Department of Planning NSW

Proposed Carrington West Wing Open Pit Mine Extension
Hunter Valley Coal Measures

Review of the Mackie Environmental Research Modeling Report

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1.0 Introduction

Coal and Allied Operations Pty Ltd (Coal and Allied) proposes to extend existing approved coal mining operations at the Carrington open cut pit. The site is located about 24 kilometers north-west of Singleton, New South Wales (NSW). The proposed new mining zone situated immediately south-west of the Carrington pit has been designated as the West Wing Extension (WWE, Figure 1, shown with an orange outline). An Environmental Assessment (EA 2010) has been prepared and has been submitted to the Department of Planning (DoP) for approval.

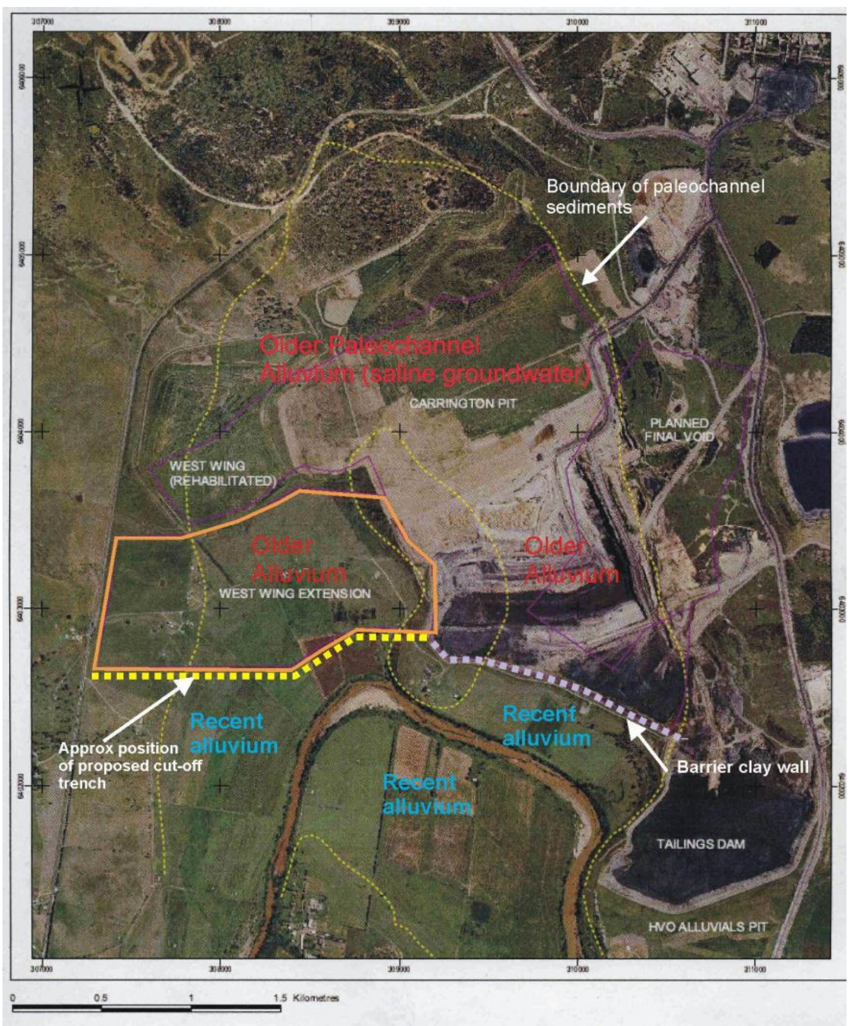

Figure 1. Key hydrogeological features of the Carrington mining site
(Base map taken from EA 2010 Appendix C - Fig 1)

Figure 1 shows the key hydrogeological elements of the site area interpreted from the EA report, and discussions with Dr Mackie. They include the paleochannel[1] (older) alluvial zone, its outer and inner boundaries; the more recent alluvial flats adjacent to the Hunter River; the existing barrier clay wall[2] across the eastern "arm" of the paleochannel and a proposed bentonite based slurry-trench cutoff[3] across the western "arm" of the paleochannel. Existing mining includes the Carrington pit and the rehabilitated West Wing mining zone situated immediately north of the proposed West Wing Extension mining zone.

The presence of paleochannel sediments lying immediately adjacent to the more recent alluvium is unique in the Hunter Valley. Based on my experience[4] (AGC 1984) and subsequently that of Dr Mackie over many years, such a feature does not occur anywhere else in the Hunter Valley coal mining area.

Prior to mining, groundwater flowed down gradient (downstream) through the recent alluvium but did not follow a flow path through the older paleochannel sediments. Brackish to moderately saline groundwater (2000 to 12000 EC), within the large body of these paleochannel sediments, drained slowly toward the more recent alluvium possibly joining the river as a brackish contribution to base flow in the Hunter River.

Since 2009, according to the Mackie report, this flow has been reversed and groundwater from the recent alluvium flowed toward the paleochannel zone due the drawdown created by the Carrington pit.

It is proposed that coal will be mined in the WWE over a period of 6 years to an increasing maximum depth southward of about 75m from the surface. Once mining is completed the WWE void will be backfilled with overburden. Following mining the Carrington pit operations will cease with partial backfilling of the pit with a remnant open void[5] where groundwater and some surface water inflow will act as an evaporative sink. That is, evaporation from the body of water in the remaining void will cause the water level in the void to lie below the surrounding recovered watertable and hence will always direct sub-surface water in the near and farther vicinity within the paleochannel to flow towards the ponded water body.

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[1] The Paleochannel zone is in this case are ancient river pathways or meanders followed by the Hunter River that have subsequently been abandoned.
[2] The exact length of this clay wall is not known precisely and the depiction in Figure 1 is diagrammatic.
[3] Based on a discussion with Dr Mackie in the KA office 14 December 2010. The length of the proposed trench is not known precisely and the depiction in Figure 1 is diagrammatic.
[4] A 3 year research project during 80's on the effects of coal mining on groundwater resources in the Upper Hunter.
[5] Marked as "planned final void" in Figure 1.

Because of the close proximity of the Hunter River to the existing mining zone (Figure 1) a clay barrier wall was constructed early in 2010 across the eastern arm of the paleochannel to impede any long term surface water leakage from the Hunter River through the adjacent river alluvium (and presumably weathered bedrock) into the existing Carrington mine pit.

It is proposed that a similar barrier, likely to comprise a bentonite based cutoff trench, would be constructed across the western arm of the paleochannel keyed into the underlying hard rock strata. This trench is also designed to impede leakage from the river to the proposed WWE pit during mining and recovery of the watertable.

One aspect of the alluvial geology that is not completely clear is where the more recent alluvium ends and the older alluvium begins, within the western arm of the paleochannel. Based purely on photo interpretation it would appear that the boundary is situated as shown in blue in Figure 2. That is, about one third of the proposed WWE area is likely to be occupied by what could be classed as more recent alluvium.

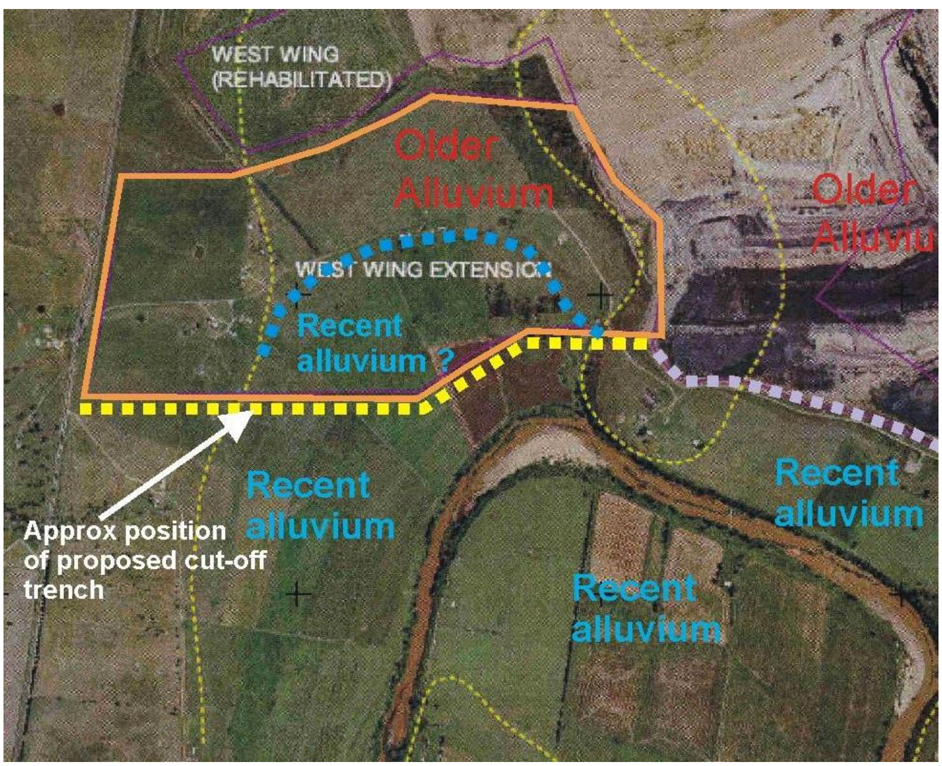

Figure 2 showing the likely extent of more recent alluvium within the proposed WWE mining zone.

Although the Mackie model has determined the flow magnitude toward the ultimate mined out zone, there is a need to address uncertainty about the permeability of the interburden[6] strata, and the barrier and cutoff trench that will control the flow rate. Further discussion on this issue is given in the next section on permeability data.

2.0 Permeability Data

The Mackie report presents tables that show the range of permeability determined from hydraulic tests performed on the various geological strata. These include core sample laboratory tests[7] of the interburden strata (Table C2 page C4-EA 2010); airlift tests from exploration holes (Table C1 page C3 –EA 2010); pumping, and slug tests from bores constructed in the paleochannel alluvial sediments (Table C3 Page C6 – EA 2010).

Unfortunately, no permeability field-testing (e.g. pumping; air lift or falling head tests) have been conducted on bores open only to the interburden rocks. Such testing would have yielded a measure of the secondary permeability (i.e. due to fracture systems or shallow weathering) within the hard rock strata particularly beneath the recent river alluvium and paleochannel sediments. It was initially thought prior to a meeting with Dr Mackie that the bores designated as the RW and PC series as shown on Figure C1, page C7 situated north-east of the site may have been used to determine interburden strata permeability. But the results are inconclusive since the exploration bores would have also been open to the underlying coal strata that are known to have higher permeability than the interburden rocks.

Dr Mackie has indicated that in his experience the fracture systems in the interburden strata are quite irregular and from evidence in the existing mine high wall exposures at Carrington do not yield appreciable visible uniform seepage and when it occurs is too small to measure[8]. I have no reason to doubt this observation as I have, during a three-year research project (AGC 1984), also observed this in a number of open cut coal mines in the Hunter Valley. However, the relevance of these observations depends on the relative magnitude of the permeability that is present in the interburden rock created by insitu[9] fractures. Much of the seepage in a number of open pits (not all) is not readily visible because of evaporation from the high walls particularly where the fracture permeability is quite low.

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[6] Interburden strata are the hard rock strata (sandstone, shale, siltstone etc) that lie between the overlying alluvial sediments and the underlying coal seams.

[7] These tests were performed to determine the porous matrix permeability of the sedimentary hard rock.

[8] Page D4, paragraph 6 states ***"Leakage emanating in the current pit highwall is generally observed as localized dampness and minor weeps".***

[9] Insitu fractures: Those fractures occurring naturally within the rock and not due to blasting and stress relief due to mining in the high wall of the mine.

AGC (1984 page 30) presents a table of eight sedimentary rock permeability values for siltstones and sandstone elsewhere in the Hunter Valley coal mine region that are in the range 4.26×10^{-1} to 1.28×10^{-3} m/day with a median value of 2.2×10^{-2} m/day. These values would represent horizontal rather than vertical secondary (fracture) permeability of the more shallow interburden rocks[10]. This median value[11] is some three orders of magnitude (1000) times greater than the median value of 1.8×10^{-5} m/day that can be calculated from the core (matrix) test values given in Table C2 (page C4 EA 2010) in the Mackie report. A median permeability of 2.2×10^{-2} m/day is representative of silt, clay and mixtures of sand, silt and clay (according to Kashef 1979 page 95); silt, loess[12] and the lower end of the silty sand range (according to Freeze 1979 page 29). That is, the permeability is of course still low.

The discussion above needs to be put into perspective. First, there is no certainty that the median permeability calculated for the interburden rocks (AGC 1984) above applies to those rocks that underlie the paleochannel or recent alluvium zone at Carrington. Secondly the observations from core samples as reported would suggest that these higher values of permeability may not apply.

However, because of the uncertainty that remains about the actual magnitude of the horizontal and vertical secondary permeability of the interburden rocks, particularly within 40m from the surface at Carrington, any modeling analysis would therefore need to take into account a scenario that included such secondary permeability for setting an upper bound on the possible, but not necessarily, probable seepage impact.

It is clear that the uncertainty could only be resolved by constructing and field hydraulic testing two (or three bores, depending on results of the first bore), open to the interburden rocks situated in a line situated outside of the proposed barrier slurry-trench site and the WWE pit. For example, the bores would need to be drilled to a total depth of 40m with the recent alluvium cased off. Drilling should then proceed through the interburden strata with airlift conducted every 5m using a V notch weir to determine the magnitude of any progressive contribution of groundwater flow into the borehole with increasing depth.

Once drilling is completed and provided there is sufficient groundwater flow available in a bore, then a short term pumping test should be conducted. However, if water flow is poor then

[10] This is so since field hydraulic tests measure the horizontal rather than the vertical permeability.
[11] The median value or the most common value is a more suitable 'average' measure of a set of permeability values because the true average tends to place too much weight on the highest values. The logarithmic mean is also often used and is close to the median value.
[12] Loess: deposits of silt (2 to 64 microns in diameter) with sedimentation caused by wind action.

recovery of water levels in that bore after attempted airlift should be conducted over time so that an estimate of the rate of inflow can be determined. This should determine whether the secondary permeability in the interburden strata is significantly higher than the core matrix values and therefore whether it should or should not be taken into account in an updated modeling scenario. Following construction and testing the bores should be completed as observation bores to monitor water levels over time. That is, each bore should be completed as a multi-piezometer installation with one piezometer set at the bottom of the hole and another at mid depth. This will enable the pressure changes to be monitored within the coal measure strata ,during mining and post mining periods.

Depending on the test results, the permeability, if significantly different from the core values, should then be included in an updated model assessment. The simulation should be stochastic with a variable distribution of secondary permeability values used in a similar manner by Dr Mackie in another recent coal mining project that I reviewed.

3.0 Barrier wall (eastern arm) and proposed slurry-trench (western arm).

The purpose of these structures is to prevent or at least impede seepage flow from the Hunter River through the recent alluvium towards the west wing pit both during mining and post mining periods.

There is very little discussion or detail given in the Mackie report about these structures, with regard to their construction, materials to be used and validation of the permeability of the backfill material. It is understood from discussions I had with Dr Mackie that the barrier wall was designed and then constructed during 2010 across the eastern arm of the paleochannel under the supervision of consultants Parson-Brinckerhoff[13]. Because the details of construction and related matters are geotechnical in scope, they are therefore not reviewed herein because they lie outside my area of expertise. However, the issue of the permeability of the backfill material of this structure has a direct influence on sub-surface seepage flow and is therefore relevant with regard to this hydrogeological assessment and modeling review.

The eastern barrier was constructed adjacent to the edge of the recent alluvial flats levee along the eastern arm of the paleochannel. The barrier extends across the eastern paleochannel arm, has outward sloping walls with a truncated top about 5 meters across (at 65mAHD) and extends through the alluvium with its base, as I understand it, keyed 1 to 2 metres into the underlying

[13] I did not have a copy of this report during this review. All information was provided by Dr Mackie during our discussion.

interburden rock. The barrier is comprised of clay that was obtained from the stripped clay overburden across the paleochannel prior to mining.

The Mackie report assumes a stripped insitu clay and bentonite (smectite clay) permeability of 10^{-6} m/day for modeling the barrier wall and proposed cutoff slurry-trench proposed across the western paleochannel arm. However, there is no evidence presented that validates the choice of such a permeability value. Bouwer (1978) indicates that a permeability value of 10^{-6} m/day is characteristic of deep clay beds, whilst Freeze (1979) puts such a value at the lower end of permeability for glacial till and un-weathered marine clay. There would be, in my opinion, uncertainty about whether such a uniform permeability could either be created or be maintained in a barrier wall of the type constructed in the long term. From my experience, a similar type of clay barrier constructed at another mine site to impede solute migration was designed to have a similar permeability as the Carrington barrier but after construction was found to have a reported permeability some orders of magnitude higher.

It would also be difficult to claim a permeability of less than 10^{-9} m/sec (i.e. ~ 10^{-4} m/day) for bentonite or bentonite-cement slurry-trench. Hence the 1 to 2 metre wide deep slurry-trench that is proposed across the western paleochannel arm should be initially modeled (subject to geotechnical expert advice) with permeability in the range 10^{-3} to 10^{-4} m/day rather than 10^{-6} m/day to indicate the possible influence that would have on seepage rates towards the mining zone.

If not already done so, there needs to be a review conducted by a qualified geotechnical consultant with the necessary experience to comment on the integrity of the methods used for the construction of barrier clay wall and proposed slurry-trench and the long term integrity of these structures including determination and/or expert opinion about the initial and long term permeability of the materials used in their construction.

4.0 Modeling procedure and reporting

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 modeling 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 groundwater levels and streams at numerous sites in NSW and elsewhere in projects that have received approval from the NSW Department of Planning (DoP).

4.1 Model geometry

The model geometry used in the Mackie model has been examined and is considered suitable. Seven layers are included that represent the alluvial deposits, interburden strata and underlying coal seams. Each layer has more than adequate cell resolution for determining drawdown responses.

4.2 Model hydraulic properties

Adopted permeability for each of the different lithologies is provided in Table D1 (page D2 EA 2010). These permeability values are porous matrix values but do not include any secondary permeability induced by fracture systems. Table D2 provides both the horizontal and vertical permeability assigned to each model layer including storage properties including specific storage (Ss) and specific yield (Sy). The matrix permeability values for the alluvium are considered suitable as are those assigned for the interburden and coal seam strata although as indicated they do not include secondary permeability. The storage parameters are also considered suitable.

4.3 Model boundary conditions.

Fixed head condition has been applied to the Hunter River with a relatively high conductance to the river bed to allow free flow to and from this stream channel. This boundary condition is suitable for this type of simulation.

To simulate open cut mining “drain” cells were used. This is standard practice. The report notes that a conductance of 100 m^2/day was used for these cells. While this is suitable it is also possible to simulate the mined out cells using the seepage face option in the MS code without the need for a conductance value. Both methods would yield essentially the same result in this case.

For rainfall recharge distributed flux was used based on a percentage of rainfall. Net rainfall has been applied rather than gross values together with evapotranspiration. The net rainfall approach is considered to be suitable.

4.4 Model Calibration – Steady State and Transient

The Mackie model report does not specifically describe the steady state calibration process but seems to rely on earlier model calibration in 2007. The main difficulty here would appear to be that mining has already modified what could be considered to be a “steady state” condition. Hence the steady state is used merely as a means of applying an approximate set of starting heads. This is acceptable in this case given that the transient simulation is a more complete method of calibration of both permeability and storativity. The methodology used is trial and error which is one form of calibration although using a parameter estimation program such as PEST code is becoming more popular. Applying this code to this model would be problematic because of its large size and cell numbers that would require considerable computation time to achieve a result.

The transient simulation results given in Figure D4 are considered reasonable to good although there are several bores where the fit is not good. However, Dr Mackie has indicated that in these cases the predicted head are mostly below that measured yielding an element of conservatism to the result in those cases. Overall I consider that the calibration is adequate based on the parameters adopted. However, as noted previously it will be necessary depending on the results of additional field investigation whether secondary permeability needs to be included. If so, then the model would need to be recalibrated with these newly adopted permeability values.

4.5 Post mining recovery

For post mining recovery the Mackie report uses a separate model with water levels derived from heads computed during the last time step in the first model. Recovery in the mined out void(s) is then simulated by assigning parameters to the material backfilling each void and allowing the model to recover to equilibrium or close to equilibrium. For the final void a steady state simulation was then subsequently conducted to determine the final equilibrium level of the water level of the ponded water. This is an acceptable approach although it would have been more complete if the method of simulating the actual pond in the computer code had been included in the description.

4.6 Water quality analysis

Sections 3.6, 5.4 Figure adequately describe the existing water quality and changes that may occur. It is concluded that proposed mining would not be expected to change groundwater quality although periods of high rainfall could lead to a reduction in salinity through shallow flushing.
I would agree with that conclusion.

4.7 Final void water quality

The report states that the final void is predicted to have salinity in the range 3000 to 4000 mg/L. It would have been useful to indicate whether this was modeled using the described steady state void model or otherwise.

4.8 Recommended monitoring

The proposed monitoring at the site outline in section 8 page 20 is considered suitable.
In addition the monitoring of multi-piezometers as outlined in this review should be included.

4.9 Spoils leachate & reaction path modeling

The discussion of spoils leachate and reaction path analysis is considered more than adequate. The results indicate (at least from the 6 month laboratory tests) that leachate total dissolved salts would be slightly less than 2000 mg/L and pH in the range 7.5 to 8.5. As noted in the report concentration levels maybe somewhat higher (or lower) over much longer time period. However, it is clear that these concentrations are substantially less than the bulk of the existing groundwater concentrations within the paleochannel.

5.0 Relevance and significance of issues raised by stakeholders

Only one stakeholders document received (i.e. NOW) contained issues concerned with groundwater and the modeling report.

5.1 The Now Review

1. The report notes that the EA 2010 and the Mackie report in particular ***"provides no assessment of the requirements in force under the Water Management Act 2000 (WMA)***", in particular sections 63(2) and 97(6) that deal with ***"no more than minimal harm"*** that may result due to water being extracted from a water source, and that no more than ***"minimal harm"*** may occur ***"as a result of an aquifer interference activity requiring an aquifer interference approval".*** The question that arises is what constitutes ***"minimal harm"***? My interpretation would be in this case that provided it can be demonstrated that the ultimate magnitude of seepage of groundwater from the more recent alluvium close to the river and that derived from the river itself is small in comparison to dry weather river flows then this would constitute minimal harm. Given that the presence of the mine will arrest moderately saline to brackish groundwater seepage to the river this would seem to be more than enough compensation for the likely relatively modest flow (yet to be demonstrated) that would be directed away from the river.

2. The second point made by NOW is that "***The proposal does not consider…..the long term consequences of destruction of the alluvial aquifer".*** This is seems to imply that an ***"alluvial aquifer"*** is necessarily always pristine and that it would always supply potable water. This is not always the case and certainly not within the paleochannel sediments. The statement also does not take into consideration the benefits that would accrue over time from having a groundwater sink situated within the paleochannel sediments. For example the groundwater within the alluvial sediments comprises brackish to moderately saline groundwater with an median electrical conductivity (EC) of 6550 microS/cm (range 2000 to 12,000) according to the Mackie report water quality

data. That is, the groundwater has no major beneficial use for irrigation, and is marginal for stock and domestic use. By having a sink within the paleochannel this groundwater will be prevented from ever entering the Hunter River stream channel as it did in the past. In addition the filling of the mining voids with backfill would likely in time improve the water quality in the paleochannel sediments because of increased recharge that was previously prevented due to the presence of thick surface clay layer across the old stream channel alluvial flats.

As indicated in Figure 2 there will be some removal of the more recent alluvium but this would not constitute “destruction” of the alluvial aquifer. A large body of recent alluvium would remain after mining that would allow continuity of groundwater flow.

3. The NOW review goes on to say that ***“the EA provides no examination of the role interchange between the Hunter alluvial aquifer and storage within the alluvial terrace provides with respect to minimum flows the regulated river”*** and that ***“destruction of a portion of the alluvial aquifer will lead to a reduction in the volume of water available to all other users”.***

With regard to first point quoted there is disagreement since the modeling conducted is set up to provide the magnitudes of seepage that may be diverted away from the River. It seems possible that even with the higher permeability changes than used in the modeling report this flow is likely to be relatively small in comparison to the low flow rates in the river. Additional modeling with the inclusion of secondary permeability, if significant, will determine more precisely the possible magnitude of diverted seepage from the river over the long term. The barrier already constructed and to be constructed would also impede seepage flow from the river through the more recent alluvium during mining operations and the post mining period.

There is perhaps a misunderstanding concerning the second point quoted because this statement assumes that:

a) the paleochannel groundwater plays an important part or role in maintaining sub-surface flow or
b) mining will cause a significant interruption to the continuity of groundwater flow down gradient through more recent alluvium.

As has already been described the groundwater within the paleochannel sediments is of poor quality and therefore it was detrimental to maintenance of better quality of water that currently percolates downstream through the more recent alluvium immediately adjacent to the Hunter River. The paleochannel sediments play no positive role in the maintenance of groundwater to downstream users. Also, as indicated previously, while there will be some removal of more recent alluvium the total down stream flow of groundwater through the remaining recent alluvium would not be affected to any major extent since continuity of the majority of this flow would not be substantially interrupted or arrested. This conclusion however needs to be validated by the Mackie model. That is, what proportion of the down stream groundwater flow would be diverted to the mining zone following construction of the two barrier structures?

4. On page 1 last paragraph where section 38 of WSPHURAS is quoted in the NOW review is not relevant because the particular conditions referred to either do not occur or are localised:
   a) *drawdown of water levels*: these would be largely confined to the paleochannel
   b) *effects on other "water supply works" or bores close by:* There are none in the zone of influence.
   c) *Increased pumping costs or cutting the [water] supply altogether:* not relevant.
   d) *Interference with results of regional water level monitoring undertaken by the Department:* There is no Departmental monitoring in the area.
   e) *Lowering of water levels in dependent ecosystems:* there would be no influence according the Mackie report.
   f) *Mobilisation of contaminated water drawing it to the point of extraction:* this would not occur because the final ponded water void will act to divert any contaminants to the remaining void.

5. The NOW review goes on to state ***"The EA does not address consideration of long term groundwater quality decline, impacts to minimum baseflows, potential impacts to Available Water Determinations, nor environmental harm provisions."*** The impacts to minimum baseflows were assessed in the Mackie report and if the model modifications indicated in this report are included in the model these effects would be reassessed. The groundwater quality issue has been dealt with indicating that there would be an improvement in low flow river water quality that would accrue as a result of diversion of the brackish and moderately saline water seeping into the river from the paleochannel sediments. Because groundwater in the paleochannel sediments is of poor quality such groundwater therefore has no major beneficial use.

6.0 Conclusions and Considerations

- The modeling procedures used in the Mackie report are considered to be suitable for determining both the effect on the groundwater flow regime in the short term during mining and longer term during the recovery phase.

- The modeling report uses exclusively the matrix porous media permeability (primary permeability) of the interburden (sandstone, shale, and siltstone) strata. It does not consider any secondary permeability created by fracture systems within these coal measure rocks except for the coal seam. Whilst there is agreement that these structures are irregularly distributed and not prevalent, data on tests conducted elsewhere in the Valley (AGC 1984) indicate that secondary structures in interburden strata can have permeability values that are up to three orders of magnitude greater than the primary permeability values adopted based on core sample tests. There is uncertainty about whether these permeability values would apply at the current site however, since no specific hydraulic field test has been conducted on the interburden strata to determine whether these structures are significant enough to influence groundwater flow rates.

  If the mining company wishes to prove that the secondary permeability at Carrington is not significant then they should proceed to conduct drilling of bores along the southern boundary area of the proposed WWE and field hydraulic testing of the interburden strata as outlined in more detail in this review.

  Following construction and testing, the bores should be completed as permanent observation bores to monitor water levels over time. That is, each bore should be completed as a multi-piezometer installation with one piezometer set at the bottom of the hole and another at mid depth. This will enable the pressure changes to be monitored within the coal measure strata, during mining and post mining periods.

  Depending on the test results, the permeability, if significantly different from the core values, should then be included in an updated model assessment. The simulation should be stochastic with a variable distribution of secondary permeability values used in a similar manner by Dr Mackie in another recent coal mining project that I reviewed.

- No specific information or data is provided in the report about the existing clay barrier wall that extends across the eastern arm of the paleochannel or the proposed slurry cut-off trench proposed across the western arm of the paleochannel. In particular there is no evidence presented that validates the adopted permeability of 10^{-6} m/day that was used for these barrier structures in the model. Initially, and without further evidence or expert geotechnical opinion, permeability values in the range 10^{-3} and 10^{-4} m/day should be adopted in the model for these barrier structures.

- There needs to be a review conducted by a qualified geotechnical consultant with the necessary experience to comment on the integrity of the methods used for the construction of barrier clay wall and proposed slurry-trench and the long term integrity of these structures including determination and/or expert opinion about the initial and long term permeability of the materials used in their construction.

7.0 References

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