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TO: James Duggleby
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FROM: Dr Noel Merrick

RE: Gloucester Gas Project - Peer Review of Conceptual Hydrogeological Model

OUR REF: HA2015/7

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1. Introduction

This report provides a Peer Review of the updated conceptual (hydrogeological) model under Condition 3.9 of the Part 3A approval (MP 08_0154) for the Gloucester Gas Project - Stage 1 GFDA. In a letter from the NSW Department of Planning & Infrastructure to AGL Energy Limited dated 5 March 2013, the Department noted that the Director-General had approved the appointment of Dr Noel Merrick as an appropriately experienced and qualified hydrogeologist for the undertaking of the review. Apart from over 40 years experience as a professional hydrogeologist, geophysicist and groundwater modeller, Dr Merrick has specific experience in the Gloucester Basin, having led the groundwater assessments for two open cut coal mine expansions (Duralie, Stratford) in the Gloucester Basin.

The timing of the updated conceptual model coincides with the anniversary of the commencement of the Waukivory pilot testing program.

2. Documentation

The peer review has been undertaken through examination of a written report, following a conceptualisation workshop and two meetings with the developers of the conceptual model.

The updated conceptual model has been documented in a report by Parsons Brinckerhoff (PB):

1. Parsons Brinckerhoff, 2015, Updated Conceptual Hydrogeological Model of the Gloucester Basin. Report No. 2200556A-WAT-REP-001 RevE prepared for AGL Upstream Investments Pty Ltd. Revision E, Final Report. Author R. Rollins. Date 17 November 2015. 108p + 3 Appendices.

A previous review was based on the following report:

2. Parsons Brinckerhoff, 2013, Hydrogeological Conceptual Model of the Gloucester Basin. Report No. 2162406A PR_7266 prepared for AGL Upstream Investments Pty Ltd. Revision B, Final Report. Authors R. Rollins and S. Brown. Date 28 June 2013. 73p + 2 Appendices.

Initial reviews were conducted on draft reports dated March 2014 and May 2014.

Document #1 has the following sections:

1. Introduction
2. Background
3. Physical setting
4. Geology
5. Monitoring of surface water and groundwater
6. Surface water
7. Groundwater
8. Model Updates
9. Influence of faulting on groundwater flow
10. Basin-wide water and salt balance
11. Conceptual model
12. Framework for numerical modelling
13. Conclusion
14. References.

The Appendices to Document #1 contain:

1. Approval conditions
2. Peer reviews
3. Groundwater and surface water hydrographs.

3. Review Methodology

There are two accepted guides to the review of groundwater models: (A) the Murray-Darling Basin Commission (MDBC) Groundwater Flow Modelling Guideline[1], issued in 2001,and (B) newer guidelines issued by the National Water Commission (NWC) in June 2012 (Barnett et al., 2012[2]). Both guides also offer techniques for reviewing the non-modelling components of a groundwater assessment. The 2012 national guidelines build on the 2001 MDBC guide, with substantial consistency in the model conceptualisation, design, construction and calibration principles, and the performance and review criteria, although there are differences in details.

The new guide is silent on modelling of coal seam gas and offers no direction on best practice methodology for such applications. There is, however, an expectation of more effort in uncertainty analysis, although the guide is not prescriptive as to which methodology should be adopted.

The updated conceptual model described in Document #1 provides an example of progressive refinement of a conceptual model (as outlined in Document #2) in line with recommendations in the NWC modelling guidelines.

4. Conditions

The terms of reference for the review are articulated in Conditions 3.8 and 3.9 of the Planning Assessment Commission (PAC) Project Approval (22 February 2011) and Condition 16 of the Department of Sustainability, Environment, Water, Population and

1 MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

2 Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A. (2012). *Australian Groundwater Modelling Guidelines*. Waterlines report 82, National Water Commission, Canberra.

Communities (SEWPaC; now Department of Environment) Approval (11 February 2013).

PAC Condition 3.8:

Prior to the commencement of construction of the project, the Proponent shall in consultation with NOW update the conceptual hydrogeological model developed during the assessment stage of the project (referred to in the document listed in condition 1.1d) based on baseline data gathered from (but not necessarily limited to), the pre-construction investigations identified below:
a) seismic surveys of the site to identify geological features of risk;
b) preliminary field sampling of hydraulic conductivity, groundwater levels, groundwater quality and surface water quality based on a packer, pump and slug testing program and surface water sampling; and
c) long-term baseline monitoring (i.e. at least six months) at groundwater and surface water locations determined in consultation with NOW, to ensure representative baseline data on pre-construction conditions (including seasonal variability) in relation to the shallow rock and alluvial beneficial aquifers, deeper coal seam water bearing zones, groundwater users and surface waters.

PAC Condition 3.9:

The updated conceptual hydrogeological model referred to in condition 3.8 shall be submitted for the Director-General's approval, prior to the commencement of construction and shall include:
a) updated assessment of the potential for drawdown and displacement of shallow rock and alluvial beneficial aquifers, considering impacts to nearby registered bore users, based on detailed baseline data gathered from condition 3.8 a) to c);
b) optimal areas for gas well location within the Stage 1 Gas Field Development Area based on minimising the risk of gas migration and of interaction with beneficial aquifers and the outcomes of the updated assessment;
c) recommendations for phased gas well development including indentifying the maximum number of gas wells that would be developed during the first phase of development and associated operational groundwater monitoring strategy consistent with the requirements of condition 4.1; and
d) include an independent peer review by an appropriately experienced and qualified hydrogeologist (who is approved by the Director-General for the purposes of this condition) on the robustness and technical veracity of the model.

SEWPaC Condition 16:

The person taking the action must consult the department on the development of the conceptual hydrogeological model required under Conditions 3.8 and 3.9 of the state approval conditions, and must provide a copy of the model to the department within twenty (20) business days of its finalisation.

In addition to the regulatory conditions, the evolution of the Gloucester Basin conceptual model since 2010, as documented in three reports cited in PB (2013), was reviewed by Dr Richard Evans (Sinclair Knight Merz) on behalf of the Gloucester Community Consultative Committee. Consideration of his recommendations, as they pertain to an updated conceptual model, is noted in Table 2.3 of the PB (2013) report and in Table 2.4 of the PB (2015) report. Recommendations 13 and 14 sought inclusion in the conceptual model of the hydraulic behaviour of faults and major structural changes related to faults. Recommendation 22 sought consolidation of the conceptual model documentation into a single report. Both recommendations are now satisfied.

The reviewer is aware of some of the correspondence between the Proponent and DPI Water [formerly Office of Water] and was present at a joint workshop between the parties in February 2015 which discussed both conceptual modelling and planned numerical modelling.

5. Checklist Evaluation

The NWC guide includes a checklist for the assessment of each stage of modelling, including the conceptualisation stage preceding the development of a numerical model. The completed checklist is offered at **Table 1**.

The comments in the checklist provide the foundation for this reviewer's certification of the robustness and technical veracity of the model, as required under PAC Condition 3.9(d).

In terms of the conditions:

- seismic reflection surveys have been conducted and their outputs examined for the identification of fault locations and persistence [PAC Condition 3.8(a)];
- there has been a very extensive field program in accordance with the requirements of PAC Condition 3.8(b), including two field tests of potential effects of faulting on groundwater hydrology;
- there is more than four years of baseline data in accordance with PAC Condition 3.8(c), covering seasonal variability, with a network of more than 50 monitoring points covering representative lithologies down to a depth of about 350 m; hydraulic conductivity measurements extend to about 1,000 m depth;
- the report includes a generic discussion on drawdown propagation from CSG activity in accordance with Condition 3.9(a), in Section 10.6.1, with inclusion of a map of registered bores in Figure 7.16, but quantitative assessment is premature until the regional 3D groundwater model has been developed;
- there is some discussion on potential subsidence from CSG activity in accordance with Condition 3.9(a), in Section 10.6.3, but consideration of *displacement of shallow rock and alluvial beneficial aquifers* is premature;
- the requested *optimal areas for gas well location* in Condition 3.9(b) are premature, although operational logistics principles are addressed in Section 10.6.4; and
- the requested *recommendations for phased gas well development* in Condition 3.9(c) are premature, although operational logistics principles are addressed in Section 10.6.5.

6. Specific Comments

As noted in Table 2.3 of Document #1, the conceptual model is based on 37 previous technical reports. Twenty-five of these reports were authored by PB while four were compiled by AGL. The number of prior studies adds confidence to the conceptualisation of the groundwater system as presented in Document #1. This reviewer is not aware of the omission of any significant study from examination.

The geological map in Figure 4.1 (PB, 2015) shows the mapped area of "Quaternary Alluvium". It is likely that much of the mapped area is colluvium, following a detailed TEM survey conducted for the Stratford Extension groundwater assessment.

While Figure 5.1 (PB, 2015) shows the AGL monitoring network centred on AGL-owned properties, there are substantial networks to the south belonging to the Stratford Mine, and to the north the Rocky Hill Project. Although no monitoring data are shown for these bores, the monitored sites are indicated in Figure 7.16 (PB, 2015).

In Section 6.1 (PB, 2015), an assessment is made of likely baseflow contributions to stream flow. There are many alternative algorithms for baseflow analysis and they can differ substantially in their estimates. It follows that the provided baseflow estimates have an associated uncertainty. Table 6.1 notes that mean baseflow is only 6% of mean total flow.

In Section 7.3.5, the high pressure heads observed at sensors 5 and 6 in WKMB05 are attributed tentatively to fracture stimulation during the Waukivory Pilot Testing Program. However, much of this overpressurisation is likely to be natural, as seen in the pressure readings at installation before the pilot test began, unless the piezometers had not sufficiently stabilised at that time.

The potential for vertical groundwater flow and its direction are explored in Section 7.3.6 in terms of vertical head differences. Apart from the vertical head differences, it would be informative to include gradients (in m/m units) by dividing the head difference by the vertical separation distance. This normalises the responses so that different locations can be compared on equal terms.

The pre-development regional groundwater level contours in Figure 7.8 are in broad agreement with the inferred levels determined by this reviewer in the Stratford Extension groundwater assessment.

The groundwater hydrographs in Figures 7.4 to 7.6 are compared with daily rainfall and the rainfall residual mass curve to illustrate cause-and-effect, with rainfall signatures dropping off with depth of investigation..

Figure 7.11 plots SAR against EC, without any information provided on what magnitudes of SAR (or SAR-EC zones) are problematic.

Chapter 8 includes a comprehensive assessment of the influence of posited faults on groundwater flow, both theoretical and actual. It is rare to find this level of analysis outside the petroleum industry where most of the pertinent research has been done. The analysis includes literature review, shale gouge ratio theory, calculations of the likelihood of sealing of a fault in the Gloucester Basin, inference of fault movement from slickenside density, dual barrier-conduit conceptualisation, analysis of 3-day and 29-day pumping tests, hydrographic statistical correlation, chemical signatures, and thorough numerical cross-section modelling of seismic-interpreted faulted systems (using FEFLOW). The reviewer was engaged in all phases of numerical model planning, conceptualisation, construction, prediction and scenario analysis and can attest to the rigour with which the modelling has been done. It is a very informative piece of work, worthy of wide publication throughout the groundwater discipline.

The reviewer was also involved in all phases of the water balance assessment in Chapter 9. The analysis has been conducted comprehensively and is considered by the reviewer to be as accurate as is reasonably possible prior to construction of a detailed numerical model. The latter method is the best way to establish a reliable water balance. *A priori* water balance analysis is necessarily imprecise as many of the components are not directly measurable.

To allow estimation of the more intractable water balance components, a simple numerical model has been constructed. This is a sensible approach, as it forces consistency between the measurable and inferred component magnitudes, and ensures conservation of mass. The water balance analysis has been useful in demonstrating that the dynamics of the groundwater system are localised to the uppermost part of the Basin, with short residence times in the alluvium. The short storage/recharge ratio, about 6 years, indicates that the groundwater system is dependent on frequent recharge episodes for sustainability as a resource. The groundwater system would not be expected to be a reliable source of water under prolonged drought conditions.

The salt balance estimates indicate a long-term benefit to the Basin by reducing salt accumulation over time. This is a plausible finding, although the magnitude of the reduction would be dependent on realised salinities.

Figure 10.1 is an effective illustration of the conceptual model for the groundwater system in the Gloucester Basin. Apart from showing recharge and discharge processes, and groundwater flow directions, it summarises hydrogeological findings from the many types of field investigations.

Chapter 11 (PB, 2015) introduces the numerical model objectives, target confidence level, model domain, hydrostratigraphic upscaling, boundaries, and processes to be simulated. This reviewer concurs with the model plan as it stands. In particular, the plan is to simulate single-phase (water) rather than dual-phase (water and gas), for both local-scale cross-sectional models and a regional 3D model. Given the lack of availability of accessible and computationally efficient dual-phase software, and the focus on environmental impacts, this reviewer agrees with a single-phase approach as it is expected to be conservative in terms of impacts of relevance to the environment and the community.

7. Conclusion

The PB (2015) report is required to satisfy three primary regulatory conditions:

1. PAC Condition 3.8:
This has been satisfied by the Proponent having consulted with DPI Water [formerly Office of Water] in updates to the conceptual hydrogeological model, taking into account fault definition based on seismic surveys, further field investigations, and a longer period of baseline monitoring

2. PAC Condition 3.9:
This has been satisfied by the Proponent having investigated potential drawdown impacts on shallow rock and alluvial beneficial aquifers, considering impacts to nearby registered bore users, as far as is possible prior to construction of a regional model. The condition also required an independent peer review by an appropriately experienced and qualified hydrogeologist (who is approved by the Director-General for the purposes of this condition) on the robustness and technical veracity of the model.

3. SEWPaC Condition 16:
This has been satisfied by the Proponent having consulted with DPI Water [formerly Office of Water] on many occasions of which the reviewer is aware. The reviewer was present at a full-day workshop attended by the Proponent, PB and staff of the Office of Water.

This reviewer attests to the robustness and technical veracity of the model as required by PAC Condition 3.9(d).

The updated conceptual model has a very strong scientific basis and is far more comprehensive than is standard practice for other mining developments. The analysis of potential impacts of posited faults on groundwater flow is a particularly strong feature of the study.

The conceptual model will provide a sound basis for ongoing numerical model development.

Yours sincerely,

Dr Noel Merrick

Table 1. Peer Review Checklist for the Gloucester Basin Conceptual Model

2. Conceptualisation	*Yes/No*	*Comment*
2.1 Has a literature review been completed, including examination of prior investigations?	Y	37 studies (Table 2.3)
2.2 Is the aquifer system adequately described?	Y	Chapter 7
2.2.1 hydrostratigraphy including aquifer type (porous, fractured rock ...)	Y	Chapter 4
2.2.2 lateral extent, boundaries and significant internal features such as faults and regional folds	Y	Entire basin; focus on faulting
2.2.3 aquifer geometry including layer elevations and thicknesses	Y	Provided as sections; detailed elevations and thicknesses deferred to numerical model
2.2.4 confined or unconfined flow and the variation of these conditions in space and time?	..	Confinement is discussed for natural and CSG conditions; premature to examine spatially and temporally
2.3 Have data on groundwater stresses been collected and analysed?	Y	
2.3.1 recharge from rainfall, irrigation, floods, lakes	..	Rainfall and residual mass
2.3.2 river or lake stage heights	Y	Stages at 4 gauges
2.3.3 groundwater usage (pumping, returns etc)	..	Mine inflow at Stratford mine; no stock & domestic, but estimate is made
2.3.4 evapotranspiration	Y	BoM map
2.3.5 other?	Y	Aquifer testing; GDE map
2.4 Have groundwater level observations been collected and analysed?	Y	
2.4.1 selection of representative bore hydrographs	Y	3 sites in alluvium; 2 shallow fractured rock; 4 in deep coal measures; nested hydrographs at 12 sites
2.4.2 comparison of hydrographs	Y	3 groups compared. Vertical head differences compared at nested sites
2.4.3 effect of stresses on hydrographs	Y	Compared with stream stage, rain and residual mass
2.4.4 watertable maps/piezometric surfaces?	Y	One pre-development regional watertable map
2.4.5 If relevant, are density and barometric effects taken into account in the interpretation of groundwater head and flow data?	N/A	
2.5 Have flow observations been collected and analysed?	Y	4 gauges; flow duration curves; EC dynamics included
2.5.1 baseflow in rivers	Y	Baseflow separation analysis
2.5.2 discharge in springs	N/A	
2.5.3 location of diffuse discharge areas?	N/A	
2.6 Is the measurement error or data uncertainty reported?		
2.6.1 measurement error for directly measured quantities (e.g. piezometric level, concentration, flows)	N	
2.6.2 spatial variability/heterogeneity of parameters	Y	Hydraulic conductivity variation with lithology and with depth; large ranges
2.6.3 interpolation algorithm(s) and uncertainty of gridded data?	N	
	Y	Metres; Days; ML; MGA; AHD

2.7 Have consistent data units and geometric datum been used?		
2.8 Is there a clear description of the conceptual model?	Y	
2.8.1 Is there a graphical representation of the conceptual model?	Y	Pre-development (Figure 10.1). During development (Figure 10.2).
2.8.2 Is the conceptual model based on all available, relevant data?	Y	Very extensive analysis
2.9 Is the conceptual model consistent with the model objectives and target model confidence level classification?	Y	Chapter 11. Objectives specified in PAC and SEWPaC conditions (for CSG impact assessment) - some unreasonable expectations of a numerical model in SEWPaC conditions. Nominated Class 2 confidence level for regional numerical model - this is appropriate
2.9.1 Are the relevant processes identified?	Y	Field and cross-sectional model investigations of potential faulting effects on groundwater hydrology.
2.9.2 Is justification provided for omission or simplification of processes?	Y	None omitted. Faulting is tested.
2.10 Have alternative conceptual models been investigated?	Y	Faulting in or out; conduit or barrier (or both).