ventilation humidity.**

Water quality monitoring should include:

- **Quarterly monitoring of basic water quality parameters pH and EC in selected piezometers and pumped mine water. Such monitoring may provide early indication of mixing of shallow groundwaters with groundwaters in deeper strata. While this process is expected within the subsidence zone, it may not be evident within the wider piezometer network at the leakage levels predicted by groundwater monitoring;**
- **Six monthly measurement of total dissolved solids (TDS) and speciation of water samples in selected piezometers to support identification of mixing of groundwater types. Speciation should include as a**

minimum - major ions Ca, Mg, Na, K, CO_3, HCO_3,, Cl, SO_4 and elements including Al, As, B, Ba, F, Fe (total), Li,Mn,P,Se,Si,Sr,Zn;

- **Graphical plotting a basic water quality parameters and identification of trend lines and statistics including mean and standard deviation calculated quarterly. Comparison of trends with rainfall and any other identifiable processes that may influence such trends.**

The monitoring network and monitoring programme should be reviewed on an annual basis to determine ongoing suitability and any proposed changes should be discussed in the Annual Environmental Management Report (AEMR).

Impact verification analyses could include:

- **Quarterly checks for departures from identified monitoring or predictive data trends. The key data sets in this regard should be the mine water seepage rate calculated from the underground water balance, and the pressure monitoring data for multi-level piezometers. If the average daily seepage rate exhibits and increase beyond the rate predicted (allowing for 0.5 ML/day additional transient storage depletion), or if consecutive pressure monitoring data over a period of six months exhibit an increasing divergence in an adverse impact sense from the previous data or from established or predicted trend, then such departures should initiate further actions. These may include a need to conduct more intensive monitoring (including installation of additional piezometers) or to invoke impacts reassessment and/or mitigative measures;**

- **Formal review of depressurisation of coal measures and comparison of responses with aquifer model predictions biennially. Expert review should be undertaken by a suitably qualified hydrogeologist;**

- **Annual reporting (including water level and water quality data) as part of the AEMR.**

Mitigation measures

Mitigate measures for any identified negative impacts beyond those predicted, may include replacement of water supply or relinquishment of groundwater or surface water allocations in order to account for leakage losses from the alluvial aquifers. "