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Watermark Coal Project KA Comments on the MER model audit and AGE Revised Modelling

Background

The Planning Assessment Commission (PAC) in June 2014 requested that Dr Colin Mackie (Mackie Environmental Research - MER) conduct a review of the AGE EIS groundwater study for the Watermark Coal Project. That review involved a detailed examination of the groundwater model data files assembled by AGE.

Consequently Dr Mackie provided AGE with a number of questions regarding various aspects of the model procedures and methods. Specifically, they included the basis for the vadose (unsaturated) zone parameters adopted by AGE; how drawdowns and their distribution were calculated; the reason for the unusually rapid recovery response of water levels in the mine pits (post mining); information regarding faults and water balance issues. In addition vertical sections of pressure heads were requested. AGE provided a response to questions in July (AGE 2014).

On 14 August 2014 Dr Mackie prepared a report for the PAC on the various areas of concern regarding the AGE model (MER 2014). The concerns were in summary: (1) the adoption of vadose zone van Genuchten (VG) parameter values based on conjecture; (2) setting of the mine pit cells reference elevations that govern the simulation of pit dewatering, in an unorthodox manner ; (3) the presence of an erratic zero pore pressure surface (watertable) in the vertical sections requested by MER and provided by AGE; (4) the highly erratic behaviour ("spikes") in the WST model inflows; (5) omission of a recovery steady state simulation. Based on the above Dr Mackie indicated he was unable to accept the results presented and recommended that the model be re-run using the 'pseudo' method instead of the vadose zone (VG) method thereby removing the need to specify VG parameters. Dr Mackie also recommended that "drains" representing seam mining elevations be set in an orthodox manner by progressively assigning reference elevations to the base of individual cells and that a steady state recovery run be included.

The updated AGE model results were presented in a memorandum dated 30 September 2014 included in the Hansen Bailey report dated 3 October 2014 (Hansen Bailey 2014) that sets out the response to the PAC review report. The memorandum key item responses are as follows:

1. *The* [AGE] *model applied AGE's standard methodology and set the drain reference elevation in the mining areas to the base of the pit floor to introduce conservatism to the modelling predictions and to aid model stability for the recovery scenario".*

2. AGE states that the *"residual saturation function"*[1] adopted was to aid stability in convergence during recovery and faster run times. That is, the original VG parameters in the EIS model with alpha (α) =0.01 in particular was chosen because it was presumed to lie within the alpha range 0.005 and 0.05 indicated in various VG references referred to by AGE (2014).

3. AGE also maintains in a somewhat brief statement that *"Fast runtimes (less than 8 hours) were essential to maintain 50m x 50m cell resolution in the mining area."* Presumably it was meant to say that because of increased resolution and therefore the increased cell count, faster run times were required to reduce the computer turn-around.

4. AGE states that in their experience the pseudo function reduces the mining impacts compared to their "conservative" outcome based on their selection of the VG parameters in particular 'alpha'.

The consequences and validity of the *"standard methodology"* adopted by AGE as highlighted in items 1 to 4 above is discussed below.

Comments

Dr Mackie in the MER (2014) report Figures 3 and 4 indicates that a much greater drawdown was obtained for a VG parameter with alpha =0.01 than for a value of 0.1 in the modelled sections showing hypothetical pressure head profiles.

I have recently also conducted some numerical simulations using MODFLOW-SUFACT (MS) and a model of seepage through an embankment with dimensions of 100m in height and width, using the example described and independently verified in (Kalf 1988). The numerical results show that a value of alpha =0.01 gave spurious zero pressure head (the watertable) results with a much lower watertable depth and very large mass balance errors, while larger values of alpha (20 to 500 greater) gave reasonable results although irregular zero pore pressure heads for alpha values just below the mid to higher end of that range. The conclusion that can be drawn is that while the AGE EIS drawdown result is fortuitously "conservative" it is nevertheless in error because of a fundamental oversight as explained below.

In their letter 22 July AGE argued that the VG parameters used were within the ranges published by a number of papers by van Genuchten et al which they quote as having the alpha parameter in the range 0.005 to 0.05 (no units given). However these ranges are at the centimetre scale of soil materials with alpha having dimensions cm^{-1}. Alpha is not dimensionless as assumed by AGE. Clearly at the consistent metre scale used in the regional model the value of alpha should have a much larger value. The above quoted alpha range would need to be converted to

[1] The 'residual saturation function' is better described as the vadose zone moisture relationship given in this case by the van Genuchten parameter effective saturation equation.

alpha = 0.5 to 5 m^{-1} to be consistent with the metre scale used in the model. Hence a value of 0.01 cm^{-1} would convert to a value of 1.0 m^{-1}. However, up scaling the alpha values is no guarantee that the zero pore pressure heads are calculated correctly or presented as accurately as possible. This is because of the large layer cell vertical dimension (discretisation) used in a regional model. Typically this dimension is up to tens of metres and therefore not at sufficient resolution to interpolate pore pressure differences that are assumed in the van Genuchten or other vadose zone equations.

I subsequently had a discussion with Dr Mackie on Friday 17 October 2014 about his original concerns and also his views about the response by AGE and the results of updated modelling (AGE 2014).

Consequently, Dr Mackie and I agreed that usage of the vadose zone method, using for example the VG parameters for MS type regional models can produce seemingly valid but unpredictable results and is best applied to small scale soil models with small cell sizes. It is relevant that in the MS user's manual, all examples that use the VG method are for small scale column type problems at the centimetre scale with the remainder examples of large scale problems that use the pseudo option. This issue was first raised in Dr Mackie's first question put to AGE (see Attachment to MER, 2014)

Confirmation advice about this issue received from *HydroGeologic,* the authors of the MODFLOW-SURFACT computer code (email response October 19, 2014), is as follows:
"Theoretically, the VG method is scale-independent. However, high vertical resolution is required to describe the vertical variation of moisture. Time steps may have to be very small to track the movement of the front accurately. Because of the high degree of non-linearity, a large number of iterations may be necessary. Therefore it is not practical for regional applications."

For regional models both Dr Mackie and I agree that the use of the vadose approach for mine scale flow modelling should be discouraged, deferring instead to the pseudo method. When this point was put to *HydroGeologic* they responded with: *"Yes, we totally agree with you".* It is relevant that both Dr Mackie and I have adopted the pseudo approach over many years without incident or any of the problems indicated by AGE and have for various reasons avoided using the vadose zone method for regional models.

Although AGE have indicated that the pseudo method can produce non-convergence we would suggest that the reasons for such behaviour probably lie elsewhere in either the model set up, the way time stepping has been invoked, implementation of Newton back-tracking or for other reasons not related to the pseudo method.

I would also suggest that AGE attempt to limit the number of cells in their models, if necessary introducing variable larger cell sizes outside the zone(s) of interest.

It is known that some other modelers also choose the vadose zone approach as it would seem to be more theoretically based given that it uses specific soil-moisture parameters in conjunction with experimental based equations as opposed to the pseudo approach where no parameters are required. But we have found the reverse is the case for large scale regional models in practice, apart from the difficulty of having to stipulate parameters (alpha and beta) as well as the residual saturation (actually *"irreducible saturation somewhat smaller than field capacity"* - *HydroGeologic* advice) required for the vadose zone approach.

AGE has indicated that no difference in drawdown results were found for variations in the VG parameters used in vadose zone method. That may be true for certain ranges, although no indication is given what range was used by AGE. However it is now clear that examples given by MER (2014) in the figures 3 and 4 and KA numerical example discussed that using a low value of alpha = 0.01 (cm^{-1}) produces a spurious result even though it might be construed to be conservative. Fast computation in this case does not mean that the solution is robust or accurate.

Dr Mackie has also indicated that using the vadose VG parameters means that the water table has to be calculated by determining the elevation of zero pore pressure in a vertical column of cells rather than simple adopting the head elevation specified in the shallowest cell in model output (HDS) file. The pseudo option does not suffer from this variation and heads can be subtracted directly to obtain drawdown. This has also been confirmed by the authors of the MS code.

Interpretation of the AGE Pseudo Method Drawdown Results and Sensitivity
The more recent AGE model update drawdown results indicate less drawdown using the Pseudo method than the AGE EIS model generated drawdowns using the invalid Vadose method with alpha= 0.01. Reference is made to Scenario 3 and 11 shown in Figure 2-15 in the memorandum in Hansen Bailey (2014). Both of these scenarios were run using the Pseudo method. Scenario 3 is for the non-backfilled case whilst Scenario 11 is for the backfilled case. Scenario 3 is one requested by Dr Mackie but merely examines the likely drawdown distribution if the pits were hypothetically not backfilled and kept "dry" and therefore establishes an upper drawdown limit for scenario 11. The mine plan however is to backfill the eastern and southern pits and therefore scenario 11 is relevant. Even for the non-backfilled case the interference drawdowns at respective production bores in the vicinity of the pits are well within the AIP minimum harm criteria (i.e. less than 2m) and for the probable scenario 11 are negligible (see Table 2-8).

Sensitivity scenarios are discussed in section 2.4 in the memorandum (Hansen Bailey 2014). The only valid cases are scenario 6 and 7. Scenario 6 was where the faults were removed whilst scenario 7 was where model storage parameters were increased by one order of magnitude (10 times). Scenario 8 (purple contour Fig 2-20) was using the original base cell elevation mine floor assignment that Dr Mackie objected to as unorthodox (point 2, third paragraph above herein) and the AGE Vadose method and is therefore invalid. The drawdowns for scenario 6 and 7 are shown in Figure 2-20 for both model layer 2 (Gunnedah Formation) and the layer 10 (Melvilles coal seam). The scenario 6 result is the 1m blue drawdown contour whilst the scenario 7 result is shown as the 1m yellow drawdown contour. Neither scenarios 6 or 7 drawdown exceeds the AIP 2m criteria in any production bore.

Practical Consequences and Conclusions
Although Dr Mackie continues to have reservations about certain aspects of the current modelling procedure we agreed in discussions that these uncertainties are unlikely to change the magnitude of the regional drawdowns obtained in the recent update. In particular:

a) The results indicate that there would be no drawdown of any consequence beyond the Eastern region of the mine boundary into the Narrabri or Gunnedah formation. That is, the production bores within the Gunnedah sediments which extend along a corridor within that formation in the direction of the creek would not be affected.

b) In the area to the south the drawdowns are within the maximum range of drawdown permitted by the Aquifer Interference Policy for production bores that lie within or in the vicinity of this area.

c) I have previously stated that as well as the observation network that includes the water level, water quality and mine water seepage monitoring plans as set out in AGE (2013), this monitoring should include observation bores both in the near vicinity of the open cut voids and more distant bores on the edges of the alluvial flats to be constructed if not available.

d) Any remaining uncertainty, as is the case with all modelling outcomes, can be assessed by ongoing monitoring of drawdown, mine inflow and water quality. I have previously recommended a review of the modelling predictions 2 years after mining commences and again after an additional 8 years unless trigger criteria are not met before those periods. However, in the present case the AGE model should now be compared to field data (water levels and inflow) every 3 years during mining and monitoring continuing for a period of at least 10 years after mining ceases. The trigger criteria based on field and model water level hydrograph comparisons should also still apply.

e) Once the Eastern pit has been backfilled two piezometers should be constructed at least 20m apart (one as a 'fall back') within the backfill and monitored for both water level over time and groundwater salinity. Similar piezometer placement and monitoring should be conducted in the southern pit backfill.

References

Australasian Groundwater and Environmental Consultants Pty Ltd 2013 *Watermark Coal project Groundwater Impact Assessment project No G1501 (update). Jan. EIS Appendix S Groundwater Assessment.*

Australasian Groundwater and Environmental Consultants Pty Ltd 2014 *Proposal for Watermark Project support to Planning Assessment Commission process. Letter dated 22 July 2014 addressed to P. Jackson Project Manager Watermark Shenhua Australia.* This letter is the response to the MER questions.

Hansen Bailey 2014. *Response to Planning Assessment Commission review Report. October. This report contains the response to the Dr Mackie review in a memorandum addressed to P Jackson (Shenhua Australia Holdings Ltd) from Neil Manewell dated 30 September 2014.*

Kalf F.R.P. 1988 *A variably saturated finite element model for three-dimensional seepage face problems. Ph.D. Thesis, School of Civil and Environmental Engineering, University of NSW, Sydney.*

Mackie Environmental Research (MER) 2014 *Proposed Watermark Coal Mine-Groundwater Environmental Impact Assessment. Letter dated 14/08/2014 addressed to NSW Planning Assessment Commission.*

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