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GLOUCESTER CSG PROJECT – IMPACTS ON GROUNDWATER: REVIEW OF ASPECTS OF THE PHASE 2 REPORT BY PARSONS BRINKERHOFF

This document presents a review of conclusions reached in the Phase 2 report by Parsons Brinkerhoff (**PB**) regarding the groundwater regime in the Gloucester Basin, and in particular the Stage 1 CSG project. The report is dated January 2012.

This review also notes important issues in respect to surface and groundwater, that are not dealt with in the PB report.

This work required for this report has not been funded by any party. It represents self-funded work by this firm.

Yours faithfully

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CONTENTS

1. SCOPE OF THIS REVIEW

This review is directed to those facets of the Parsons Brinkerhoff (**PB**) report that address, or infer, groundwater impacts of the Stage 1 CSG extraction project. It is not, primarily, directed to assessing factual data given by PB. The review is also given in the context of public statements by AGL that the Phase 2 report by PB constitutes a 'comprehensive' groundwater investigation[1]

To start one has to consider the scope of the Parsons Brinkerhoff (**PB**) report, and this is not straightforward because the Scope of Work is presented more than 70 pages into the main text (PB Section 4.2), and repeated in truncated form in the Conclusions.

An examination of the scope reveals that most of the work relates to the collection of facts, via drilling and sampling of boreholes and establishment of stream monitoring points, all vital work, but not central to this review The facts, in themselves, say nothing about the likely impacts of a mining operation, in this case CSG extraction.

However, the Scope of Works includes three facets that are assessments of impacts. These are:

(i) determine **"whether the shallow water resource aquifers are connected to the deeper coal seam water bearing zone"**,

(ii) **"assist in determining the quality of deep groundwater that is likely to be produced as the CSG field is developed"**, and

(iii) prepare a **"revised conceptual model of groundwater recharge, discharge and flow across the Stage 1 GFDA...."**

In addition, an examination of the PB Conclusions (PB Section 11) indicates that the interpretation facets of the report go somewhat further than indicated by the Scope of Works. In particular, the following Conclusions are noted:

- "There are few beneficial aquifers. These are shallow aquifers in the alluvium and shallow rock, and are only suitable for stock water supply and limited domestic purposes."
- "Shallow aquifer zones (alluvial and shallow rock) are not naturally connected to the deeper water bearing zones in the coal seams."
- "The interburden confining units are effective confining units that separate shallow groundwater aquifers from deep coal seam water bearing zones."
- "There are only two beneficial use aquifers (alluvial aquifers to 12m and shallow rock aquifers to maximum 150m but more commonly less than 100m depth)."
- "The available data suggests faults do not affect the natural groundwater flow characteristics of shallow rock aquifers, interburden confining units or coal seam water bearing zones."

[1] AGL Gloucester Gas project. Community Update 1 February 2012

In this review we will be examining whether the work documented in the report is appropriate and sufficient to warrant the conclusions that have been interpreted. We concern ourselves, also, with what relevant facts and issues are not dealt with in the report.

The PB report is a long document containing a mass of detail, which, although important, tends to blur the key information. Also facts, interpretation and opinion are mixed up. To aid our own understanding we have culled key factual information, and separated out matters of interpretation and opinion. These culled documents may aid others in their understanding of important elements of the report and are reproduced in Appendix A (Factual) and Appendix B (Interpretation).

We have not checked the detailed factual data, such as borehole logs, field permeability tests and chemical tests. We have adopted the data, assuming the measurements and documentations are correct.

2. GAPS IN PARSONS BRINKERHOFF REPORT

1. The PB report gives no information in respect to the proposed Stage 1 CSG borehole extraction field, extraction systems, proposed hydraulic fracturing and water management. There are; no plans, no tables, no words, about:

    - number of and location of wells,
    - depths of wells,
    - locations, directions and lengths of laterals (directionally drilled deviated wells),
    - hydrofracturing,
    - surface storages of ‘produced’ water, and
    - disposal of salts that are in the produced water.

2. In parallel with Item 1, the report provides no information in the form of calculations or opinions as to the quantity of water likely to be extracted from coal seam levels, and no information about the storage, processing and disposal of this water.

3. The report provides no data, calculations or assessments related to drought and flood and surface hydrology, other than some simple statements such as:

    - “Water levels respond to rainfall and flooding for alluvial aquifers and show seasonal variations.”
    - “Stream gauge data indicates that the Avon River is a gaining stream with respect to the water table in the adjacent alluvium”.

It is noted that in many places PB express flow measurements in the units of bbls/day (barrels per day). This is an unusual and unhelpful unit, as it is normally only used in the crude oil industry. The 'barrel' in this unit is 158.94 litres. This means that:

100 bbls/day = 0.184 litre/sec

= 15,894 litres per day.

3. SOME COMMENTS ON THE FACTUAL DATA

3.1 General

As already stated, we have not checked the details of factual information provided by PB. We have accepted the borehole logs, field data, calculations from field permeability tests, chemistry testing, and river flow measurements, as being correctly made and documented. We have also accepted the summary tables, and diagrams, of that factual information as being correct.

Also, as already stated, we have culled from the PB main text and appendices, factual information deemed of key relevance to our review. This is given in Appendix A. While our focus is primarily on matters of calculation and interpretation, there are items of fact that require comment, namely:

i. rainfall records,

ii. salinity,

iii. number of permeability measurements, and

iv. duration of monitoring.

These are discussed in the following sub-sections.

3.2 Rainfall records

Section 3.3 of the PB report presents climatic information relevant to hydrological (surface water) studies.

The rainfall records are from BOM Station 060112, which has records from 1976. From these records conclusions are drawn as to mean rainfall and variations in rainfall (their Figure 3.4 reproduced below).

Figure 1 shows the rainfall stations in the project area. Recording at Gloucester commenced in 1888. In addition, the Queensland Department of Environment and Resource Management (**QDERM**) provides a service whereby they generate 120 year rainfall records, for any locality, by interpolation of surrounding records. This allows filling of gaps in existing long term records, such as those from Gloucester.

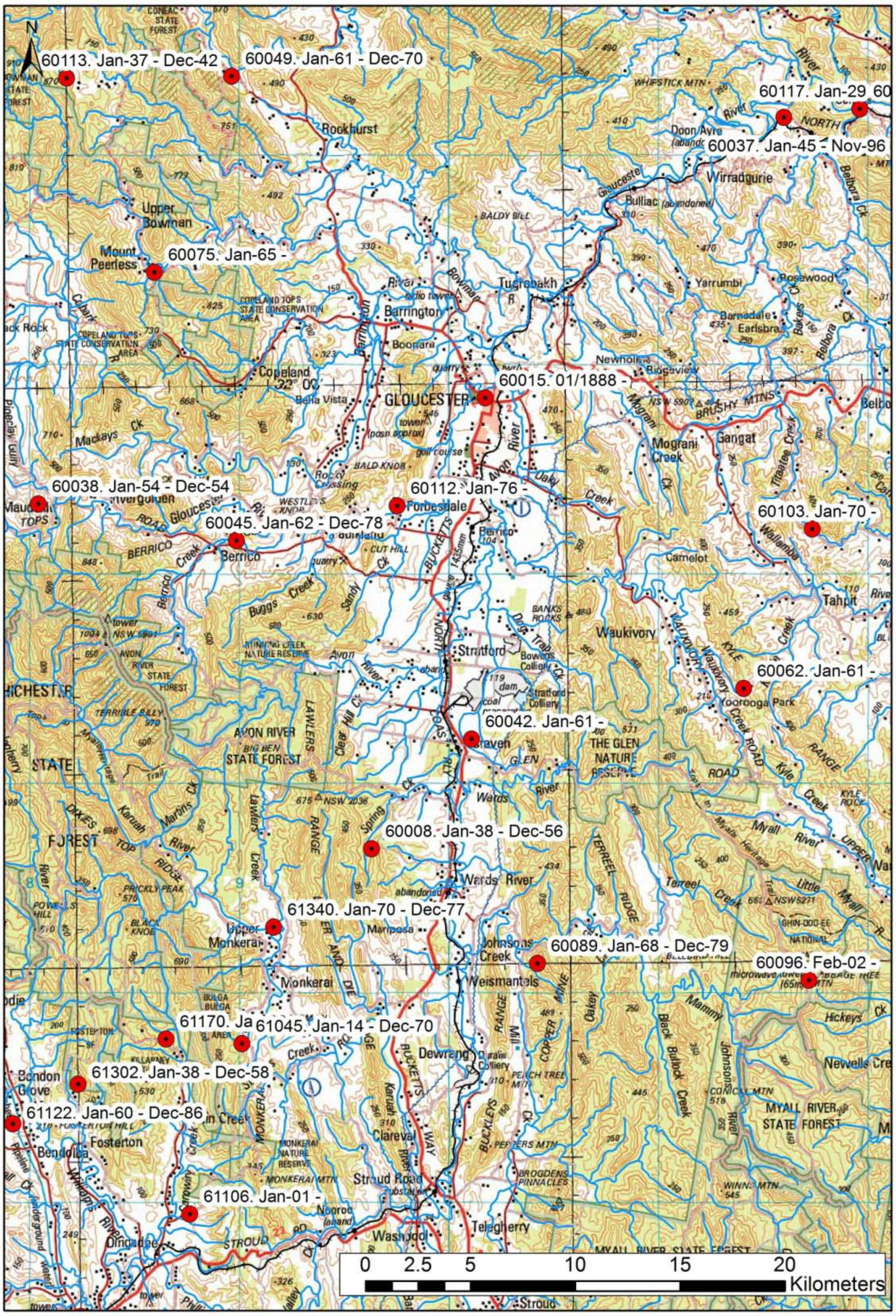


Figure 1: Rain gauges.

We have purchased the daily records from QDERM, commencing from 1889.

Figure 2 shows the cumulative rainfall, compared with the straight line if every year had average rainfall. This is to explain the meaning of a rainfall plot in the PB report.

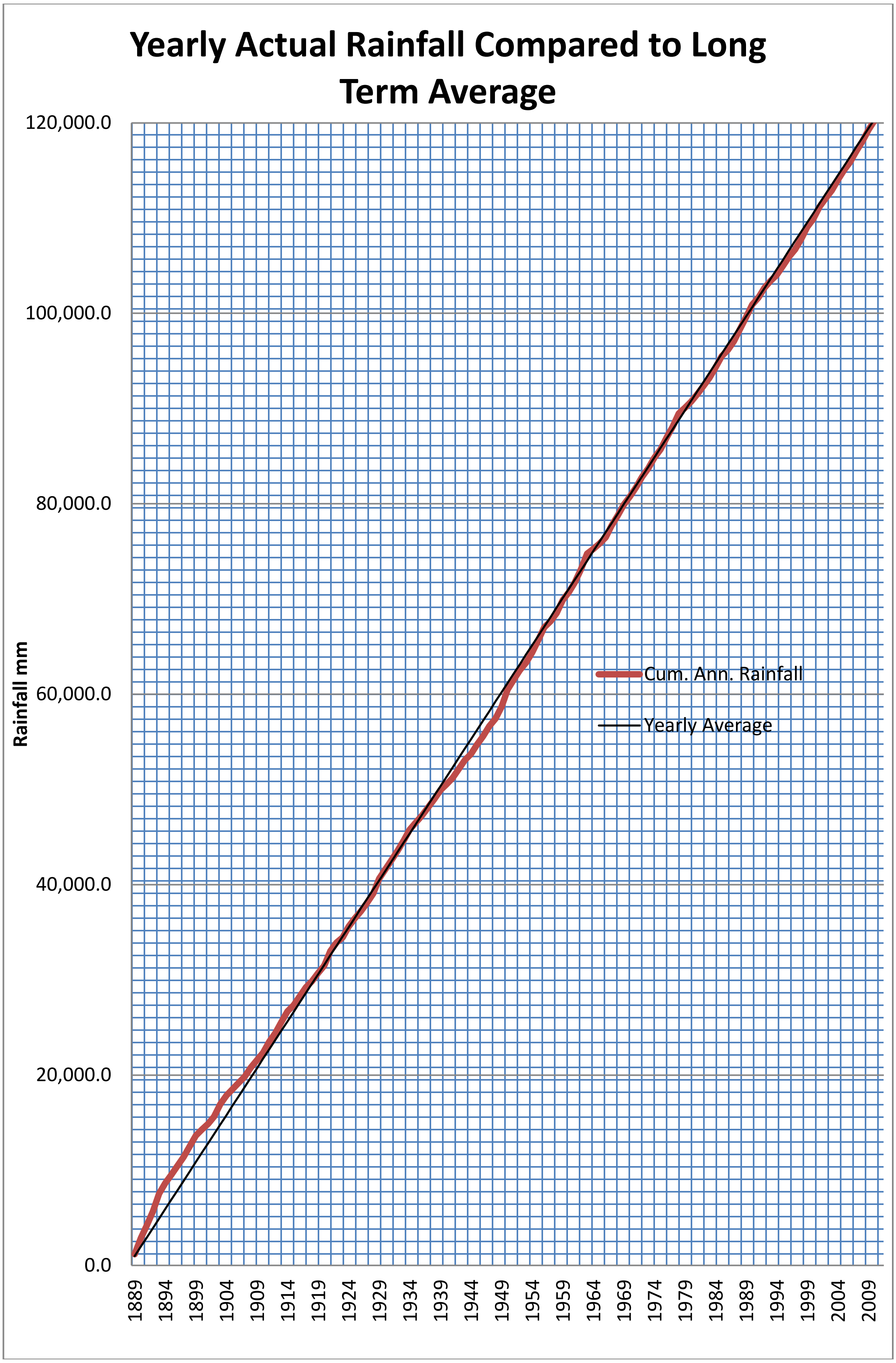


Figure 2: Cumulative rainfall from 1889.

The differences between the straight line and the actual cumulative rainfall in Figure 2, above, is what PB call “cumulative deviation rainfall”, and plot in their Figure 3.2 (reproduced below). Our corresponding graph using the data from 1889 is given in our Figure 3.

Parson Brinkerhoff Figure 3.4: Analysis of rainfall data from 1976 to 2010.

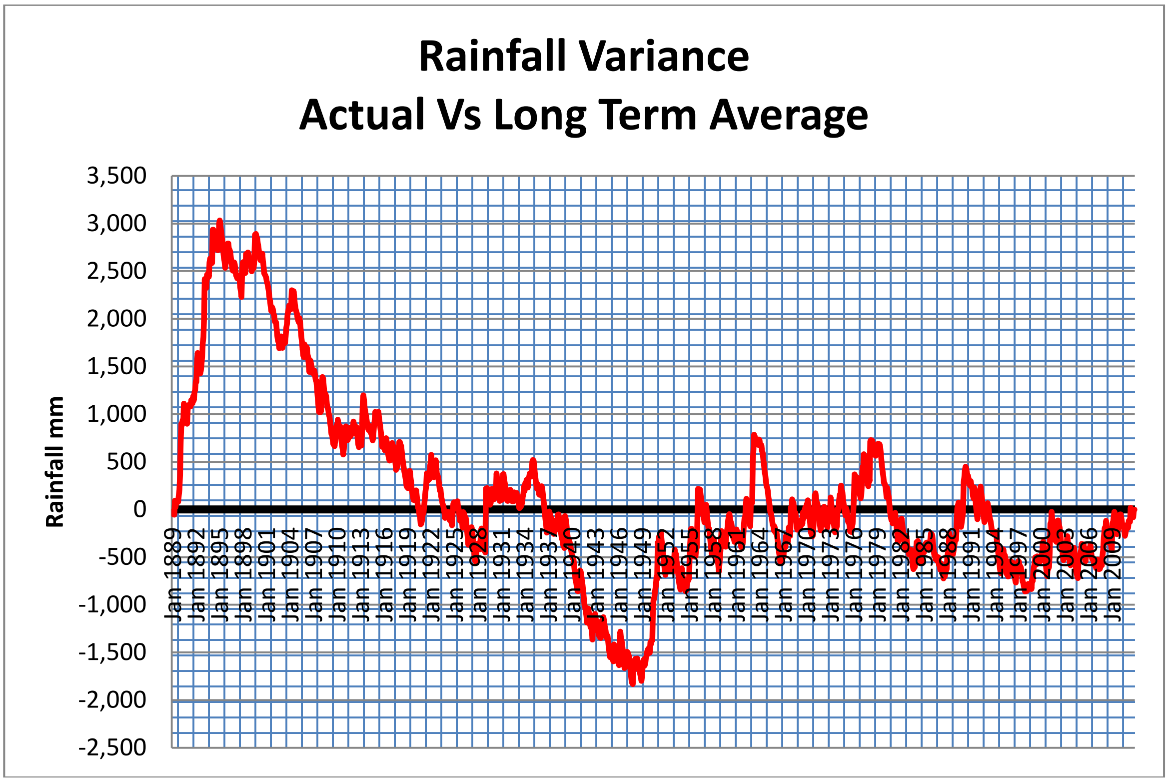


Figure 3: Rainfall data from 1889 to 2011.

It is clear that the rainfall record used by PB does not cover the quite substantial variations that have occurred since 1889. Therefore, it is reasonable to think that conclusions drawn by PB from the post-1976 records are not appropriate, even down to factual matters such as average annual rainfall.

3.3 Salinity

PB provide summary tables of groundwater chemistry testing from bores, dams and streams. There is a considerable amount of test data in the summary tables, an example being their Table 8-7 for Coal Seams Water, reproduced below.

Parsons Brinkerhoff Table 8-7 - Water Quality; Coal Seams

Parameters	Units	Range	Average
Field EC	µS/cm	**3,014-4,999**	**4,012**
Field pH	pH units	6.76-**11.13**	**8.69**
Major ions			
Calcium	mg/L	2-259	71
Magnesium	mg/L	6-68	34.5
Sodium	mg/L	653-734	693.4
Potassium	mg/L	11-36	15
Chloride	mg/L	678-1,060	867
Sulphate	mg/L	2-436	103
Total alkalinity as CaCO3	mg/L	274-711	481
Aluminium	mg/L	<0.01-**3.87**	**1.09**
Arsenic	mg/L	<0.001-0.004	0.002
Barium	mg/L	0.054-1.54	0.672
Beryllium	mg/L	<0.001	<0.001
Cadmium	mg/L	<0.0001-**0.0004**	0.0002
Copper	mg/L	<0.001-**0.004**	**0.002**
Lead	mg/L	<0.001-0.005	0.001
Manganese	mg/L	<0.001-0.64	0.22
Molybdenum	mg/L	<0.001-0.006	0.003
Nickel	mg/L	<0.001-0.157	0.034
Selenium	mg/L	<0.001	<0.001
Strontium	mg/L	0.125-6.01	2.82
Uranium	mg/L	<0.001-0.005	0.002
Vanadium	mg/L	<0.01	<0.01
Zinc	mg/L	0.006-**0.33**	**0.089**
Iron	mg/L	0.13-4.99	1.43
Bromine	mg/L	0.9-2.2	1.5
Nitrite as N		<0.01	<0.01
Nitrate as N		<0.01-0.01	<0.01
Ammonia as N	mg/L	**0.78-1.56**	**1.20**
Total Phosphorus as P	mg/L	0.03-**0.2**	**0.11**
Reactive Phosphorus as P	mg/L	0.02-**0.09**	**0.05**
Total Organic Carbon	mg/L	4-32	17
Methane	µg/L	655-39,500	21,931
Benzene	µg/L	<1	<1
Toluene	µg/L	<5-31	9
Ethyl Benzene	µg/L	<2	<2
m&p-Xylenes	µg/L	<2	<2
o-Xylenes	µg/L	<2	<2
C6-C9	µg/L	<20-80	<20
C10 -C14	µg/L	<50	<50
C15-C29	µg/L	<100-140	<100
C29-C36	µg/L	<50-100	<50

However, these summary tables do not include Total Dissolved Solids (**TDS**) which is a very important item of information as it is the proper measure of salinity, and which allows rapid calculation of quantity of salt in the produced water. We have extracted the measurements of TDS from the PB appendices and summarised them in Table 1 below.

Table 1
Summary of Total Dissolved Solids Data

MATERIAL	DEPTH	BOREHOLE & DATE	TDS mg/L
Clay	7-10	TMB01 7/4/2011	7530
Mixed Gravels	9-12	TMB02 7/4/2011	3520
Mixed Gravels and sand	5-11	TMB03 7/04/2011	5830
Siltstone	8-14	TMB04 13/04/2011	8300
Siltstone	8-9	TMB05 13/04/2011	8770
Mixed gravel\sand	5-8	WMB01 07/04/2011	2450
Sandstone	15-21	WMB02 07/04/2011	4960
Coal	32-34	WMB03 07/04/2011	4490
Sandstone	67-79	WMB04 07/04/2011	3690
Sandstone silt/stone	15-29	BMB01 07/04/2011	3870
Sandstone	124-136	BMB02 07/04/2011	3250
Mixed gravels	8-10	AMB01 08/04/2011	2340
Sandstone	42-48	RMB01 12/4/2011	11100
Sandstone	85-91	RMB02 12/04/2011	8380
Sandstone	58-64	S4MB01 06/04/2011	2890
Sandstone/siltstone	89-95	S4MB02 06/04/2011	2460
Coal	162-168	S4MB03 06/04/2011	3200
Sandstone/Siltstone	52-58	S5MB01 05/04/2011	6100
Siltstone	100-112	S5MB02 05/04/2011	4340
Coal/shale	158-164	S5MB03 05/04/2011	3770
Sandstone	175-181	TCMB02 13/05/2011	3200
Coal/sandstone	260-266	TCMB03 14/04/2011	3020
Coal	327.3-333.3	TCMB04 24/6/2011	3650
water		Tiedeman North 26/10/2010	4280
water		Tiedeman South 26/10/2010	2790
water		North Dam (Deep) 10/01/2011	4180
water		North Dam(shallow)10/01/2011	4240
water		South Dam(deep)10/01/2011	2610
water		South Dam(shallow) 10/06/2011	2650

For readers of a non-scientific bent, we point out that TDS measurements of 3,000mg/litre to 4,000mg/litre, which is typical of the water in the Gloucester coal seams, means 3 to 4 grams of salt per litre of water.

PB record (their Section 4.10.2) that some 50 million litres of 'produced' water is "currently stored on site". This must, therefore, contain about 150 to 200 tonne of salt.

Also, for every 1lit/sec of produced water from productive CSG wells there will be about 120 tonne of salt.

As stated in the March 2011 ‘Review of Environmental Factors’ for Proposed Exploration Wells, Waukivory, AGL Upstream, the options to deal with this salt are as set out in Table 2.1 of that report, reproduced below.

Table2.1	Disposal options for produced water	
Ranked Option	**Potential Environmental Impact**	**Likelihood**
1.Direct irrigation on to adjacent land	Managed/treated to minimise risk	Dependent on water quality. ECwillneedtobelessthan3,000µS/cm
2.Discharge to local waterway	Managed/treated to minimise risk	No ,as produced water is likely to be too saline
3.Treatment for irrigation	Managed/treated to minimise risk	This option is likely to be feasible only where the volume of water produced is significant and the produced water can be blended/treated for re-use
4.Aquifer re-injection	Potential groundwater contamination	Unlikely as this would require extensive investigations to minimise risk
5.Removal from site	Minimal	Likely where volumes are low, or to maintain sufficient capacity in the storage, and to dispose of water at completion of testing. Preference is for storage at a central facility with possible blending and irrigation re-use at a later date.

Based on the information obtained from previous exploration and production wells in the area it is envisaged that the produced water during the proposed exploration activities would require removal from the site for disposal (i.e. Option 5) due to the expected salinity levels.

There is no discussion in the PB as to the quantities of produced water expected from the full production CSG field; therefore calculations cannot be made of likely quantities of salt.

3.4 Extent of Investigations and Number of Permeability Measurements

Figure 4 shows the total project area; Figure 5 shows the Stage 1 project area, and Figure 6 shows the areas that have been investigated.

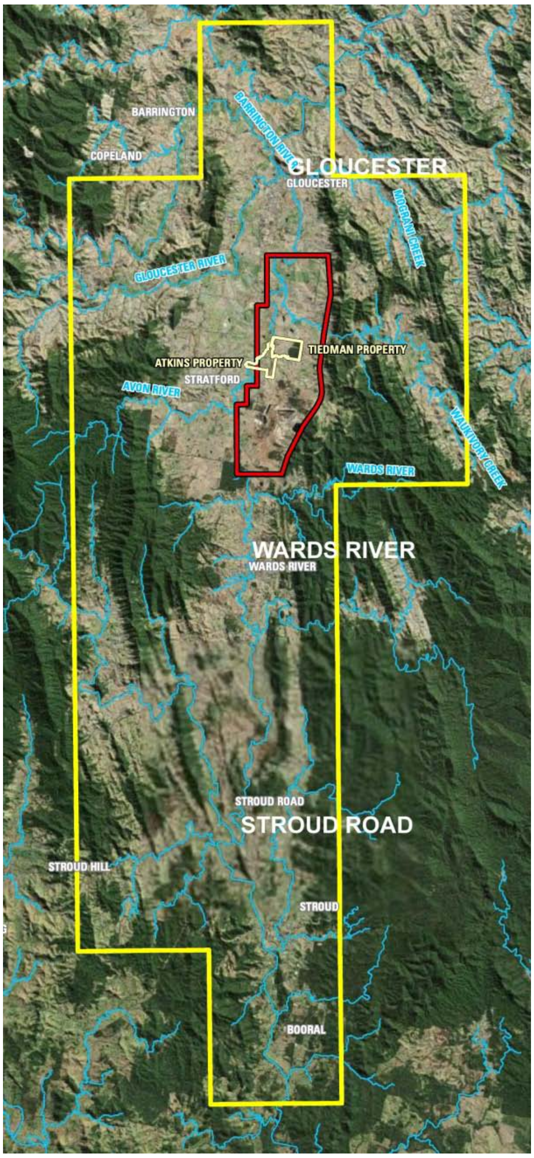


Figure 4: Total project area.

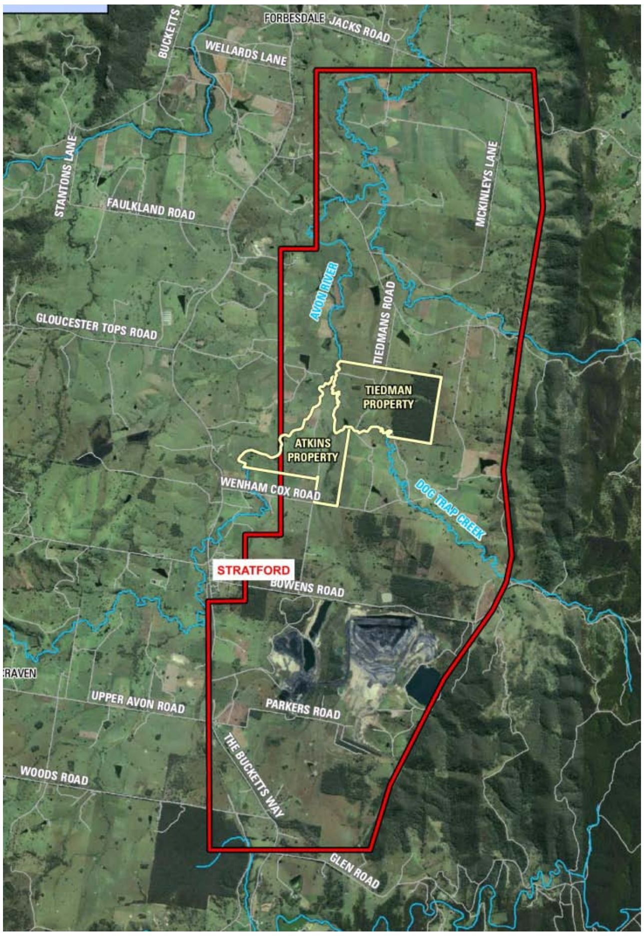


Figure 5: Stage 1 project area.

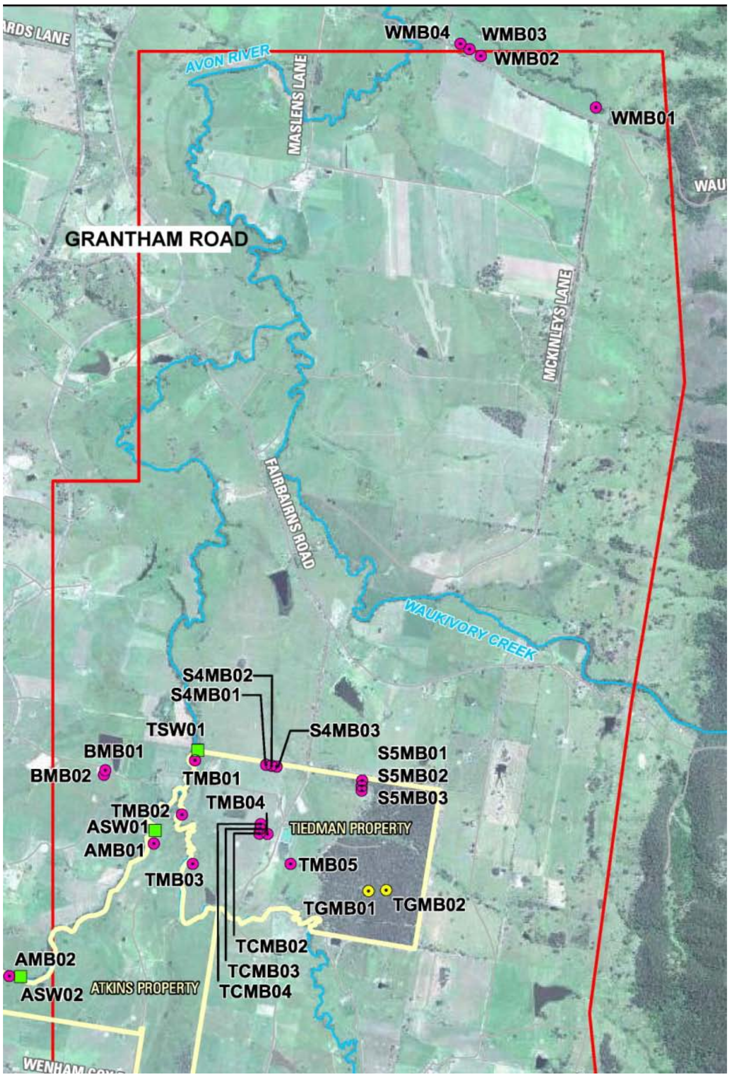


Figure 6: Investigation areas.

The following calculations are instructive:

- Stage 1 area, as a percentage of the Total project area = 3.6%
- The investigated area as a percentage of Stage 1 = 7.0%
- The investigated area as a percentage of Total = 0.25%

Within the investigated area there have been 20 permeability tests in the Permian strata, covering a depth down to 310m, of which 6 cover the 20 coal seams in the sequence.

To say that there is a small data sample, of one of the key parameters governing groundwater flow, is an understatement. The consequences of this are best described in a recent book by Kahneman[2] in respect to small data samples, namely:

> *"The strong bias toward believing that small samples closely resemble the population from which they are drawn is also part of a larger story: we are prone to exaggerate the consistency and coherence of what we see. The exaggerated faith of researchers in what can be learned from a few observations is closely related to the 'halo effect'; the sense we often get that we know and understand a person about whom we actually know very little".*

And in case the reader questions Kahneman's status to evaluate the mistakes made from small samples, it is noted that he won a 2002 Nobel Prize for his work.

A statistician would calculate that the data base discussed above, is inadequate for conclusions to be drawn about the whole ground volume of the Stage 1 project.

3.5 Duration

PB have properly implemented a program of monitoring of groundwater levels, river flows and chemical measurements. The monitoring records extend from January 2011 onwards. This, would not be an issue if Parsons Brinkerhoff had chosen not to reach quite wide ranging and important conclusions on the basis of those records.

The same statistician would calculate that 11 months of record of groundwater and surface water pressures, flows and chemistry, is not a proper basis for assessing climatically controlled trends wherein, historically, there have been variations substantially outside the 11 month monitoring period.

4. ASSESSMENT OF MATTERS OF INTERPRETATION

4.1 Hydrogeological Model

4.1.1 Geology and the Parsons Brinkerhoff Interpretations

The Gloucester Basin (technically the Stroud Gloucester Syncline) is about 55 km long with a width of 24km at its widest point (see Figures 7 and 8). <u>The syncline is a fault-bounded trough; the structure is complex</u>. These are not our words but those of Geological Survey of NSW[3].

[2] Kahneman, Daniel (2011) "*Thinking Fast and Slow*", Allen Lane, London.
[3] NSW Geological Survey, Geology of the Camberwell, Dungong and Bulahdelah 1:100 000 Sheets, 1991.

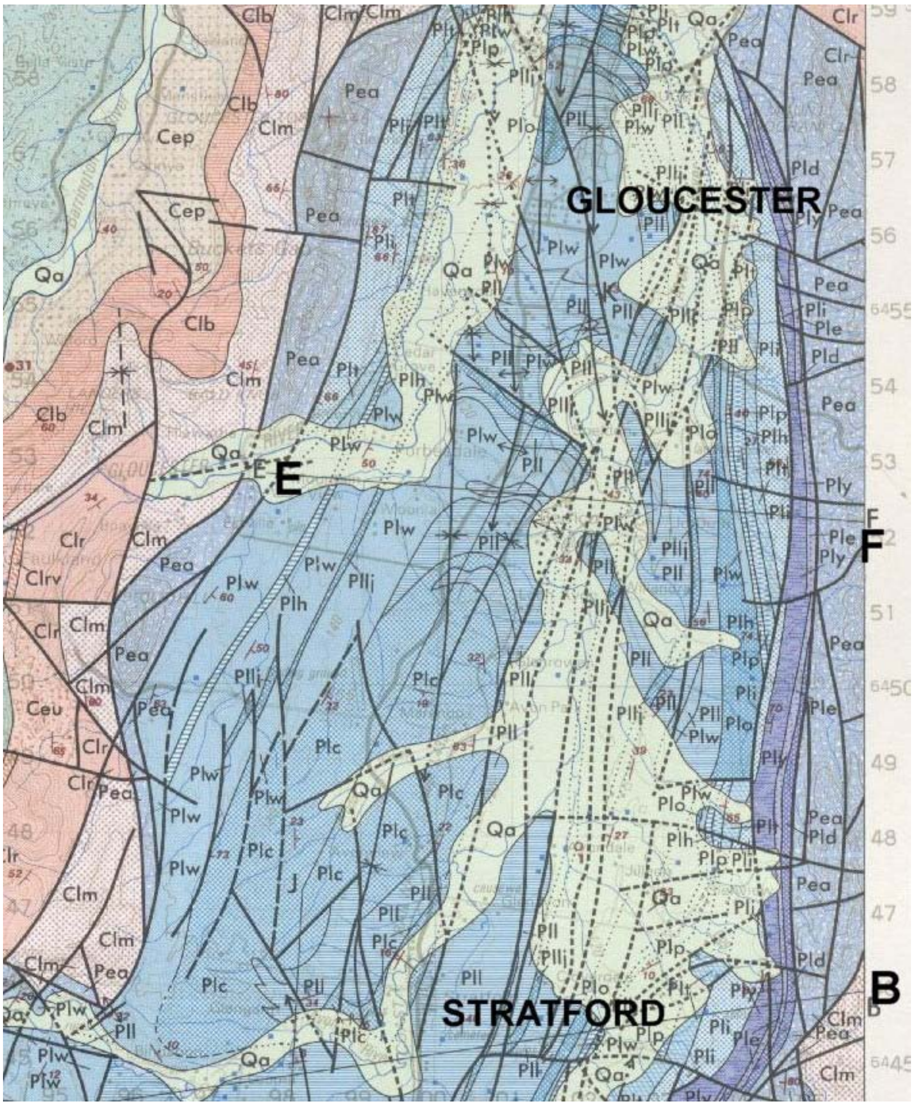


Figure 7: Gloucester Basin, 1991.

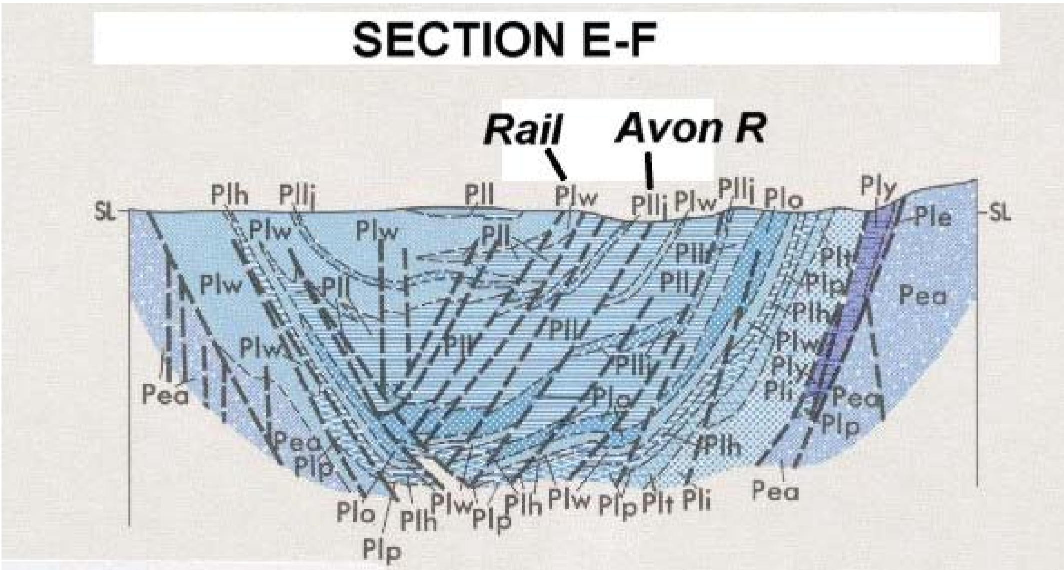


Figure 8: Section E-F, 1991.

The trough was formed during major crustal deformations about 270 million years ago (see Figure 9).

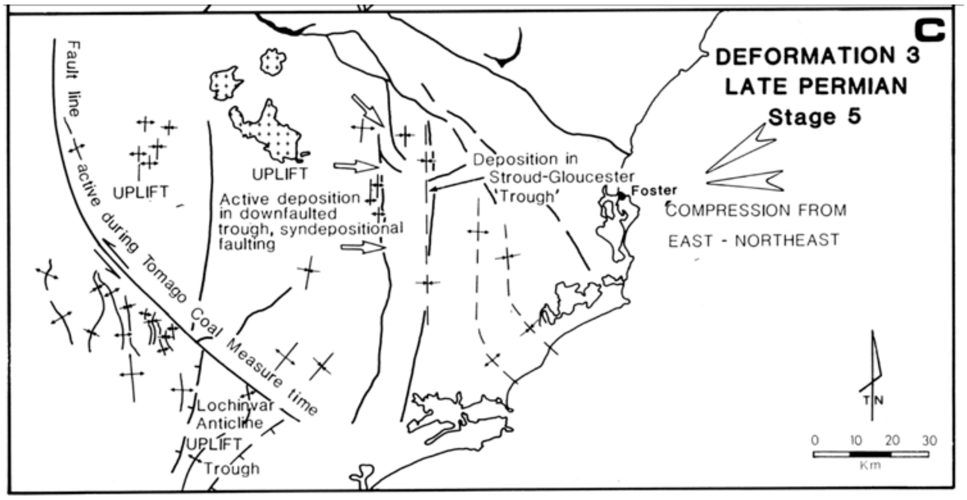
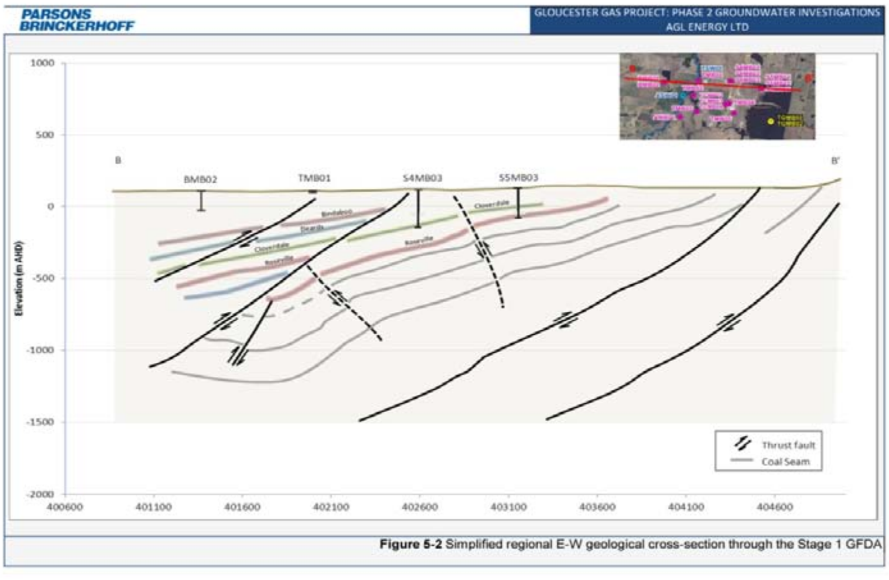


Figure 9: Tectonics during Stroud-Gloucester Trough deposition.

Coal seams in the trough are characterised by a considerable degree of lateral splitting, only 6 of the 20 or more seams can be correlated across the syncline. Faulting and folding have significantly reduced the potential for development of these resources.

As is normal practice, and necessary for groundwater calculations, PB have had to simplify the geological reality into a model. Their interpreted model is given in their Figure 5.2, reproduced below.



PB

Parsons Brinkerhoff Figure 5-2: East West geological model.

To put this into geometric context we have overlain their model on the published geological cross-section, having stretched the latter to remove the 3 to 1 vertical exaggeration (see Figure 10).

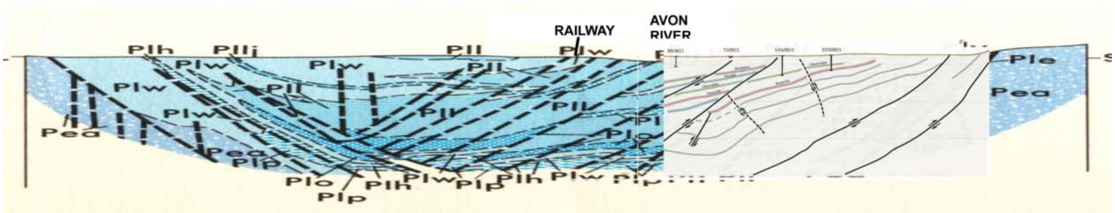
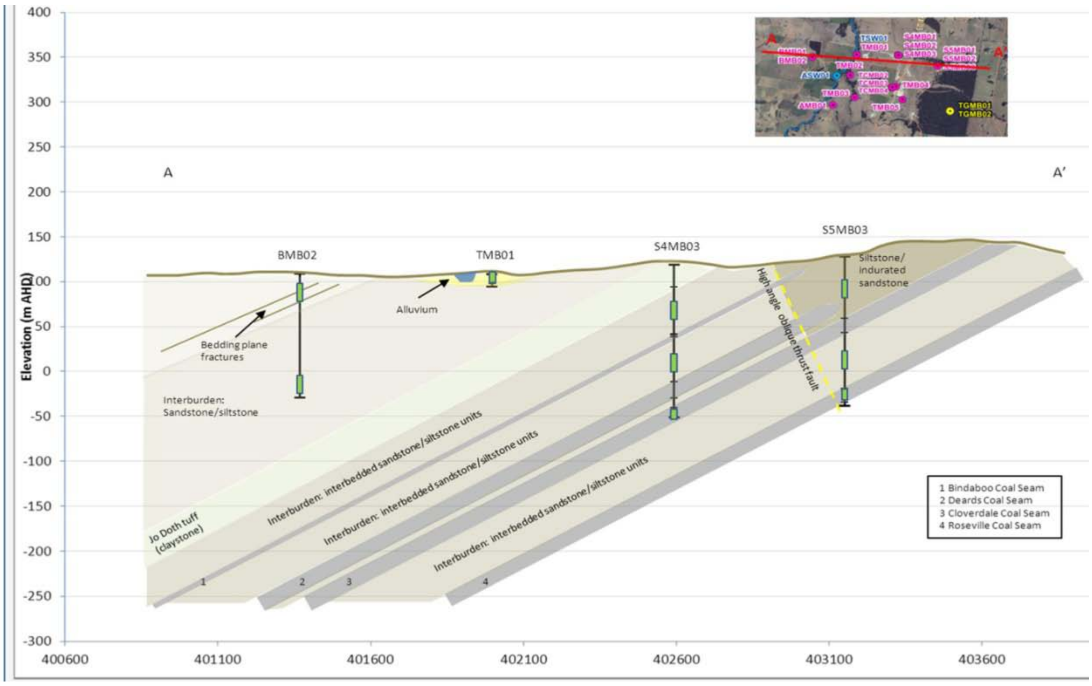


Figure 10: PB geological model superimposed approximately on Geological Survey Section E-F.

For consideration of groundwater behaviour PB have further interpreted and simplified their model to that shown in their Figures 5.3, reproduced below.



Parsons Brinkerhoff Figure 5.3: Hydrogeological Model

PB give a further version of this model in their Figure 10.2 which gives their interpretation as the how the groundwater system functions. No calculations are given to justify their interpretations.

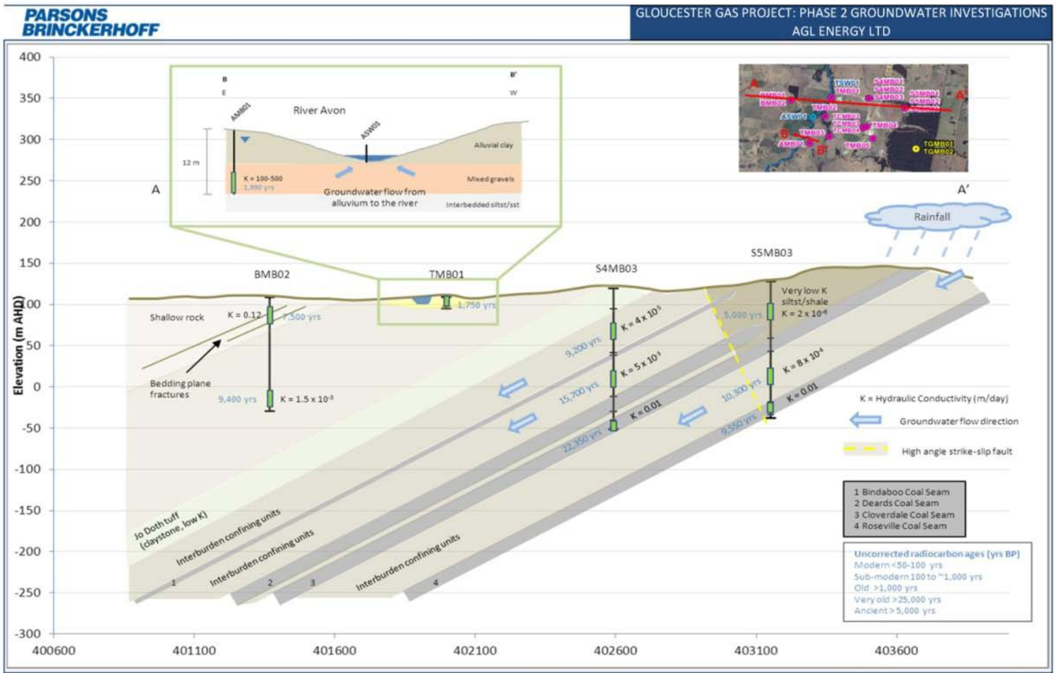


Figure 10-2 Conceptual cross-section through the Tiedman property (W-E)

Parsons Brinkerhoff Figure 10.2: Interpreted functioning of the hydrogeological model

We note the following:

- the totality of the syncline is not included,
- the complex geology is reduced to a straight line stratigraphy with four continuous coal seams,
- there are no faults, and
- the complex stratigraphy is reduced to only four units, as set out in their Table 6.4, reproduced below.

Parsons Brinkerhoff Table 6.4 : Hydrogeological Units

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Semi-confined, clay capped, porous, granular	Quaternary alluvium	0.3-500
Shallow rock units	Confined/ unconfined	Gloucester Coal Measures	0.01-20
Coal seam water bearing zones	Confined	Coal seams of the Gloucester Coal Measures	0.002-0.03 (1.82 lab*)
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures	4 x 10e-5 to 0.006

4.1.2 Assessment of hydrogeological model

We accept, fully, that a simplified model is a necessity for the performance of groundwater computations that provide guidelines as to how the real world will behave. However, it is considered that the model that has been developed is inadequate and inappropriate because:

1. The complexity of the stratigraphy and the paucity of field permeability data (20 measurements) does not warrant the simplification into only four units, where all interburden is given very low mass permeability, in the range $7x10^{8}$m/sec to $4.6x10^{-10}$ m/sec.

2. Adopting a model that encompasses about 1/3 of a synclinal basin means that it will be very difficult in any computer analyses to develop appropriate boundary conditions. If such analyses assume an axis of symmetry on the left side of the model then it implies that the western 2/3 of the basin is a mirror image of the model. As can be seen from Figures 8 and 10, this is not reasonable, because the syncline is not symmetrical and the PB model covers less than a third of the cross-section.

3. Concluding that faults play no role in groundwater movement, and do not even displace the stratigraphic units in the model, is contrary to almost all experience in hydrogeology and groundwater engineering.

4. The model includes no information about porosity (storativity) parameters of these units, and no information on compressibility parameters (stiffness). Without these parameters it is impossible to perform transient (time-based) analyses, and therefore impossible to estimate how long it will take for pressure changes to transmit through the groundwater system.

4.2 Interaction in the groundwater system

4.2.1 Aquifers and Interpretation from Piezometers

The PB report refers to aquifer interactions

The term 'aquifer' is potentially confusing because the word is used for a zone that yields a significant amount of water.[4]. The deep Permian strata in the Gloucester Basin are typically of low permeability and are not known to yield economic quantities of groundwater.

But it is not quantity of groundwater that is the key issue in respect to CSG extraction, it is depressurisation that may affect near-surface groundwater and surface water systems.

The terms 'connected' or 'disconnected' are used to define groundwater systems which are perceived to yield different quantities or qualities of groundwater. The declaration that an aquifer is 'disconnected' provides an inference that disturbances made to that aquifer will not, in any way, affect adjacent aquifers.

While the terms 'aquifer', 'connected' and 'disconnected' can sometimes aid communication, zones and layers of rock of different permeability, storage and chemical properties interact as a continuum. The interactions may be quite fast, or very slow; but they will occur and the real question we must address is: How long will it take for man-induced changes to work their way through a groundwater system?

A corollary to the above point is that measurements made of different pressure heads at different levels in a single borehole do not necessarily indicate separate groundwater systems. This may be difficult for the lay person to understand, but it is shown by an example of flow through uniform sand, given to undergraduate students and reproduced in Figure 10.

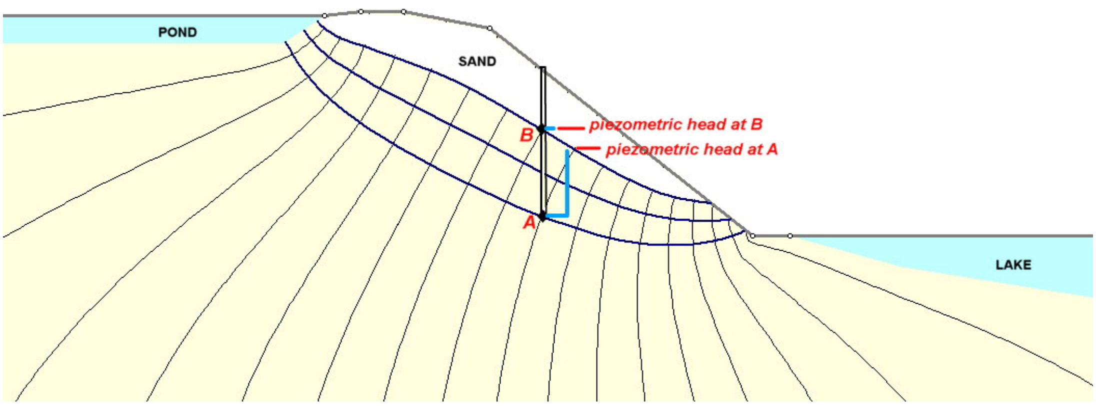


Figure 10: Flow through uniform sand giving rise to different piezometric heads.

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[4] The PB report includes the following definition:

> *Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.*

In this example we have simple seepage through uniform, homogenous, sand. Piezometers at different levels in the monitoring borehole show different levels. Such difference in levels does not mean that the measurements prove disconnected groundwater systems. It only means that seepage is not horizontal. PB use the measured difference in head by piezometers at different depths to conclude that the postulated aquifers in their model are ‘disconnected’.

4.2.2 The Crux of the Parsons Brinkerhoff Argument

The data collected by PB indicate that:

i. Groundwater at depth in the Permian rocks and coal seams is of a different chemistry and typically more saline than the groundwater near the surface.

ii. Groundwater at depth in the Permian rocks is older (thousands of years) than groundwater near the surface (a few hundred years).

We accept both these findings as true of the Stage 1 area, and probably true of the whole Gloucester Basin. However, the interpretations made by PB, and AGL, from these facts are not valid.

PB interpret as follows (their Sections 10.4 and 10.5).

- “Water salinity in the coal seam water bearing zones is brackish to slightly saline and chemical composition ranges from Na-Cl type water in the Cloverdale Seam to Na-Cl-HCO_3 in the Roseville Seam. Strontium and barium concentrations are elevated, with slightly elevated concentrations of other trace metals including aluminium, cadmium, copper, nickel and zinc. Dissolved methane concentrations are elevated in the Roseville and Cloverdale coal seams. These water attributes are typical of groundwater that has been in residence for long periods within the Permian coal seams.”

- “The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying the coal seams. 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.

  Stable isotopes ($_{18}O$ and $_{2}H$) indicate water within these interburden units is of meteoric origin, and radiocarbon data indicates water is thousands to tens of thousands of years old.”

In essence what PB are interpreting is that because the water at depth is older, and of different chemistry, it must represent aquifers that are separated from one another. So by inference, extracting water from the deep “aquifers” will not affect the near surface “aquifers” and the surface waters, which PB acknowledge are fed by the near surface aquifers.

AGL encapsulates this in the Community Bulletin of 1 February 2012, wherein they state:

- “Most importantly this investigation has shown that there is no evidence of natural connectivity between shallow and deep groundwater systems.”

It is accepted that salinity increases, and groundwater chemistry, changes occur as one gets deeper in the Gloucester Basin. These chemistry changes are probably due to multiple marine incursions when the Permian strata were deposited (see PB Table 3-2). The deeper water is also older, as is normally the case, and represents slow movement due to low hydraulic gradients and low permeabilities.

However, let us examine a conceptual basin (big bathtub) filled with uniform permeability sand, as shown in Figure 11.

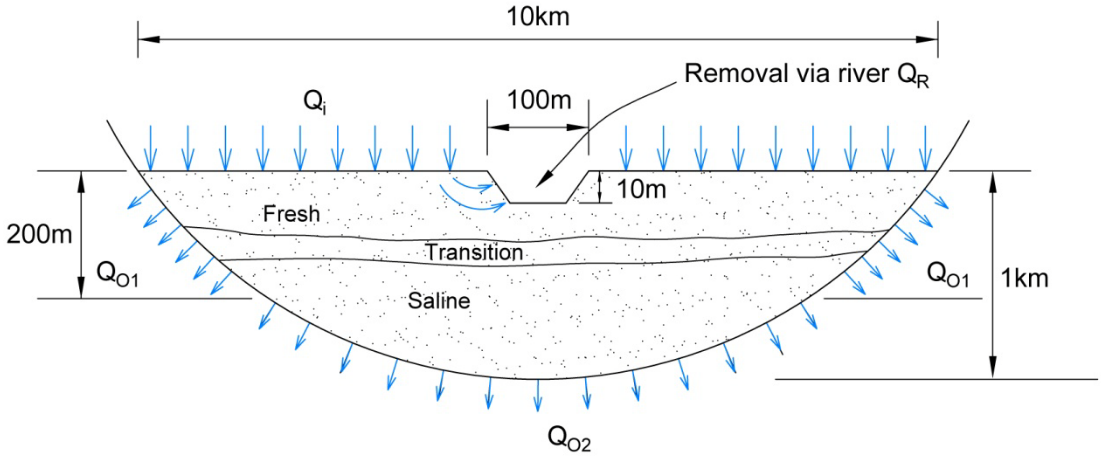


Figure 11: Simple model of a leaking basin filled with uniform sand and with initially stratified groundwater.

In this model we have, as a starting point, saline groundwater at the base, because it is more dense than fresh water, a transition zone, and fresh water near the surface. We have rainfall recharge, a river that gains water from the fresh groundwater, and we have losses from the basin through the base and sides. So in some ways it is like the Gloucester Basin.

The question is: What happens with the passage of time? The answer is, very little; the basal water remains saline and the upper remains fresh.

To demonstrate this we ran a finite element analysis of the simple model, using transient analysis, contaminant (salt) transport and saline diffusion.

The initial conditions are as per Figure 12, with salinity in the lower water being as measured by PB, namely about, 3,000 mg/litre TDS.

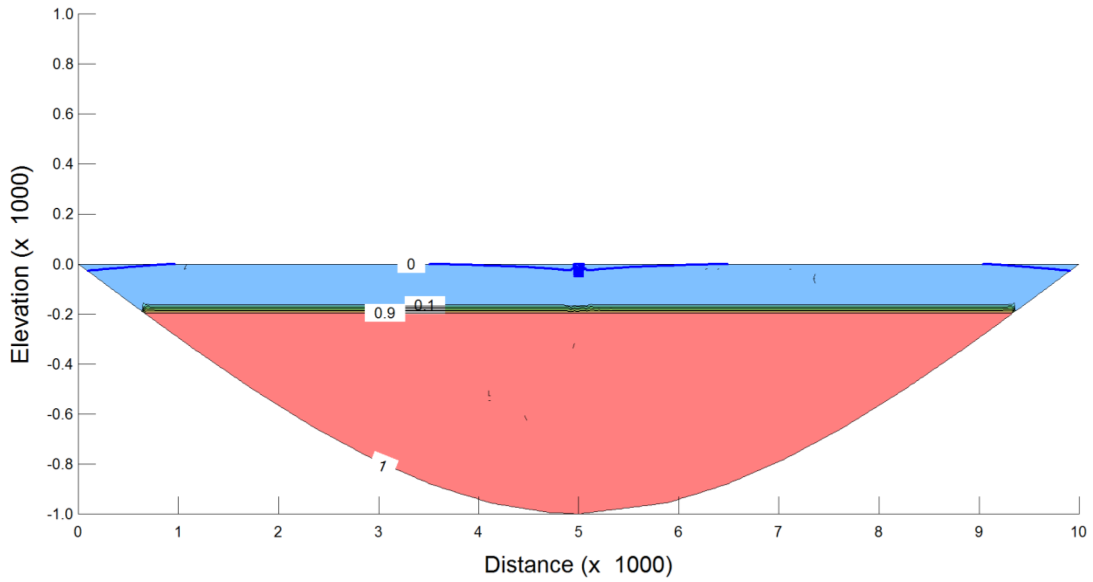


Figure 12: Initial conditions in transient, contaminant transport, seepage model. A salinity concentration of 1.0 is equal to 3,000 mg/litre.

If all the water were fresh, the seepage paths and equipotentials would be as per Figure 13.

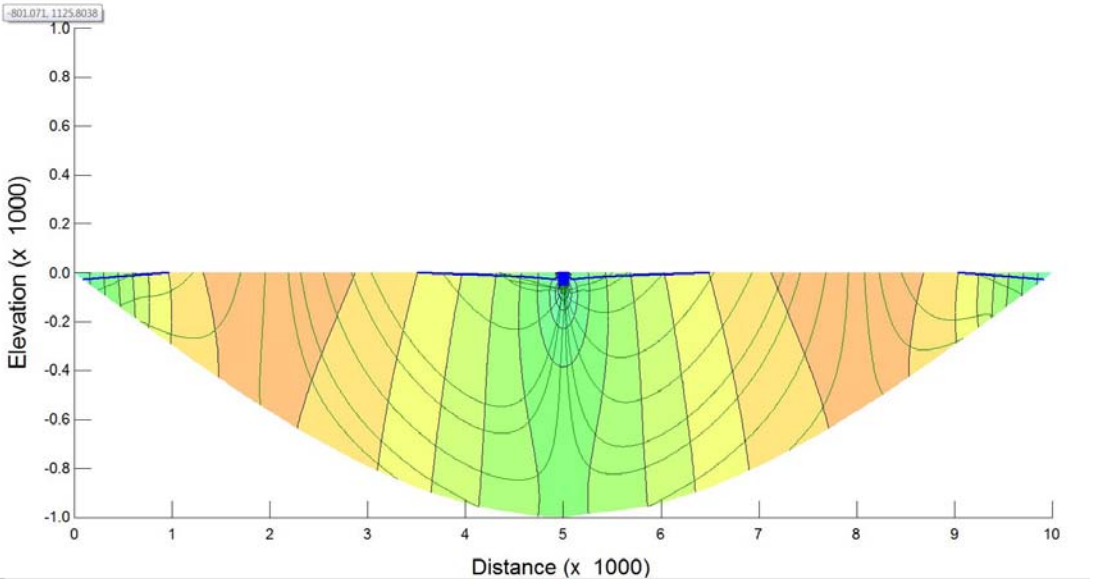


Figure 13: Flow lines and equipotentials if only fresh water in the basin.

However, with initial saline and fresh zones, the groundwater regime after 1,000 years is as per Figure 14.

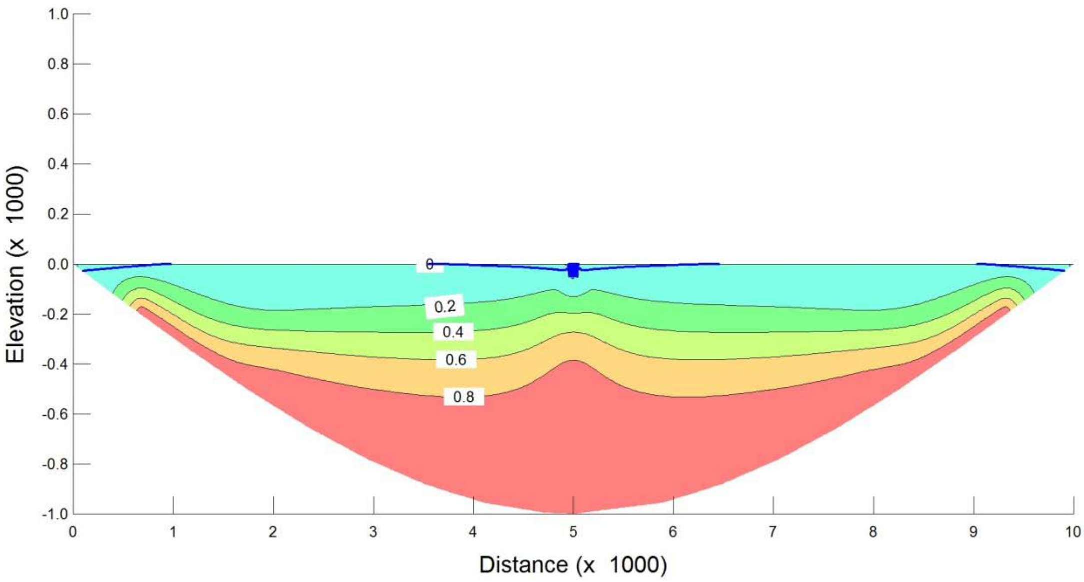


Figure 14: Salinity concentration levels after 1,000 years.

The conclusion is that the presence of older, saline groundwater at depth does not show that there are distinct, separated aquifers.

An even simpler illustration of the above point comes from studies of stratified lakes, wherein there is imperceptibly slow water movement[5]. There are no "aquifers" to consider.

As an example, Lake Powell in British Columbia, is 50km long, 2km wide with a maximum depth of 358m. Flow occurs into an upper basin, separated from the lower by two shallow straits. The lower basin is free of influx at depth, and contains saline water beneath 275m of freshwater. It has been like that for at least 10,000 years.

4.3 Behaviour of the PB groundwater model

We have discussed, in Section 4.1.1, limitations of the groundwater model proposed by Parsons Brinkerhoff. They provide no calculations based on this model, but do make interpretations and draw conclusions, including:

> "This deep groundwater is derived from rainfall in the outcrop areas and lateral groundwater flow is most likely directed toward the centre of the basin. 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 upward flows or discharge areas at this time.
>
> The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying the coal seams. 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."

---

[5] Toth, D.J and Lerman, A. "*Stratified lake and oceanic brines: Salt movement a time limit of existence".*

Limnology and Oceanography,
Vol 20 No.5 September 1975

In order to understand what the PB model would indicate arising from depressurisation of groundwater at coal seam level we have incorporated the model given in their Figure 10-2, into a 2D transient finite element analysis. We have set out to match the boundary conditions in the computer analysis to that indicated verbally in the PB report.

We realise that the following material will be difficult for the lay reader. However, do not despair, as we give a simple explanation at the end.

We have undertaken analyses assuming constant permeability, and also permeability that decreases by up to an order of magnitude as desaturation occurs.

Figure 15 shows steady state flow lines and equipotentials with no depressurisation by CSG extraction. The model indicates near hydrostatic conditions away from the interburden unit immediately above the Deards Coal Seam (see PB Figure 10-2 reproduced in Section 4.1.1 and again, for convenience, below), for which PB assign permeability 100 times higher than for the unit above the Bindaboo seam.

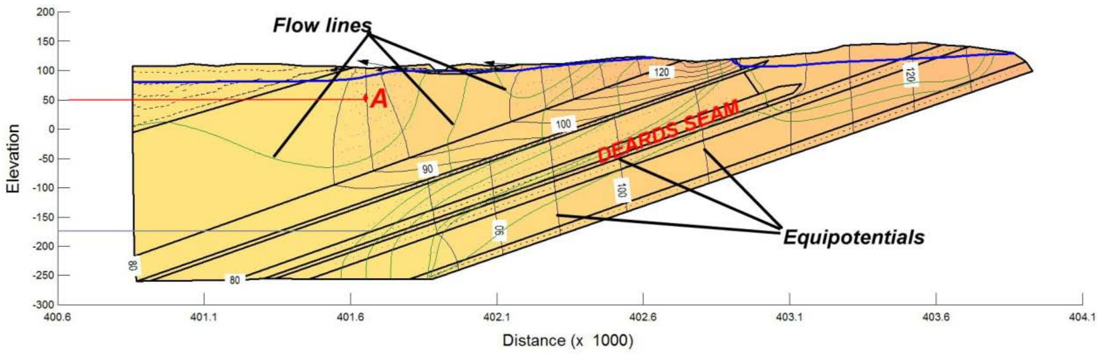
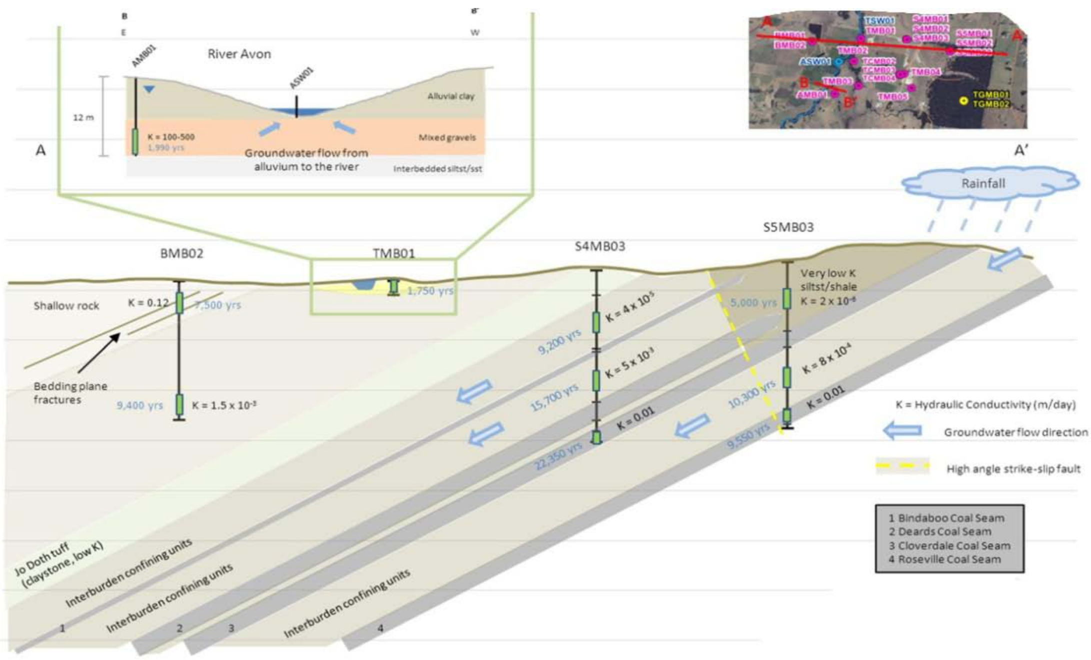


Figure 15: Numerical analysis of PB model – computed steady state pre-CSG extraction.



Parsons Brinkerhoff Figure 10-2

We then depressurised only the Deards Coal Seam, and calculated the changes in the groundwater regime after 6 months, 1 year, 2 years, 5 years, 10 years, 20 years, 50 years and 100 years. The analyses that include decrease in permeability with desaturation shows slower transmission of the effects of CSG depressurisation, and we give those results here.

Figure 16 shows the situation after 2 years, Figure 17 after 10 years and Figure 18 after 20 years.

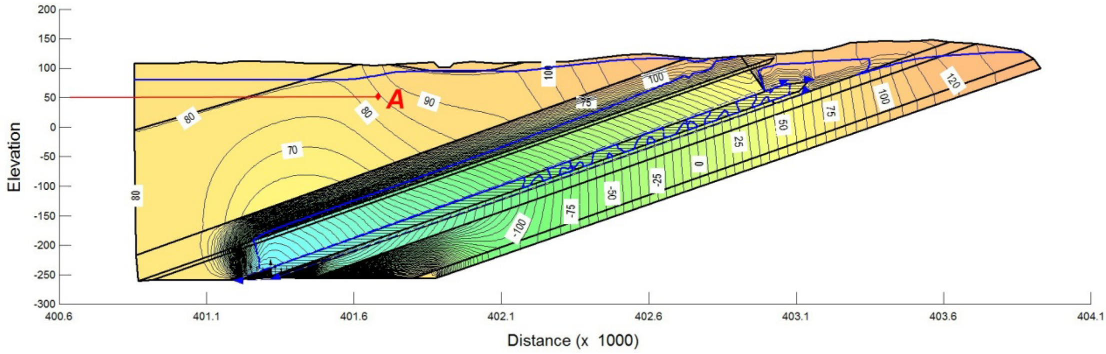


Figure 16: Equipotentials 2 years after CSG depressurisation in Deards Seam only.

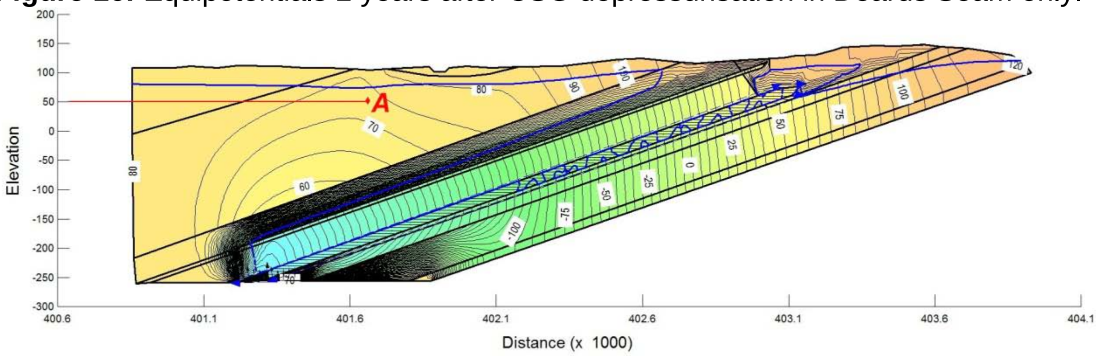


Figure 18: Equipotentials 10 years after CSG depressurisation in Deards Seam only.

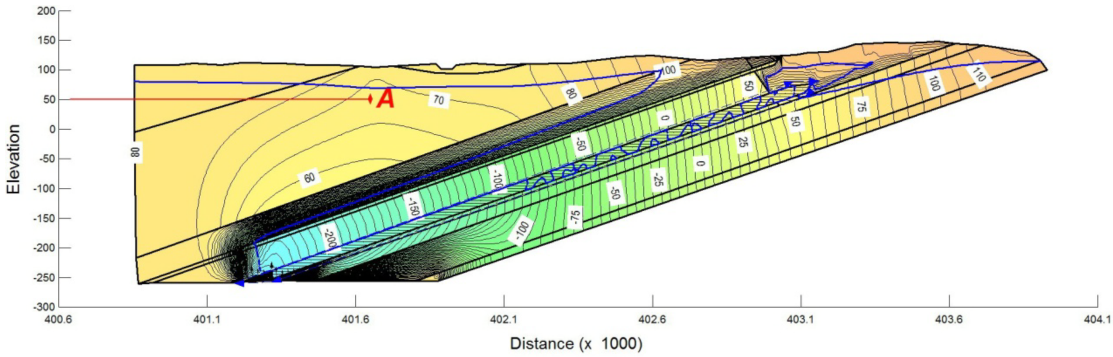


Figure 17: Equipotentials 20 years after CSG depressurisation in Deards Seam only.

What Figures 16 to 17 show is that, a reasonable numerical analysis using the PB model, gives that depressurisation occurs within less than 50m of the surface by the end of the first year, particularly near coal subcrop areas. Even at Point A in Figure 15, which is 225m above Deards Seam and on the west side of the Avon River, the computed depressurisation is as follows:

Pre-CSG depressurisation	90m head
After 1 year	85m head
After 10 years	73m head
After 20 years	68m head

As already stated, we think the PB model is inappropriate, so we do not claim the calculations given above to be an accurate representation of reality. What they do show is that the interpretations made by PB, and the conclusions reached by PB and AGL appear not to be supported by their own data and their own groundwater model.

5. SOME CONCLUDING COMMENTS

In Community Update of 1 February 2012, AGL describe the PB Phase 2 report “a comprehensive groundwater investigation”, and go on to say that “the investigation has shown that there is no evidence of natural connectivity between shallow and deep groundwater system”.

The PB report includes much valuable information and represents a large amount of detailed site investigation work. However, we think that the analyses given in this review demonstrates that it is not a comprehensive groundwater investigation.

The interpretations in the report are flawed and it does not demonstrate that depressurisation at coal seam levels will not cause alteration to the directions of flow and the pressure system in the near surface groundwater regime, hence affecting surface waters.

The database in the report is inadequate for the Stage 1 project, covering less than 7% of that project area, and is trivial in respect to the full project.

The monitoring period is too short to allow conclusions to be reached about the natural environment and provides no monitoring data relevant to groundwater behaviour under CSG Stage 1 extraction.

The report gives no information as to the extent of the CSG extraction network, the depressurisations at coal seam levels of such extraction, the likely quantities of extracted water, and the disposal of such water. The report provides no calculations of any kind in respect to changes in groundwater flows, pressures and extraction water.

The report gives inadequate attention to the interaction of near surface groundwater and surface waters. It, also, does not provide a hydrological study of droughts, floods and the possible impacts thereof on gas wells, surface storages and ‘produced’ water disposal systems.

PHILIP PELLS

APPENDIX A

CONDENSED FACTUAL INFORMATION FROM THE PHASE 2 REPORT

APPENDIX A

CONDENSED FACTUAL INFORMATION FROM THE PHASE 2 REPORT

(Note: Words which have been italicised are the words of Pells Consulting, all other words have been cut and pasted directly from the PB Report. There has been no attempt to alter the intent of statements in the PB report by the selective culling process).

1.0 PREVIOUS WORK

1.1 Previous CSG pilot/flow testing programs

Nine gas wells were flow tested as part of the Stratford pilot testing program between 2006 and December 2009. All wells apart from Stratford 1 were fracture stimulated. There are multiple perforations in each of the gas production wells, sometimes over vertical distances of more than 200m.

At Stratford, the water quality data is complicated by there being multiple perforated intervals in each of the completed gas wells. Given there are uncertain water contributions from individual coal seams, and these zones extend over 200 m vertical distances in some wells, there were complexities in the observed water quality trends.

There was no dedicated monitoring bore network in place at the time of the testing program so there is no confirmation that water levels in shallower aquifers did not react to pumping.

1.2 Previous water sampling programs

The most recent sampling of deep coal seam gas water quality was in October 2010 when water samples were obtained from the Stratford 1, Stratford 3, and Craven 6 gas production wells. No heavy metals, nutrients or isotope water samples were submitted for analysis.

The water quality characteristics of these deep coal seams (generally from below 350m) are:

- Water salinity is brackish to slightly salty
- The water type is sodium-bicarbonate-chloride dominant
- There are no TPH/BTEX compounds present.

2.0 SITE LOCATION

The site is shown in the Parsons Brinkerhoff Figure 3-1 reproduced below.

The Stage 1 GFDA represents approximately 25% of the surface area of the Gloucester Basin.

The Stage 1 GFDA is located within the Avon River catchment, a sub-catchment of the Manning River catchment.

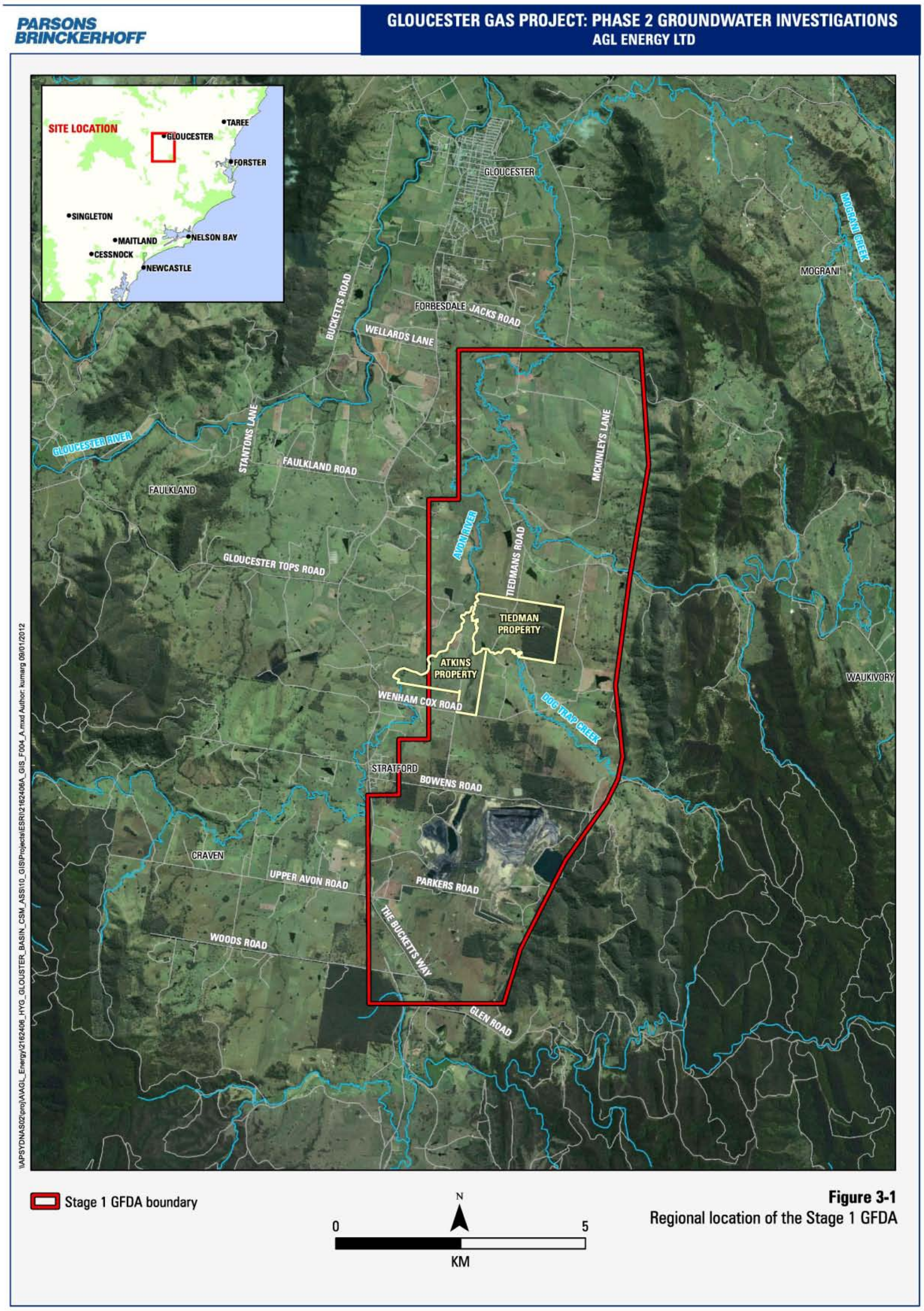


Figure 3-1
Regional location of the Stage 1 GFDA

3.0 *GENERALLY AVAILABLE INFORMATION*

3.1 Rainfall Records

Continuous rainfall data from the Gloucester Hiawatha Station (60112) is available from 1976 and is used in the Phase 2 report. (*This is despite the existence of far longer records from other stations, particularly the one at Gloucester – see Figure A).*

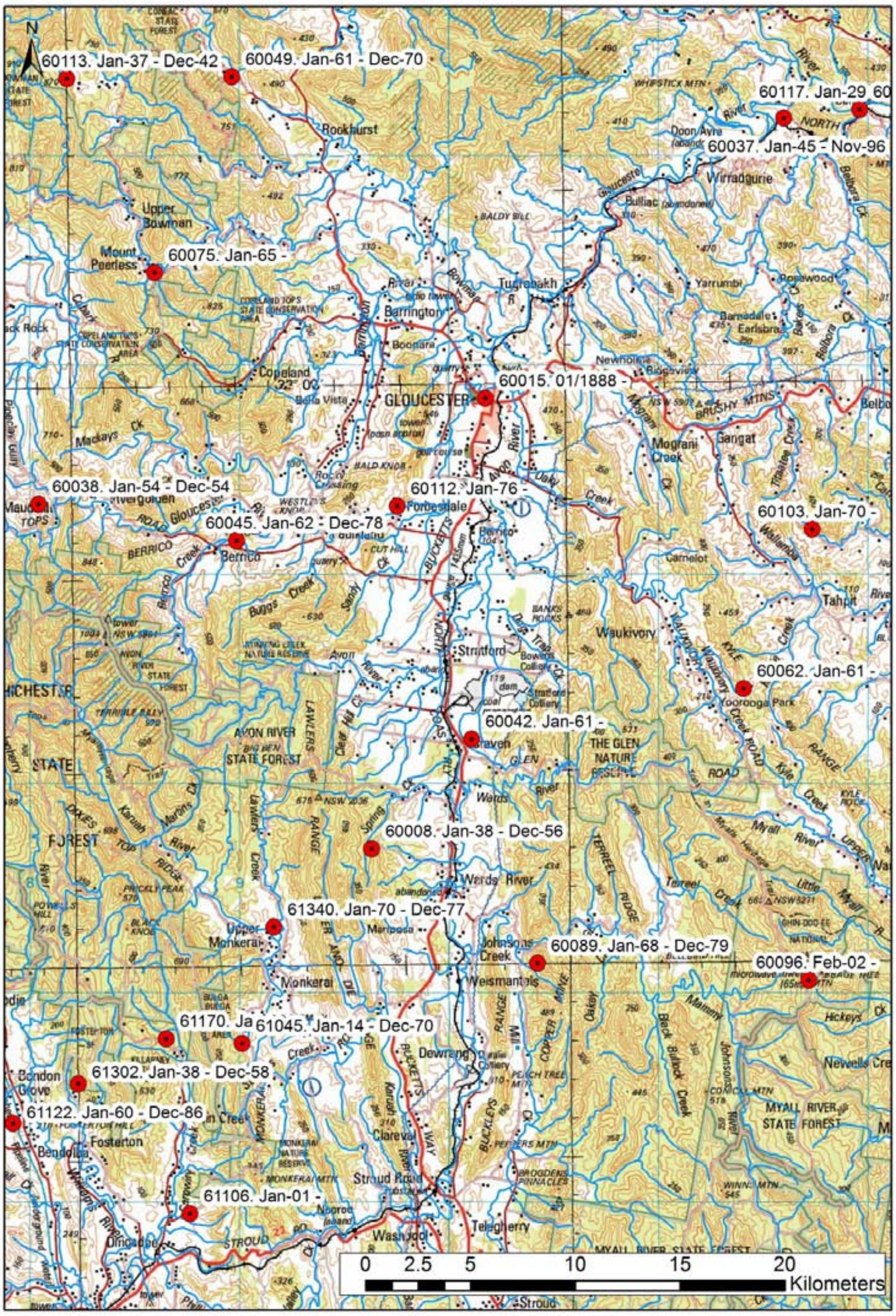


Figure A : Available rainfall gauging stations and length of record

3.2 Regional Geology

The Gloucester Basin represents a complex geological system formed by the interplay of extensional tectonic faulting and high rates of sediment supply (see Figure B).

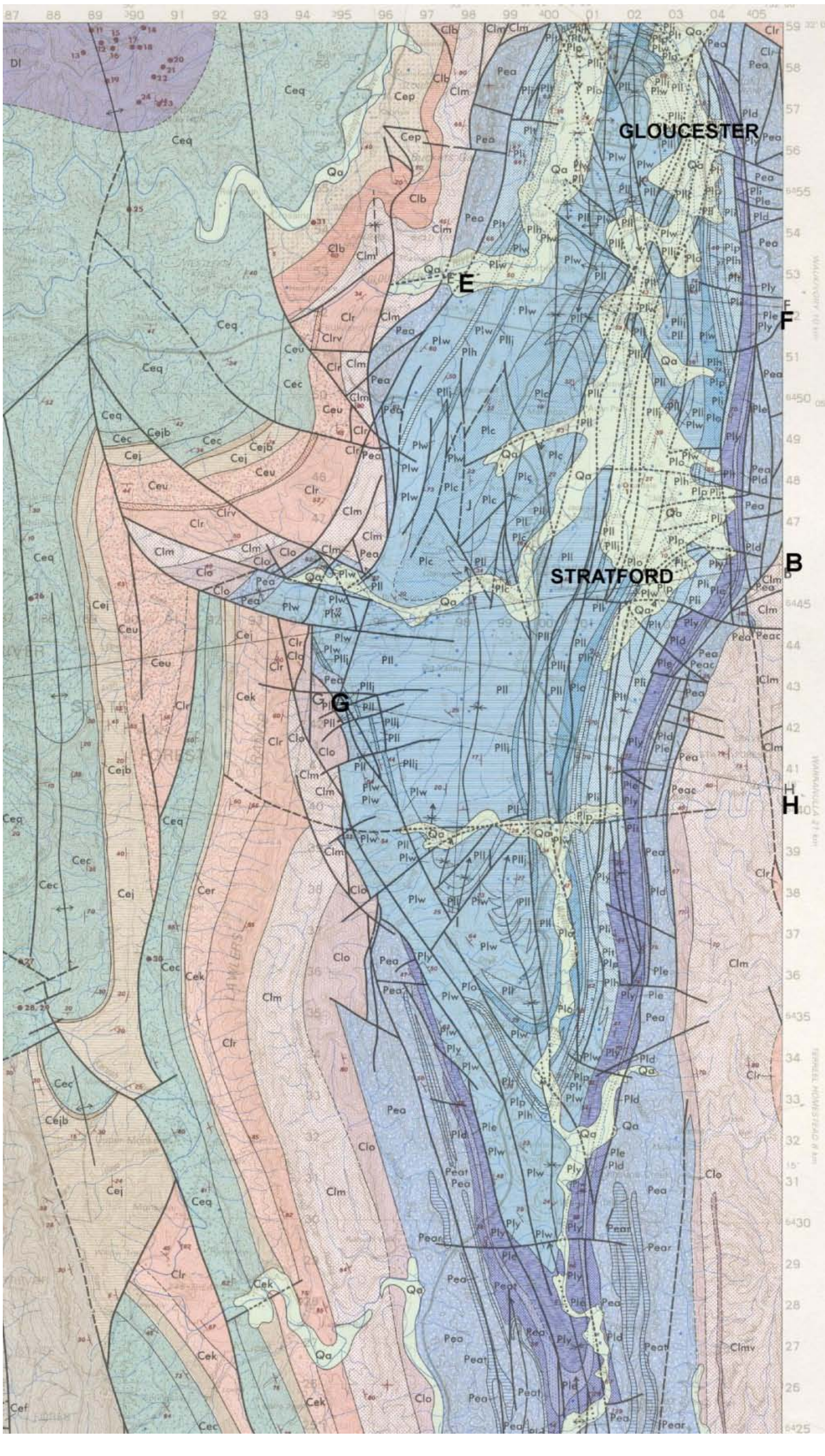


Figure B Published geological plan of Gloucester basin (*not given in the Phase 2 report)*

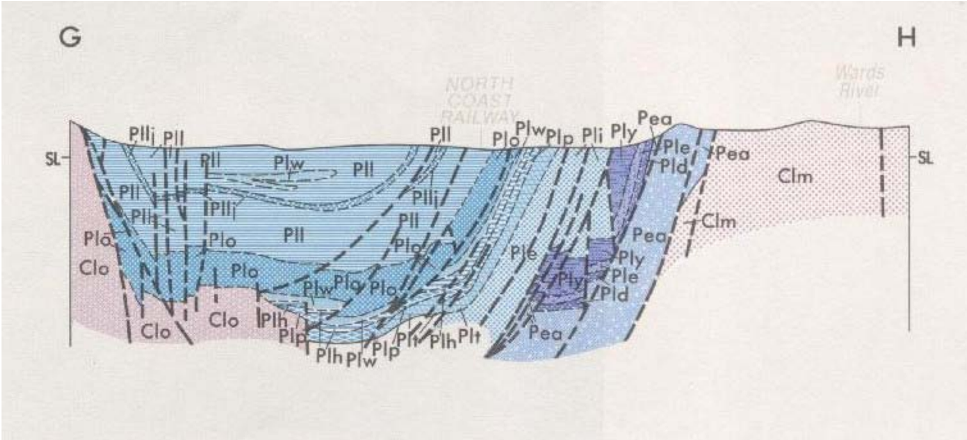


Figure C Section G-H (not given in the Phase 2 report)

(The following table summarises the formations and lists the named coal seams).

Formation	Approx thickness	Coal seam
Crowthers Road Conglomerate	350m	
Leloma Sandstone and siltstone	585m	*Linden*
		JD
		Bindaboo
		Deards
Jilleon	175m	*Cloverdale*
		Roseville
		Tereel/Fairbairns
Wards River Conglomerate	Variable	
Wenham Sandstone	24m	*Bowens Road*
		Bowens Road
Speldon Formation Sandstone mudstone, conglomerate		
Dog Trap Creek Shale, siltstone, sandstone	126m	*Glenview*
Waukivory Creek Sandstone and mudstone	326m	*Avon*
		Triple
		Rombo
		Glen Road
		Valley View
		Parkers Road
Mammy Johnsons Sandstone and mudstone	300m	*Mammy Johnsons*
Weismantel	20m	*Weismantel*
Duralie Road conglomerate	250m	

Formation	Approx thickness	Coal seam
Alum Mountain Volcanics		Clareval
		Basal

The Gloucester-Stroud Syncline is more than 55 km long. The syncline trends northwards and dips of up to 60° are displayed on the flanks of the basin.

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.

3.3 Local groundwater use

There are 65 registered bores within and immediately surrounding the Stage 1 GFDA. Thirtyfive of the 65 registered bores are noted as being for abstraction purposes with the uses listed as being for stock watering, irrigation, domestic, industrial, waste disposal, mining and monitoring.

4.0 *INVESTIGATIONS SPECIFICALLY FOR THE PHASE 2 REPORT*

4.1 Groundwater monitoring bore drilling program

Table 4-2 Groundwater monitoring bore details

(These bores have been sorted by depth, demonstrating that 42% are very shallow).

Monitoring Bore	Location	Total depth (m)	Screened interval (mbgl)	Lithology	Formation
TGMB01 (gas monitoring)	Tiedman	6	3 - 6	Weathered rock	Jilleon Formation
WMB01	Waukivory	8.5	5 - 8	Mixed gravel / sand	Alluvium
TMB05 (seepage monitoring)	Tiedman	10	6 - 9	Siltstone	Leloma Formation
AMB02	Atkins	11.5	6.5 – 11	Mixed gravels	Avon River Alluvium
TMB01	Tiedman	12	7 – 10	Clay	Avon River Alluvium
TMB03	Tiedman	12.5	5 – 11	Mixed gravels & sand	Avon River Alluvium
AMB01	Atkins	12.6	8 - 10	Mixed gravels	Avon River Alluvium
TMB04 (seepage monitoring)	Tiedman	15	8 – 14	Siltstone	Leloma Formation
TGMB02 (gas monitoring)	Tiedman	15.4	12.3 – 15.3	Weathered coal	Jilleon Formation - Roseville Coal Seam

Monitoring Bore	Location	Total depth (m)	Screened interval (mbgl)	Lithology	Formation
TMB02	Tiedman	15.5	9 – 12	Mixed gravels	Avon River Alluvium
WMB02	Waukivory	23	15 - 21	Sandstone	Wenhams Formation
BMB01	Bignell	30	15 - 29	Sandstone / siltstone	Leloma Formation
WMB03	Waukivory	36	32 - 34	Coal	Wenhams Formation - Bowens Road Coal Seam
RMB01	Rombo	51	42 - 48	Sandstone	Leloma Formation (upper)
S5MB01	Tiedman	60	52 - 58	Sandstone / siltstone	Jilleon Formation
S4MB01	Tiedman	66	58 - 64	Sandstone	Leloma Formation
WMB04	Waukivory	80.5	67 - 79	Sandstone	Wenhams Formation
RMB02	Rombo	93	85-91	-	Leloma Formation (upper)
S4MB02	Tiedman	97	89 - 95	Sandstone / siltstone	Leloma Formation
S5MB02	Tiedman	114	110 - 102	Siltstone	Jilleon Formation
BMB02	Bignell	138	124 – 136	Sandstone	Leloma Formation
S5MB03	Tiedman	166	158 - 164	Coal / shale	Jilleon Formation - Roseville Coal Seam
S4MB03	Tiedman	170	162 - 168	Coal	Jilleon Formation - Cloverdale Coal Seam
TCMB02	Tiedman	183	175 - 181	Sandstone	Leloma Formation
TCMB03	Tiedman	268	260 - 266	Coal & sandstone	Jilleon Formation - Cloverdale Coal Seam
TCMB04 (core hole)	Tiedman	334.7	327.3 – 333.3	Coal	Jilleon Formation - Roseville Coal Seam

4.2 Stream gauge installation

To assess the connectivity between shallow alluvial groundwater and stream flow, *gauges* were installed on the Avon River in March 2011

- TSW01 on the Tiedman
- ASW01 on the Atkins
- ASW02 further upstream on the Atkins

4.3 *Permeability Testing by Slug Tests*

Hydraulic testing was conducted to establish the hydraulic conductivity[6] of each screened aquifer or water bearing zone.

Field measurements of hydraulic conductivity were obtained from the analysis of rising and falling head tests. The core samples from TCMB04 were also subject to laboratory permeability testing.

The results are given in Table 6.1.

Table 6-1 Hydraulic conductivity results from slug tests

Monitoring Bore	Screened section (mbgl)	Lithology	Formation	Hydraulic conductivity (m/day)
S4MB01	58 –64 (6m)	Sandstone	Leloma Formation	4×10^{-5}
S4MB02	89 –95 (6 m)	Sandstone / siltstone	Leloma Formation	5×10^{-3}
S4MB03	162 –168 (6 m)	Coal	Jilleon Formation -Cloverdale Coal Seam	0.01
S5MB01	52 –58 (6 m)	Sandstone / siltstone	Jilleon Formation	2×10^{-6}
S5MB02	100 –112 (12 m)	Siltstone	Jilleon Formation	7.9×10^{-4}
S5MB03	158 –164 (6 m)	Coal / shale	Jilleon Formation -Roseville Coal Seam	0.01
TCMB02	175 –181 (6 m)	Sandstone	Leloma Formation	1.1×10^{-4}
TCMB03	260 –266 (6 m)	Coal & sandstone	Jilleon Formation -Cloverdale Coal Seam	1.6×10^{-3}
TCMB04	327.3 –333.3 (6 m)	Coal	Jilleon Formation -Roseville Coal Seam	2.3×10^{-3}
BMB01	15 –29 (14 m)	Sandstone / siltstone	Leloma Formation	0.12
BMB02	124 –136 (12 m)	Sandstone	Leloma Formation	1.5×10^{-3}
TMB01	7 –10 (3 m)	Clay	Avon River Alluvium	0.32
TMB02	9 –12 (3 m)	Mixed gravels	Avon River Alluvium	50 –100
TMB03	5 –1 (6 m)	Mixed gravels & sand	Avon River Alluvium	20 –50
AMB01	8 –10 (2 m)	Mixed gravels	Avon River Alluvium	100 –500
AMB02	6.5 –11 (4.5 m)	Mixed gravels	Avon River Alluvium	50 –100
WMB01	5 –8 (3 m)	Mixed gravel & sand	Alluvium	50 –150

[6] *Hydraulic conductivity is the technically correct term for permeability to water.*

Monitoring Bore	Screened section (mbgl)	Lithology	Formation	Hydraulic conductivity (m/day)
WMB02	15 –21 (6m)	Sandstone	Wenhams Formation	0.9
WMB03	32 –34 (2m)	Coal	Wenhams Formation -Bowens Road Coal	0.03
WMB04	67 –79 (12 m)	Sandstone	Wenhams Formation	2 –20
RMB01	42 –48 (6 m)	Sandstone	Leloma Formation (upper)	0.01
RMB02	85 –91 (6 m)	Sandstone	Leloma Formation (upper)	0.01

4.4 *Permeabilty by* Packer testing

Packer testing was undertaken to assess the hydraulic conductivity of strata intersected by the core hole (TCMB04).

The results are given in Table 6.2.

Table 6-2 TCMB04 Packer test results

Test	Test zone depth (mgbl)	Rock Type	Formation	Step	Pressure (psi)	Flow rate (l/s)	K m/d (USBR, 1997)	K m/d (Thiem, 1906)
1	305-308.5	sandstone	Interburden between the Cloverdale & Roseville Coal Seams	1	90	0.05	6×10^{-3}	7×10^{-3}
				2	160	0.03		
				3	200	0.06		
				4	150	0.03		
				5	100	0.02		
2	270-273.5	coal	Cloverdale Coal Seam	1	100	0.07	8×10^{-3}	9×10^{-3}
				2	150	0.06		
				3	200	0.07		
				4	150	0.03		
				5	100	0.02		
3	235-238.5	siltstone	Interburden between the Deards & Cloverdale Coal Seams	1	100	0.04	6×10^{-3}	7×10^{-3}
				2	155	0.06		
				3	200	0.05		
				4	150	0.04		
				5	100	0.02		
4	217.75-220.25	sandstone	Interburden between the Deards & Cloverdale Coal Seams	1	110	0.05	6×10^{-3}	7×10^{-3}
				2	140	0.04		
				3	220	0.05		
				4	155	0.03		
				5	105	0.02		
5	150.5-154	sandstone /siltstone	Interburden between the Bindaboo & Deards Coal Seams	1	110	0.05	7×10^{-3}	8×10^{-3}
				2	140	0.05		
				3	220	0.05		
				4	150	0.05		
				5	100	0.02		

4.5 Laboratory permeability testing

Porosity and permeability (vertical and horizontal) tests were performed on six core samples from TCMB04.

The results are given in Table 6.3.

Table 6-3 Laboratory permeability testing results

Sample Number	Formation	Orientation	Depth (m)	Hydraulic conductivity (m/d)	Porosity (%)	Comment
1	Interburden between Bindaboo & Deards Coal Seams	Horizontal	153.00	0.001	10.4	
		Vertical	153.00	0.001		
2	Interburden between Deards & Cloverdale Coal Seams	Horizontal	219.00	0.001	8.0	
		Vertical	219.00	0.001		
3	Interburden between Deards & Cloverdale Coal Seams	Horizontal	236.10	0.002	8.8	
		Vertical	236.10	0.002		
4	Cloverdale Coal Seam	Horizontal	270.4	1.82*	8.3*	Coal
		Vertical	270.4			Failed
5	Interburden between Cloverdale & Roseville Coal Seams	Horizontal	307.10	<0.001	6.0	
		Vertical	307.10	<0.001		
6	Roseville Coal Seam	Horizontal	333.3			Failed
		Vertical	333.3	0.067	7.3	Coal

4.6 Groundwater quality monitoring

4.6.1 Chemical analysis of water

The first sampling event took place between 4 April and 11 May 2011. *The factual data is given in Tables 3 and 4 of the Appendix and summarised in Table A of the main text; not reproduced herein. The summary tables do not include the important measure of Total Dissolved Solids (**TDS**), which is the proper measure of salinity. To address this we have extracted the TDS data from the Appendices and summarise in Table A below.*

Table A

SUMMARY OF TOTAL DISSOLVED SOLIDS DATA			
MATERIAL	***DEPTH***	***BOREHOLE & DATE***	***TDS mtg/L***
Clay	*7-10*	*TMB01 7/4/2011*	*7530*
Mixed Gravels	*9-12*	*TMB02 7/4/2011*	*3520*
Mixed Gravels and sand	*5-11*	*TMB03 7/04/2011*	*5830*

SUMMARY OF TOTAL DISSOLVED SOLIDS DATA			
MATERIAL	**DEPTH**	**BOREHOLE & DATE**	**TDS** **mtg/L**
Siltstone	*8-14*	*TMB04 13/04/2011*	*8300*
Siltstone	*8-9*	*TMB05 13/04/2011*	*8770*
Mixed gravel\sand	*5-8*	*WMB01 07/04/2011*	*2450*
Sandstone	*15-21*	*WMB02 07/04/2011*	*4960*
Coal	*32-34*	*WMB03 07/04/2011*	*4490*
Sandstone	*67-79*	*WMB04 07/04/2011*	*3690*
Sandstone silt/stone	*15-29*	*BMB01 07/04/2011*	*3870*
Sandstone	*124-136*	*BMB02 07/04/2011*	*3250*
Mixed gravels	*8-10*	*AMB01 08/04/2011*	*2340*
Sandstone	*42-48*	*RMB01 12/4/2011*	*11100*
Sandstone	*85-91*	*RMB02 12/04/2011*	*8380*
Sandstone	*58-64*	*S4MB01 06/04/2011*	*2890*
Sandstone/siltstone	*89-95*	*S4MB02 06/04/2011*	*2460*
Coal	*162-168*	*S4MB03 06/04/2011*	*3200*
Sandstone/Siltstone	*52-58*	*S5MB01 05/04/2011*	*6100*
Siltstone	*100-112*	*S5MB02 05/04/2011*	*4340*
Coal/shale	*158-164*	*S5MB03 05/04/2011*	*3770*
Sandstone	*175-181*	*TCMB02 13/05/2011*	*3200*
Coal/sandstone	*260-266*	*TCMB03 14/04/2011*	*3020*
Coal	*327.3-333.3*	*TCMB04 24/6/2011*	*3650*
water		*Tiedeman North Dam 26/10/2010*	*4280*
water		*Tiedeman South Dam 26/10/2010*	*2790*
water		*North Dam (Deep) 10/01/2011*	*4180*
water		*North Dam(shallow)10/01/2011*	*4240*
water		*South Dam(deep)10/01/2011*	*2610*
water		*South Dam(shallow) 10/06/2011*	*2650*

4.7 Surface water quality monitoring

4.7.1 Rivers

Water samples were collected in combination with the groundwater sampling event at three locations on the Avon River in April 2011.

4.7.2 Tiedman and Stratford storage dams

Produced water is currently stored for irrigation in the following on-site dams (Figure 4-7):

- Tiedman North (20 ML capacity)
- Tiedman South (20 ML capacity)
- Stratford 1 (8 ML capacity)
- Stratford 3 (8 ML capacity).

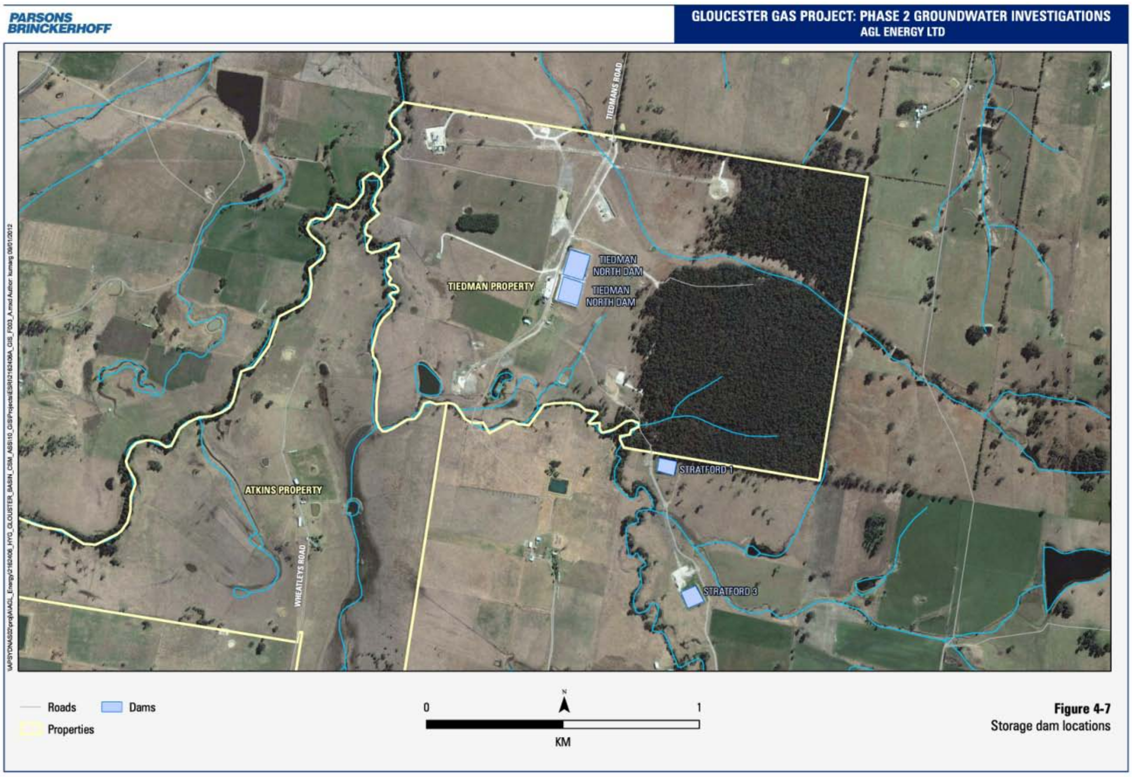


Figure 4-7
Storage dam locations

5. Updated geological model

The cross sections presented in Figures 5-1 – 5-4 detail the latest understanding of the stratigraphy and geological structure.

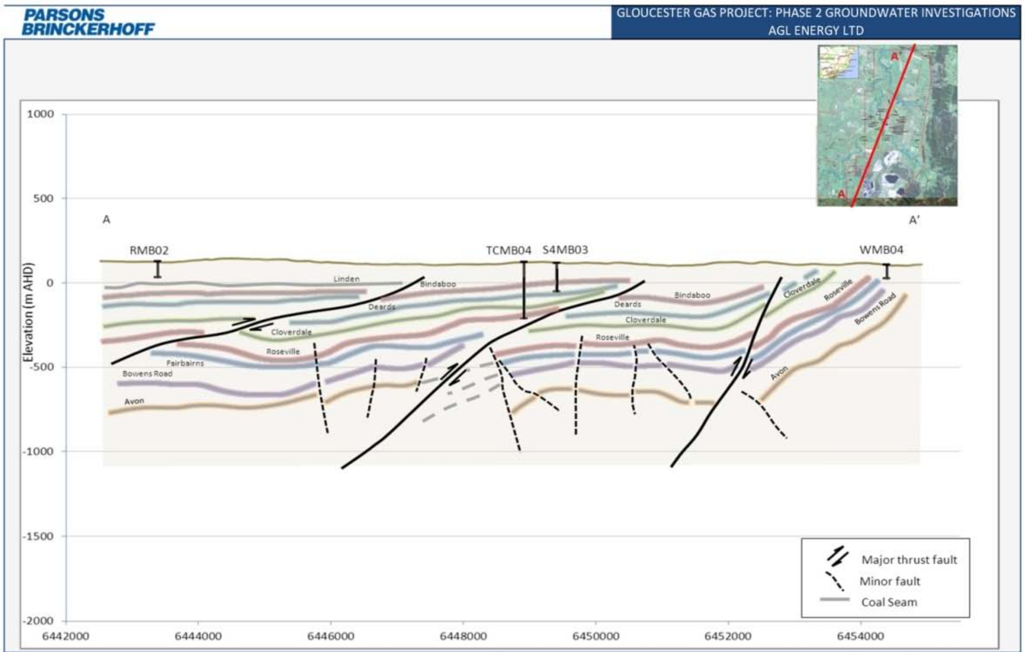


Figure 5-1 Simplified regional NE-SW geological cross-section through the Stage 1 GFDA

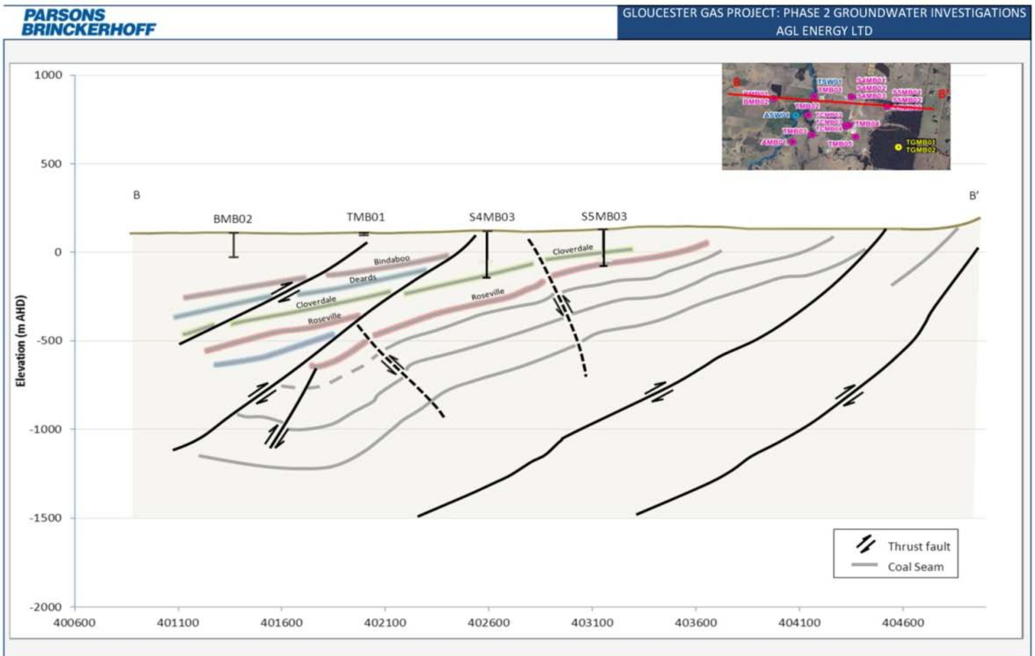


Figure 5-2 Simplified regional E-W geological cross-section through the Stage 1 GFDA

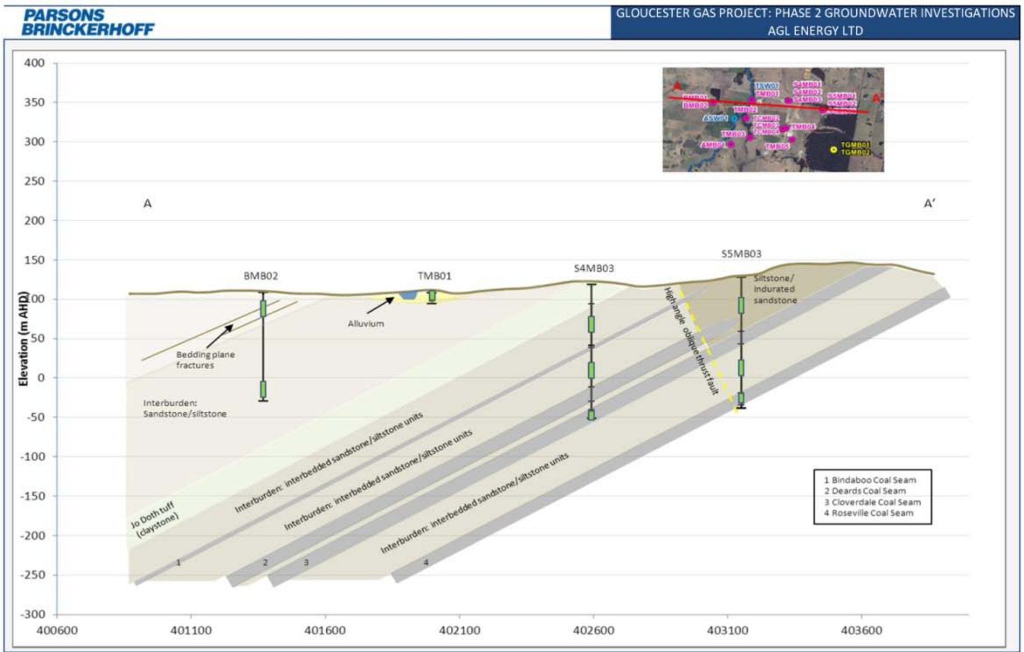


Figure 5-3 Geological cross-section through the Tiedman property (W-E)

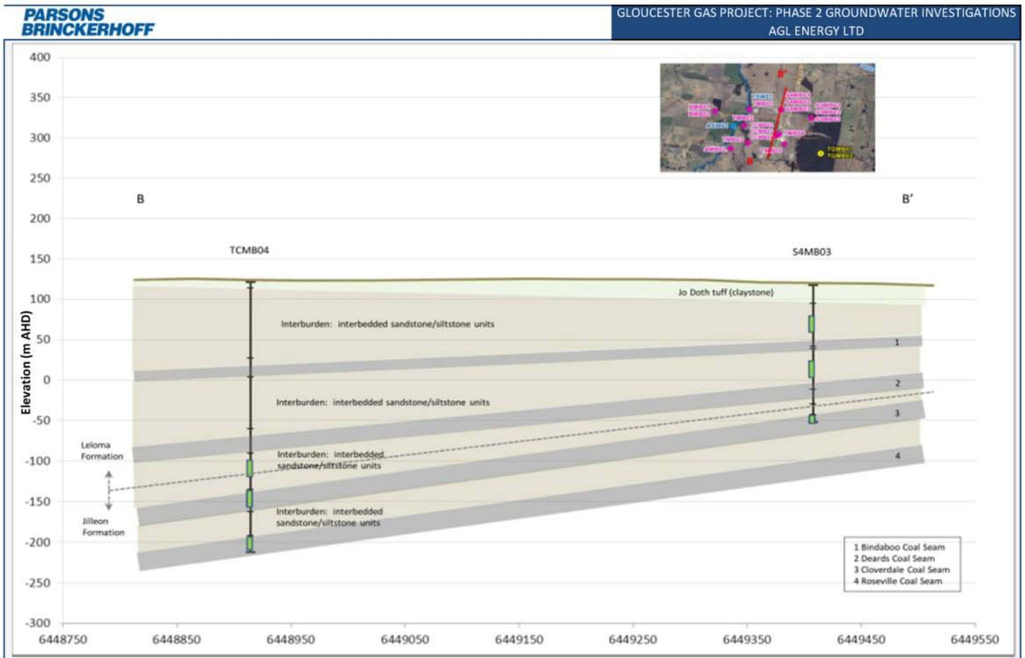


Figure 5-4 Geological cross-section through the Tiedman property (N-S)

7.0 WATER LEVEL MONITORING

Sections 7.2 and 7.3 present initial baseline groundwater and surface water level monitoring results from early January to early December 2011. *(The plots are not reproduced here, but it must be noted that the monitoring period is only 11 months, summaries of the data are given in 7.1 to 7.3.*

6.1 Shallow rock units

Waukivory groundwater monitoring bores WMB02 and WMB04 intersect the shallow rock of the Wenham Formation. Groundwater elevations at these locations were static in early 2011 then rose slightly in the second half of 2011, indicating a lagged seasonal variation and minimal response to rainfall recharge (Appendix O, AO -13 and AO-15).

The shallow rock units of the Leloma Formation, intersected by BMB01, RMB01, and RMB02 also show a minimal and lagged response to rainfall recharge. The greatest variability that may indicate some upgradient recharge is observed in RMB01 (Appendix O, AO-16).

6.2 Interburden units

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 (Appendix O, AO-10).

6.3 Coal seams

The Cloverdale Coal Seam, intersected by monitoring bores S4MB03 and TCMB03, the Bowens Road Coal Seam intersected by WMB03, and the Roseville Coal Seam intersected by monitoring bore TCMB04 all show very little fluctuation and no response to rainfall.

6.4 *Interactions between monitoring points at different depths*

(The plots that are used by PB to interpret interactions are reproduced below).

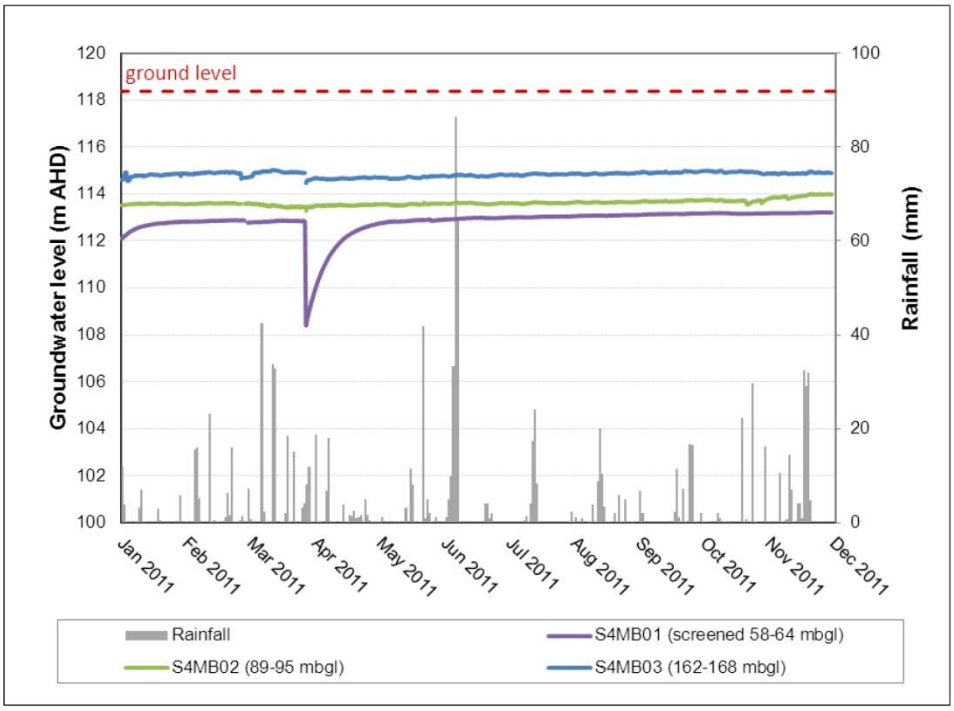


Figure 7-2 Groundwater levels at Stratford 4

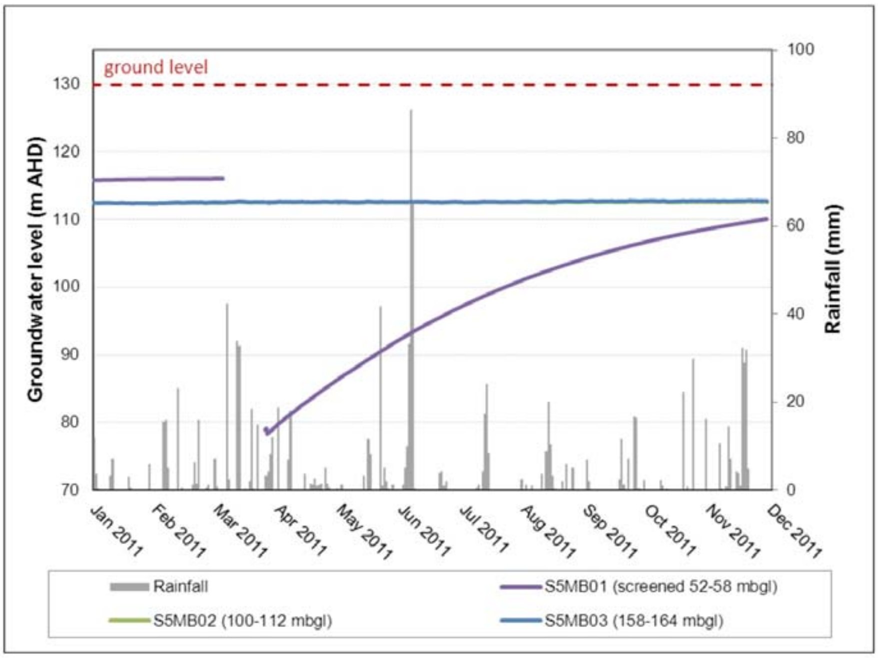


Figure 7-3 Groundwater levels at Stratford 5

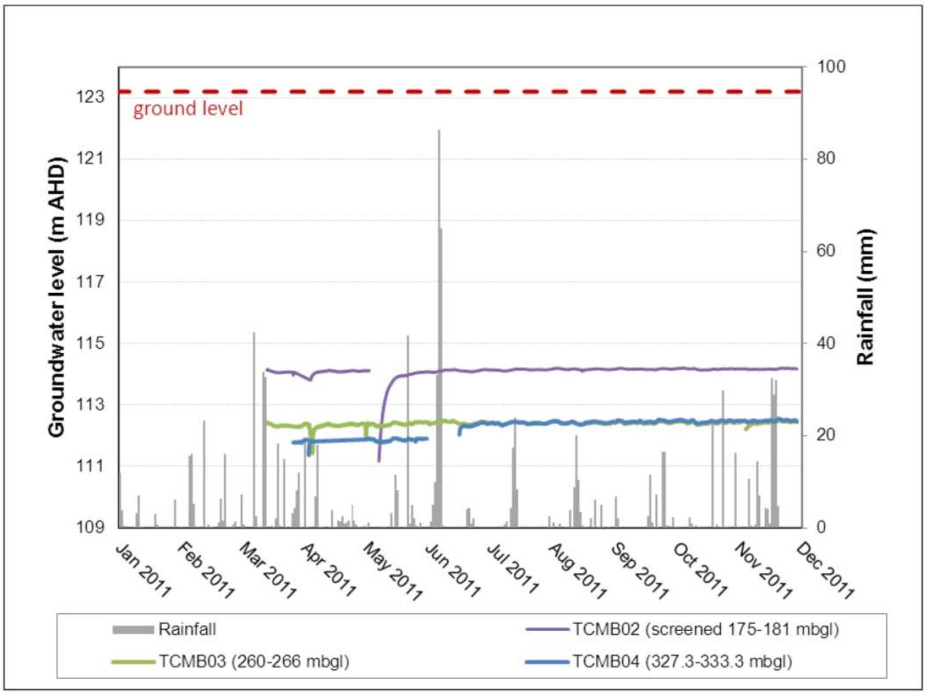


Figure 7-4 Groundwater and rainfall levels at Tiedman core hole site

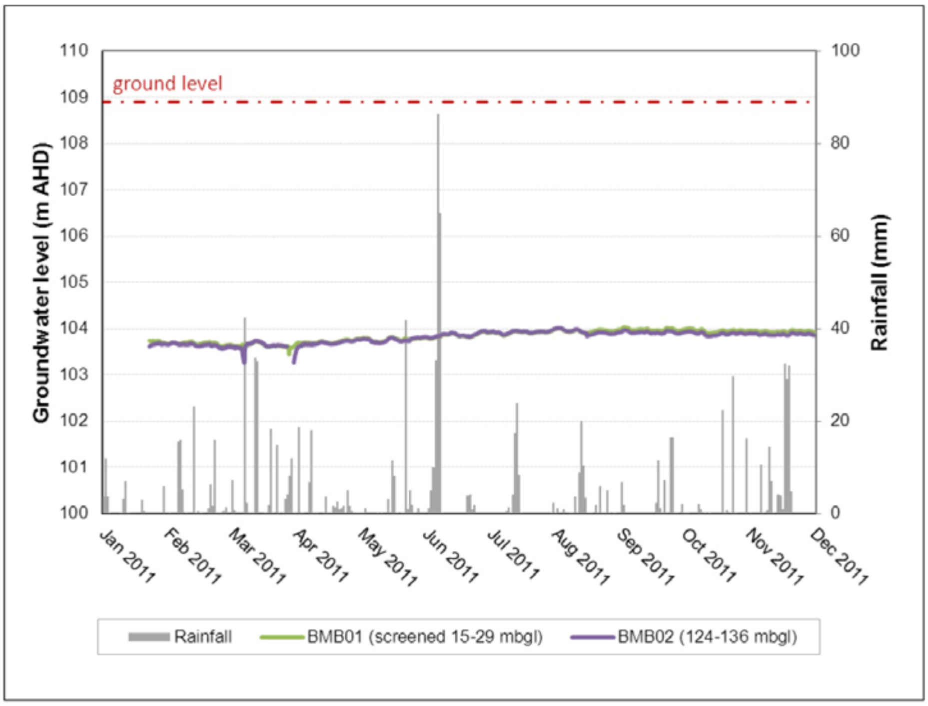


Figure 7-5 Groundwater and rainfall levels at Bignell

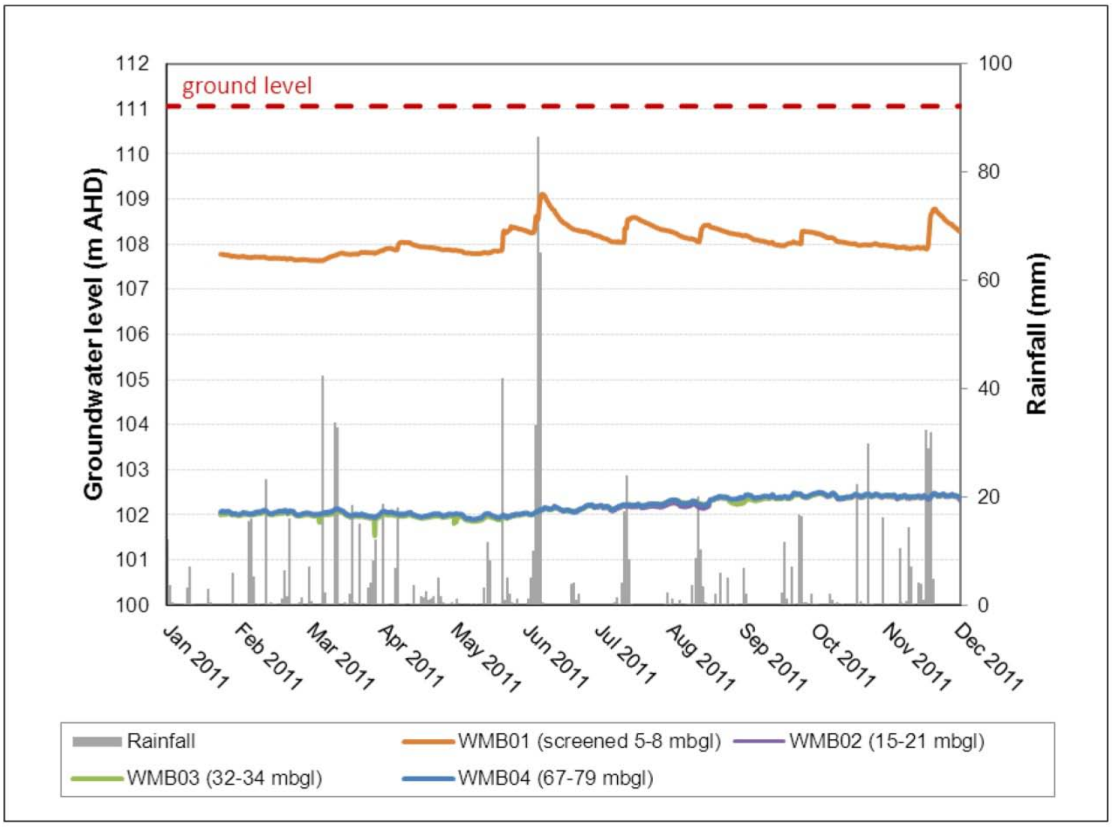


Figure 7-6 Groundwater levels at the Waukivory Road site

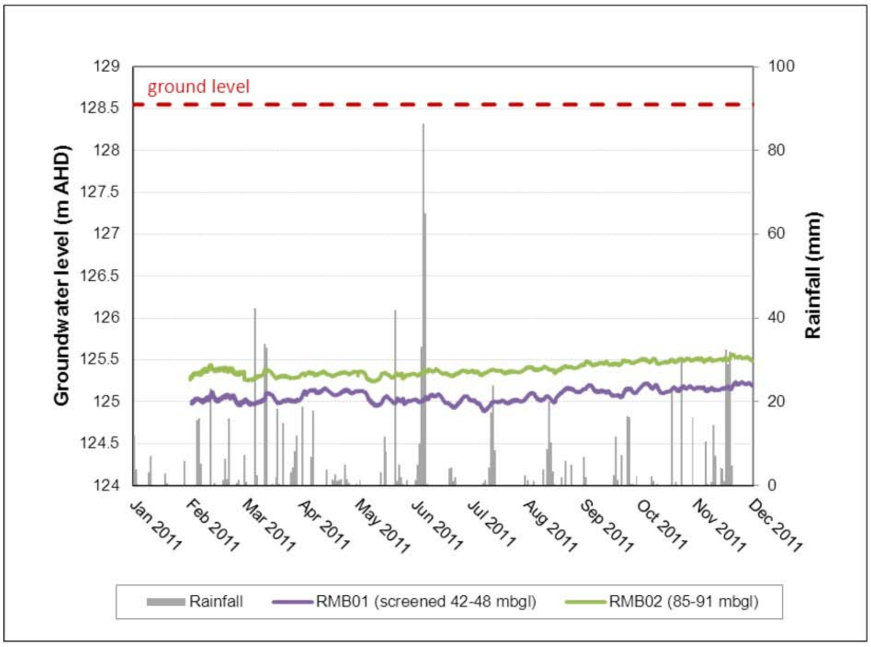


Figure 7-7 Groundwater levels at the Rombo site

7.0 WATER QUALITY MONITORING

7.1 Groundwater quality

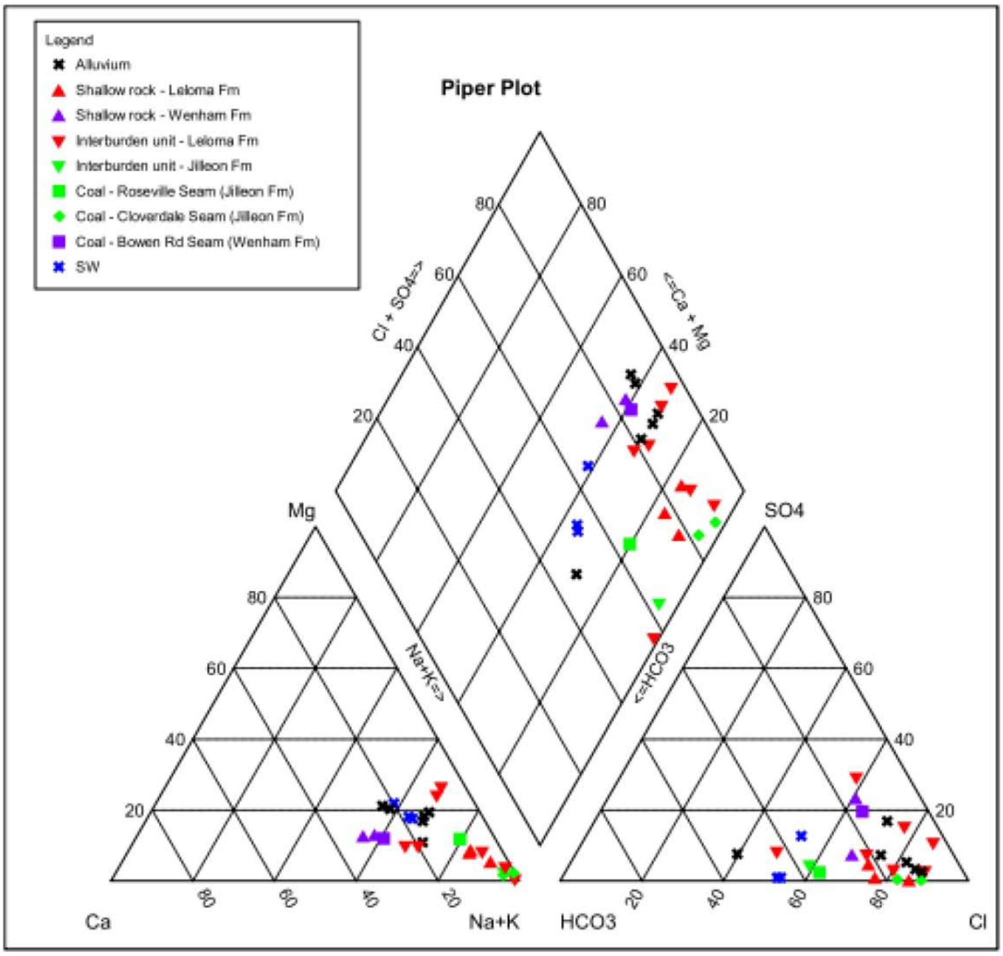


Figure 8-1 Piper diagram showing major ion composition of groundwater and surface water

7.2 *Alluvium isotopes*

The alluvial groundwater samples plot on or close to the meteoric water lines, indicating all alluvial water samples are of meteoric (rainfall) origin.

Tritium values at AMB01 and AMB02 are above the MDA confirming that at these locations shallow groundwater is modern.

7.3 Shallow rock aquifers

7.3.1 Chemistry

Monitoring bores screened in the shallow rock aquifers include the Rombo monitoring bores (RMB01 and RMB02) (Leloma Formation), the Waukivory monitoring bores (WMB02 and WMB04) (Wenham Formation), and the Bignell monitoring bore BMB01 (Leloma Formation).

7.3.2 Isotopes

The corrected radiocarbon ages for the shallow rock aquifers at the Waukivory site showed an increase in age with depth, with monitoring bores WMB02 and WMB04 having corrected ^{14}C ages of 4,300 yrs BP and 19,600 yrs BP, respectively. The Bignell monitoring bore, BMB01, had a similar corrected ^{14}C age as WMB01 at 5,600 yrs BP. At the Rombo monitoring site, an age inversion is evident, with older water occurring in the shallower monitoring bore.

7.4 Interburden units

7.4.1 Isotopes

Carbon-14 activities ($a^{14}C$) for interburden monitoring bores range from 4.36±0.06 pMC (TCMB02) to 53.24±0.16 pMC (S5MB01). These ^{14}C activities correspond to apparent (uncorrected) ages ranging from 5,004±25 yrs BP (S5MB01) to 25,110±110 yrs BP (TCMB02). The corrected radiocarbon ages ranged from 4,700 yrs BP (S5MB01) to 19,200 yrs BP (TCMB02). Groundwater ages increase with depth at the Stratford 4 and Stratford 5 monitoring locations.

7.5 Coal seams

7.5.1 Isotopes

Corrected ages range from 9,300 yrs BP to 21,600 yrs BP. Since methanogenesis in these coal seams is primarily by CO_2 reduction, only a small change in corrected age is observed in those bores where methanogenesis is the primary process affecting DIC (Saliege and Fontes 1984).

APPENDIX B

MATTERS OF INTERPRETATION

APPENDIX B

MATTERS OF INTERPRETATION

(Note: Words which have been italicised are the words of Pells Consulting, all other words have been cut and pasted directly from the PB Report. There has been no attempt to alter the intent of statements in the PB report by the selective culling process).

1.0 *INTERPRETATIONS FROM* PREVIOUS CSG PILOT/FLOW TESTING PROGRAMS

However other data sets suggest that there was no leakage from overlying aquifers because:

- Produced water volumes at all sites (except Stratford 3) diminished to less than 50 bbls/day[7] (less than 0.11 L/s) at most sites after only a few weeks/months pumping (i.e. there was no evidence of pulsating or increased water inflows).

- The salinity of the produced water was reasonably consistent (within ±20% of initial samples) at most sites during the period of testing.

The existing data from the flow testing programs suggests that water quality from gas wells with deeper perforated intervals is more saline than shallower wells (suggesting longer residence times and limited connectivity).

2.0 *INTERPRETED* HYDROGEOLOGICAL UNITS

AECOM (2009) defines a total of three hydrogeological units in the Stage 1 GFDA:

- A shallow alluvial aquifer (fresh to brackish water quality)
- A shallow bedrock aquifer (brackish to saline water quality)
- A deep bedrock aquifer (saline and alkaline water quality).

SRK (2010) added a fourth hydrogeological unit, the confining units of the Gloucester Coal Measures, Dewrang Group and the Alum Mountain Volcanics.

The Phase 2 interpretation is different to both these and comprises the material given in 2.1 to 2.3, below.

2.1 Aquifer and deeper water bearing zone interactions

2.1.1 Stratford 5 monitoring bores (S5MB)

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 (see Section 5.6). Radiocarbon data indicates that groundwater downgradient of the fault (in the interburden and Cloverdale Coal Seam) is older than in the interburden and the deeper Roseville Coal Seam upgradient of the fault (S5MB monitoring bores) (4,700 to 9,300 yrs BP). The upgradient monitoring bores are in closer proximity to the outcropping recharge zones.

[7] *The PB Stage 2 report uses the unusual unit for flow of barrels/day. It is a petroleum unit and is never normally used for groundwater. 1 barrel per day is 0.00184 lit/sec. This means that 50 barrels/day should be 0.092 lit/sec and not 0.11 lit/sec.*

2.2 Alluvial aquifers

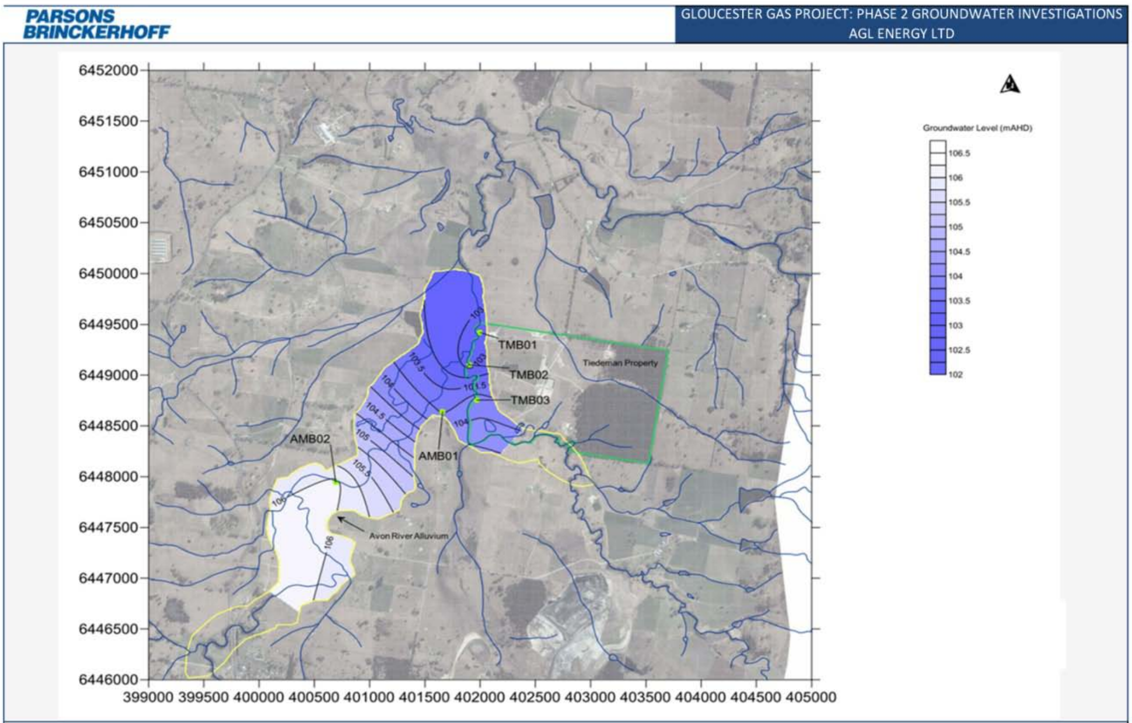


Figure 10-4 Alluvial aquifer groundwater level contours

2.3 Hydrogeological units

- Alluvial aquifers
- Shallow rock aquifers
- Interburden confining units
- Coal seam water bearing zones.

Table 10-1 Hydrogeological units of the Stage 1 GFDA (updated)

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Semi-confined, clay capped, porous, granular	Quaternary alluvium	0.3-500
Shallow rock aquifers	Confined/ unconfined	Permian Gloucester Coal Measures	0.01-20
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures	4 x 10^{-5} -0.006
Coal seam water bearing zones	Confined	Coal seams of the Gloucester Coal Measures	0.002-0.03

Figure 10-1 presents a summary of the hydraulic conductivities derived from the various testing methods.

Figures 10-2 and 10-3 show annotated cross-sections through the central area of the Stage 1 GFDA and summarise the current hydrogeological conceptual model of the area.

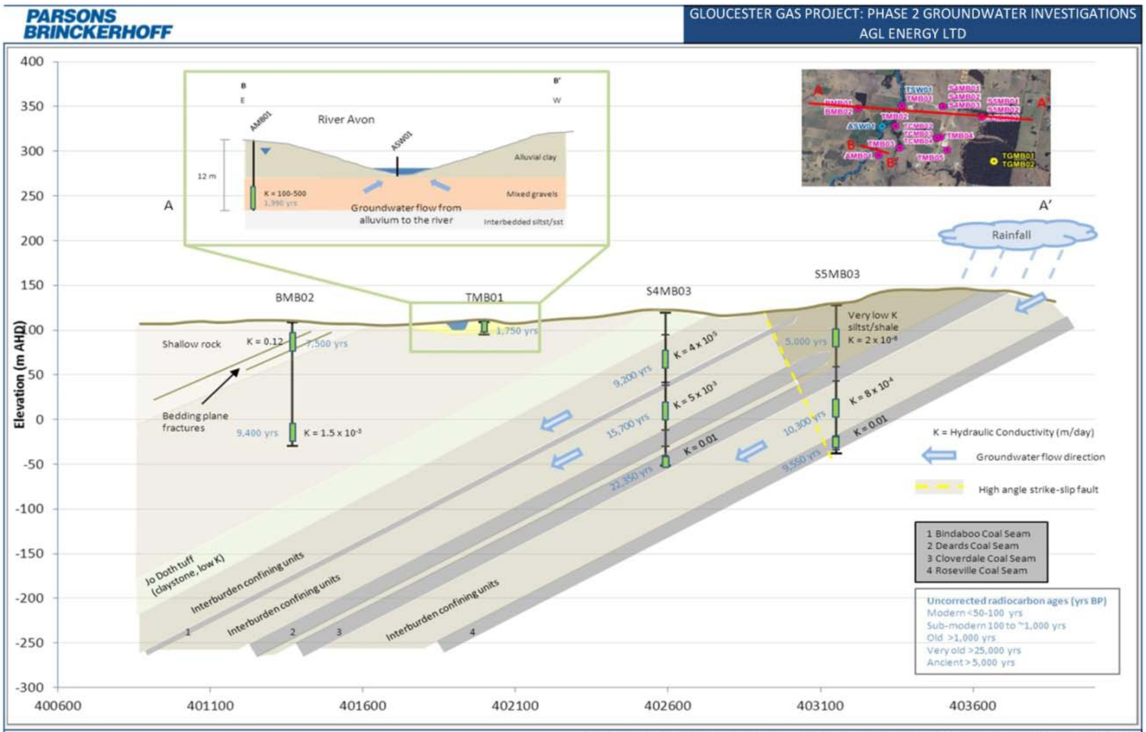


Figure 10-2 Conceptual cross-section through the Tiedman property (W-E)

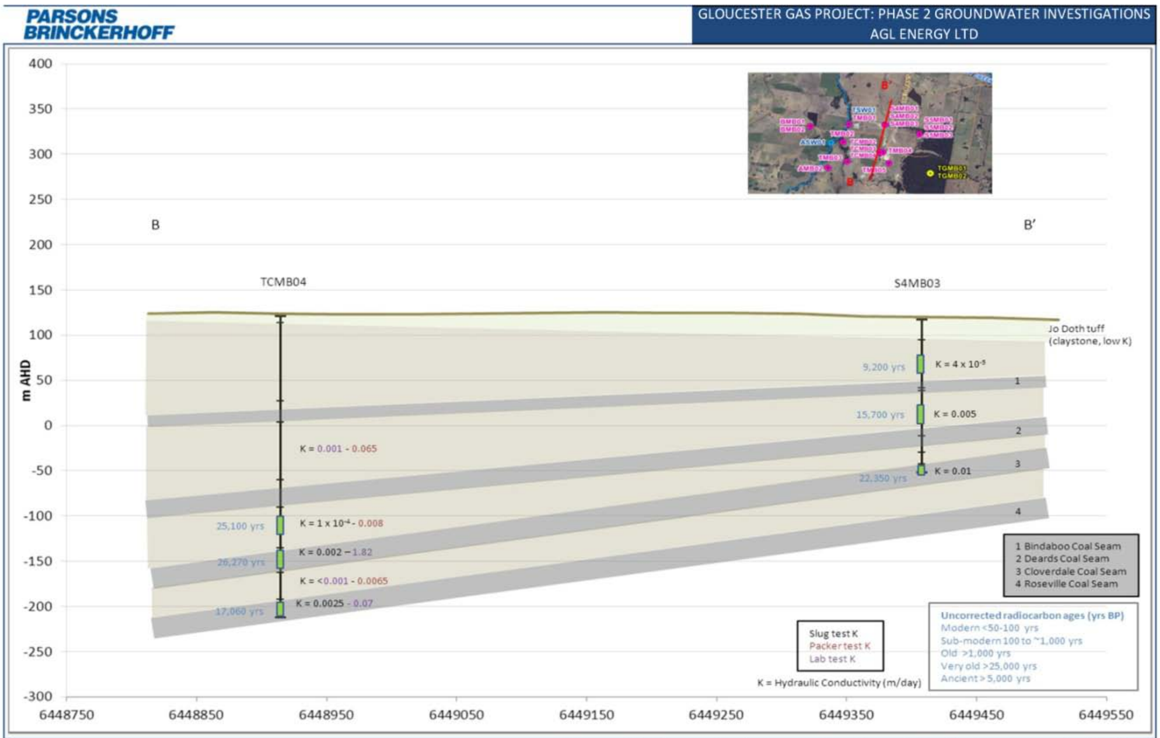


Figure 10-3 Conceptual cross-section through the Tiedman property (SW-NE)

Alluvial aquifers

The alluvium, associated with the Avon River and its tributaries is shallow (maximum 12 m thickness) and is an unconfined or semi-confined aquifer across the whole area where it is present. Groundwater level data imply groundwater flow in a northerly direction parallel to the axis of the valley (Figure 10-4).

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).

Interburden confining units

The deeper interburden units typically are of very low permeability. The groundwater is therefore moving very slowly with lateral groundwater flow within each rock unit predominating over fracture flow migration.

The low permeability interburden units are locally saturated, but generally act as confining layers between and overlying the coal seams.

Coal seam water bearing zones

Despite having low permeabilities, the coal seams in the Stage 1 GFDA have a higher permeability than the surrounding interburden and are therefore likely to be conduits for limited groundwater flow at depth. The groundwater is moving very slowly (but sometimes faster that groundwater in the overlying interburden) with lateral groundwater flow within the cleats in the coal seams predominating over fracture flow migration.

3.0 STRUCTURAL CONTROLS *FAULTS AND DYKES*

A large number of faults have been reported across the area. Little information exists concerning the hydraulic properties of these faults.

4.0 INTERPRETATIONS REGARDING RECHARGE AND DISCHARGE

Ridges and outcrops are generally considered as being zones of preferred rainfall recharge.

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.

Groundwater discharge to streams is likely to be diffuse over a large area unless there are substantial fault systems contributing.

Consequently groundwater use is minimal. Low groundwater yields to bores and wells, and marginal to poor water quality also preclude widespread groundwater use across the area.

Four key hydrostratigraphic units (equivalent to the hydrogeological units of SRK, 2010) are defined to assist discussion of the hydraulic testing, water level monitoring and water quality analysis results (Table 5-1).

5.0 INTERPRETATIONS OF PROPOSED UNITS OF THE HYDROGEOLOGICAL MODEL

5.1 Alluvium

The typical thickness of alluvium encountered in the vicinity of the Tiedman and Atkins properties was approximately 12 m.

5.2 Shallow rock

Although interbedded, the shallow rock typically has a more dominant sandstone content with suspected bedding plane fractures.

5.3 Interburden

The majority of the Stage 1 GFDA is underlain by interbedded indurated fine to medium grain sandstone and very fine grain siltstone units providing confining layers between and directly overlying the major coal seams. No significant fractures were encountered in these rock units.

5.4 Coal seams

Four main coal seams were intercepted in the monitoring bore drilling program beneath the Bindaboo, Deards, Cloverdale, and Roseville coal seams.

6.0 INTERPRETED MASS PERMEABILITY

The permeability results presented from the various methods discussed above indicate distinct hydraulic properties for each of the four hydrostratigraphic units defined in Section 5. Table 6-4 presents a summary of these units and confirms their hydrogeological classification.

Table 6-4 Hydrogeological units of the Stage 1 GFDA (updated)

Note that the permeability interpretations in this table are not the same for the Coal Seams and Interburden as given in PB's Table 10.1.

Hydrogeological unit	Aquifer type	Formation name	Hydraulic conductivity (m/day)
Alluvial aquifers	Semi-confined, clay capped, porous, granular	Quaternary alluvium	0.3-500
Shallow rock units	Confined/ unconfined	Gloucester Coal Measures	0.01-20
Coal seam water bearing zones	Confined	Coal seams of the Gloucester Coal Measures	0.002-0.03 (1.82 lab*)
Interburden confining units	Confined/ unconfined aquitard	Confining units of the Gloucester Coal Measures	4×10^{-5} -0.006

These data[8] confirm that high permeability aquifers only occur in the alluvium and shallow rock geologies and that the coal seams can be poor aquifers at shallow depth but are low permeability water bearing zones at depth.

7.0 AQUIFER INTERACTIONS

The following subsection give interpretations for individual bores.

7.1 Alluvial aquifers

In general, the higher salinities within the alluvial aquifers are due to the high clay content which impedes vertical rainfall recharge. Each of the monitoring bores is also located close to the eastern edge of the alluvial flats and could therefore be influenced by saline seeps from the underlying bedrock.

7.2 Stratford 4 Monitoring Bores (S4MB)

Groundwater level monitoring at the nested Stratford 4 site indicates three distinct groundwater regimes likely to be hydraulically isolated by a confining interburden of low permeability siltstones and indurated sandstones. The potentiometric level in the confined Cloverdale Coal Seam (S4MB03) is a higher elevation (c.115 m AHD) than the overlying interburden water bearing zones at S4MB02 (c. 113.5 m AHD) and the shallow water table at S4MB01 (c.113 m AHD). The upward gradient indicates a potential for vertical leakage from the deep to shallow water bearing zones, however, the hydraulic stratification/isolation is attributed to the presence of strong confining layers which are likely to inhibit leakage.

At the Stratford 4 monitoring location there are distinct geochemical differences between groundwater from the interburden confining units (S4MB01 and S4MB02) and the Cloverdale Coal Seam (S4MB03) indicating limited connection between them under natural conditions.

7.3 Stratford 5 Monitoring Bores (S5MB)

Groundwater monitoring at the nested Stratford 5 site identifies a downward head gradient between the shallow interbedded sandstone/siltstone unit water table (S5MB01, c.115 m AHD); and the potentiometric surface of the underlying siltstone/sandstone interburden (S5MB02) which is the same as the Roseville Coal Seam (S5MB03, c.112 m AHD) (Figure 7-3). Initial monitoring in all three bores shows static water levels indicating strong confining layers above the water bearing zones. Although the head gradient is indicative of potential downwards leakage, the very slow recovery of S5MB01 in response to the slug test suggests that this strata is itself a tight confining layer with very little potential for groundwater movement both, laterally and vertically.

Groundwater chemistry, stable isotope composition and groundwater age is similar for the deep interburden monitoring bore (S5MB02) and the Roseville Coal Seam monitoring bore (S5MB03), supporting the groundwater level data which indicates a potential hydraulic connection between the two units. Groundwater chemistry and stable isotope composition in the shallow interburden monitoring bore is distinctly different from the two deeper monitoring bores, supporting the hydraulic testing data which indicates that the strata in the upper interburden has a very low permeability with little potential for groundwater movement both laterally and vertically.

---

[8] *Note that the values in Table 6.4 are not data, they are interpretations and categorisations of the measured data.*

7.4 Tiedman core hole monitoring bores (TCMB)

Groundwater level monitoring at the Tiedman core hole site nested bores (Figure 7-4) indicates a downward head gradient between the potentiometric surfaces of the interbedded siltstone/sandstone interburden unit (TCMB02), and the Cloverdale Coal Seam (TCMB03), and Roseville Coal Seam (TCMB04). Although the bores all show the effects of slug testing and there is potential for downward leakage, minimal fluctuations are evident emphasising the low hydraulic conductivity, isolation and confining nature of the layers at this location.

Groundwater in both the Cloverdale and Roseville Coal Seams at this location has older radiocarbon ages than the equivalent seams at Stratford 4 and Stratford 5 monitoring locations, suggesting an increase in groundwater age with depth and along the regional flow paths.

7.5 Bignell monitoring bores

The monitoring bores at the Bignell site indicate a uniform piezometric pressure within the shallow rock aquifer (targeted by both bores BMB01 and BMB02) to depth (Figure 7-5). The effects of sampling and slug testing are more pronounced in the deeper bore (BMB02) indicating a relatively lower hydraulic conductivity in the deeper zone.

Both monitoring bores plot on the GMWL and groundwater ages (5,600 years for BMB01 and 8,900 years for BMB02) are similar supporting the groundwater level data which indicates a potential hydraulic connection between the two units.

7.6 Waukivory Road monitoring bores

Groundwater monitoring at the Waukivory Road site indicates a shallow alluvial water table (WMB01, c.108 m AHD) hydraulically isolated from the underlying Bowens Road Coal seam and shallow rock units (c.102 m AHD) (Figure 7-6). The head gradient between the water level of the alluvial aquifer and the potentiometric surface of the deeper water bearing zones indicates an elevated alluvial aquifer with a potential for downward leakage (although these bores are located 950 m apart).

Although hydraulic gradients indicate the potential for downward leakage from the alluvium to the shallow bedrock, the chemistry and radiocarbon ages suggest that substantial leakage is unlikely to be occurring.

7.7 Rombo monitoring bores

Groundwater levels from the monitoring bores within the shallow rock units at the Rombo site indicate two hydraulically isolated water bearing zones (Figure 7-7). The potentiometric surface of the deeper rock aquifer (RMB02, c. 125.4 m AHD) is higher than the water level of the shallower rock aquifer (RMB01, c. 125 m AHD) indicating an upward vertical gradient and a potential for upwards leakage. Both hydrographs show minimal impact of rainfall recharge, however there is a distinct rising trend over the last 6 months and the water level fluctuations are comparable.

Groundwater levels indicate there is potential for upward leakage, however an age anomaly at this location (older water in the shallow monitoring bore (17,700 yrs BP) suggest that any upward leakage may not be significant.

8.0 FAULT ZONE EFFECTS

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.

9.0 AQUIFER AND DEEPER WATER BEARING ZONE INTERACTIONS

9.1 Stratford 5 monitoring bores (S5MB)

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 (see Section 5.6). Radiocarbon data indicates that groundwater downgradient of the fault (in the interburden and Cloverdale Coal Seam) is older than in the interburden and the deeper Roseville Coal Seam upgradient of the fault (S5MB monitoring bores) (4,700 to 9,300 yrs BP). The upgradient monitoring bores are in closer proximity to the outcropping recharge zones.

9.2 Alluvial aquifers

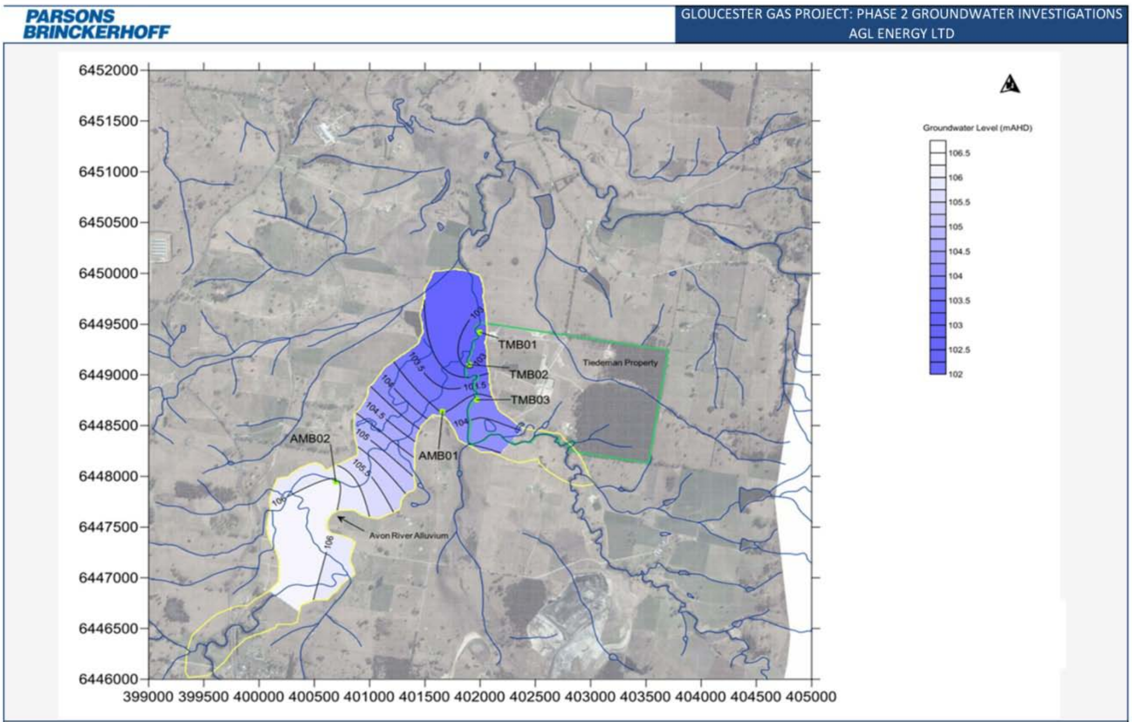


Figure 10-4 Alluvial aquifer groundwater level contours