18 October 2013

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Dear Hamish

**Carmichael Coal Project**
**Groundwater Model Peer Review Final Comments**

Further to your email of the 16 October 2013 enclosing final groundwater model peer review comments from URS dated 14 October 2013, please find below our response to the recommendations.

## 1 Recommendation 1

*Include a clear description of the conceptual model underpinning the numerical model, additional details to be considered include:*

- *Groundwater flow patterns either side of the Carmichael River, specifically the low levels north of the river;*
- *Groundwater flow contrary to the dip of the strata;*
- *Structural geology;*
- *Recharge mechanisms and rates with regard to the confined Permian units;*
- *Groundwater flow rates, movement and discharge in terms of considering the system dynamic or static. For consideration of drawdown cone extent;*
- *Pre-and post mining conceptual model figures, cross sections will add value and ease of understanding concepts adopted in the model.*

The key hydrogeological processes thought to be operating in the Project Area are described in Section 2.4 of the Mine Hydrogeology SEIS report addendum. These key processes are also illustrated in two illustrative conceptual cross sections:

- A roughly south-west to north-east section from the Doongmabulla Springs through the subdued ridge line, which lies close to the western edge of the Mine Area, and continues beyond the eastern limit of the Mine Area;
- A second south-west to north-east section, through an area to the south of the Mine Area, which runs across the same north-south ridge line and terminates close to the Mellaluka Springs.

These figures and the associated text provide further information on the majority of the items listed above. Further information on groundwater levels is also provided in Section 2.3 of the Mine Hydrogeology SEIS report addendum.

## 2 Recommendation 2

*Calibrate the model with transient head targets and stream flow data and also preserve vertical head gradients in the model based on the observed head data.*

As previously outlined in Section 5.5.1 of the Mine Hydrogeology SEIS report, whilst GHD agree that a transient calibration to both groundwater level and flow data should be undertaken this would be of limited value at the current time on the basis that:

- Only a relatively short groundwater level record is available for most monitoring bores;
- Few of the monitoring bores completed into the deeper Permian-age strata show any significant rainfall related fluctuations in groundwater levels; and
- The accuracy of the available flow data for the Carmichael River is unknown.

As the length of the monitored period increases then a transient calibration may become worthwhile, particularly where significant recharge events occur and/or the aquifers are stressed in other ways (e.g. by long term pumping tests or development of a starter pit or box-cut). We would suggest therefore that Adani commit to:

- Accurate monitoring of flows in the Carmichael River on a continuous basis at the upstream and downstream boundary of the proposed Mine Area and where possible upstream and downstream of the Doongmabulla spring complex;
- Updating, refining and where necessary re-calibrating the groundwater model as the Project proceeds and additional data become available.

## 3 Recommendation 3

*In the model mass balance, recharge in the output file is not zero, showing a value of recharge out of the model of 786 $m^3$/d (31% of the recharge in). An explanation is required to discuss this value in the mass balance and the model should be revised to remove negative recharge from the mass balance.*

The recharge out component in the modelled water balance represents discharge from MODFLOW-SURFACT recharge seepage face (RSF) boundary cells. As outlined in Section 5.4.2 of the Mine Hydrogeology SEIS report, RSF boundaries have been set at the modelled ground level throughout the model area to prevent modelled heads rising above the ground surface. Recharge out will therefore occur in any cells where the modelled groundwater level rises above the modelled ground surface.

Further analysis of the modelled output confirms that all of the cells where RSF discharge are occurring are located close to the Carmichael River (i.e. an area of known high groundwater levels where actual groundwater discharge is thought to be occurring). Discharge in this area of the model is therefore considered to be both realistic and consistent with the conceptual model. However, rather than discharging via RSF cells, from where it is effectively removed from the model, it would be preferable if this water instead discharged via the routed modelled stream boundary (STR) cells, from where it could potentially leak back into groundwater. Future refinements of the model should therefore include de-activating the RSF boundary condition in these cells and adding an STR boundary condition in its place. If no other changes were made to the model this would effectively add 786 $m^3$/d or around 11% to the predicted pre-development STR flow out component (i.e. predicted baseflow to the Carmichael River) of 7083 $m^3$/d. It should be stressed, however, that the measured volume of baseflow is largely unknown. Determining the long term average actual baseflow to the Carmichael River (whether that be 70, 700, 7000 never mind 7000 or 7800) requires a long time series of reliable surface water flow data. Even where data are available, since groundwater discharge or evaporation from the riparian zone cannot be directly measured, any estimate of actual baseflow to the Carmichael River will remain subject to a high degree of error. In this context the non-optimal boundary condition set up in this area is considered to be a minor issue although it does highlight the importance of obtaining a long time series of reliable flow data for the Carmichael River.

## 4 Recommendation 4

*Reduce cumulative percentage error to be under 1%*

This has now been addressed as described in Section 3.4 of the Mine Hydrogeology SEIS report addendum.

## 5 Recommendation 5

*The model flow components, as presented in the report, require clarification. These include:*

- *In Table 22 the Carmichael River Leakage in flow is equal to out flow, this indicates that stream leakage was balanced by baseflow. This requires an explanation;*
- *For evapotranspiration, at model stress period 59 the evapotranspiration flux was 3,585 $m^3$/d. This flux is more than the recharge of 2,533 $m^3$/d. This is not sustainable. This requires validation and clarification of the influence of model boundaries on the model predictions; and*
- *The model output files indicate the modelled pumping rate was 201.5 $m^3$/d, whilst the model output files indicate a pumping rate of 152 $m^3$/d. This requires clarification.*

With regard to the modelled leakage from the Carmichael River (i.e. Stream Flow OUT) being equal to modelled baseflow (i.e. Stream Flow IN) during the post closure period as shown in Table 22. This reflects that all of the modelled baseflow gained in the area upstream of the Mine Area is lost as leakage further downstream. Modelled long term average baseflow in the Carmichael River post closure at the downstream limit of the modelled stream network, which is located at confluence with the Cabbage Tree Creek, is 0 $m^3$/d, although since the modelled accretion profile shown in Figure 38 terminates upstream of this point, this is not illustrated in the SEIS report. Figures 33 and 38 terminate upstream of the end of the modelled profile since the model grid resolution was found to be too coarse to accurately simulate losses towards the lower downstream end of the modelled reach.

With regard to the comments relating to evapotranspiration. It should be stressed that:

- Given the high water table conditions which can be observed along the Carmichael River all year round, potentially significant losses of groundwater via evapotranspiration from the riparian zone along the river must be expected; and
- Recharge represents only part of the total modelled inflows and hence there is no reason why evaporation and other individual modelled outflows cannot exceed modelled recharge.

Reference to the pre-development steady state water balance (Table 1) indicates that:

- Modelled inflows and outflow balance i.e. evapotranspiration losses of 4001 $m^3$/d are sustainable;
- In addition to 2,533 $m^3$/d of recharge the other main source of net inflow to the model is 3,214 $m^3$/d of net lateral inflow from adjoining areas;

It is recognised, however, that the current model may under-estimate the recharge component of the water balance and/or over-estimate the contribution of adjoining areas (i.e. that the modelled balance between local recharge and sub-surface flows from adjoining areas is incorrect). In recognition of this possibility the sensitivity of model predictions to a wide variety of different recharge rates has been assessed as summarised in Sections 3.5 and 3.6 of the Mine Hydrogeology SEIS report addendum. These results suggest, as would be expected, that increasing the modelled recharge rate tends to reduce the majority of predicted impacts of the development since the predicted cone of influence of the development is reduced. Predicted baseflow impacts on the Carmichael River do tend to increase slightly with increasing recharge, although increasing recharge by a factor of 10 to around 25,000 $m^3$/d results in a 600 $m^3$/d or 60% increase in predicted baseflow impacts.

**Table 1 Calibrated steady state model – water balance**

| Component | Flow IN ($m^3$/d) | Flow OUT ($m^3$/d) | IN - OUT |
|---|---|---|---|
| Recharge | 2,533 | 0 | 2,533 |
| Evapotranspiration | 0 | 4,001 | -4,001 |
| Discharge from/to Adjoining Areas | 44,680 | 41,466 | 3,214 |
| Groundwater Extraction | 0 | 152 | -152 |
| Carmichael River Leakage | 6,662 | 7,084 | -421 |
| Discharge to Other Water Courses | 0 | 1,200 | -1,200 |
| TOTAL | 53,876 | 53,904 | -28 (-0.05%) |

With regard to the apparent discrepancy between modelled input and output extraction rates. The MODFLOW package input file used for all simulations includes all known licensed extractions which fall within the 93 km by 108 km area covered by the model grid. As shown in Figure 29 of the Mine Hydrogeology SEIS report some of these extractions fall within the inactive grey cells outside of the active model area. Since they fall outside the active area, MODFLOW correctly switches these extractions off and hence the model output files indicate less extraction. For the sake of clarity it may have been preferable to remove these extractions from the input file, but since they are effectively ignored in the flow calculations then this would make no difference to the model results.

## 6 Recommendation 6

*Conduct sensitivity analysis for the transient predictive model based on the sensitive parameters*.

A detailed analysis of the sensitivity of model predictions to a range of model parameters was previously presented in Section 5.8 of the Mine Hydrogeology SEIS report (GHD, 2013). However, subsequent comments have suggested that this information could have been presented in a way which more clearly identifies the sensitivity of key impact predictions to modelled parameters. A series of revised plots were therefore developed to re-present the information with more clarity and are presented in Section 3.5 of the Mine Hydrogeology SEIS report addendum.

Additional sensitivity runs were also carried out with particular focus on the sensitivity of model predictions to:

- An expanded range of values for the hydraulic conductivity of the Rewan Group and modelled recharge quantities; and
- General head boundary conductance.

The results of which are presented in Section 3.6 of the Mine Hydrogeology SEIS report addendum.

It should be noted that the majority of the sensitivity analysis work undertaken was conducted based on the steady state post closure model, rather than the transient predictive model. Unfortunately given the number of model runs required and the long run times of the transient model, especially following resolution of the cumulative water balance errors (see Recommendation 4), it was not possible to use the transient predictive model for the sensitivity runs. However, a limited number of transient runs were undertaken to confirm the sensitivity of model predictions to different storage values, as reported in Section 5.8 of the Mine Hydrogeology SEIS report. As is often the case these runs confirmed that whilst the timing of predicted drawdown related impacts is sensitive to alternative storage parameters, the magnitude of the predicted peak impact is not. Furthermore impacts calculated using the steady state post closure model are either similar to, or in many cases greater, than those calculated using the transient predictive model. There is no reason to suspect that the sensitivity of predictions made using the steady state or transient versions of the model would be significantly different. If it had been practicable to use the transient predictive model for the sensitivity analysis then the range of predicted impacts outcomes would have been similar to those already included in Section 3.5 and 3.6 of the Mine Hydrogeology SEIS report addendum.

Sincerely
GHD Pty Ltd

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