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Gloucester Coal Seam Gas Project

PEER REVIEW OF GROUNDWATER STUDIES – REPORT TO GLOUCESTER COMMUNITY CONSULTATIVE COMMITTEE

- FINAL
- 3 May 2012

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Executive Summary

This report presents the findings of an Independent Review of hydrogeological aspects of the Gloucester Gas Project. AGL is the holder of Petroleum Exploration Licence (PEL) 285, under the Petroleum (Onshore) Act 1991, covering the whole of the Gloucester Basin, NSW, approximately 100 km north of Newcastle. AGL is proposing to build the Gloucester Gas Project (GGP), comprising several stages of development. Only Stage 1 has obtained planning approval at this time and this review is only concerned with the Stage 1 development (referred to as the Stage 1 GFDA).

The scope of the review is described in Section 2 of this report, but can be summarised as assessing the suitability of the conceptual model developed in three reports (URS, 2007; SRK, 2010 and PB, 2012) and assessment of the adequacy of the current monitoring infrastructure for measuring potential impacts under the Stage 1 GFDA development, including identification of any gaps in the monitoring network. This review has largely focused on the PB (2012) report, as it presents an updated conceptual model of the area, building on the URS (2007) and SRK (2010) studies.

This review concludes that the conceptualisation presented in the PB (2012) report is broadly considered to be appropriate, and the fundamentals of the conceptual model are reasonable. The PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current/proposed investigation programs), however some further work is recommended as a result of this review. Similarly, some additional monitoring infrastructure is recommended.

In some instances it is considered that the PB (2012) study has drawn inaccurate conclusions from the data or omitted some work which would improve conceptual understanding. These generally fall into categories of: connectivity between deep and shallow systems, recharge and discharge processes, characterisation of vertical hydraulic conductivity and specific improvements that can be made to the conceptual model.

Regarding improvements to the conceptual model, the most important improvements relate to the spatial coverage of the model, definition of model boundaries and preliminary quantification of key processes (i.e. a water balance). It is apparent that not all available information has been used to develop the conceptual model, and incorporation of additional data will enhance the current conceptualisation. This review has highlighted the importance of not directly extrapolating conclusions regarding the developed hydrogeological system based on observations from the natural (i.e. unstressed or lightly stressed) condition.

None of the criticisms presented in this review are considered to be issues that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not

identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective, however it is the role of the numerical modelling to assess the location and magnitude of impacts.

Recommendations for further work have been divided into field based activities and desk based activities, and then further divided into High and Moderate priority activities. The high priority field related recommendations include assessment of hydraulic behaviour of faults, rating of stream gauges to enable flow determination, installation of some new bores (including VWP), and investigation of the nature of stream-groundwater interaction over the recharge areas. The high priority 'desk-based' recommendations include development of a conceptual model of fault behaviour (after completion of relevant field programs), development of a natural and developed water balance (including definition of model boundaries) and additional analysis of hydraulic conductivity data, including assessment of vertical hydraulic conductivity. It is suggested that all of these recommendations can occur in parallel with the Waukivory Flow Testing Program and should not be delayed pending the results of that program.

It is important that this report is read in its entirety. Selective quoting of individual sections may result in an inaccurate understanding of the report's contents.

1. Introduction

This report presents the findings of an Independent Review of hydrogeological aspects of the Gloucester Gas Project, conducted by Dr Richard Evans. Based on the recommendation of the Gloucester Community Consultative Committee (GCCC), Dr Evans was appointed the Independent Peer Reviewer and commissioned by AGL on 21st February. The scope of the review is described in Section 2 of this report.

On 23rd February 2012, Dr Evans inspected the project area with representatives of the GCCC. This included inspection of the project area, some of the pilot wells and the produced water holding dams.

It is important that this report is read in its entirety. Selective quoting of individual sections may result in an inaccurate understanding of the report's contents.

2. Scope of Peer Review

The scope of this Peer Review is described below:

a. conduct independent technical review of the following reports:

- *Hydrogeological Review: Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin*, NSW (URS, 2007);
- *Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model.* Report No AGL002_Glouceser Basin Hydrogeology Study_Rev 2 (SRK Consulting, 2010); and
- *Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project* 2162406A PR_5630 (Parsons Brinckerhoff, January 2012).

b. conduct independent technical review of underlying data which are:

- additional water quality data as included in Gloucester Gas Project: irrigation trial water monitoring - baseline results (PB letter dated February 2012);
- groundwater level data for the monitoring network, plotted hydrographs in excel spreadsheets;
- surface water level and salinity (EC) data for the monitoring network and plotted hydrographs and EC traces in excel spreadsheets, and
- the summary water quality data for all monitoring network sites in excel spreadsheets.

c. conduct a review of the installed monitoring networks; and

d. consider any other technical data and reports/papers referenced in the three groundwater reports as required,

for the purpose of providing an expert opinion on the following:

e. scope and methodologies adopted for the Reports and the investigations/baseline data;

f. whether the Reports are adequate for the purposes of assessing the hydrological catchment and the different groundwater systems, and for assessing impacts to surface water and groundwater resources, and the connectivity of aquifers as a result of deep coal seam dewatering; and

g. any recommendations to address any technical gaps identified relating to the matters set out in (a) above.

In addition to the above scope, the brief was expanded to include addition of "contextual comments on the issues relevant to extraction activity and completion methods (hydraulic fracturing and under reaming)" (as per email from John Ross to Richard Evans on 24th February 2012).

The scope is not considered to include issues related to hydraulic fracturing other than as described here (i.e. potential water quality issues related to hydraulic fracturing are not in scope). Also, possible groundwater issues associated with the proposed irrigation based water disposal system are not in scope.

3. Project Background

AGL is the holder of Petroleum Exploration Licence (PEL) 285, under the Petroleum (Onshore) Act 1991, covering the whole of the Gloucester Basin, NSW, approximately 100 km north of Newcastle. AGL Upstream Gas Pty Limited (AGL) is proposing to build the Gloucester Gas Project (GGP), comprising several stages of development. Only Stage 1 has obtained planning approval at this time.

The concept plan for the whole project and the project application for the GGP were lodged and exhibited in late 2009. Concept Plan and Project Approval for the Stage 1 Gas Field Development Areas (GFDA) was granted on 22 February 2011 under Part 3A of the Environmental Planning and Assessment Act (1979).

The Stage 1 GFDA involves the extraction of coal seam gas (CSG) from the Gloucester Basin within the PEL 285 area, including the development of CSG wells and associated infrastructure. This will involve the dewatering of formation water and the extraction of gas from multiple coal seams within the Gloucester Coal Measures. Target coal seam depths will vary from site to site but are expected to range between 200 and 1000 metres below ground level (mbgl). It is understood that approximately 110 CSG wells will be required within the Stage 1 GFDA (SRK, 2010). These are understood to be approximately evenly distributed across the area.

Further to the Environmental Assessment for the Gloucester Gas Project, the Submissions Report for the Gloucester Gas Project and the Approvals, AGL commissioned the following groundwater assessment and investigations:

1) URS (2007). *Hydrogeological Review: Proposed Coal Seam Gas Exploration Areas, Gloucester-Stroud Basin, NSW*;
2) SRK Consulting (2010). *Gloucester Basin Stage 1 Gas Field Development Project: Preliminary Groundwater Assessment and Initial Conceptual Hydrogeological Model* Report No AGL002_Glouceser Basin Hydrogeology Study_Rev 2; and
3) Parsons Brinckerhoff (2012). *Phase 2 Groundwater Investigations – Stage 1 Gas Field Development Area Gloucester Gas Project* 2162406A PR_5630.

The role of the Peer Reviewer is to provide independent advice to the GCCC on scientific and technical matters relating to Coal Seam Gas (CSG) groundwater and surface water studies completed to date for the GGP, primarily the Stage 1 GFDA. This includes determining whether the AGL studies are 'fair and reasonable', and to provide an expert view to the community on the extent of these studies, the baseline data collected to date, their suitability for assessing impacts to water resources, any gaps identified in the baseline data, and the connectivity of aquifers as a result of deep coal seam dewatering. The main documents reviewed as part of this study are the three report listed above, in addition to raw water level and water quality monitoring data sets.

4. Overview Comments

This review has largely focused on assessment of the PB (2012) report, as it presents an updated conceptual model of the area, building on the URS (2007) and SRK (2010) studies. It therefore presents the most current conceptualisation upon which the impact assessment and numerical modelling will be based. (The URS and SRK reports have been reviewed and commented on where appropriate).

The primary objectives of the PB (2012) study are described as:

- Complete baseline studies to effectively characterise the groundwater systems in the Stage 1 GFDA.
- Provide site specific information on groundwater occurrence and flow by investigating the different groundwater systems, and determining whether the shallow water resource aquifers are connected to the deeper coal seam water bearing zones.
- Assist in determining the quantity and quality of deep groundwater that is likely to be produced as the CSG scheme is constructed.
- Establish a monitoring network across the Stage 1 GFDA that is spatially diverse and sufficient to cover staged development of the scheme, and is representative of the catchment, local geologies, and complexities associated with the geological structure.
- Prepare a comprehensive technical report that includes a revised conceptual model of groundwater recharge, discharge and flow across the Stage 1 GFDA together with all the Phase 2 site investigation activities, data, results and conclusions.

  (PB, 2012: xxiv)

In general the conceptualisation as presented in the PB (2012) report is broadly considered to be appropriate. The fundamentals of the conceptual model are reasonable, including:

- The breakdown of the hydrogeology into four basic hydrostratigraphic units
- The principle of decreasing hydraulic conductivity with depth in the interburden confining units, and the relatively high hydraulic conductivity of the coal water bearing zones
- That the major discharge mechanism from the alluvium is as baseflow to rivers, and that the main discharge of the shallow rock aquifers is to the alluvium (although this is likely to be small compared to the water balance of the alluvial unit).
- In the natural state (within the Stage 1 GFDA), lateral flow process within units are dominant, with vertical processes being relatively small
- The likelihood of other groundwater dependent ecosystems (apart from baseflow) within the study area being significantly dependent on groundwater is considered to

be low (with the possible exception of springs, although more information is required to determine their significance and vulnerability to potential impact)

- That further work is necessary to understand the hydraulic significance of faults

Further, it is considered that the PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current investigation programs), however some further work is recommended as a result of this review.

In some instances it is considered that the PB (2012) report has:

- drawn the wrong conclusion from the data, or,
- omitted some work/calculations which would improve conceptual understanding

These issues are dealt with in Chapter 5 – however it is emphasised that based on the data presented in the PB report, none of these represent criticisms that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective - not that this was the scope of the review, as it is the role of the numerical modelling to assess the location and magnitude of impacts.

5. Specific Comments

5.1. Conceptual model

This section discusses issues relevant to the conceptual model including:

1. The limited geographic coverage of the conceptual model
2. Absence of a water balance
3. Model boundaries
4. Consideration of processes in the natural versus developed state
5. Potentiometric surface data
6. Recharge processes
7. Continuity of coal seams

5.1.1. Limited coverage of conceptual model

The conceptual model presented in PB (2012) is the conceptualisation on which the numerical model will be built for the Stage 1GFDA (and associated impact assessment):

> The adopted methodology aims to establish detailed spatial and depth coverage of the different groundwater systems across the Stage 1 GFDA to confirm the conceptual model and build a database of information for the pending numerical model. (PB, 2012: xxv)

This being the case, it is apparent that the conceptual model is spatially and vertically limited in its ability to represent the Stage 1 GFDA area:

a. *Spatially limited* – Cross sections, block diagrams or other graphical aids are an important part of the conceptual model. The cross sections presented in PB (2012) are contained almost entirely within the Tiedman property, which represents a relatively small part of the Stage 1 GFDA. This in turn, is because the observation bores installation are mainly on the Tiedman property. There are bores located on the northern and southern boundaries of the Stage 1 GFDA (the RMB and WMB series bores), however these are not incorporated into the cross sections and further they are relatively shallow compared to the bores in the Tiedman area.

It may be argued that the seismic survey provides a geological model across the whole area, with the bores on the Tiedman property calibrating the seismic data. (*however the seismic surveys do not appear to cover the whole area, see page 26 & 27 of the PB report – the scale on the axis of these surveys seems to contradict the coverage indicated on the inset map of the survey*). It is agreed that the seismic model is an important dataset which contributes to development of the numerical model, however additional bores - particularly north and south of the Tiedman property - would provide better spatial coverage of the Stage 1 GFDA, add confidence to interpretation / calibration of the seismic survey and allow development of a cross section which would better cover the Stage 1 GFDA.

In an east-west direction, one would expect to see a cross section covering the full synclinal basin or at least an area greater than the Stage 1 region. This is because it is expected that the numerical model would cover an area significantly greater than the Stage 1 region.

Further, it can be important for a conceptual model to capture information outside of the numerical model boundary, in order to better define the boundary conditions of the numerical model.

b. *Vertically limited* – The conceptual model (including the cross sections) only describes/characterises the relatively shallow layers, down to approximately 300-350m. It is understood that the target coal seams will vary from site to site but are expected to range between 200 – 1000 metres below ground level. Given that a significant amount of extraction will occur much deeper than the exploration depths in the PB conceptualisation study, it is uncertain how the deep coal seams, and in the deep interburden, will be characterised within the numerical model. It is likely that potential impacts (on the shallow aquifers, creeks) will be most sensitive to the properties of the interburden material in the upper 200m, and in this sense it is appropriate that the conceptual model should focus on the upper 200m. However, the deeper units cannot be ignored in the conceptual model and some discussion on the behaviour and properties of units below this depth is warranted in the conceptual model report. This conceptualisation may not necessarily include detailed field investigation (however at least one site to monitor pressures in the target coal seams is recommended elsewhere in this report), and may be based on literature of properties of similar units elsewhere. . The current conceptual model lumps the interburden confining units in the range of 150m to 1000m into one category, however it is unlikely the permeability of this unit will be the same at 150m compared to 1000m, assuming uniform lithology which is probably not the case.

The conceptual model provided in the SRK report (Figure 6-2, p41) is an appropriate cross section for conceptualisation in that it shows the full depth of the target coals layers. The PB conceptual model is helpful in that it focuses on the unit that will be critical in terms of potential surface impacts, however the model needs to be placed in the wider context of the target coal seams and the basin.

Recognising that it is the upper 200m that is the most important part of the characterisation, the rigour of the characterisation of the upper 200m is discussed below.

Two of the monitoring bores are screened deeper than 180m, three are screened between 150 to 200m and two are screened between 100 – 150m. Hence, most of the 22 monitoring bores are relatively shallow. Given that the PB conceptualisation is of the "interburden confining units" being from 150 – 1000 m depth and of relatively low hydraulic conductivity, (whereas the overlying shallow rock aquifers are more permeable), there is a fairly small sample size of the hydraulic conductivity of the "interburden confining units". The combination with the lack of spatial coverage further suggests that the units between the target coal seams and the upper ('shallow rock aquifers') have not been adequately characterised.

Further, the monitoring network is not only for calibration of the numerical model, but also for monitoring of impacts during the CSG production phase. In this respect the monitoring network also does not appear to be spatially or vertically comprehensive, and could not reasonably be considered to provide 'detailed spatial and depth coverage' (PB, 2012, xxv) of the Stage 1 GFDA.

It is acknowledged that the Waukivory Flow testing program will significantly add to the monitoring network towards the north of the study area. It is further recommended that a (deep) monitoring site be installed further north again (the rationale for this is discussed further in Section 5.4). In addition a site of nested vibrating wire piezometers is recommended (near the centre of the Stage 1 GFDA) in order to measure pressure / pressure changes at depth within the target coal seams. Correspondence from AGL post the draft IPR indicates that plans are underway that will address this data gap, utilising a reservoir corehole after testing and sampling is complete.

In addition, further correspondence from AGL post the draft IPR indicates that additional water level and hydraulic conductivity data beyond that presented in PB (2012) will be obtained from the following sources:

- AGL/LE coreholes and stratigraphic holes where intrinsic permeability tests have been undertaken, and ,
- GRL and GCL models, monitoring data and networks

It is possible that this data will address some (or all) of the data gaps described above, but without details of these activities it is not possible to provide any detailed comments.

5.1.2. Absence of a water balance

A water balance (or budget) is an important part of conceptual model development. The water balance is a quantification (estimation) of the inflows and outflows across the model domain boundaries, plus any internal consumptive uses. The Murray Darling Basin (MDB) Groundwater Modelling Guidelines are the closest document that exists to national guidelines for developing a groundwater model, including the conceptual model. (They are widely considered a standard for groundwater model development). Regarding a water balance, the MDB guidelines indicate that "the definition of a water budget and associated boundary conditions for the model domain are integral components of the conceptual model" and "The conceptual model should present in descriptive and quantitative terms the essential system features outlined in Table 2.4.1 (geological framework and boundaries), and the hydrological behaviour (natural and human-induced stresses), including a preliminary water balance" (Middlemis et al., 2000).

The conceptual model developed in the PB report (or SRK and URS studies) does not include a water balance. The advantage of developing a water balance in terms of the numerical model and associated impact prediction is that:

- It starts the process of defining and conceptualising the boundaries of the model area, which is a necessary step when developing a numerical model (discussed further in the following section).
- It will highlight aspects of the water balance where there is significant uncertainty, and can provide focus for where further information may need to be gathered. This uncertainty is not just in terms of the magnitude of fluxes but also in terms of processes and direction of flow and locations of discharge. For example, examination of the cross sections in the PB report provides no indication of where groundwater discharges (there is some discussion of this in the text, but not in the diagrams). It shows recharge and some flow paths but as currently presented there is only water entering the groundwater system.
- Quantifying components of the water balance (even if only approximately), begins to put into perspective the possible scale of the potential impacts compared to the natural water balance. The PB report implies that the hydrological impacts of the development will be small, but this is a difficult conclusion to assess when the water balance has not been quantified.

- It will highlight the assumed rate and timing of recharge after the end of the CSG development and thus allow the relative significance of long term changes in recharge and discharge to be placed in the context of natural recharge and discharge rates.

Development of a water balance for the area should include:

- Defining model boundaries and any fluxes across the boundaries,
- Estimating the various components of the water balance (internal and external), including recharge, discharge and change in storage .

The impact of temporal scales is also important - depending on the component of the water balance being assessed its importance will also change. It is suggested that pre development , maximum development and post development water balances be postulated.

5.1.3. Model boundaries

This point is closely related to the above discussion regarding a water balance. The conceptual model should define the boundaries of the numerical model, otherwise this step becomes wrapped up in the numerical modelling process. Good practice is to develop a robust conceptual model, inclusive of model boundaries, so that the whole conceptual model can be reviewed prior to development of the numerical model. As described in Section 5.1.2, the MDB Groundwater Modelling Guidelines consider definition of the model boundaries as a key part of the conceptual model and water balance. They further state that:

> The model domain covers the entire area of interest, including areas of potential future impact, although its size should be minimised to reduce computational effort. Model boundaries are the interface between the model calculation domain and the surrounding environment (Spitz and Moreno, 1996), and occur notably on the edges of the domain. Other ("internal") boundary conditions reflect influences from other environmental factors (such as rivers, wells, etc.) that are manifest inside the domain. The external boundaries of the model domain should take advantage of natural or physical groundwater boundaries (eg. aquifer extents, coastlines, rivers, lakes). Middlemis et al. (2000)

At the moment it is not clear what the boundaries of the numerical model will be. The conceptual model as presented in PB (2102) does not appear to cover the same extent that a numerical model would be required to cover. Defining the boundaries of the model (and associated boundary conditions) will address this issue.

5.1.4. Consideration of processes in the natural versus developed state

The conceptualisation reports (PB, URS, SRK) make conclusions like "there is no evidence of natural connectivity between shallow and deep groundwater systems" (PB 2012, xxviii). While that may or may not be true (that issue is discussed further in Section 5.2), the point here is that it is not only the natural state that requires consideration. Just because there may be a lack of connection in the natural (unstressed) condition, this does not mean there will be a lack of connection in the developed (stressed) conditions. The pressures changes induced during the CSG related extraction are significant compared to the natural gradients between the shallow and deep systems, and it cannot be implied that because there is no connection in an unstressed condition that there will be no connection in the stressed condition. (Typical head declines are 200m, with a maximum decline of approximately 400m).

There are fleeting references to this issue, e.g. in the chemistry section in PB (2012:111); 'indicating limited connection between them under natural conditions', but the concept is not discussed elsewhere in the report.

Discussion of this issue would normally be expected, but there are also a range of tools available (analytical models, simple numerical models) to conduct a preliminary quantitative assessment of changes under the stressed condition. These types of tools would be required to assist in development of the stressed state water balance. In turn these tools highlight the sensitivity of the various aspects of the water balance to identify where effort should be directed in terms of data gathering for the numerical model.

5.1.5. Potentiometric surface data

It is noted that the PB report only includes a potentiometric surface map for the alluvial aquifer. There is no potentiometric surface provided for the underlying three (conceptual) layers: shallow rock aquifers, interburden confining units and coal seam water bearing layers. While the PB report has collected some data in the shallow rock aquifers and interburden confining units, it is acknowledged that it may be difficult to construct a potentiometric surface given the limited number of points available.

There are apparently only two bores screened in the target coal seams (Bores S5MB03 and TCMB04 are screened in the Roseville Coal Seams), and these are only in the very upper of the target coal seams. It is suggested that, in the absence of a potentiometric surface for the target coal seams, the conceptual model should include an estimation of the starting heads in the coal seams (which is a necessary input to the numerical model). The VWPs within the coal seams recommended above will assist in this process.

5.1.6. Recharge Processes

The PB (2012) report could be enhanced by further discussion of the following issues related to recharge processes:

- The SRK (2010) report (p45) indicates that some recharge will also occur via vertical leakage (not just via outcropping areas at the margin of the basin). The vertical gradients at some nested bores suggest that this is the case. While this process may be very small compared to lateral recharge, it warrants some discussion (and ideally preliminary quantification).
- The SRK (2010) report (p45) suggests that faults may act as potential enhanced recharge zones. It is acknowledged that work is currently underway to assess the hydraulic conductivity of the fault zones, and hence at this point a conclusive answer is not possible, however a discussion of the potential role of faults in recharge processes would seem appropriate.
- The PB (2012) report does not discuss the potential for recharge of the interburden confining units or the coal seams via streams over the areas where these units outcrop or subcrop (in particular Waukivory Creek and Dog Trap Creek). It is not known if these are gaining, losing or losing-disconnected streams in these areas; discussion of the conceptual understanding of how these streams interact with groundwater would be useful. If they are losing streams, it may be that the rates of recharge are very low compared to rainfall recharge, but discussion of this process is desirable. The conceptual understanding of the streams (and how they are incorporated into the model) affects whether the streams may be impacted under the developed state (and the magnitude of impact).

5.1.7. Continuity of Coal Seams

The conceptualisation reports do not discuss the lateral continuity of the coal seams. The inference in the reports is that they are more or less laterally continuous (with the exception of fault zone truncation), but this is not specifically discussed or stated. Many of the CSG developments in other parts of Australia (e.g. Surat Basin) are characterised by target coal seams of limited lateral continuity, so continuity cannot be assumed and should be stated. How the coal seams are characterised is an important part of the conceptual model because it indicates the potential lateral transmission of pressures within coal seams.

5.2. Connectivity and potential shallow aquifer / surface impacts

The PB report makes the following statements regarding connection between the deep groundwater system and the shallow groundwater system / surface waters:

> "Rainfall recharge is low groundwater flow is mostly lateral within the different strata, and there is no evidence of natural connectivity between shallow and deep groundwater systems" (PB 2012, xxviii).
>
> "The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying coal seams. The layered aquitards of the interburden units create separate and distinct groundwater systems with no connection evident between the deeper coal water bearing zones and the shallow rock alluvial aquifers" (PB, 2012; para 4, p131)
>
> "The interburden confining units are effective confining units that separate shallow groundwater aquifers from deep coal seam water bearing zones" (PB, 2012; para 13, p134)

The following sub-sections address different aspects of these statements.

5.2.1. Assessment of Evidence for PB Conceptual Model of Hydraulic Isolation of Shallow and Deep Groundwater Systems

The following comments are made regarding these, and other similar statements within the PB (2012) report:

- The statements imply that because the interburden is 'low permeability' and are 'confining layers' that they form a layer that hydraulically separates the deep coal seams and the shallow aquifer system. However neither of these properties of the interburden makes the interburden a hydraulically separating layer. Only if the interburden is of zero hydraulic conductivity or an unsaturated zone exists within the interburden, would the interburden act as a hydraulically separating layer. (The PB or other reports do not appear to make either of these claims, however use of the phrase 'locally saturated' is discussed below).

  If the interburden is of low hydraulic conductivity (not zero hydraulic conductivity), the discussion around potential effects on upper aquifers and surface water should be framed around the timeframes and magnitude of interaction (e.g. over very long timeframes and very low rates of leakage) rather than no interaction. No evidence is presented to warrant the claim of hydraulic isolation of the units.

  It is acknowledged that PB do use the term "aquitard" to define the interburden, and therefore by definition imply the potential of this unit to leak. However, use of the term appears to contradict description of the unit elsewhere in the PB report, i.e. that they hydraulically separate layers above and below, implying no leakage.
- The term "locally saturated" is used in the PB report to describe the interburden (refer above quote) but the term is not defined. Hence what "locally saturated" means is unclear, but if it is a reference to the interburden containing perched groundwater systems, this should be explicitly stated. If this is the intended claim and it is true, it would have significant implications for the set-up of the numerical model. It would mean that by definition the

shallow groundwater system and deeper groundwater system are hydraulically isolated (and in terms of assessing potential surface water impacts, it would mean there is limited value in constructing / using a numerical model at all). A conceptual model of complete hydraulic separation between the deeper and shallow groundwater systems is certainly the hydrogeological exception rather than the norm . Hence if this term is suggesting that groundwater in the interburden is perched, this claim has far reaching consequences and firm evidence to support the assertion is required (e.g. some dry bores screened in the interburden, or evidence in certain types of geophysical surveys).

- In different locations throughout the report the following evidence is provided for the hydraulic separation of the deeper and shallow groundwater systems:
  - *The different chemistries of the groundwater at nested sites* – for example "Groundwater in the shallow interburden monitoring bore (S5MB01) is distinctly different from the deep interburden monitoring bore (S5MB02) and the Roseville Coal Seam monitoring bore (S5MB03), as shown on Figure 8-4 indicating limited connection between them under natural conditions" (PB, 2012: 111). The terminology used by PB is accurate – the different chemistries indicate *limited* connection / limited movement of water between the shallow and deep systems - not 'no connection', as inferred in the above quotes. Where there is a head (i.e. pressure) difference between two layers and some permeability, there will be some leakage of water from the higher head unit to the lower head unit. The vertical leakage may be very small compared to the lateral recharge and hence the chemistries of the water will be very different. However the difference between low or limited leakage and no leakage is critically important for conceptualisation and set up of the model. In the chemistry section of the PB report, the chemistry differences are used to suggest low leakage (not quantified but considered likely to be true) but the conclusion reached in other parts of the report regarding isolation of the units cannot be made based on chemistry differences.

  - *Static nature of hydrographs* – "Initial monitoring in all three bores shows static water levels indicating strong confining layers above the water bearing zones" (PB, 2012: 82) – The link between static water levels and strong confining layers is not explained in the PB report. Presumably the inference is that the absence of any fluctuations or trends in the groundwater suggests that the hydraulic conductivity is so low that the units are not being recharged (or discharged) and hence is evidence of (effective) hydraulic isolation. Closer examination of the hydrographs, as discussed in the dot point below, suggests that they are not in fact static and hence this argument does not appear to be supported.

- *Absence of response to rainfall recharge* – “The interbedded indurated sandstone/siltstone units of the Leloma and underlying Jilleon Formation are intersected by monitoring bores S4MB01, S4MB02, S5MB01, S5MB02, and TCMB02. These bores show negligible seasonal variation and no response to rainfall recharge, however, the effects of dewatering during groundwater sampling and slug testing are pronounced and these responses are indicative of the very low permeability of the units”. The hydrographs of these five bores (plus bores screened in the coal) are presented and discussed in the following section. The data seems to contradict the finding that there is no response to rainfall recharge observable in groundwater levels.

5.2.2. Assessment of Monitoring Bore Hydrographs

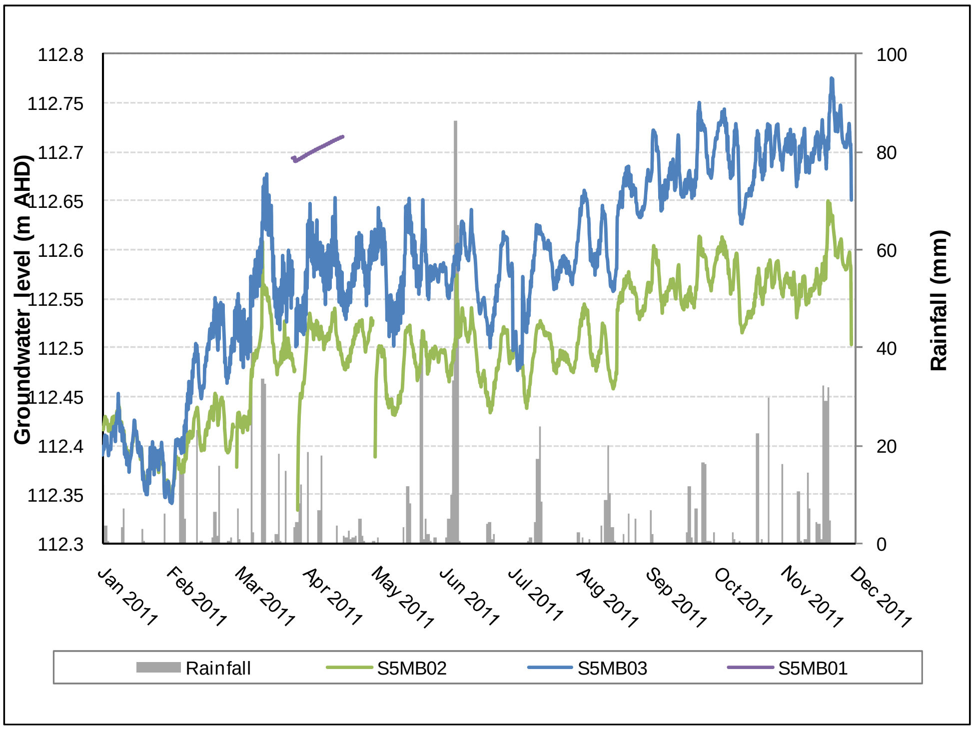
The groundwater level hydrographs of bores in the interburden units and the coal seams are discussed below:

S5MB02 (Sc. : 89 – 95m, Sandstone/siltstone) and **S5MB03** (Sc: 158-164m, Coal/shale) – The effect of the high rainfall in mid-June 2011 (195 mm between 13th and 16th June 2011, as measured at the Gloucester, Hiawatha, rainfall gauge) is apparent in these two bores. The rise in the hydrograph after the intense period of rainfall may not be coincidental. There is a delay of approximately one to two months before the hydrographs begin to rise, which may be the time for the pressure transmission of the recharge event to impact the point in the aquifer where the bores are screened. This suggests there is hydraulic continuity laterally within the units (and also possibly vertically), and that the hydraulic conductivity is not negligible. (The one to two month delay suggests this water level rise is not caused by a hydraulic loading effect).

Further, regardless of the link between the June 2011 rainfall and hydrograph response, there is a total rise in groundwater elevation of around 0.3m and 0.4m within the 12 month monitoring period (for S5MB02 and S5MB03 respectively), indicating recharge is occurring. There is also a very strong correlation in the micro-fluctuations between S5MB02 and S5MB03. This may be explained solely by barometric response, however an analysis of water levels with barometric effect removed is recommended to confirm that this is the case.

S5MB01 (Sc. :52 – 58m, Sandstone/siltstone) – not analysable for water level trends due to impact of slug test.

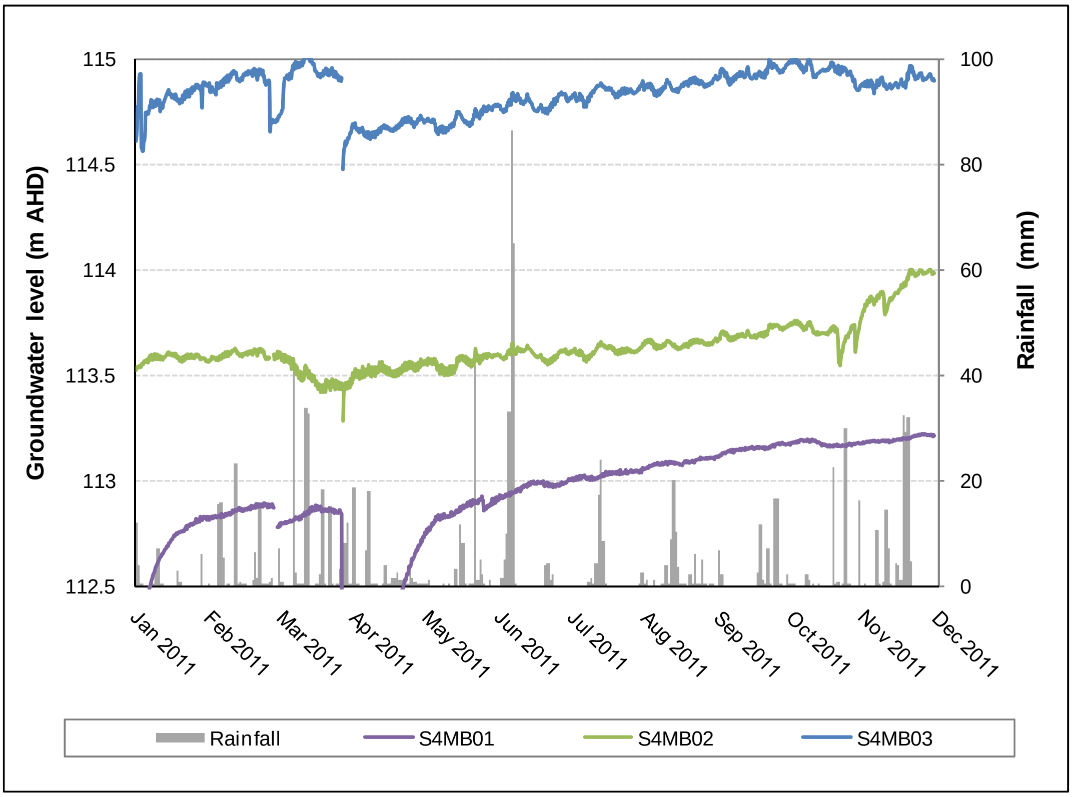
■ **Figure 1 Groundwater levels and rainfall at S5MB nested site**



S4MB01 (Sc. : 58 – 64m, Sandstone) – This bore does not show a clear response to the high rainfall in mid-June 2011 (e.g. as observed at the S5MB nested site), but (excluding the first month of data which may have been influenced by sampling/testing), does show an increase in water level of 0.5m over 2011.

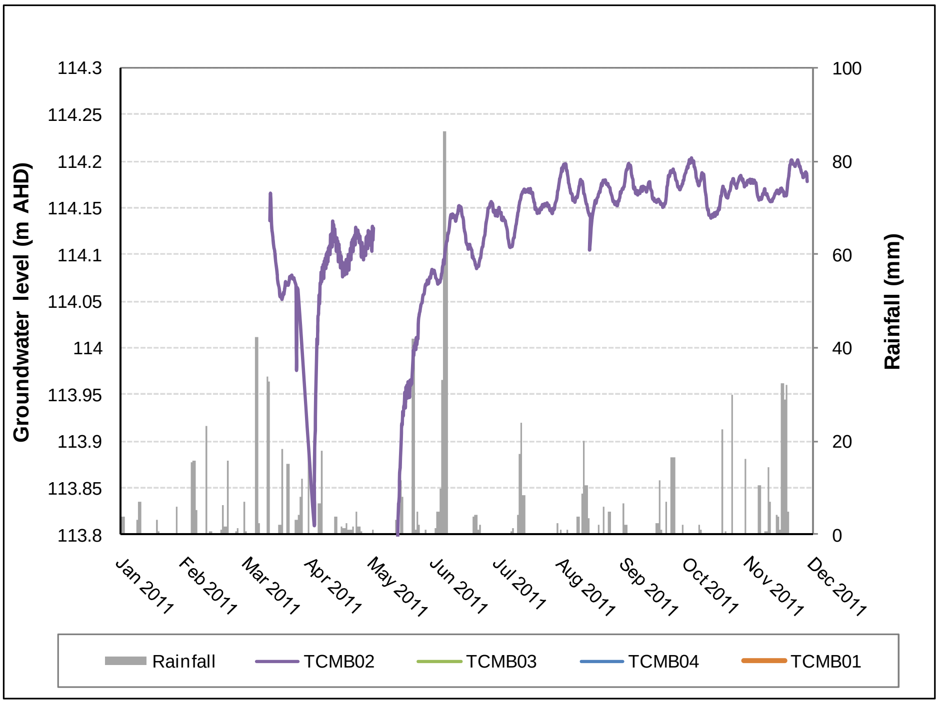
S4MB02 (Sc. : 89 – 95m, Sandstone/siltstone) – This bore shows a similar overall trend to S4MB01 (above) with an increase in water level of 0.5m over 2011. For this bore and S4MB01, the yearly increase in water level is the same as the deeper bore screened in the coal at this nested site (S4MB03, Sc: 162-168m) which is also 0.5m. Fluctuations at a small scale (e.g. weekly) do not always correspond across these three bores, but the annual increase in water level is similar. In contrast to the above statement (p80 in the PB report) this suggests that these units are responding to the effect of rainfall recharge, or else possibly recovery from flow testing in 2010. Either way, the results do not support a conceptual model of hydraulic isolation of interburden layers.

Figure 2 Groundwater levels and rainfall at S4MB nested site



TCMB02 (Sc.: 175 – 181m, Sandstone) – This bore exhibits a rise in water levels of around 0.15m within the monitoring period (ignoring the impact of the hydraulic testing and sampling on the bore), as shown in Figure 3.

▪ **Figure 3 Groundwater levels and rainfall at TCMB02**

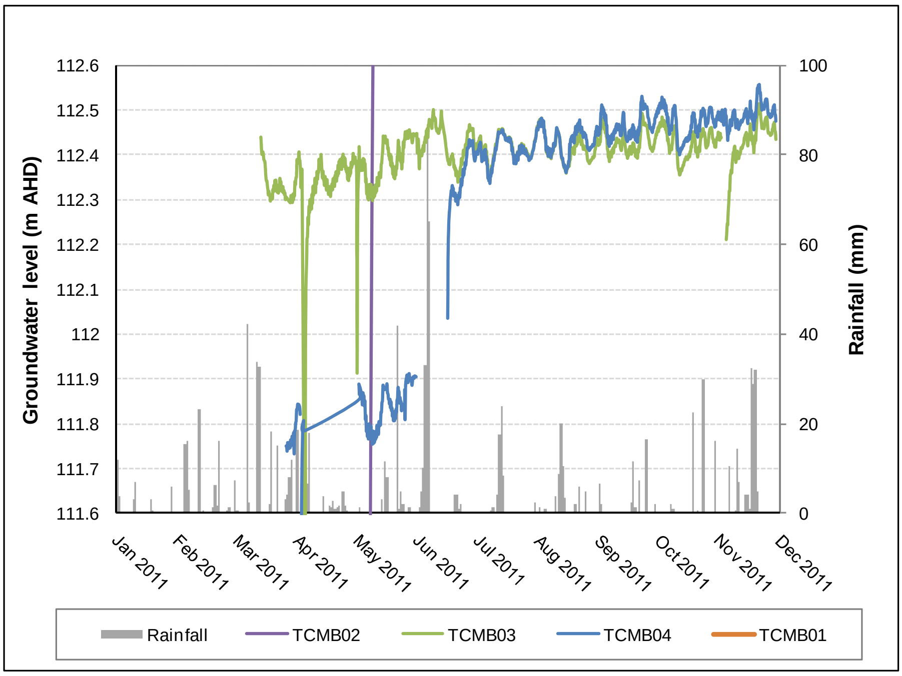


The above section discussed bores screened in the interburden. The section below discusses bores screened in the coal seams.

TCMB03 – (Sc.: 260 – 266m, Coal and Sandstone) – The PB report states that this bore shows "negligible seasonal variation and no response to rainfall recharge" (PB, 2012: 80). Figure 4 shows that there has been a water level rise of around 0.2m within the monitoring period. This suggests the bore is responding to recharge.

TCMB04 – (Sc.: 327 – 333m, Coal and Sandstone) – The PB report states that this bore shows "negligible seasonal variation and no response to rainfall recharge" (PB, 2012: 80). Figure 4 shows that there has been a water level rise of around 0.75m within the monitoring period. However, correspondence from AGL post the draft IPR indicates that the early data in this bore is not representative due to the bore being 'shut in' to monitor gas build up. The bore was vented in June 2011, which has resulted in the step change apparent in the hydrograph at this time. Examining only the data after June 2011, there has been a water level rise of around 0.45m in this bore. If the steep rise in the data in late June is assumed to be part of the bore re-equilibrating after the venting (and also assumed invalid), then there is a water level rise of around 20cm post-June 2011 in the bore. Regardless which interpretation is correct, it is apparent the bore is responding to recharge. This response is particularly significant given that this is the deepest of the monitoring bores, and screened in one of the target coal seams.

- **Figure 4 Groundwater levels and rainfall at TCMB03 and TCMB04**



S4MB03 – (Sc.: 162 – 168m, Coal) – The PB report states that this bore shows "negligible seasonal variation and no response to rainfall recharge" (PB, 2012: 80). Figure 2 shows that there has been a water level rise of around 0.4m within the monitoring period. It might be argued that the rise in water level post-April 2011 is related to slow recovery from the sampling in early April, however this is unlikely based on the shape of the recovery (e.g. compared to the recovery from the slug test in March 2011), and is more likely a recharge response. Further, there is a 0.4m rise in water level observed between January and March is not impacted by either the slug testing or sampling.

In summary, the water levels of bores screened in the "Interburden units" and the "Coal seams" each indicate one or more of the following:

- A response (increase in water levels) to rainfall recharge associated with high rainfall in mid- June 2011(195 mm between 13th and 16th June 2011, as measured at the Gloucester, Hiawatha, rainfall gauge) , with a lag of up one to two months.
- An overall upward trend across the monitoring period, ranging between 0.15 to 0.75m. This corresponds with the fact that since early 2008 there has been a period of above average rainfall in the study area (refer rainfall residual mass curve: Figure 3-4 in PB, 2012) and groundwater levels are responding to recharge caused by this rainfall.
- In addition to the overlying upward trend, some bores show a fall and rise, possibly indicative of a seasonal trend.

These observations suggest that deeper confining units are responding to recharge relatively quickly, and are not hydraulically isolated units. The conceptual model should account for this variability. A potential alternate cause of the response in the hydrographs is that of hydraulic loading (i.e. an increase in total weight overlying the screened interval), however this is considered an unlikely cause, in part due to the time lag observed in the response in some bores.

5.2.3. Potential Impacts on Surface Water Features in Recharge Areas

The PB assessment appears to mainly consider potential impacts caused by vertical transmission of pressure and associated decline in water levels in the shallow rock units / alluvial aquifers in the valley floor. A potential mechanism for impact on water levels which seems to have been overlooked is lateral transmission of pressures back along the coal seams (and interburden) and into the areas where these units outcrop/sub-crop in the hills east of the site. (It is acknowledged that the PB report recognises the importance of lateral recharge where the units outcrop/sub-crop, e.g. PB, 2012:131, – the point here however is that the implication of this for potential impacts under the developed case does not seem to be discussed in the report).

Depending on the nature of the connection with the streams (in particular Waukivory Creek and Dog Trap Creek but also other unnamed smaller streams) in the outcrop/sub-crop areas, there may be an impact on stream flow in these creeks, as either the baseflow sustaining a gaining stream is reduced, or losses from the streams are increased due to lowering of groundwater levels. The impact is likely to occur more quickly than vertical impacts to the valley floor, as the change in pressure will be transmitted along units rather than across units (i.e. K_h is typically about one order of magnitude greater than K_v).

A first step towards assessing potential impacts to these creeks is to understand the nature of the connection (if any) between groundwater and the creeks where they overlie the recharge areas.

5.3. Characterisation of Vertical Hydraulic Conductivities

The vertical hydraulic conductivity (K_v) of the layers overlying the target coal seams is often the most important parameter influencing the prediction of impacts (including magnitude and timing) on upper aquifers and surface water. Characterising K_v is therefore a very important part of conceptual model development.

5.3.1. Vertical and horizontal conductivity

The PB (2012) report currently does not address in any detail the distinction between vertical (K_v) and horizontal hydraulic conductivity (K_h). The only time this differentiation is made is in the section reporting on laboratory permeability tests, where both horizontal and vertical permeabilities were reported. Generally slug testing and packer testing are methods that predominantly determine the K_h value of the unit tested, however this is not discussed in the report. It is therefore uncertain how the hydraulic conductivity values produced will be used to determine K_v values for the numerical model. Given the likely sensitivity of model outcomes to K_v it is considered important that this process / method is clearly described.

Of the four laboratory test results where both K_v and K_h were tested, three of the four indicated K_v and K_h were the same, and one test indicated K_v was higher than K_h (PB, 2012: 75-76). In general, empirical data suggest that it is typical for K_v values to be at least one order of magnitude smaller than K_h (due to the nature of sediement deposition and diagenesis). The fact that these results are contrary to this "rule of thumb" is therefore significant and warrants further discussion / investigation, e.g. if it is proposed that the numerical model adopt K_v values of 10% x K_h then an explanation of why the laboratory data, suggesting K_v is approximately equal to K_h, was discounted will be necessary.

5.3.2. Evaluation of collected conductivity data

In addition to the issue of vertical and horizontal hydraulic conductivity (described above), the PB (2012) report would benefit from further evaluation of the hydraulic conductivity data collected, in the following areas:

- Monitoring site TCMB04 was tested for hydraulic conductivity using packer tests, laboratory tests and slug tests. A discussion of the results derived from these various methods, including which is considered most reliable, would be helpful. Figure 5 presents hydraulic conductivity results for the shallow rock and interburden units from the PB (2012) field program. A general trend of decreasing hydraulic conductivity with depth can be seen in the slug test data, with a few anomalies. [The result at WMB04 in particular warrants further discussion – the text suggests that this high value results from 'the likely contribution of secondary permeability in the form of localised bedding plane fracture flow' (PB, 2012:70). This may be the case, but even if this result is returned infrequently for some bores, the implication for overall rock mass permeability will be significant].

At the nested site where the three slug tests were undertaken (TCB02, 03 and 04), the alternate method (packer tests and core permeability in the laboratory) at the same depth returned a significantly higher hydraulic conductivity, ranging between 30 to 900 times higher. (A comparison with the exact depth was not possible, but was interpolated between the lab and packer tests). If the packer tests and laboratory tests are more accurate, does this mean the remainder of the bores which have only been slug tested (19 tests) are an underestimate of actual hydraulic conductivity?

The literature generally indicates that laboratory permeability tests tend to underestimate actual regional hydraulic conductivity (e.g. Hart, 2006) compared to insitu tests because they do not measure secondary permeability (i.e. fracture flows). If this is the case at this site, this compounds the issue described above as the lab tests indicate higher permeabilities than the packer tests.

A further observation from Figure 5 is that the packer and laboratory tests do not indicate a trend of decreasing hydraulic conductivity with depth. Again, some explanation of why this may be the case is required, as the current conceptual model appears to be based on the slug test results but ignores the packer and laboratory tests.

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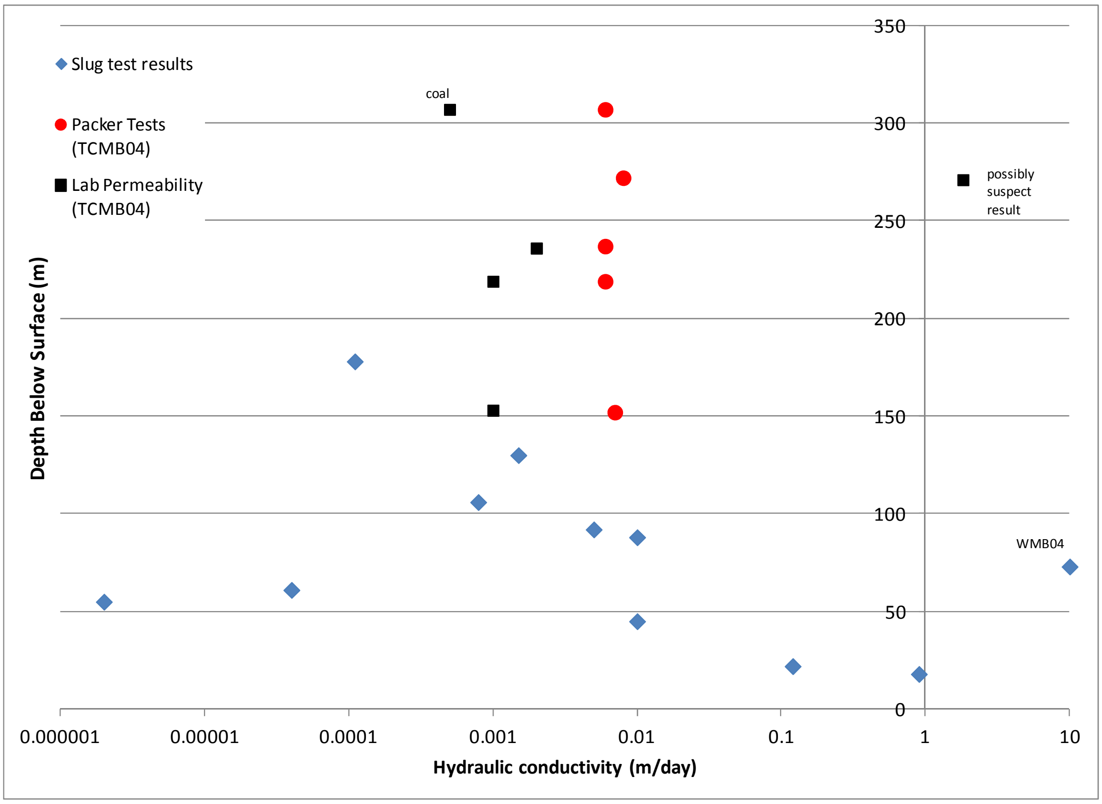
- **Figure 5 Hydraulic conductivity results for shallow rock and interburden from PB (2012) field program**



- The results for each of the four conceptual model layers are simply presented in the PB (2012) report as a range for each of the four categories (refer Table 6-4 in PB, 2012):
  - Alluvial aquifers: 0.3 – 500 m/day
  - Shallow rock units: 0.01 – 20 m/day
  - Coal seam water bearing zones: 0.002 – 0.03 m /day
  - Interburden confining units: 4 x 10^{-5} – 0.006 m/day

  The range in these categories is quite large. The numerical model would normally only use one number for each layer, hence it would be helpful to include a discussion on what is considered the representative value for each layer as the initial input values to the model. While the values will be refined during model calibration, it is important to know how to depart from the initial estimates. (Sensitivity testing or Monte Carlo analysis could be used to asses results across a wide range of values, however ultimately a decision will still need to be made regarding which of the multiple results is considered most representative). Presentation of average and median values may be helpful in this assessment.

5.3.3. Comparison with other areas

The implication in the PB (2012) report is that the interburden confining units are of very low hydraulic conductivity, e.g. refer to the quotes at the start of Section 5.2 (in this report) which imply the hydraulic conductivity is sufficiently low to create hydraulic separation. In reality the values appear typical of hydraulic conductivity for the given rock type. In the author's experience, typical average values of vertical hydraulic conductivity of coal measure siltstones and claystones in deep sedimentary basins are around 10^{-4} to 10^{-5} m/day.

5.3.4. How representative are the results?

The hydraulic conductivity for the vast majority of bores has been determined using slug tests. These are a valid method for testing hydraulic conductivity, but intrinsically only test the hydraulic conductivity very close to the bore screen (typically in the order of tens of centimetres only). Similarly, laboratory permeability tests of core material are also (very) local scale, only testing the rock material extracted. Packer tests test the material in a slightly larger radius away from the bore (e.g. metres), but are still a relatively local test of relatively short duration.

All of these methods are a local scale test which generally does not indicate the broader hydraulic conductivity of the unit tested. This is particularly important in fractured rock aquifers, where the overall rock mass hydraulic conductivity is strongly controlled by the fractures – and these are more likely to be missed than intercepted by an observation bore. Hence these methods in fractured rock aquifers will tend to underestimate hydraulic conductivity compared to methods which assess the hydraulic conductivity across a much larger area by stressing the aquifer over a longer time period (allowing for a larger spread of drawdown in the tested unit), such as aquifer pumping tests or monitoring during flow testing. Longer terms tests will therefore generally provide more reliable hydraulic conductivity data.

It is unfortunate that the flow testing conducted between 2006 and 2009 did not include any monitoring bores in the target coals seams or interburden, or measure recovery rates in the production wells. (Documentation of the Stratford Flow Testing program is contained in the AGL Summary Report, 25 January 2012). Either of these data sets could have been used to determine vertical hydraulic conductivities in the interburden with higher levels of confidence than from slug tests. It is recommended that the upcoming flow test program should be used to determine vertical hydraulic conductivities, and these results compared with the slug testing results in PB (2012).

5.3.5. Use of other data to support the data set

The PB (2012) report has not made use of other potentially relevant data sets in characterising the hydraulic conductivity of the interburden and coal seams. For example, the URS (2007) report (in Section 4.4.1) describes hydraulic conductivities from two previous investigations in the area; Resource Strategies (2001) and Woodward-Clyde (1996). A discussion of the applicability of these hydraulic conductivity numbers to the Stage 1 GFDA site would enhance the data set collected by PB (2012). The Resource Strategies (2001) report is of interest as it describes permeabilities around the Bowens Rd North mine (i.e. within the Stage 1 GFDA). The Woodward-Clyde (1996) report was for the Duralie mine EIS; while the site is approximately 10km south of the Stage 1 GFDA, and the interburden is of a different (lower) stratigraphy, the result should not necessarily be dismissed as irrelevant. Woodward-Clyde (1996) report hydraulic conductivity values of between 0.04 and 3 m/day for the interbedded siltstones and sandstones assessed for the Duralie mine EIS. Evaluation of the relevance of this data to the Stage 1 GFDA site would be helpful (depths of the bores may limit relevance to the interburden confining units in the Stage 1 GFDA).

The SRK (2010) report also includes additional information on hydraulic conductivity in the area. Table 4-1 in SRK (2010) presents:

- Hydraulic conductivity data for coal seams in the area based on 28 tests in coal intervals by Pacific Power in 1999. Based on this data the SRK (2010) report develops a conceptual framework of permeabilities in the coal seams for different depths. This is a much larger sample size that the slug tests conducted in the coal seams in PB (2012), including to significantly greater depths. It would be useful for the conceptual model to draw upon this data.
- Hydraulic conductivity data from Duralie Extention Project Groundwater Assessment report (after Golder Associates 1982 and DCPL 1996 and 2009). This is apparently information additional to the original Duralie project referred to in Woodward-Clyde (1996). Again, while the site is some 10km from the Stage 1 GFDA and the stratigraphic units are different (sandstones of the Dewrang Group: Mammy Johnsons Formation , Weismantel Formation and Duralie Road) an evaluation is necessary to determine the relevance of the data to this area (e.g. the SRK conceptual model of the area adopted values from that study as applicable to the upper 150m profile for the Stage 1 GFDA). The relevance would need to consider the lithological similarity between the interburden at the two sites, structural similarities (e.g. degree of faulting) and the method of test data collection (e.g. SRK, 2010 indicates that some of this data was collected from pumping tests – normally hydraulic conductivity values from pumping tests are more reliable than from slug tests).

- Regional hydraulic conductivity data for the Hunter Valley and Sydney Basin lithologies (coal seams, sandstones, sills and interburden) – these may be of limited relevance to the site, but may help to place the test results into a regional context.

5.3.6. Abandonment of exploration bores

There is no detail provided in the reports on the method of abandonment of exploration bores in the area. If these bores are not decommissioned properly, they represent a (potentially) significant risk of inter-aquifer connection and enhanced vertical hydraulic conductivity of the rock mass. It is recommended that the method of abandonment of exploration bores be identified and that they are sealed / grouted appropriately, if this has not already occurred.

5.4. Characterisation of discharge processes and groundwater dependent ecosystems

5.4.1. Discharge processes

The conceptual understanding of regional discharge processes in the study area is summarised in the extracxts below:

> "As the Gloucester Basin is a closed feature bound by impermeable volcanic rocks, discharge from the water bearing units is likely to occur by seepage to springs, rivers and streams, as well as evapotranspiration from terrestrial vegetation. Most groundwater is expected to discharge in the lower catchment areas of the Avon River and Gloucester River in the vicinity of Gloucester". (PB, 2012: 30)
>
> "Groundwater baseflows (and even discharge from deeper aquifers/water bearing zones) are suspected in the northern catchment area around Gloucester" (SRK, 2010: 39) and "Discharge from all the hydrogeological units occurs by seepage to springs, rivers and streams. As the Gloucester Basin is a closed basin, most groundwater is expected to discharge in the lower catchments areas of the Avon River and Gloucester River in the vicinity of Gloucester" (SRK, 2010:45)

The nested monitoring bores on/in vicinity of the Tiedman property indicate gradients of varying direction between the deeper and shallow aquifers. The S4MB site has an upward head gradient (of approximately 2m) between the deepest unit screened (162-168m in the Cloverdale Coal Seam) and the shallowest unit screened (58-64m in the Leloma Formation). There are however two sites with a downward gradient: S5MB and TCMB, with a head of approximately 3m and 2m respectively between the shallow and deepest monitoring bore. (At the TCMB site however the shallowest bore is screened from 175-181m, hence the comparison is not exactly the same as for the S4MB and S5MB sites which both have shallower bores. A new shallow monitoring bore has been constructed at the TCMB site, completed in November 2010, and screened from 87 – 93m. It was not included in the PB report as drilling/testing had not been completed in time to incorporate the data into the study. The screened depth of the bore will allow a comparison of vertical gradients between the deeper and shallow aquifers at this site, similar to that described above at other nested sites).

On the basis of these three nested sites, the interaction between the upper and shallow units within the vicinity of the Tiedman property is complex and varying in direction of flux over relatively short distances. It is however agreed with the conceptual process outlined above from PB and SRK that further down catchment (in the vicinity of Gloucester), all units will discharge, implying upward gradients from deep to shallow aquifers in that area. A nested monitoring site in the Gloucester area is therefore recommended, firstly to confirm this conceptual understanding which will add confidence in the numerical model and secondly to monitor potential (pressure) impacts on that area during the Stage 1 GFDA development.)

The above descriptions outline regional discharge processes - PB (2012) further describes discharge for each of their four conceptual hydrostrigraphic units:

Alluvial aquifers

> "Groundwater discharge from the alluvium is primarily to the rivers as baseflow. Hydrographs indicate a gaining river system and hydraulic gradients are evident between the shallow alluvial deposits and adjacent river stage levels (Figure 10-5). This hydraulic connection between the alluvial groundwater and river system is supported by the steady increases in salinity in the river during periods of low rainfall and low flow…. A secondary discharge route for shallow alluvial groundwater is likely to be transpiration by riparian vegetation. Minor volumetric abstractions by private bores and wells are the only other discharge from these alluvial aquifers" (PB, 2012:128)

Shallow rock units

> Lateral groundwater flow is most likely directed toward the centre of the basin through bedding plane partings and minor fractures. The unit is likely to discharge to the alluvium that has been deposited along the floor of the valley. This discharge is likely to be minor in the Stage 1 GFDA due to low recharge and the presence of low permeability siltstone and claystone underlying the alluvium.
>
> (PB, 2012: 130-131)

Interburden confining units

> The layered aquitards of the interburden units create separate and distinct groundwater systems with no connection evident between the deeper coal seam water bearing zones and the shallow rock and alluvial aquifers. (PB, 2012: 131)

Coal seam water bearing zones

> The unit is likely to discharge to the shallow rock areas toward the centre of the basin (and eventually and indirectly to the alluvium that has been deposited along the floor of the valley). Faults are suspected to be conduits for some of this upward flow but there is no evidence of any upwards flows or discharge areas at this time. (PB, 2012: 131)

These conceptual processes generally appear sound, with the exception of the description for the interburden units. A discharge process for this unit is not described. It is inferred that this water does not discharge anywhere, because it is contained in isolated and distinct groundwater systems. However this does not agree with some of the key data – for example the age of the groundwater in the interburden is generally similar to that of the water in adjacent coals seams, implying that it is moving laterally (i.e. to somewhere) at a similar rate to water in the coal seams. Further the water level data indicates there is a gradient between the interburden and adjacent units (and the hydraulic testing shows it has some permeability) – hence in addition to any lateral movement there must be some vertical leakage.

Based on available data, an alternate conceptual model for the interburden is one of spatial variability within the Stage 1 GFDA, with some discharge upwards to shallow rock areas and some downward to underlying deeper coal seams and interburden. Further down catchment it is expected that discharge will be more consistently upward from the interburden, and into the shallow rock (and ultimately to the alluvial aquifers). Also, if faults 'are suspected conduits' for upward flow from the coal seams, the potential for faults to act as conduits / preferred pathways within the interburden should also be allowed for (refer Section 5.6 for further discussion).

5.4.2. Groundwater Dependent Ecosystems

Based on the conceptual model of discharge in the above section, there is potential for the following groundwater dependent ecosystems (GDEs) within the study area (discussion of stygofauna is not considered important here):

Baseflow GDEs –Baseflow is recognised in the PB report as the key discharge mechanism from the alluvial aquifers. The following comments are made:

- "the corresponding baseflow contributions are expected to be small as there are no visible discharges to the Avon River in the main area of investigation" (PB, 2012:31). Firstly, visual inspection of a stream/river is not a definitive means of assessing the size of the baseflow. For example, the discharge could be occurring below the surface of the water, so a seepage face above the river level is not a reliable means of assessing baseflow contribution. Secondly, baseflow contribution can be temporally variable (within and across years), so a once off visual inspection is not a reliable means of assessing baseflow contribution. Finally, even though baseflow contribution may be small it can still be important . For example, baseflow may only sustain a river for one or two months of the year or even less frequently (e.g. during a drought), but it may sustain ecological communities through these periods of low flow. Rather than assuming that baseflow contributions are small, a baseflow analysis is recommended to assess the contribution and timing of baseflow to the river. (This will require rating of (at least one of) the stream gauges, which are currently only able to measure stream flow).

- "Also the groundwater that is discharging to the alluvium and to the creeks/rivers is brackish to saline, and is unlikely to sustain any ecosystems because of its poor quality" (PB, 2012:31) – Figure 8-6 in the PB report (2012) presents EC levels at the three gauging stations. EC levels during periods of baseflow range between approximately 300 to 600 µS/cm. This is not brackish or saline and certainly capable of sustaining ecosystems. (It is acknowledged that 2011 was a year of average to above average rainfall in the catchment, and that there were not very long periods without rainfall. Nevertheless, examination of available data suggests that there were sufficiently long periods post-runoff events where baseflow appears to be a very significant contribution to stream flow. In years of lower rainfall this may become proportionally more significant and during low flow conditions streamflow salinity will increase beyond that observed in 2011). The PB report describes EC in the alluvial aquifers as ranging from 390 -5800 µS/cm (with an average of 3000 µS/cm). The difference between the salinity observed in the baseflow in the stream compared to the salinity measured in the alluvial aquifers suggests one or more of the following:
    - The salinity of the alluvial aquifers may not have been adequately characterised by the PB investigation
    - The part of the alluvial aquifers contributing most significantly to baseflow have not be adequately characterised by the PB investigation (e.g. high hydraulic conductivity zones of lower EC within the alluvial material may be contributing most of the baseflow)
    - The baseflow observed in the river is not predominantly *groundwater* baseflow but another type of baseflow (e.g. bank storage, interflow etc). This is potentially an important aspect requiring additional investigation, because if the baseflow is mainly not from groundwater, then the potential impacts on baseflow from the Stage 1 GFDA will be minor to negligible.
- The following statement in the PB report: "Surface water flows dominate the catchment so it is extremely unlikely that any ecosystems or species could be groundwater dependent (or even partially dependent) (AH Ecology, 2012)" (PB,

2012; para 3, p132) does not concur with preliminary assessment of stream level data and stream EC data provided in the PB report. The stream level and EC datasuggest that during 2011, streamflow was maintained for considerable lengths of the year by flow that is not associated with rainfall runoff (i.e. baseflow) and hence is an important process sustaining stream flows. (If flow data was available, instead of only level data, conclusions could be drawn with more certainty). Further, even though baseflow contribution may be volumetrically small (and surface flows may "dominate" from a total flow perspective), the baseflow can nevertheless be quite significant. Hence the AH Ecology conclusion does not seem to concur with other data and statements in the PB (2012) report. Finally, the statement seems to unreasonably extrapolate from commenting on streamflow to the potential for other types of GDEs (springs, terrestrial vegetation etc).

- The conceptual model describes groundwater baseflow north of the study area (in the vicinity of Gloucester) as a likely discharge location for most of the hydrostratigraphic units in the study area. Hence a stream gauge (including EC monitoring) would be useful in this area.

Springs – There is two references to springs in the PB report, the first is replicated at the start of Section 5.4.1 (in this report) and the second is below:

> It is recommended that at least two groundwater monitoring sites should target the alluvial aquifers within the Stage 1 GFDA, and at least one spring and one borehole located in the Alum Mountain Volcanic formation be surveyed. (PB, 2012: 10)

The number and location of springs in the Alum Mountain Volcanic Formation is not discussed in the report, or the importance of the springs from an ecological or consumptive use perspective. Further information on the springs would be helpful to assess their importance relative to the proposed development. (It is noted however that spring identification and analysis was not part of the PB scope).

The presence of springs in the Alum Mountain Volcanics also somewhat conflicts with another statement in the PB report: "the Gloucester Basin is a closed feature bound by impermeable volcanic rocks" (PB, 2012: 30). The fact that there are springs in this formation implies the unit is not impermeable. This raises the issue of how the bedrock in the numerical model is to be conceptualised.

The URS study refers to the possible presences of "springs/seeps where the aquifer is truncated by a fault which extends to the surface" (URS, 2007: 13). It proceeds to describe a swampy area in the north-west corner of the Bowens Road mine which "could be attributed to an east west aligned fault forcing groundwater to the surface" (URS, 2007: 14). This is not discussed any further in the

PB report – based on the additional seismic data collected post-2007, it may be possible to assess whether the area referred to is caused by a fault related spring.

Terrestrial vegetation - Wherever there is shallow groundwater, there is the potential for groundwater dependent terrestrial vegetation. This would be most likely for riparian vegetation. A depth to watertable map overlain with vegetation would assist in determining areas of potential groundwater dependent vegetation. It is however agreed with the PB (2012) conclusion that this is unlikely to be a relationship of high dependence, given the (generally) brackish nature of the alluvial groundwater and relatively consistent nature of rainfall within the area.

5.5. Approach to development of monitoring infrastructure

The approach and rationale behind development of the monitoring infrastructure (bores and stream gauges) is not clearly described in the PB (2012) report. For example, a logical approach to developing a monitoring network would be to adopt a risk based strategy which starts with the position of "what are the possible impacts from the Stage 1 GFDA development?" This would include consideration of a wide range of potential processes and pathways for impact (some of which would be dismissed as improbable to the point of impossible), the consequences of possible impacts and then design of a monitoring network around those potential risks.

There is essentially no discussion in the PB report of what the Stage 1 GFDA development will be (e.g. in terms of numbers of bores, locations, depths, construction information, estimated extracted volumes etc), and hence the logic and adequacy of the proposed monitoring program is difficult to assess. (It is acknowledged however that details of the Stage 1 GFDA and production well layout are provided in the Environmental Assessment (AECOM, 2009), which is a publically available document).

This thinking may have already been undertaken as background to the PB (2012) report, but it would be helpful to see this documented. For example, description of this thinking may help to explain the rationale behind:

- why the bore monitoring infrastructure is located in a relatively small part of the Stage 1 GFDA area.
- the selected screen depths of the bores
- the absence of monitoring bores screened in the target coal seams
- how the monitoring system would provide early warning of possible impacts (as opposed to simply indicating that an impact has occurred)

An additional consideration is the use of preliminary modelling to assist in the design of the monitoring network (e.g. use of analytical models or a very simplified numerical model to assess timing / magnitude of potential impacts). While this modelling may be relatively simple (and hence have a reasonable degree of uncertainty), it would nevertheless assist in identifying the range of potential impacts and timing of impacts, which would in turn assist in design of the monitoring network. Essentially there needs to be a feedback loop between the process of modelling impacts and design of the monitoring network. It is likely for example, that the numerical modelling stage will identify with more clarity than currently understood, the most pertinent risks resulting from the Stage 1 GFDA development and this may required installation of new monitoring infrastructure.

5.6. Characterisation of fault zones

A summary of the key points regarding faults in the area are listed below, and then further expanded below:

1. Fault zones are potentially important influences on groundwater hydraulics, but at present not enough is known about the faults to conclude whether they are flow enhancing or flow impeding (or variable).
2. There is an investigation program underway to improve understanding of the faults
3. Siting production bores away from faults in an important, but not necessarily sufficient control, to prevent minimise the impact of faults as potential preferred pathways

5.6.1. Faults zones are potentially important

Fault zones are potentially important influences on groundwater hydraulics. In the author's opinion it is common for faults in fine grained rocks to produce a clayey, low hydraulic conductivity material that will impede groundwater flow. However, depending on the nature of the faulting and the rock material, faults can cause significant fracturing such that the hydraulic conductivity is enhanced. At present there is insufficient evidence to conclude how faults are behaving in the area. The following comments have been made regarding faults in the three main reports to date:

URS (2007) report

- "the significant faulting known to exist within the Gloucester-Stroud Basin is likely to have resulted in the development of secondary permeability and localised increases in aquifer hydraulic conductivities (Woodward-Clyde, September 1996, in URS, 2007:12)
- URS (2007:12) suggested that "the confining units may be 'leaky', particularly given the likely presence of fracturing/faulting", based on results from the Duralie EIS report.

- Groundwater may occur "as springs/seeps where the aquifer is truncated by a fault which extends to the ground surface" URS (2007:13)
- Groundwater is likely to "flow vertically between aquifers, facilitated by the presence of fractures/faults, leaking confining layers and differences in potentiometric head" URS (2007:13)
- "Faulting in the basin was suggested to have compartmentalised groundwater flow" URS (2007:13), commenting on conclusions from Resource Strategies (2001)
- "A swampy area in the north-west corner of the Bowens Road mine could be attributed to an east west aligned fault forcing groundwater to the surface" (URS, 2007: 14)
- "The source of this existing (high) permeability may be local faulting, including a fault which was intersected during the drilling of an in-seam horizontal hole at LMG02" (URS, 2007: 15)
- The URS report concluded that "the conductivity of the coal seams and interbedded rocks genenerally low to moderate…..however (is) likely to vary significantly near to fault and fracture planes, where secondary permeability may be well developed. This is apparent at the Stratford exploration area" (URS, 2007: 17).

SRK (2010) report

- Faults are "variously interpreted as fully or partially penetrating through the full geological sequence (SRK, 2010:12)
- Normal and reverse faults are characteristic of the area. Seismic interpretation of the area around Stratford shows high angle faulting at the basin edge and low angle sub-parallel faulting towards the basin centre (SRK, 2010:12)
- "A normal fault intersected at 325m in the Bowens Road coal seam by cored well SGSD3 (Pacific Power, 1999) increased the hydraulic conductivity of the coal seam by one order of magnitude (~ 5.8×10^{-2} m/day)" (SRK, 2010:24)
- "Upward leakage may occur through fault zones" (SRK, 2010:24)

PB (2012) report

- "Recent seismic data acquired by AGL maps a number of westerly dipping thrust faults striking north-south, and north-south striking high angle oblique faults. The resolution of the vertical seismic profiles is good to depths of approximately 1 km, however the technique returns poor resolution in the top 200 m. This inhibits the ability to map these fault structures through the shallow surface rock and currently lineament traces can only be inferred" (PB, 2012:25)

- "The major thrusts dip toward the west, and in some cases, have up to 230m of vertical displacement, confirmed by well data. Back thrusts dip to the east and displacement appears minimal. It is likely that most fault systems in the basin will have an oblique slip component due to the complex geometries present" (PB, 2012:68)
- "Two of the nested monitoring bore locations at the central location were also located either side of a fault structure on the Tiedman property to assess whether such faults influenced groundwater flow" (PB, 2012:38) These sites are S4MB and S5MB.
- "Groundwater levels in different strata at the S4MB and S5MB monitoring bores do not provide any clear evidence to determine whether the high-angle oblique thrust fault trending north-south between the two locations is a conduit for groundwater or an impediment for groundwater flow. Due to these uncertainties it is recommended that a specific study be undertaken to further investigate potential fault zone effects between these locations". (PB, 2012:86) (The proposed works are described later in this section)
- "Groundwater chemistry, stable isotope composition and age is distinctly different on either side of the high-angle oblique fault running through the Tiedman property (Figure 8-4) indicating that the geological structure is compartmentalised at this location" (PB, 2012:112)
- Referring to the coal seam water bearing zones: "Faults are suspected to be conduits for some of this upward flow but there is no evidence of any upwards flows or discharge areas at this time" (PB, 2012:131)
- Summarising on the significance of fault zones, the PB study concludes:

  > Even though several of the completed monitoring bores are located close to faults or straddle fault zones, the available data suggests the faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones. Water quality and isotope data on the Tiedman site is less conclusive and may suggest near surface faults are enhanced recharge areas.
  >
  > Current understanding based on earlier flow testing programs, water level data, water quality data and isotope aging results from this study is that faults are not major features with respect to natural groundwater flow pathways across the area. However, further studies are under way and planned to better understand groundwater flows within and adjacent to faulted areas when deep coal seams are dewatered. (PB, 2012:132)

To summarise the above knowledge regarding the effect of fault zones, the studies all agree that fault zones are potentially important, but there is insufficient evidence within the study areas to conclude that faults are zones of enhanced hydraulic conductivity. However the URS (2007) and SRK (2010) studies favour the theory that they are more likely to be areas of enhanced hydraulic conductivity. This is supported by the evidence of increased hydraulic conductivity (by approximately one order of magnitude) in a bore in the Bowen Road coal seam. This was in the coal seam not the interburden.

The only new evidence related to the hydraulic properties of the faults that appears to be collected in the PB study (so excluding the seismic data which is new but not directly helpful regarding hydraulics) is the chemistry, age and isotope date collected in two bores drilled either side of a high-angle oblique fault (S4MB and S5MB). However the conclusion regarding faults seem mixed. On the one hand it is concluded that "faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones" and yet in another part of the report it is stated that "Groundwater chemistry, stable isotope composition and age is distinctly different on either side of the high-angle oblique fault running through the Tiedman property". The two statements appear contradictory. And further it is suggested that these bores possibly suggest that "near surface faults are enhanced recharge areas".

Hence there is a somewhat confused picture presented regarding the effect and importance of faults. The overall conclusion is agreed with however, that further studies are required to understand their significance and behaviour.

5.6.2. Fault investigation

It is understood that there are two investigations proposed / underway to improve understanding of the faults within the Stage 1 GFDA:

i. The program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB.

ii. The Waukivory Flow Testing Program, as described in EMGA Mitchell McLennan (2011) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012).

Fault in the vicinity of S4MB and S5MB
The investigation of the fault in the vicinity of S4MB and S5MB is described in PB (2012) and involves:

- A surface geophysical survey to map the fault zone in the shallow subsurface
- Drilling of one test production bore to target the fault
- Drilling of two test monitoring bores; one along the strike of the fault, and one perpendicular to the strike
- 72 hour duration pumping test (and associated recovery) whilst monitoring groundwater levels in the new monitoring bores as well as the S4MB, S5MB and TCMB bores

- Geochemical parameters be recorded during the test, and water should be sampled regularly for laboratory analyses (chemical composition and isotope characteristics).

"The investigation will determine whether this type of fault is open or closed, will provide permeability data to compare with the adjacent (non-fractured) bedrock, will determine the shape of the drawdown cone (and whether groundwater flow is towards or contained within the fault), and will provide an insight into the source of the groundwater, water migration and connectivity with deeper water bearing zones" (PB, 2012:87)

It is understood that this investigation program has already commenced. The program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB appears suitable for assessing the hydraulic characteristics of the fault, however the following is suggested:

- If the fault zone is narrow and the production bore screen cannot target the fault zone with confidence, consideration should be given to an alternate approach of siting the production bore on one side of the fault, with comparison of drawdown in observation bores either side of the fault.
- Contingency for a longer pumping period than 72 hours should be allowed for, to provide sufficient time for a drawdown response in all relevant bores.
- The program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units – this will not require any additional bores, but a longer pumping period is likely to benefit this objective.

Fault in the vicinity of the Waukivory Flow Testing Program

The Waukivory Flow Testing Program is described in EMGA Mitchell McLennan (March, 2011) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012).

The proposed Waukivory program involves five monitoring bores to be constructed in the near vicinity of the gas wells that will comprise the Waukivory pilot. These are all located west of the Avon River and are dedicated AGL monitoring bores for this pilot (and will also be incorporated into the broader monitoring network for the Gloucester Gas Project and the Stage 1 GFDA). In addition there will be three alluvial monitoring bores owned and monitored by Gloucester Resources east of the Avon River (within the Avon River alluvium) that will be additional (nearby) monitoring bores for this study. There are also remote AGL monitoring bores (to distances of 3kms) that will used to assess any wider water level impacts.

The AGL proposal is to monitor the watertable aquifer at two sites (WKMB01 and WKMB02); the deep Roseville coal seam (the shallowest coal seam likely to be the target of CSG testing) at one site (WKMB04); and the thrust fault at two sites (WKMB03 and WKMB05). The rationale for the observation network and program is to:

- Monitor shallow and deep groundwater conditions pre-flow testing and any CSG drilling and development
- Monitor the beneficial aquifers in the vicinity of the pilot (alluvium and shallow rock)
- Determine if the thrust fault is a conduit or impediment for groundwater flow
- Determine any differences in fault permeability at depth (immediately above the targeted coal seams) and at shallow intervals (adjacent to the Avon River)
- Determine if vertical leakage from shallow aquifers is likely to occur in the vicinity of the depressurised gas wells
- Enhance the conceptual model and determine whether significant fault features should be included in future numerical modelling
- Determine whether shallow aquifers and deeper water bearing zones are isolated or connected when deep coal seams are depressurised in areas of faulting

The monitoring program will comprise the following (at each of the AGL sites) during each of the following phases:

Baseline for a period of at least 3 months (ie pre fracture stimulation and flow testing)

- Permeability testing (slug testing)
- Water levels
- Water quality

Fracture Stimulation for the days and weeks of the fracture stimulation program

- Water level variations
- Water quality variations

Flow testing for periods of around 6 months

- Produced water profile
- Water level variations
- Water quality variations

The above information was provided from AGL (email from John Ross to Rick Evans on 13 March 2012) and the information supplements the detail provided in the Draft Groundwater Management Plan for the Waukivory Flow Testing Program dated 8 March 2012.

The program appears suitable for assessing the hydraulic characteristics of the fault, however it is suggested that consideration be given to installing one observation bore in the interburden, in relatively close proximity to test well WK-11 (e.g. 20-50m, or as close as safely possible) and screened approximately 20-30m above the fault. These two characteristics of the observation bore (i.e. vertically closer to the fault and laterally closer to the test well), will mean greater likelihood of water levels in the bore responding over the six month pumping period and minimise the possibility of obtaining a non-conclusive result from the test program. As per the fault testing program at S4MB and S5MB,the program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units.

5.6.3. Siting CSG wells away from faults

Siting CSG wells away from faults (PB, 2102: 132) is an important, but not necessarily sufficient control, to prevent the impact of faults acting as potential preferred pathways. It is important that the results of the characterisation of the faults (i.e. conceptualisation of fault behaviour) derived from the above two programs is brought into the conceptual model, so that the effect of faults can be accounted for (if required) in the development of the numerical model.

5.7. Overview of possible risks associated with hydraulic fracturing and under-reaming

5.7.1. Hydraulic fracturing

This review provides some general contextual comments on the potential risks associated with hydraulic fracturing in the Gloucester Valley. The review focuses on the risks associated with hydraulic changes to aquifer behaviour and does not consider any potential issues resulting from the use of chemical hydraulic fracturing fluids.

The fracturing process

Hydraulic fracturing is the process of inducing fractures in coal measure sequences to enhance permeability and gas yields. Advances in hydraulic fracturing technology allow the opportunity to produce gas from rock formations that previously would have been too difficult and expensive to consider.

Hydraulic fracturing occurs after a well is drilled, cased and cemented by pumping water, often containing a suspended proppant, such as sand, down into a wellbore in order to increase productivity of a well. The pressure applied cracks the rocks and the proppant lodges in the cracks keeping the fracture open. The newly created fracture enables natural gas and formation water to flow to the CSG well.

The hydraulic fracturing operation typically takes place only once at the beginning of the well operation. Most wells then produce for years without requiring any further fracturing.

Assessment of potential risks
The practice of hydraulic fracturing, or fraccing, to increase gas output, has the potential to induce connection and cross-contamination between aquifers, with impacts on groundwater quality (National Water Commission, 2011). There are two possible mechanisms for this process:

- Poor well construction practices allowing pathways to develop in and around the well casing causing interaction with overlying aquifers/aquitards;
- Vertical fracture propagation in the target formation creating preferred pathways to overlying or underlying aquifers/aquitards.

Both of these mechanisms will result in an increased vertical hydraulic conductivity, which, particularly if extending into the 'shallow rock aquifers' and 'interburden confining units' in the upper 200m will increase downwards leakage from these units. The risk of these two mechanisms actually occurring is discussed below.

Potential for pathways to develop in and around the well casing
Development of pathways in and around the well casing can be avoided through appropriate well construction. Ensuring there is an impermeable grout or cement barrier around the well casing separating the target coal seams from the overlying aquifers will prevent inter-aquifer contamination. AGL state that the hydraulic fracturing in CSG production wells in the Gloucester Basin will consist of perforating pressure cemented casing over relatively small coal intervals (AGL email 16th March 2012). Thus the individual coal seams will be effectively hydraulically isolated from each other around the well annulus due to the cement seal.

The NSW Department of Trade Investment Resources and Energy require that all exploratory and production wells be constructed to hydraulically isolate the target formation from overlying aquifers. AGL are required to follow these conditions as a condition of their licence. Provided these requirements are followed, the potential for inter-aquifer leakage via the drill hole is eliminated. Also AGL will be undertaking hydraulic testing of the pressure cemented seals around the well annulus prior to any hydraulic fracturing or development work (AGL email dated 16th March 2012).

Potential for pathways to develop within overlying/underlying strata

Analysis of the depth of induced fractures compared to depth to overlying aquifers can provide some indication of the risk of inducing inter-aquifer connectivity through hydraulic fracturing. The liberation of coal seam gas can only occur when coal seams under significant hydraulic pressure are depressurised. Coal seam gas is trapped in pores inside the coal, held in place by the water pressure. The depressurisation through pumping of natural groundwater causes the coal seams to release the methane dominated gases. The pressures required to 'seal' the gas insitu are high, meaning reasonable depths are required before these natural hydrostatic pressures are obtained. In the Gloucester Valley, the coal seams where the liberation of coal seam gas is possible are hundreds of metres deep. For instance, the depth of the four proposed exploration CSG wells in the Waukivory Flow Testing Program is likely to be up to 1,000m (EMGA/ Mitchell Mclennan, March 2011). Given that the propagation of induced fractures through the hydraulic fracturing process is typically tens of metres (mostly horizontal) and the thickness of material between the target coal seam and the only usable aquifer close to the surface is hundreds of metres, the risk of creating a preferred pathway to the surface alluvial aquifers is considered to be very small.

The only potential process where hydraulic fracturing could result in the interconnection of the target coal seams and watertable is if the fracturing were to intersect a fault or fracture zone and where there was preferential flow along the fault or fracture zone. There are known faults in the Gloucester Basin so there is potential for this process to occur. AGL propose to investigate this process in the Waukivory Flow Testing program by monitoring a series of eight designated monitoring bores either side of a known thrust fault for a period before and after hydraulic fracturing of the four proposed exploration wells (AGL email dated 13th March 2012). The conclusions drawn from analysis of the monitoring results for the Waukivory pilot program will be an important indicator of the possible impact of hydraulic fracturing.

It is also important to recognise that it is not in AGL's interest for the hydraulic fracturing process to result in fractures to any formations other than the target coal seams. If the fractures do result in interconnection of overlying aquifers, then the coal seam gas can permeate into these aquifers rather than being drawn into the well. AGL will be undertaking diagnostic monitoring of fracture development to ensure the fracture propagation remains within the target coal seam. The use of tools such as micro-seismic, tilt meters and dipole sonic logs provide important information on the orientation and length of induced hydraulic fractures.

5.7.2. Under-reaming

Under-reaming is the process of enlarging the diameter of the hole beneath the end of the cemented casing. Under-reaming is a useful process to increase the surface area of the hole thus increasing gas liberation from the intersected coal seams. The technique is useful in particularly permeable coal seams where increased surface area of the hole can result in increased flow of liberated gas without the need for hydraulic fracturing.

All intervals that are under reamed are open and hence there will be hydraulic connection of coal seams and aquitards within this interval. This is in contrast to the hydraulic fracturing process where the casing is only perforated at specific coal intervals with the cement around the hole annulus remaining intact, thus isolating individual coal seams. The potential hydraulic linking of individual coal seams in the under-reaming process can cause migration of water between coal seams. However, in the case of the Gloucestor Basin, the groundwater chemistry of individual coal seams is reasonably similar (albeit slightly increasing in EC at depth) and there are no known good groundwater quality and/or high yielding aquifers within the target coal seam formations so the risk is considered to be negligible.

5.8. Seepage Monitoring

The PB (2012) report describes seepage monitoring bores around the Tiedman South dam (TMB04 and TMB05). The two monitoring bores are considered sufficient to assess potential seepage impacts from the dam. (A more distant down-gradient bore is not considered necessary; this could be installed in the event that any seepage was detected in TMB05, the down-gradient bore). It is not known if there are water level data loggers in these two bores; if there are none present this is recommended as an additional indicator of potential seepage (i.e. in addition to water quality monitoring).

The Stratford 1 and Stratford 3 dams do not have any nearby observation bores for detecting seepage assessment. If construction techniques or liners in Stratford 1 and Stratford 3 dams were the same as for the Tiedman dams, then the Tiedman monitoring is considered a sufficient indicator of the performance of all the dams. If different construction techniques or liners have been used in the Stratford dams, then (depending on those construction techniques / liners) consideration should be given to installing a monitoring bore down-gradient of one of the dams.

6. Conclusion

In general the conceptualisation presented in the PB (2012) report is broadly considered to be appropriate, and the fundamentals of the conceptual model are reasonable. The PB (2012) study has largely gathered sufficient information to enable development of a suitable conceptual model (which will be supplemented by current/proposed investigation programs), however some further work is recommended as a result of this review. Similarly, some additional monitoring infrastructure is recommended.

In some instances it is considered that the PB (2012) study has drawn inaccurate conclusions from the data or omitted some work which would improve conceptual understanding. These generally fall into categories of: connectivity between deep and shallow systems, recharge and discharge processes, characterisation of vertical hydraulic conductivity and specific improvements that can be made to the conceptual model. Regarding the latter, the most important improvements relate to the spatial coverage of the conceptual model, definition of model boundaries and preliminary quantification of key processes (i.e. a water balance). It is apparent that not all available information has been used to develop the conceptual model, and incorporation of additional data will enhance the current conceptualisation. This review has highlighted the importance of not directly extrapolating conclusions regarding the developed hydrogeological system based on observations from the natural (i.e. unstressed or lightly stressed) condition.

There is currently insufficient information available to characterise the hydraulic behaviour of faults within the project area. Given the potential importance of faults to groundwater movement, the two proposed field programs are important activities to fill this knowledge gap.

None of the criticisms presented in this review are considered to be issues that cannot be readily addressed or the conceptual model revised to take account of the comments. The review has not identified any issues which necessarily indicate the project represents a high or unacceptable risk from a hydrogeological impact perspective, however it is the role of the numerical modelling to assess the location and magnitude of impacts.

7. Recommendations for Further Work

This section presents recommendations for further work. It is divided into field based activities and desk based activities, and then further divided into High and Moderate priority activities.

It is suggested that all of these recommendations can occur in parallel with the Waukivory Flow Testing Program and should not be delayed pending the results of that program.

7.1. Field work

7.1.1. High Priority

It is recommended that:

1) The currently planned investigations be undertaken to assess the hydraulic significance of faults in the study area. It is understood that there are two proposed programs to assess faults in the area:

    i. Regarding the investigation program outlined in Section 7.3 of PB (2012), involving investigation of the fault between S4MB and S5MB; this program appears suitable for assessing fault characteristics, however the following is suggested:

    - If the fault zone is narrow and the screen cannot be targeted with confidence, consideration should be given to an alternate approach of siting the pumping test production bore on one side of the fault, with comparison of drawdown in observation bores either side of the fault.
    - Contingency for a longer pumping period than 72 hours should be considered, to provide sufficient time for a drawdown response in all relevant bores.
    - The program should also be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units – this will not require any additional bores, but a longer pumping period is likely to benefit this objective.

    ii. Regarding the Waukivory Flow Testing Program, as described in the AGL report (8 March 2012) and supplementary information provided by email from AGL (email from John Ross to Rick Evans on 13 March 2012). This program appears suitable for assessing fault characteristics, however it is suggested that consideration be given to installing one observation bore in the interburden, in relatively close proximity to test well WK-11 (e.g. 20-50m, or as close as safely possible) and screened approximately 20-30m above the fault, to minimise the possibility of obtaining a non-conclusive result from the test program. The program at S4MB and S5MB should be viewed as an opportunity to gather vertical hydraulic conductivity data in the interburden confining units. The Waukivory Flow Testing Program is an important part of the overall hydrogeological investigation and should proceed.

2) That at least one of the three existing stream gauges is rated to enable determination of flows. This will allow determination of baseflow contribution to the Avon River (refer Section 7.2).
3) To provide better spatial coverage across the Stage 1 GFDA, and to provide an indication of potential impacts in the area where the target coal seams (and interburden) are most likely to be discharging to the shallow rock/alluvial sediments, an additional nested monitoring site be installed (two bores are suggested) in the vicinity of the township of Gloucester.
4) Field work be undertaken to investigate the relationship between groundwater and Waukivory Creek and Dog Trap Creek, where these creeks run over the recharge areas of the coal seams (This is likely to involve at least one shallow observation bore at each creek in these areas). Depending on the relationship identified, gauging of one or both creeks may be required.
5) At least one VWP (nested site) should be installed in the target coal seams and interburden in order to determine pressure changes at depth as a result of the CSG extraction. The most logical location for this site would be around the central observation (nested) bore sites (e.g. on the Tiedman property), so that deeper pressure changes can be compared to the adjacent shallow pressures. Correspondence from AGL post the draft IPR indicates that up to two deep VWPs are planned on the Tiedman property (or more likely Farley property immediately to the north of the Tiedman property). The VWPs will utilise reservoir coreholes after sampling and investigation is complete. The REF for these works is currently with DTIRIS for approval (EMGA Mitchell McLennan, November 2011). It is noted that the REF states that the depths for the VWPs have not yet been determined, but assuming they target the deep coal seams and interburden, these works would address this recommendation.
6) At least one shallow monitoring site in the coal seam outcrop areas (with multiple monitoring levels) be installed to investigate the potential of up dip gas migration, as per SRK (2010) recommendation no. 11. This refers to the installation of gas monitoring bores further east than the current gas observation bores, in the coal seam outcrop/subcrop areas targeting seams underlying the Roseville coal seam. It is possible that a nil response might be observed in these bores, but the need to prove this is considered important.
7) The method of abandonment of exploration bores should be identified. The bores should be sealed / grouted appropriately, if this has not already occurred.

7.1.2. Moderate Priority

It is recommended that:

8) An investigation of the sources of baseflow to the Avon river be conducted. This is potentially significant, as it will indicate the importance of groundwater contribution to baseflow. (Currently there is a discrepancy between the salinity of the baseflow recorded in the river and the alluvial groundwater salinity).
9) Water level data loggers should be included in TMB04 and TMB05 (if they are not already).
10) If different construction techniques or liners have been used in the Stratford holding dams then, depending on those construction techniques / liners, consideration should be given to installing a monitoring bore down-gradient of one of the dams. Correspondence from AGL post the draft IPR indicates that the Stratford holding dams are to be decommissioned shortly; assuming this occurs, this recommendation will be redundant.
11) All of the private bores surveyed and dipped in the SRK (2010) study (p30-33) be re-dipped and incorporated into either the alluvial or shallow aquifer potentiometric surface
12) Surveying of springs in the project area be undertaken (including location, flow, use, ecological value).

7.2. Desk-based study / analysis

7.2.1. High Priority

It is recommended that:

13) Based on the two proposed field programs for investigating faults (refer Recommendation 1 above), a conceptual model of the hydraulic behaviour of the faults should be developed. If the field programs are inconclusive regarding hydraulic fault behaviour, further field investigations may be required. If the field investigations indicate the faults are significant preferred pathways, then geophysical mapping of faults in the shallow subsurface may be required to allow for inclusion of faults in the numerical model (as the current seismic surveys have very poor resolution in the upper 100-200m).
14) The conceptual model should account for major structural changes related to the faults. For example, the conceptual cross sections in PB (2012) do not appear to show some of the major fault-related displacements of units. While the conceptual model is necessarily a simplification of reality, major displacements should be included in the conceptual and numerical model.
15) The proposed numerical model boundaries should be defined, and the conceptual model expanded to include this area. The boundaries of the conceptual model should be expanded in

an east-west direction to include the full synclinal trough. They should also be expanded in a north-south direction to include the area around Gloucester (where the current conceptual model suggested target coal seams and interburden may be discharging).

16) A water balance be conducted (using the above boundaries). This should include a water balance for the natural and the developed case.
17) To provide better spatial coverage across the Stage 1 GFDA, additional bore data should be incorporated into the conceptual model to improve spatial coverage away from the central area where the PB (2012) investigation was focused. For example, it appears that there are a number of bores described in SRK (2010) report which would improve spatial coverage within the Stage 1 GFDA, such as:
    a. Some of the existing gas production wells e.g. Craven 6, Faukland 3 and Waukivory 3 provide lithological information away from the centre of the Stage 1 GFDA,
    b. Previous exploration bores drilled by Lucas Energy
    c. Some of the deeper monitoring bores associated with the Gloucester coal mine
    d. Some of the DNR bores (e.g. as shown in Figure 5-1 in SRK, 2010 - these may be shallow and not useful, however this should be investigated)

    Many of these will not contain water level data (and most will not be suitable to form part of the monitoring network) but they will be useful for developing the hydrostratigraphy in the conceptual model.
18) Additional analysis of the existing hydraulic conductivity data be undertaken. This should include:
    i. estimation of the vertical hydraulic conductivity of the units, recognising that the data currently collected is predominantly horizontal hydraulic conductivity.
    ii. consideration of the difference between the slug test data and the packer test and laboratory data, and a conclusion reached as to which is considered more reliable.
    iii. consideration of reasons for the absence of a trend in hydraulic conductivity and depth for the packer and lab test data.
    iv. representative values for the four hydrostratigraphic units should be proposed (recognising that this may change during model calibration). Upper and lower bounds that will be permitted within the model should also be described.
19) Further evaluation of the relevance of hydraulic conductivity data collected in or close to the Stage 1 GFDA area be undertaken, and incorporated into the numerical model as appropriate.
20) Baseflow separation be undertaken for the Avon River downstream of Waukivory Creek gauge (GS208028). If there is an additional gauge within a reasonable distance downstream of

GS208028 (e.g. within approximately 10-15km), baseflow separation should also be undertaken on that gauge.

21) Once the new stream gauge(s) have been rated, baseflow separation be undertaken on the gauge(s). (This should consideration of using the EC data to assist in calibration of the baseflow separation).
22) Once all of the above recommendations have been completed (1-21), the conceptual model should be updated and consolidated into one report.

7.2.2. Moderate Priority

It is recommended that:

23) An analysis of water levels with barometric effect removed be undertaken. This will allow a clearer evaluation of trends at nested sites.
24) Aspects of the conceptual model which are currently located partly in PB (2012) and partly in SRK (2010) be consolidated. For example, the stream gauge (GS208028) located near the northern boundary of the Stage 1 GFDA (a location highly relevant to the study) is referred to in the SRK (2010) report but not the PB (2012) report. Another example is the map of groundwater users presented in the SRK (2010) report but not in the PB (2012) report.

8. References

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