Department of Urban Affairs and Planning

REVIEW OF HYDROGEOLOGY ASPECTS OF SYERSTON NICKEL COBALT PROJECT ENVIRONMENTAL IMPACT STATEMENT

by

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1. Introduction

Black Range Minerals Ltd (BRM) proposes to develop the Syerston Nickel Cobalt Project, north of Fifield in the Central Western Region of New South Wales. The project includes the construction, operation and rehabilitation of a nickel-cobalt mine, processing facility and service infrastructure to provide access, water and natural gas to the site (BRM, 2000).

The proposal is for the production of an average of 2 Mtpa[1] of nickel cobalt ore, mined from a series of open pits. The ore will be treated in a process plant constructed adjacent to the mine site, with tailings disposal to a tailings storage facility (TSF) also at the mine site. Production plants for certain ore processing reagents are also to be constructed at the mine site. Because of metallurgical difficulties with re-use of tailings reclaim water in the process, it is proposed to dispose of excess tailings reclaim water from an evaporation pond facility adjacent to the TSF.

BRM also proposes to mine limestone for use in the process plant from a small quarry to be developed south-east of Fifield, about 20 km from the mine.

It is proposed to obtain the 6,300 ML/year water supply for the project from two borefields 50-60 km south of the mine site. The two borefields would draw water from a paleochannel aquifer in the Lachlan Formation, beneath the Lachlan River floodplain. Water would be transported to the site via a water supply pipeline to be constructed for the project.

It is proposed to construct a gas pipeline about 80 km from a connection point on the existing Natural Gas Pipeline about 40 km south of Condobolin, to supply energy to the project.

Nickel and cobalt products from the operation would be transported by road to a new railway siding about 25 km south-east of the mine site.

The company has prepared an Environmental Impact Statement (EIS) which outlines the proposals, the likely environmental impacts of the project, and the proposed mitigation measures (BRM, 2000).

This report presents a review of groundwater aspects of the EIS. The review has addressed relevant sections of the Executive Summary, Main Report and Appendices D and E of the EIS. Supporting documents to the EIS prepared by Coffey Geosciences Pty Ltd (Coffeys) and Golder Associates Pty Ltd (Golder) have also been reviewed, and discussions have been held with officers of the Department of Land and Water Conservation. The letter report submitted by BRM on 12 January 2001 in response to a 22 December 2000 meeting between the DLWC, EPA, BRM and Golder concerning aspects of the proposed tailings storage facility (BRM, 2001) has also been reviewed. A brief site visit was also made as part of the review.

[1] Mtpa = million tonnes per annum

The major focus of this review has been the groundwater model of the Lachlan Valley groundwater system used by Coffeys, and its appropriateness for predicting impacts of the proposed groundwater extraction. The reliability of the model is critical to assessing whether the aquifer system is able to sustain the proposed water supply, without unacceptable impacts on the resource and other users.

Other factors covered by the review include the potential for impact on the local or regional groundwater of mining and tailings disposal at the mine site, and the limestone quarry.

In this review, each relevant project component is discussed in turn, starting with the water supply borefield development in the Lachlan Valley, then the mine site area, and lastly the limestone quarry.

This review has been prepared by Peter Dundon, of Peter Dundon and Associates Pty Ltd, for the Department of Urban Affairs and Planning, Development and Infrastructure Branch.

2. Proposed Water Supply Borefield Areas – Lachlan Valley Paleochannel

2.1 Existing Groundwater Environment

The Lachlan Valley is underlain by up to more than 140 m of alluvium, comprising Quaternary to Tertiary age fluvial clay, silt, sand and gravel sediments. The sediments are contained within the Cowra Formation and the underlying Lachlan Formation.

The Lachlan Formation occupies the deeper parts of the Lachlan Paleo-Valley alluvials, where it occurs as a relatively narrow (generally 2-8 km wide in this area) paleochannel incised into the underlying Silurian basement rocks. The Lachlan Formation is not exposed at the surface, and in the area of interest occurs between about 80 and 140 m below ground surface, but with a developed thickness of around 20-40 m. The Lachlan Formation consists of light grey interbedded sands and gravels, with minor silts and clays.

The Cowra Formation overlies the Lachlan Formation, but has a much broader occurrence within the Lachlan Valley, where it reaches up to 20 km in width to the east of the proposed water supply area. Thus the Cowra Formation is underlain by Lachlan Formation sediments in the central (deeper) parts of the valley, and by Silurian basement rocks near the (shallower) flanks of the valley. The Cowra Formation consists of orangebrown and brown interbedded clays and silts, with minor sands and gravels.

The Cowra Formation reaches a maximum thickness of about 100 m in the area of interest.

The Lachlan Paleo-Valley is aligned roughly east-west, and is joined by the north-south Bland Creek paleochannel tributary close to the proposed water supply area. The Lachlan Paleo-Valley becomes progressively deeper to the west along with an increasing thickness of the Cowra Formation.

Groundwater flows generally downstream within the paleo-drainage system, ie northwards within the Bland Creek tributary, and from the east to the west within the main Lachlan Valley. [Local reversals of flow may have occurred in some places, at least in the shallower, near-surface groundwater, as a result of lowered groundwater levels due to pumped extractions, or elevated groundwater levels due to increased recharge from irrigation.]

The principal aquifer is the Lachlan Formation. This aquifer is confined by the less permeable clays and silts of the overlying Cowra Formation, and probably induces leakage from the Cowra Formation under pumping conditions. The Lachlan Formation has previously been developed in the area of interest, mainly for irrigation water supplies, while upstream of Jemalong Gap to the east of the project area, it has been developed for town water supply for the town of Parkes and for mine water supplies to the Northparkes Copper-Gold Mining Project.

The Cowra Formation also contains a number of sandy clay and gravel aquifers separated by thick silty clay beds. The individual aquifer horizons are believed to be reasonably extensive, and are able to support useful water supplies. However, the potential for water supply development is considered to be much less than for the Lachlan Formation. The Cowra Formation is tapped by a number of licensed water supply bores in the general vicinity of the proposed water supply area.

2.2 Groundwater Investigation Program

The Applicant engaged Coffeys to carry out groundwater investigations and make recommendations for the project water supply.

Coffeys were first engaged around September 1998. The work subsequently carried out by Coffeys included:

- Construction of two 250 mm diameter test production bores, with screens in the Lachlan Formation;
- Installation of two 50 mm diameter PVC cased monitoring piezometers in the Lachlan Formation;
- Pumping tests (one short multi-stage test and a 72-hour constant rate test) on each of the two test production bores;
- Assessment of aquifer hydraulic properties, based on the pumping test results and other data;
- Sampling and water quality assessment of the Cowra and Lachlan Formation aquifers;
- Computer modelling of the groundwater system to assess potential hydrogeological and hydrochemical impacts due to pumping at 200 L/sec (6,300 ML/a); and

- Computer simulation of potential long-term changes in groundwater salinity.

Two groundwater modelling exercises were carried out by Coffeys. After review of the first exercise by DLWC, Coffeys made significant changes to the model, and redid the model calibration and simulation modelling of impacts.

2.3 Adequacy of the Investigations

The investigation program summarised above in broad terms is considered adequate to have developed a reliable understanding of the groundwater flow system, and to have determined the potential of the Lachlan Formation to support the project's water supply.

However, as discussed in the following sections, I do not believe that Coffeys have demonstrated that the supply would be sustainable without causing an unacceptable impact on other users. My principal concern relates to the mechanism for recharge of the Lachlan Formation, which I believe has been misrepresented in the groundwater model by Coffeys. As a consequence, the predictive modelling performed using their groundwater model cannot be considered a reliable indication of long-term impacts. [The water supply may well be available without unacceptable impact, but this cannot be established from the work completed by Coffeys.]

2.4 Recharge

Coffeys state at page 26 of their report (Coffey Geosciences, 2000):

"The Lachlan Formation gravels are potentially confined beneath the Cowra Formation clays and sands. Recharge to the Lachlan Formation and the lower portion of the Cowra Formation is indirect due to laterally extensive clay layers … The Cowra Formation comprises a number of confined aquifers that are linked more directly in the lateral

rather than vertical direction."
and further:
"…the Lachlan Formation is recharged by the lower portion of the overlying Cowra Formation. Vertical flowpaths which could potentially enable recharge to the Lachlan Formation may be impeded by clay layers …"
Although acknowledging the impeding influence of clays in the Cowra Formation, Coffeys assumed in the groundwater model that the Cowra Formation is an aquifer rather than an aquitard, and that recharge to the Lachlan Formation occurs by downward leakage from the surface through the Cowra Formation.

The abundance of low permeability clays between the surface and the Lachlan Formation suggests to me that recharge to the Lachlan Formation in the area of interest is more likely to be derived from lateral flow within the aquifer itself, from some more distant source, either around the margins of the valley or somewhere upstream. Although the upper Cowra Formation aquifer would be recharged from the surface, and there is the potential for leakage to occur slowly through the clay layers down to deeper horizons, I believe that the middle and lower Cowra Formation aquifers would be recharged in a similar way to the Lachlan Formation, ie predominantly by lateral flow from some more distant recharge source.
Evidence against downward leakage from the surface through the Cowra Formation as the recharge mechanism includes the following:
- In almost every case where hydrographs are available from multiple levels in the DLWC monitoring wells, groundwater pressure levels in the upper part of the Lachlan Formation are higher than those in the lower parts of the Cowra, and higher in turn than in the middle and upper parts of the Cowra Formation – refer Figure B1 [GW036089], Figure B3 [GW025151], Figure B4 [GW036079] and Figure B7 [GW036526] in Appendix B of Coffey (2000). In two other monitoring wells, GW036523 and GW036552 (Figures B8and B9) the groundwater pressure levels are higher in the lower part of the Cowra Formation than in the upper Cowra Formation. This pattern of increasing head with depth has prevailed for up to 30 years or more.

Accordingly, if there is vertical flow of groundwater between aquifers, it would be upwards, rather than downwards, meaning that the Cowra Formation would be recharged by the Lachlan Formation, not the other way.
- The similar trends in the hydrographs for piezometers at different levels at the one site suggests a common source for recharge, rather than recharge from one aquifer to another.
- Formation of a water table mound in the (upper) Cowra Formation (the Warroo Groundwater Mound) within the Jemalong-Wyldes Plains Groundwater Management Area to the south of the proposed water supply area, has not been accompanied by a corresponding mound in the deeper aquifers within the Cowra Formation or the underlying Lachlan Formation.
- Several years' abstraction from the Parkes town / Northparkes mine borefield upstream of Jemalong Weir, at a rate of up to 4,000 ML/a, from a similar borefield to that proposed for the Syerston project, has reportedly

led to drawdowns of around 20 m in the Lachlan Formation, and around 5 m in the lower Cowra Formation, but has caused negligible impact in the

upper Cowra Formation (Brereton, pers comm[2]).

- The pumping tests carried out on test bores PB-E1 and PB-W2 by Coffeys (2000) showed no evidence of leakage or delayed yield in the water level data from the pumped bore. Such effects may become apparent after a longer period of pumping, but their non-appearance during the 72 hours of pumping in those tests indicates that if leakage is to occur, the leakage rate from the overlying clays would be quite low.

2.5 Groundwater Modelling

2.5.1 Modelling Objectives

Coffeys (2000) carried out modelling of the groundwater system, with the following stated aims:

- *"identify regional drawdown effects from groundwater extraction from the proposed borefields for up to 30 years; and*
- *identify potential impacts of groundwater extraction on other groundwater users in the area."*

Coffeys undertook two modelling exercises, described in their reports and in the EIS as Model 1 and Model 2.

2.5.2 Model Code

Coffeys used the MODFLOW package (McDonald and Harbaugh, 1988) to model the Lachlan Valley groundwater system. The choice of the MODFLOW package is considered appropriate.

2.5.3 Model Geometry

The model set up by Coffeys comprises two active layers, the uppermost representing the Cowra Formation aquifer, and the lower layer representing the Lachlan Formation aquifer, underlain by zero permeability representing the low permeability Silurian basement rocks. The geometry of the two aquifer layers in the model has been derived from a combination of data sources, including drilling results from the Syerston water supply investigation, the DLWC bore records, contours of depth to basement prepared by the Australian Geological Survey Organisation (AGSO), and results of previous investigations in the general area. The lateral extent and thickness of the Cowra Formation and the Lachlan Formation assumed in the model are considered appropriate.

[2] Telephone discussion with Greg Brereton, DLWC Dubbo.

Cell size in the model ranges from 200 m square in the central part of the model occupied by the proposed borefields, expanding gradually to a maximum of 1000 m square in some of the outer model cells. This is considered appropriate.

The boundaries of each layer were determined by the known or inferred geological extent of each layer, determined as described above, except that artificial boundaries were set at distances of about 20 km from the proposed borefield area in the upstream (easterly) direction, the downstream (westerly) direction along the main Lachlan paleo-valley, and upstream in the Bland Creek tributary to the south. Both the Cowra and Lachlan Formations are known to continue beyond this distance in those three directions. The appropriateness of these artificial boundaries at 20 km distance is dependent on the likely extent of impact from pumping, and/or the boundary conditions assumed at those limits. The implications of the boundary assumptions adopted by Coffeys is discussed below in Section 2.5.7.

The boundary conditions assumed for the Cowra Formation and Lachlan Formation layers were “no flow” conditions at all natural boundaries, and “constant head” conditions at the eastern (RL 222 m) and western (RL 189 m) artificial boundaries along the Lachlan Valley (corresponding to Jemalong Weir and Mt Wollomundry respectively). No comment was made in the Coffeys report about the assumed condition at the southern (Bland Creek) boundary, so it is assumed that a “no flow” condition was adopted at this boundary as well. The implications of these assumptions is discussed below in Section 2.5.7.

2.5.4 Recharge

As detailed above in Section 2.4, Coffeys described recharge as occurring laterally rather than vertically, yet in their model they assumed a layer configuration and hydraulic parameters that represent recharge as occurring by downwards leakage through the Cowra Formation.

Their model (Section 5.1, page E-14 of Appendix E of the EIS) comprises two active layers, both aquifers. The uppermost layer corresponds to the Cowra Formation aquifer, and it is underlain by another aquifer, the Lachlan Formation. Coffeys have defined a VCONT (or leakance) value to represent the presence of a confining layer between the two aquifer layers. However, the VCONT values they have used in their modelling are very high values (in the range 0.01 to 0.1 day^{-1} in Model 1, and in the range 0.002 to 8.0 day^{-1} in Model 2), suggesting very little impedance between the two aquifers, with the effect that the model represents the sequence as hydraulically continuous virtually from the Lachlan Formation right through to the surface. The model will therefore allow recharge to the Lachlan Formation by vertical flow from the surface through the Cowra Formation, contrary to Coffeys' description of the recharge mechanism, and the considerable evidence against this mechanism as described in Section 2.4 above.

Based on an examination of the bore logs presented in the EIS and in Coffey (2000), and to be consistent with the description of the recharge mechanism given by Coffeys in the EIS, an appropriate VCONT value for the clay confining beds within the Cowra Formation would more likely be around 10^{-6} to 10^{-7} day^{-1}. With such VCONT values, the model would then require recharge of the Lachlan Formation to occur predominantly by horizontal flow. However, a more appropriate representation of the important aquifers and their hydraulic inter-relationship would be to assume three aquifer layers (representing the upper Cowra Formation, middle and lower Cowra Formation, and the Lachlan Formation respectively), and a low permeability confining layer between the upper Cowra Formation and the middle Cowra Formation. Thus there would be four active model layers, instead of two.

In order to allow for recharge to the Lachlan Formation, and to the middle and lower Cowra Formation aquifers, it would then be necessary to introduce a recharge component either around the margins of the catchment, and/or upstream from the area of interest. Steady state calibration modelling would be needed to determine appropriate recharge rates to the relevant cells in the model.

2.5.5 Model Hydraulic Parameters

Coffeys undertook two modelling exercises. The first, described in the EIS as Model 1, had the Lachlan River represented as a “drain”. Hydraulically, this would allow water to discharge from the upper Cowra Formation aquifer to the river, but would not allow water from the river to recharge the aquifer. This is unrealistic, and led to a second modelling exercise, referred to in the EIS as Model 2, in which the river was represented as a “river” rather than as a “drain”. In Model 2, flow could take place from the river to the aquifer, or from the aquifer to the river, depending on the relative water levels at any time in the simulations.

However, as well as this change between Models 1 and 2, Coffeys also made substantial changes to the assumed hydraulic parameters values in the model, as follows:

Formation	Parameter	Value – Model 1	Value – Model 2
Cowra	Horizontal hydraulic conductivity (K_h)	2 – 0.5 m/d	7 – 30 m/d
	Specific Yield (S_y)	0.2	0.02
Lachlan/Cowra	Leakage (VCONT)	0.01 – 0.1 m/d/m	0.002 – 8.0 m/d/m
Lachlan	Transmissivity (T)	200 – 2000 m2/d	30 – 600 m2/d
	Storage Coefficient (S_c)	0.0001	0.008

No explanation was given for such wholesale changes.

For example, the transmissivity value for the Lachlan Formation aquifer at the site of test bore PB-W2 appears to have been 1000 m2/d in Model 1, but only 30 m2/d in Model 2 (Figures G2 and H3 in Coffey Geosciences, 2000).

Coffeys’ interpretation of the test pumping of PB-W2 suggested the transmissivity at that site is around 600-1000 m2/d (Section 4.2.1, page E-10 of the EIS).

Secondly, the spatial distribution of hydraulic conductivity values for the Cowra Formation, transmissivity values for the Lachlan Formation, and leakage coefficient values between the Cowra and Lachlan Formations (Figures G1 to G3 and H1 to H3 in Coffey Geosciences, 2000) are vastly different between Models 1 and 2. So, rather than the model values being based on the results of the test pumping, it appears that it must have been necessary to vary the parameters until the model calibrated.

Both models have leakage coefficient values for all cells in the model occupied by Cowra Formation, even those cells where the Cowra Formation is underlain by basement rather than the Lachlan Formation. While this may not be significant mathematically, it is conceptually incorrect.

Finally, Coffeys have reported the results of Models 1 and 2 as “worst case” and “best case” respectively, and have indicated that the *“… actual conditions will be between the two scenarios.”* These statements imply that both models have validity. However, it is difficult to see how both models can have validity, when the input parameters are so different.

This, in addition to the mis-representation of recharge in the model, causes me to lack confidence in the model outcomes.

2.5.6 Model Calibration

Coffeys’ calibration results are presented in Appendix E of the EIS as plots comparing observed and simulated groundwater levels for various DLWC monitoring bores during the 15 year period 1985-1999 (Figures E-18 to E-21).

More details are presented in Coffey Geosciences (2000).
Coffeys stated that they were unable to simulate actual river stage heights, and so they were not able to accurately simulate the actual recharge events during that period. However, they reported that they did assume a seasonal rise and fall in river stage. Accordingly, the simulated water level plots would not be expected to match the observed data in detail. However, it would be expected that the simulated plots would show fluctuations of similar magnitude to those observed, even if they did not match up in detail.
This is not the case. The simulated plots generated by the model may yield similar *average* water levels to the observed data, but if the model is unable to simulate fluctuations of similar magnitude to those observed, it cannot be considered a good calibration.
I consider this further evidence that the representation of recharge in the model is incorrect.

2.5.7 Model Boundaries
The model boundary conditions assumed are very important. Since recharge to the middle to lower Cowra Formation and the Lachlan Formation aquifers occurs principally by lateral flow to the area of interest, it is likely that significant inflows occur either from the adjacent (and underlying) basement rocks, and/or from upstream within those aquifers. [It is certain that *somewhere* recharge would be occurring through the overlying Cowra Formation confining beds, but the relative water levels in DLWC monitoring bores indicates that this mechanism is not active within the area modelled by Coffeys.]
Consequently, recharge has to be accommodated in the model by inflows at the model boundaries. Coffeys' assumption of a constant head boundary at the downstream (western) and upstream (eastern) boundaries of the Lachlan Formation would be appropriate, providing the model predictions indicate negligible drawdown at these boundaries under long-term pumping.
However, if predicted drawdowns at these boundaries are not negligible, then it would be necessary either to expand the size of the model, or change the nature of these boundary conditions to allow for realistic ongoing inflow rates across these boundaries. A constant head condition would not do this accurately, nor would a no-flow condition.
The boundary condition assumed by Coffeys for the Lachlan Formation at the southern boundary, in the Bland Creek tributary paleochannel, is not clear from Coffeys' reports. I consider that this boundary should also allow inflow. Again the appropriate boundary condition for this boundary would depend on whether there is negligible drawdown predicted at this boundary under longterm pumping conditions.
Because of the shortcomings of Coffeys' model, it cannot be confirmed that drawdowns will be negligible at these boundaries. This has implications for the assessment of impacts of the proposed borefield on other users, ie it cannot be verified that the borefield will have no impact on the Parkes town / Northparkes mine or Forbes borefields to the east of Jemalong Gap, or the proposed Lake Cowal project to the south.
Although some recharge to the Lachlan Formation aquifer is likely to occur by inflow from the enclosing basement rocks, the groundwater contours suggest that it is more likely to occur from upstream within the Lachlan Formation

itself. It may therefore be appropriate to assume a no flow boundary condition for all other boundaries of the model, as Coffeys have done, although this would have to be confirmed by calibration modelling after a more appropriate recharge mechanism were incorporated in the model.

2.5.8 Conclusions Concerning the Modelling

In conclusion, I consider that: the modelling carried out by Coffeys is not reliable, for the following reasons:

- The model does not incorporate the “confining” nature of the low permeability clay layers within the Cowra Formation. I believe the model should include an additional low permeability layer between the upper Cowra Formation and the middle to lower Cowra Formation.
- The model incorrectly represents recharge as occurring from surface infiltration into the upper Cowra Formation, then by downward leakage to the underlying Lachlan Formation. I believe that recharge to the middle to lower Cowra Formation and to the Lachlan Formation should be represented in the model as occurring around the catchment margins, and/or upstream.
- Coffeys have made substantial changes to the input hydraulic parameters, and their spatial distributions, between Model 1 and Model 2, without adequate justification or explanation.
- Model calibrations carried out were not able to simulate the patterns of seasonal fluctuations in water levels observed in DLWC monitoring wells. Consequently, any long-term predictions made using the model (both Models 1 and 2) cannot be considered reliable.

2.6 Potential Impacts of the Proposed Water Supply Borefield

The EIS has detailed the following potential impacts:

- Depletion of water levels in the aquifer[3], since the proposed extraction rate is greater than the estimated recharge rate;
- Drawdown of up to 3-4 m around the aquifer[3] boundaries, and up to 14 m near the proposed bores, at the end of 30 years pumping;
- Variable impacts on shallow bores in the Cowra Formation;
- Increased recharge from the Lachlan River to the groundwater system;
- Lowering of the groundwater mound beneath Jemalong-Wyldes Plains;
- Reversal of groundwater flow near the groundwater mound beneath Jemalong-Wyldes Plains, restoring flow to a northwards direction from the Bland Creek paleochannel;
- Lowering of groundwater levels in deeper aquifers; and
- An additional drawdown[4] of up to 5 m in the proposed Lake Cowal Gold Mine water supply borefield.

The EIS further states that no impacts are predicted on Lake Cowal, Nerang Cowal and Bogandillon Swamp.

Because of shortcomings with Coffeys’ model, the predictive modelling cannot be used as a reliable indication of the likely impacts of the proposal.

[3] Note – the EIS does not specify which aquifer this impact refers to. It is presumed to be the shallow upper Cowra Formation aquifer.

[4] No aquifer is specified – it is presumed that this comment refers to the Lachlan Formation aquifer.

The proposed borefields are within the DLWC Upper Lachlan Groundwater

Management Area 11, near the southern boundary of Zone 5 where it borders on Zone 6. Hence, extractions from the borefields would be expected to initially impact water levels in Zones 5 and 6.

Coffeys reported that the Area 11 Groundwater Management Plan for the years 1997-2002 listed available groundwater allocations in Zones 5 and 6 as 125,801 ML/year and 71,443 ML/year respectively. These figures have since been reduced by DLWC, who now consider the sustainable yield of Zone 5 to be 50,000 ML/a and of Zone 6 to be 35,000 ML/a (Brereton, pers comm[5]).

Coffeys reported (Section 3.4.2, page E-6 of the EIS) that current allocations (at December 1999) were only 18,537 ML/year and 16,704 ML/year in Zones 5 and 6 respectively. However, these entitlements are not fully used, and current usage is probably only around 1,000 ML/a in total from these two Zones (Brereton, pers comm[5]). The proposed Syerston project extractions of 6,300 ML/year would increase the current Zone 5 allocation by around 34% to around 25,000 ML/year, which would represent about 50% of the currently estimated sustainable yield of that Zone.

As an independent check, I have made a crude assessment of the groundwater storage potentially commandable by the proposed borefields. Assuming a specific yield value of 15 % for the shallow sediments, and assuming that it is possible to recover water by dewatering those sediments, then it is calculated that 150 ML could be released from storage from each square kilometre of sediments per metre of dewatering. Accordingly, to meet the project's requirement of 6,300 ML/year for 30 years from storage alone, it would be necessary to dewater a volume of sediments equivalent to around 125 km^2 in area to a depth of 10 m. Such a volume is clearly present in storage, so extraction of the required volume of water is considered technically feasible. [This calculation makes no allowance for recharge, which would of course reduce the volume that would need to be extracted from storage.]

Based on the DLWC assessment of available groundwater allocations, and the independent assessment of potentially commandable groundwater storage, it would seem that the desired water supply would feasibly be available from the Lachlan Valley groundwater system. However, without a reliable model, it is difficult to assess the potential impacts on other users, both local users and the more distant Parkes, Forbes and Lake Cowal borefields.

The best available indication of potential impact from the proposed Syerston project water supply borefields is the experience at the Parkes borefield. It is reported (Brereton, pers comm[5]) that after several years' pumping from the Parkes town borefield at up to 4,000 ML/year, groundwater levels have been drawn down by around 20 m in the Lachlan Formation, by around 5 m in the lower parts of the Cowra Formation, but with negligible impact in the upper Cowra Formation. It is reasonable to expect that similar impacts will be

[5] Telephone discussion with Greg Brereton, DLWC Dubbo.

experienced in the proposed Syerston borefield area, but possibly of a larger magnitude, and over a larger area of impact than at the Parkes borefield, because the size and duration of the proposed water supply are greater than seen at the Parkes borefield to date.

Hence, it can be expected that some existing water users will be impacted by the proposed project. Existing nearby water supplies from shallow bores in the Cowra Formation may suffer minimal impact in the short term, based on performance of the Parkes borefield. Deeper bores, into the lower Cowra Formation or Lachlan Formation aquifers, are likely to be impacted, probably throughout the area covered by Coffeys' model.

BRM has suggested (Section C4.2.2, page C 4-3 of the EIS) that *"… (s)hould disruption to surrounding bores occur, due to water table drawdown, then ameliorative measures such as bore reconditioning, lowering existing pump sets and/or refitting would be undertaken."* These measures may be appropriate, however it is possible that in some instances, the existing bores may not be suitable for reconditioning or lowering of the pump (eg if the bore is not deep enough to allow the pump to be lowered), in which case a replacement bore may be required.

Increased recharge from the Lachlan River is only likely to occur in areas where the pumping induces drawdowns in the shallow upper Cowra Formation aquifer. Based on the performance of the Parkes borefield, this may not be a significant impact.

Similarly, the groundwater mound below the Jemalong-Wyldes Plains area will only be lowered if the pumping induces drawdowns in the shallow upper Cowra Formation aquifer, which appears unlikely, at least in the short term. [Hydrographs of DLWC monitoring bores from this area suggest that the mounding in the shallow groundwater has not been reflected in a change in groundwater levels in the deeper aquifers. Accordingly, while there may have been a reversal of flow in the shallow groundwater, I do not believe there has been a reversal of flow in the deeper Cowra Formation or Lachlan Formation aquifers.]

BRM's proposal to alternate pumping from each of the two borefields on a sixmonthly
cycle is considered likely to have minimal effect on the extent of
impact on other users. It may limit the magnitude of drawdown in the source aquifer close to the pumping bores, by reducing the amount of mutual interference between pumping bores, but is expected to make little difference to long-term drawdown levels further afield.

2.7 Conclusions Concerning the Proposed Water Supply

I am confident that the proposed water supply for the Syerston project would (technically) be available from the proposed borefields in the Lachlan Formation in the Lachlan paleaochannel. The supply would be met partly

from depletion of groundwater storage, and partly from interception of recharge.

The extraction of this supply is expected to have both local and more distant impacts on groundwater levels, which can be expected to have an impact on other users. However, it is not possible, because of shortcomings in Coffeys' model, to predict the magnitude of impacts.

It is important therefore for BRM to commit to comprehensive monitoring, and appropriate mitigation measures, which are flexible enough to accommodate whatever impacts may arise.

3. Mine and Processing Facility

3.1 Site Components

The major infrastructure components of the Mine and Processing Facility

(MPF) are:
- Open pits
- Waste rock emplacements
- Ore stockpiles
- Process plant area
- Tailings storage facility (TSF)
- Evaporation ponds and evaporation surge dam
- Topsoil stockpiles; and
- Roads and haulroads.

The minesite groundwater conditions have been investigated by Golder Associates Pty Ltd, and the results presented in two reports (Golder, 2000a and 2000b). The results are summarised in Appendix D of the EIS, as well as in relevant sections of the EIS Main Report.

Further information on the potential impacts of tailings disposal on groundwater quality have been provided in a BRM letter report (BRM, 2001).

3.2 Existing Groundwater Environment

Golder (2000a) identified three types of aquifers likely to occur in the region, viz alluvial, fractured rock and chemical aquifers.

Alluvial aquifers are apparently of limited development in the MPF vicinity. Sediments occupying paleochannels were identified by Golder as a potential significant aquifer, but there are conflicting statements in the Golder reports and BRM letter report about whether the paleochannels crossing the site are saturated or not. Golder reported [page 9, Section 5.1 of Golder, (2000a)]

that an unsaturated paleochannel (ie above the water table) was observed crossing the mine lease, although other information presented by Golder suggests that it is more likely partly saturated, viz:

- Figure 6 (Golder, 2000a) shows the water table to be within paleochannel sediments,
- Table 5 (Golder, 2000a) reports that water was intersected at 10 m depth in paleochannel bore GAM16, and
- Section 6.2, page 23 of Golder (2000b) states that saturated gravel and/or sand was intersected in one monitoring bore in the paleochannel.

Irrespective of the present saturated or unsaturated state of the paleochannel sediments at the site, nevertheless these sediments are likely to contain zones or lenses of higher permeability, which could constitute preferred pathways for sub-surface flow away from the site if they become saturated by seepage from the TSF or evaporation ponds during or after mining.

Fractured rock aquifers occur in association with fault zones, and are generally only locally important. Fractured faults are reported by Golder to be present at the mine site, generally in the western part of the mine lease. One fractured rock aquifer was identified in the north-west of the site, and it is possible that other permeable fractured zones may occur.

Chemical aquifers may exist where chemical alteration has enhanced the permeability of the basement rocks.

Golder reported (Golder, 2000a) that no aquifers were identified within the potential zone of influence of the TSF and evaporation ponds. Nevertheless, groundwater was detected in many of the test bores drilled at the site, albeit in most cases associated with low permeability.

Based on groundwater levels measured in the test bores, Golder have interpreted a groundwater divide extending in a north-easterly direction from beneath the proposed site of the TSF. Therefore, groundwater can be expected to flow both to the east and the west from beneath the TSF. The evaporation ponds are situated on the eastern side of the groundwater divide. Groundwater levels were measured in the test bores at depths of 25 to 65 m below ground surface. [Golder reported that no perched aquifers were interpreted to exist at the site. However, Table 3 on page 12 of Golder (2000b) shows that in four test bores (GAM-3, GAM-7, GAM-9 and GAM-16) water was intersected at a level above the static water level subsequently measured, suggesting that there may in fact be perched aquifers. It is noted that three of these four are within the main paleochannel that crosses the site. In any event, there may be zones of permeability above the present water table that could be avenues for enhanced flow of seepage from the TSF or the evaporation ponds once a groundwater mound develops beneath them.]

3.3 Groundwater Investigation Program

The mine site hydrogeology was investigated by a program involving:

- Drilling of 17 test bores and installation of monitoring piezometers;
- Permeability testing, using rising or falling head tests on the piezometers, and packer testing of cored geotechnical investigation holes;
- Groundwater sampling and analysis, from the test bores and from Anderson's Pit;
- Groundwater/seepage modelling of the proposed TSF and evaporation ponds.

Most bores intersected groundwater. Permeability testing revealed that the rocks are generally poorly permeable, with hydraulic conductivity values generally in the range 1×10^{-7} to 5×10^{-11} m/sec, only one bore (bore GAM-1) giving a value above this range, at 10^{-4} m/sec.

Groundwater quality was found to range from fresh to saline (214 mg/L TDS at bore GAM-1 to 10,100 mg/L at bore GAM-11). The water sample collected from Anderson's Pit had a measured TDS of only 70 mg/L, and is probably (predominantly) surface water.

The groundwater is slightly alkaline, with measured pH values in the range 7.3 to 8.5. The groundwater contains trace levels of heavy metals, but none were measured at concentrations in excess of the livestock drinking water criteria (ANZECC, 1992).

3.4 Adequacy of the Investigations

I consider the investigation program is adequate for the characterisation of the site, and evaluation of potential impacts.

3.5 Assessment of Groundwater Impacts

Golder undertook groundwater modelling of a section beneath the TSF and evaporation pond areas, to investigate the development of seepage from the base of these facilities. Golder used the SEEP-W computer model, which is a two-dimensional finite element numerical modelling package for variablysaturated groundwater flow. The model is able to simulate groundwater flow in the partially-saturated zone above the water table, and the saturated zone below the water table. It is considered an appropriate modelling package for this purpose.

Golder assumed four layers in the model, an upper layer for the surface alluvium, two intermediate layers for very weathered rock and moderately weathered rock respectively, and a lower layer for (unweathered) basement rock. The model was run using a range of possible hydraulic parameter

values for the model layers, and for a range of TSF and evaporation pond construction and operation scenarios, including the use of liners, toe drains, etc.

The results of Golder's modelling were:

- High initial seepage rates are predicted to occur, but are seen to reduce with time as the ground saturates and as the TSF becomes lined with low permeability tailings that reduce the rate of downward seepage.
- Within 6 years from commencement of mining operations, a groundwater mound is predicted to be developed under both the TSF and the evaporation ponds, or after 8 years with a clay liner.
- By this time, there would be no seepage visible at the ground surface beyond the edges of the TSF or evaporation pond areas.
- With no liner, total seepage flux through the base of the TSF over a 20 year life is predicted to be 5,300 ML, or 9 % of the total water component of the tailings deposited into the TSF.
- With a clay liner, total flux is predicted to be 4,600 ML, or 15 % less than the seepage predicted without a liner.
- Smaller fluxes are predicted through the base of the evaporation ponds, at 1900 ML without liner and 1600 ML with liner.
- It is predicted that the saline seepage from the TSF would migrate up to 850 m from the edge of the TSF by 50 years after commencement of mining, for an unlined TSF, or 800 m for a clay-lined TSF.
- Effective lateral groundwater velocities of the seepage, at the outer edge of the TSF or ponds, is predicted to be 5 to 10 m/year, for both lined and unlined cases, compared with natural groundwater velocities of around 0.1 m/year.

The Golder study makes no comment on the quality of the TSF seepage water, other than that it would be saline, but probably of better quality than the tailings input solution or tailings pore water, due to natural mixing/retardation and adsorption effects (BRM, 2001).

BRM (2001) also states that the seepage flow will be *"… controlled by the mean permeability"*. This would be true if there are no zones or lenses of enhanced permeability that extend for some distance from the TSF area. Such zones of enhanced permeability could allow migration of seepage to greater distances than predicted by use of mean values of permeability. It is unlikely that any bedrock fracture zones would extend for significant distance, but permeable zones within the paleochannel sediments (either above or below the existing water table) could be quite extensive.

The Golder modelling (Golder, 2000a and 2000b) and sensitivity modelling (BRM, 2001) indicate that the presence of enhanced permeability in the paleochannel sediments would only be of possible concern in the case described as "Upper Bound Permeability" [Figures 5 and 6, BRM (2001)]. This case assumes a clay liner permeability 10 times higher, and underlying weathered rock profile 10 times higher, than the base case. All other model

runs suggested that the seepage plume would not have migrated as far as the

main paleochannel even after 50 years.
It is therefore considered to have a low probability of occurrence.
Nevertheless, because the existing licensed bores in the region [Figure 2 of BRM (2001)] are predominantly located in the paleochannel environments, it is recommended that BRM's monitoring bore network include appropriate paleochannel bores to allow early detection of any more rapid seepage migration towards the paleochannels.
Further, the modelling has predicted the fate of seepage for up to 50 years, but no comment is made about longer time periods. Based on the base case modelling results, the rates of migration are expected to be so slow that long term effects can be safely ignored. However, in the event that preferred flowpaths of higher permeability are present, longer-term effects may become important. Once again, this requires that BRM establish and maintain appropriate monitoring of seepage around the TSF and evaporation pond facility, so that the model predictions can be verified.

3.6 Conclusions Concerning the Mine and Processing Facility Hydrogeology

Notwithstanding that some seepage from the TSF and evaporation pond areas is expected to reach the groundwater and migrate away from these facilities, I consider the proposals for the Mine and Processing Facility to have a generally low potential for impact on the region's groundwater resources.

4. Limestone Quarry and Other Project Facilities

The limestone quarry and other proposed facilities are considered to have minimal potential for groundwater impact.

5. References

Australian and New Zealand Environment and Conservation Council (ANZECC), 1992. *Australian Water Quality Guidelines for Fresh and Marine Waters.* November 1992.
Black Range Minerals Ltd, 2000. *Syerston Nickel Cobalt Project, Environmental Impact Statement*, October 2000. Prepared by Resources Strategies for BRM.
Black Range Minerals Ltd, 2001. *Syerston Project EIS, Tailings Facility Response, January 2001.* Letter report prepared by BRM.

Coffey Geosciences Pty Ltd, 2000. *Black Range Minerals NL, Syerston Nickel Project Water Supply Study, Warroo, NSW*, September 2000. Consulting report prepared for BRM.
Golder Associates Pty Ltd, 2000a. *Regional and Local Hydrogeological Impacts of the Proposed Syerston Nickel Mine, Fifield NSW*, March 2000. Consultant report prepared for BRM.
Golder Associates Pty Ltd, 2000b. *Hydrogeological Impacts of the Tailings Storage Facility of the Proposed Syerston Nickel Mine, Fifield NSW*, March 2000. Consulting report prepared for BRM.
McDonald and Harbaugh, 1988. *A Modular Three-Dimensional Finite-Difference Groundwater Flow Model*. Techniques of Water Resources Investigations, Chapter 6. USGS, 1988.