CHIEF SCIENTIST AND ENGINEER, NSW

INQUIRY INTO COAL SEAM GAS OPERATIONS IN NEW SOUTH WALES

SUBMISSIONS BY DR PHILIP PELLS

NOTE

The submissions in this document represent different pieces of work undertaken by Dr Philip Pells and Steven Pells in connection with aspects of groundwater and Produced Water arising from existing and proposed coal seam gas operations in New South Wales. The work was not financed by any external parties; neither CSG companies nor groups opposed to CSG operations.

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P034.L3

28 March 2013

Chief Scientist and Engineer NSW
State Parliament
Macquarie Street
Sydney

Attention: Prof M O'Kane

RE: REVIEW OF COAL SEAM GAS ACTIVITIES IN NSW

Dear Madam,

1. INTRODUCTION

In accordance with the Terms Of Reference for your review of coal seam gas activities in NSW, and in particular in respect to Item 2 , I submit the attached material as being relevant to assessment of risks to "the environment and water catchments:.

I take the above quoted phrase to include groundwater systems because changes to groundwater systems, apart for potentially affecting groundwater resources, also impact on baseflows to streams and rivers. I can do no better than to quote Dr Rick Evans, Principal Hydrogeologist of Sinclair Knight Merz, and peer reviewer of AGL's Gloucester CSG groundwater study, who said:

> There is no free lunch here. Its very simple– every litre of water you pump out of the ground reduces river flow by the same amount.
>
> *Australian Financial Review,* 24 May 2007, p. 10

My involvement in the CSG industry in NSW grew out of decades of work in relation to impacts of coal mining on groundwater systems. I recognised that from the groundwater viewpoint there is little difference between coal mining and CSG extraction. The particular project I have been involved with is the AGL Stage 1 CSG extraction at Gloucester. I produced a self-financed review of what is termed Phase 2 of the AGL groundwater assessment of the Gloucester project.

The material I submit for your considerations comprises:

1. A memorandum I prepared early in my involvement in the Gloucester project setting out some fundamental considerations of CSG mining.

2. A paper, in two parts, published in the Australian Geomechanics Journal covering aspects of the science of groundwater impacts CSG extraction.

3. The review of the Phase 2 AGL study for the Gloucester project, which was presented to a public meeting at Gloucester and was made available for anyone on our website.

4. An Opinion Piece published in the Newcastle Herald that summarises my primary concerns.

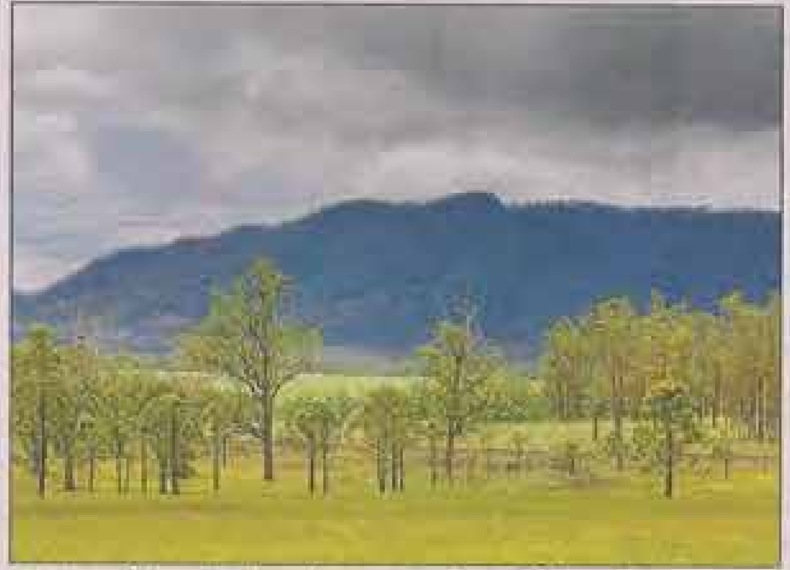
I have uploaded the material with this letter by YouSendit because of the file sizes, and will post paper copies with this same letter. I trust the material may be of some value to your review.

Yours sincerely,

PHILIP PELLS
FTSE BSc(Eng) MSc DSc(Eng) FIEAust MASCE

Reckless gambles threaten our future

NSW's coal seam gas plans must be wound back until science can guarantee its safety, writes **Philip Pells.**



PRECIOUS: Gloucester is under pressure from CSG projects.

MINING has been part of this country from the ochre pits of the Aboriginals, the first coalmine at the mouth of the Hunter, the gold shafts at Hill End and on to the wealth coming from Cadia gold and copper mine, near Orange.

It has made an enormous economic contribution to this nation.

As a specialist engineer I have spent most of my 40-year career working for major construction and mining companies on underground and open-cut mines, and in the disposal of the waste products of those mines.

I have worked, and continue to work, for most of the major mining companies and for the big construction companies in Australia and south-east Asia.

Until a few decades ago, mining in this country tended to be confined to relatively small areas.

So even if some mines had adverse impacts on land, water systems, and important environments – take the massive landslides in the Burragorang Valley and at Katoomba, the cracking of the Cataract River, and the draining of swamps on the Newnes Plateau – most impacts from these mines covered limited areas.

But with coal seam gas (CSG) extraction we are dealing with a new animal.

CSG extraction is a relatively new industry and a form of mining that covers very large areas very quickly. It has the potential to adversely affect groundwater systems over large parts of this state.

In order to extract coal seam gas, one first has to depressurise the groundwater in the coal seams and move it to the surface.

So the coal seams are, in effect, groundwater voids – the same as coalmines. But we are no longer talking about relatively localised effects. We are talking huge areas.

The enormous expansion of CSG mining has occurred in a poorly controlled manner over a very short period.

Large areas of our state will be affected by a relatively new industry where the science behind these impacts and the key hydrogeological parameters are poorly understood.

We have very little empirical information about long-term impacts from CSG operations because the industry is so young.

What we do know is that the impacts will develop over many years – and that, if the impacts are substantial, they will be almost impossible to reverse.

The current NSW government listing of exploration licences for CSG totals 189,567 square kilometres, almost 19 million hectares.

To this we must add 24,000 hectares in production leases for CSG and all the coalmining areas.

Together this comprises much of our populated area, our forested wilderness, our wetlands and rivers, and our productive agricultural land.

What we do with our water matters.

Rainfall is our primary water source and is subject to huge swings.

In times of plenty, our rivers flow, our dams fill, but most importantly our groundwater systems replenish.

Huge quantities seep into the Great Artesian Basin from the recharge zone along the east coast, into the porous and fractured rocks in the Sydney-Gunnedah geological basin that extends from Sutton Forest to Narrabri, and also into the older rocks west of the divide.

Apart from feeding bores, groundwater sustains the baseflows of our creeks and rivers, and our wetland systems.

Diminish those groundwater systems and you create a tendril effect of damage that extends from an individual vegetable farmer at Picton to a complete river system in the Yarramalong Valley, or at Gloucester.

CSG mining puts our groundwater under enormous pressure.

It is simply a matter of physics, not of opinion, that this depressurisation from CSG mining will adversely affect the whole groundwater system, because like the apple that fell on Isaac Newton's head, groundwater is controlled by gravity and flows from zones of high elevation to zones of lower potential energy.

How long will it take for the changes to our groundwater to be substantial?

We don't know.

How extensive will they be?

We don't know.

One thing we do know is encapsulated by Dr Richard Evans, principal hydrogeologist of Sinclair Knight Merz.

"There is no free lunch here – every litre of water you pump out of the ground reduces river flow by the same amount."

I don't believe as a society we should just let this process run helter skelter – a process whose consequences on our environment are not yet fully understood by scientists and engineers.

And we cannot rely on what is called "adaptive management", because if monitoring of CSG does show significant impacts on water systems, there is very little that can be done to reverse the process once the damage is done.

Wisdom demands that the whole process of CSG extraction in this state be urgently wound back.

That may allow the science to catch up with the present rapacious desire to exploit a resource.

To allow CSG mining to proceed before more is done to understand its impact is a reckless gamble with our future.

Perhaps we can learn from past lessons involving asbestos, tobacco, thalidomide and Agent Orange.

Damage may be done that cannot be repaired.

Dr Philip Pells is a civil engineer who has spent four decades in geotechnical and groundwater engineering.

IMPACTS OF LONGWALL MINING AND COAL SEAM GAS EXTRACTION ON GROUNDWATER REGIMES IN THE SYDNEY BASIN PART 1 –THEORY

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University of New South Wales and Pells Consulting

Australian Geomechanics Journal Vol 47 No. 3, p.35, September 2012

ABSTRACT

The mathematics of steady state and transient downwards Darcian flow are given for full or limited recharge and saturated homogenous ground, layered ground, and for unsaturated flow. Data are presented from a physical model that supports the theoretical analyses.

A hypothesis is presented for unsaturated hydraulic conductivity in the Triassic rocks of the Sydney Basin. The theoretical analyses coupled with the important inferences from unsaturated hydraulic conductivity provide valuable aids to understanding possible impacts of depressurisation due to underground coal mining and coal seam gas extraction in the Sydney Basin.

It is acknowledged that flow through jointed rock masses is very complex, and there are limits to the applicability of the equations of flow through porous media. However, as with elastic theory in geomechanics analyses, it is considered that the rigor gained from Darcian flow analysis assists greatly in avoiding flawed thought processes in hydrogeology.

1 INTRODUCTION

Changes to groundwater regimes associated with underground mining in the Sydney Basin are a significant issue in the ongoing operation of existing mines, in the planning of new mines, and in the burgeoning industry of Coal Seam Gas (CSG) extraction. This issue has been alive since the time of the Reynolds Inquiry in 1975-1979, when there were concerns in relation to mining beneath the reservoirs in the Southern Coalfields.

Currently, Environmental Assessments for new mines and extensions to existing mines are typically accompanied by analyses of likely groundwater impacts using 3D numerical models (MODFLOW, FEFLOW or equivalent). However, large complex 3D models may mask important features regarding groundwater impacts. Cheng and Ouazar (in Bear *et al*, 1999, pp 163) wrote:

> *"... analytical solutions are useful in presenting fundamental insights, while numerical solutions are often not. In fact, a person without such physical insights should not be entrusted with a powerful numerical tool to solve complicated problems, as such a person can have blind spots that harbor catastrophic consequences"*

With respect for this comment, solutions to a range of idealised examples of vertical groundwater flow are presented in this paper, including:

- steady and non-steady (transient) flows;
- homogeneous and heterogeneous geology, and;
- saturated and unsaturated flow systems.

The equations presented herein are unapologetically simple, being devised with the purpose of providing a framework for explaining the observed effects on groundwater systems from large-scale depressurisation of underground regions, such as from longwall mining and coal seam gas production (CSG). The specialist literature contains many theoretical analyses of vertical flow, far more sophisticated than those presented herein (eg Philip,1986).

The findings, specifically those related to unsaturated groundwater flow, are considered to be of appreciable importance to those concerned with minimising impacts on groundwater from longwall mining or CSG, and it is believed that these findings have, at this time, not been fully appreciated or purposefully applied.

Due to publication constraints, this paper has been split into two sections. The first part, this paper, contains the theory. Equations are presented and are tested against the results of: physical model tests, based on those of Darcy and Baumgarten in 1833, and; against numerical solutions. Limitations in certain software packages, which are known to some specialists but may not be widely appreciated, are also briefly presented.

The mathematical results presented herein lead to some immediate practical conclusions that are touched on in this Part 1. However, field data and interpretative remarks, related to the topics of longwall mining and coal seam gas production are presented in Part 2. Those practical considerations make reference to the theoretical framework established herein.

2 STEADY STATE DOWNWARDS FLOW

2.1 VERTICAL FLOW TO UNDERGROUND WORKS

Longwall mining regions in the Sydney basin are typically 2km to 3km long and between 250m and 400m wide. In the Appin region of the Sydney basin (the Southern Coalfields) the longwalls are at a typical depth of 450m. At Ulan, north-west of Mudgee they are typically between 150m and 250m deep. Proposed longwalls in the Wyong area are about 500m deep.

In an isotropic homogenous world, the long term, steady state groundwater flow system in terrain similar to the Southern Coalfields area, is represented in Figures 1 and 2. Prior to mining, groundwater flows from high ground towards rivers and the ocean, but after depressurisation at depth, and in the long term, there is flow down to the depressurised zone. With layered stratigraphy the flow pattern is more complicated and the time frame may be longer, but conceptually the changes are similar.

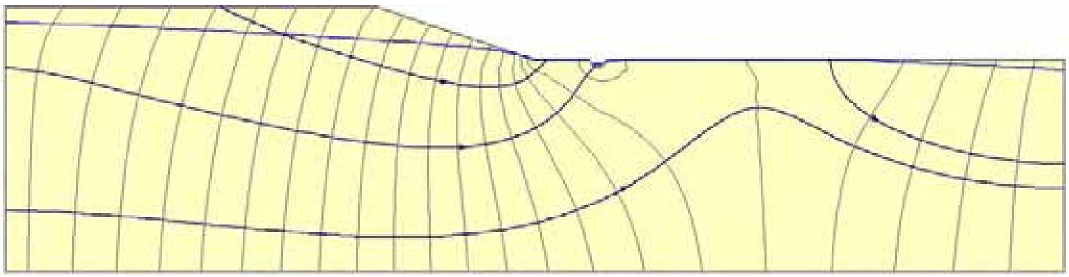


Figure 1 – Example flow regime prior to mining;

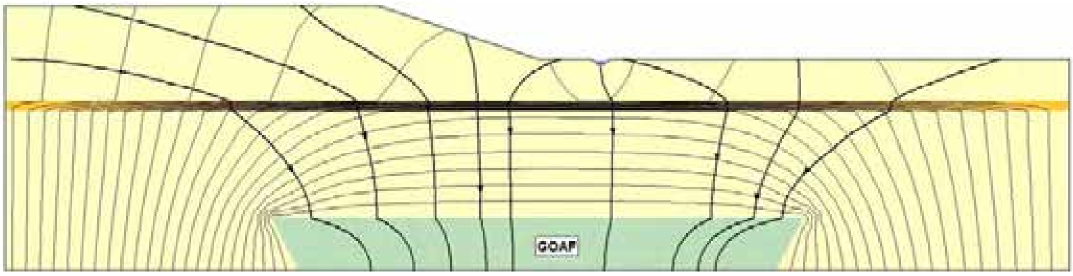


Figure 2 – Steady-state flow regime after mining 900m width of longwall panels

It can be seen that there is a central zone where the flow is close to vertical downwards, with horizontal flow into the sides of the set of longwalls and along the coal seam. We consider that proper understanding of this simple flow situation is critical to understanding the more complex picture.

2.2 PROBLEM CONCEPTUALISATION

We consider a stratified column of length “L”, width “W” and unit thickness (ie. into the page). The notation used to describe the column is as shown in Figure 3.

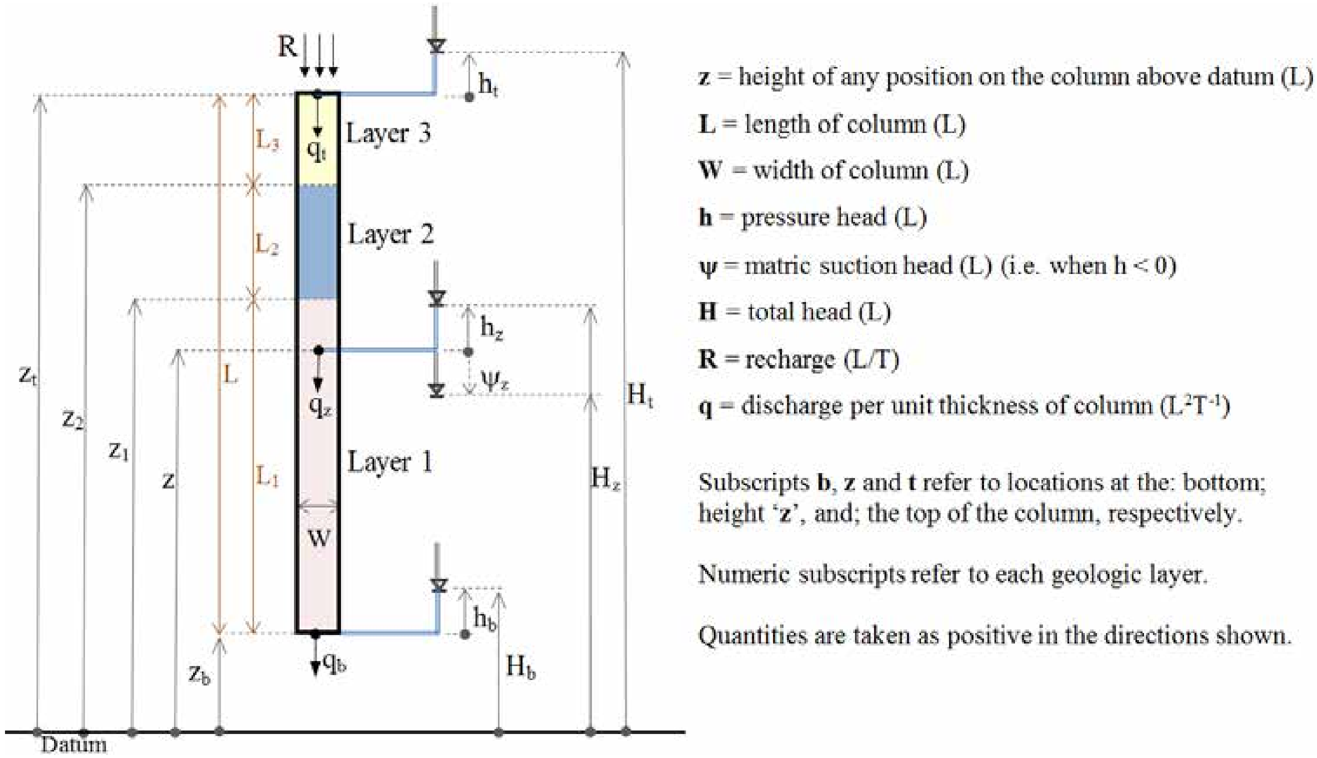


Figure 3: Model for a Stratified Column

The total head is the sum of pressure head and elevation:

$$H_z = z + h_z \tag{1}$$

Steady discharge through the column "q" is given by Darcy's law as

$$q_{steady}(\text{for } q_t = q_b, when\ time \rightarrow \ \infty) = \mathrm{R.W} = \ k.i.W \tag{2}$$

Where: i = the hydraulic gradient over the column $= \frac{H_T - H_b}{z_t - z_b}$ (3)

k = the hydraulic conductivity, and where, for a heterogeneous column k is taken as 'k_{eff}' which is given by:

$$\frac{L}{K_{eff}} = \left[\frac{L_n}{k_n} + \frac{L_{n+1}}{k_{n+1}} + \frac{L_{n+2}}{k_{n+2}} + \ \dots\right] \tag{4}$$

The total head at any point in the column is given by:

$$H_{z_n} = H_{z_{n-1}} + \frac{q(z_n - z_{n-1})}{k_n W}$$

$$= H_{z_{n-1}} + \frac{qL_n}{k_n W} \tag{5}$$

where: subscript 'n' refers to the nth layer from the base.

For a homogeneous column, this can be reduced to:

$$H_z = H_B + \frac{q(z - z_b)}{kW} \tag{6}$$

The distribution of pressure head throughout the column can then be found by application of Equation (1).

2.3 SATURATED FLOW EXAMPLES WITH VARIOUS RECHARGE CONDITIONS

2.3.1 Saturated Vertical Flow in the Presence of Excess Recharge

Many geotechnical texts present examples of groundwater flow which occurs in the presence of 'excess recharge'. Under this condition, it is assumed that rainfall of a sufficient intensity is delivered to maintain saturation of the ground, but without any development of ponding at the surface. Excess rainfall moves away as runoff.

This creates an idealised condition such that the pressure head at the top of the column '$\mathbf{h_t}$' remains constant at zero and, if the pressure at the base is zero, a hydraulic gradient of unity prevails. A common application of this assumption is demonstration of zero pore pressures behind a retaining wall in the presence of an idealised vertical flow field.

Equations (1) to (6) were solved for a number of generalised cases under the assumption of 'excess recharge' - pressure head at the top of the column 'h_t' was held constant at zero and the representation of underground works achieved by a reduction in the pressure head at the base ('$\mathbf{h_b}$').

Figure 4, Case A, shows an initial situation under hydrostatic conditions. Total head is constant, and pressure head increases linearly with depth. All the other cases presented in this paper should be compared, mentally, with the hydrostatic case. Cases B and C in Figure 4 are for partial and total depressurisation at the base under steady, saturated, homogenous conditions.

If the vertical column is layered (heterogeneous), then matters get a little more complicated, as indicated in the three examples in Figure 5, for different variations in permeability and basal depressurisation.

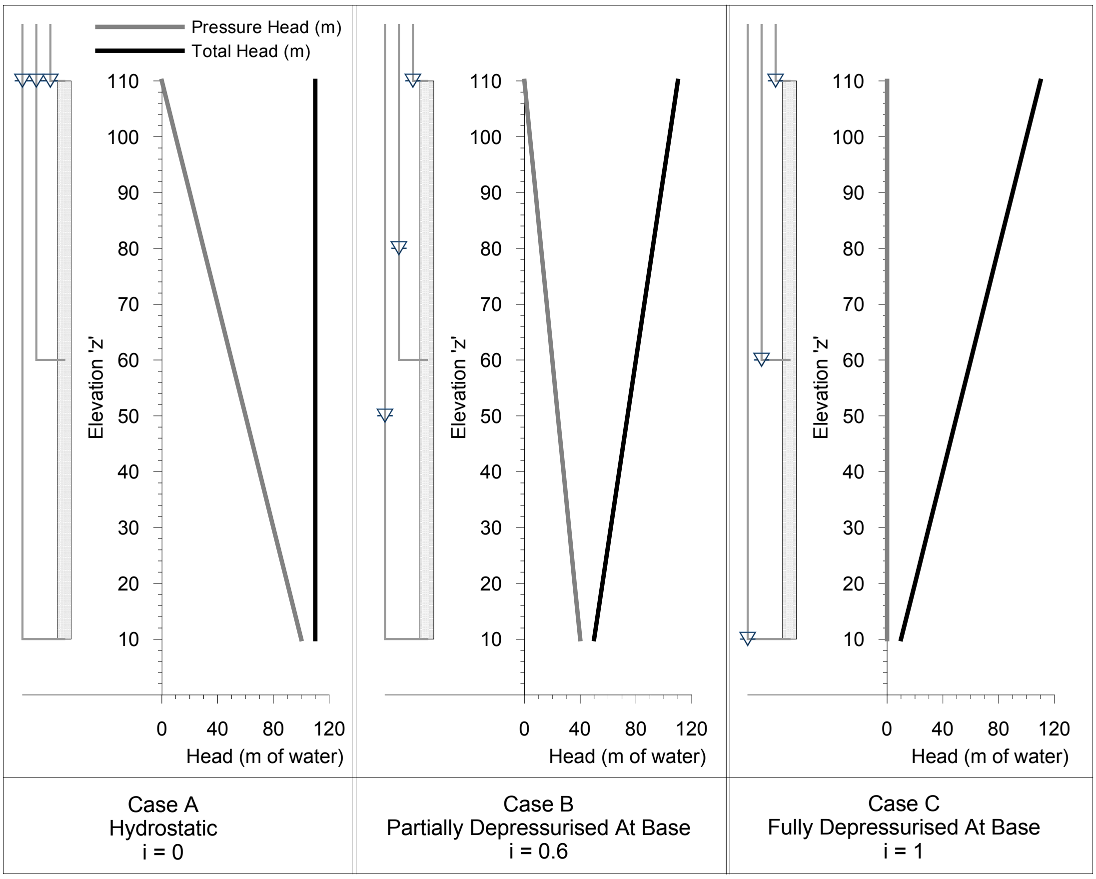


Figure 4: Steady saturated downwards flow, homogenous earth and 'excess recharge'

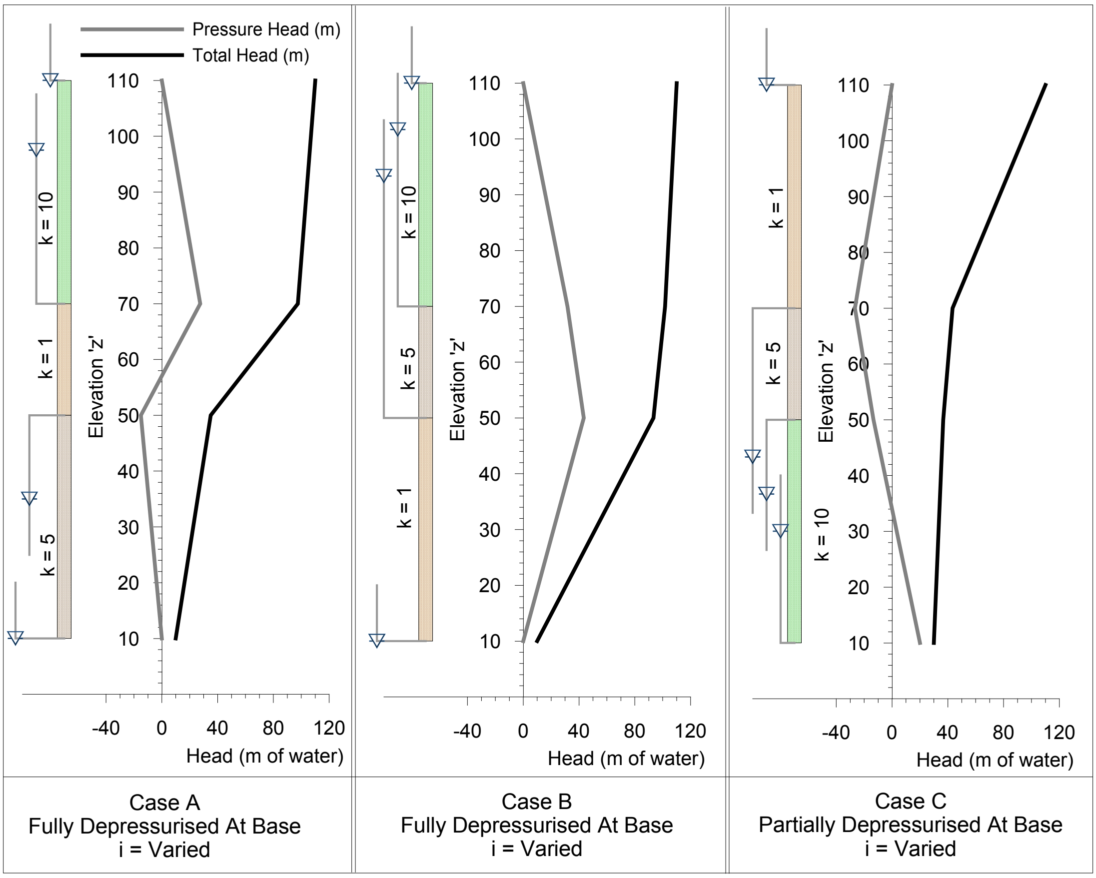


Figure 5: Steady, saturated downwards flow through layers of different permeability and with 'excess recharge'

2.3.2 Saturated Vertical Flow in the Presence of Limited Recharge

In real-world conditions the assumption of excess recharge is not always valid. It can be shown from Equation 2 that when underground works reduce the local pressure to zero, the recharge required to maintain saturation throughout the column occurs when the ratio **R / k** (or $\mathbf{R / k_{eff}}$ for heterogeneous formations) is greater than unity.

Typical values for hydraulic conductivity for various formations are presented in Figure 6 in terms of metres per second ($m.s^{-1}$) and metres per day ($m.day^{-1}$). For reference, a scale in units of millimetres per day ($mm.day^{-1}$), the typical units of recharge, is also shown.

Typical recharge values in the Sydney Basin are less than 40 mm per year (Australian Rainfall and Runoff, 1987). Therefore, according to Figure 6, it would not be possible to maintain saturation at or near the surface, in the long term, if depressurisation occurs at depth. Desaturation of part, or all, of the column must ensue.

This can also be explained in terms of a "continuity of mass" principle, which states that the change in storage for a closed system is equivalent to the difference between inflows and outflows. Depressurisation at the base of this ideal column will, eventually, maintain an outflow velocity equivalent to the hydraulic conductivity of the formation (or k_{eff}, for a heterogeneous formation). The inflow, on the other hand, is limited by recharge availability which, in the Sydney basin, is typically a lesser quantity. Hence, over time, the storage of water in the column will decrease. Under a steady state condition (ie in the 'long term'), the storage will be completely depleted.

How long is 'long term', is dealt with later is this paper.

Examples using recharge values less than the critical value for 'excess recharge' are presented in Figure 7. These analyses allow negative pore pressures to develop but do not allow air to enter the system. In other words saturated permeability is maintained.

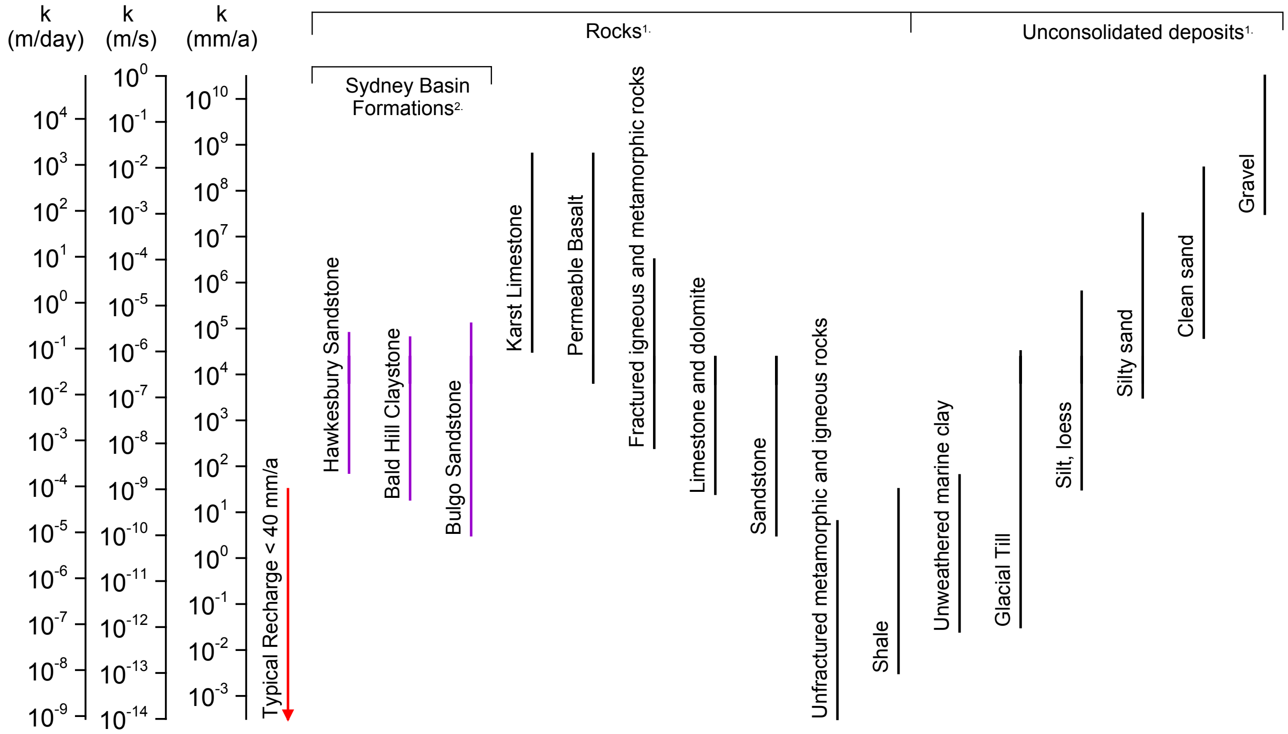


Figure 6: Hydraulic conductivity and recharge
(1. Freeze and Cherry, 1979; 2. Part 2 of this paper)

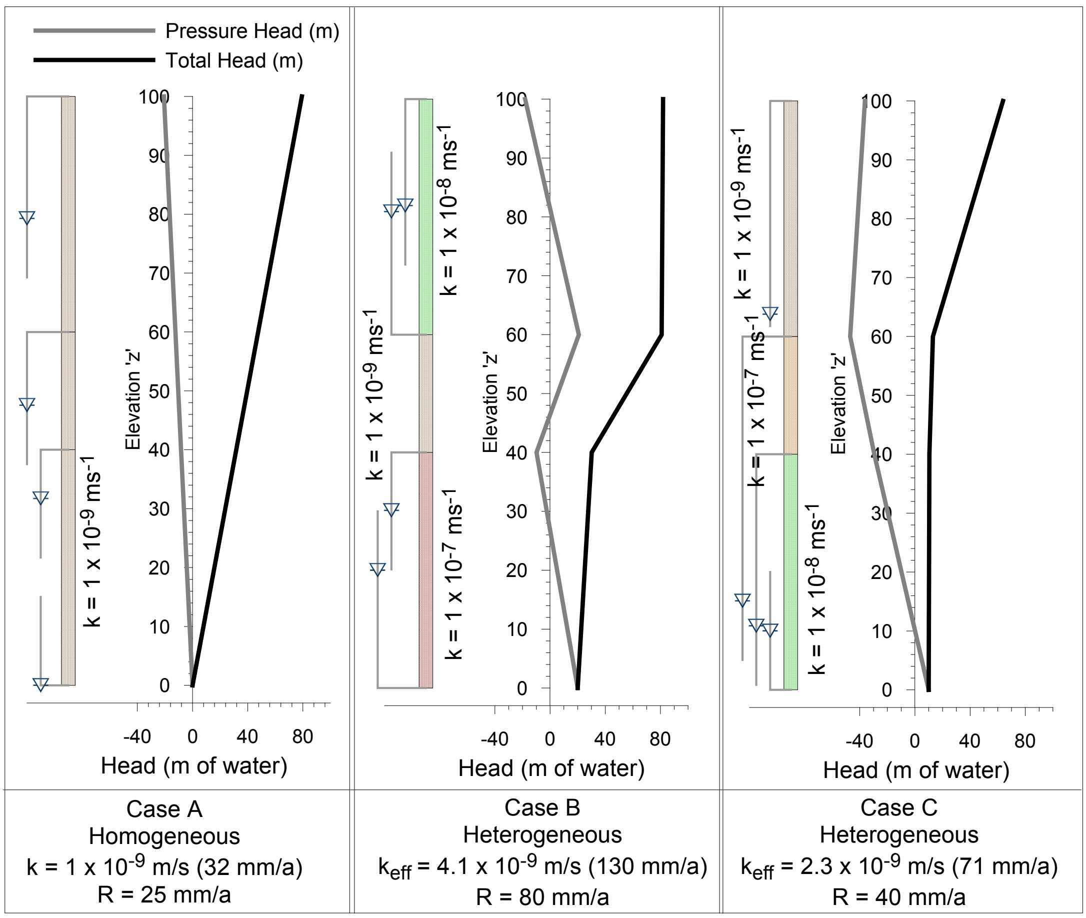


Figure 7: Effect if limited recharge, using 'real world' values (R < k_{eff})

2.4 EFFECT OF UNSATURATED FLOW

2.4.1 Permeability Changes Due to Desaturation in Soil and Rock

It is well established that, for a given material, the hydraulic conductivity when partly saturated is much lower than the saturated hydraulic conductivity. Various equations have been proposed to represent the change in hydraulic conductivity as a function of matric suction in soils. The Van Genuchten (1980) solution is given as Equation (7) below.

$$\mathrm{k}_{unsat}(\psi) = k_{sat}.k_r(\psi) \qquad (7)$$

where: $\mathrm{k}_{\mathrm{sat}}$ = saturated hydraulic conductivity

$$\mathrm{k}_{\mathrm{r}}(\psi) = \left[\frac{\{1-(\delta\psi)^{n-1}[1+(\delta\psi)^{n}]^{-m}\}^{2}}{[1+(\delta\psi)^{n}]^{m/2}}\right]$$

n and δ are factors and m = 1-1/n

In Figure 8, the relationship of $\mathrm{K_r}(\psi)$ to matric suction (m head) is presented, based on solution of Equation (7) using various of Van Genuchten's values for n and δ. The fitted data come from University California, Davis (Course SSC107, Chapter 4, 2000). It can be seen from Figure 6 that there can be many orders of magnitude reduction of hydraulic conductivity due to desaturation., and these can occur at quite small matric suctions.

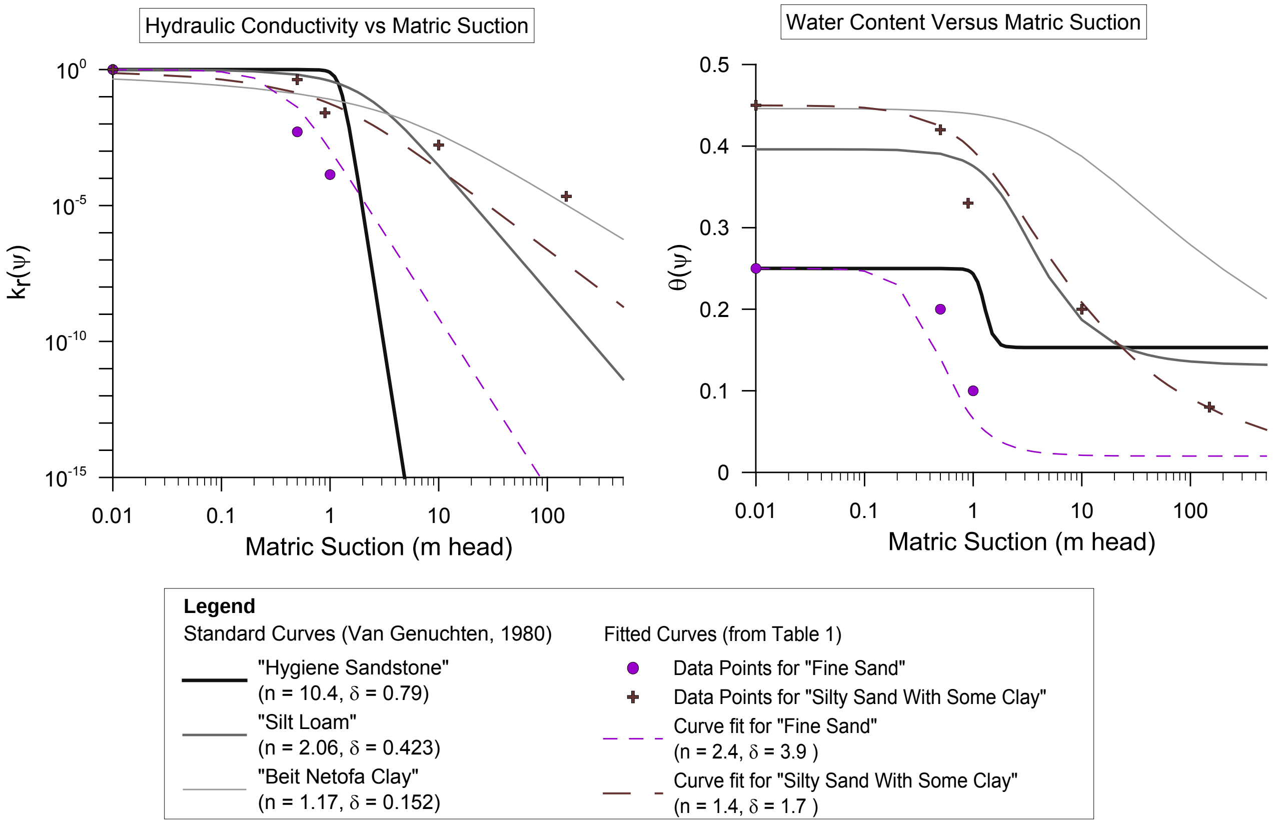


Figure 8: Hydraulic conductivity and soil moisture content versus matric suction (m)

There is scant knowledge as to the appropriate functions for jointed rock masses, and this is an area requiring substantial research. Our present understanding, as discussed below, is that, in a jointed rock mass, permeability reduction when desaturated is similar to the dramatic reduction indicated by the Van Genuchten equation.

Consider a borehole intersecting fissures in a rock mass, as shown in Figure 9. If we have 'N' fissures over a length 'L', then from the fluid mechanics of flow (Morgenstern, 1967) along a planar gap we have:

$$Q = \frac{NL(P_0 - P_r)d^3\,\Pi}{6uLog_e(\frac{r}{r_o})} \qquad (8)$$

Where: u =viscosity

P =pressure

$d, P_0,\ P_r,\ r,\ r_0$ as shown in Figure 7

If the same borehole were in a uniform permeability, porous, medium we would have:

$$Q = \frac{2\,\Pi L\,k(P_0 - P_r)}{\gamma_w Log_e(\frac{r}{r_o})} \qquad (9)$$

Where: k = hydraulic conductivity = $\frac{K\gamma_w}{u}$
K = true 'Darcy' permeability having the units L^2

Thus from equations 8 and 9 the hydraulic conductivity for the simple jointed model is

$$k = \frac{Nd^3\,\gamma_w}{12u} \qquad (10)$$

So we see that the hydraulic conductivity is a function of the cube of joint opening.

In real rocks the joints are not smooth, and equation 9 can be written

$$k = \frac{cNd^3\,\gamma_w}{12u} \qquad (11)$$

Where: c = roughness value, equivalent of tortuosity.

The fundamental permeability is:

$$K = \frac{cNd^3}{12} \qquad (12)$$

Equation (12) can be used to demonstrate why fissure flow dominates rock mass permeability. For example, suppose we have a rock substance with hydraulic conductivity of 10^{-10} m/sec. If we have one fissure with a gap of .0075mm (7.5 micron) every 0.3m then the mass permeability is 10^{-6} m/sec.

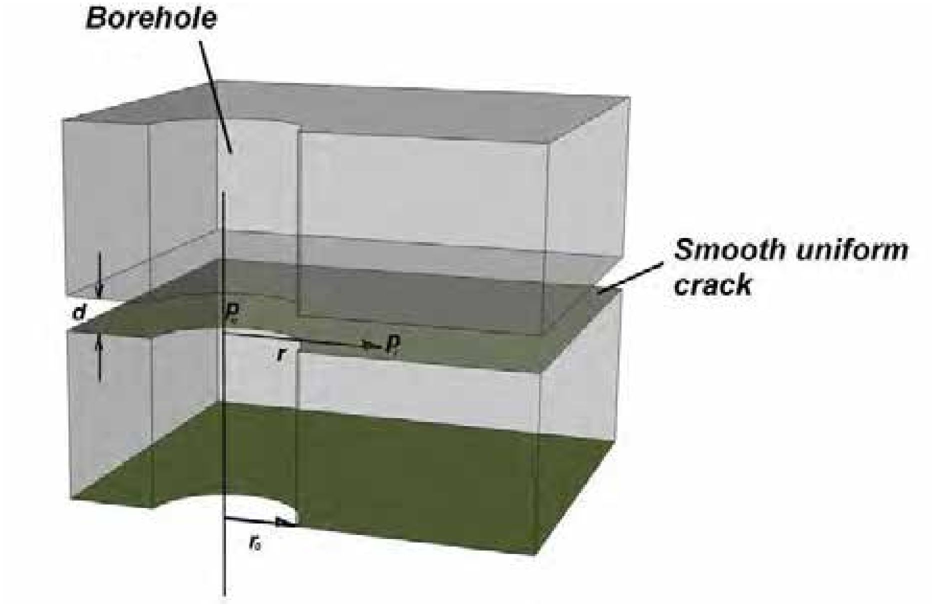


Figure 9: Model of fracture flow in rock.

Some quite substantial research has been conducted on fissure flow taking into account that real fissures are rough and in contact in many places over diverse areas. Kilbury, Rasmussen and Evans (1986) conducted field measurements in a welded tuff that supported the cubic relationship of Equation 10. They computed fissure apertures of between 10 and 35 micron (m^{-6}). Moreno et al (1988) pointed out that flow channelled through the most open areas of joints, with many dead areas of almost no flow. Clearly their findings must be taken into account in assessing joint permeability under partial saturation, as air first forms flattened bubbles in the most open parts of fissures.

Most of the above material is drawn together by Peters and Klavetter (1988) in conjunction with research done for a nuclear water repository in Yucca Mountain. The gist of their findings is that fissures dewater at suction of less than 1m and thereafter flow along fissures is trivial, and flow through a rock mass is controlled by hydraulic conductivity of the matrix.

Based on the test data, and theory, presented by Peters and Klavetter, it hypothesised that the relationship between hydraulic conductivity and matric suction for Triassic rocks of the Sydney Basin as set out in Table 1.

Table 1 Hypothesized hydraulic conductivity versus matric suction, Triassic rocks of the Sydney Basin

Matric Suction metres	**Hydraulic Conductivity**
0	Saturated value for the jointed rock mass as measured by field tests; typically about 1 x 10^{-8} to 1 x 10^{-9} for Hawkesbury Sandstone
-1.0	As above
-5.0	Matrix permeability. This is between 5 x 10^{-11} and 1 x 10^{-9} m/sec for Hawkesbury Sandstone.
-10	About 10^{-11} to 10^{-12} m/sec
-100	About 10^{-14} m/sec

As will be shown below, and in Part 2 of this paper, this is a very important area warranting research, because reduction in permeability in unsaturated zones can be, in-effect, a form of self-grouting

However, one word of caution is warranted. Major fault structures can dominate field behaviour because their saturated hydraulic conductivity may be orders of magnitude greater than the typical rock mass.

2.4.2 Examples Highlighting the Effects of Desaturation on Vertical Flow

Consider Case B from Figure 7 above. Saturated flow theory predicts that, over time, the pressure will decrease below atmospheric pressure at the elevation of approximately 40 m in the column, due to the characteristics of the layering relative to recharge. If air (or gas) is allowed to enter, the formation may begin to desaturate at this location.

Desaturation lowers the hydraulic conductivity at this location, forming, in effect, a new layer retarding vertical discharge. The column below the new retarding layer, starved of flow from above, but still capable to transferring flow downward, will begin to desaturate further. A positive feedback loop is thus formed, as further desaturation leads to further reductions in hydraulic conductivity, and so on.

Above the obstruction, downflowing water will begin to gather, increasing the potential to resaturate the obstruction. Depending on: the nature of layering; the available recharge, and; the relationship of hydraulic conductivity to matric suction, a number of outcomes may occur.

Interestingly, one possible outcome is the rapid formation of a self-sealing system. Continuing with the concept of Equation 3, the occurrence of de-saturation will change the effective hydraulic conductivity 'k_{eff}' of the column, and therefore control to what extent, if any, groundwater resources at the surface are affected. Inflow into a longwall mine, for example, may be reduced significantly due to the nature of any such desaturation.

The effect of unsaturated flow is therefore of key interest to this study. Desaturation introduces a new facet of heterogeneity. In hydrogeologists terms, processes of desaturation and re-saturation potentially have the power to dynamically create and extinguish aquitards.

Analyses of unsaturated flow for the same conditions as given in Figure 7 are summarised in Figure 10, by application of Equations (1) to (7), and using the Van Genuchten relationship given in Figure 8 (values for 'Hygiene Sandstone' assumed). It can be seen that the development of unsaturated flow conditions are effective in reducing the extent of depressurisation. This effect of unsaturated flow was examined with a physical model, as described below.

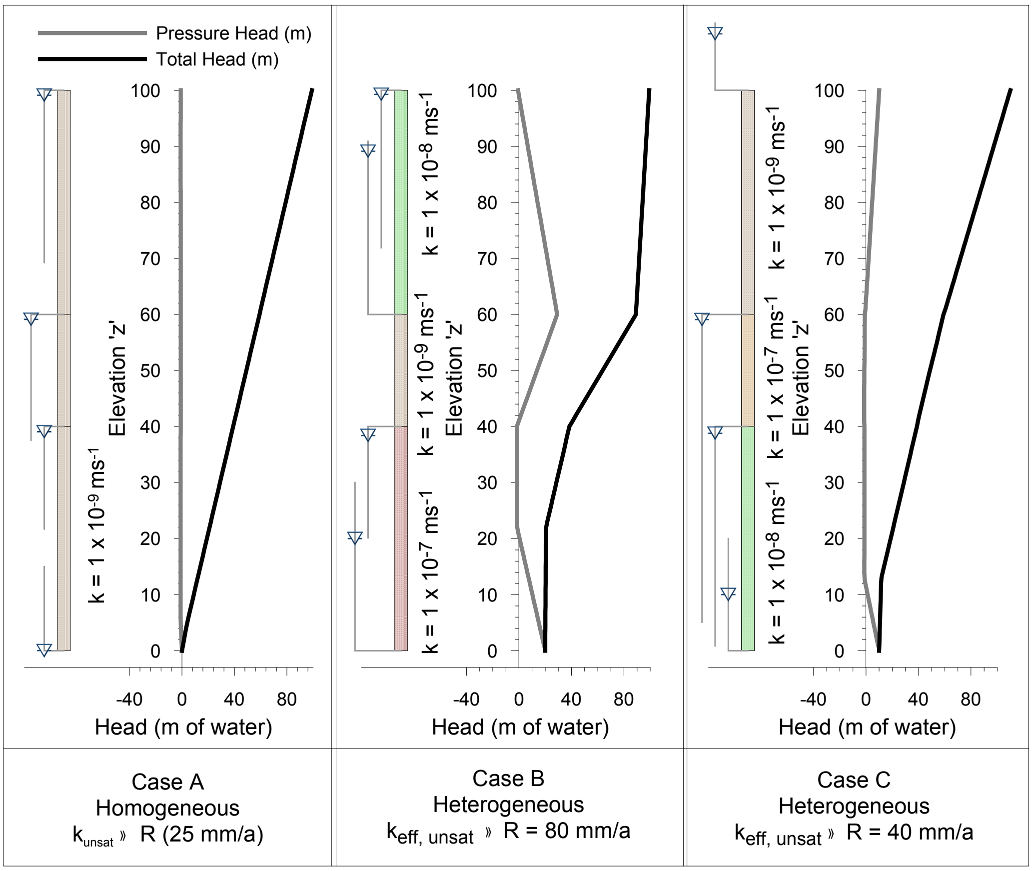
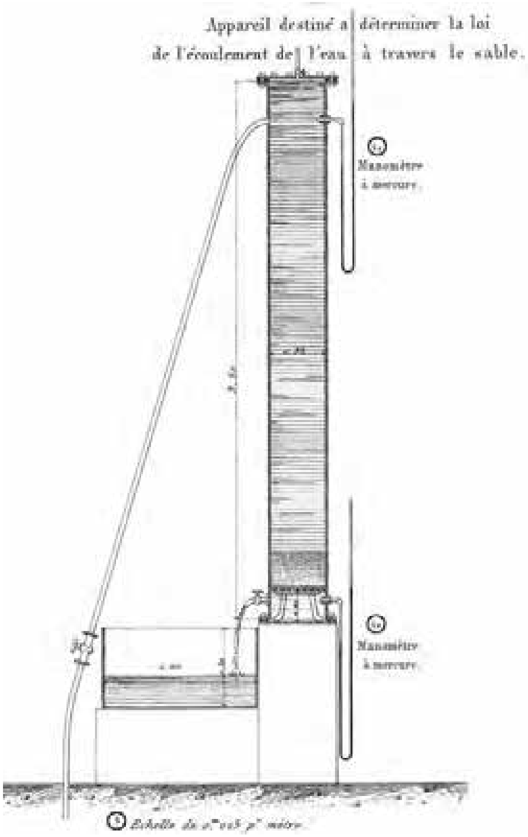


Figure 10: Steady state unsaturated flow examples (cf to Figure 7)

3 PHYSICAL EXPERIMENT



The test apparatus shown in Figure 11 is that used by Henry Darcy in 1855, from which were developed the widely used equations of groundwater flow.

Darcy's column was made of steel, with sealed, bolted plates, top and bottom. Darcy used a coarse sand and he did his initial tests with pressures at the top of the column of between 1m and 12m excess head, and free flow through a tap at the base. Subsequently his offsider, Ritter, repeated the experiments with heads between - 3m and + 10m at the base. An important consideration is that there was no means for air to enter the sand column, even when Ritter had negative heads up to 36kPa.

We constructed a similar test apparatus, featuring a 240mm internal diameter acrylic tube. The column was filled with a 1.875m height of coarse river sand. Manometers were connected at: 385mm; 781mm, and; 1183mm above the base of the sand (see Fig 12). The coarse sand was not expected to exhibit a great reduction in hydraulic conductivity with increasing matric suction, but we hoped to see some effect.

Figure 11: Darcy's experimental setup, 1855

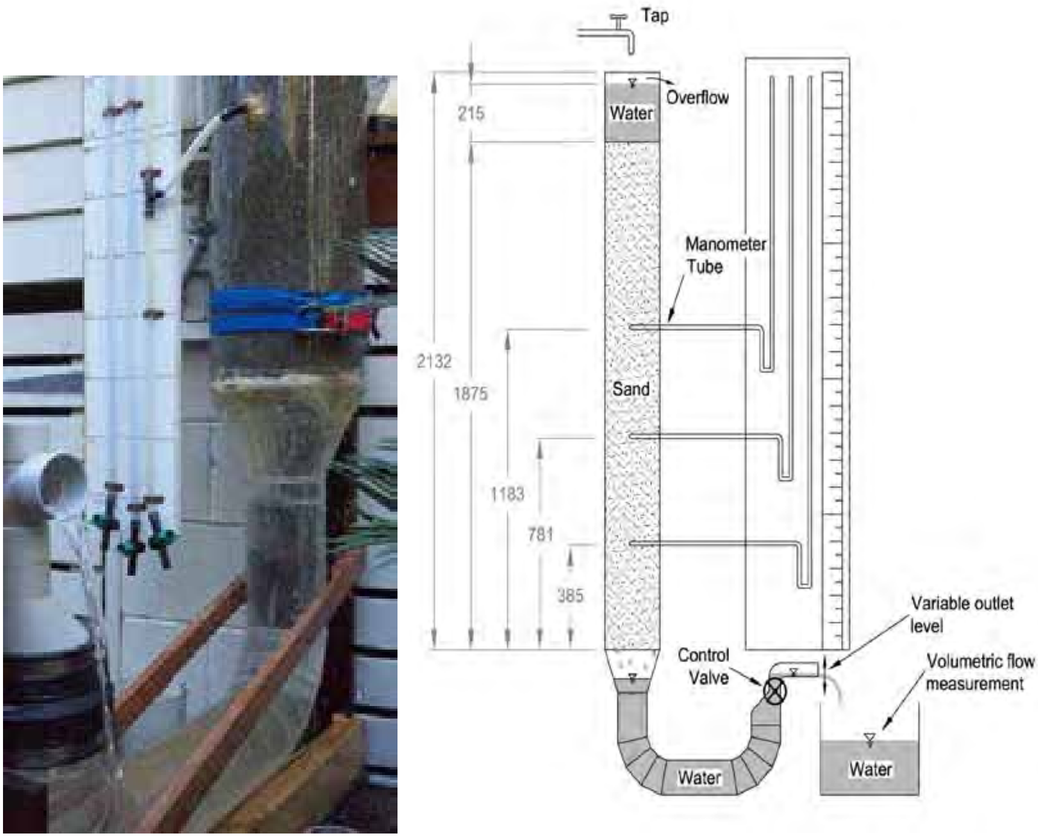


Figure 12: Details of the Model

The tests were conducted with a constant head of 215mm above the top of the sand. The initial tests maintained the head at the base equal to base level, therefore giving a head loss of 2.09m over the sand column of 1.875m (i=1.115). Tests were also run with the outlet throttled so as to decrease the gradient, which was then measured using the manometers. These measurements gave an average permeability of 2.1×10^{-4} m.sec^{-1}. Using the throttled outlet manometer measurements showed that the upper part of the column was slightly less permeable than the lower

With constant upper head level, the conditions at the base of the column were changed to cascading flow (see Fig 13).

Figure 13: Final test; water allowed to cascade from base of column

Three things happened:

1. The total flow decreased by about 3% - consistently and repeatably
2. The pressures in the upper two manometers increased a small amount; about 5mm of water
3. The lowermost manometer, 385mm above the base, sucked in air; it could be seen through the perspex that most of the lower part of the sand column contained void air.

The *reduction* of flow observed alongside an *increase* in the head potential is not explained by saturated flow theory. The observations are consistent, however, with the unsaturated flow processes as described above. Specifically, the desaturation of the base of the column resulted in lowering of the hydraulic conductivity at this location, reducing outflow and simultaneously increasing potential further up the column. The experiment was simulated near perfectly by finite element analysis using software by Rocscience.

4 NON-STEADY VERTICAL FLOW

The above steady-state analyses show the ultimate predicted effect on the draining of the column due to underground works. Non-steady (transient) flow analyses were also undertaken to examine how long it takes for these effects to develop.

To examine transient flows, consideration must be given to the changes that occur over this time in water stored within the geological material. We have to consider the volume of water that a unit volume of ground will release under a unit decline in hydraulic head, plus water that may drain from voids.

The specific storage "S_S", is defined as:

$$S_S = \rho_w g(\varepsilon + \emptyset\beta) \tag{13}$$
$$= \rho_w g m_v$$

where:
- S_S = specific storage (L^{-1})
- r_w = mass density of water ($M.L^{-3}$)
- g = acceleration due to gravity ($L.T^{-2}$)
- ε = compressibility of the aquifer matrix ($T^2.L.M^{-1}$)
- ϕ = porosity
- β = fluid compressibility ($T^2.L.M^{-1}$)
- m_v = coefficient of compressibility ($T^2.L.M^{-1}$)

Transient groundwater flow through a column can be described by the diffusion equation which is, (in 1D):

$$\frac{d^2h}{dz^2} = \frac{S_S}{k}\frac{dh}{dt} = \frac{1}{\alpha}\frac{dh}{dt} \tag{14}$$

where:
- S_s is the aquifer specific storage (L^{-1})
- α is called the hydraulic diffusivity (L^2/T)

Hydraulic diffusivity "α", is permeability divided by specific storage, and, as such, takes into account the compressibility of the skeleton. Equation 14 is the same as Terzaghi's equation for consolidation, with hydraulic diffusivity being the inverse the Coefficient of Consolidation.

In the real world, hydraulic diffusivity varies by over 8 orders of magnitude. Hence, the rate of change in pressure in an aquifer due to seepage processes also varies by this range from site to site, depending on the geological characteristics. As such, there is no simple one-off description of the time frame of impacts from underground works.

The process of depressurisation of a homogeneous column can be estimated using Equation (15).

$$\Delta H_{z,t} = \Delta H_{b,t=0} \times erfc(\lambda) \tag{15}$$

Where:
- erfc( ) is an error function (note: an existing Microsoft Excel function)
- $\lambda = \frac{z}{2\sqrt{\alpha t}}$

Equation (15) is modified from one commonly provided in hydrogeological texts as a solution to aquifer flow due to sudden change at a boundary (In Kresig (2007), the equation is credited to Lebedev, in Huisman (1972) it is credited to Edelman). It accurately simulates transient flow through the column as validated against various numerical solutions.

Equation (15) was used to solve some examples of depressurisation and dewatering of a homogeneous formation shown in Figure 14. The analysis of depressurisation and dewatering of a heterogeneous formation is more complex, and numerical techniques (using SEEP/W) were adopted to solve the selected examples given in Figure 15.

The hydraulic diffusivity "α" was kept as a variable in Figures 14 and 15. The reader can apply values applicable to their region of interest to view estimates of the timing of depressurisation of an aquifer due to vertical flow into an underground cavern.

To give further indications of the range of rates of depressurisation, the time taken for the depressurisation through a one dimensional profile was assessed using numerical techniques, for cases as presented in Figure 16.

The initial conditions for each column comprised a hydrostatic pressure distribution with a water table at the ground surface. At t=0, the pressure at the base was instantaneously reduced to zero, and the time taken to reduce the head by 0.1 m, 1 m and 10 m, at a location at 80% of the column height was assessed, and is tabulated in Table 3 below. This was repeated for analyses based on saturated and on unsaturated flow mechanics.

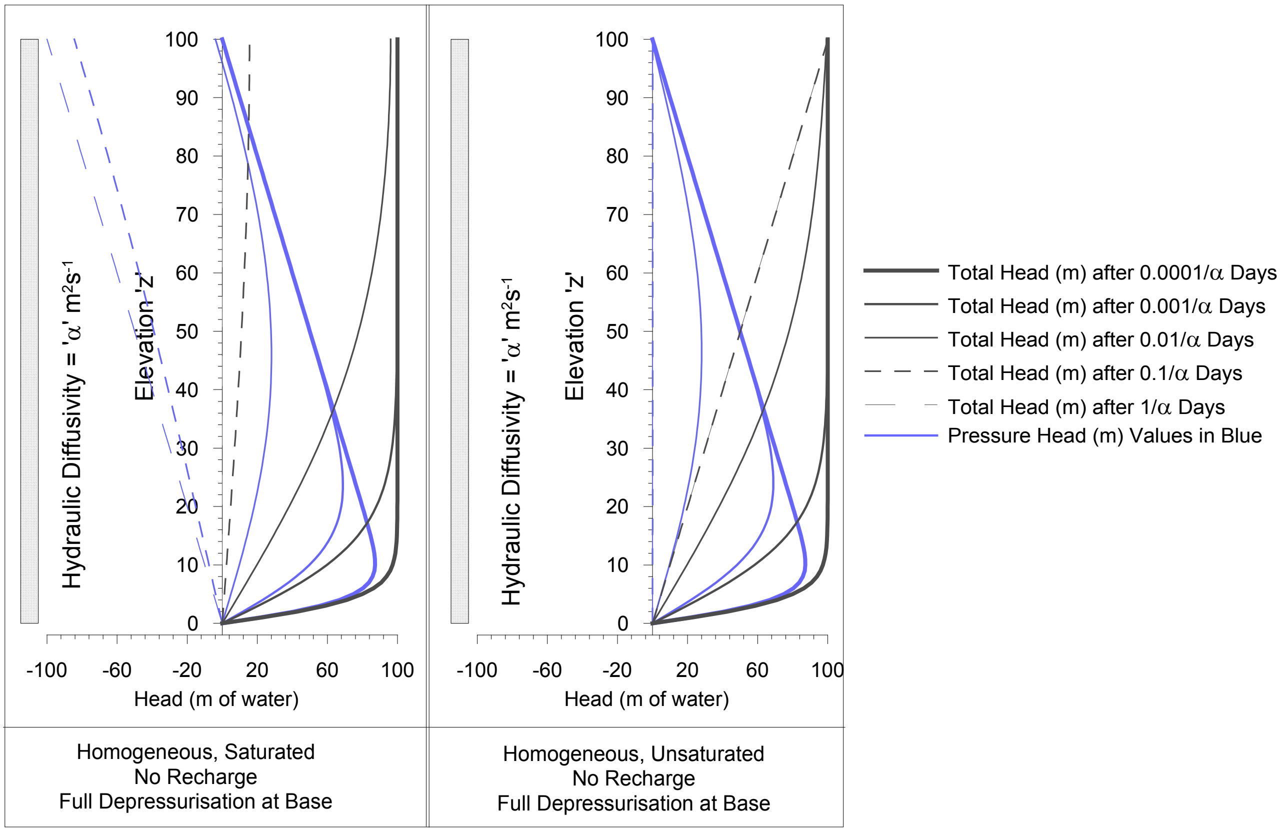


Figure 14: Transient depressurisation of a homogeneous column

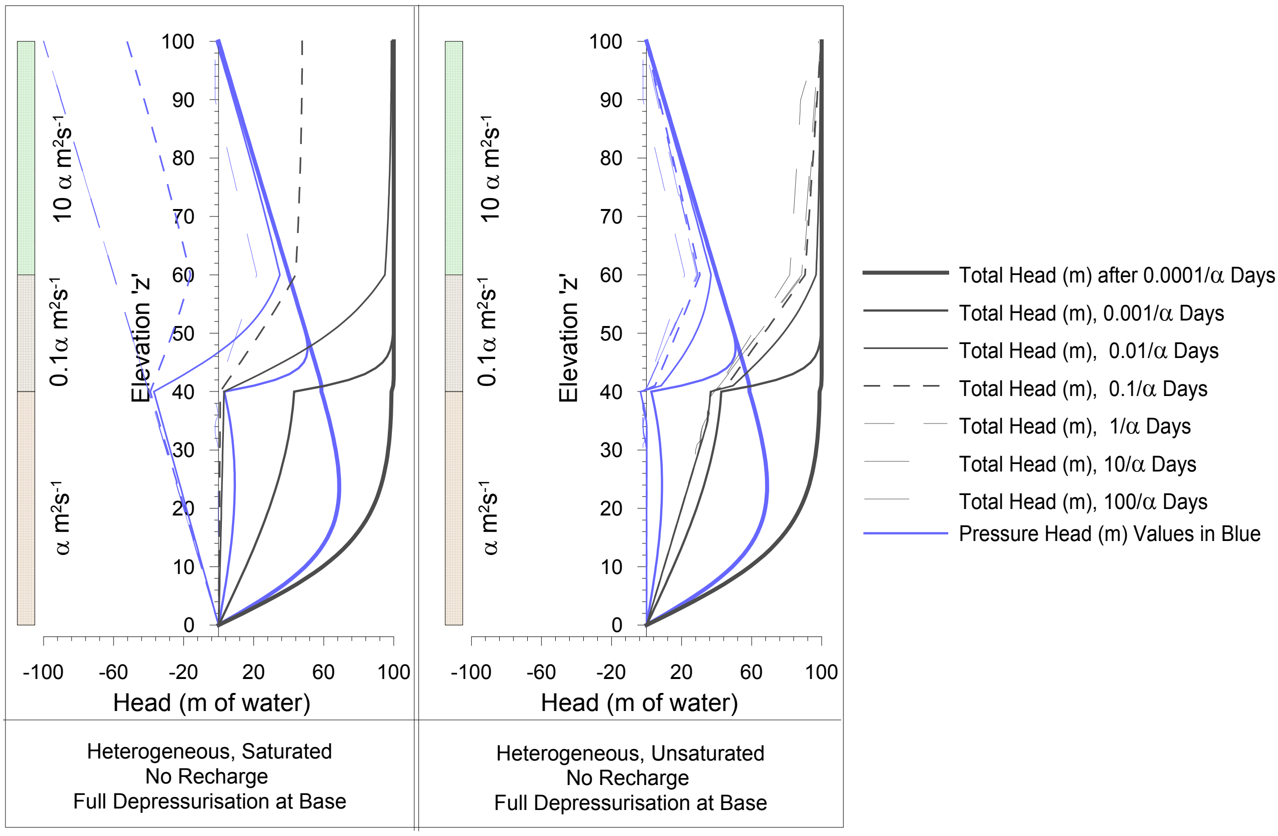


Figure 15: Transient depressurisation of a heterogeneous column

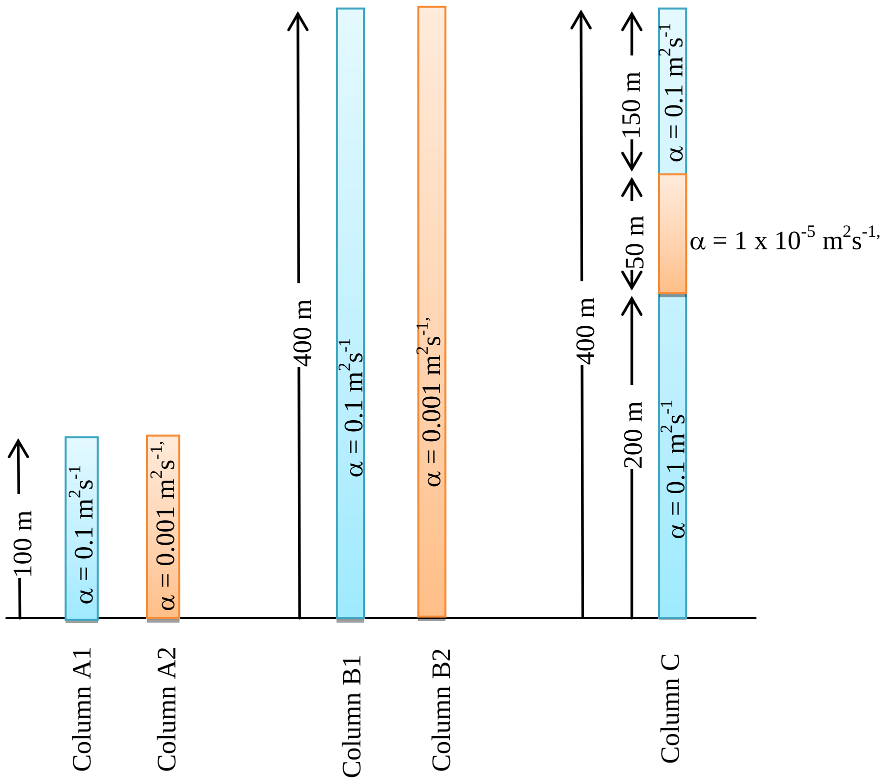


Figure 16: Some cases that may represent profiles above a depressurised coal seam

With reference to Table 3, it is noted that the inclusion of unsaturated flow equations does not significantly alter the result. The exception is where an aquitard is present (Case C), for which the effects of unsaturation which develop below the aquitard have a profound effect of delaying the process of depressurisation of upper formations, as discussed in Section 2.4.2.

Table 3: Indicative times for depressurisation to travel upwards from coal seam level

Analysis	Column	Hydraulic Diffusivity m^2/sec	Indicative of:	Time Taken to Reduced Head at 80% Column Height by		
				0.1 m	1 m	10 m
Saturated	A1	0.1	Medium grained sandstone	45 Minutes	1.3 Hours	3.1 Hours
	A2	0.001	Fine grained sandstone	3.2 days	5.4 Days	12.7 Days
	B1	0.1	Medium grained sandstone	10 Hours	14 Hours	1.1 Days
	B2	0.001	Fine grained sandstone	40 Days	60 Days	115 Days
	C	Layered	Medium grained sandstone with shale band	170 Days	290 Days	1.8 Years
Unsaturated	A1	0.1	Medium grained sandstone	45 Minutes	1.3 Hours	3.7 Hours
	A2	0.001	Fine grained sandstone	3.2 days	5.4 Days	15 Days
	B1	0.1	Medium grained sandstone	10 Hours	14 Hours	1.1 Days
	B2	0.001	Fine grained sandstone	40 Days	60 Days	115 Days
	C	Layered	Medium grained sandstone with shale band	190 Days	76 Years	1350 Years

It should be noted that, in the numerical code MODFLOW (in its standard 'saturated flow' state), development of negative pressure heads results in 'drying' of cells which causes the cessation of any further flows past the dry cells. For example, where recharge is insufficient, and /or where layers of higher hydraulic conductivity underlie layers of lower hydraulic conductivity, cells will dry out and vertical flows will cease. This is illustrated in Figure 17 below. This drying mechanism mimics, but overstates, the sudden lowering of hydraulic conductivity due to desaturation. There are some ‘work-arounds’ in MODFLOW, but it is cautioned that this cell-drying error would give an erroneous (ie very optimistic) representation of the effects of longwall mining on groundwater resources.

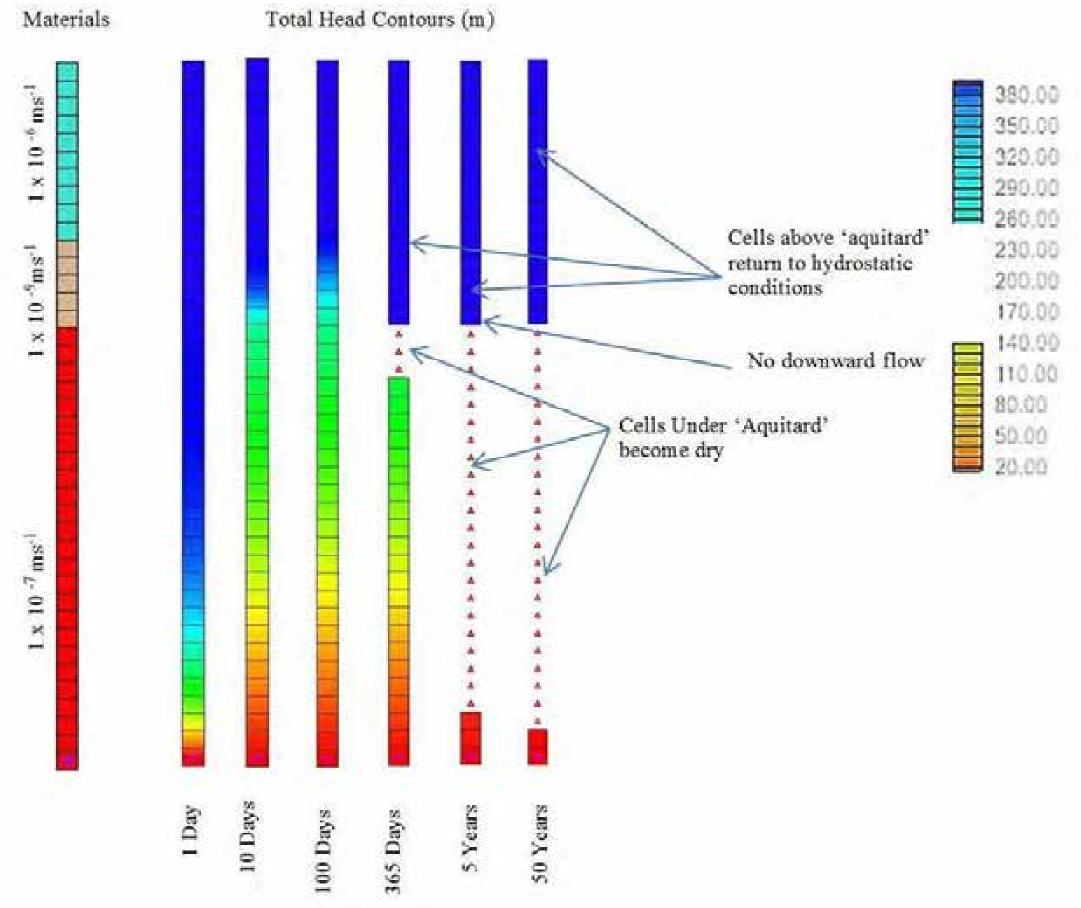


Figure 17: Example of Erroneous Representation of Vertical Seepage Flow in MODFLOW

5 SUMMARY OF FINDINGS

A range of analytical solutions have been presented for idealised cases representative of purely vertical groundwater flow from the land surface to a depressurised cavern. These solutions were validated against a physical model and numerical solutions. The solutions serve to highlight a number of interesting properties of vertical flow, which have important implications for design and assessment of longwall mining and coal seam gas projects. These are:

1. When vertical flow is present, the level of water that would be encountered in a bore is not equivalent to the position of the phreatic surface.
2. Piezometric heads throughout the column will ultimately be reduced significantly due to depressurisation at the base of the column. This impacts on the water levels encountered in bores placed in the column, as evidenced by the ‘stick plots’ shown in Figure 4. In cases where zero or negative pressures are developed, bores placed in the column could have no water at all despite the possibility of a water table being maintained at the surface.
3. Layering of the geology (heterogeneity) can result in a wide range of hydraulic gradients and development of negative pressures, leading to creation of a perched water table. This occurs in the presence of purely vertical flow - the presence of a perched water table does not indicate that vertical flow has ceased.
4. The effective saturated vertical hydraulic conductivity of a heterogeneous column can be estimated using Equation 4.
5. When excess rainfall recharge is available, the rate of vertical flow under a steady state condition is limited to the value of the effective saturated vertical hydraulic conductivity.

6. In many real-world cases, the quantum of recharge is less than the saturated vertical flow rate. In such cases, the impacts of depressurisation at depth are more severe than with ‘excess recharge’ - the steady state condition for homogenous formations is complete desaturation of the entire column. Regions of desaturation will also develop for heterogeneous formations, although a perched water table can still be maintained in perpetuity, depending on the nature and distribution of geological layers.

7. In regions where desaturation occurs and air is allowed to enter the formation, the hydraulic conductivity will be reduced in accordance with unsaturated flow theory. This reduction can be large.

8. The reduction of hydraulic conductivity can, in certain circumstances, lead to a positive feedback loop, allowing the formation to approach a self-sealing condition. This feature could be used purposefully by the mining industry to reduce mine inflows and impacts from mining activities.

9. There is a paucity of data on unsaturated hydraulic conductivity values applicable to fractured rock. Some guideline values applicable to the Sydney basin are proposed in Table 1, but further studies are required.

10. An estimation of the transient process of depressurisation through a homogeneous column can be calculated using Equation 15. For heterogeneous formations, numerical solutions are required. Estimations of the nature and rate of depressurisation through a vertical column can be found by using Figures 14 and 15.

11. The time taken for a depressurisation wave to move through a column is directly related to the hydraulic diffusivity of the formation, which ranges over many orders of magnitude in nature. Hence it follows that the rate of depressurisation will vary significantly (i.e. by orders of magnitude) from site to site.

12. The velocity that the wave of depressurisation moves through a formation is significantly faster that the velocity of seepage flow. This is analogous to comparing the water hammer wave propagation against the flow velocity in a pipeline.

13. The aquifer characteristics (ie hydraulic conductivity) does not alter the ultimate (ie steady-state) pattern and extent of depressurisation that occurs, it alters only the discharge under which is occurs. The quantity of water drawn by the underground works is therefore not, alone, a good indicator of the extent of depressurisation in the aquifer that is incurred.

14. The complexities of saturation and desaturation that are important for proper representation of vertical flow are not always represented well in popular numerical solutions. One important and common cautionary example is presented for the case of the MODFLOW numerical model.

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IMPACTS OF LONGWALL MINING AND COAL SEAM GAS EXTRACTION ON GROUNDWATER REGIMES IN THE SYDNEY BASIN PART 2 – PRACTICAL APPLICATIONS

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ABSTRACT

Part 1 of this paper presented simple equations for transient and steady state downwards flow, in saturated and unsaturated ground, that are considered to be useful in understanding flow and pressure regimes above extensive areas of longwall mining and coal seam gas extraction. This Part 2 paper presents field data from longwall mines in the Sydney Basin and relates the data to findings from Part 1. This Part 2 also analyses how different views have been expressed in relation to impacts of longwall mining on groundwater regimes, and proposes that these differences have largely arisen out of poor differentiation between seepage flows and pressures.

The field data presented in this part support a finding of Part 1, namely that the question that should be asked in respect to groundwater impacts from longwall mining, and CSG extraction, is not "if" impacts will occur, but "how long" will they take to occur.

1 INTRODUCTION

Impacts of underground coal mining on near-surface groundwater, and surface waters, in the Sydney Basin have elicited strong opposing views for about fifty years. Now those opposing views extend to coal seam gas (**CSG**) extraction. A link between these two activities is that both require substantial depressurisation and removal of groundwater from the coal seam. The strongly opposing views were encapsulated in the 1974-1975 Reynolds Inquiry into "Coal Mining Under or in the Vicinity of the Stored Waters of the Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs". For that Inquiry Messrs Orchard, Wardell, Williamson and Morton, working as consultants to the mining industry, expressed strong views that there was no downward flow through the Bald Hill Claystone and underlying Narrabeen rocks to the workings in the Bulli and Wongawilli seams. Equally, Professor John Knill and Messrs Williamson and Winchup, working on behalf of the Metropolitan Water Sewerage and Drainage Board concluded that downward seepage from the reservoirs was occurring and constituted a significant risk.

Not much has changed since 1975 and we must ask ourselves, why is this so given that all parties have access to the same facts. We think there are two reasons, one psychological and one technical.

The first reason is explained succinctly by psychologist Daniel Kahneman, 2002 Nobel Prize Laureate for Economics. He explains that we humans have two systems of thinking. System 1 operates automatically, quickly and with little effort. It is the originator of impressions and feelings that are the main sources for our explicit beliefs and deliberate choices of our second system of thinking. System 2 involves effortful mental activity, including complex computations; making choices, and decides what to do. However, a key point Kahneman makes is that "*System 2 is more of an apologist for the emotions of System 1 than a critic of those emotions – an endorser rather than an enforcer. Its search for information and arguments is mostly constrained to information that is consistent with existing beliefs.....*" This, we believe, explains our observation that publications on the issues of groundwater impacts show an almost one to one correlation between assessment of probable impacts and the authors' relationships to the mining and gas industries, or to environmentalist groups, or to their emotions about the environment, or their personal piece of countryside.

The second reason relates to differences of opinion regarding technical facets of groundwater impacts. These technical facets are the topic of this paper.

In Part 1 of this paper, analytical solutions to a range of idealised examples of vertical groundwater flow were presented with the purpose of providing a framework for explaining the observed effects on groundwater systems from large-scale depressurisation of underground regions, such as from longwall mining or CSG. In this paper, which is Part 2, the findings from theoretical analysis in Part 1 are applied with reference to factual data from the field, specifically within the Sydney geological basin.

The following technical matters are discussed.

- The differences between impacts of longwall mines, or CSG, on groundwater pressure and on groundwater flow.
- The impacts of heterogeneity and the nature of perched water tables, and 'disconnected' groundwater systems.

- The influence of lower permeability stratum on groundwater impacts, with specific reference to the Bald Hill Claystone found in the Sydney basin.
- Changes in hydraulic conductivity above longwalls due to fracturing.
- Transient effects and timing of impacts to groundwater systems.
- The effects of unsaturated groundwater flow, and important implications for groundwater impacts.

It is our aspiration that the material presented herein will assist with clarifying these issues from a scientific basis, and will assist with improving the quality of debate that is ongoing.

2 COAL MINING AND CSG IN THE SYDNEY BASIN

The reader may find descriptions of the stratigraphy of the Sydney Basin and underground coal mining operations in many publications (Herbert and Helby, 1980; Holla and Barclay, 2000)

In the Southern Coalfields, from which much of the field data are taken that are presented herein, mining is typically at depths of 200 to 500m. Very substantial areas have been extracted by both bord-and-pillar workings and longwall mines. For example in a 55km^2 area around Appin, the combined footprints of longwall extractions occupies 26km^2, and much of the remainder contains first workings.

While the only operating GSC extraction facility at the time of writing is at Camden (86 wells), huge areas are being explored covering thousands of square kilometres. There is the potential for thousands of wells, and in all cases the groundwater at seam levels has to be depressurised and extracted before the gas starts to flow in commercial quantities.

3 PIEZOMETRIC LEVEL DATA ABOVE COAL MINING IN THE SYDNEY BASIN

3.1 General Effects on Groundwater

Figure 1 presents the first 7 years of a 18 year record of multi-level piezometers data above a longwall mine near Cataract dam in the Southern coalfields. The timing of the passing longwalls 501 and 502, directly below the piezometers is also shown (Singh and Jakeman, 2001). Responses to the longwalls are observed, but the effects appear to be temporary for the shallower piezometers.

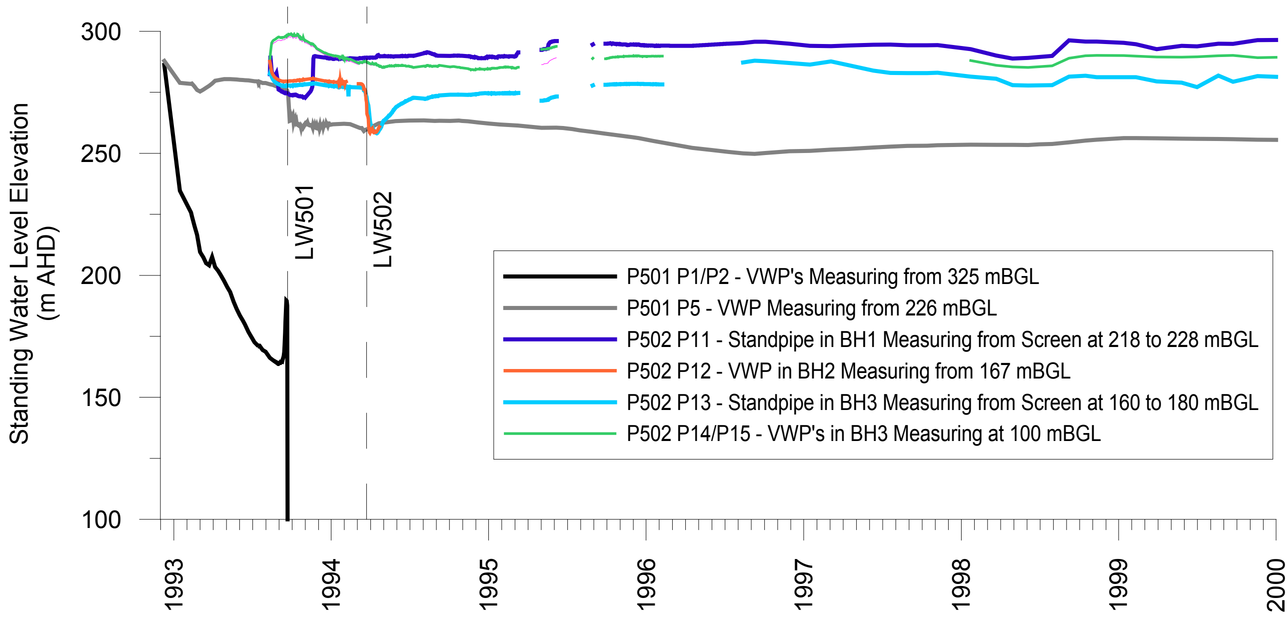

Figure 1 – Example of a Time-series of Piezometric Data from the Southern Coalfields During Passing of Longwalls

Such sudden decline and subsequent recovery has been observed at many mines (Matetic and Trevits, 1991; Booth et al, 1998; Booth, 2000). The rapid decline has been attributed to a temporary increase in secondary porosity during tilting and fracturing, and the subsequent recovery has been stated to be due to settlement of the overburden, reducing the secondary porosity again (ibid).

An expectation of continuing ground water recovery is reflected in many publications. Madden, et al (2009), citing Booth (2002), state that response of shallow confined groundwater systems to longwall mining includes a “long term groundwater level recovery due to settlement and recharge”. Booth and Spande (1992) and Booth (1999, 2006) document the recovery of groundwater levels over a 7 year period in a shallow, 25m thick, bed of sandstone overlying 170m of shale, following longwall mining in Jefferson County, Illinois. However, there is no record of recovery of the precipitous drop in piezometric level in the shale at 100m depth. As acknowledged in the above-cited papers, recovery does not always occur.

Clearly, once mining has completed, and the mine and shafts fill with water, groundwater levels will return toward pre-mining conditions, although the time and nature of recovery will vary from site to site. However, it is the 30 year to >100 year period between depressurisation at seam level and mine refilling that is of key interest in this paper.

In Part 1 of this paper, it is shown that in the Sydney Basin, even if no fracturing takes place, the capacity for saturated vertical seepage into lower, depressurised, strata is typically higher that the available recharge. It follows, then, that depressurisation will continue to propagate outwards from the depressurised strata throughout the period of dewatering. Where fracturing occurs, the capacity for saturated vertical seepage will be increased. Hence, while an initial response and recovery may be observed, an ongoing growth in impacts is expected during the operation of mines in the Sydney basin.

Many of the dramatic effects on groundwater from longwall mining are related to fracturing. As such, interpretations for whether recovery will or will not be observed are commonly also given in terms of fracturing (e.g. Jankowski, et al 2008). The corollary, tacitly assumed in many publications - that groundwater impacts from longwall mining (or CSG) are not expected where fracturing is not present - is not supported by the analyses in Part 1 of this paper.

3.2 Perched Water Systems and Downward Flow.

Selected case examples of multilevel piezometer data taken during longwall mine operations in the Sydney Basin are presented in Figures 2 to 5.

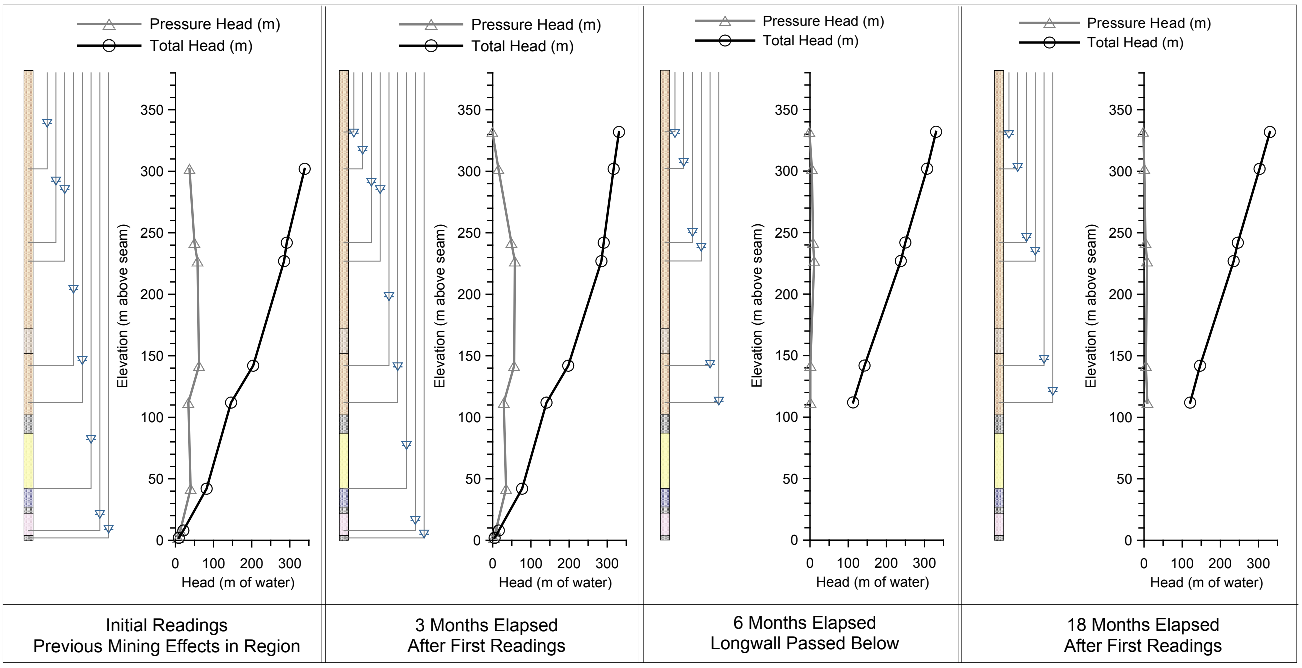

Figure 2 – Piezometric Profiles, Western Coalfields (using data from ACARP, 2007).

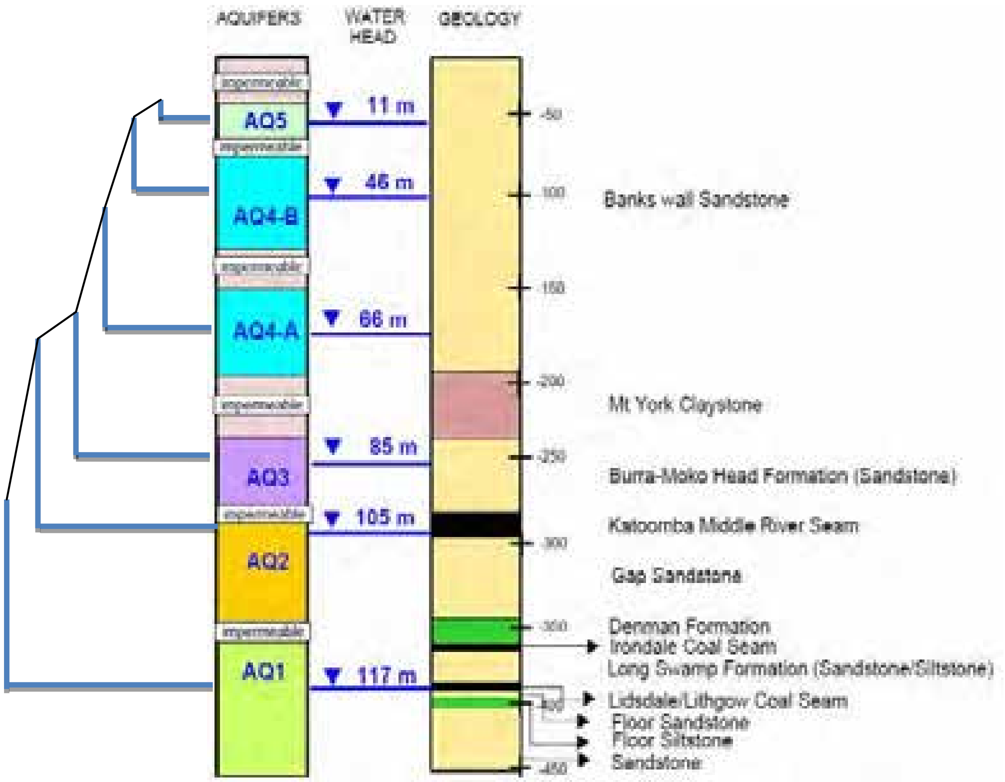

Figure 3 – Summary of Recorded Piezometric Levels, Western Coalfields (ACARP, 2007). Note their interpretive annotation of a series of 'aquifers' and 'impermeable' layers The piezometer lines on left are from authors of this paper

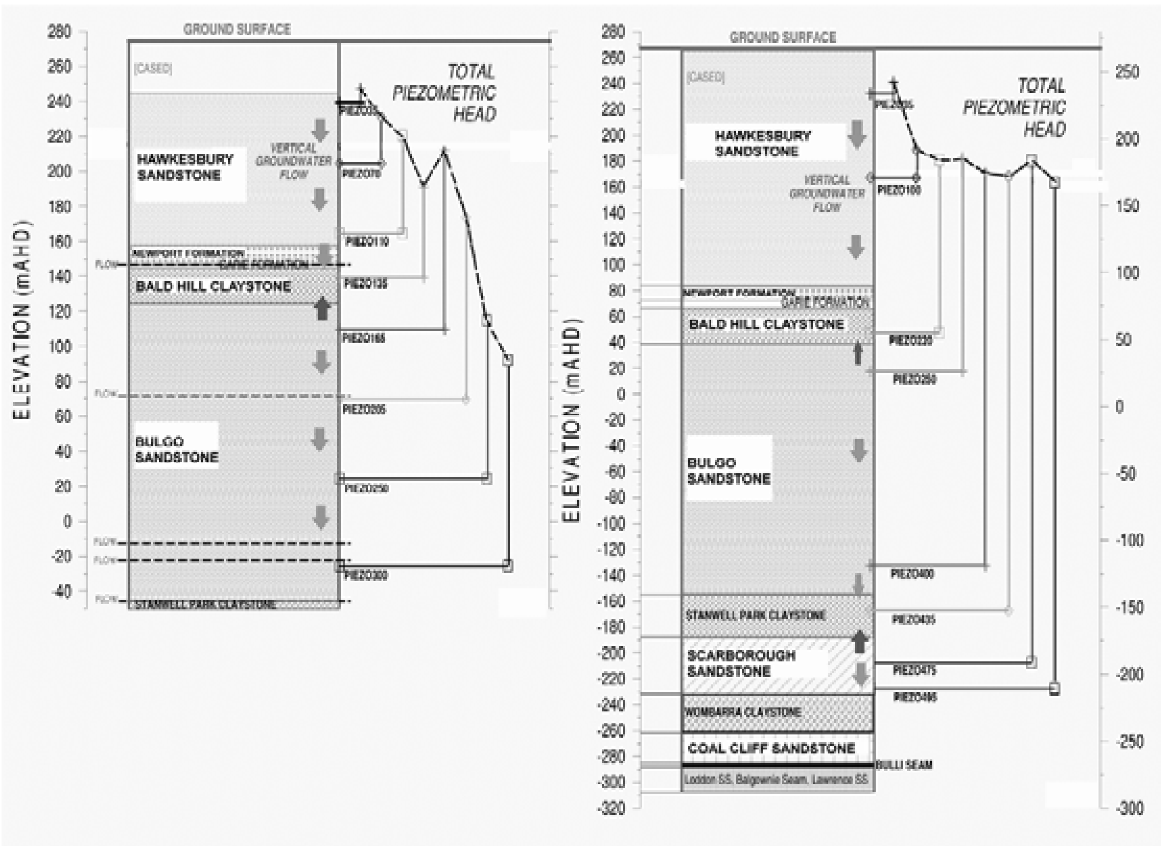

Figure 4 – Measured Piezometric Heads, Southern Coalfield Mined (Left) and in Unmined (Right) Regions Reproduced from Merrick 2009

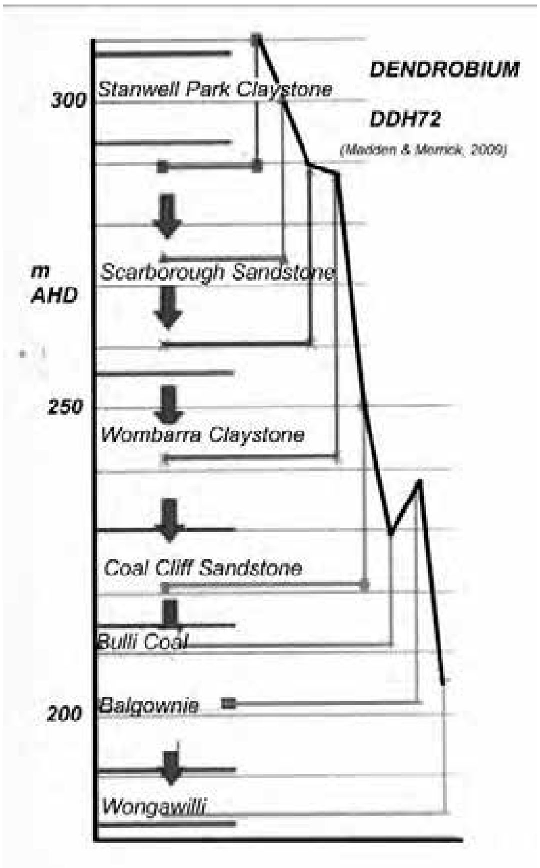

Figure 5 – Piezometric Profile, Southern Coalfields.
(from Madden and Merrick, 2009)

It is clear from these figures, and similar data not in the public domain, that piezometric data above a longwall mining region are commonly indicative of downwards hydraulic gradients.

This observation has historically been interpreted in two ways. Some see the vertical profile as a series of perched aquifers, exhibiting primarily lateral flow and disconnected from one another by horizontal ‘aquitards’ or ‘aquicludes’ (e.g. as interpreted by the authors of Figure 3). Others see the observed vertical gradient as indicative of a vertical flow profile. Those in this second camp, like the present authors are cognisant of the physics of groundwater flow whereby, as shown in the trivial example in Figure 6, piezometers at different levels in the same borehole in homogenous strata will show different heads, which have nothing to do with perched water tables, depending only on flow direction.

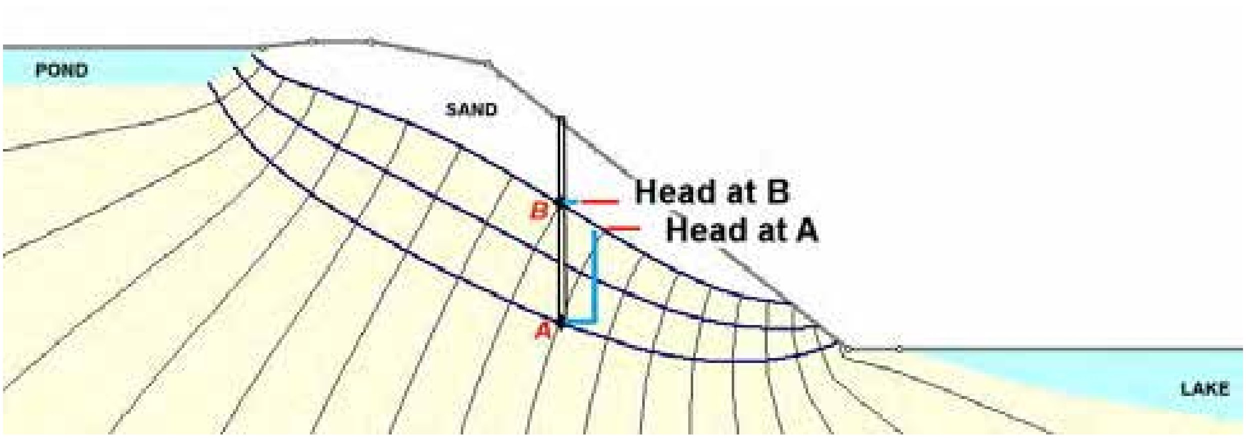

Figure 6 Different piezometric levels in vertical borehole in homogenous material

A debate between these two views polarised advisers to the Reynolds Enquiry (Reynolds, 1976). Those subscribing to the former viewpoint cited the many cases of mines or underground works for which the visible inflow rate was small. They also presented arguments based on provenance – the heritage of the terms ‘aquifer’, ‘aquiclude’ and ‘aquitard’, which had served the hydrogeological profession for many decades. This ‘heritage’ facet is discussed below, because it is one of the largest matters of contention between many hydrogeologists and geotechnical engineers.

3.3 Aquifers and Aquicludes, or a Continuum

The July 2008 report titled “Impacts of Underground Coal Mining on Natural Features in the Southern Coalfields” (**SCI)** (Hebblewhite, 2009) provides a typical exposition of the hydrogeology of the Southern Coalfields. The Hawkesbury Sandstone and Narrabeen Group rocks are described as either aquifers or aquicludes, with aquicludes defined as impermeable layers such as shale, clay or some claystones. The report takes on the view that there is no evidence of “any change in the hydraulic connectivity of water from reservoirs to mine workings”. The report uses Everett et al (1998), Barclay and Holla (2000), Waddington & Kay (2002) and Galvin (2005) to support this view, and concludes that the reason for this absence of connectivity is either because of “the significant depth of mining (~ 500m), or the presence of the Bald Hill Claystone acting as an undisturbed aquiclude”. The specifics of the Bald Hill Claystone formation are discussed in Section 7 below.

Clearly, horizontal layers of low conductivity material in the geological strata will introduce impedance to vertical flow. However, as demonstrated in Part 1 of this paper, the development of perched water tables will occur under purely vertical flow and do not have to represent lateral seepage along ‘aquifers’. Furthermore, the presence of a perched water table does not indicate the cessation of vertical seepage. Rather, the water table represents a stored potential, which gathers to support ongoing vertical seepage at a rate of in accordance with the hydraulic properties of the material.

The present authors subscribe to the second viewpoint of the two discussed in the Reynolds enquiry – that these observed vertical profiles are indicative of vertical flow systems, not separate ‘disconnected aquifers’. This is not a belief system; it is the direct result of the mathematics of Darcian groundwater flow as presented in Part 1.

It is considered that the ‘provenance’ of hydrogeological language has hindered understanding, as explained below.

It is postulated that many of the terms adopted in the hydrogeology field were done for conceptualisation of the earth into regions that could be solved with analytical mathematical solutions. Prior to the advent of computer and powerful numerical methods it was not possible to solve problems of heterogeneous permeability with complex boundary conditions. Aquifers and aquicludes were necessary to allow development of useful closed form solutions (e.g. Thiem’s formula; Dupuit’s formula etc); just as elasticity theory was useful in structural engineering. Thus a boundary through which water cannot flow became termed an aquiclude.

A fundamental component behind this characterisation is an assumption of horizontal flow systems. The equations, which could be developed on the back of the mathematical conceptualisations typically apply for situations where the vertical flow component is assumed to be negligible. This assumption of horizontal flow is also embodied in the widespread use of the term 'transmissivity' amongst hydrogeologists.

A further demarcation used is to designate whether aquifers are 'confined' or 'unconfined'. This demarcation makes reference to the position of an aquifer relative to adjacent 'aquicludes' or 'aquitards'. Lastly, hydrogeologists expend considerable effort in defining whether these regions are 'connected' or 'disconnected', with respect to the spatial distribution of these 'aquifers' and 'aquitards'

In the real world, the differentiation between aquicludes, aquitards and aquifers is unclear. There is no accepted standard of measurement which differentiates or defines them. In reality, geological formations represent a continuum of materials with wide ranging properties in regard to how water is stored and transmitted. Because the reality is a continuum, there is no accepted standard of measurement which differentiates or defines whether a portion of ground is 'confined' or 'unconfined'. For example, an aquifer that may be traditionally referred to as 'confined' will in fact still have 'unconfined' characteristics due to the 'leakiness' from adjacent formations. Similarly, an aquifer that has a free water table with an identifiably separate geological formation may be called 'unconfined', but it will still display characteristics of a 'confined' aquifer in that a change is head released water not just through the draining of pores but also due to changing in stresses in the matrix.

It is accepted that these terms adopted in the hydrogeological fraternity are descriptors, not absolutes. The terms are useful tools to describe geology in some environments and, by differentiating different regions, have supported the conceptualisation and development of various equations of groundwater flow. However, in many situations, the terms are neither helpful nor accurate, particularly in the assessment of vertical flow. The arguments made in the Reynolds Inquiry asserting negligible vertical flow based on provenance are thus without scientific basis.

It was therefore with some satisfaction that we note, and fully adopt, the following statement in the draft NSW Government Aquifer Interference Policy of March 2012:

> *"A groundwater system is any type of saturated geological formation that can yield anywhere from low to high volumes of water. For the purpose of this Policy the term aquifer has the same meaning as groundwater system---"*

4. FLOWS AND DEPRESSURISATION

It is evident that many underground mine workings exhibit very little inflow. The mines of the Southern Coalfields are mostly remarkably dry. The authors have inspected mine workings directly under the piezometers string from which the readings in Figure 1 (and 9 below) are produced – the workings were visibly dry, with clouds of dust kicked up as one walked. This is despite being located directly underneath Cataract reservoir.

The relatively small quantities of groundwater removed for some CSG activities has also been presented as evidence of 'lack of connectivity' between the depressurisation of the seam and upper aquifer systems (Ross, 2011).

However, low flows are not necessarily indicative of small pressure changes, but can occur under large pressure changes with low hydraulic conductivity. Flow quantities are a function of hydraulic conductivity, pressure head changes are a function of changed boundary conditions causing changed flow directions.

As shown in Part 1 of this paper, small inflows are explained by the hydraulic conductivity and storage characteristics of the groundwater system. They may also be explained, by significantly decreased hydraulic conductivities associated with unsaturated flow conditions following depressurisation (this latter point is discussed in Section 9, below).

As an example, undisturbed rock units typical in the study area represented by Figure 2 may be expected to have vertical saturated hydraulic conductivities in the order of $1x10^{-8}$ to $1x10^{-11}$ m/s. Under a hydraulic gradient of unity (as discussed in Part 1), this is equivalent to flow velocities of 0.3 to 300mm per annum, or discharges of $1x10^{-8}$ to $1x10^{-6}$ litres per second per square metre of mine. Such seepage rates would be imperceptible to the observer. Nonetheless, over time and a large mining area, this amounts to accumulation of 0.025 to 2.5 ML/month per square kilometre of mine, which is why such 'dry mines' still require ongoing dewatering. This is consistent with calculations by Williamson, for the Reynolds Inquiry, using flows into the mines of the Southern Coalfields. These gave a computed average gross hydraulic conductivity of $5.2x10^{-9}$m/sec to $0.7x10^{-10}$m/sec for the rocks overlying the Bulli Seam. As discussed in Section 7, these are reasonable values. In contrast to arguments made in the Reynolds Inquiry, low inflows are therefore not a good indicate of no vertical flow. They are simply a function of the hydraulic conductivity.

5. IMPACTS ON WATER BORES

As shown in Part 1 of this paper, where depressurisation at the base of a column propagates through the column, the resulting vertical flow system has a pressure distribution less than hydrostatic. This has a direct impact on the water level in bores situation and screened within the column.

Consider a homogeneous column such as Figure 7 taken from Part 1 of this paper.

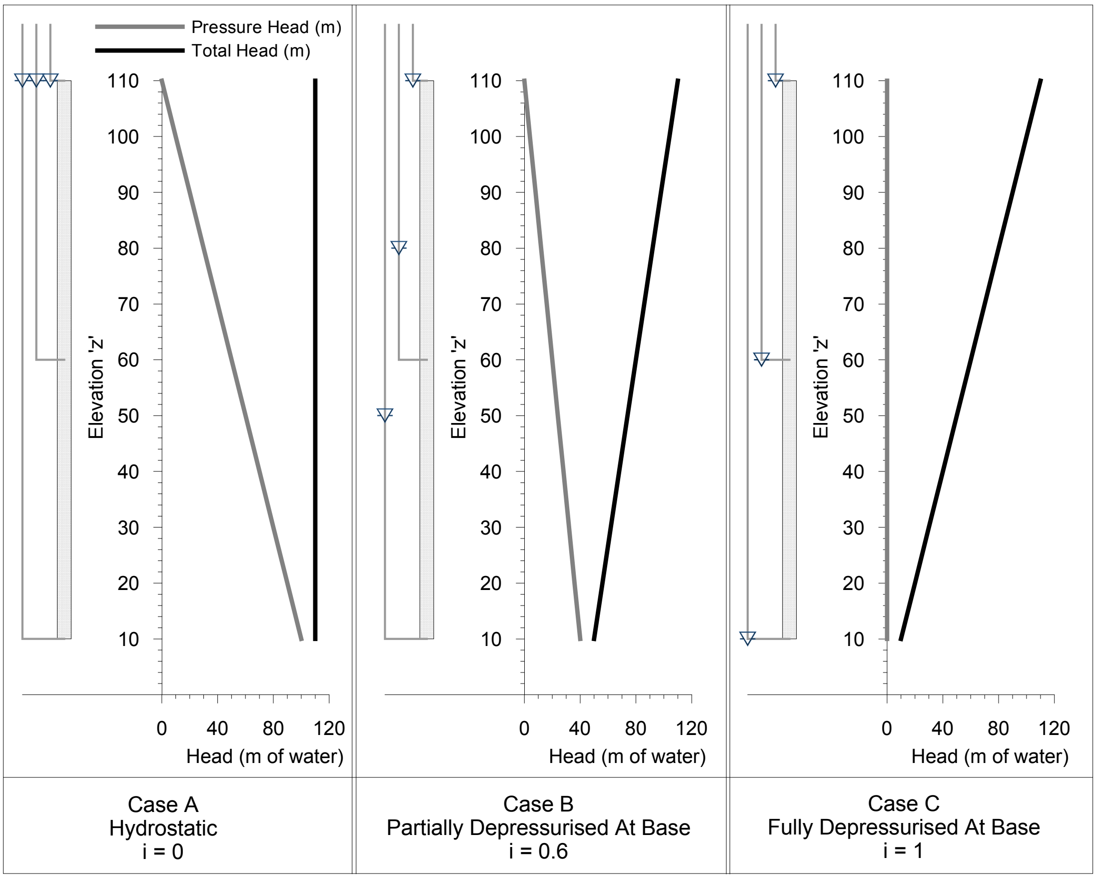

Figure 7

If the saturated vertical hydraulic conductivity of the formation is 1×10^{-9} ms^{-1}, under steady state conditions flow downwards into a depressurised cavern would occur at a maximum rate equivalent to the hydraulic conductivity – a rate of only 0.03 litres per square meter of formation per year. This remarkably low flow rate would nonetheless ultimately support the complete depressurisation of the column, and disappearance of all water from any bores situated in the column. Depending on the hydraulic diffusivity, this effect can also propagate through the formation in a short period of time (i.e. much less than the period of mining).

This is not simply a theoretical postulation. The authors have been personally involved in reviewing bores situated above longwall mining activities in the Sydney Basin. There are numerous instances where the standing water level in their bores dropped considerably following undermining, and the yield was, and remains, significantly reduced or completely removed. These effects have been noted in both inside and outside of regions of subsidence and fracturing.

6. PROPAGATION OF DEPRESSURISATION, AND 'DISCONNECTION'

In Part 1 of this paper, it was shown that the velocity of a wave of depressurisation is proportional to the hydraulic diffusivity of the formation. The hydraulic diffusivity varies by orders of magnitude, hence the velocity of depressurisation also varies considerably. It was also shown that the velocity of the depressurisation wave is typically orders of magnitude faster than the velocity of groundwater flow.

Ross (2011) presents evidence of 'disconnectivity' of various identified aquifers at a proposed CSG site, based on the results of a 150 day duration pumping tests and chemical and isotopic indicators. During this pumping test period, no effects of depressurisation were observed in bores placed in shallow aquifers or in the formation approximately 100 m above the well intake location.

A 150 day test period is long in terms of pumping test practice, although it is not long in terms of groundwater processes, or the life of a mine, or CSG project. Such a test could indicate that proposed CSG works will not impact largely on shallower aquifers, but also could simply indicate that the depressurisation wave had not yet arrived in accordance with the hydraulic diffusivity characteristics of the site. An estimation of this can be made with application of Equation (15) in Part 1 of this paper, or more accurately with a simple numerical model study.

Similarly, the application of chemical tracers study should consider the fact that the flow velocity is appreciably slower than the depressurisation wave velocity.

Certainly, identifiably distinct regions of groundwater chemistry and flow systems do exist. However, with respect to the discussion in Section 3.3 of this paper, it is questioned whether the designation of 'connected' or 'disconnected' is a helpful or accurate one. In most situations, the question of 'whether' a disturbance will arrive is less appropriate that the questions of 'when' it will arrive, and what its extent will be.

7 THE BALD HILL CLAYSTONE – AN AQUICLUDE?

Kay et al (2006) state explicitly that the Bald Hill Claystone (BHC) "acts as an aquiclude". Jankowski, Madden and McLean, (2008) state:

> *"The Southern Coalfield mines are typically sealed by a low permeability material that underlies fractured sandstone aquifers, mostly preventing inflow of surface water to mines"*

The NSW Planning Assessment Commission report for Bulli Seam Operations (2010) adopts the view of the SCI, explicitly stating:

> *"The deeper matrix type flows are apparently constrained in some areas to near horizontal flows by the presence of aquitards and aquicludes like the Bald Hill Claystone"*

In reviewing reports for various mines in the Sydney Basin, it is the authors' observation that this is the commonly accepted nature of the Bald Hill Claystone.

The authors compiled the available packer test data following review of a mine in the Southern coalfields, as summarised in Figure 8.

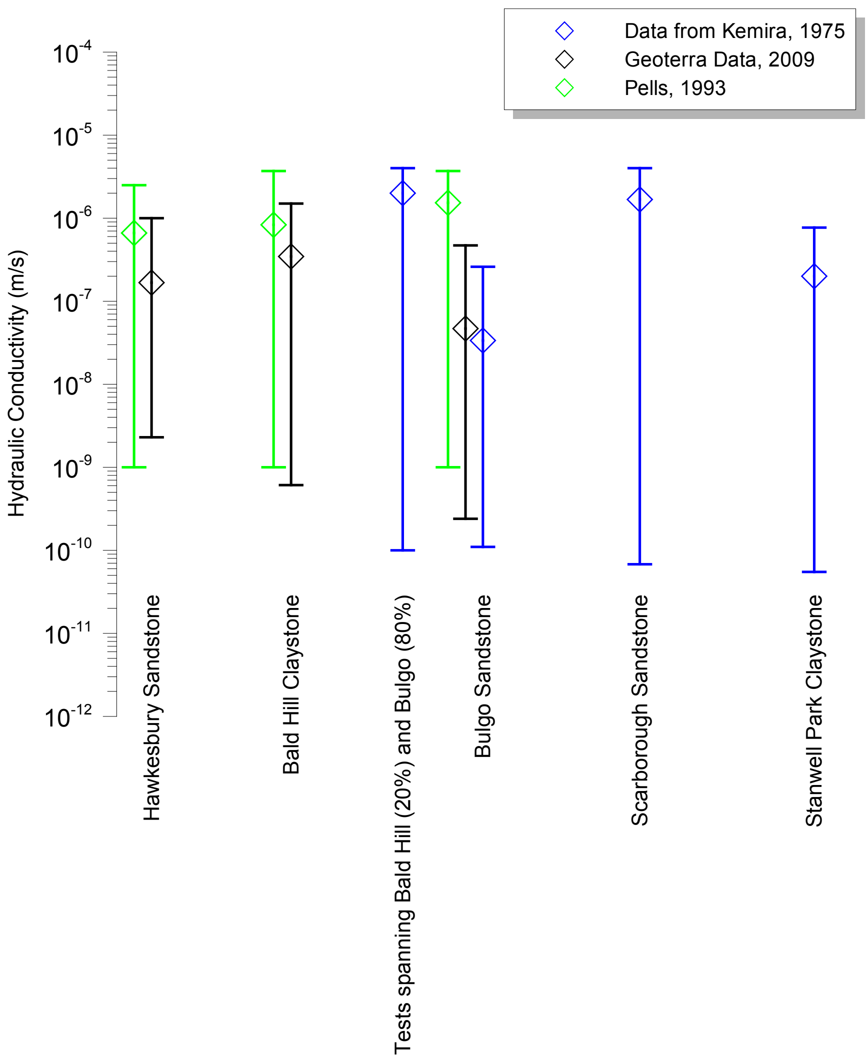

Fig 8 Hydraulic conductivity data for Triassic rocks of the Sydney Basin

The data in Figure 8 do not support the BHC having distinguishing features of an ‘aquiclude’ or ‘aquitard’. The Packer test results for the BHC span the same range for the Hawkesbury and Narrabeen Formations, and the log mean values are very similar.

Permeability data, additional to that given above, is presented in Reid (1996). The following points made by Reid are consistent with our evaluation:

> *“The Bald Hill Claystone has a narrower range of both joint spacing and laboratory permeabilities, however the laboratory permeabilities are significantly less than the Lugeon values. This suggests that the permeability of the Bald Hill Claystone is dominated (as one would expect) by secondary permeability.*
>
> *The typical Lugeon permeabilities of the Bald Hill Claystone and the Hawkesbury Sandstone are of a similar order, despite their marked lithological differences. The similarity between the laboratory and Lugeon permeabilities for the Hawkesbury Sandstone suggests that intergranular permeability makes a significant contribution to the overall permeability, in contrast to the Bald Hill Claystone.”*

In assessing these results cognisance must be taken of the fact that, where boreholes do not intercept joints, permeability is largely controlled by near horizontal bedding planes. To make an assessment of the vertical permeability of the BHC consideration must be given to the evidence regarding defects.

The BHC contains as many as eight soil profiles (i.e. eight superimposed palaeosols), is fissured and jointed, and is transgressed (in places) by faults and igneous intrusions (see Figures 9a and 9b).

Figure 9a: Through going joints in road cutting at Bald Hill, just north of Stanwell Park.

Figure 9b: Joints and Shears in Bald Hill Claystone at the Type Location (Anne Young photo)

Given the detailed sedimentary and structural data, of the kind summarised above, the authors consider that the vertical hydraulic conductivity of the BHC may be lower than the horizontal but, possibly, by only about one order of magnitude. This would suggest a log mean value of about 10^{-8} m/sec (~0.1 Lugeon). It is not an aquiclude; it is a low permeability horizon.

8 CHANGES IN HYDRAULIC CONDUCTIVITY ABOVE LONGWALLS

It is widely accepted that changes occur to the ground above longwalls in the Sydney coalfields similar to those shown in Figure 10. Many publications give versions of this figure that suggest clearly demarcated zones, commonly termed:

- "Caved/fractured" zone immediately above areas of full extraction, with major increase in permeability,
- "Constrained" zone, above 150m, or thereabouts, above the seam, with some increase in horizontal permeability, but little or no increase in vertical permeability , and
- "Surface "zone, with increased vertical permeability.

In fact, there is no information to justify demarcation of specific zones. That which is available publically is from work done by Holla (1989) at four collieries, Forster (1995) in the Central Coast, and south of Wollongong (Thomas, 1974). In our view the data only justify the postulation of gradational changes in hydraulic conductivity through the profile, as indicated in Figure 10.

The self-fulfilling nature of the concept of a "Constrained" zone is illustrated by the following quote from the Planning Assessment Commission report on Bulli Seam Operations (2010):

> "However, the SCI also noted that *'more commonly, mining is conducted at a sufficient depth to support the long term presence of a constrained zone'* which is a zone where vertical conductivity is negligible and downwards flow is governed by the natural (vertical) permeability of the strata."

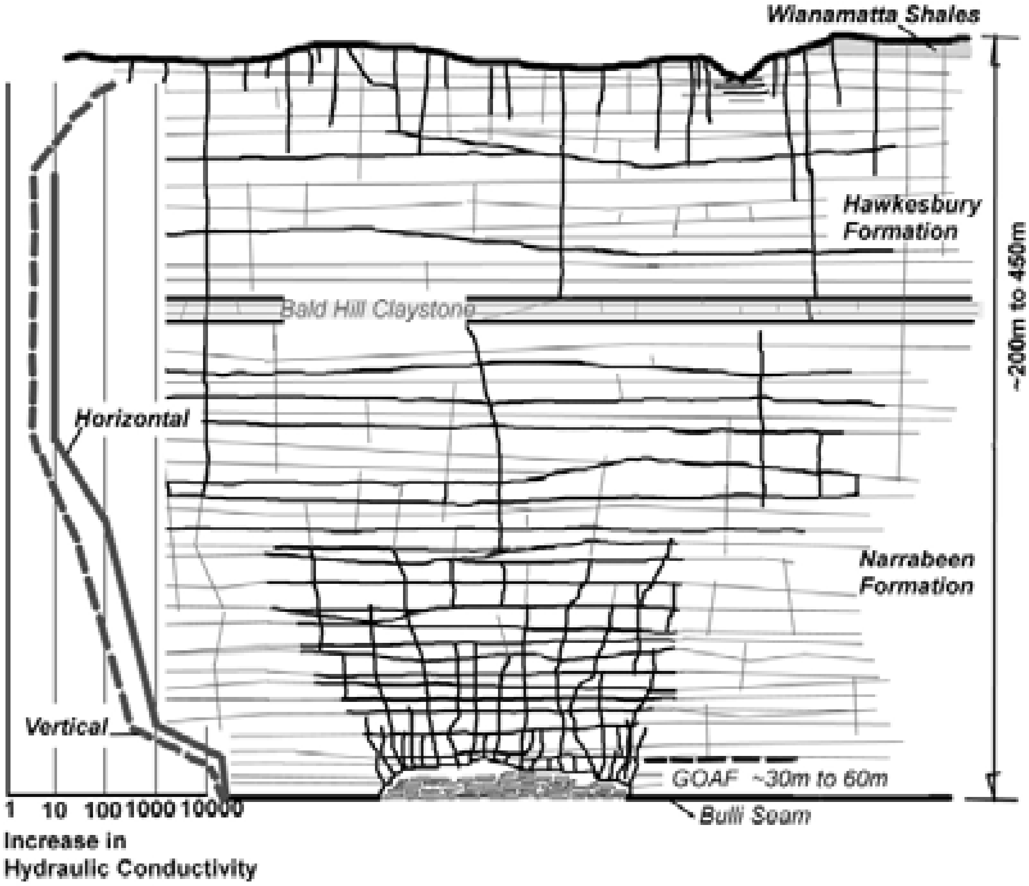

Figure 10 - Cartoon of postulated impact of longwall mining

Holla's data from Tahmoor is particularly interesting because measurements were made of strata dilation and permeability increases from the surface to below the Bald Hill Claystone at a depth of 155m (mining of Bulli Seam at 424m). The extensometer measurements showed that 35mm bedding opening occurred across the Bald Hill Claystone, giving an average tensile strain of 3.5mm/m.

Holla's measured permeabilities, expressed as log mean values, are summarised in Table 1

Table 1 Pre- and Post-longwall extraction Packer Test data from Tahmoor (Holla, 1989)

Unit	Packer test data (Lugeon) 1 Lugeon ~ 10^{-7} m/sec	
	Pre-longwall extraction	Post-longwall extraction
Hawkesbury Sandstone	1.4 (10 tests)	10.3 (9 tests)
Bald Hill Claystone	1.2 (1 test)	10 (1 test)
Narrabeen Formation	0.18 (6 tests)	12.1 (9 tests)

We acknowledge, as did Holla, the statistical limitations of the Tahmoor data. We also acknowledge that Packer tests in vertical holes will tend to be dominated by horizontal hydraulic conductivity.

The data in Table 1 are consistent with Holla's other measurements at sites with lesser cover at Invincible Colliery (110m cover) and Wyee State Colliery (206m). They are also consistent with Foster's data from the Wyong-Wyee area. We have used all this data to hypothesize that permeability increases above areas of longwall extraction are approximately as indicated in Figure 10. The thicknesses of the gradational zones depend on the extracted thickness, the depth of cover and particulars of the geology of the Triassic strata that overlie the Permian coal seams.

For example, at Ulan, where the Triassic strata are dominantly sandstones, and where there are Jurassic sandstones, the experience is that cracking propagates from the seam to the surface, albeit in a complex pattern of non-continuous cracks.

In the situation of CSG extraction there is no cracking induced in the overlying strata due to subsidence, although hydrofracturing may induce fractures propagated from the directionally drilled boreholes. For this situation we assume no changes to the rock mass permeability regime, only depressurisation of the groundwater at the levels of coal seams.

In Part 1 of this paper we discuss the role of fractures (bedding planes, joints and subsidence induced fractures) on rock mass hydraulic conductivity.

Analyses of many borehole camera measurements are given by De Castro, Rotter and Tammetta (2009). They note that the RAAX test equipment could not resolve openings of <0.3mm.

As would be expected in the real world of geology, there is much scatter in their data, but an overall summary is possible as given below.

1. Sub –horizontal bedding spacings average at about 0.9m down to 100m and appear wider below this depth
2. Near vertical joints average at about 1m down to 160m
3. The average measured opening of bedding planes was between about 1mm and 3mm down to 100m, and <0.3mm below that.
4. The average measured opening of near vertical joints was between , nominally 0.3mm and 1mm down to 160m

Intuitively, we think that bedding openings of 1mm to 3mm are too wide, and we suspect that erosion during drilling may have influenced the data. We also note that it is clearly impossible for any of the bedding planes or joints to be continuously open. The average proportion of wall-wall contact is unknowable. If we guess an average 80 % contact area, then by Equation 11, given in Part 1, we calculate an average mass horizontal conductivity of Hawkesbury Sandstone of about 10^{-5} m/sec (~100 Lugeon) for 1mm bedding opening and 2 x 10^{-7} m/sec (~2 Lugeon) for 0.2mm opening. Whilst of some interest when it comes to considering grouting of Hawkesbury Sandstone, these theoretical calculations have the main value of illustrating how a small increase in defect opening due to mine subsidence can lead to substantial increase in hydraulic conductivity.

9 THE SIGNIFICANCE OF UNSATURATED FLOW

Two further examples showing multilevel piezometric data from above longwall mines in the Sydney basin are shown in Figure 11 to 13.

Figure 11 covers the full set of data from the site described in reference to Figure 1, only plotted as pressure head and total head profiles. The first measurements were made prior to longwall mining impacts in the region. It can be seen that a hydrostatic profile prevailed. Following the passing of the longwalls, the levels in the lowest piezometers declined significantly. Unfortunately, several piezometers failed, but the data suggests that, some 17 years since mining, a wave of depressurisation may still be slowly progressing upwards.

The data in Figures 12 and 13 are from sets of piezometers in two holes just adjacent to the first two longwalls in Area 3A of Dendrobium Colliery in the Southern Coalfields (Merrick and Akhter, 2011). Being neither above an extensive area of longwall extraction, nor directly above even a single longwall, these piezometers are not in the areas where boundary conditions are valid for the 1D flow analysed in Part 1, and discussed above. However, the data provide some interesting insights that support the thrust of this paper.

The data in Figure 12 are from borehole DDH92. This indicates depressurisation to about 50m above longwall level in the Wongawilli seam, but no depressurisation in the upper 300m of Hawkesbury Sandstone and Bulgo sandstone. However, Figure 13 is data from borehole DDH97, a similar distance from the edge of the longwalls. This shows a significant, and upward expanding depressurisation through the whole profile

Full analysis of the Dendrobium Area 3A data would require 3D analyses because it is clear from the geometry that flow must be sideways and downwards. However, as a minimum, the data show progressive growth of depressurisation, and the fact that rock masses are complex, as the differences between DDH92 and DDH97 cannot be explained by stratigraphy or geometry – they must be due to geological structures.

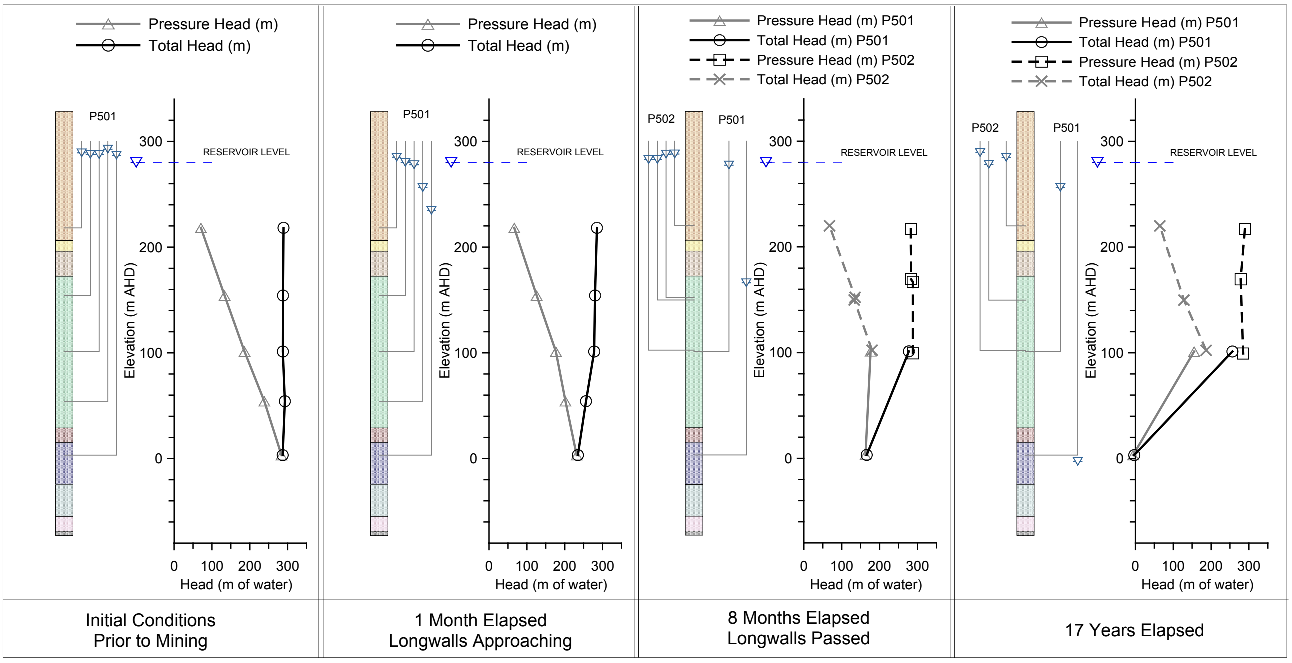

Figure 11 – Piezometric Profiles, Southern Coalfields
Using data from Coffey 1992, 1993a, 1993b; Singh and Jakeman, 2001, and data from mine owners

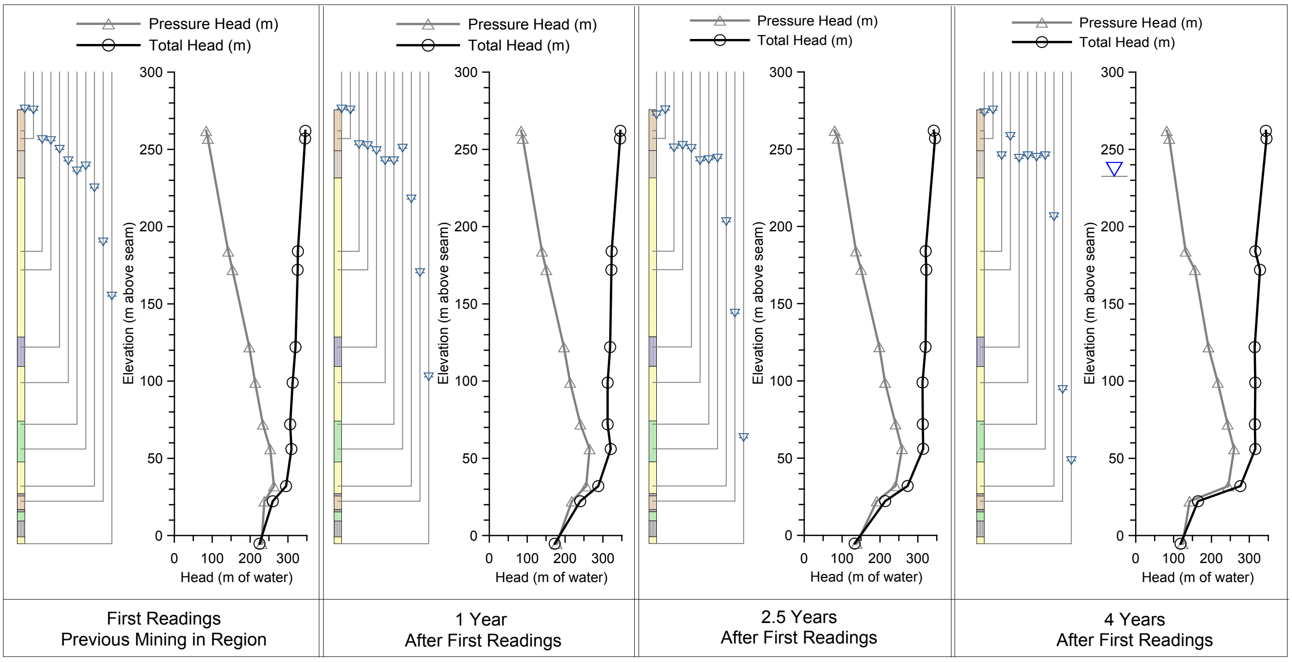

Figure 12 – Piezometric Profiles, Southern Coalfields. Dendrobium Area 3 DDH92

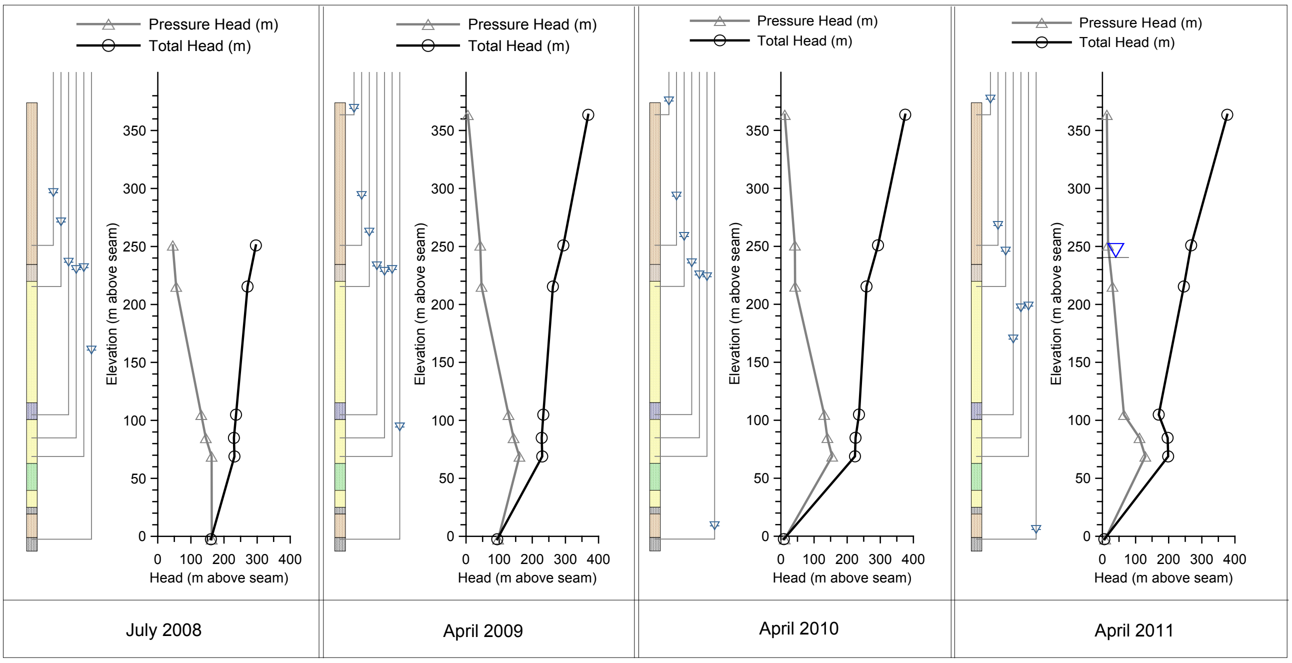

Figure 13 – Piezometric Profiles, Southern Coalfields. Dendrobium Area 3 DDH97

4 SUMMARY

As shown in Part 1 of this paper, aquifer characteristics do not alter the ultimate (steady-state) pattern and extent of depressurisation that occurs, they alter only the discharge under which is occurs. The quantity of water drawn by underground works is therefore not, alone, a good indicator of 'connectivity' or of impacts. Clearly, the removal of a small quantity of water does limit the volume of water lost from adjacent groundwater systems or surface water features. However, removal of small quantities of water can have profound impacts on the pressure distribution and hence the water available for bore users and recharge of swamps and streams.

The matter of changes in the directions of groundwater flows and the associated changes in equipotentials and pore (or joint) pressures must be distinguished from estimates of the quantity of groundwater flow. It is the view of the authors that this facet has not been properly recognised by those with a mining, or CSG extraction, predisposition. Professor Knill, was correct when he submitted to the Reynolds Inquiry:

> *Undermining of a body of water by mining or tunnelling will result in a downward movement of ground water towards the excavation and thus a radical change in the ground water flow pattern.*

As a final point it is noted that there is evidence to support the findings of Part 1 that reduction in hydraulic conductivity due to desaturation of jointed rock masses probably has a major impact on the time it takes for pressure changes to transmit from the level of depressurisation to near surface groundwater systems. This is a poorly understood area of the science that warrants detailed research. It may be the missing link in reconciling field measurements and theory.

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MEMORANDUM

A NOTE ON KEY ISSUES IN RELATION TO COAL SEAM GAS EXTRACTION IN NEW SOUTH WALES

TO: FILE

FROM Philip Pells

OUR REF: P034.M1

DATE: 13 March 2012

1. INTRODUCTION

The issue of Coal Seam Gas (**CSG**) extraction has now become a source of confrontation between many in the farming community, together with some city people, against the burgeoning natural gas industry.

One of the first confrontations was in the Yarramalong and Dooralong valleys near Wyong, where, in 2005, the community fought against, and stopped, the implementation, by Sydney Gas of a major CSG project.

Now there is CSG exploration, or production, across large areas of NSW, and some 46 community protest groups have sprung up to resist the industry. These groups range from communities in the Liverpool Plains, to the Gloucester Basin, to Bylong, Broke, Putty, Camden, Oakdale, Helensburg, Wollongong and Suttons Forest. Then there are broader based groups such as the NSW Farmers Federation and the Greens Party that are just as stirred up as the local communities.

The purposes of this note are to summarise the sources of community concern, and to attempt, from a scientific viewpoint, to rank those concerns. This whole document should be read to obtain what we think is a balanced understanding, but for the lazy we have yellow-highlighted the key findings

2. WHAT IS COAL SEAM GAS

Some 250 to 300 million year ago, when Australia was still attached to Antarctica, unimaginably thick swamps of peat were laid down, and just as in any decomposing vegetation, large quantities of methane were generated.

Now these swamps are the coal seams of New South Wales, separated by beds of claystone, sandstone and conglomerate, and mostly beneath the water table.

A thinly cut section of coal, viewed under a microscope, is not black, but, as shown in Figure 1, the remains of woody tissue are red; while yellow patches are coalified spores

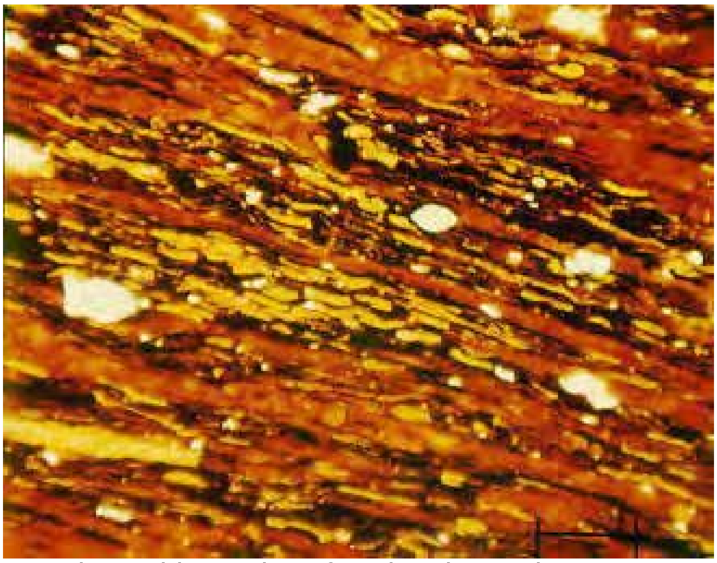

Fig 1: Thin section of coal under a microscope

And the methane? Well, that is stored in tiny, tiny pores within the coal.

About 90% of the methane comprises molecules adsorbed on the walls of the pores, at near liquid density. This can be thought of as methane molecules "painted" on the surfaces of pores that themselves are only about 10 times the diameter of a methane molecule.

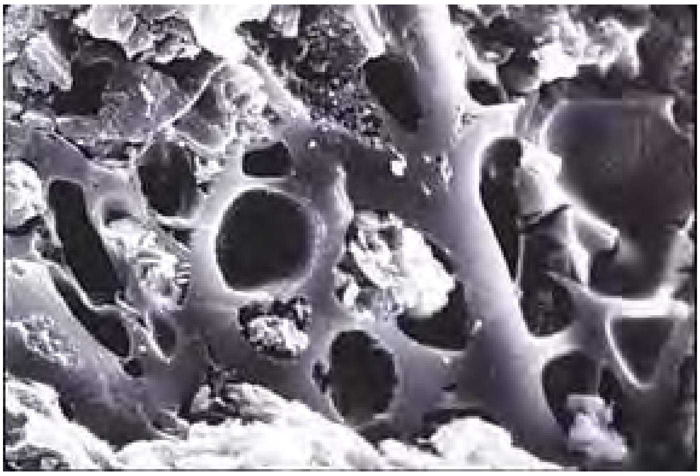

Fig 2: Coal viewed under a scanning electron microscope

There is no water in the micro-pores; the water is in fractures in coal, called cleats. All coal has such cleats, and the pressure of the water in the cleats keeps the methane locked up in the micro-pores. There is some methane dissolved in the water, but not an economically significant quantity.

Fig 3: Cleats (fractures) in coal – an 18th Century coal mine in the UK

So, the simple trick to turn the adsorbed methane into gas is to depressurise, and remove, the water from the cleats. When this depressurisation occurs, the methane molecules start to diffuse through the coal to the cleats, and if there is connection from the cleats to a borehole, the gas can be extracted. The process is illustrated in Figure 4. This diffusion process takes quite a long time.

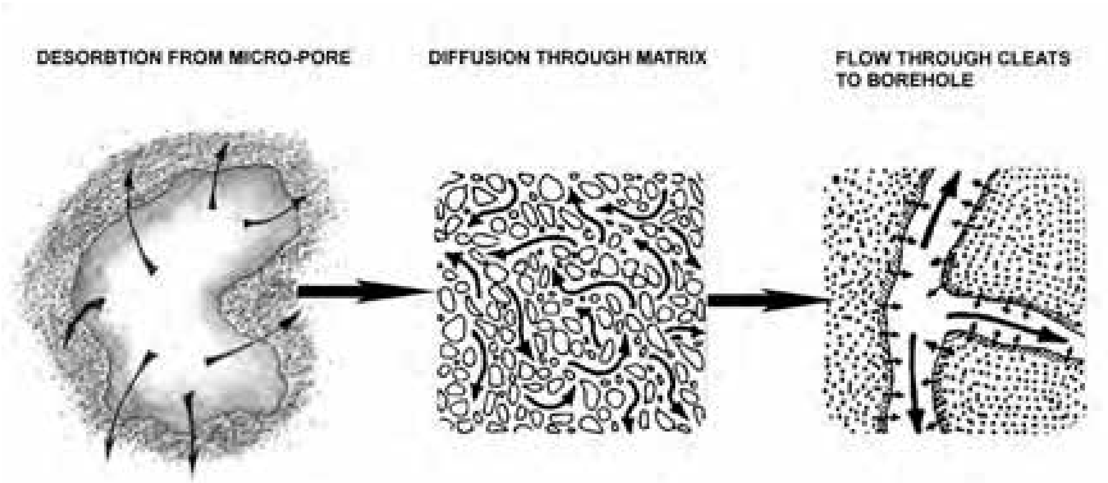

Figure 4: Release of methane from micro-pores in coal

Coal seam gas has been a significant issue in the NSW coal mining industry for more than 100 years. The issue for the miners was, and is, that the gas can cause explosive outbursts of coal that kill.

By the 1980s more than a dozen explosive outbursts occurred every year in the underground mines of the Sydney Basin, always during cutting the coal, and almost always associated with faults and dykes... These explosive ejections ranged from a wheelbarrow load of coal to many tons. This was taken as part and parcel of working as a miner in the Bulli Seam (Harvey and Singh, 1998).

In 1985 the operator of mining equipment at Tahmoor Colliery, Michel Penny, was killed by the explosive outburst of 200 tons of coal and about 3500 cubic metres of gas. Thereafter, in an attempt to protect the operators, continuous miner machines were encapsulated and provided with independent air supplies. However, in 1992 there were multiple fatalities due to an outburst of some 330 tons, at the South Bulli Colliery. Thereafter the Department of Mines forced implementation of coal seam gas drainage, which had been shown by Dr Lama, and others, to substantially reduce the probability of explosive outbursts.

Since that time thousands of kilometres of drainage boreholes have been drilled in the seams of the Southern Coalfields, to pre-drain gas from the coal to pre-defined residual quantities, unique to each mine. Figure 5 shows the criteria for the Tahmoor colliery.

Figure 6 shows, as an example, the pre-longwall mining boreholes installed in one area of the Tahmoor Mine. Each drainage borehole is operated under suction for, typically, about 6 months, to first extract the water in the cleats, and then drain sufficient gas from the coal that is to be mined.

At mines such as Tahmoor and Appin, the extracted gas is used to generate power; a substantial 97MW in the case of the combined Appin operations. However, much gas is vented to the atmosphere. At Tahmoor the 1910-1911 Environmental Report states:

> Gas discharges during the reporting period were consistent with historical monitoring and predictions. Discharge parameters were approximately 2900l/s discharge volume, consisting of approximately 20% methane and 40-45% carbon dioxide with the remainder being air.

This amounts to 60 million cubic metres of CO_2 and methane per annum

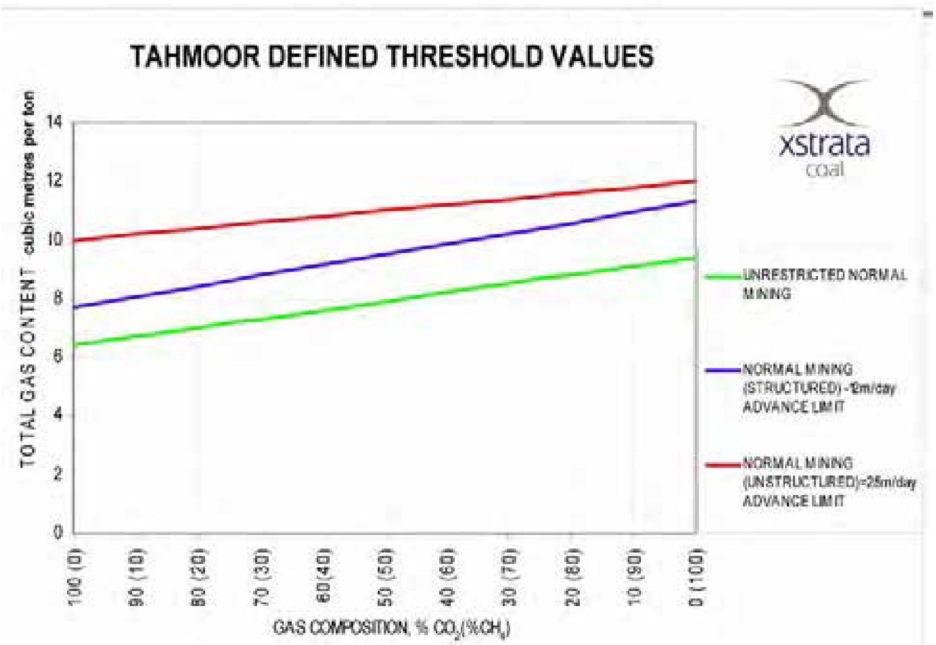

Fig 5: Drainage criteria for Tahmoor Colliery, NSW

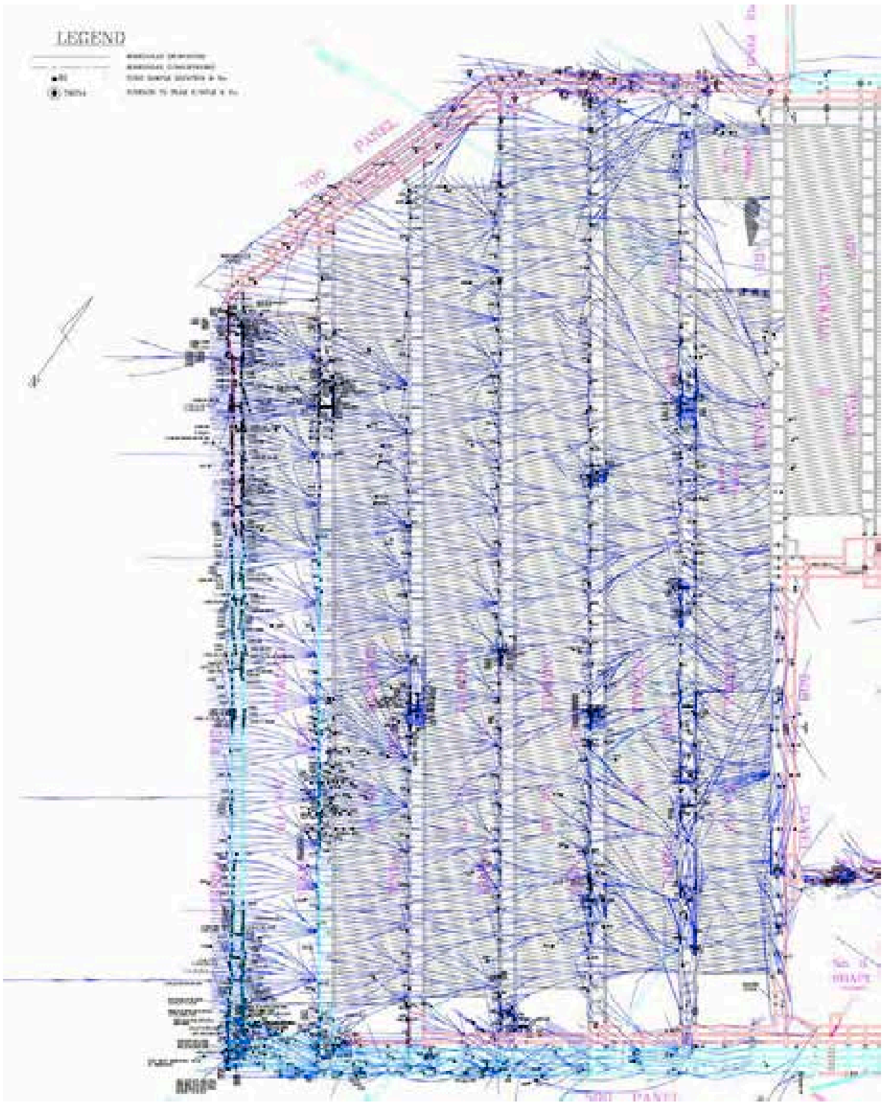

Fig 6: Example of in-seam gas drainage holes.

3. WHY HAS THE CSG INDUSTRY GROWN SO RAPIDLY SO SUDDENLY?

Given that coal seam gas extraction has been part and parcel of coal mining for such a long time, why has the "new'" CSG industry grown to prominence so rapidly?

The primary reasons probably are:

- developments in drilling technology, and
- politics associated with claimed human-induced global warming created by CO_2 emissions.

There are numerous reports on gas exploration at coal seam level in the Southern Coalfields going back to the mid-1960s that all conclude there to be insufficient gas to warrant extraction, using the then available technology. That technology included hydrofracturing (fracking). There is even a study by Halliburton in the late 1960s that contemplated using hydrochloric acid as the hydrofracturing agent near Picton, NSW!

The major technology change was the development and implementation of down-hole drilling motors that could be steered with good accuracy (see Figure 7). Such motors allow borehole to be deflected horizontally, as shown in Figure 8, thereby allowing a hole to track several kilometres along a coal seam, creating a hole that intersects millions of cleats in the seam.

Fig 7: Down-hole steerable drilling motor and drill bit

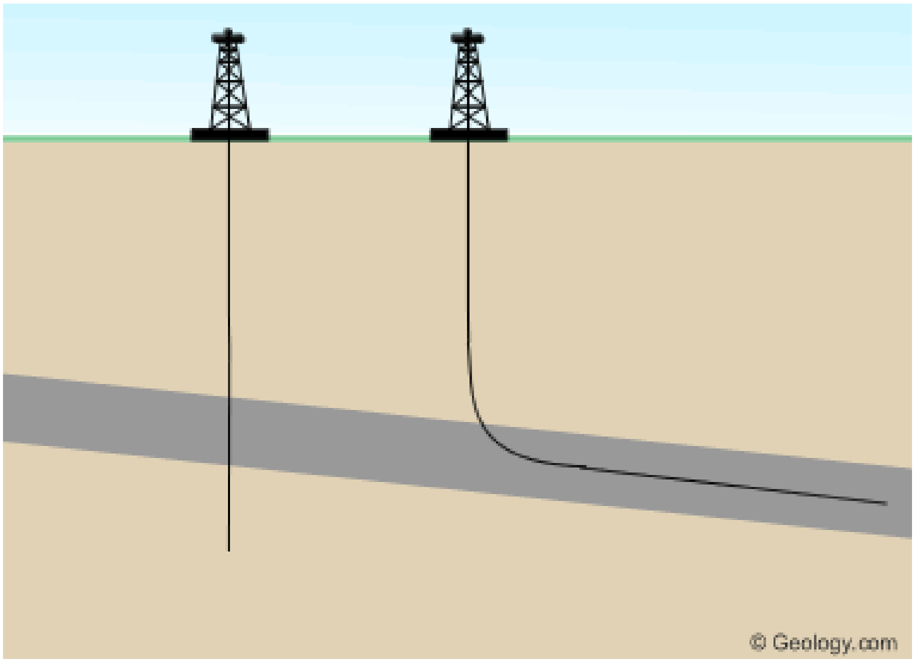

Fig 8: The old and the new – a directionally drilled borehole

However, turning a drill string around a bend, and drilling a kilometre or more, involves a great deal of friction. Therefore considerable attention had been given to drill fluid additives that reduce friction, and reduce drill fluid loss. We will return to these fluids shortly.

It was discovered in the USA, that there is a huge amount of gas in some very thick shale beds. However, shale has few natural fractures and certainly does not contain cleats. Therefore, to release the gas it is necessary to pump high pressure fluid in the boreholes so as to create many, and long, fractures in the shale. Such hydrofracturing had been used in the oil industry for decades, and has always been termed “fracking”.

In addition the new fractures have to be kept open by injecting sand. But including sand in the drilling fluid creates more friction, so more additives are necessary to improve fluidity.

Figure 9, taken from Scientific American, November 2011, illustrates the American shale gas drilling, fracking and extraction system.

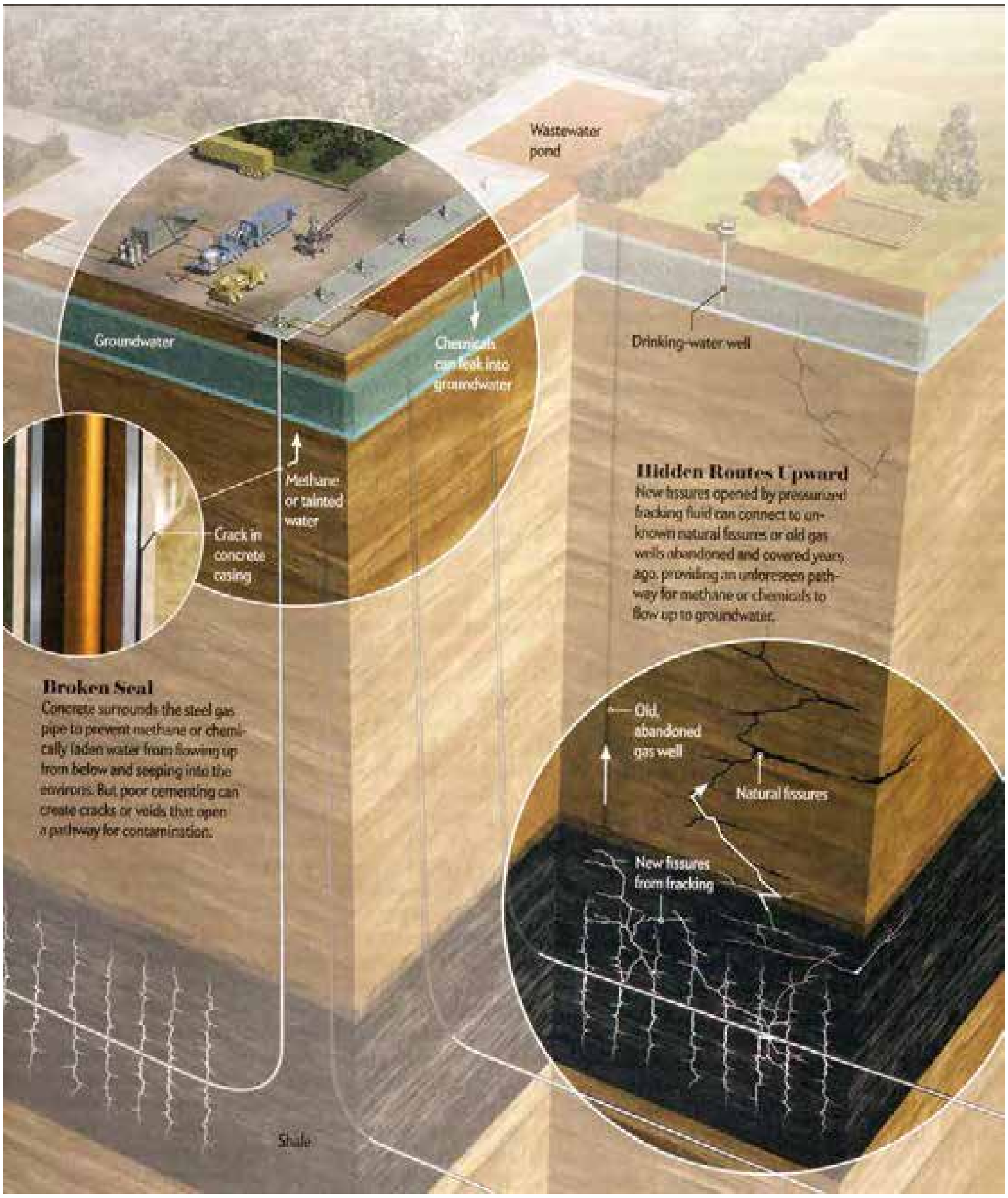

Figure 9 Shale gas extraction in the USA

As is discussed in Section 4, below, there is much to learn from the experience with shale gas extraction in the USA, but also, there are facets that cannot validly be transferred to the NSW coal seam gas projects. In America there has also been CSG extraction for far longer than in Australia, and there is a great deal to learn from that experience (David, Bryant & Johnson, 2009)

Two final points should be noted that set CSG exploitation apart from most other mining ventures.

Firstly, a CSG project can be initiated with relatively low capital injection. The drilling rigs and specialist equipment are hired, the surface facilities are small by comparison with coal and hard rock mines, roads are unsealed, there are no ventilation shafts, mills, floatation circuits, washeries, conveyor systems, stacker-reclaimers, railway lines and so on. Under full production there are a lot of quite small well-heads, some ponds for produced water and a pipeline system for the gas product.

Secondly, in order to produce a lot of CSG one needs a lot of production wells – typically 100 to 400 in a production area... Each well may recover gas from an area of about 5 hectare. Therefore the “mine” may cover an area of 500 to 2000 hectare. To put this in context, there are 48,800 farms in NSW with an average size of 1,270hectare. However, this figure is skewed by the extensive grazing properties in the far west where the average size is 43,000hectare. Coastal farms are quite small at 500hectare, and highland properties closer to average at 1,200hectare (NSW Department of Lands, Atlas of NSW)

In summary, this means is that low capital requirements and overall simplicity makes it possible for an exponential growth in an industry that then has a footprint growth far greater than any other previous mining industry in Australia.

The writer shares the opinions of many fellow engineers that the CSG industry has bolted ahead of its constraining science, as is discussed in Section 5, below.

5 THE ISSUES

5.1 Summary of Issues

The issues relating to CSG in NSW that warrant consideration are set out below:

1 Groundwater at coal seam extraction levels has to be depressurised and removed from the ground (termed ‘produced water’), unless this has already occurred due to previous coal mining.

2 The produced water has to be stored in a safe manner, and disposed safely.

3 Numerous drill well sites are necessary, each one occupying up 100metres by 100metres (1hectare), and all have to be connected by roads.

4 Directional drilling requires the use of various chemicals in the drill fluid additives.

5 Hydrofracturing, where used, involves additional drill fluid additives, and the extent and locations of the artificial fractures is uncertain.

6. Poorly sealed boreholes can be conduits for gas to escape to the surface.

7 Surface infrastructure requires pipelines and associated facilities.

These issues are expanded on in the following sub-sections.

5.2 Depressurisation of groundwater at depth

It is an indisputable consequence of Newtonian physics that, if there is depressurisation of groundwater at depth, there will be changes to the whole groundwater regime.

It is not a matter of **'if'**, it is a matter of **'how long'** will it take for the effects to be transmitted through the system.

This is not the place for a detailed analysis of possible groundwater impacts, for several reasons.

- Firstly, each geological environment is special, has particular stratigraphy, particular ground permeabilities, and particular chemistry.

- Secondly, the science is complicated.

- Thirdly, the science is not fully understood, even by specialists.

It is sufficient to quote the draft NSW Aquifer Interference Policy of March 2012 that classifies CSG extraction **as a high risk activity in respect to groundwater systems**.

There is no doubt in this writers mind, that impacts on near surface groundwater is the most important single consideration in respect to CSG extraction in NSW, and one that, to date, has not been properly policed.

There is, however, one rider to this appraisal. Some CSG projects are seeking to recover gas from areas that have already been mined, either by old bord-and–pillar methods, or modern longwall mining. In these areas the groundwater at coal seam level has already been depressurised. In addition much methane has already diffused from the micro-pores and is "gas methane", trapped in the fractured rock above the old workings. In such situations CSG extraction will not have significant additional impacts on the groundwater regime – the metaphorical horse has already left the stable.

As of the second week of March 2012 the scene in NSW in respect to impacts of CSG operations on groundwater systems has been changes by the Draft NSW Aquifer Interference Policy- Stage 1. This is a very complex document that includes many good initiatives. Amongst these is the explicit statement that *"for the purposes of this Policy the term aquifer has the same meaning as groundwater system and includes low yielding systems.*"

However, a particular point of great concern to the writer is the definition of Highly Productive Groundwater as being groundwater that *"contains water supply works that yield greater than 5 L/sec"*. This categorisation of Highly Productive Groundwater has major implications, as set out in the Policy.

An examination of the recorded yields of registered bores on the NSW Government database reveals that only a few patches within the Triassic rocks of the Sydney

Basin have provided bores with documented yields of >5L/sec. The same is true for the Lachlan Fold belt.

Figure 10 is the NSW Government contour plan, of 2007, of bore yields in the Hawkesbury Sandstone (Russell et al, 2009). It can be seen that most of the area, including, for example, productive orchards, wholesale nurseries and vegetable farms in the Picton- Bargo areas, has yields of less than 5L/sec.

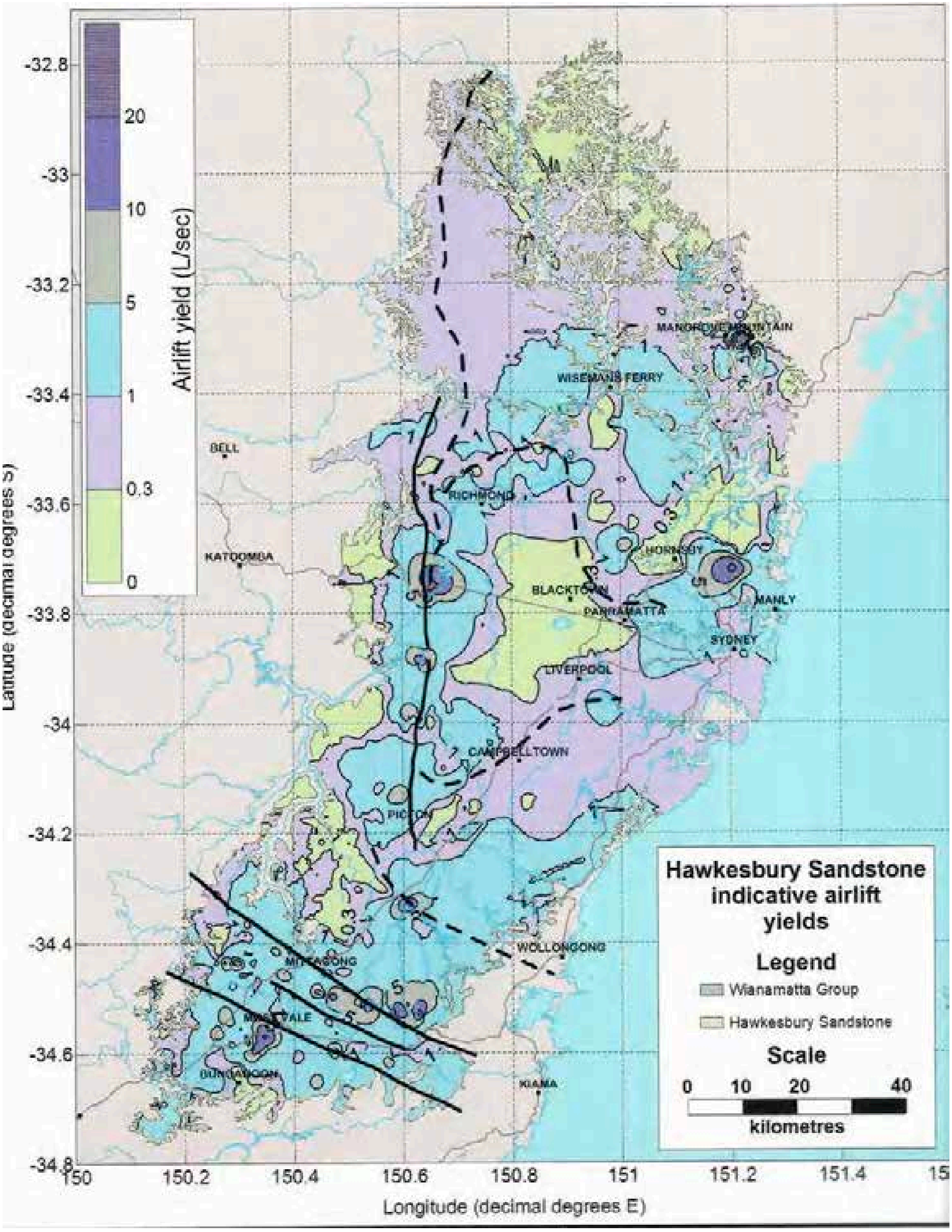

Fig 10 NSW Government plan showing bore yields in the area of the Hawkesbury Sandstone.

We have plotted all bores from the NSW Government database and from this plot Figure 11 is the area around Sutton Forest, an area acknowledged as the best groundwater system (quality and quantity) in the Sydney Region (NSW Dept Infrastructure Planning and Natural Resources, 2004). Yet, Figure 11 shows that most bores in that area have documented yields of less than 5L/sec. The consultants, Parsons Brinkerhoff (2003) reported that only 12.4% of bores in the Southern Highlands recorded yields >6litre/sec.

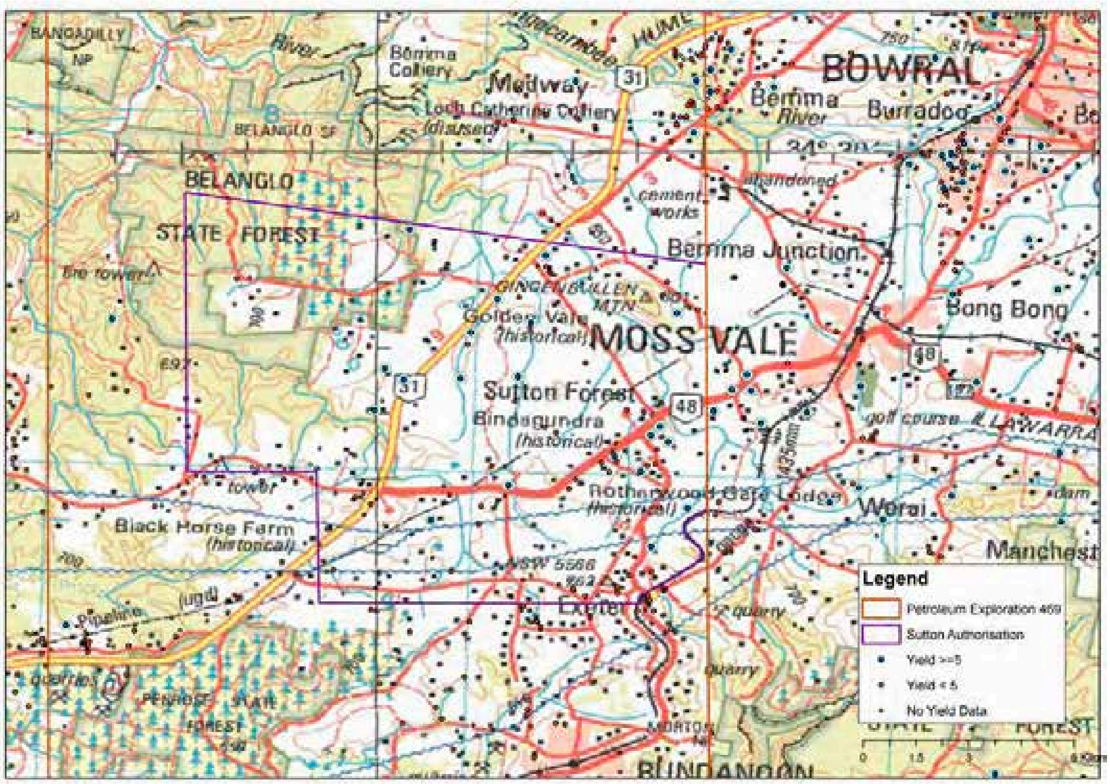

Fig 11 Groundwater bores in the Sutton Forest area. Note the circles around the blue dots measure the 150m radius defined in the draft Aquifer Interference Policy.

We have also considered the embargoed groundwater resource in the basalts near Orange (see Fig 12). We note that a dominant proportion of the bores have documented yields of less than 5L/sec, yet we know that many of these bores sustain productive fruit orchards.

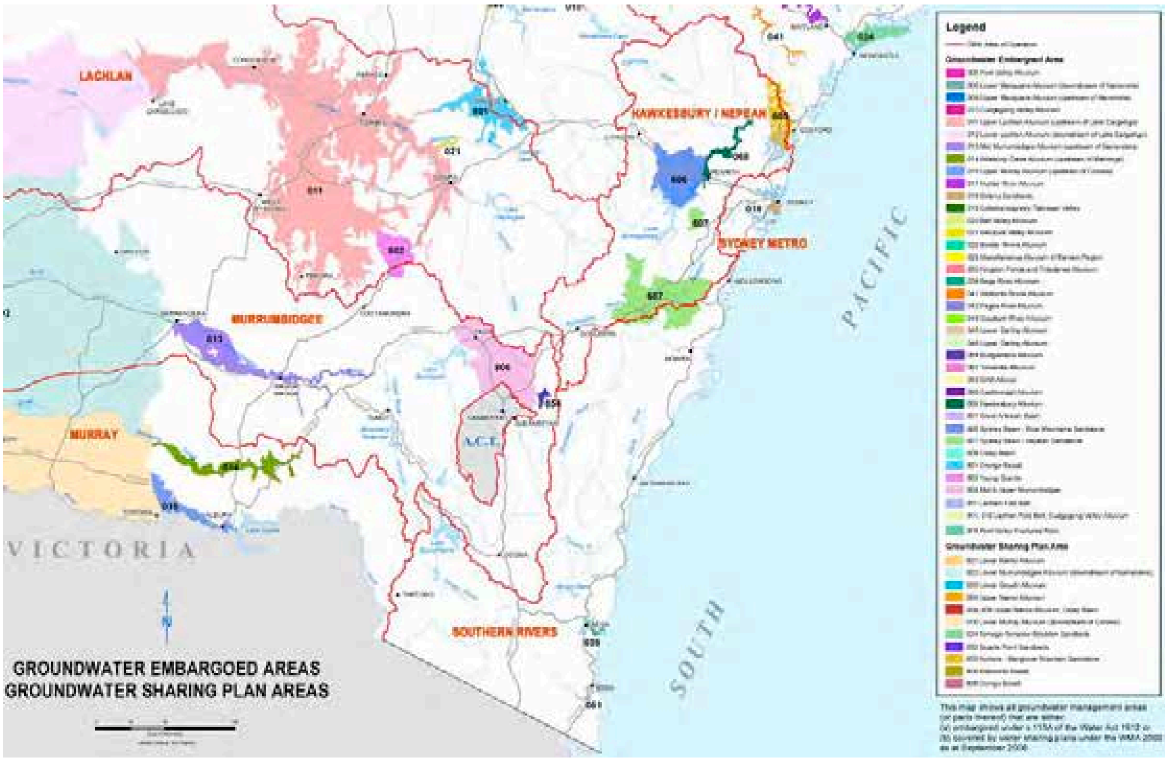

Fig 12: Embargoed Groundwater Areas

It is the writer's opinion that the factual data on registered bores in NSW makes nonsense of the adoption of 5L/sec for the definition of Highly Productive Groundwater, and, in turn, will probably make it very difficult to guard against inappropriate destructive, impacts from some CSG operations.

5.2 Produced water

Groundwater extracted from the coal seams of NSW is typically slightly too moderately saline.

Salinity is measures in terms of Total Dissolved Solids (TDS) in the groundwater, normally in the units of milligrams per litre (mg/l). This can be thought of, colloquially, as the residue left in a cooking pot after boiling dry one litre of the water,

The residue is called 'salt' but is not all sodium chloride (kitchen salt).

Typically NSW coal seam water tests at about 3000 mg/l – certainly that is the average figure in the Gloucester CSG project. This means that each litre contains 3 grams of salt, which is half a teaspoon.

It is not unreasonable to assume that a CSG bore field of 150 producing wells could extract about 10 lit/sec to 30 lit/sec produced water((David et al, 2009). A figure of 20 lit/sec would equate to about 1800 tons of salt per annum.

This water constitutes a pollutant[1] and has to be stored on surface in a manner and place that will not leak or be damaged by natural flooding. It then has to be disposed.

---

[1] Wright, I A "Coal mine 'dewatering' of saline wastewater into NSW streams and rivers; a growing headache for water pollution regulators" Referred paper, Proc 6th Australian Stream management Conference, Canberra, 2011

It is possible to reinject the water into the coal seams, but that is technically difficult, and expensive. It is, also, possible to treat the water by reverse osmosis to remove the salt, so that the water can be used productively. That leaves the issue of disposing the salt, which is not kitchen grade sodium chloride.

In the writers opinion the issue of produced water is the second-most important issue in NSW CSG operations.

5.3 Drill sites, producing well sites and roads

The surface disruption associated with CSG exploration boreholes, and producing wells, that may be only a few hundred metres apart, and the emotive issue of access by CSG Producers on private farm land are matters of ethics, politics and the law. The writer has personal views on these matters, but they are not matters of scientific expertise

5.4 Drill fluid chemicals

The writer is not a specialist chemist and does not have detailed knowledge of the chemicals that are used as drill fluid additives by the CSG industry in NSW. However, from the writer's knowledge of other drilling operations, it would appear that this is not a primary issue. It is also one readily amenable to regulatory control.

5.5 Hydrofracturing

Based on the writers knowledge of the CSG industry in NSW it is considered inappropriate to transfer to NSW coal seams, the North American experience with 'fracking' in shale.

As already explained, coal is closely fractured by the system of cleats. There is no need for extensive, expensive hydrofracturing. However, there is no doubt that hydrofracturing, and sand injection can be, and is, used in most CSG wells to open , and then maintain open, the natural cleats. However, this is not like the scale of North American shale fracking.

Furthermore, it should be noted that CSG projects that are targeting areas above and below areas of previous coal extraction are unlikely to make extensive, or even any, use of hydrofracturing This is because they are targeting areas fractured and disturbed by coal extraction. There may be some use of hydrofracturing where they target seams below the extracted seam or seams (the Bulli seam, or in places also the Wongawilli seam).

Whilst negative impacts from hydrofracturing can be significant, it is the writer's opinion that, in many CSG production situations in Australia, these are swamped by the potential impacts on groundwater systems, and the disposal of produced water.

5.6 Leaking wells

The issue of poorly sealed exploratory holes, and production wells, is important, as it is very difficult to retro-seal a hole that was not properly sealed during initial construction.

It is correct to say that the technology exists to properly seal exploration and production wells (see inset in Figure 9). Also the evidence suggests that most wells are properly sealed. However, there would appear to be a need for independent monitoring and supervision of all hole sealing if the 'cowboys' of the industry, to use a description by Santos, are to be controlled.

The writer notes that some who are strongly opposed to CSG exploitation of any kind, cite the case in Java, where a well drilled in an active volcanic area has poured incredible quantities of volcanic mud and ash across the countryside. It is quite inappropriate to imply that such an occurrence could occur in NSW. Geological conditions in the continental plate structure of Australia are completely different from those in the "ring of fire" around the Pacific rim.

5.7 Surface infrastructure

As discussed in Section 3, surface infrastructure typically involves:

- individual wells in enclosures, typically a kilometre, or so apart,
- storages for Produced water that range from plastic tanks to large open ponds
- gravel roads interconnecting the wells, and
- pipelines for collecting and exporting the gas from the production area.

The main technical issue relating to the surface facilities is their protection against major natural floods, and fire. The social issue, which dominates community concerns is that the surface facilities are often on private land. The issue is as dealt with in the movie 'The Castle', and is one for politicians and the law.

Yours faithfully,

PHILIP PELLS
FTSE BSc(Eng) MSc DSc FIEAust MASCE

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ON THE DISPOSAL OF PRODUCED WATER FROM COAL SEAM GAS PRODUCTION – A CASE STUDY, GLOUCESTER NSW

by Philip J Pells FTSE, DSc

1. INTRODUCTION

This note deals with the proposal for disposal of produced water in the approved Stage 1 Coal Seam Gas (CSG) project at Gloucester, NSW. Details of the project are available on the Australian Gas Light Company (AGL) website and are not repeated here. The location of the 110 well Stage 1 project is shown in Figure 1.

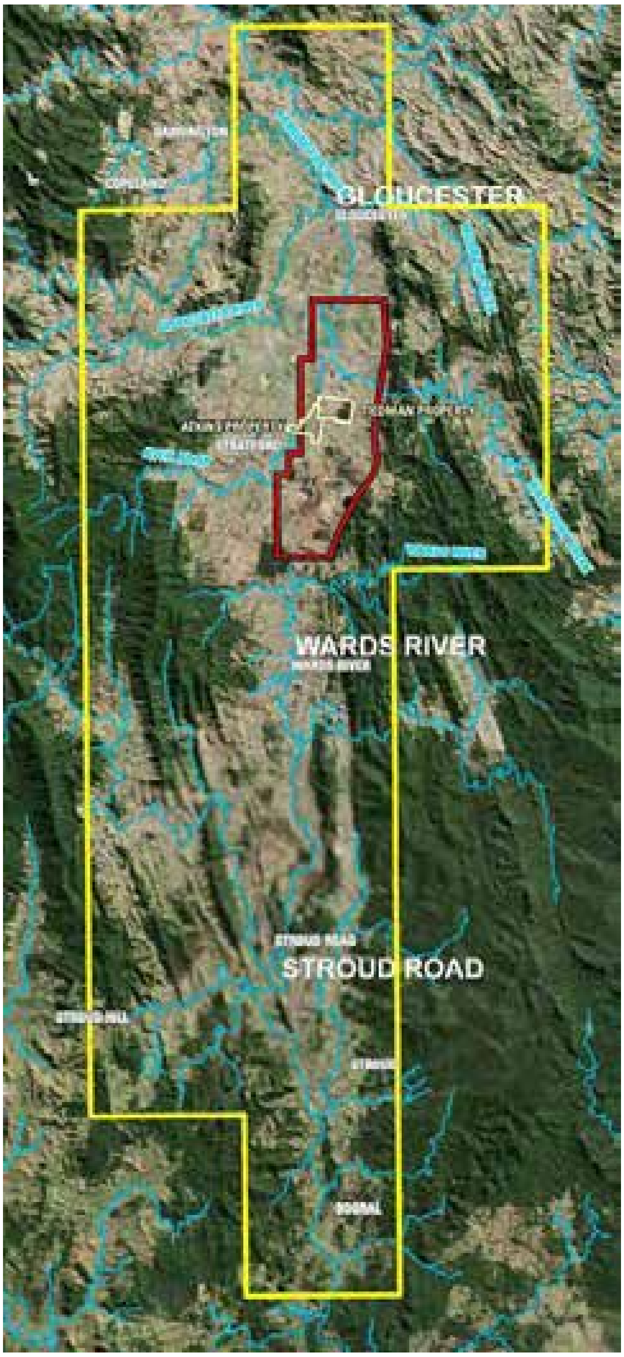

Figure 1: AGL Exploration lease in yellow and Stage 1 in red outline.

The extent of groundwater investigations within the Stage 1 area, as provided by AGL is shown in Figure 2.

Figure 2: AGL groundwater investigations (AGL Industry Briefing 14 Nov 2011 as cited on AGL website May 2013)

2. PROPOSED DISPOSAL OF PRODUCED WATER

At a presentation to a public meeting at Gloucester on 16 May 2013, a manager of AGL, Mr Mike Moraza, stated that salt from produced water would not be removed from site to the Taree waste disposal facility, as had previously been documented by AGL. Also Mr John Ross of AGL stated that produced water would not be disposed into the Avon River.

Mr Ross stated that it was intended that the produced water would be diluted and used for irrigation in accordance with a trial that is detailed on the AGL website, reproduced below:

> "AGL has initiated a produced water irrigation trial on its Tiedmans property that will involve the reuse of up to 70 ML of produced water over separate areas within the Stage 1A/1B areas. Most water is to be blended and irrigated over an intensively monitored 12ha area"

When questioned about the process, Mr Ross explained that the high salinity produced water would be diluted with fresh water, source unstated, and be fruitfully used for irrigation. When questioned about what would happen to the salt he said that it would not enter the streams and the Avon River but somehow be retained just below the topsoil level, and hence would be considered to be 'disposed'.

3. PROBABLE NATURE AND QUANTITY OF PRODUCED WATER

AGL have not undertaken any numerical groundwater of the Stage 1 project. They have produced a conceptual groundwater model in the Phase 2 Groundwater Report (January 2012, http://agk.com.au/gloucester/assets/pdf/PB%20Gloucester%20Groundwater%20Report%20Phase%202%20Text.pdf) but no calculations of the probable volumes of produced water.

However, a good, 3D MODFLOW model of the groundwater impacts of the AGL Stage 1 project is included in the EIS for the Stratford Coal Expansion Project (Heritage Computing report GCL-10-12, April 2102). From this model it is concluded that the Stage 1 wells will produce between 4.4 and 6.5 megalitres per day.

The quality of the water in the coal seams is summarised in the Phase 2 Groundwater report as:

> "Groundwater within the coal seams is typically slightly alkaline and brackish to slightly saline (3,000 < EC < 9,500 µS/cm) with EC measurements increasing with depth. Recharge of coal seams is low, as indicated by the groundwater quality, and occurs where the formations outcrop on the basin ridgelines (SRK, 2010). It is suspected that artesian conditions may occur in coal seams towards the centre of the Basin.) (p29)

The seam-level groundwater testing is summarised as:

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Water Quality parameters				
Field EC	µS/cm	125-2,200[b]	**3,014-4,999**	**4,012**
Field pH	pH units	6.5 – 8.0[b]	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 $CaCO_3$	mg/L		274-711	481
Metals				
Aluminium	mg/L	0.055 (pH>6.5)	<0.01-**3.87**	**1.09**
Arsenic	mg/L	0.013 (AsV), 0.024 (AsIII)	<0.001-0.004	0.002
Barium	mg/L	-	0.054-1.54	0.672

Parameters	Units	ANZECC (2000) guidelines[a]	Range	Average[c]
Beryllium	mg/L	ID	<0.001	<0.001
Cadmium	mg/L	0.0002	<0.0001-**0.0004**	0.0002
Copper	mg/L	0.0014	<0.001-**0.004**	**0.002**
Lead	mg/L	0.0034	<0.001-0.005	0.001
Manganese	mg/L	1.9	<0.001-0.64	0.22
Molybdenum	mg/L	ID	<0.001-0.006	0.003
Nickel	mg/L	0.011	<0.001-0.157	0.034
Selenium	mg/L	0.011 (total)	<0.001	<0.001
Strontium	mg/L	-	0.125-6.01	2.82
Uranium	mg/L	ID	<0.001-0.005	0.002
Vanadium	mg/L	ID	<0.01	<0.01
Zinc	mg/L	0.008	0.006-**0.33**	**0.089**
Iron	mg/L	ID	0.13-4.99	1.43
Bromine	mg/L	ID	0.9-2.2	1.5
Nutrients				

The writer has highlighted some of the elements in the above table for consideration.

Turning first to salinity, as given by the Total Dissolved Solids, averaging 4.012 grams per litre, one can calculate the present estimate of produced 'salt' as between:

$4.4*10^6*4.012/1*10^6$ = 17.7 tonne per day

and

$6.6*10^6*4.012/1*10^6$ – 26.5 tonne per day.

These numbers suggest an annual production of 'new' salt brought to the surface, from the old groundwater at depth, of 6,500 to 9,700 tonne per year. If, as was stated by the AGL personnel on 16 May 2013, the project is expected to produce for about 15 years then there could be about 98,000 to 150,000 tonne of new salt deposited into the surface soils by the proposed irrigation 'disposal' method.

In the same way, one can calculate the increases in zinc, manganese, nickel, copper and aluminium deposited on the surface.

4. DISCUSSION

The writer is not expert in all the aspects of salinity impacts on land and agriculture. However, there are two well known facts, namely:

- salinity of surface soils is a serious issue in Australia (viz the document 'Salinity" by the CSIRO land and Water Division), and

- our normal issue has been dealing with salt being lifted to the surface due to rise of the groundwater table, associated with deforestation, viz:

  Dry land salinity is the movement of salt to the land surface with groundwater, occurring on land that is not used for irrigation, and it causes the most widespread damage. The amount of salt in Australia is not increasing but is being brought towards the surface: Before European settlement and extensive farming this salt was stored safely in the earth below the depth of plant roots. (CSIRO report, highlighting by the writer).

Given that the salt brought to the surface at Gloucester will not disappear as if by magic, and given that it is 'new' salt brought from depth, the writer considers that that AGL's proposal at Gloucester cannot be considered to be an acceptable means of disposal of the Produced Water.

18 May 2013

ON THE ABSENCE OF QUANTITATIVE CRITERIA FOR STOP-GO ASSESSMENT OF COAL SEAM GAS PROJECTS IN NSW USING GLOUCESTER STAGE 1 AS A CASE STUDY

By Philip Pells FTSE DSc

1. INTRODUCTION

At a public meeting held in Gloucester on 16 May 2013, it was stated by a manager of AGL, Mr Mike Moraza, that his company had to abide with approximately 36 conditions in developing the approved Stage 1 Coal Seam Gas (CSG) project at Gloucester. In response the writer suggested that most of these State and Federal Government conditions contained no quantitative criteria whereby it could be objectively judged that appropriate protection of the groundwater and surface water resources. This note is intended to provide the basis for that statement by the writer. It applies only to matters in the writer's areas of expertise, being groundwater and surface water.

One point should be made at the start.

There is one State document that does provide unambiguous criteria in respect to groundwater impacts, namely the NSW Aquifer Interference Policy (AIP) of 2013. However, this is only a policy, and in any event, there is no indication that it applies to the CSG project at Gloucester, which has been approved at State and Federal level with no reference to the AIP.

2. STATE GOVERNMENT CONDITIONS ON STAGE 1 CSG AT GLOUCESTER IN RESPONSE TO THE ENVIRONMENTAL IMPACT STATEMENT

The writer refers to conditions given in the following document:

Director-General's Requirements

Section 75F of the *Environmental Planning and Assessment Act 1979*

Concept Plan	Construction and operation of the Gloucester Coal Seam Gas Project, comprising: • a concept plan application for: ○ gas wells and gathering lines within a Field Area; ○ a Central Processing Facility; and ○ an approximately 1 kilometre width pipeline corridor between Stratford and Hexham; and • concurrent project applications for: ○ 60-90 gas wells and gathering lines within a sub-area of the total concept plan Field Area; ○ the Central Processing Facility; and ○ an approximately 100 metre wide pipeline corridor within the 1 kilometre width concept plan pipeline corridor, between Stratford and Hexham.

In respect to groundwater and surface water the Director-General's requirements are as reproduced below (highlights by the writer).

- **Surface and Groundwater** – the EA must include a justified and tiered assessment of impacts on surface and groundwater, including:
  - quantification of the coal seam groundwater volumes likely to be require extraction as part of the Field Area (including future stages of the concept plan) and an assessment of the impact of that extraction on existing groundwater resources and users, including measures to monitor and mitigate impacts, as necessary;
  - identification of how extracted water would be stored, used, disposed of and/ or re-supplied to other users at the Central Processing Facility;
  - identification of watercourses to be traversed by the proposal or otherwise impacted by activities within the riparian corridor and an assessment of how the hydrology, water quality, aquatic habitat and riparian vegetation of the watercourses would be protected during the construction and operation of the proposal; and
  - an assessment of erosion and sedimentation risk associated with the proposal, particularly in areas of acid sulphate soils and measures to contain and manage impacts.

It can be seen that the proponent must provide some important quantitative information, namely:

- calculation of amount of Produced Water,
- assessed impacts on groundwater resources,
- identification of potentially impacted watercourses, and
- assessment of risks pertaining to erosion, sedimentation and acid sulphate soils.

But there are no stated criteria that have to be met. There are no rules. In the 'high jump' analogy, the bar has not been set at any height for any of the conditions.

It would seem, therefore, that the criteria, by which it would be judged, that the project may proceed, are either undocumented in the public space or are subjective and in the minds of unknown bureaucrats.

3. FEDERAL CONDITIONS BY MINISTER BURKE

The document referred to is:

person to whom the approval is granted	AGL Upstream Infrastructure Investments Pty Ltd
proponent's ACN	002 684 010
proposed action	To construct, operate and decommission: • not more than 110 coal seam gas wells and associated infrastructure including gas and water gathering lines; • a central processing facility (at one of two proposed alternative sites); • a gas receiving station at Hexham; and • a pipeline from the central processing facility to the Hexham receiving station, as described in the referral received on 29 August 2008 and subsequently varied on 1 May 2012 (referral EPBC 2008/4432).

approval decision

controlling provision	decision
wetlands of international importance (sections 16 & 17B)	approve
listed threatened species and communities (sections 18 & 18A)	approve

decision-maker

name and position	The Hon Tony Burke MP Minister for Sustainability, Environment, Water, Population and Communities
signature	Tony Burke
date of decision	11 February 2013

The Conditions in this document, germane to ground and surface water, are numbers 16 to 19, 21 and 22.

Condition 16 reads:

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

This is a requirement to consult on a non-quantitative conceptual model of the groundwater regime, a model that has already been presented by AGL in the Phase 2 Groundwater Study. There can be no criteria attached to such a conceptual model that could impact on the project proceeding as chosen by AGL.

Condition 17 reads:

17. The person taking the action must revise the water balance model to:
    a) take into account the following inputs:
        i. field-based investigation of the spatial distribution of strata and structures within the project area and the role of faulting and its influence on migration of groundwater and/or gas into surface water systems;
        ii. investigation of the age, depth and location of groundwater including proximity to known faults and fractures;
        iii. a baseline investigation of gas occurrence in surface and groundwater;
        iv. results from pilot testing of the Stratford and Waukivory pilot wells;
        v. baseline data associated with Phase 1 and Phase 2 studies;
        vi. information on the assessment of a representative site for fault testing; and
    b) extend to 1000 metres below ground level;
    c) ensure that all hydrological inputs and outputs are accounted for (sum to zero); and
    d) include a list of information sources and statements on confidence, accuracy and precision.

    A report on the revised water balance model, including the inputs described in a) above, must be approved by ***the minister*** prior to the finalisation of the numerical hydrogeological model (refer to Condition 18).

The requirements given in Condition 17 as to matters to be included in the water balance are good and proper. But there is no quantification as to what changes to the natural, pre-mining, water balance are, or are not, acceptable. It must also be realised, from the technical viewpoint, that without the results of the numerical hydrogeological model (pink highlight) as to the probable quantity of Produced Water, the water balance model required by Condition 17 is substantially speculative. So again we find no stop-go criteria.

Conditions 18 and 19 relate to the groundwater model and are reproduced below with highlights by the writer.

18. The person taking the action must provide ***the minister*** with a numerical hydrogeological model that explores the pressure at which gas and water may be released and transmitted along faults. The model must be based on the water balance model described in Condition 17 and informed by monitoring data, for example as collected in accordance with Condition 4.1 of the ***state approval conditions***.

    The model must be approved by ***the minister*** prior to the commissioning of the approved central processing facility.

    Note: It is expected that *the minister* will require the model to be peer-reviewed prior to approval.

19. Within three (3) months of the approval of the numerical hydrogeological model described in Condition 18, or the conceptual hydrogeological model required under Conditions 3.8 and 3.9 of the ***state approval conditions*** (whichever is the later), the person taking the action must use the models to complete a risk analysis in relation to the following potential impacts on the green and golden bell frog and giant barred frog, and their potential habitats:

    a) surface expression of methane gas;

    b) water pollution including salinity;

    c) water drawdown; and

    d) any impacts on surface water.

The groundwater model referenced in Conditions 18 and 19 is <u>the</u> critical tool in the understanding of the probable impacts on the groundwater and surface water systems. However, there are no criteria in these conditions that are of the kind that are in the NSW Aquifer Interference Policy, which allow an objective evaluation as to whether impacts are acceptable or not. The 'risk analysis' alluded to in Condition 19 is simply a process, without set criteria it cannot be a measurement of acceptability.

As stated above, in respect to the State Government EIS, it would seem, therefore, that the criteria, by which it would be judged, that the project may proceed, are either undocumented in the public space, are subjective, being in the minds of unknown bureaucrats.

Conditions 21 to 23 relate to Produced Water and read:

21. The person taking the action must provide ***the department*** with a copy of the extracted water management strategy (also known as produced water management strategy) required under ***state approval conditions***. If the strategy is not to the satisfaction of ***the minister*** (and in particular if it does not consider the feasibility and likely effectiveness of reinjection of extracted water), he may require a supplement to be developed, which must be approved by ***the minister*** prior to ***commencement*** of the action, and must be implemented.

22. The person taking the action must ensure that no more than 2 megalitres per day (averaged over a twelve month period) of groundwater is extracted. In addition, the person taking the action may only extract sufficient groundwater as is required to undertake the action in accordance with the conditions of this approval.

23. The person taking the action must ensure that any water storage ponds associated with the action are appropriately lined to ensure no leaching of stored waters and designed consistent with a 1 in 100 year flood design standard.

Condition 21 should be considered in relation to the statement by AGL on 16 May 2013 that Produced Water from Stage 1 at Gloucester will be disposed of on the surface by irrigation[1]. As set out in the document cited in Footnote 1, in the writer's opinion, the irrigation proposal is scientifically untenable.

Clearly, the evaluation criteria for acceptable disposal of Produced Water are ***"the satisfaction of the minister".*** In the wake of recent revelations at ICAC in relation to mines at Mt Penny and Broke, this form of evaluation may not be considered appropriate by many members of the public.

The Condition of not more than 2 megalitres per day of Produced Water, given in Condition 22 is an unambiguous quantitative criterion. However, there already exists a good 3D groundwater model of the Gloucester Basin that calculates the probable quantity of Produced Water from the Stage 1 CSG project. The amount is between 4.4 and 6.6 megalitres per day (see paper referenced in Footnote 1).

This immediately begs the question. What is the status of the project if the likely quantity of Produced Water is much greater than the specified 2 megalitres per day?

4 THE INDEPENDENT EXPERT SCIENTIFIC COMMITTEE ON COAL SEAM GAS AND MINING DEVELOPMENT

This committee has produced a three page report on the Stage 1 Gloucester project that includes recommendations that are not Conditions.

Point 2 in this report is:

2. The committee recommends that a thorough risk assessment of the impact of faulting is undertaken that is informed by:
    a. A baseline investigation of gas occurrence in surface and groundwater ;
    b. A field-based investigation of the spatial distribution of strata and structure within the project area and the role of faulting and its influence on migration of groundwater and/or gas into surface water systems;
    c. A peer-reviewed, predictive numerical model that explores the pressure at which gas and water may be released and transmitted along faults; and
    d. The potential impact of fugitive gas emissions on surface water and groundwater quality, which may affect matters of national environmental significance, such as the endangered Giant Barred Frog and the vulnerable Green and Golden Bell Frog.

It is to be commended that the Committee has highlighted the potential importance of the pervasive faulting of the Gloucester Basin, an issue dismissed by AGL in the stated 'comprehensive' Phase 2 Groundwater report. However, there are no measurable criteria set in Point 2 against which the recommended studies would be evaluated.

[1] See paper by Pells of 18 May 2013 titled **"ON THE DISPOSAL OF PRODUCED WATER FROM COAL SEAM GAS PRODUCTION – A CASE STUDY, GLOUCESTER NSW"**

Point 3 of the IESC report relates to the water balance study (see Condition 17 of Burke, above), and states:

3. The conceptual water balance should be revised in light of the above concerns and utilising the additional information gathered from 2(a) to 2(d). In addition, the model should be extended to 1000 m depth below ground surface. It should be underpinned by:

    a. Sufficiently detailed, scientifically robust data or analysis to adequately model water movement and rate of flow through the hydrogeological units;

    b. Data on water fluxes which should, but currently does not, balance (e.g. total rainfall 193 GL/a, aquifer recharge 7.7 GL/a, evaporative transpiration 99.2 GL/a, and surface runoff 94.2 GL/a); and

    c. Modelling of the faults or fracturing and the potential effects of coal seam depressurisation. Indications of confidence, accuracy and precision in populating the water balance should be included.

Once again we are dealing only with procedures, good though they may be. But it is the product that is ultimately important, and we are given no indication as to how to measure whether the product is acceptable, or not.

The IESC Point 6 is:

6. The committee suggests that the draft approval conditions could be strengthened by the following requirements:

    a. Regular reporting on the actual use of hydraulic fracturing and accurately specifying well locations, to be incorporated into the groundwater model; and

This may be tedious, but again it must be noted Point 6 is <u>procedure</u>, not product and product evaluation.

Finally, Point 7 is, in effect, a repeat of Minister Burke's Conditions, and reads:

7. In relation to Minister Burke's eight hydrological concerns/requirements in the letter dated 21 September 2011, the committee notes that the draft approval conditions incorporate the specified requirements as outlined below (using the numbering as contained in the Minister's letter):

    1. '*data for the Planning Assessment Commission's requirements 3.5 to 3.13 and 4.1 to 4.2*';

       Condition 14 specifies this requirement. In addition, conditions 22, 25 and 26 require the Minister's approval to an extracted water management strategy, an acid sulphates soils management plan and a water course crossing management strategy.

    2. '*data from pilot testing at Waukivory and Stratford*';

       Condition 16 specifies this requirement.

    3. '*baseline data associated with Phase 1 and Phase 2 studies*';

       Condition 17 specifies this requirement.

    4. '*The numerical groundwater model*';

       Condition 20 specifies this requirement.

    5. '*data on the location, depth and age of groundwater samples including proximity to known faults and fractures*';

       Condition 15.b specifies this requirement.

    6. '*the Produced Water Management Strategy*';

       Condition 22 specifies an 'Extracted Water Management Strategy as required under state approval conditions'. This would meet the Minister's condition if an 'Extracted Water Management Strategy' is the same as a '*Produced Water Management Strategy*'. This should be clarified.

    7. '*details on when the Extracted Water Management Strategy will be available*'; and

       Condition 22 specifies this requirement.

    8. '*information and data about the assessment of a representative site for fault testing*'.

       Condition 18 specifies this requirement.

5 DISCUSSION

The writer does not claim to have covered all the conditions that have been set by State and Federal Governments in respect to the totality of the Stage 1 CSG project at Gloucester. However, the writer thinks that the material presented above covers most of the material germane to groundwater and surface water, and thinks, also, that the details given above support the view that most of the conditions do not contain objective stop-go criteria for the project. This creates the danger that the complex and expensive processes demanded of AGL may be no more than a system of box-ticking of procedures with there being no penalties, and no real protection of the water systems.

Under such situations there has, in recent years in Australia, developed the practice of invoking 'Adaptive Management" for impacts on groundwater and surface water, whereby goalposts are moved, and some project procedures are adjusted, to deal with what actually develops as the project proceeds.

In the matter of SHCAG v Boral and others the NSW Land and Environment Court has shown this to be unacceptable, citing Preston C J:

> ***"in adaptive management, the goal to be achieved is set, so there is no uncertainty as to the outcome*** *and conditions requiring adaptive management do not lack certainty, but rather they establish a regime which would permit changes, within defined parameters, to the way the outcome is achieved."*

18 May 2013

ON THE CYNICISM OF THE PUBLIC TO INFORMATION PROVIDED REGARDING COAL SEAM GAS OPERATIONS – GLOUCESTER, NSW EXAMPLE

By Philip Pells FTSE DSc

1. INTRODUCTION

It is apparent to any objective observer that typical members of the public who are affected, or may be affected, by Coal Seam Gas (CSG) exploration and production in NSW are highly cynical of the information they are being given by politicians and the energy companies in respect to possible impacts of CSG on their farmland, house prices, health, groundwater systems, and surface water supplies. This has been exacerbated by the rapid issuing of exploration licences covering a substantial proportion of farmland and populated areas in NSW, and in an industry that is poorly understood.

The writer, who has reasonable knowledge of groundwater and surface water matters, was present at a public, information, meeting at Gloucester on 16 May 2013, at which some 450 citizens were present. The writer was one of the speakers at the meeting. The meeting included a 1 hour question and answer session.

2. SOME SOURCES OF MISTRUST

The meeting encapsulated facets which highlight sources of distrust in the public.

2.1 What are you hiding?

At the outset the Chairman informed the meeting that while members of the media were free to be in the meeting there was to be no recording, and he instructed the two television camera crews that were present to cover their cameras. He said that this was a condition of AGL in allowing their personnel to speak at the meeting. A member of the audience proposed that the meeting be recorded, and televised, so that those members of the public who were unable to be present, could be properly informed. This was put to the vote, and an estimated 90% of the audience voted in favour. The Chairman put this to the AGL manager present in the hall and he declined to change the requirement of no recording. There were cries of; 'What are you hiding?'

2.2 Spin and misuse of science

A typical member of the public has little knowledge of the engineering and scientific facets of CSG extraction, hydrogeology and hydrology. They don't even know what the latter two words mean.

But they have been brought up, and taught at school, to believe science. This puts great responsibility on engineers and scientists to present their work truthfully, and with proper expression of uncertainties in their data and calculations. Spin should play no part in engineering and science.

During the course of the meeting there were many examples of misleading presentations of so-called factual and scientific material. The writer cites the following examples that fall within his areas of expertise. These are from notes made by the writer immediately after the meeting, and the tense reflects that fact.

- It was stated that the coal seams at Gloucester were low permeability – like at Camden.

  The available truth, in AGL's own documentation cited by AGL tonight, is that "*the main aquifers in the Gloucester Basin are coal seams*" (URS, 2007: Woodward Clyde, 1996 and Duralie Coal, 2006).

- It was stated by AGL tonight that the Phase 2 report was actually not a comprehensive groundwater report and that a comprehensive study was underway and would eventually appear.

  The truth is that the 2012 AGL documentation, cited tonight, states: "A comprehensive groundwater investigation (Phase 2 Groundwater Investigations) was completed in early 2012" (AGL September 2012). Note the past tense.

  Furthermore that Phase 2 report reached a critical conclusion, namely:

  "there is no evidence of natural connectivity between shallow and deep groundwater systems".

  It also stated that *"the available data suggests the faults do not affect the natural groundwater flow characteristics …".* Yet the URS 2007 report, cited by AGL tonight, says" *Groundwater is also likely to flow vertically between aquifers, facilitated by the presence of fracture/faults…."*

- It was stated that the CSG wells would remove about 2 Megalitres per day (700Ml per year); this being taken from the Water Balance Study (AGL, August 2012) and that this was minuscule in relation to the average of 193 Megalitres per day rainfall that falls on the 'Northern basin'.

  The truth is that the Water Balance Study states : "*It is understood that Stage 1 GFDA development may result in a net consumptive dewatering volume of approximately 700 ML per annum in the initial years of the project".* i.e. this is not a computation, but an assumption.

  The only computation we have is in the good Stratford Expansion 3D model (in Stratford Coal EIS) that calculates *"that the expected (extreme case) production of CSG water will range from 4.4 ML/day to 6.6 ML/day on average over 11 years"* . This is 2 to 3 times higher than the value presented tonight.

  The Water Balance Study says that average baseflow is about 6.6 megalitres per year. So this means that the CSG wells will remove most, or all, of average baseflow.

  In drought periods it is baseflow that is critical to stream flows..

- It was stated tonight that the average flow in the Avon from the Northern basin (the Stage 1 area) is about 117 gigalitres per annum (taken from the AGL Water Balance Study p28).

  The truth is that the figure given in the Water balance Study is from records between January 2005 and June 2012 (7 years). And no hydrologist in his or her right mind, in any country, would draw conclusions from 7 years of record, and particularly not in southern and eastern Australia where drought and flood dominate our water systems.

- It was stated that the salt brought up from the coal seam levels in Produced Water would not be removed to Taree, and would not be put into the Avon River, but would mixed with fresh water (presumably from the Avon) and used for irrigation thereby disposing of the salt.

  It is a matter of physics that the salt has to re-enter the ground where it is sprayed; it does not evaporate. How far down into the ground it goes, and how far it moves sideways into creeks, and the Avon, is a matter of time and geology. But it has not been disposed of and it must increase salinity levels in the ground, and eventually in the creeks.

  As AGL alluded, the reason AGL are diluting it is that if you irrigate directly with the Produced Water, with its approximately 3 grams per litre salt, it will kill crops so the irrigation will be a visual failure, seen by all..

  It is also a matter of physics that if one adopts the best calculation we currently have as to volume of Produced Water (from the Stratford Expansion model), and the salinity values in the AGL Phase 2 report, AGL will produce between 17 and 29 tonne of new salt per day, i.e. 6200 to 10000 tonne per year.

- It was stated by AGL that there had been zero leakage from wells at Camden, in 90 wells, and therefore that would apply at Gloucester.

  However, the AGL manager of the Camden Gas Project said in public, on 29 April, that it had to be acknowledged that for much of the first decade at Camden there had been no consideration of fugitive gas, because this had not been thought, in the industry and in the scientific community, to be a significant issue. Only in the past couple of years had measurements been commenced. Some leakage had been found and had been dealt with. This was a reasonable and accepted answer.

  AGL officially say in their website, as of May 2013: *"01 March 2013 The Camden Gas Project will become the first coal seam gas project in New South Wales to implement a fugitive methane emissions monitoring program, AGL Energy Limited (AGL) announced today."*

  So the truth is that there is no way of knowing that there has been zero leakage from the bores themselves. Experience from elsewhere in the world suggests that leakage will occur in 5% to 15% of wells, getting worse with the passage of time.

- It was stated that AGL had operated the Camden gas field since 2001 and this should give the people of Gloucester great confidence in respect to safe operations in the Gloucester basin.

  The truth is that the Camden gas field had been owned and operated by Sydney Gas since 2001, and AGL only bought Sydney Gas in 2008.

  The writer has gone on record, in public, noting that the location of the existing AGL operations at Camden is appropriate for extraction of CSG, in relation to groundwater systems, that the wells are not visually intrusive from the ground and from the air, and that AGL appears to operate a technologically and professionally competent operation. But this does not mean that Camden is a direct analogy for a CSG field in a completely different geological, surface water and agricultural environment such as at Gloucester. One simple example of the difference is that AGL have stated (EIS for proposed Camden North extension) that no future wells in Camden will involve hydrofracturing, whereas at the meeting on 16 May, the manager of AGL stated that hydrofracturing (fracking) would be used in <u>all wells at Gloucester.</u>

3. DISCUSSION

The writer is not a social scientist, has no political affiliations, is paid by nobody in relation to CSG and is actually in favour of CSG extraction in appropriate locations. But, from meeting with concerned public in places as diverse as Moree, Liverpool Plains, Picton, Sutton Forest and Gloucester, it is clear that there is substantial pain and perplexity in the people, and the present process of evaluation and communication is not working.

18 May 2013

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15 February 2012

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

PHILIP PELLS
FTSE BSc(Eng) MSc DIC DSc FIEAust MASCE

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.

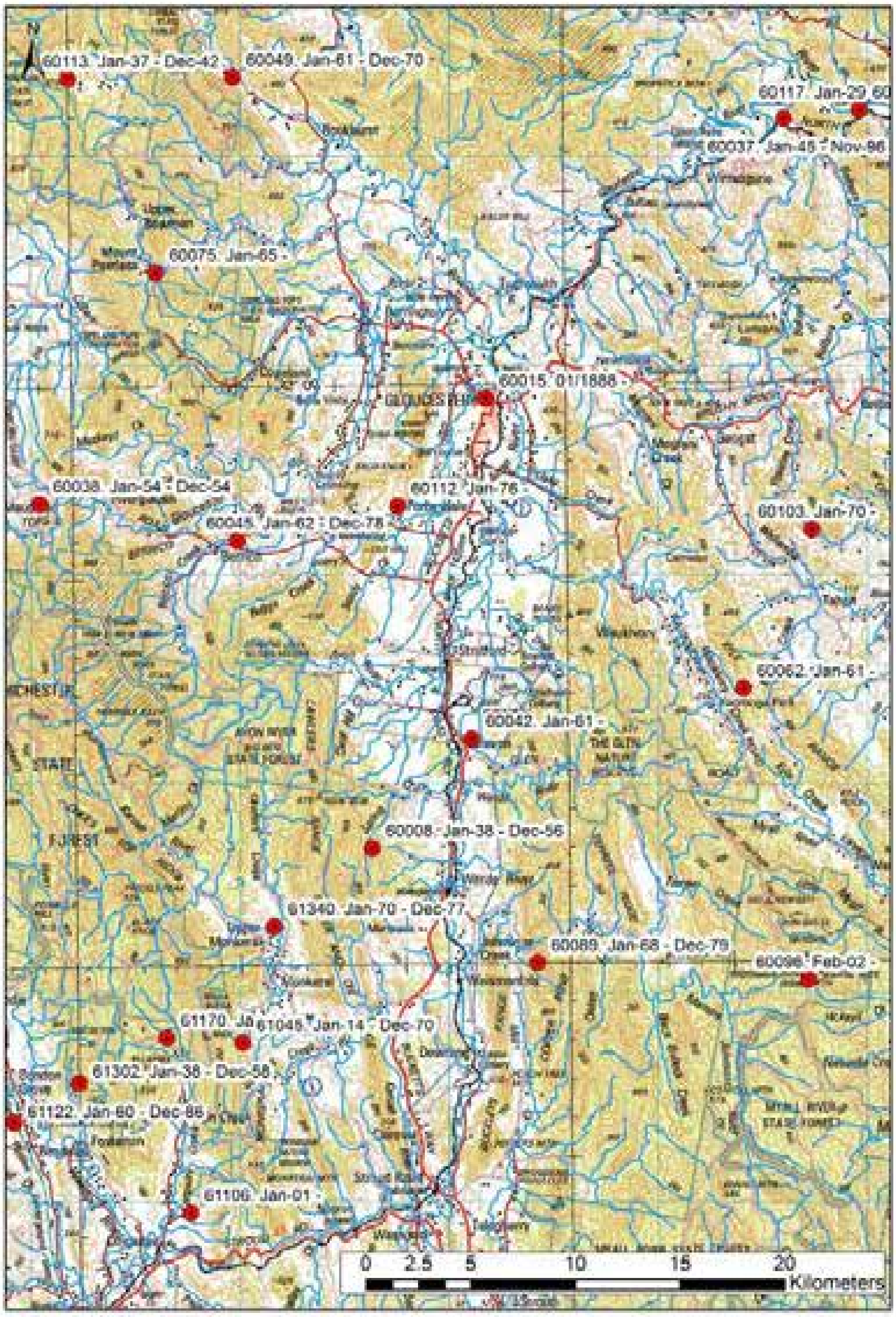


Figure 1: Rain gauges.

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.

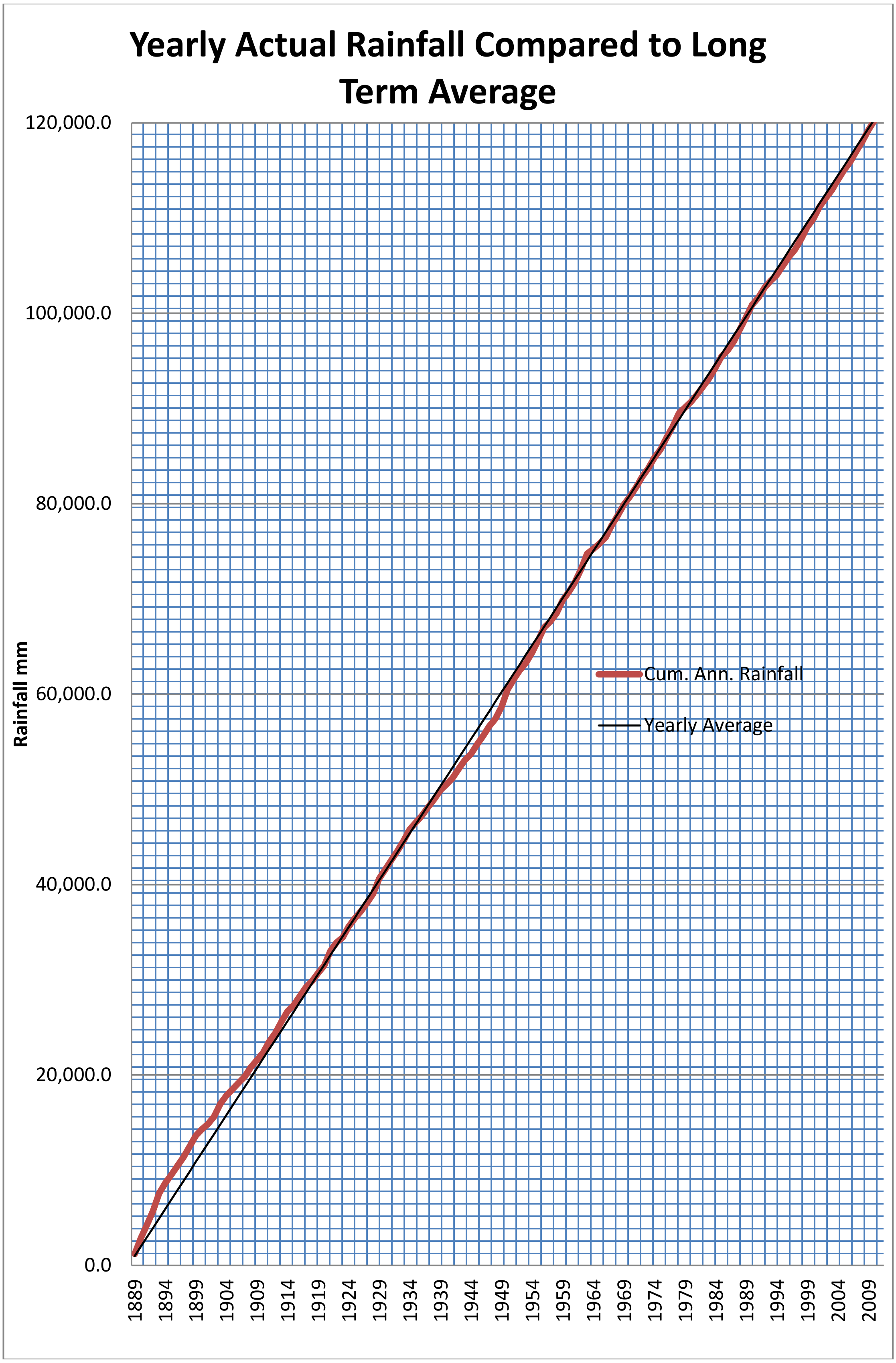
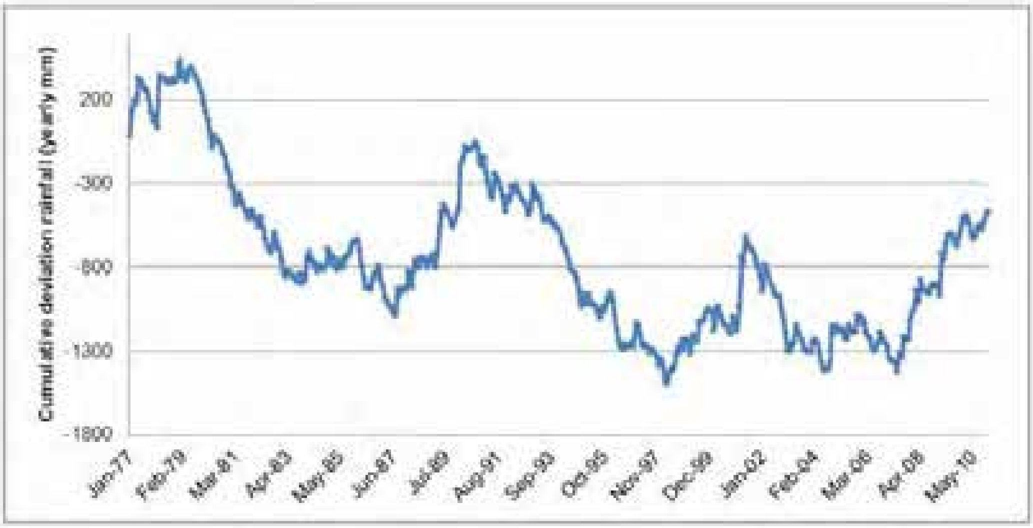


Figure 2: Cumulative rainfall from 1889.

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.

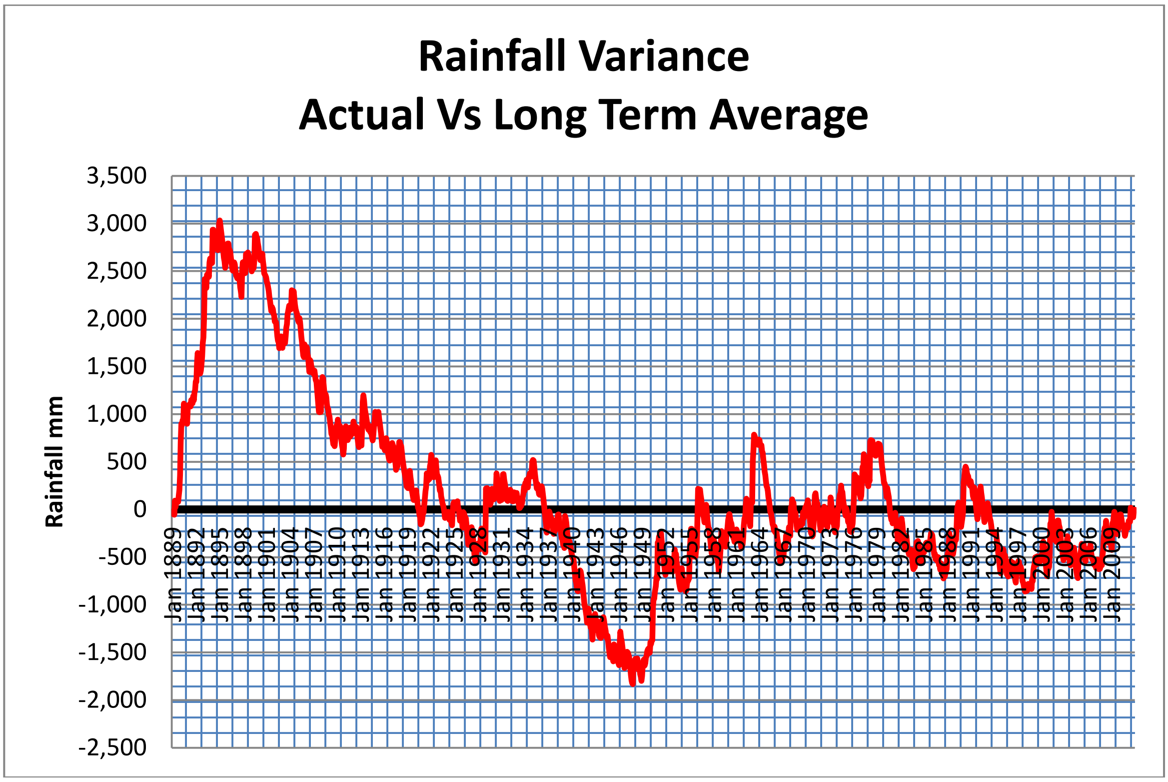


Figure 3: Rainfall data from 1889 to 2011.

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.

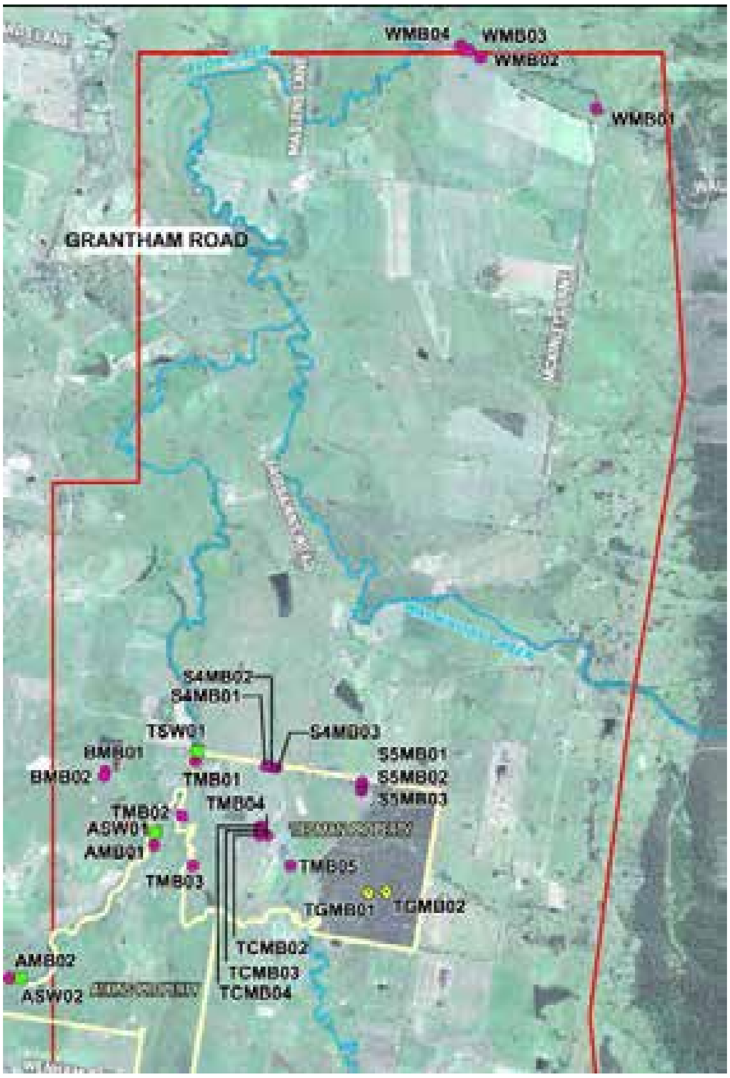


Figure 6: Investigation areas.

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.

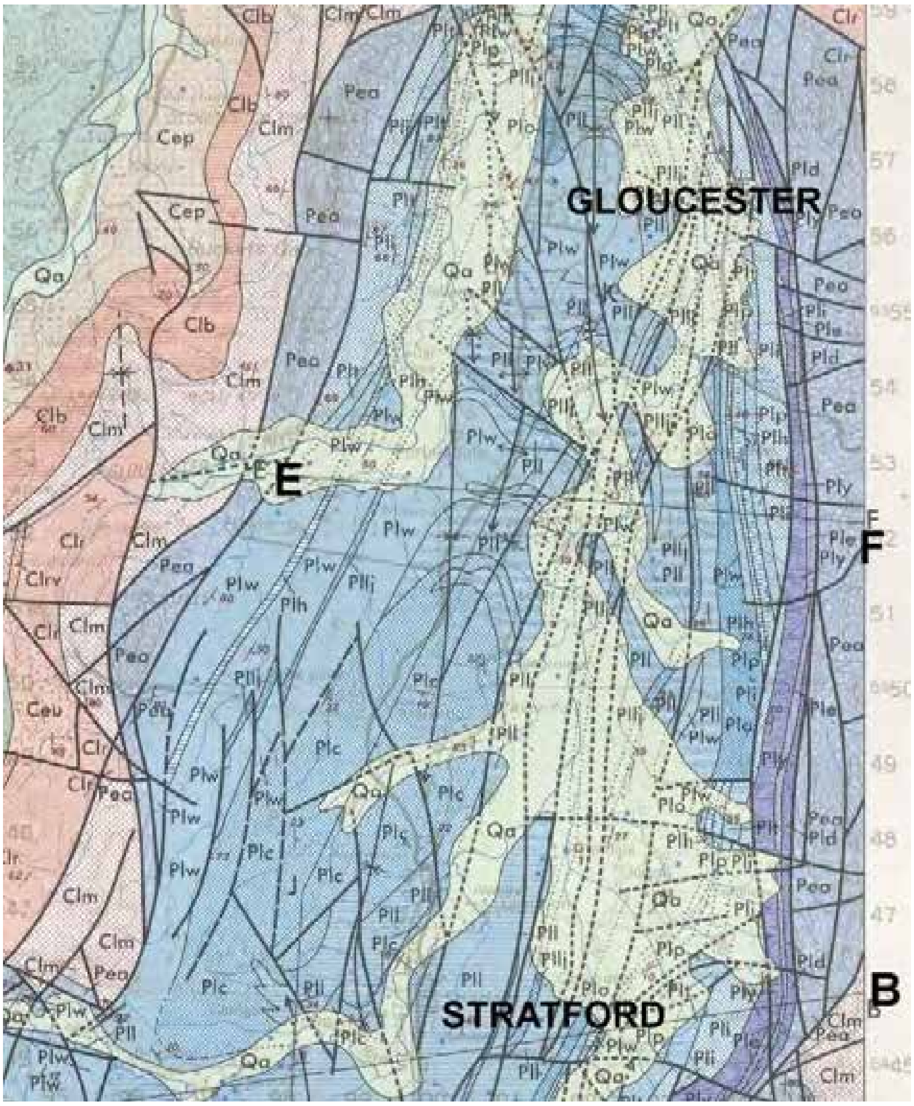


Figure 7: Gloucester Basin, 1991.

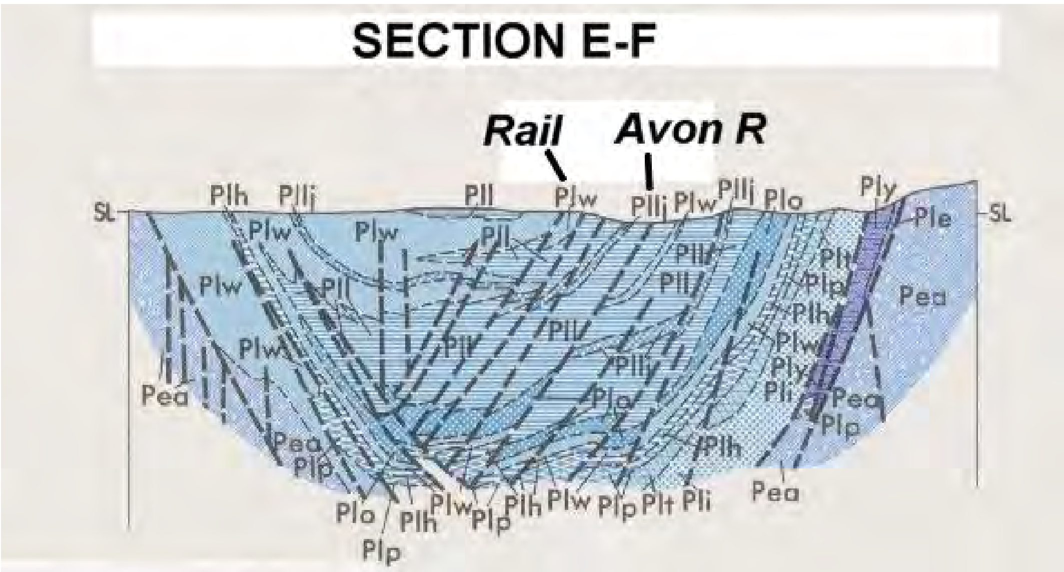


Figure 8: Section E-F, 1991.

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

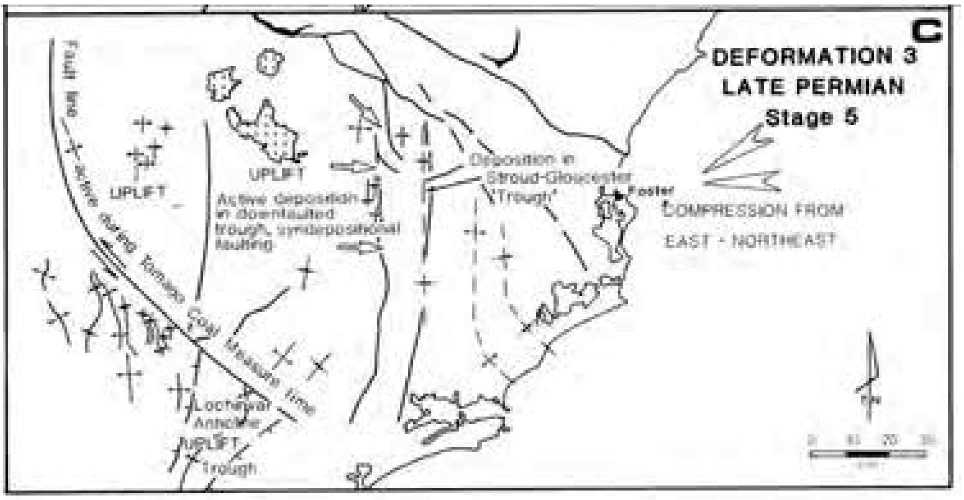
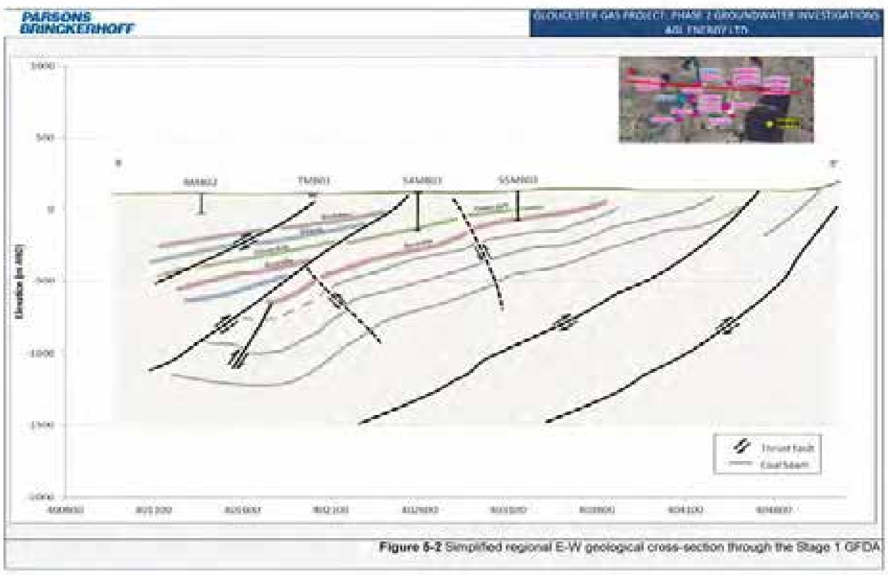


Figure 9: Tectonics during Stroud-Gloucester Trough deposition.

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).

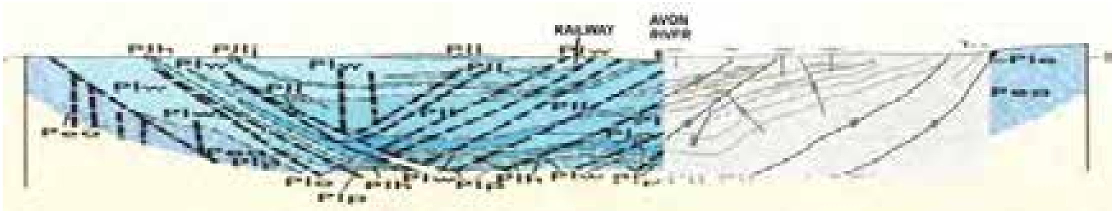
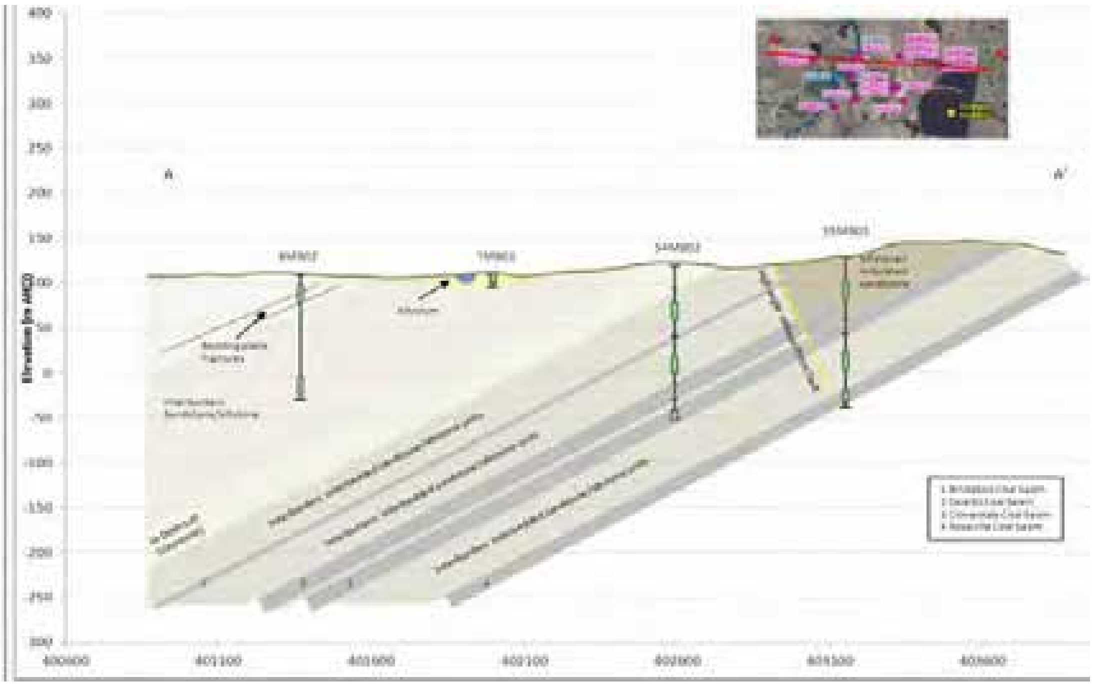


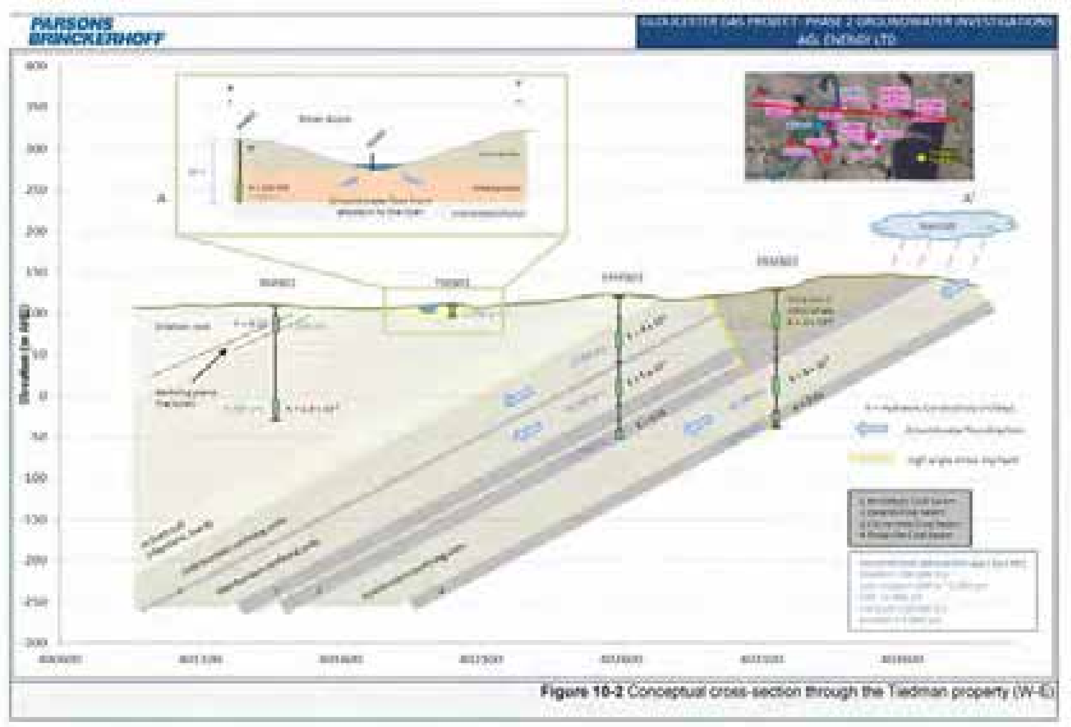
Figure 10: PB geological model superimposed approximately on Geological Survey Section E-F.

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.



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.

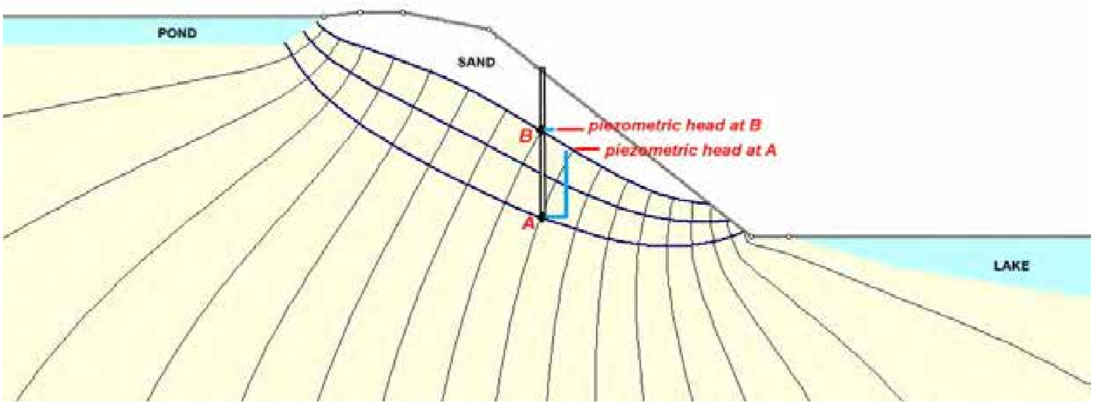


Figure 10: Flow through uniform sand giving rise to different piezometric heads.

[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 $_2H$) 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.

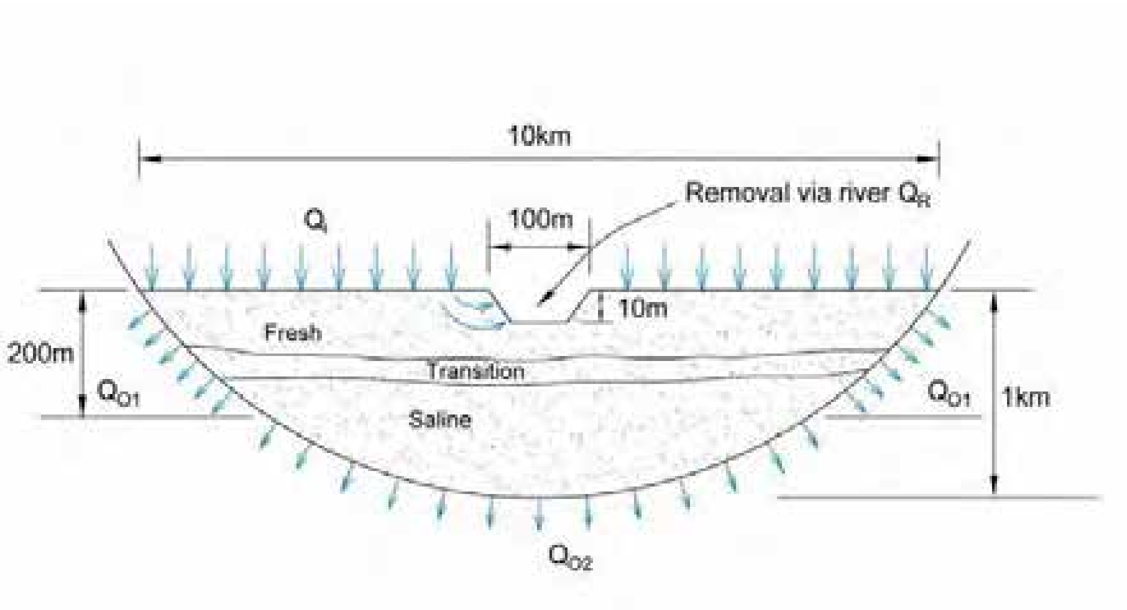


Figure 11: Simple model of a leaking basin filled with uniform sand and with initially stratified groundwater.

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.

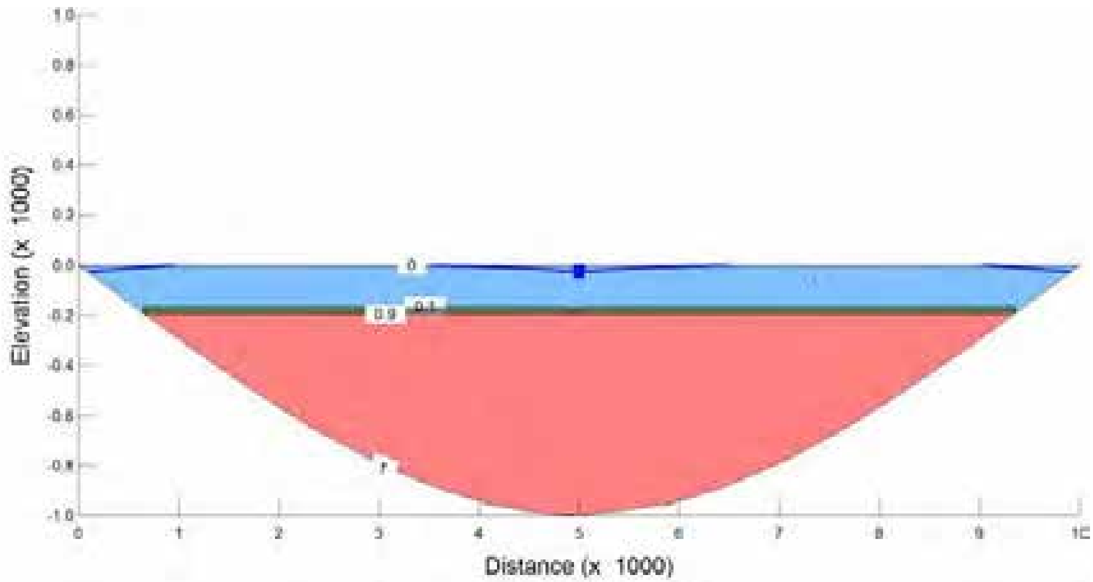


Figure 12: Initial conditions in transient, contaminant transport, seepage model. A salinity concentration of 1.0 is equal to 3,000 mg/litre.

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

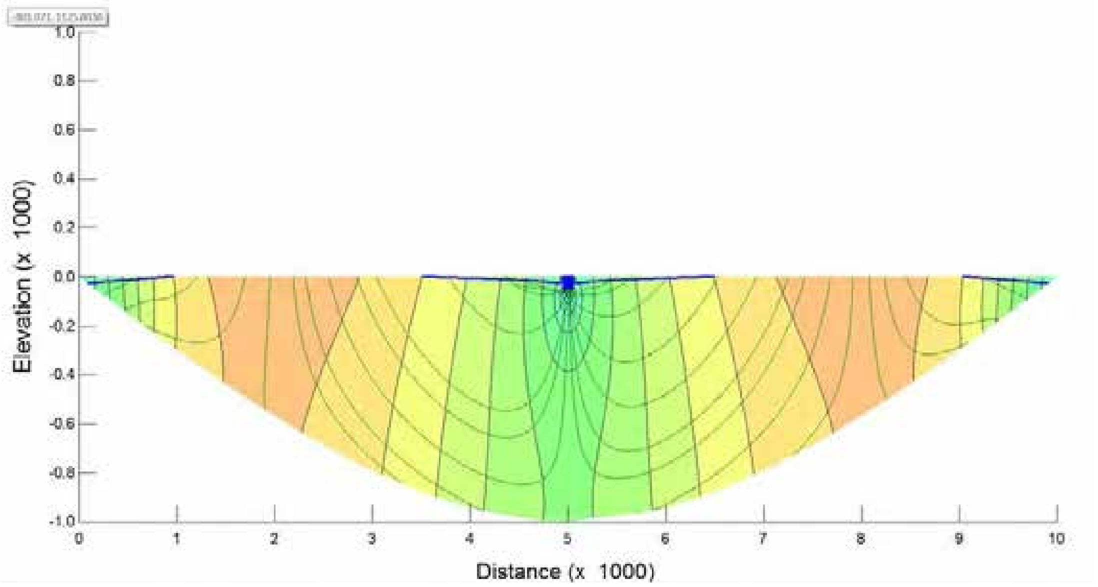


Figure 13: Flow lines and equipotentials if only fresh water in the basin.

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

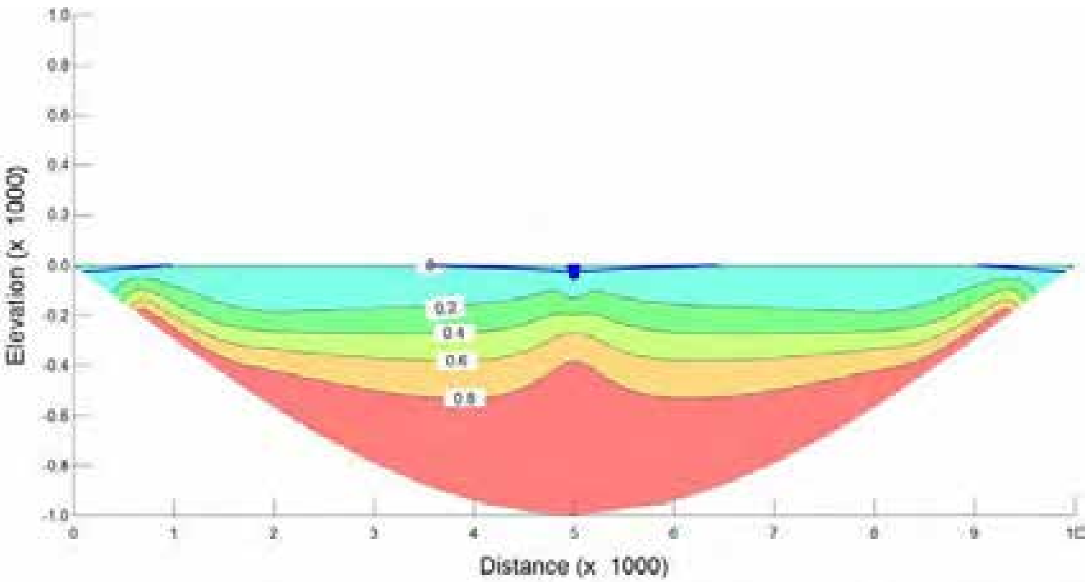


Figure 14: Salinity concentration levels after 1,000 years.

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."

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[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.

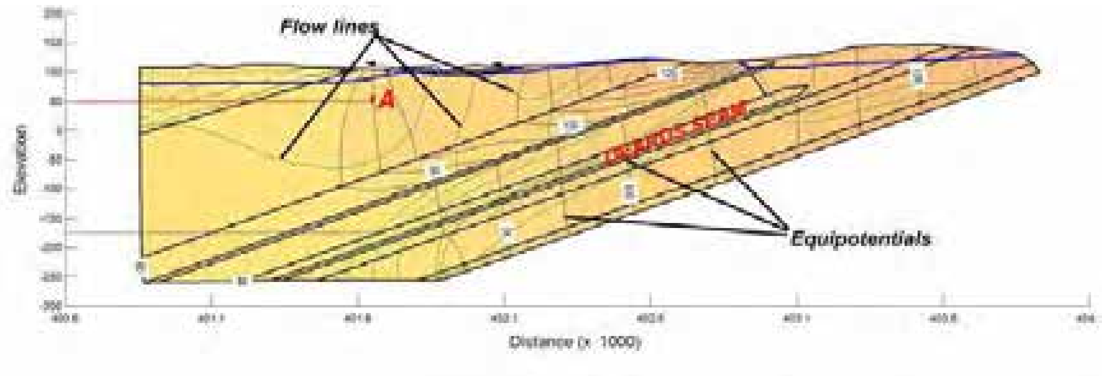
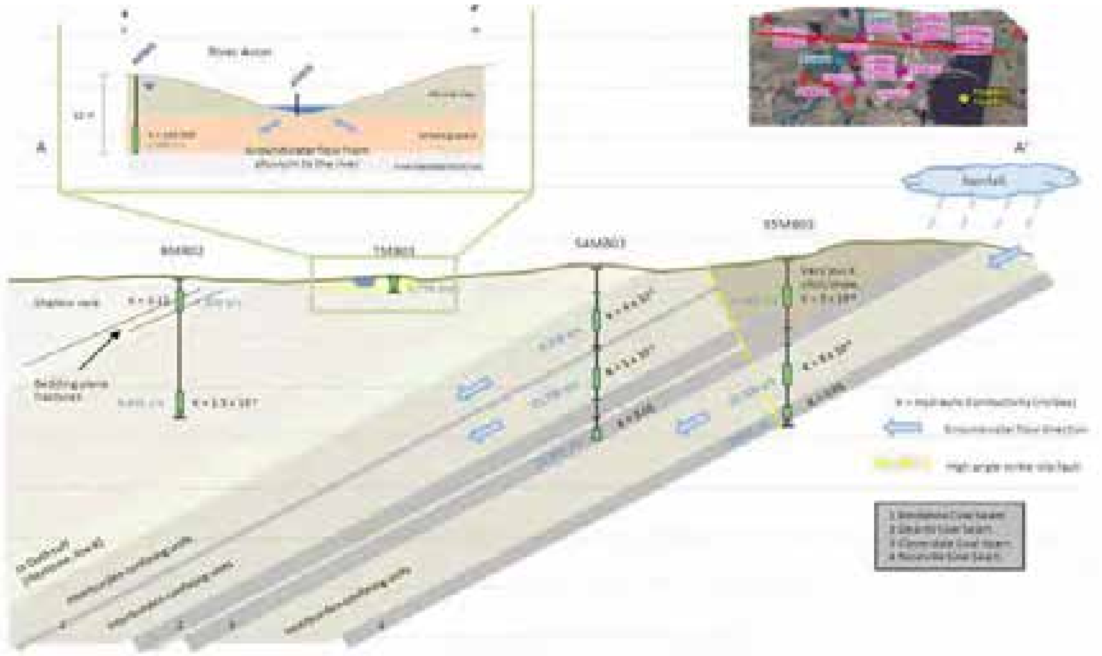


Figure 15: Numerical analysis of PB model – computed steady state pre-CSG extraction.



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 <u>slower</u> 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.

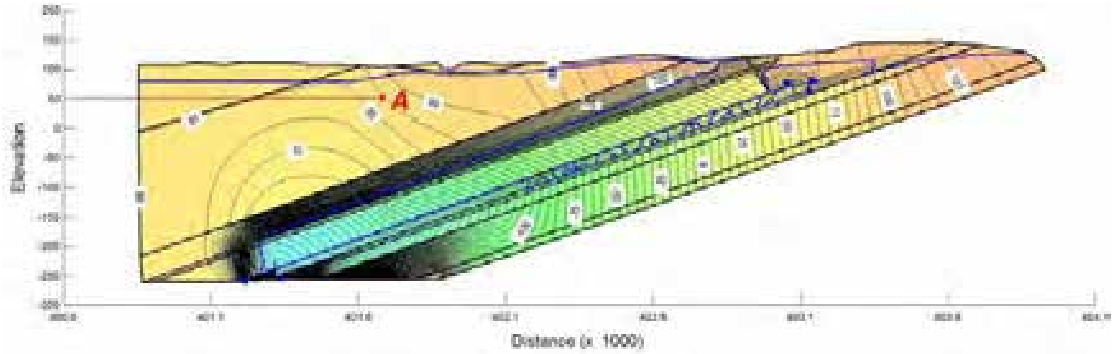


Figure 16: Equipotentials 2 years after CSG depressurisation in Deards Seam only.

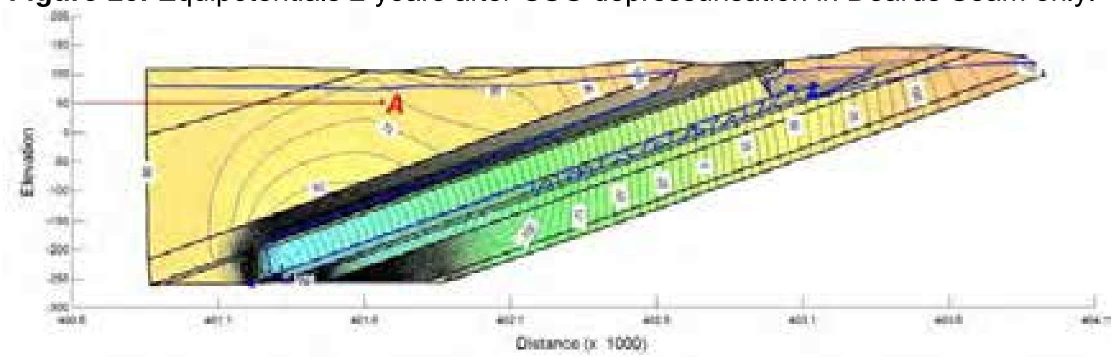


Figure 18: Equipotentials 10 years after CSG depressurisation in Deards Seam only.

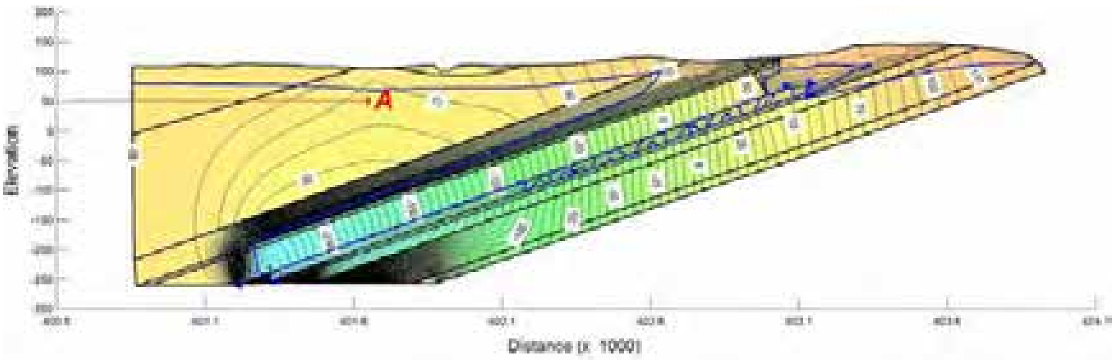


Figure 17: Equipotentials 20 years after CSG depressurisation in Deards Seam only.

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.

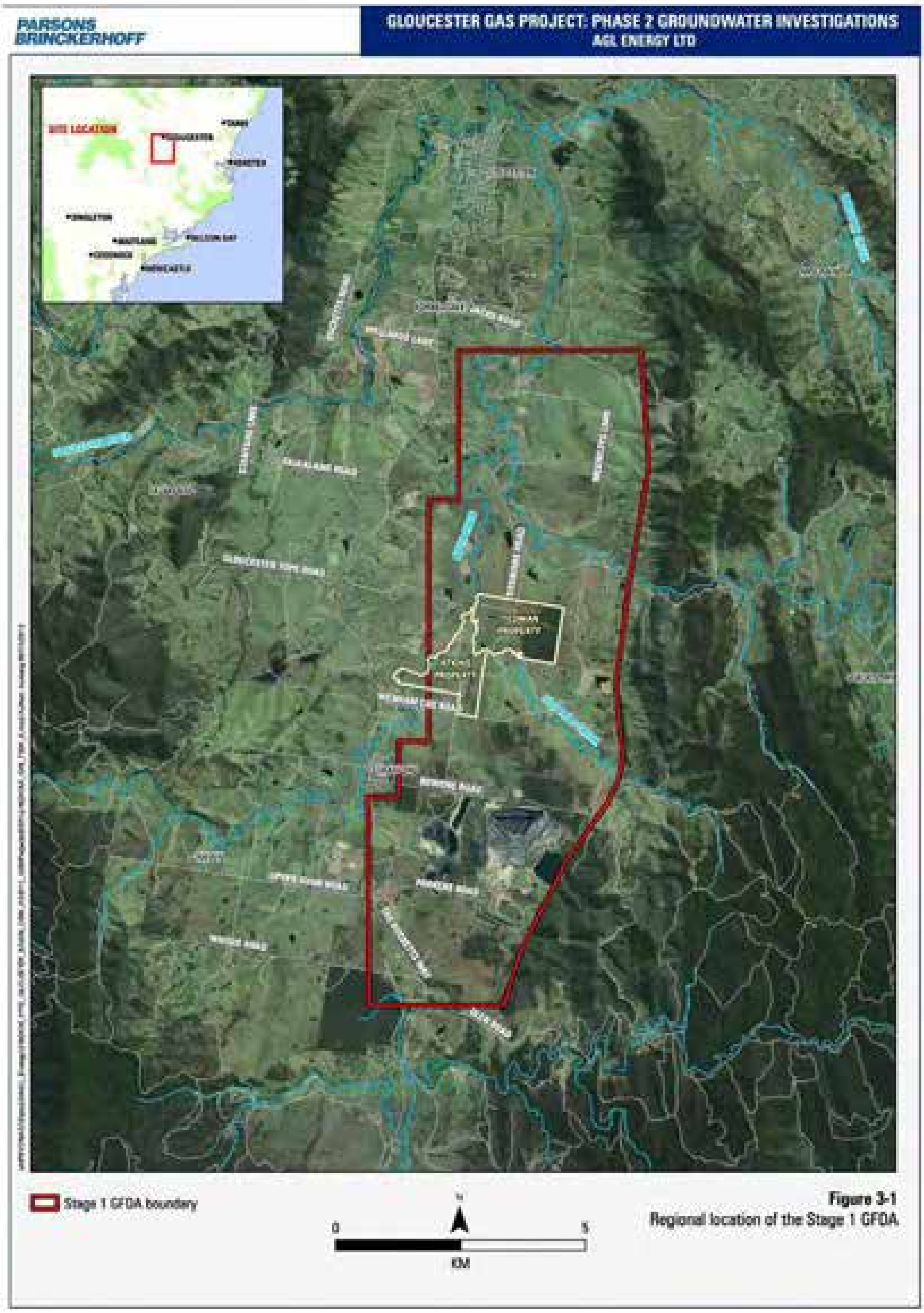


Figure 3-1
Regional location of the Stage 1 GFDA

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).*

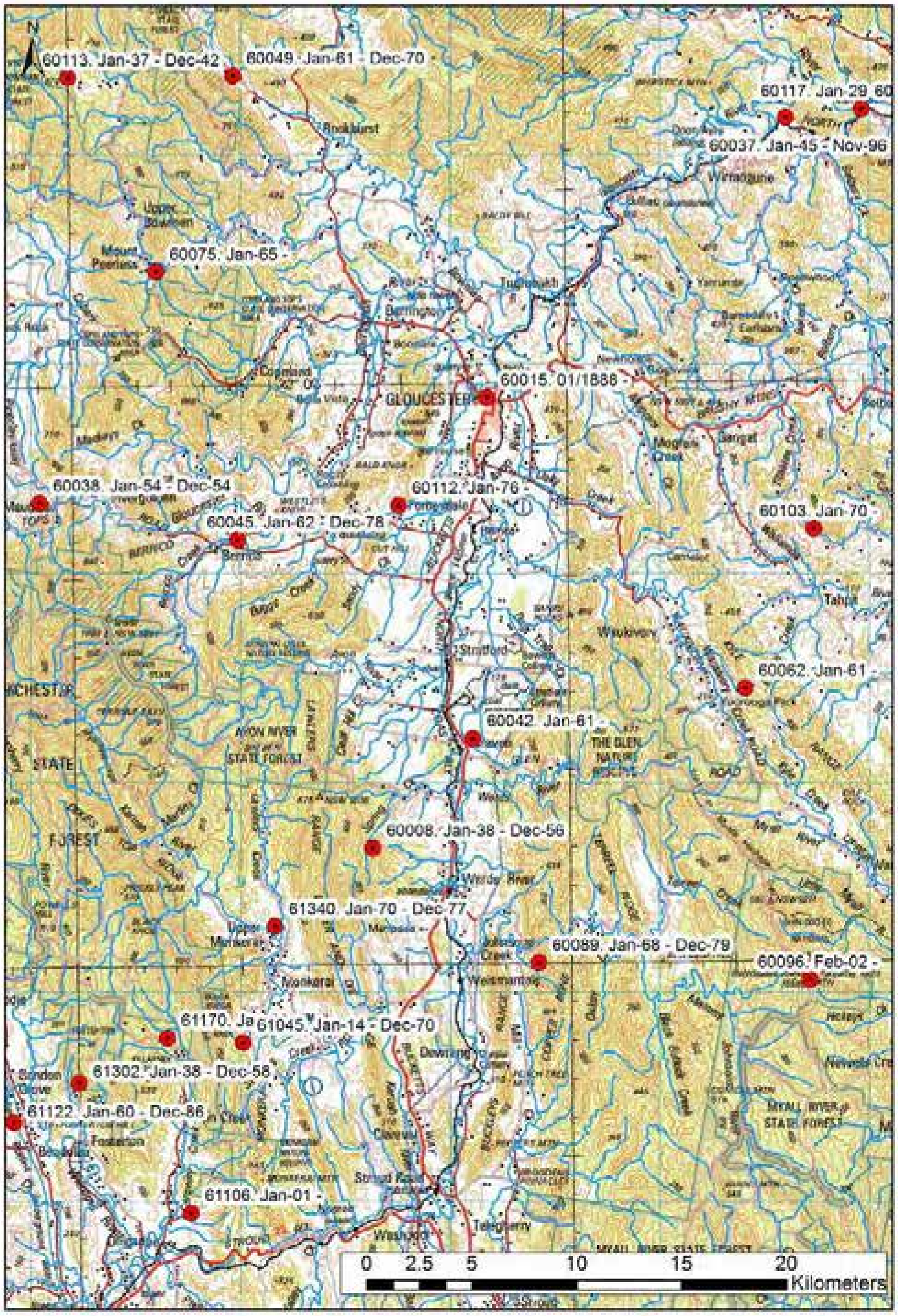


Figure A : Available rainfall gauging stations and length of record

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).

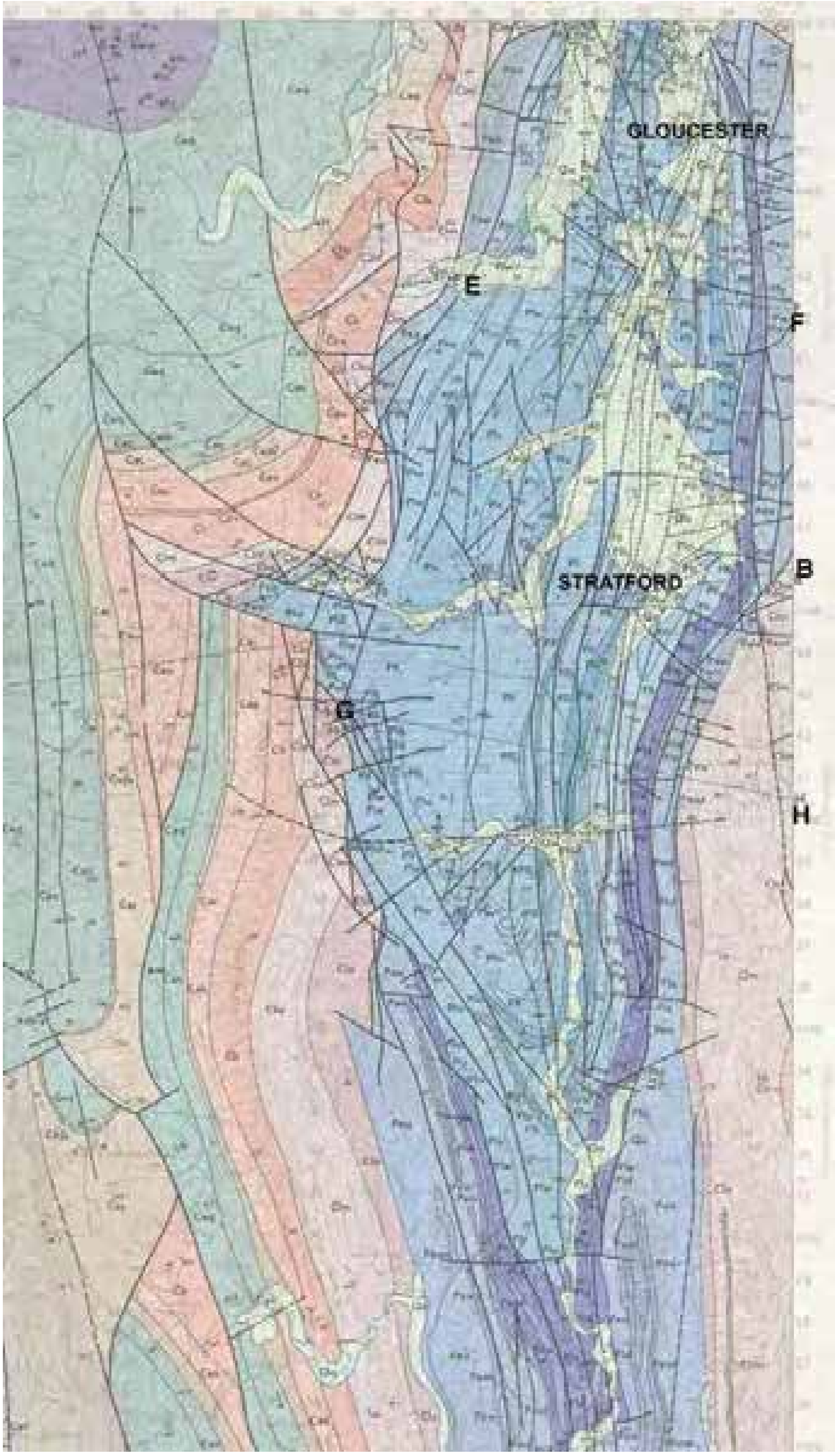


Figure B Published geological plan of Gloucester basin (*not given in the Phase 2 report)*

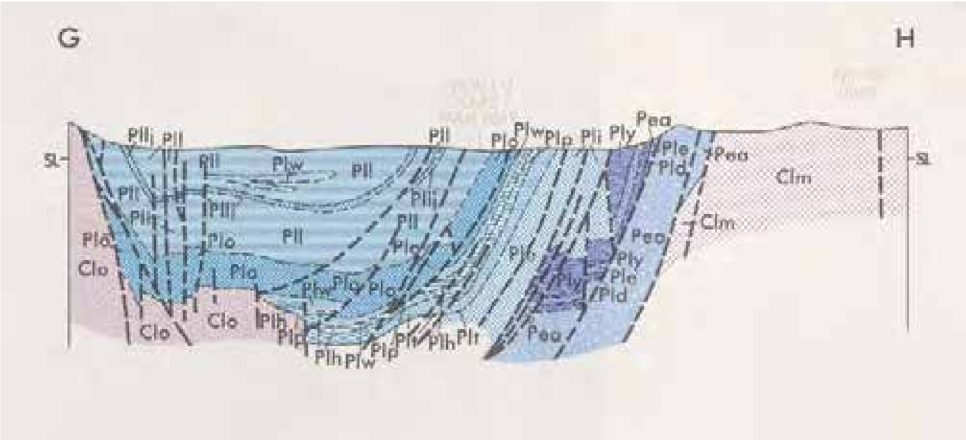


Figure C Section G-H (not given in the Phase 2 report)

(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).

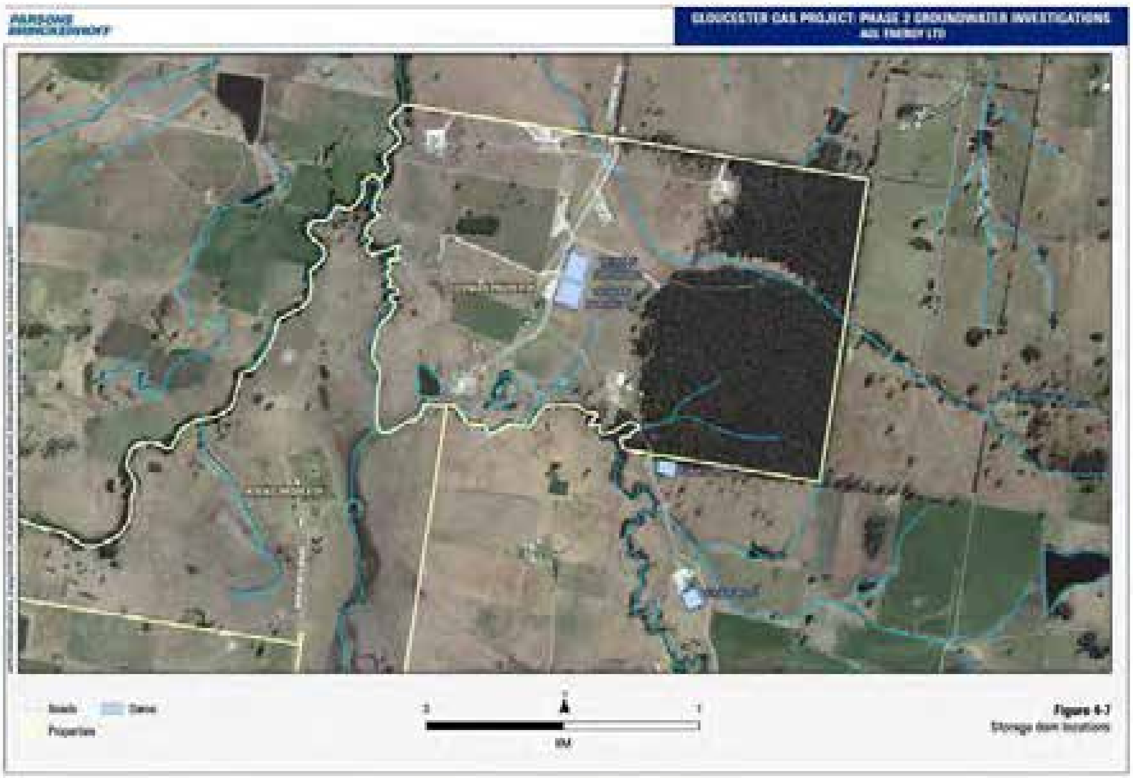


Figure 4-7
Storage dam locations

5. Updated geological model

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

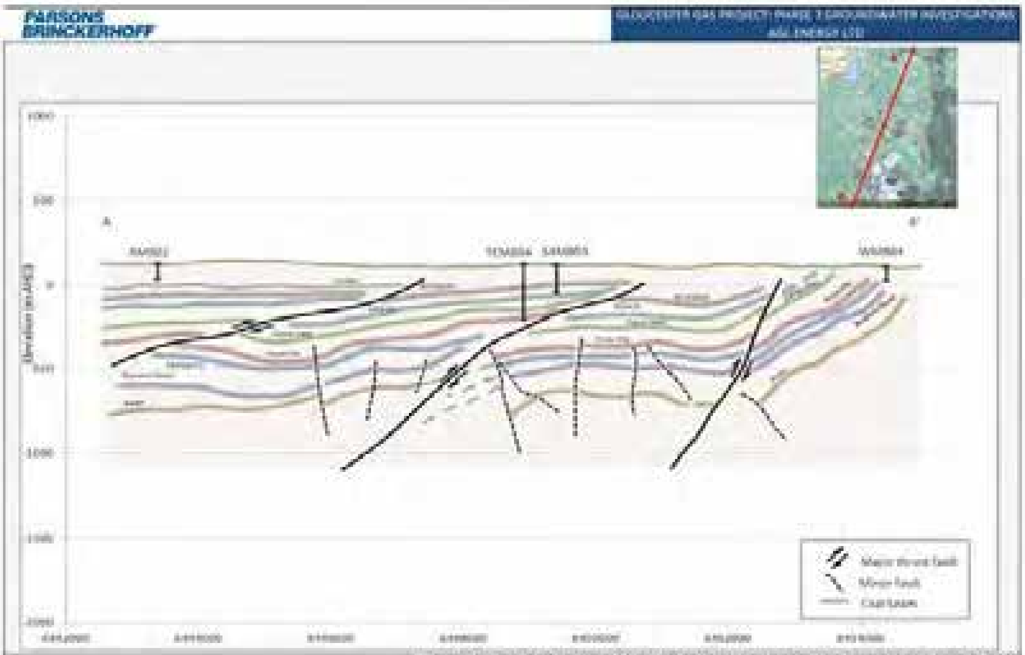


Figure 5-1 Simplified regional NE-SW geological cross-section through the Stage 1 GFDA

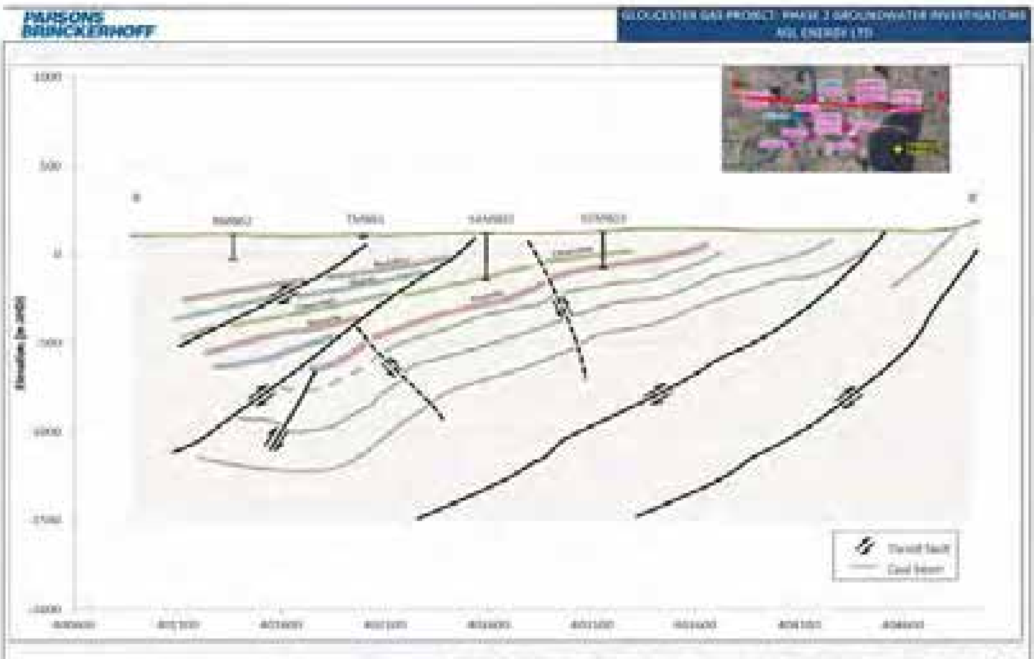


Figure 5-2 Simplified regional E-W geological cross-section through the Stage 1 GFDA

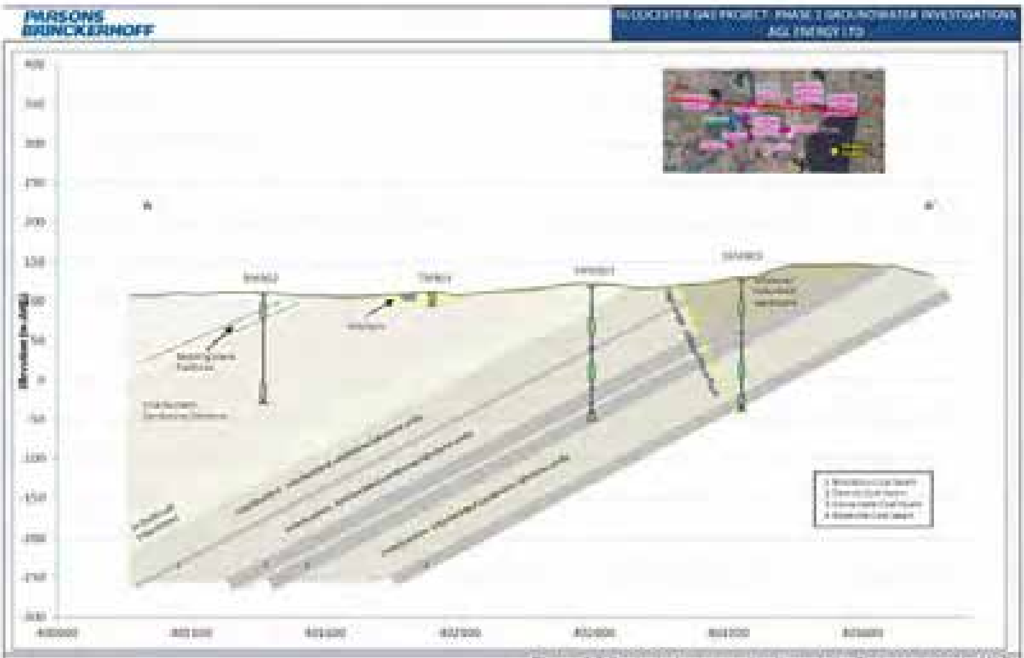


Figure 5-3 Geological cross-section through the Tiedman property (W-E)

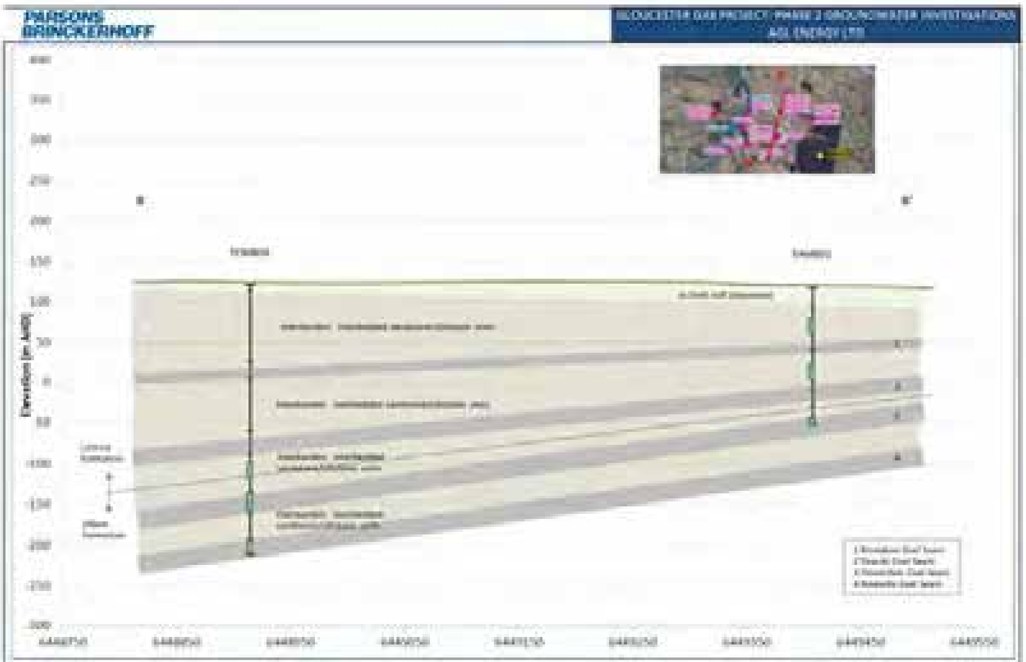


Figure 5-4 Geological cross-section through the Tiedman property (N-S)

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).

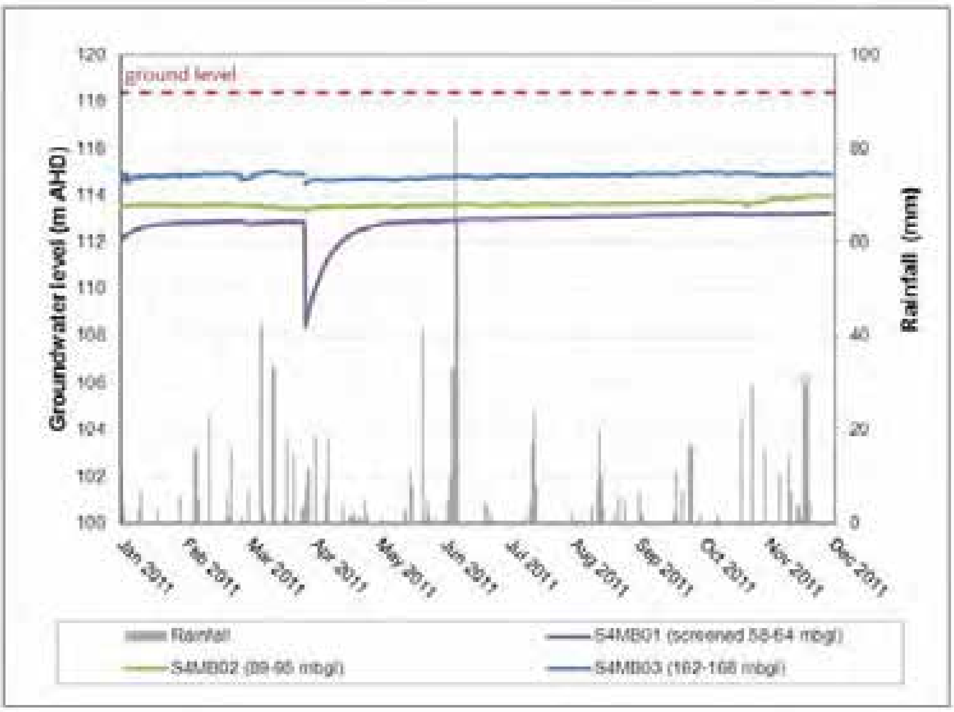


Figure 7-2 Groundwater levels at Stratford 4

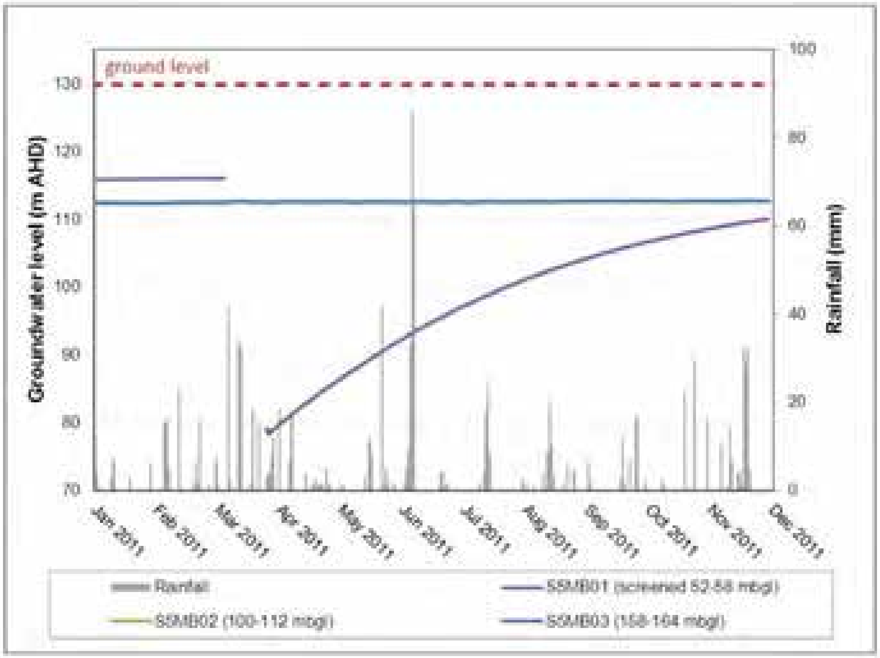


Figure 7-3 Groundwater levels at Stratford 5

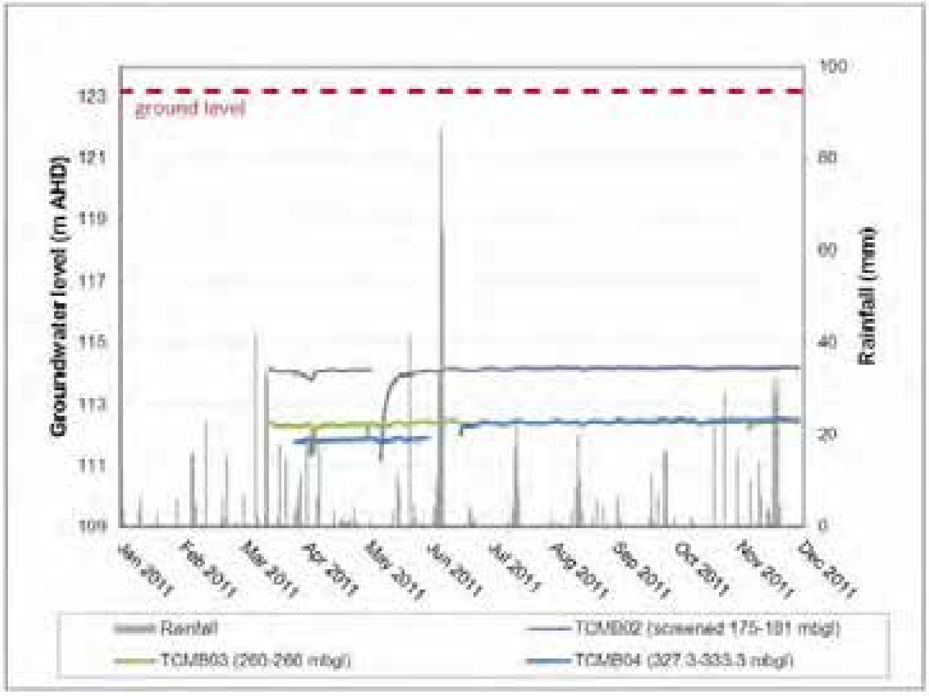


Figure 7-4 Groundwater and rainfall levels at Tiedman core hole site

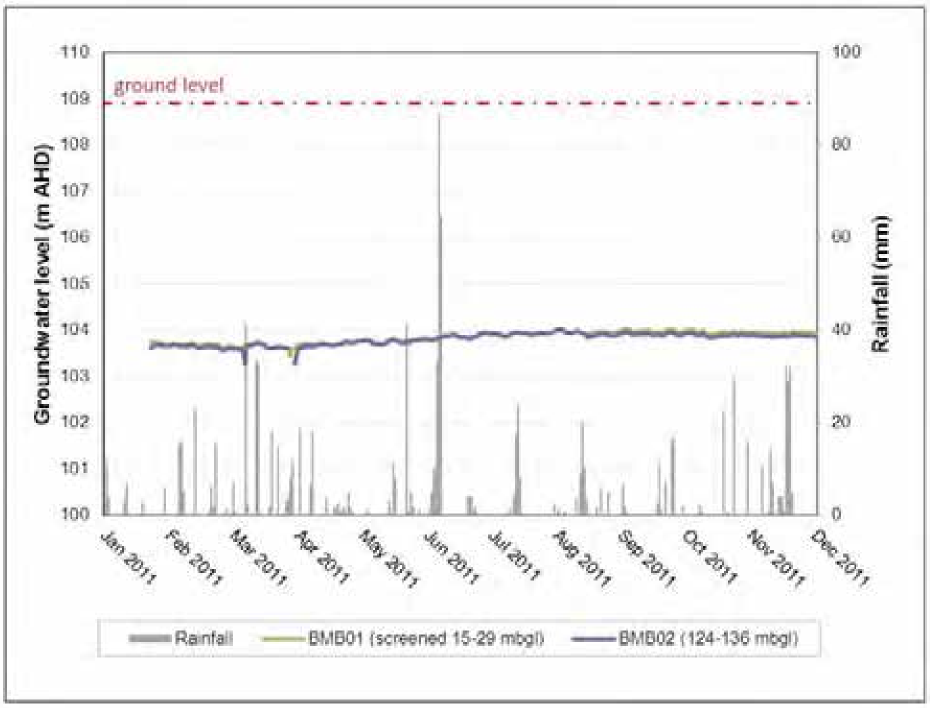


Figure 7-5 Groundwater and rainfall levels at Bignell

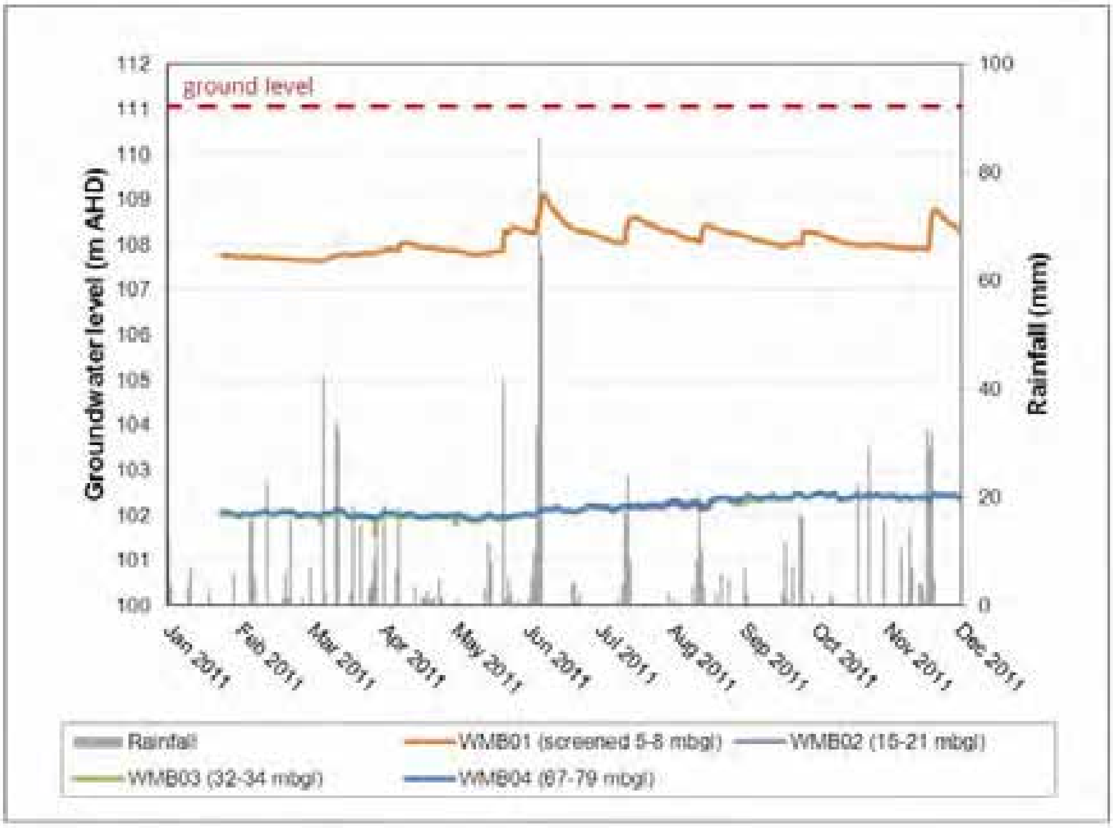


Figure 7-6 Groundwater levels at the Waukivory Road site

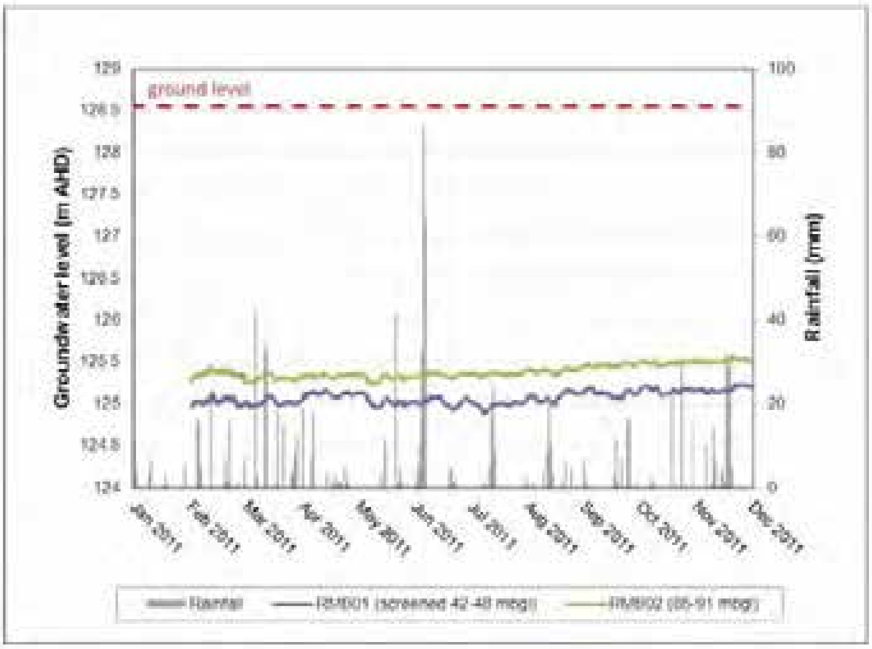


Figure 7-7 Groundwater levels at the Rombo site

7.0 WATER QUALITY MONITORING

7.1 Groundwater quality

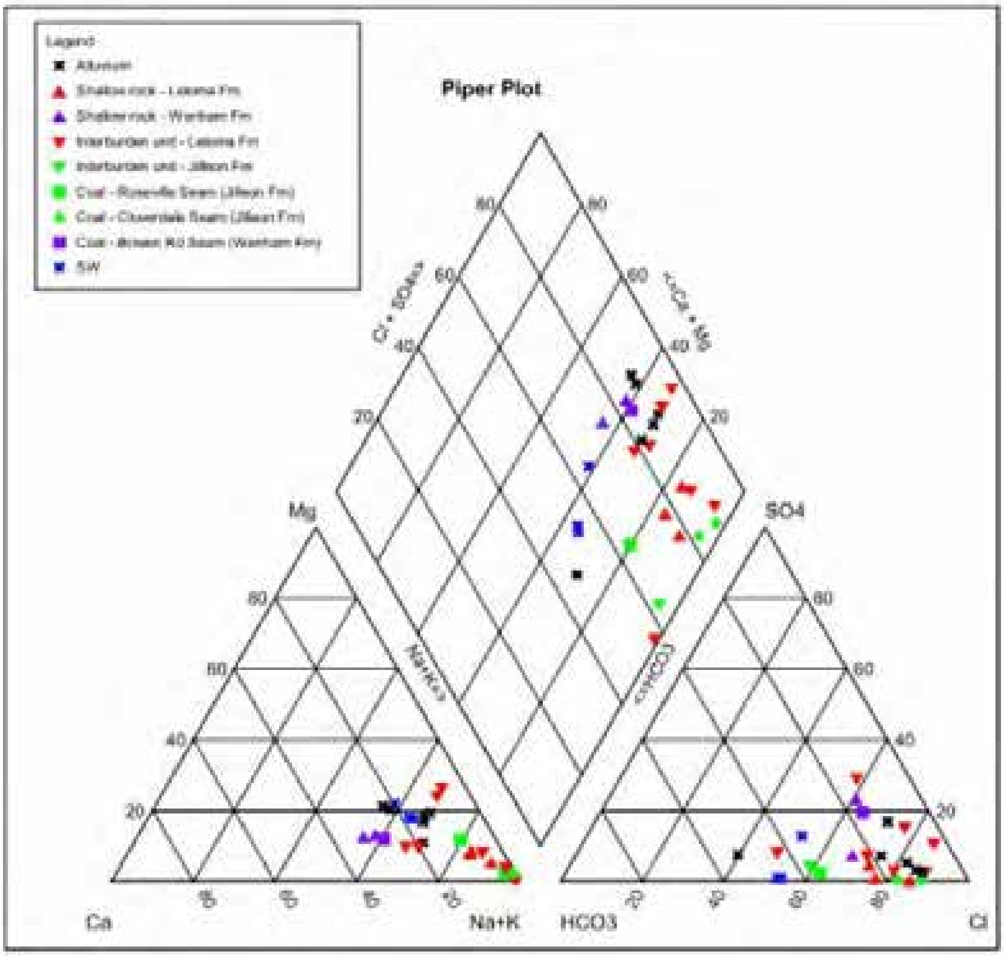


Figure 8-1 Piper diagram showing major ion composition of groundwater and surface water

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.

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[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

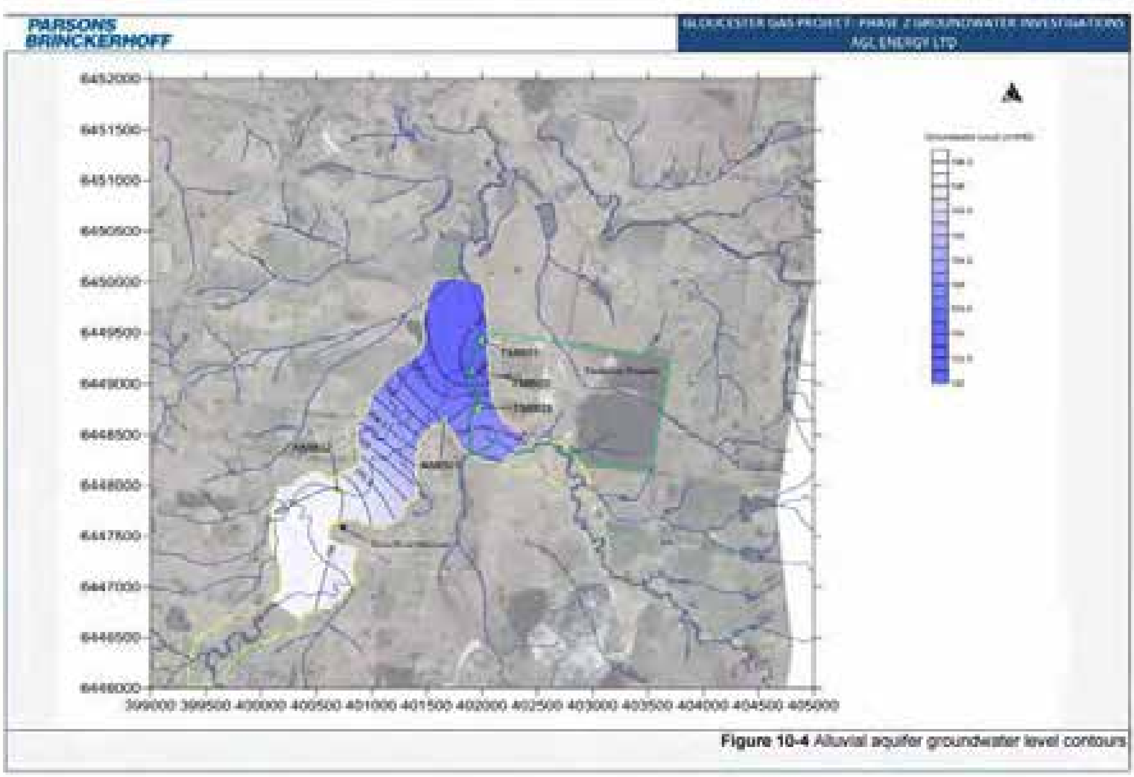


Figure 10-4 Alluvial aquifer groundwater level contours

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	4×10^{-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.

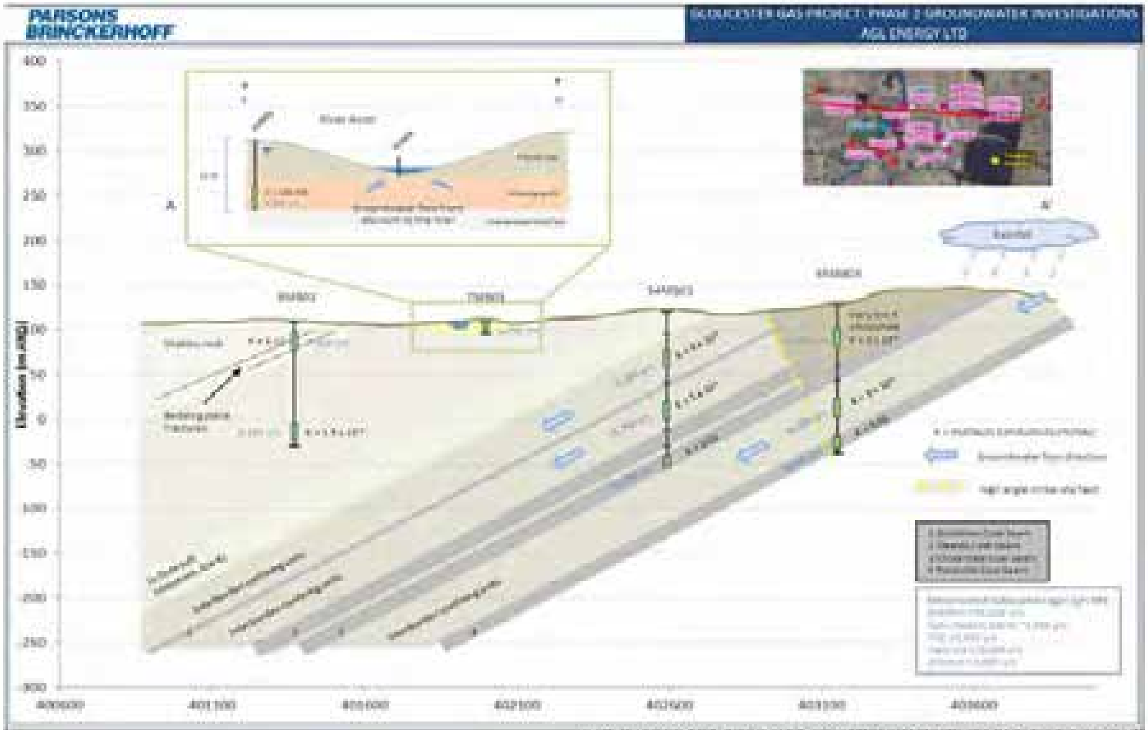


Figure 10-2 Conceptual cross-section through the Tiedman property (W-E)

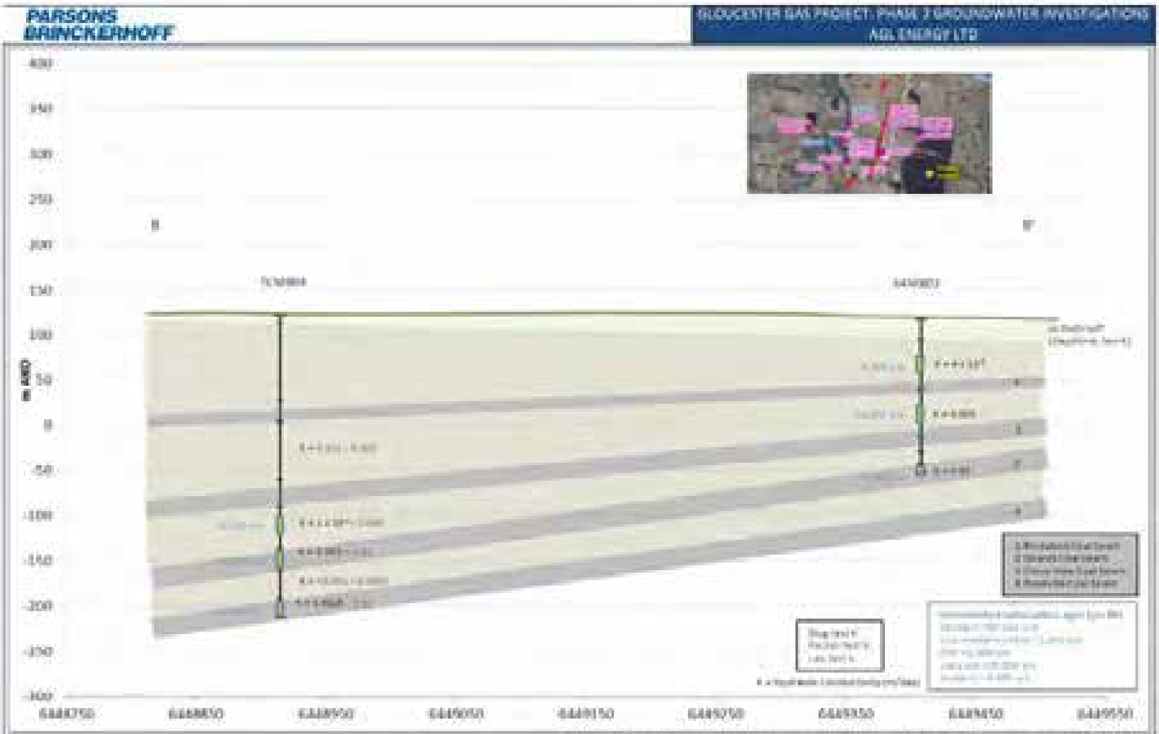


Figure 10-3 Conceptual cross-section through the Tiedman property (SW-NE)

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

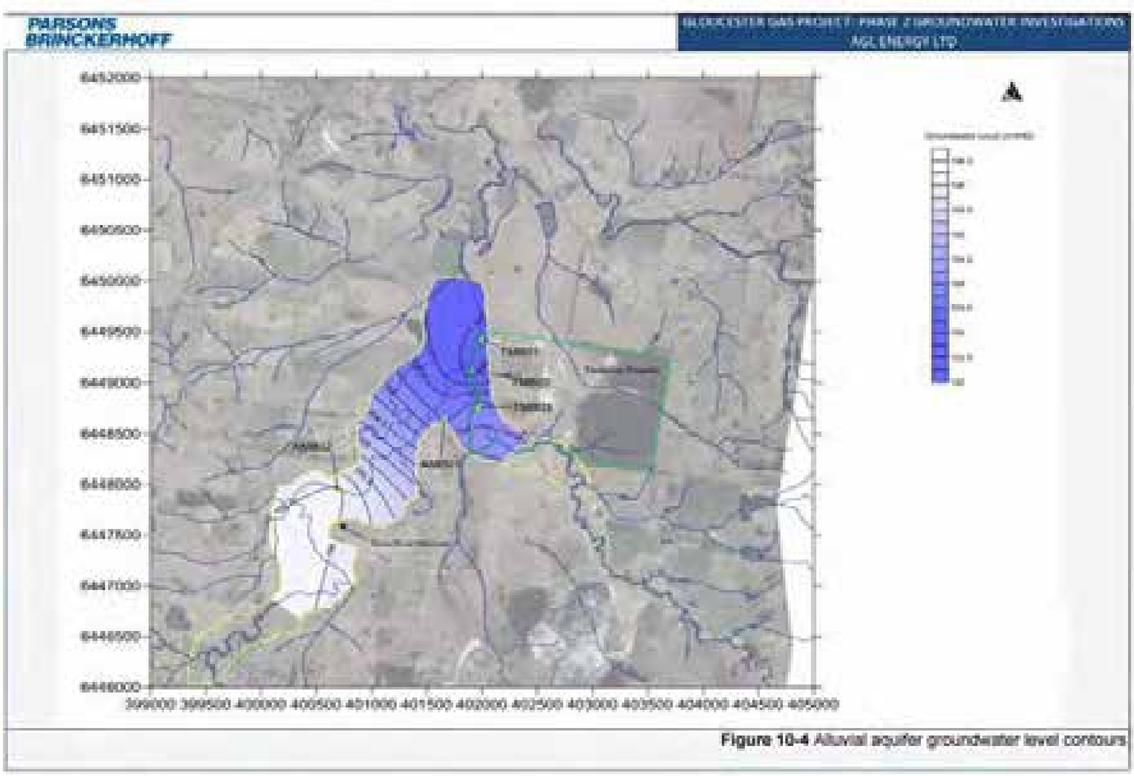
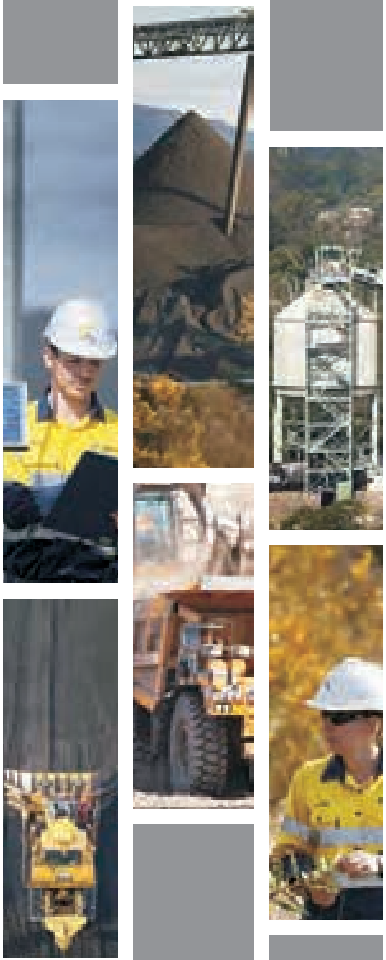


Figure 10-4 Alluvial aquifer groundwater level contours

STRATFORDCOAL
Part of the Yancoal Australia Group

HIGHLIGHTS AND COMMENT on p A65 by P Pells
15 May 2013



Stratford Extension Project
Environmental Impact Statement

APPENDIX A

GROUNDWATER ASSESSMENT

On Thursday 28 June 2012, Yancoal Australia Limited was listed on the Australian Stock Exchange and merged with Gloucester Coal Ltd (GCL) under a scheme of agreement on the same date. Stratford Coal Pty Ltd is now a wholly owned subsidiary of Yancoal Australia Limited. Any reference to GCL in this Appendix should be read as Yancoal Australia Limited.

HERITAGE COMPUTING REPORT

APPENDIX A

GROUNDWATER ASSESSMENT

A HYDROGEOLOGICAL ASSESSMENT IN SUPPORT OF THE STRATFORD COAL PROJECT ENVIRONMENTAL IMPACT STATEMENT

FOR

STRATFORD COAL PTY LTD

By

Dr N. P. Merrick and Dr M. Alkhatib

Heritage Computing Pty Ltd

Project Number: GCL-10-12
Report HC2012/2

Date: April 2012

DOCUMENT REGISTER

Revision	Description	Date	Comments
A	Initial Draft	25 February 2012	Incomplete draft for initial external review
B	Draft	21 March 2012	Complete draft for external review
C	Final Draft	19 April 2012	Revision for final external review
D	Final	30 April 2012	Final version for public exhibition

ACKNOWLEDGMENTS

Person	Company	Activity
Al Laase	A. D. Laase Hydrologic Consulting	Model setup and calibration
Andrew Fulton	Groundwater Exploration Services Pty Ltd	Report sections

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A1 INTRODUCTION

This report has been prepared for Stratford Coal Pty Ltd (SCPL). SCPL is a wholly owned subsidiary of Gloucester Coal Limited (GCL). SCPL owns and operates the Stratford Coal Mine (SCM) and Bowens Road North Open Cut (BRNOC), collectively referred to as the Stratford Mining Complex. The Stratford Mining Complex is located approximately 100 kilometres (km) north of Newcastle and 10 km south of Gloucester in New South Wales (NSW) (**Figure A-1**).

Seven mining leases (MLs) cover the operations at the Stratford Mining Complex (i.e. ML 1577, ML 1528, ML 1409, ML 1447, ML 1360, ML 1538 and ML 1521) (**Figure A-2**). The Project extensions to the Stratford Mining Complex would require additional Mining Lease Applications (MLAs) 1, 2 and 3 as shown on **Figure A-2**.

Operations at the Stratford Mining Complex commenced in 1995 at the SCM and 2003 at the BRNOC. The current mining operations at the Stratford Mining Complex are approved to produce up to 2.1 and 1 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal at the SCM and BRNOC, respectively.

This report provides a groundwater assessment of the proposed Stratford Extension Project (the Project). The proposed extension would increase the life of the Project by approximately 11 years, to 2024.

The approximate extents of the existing and approved surface development (including open cut, mine waste rock emplacement, soil stockpiles and infrastructure areas) at the Stratford Mining Complex are shown on **Figure A-2**. The approximate extent of the Project surface development (incorporating the existing and approved development) lies within MLAs 1, 2 and 3 as well as within existing MLs, and is also shown on **Figure A-2**.

Mining is currently conducted at the BRNOC and the Roseville West Pit, with backfilling of the BRNOC, Stratford Main Pit and Roseville Extended Pit ongoing. Mining has been completed at the Stratford Main Pit and the Roseville Pit (**Figure A-2**). The Stratford Main Pit is now used for water storage and as an emplacement area for co-disposed rejects from the coal handling and preparation plant (CHPP). The Roseville Pit has been backfilled and rehabilitated (**Figure A-2**).

A description of the Project is provided in Section 2 in the Main Report of the Environmental Impact Statement (EIS).

A1.1 SCOPE OF WORK

The key tasks for this assessment were:

- Characterisation of the existing groundwater regime, including identification of groundwater users (including a bore census) and potential groundwater dependent ecosystems in consultation with other relevant specialists.
- Collation and review of baseline geological and groundwater data including:
  - existing SCPL exploration programme (i.e. geological) data;
  - results of searches of NSW Office of Water (NOW) Pinneena database including registered bores and continuous monitoring data;
  - existing water management records at the SCM (past and present);
  - groundwater monitoring data from monitoring programs and investigations undertaken by SCPL at the SCM and surrounding operations (past and present);
  - groundwater quality data from the above monitoring programs and investigations; and
  - other additional geological and regional mapping data available.
- Development and refinement of a conceptual groundwater model as a basis for development and calibration of a numerical groundwater model to predict potential impacts of future mine development on the existing groundwater regime.
- Preparation of a Groundwater Assessment report for inclusion in the EIS that includes the following:
  - assessment of potential mine groundwater impacts (e.g. pit inflows, depressurisation/drawdown, groundwater quality and recharge mechanisms), including assessment of mining scenarios and cumulative impacts with other proposed/approved surrounding mines in the area and coal seam gas (CSG) operations;
  - assessment of post-mining groundwater impacts (e.g. recovery of groundwater levels and groundwater quality); and
  - assessment of any potential groundwater impacts associated with other Project-related infrastructure.
- Development of measures to avoid, minimise, mitigate and/or offset (if necessary) potential impacts on groundwater resources and provide recommendations for future groundwater monitoring for the purposes of model validation and to measure actual impacts on groundwater resources, as the mine develops.

In accordance with the NSW Department of Planning and Infrastructure (DP&I) Director-General's Requirements (DGRs) for the Project, this assessment has been prepared in consideration of the following groundwater-related technical policies, guidelines and plans:

- *National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia* (Agriculture and Resource Management Council of Australia and Australian and New Zealand Environment and Conservation Council [1995]);
- *NSW State Groundwater Policy Framework Document* (NSW Department of Land and Water Conservation [DLWC], 1997);
- *NSW State Groundwater Quality Protection Policy* (DLWC, 1998);
- Draft *NSW State Groundwater Quantity Management Policy* (DLWC, 2002a);
- *NSW Wetlands Policy* (DECCW, 2010);
- *NSW State Groundwater Dependent Ecosystem Policy* (DLWC, 2002b);
- *Water Sharing Plan for the Lower North Coast Unregulated and Alluvial Water Sources 2009* (the WSP) under the *Water Management Act, 2000*;
- *Murray-Darling Basin Groundwater Quality Sampling Guidelines. Technical Report No 3* (Murray-Darling Basin Commission [MDBC], 1997);
- *MDBC Groundwater Flow Modelling Guideline* (MDBC, 2001); and
- *Guidelines for the Assessment and Management of Groundwater Contamination* (NSW Department of Environment and Conservation, 2007).

The specific DGRs of relevance to water resources (including groundwater components) are:

*"**Water Resources – including:***
- *detailed assessment of potential impacts on the quality and quantity of existing surface and groundwater resources, including:*
  - *detailed modelling of potential groundwater impacts;*
  - *impacts on affected licensed water users and basic landholder rights; and*
  - *impacts on riparian, ecological, geo-morphological and hydrological values of watercourses, including environmental flows;*
- *a detailed site water balance, including a description of site water demands, water disposal methods (inclusive of volume and frequency of any water discharges), water supply infrastructure and water storage structures;*
- *an assessment of proposed water discharge quantities and quality/ies against receiving water quality and flow objectives;*
- *assessment of impacts of salinity from mining operations, including disposal and management of coal rejects and modified hydrogeology, a salinity budget and the evaluation of salt migration to surface and groundwater sources;*
- *identification of any licensing requirements or other approvals under the Water Act 1912 and/or Water Management Act 2000;*
- *demonstration that water for the construction and operation of the development can be obtained from an appropriately authorised and reliable supply in accordance with the operating rules of any relevant Water Sharing Plan (WSP);*

- *a description of the measures proposed to ensure the development can operate in accordance with the requirements of any relevant WSP or water source embargo;*
- *a detailed description of the proposed water management system (including sewage), water monitoring program and other measures to mitigate surface and groundwater impacts; and*
- *a detailed flood impact assessment, which identifies impacts on local flood regimes, including:*
  - *an assessment of the potential for flooding to occur in the open-cup pits; and*
  - *any measures proposed to mitigate potential flood impacts."*

The surface water components of the assessment are provided separately in the Surface Water Assessment (Gilbert & Associates, 2012) (Appendix B of the EIS).

In addition, this assessment has considered the mapped biophysical strategic agricultural lands in the region that are defined in the Draft Upper Hunter Strategic Regional Land Use Plan (DP&I, 2012) and the Draft NSW Aquifer Interference Policy – Stage 1 (NSW Department of Trade and Investment, Regional Infrastructure and Services [DTIRIS], 2012).

As part of the assessment process an environmental risk assessment (ERA) (Appendix R of the EIS) was undertaken. This included a facilitated, risk based workshop involving experts across a range of disciplines and experienced SCPL personnel. The risk assessment team included a representative of Heritage Computing. The workshop was conducted on the 19th January 2012 and was facilitated by a risk assessment specialist (Safe Production Solutions Pty Ltd). The objective of the assessment was to identify key potential environmental issues for further assessment in the EIS. The key potential groundwater related issues identified in the ERA (Appendix R of the EIS) are summarised below:

- Potential cumulative groundwater impacts as a result of the AGL Gloucester LE Pty Ltd (AGL) Gloucester Gas Project, proposed Rocky Hill Coal Project and the Project.
- Final void water management and development of groundwater sinks in the long-term.
- Potential groundwater related impacts (e.g. baseflow loss) on Dog Trap Creek, Avondale Creek and associated alluvium.
- Potential reduction in yield in surrounding landholder bores (e.g. Stratford) resulting from the Project.
- Potential leakage of stored mine water in the Stratford East Dam through underlying coal seams to Stratford East Open Cut – resulting in higher groundwater inflows requiring management.

A1.2 PROPOSED MINE DEVELOPMENT

The main activities associated with the development of the Project would include (**Figure A-2**):

- ROM coal production up to 2.6 Mtpa for an additional 11 years (commencing approximately 1 July 2013 or upon grant of all required approvals) including mining operations associated with:
  - completion of the BRNOC;
  - extension of the existing Roseville West Pit; and
  - development of the new Avon North and Stratford East Open Cuts;
- exploration activities;
- progressive backfilling of mine voids with waste rock behind the advancing open cut mining operations;
- continued and expanded placement of waste rock in the Stratford Waste Emplacement and Northern Waste Emplacement;
- progressive development of new haul roads and internal roads;
- coal processing at the existing CHPP including Project ROM coal, sized ROM coal received and unloaded from the Duralie Coal Mine (DCM) and coal recovered periodically from the western co-disposal area;
- stockpiling and loading of product coal to trains for transport on the North Coast Railway to Newcastle;
- disposal of CHPP rejects via pipeline to the existing co-disposal area in the Stratford Main Pit and, later in the Project life, in the Avon North Open Cut void;
- realignments of Wheatleys Lane, Bowens Road, and Wenham Cox/Bowens Road;
- realignment of a 132 kilovolt power line for the Stratford East Open Cut;
- continued use of existing contained water storages/dams and progressive development of additional sediment dams, pumps, pipelines, irrigation infrastructure and other water management equipment and structures;
- development of soil stockpiles, laydown areas and gravel/borrow areas including minor modifications and alterations to existing infrastructure as required;
- monitoring and rehabilitation;
- all activities approved under Development Application (DA) 23-98/99 and DA 39-02-01; and
- other associated minor infrastructure, plant, equipment and activities, including minor modifications and alterations to existing infrastructure as required.

A2 HYDROGEOLOGICAL SETTING

A2.1 RAINFALL AND EVAPORATION

The Project area generally experiences a temperate climate with rainfall in the moderate to high range. Rainfall records are available from Gloucester and Stroud Post Offices (PO), Craven and Commonwealth Bureau of Meteorology (BoM) rainfall gauges, with averages between approximately 985 millimetres (mm) and 1,146 mm per year. Average potential (pan) evaporation (based on the Chichester Dam station) is 1,061 mm per year. The average monthly rainfall and potential evaporation statistics from Gloucester and Stroud POs and Craven stations are summarised in **Table A-1**, and indicate that rainfall over the Project area is typically lower during the winter months with maxima generally experienced during the summer months. **Figure A-3** illustrates the spatial pattern for average annual rainfall.

Table A-1. Monthly Average Rainfall and Daily Evaporation

Month	Monthly Average Rainfall (mm)			Monthly Average Pan Evaporation (mm)
	Craven (Longview)[1] (Site 060042)	Gloucester (PO)[2] (Site 060015)	Stroud (PO)[3] (Site 061071)	Chichester Dam[4]
Jan	125.3	114.8	115.5	139.5
Feb	136.8	121.7	125.2	110.2
Mar	133.9	127.9	145.2	93.0
Apr	85.2	77.3	101.8	69.0
May	88.3	68.6	92	46.5
Jun	79.2	68.4	99	33.0
Jul	40.3	51.4	75.1	40.3
Aug	44.3	46.6	65.4	58.9
Sep	47.4	51.2	63.9	87.0
Oct	79.3	69.2	78.5	108.5
Nov	91.8	83.9	82.1	123.0
Dec	98.5	104.4	102.9	151.9
Annual Average*	**1,050.3**	**985.4**	**1,146.6**	**1,060.8**

Source: BoM, 2011.

* Sum of average monthly records.

1 Craven Station Record 1961 - 2011.

2 Gloucester PO Station Record 1888 - 2011.

3 Stroud PO Station Record 1889 - 2009.

4 Chichester Dam Station Record 1974 - 2011.

The actual evapotranspiration in the district is about 750 mm per annum according to BoM (2011). The definition for actual evapotranspiration is: "*... the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average. For example, this represents the evapotranspiration which would occur over a large area of land under existing (mean) rainfall conditions*".

Rainfall intensity is a particular feature of the area which has a significant bearing on the moisture levels in catchment soils, and on the hydrological response of the local catchments.

Fluctuations in the groundwater table result from temporal changes in rainfall recharge to aquifers. Typically, changes in the groundwater elevation reflect the deviation between the long-term monthly (or yearly) average rainfall, and the actual rainfall often illustrated by the Residual Mass Curve (RMC).

The groundwater levels recorded during periods of rising RMC are expected to rise, while those recorded during periods of declining RMC are expected to decline. A plot of RMC at Gloucester PO since 1888 is shown in **Figure A-4**, and a detailed view at the Stratford Mining Complex (based on an on-site weather station) is shown in **Figure A-5** since the commencement of BRNOC mining in 2003. The long-term plot at Gloucester (**Figure A-4**) shows major dry periods from 1899 to 1928 and from 1935 to 1949. Since then, less emphatic wet and dry cycles of about 10 years duration have occurred. The short-term plot at SCM (**Figure A-5**) shows a similar pattern to Gloucester for the same period (since 2003), with dry periods from mid-2003 to mid-2004, early 2006 to mid-2007, and mid-2008 to early 2009.

A2.2 TOPOGRAPHY AND DRAINAGE

Surface elevations in the area vary from approximately 100 metres (m) Australian Height Datum (AHD) along the river flats of Avondale Creek and Dog Trap Creek to a maximum of 475 m AHD along the ridge line to the east (**Figure A-6**). Lower ridge lines typically rise between 50 m and 150 m above the drainage floor. The land within the Project area is gently sloping and undulating.

The Stratford Mining Complex is located wholly within the Avon River Catchment. A catchment divide at Craven separates the Avon River Catchment from the Karuah River Water Source to the south.

The main local drainage systems associated with the Project area are Avondale Creek and Dog Trap Creek. Avondale Creek runs northwards and flows into the Avon River. Dog Trap Creek runs to the north-west along the northern boundary of the Stratford Mining Complex. A number of minor ephemeral drainage lines also cross the Project area.

Under normal conditions these streams have low to zero flow for long periods. The water chemistry of Dog Trap Creek suggests that it is fed by groundwater seepage (Parsons Brinckerhoff, 2012). Short duration high peak flows and shallow flooding of alluvial lowlands, principally due to rapid runoff from steeper slopes, can result following heavy rain events.

Surface water hydrology is addressed in detail in Appendix B of the EIS.

A2.3 LAND USE

The Stratford Mining Complex is located in a rural area characterised by cattle grazing on native and improved pastures, along with some poultry farming and other agricultural production. The majority of the Project area and surrounds has been cleared as part of past land use practices.

Other land uses in the district include dairying, timber milling, cropping and recreation.

The Stratford Mining Complex and the DCM (located some 20 km to the south) (**Figure A-1**) are the main mining developments in the area. AGL has commenced CSG exploration in the area, and Gloucester Resources Ltd (GRL) is undertaking investigations for a proposed open cut coal mine approximately 5 km to the north of the Stratford Mining Complex.

A2.4 STRATIGRAPHY AND LITHOLOGY

The Gloucester Basin coal measures are of Permian age and contain conglomerate, sandstone, siltstone, mudstone and coal. The underlying Early Permian and Carboniferous strata, principally tuffs, mudstones and acid volcanics were also folded during formation of the basin. They form two sub-parallel lines of hills, are typically erosion-resistant and form the more prominent ridges to the east and west of the SCM, while the Permian Coal Measures occupy the valley floor between.

Gloucester Coal Measures are separated into two subgroups: (1) Avon Subgroup (Middle Permian) and (2) Craven Subgroup (Upper Permian) (**Figure A-7**). They subcrop over a major portion of the SCM (**Figure A-8**) and consist of coarse and medium grained sandstones with minor siltstone, conglomerate and coal seams. The Craven Subgroup hosts the Cloverdale, Roseville and Bowens Road coal seams, while the Avon Subgroup hosts the Avon coal seam. The underlying Dewrang Group (Early Permian) hosts the Weismantel and Clareval coal seams.

The main stratigraphic units (Figure A-7), from youngest to oldest, include:

- Alluvium/Regolith;
- Craven Subgroup;
- Crowthers Road Conglomerate;

- Leloma Formation - including Bindaboo and Deards coal seams;
- Jilleon Formation - including Cloverdale and Roseville coal seams;
- Wards River Conglomerate;
- Wenhams Formation - including Bowens Road coal seam;
- Speldon Formation;
- Avon Subgroup;
- Dog Trap Creek Formation;
- Waukivory Creek Formation - including Avon coal seam;
- Dewrang Group;
- Mammy Johnsons Formation;
- Weismantel Formation - including Weismantel coal seam;
- Duralie Road Formation - including Clareval coal seam; and
- Alum Mountain Volcanics.

Leloma Formation
The Leloma Formation (formerly Woods Road Formation) contains numerous thin coal seams in upper 200-300 m, particularly within the eastern limb of the syncline. It is characterised by fine-medium sandstone and interbedded siltstone. There are occasional conglomerate lenses which are more prevalent in the syncline's western limb and core area.

Jilleon Formation
The Jilleon Formation contains sandstone, shale, mudstones, and numerous thin coal seams. Significant coal seams within this formation include the Cloverdale Seam (uppermost) and Roseville Seam (with heavy banding in thicker seams).

Wards River Conglomerate
The Wards River Conglomerate is dominantly a conglomerate and sandstone. It thickens rapidly on the western side of the basin but thins (to 15 m) on eastern limb. Along the western margin of the basin, the Wards River Conglomerate occupies the entire Gloucester Coal Measure sequence.

Wenham Formation
The Wenham Formation consists of bioturbated and alluvial plain sediments. Coal is present with the Lower Bowens Road Coal Seam and Bowens Road Seam.

Speldon Formation
This separates the lower Avon Subgroup from the upper Craven Subgroup of the Gloucester Coal Measures. It contains a mixture of bioturbated mudstones, sandstone and poorly sorted conglomerate. It also contains the Glenview Coal Seam.

Dog Trap Creek Formation
Near Stratford the lowest unit of the Dog Trap Creek Formation is a weak laminated mudstone overlain by siltstones, mudstones and sandstones. The upper part of the formation contains the Glenview Coal Seam. As with all other formations the stratigraphic interval occupied by the Dog Trap Creek Formation is represented almost exclusively by conglomerate on the western limb.

Waukivory Creek Formation
The Waukivory Creek Formation contains well developed coal on the eastern limb with major seams including Parkers Road Seam, Valley View Seam, Glen Road Seam, Rombo Seam, Triple Coal Seam, Avon Seam and the Lower Avon Seam. It generally becomes coarser to the west where medium grained lithic sandstones are frequent.

Mammy Johnsons Formation
The Mammy Johnsons Formation is highly compressed and is equivalent to the uppermost formation at the DCM. It generally contains coarse grained lithic sandstones with minor poorly developed coal. The uppermost layer is thick shale.

Weismantel Formation
The Weismantel Formation comprises fine to medium grained sandstones over thick shale covering the Weismantel Seam.

Duralie Road Formation
The Duralie Road Formation forms the base of the Dewrang Group and comprises mostly marine sandstones and conglomerate covering the Clareval Seam.

Alum Mountain Volcanics
The Alum Mountain Volcanics are a rhyolitic rock unit, which is underlain by undifferentiated rocks of Carboniferous age.

A2.5 STRUCTURAL GEOLOGY

The Project coal resource is located within the Permian-aged Gloucester Basin in NSW, within a north-south trending synclinal structure some 40 km long by 13 km wide.

The geological structure in the project area (**Figure A-8**) is dominated by a synclinal structure with the coal outcropping at fairly steep angles (up to 45 degrees (^{o}) dip) on the eastern and western limbs. The eastern flank and southern core of the coal measures are significantly affected by low-angle thrust faulting which has caused coal members in places to be stacked on top of each other, often with several repetitions of the main coal seams. The thrust fault planes are generally parallel to the axis of the syncline and range in inclination from sub-horizontal to 60o. Coal seams in close proximity to the fault planes show highly distorted bedding and cleating but are not intensely brecciated. Normal faulting has also been observed. A significant east-west fault along Bowens Road (with about 60 m throw) separates the Stratford Main Pit from the Bowens Road North Pit.

Both normal and reverse faults are characteristic of the basin. The Gloucester Basin is a fault-controlled depositional trough, and subsequent compression tectonics has induced folding, which has accentuated the dip of the strata and, in places, has resulted in the thrust-faulted repetition of the stratigraphic units.

Independent of the formation present, the overburden is almost always described as variable, and showing consistent variation from south to north. Siltstones and mudstones in the south give way to sandstones to the north. There are variable numbers of weak layers. The coal seams are reported to have reasonably constant thicknesses except on the eastern limb where thrust faulting has thickened and repeated strata, complicated further by steep dips. The Avon Seam for example is about 15 m thick but can have an apparent vertical thickness of 50 m.

A2.6 ALLUVIAL GEOLOGY

A thin and narrow deposit of Quaternary to Recent Age alluvial deposits occurs in association with Avondale Creek and Dog Trap Creek in the vicinity of the SCM (**Figure A-6**). The alluvium consists of silty sands and silts with lenses of gravelly sands and sandy, coarse gravel, particularly towards the base of the alluvium. The gravel lenses correspond to former channel deposits and are evident in the present bed and banks of the creeks.

Monitoring bores in the alluvium are drilled to maximum depths of 4.1 m; other evidence from exploration holes suggests an average thickness of about 9 m for the alluvium, but the maximum thickness is unknown.

To better define the geometry and properties of the Dog Trap Creek alluvium to the immediate north of the Project area, SCPL installed a transect of three shallow boreholes (DTTR1 – DTTR3) and commissioned a transient electromagnetic (TEM) survey (Groundwater Imaging, 2011). The bore transect revealed thin alluvial thickness from 1.5 m to 4 m with a median thickness of 3 m. Bore locations are shown in **Figure A-9**. A TEM survey was also conducted on alluvium associated with Avondale Creek to the south.

The TEM survey results are shown in **Figure A-10** (Dog Trap Creek) and **Figure A-11** (Avondale Creek) in terms of (inverted) true resistivity (ohm.metres) for depths 1 m and 7 m. The white-red tones indicate the most conductive material, either dry weathered rock or alluvium with a high clay content or high salinity. The green-blue tones show more resistive material, generally associated with alluvium at shallow depths.

The TEM survey was successful in mapping a narrow alluvial channel along Dog Trap Creek, with resistivities of 30-100 ohm.metres typical of sandy material. The depth of alluvium was found to be variable but generally less than about 10 m. The TEM survey at Avondale Creek had less continuous coverage (due to access constraints) and was able to track only portions of the alluvial channel. Alluvial resistivities are generally 30-60 ohm.metres in the central part of the survey area and are very low (4-10 ohm.metres) in the southern part, typical of clay.

The inferred alluvial channel outlines, as shown in **Figure A-6**, have been represented in the groundwater model as higher-permeability features.

A2.7 GROUNDWATER BORE CENSUS

Locally, there is little reliance on groundwater bores as a source of water, as agricultural enterprises predominantly rely on surface water sources which are more abundant and generally better quality. The number of privately held bores in the Stratford Mining Complex area and surrounds is low due to the generally poorer groundwater quality, high rainfall and subsequent high rates of runoff. A search of the NOW Pinneena Groundwater Works Database identified 62 registered bores and wells within approximately 5 km of any proposed pit (**Figure A-12**).

The majority (48) of the registered bores are on land owned by GCL/SCPL. One registered bore is on land owned by AGL.

Privately owned bores in the vicinity of the Project include:

- 11 bores in Stratford; and
- One private bore to the south (GW079759 at northing 6438780).

The bores are licensed for stock and domestic use. Another privately owned bore is located more than 5 km from the proposed pits (GW200398) (**Figure A-12**).

A2.8 GROUNDWATER LICENSING

The Project is located in the NSW Lower North Coast Water Management Area.

The Project area is covered by the WSP under the *Water Management Act, 2000* and is located within the Avon River Water Source in the Manning Extraction Management Unit. The WSP applies to all surface water and groundwater (i.e. water beneath the ground surface in the saturated zone) within alluvial sediments.

The WSP provides the detailed rules by which water is preserved for basic landholder uses and the environmental needs of the river, and by which the water available for extraction is shared amongst access licence holders. The WSP contains the rules for managing water allocation accounts, trading of licences and the making of water allocations under the different classes of licence.

Although the Project coal resource is located within the boundary defined in the WSP, the WSP does not apply to the groundwater contained in the fractured rocks and basement rocks within which the Project coal resource exists.

As no water sharing plan applicable to the Project coal resource has commenced, the *Water Act, 1912* remains the relevant Act for approval of groundwater extraction. There are currently no embargoes on applications for groundwater licences applicable to the Project area.

A summary of the existing groundwater licensing regime at the Stratford Mining Complex is provided below. Future groundwater licensing for the Project is discussed in Section A8.2.

Licences Pursuant to Part 5 of the Water Act, 1912

SCPL holds existing groundwater licences (20BL168400; 20BL169101; 20BL169102; 20BL169104) under Part 5 of the *Water Act, 1912* for pit dewatering activities at the Stratford Mining Complex that allows for the extraction of up to 1,021 megalitres (ML) of groundwater in any 12 month period:

- Stratford Main Pit (20 megalitres per annum [ML/annum]);
- Roseville Pit (315 ML/annum);
- Bowens Road North Pit (500 ML/annum); and
- Parkers (Bowens Road West) Pit (186 ML/annum).

Groundwater monitoring boreholes at the Stratford Mining Complex are also licensed which set out conditions of use for the monitoring bores.

Licences Pursuant to Water Management Act, 2000

The water sharing rules for the Avon River Water Source apply to all surface waters, as well as alluvial groundwater that is highly connected to the surface waters (NSW Department of Water and Energy, 2009).

At August 2009, there were 43 surface water licences with a total entitlement of 1,997 ML/annum in the Avon River Water Source. Some trading between water sources is permitted within water sources in the Manning Extraction Management Unit.

The existing operations at the Stratford Mining Complex do not involve extraction of surface waters or alluvial groundwater within 40 m of an unregulated tributary in the Avon River Water Source (e.g. Avondale Creek or Dog Trap Creek). Therefore, no aquifer interference approvals or licences under the *Water Management Act, 2000* are currently required or held by SCPL.

Notwithstanding, SCPL holds existing access licences (WAL 19536; WAL 19514) within the Avon River Water Source:

- 133 Units (Irrigation and Farming); and
- 7 ML (Unregulated River).

A2.9 GROUNDWATER DEPENDENT ECOSYSTEMS

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002b) describes the five broad types of groundwater systems in NSW, each with associated dependent ecosystems as follows:

- **Deep Alluvial Groundwater Systems –** occurring under floodplains of major rivers west of the Great Dividing Range (e.g. Namoi, Macquarie, Lachlan, Murrumbidgee and Murray alluvium).
- **Shallow Alluvial Groundwater Systems –** coastal rivers and higher reaches west of the Great Dividing Range (e.g. Hunter, Peel and Cudgegong alluvium, and beds and lateral bars of the lower Macleay, Bellinger and Nambucca Rivers).
- **Fractured Rock Groundwater Systems** – outcropping and sub-cropping rocks containing a mixture of fractures, joints, bedding planes and faults that contain and transmit small and occasionally large amounts of groundwater (e.g. Alstonville Basalt, Molong Limestone and the Young Granite).
- **Coastal Sand Bed Groundwater Systems –** significant sand beds along the coast of NSW (e.g. Botany and Tomago sand beds).
- **Sedimentary Rock Groundwater Systems –** sedimentary rock aquifers including sandstone, shale and coal (e.g. Great Artesian Basin, Sydney Basin and Clarence Moreton Basin).

The Project coal resource is located within the Craven and Avon Subgroups of the Gloucester Coal Measures and the underlying Dewrang Group (refer Section A2.4) which is within the fractured rock groundwater systems of the Gloucester Basin. These fractured rock groundwater systems lie within the boundary defined in the WSP (as described in Section A2.8).

Groundwater resources in the north and north-west of the Project area are associated with alluvial groundwater of unregulated tributaries in the Avon River Water Source (Section A2.8). There are no high priority groundwater dependent ecosystems identified in the WSP in the Avon River Water Source.

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC, 2002b) also recognises the four Australian groundwater dependent ecosystem types (Hatton and Evans, 1998) that can be found in NSW, namely:

- terrestrial vegetation;
- base flows in streams;
- aquifer and cave ecosystems; and
- wetlands.

Parsons Brinckerhoff (2012), for the AGL Gloucester Gas Project, noted that there are "no known wetlands, lakes or other surface features that are indicative of shallow groundwater processes and possible groundwater dependent ecosystems". Furthermore, they note that the brackish-saline nature of groundwater baseflow is unlikely to be conducive to the sustenance of groundwater dependent ecosystems.

The Flora Assessment (Appendix E of the EIS) concludes that there is no groundwater dependent terrestrial vegetation known to occur within the Project area.

The Aquatic Assessment (Appendix G of the EIS) concludes that there are no aquatic ecosystems or wetlands in the Project area or surrounds that are dependent on groundwater.

Notwithstanding, the potential impacts of the Project on base flows in streams are described in the Surface Water Assessment (Appendix B of the EIS) and potential aquifer ecosystems (stygofauna) are described in the Main Report of the EIS.

A2.10 GROUNDWATER MONITORING

The locations of groundwater monitoring locations (past and present) at the SCM and surrounds are shown on **Figure A-13**. A number of monitoring bore designations have been developed for specific areas of the SCM. Four bores (RB1 – RB4) were installed in compliance with amended Development Consent conditions issued in 1996 for the Roseville Pit. Between the backfilled Roseville Pit / western co-disposal area and the Stratford Main Pit and Waste Emplacement area, groundwater levels are monitored by the GW series introduced in 1999; six groundwater monitoring wells (designated GW1 – GW5 and GW7). GW8 was installed in 2001 at the time of approval of the Roseville void for storage of washery reject material. Following approval for the deposition of rejects within the Bowens Road West North pit in May 2003, monitoring bore BRWN1 was also added to the network in this area. Bores MW1-MW9 were installed around the perimeter of the BRNOC in 2002, and additional bores (MW10-MW12) have followed in 2005-2007. SCPL also monitors a number of bores in Stratford Village and a disused SCPL bore on the eastern edge of the village, as well as bores on the former Griffin and Bramley properties.

The groundwater monitoring program (**Table A-2**) has been developed in accordance with Condition 29(b), Schedule 3 *Environmental Performance Conditions* of the SCM Development Consent.

Table A-2. Groundwater Monitoring Program

Monitoring Locations	Frequency	Parameters
Stratford (Village) Bores	Six monthly	• Water level.
	Annually	• Electrical Conductivity (EC), pH, Oxygen Reduction Potential (ORP), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg), Cholride (Cl), Sulphate (SO_4), Iron (Fe), Manganese (Mn), Lead (Pb), Zinc (Zn), Phosphorous (P), Bicarbonate.
MW1 – MW9, MW11, MW12, Griffin	Monthly	• Water level.
	Quarterly	• EC, pH, ORP, Na, K, Ca, Mg, Cl, SO_4, Fe, Mn, Pb, P, Bicarbonate.
GW1-GW3	Quarterly	• Water level.
	Quarterly	• EC, pH, Total Suspended Solids (TSS), ORP, Na, Cl, SO_4, filtered Fe.
RB1 – RB3	Quarterly	• Water level.
	Quarterly	• EC, pH, Na, Cl, SO_4.
GW4, GW5, GW7, GW8, BRWN1	Six monthly	• Water level.
	Six Monthly	• EC, pH, TSS, ORP.

Groundwater monitoring, water level measurements and sample collection, storage and transportation are undertaken in accordance with the procedures outlined in the *Murray-Darling Basin Groundwater Quality Sampling Guidelines* (MDBC, 1997), and in accordance with the mine's Water Management Plan (currently in review). Analysis is undertaken by a laboratory which has been accredited by the National Association of Testing Authorities, Australia (NATA) to undertake testing for the parameters being determined.

Additional groundwater level monitoring and groundwater quality sampling/analysis have also been undertaken as part of the groundwater investigation testwork commissioned by SCPL in 2011.

The lithologies being monitored are summarised in **Table A-3**.

Table A-3. Groundwater Monitoring Lithologies

Lithology	Monitoring Site	Maximum Depth (m)
Alluvium / Regolith / Waste	MW8, MW9, GW1, GW2, GW4, GW5, GW7, RB1, RB2,RB4, CD9, CD10, PBM2	17
Coal	MW1, MW2, MW3, MW4, MW6, GW3, CD6, Griffin, PB1	15
Coal Measures (interburden)	MW5, MW7, MW10, MW11, MW12, RB3,BRWN1, Bagnell Shop, Bramley, Butler, Forbes, Fardell, Germon, Hooker, Mitchell, Nelson, Smith, SCPL Bore, PBM1	95

In addition to the existing monitoring network, SCPL in 2011 installed monitoring standpipes in five locations and vibrating wire piezometers in four holes surrounding SCM and installed pump and monitoring bores in the Avon seam and overlying alluvium adjacent to Dog Trap Creek (**Figure A-13**). Details are provided in **Table A-4** and **Table A-5**. Bore NS246 (5 piezometers) is located to the west of the backfilled Roseville Pit, NS585 (6 piezometers) is located to the east of Stratford Main Pit, GC207 (5 piezometers) is located in the vicinity of Craven and NS256 (5 piezometers) is located in elevated terrain within the south-eastern margin of the mine lease just to the north of Glen Road. The monitored depths and lithologies are summarised in **Table A-4**.

As part of the groundwater investigation programme undertaken in 2011, SCPL also installed standpipe piezometers in PB1, PBM1 and PBM2 for the pumping test, and a number of standpipe piezometers comprising 50 mm Polyvinyl Chloride [PVC] standpipes. Locations are shown in **Figure A-13**. The installation details are summarised in **Table A-5**. The results of the aquifer tests are presented in Section A3.1.

Separate groundwater monitoring networks have been established for neighbouring developments. A network of 13 groundwater monitoring bores has been established for the proposed Rocky Hill Coal Project for GRL (R.W. Corkery & Co. Pty. Limited, 2012), to the north of the Stratford Mining Complex. Parsons Brinckerhoff (2012) has established a network of 22 groundwater monitoring bores for the AGL Gloucester Gas Project for the Stage 1 Gas Field Development Area surrounding and coincident with the Stratford Mining Complex.

Table A-4. Multi-Level Groundwater Monitoring Piezometers

Monitoring Site	Depth (m)		Lithology	
Avon North (NS585 Site 12)	(1)	13	(1)	Dog Trap Creek Formation
	(2)	27	(2)	Dog Trap Creek Formation
	(3)	49	(3)	Avon Seam
	(4)	89	(4)	Waukivory Creek Formation
	(5)	99	(5)	Waukivory Creek Formation
	(6)	119	(6)	Waukivory Creek Formation
South Stratford (GC207)	(1)	45	(1)	Dog Trap Creek Formation
	(2)	62	(2)	Dog Trap Creek Formation
	(3)	84	(3)	Avon Seam
	(4)	105	(4)	Waukivory Creek Formation
	(5)	125	(5)	Waukivory Creek Formation
Stratford East (SS256)	(1)	51	(1)	Duralie Road Formation
	(2)	71	(2)	Duralie Road Formation
	(3)	101	(3)	Clareval Seam
	(4)	121	(4)	Lower Duralie Road Formation
	(5)	140	(5)	Lower Duralie Road Formation
Roseville West (NS246)	(1)	28	(1)	Woods Road Formation
	(2)	69	(2)	Cloverdale Seam (CV6)
	(3)	88	(3)	Cloverdale Seam (CV8)
	(4)	126	(4)	Jilleon Formation
	(5)	148	(5)	Roseville Seam (RV1)

Table A-5. Standpipe Piezometer Installation Details

Bore	Coordinates		Drilled Depth	Screened Interval	Formation Screened	Water Level August 2011
	Easting	Northing	(m BGL)	(m BGL)		m BGL
NS581	403775	6445688	37.5	6 - 12m	Avon Seam	0.51
				31.5 - 37.5	Waukivory Creek Formation	2.42
NS581R	403775	6445693	37.5	5 - 9m	Avon Seam	2.01
				31.5 - 37.5	Waukivory Creek Formation	2.4
PBM2	404079	63446426	4	2.5 - 4	Dog Trap Creek Alluvium	1.69
PBM1	404076	6446420	23	18.5 - 23	Dog Trap Creek Formation	1.77
PB1	404080	6446426	49	42 - 48	Avon Seam	1.82
DTTR1	404096	6446520	1.5	N/A	Dog Trap Creek Alluvium	-
DTTR2	404114	6446566	1.9	N/A	Dog Trap Creek Alluvium	-
DTTR3	404136	6446613	2.7	N/A	Dog Trap Creek Alluvium	-
NS584	403399	6445369	37.5	31.5 - 37.5	Dog Trap Creek Formation	21.4
NS584R	403398	6445374	37.5	31.5 - 37.5	Dog Trap Creek Formation	21.44
NS596R	401443	6445501	43.7	39 - 42	Bindaboo Coal Seam	20.4
NS593R	401438	6445499	41	37 - 40	Woods Road Formation	22.6
NS592R	402450	6441865	48	40 - 48	Duralie Road Formation	8.21
GC207R	401130	6441589	48	42 - 48	Waukivory Creek Formation	4.67

Note: BGL = below ground level

A2.11 BASELINE GROUNDWATER LEVEL DATA

A2.11.1 Groundwater Pressure Heads

The vibrating wire piezometer pressure head profiles at NS585, NS246, GC207 and SS256 are displayed in **Figure A-14** and **Figure A-15**, respectively. These plots show pressure head at various sampling depths compared to the expected hydrostatic head profiles. Generally, under pre-mining conditions, pressure heads should plot close to the 45° "hydrostatic line". Although there is a slight shift from the line in some cases, all data points lie reasonably close to the hydrostatic pressure head line suggesting no significant mining effects have yet been recorded at these locations.

A2.11.2 Spatial Groundwater Level Data

Natural groundwater levels are sustained by rainfall infiltration and are controlled by ground surface topography, geology and surface water elevations. Typically, local groundwater would mound beneath hills and would discharge to incised creeks and rivers. During short events of high surface flow, streams would lose water to the surrounding groundwater system, but during recession groundwater would discharge slowly back into the stream from bank storage. Groundwater flows from elevated to lower lying terrain.

A contour map of inferred groundwater levels has been prepared (**Figure A-16**) for the regional area, based on measurements taken at the SCM, GRL and AGL networks (**Figure A-13**). The SCM measurements are the averages of all data through to 2010 at shallow bores. The GRL measurements are the averages at shallow sites in 2011 (Parsons Brinckerhoff, 2011). The AGL measurements are spot values taken in May 2010 (SRK Consulting, 2010) and average values in the first quarter of 2011 (Parsons Brinckerhoff, 2012). In areas where no data are available, estimates of river and creek water levels have been used to approximate the spatial pattern. No measurements are available in the eastern and western ridge areas.

The direction of groundwater flow in the vicinity of the Stratford Mining Complex is from the south-east to the north-west, and the main groundwater discharge zones are Avondale and Dog Trap Creeks, and the Avon River. A groundwater divide is present in the Craven area (near northing 6442000, **Figure A-16**), which separates the surface catchments and groundwater systems in this part of the Gloucester Basin. South of Craven, groundwater flows generally in a southerly direction and towards Wards River.

The hydraulic gradients are strongly controlled by regional topography with the hills bounding the groundwater flow regime. Gradients flatten appreciably within central parts of the valley due to the natural gradients of watercourses and higher hydraulic conductivity of alluvial sediments associated with the Avondale Creek, Dog Trap Creek and the Avon River.

A2.11.3 Temporal Groundwater Level Data

Monitoring bores have been established in a number of different time frames – generally associated with different stages of development approval. Some bores are off-site (i.e. in Stratford) while others within the mine lease have targeted specific areas during the various operational phases of excavation.

Groundwater levels have been monitored from 1994 at the earliest at locations shown in **Figure A-13**.

Groundwater hydrographs have been grouped into four categories to illustrate possible cause-and-effect relationships with rainfall and mining:

- Coal seam bores (**Figure A-17**);
- Regolith bores (**Figure A-18**);
- Interburden bores (**Figure A-19**); and
- Stratford (village) bores (**Figure A-20**).

The hydrographic plots include the rainfall RMC at the on-site weather station and the starting dates of mining at the BRNOC, Roseville Extended Pit and Roseville West Pit.

The northern coal seam hydrographs (**Figure A-17a**) show a pronounced mining effect at MW6 (north of BRNOC) shortly after mining commenced in 2003, with a drawdown of approximately 8 m from 2007 onwards, this bore responds to weather variations. Bores MW3 and MW4 between the BRNOC and the Roseville Extended Pit show a mild but gradually increasing effect from both the approaching BRNOC and the receding Roseville Extended Pit, and a sharp response at the onset of Roseville West Pit. All bores show responses to rainfall trends.

The southern coal seam hydrographs (**Figure A-17b**) show no response to BRNOC but most have a mild response to Roseville Extended Pit and a sharper response to Roseville West Pit. Responses to weather variations are more subdued than in the north.

All regolith bores (**Figure A-18**) are fairly stable with only mild responses to weather. As bores RB1 and RB2 to the west of the Main Pit show an increasing trend contrary to the rainfall trend, their water levels are likely to be recovering slowly from past mining of the Main Pit. Bore MW9 also has an increasing trend, due probably to enhanced recharge through the adjacent waste emplacement area. Only bores MW9 and MW8 (adjacent to BRNOC) show any effect from BRNOC mining, with drawdowns of about 5 m, and bore RB4 (north of Roseville Extended Pit) is the only one to respond to Roseville mining. Bore RB4 was subsequently removed by mining in 2009.

Interburden bores close to the pits all show a mining response (**Figure A-19**), while the former Griffin and Bramley bores (1.2 km and 2 km respectively from historical [BRNOC and Stratford Main Pit] mining areas) show no mining effects. As bore MW5, with about 10 m drawdown at the commencement of BRNOC, has an almost identical response to MW6 situated in a coal seam, it is likely that MW5 has also intercepted coal. Bore MW7 has a milder 3 m drawdown in 2003. Bore RB3 to the east of the Roseville Extended Pit shows a gradually decline in water level of about 3 m during mining in the Roseville Extended Pit, and a sharp decline of about 4 m when Roseville West Pit commences.

The bores in Stratford Village (**Figure A-20**) have dynamic water level fluctuations of about 2 m, with trends generally in accord with rainfall trends but influenced by local pumping effects. No mining effects have been observed in any privately owned bores in Stratford. An SCPL owned bore at the eastern edge of the village has recorded a mild decline of about 0.5 m from 2003 to 2010.

A2.12 MINE INFLOWS

At the Stratford Mining Complex, records are kept of pumped water volumes from operational pits (BRNOC and Roseville West Pit) and the Roseville Extended Pit. Total pumped volumes are a combination of groundwater inflow combined with rainfall and runoff from the local catchments and waste emplacements, and in some cases water transfers.

Figures A-21 to **A-23** show the equivalent pumping rates at the operational open cuts compared with monthly rainfall. While there is generally good correlation between pumping peaks and rainfall events, the capacity of the pits to hold water will necessarily occasion a delay in the onset of pumping. As a result, the dynamics of pumping are not a good indication of temporal variability in groundwater inflows, but the curves provide an upper limit on groundwater inflow rates.

The trend lines in **Figures A-21** to **A-23** show that pumping rate is about 1 megalitres per day (ML/day) at BRNOC, declining with time; about 0.6 ML/day at Roseville Extended Pit, declining with time; and about 0.3 ML/day at Roseville West Pit but increasing steadily with time.

A2.13 BASELINE GROUNDWATER CHEMISTRY DATA

Table A-6 summarises the EC statistics for laboratory samples analysed from the SCM monitoring network from commencement of sampling to the present day. The median values are generally about 5000 microSiemens per centimetre (µS/cm) in coal (400-7300 µS/cm), about 4500 µS/cm in alluvium and regolith (2200-11700 µS/cm), and about 3500 µS/cm in coal measures interburden (400-7800 µS/cm). Apart from two private bores in Stratford and Bore MW12 (that intercept better quality alluvial waters), most groundwaters are beyond the limit of potable use but on the basis of salinity are suitable for livestock, selective irrigation and other general uses (**Table A-7**).

Table A-6. Electrical Conductivity at SCM Groundwater Monitoring Sites

Bore	Median [µS/cm]	Mean [µS/cm]	Standard Deviation [µS/cm]	Lithology
RB1	8300	8187	1786	Alluvium
RB2	9200	8998	1443	Alluvium
RB3	3930	3754	1248	Wards River Conglomerate
RB4	6550	6323	1817	Alluvium
GW1	4850	4234	1781	Alluvium
GW2	3880	3676	1015	Alluvium
GW3	3395	3597	998	Alluvium
GW4	11700	11303	3651	Alluvium
GW5	3860	4029	1125	Alluvium
GW7	4350	5121	3152	Alluvium
GW8	3850	3706	1027	Wards River Conglomerate
MW1	6100	5450	1471	Roseville Seam
MW2	7338	5919	3647	Bindaboo / Cloverdale / Roseville Seams
MW3	6300	6303	1979	Roseville Seam
MW4	6900	6590	1432	Roseville Seam
MW5	5763	6559	2875	Wards River Conglomerate
MW6	449	989	1011	Roseville Seam
MW7	4090	3911	1506	Wards River Conglomerate
MW8	2400	2422	688	Alluvium

Table A-6. Electrical Conductivity at SCM Groundwater Monitoring Sites (Continued)

Bore	Median [µS/cm]	Mean [µS/cm]	Standard Deviation [µS/cm]	Lithology
MW9	4515	4300	828	Alluvium
MW10	3400	3371	426	Dog Trap Creek Formation
MW11	1276	1273	157	Dog Trap Creek Formation
MW12	437	733	1063	Leloma Formation
Griffin	1600	1599	230	
CD6	4350	4196	820	Roseville Seam
CD9	4170	3903	1217	Alluvium / Regolith
CD10	2240	2806	1193	Alluvium / Regolith
BRWN1	5390	5283	1447	Leloma Formation
Bagnell	1950	1970	198	Leloma Formation
Smith	563	526	171	Leloma Formation
Butler	4050	3976	576	Leloma Formation
Forbes	3530	2325	1245	Leloma Formation
Mitchell	3100	3027	614	Leloma Formation
Glew/Nelson	3595	3502	494	Leloma Formation
Germon	3505	3305	812	Leloma Formation
Hooker	420	425	30	Leloma Formation
Fardell	2600	2449	1362	Leloma Formation
Bramley	7800	7564	860	Wards River Conglomerate
SCPL Bore (Wood St)	6370	6292	906	Leloma Formation

Table A-7. Groundwater Salinity Categories

Potable	Up to 781µS/cm (500 mg/L TDS)$^{+}$	Suitable for all drinking water and uses.
Marginal Potable	781-2,344 µS/cm (500-1500 mg/L TDS) $^{+}$	At the upper level this water is at the limit of potable water, but is suitable for watering of livestock, irrigation and other general uses.
Irrigation	2,344-7,813 µS/cm (1500-5000 mg/L TDS) $^{+}$	At the upper level, this water requires shandying for use as irrigation water or to be suitable for selective irrigation and watering of livestock.
Saline	7,813-21,875 µS/cm (5000-14000 mg/L TDS) $^{+}$	Generally unsuitable for most uses. It may be suitable for a diminishing range of salt-tolerant livestock up to about 6,500mg/L [~10,150 µS/cm] and some industrial uses.
Highly Saline	> 21,875 µS/cm (14000 mg/L TDS) $^{+}$	Suitable for coarse industrial processes up to about 20,000 mg/L [~31,000 µS/cm].

$^{+}$Conversion Factor of 0.64 applied.
Source: MDBC (2005).
mg/L = milligrams per litre.
TDS = total dissolved solids.

The spatial pattern of baseline groundwater salinity is illustrated in **Figure A-24**. This plot consists of median laboratory values at bores in the SCM monitoring network. Best estimates of the sample lithologies are differentiated by symbol, and the magnitude of the concentration is proportional to symbol size. The distribution of salinity is fairly uniform spatially, with the highest value in Avondale Creek alluvium to the south of the SCM, and generally lower values in Stratford closer to the Avon River. There is no clear differentiation between the salinity signatures of different lithologies. In particular, the salinity of alluvial/regolith waters is no better than coal groundwaters.

Groundwater samples taken close to Avondale Creek show generally high salinities in the alluvium and in sub-cropping coal seams. Intermittent seepage of more saline groundwater into the creek has caused gradually increasing salinity of surface water in the downstream direction.

Agricultural use and raw water for drinking are the only beneficial groundwater quality uses. Water quality decline is deemed unacceptable if groundwater extraction causes water quality to decline to a lower beneficial use class. It is clear from **Table A-7** that in the local area most groundwater is neither “potable” nor "marginal potable" in status. Only three bores, all in shallow coal measures interburden, have consistently potable water.

Groundwater in the coal seams is highly mineralized and hard with slightly acidic pH (range 6.2 to 7.0) which is unsuitable for domestic consumption and in some cases unsuitable for stock / irrigation. The total hardness of the coal seam groundwater increases from 300 mg/L to 730 mg/L at depth.

Water quality attributes for all sample groundwaters are summarised in **Table A-8**. Mean salinity (as TDS) is about 3,000 mg/L, while pH averages 6.4.

Table A-8. Water Quality Data at SCM Groundwater Monitoring Sites (July 1981 to December 2010)

Analyte	Unit	Median	Minimum	Maximum	Mean
pH	-	6.7	3.4	8.4	6.4
EC	µS/cm	3,700	425	11,350	4,060
SO_4	mg/L	70	1.7	1,380	158
Ca	mg/L	139	10	1,870	244
Mg	mg/L	50	0.2	238	75.5
Na	mg/L	600	58	2,360	689
K	mg/L	6.5	1.0	22.7	8.1
Cl	mg/L	1,035	73	4,860	1,370
Fe	mg/L	2.2	0.0	110	12.4
Mn	mg/L	0.6	0.0	409	17.1
Zn	mg/L	20	15	550	195
Alkalinity as $CaCO_3$	mg/L	1.0	0.0	350	40.8
TSS	mg/L	14	1.0	3920	377
TDS	mg/L	2,210	200	19,700	3,100
ORP	mV	46.5	6.2	212	60.7
Bicarbonate	mg/L	209	0.0	743	268
Copper (Cu)	mg/L	26	3.0	200	61
Pb	mg/L	0.1	0.0	378	21
P (total)	mg/L	0.3	0.1	312	20

$CaCO_3$ = calcium carbonate.
mV = millivolt.

The median values from commencement of sampling to the present day of the major ions analysed at bores that are monitored routinely are displayed as Schoeller diagrams in **Figure AE-1** for alluvium, **Figure AE-2** for coal seams and in **Figures AE-3** and **AE-4** for interburden (**Attachment AE**). A Schoeller Diagram is a semi-logarithmic plot of the concentrations of the major ionic constituents in groundwater, expressed in milliequivalents per litre. These diagrams have the advantage of showing absolute concentrations at the same time as comparing ionic ratios. If the lines joining adjacent points are parallel from one bore to another, their ionic ratios are the same.

Figure AE-1 shows a similar signature for the two alluvial/regolith bores, with Na+K and Cl as the dominant type. The ionic ratios are almost identical.

Figure AE-2 suggests similar but slightly higher concentrations in coal seam bores as observed in alluvial/regolith bores, with the same Na+K and Cl dominance, but with atypically lower concentrations at site MW6 (at the northern end of Bowens Road North Pit). Ionic ratios are fairly uniform across the sites except for disproportionate lowering in SO_4.

Figure AE-3 shows that the concentrations in interburden bores in the SCPL monitoring network bracket the same range as the alluvium/regolith and coal seam bores. The ionic ratios are uniform at most bores, but sulphate is low in nearly all cases. **Figure AE-4** has a similar pattern for interburden water samples at Stratford but a few bores have anomalous ionic ratios. The same Na+K and Cl dominance is clear.

Parsons Brinckerhoff (2012) has undertaken a substantial water quality assessment for the AGL Gloucester Gas Project based on major ion chemistry, radioactive isotopes and stable isotopes. They found that alluvial groundwater is fresh to brackish, shallow rock groundwater is brackish, and both interburden materials and coal seams contain brackish to slightly saline groundwater. The brackish nature of most samples indicates minimal aquifer recharge from rainfall. The relatively high salinities in alluvium are attributed to high clay content which counters rainfall recharge.

Isotopic dating has revealed that alluvial groundwater is young (less than a few hundred years) while shallow rocks contain water that is several thousand years old (Parsons Brinckerhoff, 2012). They conclude that there can be no more than limited connectivity between the alluvial aquifer and the shallow rock aquifer. Interburden units and coal seams contain groundwater that is much older, in the order of thousands to tens of thousands of years old.

Surface water salinity has been observed to increase as stream flow reduces and groundwater discharge contributions become more prevalent. However, the near-neutral acidity of surface water indicates that baseflow contributions remain small in magnitude (Parsons Brinckerhoff, 2012).

A3 CONCEPTUAL MODEL

A conceptual model of the groundwater regime has been developed based on the review of existing hydrogeological data as described in Section A2, including:

- Gloucester Basin geology mapping (Dungog NSW, 1:100,000 Geological Sheet 9233 [Roberts *et al*., 1991]);
- GCL exploration (geological) data and logs[1];
- NOW Pinneena Groundwater Works Database records;
- Previous hydrogeological assessments/reviews undertaken for the Stratford Mining Complex;
- Water level data from groundwater monitoring programs undertaken at the Stratford Mining Complex and other projects; (e.g. SCPL, 2007; 2008; 2009; 2010; 2011; SRK Consulting, 2010; Parsons Brinckerhoff, 2012; R.W. Corkery & Co. Pty Limited, 2012); and
- Other groundwater investigation testwork (e.g. piezometer installations, pumping and slug/aquifer tests, alluvial boreholes and TEM survey) commissioned by SCPL in 2011.

This assessment has also considered the requirements of the WSP under the *Water Management Act, 2000*.

In addition, this assessment has considered the mapped biophysical strategic agricultural lands defined in the *Draft Upper Hunter Strategic Regional Land Use Plan* (DP&I, 2012).

Based on the above, and consistent with the relevant WSP and conceptual hydrogeological model (and its update) for the AGL Gloucester Gas Project (SRK Consulting, 2010 and Parsons Brinckerhoff, 2012), the data supports two groundwater systems:

- **Fractured Rock groundwater system** - including shallow rock groundwater bearing structures and the Gloucester Coal Measures and underlying Dewrang Group; and
- **Alluvial groundwater system –** including alluvial (narrow channel) sediments of Dog Trap Creek, Avondale Creek and the Avon River.

The conceptual groundwater models for the Project prior to mining and during mining are displayed schematically in **Figure A-25**. The diagrams indicate the dominant recharge and discharge processes acting on the groundwater system under natural conditions, and the effect on the watertable when mining and waste emplacement occur.

1 Refer Enclosure 1.

Recharge to the groundwater systems occurs from rainfall and runoff infiltration, lateral groundwater flow and some leakage from surface water storages and occasionally from streams (e.g. Dog Trap Creek).

Although groundwater levels are sustained by rainfall infiltration, they are controlled by topography, geology and surface water levels in local drainages. Local groundwater tends to mound beneath hills, with ultimate discharge to local drainages and loss by evapotranspiration (ET) through geological outcrops and vegetation where the watertable is near the ground surface (generally less than 2 m to 3 m bgl). The typical depth to water is generally 1-10 m in the vicinity of the Stratford Mining Complex tenements. Greater depths are expected on elevated slopes. Where groundwater levels occur close to surface elevations (e.g. alluvial sediments associated with Avondale Creek), evapotranspiration is a likely occurrence.

During mining, the potentiometric heads in the fractured rock groundwater system will be reduced in the vicinity of the mine, but the watertable will tend to rise beneath emplacement mounds.

The steeply dipping eastern limb of the syncline is made up of complex mixed lithologies and compressed strata with alluvial cover in places. Further to the west, strata become more horizontal and are noticeably coarser. The western limb is not encountered in the mining area.

The dipping coal seams are expected to receive enhanced rainfall recharge where they subcrop or outcrop.

A3.1 HYDRAULIC PROPERTIES

Indicative permeabilities for the various stratigraphic units, summarised in **Table A-9**, have been determined from slug/pumping tests and core measurements conducted by previous studies including Golder Associates (1981, 1982a); Australasian Groundwater and Environmental Consultants Pty Ltd (AGE) (2001); RPS Aquaterra (2011); and Parsons Brinckerhoff (2012). The hydraulic property data collected and reviewed as part of this assessment provide a firm basis for the development of the numerical groundwater model.

Golder Associates undertook a comprehensive groundwater investigation in the area in 1981 and 1982. Although the investigation was centred on the Stratford Main Pit area, it also encompassed the Bowens Road North pit area. A total of 34 rising/falling hydraulic tests and nine pumping tests were undertaken during the 1981 study to determine hydraulic conductivities of the rocks.

Table A-9. Indicative Hydraulic Conductivities of Stratigraphic Units

Unit	Field Horizontal Hydraulic Conductivity Kx (m/day)	Core Horizontal Hydraulic Conductivity Kx (m/day)	Core Vertical Hydraulic Conductivity Kz (m/day)
Alluvium	0.1 - 10		
Leloma Formation	0.05 @40m		
Bindaboo/Cloverdale Seam	0.04 @42m 0.01 @ 270m^	0.07 @ 333m^	
Bowens Road Seam	0.2 - 0.5		
Dog Trap Creek Formation	0.003 - 0.05 @23-50m	8E-5 @20-78m	4E-6 @20-78m
Avon / Triple Seams	0.004 - 0.2 @12-48m		
Waukivory Creek Formation	0.06 @37m	6E-4 @32-53m	2E-4 @32-53m
Mammy Johnsons Formation	0.06 - 0.1	2E-6 @75-131m	2E-7 @75-131m
Weismantel Seam	0.08 - 1.6		
Durallie Road Formation	0.02 @48m 0.04 - 3	2E-6 @144-157m	8E-7 @144-157m
Clareval Seam	0.04 - 0.3		
Deep Coal Seams^	0.09 @ 100m 0.006 to 0.02 @ 300m 0.0005 @ 500m		
Deep Interburden^	4E-5 to 6E-3		

Sources: RPS Aquaterra (2011); Heritage Computing (2009); Golder Associates (1982a);

^ Parsons Brinckerhoff (2012)

m/day = metres per day.

The overburden showed extremely variable hydraulic conductivity, ranging from effectively zero to moderately high. In several boreholes, sharp increases in flow (with depth) were observed. These were interpreted as probably reflecting faulting or closely spaced jointing encountered during drilling. Very little increase in water flow was observed in the floor of the main coal seams. Hydraulic conductivities varied between 0.01 m/day to 2.9 m/day in alluvium. Moderate hydraulic conductivities were observed for some sandstone units.

The pumping tests, each of 72 hours duration, confirmed that the coal seams are the main aquifers. Transmissivities varied between 3.3 square metres per day (m^2/day) and 29 m^2/day and storativities varied between 7.5 x 10^{-5} and 1.1 x 10^{-3}.

AGE (2001) conducted airlift flow testing on seven resource holes in the Bowens Road North pit area. The results indicated that the groundwater inflows from the Bowens Road seam vary from no inflow up to 3 litres per second (L/s). Inflow from overburden typically varied between virtually no flow and 0.01 L/s. Exceptional high inflows (4 L/s) were found occasionally in weathered overburden and coarse grained conglomerate, probably due to localised fracturing of the rocks in vicinity of the tested holes.

The hydraulic conductivity values in **Table A-9** are based mainly on results of the groundwater investigation program undertaken by RPS Aquaterra in 2011 at the Stratford Mining Complex, at locations shown in **Figure A-13**:

- Core testwork - 31 samples from five drill holes [NS497, SS172C, SS181C, SS185C, SS221C];
- Pumping test in the vicinity of Dog Trap Creek [PB1]; and
- Slug tests at five locations.

Recent data has become available from the field groundwater investigation for the AGL Gloucester Gas Project for the Stage 1 Gas Field Development Area, undertaken by Parsons Brinckerhoff (2012).

Overall, field tests have found an hydraulic conductivity for shallow coal generally in the range 0.04 m/day to 0.5 m/day. Deeper coal seams can reduce in hydraulic conductivity down to 10^{-4} m/day. Shallow interburden formations have horizontal hydraulic conductivity values generally in the range 0.003 m/day to 0.1 m/day. Deeper interburden, based on core measurements, has horizontal hydraulic conductivity in the order of 10^{-6} to 10^{-3} m/day and vertical hydraulic conductivity in the order of 10^{-7} to 10^{-4} m/day.

A3.1.1 Core Testwork

The core samples were tested to determine vertical and horizontal hydraulic conductivity. The vertical hydraulic conductivity tests were taken perpendicular to the bedding planes and horizontal hydraulic conductivity was taken parallel to the bedding planes. Care was taken to orient the samples due to the steep dip of bedding planes within the vertical drill holes. Of these, one horizontal and four vertical samples failed under the testing regime. Additional samples were also taken for total porosity.

A summary of the core testwork results is provided in **Table A-10**. These results can be regarded as lower limits for use in model calibration, as cores will not capture the bulk fractured characteristics of a formation. The anisotropy ratio between horizontal hydraulic conductivity (arithmetic mean) and vertical hydraulic conductivity (harmonic mean) varies from 2 to 30.

Table A-10. Summary of Groundwater Investigation Program Core Testwork Results

Unit		Clareval Interburden	Dog Trap Creek Formation	Duralie Road Formation	Mammy Johnsons Formation	Waukivory Creek Formation
Model Layer						
Horizontal	Arithmetic Mean	1.5×10^{-6}	7.5×10^{-5}	3.16×10^{-5}	2.0×10^{-6}	6.3×10^{-4}
	Max	2.48×10^{-6}	5.84×10^{-4}	1.968×10^{-6}	7.37×10^{-6}	2.15×10^{-3}
	Min	6.04×10^{-7}	1.23×10^{-6}	8.42×10^{-7}	1.45×10^{-7}	6.23×10^{-6}
	Sample Count	2	10	8	4	4
Vertical	Harmonic Mean	8.1×10^{-7}	4.1×10^{-6}	1.1×10^{-6}	1.6×10^{-7}	2.2×10^{-4}
	Max	2.00×10^{-5}	1.18×10^{-4}	2.47×10^{-5}	1.59×10^{-7}	2.57×10^{-4}
	Min	4.15×10^{-7}	7.65×10^{-7}	3.18×10^{-7}	1.55×10^{-7}	1.69×10^{-4}
	Count	2	9	7	2	3

Source: RPS Aquaterra (2011)

A3.1.2 Dog Trap Creek Pumping Test

To the north-east of the Project area, on alluvial terraces associated with Dog Trap Creek, three bores (PB1, PBM1, PBM2) were installed 50 m from the creek for a pumping test (**Figure A-9**). PB1 was drilled to 48 m and screened across the Avon Seam from 42 m to 48m. The coal seam was screened and sealed above with a bentonite/cement seal. Two 50 mm PVC monitoring bores were also installed 5 m away from PB1, with PBM1 screened in overburden from 18.5 m to 23 m and PBM2 screened within alluvium associated with Dog Trap Creek from 2.5 m to 4 m depth (**Figure A-9**). A six-day constant rate test at 22 cubic metres per day, and recovery test, was undertaken to establish hydraulic conductivity of the coal seam aquifer and to assess vertical connectivity with the overlying alluvium by monitoring coincident changes in alluvial water levels.

The test was undertaken following heavy rainfall in the preceding week which had resulted in excess surface runoff and a higher than average water level in the nearby Dog Trap Creek. During the pumping test, a recession in stream levels was observed and no rainfall was recorded during the test period. A recession in groundwater levels was also observed within the PBM2 screen within the alluvium and this coincided with the fall in water levels within Dog Trap Creek (**Figure A-26**).

To confirm that the observed recession in PBM2 was not the result of pumping from the deeper coal seam, the test was restarted for a 24 hour period to further test the effect on alluvial water levels due to pumping from the Avon Seam while stream levels in Dog Trap Creek were at normal low levels. No response was seen within this test in PMB2 (**Figure A-27**).

Additional monitoring was undertaken for a three-week period following the coal seam pumping tests to further monitor any potential connection (i.e. recharge) between alluvium and the underlying Avon Seam. Groundwater level loggers were installed within PB1 (Avon Seam) and PBM2 (alluvium). The results are shown in **Figure A-28**, together with rainfall data collected at the SCM meteorological station. The response to a rainfall event was relatively rapid within both the alluvium and Avon Seam. As expected, there is some connection between alluvium and the coal seam which is likely to occur where the Avon Seam subcrops within the extent of Dog Trap Creek or its associated alluvium; however, there is very limited direct vertical hydraulic connection between the coal seam and the alluvium through the overburden.

The pumping test interpretation record is presented in **Figure A-29**.

A3.1.3 Slug Tests

Slug tests (including low-yield short-term pumping) were conducted at five locations as shown in **Figure A-13**. Tests were undertaken to assess the hydraulic conductivity of the selected interburden strata and coal seams. A summary of the results is provided in **Table A-11**.

Table A-11. Summary of Pumping and Slug Test Results

Bore	Depth (m)	Screened Interval (m)	Formation Screened	Calculated Hydraulic Conductivity (m/day)
NS581A	12	6 - 12m	Avon Seam	0.004
NS581B	37.5	31.5 - 37.5	Waukivory Creek Formation	0.06
NS581RB	37.5	31.5 - 37.5	Waukivory Creek Formation	0.06
PBM2	4	2.5 - 4	Dog Trap Creek Alluvium	10
PBM1	24	18.5 - 23	Dog Trap Creek Formation	0.04
PB1	48	42 - 48	Avon Seam	0.22
NS584	37.5	31.5 - 37.5	Dog Trap Creek Formation	0.003
NS596R	42	39 - 42	Bindaboo Seam	0.04
NS593R	40	37 - 40	Leloma Formation	0.05
NS592R	48	38 - 48	Durallie Road Formation	0.02
GC207R	50	44 -50	Dog Trap Creek Formation	0.05

Source: RPS Aquaterra (2011)

Samples of slug test interpretation records are presented in **Figure A-30** to **A-32**. A suite of published analytical methods (Kruseman and de Ridder, 1991) was used by RPS Aquaterra (2011) to analyse the test data from the piezometers. The following methods were used in the analysis:

- Jacob's straight-line method for unsteady flow in a confined aquifer.
- Theis's Recovery method, which is derived for confined aquifers.
- Theis's Distance Drawdown method, which is derived for confined aquifers.
- Bouwer-Rice and Hvorslev solutions, for analysis of falling head slug test data.

Roseville West Pit Extension

Testing localities within the Roseville West Pit Extension area included NS593R and NS596R (**Figure A-13**). Test targets included the Leloma (Woods Road) Formation and the Bindaboo Coal Seam.

Avon North Open Cut

Testing localities within the Avon North Open Cut area included NS584 located just to the northeast of Stratford Main Pit and NS581 to the north of Wenham Cox Road (**Figure A-13**). Slug tests were also conducted on the monitoring bores at the pumping test location on the alluvial floodplain associated with Dog Trap Creek north of Wenham Cox Road (**Figure A-13**).

At NS584, the test target was the Dog Trap Creek Formation. Two holes were drilled with 50 mm PVC installations screened in the Dog Trap Creek sandstone. At NS581, test targets included the Waukivory Creek Formation and the Avon Seam. Two 125 mm holes were drilled with paired 50 mm PVC installations screened in the Waukivory Creek sandstone and overlying Avon Seam. A low yielding short-term (1 hour) constant rate pumping test within the Waukivory Creek Formation and a distance drawdown analysis were undertaken.

Stratford East Open Cut

A single standpipe was installed adjacent to GC207 in the vicinity of Craven (**Figure A-13**) and was screened in the interburden complex within the Dog Trap Creek Formation. Similarly, a single standpipe installation was installed adjacent to the existing SS256R and was screened in the interburden of the Duralie Road Formation.

A3.1.4 Depth Dependence

All field investigations to date have provided estimates of horizontal hydraulic conductivity (K_x) at depths less than 50 m and, apart from core measurements there are no known estimates for vertical hydraulic conductivity (K_z). The field hydraulic conductivities in **Table A-9** are relatively high due to fractured/weathered materials at shallow depth. In general, hydraulic conductivities of the rock strata decrease with depth.

Figure A-33 displays a published depth dependence for Stratford coal seams in the Gloucester Basin to a maximum depth of 900 m (Smith, 2001). There is a linear logarithmic decrease in permeability from a maximum value near surface of about 500 millidarcies (mD) (<0.5 m/day) to a minimum value of 0.01 mD (~10^{-5} m/day) at 900 m depth.

Figure A-34 places the Gloucester Basin coal seam permeability decrease into a broader context by comparing it with Hunter Valley and Sydney Basin lithologies (coal seams, sandstones, sills, interburden) (Tammetta, pers. comm., 2009). There is a distinct decay with depth to 800 m but scatter is substantial at all depths, particularly near ground surface where coal seam hydraulic conductivity can range from 0.001 to 10 m/day.

As the Project open pits would extend to a maximum depth a little less than 200 m below surface, some variation of hydraulic conductivity with depth can be expected in each formation. However, the near-surface hydraulic properties are of most relevance to this investigation.

The hydraulic property measurements and expected variations with depth have been used in the development of the numerical groundwater model as an initial set of hydraulic conductivity values.

A4 GROUNDWATER SIMULATION MODEL

A4.1 MODEL SOFTWARE AND COMPLEXITY

Groundwater modelling has been conducted in accordance with the MDBC Groundwater Flow Modelling Guideline (MDBC, 2001). As this is mostly a generic guide, there are no specific guidelines on special applications such as coal mine modelling.

Under the modelling guideline, the model is best categorised as an Impact Assessment Model of medium complexity. The guide (MDBC, 2001) describes this model type as follows:

> *Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.*

Numerical modelling has been undertaken using the Groundwater Vistas (Version 6.11) software interface (Environmental Simulations Inc, 2011) in conjunction with MODFLOW-SURFACT (Version 4) distributed commercially by Hydrogeologic, Inc. (Virginia, USA). MODFLOW-SURFACT is an advanced version of the popular MODFLOW code developed by the United States Geological Survey (McDonald and Harbaugh, 1988). MODFLOW is the most widely used code for groundwater modelling and is considered an industry standard.

MODFLOW-SURFACT is a three-dimensional modelling code that is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers without the “dry cell” problems of Standard-MODFLOW. This is pertinent to the dewatering of layers adjacent to open pit coal mines. Standard-MODFLOW can handle this to some extent, but model cells that are dewatered (reduced below atmospheric pressure) are replaced by “dry cells”.

The model complexity is considered adequate to simulate contrasts in hydraulic properties and hydraulic gradients that may be associated with changes to the groundwater system as a result of the Project.

A4.2 PRIOR MODELLING

A numerical model of the Stratford Main Pit was developed by Golder Associates in 1982, using proprietary finite element software called AFPM that was developed in-house by Golder Associates (1982a, 1982b). A conference paper (Marlon-Lambert, Manoel & Friday, 1979) which describes the development of the software is included in Golder Associates (1982a). The software pre-dates the introduction of the IBM personal computer (circa 1982) and standard MODFLOW groundwater modelling software (circa 1985). The objective of the modelling study was to assess mine water inflows. Anticipated pit inflows were in the range 0.7 to 1.0 ML/day.

An uncalibrated numerical model of the Bowens Road North Project was developed by AGE in 2000, and was reported in January 2001 as Appendix C to the EIS report. The model was developed in Standard-MODFLOW within the PMWIN (version 3) graphic user interface. A full audit of this model was undertaken by Merrick and Dent (2008). The objectives of the modelling study included assessment of potential groundwater inflow rates to the pit, quantification of dewatering requirements, and assessment of impacts on the groundwater resource and users. The stratigraphy was represented by two layers only (overburden and the Bowens Road North coal seam), with no consideration of alluvium. The layers were uniform across the model extent except for increasing elevations at the eastern edge of the pit. The model extent did not include the neighbouring Main Pit or the Roseville Pit, on the basis of expected compartmentalisation by faulting. At the time of modelling, there was limited groundwater level data available. Despite that, a plausible regional groundwater elevation contour map was prepared from seven monitoring bores and six open exploration holes.

Based on coal hydraulic conductivity of 2.4 m/day, the AGE (2001) model predicted pit inflows of about 3 L/s [0.26 ML/day] initially, rising to 13 L/s [1.1 ML/day] and finishing at 11 L/s [0.95 ML/day] at the end of year 7. The only guidance on the plausibility of pit inflow magnitudes at the time was the experience at the Roseville Pit of 10-15 L/s [0.9-1.3 ML/day], and Stratford Main Pit inflows dropping from 25-30 L/s [2.2-2.6 ML/day] initially to a fairly steady 4 L/s [0.35 ML/day].

A model of the DCM 20 km to the south was developed by Heritage Computing (2009) using MODFLOW-SURFACT software. The target coal seams were the Weismantel Seam and the Clareval Seam which occur at the bottom of the stratigraphic sequence at Stratford. The model predicted pit inflows in the order of 0.3 ML/day at the completion of mining, ranging between 0.2 and 1.0 ML/day over the nine years of mining.

A4.3 MODEL EXTENT

The regional model extent was selected for this Project to take into account distributed mining at four open cut pits and, originally, to include the cumulative impacts of CSG production. When the details of the proposed Rocky Hill Coal Project were made available in February 2012 (R.W. Corkery, 2012), the proposed open cut mining operations were shown to be coincident with the northern extent of the model, and therefore have also been included in the cumulative impact assessment.

The model extent, indicated in **Figure A-6** and **Figure A-16**, extends between MGA Eastings 392325 and 407500 and MGA Northings 6435000 and 6452000. The area of coverage is 15.2 km east-west by 17 km north-south, of which 179 square kilometres is active.

A4.4 MODEL LAYERS

Thirteen layers are conceptualised in **Table A-12** for the purpose of numerical modelling. Layers 8-13 are equivalent to layers 2-7 in the Duralie model (Heritage Computing, 2009).

Table A-12. Numerical Model Layers

Layer		Lithology	Geology Key	Lumped Formations
1		**Alluvium**	Qa	
1		**Regolith/Weathered Permian**		
2		**Leloma Formation**	Plc/Pll/Pllj	Crowthers Road Conglomerate / Woods Road Formation
3		**Bindaboo/Cloverdale/Roseville Seams**	Plj	Jilleon Formation
4		**Wards River Conglomerate**	Plw	
5		**Bowens Road Seam**	Plh	Wenhams Formation
6		**Dog Trap Creek Formation**	Plp/Plt	Speldon Formation
7		**Avon / Triple Seams**	Pli	Waukivory Creek Formation
8		**Waukivory Creek Formation**	Ply/Ple	Mammy Johnsons Formation Weismantel Formation
9		**Weismantel Seam**	Ple	Weismantel Formation
10		**Upper Durallie Road Formation**	Pld	
11		**Clareval Seam**	Pld	Durallie Road Formation
12		**Lower Durallie Road Formation**	Pld	
13		**Alum Mountain Volcanics**	Pea	

The top layer comprises alluvium, regolith or weathered overburden in different parts of the model area. The odd-numbered layers represent coal seams targeted by different open cut pits, with interburden lithologies forming the even-numbered layers. The eastern and western limits of the active model area were chosen to coincide with topographic ridgelines and outcropping Alum Mountain Volcanics.

Where multiple seams occur in the one model layer, the layer is given the aggregate thickness of the coal seams/plies. Interburden between the plies is allocated to the overlying sandstone/siltstone aquitard layer.

A4.5 MODEL GEOMETRY

The model domain is discretised into 1.35 million cells (of which 930 thousand are active) comprising 340 rows and 306 columns (**Figure A-35)**. The dimensions of the model cells are uniform at 50 m.

The geometry of the coal seams is defined by the floor elevations of named seams (Bindaboo/ Cloverdale/Roseville, Bowens Road, Avon/Triple, Weismantel and Clareval). The layer thickness is the aggregate of recorded coal thicknesses within the designated groupings.

A comprehensive geological model for the entire groundwater model area was available. Coal ply thicknesses and structure contours for the floor of each model layer were provided by SCPL.

Where layers pinch out or are eroded, the layers must continue laterally in a MODFLOW model and therefore have a notional thickness but are given properties associated with the underlying lithology.

Figure A-35 shows that the sedimentary column has a basal elevation of about -1800 m AHD in the vicinity of Stratford.

Representative model cross-sections through each of the four pits are displayed in **Figure A-36** for west-east profiles and in **Figure A-37** in the south-north direction. The coal layers (black and green) have sudden changes in elevation due to severe dips and faulting, and are clearly synclinal in form.

A4.6 MODEL STRESSES AND BOUNDARY CONDITIONS

The elevated basement forms natural boundaries along the eastern and western edges of the model, approximated as no-flow boundaries due to the exposure of low-permeability rocks of Carboniferous Age.

The northern and southern model edges are arbitrary transects across the valley at distances of 5-6 km from the nearest future mining. No specified boundary conditions are applied here, as the watertable contour map (**Figure A-16**) suggests that lateral flow is primarily parallel to the boundaries. As there will be lateral throughflow in the alluvial sediments, the model relies on "river" cells in layers 1 and 2 to receive groundwater discharge at both northern and southern edges.

As there is a natural groundwater divide near Northing 6441000, the southern model boundary could have been moved farther northward. However, as future Stratford East mining is planned to approach this divide, it was considered prudent to extend the model in order to check if mining effects might cross the divide.

Major and minor streams are established as “river” cells in model Layer 1 (and occasionally Layer 2, depending on local ground elevations) using the MODFLOW RIV package (**Figure A-35a**). The RIV package allows water exchange in either direction between the stream and the groundwater system, unless the river stage is set equal to the bottom elevation of the streambed layer in the model river. This has been done for minor streams so that these cells will accept baseflow when the watertable breaches the bed elevation of the stream, but they will never provide a source of water for the groundwater system. The river conductances vary from 25 to 100 m^2/day[2].

River cells along the Avon River are assigned water levels that are 0.5 m below topographic surface. The bottom of the river cells is varied linearly from a depth of 0.5 m in the upper reaches to 2.0 m in the lower reaches.

Drain cells (i.e. river cells with stage equal to the bottom elevation of the streambed layer) are assigned head values 0.1 m below topographic surface. Based on observations made in the field, the river stages for Dog Trap Creek and Avondale Creek are defined as 2 m below topographic surface, and the streambed elevation is set at 0.5 m below the stage.

The Stratford East Dam and the Return Water Dam also are represented as "river" cells.

“Drain” cells using the MODFLOW DRN package are used to represent mining in Layers 3, 5, 7, 9 and 11. Invert levels are generally 0.1 m above the floor of the lowest mined coal seam, and 0.1 m below base levels for layers overlying the mined seam (to avoid artificial perched conditions with SURFACT software). The drain conductance value was set at 1,000 m^2/day to virtually eliminate any resistance to flow.

Rainfall infiltration has been imposed as a percentage of actual rainfall (for transient calibration) or long-term average rainfall (for prediction simulations) across four zones (**Figure A-34**):

1. Alluvium associated with drainage channels;
2. Alluvium associated with broader floodplains;
3. Regolith; and
4. Elevated Volcanics.

The recharge rates were determined during model calibration.

[2] Leakage coefficient approximately 0.05 to 0.2 d^{-1}.

In the vicinity of the Stratford Mining Complex, there is no historical groundwater production other than stock and domestic use. While this occurs at the Stratford bores, and will affect the character of the monitored groundwater hydrographs, the usage is too small and too irregular for inclusion in the model. Large-scale groundwater pumping associated with CSG production in the Gloucester Valley is included in one of the prediction simulations to assess cumulative impacts. Rather than impose specified pumping rates, the model has applied conventional drain cells with inverts set at one of two target water depressurisation levels that are required to allow gas to flow.

Evapotranspiration is applied uniformly using MODFLOW's linear function, with a maximum rate of 4 x 10-4 m/day (about 146 millimetres per annum [mm/annum]) and an extinction depth of 2 m.

A4.7 HYDRAULIC CONDUCTIVITY ZONE CONFIGURATION

Hydraulic conductivity in the vicinity of the Stratford Mining Complex was initially discretised into 17 unique zones to allow for reducing hydraulic conductivity with depth, as illustrated by field and laboratory measurements in **Figure A-33** and **Figure A-34**. Hydraulic conductivity zone 1 represents alluvial deposits in the vicinity of surface water features. Hydraulic conductivity zones 2 to 7 represent the interburden rock material surrounding the coal seams. The remaining hydraulic conductivity zones, 8 to 17, represent the coal seams.

Within the rock and coal model layers, hydraulic conductivities were assumed to decrease with depth in 100 m increments (**Table A-13**). The entries in this table are based on the following formulas for K in m/day units and depth in metres below ground surface:

- Rock $K = 0.0057 \exp(-0.025 \times \text{depth})$.
- Coal $K = 0.4211 \exp(-0.014 \times \text{depth})$.

The shallower rock and coal hydraulic conductivities are based on site-specific hydraulic conductivity measurements. In the absence of hydraulic conductivity measurements with depth, minimum rock and coal hydraulic conductivities were assumed to be 1×10^{-7} m/day and 1×10^{-6} m/day, respectively. For configuration purposes, initial vertical hydraulic conductivity was assumed to be one-tenth of horizontal hydraulic conductivity.

The individual horizontal and vertical hydraulic conductivity zone values were adjusted during model calibration, at which time additional zones were introduced for finer resolution spatially.

Table A-13. Hydraulic Conductivity Zone Descriptions and Initial Values

Zone	Description	Kx [m/day]	Kz [m/day]
1	Alluvium	1.00e+000	1.00e-001
2	Rock: 0 to 100 m depth	5.00e-003	5.00e-004
3	Rock: 100 to 200 m depth	4.07e-005	4.07e-006
4	Rock: 200 to 300 m depth	6.72e-006	6.72e-007
5	Rock: 300 to 400 m depth	1.11e-006	1.11e-007
6	Rock: 400 to 500 m depth	3.04e-007	3.04e-008
7	Rock: 500 m plus depth	1.00e-007	1.00e-008
8	Coal: 0 to 100 m depth	2.20e-001	2.20e-002
9	Coal: 100 to 200 m depth	5.43e-002	5.43e-002
10	Coal: 200 to 300 m depth	1.34e-002	1.34e-003
11	Coal: 300 to 400 m depth	3.30e-003	3.30e-004
12	Coal: 400 to 500 m depth	8.14e-004	8.14e-005
13	Coal: 500 to 600 m depth	2.01e-004	2.01e-005
14	Coal: 600 to 700 m depth	4.95e-005	4.95e-006
15	Coal: 700 to 800 m depth	1.22e-005	1.22e-006
16	Coal: 800 to 900 m depth	3.01e-006	3.01e-007
17	Coal: 900 m plus depth	1.00e-006	1.00e-007

A4.8 MODEL VARIANTS

The modelling approach has necessitated the development of five model variants:

A. *Steady-State calibration model*.
Calibration of shallow aquifer permeabilities against the inferred recent groundwater levels in **Figure A-16**.

B. *Transient calibration model*.
Thorough calibration of groundwater system properties against hydrographic responses at Project monitoring bores (**Figures A-17** to **A-20**) for dynamic rainfall recharge and static stream water levels.

C. *Transient prediction model*.
Simulation of the annual progression of open cut mining, with prediction of potential impacts of mine development on the groundwater regime (particularly stream-aquifer interaction, alluvium-coal interaction and groundwater dependent ecosystems) and prediction of mine inflow rates. Two versions of the model were developed:

1) Project open cut mining (excluding neighbouring operations); and
2) Project open cut mining with CSG production and the proposed Rocky Hill Coal Project open cut mining to assess the cumulative impacts of the Project in association with other major stresses.

D. *Transient recovery model*.
Simulation of dynamic groundwater levels for the final landform and evolving pit voids (Project only).

E. *Steady-State recovery model*.
Simulation of equilibrium groundwater levels for the final landform and final void water levels (Project only).

A4.9 STEADY-STATE CALIBRATION

The model was set up and initially run in steady-state mode to replicate the broad groundwater elevation and hydraulic gradient spatial patterns shown in **Figure A-16**, inferred from field measurements and drainage controls.

Calibration was performed against 39 shallow head targets averaged at each site over the monitoring record to 2010, concentrated near past and current mining and in Stratford.

Automated calibration using PEST software was done iteratively both before and after transient calibration, initially on the full model and subsequently on a sub-model that circumscribed the monitoring network. The simulated watertable contours are shown in **Figure A-38a** for comparison with the inferred actual pattern in **Figure A-16**.

This preliminary model reproduced the broad features of the groundwater system, in particular the groundwater divide and the primary groundwater flow directions.

A4.10 TRANSIENT CALIBRATION

Calibration was conducted on model variant B for the time period January 2003 to July 2010 for 90 monthly stress periods[3]. The starting date precedes the commencement of mining at the BRNOC in March 2003, and the duration of the calibration period includes commencement of the Roseville Extended Pit in June 2006 and the Roseville West Pit in June 2009.

Initial heads were provided by preliminary steady-state simulation.

In all, 1,145 target heads were established for 39 sites. Calibration was conducted manually. A separate verification process was not conducted as the full length of mine monitoring records was required for calibration of hydrographs exhibiting mining effects.

Head targets were allocated to layer 1 (12 sites; 370 data points), layer 2 (12 sites; 165 data points), layer 3 (8 sites; 415 data points), layer 4 (5 sites; 127 data points) and layer 6 (2 sites; 68 data points) - all equally weighted.

[3] A stress period is the timeframe in the model when all hydrological stresses (e.g. rain recharge, river stage, etc.) remain constant.

Pit inflow limits for BRNOC, Roseville Extended Pit and Roseville West Pit were also taken into consideration during calibration. The upper limits on pit inflows are indicated in **Figures A-21** to **A-23**.

Where aquifer properties differ from the initial values in **Table A-13**, the modified or introduced values are listed in **Table A-14**. Full distributions and databases for hydraulic and storage properties are given in **Attachment AA**. Shallow coal seams were found to have horizontal hydraulic conductivities (Kx) ranging from 0.04 to 1 m/day, in good agreement with prior field estimates. Shallow vertical hydraulic conductivities (Kz) range from 0.01 to 0.1 m/day.

Table A-14. Calibrated Aquifer Properties

Zone	Description	Kx [m/day]	Kz [m/day]	Sy [-]	S [-]
1	Colluvium/Regolith	0.2	2.0e-003	0.01	-
18	Spoil (Roseville Pit)	1	1	0.1	5.0e-003
19	Alluvium (Channels)	10	1	0.2	-
20	Alluvium (Flood Plain)	0.2	2.0e-003	0.05	-
21	Western Co-Disposal	0.01	1.0e-004	0.01	-
26	Colluvium/Regolith (Village)	2.35	0.041	Zone 1	-
2	Rock: 0 to 100 m depth	6.78e-003	7.47e-004	5.0e-003	1.0e-004
32	Leloma Formation	1.0e-005	7.15e-004	5.0e-003	1.0e-004
33	Leloma Formation (Village)	6.78e-005	1.12e-003	5.0e-003	1.0e-004
8	Coal: 0 to 100 m (AN, SE)	0.05	0.01	0.01	5.0e-004
23	Coal: 0 to 100 m (BRN)	0.4	0.05	0.01	1.0e-003
27	Coal: 0 to 100 m (BRN)	1	0.1	0.01	1.0e-003
28	Coal: 0 to 100 m (R)	0.04	0.01	0.01	1.0e-003
9	Coal: 100 to 200 m (AN, SE)	0.02	0.01	5.0e-003	1.0e-004
10	Coal: 200 to 300 m (SE)	1.28e-004	1.0e-003	5.0e-003	1.0e-004
11	Coal: 300 to 400 m (SE)	2.47e-005	2.99e-004	5.0e-003	1.0e-004

Note: AN = Avon North pit; SE = Stratford East pit; BRN = Bowens Road North pit; R = Roseville pits; Sy = specific yield; S = storage coefficient

Rainfall recharge is applied to five distinct zones, as shown in Attachment AA. The adopted values for rainfall recharge expressed as percentages (%) of rainfall recorded at Craven (Station 060042) are:

- Flood Plain Alluvium [Zone 2]: 8%
- Channel Alluvium [Zone 3]: 8%
- Colluvium / Regolith [Zone 1]: 1%
- Western Co-Disposal Area [Zone 5]: 3%
- Hills [Zone 4]: 0.25%

Open cut drain cells were activated in the model wherever pit floor contours breached the top of a coal seam layer (Layer 5 for the BRNOC; Layer 3 for the Roseville Extended Pit), and were deactivated when backfilling restored the ground level above the roof of the model seam. As the pits retained low elevations (well below natural surface) throughout the calibration period, no time-varying changes were made for spoil properties (hydraulic conductivity and recharge). The rising water level in the Stratford Main Pit was simulated by a gradually rising drain invert level up to a maximum of 75.3 m AHD at June 2010. Drain conductance was set at 1000 m^2/day for each pit.

A4.10.1 Transient Calibration Performance

The simulated pit inflows illustrated in **Figure A-39** for the BRNOC and in **Figure A-40** for the combined Roseville pits, are consistent with recorded pit pumping rates, which include sources of water other than groundwater. The recorded pumped volumes are a combination of groundwater inflow, rainfall runoff, seepage from waste emplacements and (in some cases) water transfers. The large peaks represent surface water inflow from pit runoff and direct rainfall. The lower continuous values are more representative of the groundwater inflow component. The simulated groundwater inflows are not meant to fit the "recorded trend" but should have a magnitude similar to the lowest pumping rates.

The simulated pit inflow shown in **Figure A-41** for the Stratford Main Pit is consistent with rates reported in Golder Associates (1982b) and AGE (2001). For the calibration period, the average simulated rates are 0.28 ML/day for the BRNOC, 0.26 ML/day for the combined Roseville pits and 0.37 ML/day for the Main Pit.

A scattergram of simulated versus measured heads in **Figure A-42** demonstrates good agreement across the whole range of measurements. There is no bias towards overestimation or underestimation.

The overall performance of the transient calibration is quantified by a number of statistics in **Table A-15**. The key statistic is 7.8% Scaled Root Mean Square (SRMS), which is below the target 10% SRMS suggested in the MDBC flow model guidelines (MDBC, 2001).

Sites MW1-4 and MW6 to the immediate west of the BRNOC are allocated to Layer 3 in the model, but their observed hydrographic responses are more consistent with those of Layer 4.

Table A-15. Transient Calibration Performance

Calibration Statistics	Value
Number of Data (n)	1,144
Root Mean Square (RMS) (m)	2.6
SRMS (%)	7.8
Average residual (m)	0.3
Absolute average residual (m)	2.1

As the real responses are transitional between Layer 3 and Layer 4, it is likely that the sites are responding to dewatering of coal plies whose elevation would be within Layer 3 in reality but are aggregated in Layer 4 in the model. This is an unavoidable consequence of using discrete layers in the model to represent all-interburden (Layer 3) and all-coal (Layer 4) lithologies. The best match of the mining-induced water level trends at these sites is achieved by weighting the Layer 3 (80%) and Layer 4 (20%) simulated levels. This degrades the calibration statistics a little to 8.3 % SRMS and 2.7 m RMS.

The ability of the model to replicate observed groundwater hydrographs is reported in full in **Attachment AB**. For illustration, **Figures A-43** to **A-46** show comparisons at representative sites within the Stratford Mining Complex monitoring network for bores screened in coal (**Figure A-43**), regolith (**Figure A-44**), interburden (**Figure A-45**) and for two Stratford bores (**Figure A-46**). Model water level trends and absolute elevations, in the majority of cases, are consistent with the observed water levels.

A4.10.2 Transient Water Balance

The instantaneous transient water balance across the entire model area is summarised in **Table A-16** at the end of the calibration period (June 2010). The total inflow (recharge) to the groundwater system was approximately 21 ML/day at that time, fairly evenly split between leakage from the rivers and creeks into the aquifer (55%) and rainfall recharge (45%). The leakage from all streams is simulated to be about 11 ML/day. There are no boundary inflows in the model.

Groundwater baseflow to the streams is the dominant discharge mechanism, accounting for 61.5% of the total outflow. Next in order of importance is evapotranspiration (35%). The computed inflow to all mines active at that time (0.78 ML/day) is about 3.5% of the total groundwater discharge over the model area.

At the end of the calibration period (July 2010), discharge exceeded recharge by a little less than 1 ML/day.

Table A-16. Simulated Water Balance for the Transient Calibration Model at the End of the Calibration Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	9.3	-
Evapotranspiration	-	7.6
Rivers/Creeks	11.3	13.2
Mines	-	0.78
Boundary Flow	0	0
TOTAL	**20.6**	**21.6**
Storage	**0.9 LOSS**	
Discrepancy (%)	**0.1**	

A4.10.3 Transient Sensitivity Analysis

Sensitivity analysis has been conducted on a number of attributes of the groundwater system to identify key parameters, through observing the impact they have on calibration statistics. The investigated parameters were:

- global horizontal hydraulic conductivity (Kx) of coal zones;
- global vertical hydraulic conductivity (Kz) of coal zones;
- host interburden (Zone 2 Kx) at the Stratford East pit; and
- rainfall recharge rate in the hills.

The results are summarised in **Table A-17**. Global increase in coal horizontal hydraulic conductivity by a factor of 10 causes a severe disruption to calibration; however, an increase in the vertical value gives a slight improvement. There is also a slight improvement in calibration by increasing the rainfall recharge through the hills from 0.25% to 2.5%. Increasing the connectivity between the Stratford East Dam and the Stratford East Pit through the intervening interburden causes a noticeable degradation in calibration performance, although it would still be regarded as an acceptable calibration.

Table A-17. Calibration Sensitivity Analysis

Parameter	Change	% SRMS	mRMS	Average residual (m)
BASE		7.9	2.6	0.38
Global Coal Kx	x 10	15.4	5.1	2.3
Global Coal Kz	x 10	7.6	2.5	0.28
Stratford East Interburden Kx [Base 6.8e-3]	x 10	8.9	2.9	0.25
Hills Recharge [Base 0.25%]	x 10	7.7	2.5	0.33

A5 SCENARIO ANALYSIS

Two model versions were considered for predictive scenario analysis:

A. Stratford Mining Complex (SMC) open cut mining (excluding neighbouring operations);

B. SMC open cut mining with AGL Gloucester Gas Project CSG production and the proposed Rocky Hill Coal Project open cut mining, to assess the cumulative impacts of the Project in association with other major stresses.

A5.1 MINE SCHEDULE

Using the hydraulic and storage properties found during transient calibration, the model was run in transient mode from July 2010 to June 2024 in annual steps for both Model A ("base case" model) and Model B ("CSG model"). The Model A Project is taken to commence in July 2013 (stress period 94) and finish in June 2024 (stress period 104). Given the relatively short duration of Project mining, the lag in placement of backfill, and the time required for backfill to wet up, no time-varying change was made in spoil properties or spoil recharge. As was done during the calibration period, open cut drain cells were activated according to design pit floor contours and were deactivated in line with progressive backfilling.

The progression of mining in the model was applied consistent with the general arrangement snapshots for the Project presented in Section 2 in the Main Report of the EIS. **Attachment AC** summarises the stress period setup in the model and the sequencing of open cut operations, backfilling, and use of voids as water storages.

Four open cut pits are simulated in parallel, with floors in Layer 3 (Roseville), Layer 5 (Bowens Road North), Layer 7 (Avon North) and Layer 11 (Stratford East). Both Avon North and Stratford East open cuts commence in 2013-2014 (stress period 94) in the model. The Bowens Road North pit and the Main Pit are assumed to be backfilled after mid-2019 (during stress period 100). The Roseville, Avon North and Stratford East pits have residual voids at the end of the Project.

The rising water levels in the water storages due to natural inflows, transfers and placement of rejects, were taken as the median water levels for the 123 climate realisations simulated by Gilbert & Associates (Appendix B of the EIS). The water level in the Main Pit was assumed to rise to a final elevation of 89 m AHD in mid-2019 (stress period 99). It was simulated by a drain feature during the calibration period and initially by a constant head boundary during prediction to allow for the possibility of flux reversal (i.e. at high free water levels, it was anticipated that the Main Pit could leak water back to the groundwater system). As this did not occur, drain features were reinstated during the prediction period.

The water level in the Bowens Road North Pit was assumed to rise to a maximum elevation of 39.6 m AHD in mid-2016 (stress period 96) and then settle at 31 m AHD in mid-2019 (close to model layer floor) (stress period 99). The water level in the Avon North Pit was assumed to rise to a final elevation of 78.8 m AHD at the end of the Project in 2024 (stress period 104).

For Model A, the only time-varying stress in the prediction model is mining. Rainfall recharge and stream stages were held at static levels from 2010 to 2024 to prevent confusion between weather and mining stresses when examining hydrographic responses.

A5.2 WATER BALANCE

Simulated water balances for the entire model extent have been averaged over the 11 years of proposed Project life (stress periods 94 to 104) and are examined in **Table A-18**.

Table A-18 compares the Project averages with simulated values at the commencement of the Project (end of stress period 93, June 2013), considering only SMC mining. An increase in mine inflow of about 0.3 ML/day is expected, on average. This increase in inflow coincides with a reduction in net baseflow of 0.2 ML/day and a reduction in evapotranspiration by 0.3 ML/day. On the whole, less groundwater is taken from storage.

Table A-18. Simulated Net Water Balance Changes Due to the Project

Component	Project Start (ML/day)	Project Average (ML/day)	Difference (ML/day)	Change (%)
Rainfall Recharge	8.8	8.8	0.0	0.0
Evapotranspiration	-7.3	-7.0	-0.3	-4.5
Rivers/Creeks	-1.6	-1.4	-0.2	-14
Mines	-1.0	-1.3	0.3	27
Boundary Flow	0.0	0.0	0.0	0.0
Storage	1.1 LOSS	0.9 LOSS	0.2	26

A5.3 PREDICTED PIT INFLOW

The time-varying pit inflows predicted by the model since mining commenced at the Bowens Road North pit in 2003 are illustrated in **Figure A-47** for each of the four operating pits and the Stratford Main Pit water storage. The average and maximum inflow rates are listed in **Table A-19**.

The Roseville West Pit Extension is expected to attract the highest inflow with an average of about 0.5 ML/day, while Stratford East Open Cut should receive the least (about 0.1 ML/day). The combined pit inflows (**Figure A-48**) are expected to peak around 1.3 ML/day, with a minimum of about 0.7 ML/day at the end of the Project.

Table A-19. Predicted Pit Inflows

Pit	Project Average (ML/day)	Project Maximum (ML/day)
BRNOC	0.22	0.43
Roseville West Pit Extension	0.50	0.69
Avon North Open Cut	0.25	0.32
Stratford East Open Cut	0.11	0.17
Stratford Main Pit	0.11	0.25

A5.4 PREDICTED BASEFLOW CHANGES

Stream-aquifer water exchanges with alluvium have been examined for Dog Trap Creek, Avondale Creek and THE Avon River since mining commenced at the BRNOC in 2003. The predicted fluxes are shown in **Figure A-49**. Only during the calibration period (2003-2010) was rainfall varied in the model. Stream stages were held constant at all times.

Only in the Avon River is there an occasional switch from a predominantly gaining system to a losing system. On average, the Dog Trap and Avondale Creeks have a net gaining status (i.e. with some baseflow component). The baseflows are estimated to be about 0.4 ML/day (Dog Trap Creek) and about 0.2 ML/day (Avondale Creek) on average.

Project mining is too far away from Avon River for any discernible effect on net baseflow for that stream. The changes in baseflow at the other two steams are illustrated in **Figure A-50**. Dog Trap Creek has an average baseflow reduction of 0.07 ML/day during the Project; it peaks at a little over 0.08 ML/day but becomes less when the BRNOC is backfilled in 2019. Avondale Creek has a complicated pattern. The change in baseflow varies from a peak reduction of 0.17 ML/day to a maximum gain of about 0.05 ML/day. Overall, there is an average net reduction in baseflow of about 0.02 ML/day.

The reason for the complicated Avondale Creek pattern is elucidated in **Figure A-51**, which shows the baseflows partitioned between four reaches of similar length from north to south. The northern reach initially leaks more water (negative baseflow) to the underlying aquifer when the active Roseville pit is close. As mining moves to the south, the amount of leakage reduces in the northern reach and increases in the upper middle reach. As mining moves farther south, the lower middle reach is affected gradually. The southern reach shows a slight downwards trend in baseflow as the Stratford East Open Cut approaches from north to south, with a more pronounced effect from 2022 onwards.

A5.5 CUMULATIVE IMPACTS

Model B considers the cumulative effects of SMC open cut mining, AGL Gloucester Gas Project CSG production and Rocky Hill Coal Project open cut mining. Outlines of the lease areas are shown in **Figure A-52**.

The AGL Gloucester Gas Project has current Stage 1 approval for 110 CSG wells within the outline in **Figure A-52** at depths greater than 150 m. The Rocky Hill Coal Project plans to conduct open cut mining in a number of pits: Main Pit to floor -65 m AHD; two sub-pits within the Main Pit; Bowen Road 2 Pit to floor +25 m AHD; Avon Pit to floor +25 m AHD; and Weismantel Pit to floor +50 m AHD. As the sequencing of the wells and pits is unknown, a conservative cumulative assessment has been done by assuming all stresses are active continuously for the 11 years of Project mining.

For the Rocky Hill Coal Project, the pits have been simulated as "drain" cells down to model layer 5 (Main Pit and Bowen Road 2 Pit), layer 7 (Avon Pit) and layer 9 (Weismantel Pit).

For the AGL Gloucester Gas Project, the CSG wells have been simulated as stacked blanket drains[4] from model layer 3 down to model layer 11. Coal depths less than 150 m have been excluded. The active drain cells (for the SMC Project and the AGL Gloucester Gas Project) in each layer are shown in **Figure A-53**. Due to the strong dip of the strata, the active area extends farther to the east for older target coal seams.

Initial cumulative impacts were conducted without the Rocky Hill Coal Project and with four CSG scenarios:

- either zero or 40 m pressure head above the roof of a target coal seam; and
- including or excluding the SMC MLs.

The average groundwater inflow rates to the SMC pits and the CSG produced water are summarised in **Table A-20**.

Table A-20 shows that the expected (extreme case) production of CSG water will range from 4.4 ML/day to 6.6 ML/day on average over 11 years (assuming all wells are active). The pressure head required to induce gas flow has an effect of about 15% on produced water for a 40 m range in required pressure head. If CSG wells are active over the SMC area in parallel production, the SMC pit inflows would reduce by 0.4-0.5 ML/day on average, which is almost 50% of expected inflows. If no CSG activities occur within the SMC lease areas during the 11 years of the Project, the pit inflows would reduce by a little over 0.1 ML/day (about 10-15% lower).

Cumulative drawdown impacts are addressed in Section A6.1.8.

[4] Pervasive continuous drain cells are applied in each coal seam model layer (below 150 m depth).

Table A-20. Simulated Water Make for Various CSG Scenarios

	Base Case (ML/day)	Excluding SMC, Zero Pressure Head (ML/day)	Excluding SMC, 40m Pressure Head (ML/day)	Including SMC, Zero Pressure Head (ML/day)	Including SMC, 40m Pressure Head (ML/day)
BRNOC	0.21	0.15	0.17	0.06	0.07
Roseville West Pit Extension	0.50	0.44	0.45	0.30	0.36
Avon North Open Cut	0.23	0.21	0.21	0.10	0.12
Stratford East Open Cut	0.10	0.09	0.11	0.06	0.07
Total Pit Inflow	**1.04**	**0.89**	**0.94**	**0.52**	**0.62**
CSG Northern Zone	0	3.95	3.24	3.70	3.06
CSG Central Zone	0	-	-	1.88	1.62
CSG Southern Zone	0	1.23	1.10	1.03	0.93
Total CSG Produced Water		**5.2**	**4.3**	**6.6**	**5.6**
Pit Inflow Reduction		**0.16**	**0.11**	**0.53**	**0.44**

A5.6 SENSITIVITY ANALYSIS

As the Stratford East pit was estimated to receive the least groundwater inflow (about 0.1 ML/day), a series of sensitivity runs were conducted to assess the uncertainty in pit inflow for possible variations in rainfall recharge (to the adjacent hills), coal seam hydraulic conductivity (Kx and Kz) and the overburden hydraulic conductivity separating the pit from the Stratford East Dam. The results are shown in **Figure A-54**.

The magnitude of the pit inflow is very sensitive to increases in coal seam and overburden horizontal hydraulic conductivity. However, as the calibration performance is degraded for these perturbations, they are unlikely to be realised (see Section A4.10.3 and **Table A-17)**. Pit inflow is also very sensitive to much higher rain recharge (10% of rainfall) but sensitivity to 2.5% of rainfall is slight (no more than 0.05 ML/day extra). Sensitivity to coal seam vertical hydraulic conductivity is very low.

A5.7 POST-MINING EQUILIBRIUM

A final void water balance was prepared by Gilbert & Associates (Appendix B of the EIS) using a rainfall-runoff model. Estimates of groundwater inflow over time required as inputs to the model were provided by conducting a transient groundwater recovery simulation for 200 years with the three voids (Roseville, Avon North and Stratford East) treated as highly permeable water bearing material (K = 1000 m/day; Sy = 1.0) accepting 100% rainfall with open water evaporation rates in place of evapotranspiration.

The results of the post-mining estimates of groundwater inflows are presented in **Table A-21**.

Table A-21. Post-mining Transient Simulation Results – Input to Rainfall-Runoff Model

Year	Roseville Void	Roseville Void	Avon North Void	Avon North Void	Stratford East Void	Stratford East Void
	Water Level (m AHD)	Inflow (ML/day)	Water Level (m AHD)	Inflow (ML/day)	Water Level (m AHD)	Inflow (ML/day)
5	75.0	0.75	83.3	0.29	56.7	0.45
10	80.6	0.74	86.0	0.30	62.9	0.33
15	85.5	0.67	87.9	0.31	66.9	0.31
20	91.3	0.59	90.0	0.31	70.6	0.31
25	98.9	0.40	92.5	0.30	75.3	0.27
30	103.7	0.35	94.3	0.30	79.1	0.32
40	106.1	0.27	95.5	0.30	81.8	0.35
50	107.8	0.20	96.5	0.30	84.0	0.35
75	108.9	0.15	97.2	0.30	85.7	0.35
100	109.7	0.12	97.8	0.30	87.1	0.35
125	110.5	0.09	98.5	0.29	88.7	0.34
150	111.1	0.06	99.1	0.29	90.2	0.34
200	111.6	0.04	99.6	0.29	91.4	0.34

The groundwater recovery in each model layer at four representative sites adjacent to the three voids and between the Roseville and Bowens Road North pits is illustrated in **Figure A-55**. Substantial recovery is apparent after about 40 years.

Appendix B of the EIS provides estimates of equilibrium final void water levels. A steady-state groundwater simulation that has been run with these final levels shows that each void remains a permanent and localised groundwater sink with total inflows of about 0.9 ML/day partitioned between Roseville West (0.77 ML/day), Avon North (0.03 ML/day) and Stratford East (0.11 ML/day). The relatively high final inflow rates are due mainly to enhanced recharge through waste rock emplacements at a rate of 5% of rainfall.

The predicted long-term equilibrium watertable pattern is displayed in **Figure A-56**. Comparison is made with the simulated pattern at the end of the calibration period (June 2010). The patterns are generally similar, with lower heads at the three voids and higher heads around the Stratford Main Pit.

A6 IMPACTS ON THE GROUNDWATER RESOURCE

A6.1 POTENTIAL IMPACTS ON GROUNDWATER

A6.1.1 Changes in Hydraulic Properties

There would be a change in hydraulic properties over the mine footprint where mine waste rock infills the excavations down to the floors of the mined coal seams, and in the waste rock out-of-pit emplacements. As mine waste rock would have a higher hydraulic conductivity than any natural material in this area, with the possible exception of alluvium, there would be associated reductions in hydraulic gradients in accordance with Darcy's Law. As one increases, the other must decrease to maintain the same flow.

A flattening of hydraulic gradients in the mine waste rock material is expected. Also, rainfall recharge is expected to be higher in the mine waste rock than in any natural local material. This accounts for the relatively high equilibrium groundwater inflows to the final voids noted in Section A5.7:

- Total inflow: about 0.9 ML/day;
- Roseville West Pit Extension inflow: 0.77 ML/day;
- Avon North Open Cut inflow 0.03 ML/day; and
- Stratford East Open Cut inflow: 0.11 ML/day.

A6.1.2 Changes in Groundwater Flow and Quality

As mining progresses, the active voids would act as groundwater sinks. This would cause a temporary change in groundwater flow direction, in places reversal of direction, until mining is completed and the groundwater system recovers to a new equilibrium (**Figure A-56**). The final groundwater flow pattern, as shown in **Figure A-56**, is similar regionally to the pre-Project pattern, apart from localised changes in the vicinity of Stratford Mining Complex operations. The post-mining steady-state groundwater simulation has demonstrated that each void remains a permanent groundwater sink.

The quality of the inflow water during mining will be a mixture of the qualities of the waters in source lithologies, primarily coal and coal measures. After mining is completed, the geochemistry of waste rock would become a major contributor to void water chemistry (see Section A6.1.3).

The chemical characteristics of groundwater have been assessed in Section A2.13. It was found that, apart from two Stratford bores and Bore MW12, most groundwaters are beyond the limit of potable use but on the basis of salinity are suitable for livestock, selective irrigation and other general uses (**Table A-7**). Not much difference was found between the baseline salinities of different formations. The median EC in the coal samples was found to be only 10% higher than for alluvial/regolith samples, which in turn was about 25% higher than coal measures interburden samples (3500 µS/cm).

The spatial pattern of baseline groundwater salinity (i.e. measured EC) was illustrated in **Figure A-24**. The distribution of salinity was found to be fairly uniform spatially, with the highest value in Avondale Creek alluvium to the south of the SCM, and generally lower values in Stratford. There is no clear differentiation between the salinity signatures of different lithologies. In particular, the salinity of alluvial/regolith waters was found to be no better than coal groundwaters.

Given the similarity of salinity for the various source waters, no appreciable change in groundwater salinity is expected as a consequence of mining.

Over time, the salinity in the final voids will increase through evaporative concentration. As long as the voids remain as groundwater sinks, as is predicted, there will be no deleterious effect on the beneficial uses of any groundwater sources.

Appendix B of the EIS includes predictions of salinity evolution in each of the three final voids. Final void salinity is generally predicted to increase slowly with time, reaching about 9,000 µS/cm at Avon North, about 12,000 µS/cm at Roseville West and about 6,000 µS/cm at Stratford East after 200 years (Appendix B of the EIS). Given the long time frame, and the radially focussed groundwater flow direction, the surrounding groundwater quality would therefore not be affected by the water contained within the final void after mining.

A6.1.3 Geochemistry

Geochemical investigation undertaken in Appendix L of the EIS (Environmental Geochemistry International Pty Ltd [EGI}, 2012) has concluded that the overburden and interburden materials in the proposed pit expansion areas are expected to be non-acid forming at the Bowens Road North pit, the Roseville West pit and the Avon North pit. However, waste rock materials are expected to be potentially acid forming (PAF) at the Stratford East pit.

In addition, no significant elemental enrichment is expected apart from sulphur, and negligible mobilisation of metals/metalloids is anticipated due to near-neutral pH conditions (Appendix L of the EIS).

EGI (2012) has recommended that PAF waste be segregated and selectively handled, with placement in-pit or in out-of-pit engineered PAF waste cells.

The rejects from the Project will be disposed in accordance with the approved Life of Mine Rejects Disposal Plan. The rejects during the Project are expected to have lower acid generating potential than those currently being generated (Appendix L of the EIS).

Based on these results, it is expected that use of the existing mine waste segregation and handling practices, and rejects disposal protocols, would be sufficient to maintain adequate control over acid rock drainage risk on-site.

In consideration of the above, there would be negligible impacts to groundwater quality (either directly or via final pit voids) as a result of PAF material.

A6.1.4 Pit Inflows

Up to the end of mining, there would be a continuous loss of groundwater from the fractured rock to the mining void. A minor amount of water would be drawn in from the regolith and the thin veneer of floodplain sediments.

The predicted groundwater inflows are graphed in **Figure A-47**.

The year-by-year expected pit inflows (without mitigating effects from CSG production) are listed in **Table A-22**. The analysis of cumulative effects in Section A5.5 indicates that the Project inflows could be reduced by a maximum of 0.5 ML/day if CSG activities are coincident with SMC mining.

Table A-22. Predicted Pit Inflows for Each Open Cut [ML/day]

Year	Bowens Road North	Roseville West	Avon North	Stratford East	Total
1	0.29	0.69	0.23	0.11	**1.32**
2	0.40	0.61	0.23	0.11	**1.35**
3	0.40	0.43	0.22	0.13	**1.18**
4	0.42	0.49	0.24	0.12	**1.27**
5	0.43	0.50	0.23	0.11	**1.27**
6	0.43	0.48	0.32	0.09	**1.32**
7	0.00	0.50	0.28	0.09	**0.87**
8	0.00	0.46	0.27	0.10	**0.83**
9	0.00	0.44	0.23	0.07	**0.74**
10	0.00	0.43	0.23	0.17	**0.83**
11	0.00	0.46	0.20	0.08	**0.74**

A6.1.5 Alluvium

The Project open cuts would not be located within 40 m of Avondale Creek or Dog Trap Creek. In addition, no direct pumping of water from alluvial sediments is proposed for the Project.

Approved mining and proposed mining will pass through an area classified as Quaternary Alluvium on the geological map (**Figure A-8**). However, the TEM survey results and the cross-section alluvial transect holes (**Figure A-9**) demonstrate that the alluvial sediments are primarily confined to the alignment of the drainage line (i.e. Dog Trap Creek) and are less likely to be associated with the topographic highs mapped at the regional scale (i.e. some mapped areas are more likely to be regolith). In addition, no deep alluvium with favourable subsoil properties (i.e. with the potential for use as rehabilitation material) was identified within the proposed Project open cut mining areas despite attempts in the regionally mapped alluvial/colluvial areas with the use of 3 m depth soil pits as part of the Agricultural Resource Assessment (McKenzie, 2012) (Appendix K of the EIS).

As there is only one groundwater licence with a total entitlement of 20 ML/annum for the Avon River Water Source, the mapped Quaternary Alluvium (other than the alluvium identified by the TEM survey along Dog Trap Creek and Avondale Creek, and the alluvium along the channel of the Avon River) are not significant alluvial water sources.

Water can be lost from the alluvium/regolith groundwater source by three mechanisms:

- enhanced leakage from the alluvium/regolith to the underlying fractured rock;
- interruption of rainfall recharge to excavated alluvium/regolith; and
- direct excavation of alluvium/regolith materials as part of the mine pit.

As mining progresses, an increase in natural leakage of groundwater from the alluvium/regolith to the underlying fractured rock would be expected. This has been examined in the model for the mapped Quaternary Alluvium intersections with the Roseville West pit and the Avon North pit, and is estimated to be about 33 ML/annum (0.09 ML/day). Of this amount, the TEM-identified Dog Trap Creek alluvium would account for about 6 ML/annum on average over the life of the Project. The Dog Trap Creek alluvium would lose additional water to the underburden in Project years 1 to 8, after which time the alluvium would gain more water from beneath (relative to Project commencement), due to rising water levels as mining moves to the south.

The removal of alluvium/regolith during mining will reduce rainfall recharge temporarily by about 144 ML over the life of the Project. This is equivalent to about 13 ML/annum (0.036 ML/day), assuming 8% infiltration over an area of about 2.6×10^5 square metres. After mining has finished, recharge will resume through waste rock infill.

The direct loss of water from storage due to excavation of alluvium/regolith is estimated to be about 31 ML over the life of the Project. This is equivalent to about 3 ML/annum (0.085 ML/day) assuming 2 m saturated thickness and 10% porosity.

A6.1.6 Fractured Rock

There is not yet any separate water sharing plan for the fractured rock groundwater system.

Up to the end of mining, there would be a continuous loss of water from the fractured rock groundwater system to the mining void. The combined pit inflows (Figure A-48) are expected to peak around 1.3 ML/day, with a minimum of about 0.7 ML/day at the end of the Project.

The average combined pit inflow over the life of the Project is predicted to be about 1.1 ML/day (390 ML/annum) (**Table A-22**). All but about 1.5% (6 ML/annum) of this water will be derived from the fractured rock groundwater source. The predicted flows from this source are expected to reduce during post-mining recovery to about 0.6 ML/day (**Table A-21**).

A6.1.7 Potential Impacts on Registered Production Bores

Locally, there is little reliance on groundwater bores as a source of water as agricultural enterprises make use of surface water sources. Within 5 km of any proposed pit, there are only 12 private bores other than those on SCM land. There are 11 bores in Stratford and one bore located to the south (GW079759). The private bores are licensed for stock and domestic use.

Figure A-57 shows the drawdown magnitude and pattern for the watertable being accessed by the private bores. Drawdowns are naturally limited to the east by outcropping volcanics. The 1 m drawdown threshhold does not reach the bores in Stratford or the other private bore to the south.

The impact on the water level in each privately owned bore is expected to be negligible.

Where end-of-mining drawdowns exceed 1 m, the drawdown extents are approximately:

- 0.8 km to the west of Roseville West Pit Extension;
- 1.6 km to the south of Roseville West Pit Extension;
- 0.2 km to the north of Avon North Open Cut;
- 0.7 km to the west of Avon North Open Cut;
- 1.0 km to the east of Avon North Open Cut;
- 0.3 km to the south of Avon North Open Cut;

- 0.1 km to the north of Stratford East Open Cut;
- 0.8 km to the west of Stratford East Open Cut;
- 0.8 km to the south of Stratford East Open Cut; and
- 0.1 km to the north of Stratford East Open Cut.

The predicted regional drawdowns in each of the target coal seam layers (2, 3, 5, 7 and 11) are presented in **Attachment AD**. The Layer 3 drawdowns are very similar to the predicted watertable drawdowns. For deeper layers the drawdown extents are similar, except that the effect of Roseville West mining dies off rapidly below Layer 3, and the effect of Avon North mining dies off rapidly below Layer 7.

A6.1.8 Potential Cumulative Impacts

A conservative assessment of the cumulative effects of the Project, the AGL Gloucester Gas Project CSG production and the proposed Rocky Hill Coal Project open cut mining has been undertaken.

Figure A-58 shows the cumulative drawdown magnitude and pattern for the watertable being accessed by private bores for one of the CSG scenarios (namely, zero pressure head and broad deployment of CSG wells including the SMC MLs), with coincident mining at the SMC and the proposed Rocky Hill Coal Project.

While drawdowns are naturally limited to the east by outcropping volcanics, the extents of the 1 m drawdown contours are much broader. CSG activity would cause pronounced drawdown in the watertable between the Project and Stratford. Nevertheless, the predicted drawdowns at the Stratford bores are less than 1 m for bores in the northern half and 1-2 m for the southern half. There would be no impact on the other private bore to the south, given that drawdown is generally limited to the natural groundwater divide and the southern private bore (GW079759) lies to the south of the divide.

The predicted cumulative drawdowns in each of the target coal seam layers are presented in **Attachment AD**. The Layer 3 drawdowns are very similar to the predicted watertable drawdowns. Deeper layers show a pronounced line of strong drawdown trending north-south centred approximately on the Roseville Pit. However, the western extent is tightly constrained by reducing coal seam hydraulic conductivity as the seams dip to the west.

Based on the modeling results, cumulative effects are expected to be substantially greater than would be produced by the Project acting alone.

A6.1.9 Effects on Mapped Biophysical Strategic Agricultural Land

The *Draft Stage 1 Aquifer Interference Policy* (DTIRIS, 2012) and the *Draft Upper Hunter Strategic Regional Land Use Plan* (DP&I, 2012) were released in early March 2012. As the Project open cut mining areas (nearest being the Roseville West Pit Extension) are more than 2,000 m from the nearest biophysical strategic agricultural land mapped along the Avon River (**Figure A-59**), the conditions of the *Draft Stage 1 Aquifer Interference Policy* have not been considered further.

Notwithstanding, **Figure A-57** (Project alone) and **Figure A-58** (Cumulative) demonstrates that the predicted watertable drawdown contours at the end of the Project would not extend as far as the nearest mapped biophysical strategic agricultural land.

A6.2 POTENTIAL IMPACTS ON SURFACE WATERBODIES

A6.2.1 Changes in Water Balance

The main local drainage systems associated with the Project area are Dog Trap Creek, Avondale Creek and Avon River. The stream-aquifer interaction status of these streams has been examined in Section A5.4 and in **Figures A-49** to **Figure A-51**.

Project mining is too far away from Avon River for any discernible effect on that stream.

Dog Trap Creek would continue as a gaining stream (i.e. with some baseflow component) and would have an average baseflow reduction of about 0.07 ML/day during the Project. The baseflow reduction would peak at a little over 0.08 ML/day and would become progressively less (i.e. reducing to <0.05 ML/day over time) when the BRNOC is used as a water storage and ultimately backfilled with waste rock in 2019 (i.e. when the system recovery commences).

Avondale Creek would have a complicated pattern of changes in baseflow that would vary from a peak reduction of less than 0.2 ML/day to a gain in baseflow of about 0.05 ML/day. Overall, an average net reduction in baseflow of about 0.02 ML/day is expected. The variation from reduced baseflow to gaining baseflow is illustrated in **Figure A-51**, which shows the baseflows partitioned between four reaches of similar length from north to south. The predicted behaviour is readily explained by considering the proximity of various creek reaches to active mining as the BRNOC, Roseville West Pit Extension and Stratford East Open Cut pits progress to the south.

The predicted decreases and increases in baseflow would have a negligible effect on natural stream flow.

The small predicted drawdown which extends to the south across the catchment divide would have negligible impact on the Karuah River Water Source (**Figure A-57**).

A6.2.2 Changes in Surface Water Quality

Overall, there is predicted to be a slight reduction in baseflow of about 0.1 ML/day to Dog Trap Creek and Avondale Creek over the life of the Project and no effect at Avon River.

As the reductions in baseflow would occur close to where target coal seams are subcropping, the reductions in baseflow would mean a lower contribution of coal seam waters to flow in the two creeks. The median EC in coal samples has been found to be about 10% higher than for alluvial/regolith samples. It follows that the baseflow waters can be expected to be slightly fresher. However, the change in salinity is unlikely to be measureable.

A6.2.3 Effects on Surface Ecosystems

Given the localised disturbance of open pit mining, and the demonstration of inconsequential changes in stream baseflow, no effects on surface ecosystems are anticipated in relation to mining-induced changes to the water system.

Parsons Brinckerhoff (2012), in an independent assessment for the AGL Gloucester Gas Project, noted that there are *no known wetlands, lakes or other surface features that are indicative of shallow groundwater processes and possible groundwater dependent ecosystems*. Furthermore, they note that the brackish-saline nature of groundwater baseflow is unlikely to be conducive to the sustenance of groundwater dependent ecosystems.

A6.3 PROPOSED GROUNDWATER MONITORING PROGRAM

The proposed groundwater monitoring program for the Project is summarised in **Table A-23** and described below. The groundwater monitoring program should augment the existing SCPL groundwater monitoring program and utilise the results of other mine groundwater monitoring programs in the vicinity of the Project (i.e. the AGL Gloucester Gas Project and the proposed Rocky Hill Coal Project). The groundwater monitoring program should comply with the *Murray-Darling Basin Groundwater Quality Sampling Guidelines* (MDBC, 1997).

The groundwater monitoring program should monitor groundwater conditions for changes as a result of mining, and should include consideration of aquifer definition and interactions, strata hydraulic properties, expected drawdown extent and groundwater quality.

The results of the groundwater monitoring program should be used to validate modelling predictions.

Table A-23. Proposed Groundwater Monitoring Program

Parameter	Location	Timing
Piezometers (Groundwater Levels – m AHD)	Existing monitoring network (SCPL and surrounding mines/projects).	Quarterly for Project life.
	Additional Fractured Rock groundwater system monitoring bores (west of pits).	Years 1-11 and 2 years post-mining.
	Additional bore installations in the mine waste rock emplacement behind the advancing open cut.	Progressive over the Project life.
Groundwater Quality (pH, dissolved oxygen [DO], EC, TDS, Fe, aluminium [Al], arsenic [As], molybdenum [Mg], Mo, selenium [Se], Ca, Na, Cl, SO_4)	At piezometers above (except vibrating wire installations).	Quarterly for Project Life.
Mine Water Balance	Measurement of volumes extracted from the open cut sumps, pumped water, coal moisture, etc.	Annual for Project life.

A6.3.1 Monitoring Piezometers

As mining progresses, the existing SCPL network of piezometer installations should be augmented near the locations marked on **Figure A-60** as sites F1 to F7. Sites F1 to F3 are selected as monitors on the watertable elevation in waste rock infilling the Roseville West Pit, the Avon North Open Cut and the Stratford East Open Cut. These piezometers will allow assessment of the waste rock hydraulic conductivity and the rainfall recharge rate through the infill material.

Sites F4 to F7 are selected to the west of the three pits where end-of mining groundwater drawdowns are anticipated.

Site F4 is midway between the Roseville West Pit and the most easterly monitoring bore near Stratford. This piezometer should be screened in the Roseville Seam (model layer 3) so that it will provide an early warning of effects approaching users in Stratford in case they exceed model predictions.

Sites F5 to F7 are all in predicted drawdown areas associated with the Stratford East Open Cut. All piezometers should be screened no higher than the Bowens Road Seam (model layer 5). Ideally, site F6 should be a vibrating wire installation with piezometers placed in each of the major coal seams (model layers 3, 5, 7, 9 and 11).

The timing for installation should be after final rehabilitation at sites F1-F3 and in advance of excavation at the same northing for sites F4 (Roseville West Pit Extension) and F5-F7 (Stratford East Open Cut) as mining progresses.

The final location of piezometers should include consideration of site characteristics, their location relevant to the mine plan, access and site inspection.

Water level measurements should be automated with daily or more frequent recordings and should continue for at least two years following mining.

A6.3.2 Groundwater Quality

The groundwater monitoring network should be sampled for water quality on a regular basis during mining, and for at least two years following mining. Groundwater quality samples should also be taken during drilling of any new/future piezometer or hydrogeological investigation bores.

Groundwater quality monitoring should include, but not necessarily be limited to, analysis of the following parameters: pH, DO, EC, TDS, Fe, Al, As, Mg, Mo, Se, Ca, Na, Cl and SO4. Analysis should be undertaken at a NATA accredited laboratory. Water quality data should be evaluated as part of the Annual Environmental Management Report (AEMR) process and should aim to identify any potential mining related impacts.

A6.3.3 Mine Water Balance

Water balances should be conducted continuously, accounting for all monitored volumes (including pit groundwater inflows/pumping records) and should be reported in the AEMR.

The water balance should be reviewed annually to confirm groundwater transmission characteristics and modelling predictions. Monitoring results which indicate anomalous/high groundwater inflows should be investigated. If anomalous/high groundwater inflows are detected, SCPL should notify and consult with the relevant regulator regarding further courses of action.

The Project water management system is discussed further in the Surface Water Assessment (Appendix B of the EIS).

A7 CLIMATE CHANGE AND GROUNDWATER

The effects of climate change on groundwater are projected to be negative in some places on earth, but positive in other places. In the Netherlands, for example, beneficial effects are anticipated (Kamps et al., 2008). There it is expected that coastal watertables will rise, but evapotranspiration will reduce in response to the adaptation of vegetation to higher levels of carbon dioxide. Modelling shows more pronounced seasonal watertable fluctuations by accounting for vegetation feedback mechanisms (Kamps et al., 2008). Plants are expected to have a lower water demand under higher carbon dioxide levels due to production of more biomass, increased leaf area index, and a shorter time to reach the saturation point for carbon demand (Kamps et al., 2008).

In New Hampshire USA, on the other hand, negative effects on the watertable are expected due to the onset of spring recharge two to four weeks earlier (Mack, 2008). This shift will allow a longer period for evapotranspiration prior to summer months, at which time groundwater availability is likely to decrease.

The modelling of climate change effects needs to take into account complex vegetation and hydrologic feedback mechanisms, coupled surface water and groundwater interactions, and inter-annual temporal variations. Very few modelling studies have been conducted so far. Hunt et al. (2008) reported on the difficulties to be overcome in doing comprehensive modelling using newly released integrated GSFLOW software (MODFLOW plus PRMS).

Order of magnitude estimates can be found by ignoring feedback mechanisms and changing the currently calibrated rain infiltration percentages. However, more intense rainfall events would be expected to increase fast runoff and lead to a reduction in infiltration. This should be taken into account to allow for short-term temporal variations.

Annual rainfall is expected to change by -10 to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual average temperatures are projected to increase by 0.4 to 2.0° Celsius (relative to 1990) at that time.

The approach taken for this assessment has been to conduct a transient simulation for the calibration period and the prediction period for rainfall infiltration reduced by 20%.

If the climate change effects had occurred during the calibration period, the calibration performance statistics would have deteriorated slightly from 7.86% RMS (base case) to 7.95 % RMS and 2.58 m RMS (base case) to 2.61 m RMS. This means that the model is not sensitive to this level of change and any resulting effects would lie within the envelope of uncertainty for base case modelling.

The effect of the postulated climate change on pit inflow has been assessed for one pit (Stratford East Open Cut). It was found that the average reduction in pit inflow over the life of the Project would be about 2% for 20% less recharge from rainfall. This is illustrated in **Figure A-54**. The simulated reduction in pit inflow is due to reduced groundwater levels adjacent to the active void during mining.

A8 MANAGEMENT AND MITIGATION MEASURES

SCPL should implement the proposed groundwater monitoring programme outlined in Section A6.3.

The numerical groundwater model developed as part of this groundwater assessment should be used as a management tool for validating the predicted groundwater impacts throughout the Project life. The results of the groundwater monitoring programme (Section A6.3) should be used to assess progressive development, verification and refinement of the numerical model. Revised outputs from the numerical model should be reported in subsequent relevant groundwater assessments over the life of the Project.

A8.1 GROUNDWATER USERS

The numerical modelling indicates that the drawdown effects on groundwater users in the vicinity of the mine are not likely to be significant (i.e. less than 1 m) and would not materially affect the existing or potential future beneficial use of groundwater (refer to Section A6.1.7). Notwithstanding the above, it is recommended that a comprehensive groundwater monitoring programme (Section A6.3) be established to monitor the groundwater effects of the Project (including triggers for investigation), and to enable contingency measures to be implemented in the event that agreed trigger levels are exceeded.

In the event that a complaint is received in relation to depressurisation of a privately owned bore, well or spring by local groundwater users, the relevant data set should be reviewed by SCPL as part of a preliminary evaluation to determine if further investigation, notification and mitigation is required.

A8.2 GROUNDWATER LICENSING

Water licensing requirements including consideration of water management principles and access licence dealing principles are addressed in detail in the Water Licensing Addendum (Attachment 5) to the EIS.

The Project has the potential to intercept groundwater from two water sources associated with fractured rock and alluvium. Groundwater extraction from the fractured rock aquifer is not currently covered by any water sharing plan. In that case, the *Water Act, 1912* is the relevant Act for approval of groundwater extraction. The relevant alluvial source is the *Lower North Coast Unregulated and Alluvial Sources 2009*.

The predicted annual groundwater volumes required to be licensed over the life of the Project are summarised in **Table A-24**. The estimates for alluvium are justified in Section A6.1.5.

Table A-24. Project Groundwater Licensing Summary

Groundwater System	Water Sharing Plan	Water Source	Predicted Average and Maximum Annual Inflow Volumes requiring Licensing [ML/annum]			
			BRNOC^	RWPE	ANOC	SEOC
Fractured Rock	None	None	Av. 152 Max. 163	Av. 188 Max. 261	Av. 92 Max. 119	Av. 38 Max. 57
Alluvium	Lower North Coast Unregulated and Alluvial Sources 2009	Avon River Water Source	Max. 6[+]	Max. 14[#]	Max. 34[@]	Nil

^ Until backfilled.

\+ No more than 6 ML/annum from Dog Trap Creek alluvium; after year 8 the alluvium will gain water.

\# The regolith / floodplain alluvial veneer will provide about 2 ML/annum from extra leakage to fractured rock, 10 ML/annum from reduced rainfall recharge, and 2.2 ML/annum in excavated sediments.

@ The regolith / floodplain alluvial veneer will provide about 31 ML/annum from extra leakage to fractured rock, 2.8 ML/annum from reduced rainfall recharge, and 0.6 ML/annum in excavated sediments.

BRNOC = Bowens Road North Open Cut; RWPE = Roseville West Pit Extension; ANOC = Avon North Open Cut; SEOC = Stratford East Open Cut.

GCL currently holds a combined total of 1,021 ML volumetric licence allocation under Part 5 of the *Water Act, 1912* for the operations at the Stratford Mining Complex which is greater than the predicted maximum for all Project open cut mining areas combined (i.e. approximately 600 ML).

While negligible drawdown in the aquifers of the alluvial groundwater system and negligible impact on groundwater levels or groundwater yield for groundwater users with privately owned bores in the alluvial groundwater system are predicted, the numerical model has accounted for water that could be lost from the alluvium/regolith groundwater source.

There is only one known groundwater licence with a total entitlement of 20 ML/annum for the Avon River Water Source (DWE, 2009). Notwithstanding, GCL currently holds a combined total of 140 megalitres per unit volumetric licence allocations under the *Water Management Act, 2000* for unregulated rivers in the Avon River Water Source, which is greater than the predicted maximum inflows from the alluvial groundwater system for all Project open cut mining areas combined (i.e. 54 ML).

A9 MODEL LIMITATIONS

Although MODFLOW-SURFACT is capable of simulating unsaturated conditions, the focus in this study has been on the saturated part of the groundwater system. Nevertheless, MODFLOW-SURFACT will report groundwater heads (equivalent to negative pore pressures) in dry portions of model layers.

The model has adopted uniform rainfall recharge across five zones. As more data are gathered, the spatial distributions of aquifer properties can be refined.

There is substantial faulting through the study area. The model has not represented the faulting explicitly but has honoured the structural geometry by complying with the stratigraphic picks in the geological resource model. In effect, the model assumes that coal seams “roll over” a fault, rather than suffering dislocation. If discontinuity occurs in reality, the model will overestimate drawdown extent, as drawdown impacts could be compartmentalised.

This model has implemented declining hydraulic conductivity with depth in a discrete number of depth ranges. Separate depth functions were applied initially for the interburden as a group and for coal seams as another group. Subsequently, some fine-tuning of hydraulic conductivity values was done at shallow depths during calibration. As strata dips are often severe (of order 45^{o}), there can be sudden reductions in hydraulic conductivity from east to west along any layer. This has resulted in fairly sharp limits to predicted drawdown extents.

As lower pit inflows can be expected as coal seam hydraulic conductivity reduces with depth, the predicted inflows for the deeper pits could be underestimated if the applied hydraulic conductivity is too low.

At this stage, there is no hydrographic evidence for hydraulic conductivity reduction with depth, but this can be expected as mining proceeds to greater depths. Vibrating wire piezometers have been installed as part of this study to provide information on deep groundwater responses to mining.

Note;
The highlighted statement above arises from the fact that MODFLOW cannot in the formulation used for this work, model inclined or vertical faults. This means that a highly permeable fault zone is ignored, and it is not a general truth that the model presented here will overestimate drawdown extent (or impacts, or inflows to depressurised zones in coal seams.
(P Pells 15 May 2013)

A10 CONCLUSIONS

In the vicinity of the Stratford Mining Complex, there is little reliance on groundwater bores as a source of water, as agricultural enterprises predominantly rely on surface water sources which are more abundant and generally better quality. Within 5 km of proposed Project open cut mining operations, there are 12 private bores other than those on land owned by SCPL. There are 11 bores in Stratford and one bore to the south (GW079759). The private bores are licensed for stock and domestic use.

Groundwater is found within two groundwater systems:

- **Fractured Rock groundwater system** - including shallow rock groundwater bearing structures and the Gloucester Basin coal measures of Permian age; and
- **Alluvial groundwater system –** including alluvial (narrow channel) sediments of Dog Trap Creek, Avondale Creek and Avon River.

The Stratford Coal Mine commenced operations in 1995 and the earliest groundwater monitoring dates from 1994. The groundwater monitoring network was expanded in 2003 and subsequent years to coincide with the commencement of mining at the BRNOC.

Mining is conducted currently at the BRNOC, and the Roseville West Pit, with backfilling of the Roseville Extended Pit ongoing. Mining has been completed at the Stratford Main Pit and the Roseville Pit. CSG production is scheduled to commence shortly by AGL for the approved AGL Gloucester Gas Project, and GRL is currently investigating and seeking approval for a new open cut coal mining operation to the north at the proposed Rocky Hill Coal Project.

The Project includes continuation of mining at the BRNOC and the Roseville West Pit Extension, with new excavations in the Avon North and Stratford East Open Cuts.

Based on analysis of field hydrographic data, there is clear evidence of a mining effect on some of the groundwater hydrographs in regolith, interburden rocks and coal seams, but no discernible effect on the alluvial groundwater system. There is no field evidence of current mining effects on the private bores in Stratford. The simulation results indicate that future mining will have minimal effect on water levels in the private bores in Stratford, well within the range of fluctuations experienced under dry to wet weather conditions.

Groundwater sinks have developed in the voids formed by current mining, which have locally altered natural groundwater flow directions.

Numerical modelling has been undertaken to provide a basis for the groundwater assessment for this Project and to quantify the likelihood and magnitude of potential drawdown and water quality impacts.

Based on the numerical groundwater modelling, there is expected to be:

- negligible groundwater drawdown in the Alluvial sediments;
- negligible impact on groundwater levels or groundwater yield for groundwater users with privately owned bores in any groundwater system;
- substantial reduction in potentiometric head in the Fractured Rock groundwater system in the near vicinity of the Project;
- a maximum drawdown extent of 1.6 km from the Roseville West Pit Extension at the end of mining;
- a maximum drawdown extent of 1.0 km from the Avon North Open Cut at the end of mining;
- a maximum drawdown extent of 0.8 km from the Stratford East Open Cut at the end of mining;
- no effect on the nearest Biophysical Strategic Agricultural Land along the Avon River, west of Stratford;
- negligible reduction in natural baseflow to surface stream systems (i.e. Dog Trap Creek, Avondale Creek and the Avon River);
- total pit inflows ranging between approximately 0.7 ML/day and 1.3 ML/day during the Project open cut operations;
- a final combined pit inflow in the order of 0.7 ML/day at the completion of mining (Year 11) reducing to about 0.6 ML/day once the final void water level reaches equilibrium;
- an average combined pit inflow of 1.0 ML/day during the 11 years of the Project; and
- negligible change in groundwater quality as a result of mining in the short-term and in the long-term.

Cumulative effects are expected to be substantially greater than would be produced by the Project acting alone. CSG activity would cause pronounced drawdown in the watertable between the Project and Stratford. Nevertheless, the predicted drawdowns at the Stratford privately owned bores are less than 1 m for bores in the northern half and 1-2 m for the southern half. There would be no impact on the other known private bore located within 5 km of the Stratford Mining Complex.

The potential impacts of mining on surface water resources, other than those assessed within this report, are assessed in Appendix B of the EIS.

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ILLUSTRATIONS

Figures A-1 to A-60

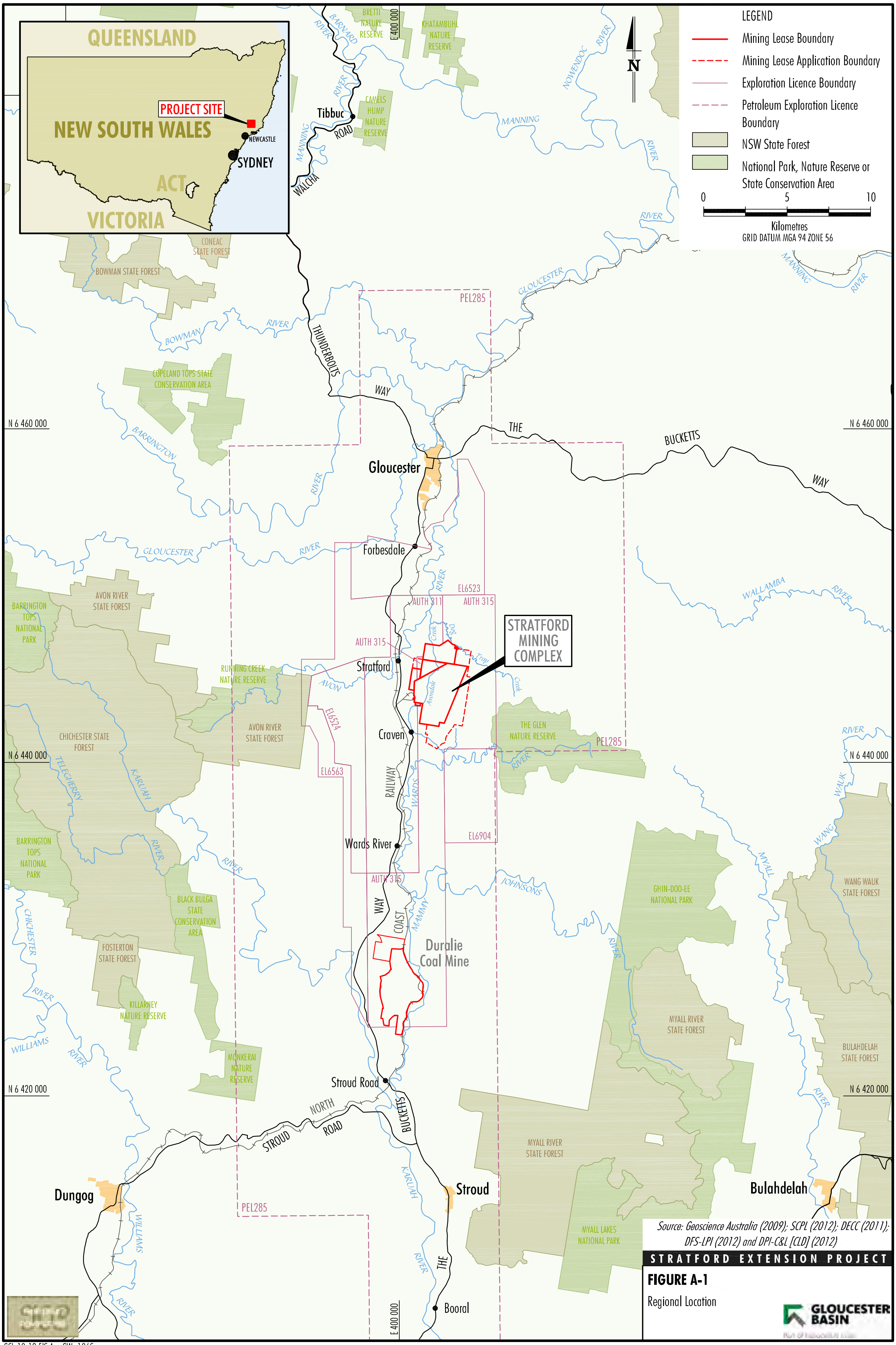


FIGURE A-1
Regional Location

GCL-10-12 EIS App GW_106C

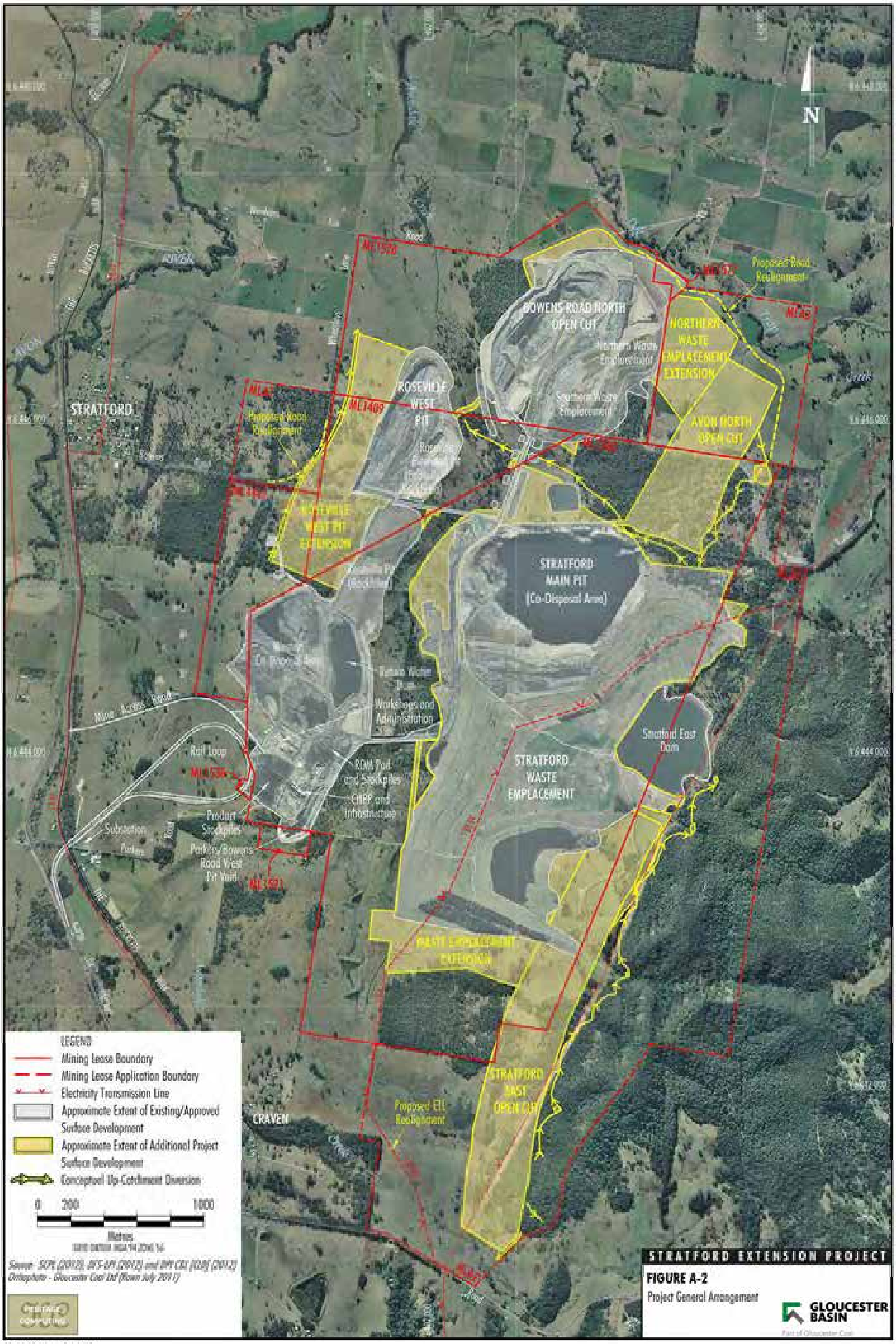


FIGURE A-2
Project General Arrangement

GCL-10-12 EIS App GW_1050

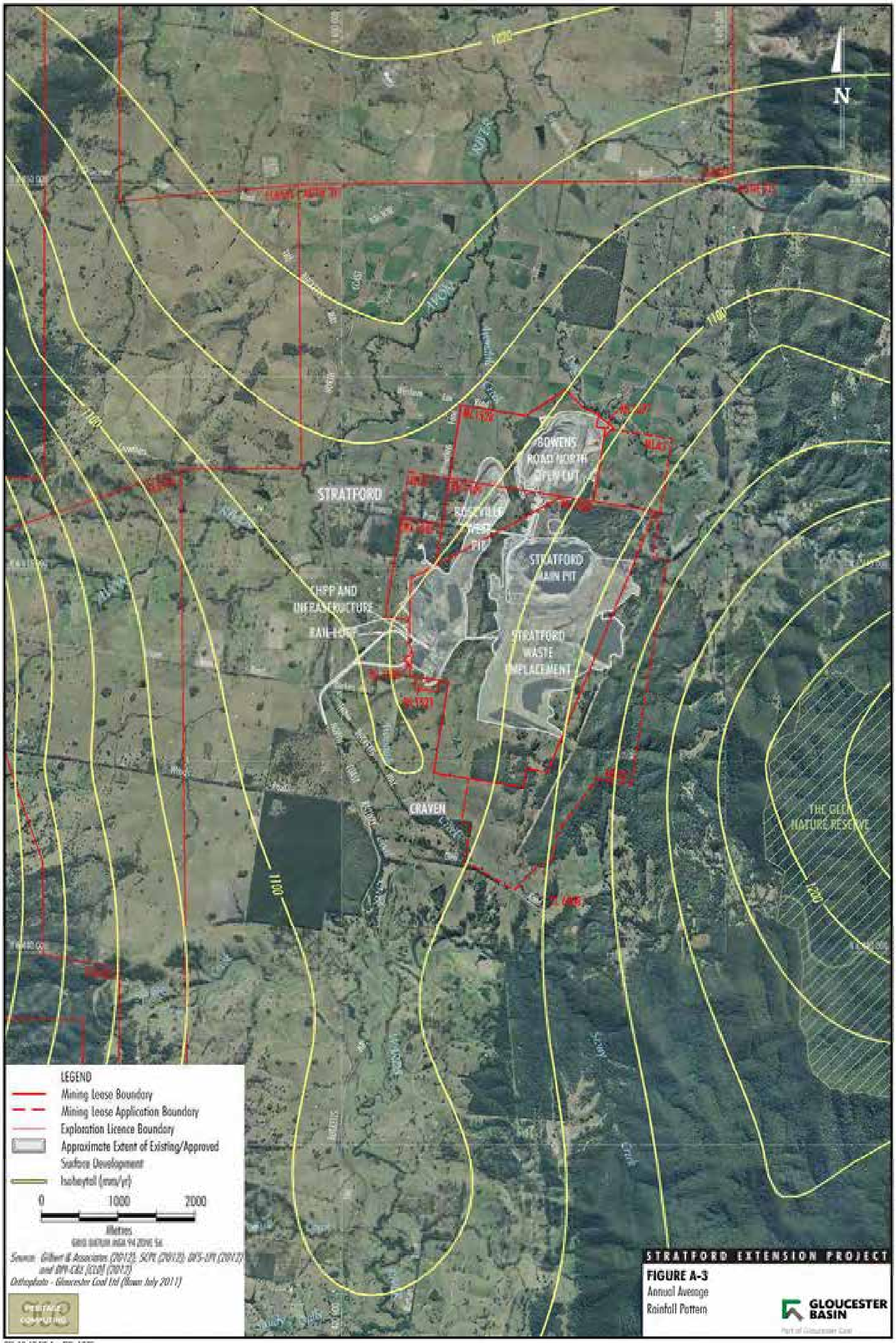


FIGURE A-3
Annual Average Rainfall Pattern

GCL 10-12 EIS App GW_107C

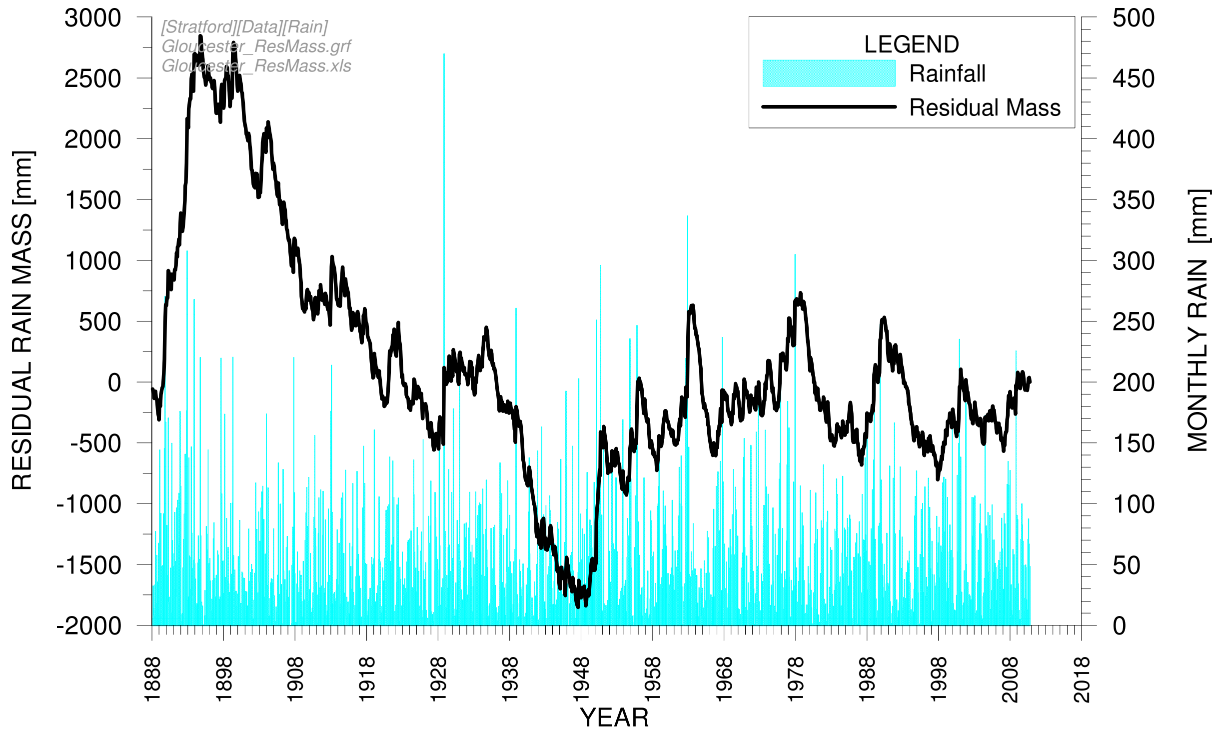


Figure A-4 Rainfall Residual Mass Curve for Gloucester Post Office (since 1888)

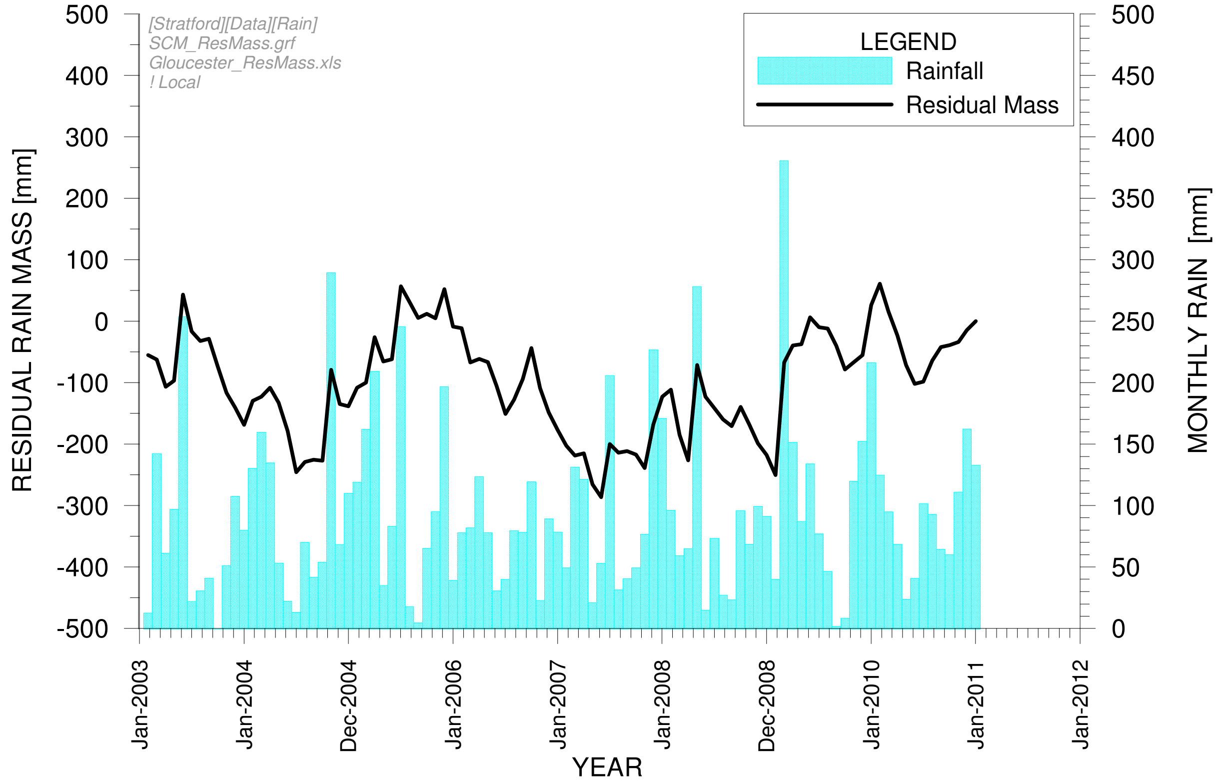


Figure A-5 Rainfall Residual Mass Curve for Stratford Coal Mine Meteorological Station

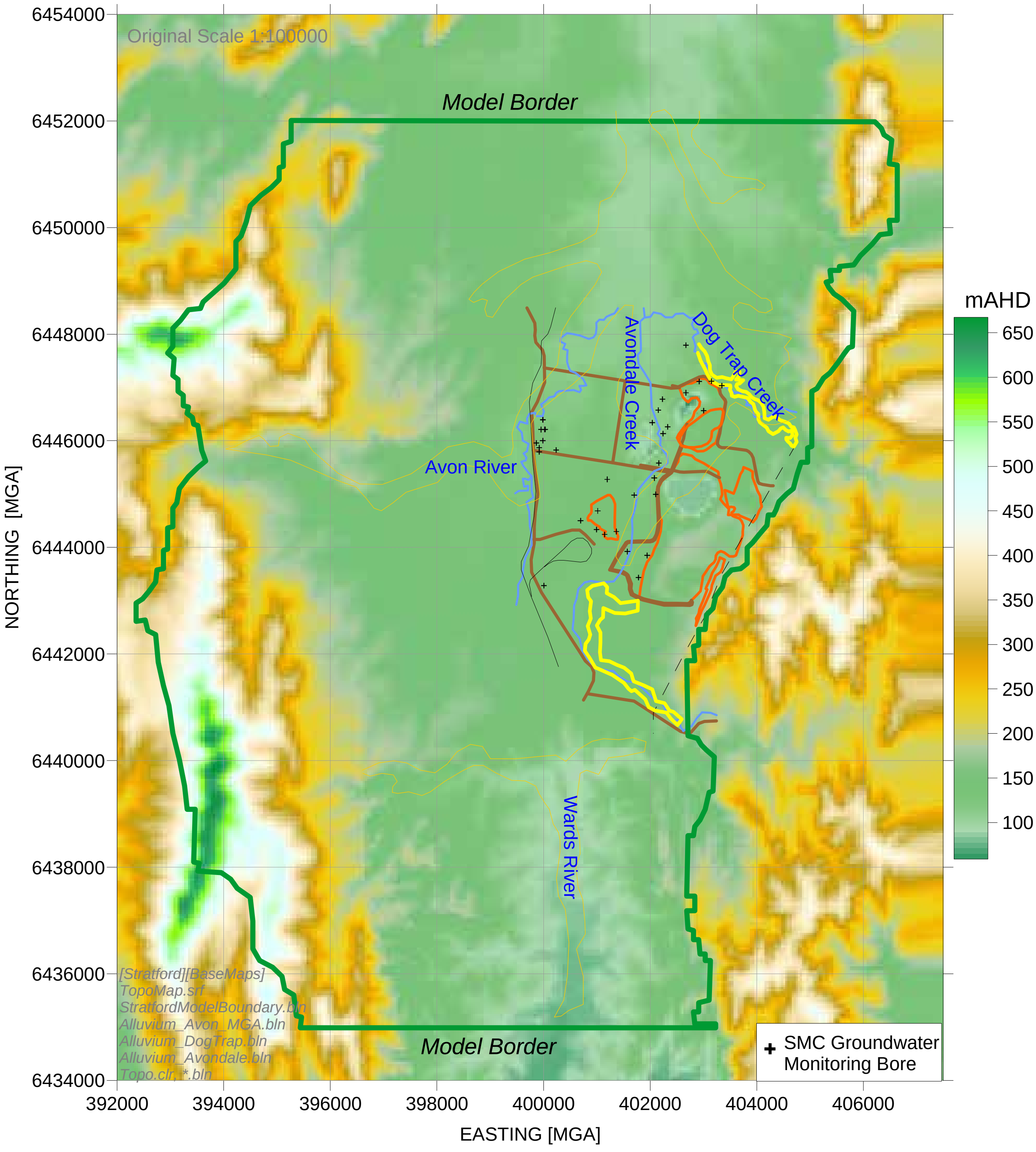


Figure A-6 Regional Topography and Model Extent

[The thin orange outlines show the extents of alluvium as they appear on published geological maps; the thick yellow outlines mark the main channels detected by a TEM survey]

BASIN	PERIOD	GROUP	SUB-GROUP	FORMATION	COAL SEAMS
GLOUCESTER	PERMIAN	GLOUCESTER COAL MEASURES	CRAVEN	Crowthers Road	[*Conglomerate*]
				Woods Road (Leloma)	*Linden, Marker (M6,M7[2]), Bindaboo[1,2], Deards[1,2]*
				Bucketts Way (Jilleon)	*Cloverdale[1,2], Roseville[1,2], Marker (M3, M8, M1)[1]*
				Wards River	[*Conglomerate*]
				Wenham	*Bowens Road[1,2], Bowens Road Lower[1]*
			SPELDON FORMATION		
			AVON	*Dog Trap Creek*	*Glenview, Marker 2*
				Waukivory Creek	*Avon[1,2], Triple[1], Rombo, Glen Road, Valley View, Parkers Road*
		DEWRANG GROUP		*Mammy Johnsons*	*Mammy Johnsons*
				Weismantel	*Weismantel*
				Duralie Road	*Cheer-up[2], Clareval[2]*
		ALUM MOUNTAIN VOLCANICS			

[1] Coal reserves currently/previously mined at the Stratford Mining Complex

[2] Coal reserves to be mined by the Project

Source: Tamplin Resources (2010), Stratford Coal (1994) and SCPL (2012)

STRATFORD EXTENSION PROJECT

FIGURE A-7

Stratigraphic Units of the Development Application Area

GLOUCESTER BASIN

Part of Gloucester Coal

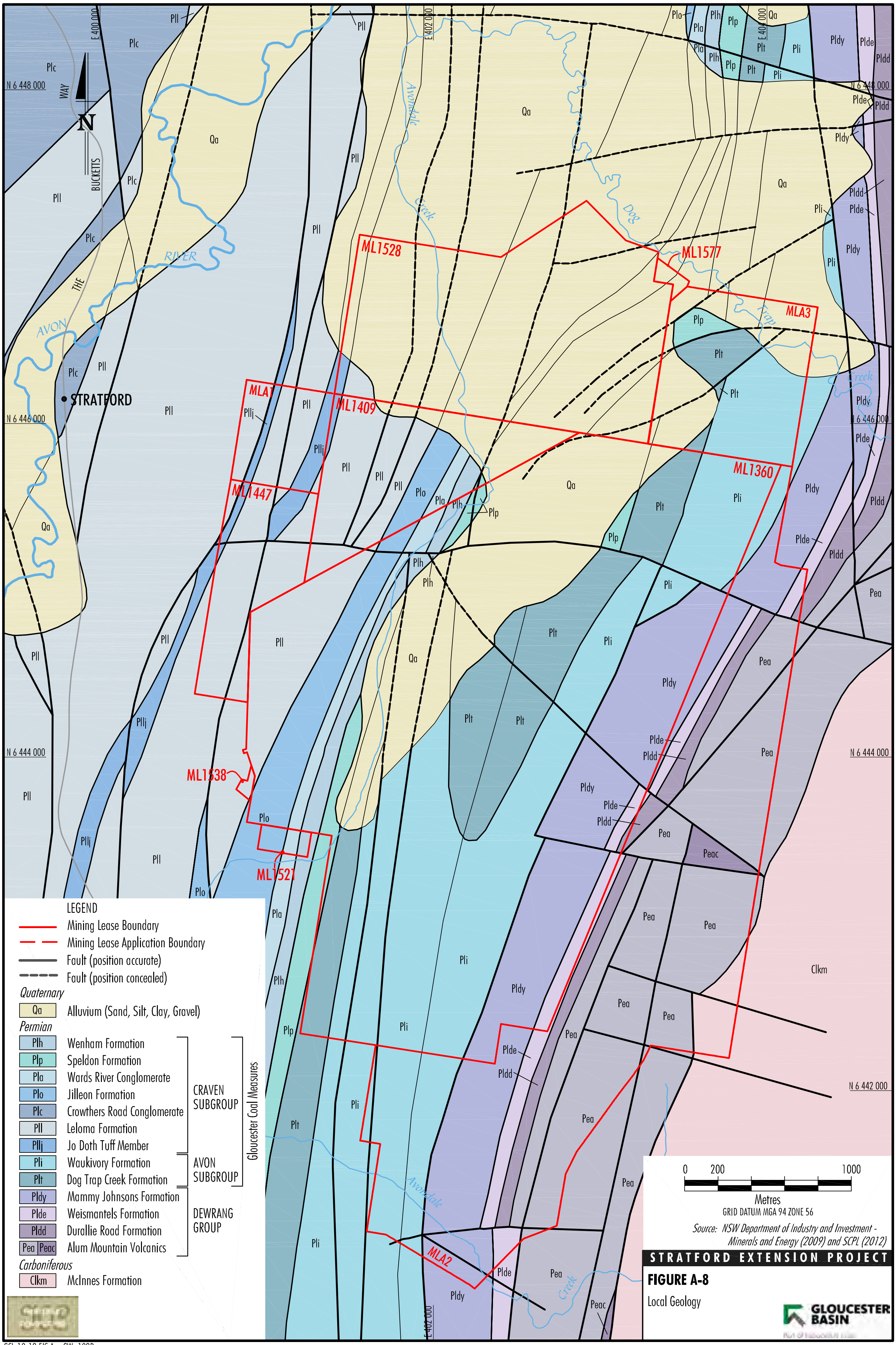
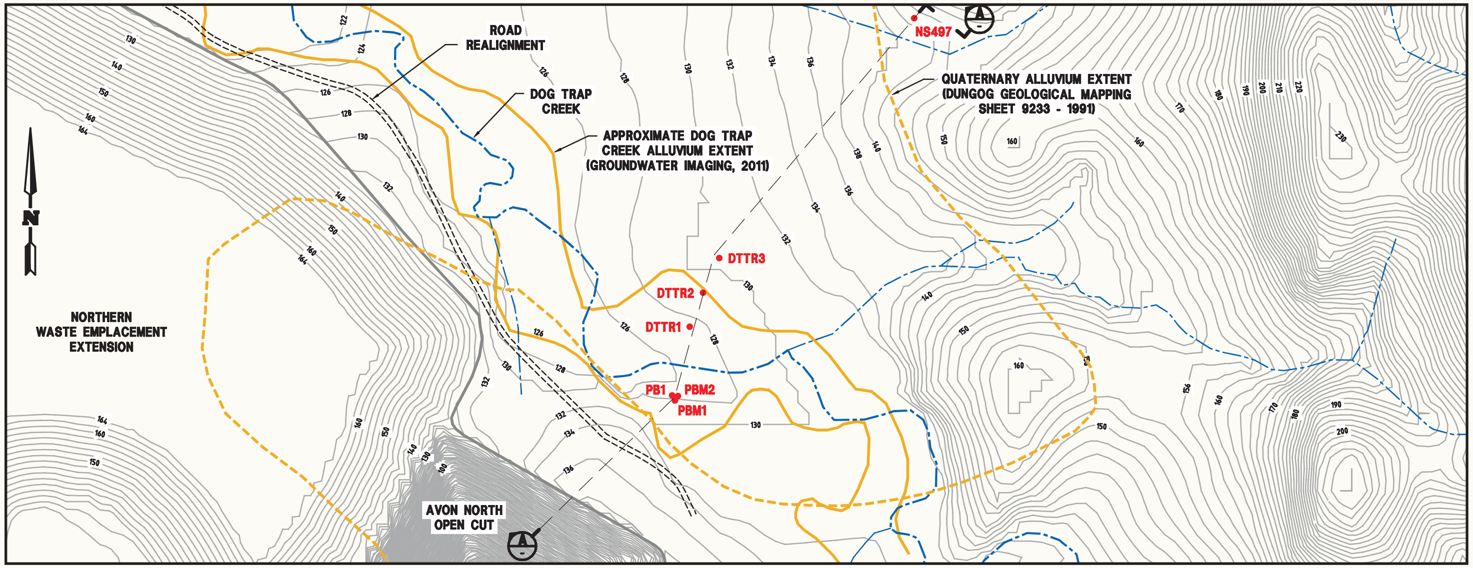
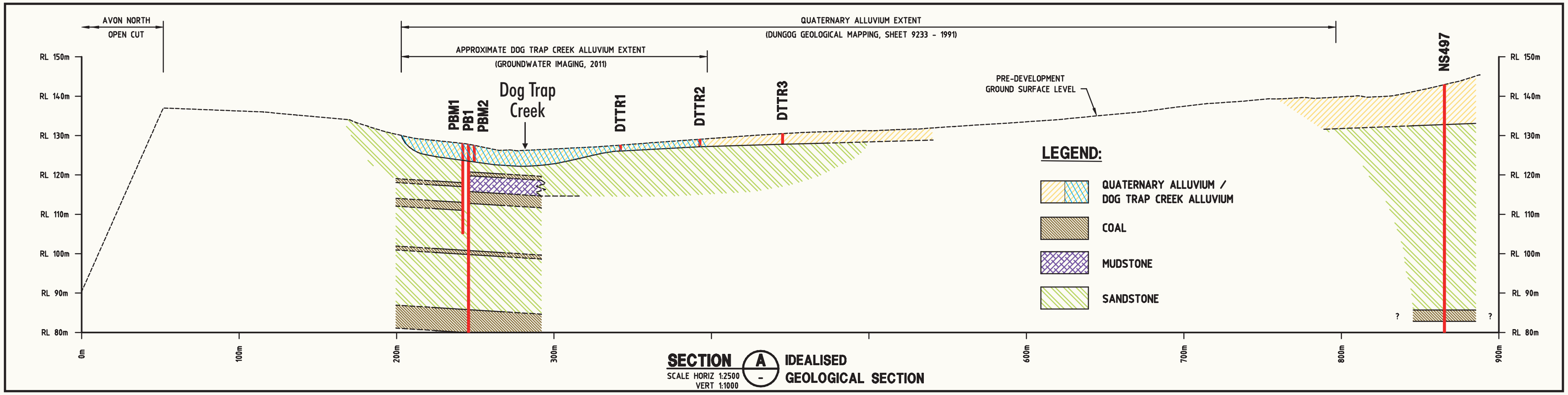


FIGURE A-8
Local Geology



Source: Allan Watson Associates (2011)

Dog Trap Creek Alluvium - Plan View



Source: Allan Watson Associates (2011)

Dog Trap Creek Alluvium - Section

STRATFORD EXTENSION PROJECT

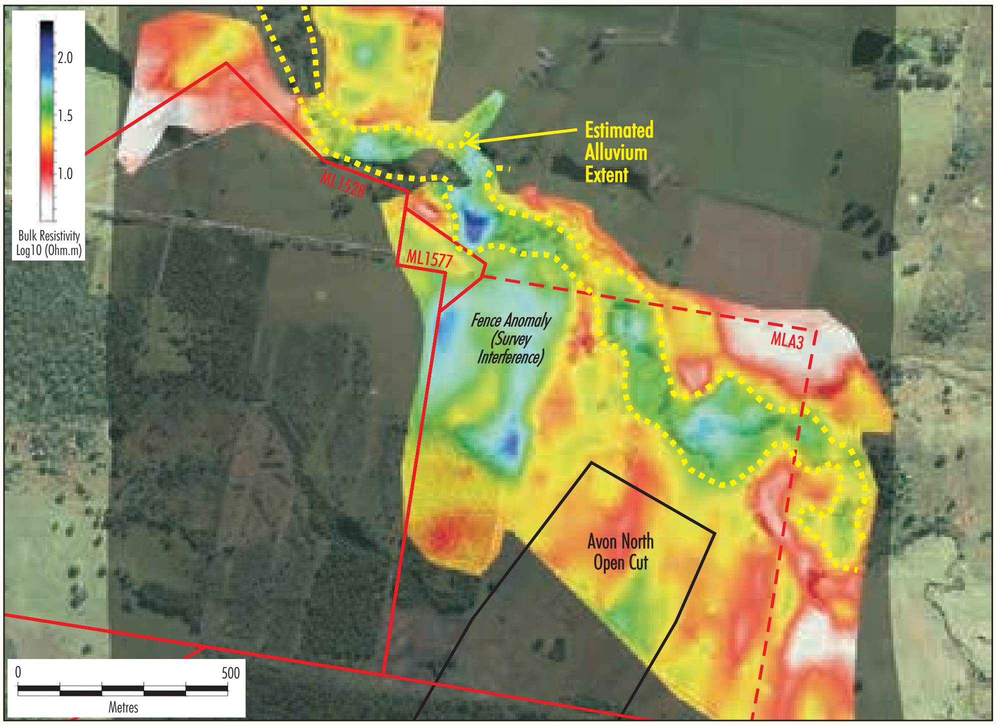
FIGURE A-9

Transect of Alluvial Bores across Dog Trap Creek

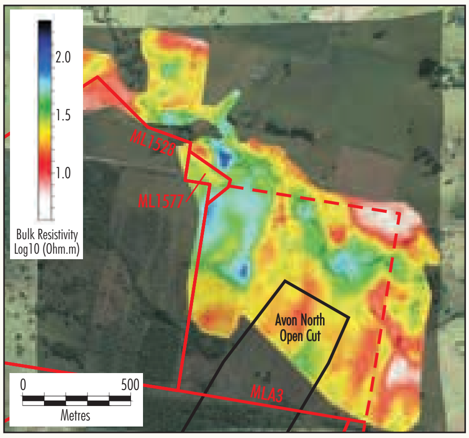
GLOUCESTER BASIN
Part of Gloucester Coal

HERITAGE COMPUTING

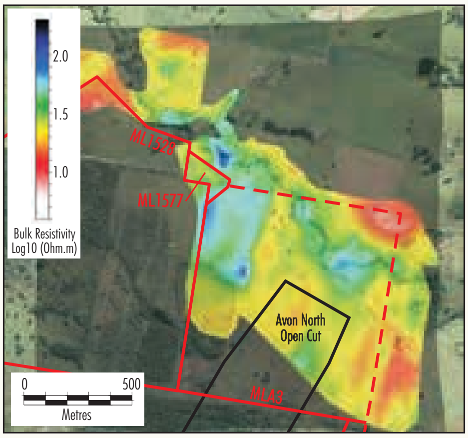
GCL-10-02 EIS AppGW_006D



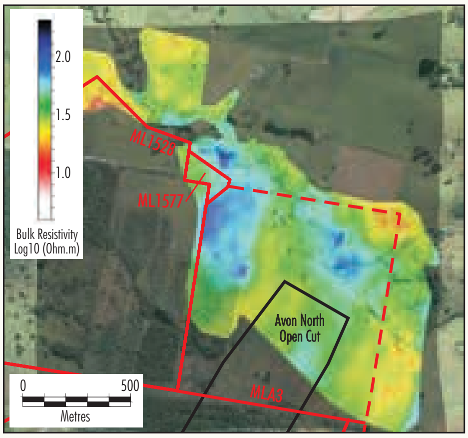
TEM Results @ 1m Depth (Including Estimated Alluvium Extent)



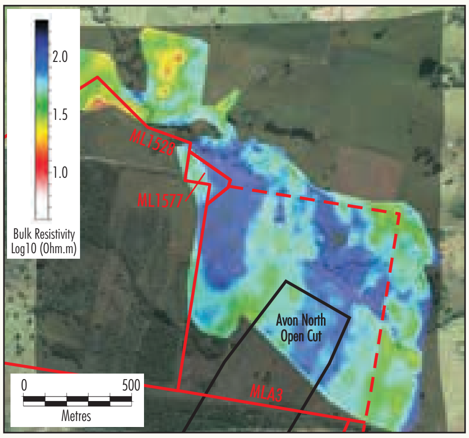
TEM Results @ 3m Depth



TEM Results @ 7m Depth



TEM Results @ 12m Depth



TEM Results @ 20m Depth

Source: Groundwater Imaging (2012)

Mining Lease Boundary
Mining Lease Application Boundary

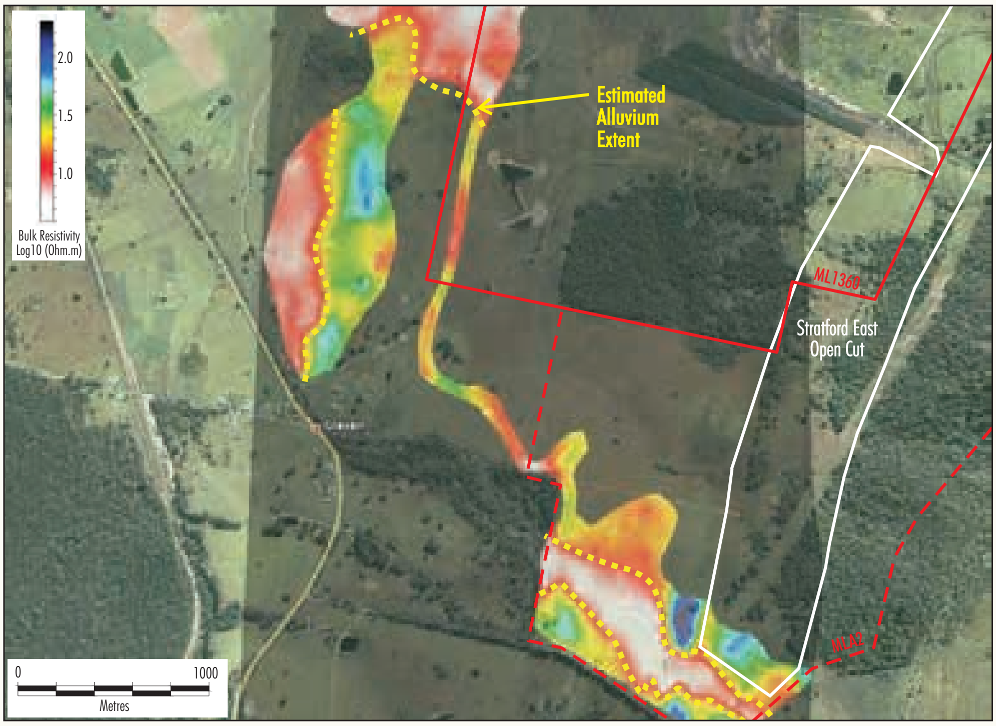
STRATFORD EXTENSION PROJECT

FIGURE A-10

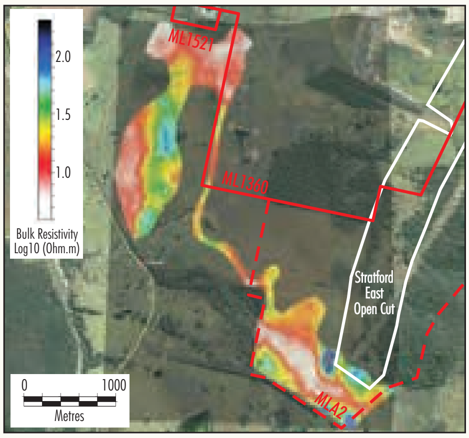
TEM Survey Results
Dog Trap Creek

GLOUCESTER BASIN
Part of Gloucester Coal

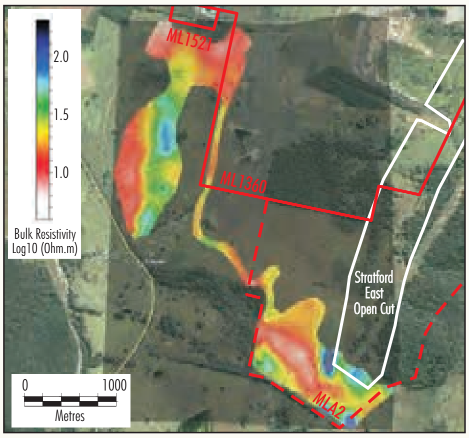
GCL-10-02 EIS AppGW_003D



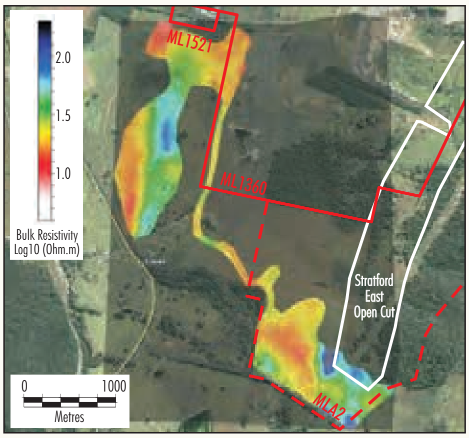
TEM Results @ 1m Depth (Including Estimated Alluvium Extent)



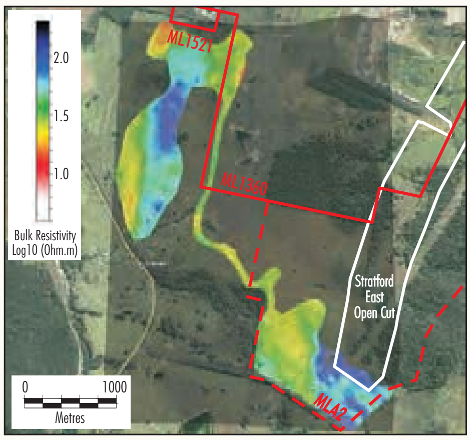
TEM Results @ 3m Depth



TEM Results @ 7m Depth



TEM Results @ 12m Depth



TEM Results @ 20m Depth

Source: Groundwater Imaging (2012)

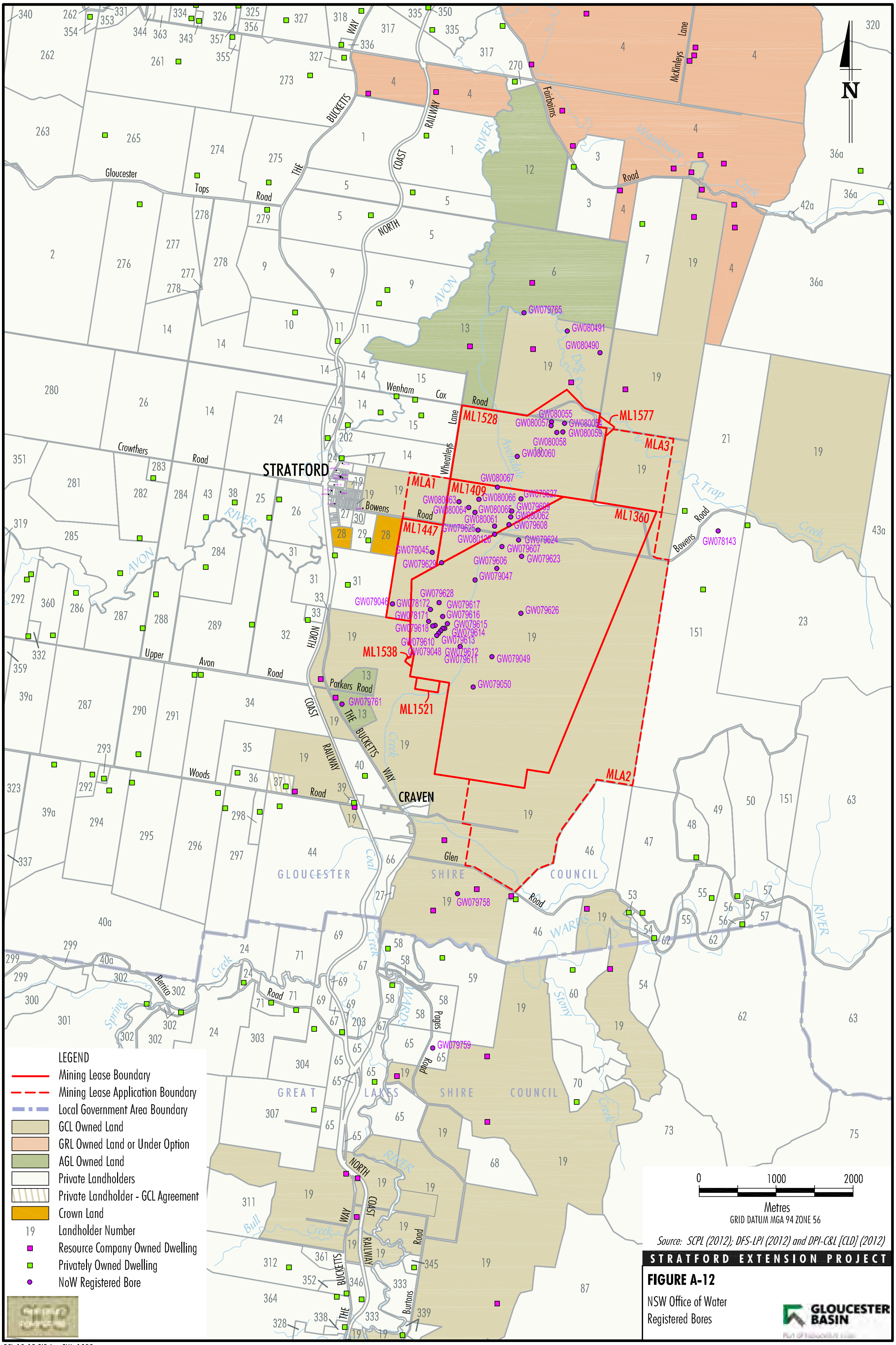
Mining Lease Boundary
Mining Lease Application Boundary

STRATFORD EXTENSION PROJECT

FIGURE A-11
TEM Survey Results
Avondale Creek

GLOUCESTER BASIN
Part of Gloucester Coal

GCL-10-02 EIS AppGW_002D



GCL-10-12 EIS App GW_109C

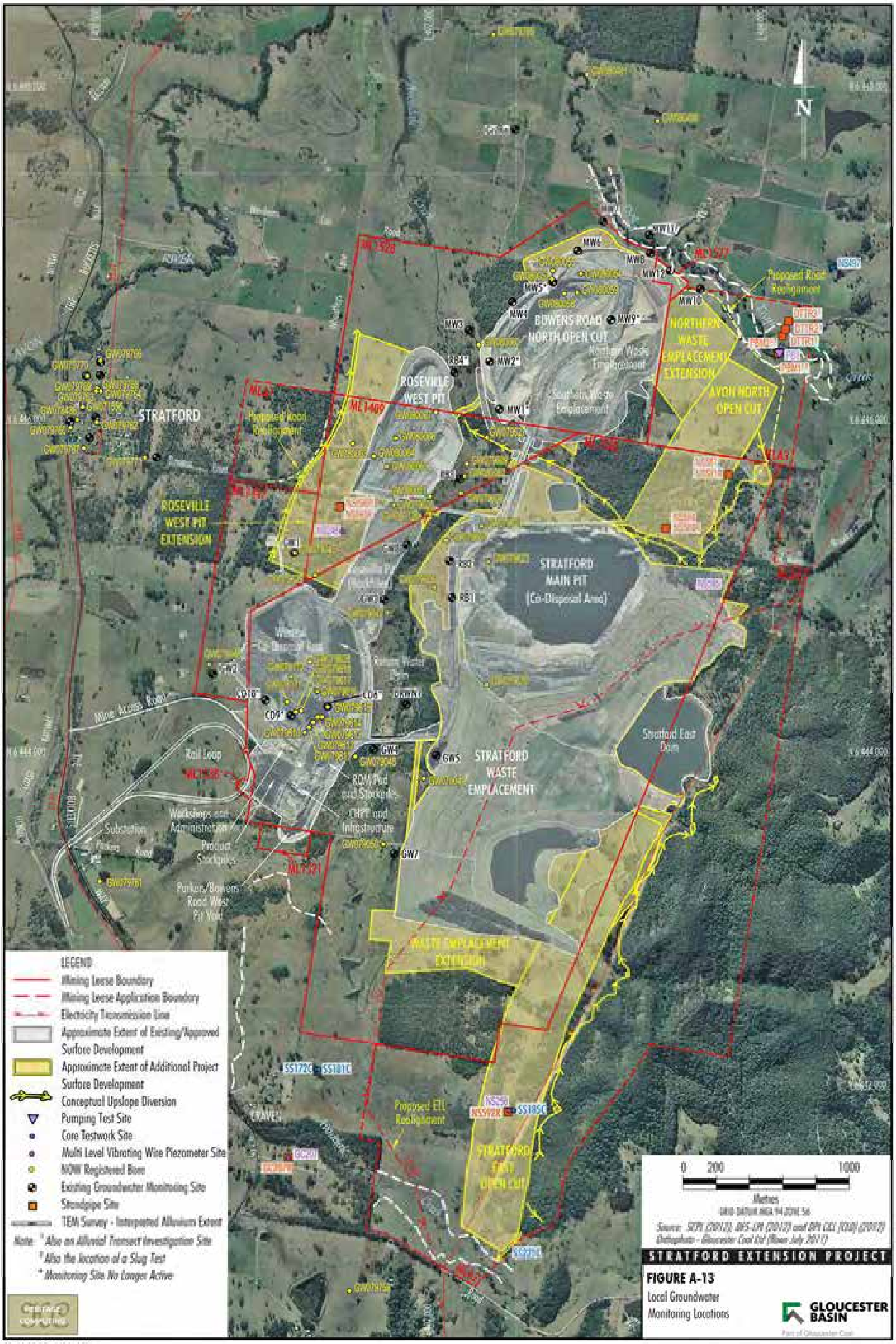


FIGURE A-13

Local Groundwater Monitoring Locations

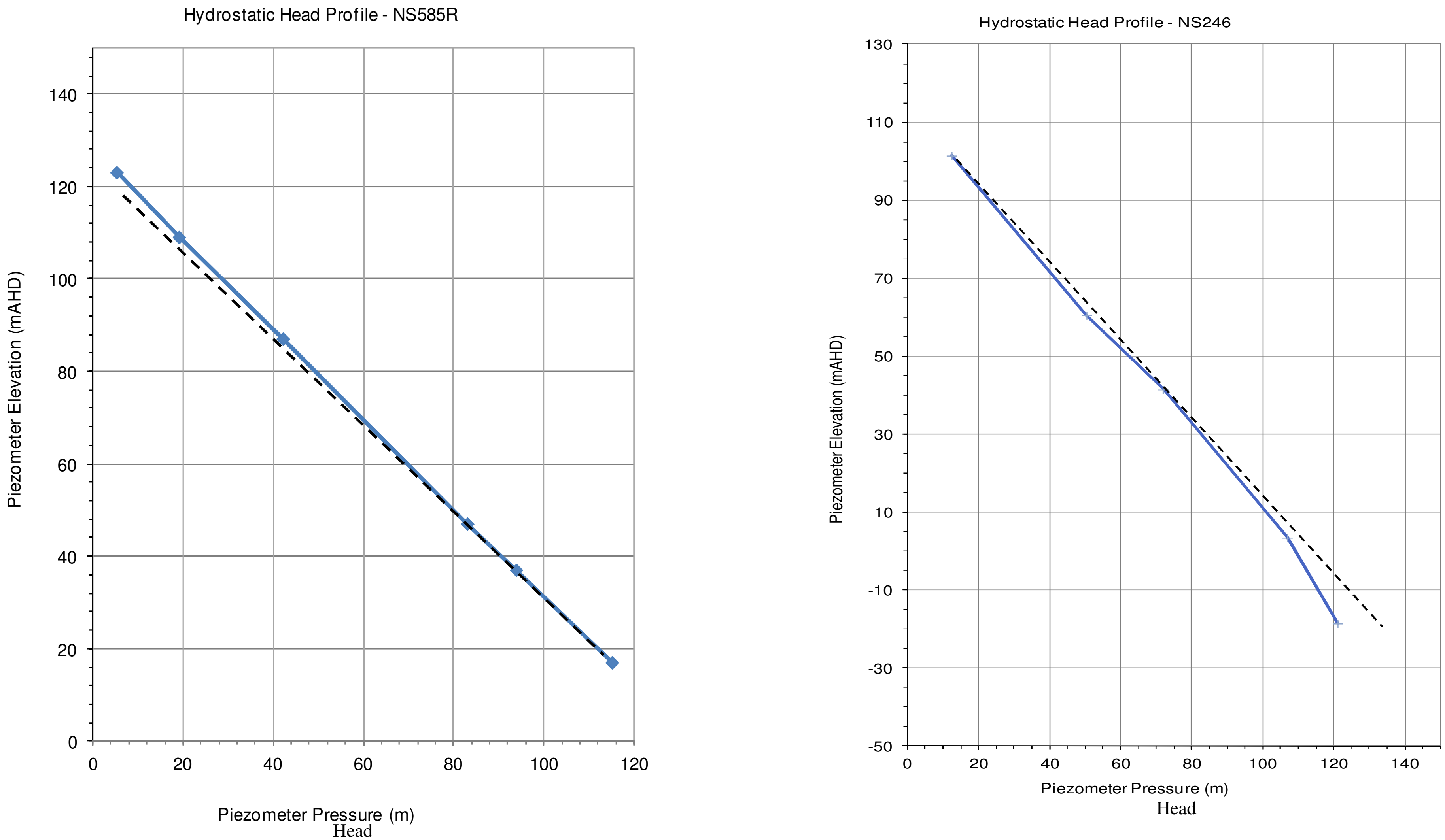
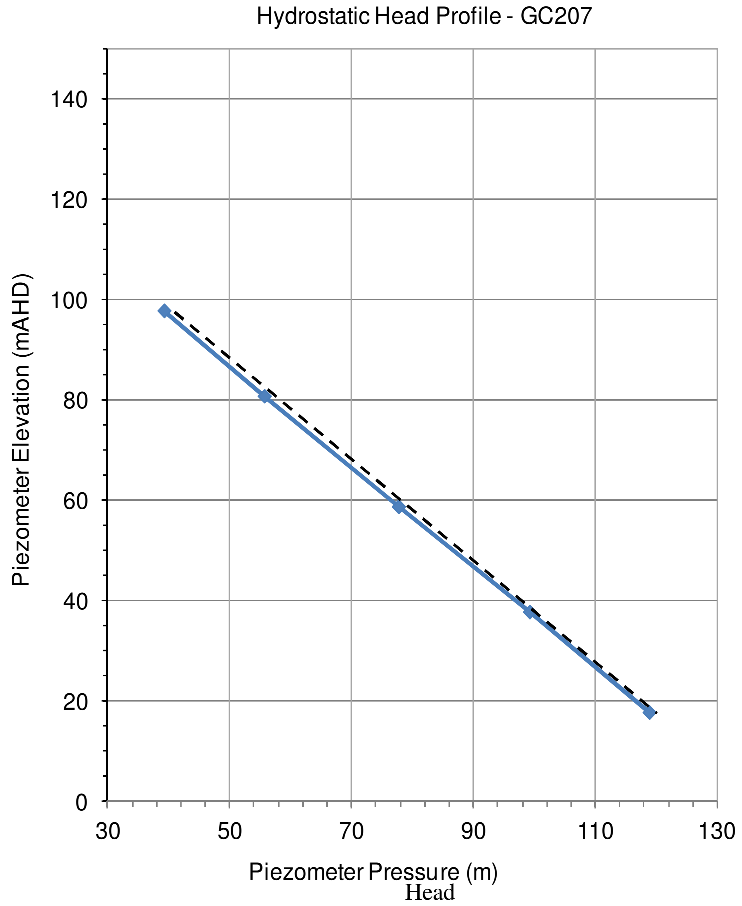


Figure A-14 Multi-level Vibrating Wire Groundwater Piezometer Hydrostatic Plots for NS585 and NS246



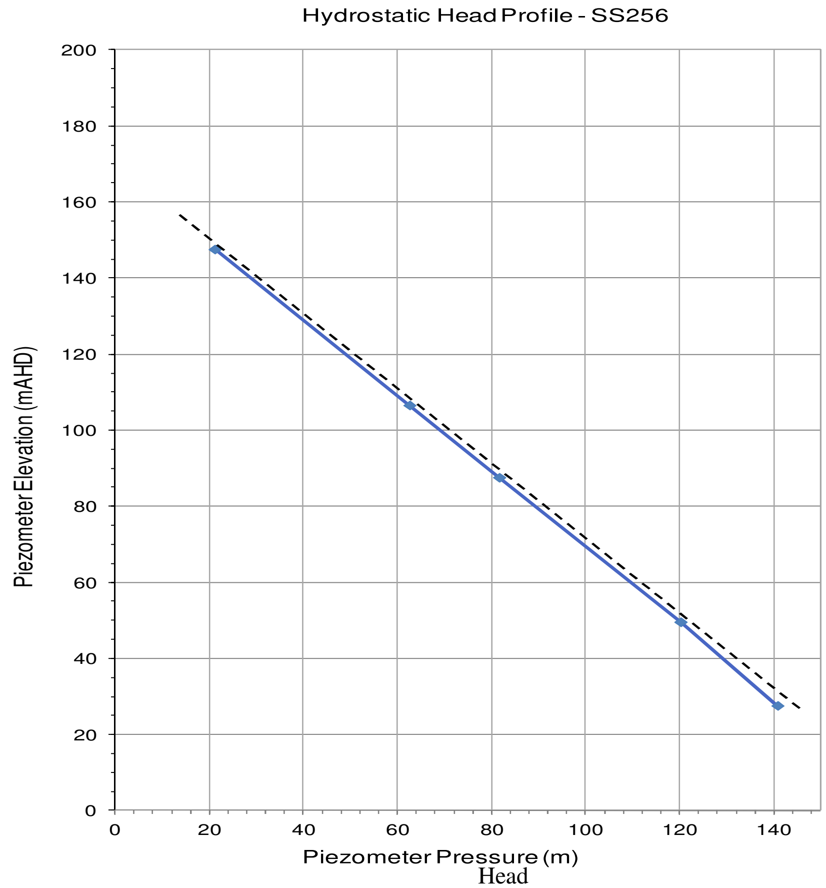


Figure A-15 Multi-level Vibrating Wire Groundwater Piezometer Hydrostatic Plots for GC207 and SS256

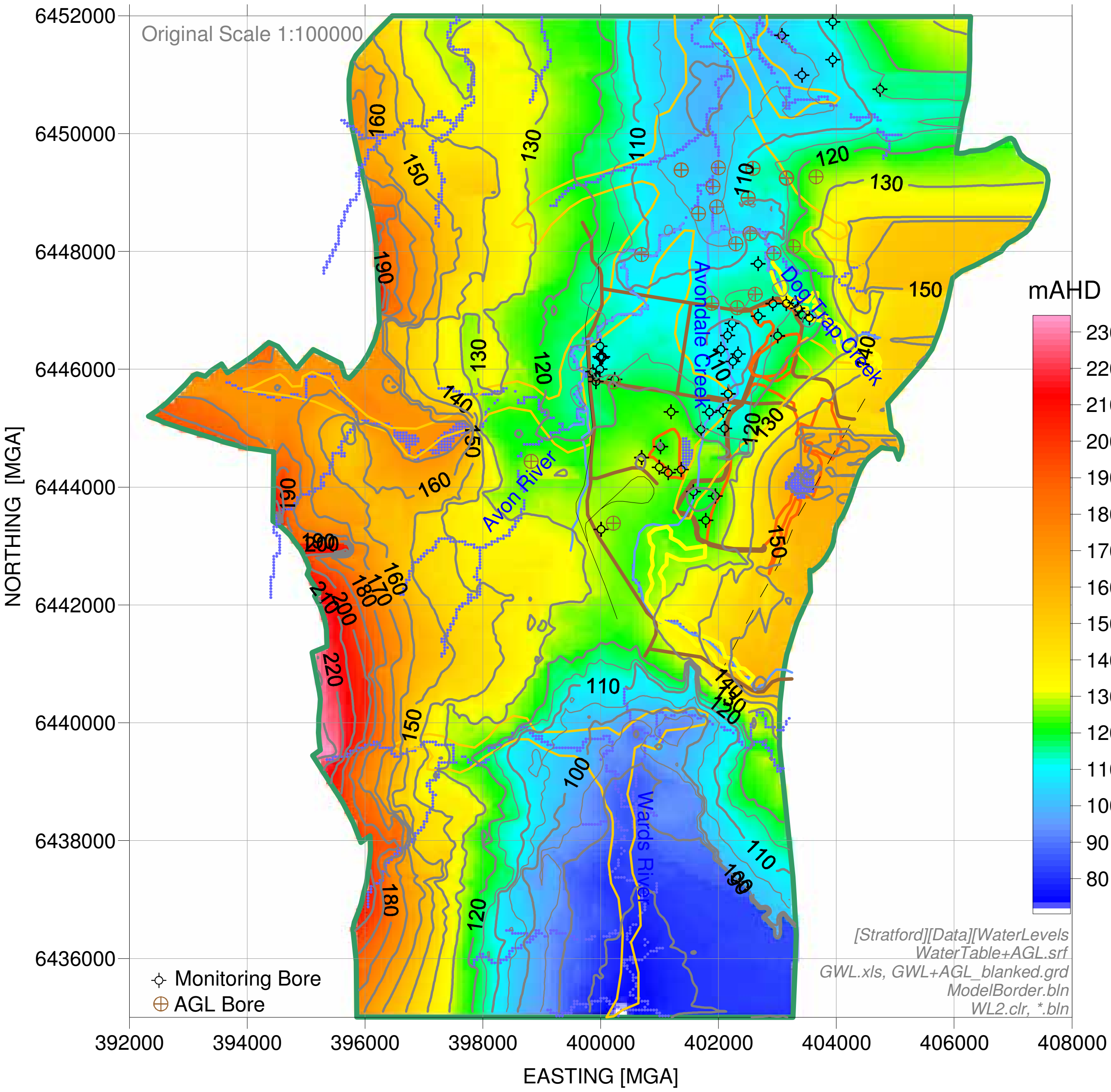
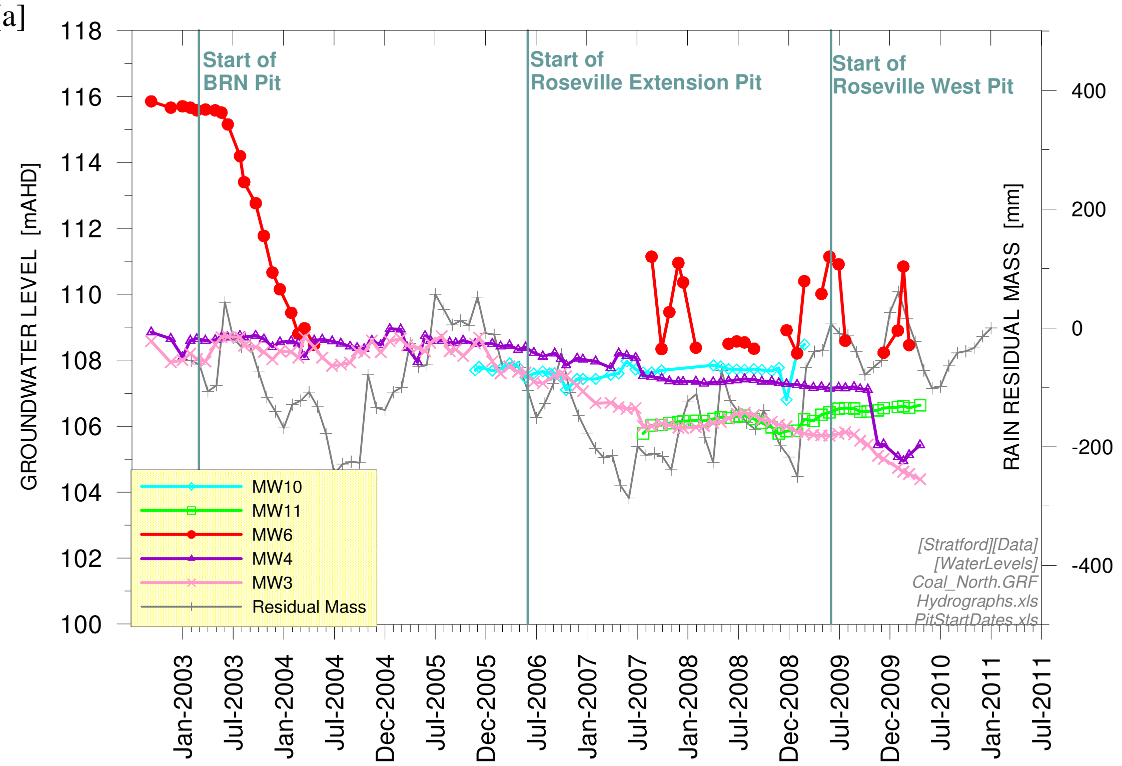


Figure A-16 Inferred Regional Shallow Groundwater Elevations [mAHD]

[a]



[b]

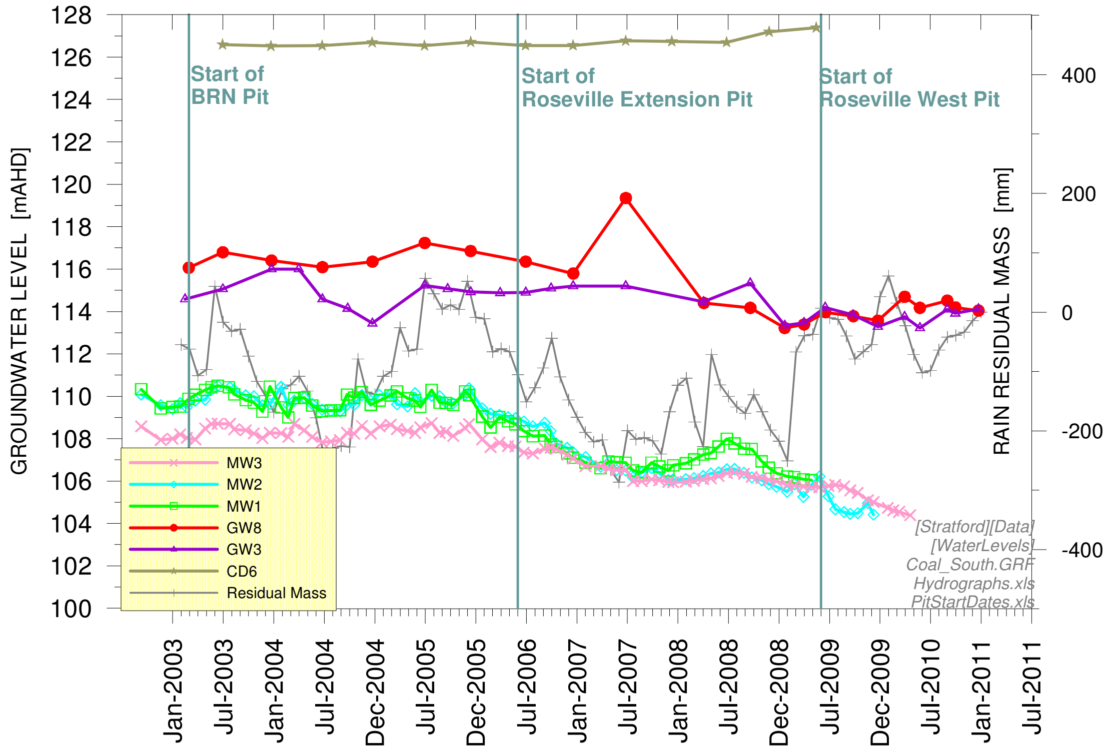
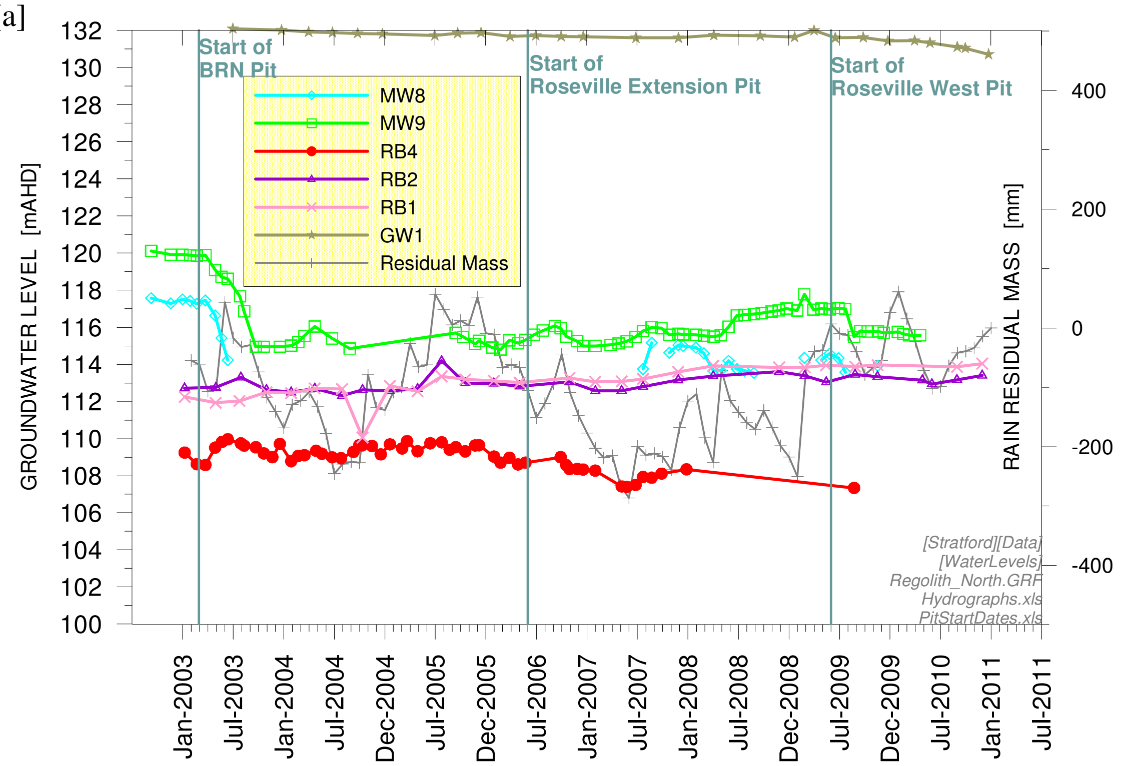


Figure A-17 Groundwater Hydrographs in Coal Seams: [a] north; [b] south

[a]



[b]

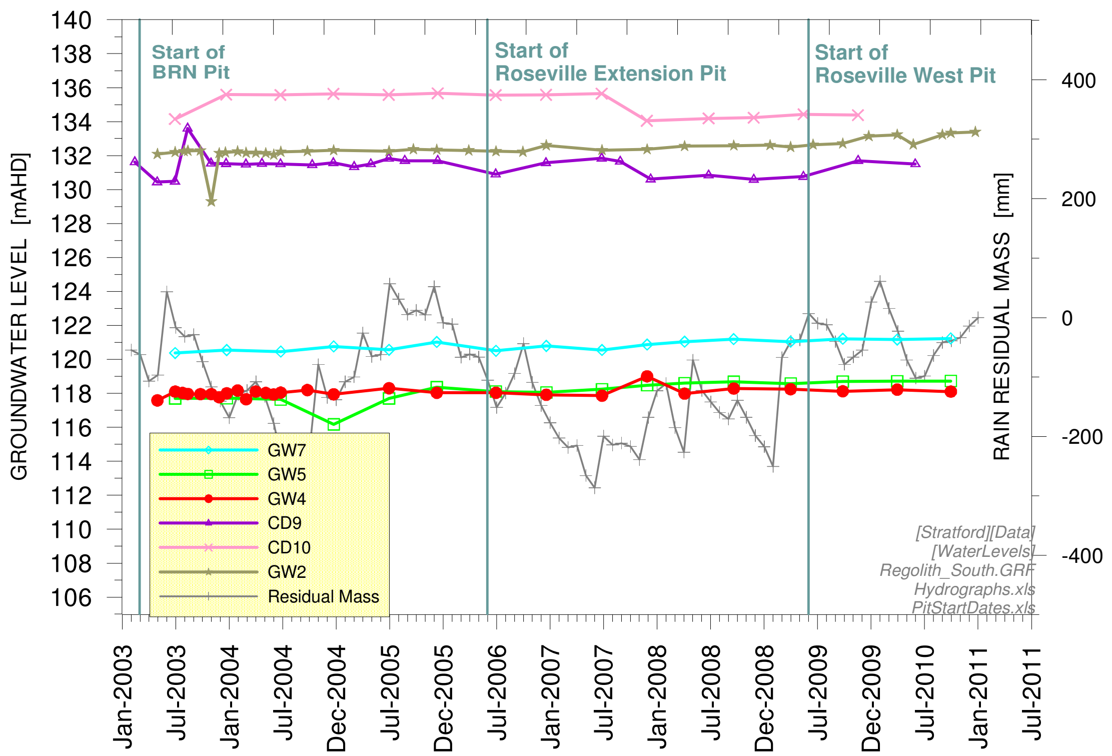
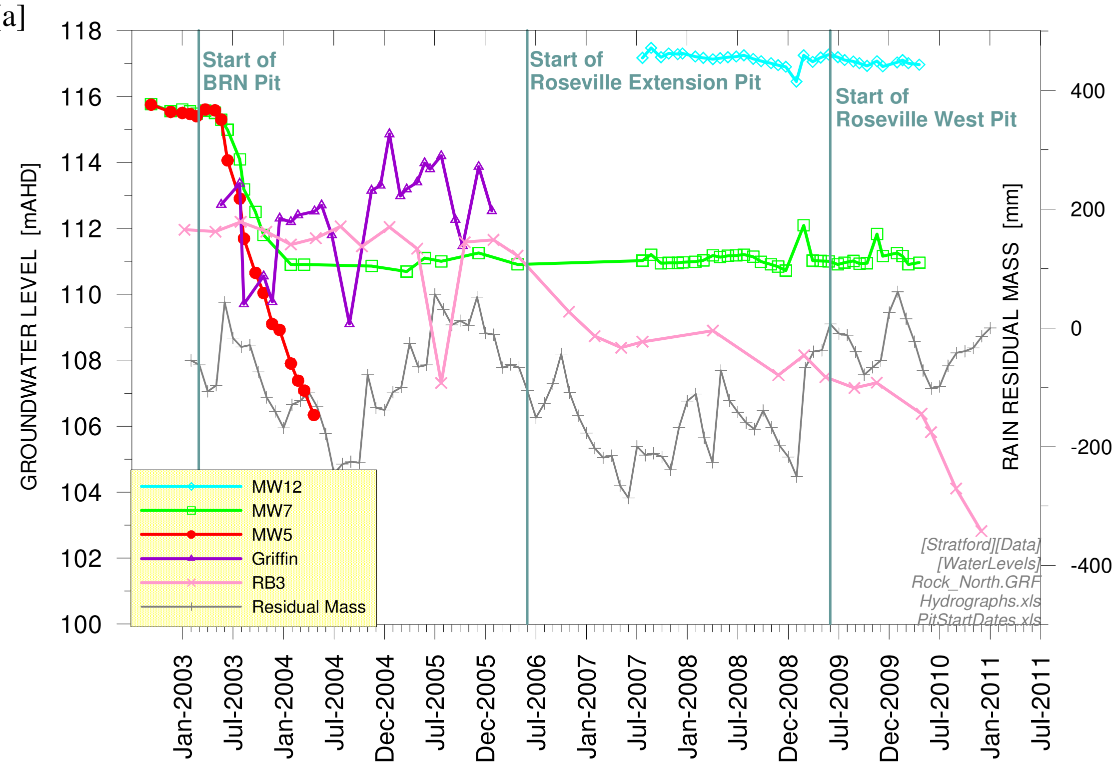


Figure A-18 Groundwater Hydrographs in Regolith: [a] north; [b] south

[a]



[b]

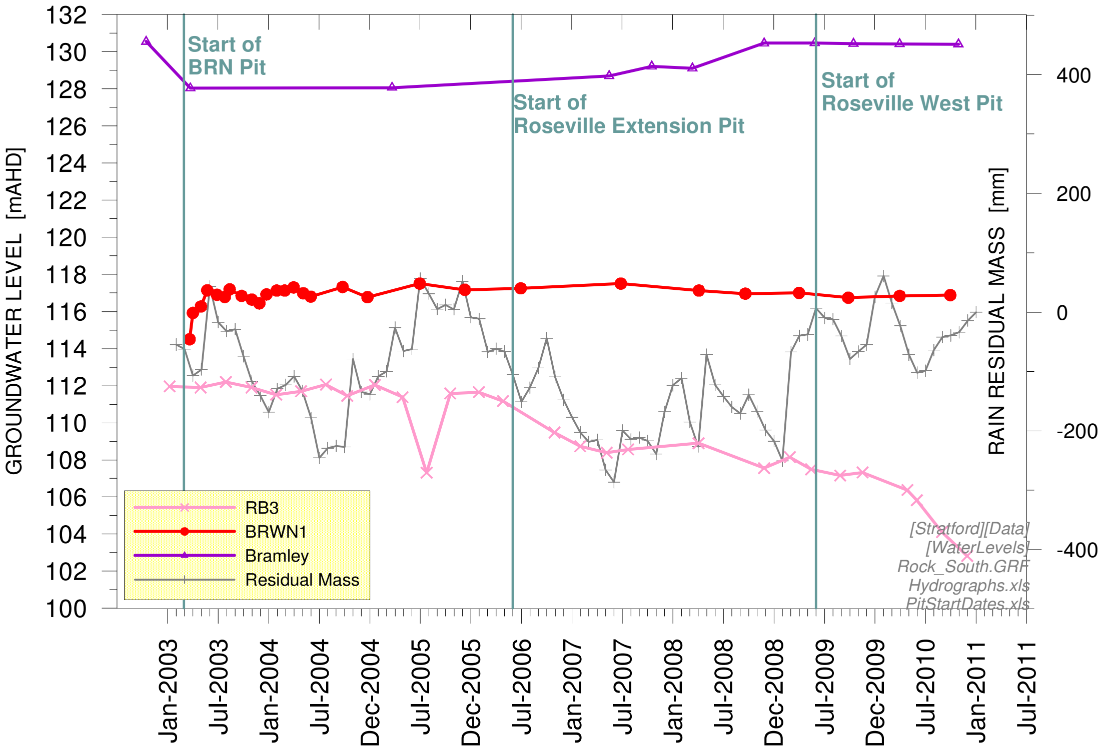
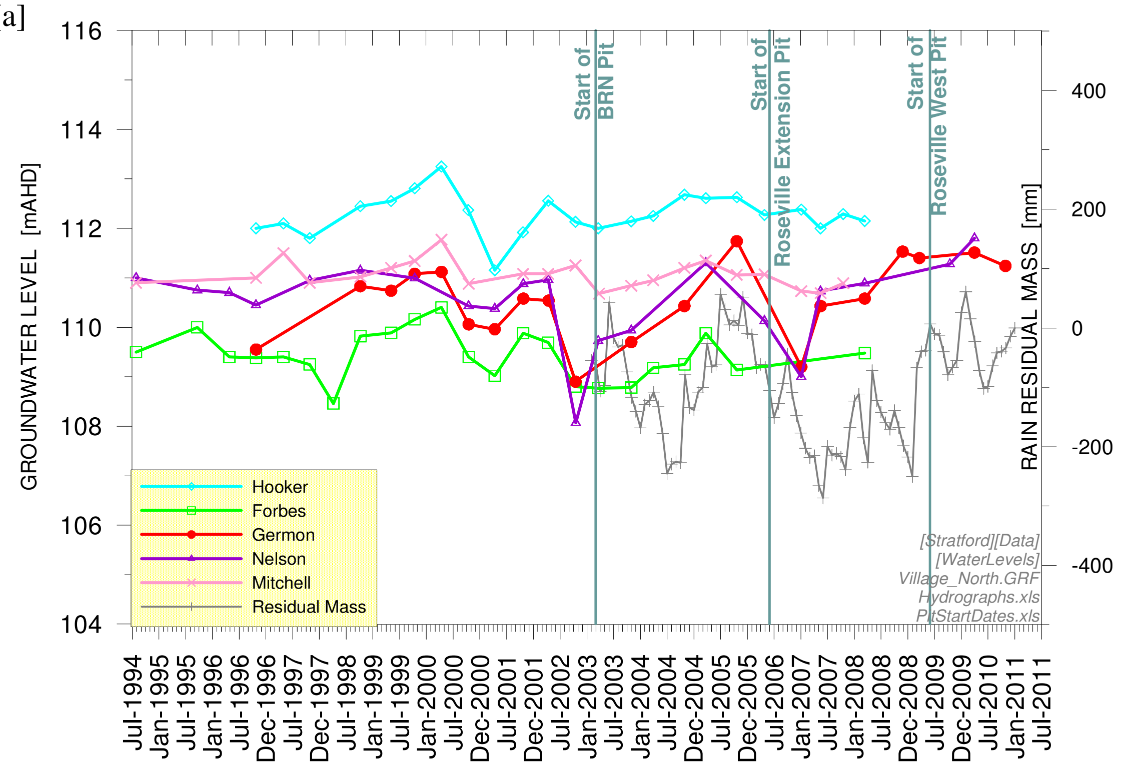


Figure A-19 Groundwater Hydrographs in Interburden: [a] north; [b] south

[a]



[b]

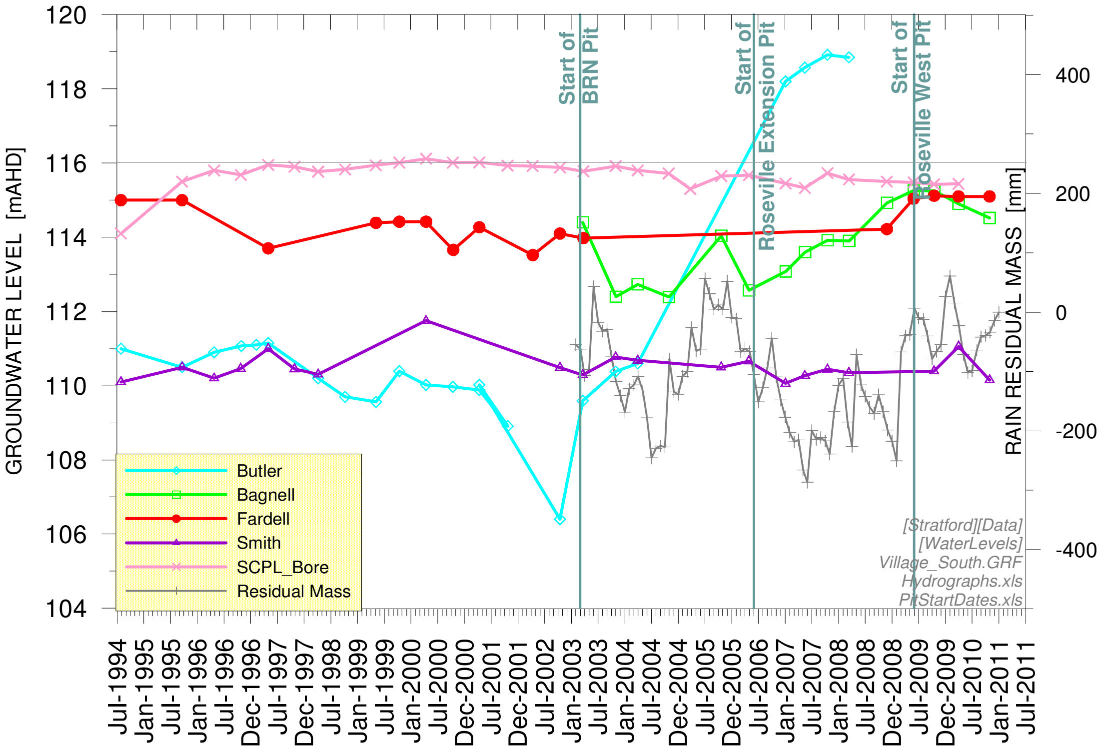


Figure A-20 Groundwater Hydrographs at Stratford Village: [a] north; [b] south

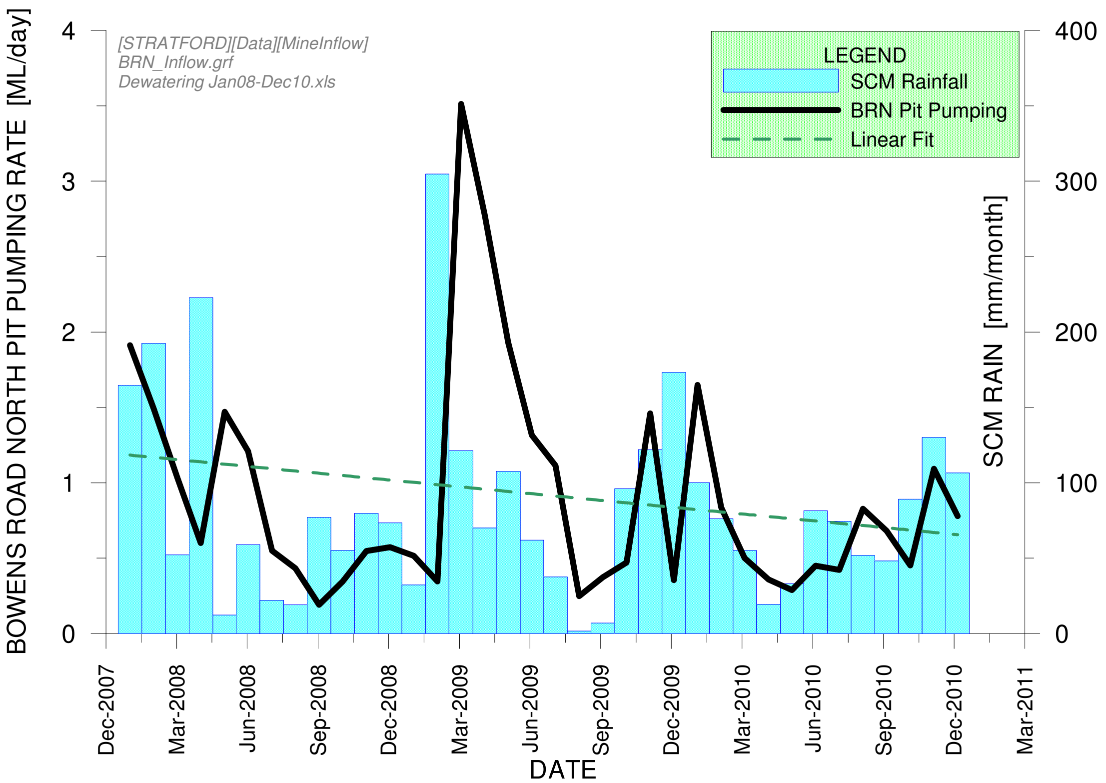


Figure A-21 Recorded Pumping Rates from the Bowens Road North Pit [ML/day]

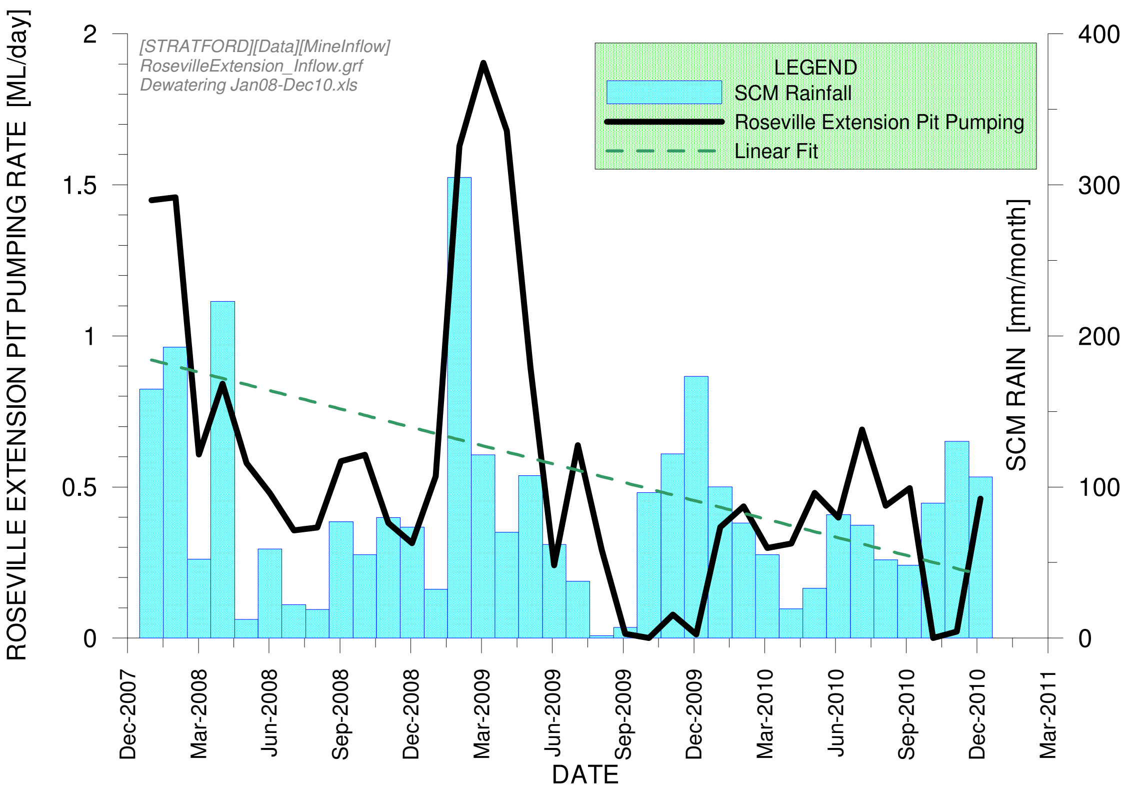


Figure A-22 Recorded Pumping Rates from the Roseville Extension Pit [ML/day]

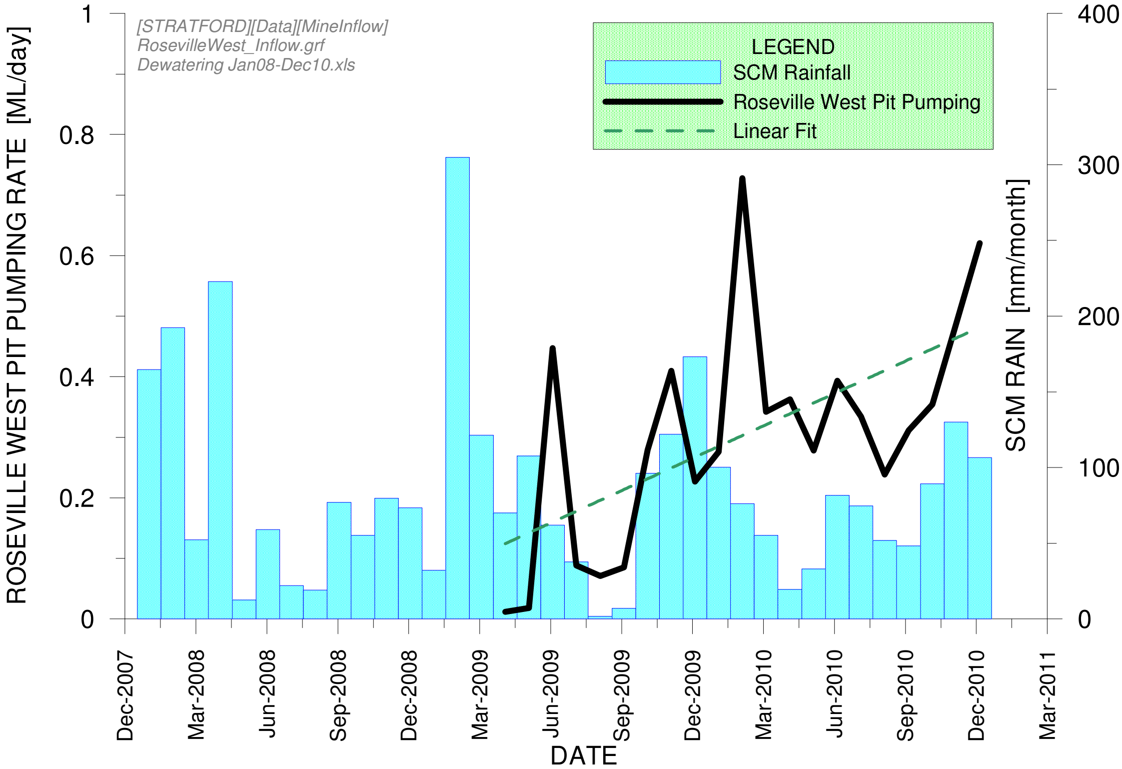


Figure A-23 Recorded Pumping Rates from the Roseville West Pit [ML/day]

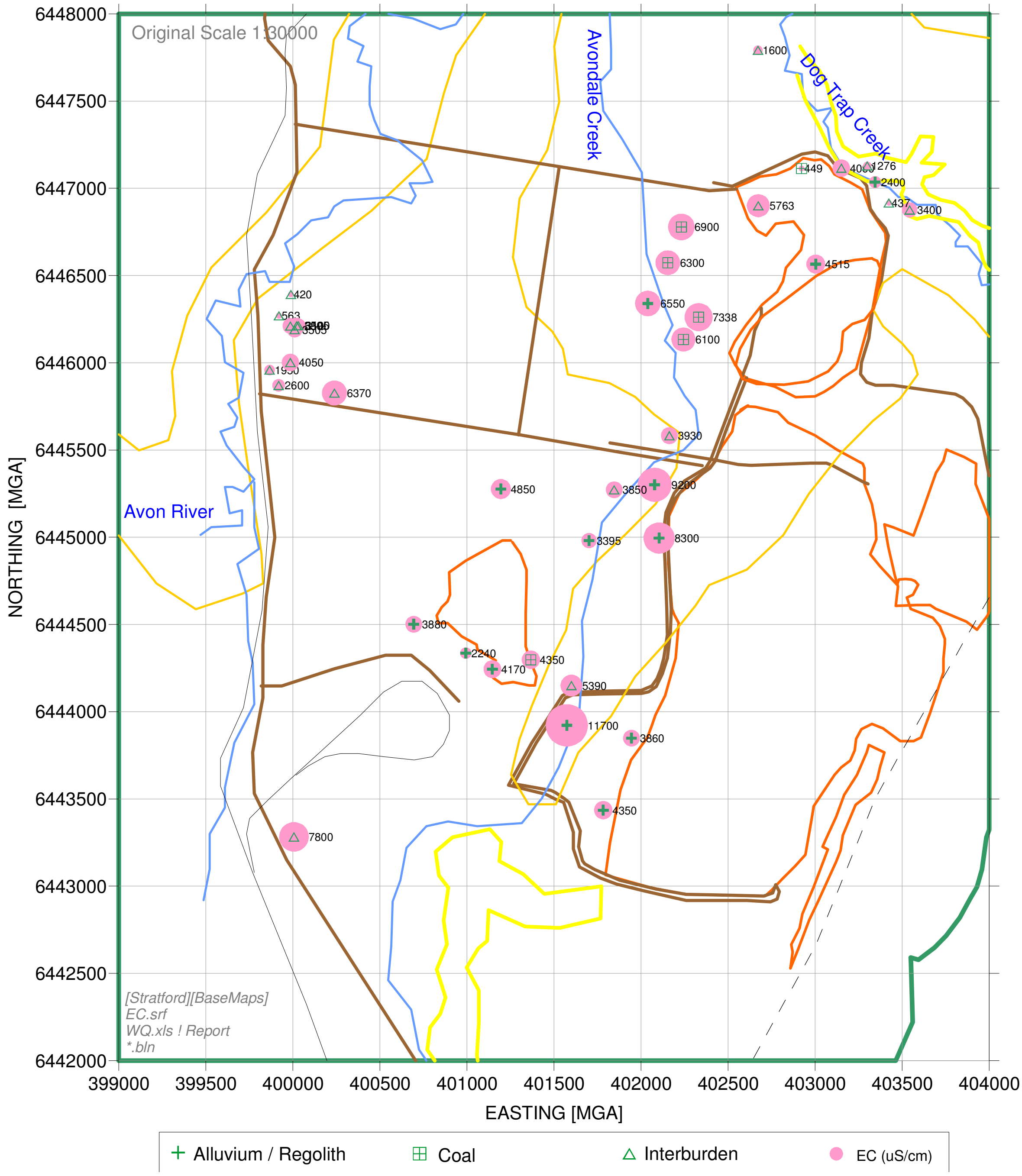


Figure A-24 Spatial Distribution of Groundwater Electrical Conductivity [µS/cm]

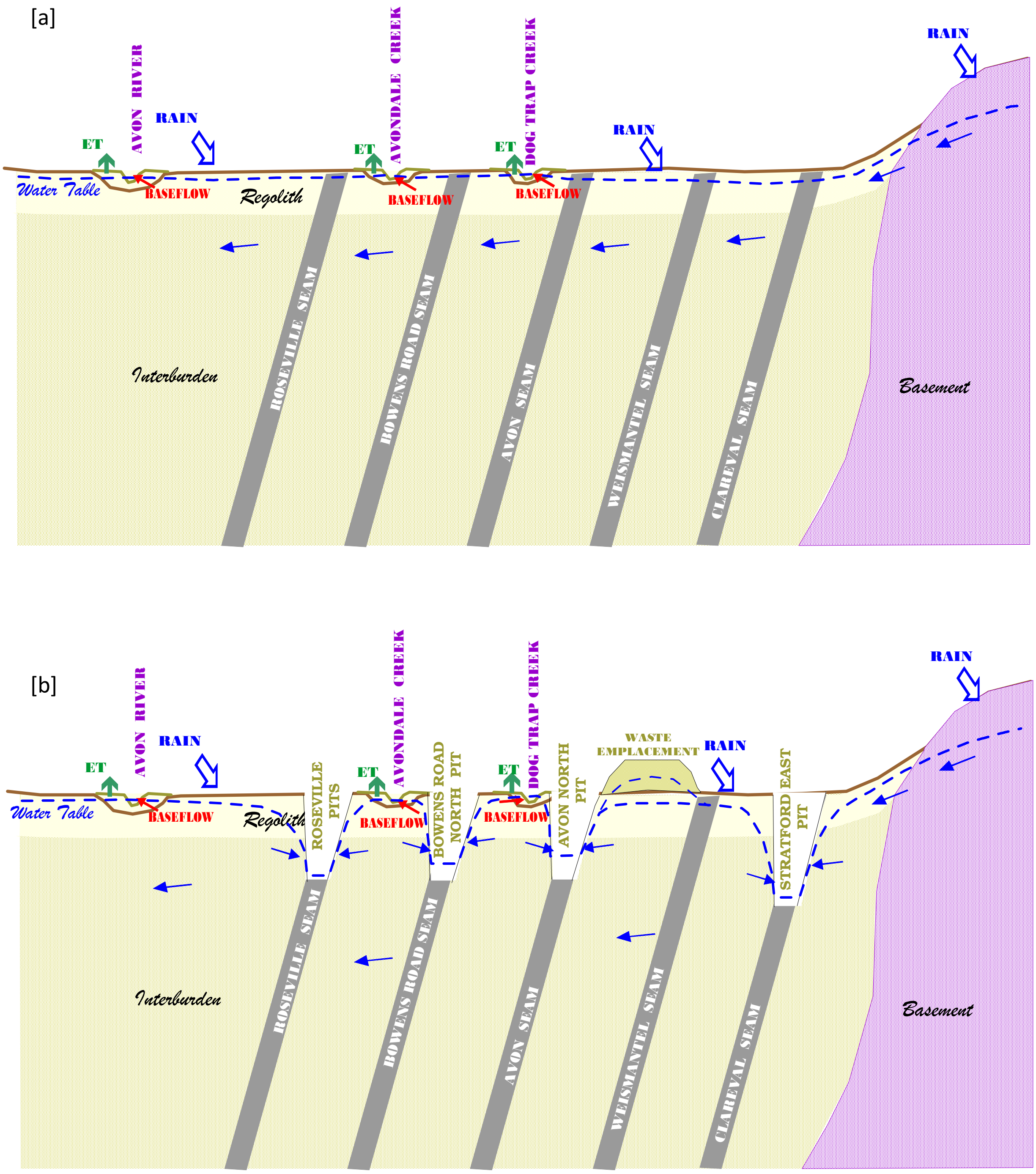


Figure A-25 Conceptual Groundwater Models [a] Natural conditions; [b] During mining.

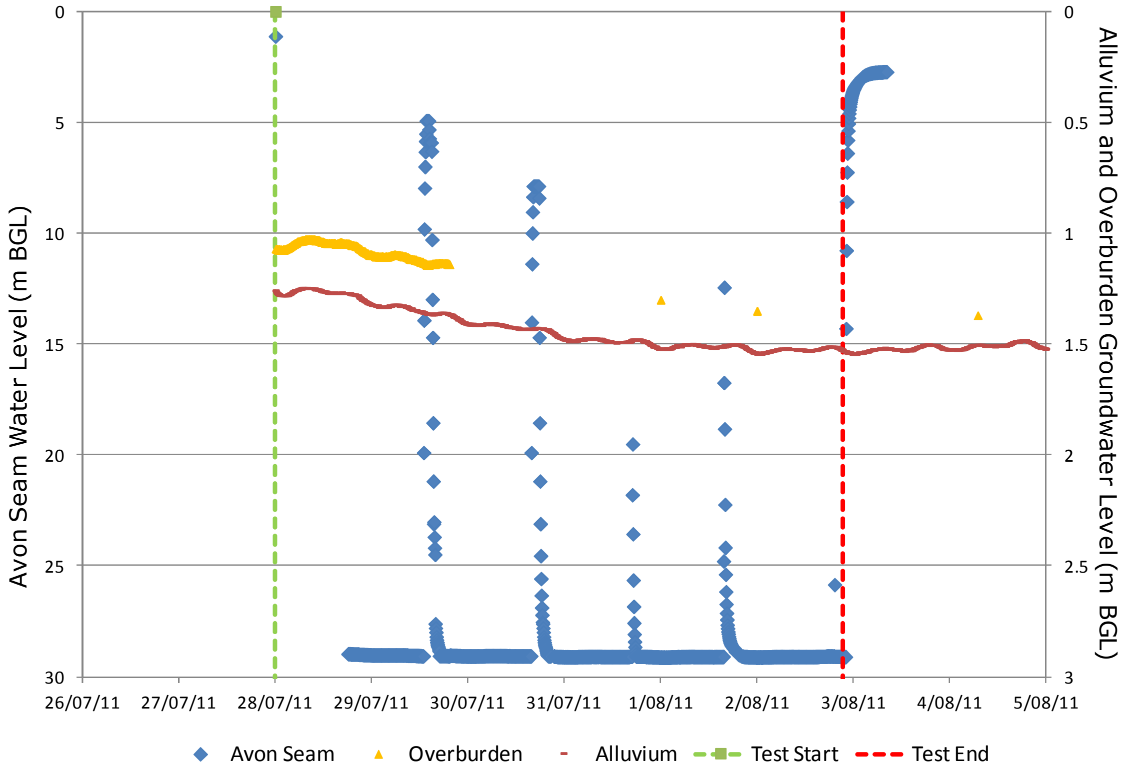


Figure A-26 Pumping Test at Dog Trap Creek (Source RPS Aquaterra, 2011)

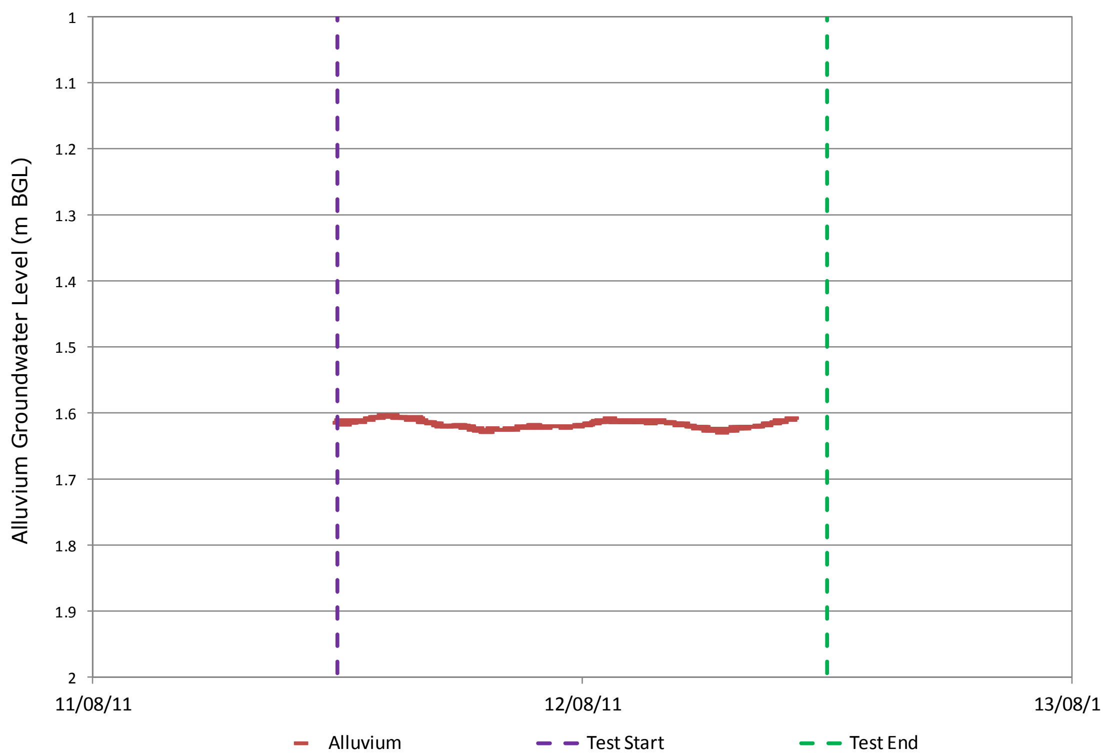


Figure A-27 Pumping Test Restart at Dog Trap Creek (Source RPS Aquaterra, 2011)

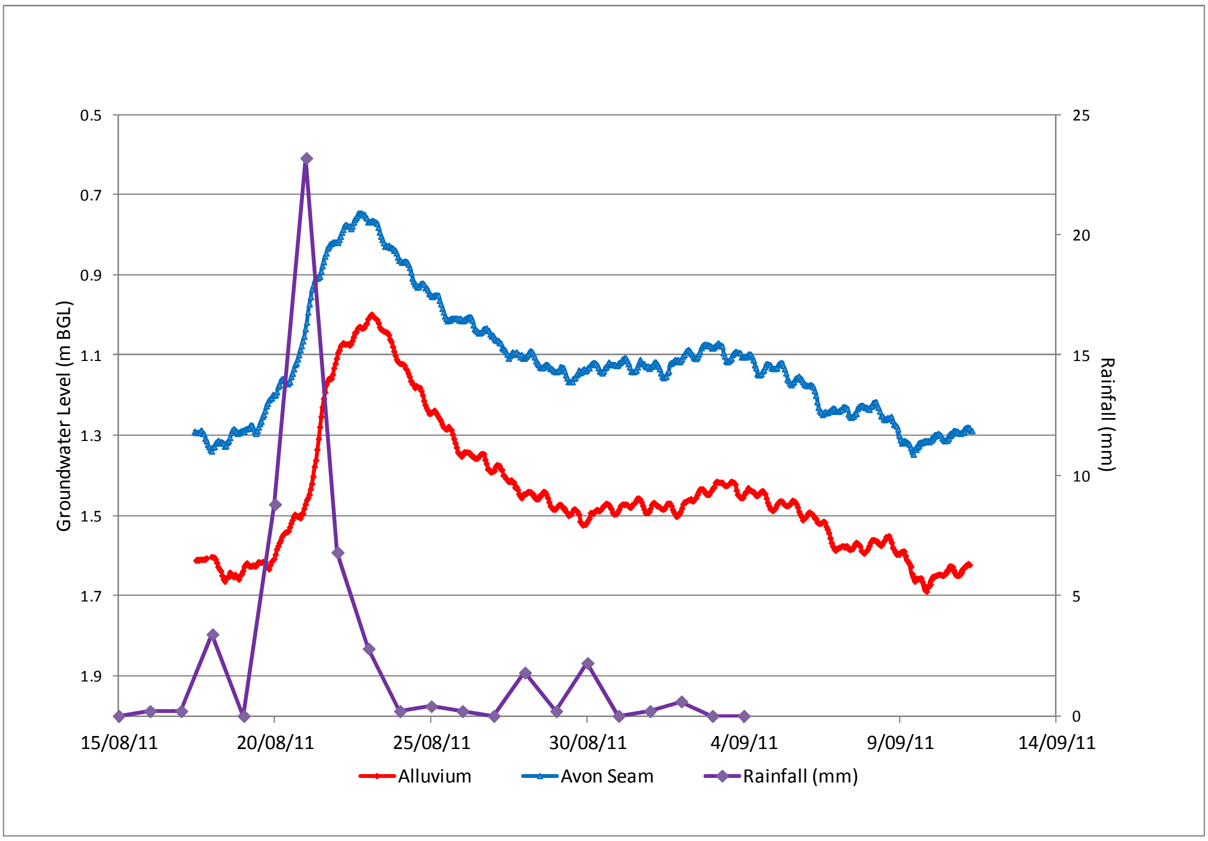
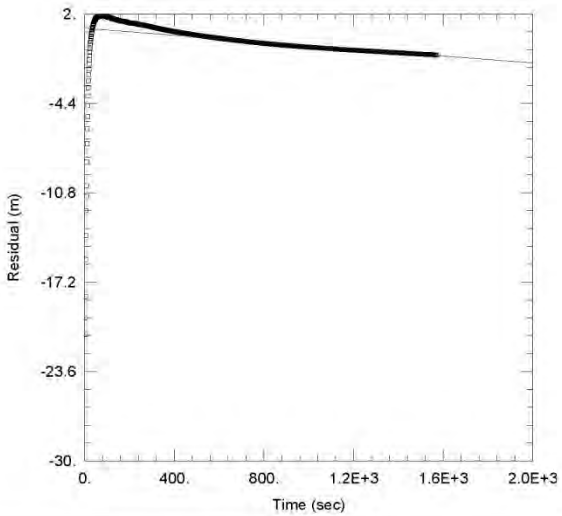


Figure A-28 Monitoring at Dog Trap Creek - (Source RPS Aquaterra, 2011)



WELL TEST ANALYSIS

Data Set: C:\GCL\PB1 Pump Test Drawdown.aqt
Date: 09/15/11 Time: 08:12:14

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: PB1

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
New Well	0	0

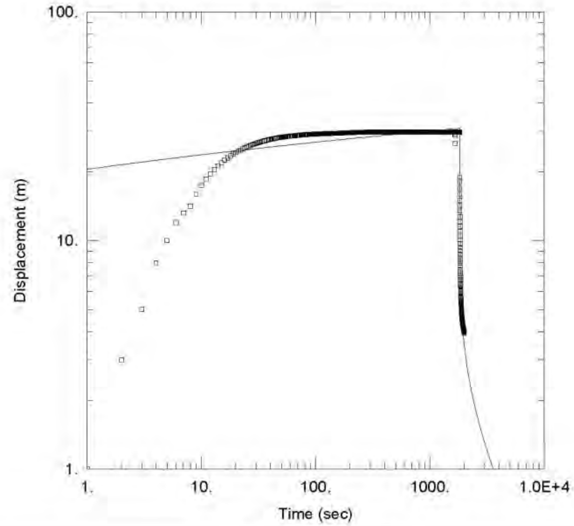
Observation Wells

Well Name	X (m)	Y (m)
▫ New Well	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 1.435 m^2/day
S = 1.0E-10
Kz/Kr = 0.5
b = 10. m



WELL TEST ANALYSIS

Data Set: C:\GCL\PB1 Pump Test and Recovery.aqt
Date: 09/15/11 Time: 08:13:43

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: PB1

WELL DATA

Pumping Wells

Well Name	X (m)	Y (m)
New Well	0	0

Observation Wells

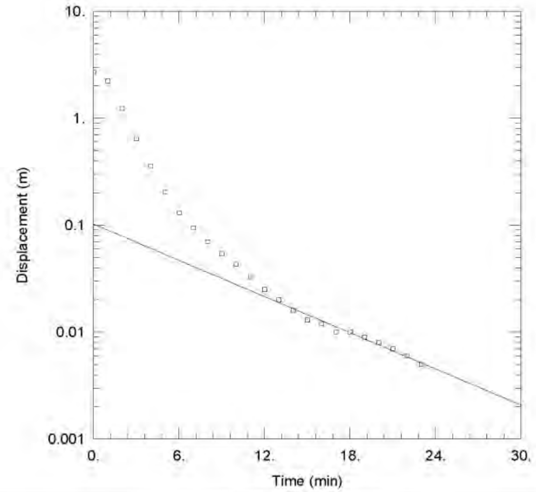
Well Name	X (m)	Y (m)
▫ New Well	0	0

SOLUTION

Aquifer Model: Confined
Solution Method: Theis

T = 1.233 m^2/day
S = 3.121E-9
Kz/Kr = 0.1
b = 6. m

Figure A-29 Groundwater Investigation – Pumping Test (PB1) Drawdown and Recovery (Source RPS Aquaterra, 2011)



WELL TEST ANALYSIS

Data Set: C:\GCL\NS593R.aqt
Date: 09/15/11 Time: 06:52:24

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: NS593R

AQUIFER DATA

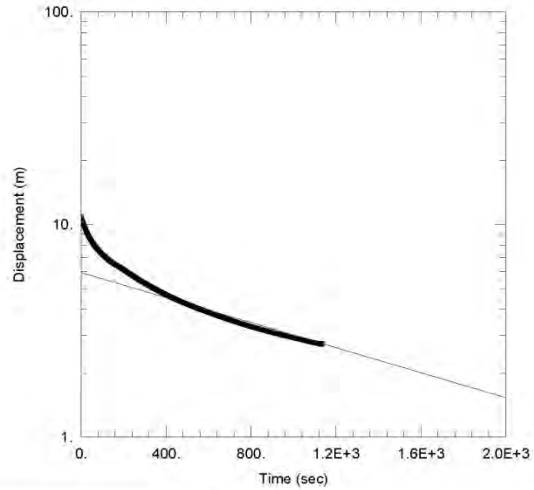
Saturated Thickness: 6. m Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (New Well)

Initial Displacement: 2.7 m
Total Well Penetration Depth: 29. m
Casing Radius: 0.025 m
Static Water Column Height: 25. m
Screen Length: 6. m
Well Radius: 0.025 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Confined Solution Method: Bouwer-Rice
K = 0.05191 m/day y0 = 0.1023 m



WELL TEST ANALYSIS

Data Set: C:\GCL\NS596R.aqt
Date: 09/15/11 Time: 06:55:39

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: NS596R

AQUIFER DATA

Saturated Thickness: 6. m Anisotropy Ratio (Kz/Kr): 0.1

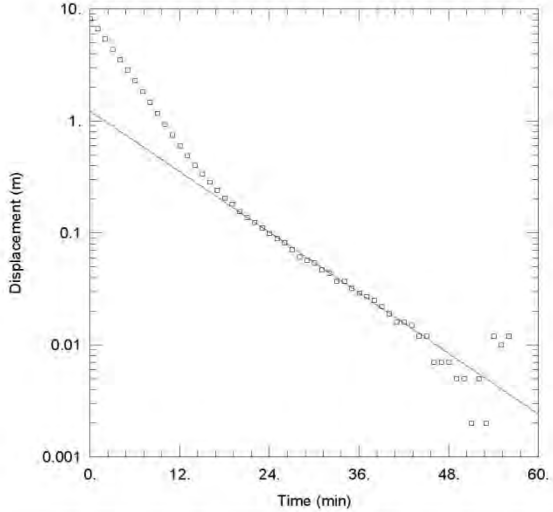
WELL DATA (New Well)

Initial Displacement: 10.93 m
Total Well Penetration Depth: 42. m
Casing Radius: 0.025 m
Static Water Column Height: 20. m
Screen Length: 3. m
Well Radius: 0.025 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev
K = 0.04043 m/day y0 = 5.936 m

Figure A-30 Groundwater Investigation – Slug Test Results 1 (Source RPS Aquaterra, 2011)



WELL TEST ANALYSIS

Data Set: C:\GCL\NS592R.aqt
Date: 09/15/11 Time: 06:49:36

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: NS592R

AQUIFER DATA

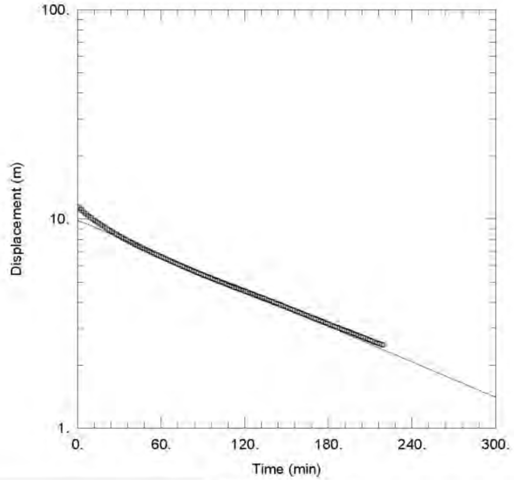
Saturated Thickness: 10. m Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (New Well)

Initial Displacement: 8.183 m
Total Well Penetration Depth: 48. m
Casing Radius: 0.025 m
Static Water Column Height: 40. m
Screen Length: 10. m
Well Radius: 0.025 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 0.02476 m/day y0 = 1.226 m



WELL TEST ANALYSIS

Data Set: C:\GCL\NS583.aqt
Date: 09/15/11 Time: 07:00:07

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: NS583

AQUIFER DATA

Saturated Thickness: 6. m Anisotropy Ratio (Kz/Kr): 1.

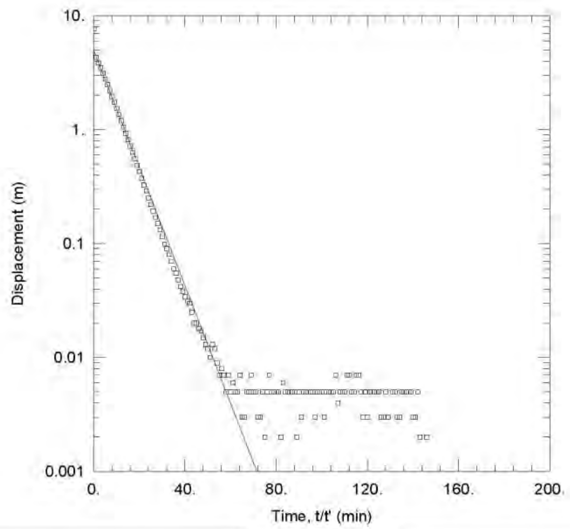
WELL DATA (New Well)

Initial Displacement: 11.4 m
Total Well Penetration Depth: 37. m
Casing Radius: 0.025 m
Static Water Column Height: 25.5 m
Screen Length: 6. m
Well Radius: 0.025 m
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 0.002584 m/day y0 = 9.87 m

Figure A-31 Groundwater Investigation – Slug Test Results 2 (Source RPS Aquaterra, 2011)



WELL TEST ANALYSIS

Data Set: C:\GCL\GC207R.aqt
Date: 09/15/11 Time: 06:46:53

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: GC207R

AQUIFER DATA

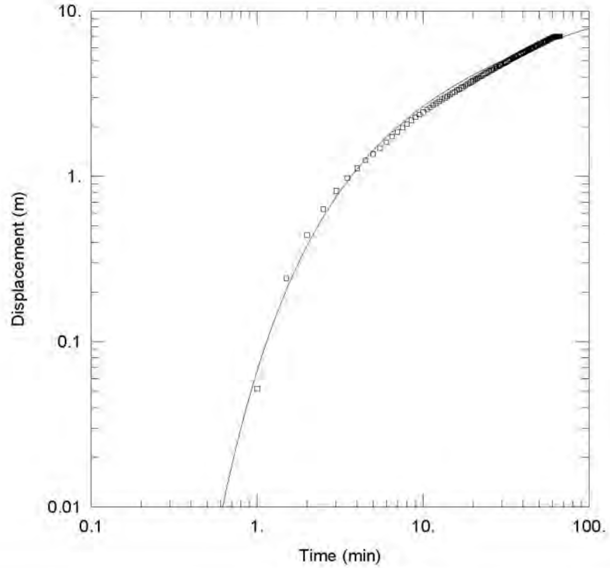
Saturated Thickness: 6. m Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA (New Well)

Initial Displacement: 7.7 m
Total Well Penetration Depth: 50. m
Casing Radius: 0.025 m
Static Water Column Height: 42.3 m
Screen Length: 6. m
Well Radius: 0.025 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 0.04734 m/day y0 = 4.973 m



WELL TEST ANALYSIS

Data Set: C:\GCL\NS581B.aqt
Date: 09/15/11 Time: 07:43:26

PROJECT INFORMATION

Company: GCL
Client: GCL
Project: S146
Location: Stratford
Test Well: NS581B

WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (m)	Y (m)	Well Name	X (m)	Y (m)
New Well	0	5	□ New Well	0	12

SOLUTION

Aquifer Model: Confined Solution Method: Theis
T = 0.3311 m^2/day S = 4.59E-5
Kz/Kr = 0.5 b = 6. m

Figure A-32 Groundwater Investigation – Slug Test Results 3 (Source RPS Aquaterra, 2011)

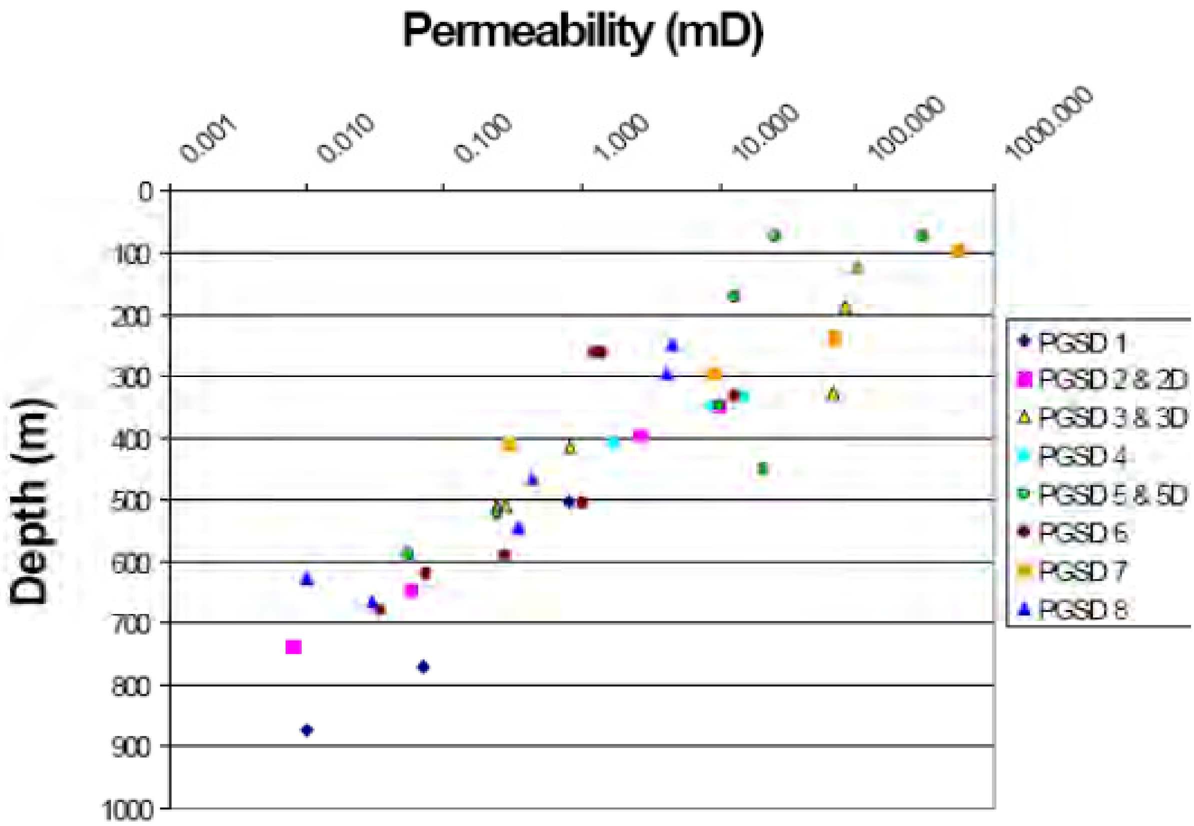


Figure A-33. Intrinsic Permeability Measurements of Coal Seams at Stratford in the Gloucester Basin [Source: Smith, 2001]

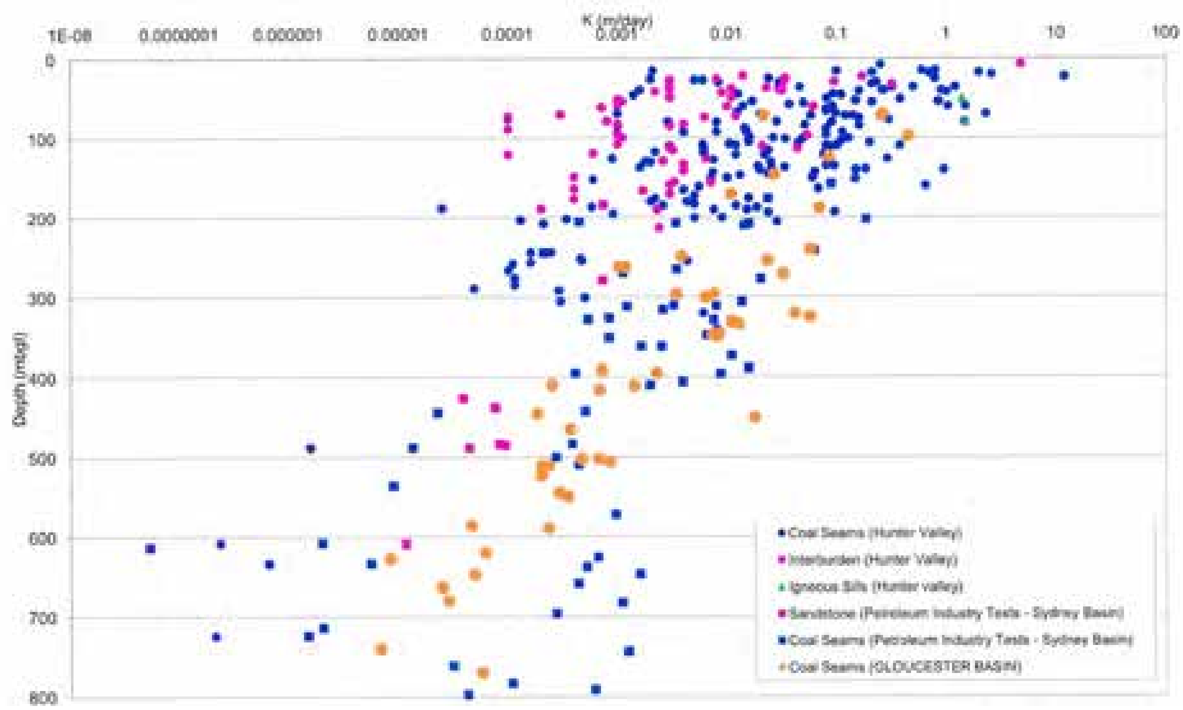


Figure A-34. Comparative Hydraulic Conductivity Measurements in the Gloucester Basin, Sydney Basin and Hunter Valley [Source: Tammetta, 2009]

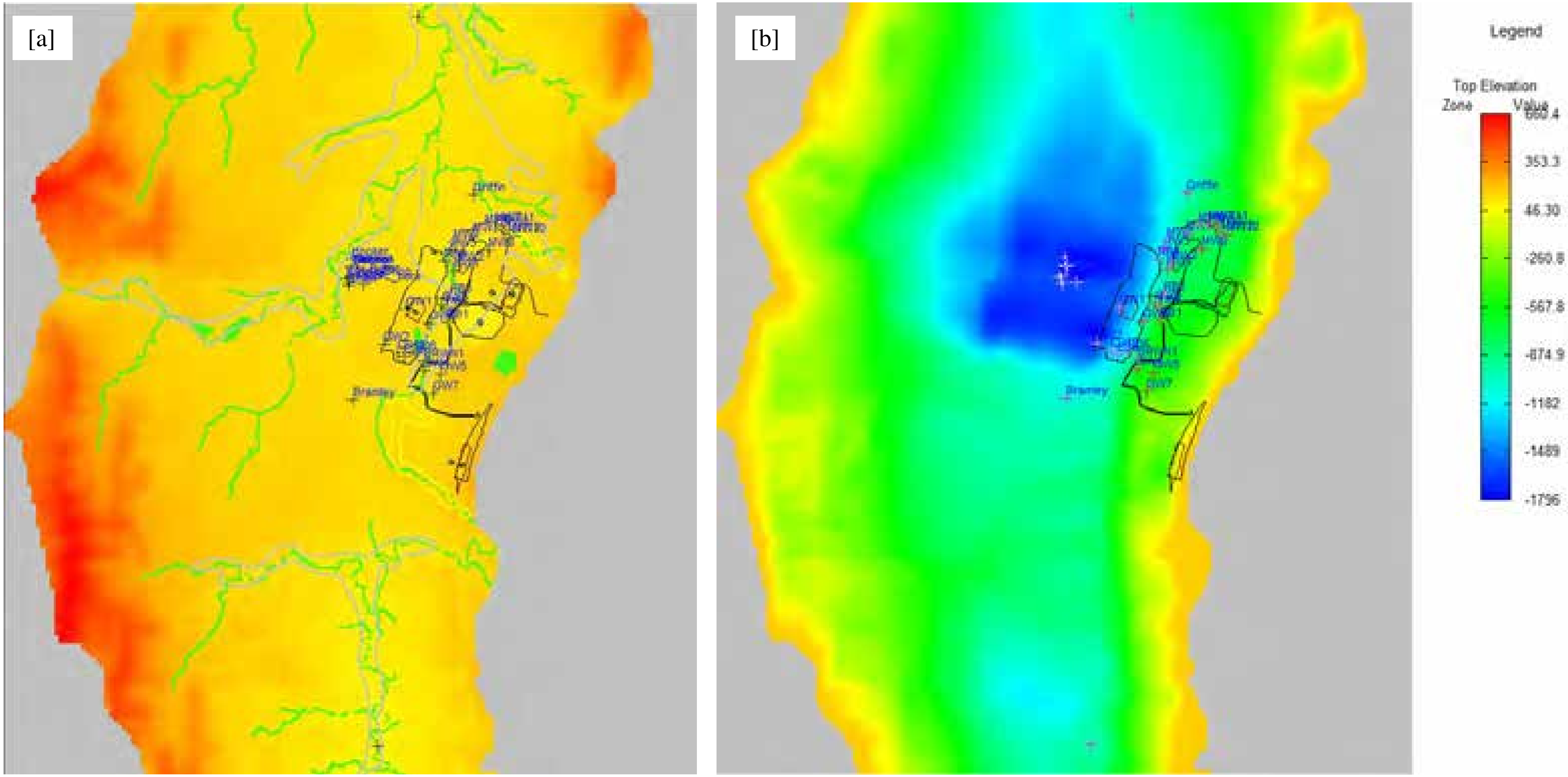
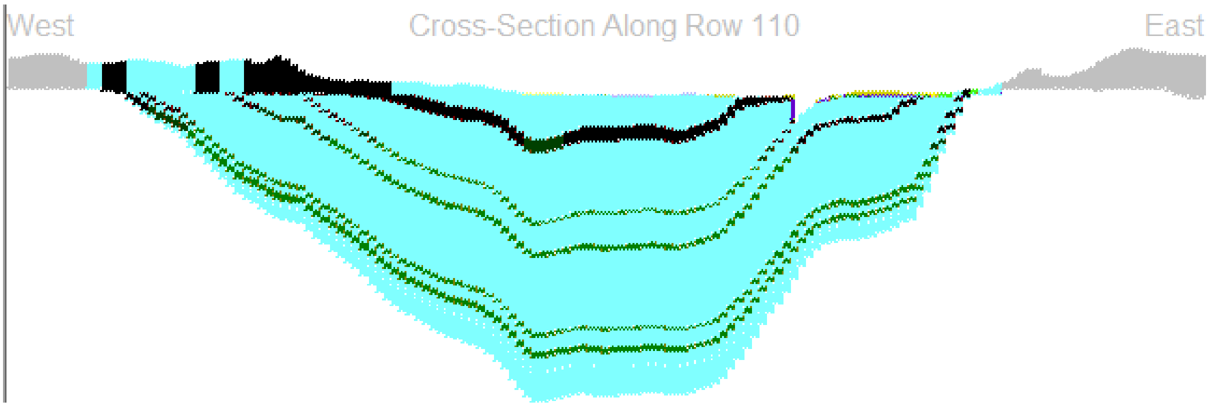
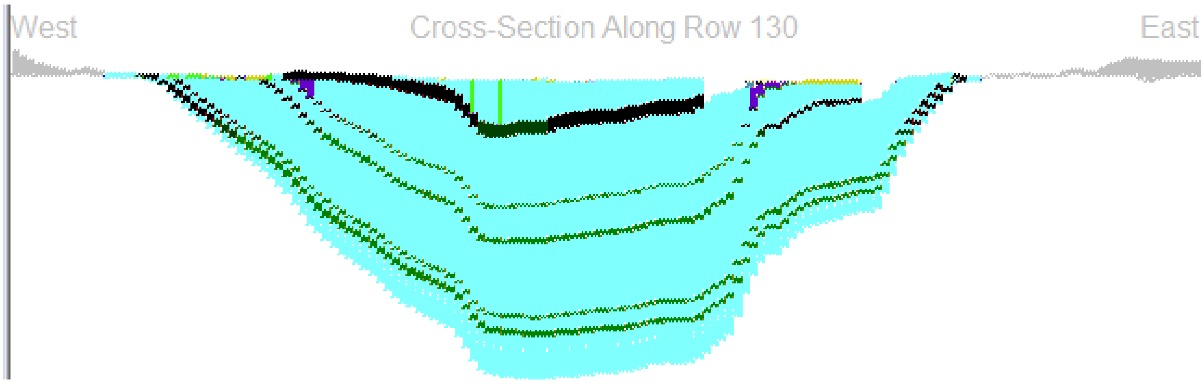


Figure A-35. Active Model Extent Showing [a] Layer 1 Land Surface Topography and Boundary Conditions, and [b] Elevations for the Top of Layer 13 [mAHD]

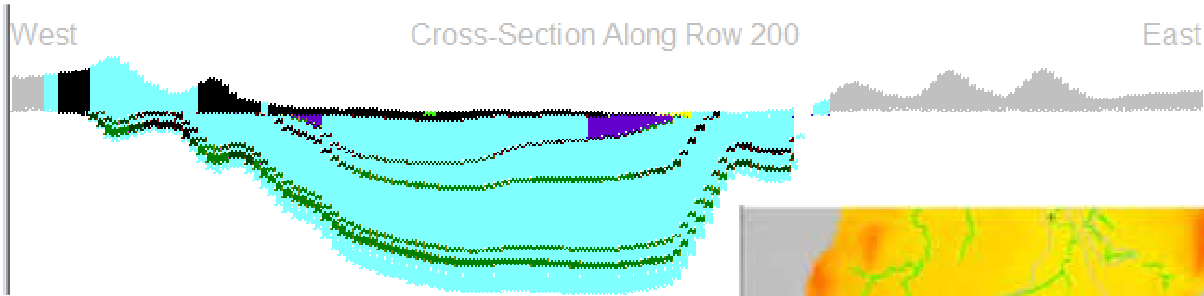
[a]



[b]



[c]



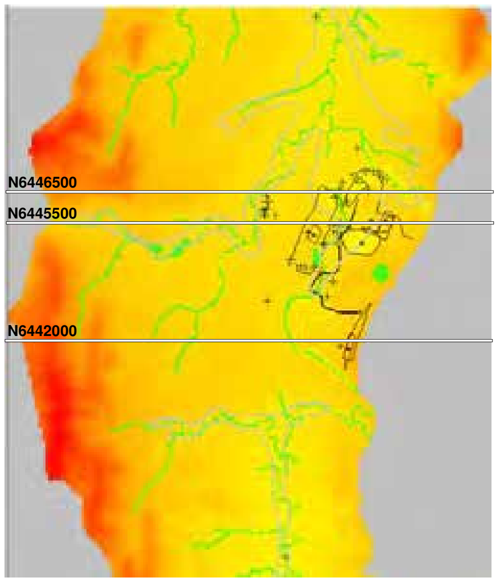
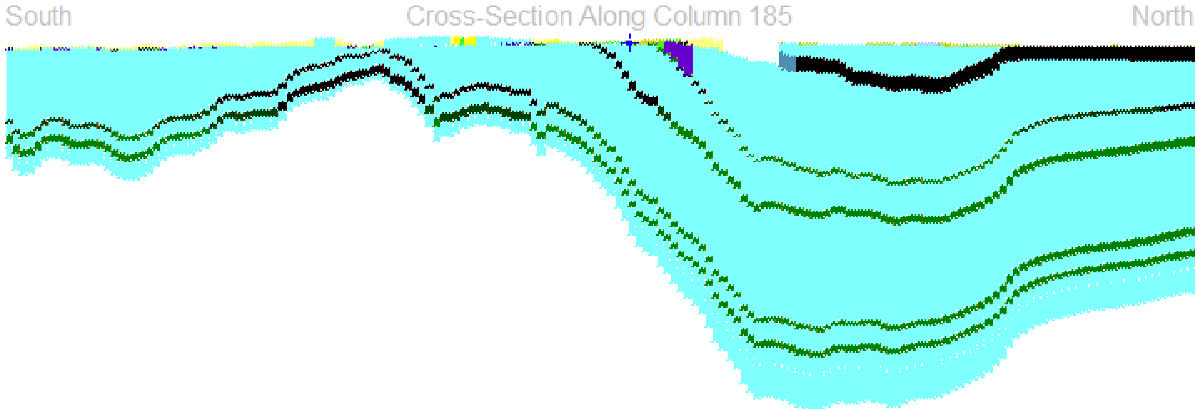
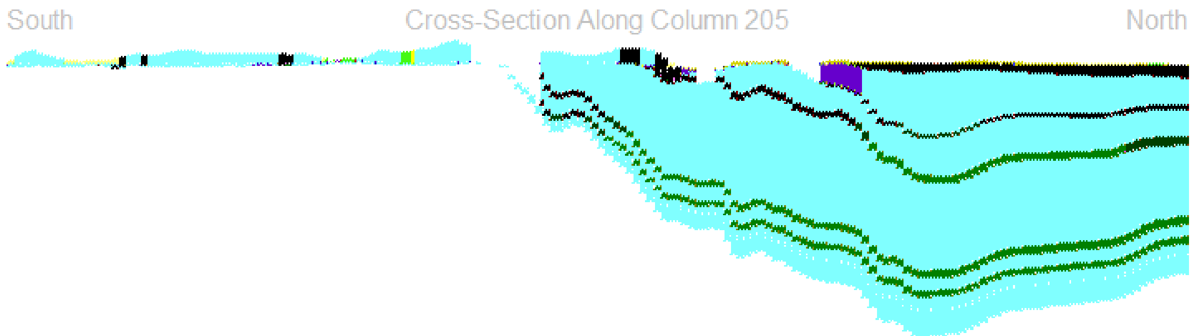


Figure A-36. Representative West-East Model Cross-Sections through [a] Bowens Road North Pit (Northing 6446500); [b] Roseville and Avon North Pits (Northing 6445500); and [c] Stratford East Pit (Northing 6442000)

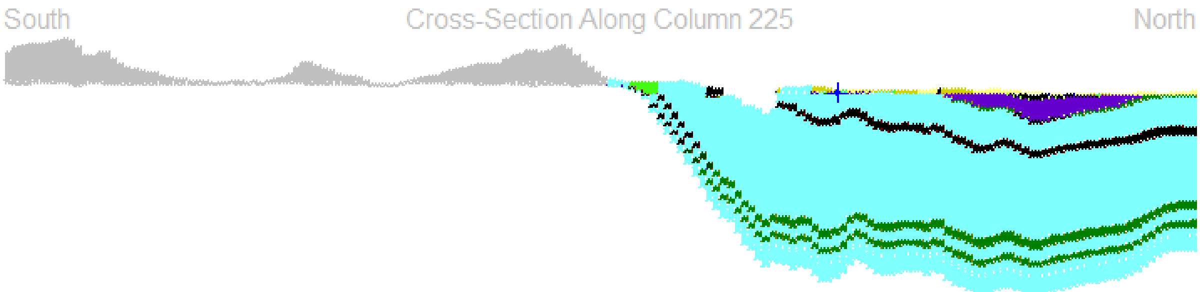
[a]



[b]



[c]



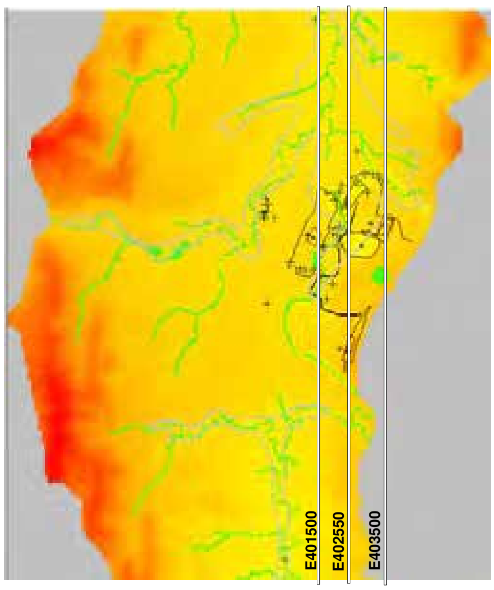


Figure A-37. Representative South-North Model Cross-Sections through [a] Roseville West Pit (Easting 401500); [b] Bowens Road North, Stratford Main and Stratford East Pits (Easting 402550); and [c] Avon North Pit and Stratford East Dam (Easting 403500)

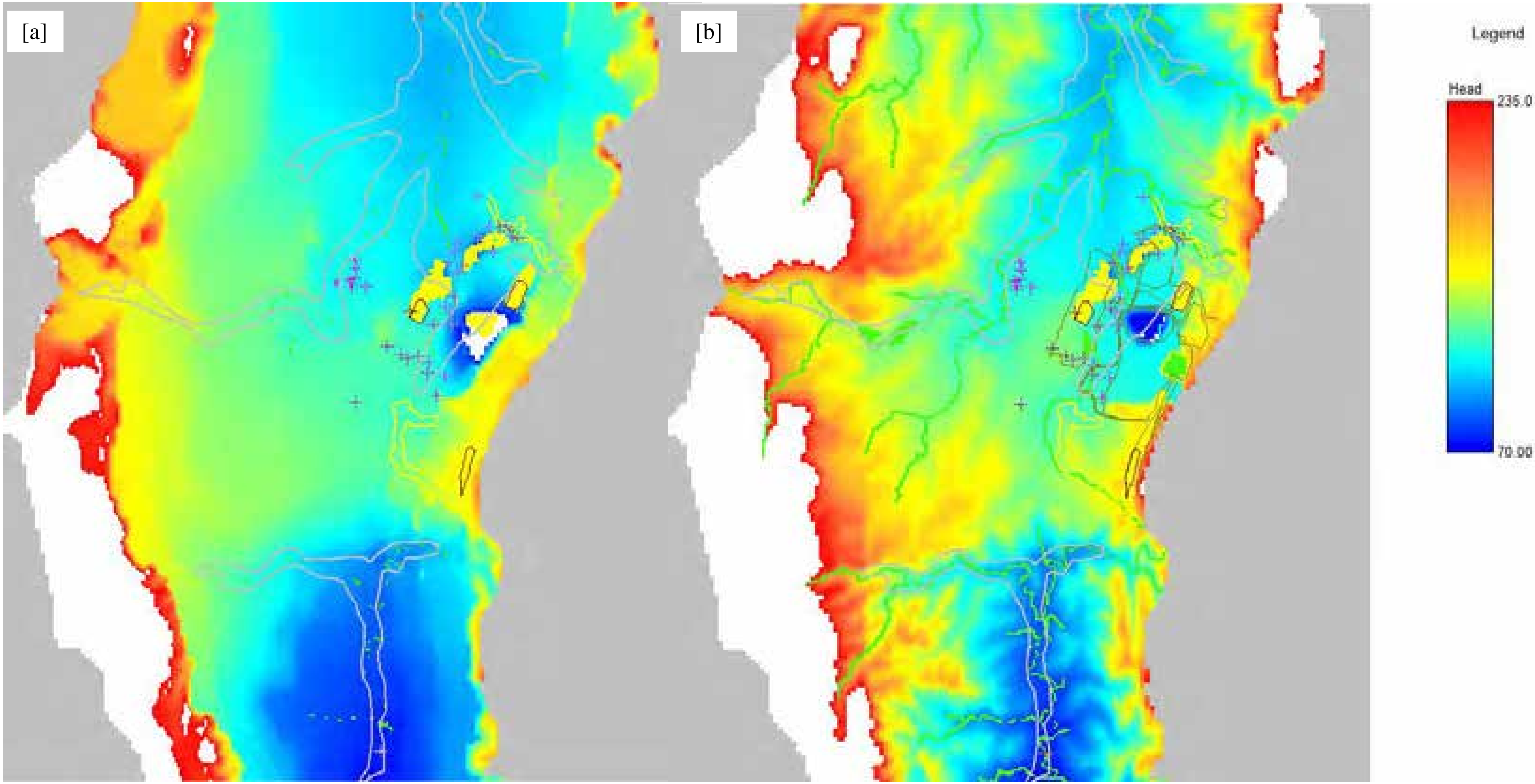


Figure A-38. Simulated Layer 1 Watertable Elevations at [a] Steady State; [b] End of Transient Calibration Period (June 2010) [mAHD]

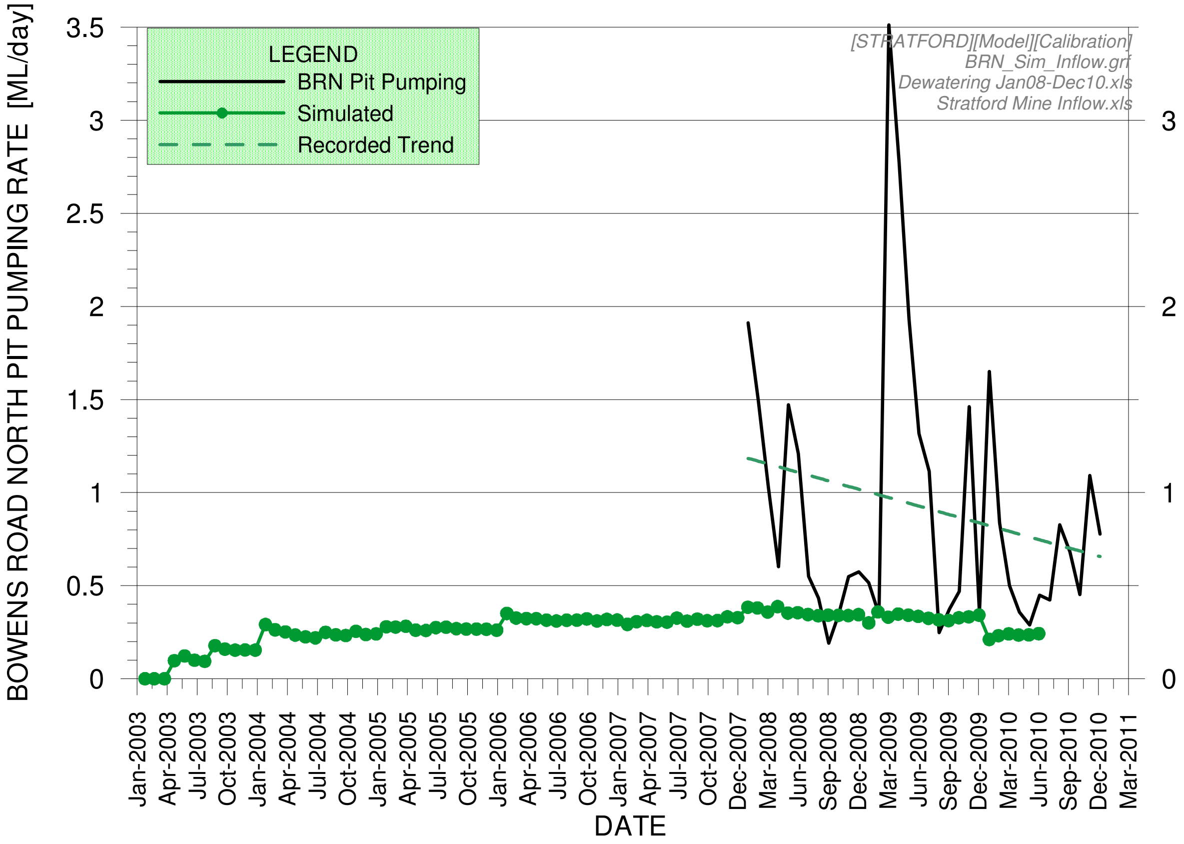


Figure A-39. Bowens Road North Pit Inflow Simulated during the Calibration Period

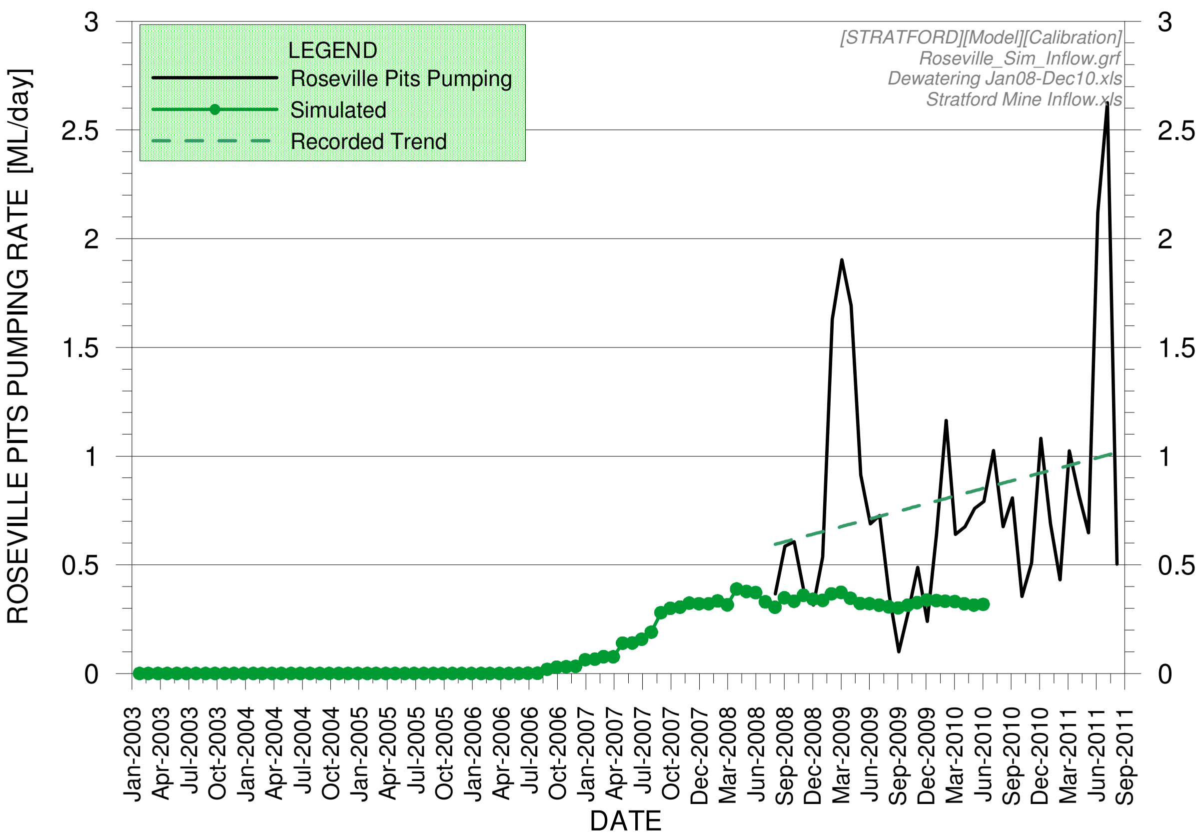


Figure A-40. Combined Roseville Pits Inflow Simulated during the Calibration Period

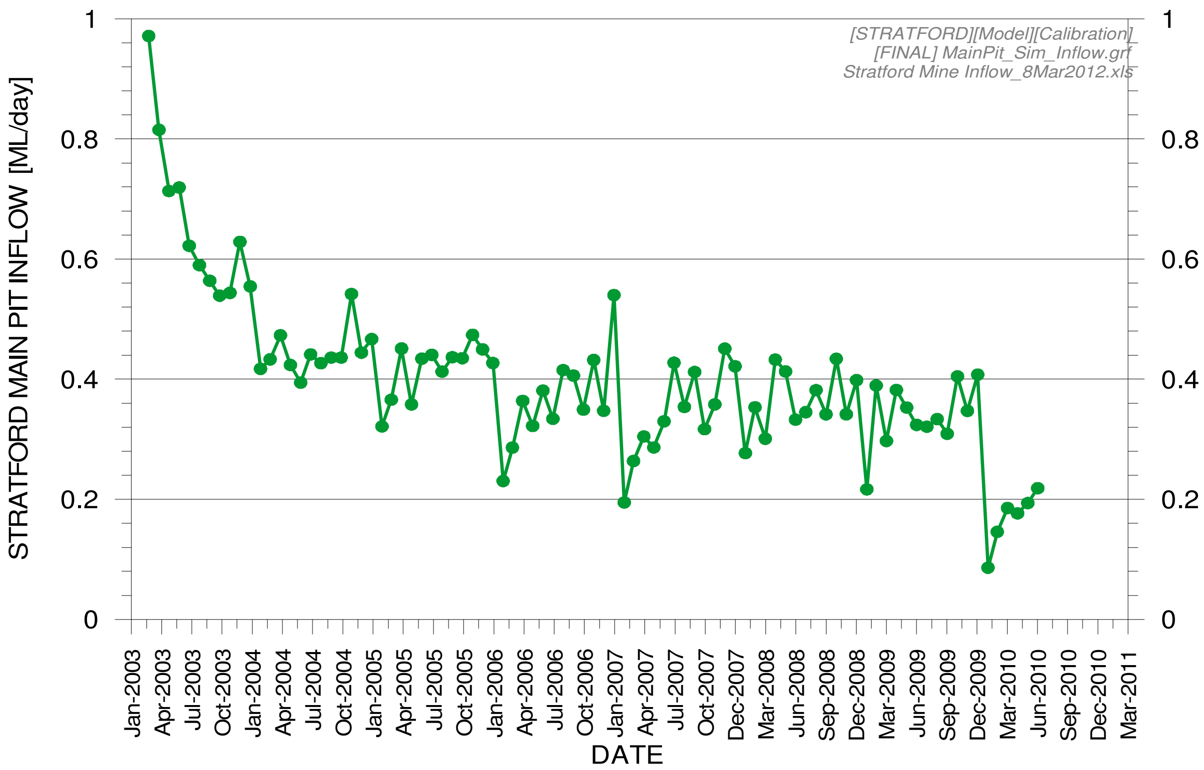


Figure A-41. Stratford Main Pit Inflow Simulated during the Calibration Period

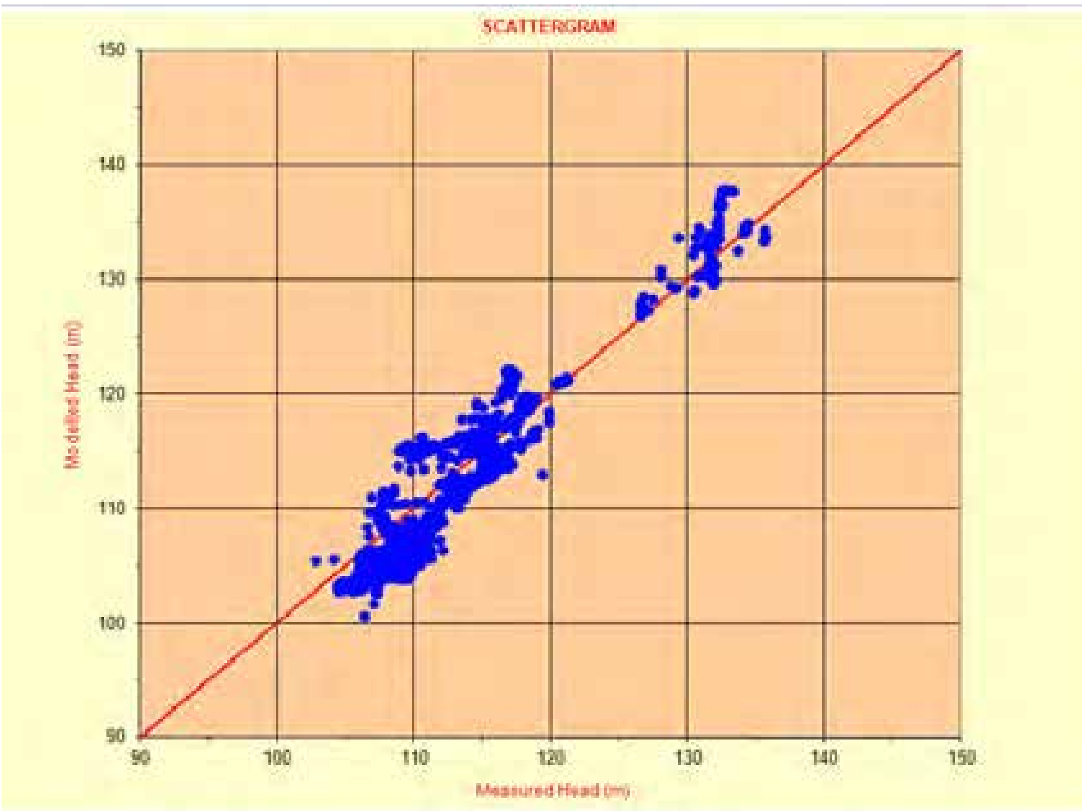
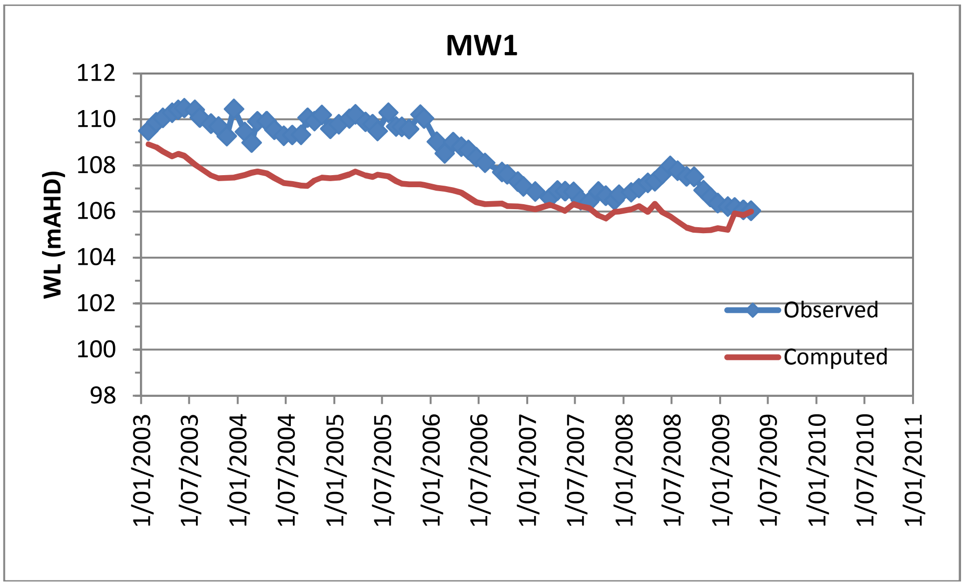


Figure A-42. Scattergram of Simulated and Measured Heads for Transient Calibration



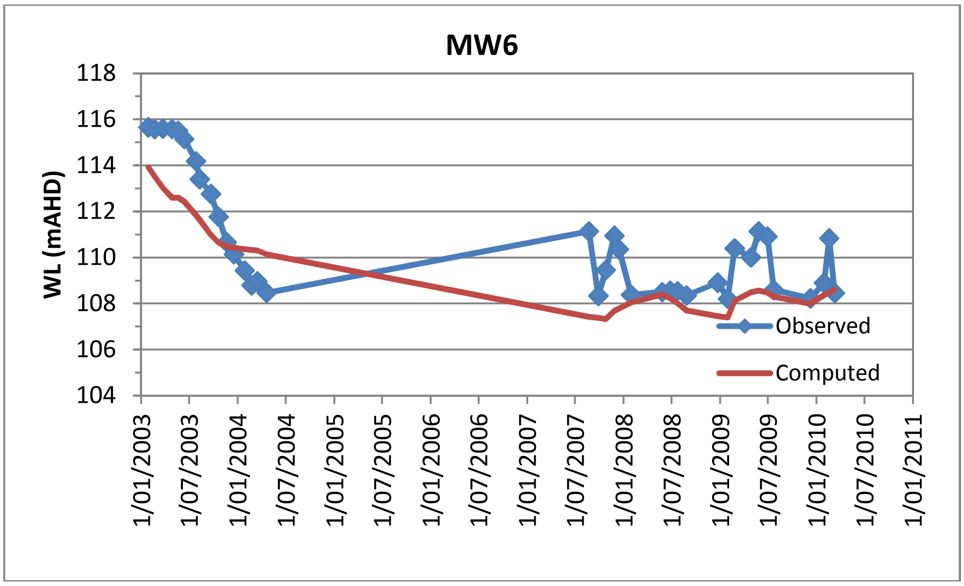
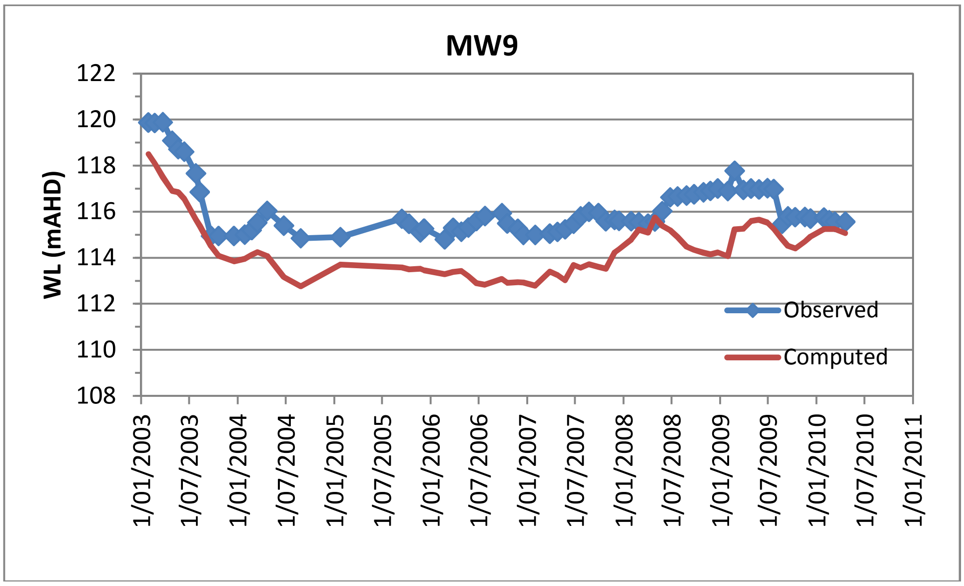


Figure A-43. Representative Simulated and Measured Hydrographs at Bores Screened in Coal [MW1 and MW6]



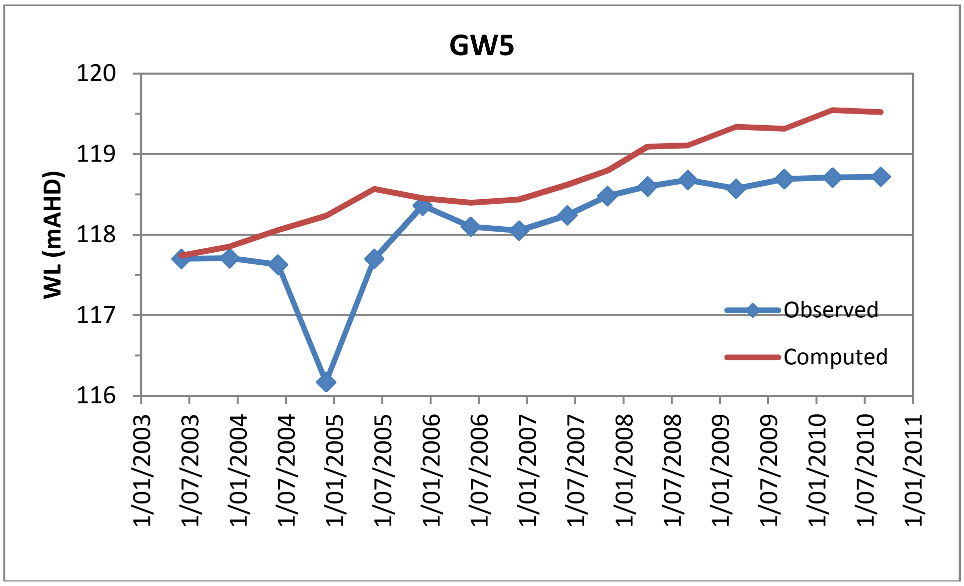
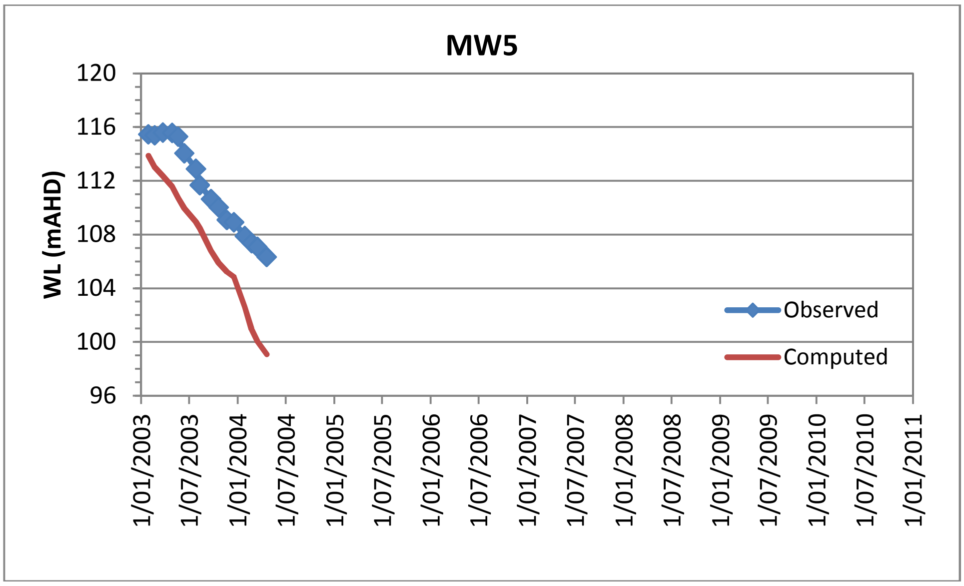


Figure A-44. Representative Simulated and Measured Hydrographs at Bores Screened in Regolith [MW9 and GW5]



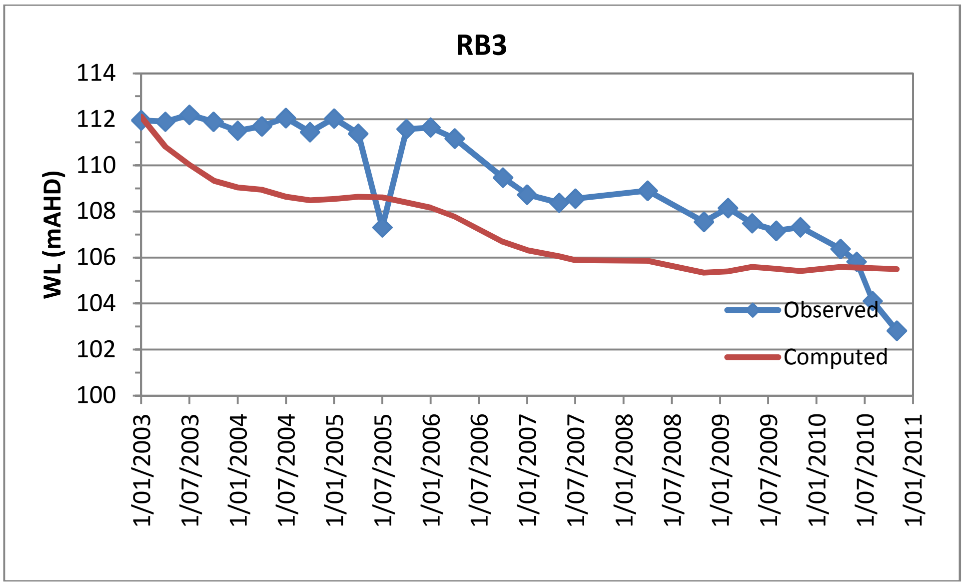
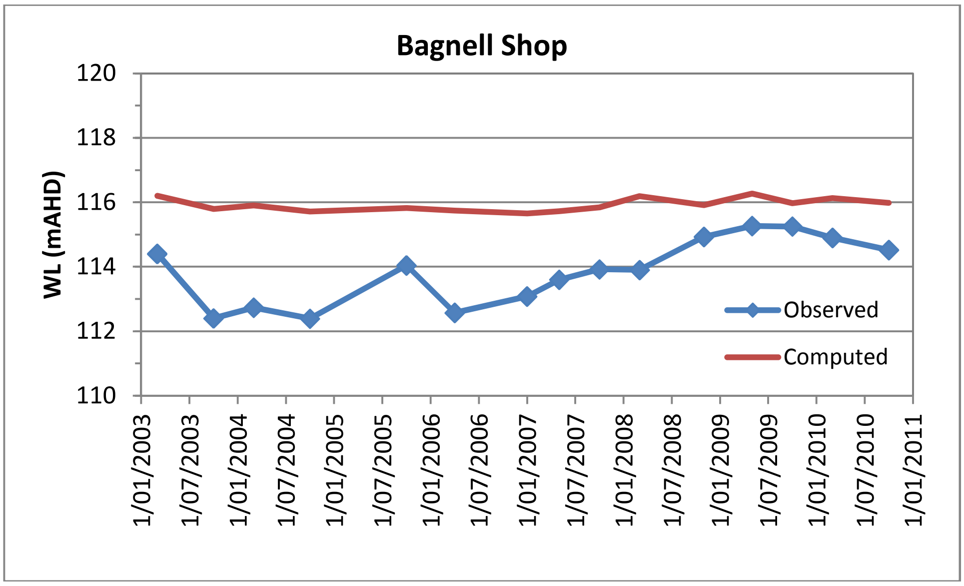


Figure A-45. Representative Simulated and Measured Hydrographs at Bores Screened in Interburden [MW5 and RB3]



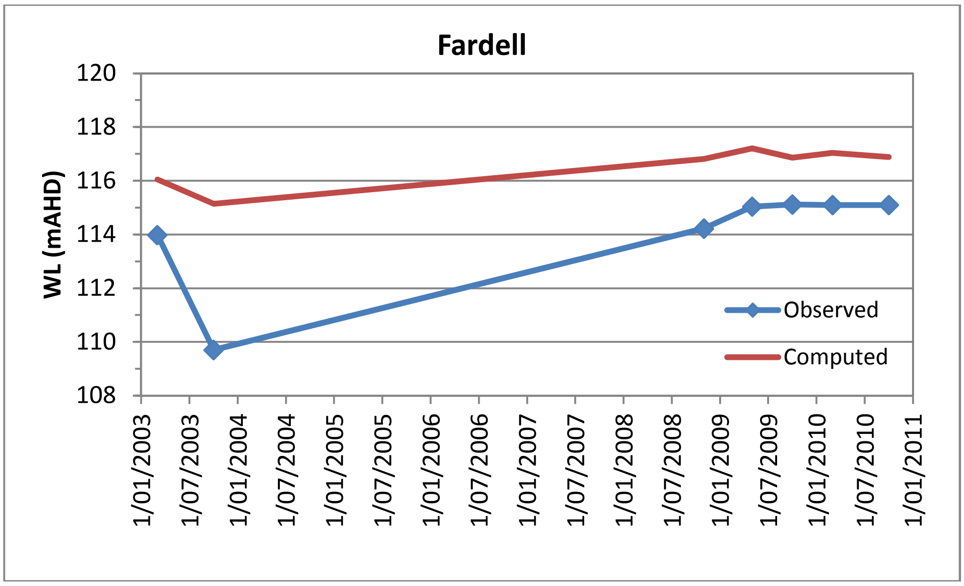


Figure A-46. Representative Simulated and Measured Hydrographs at Stratford Village [Bagnell and Fardell]

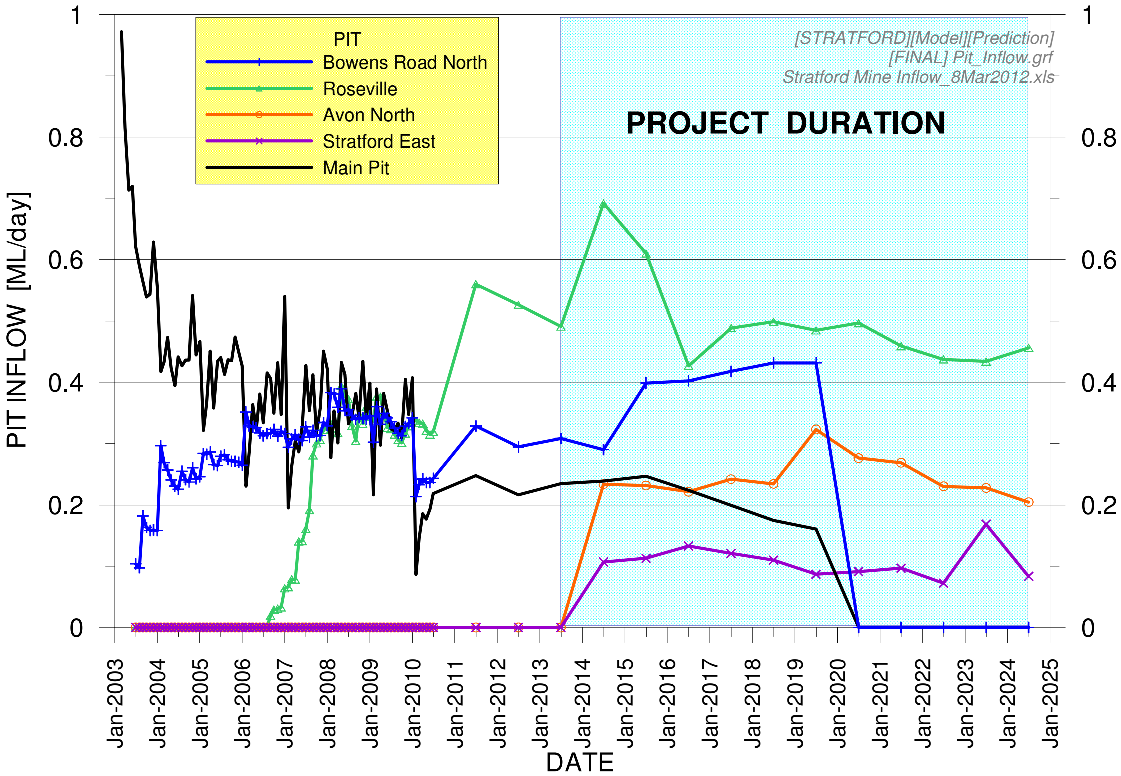


Figure A-47. Simulated Groundwater Inflow to Each Pit

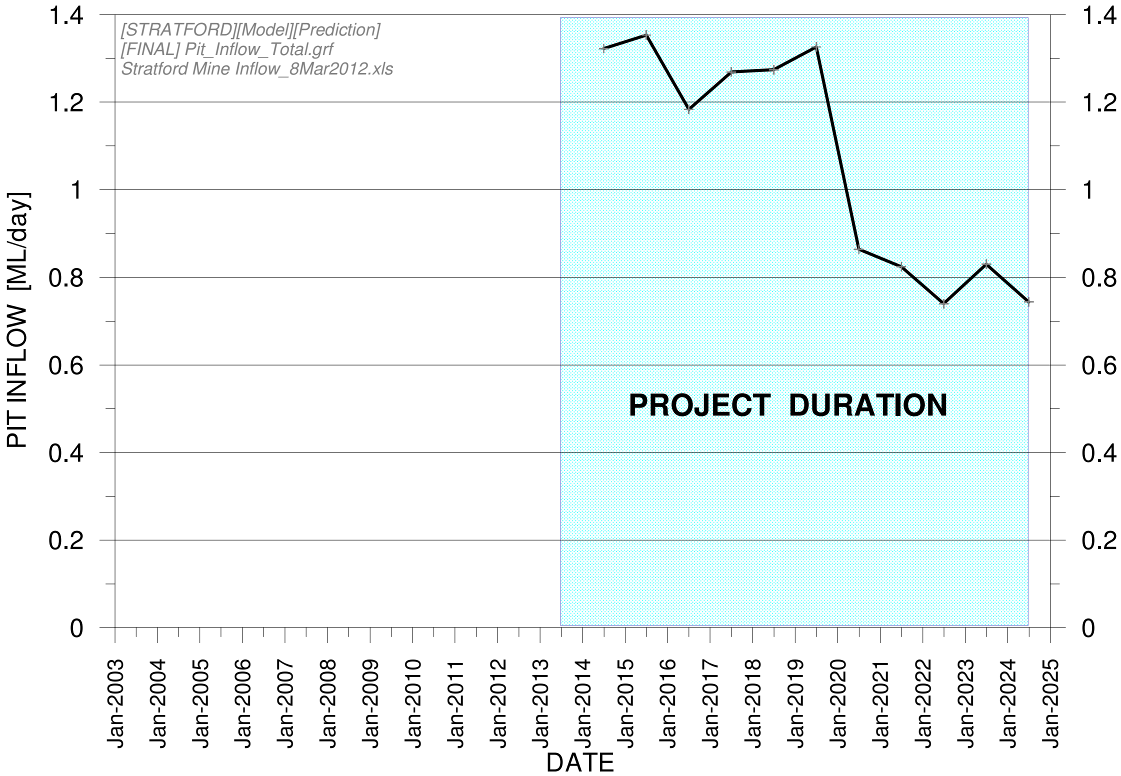


Figure A-48. Simulated Total Groundwater Inflow to Bowens Road North, Roseville, Avon North and Stratford East Pits during the Project

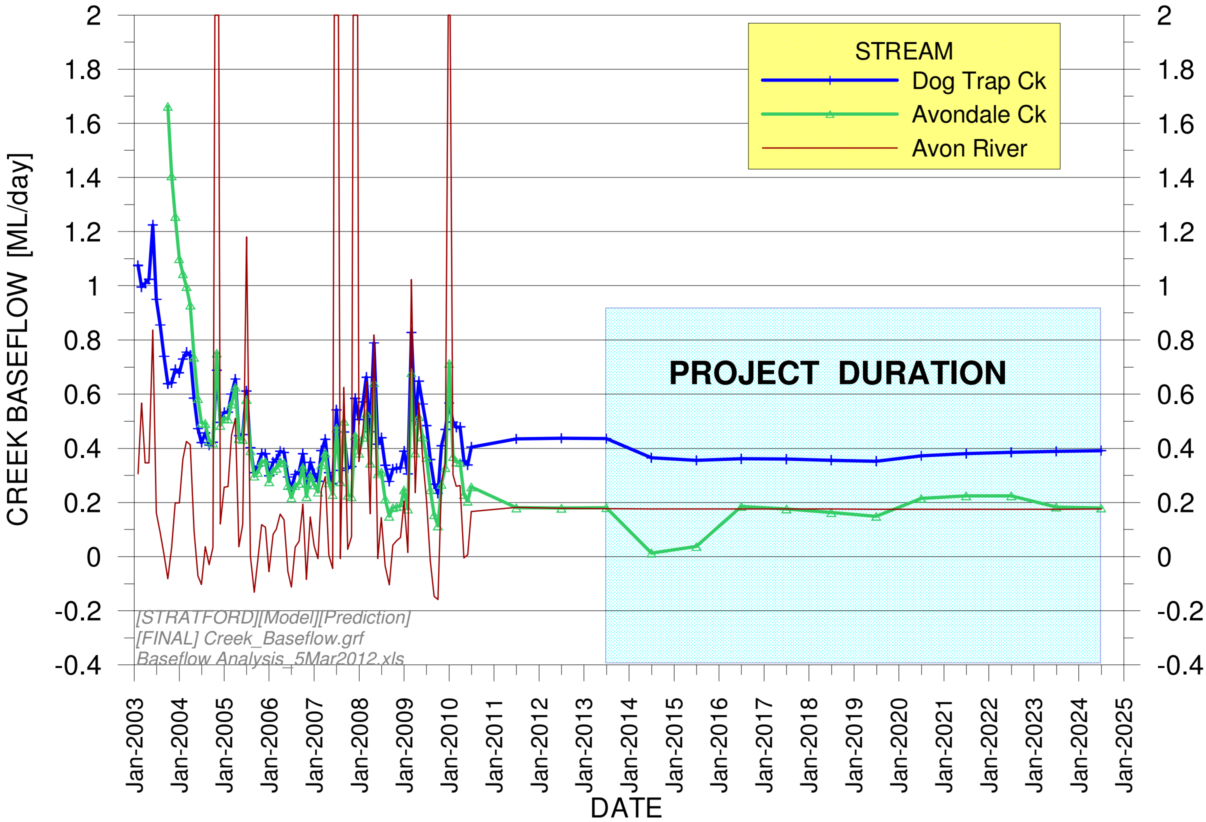


Figure A-49. Simulated Stream-Aquifer Exchanges for Dog Trap Creek, Avondale Creek and Avon River

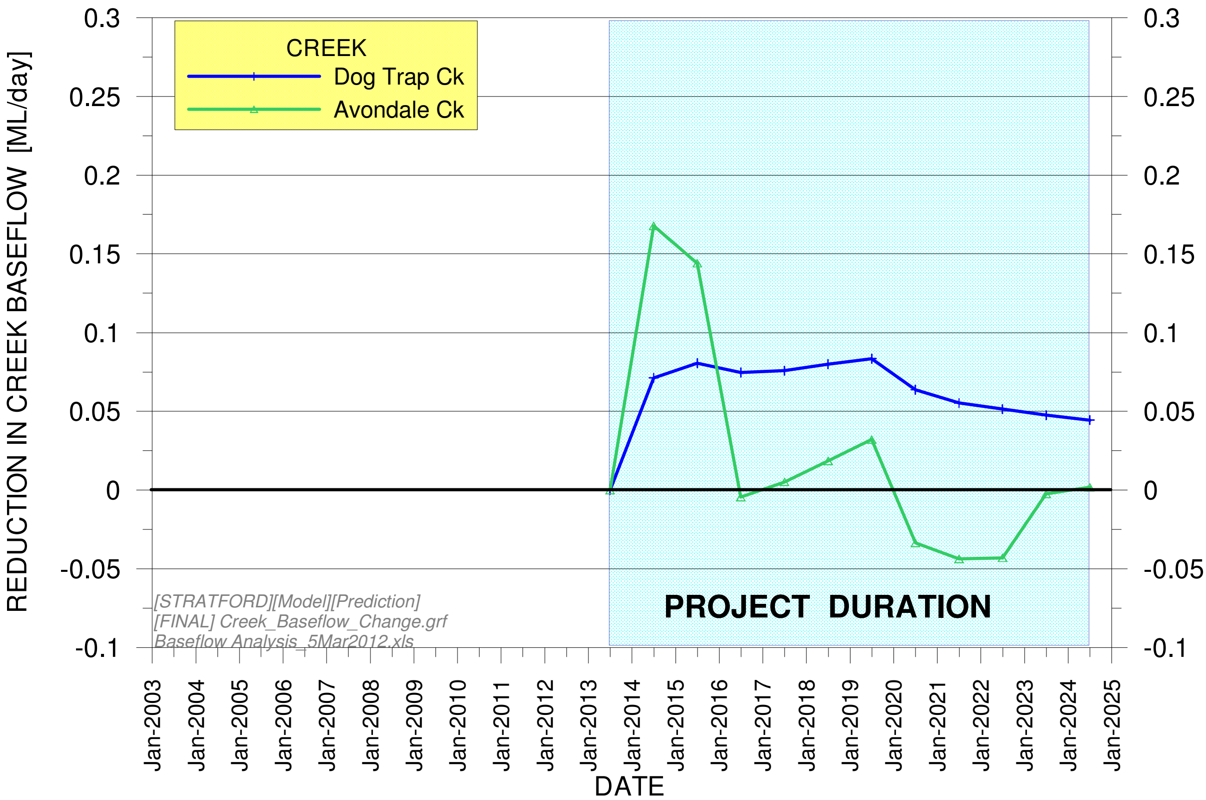


Figure A-50. Simulated Reduction in Baseflow to Dog Trap Creek and Avondale Creek during the Project

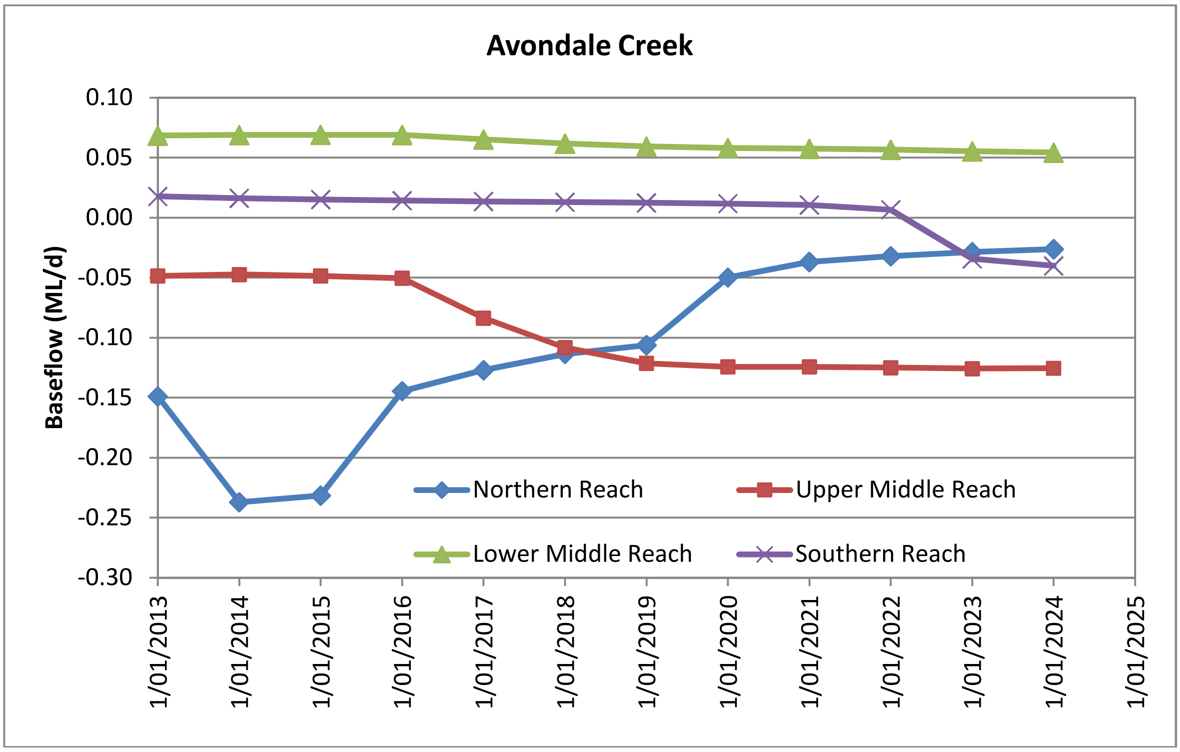


Figure A-51. Simulated Changes in Baseflow to Avondale Creek Reaches during the Project

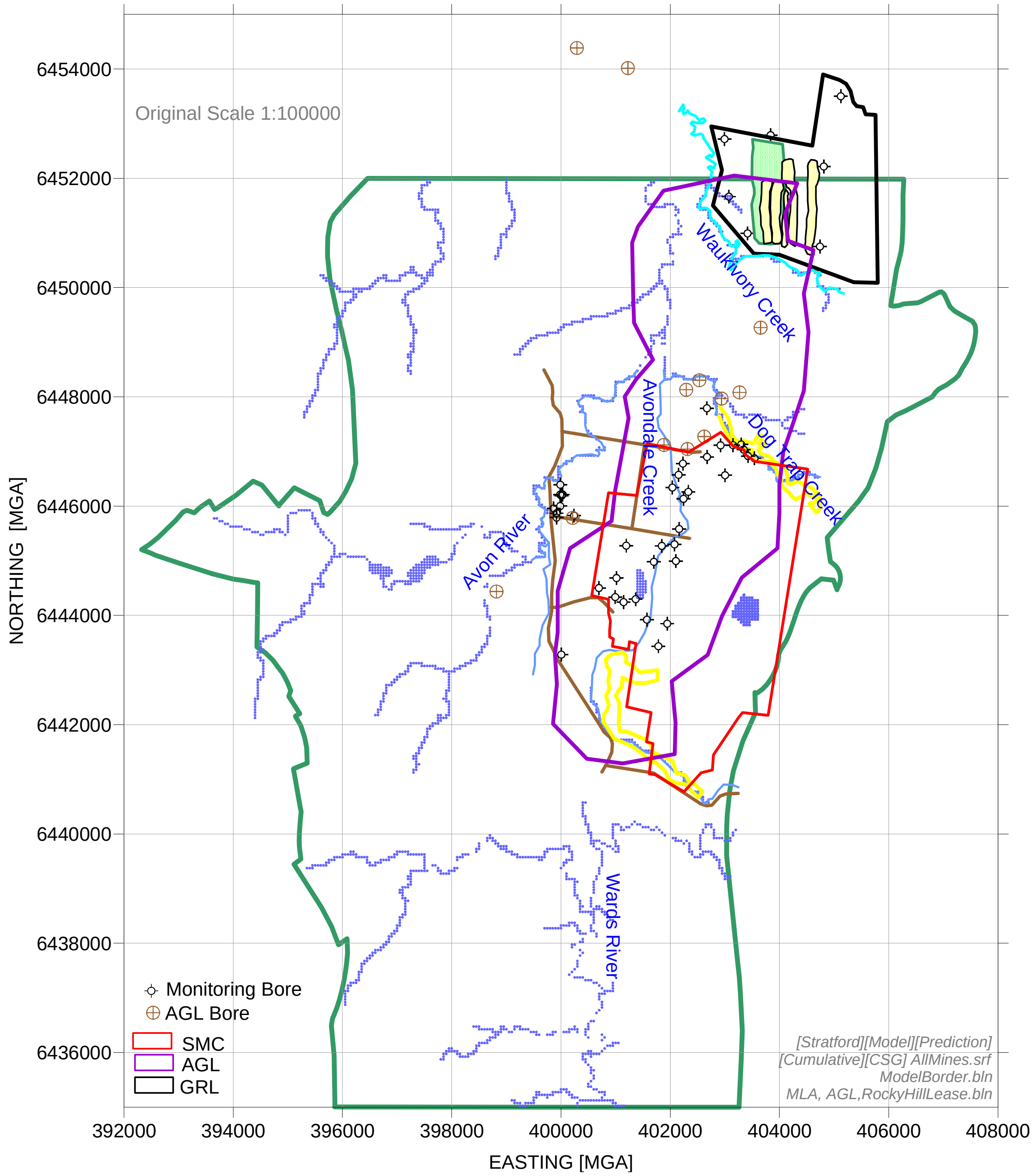


Figure A-52. Lease Areas for Cumulative Impact Assessment

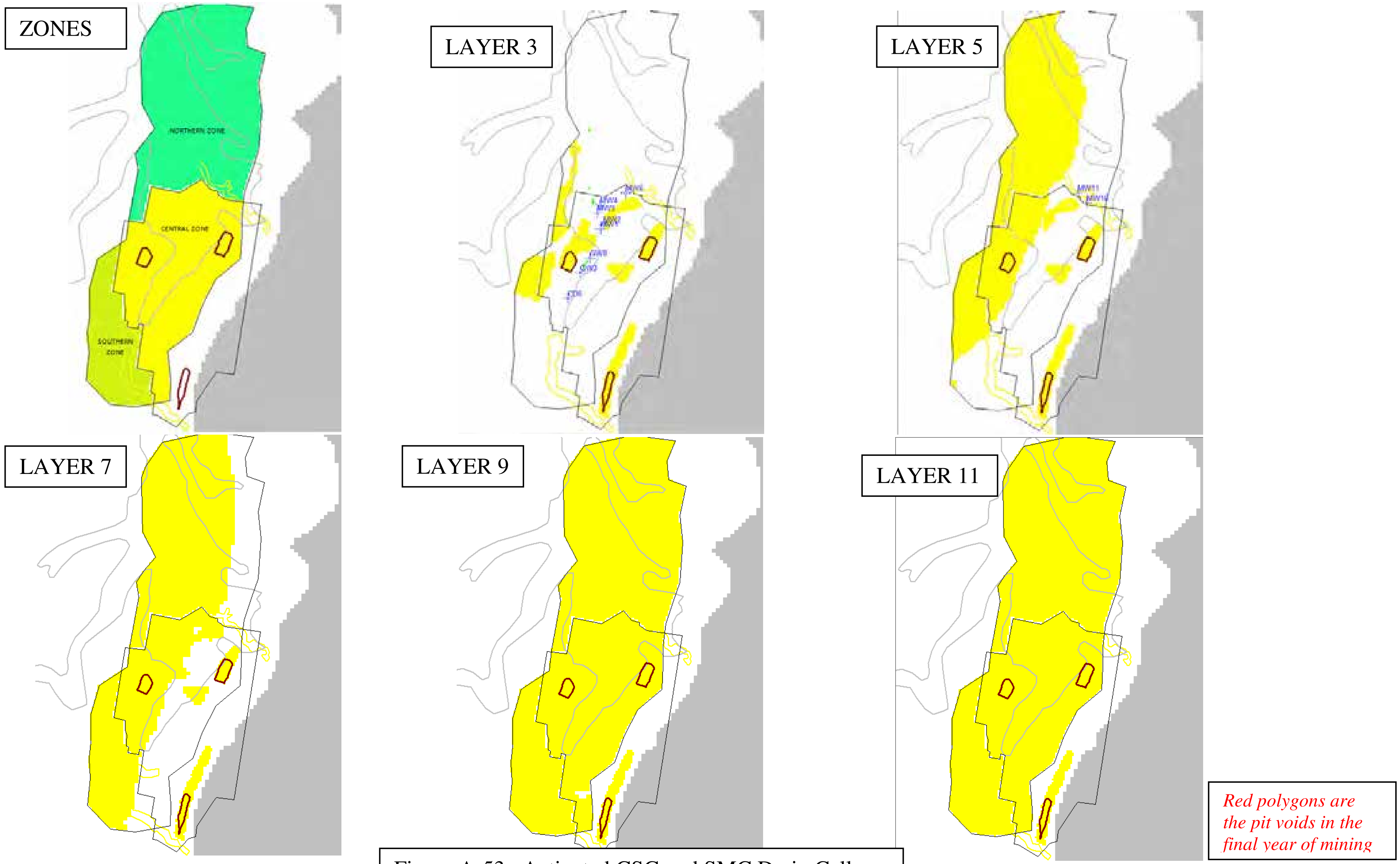


Figure A-53. Activated CSG and SMC Drain Cells

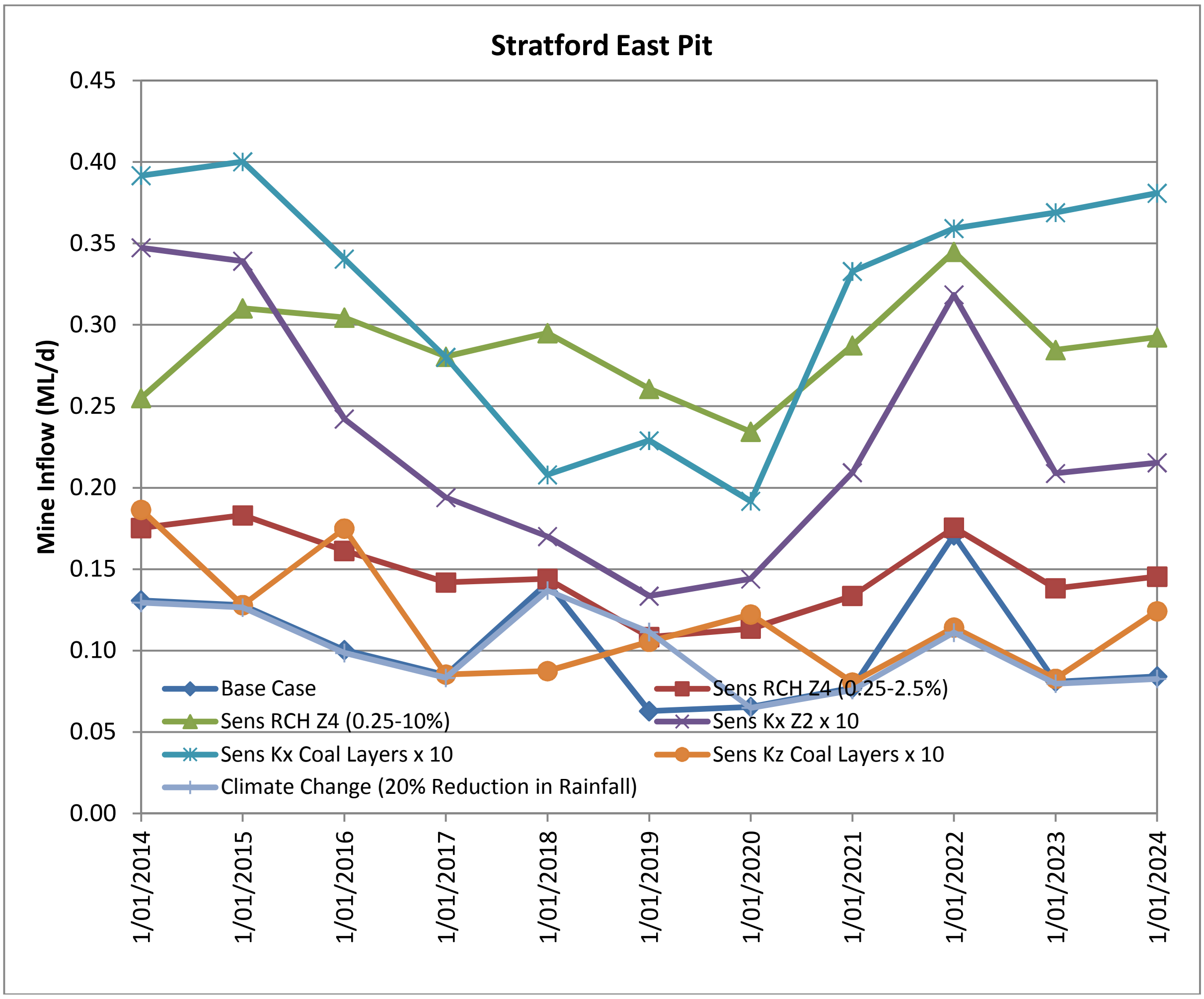


Figure A-54. Sensitivity Analysis for Stratford East Pit Inflow

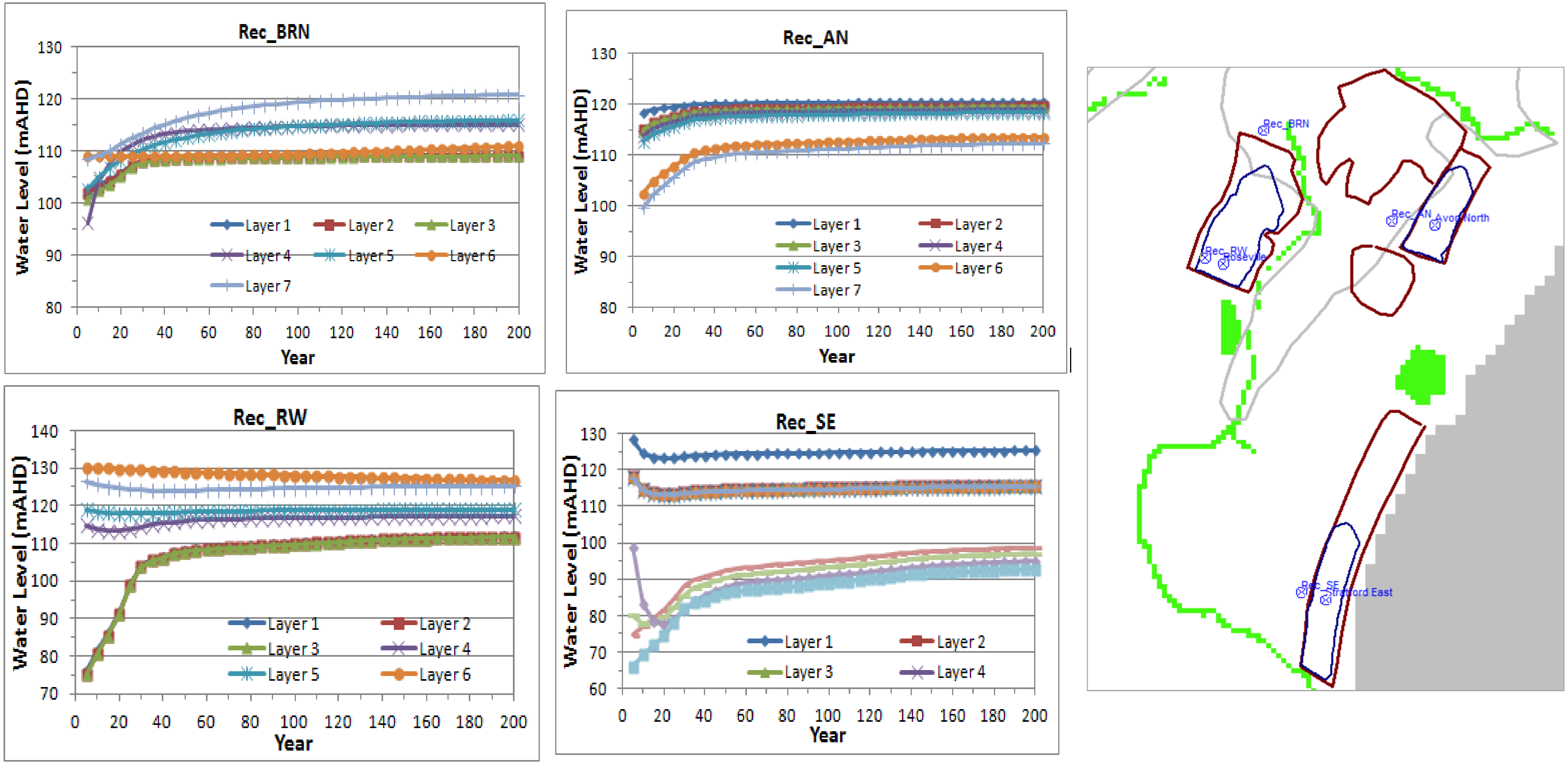


Figure A-55. Recovery Groundwater Hydrographs at Representative Sites

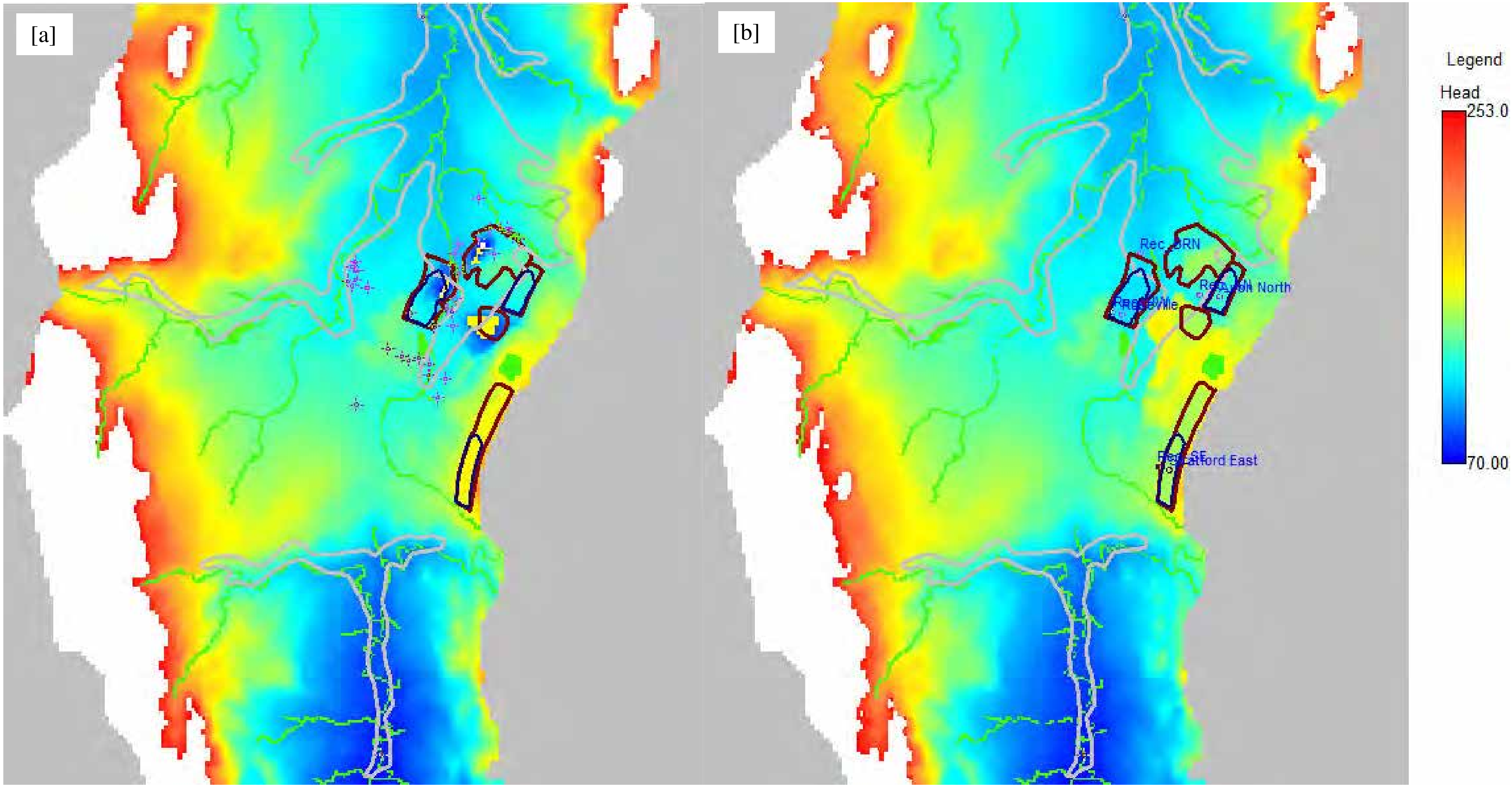


Figure A-56. Simulated Layer 1 Watertable Elevations at [a] End of Transient Calibration Period (June 2010); [b] Post-Mining Final Equilibrium [mAHD]

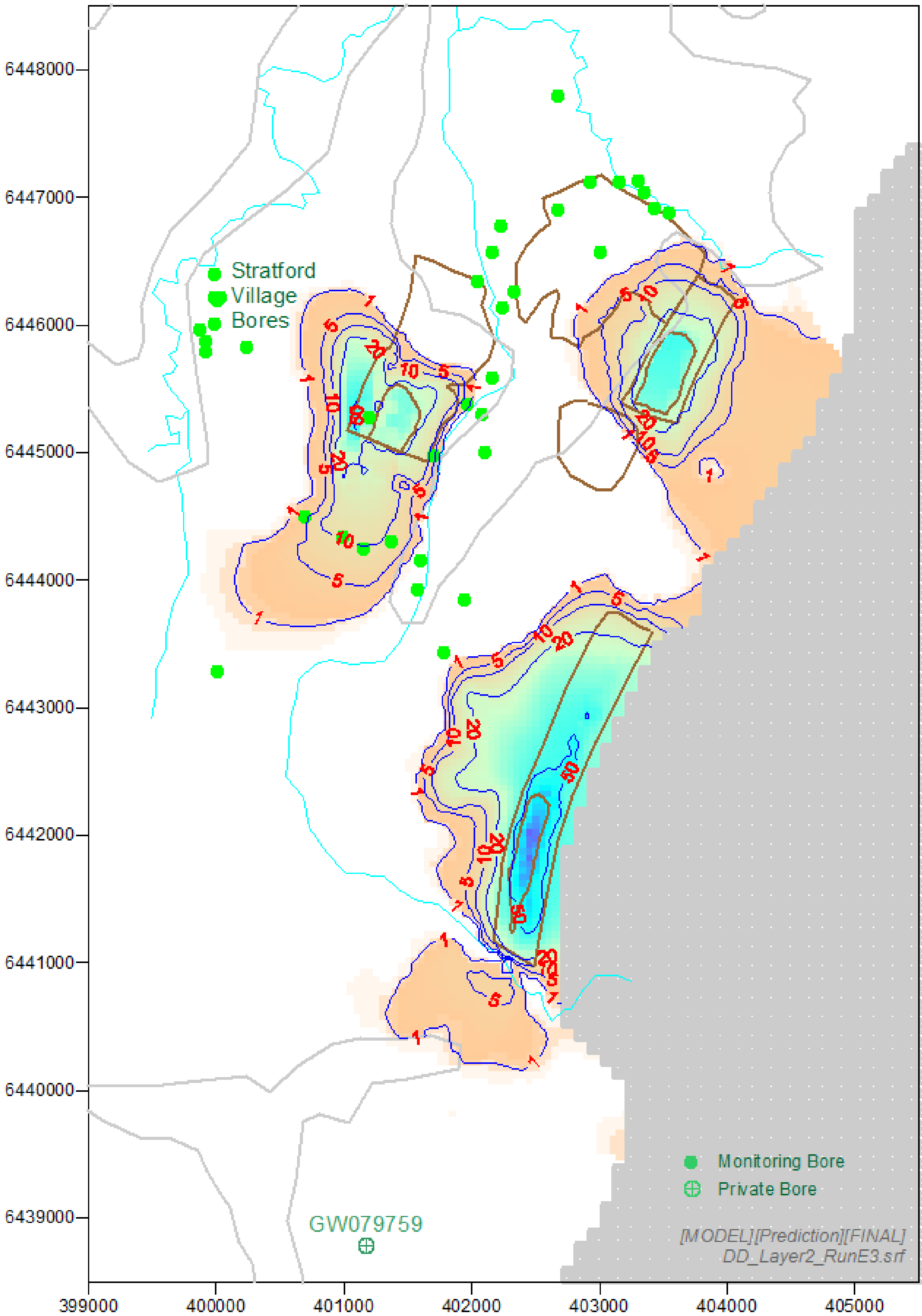


Figure A-57. Predicted Watertable Drawdown Contours at the end of the Project [m]

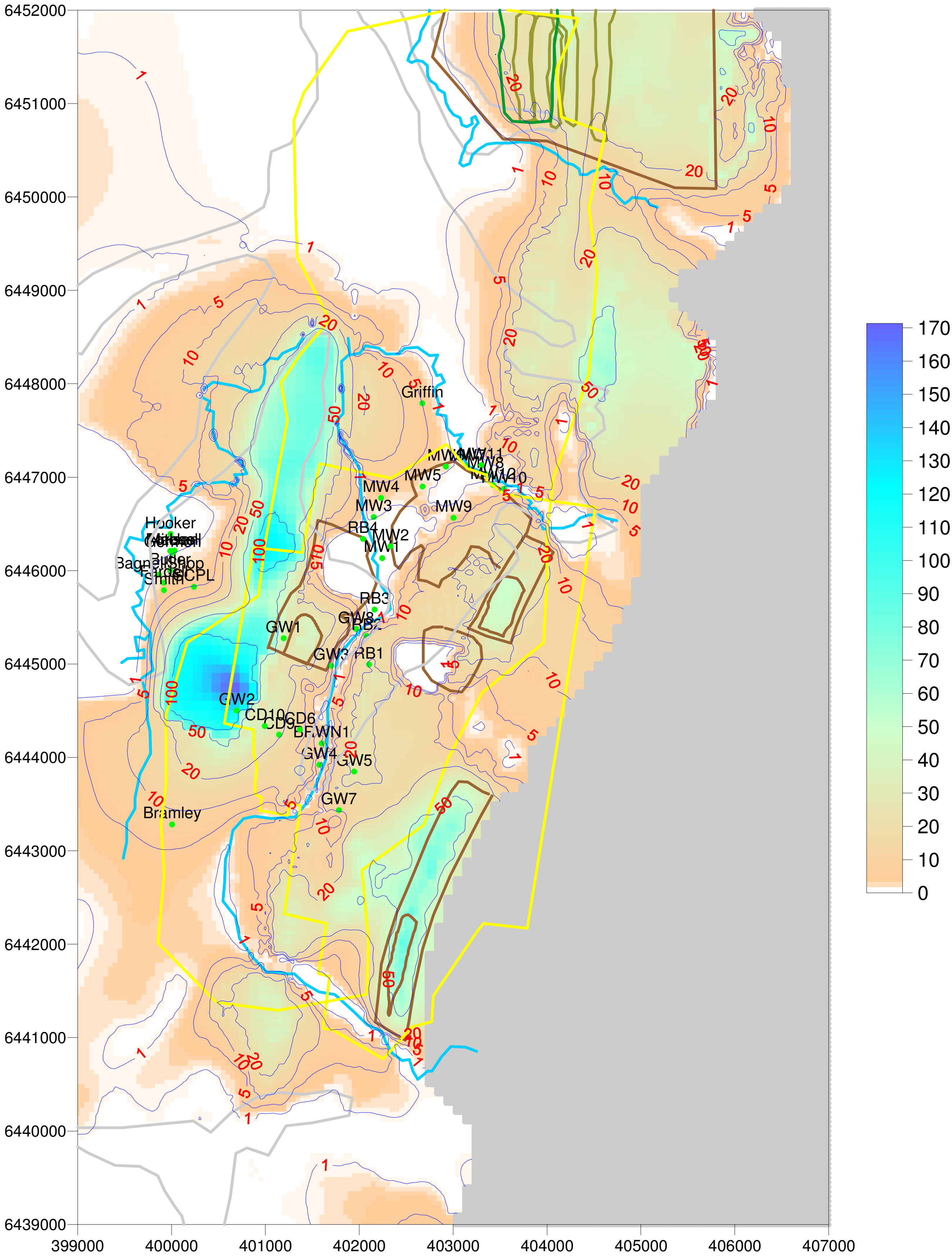


Figure A-58. Predicted Watertable Drawdown Contours Resulting from the Cumulative Effects of All Three Projects at 2024 [m]

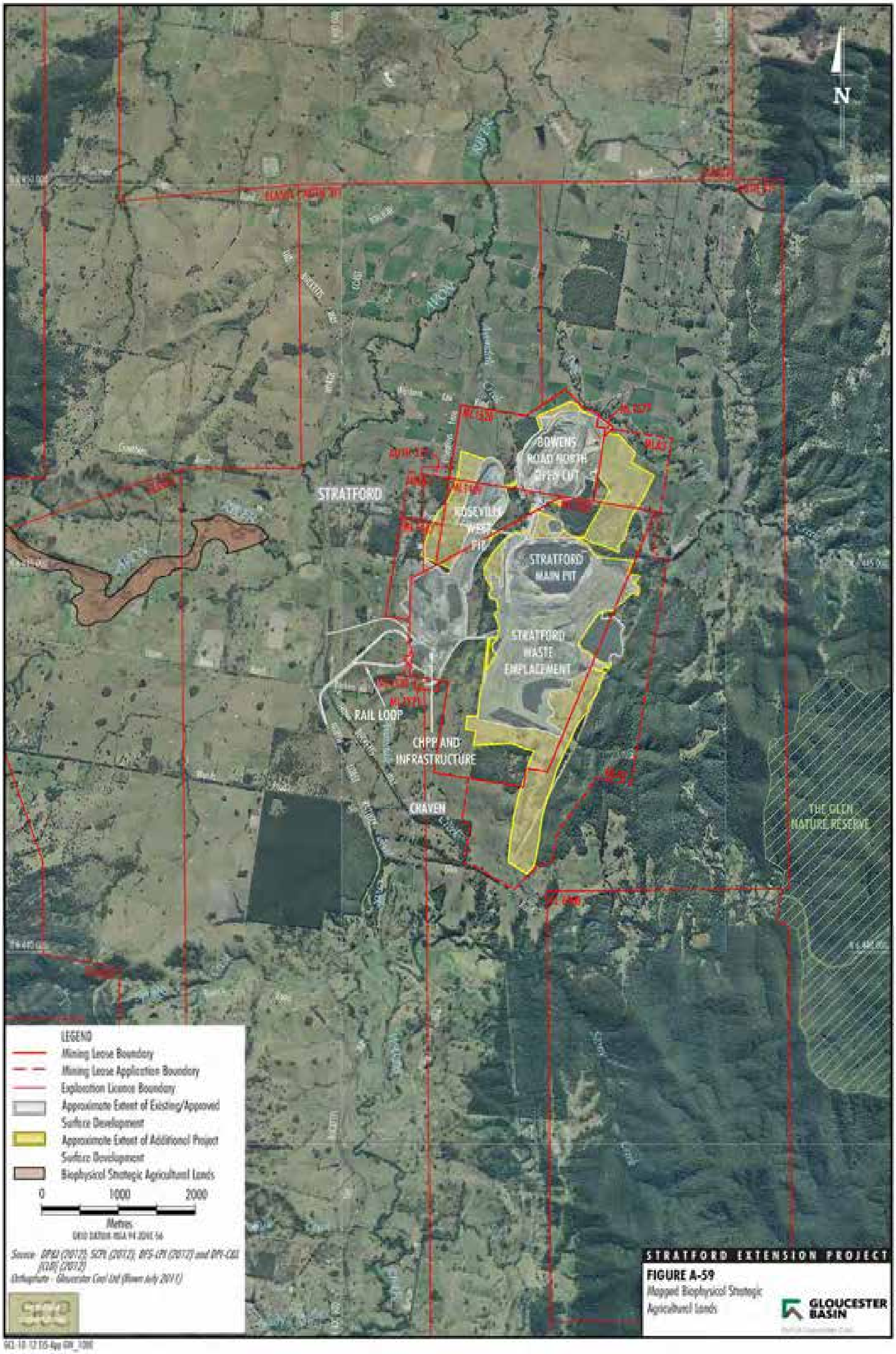


FIGURE A-59
Mapped Biophysical Strategic Agricultural Lands

GCL-10-12 ES App GW_109E

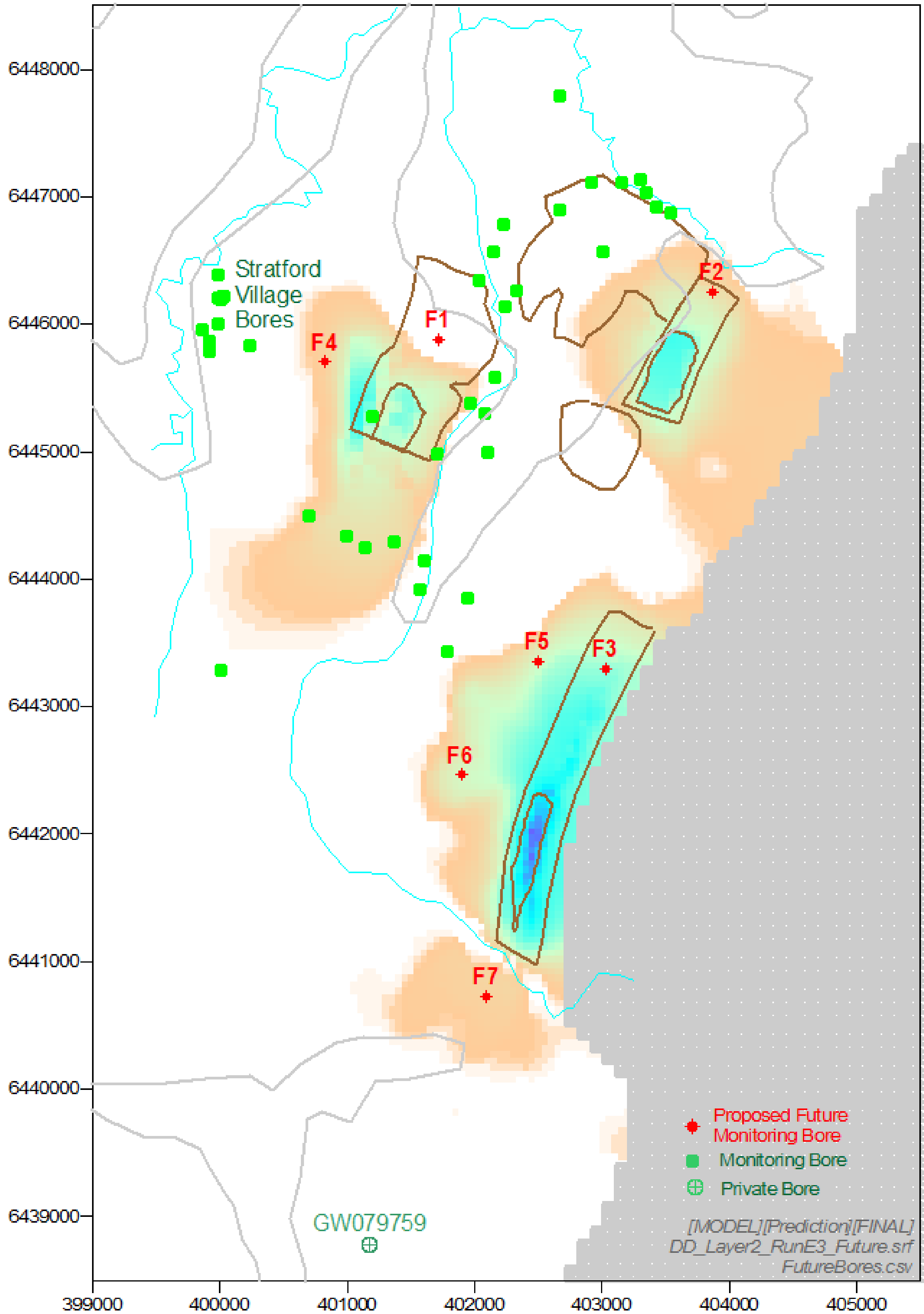


Figure A-60. Proposed Expansion of the Groundwater Monitoring Network

ATTACHMENTS

AA to AE

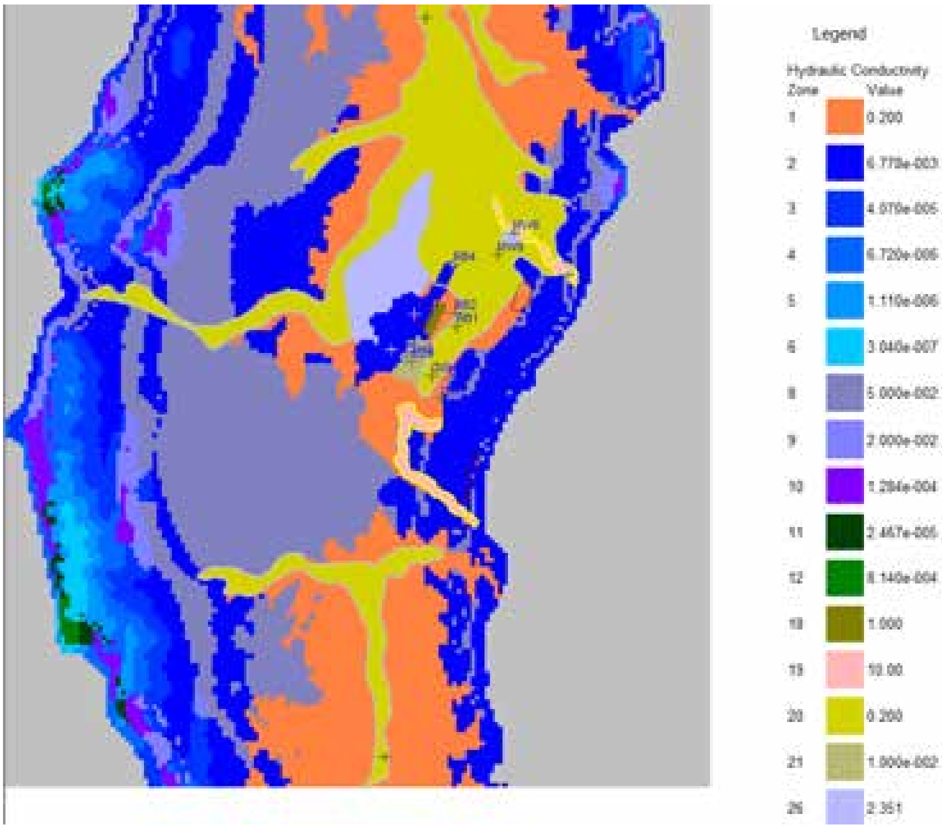
ATTACHMENT AA

Calibrated Hydraulic Conductivity [m/day]

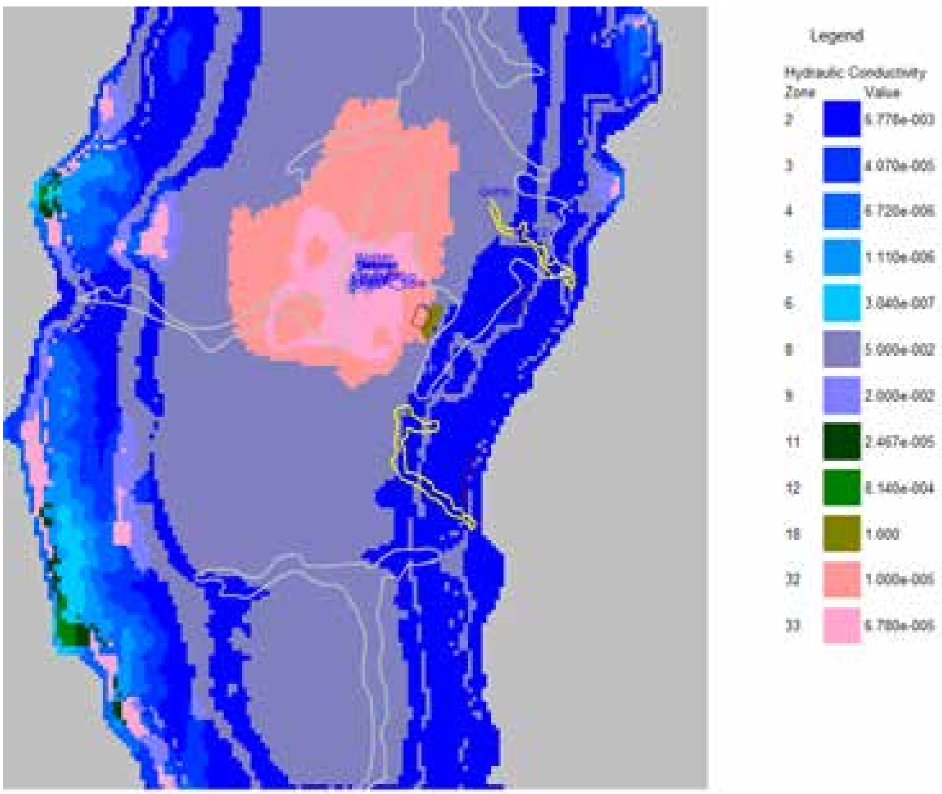
Specific Yield [-], Storage Coefficient [-]

and Rainfall Recharge Distributions

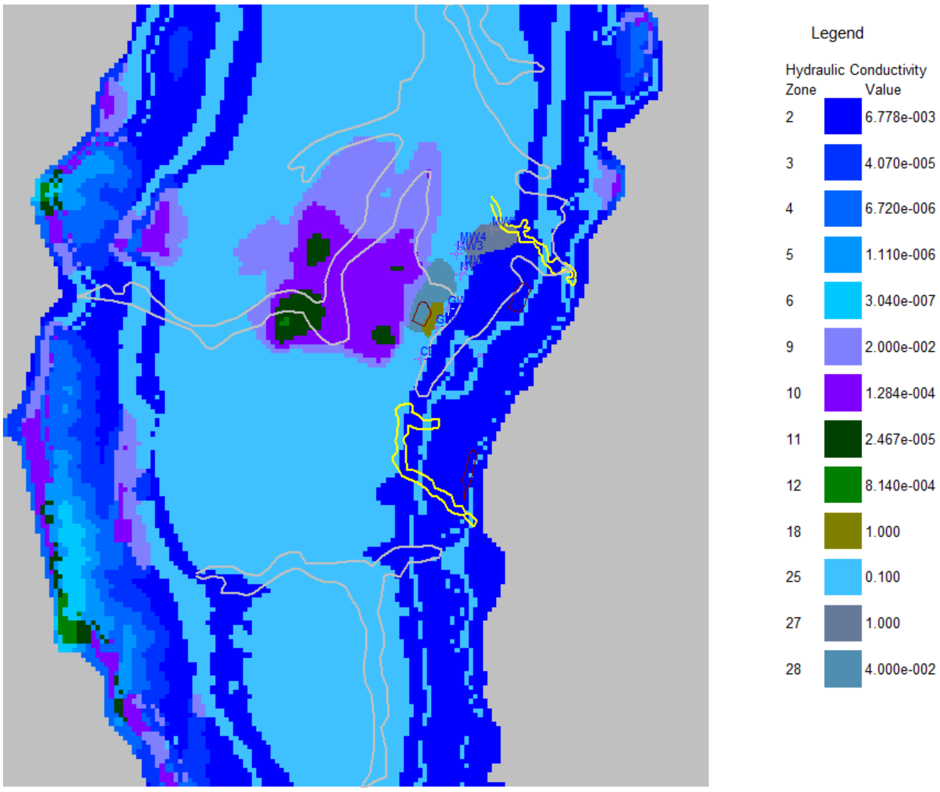
LAYER 1



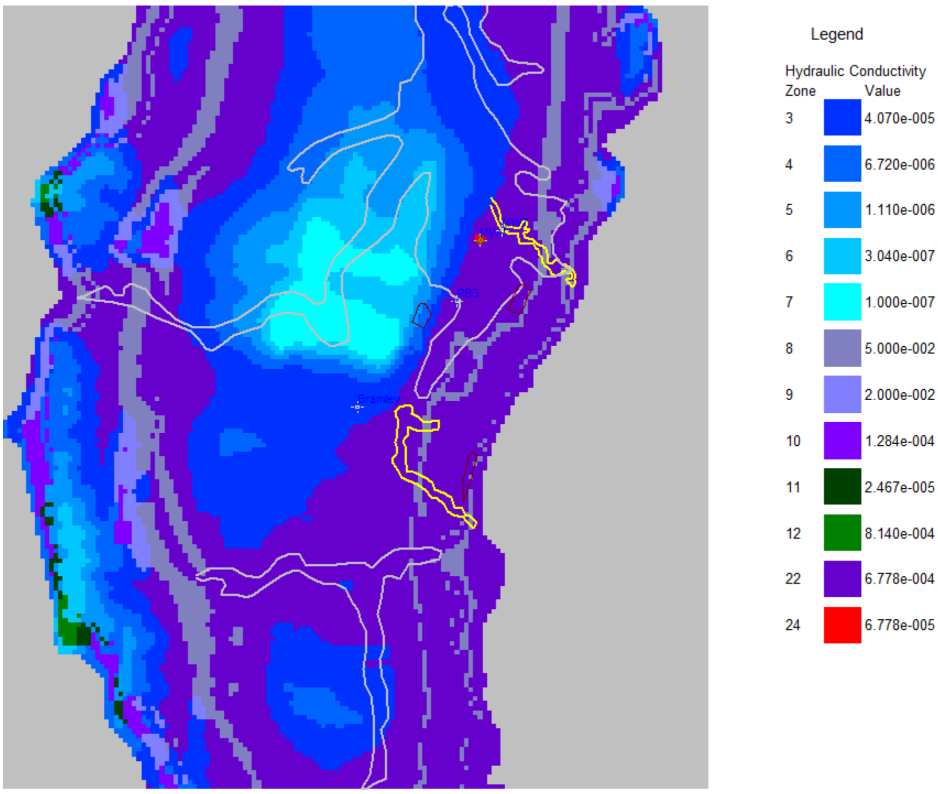
LAYER 2



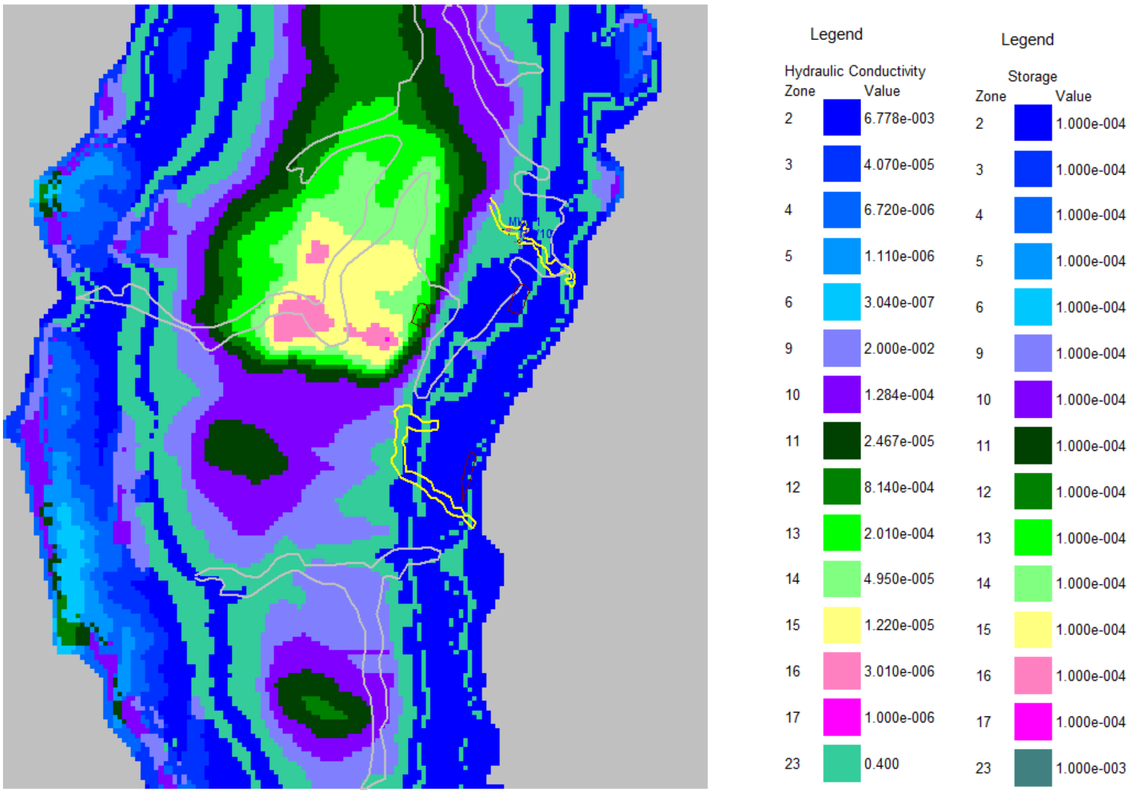
LAYER 3



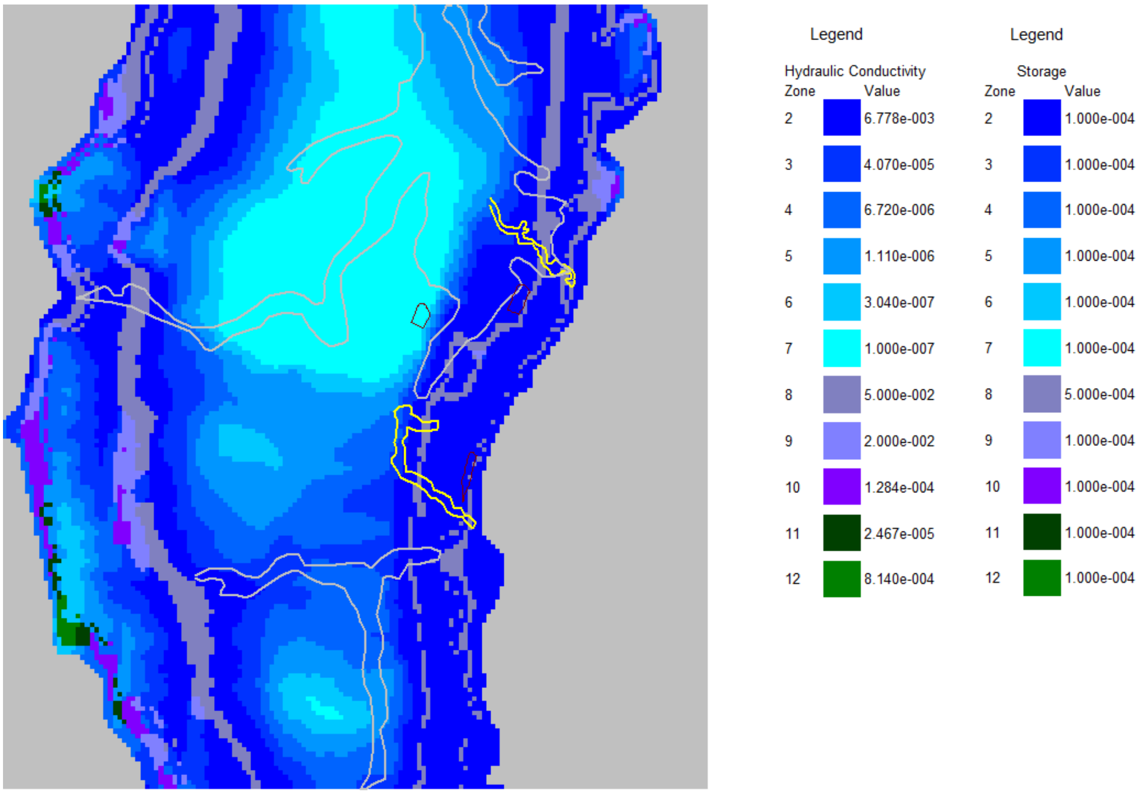
LAYER 4



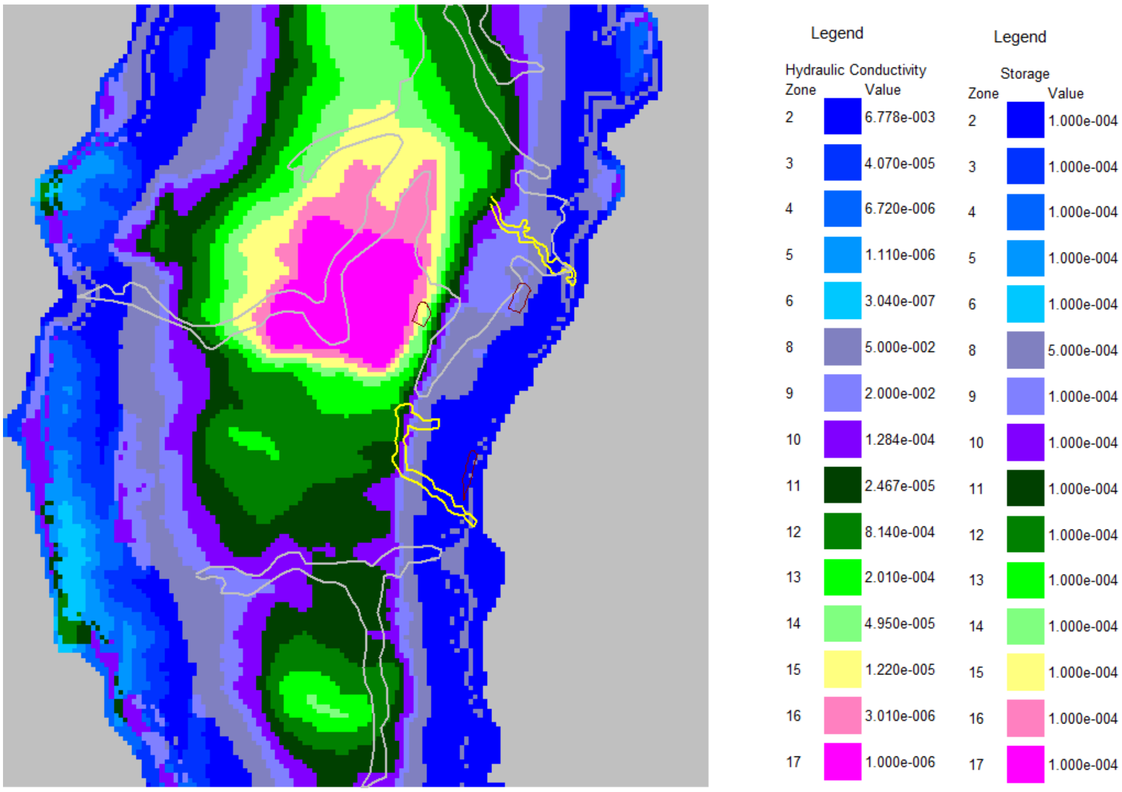
LAYER 5



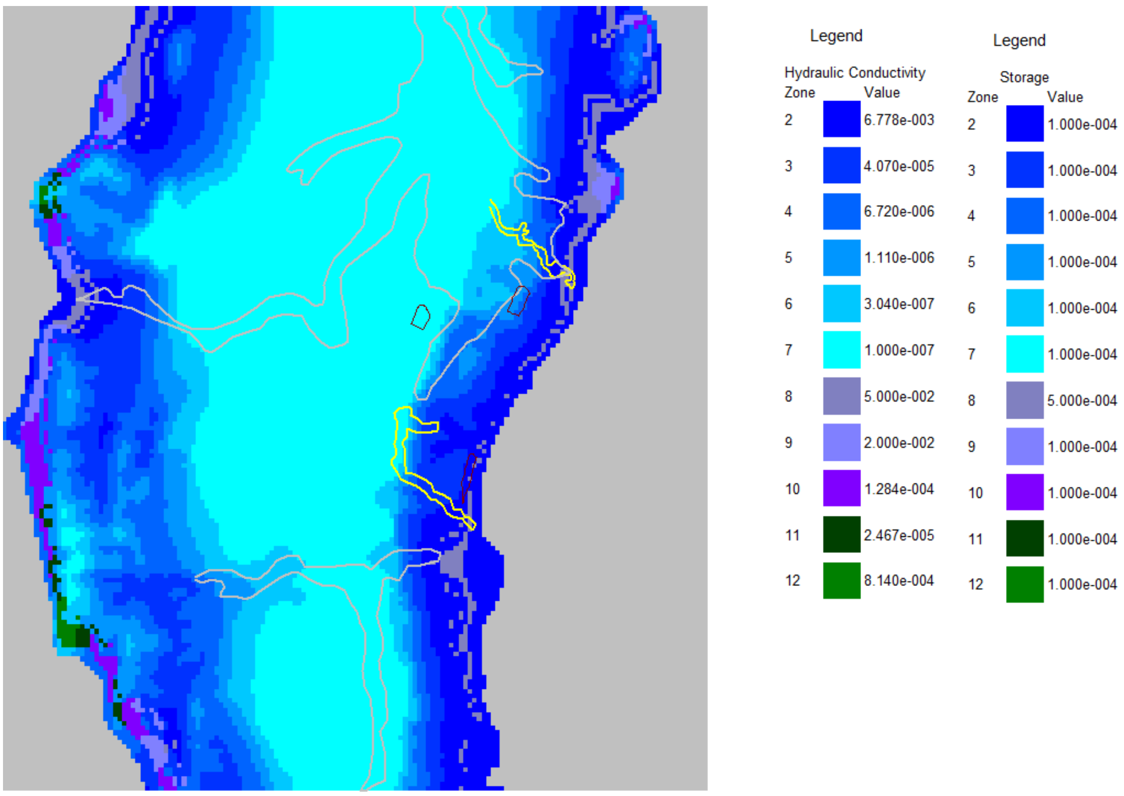
LAYER 6



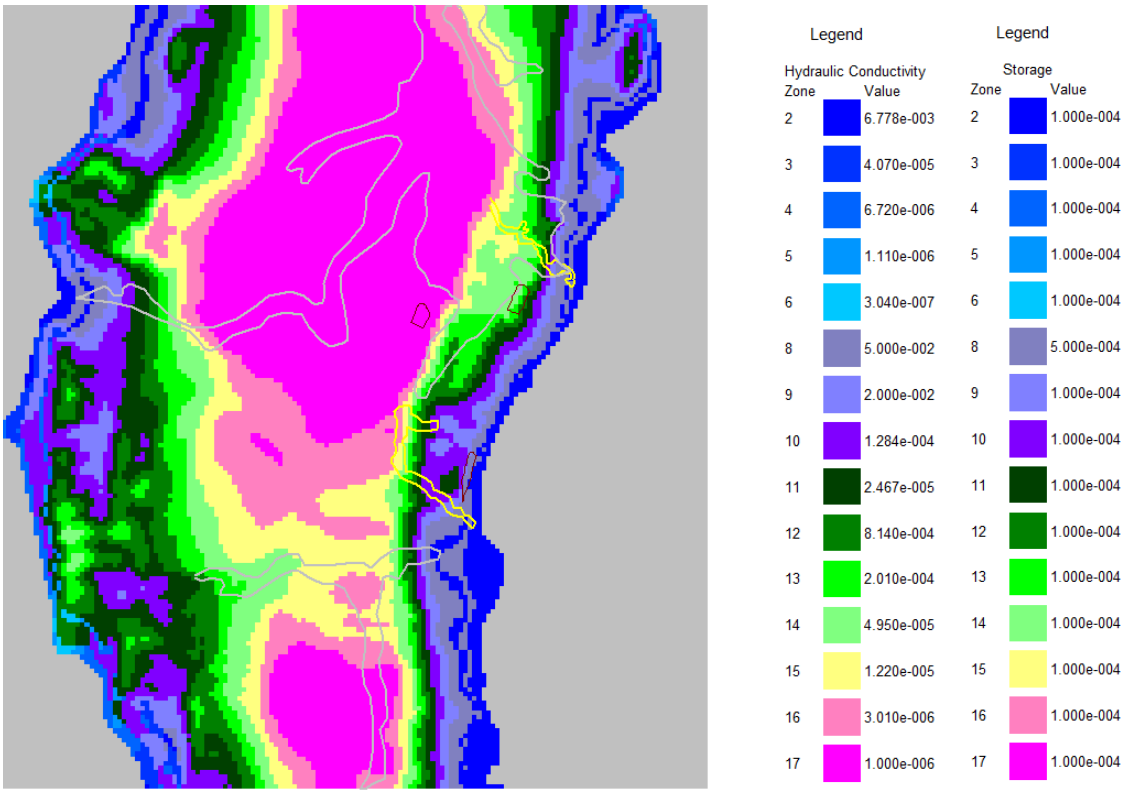
LAYER 7



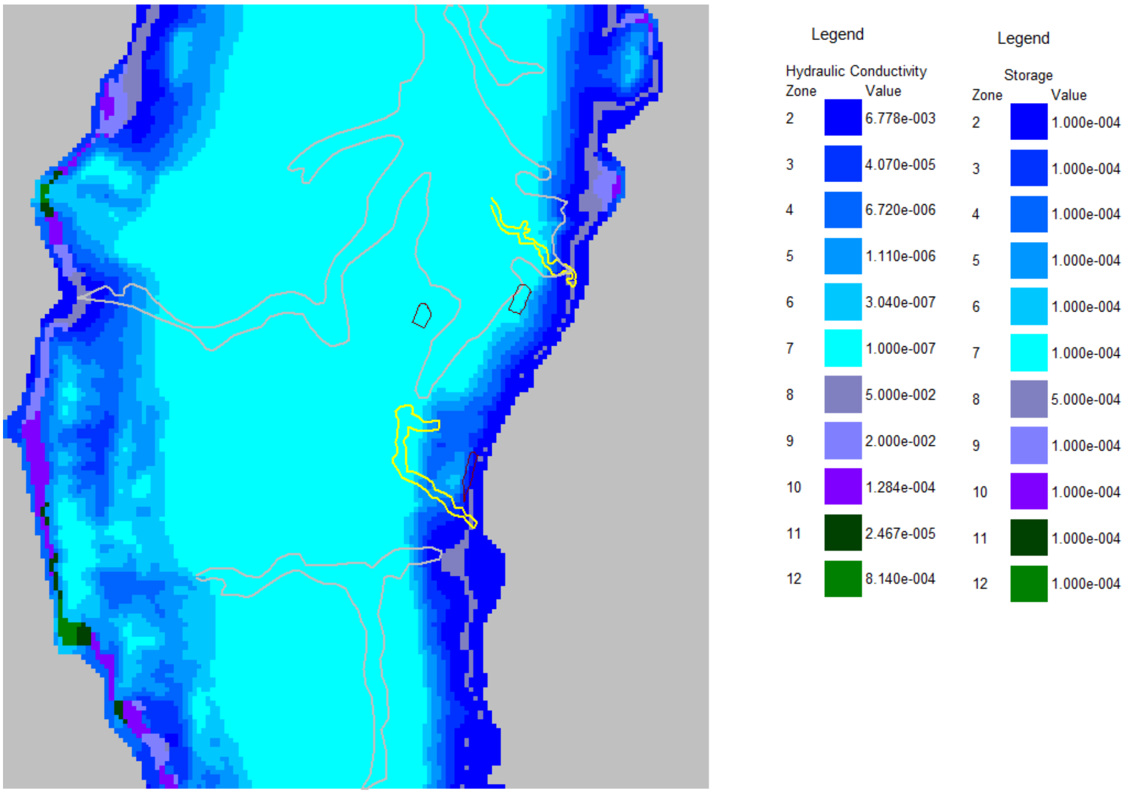
LAYER 8



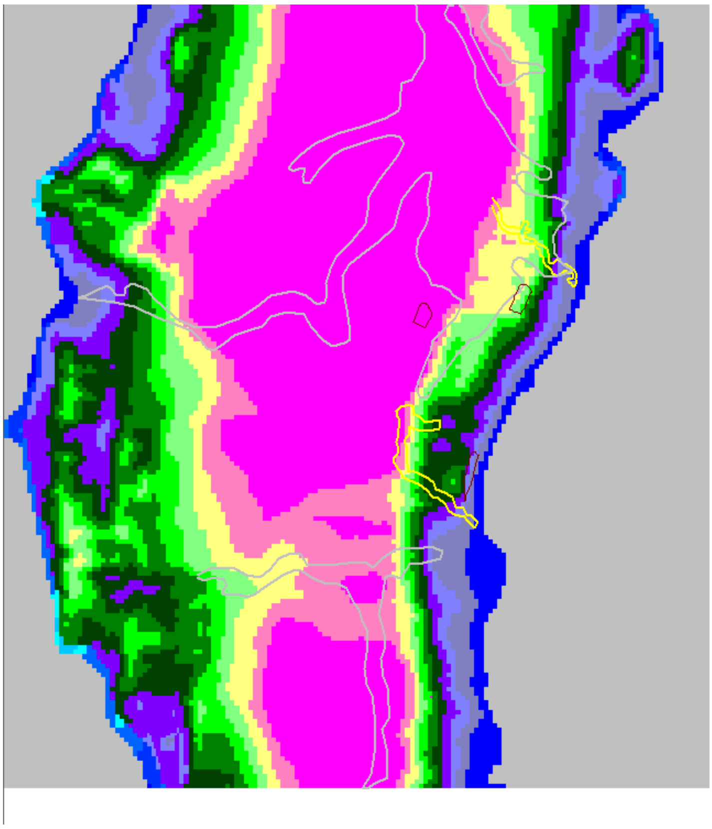
LAYER 9



LAYER 10



LAYER 11



Legend

Hydraulic Conductivity

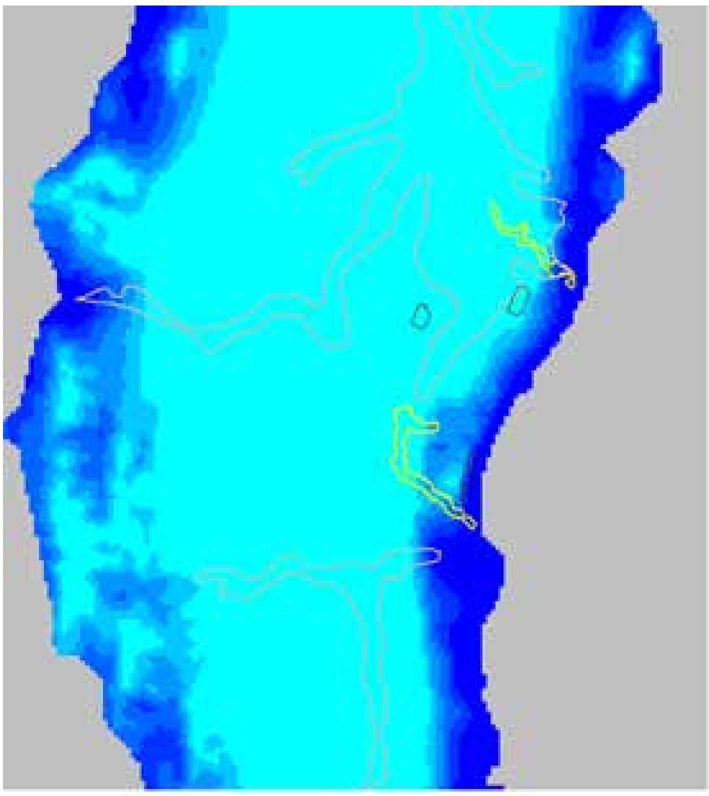
Zone	Value
2	6.778e-003
3	4.070e-005
4	6.720e-006
5	1.110e-006
6	3.040e-007
7	1.000e-007
8	5.000e-002
9	2.000e-002
10	1.284e-004
11	2.467e-005
12	8.140e-004
13	2.010e-004
14	4.950e-005
15	1.220e-005
16	3.010e-006
17	1.000e-006

Legend

Storage

Zone	Value
2	1.000e-004
3	1.000e-004
4	1.000e-004
5	1.000e-004
6	1.000e-004
7	1.000e-004
8	5.000e-004
9	1.000e-004
10	1.000e-004
11	1.000e-004
12	1.000e-004
13	1.000e-004
14	1.000e-004
15	1.000e-004
16	1.000e-004
17	1.000e-004

LAYER 12



Legend

Hydraulic Conductivity

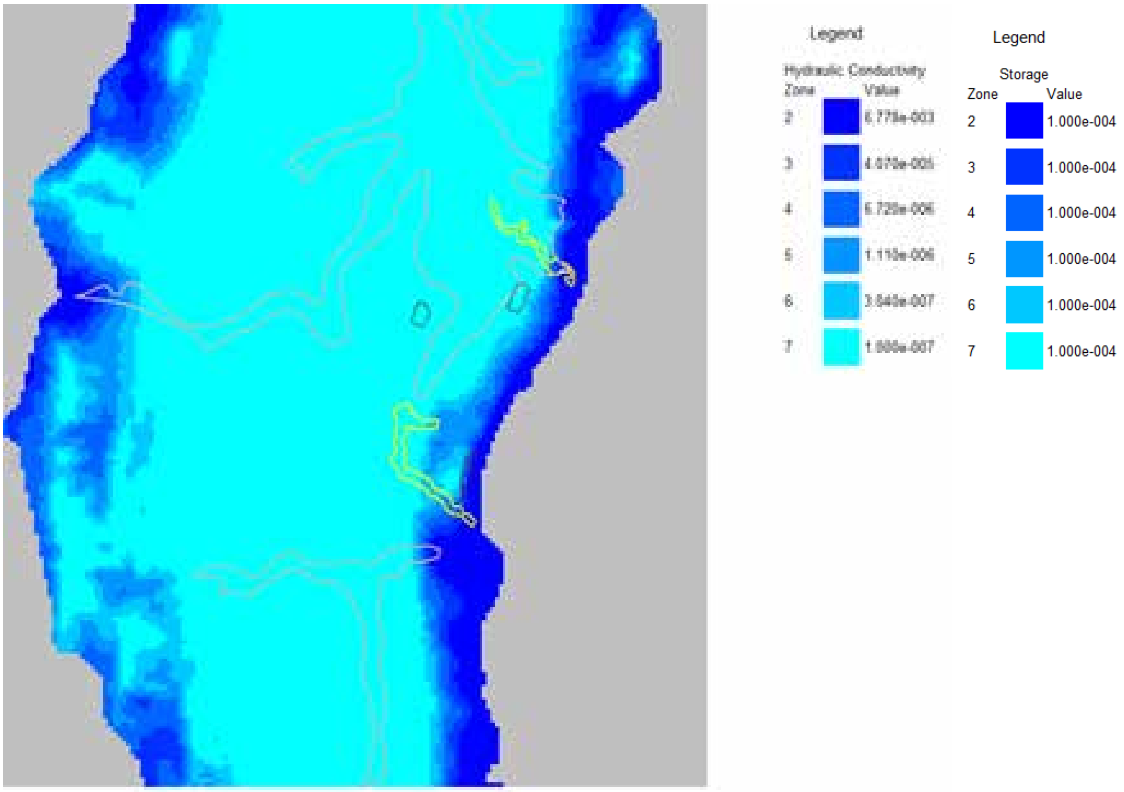
Zone	Value
1	0.200
2	6.778e-003
3	4.070e-005
4	6.720e-006
5	1.110e-006
6	3.040e-007
7	1.000e-007

Legend

Storage

Zone	Value
1	1.000e-003
2	1.000e-004
3	1.000e-004
4	1.000e-004
5	1.000e-004
6	1.000e-004
7	1.000e-004

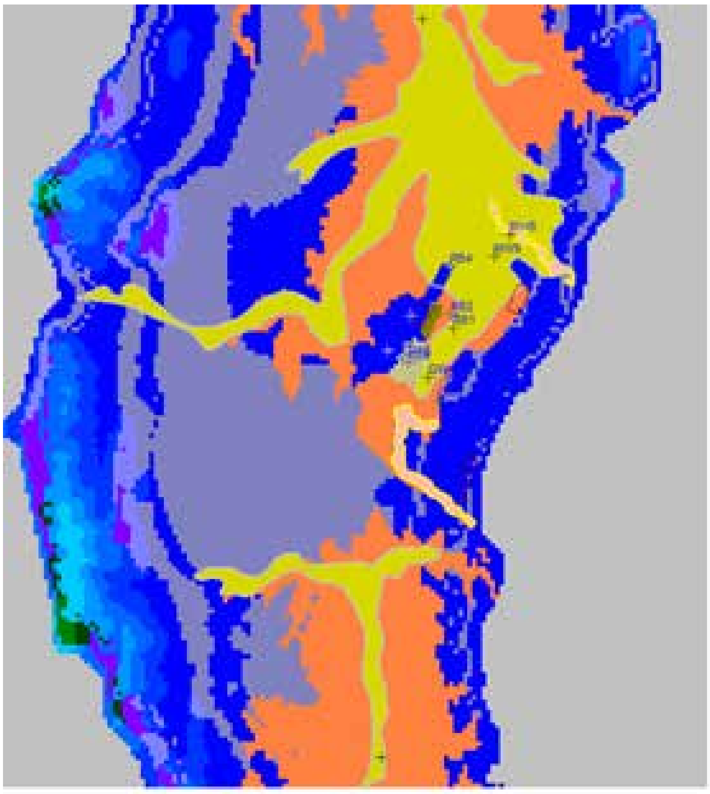
LAYER 13


Legend
Hydraulic Conductivity
Zone Value
2 6.778e-003
3 4.070e-005
4 6.720e-006
5 1.110e-006
6 3.840e-007
7 1.000e-007
Legend
Storage
Zone Value
2 1.000e-004
3 1.000e-004
4 1.000e-004
5 1.000e-004
6 1.000e-004
7 1.000e-004

HYDRAULIC CONDUCTIVITY DATABASE

K_Zone	Kx	Ky	Kz
1	2.00E-01	2.00E-01	2.00E-03
2	6.78E-03	6.78E-03	7.47E-04
3	4.07E-05	4.07E-05	4.07E-06
4	6.72E-06	6.72E-06	6.72E-07
5	1.11E-06	1.11E-06	1.11E-06
6	3.04E-07	3.04E-07	3.04E-08
7	1.00E-07	1.00E-07	1.00E-08
8	5.00E-02	5.00E-02	1.00E-02
9	2.00E-02	2.00E-02	1.00E-02
10	1.28E-04	1.28E-04	1.00E-03
11	2.47E-05	2.47E-05	2.99E-04
12	8.14E-04	8.14E-04	8.14E-05
13	2.01E-04	2.01E-04	2.01E-05
14	4.95E-05	4.95E-05	4.95E-06
15	1.22E-05	1.22E-05	1.22E-06
16	3.01E-06	3.01E-06	3.01E-07
17	1.00E-06	1.00E-06	1.00E-07
18	1.00E+00	1.00E+00	1.00E+00
19	1.00E+01	1.00E+01	1.00E+00
20	2.00E-01	2.00E-01	2.00E-03
21	1.00E-02	1.00E-02	1.00E-04
22	6.78E-04	6.78E-04	3.47E-05
23	4.00E-01	4.00E-01	5.00E-02
24	6.78E-05	6.78E-05	7.47E-07
25	1.00E-01	1.00E-01	5.00E-02
26	2.35E+00	2.35E+00	4.13E-02
27	1.00E+00	1.00E+00	1.00E-01
28	4.00E-02	4.00E-02	1.00E-02
32	1.00E-05	1.00E-05	7.15E-04
33	6.78E-05	6.78E-05	1.12E-03

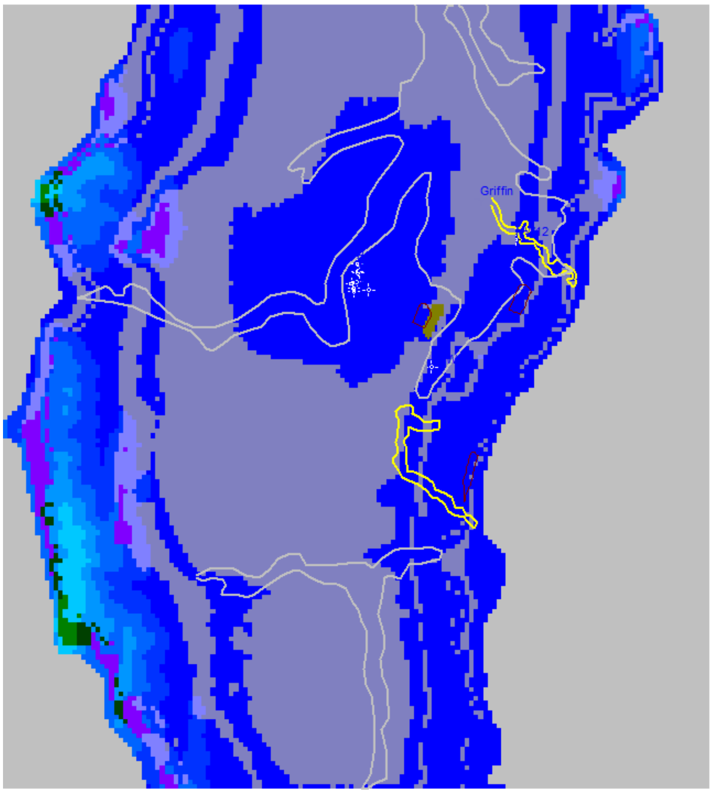
LAYER 1 STORAGE COEFFICIENT



Legend

Zone	Storage Value	
1	1.000e-003	Sy = 0.01
2	1.000e-004	Sy = 0.005
3	1.000e-004	Sy = 0.005
4	1.000e-004	Sy = 0.005
5	1.000e-004	Sy = 0.005
6	1.000e-004	Sy = 0.005
8	5.000e-004	Sy = 0.01
9	1.000e-004	Sy = 0.005
10	1.000e-004	Sy = 0.005
11	1.000e-004	Sy = 0.005
12	1.000e-004	Sy = 0.005
18	5.000e-003	Sy = 0.1
19	1.000e-003	Sy = 0.2
20	1.000e-003	Sy = 0.05
21	1.000e-004	Sy = 0.01

LAYER 2 STORAGE COEFFICIENT

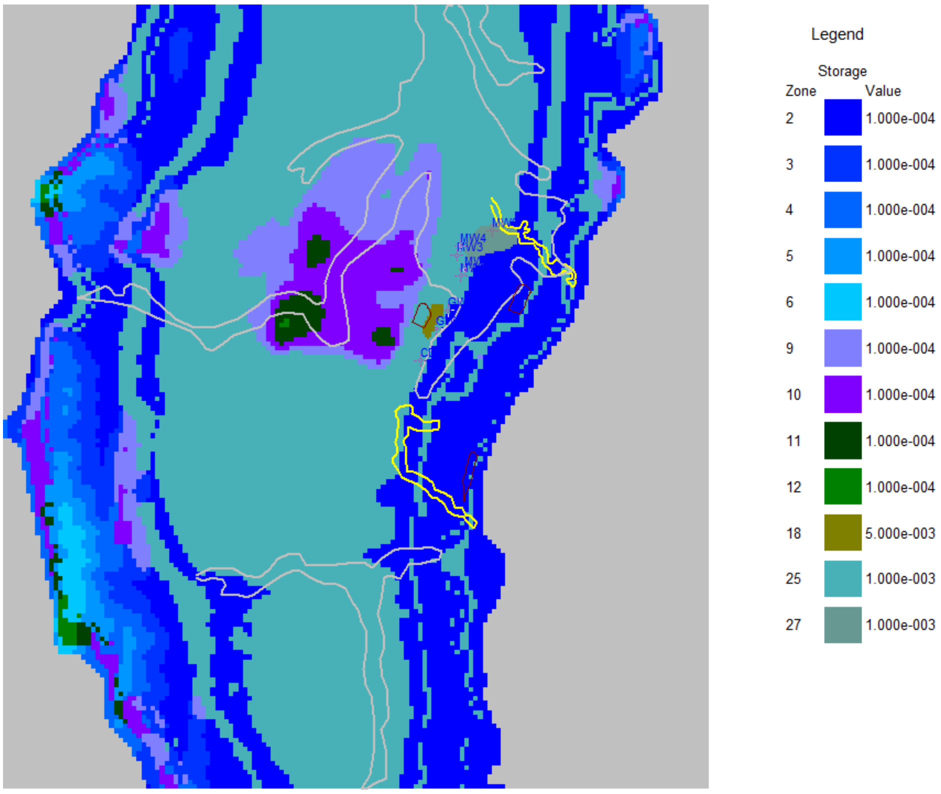


Legend

Zone	Storage Value	
2	1.000e-004	Sy = 0.005
3	1.000e-004	
4	1.000e-004	
5	1.000e-004	
6	1.000e-004	
8	5.000e-004	Sy = 0.01
9	1.000e-004	
10	1.000e-004	
11	1.000e-004	
12	1.000e-004	
18	5.000e-003	Sy = 0.1

Sy = 0.005 for other zones

LAYER 3 STORAGE COEFFICIENT



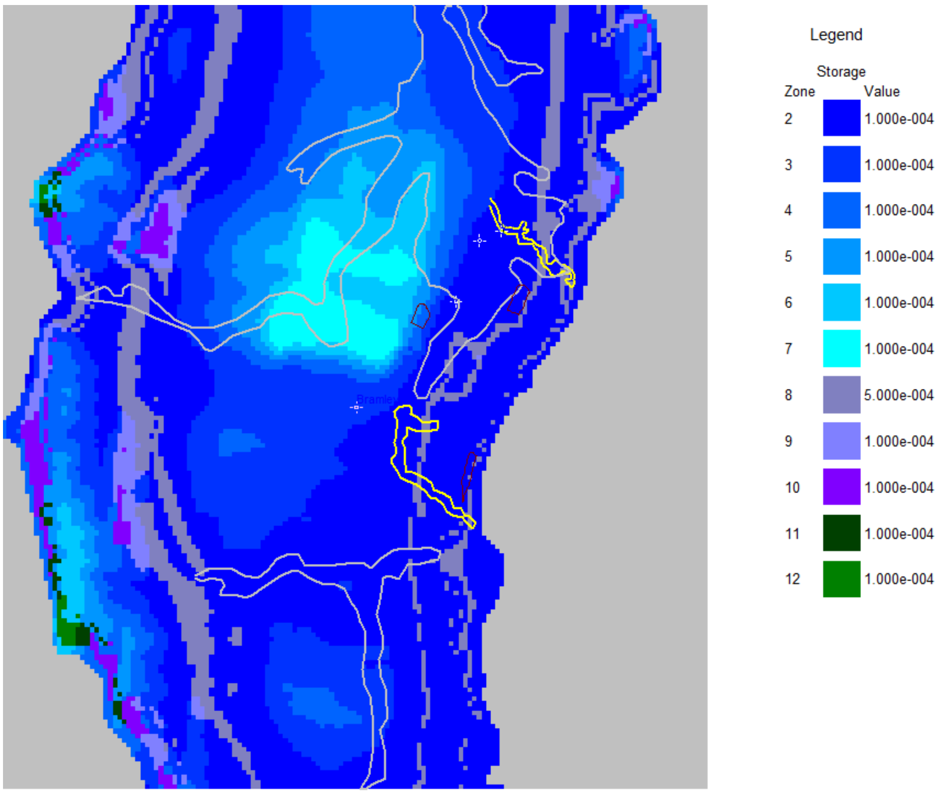
Sy = 0.1

Sy = 0.01

Sy = 0.01

Sy = 0.005 for other zones

LAYER 4 STORAGE COEFFICIENT



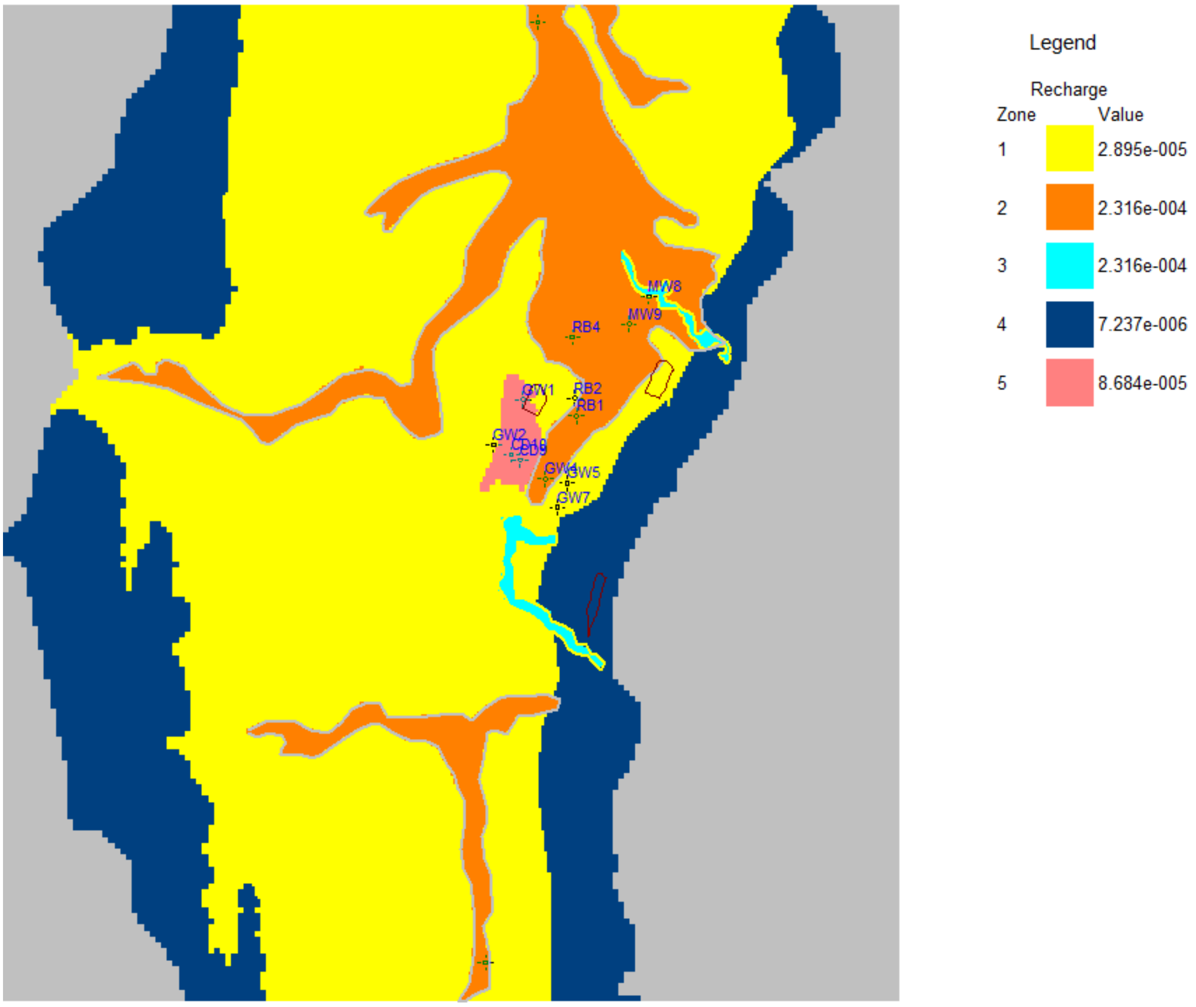
Sy = 0.01

Sy = 0.005 for other zones

STORAGE DATABASE

S_Zone	S	Sy
1	1.0E-03	1.0E-02
2	1.0E-04	5.0E-03
3	1.0E-04	5.0E-03
4	1.0E-04	5.0E-03
5	1.0E-04	5.0E-03
6	1.0E-04	5.0E-03
7	1.0E-04	5.0E-03
8	5.0E-04	1.0E-02
9	1.0E-04	5.0E-03
10	1.0E-04	5.0E-03
11	1.0E-04	5.0E-03
12	1.0E-04	5.0E-03
13	1.0E-04	5.0E-03
14	1.0E-04	5.0E-03
15	1.0E-04	5.0E-03
16	1.0E-04	5.0E-03
17	1.0E-04	5.0E-03
18	5.0E-03	1.0E-01
19	1.0E-03	2.0E-01
20	1.0E-03	5.0E-02
21	1.0E-04	1.0E-02
23	1.0E-03	1.0E-02
25	1.0E-03	1.0E-02
27	1.0E-03	1.0E-02

AVERAGE RAINFALL RECHARGE [m/day]

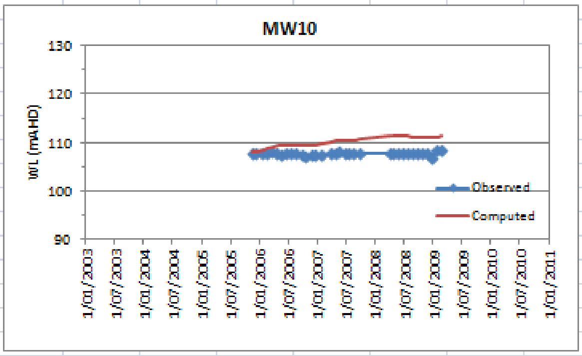


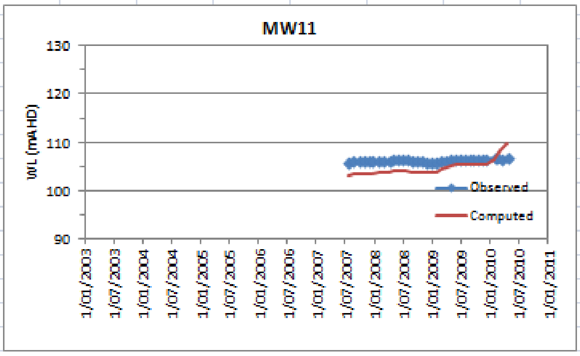
ATTACHMENT AB

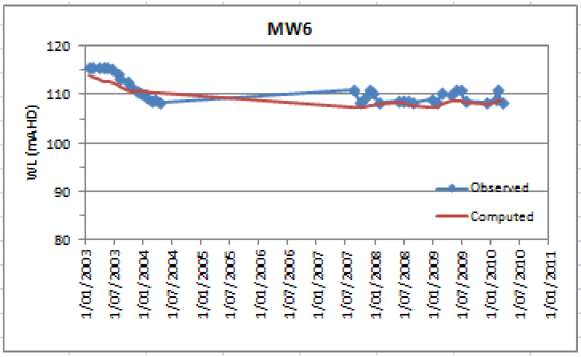
Hydrographic Calibration

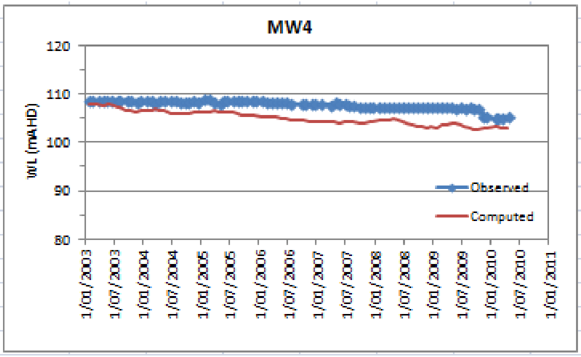
BORES SCREENED IN COAL

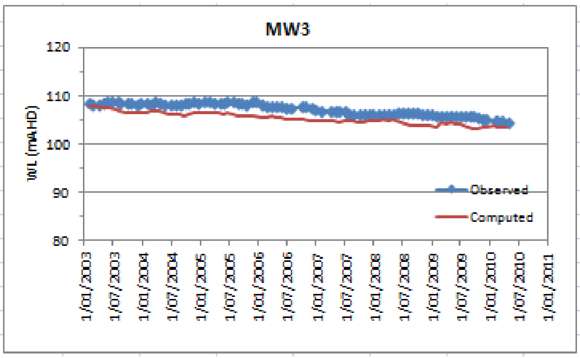
[Ordered North to South]

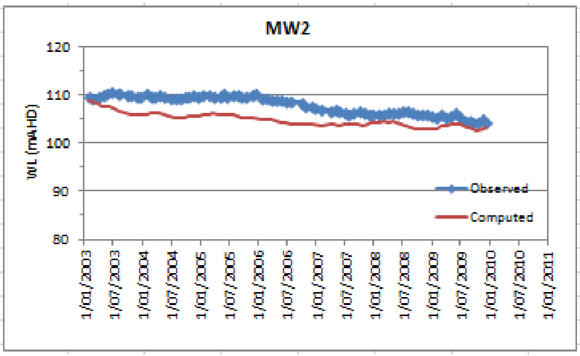






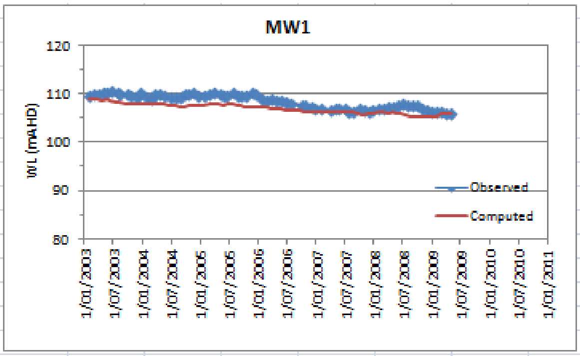


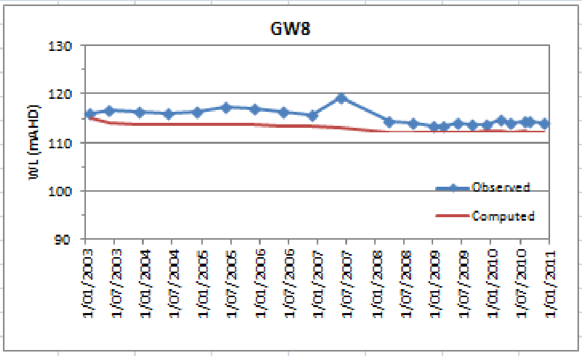


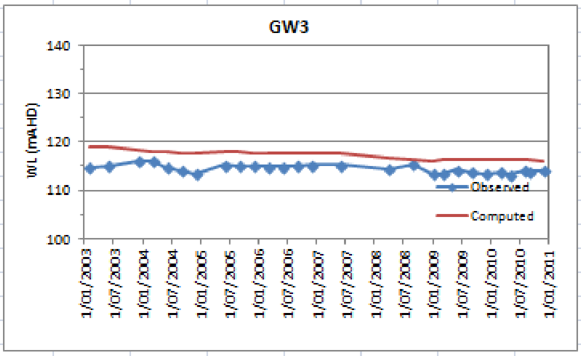


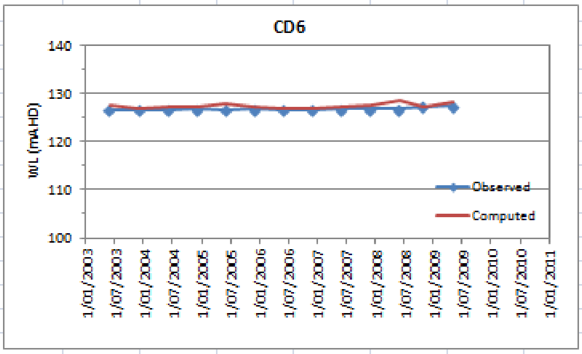
BORES SCREENED IN COAL

[Ordered North to South]



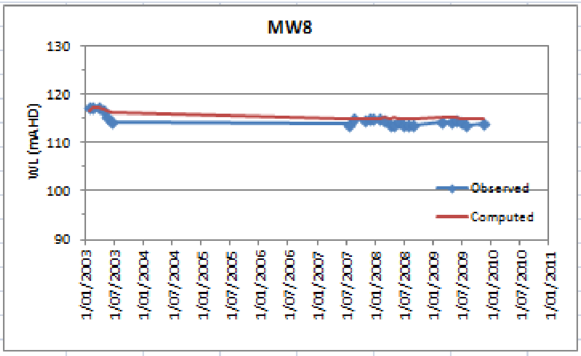


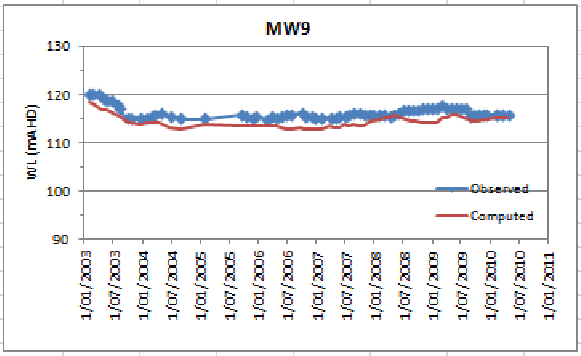


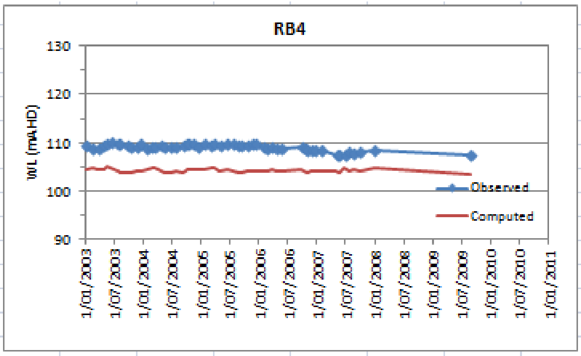


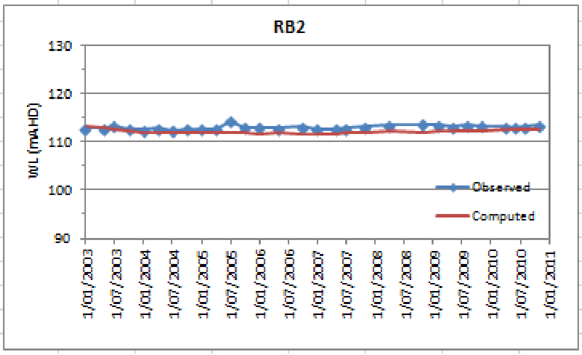
BORES SCREENED IN REGOLITH

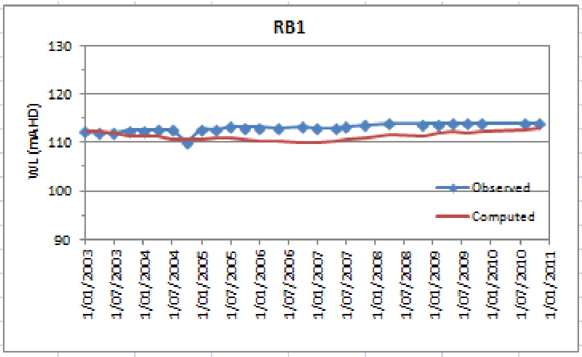
[Ordered North to South]

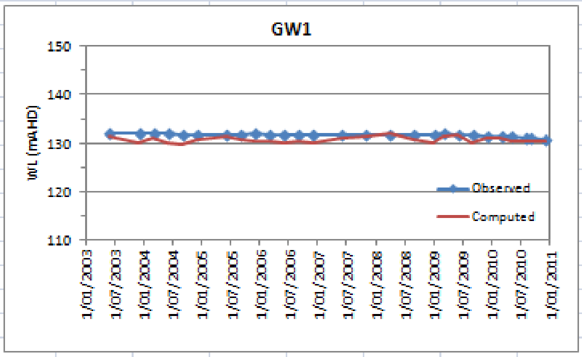






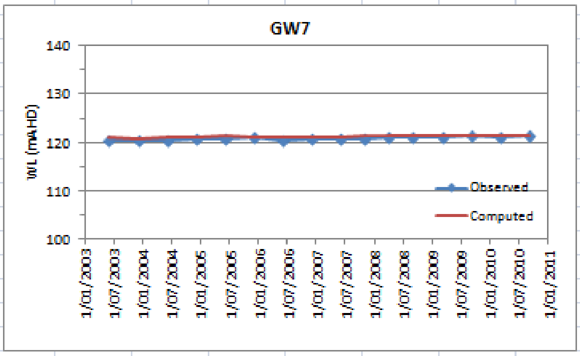


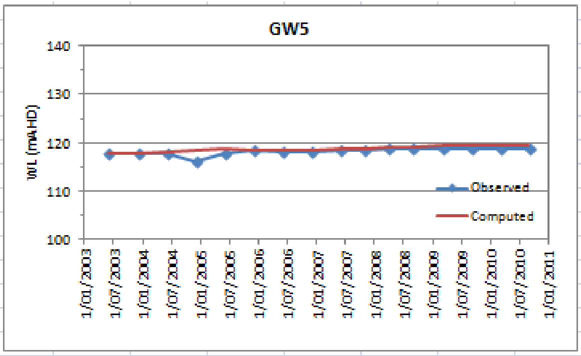


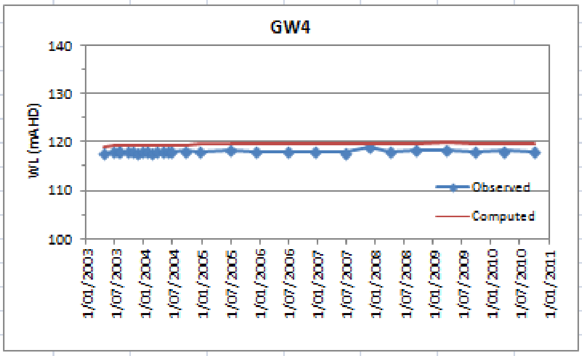


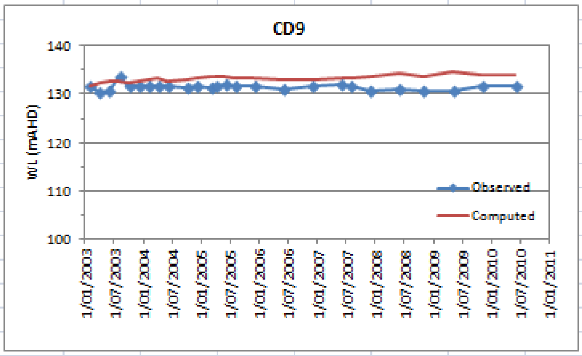
BORES SCREENED IN REGOLITH

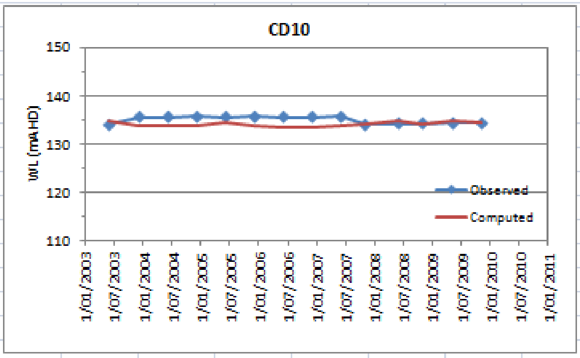
[Ordered North to South]

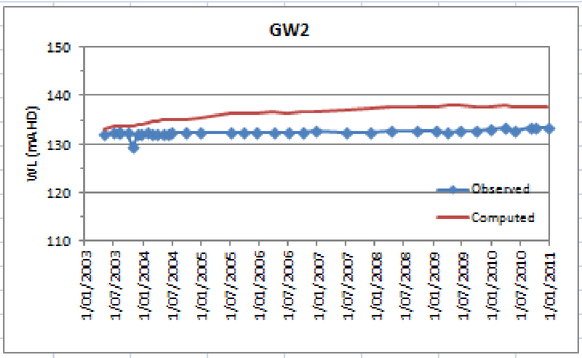






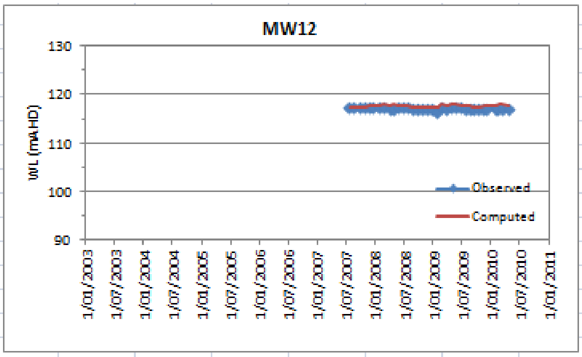


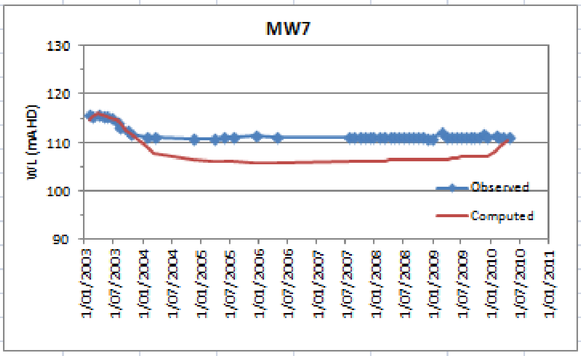


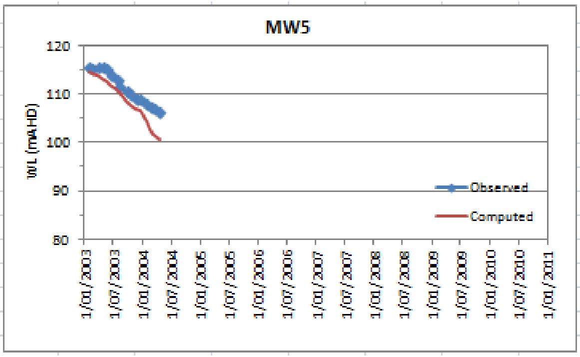


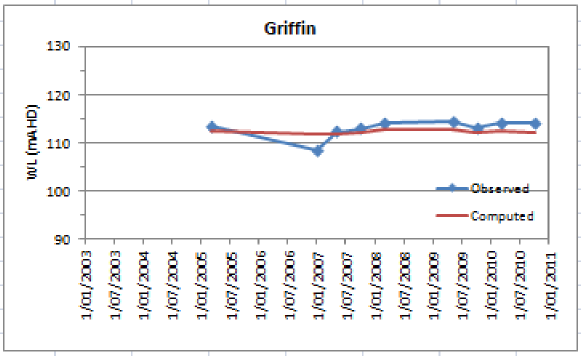
BORES SCREENED IN INTERBURDEN

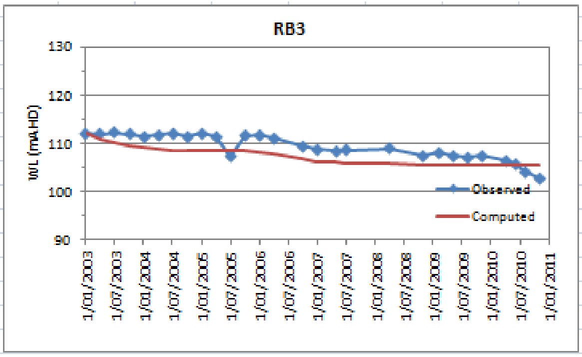
[Ordered North to South]

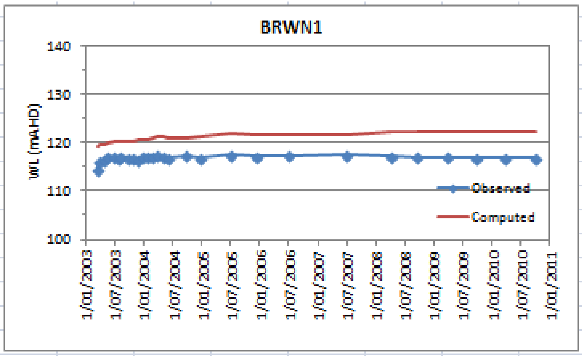


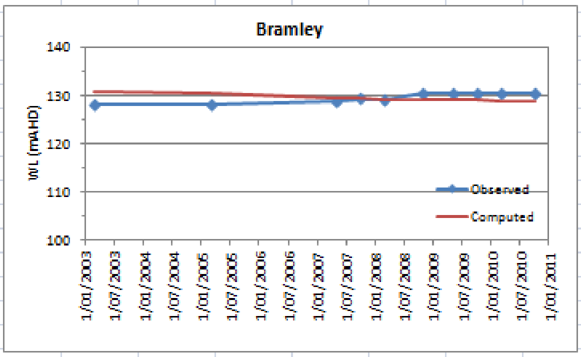






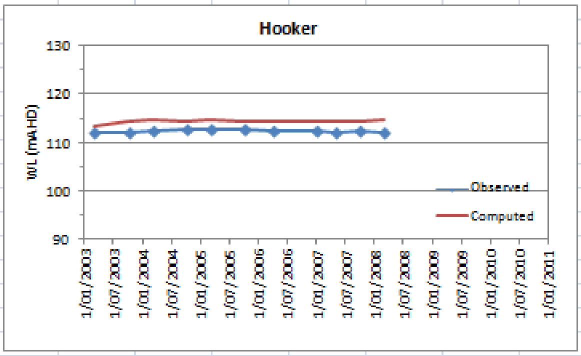


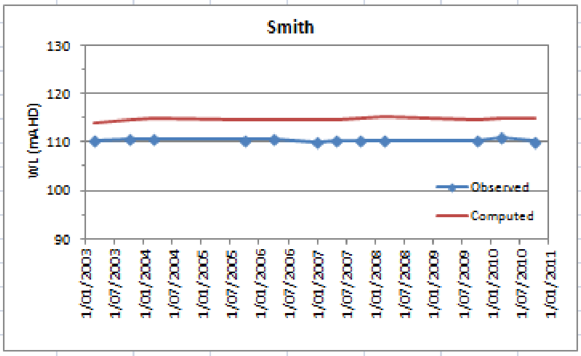


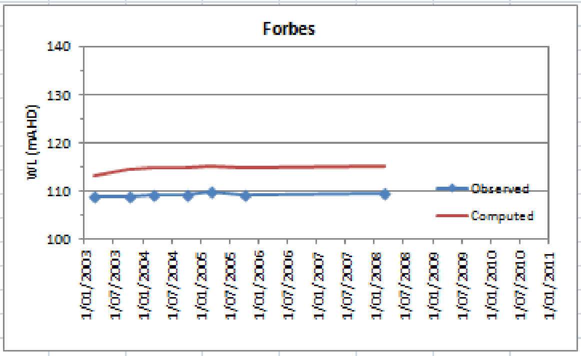


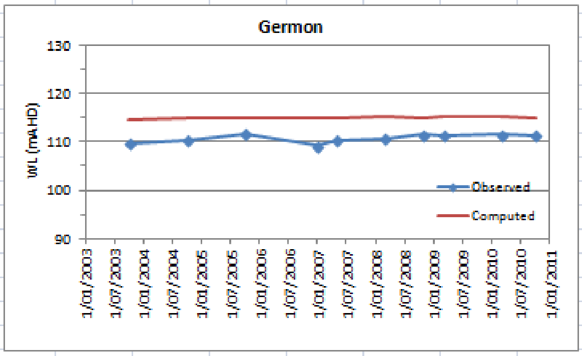
STRATFORD VILLAGE BORES

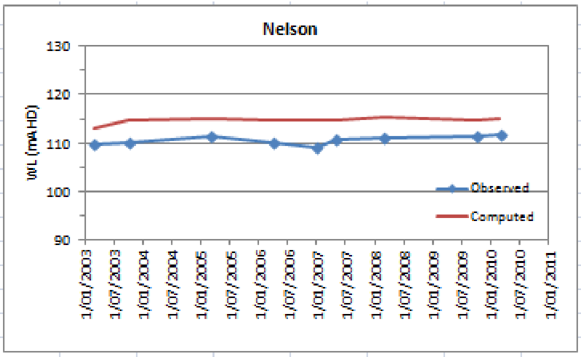
[Ordered North to South]

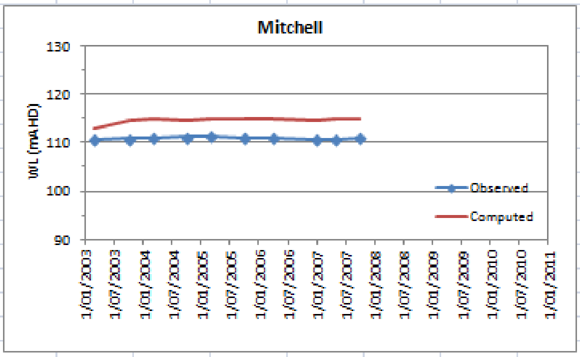












STRATFORD VILLAGE BORES

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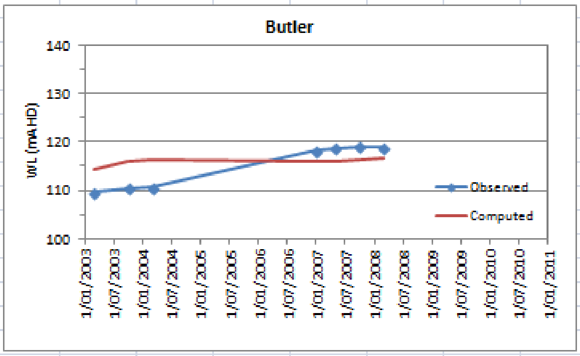

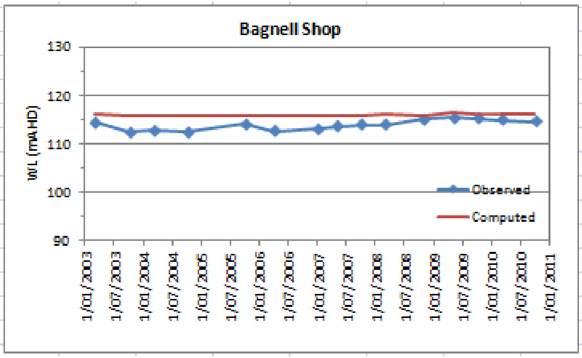

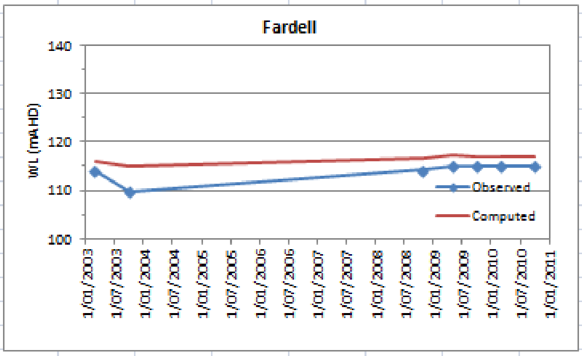

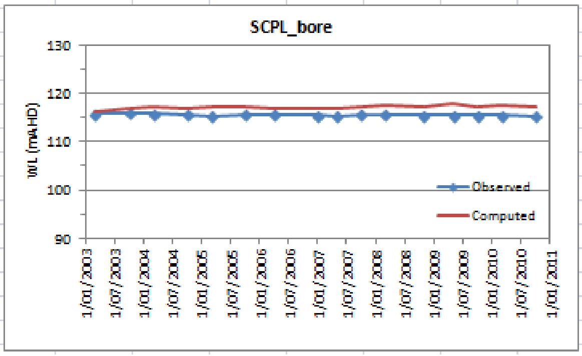

ATTACHMENT AC

Model Stress Period Setup

Table AC-1. Model Stress Period Setup

Model Purpose	Model Type	Stress Period	Start Date	End Date	Period Length	Timing of Operation				
						BRNOC Layer 5	Roseville West Pit Extension Layer 3	Stratford Main Pit Layer 7	Avon North Open Cut Layer 7	Stratford East Open Cut Layer 11
CALIBRATION	Transient	1	Jan-03	Jan-03	Monthly			Water Storage (DRN Cells)		
	Transient	2	Feb-03	Feb-03	Monthly					
	Transient	3	Mar-03	Mar-03	Monthly					
	Transient	4	Apr-03	Apr-03	Monthly	Open Cut				
	Transient	5	May-03	May-03	Monthly					
	Transient	6	Jun-03	Jun-03	Monthly					
	Transient	7	Jul-03	Jul-03	Monthly					
	Transient	8	Aug-03	Aug-03	Monthly					
	Transient	9	Sep-03	Sep-03	Monthly					
	Transient	10	Oct-03	Oct-03	Monthly					
	Transient	11	Nov-03	Nov-03	Monthly					
	Transient	12	Dec-03	Dec-03	Monthly					
	Transient	13	Jan-04	Jan-04	Monthly					
	Transient	14	Feb-04	Feb-04	Monthly					
	Transient	15	Mar-04	Mar-04	Monthly					
	Transient	16	Apr-04	Apr-04	Monthly					
	Transient	17	May-04	May-04	Monthly					
	Transient	18	Jun-04	Jun-04	Monthly					
	Transient	19	Jul-04	Jul-04	Monthly					
	Transient	20	Aug-04	Aug-04	Monthly					
	Transient	21	Sep-04	Sep-04	Monthly					
	Transient	22	Oct-04	Oct-04	Monthly					
	Transient	23	Nov-04	Nov-04	Monthly					
	Transient	24	Dec-04	Dec-04	Monthly					
	Transient	25	Jan-05	Jan-05	Monthly					
	Transient	26	Feb-05	Feb-05	Monthly					

	Transient	27	Mar-05	Mar-05	Monthly					
	Transient	28	Apr-05	Apr-05	Monthly					
	Transient	29	May-05	May-05	Monthly					
	Transient	30	Jun-05	Jun-05	Monthly					
	Transient	31	Jul-05	Jul-05	Monthly					
	Transient	32	Aug-05	Aug-05	Monthly					
	Transient	33	Sep-05	Sep-05	Monthly					
	Transient	34	Oct-05	Oct-05	Monthly					
	Transient	35	Nov-05	Nov-05	Monthly					
	Transient	36	Dec-05	Dec-05	Monthly					
	Transient	37	Jan-06	Jan-06	Monthly					
	Transient	38	Feb-06	Feb-06	Monthly					
	Transient	39	Mar-06	Mar-06	Monthly					
	Transient	40	Apr-06	Apr-06	Monthly					
	Transient	41	May-06	May-06	Monthly					
	Transient	42	Jun-06	Jun-06	Monthly		Open Cut			
	Transient	43	Jul-06	Jul-06	Monthly					
	Transient	44	Aug-06	Aug-06	Monthly					
	Transient	45	Sep-06	Sep-06	Monthly					
	Transient	46	Oct-06	Oct-06	Monthly					
	Transient	47	Nov-06	Nov-06	Monthly					
	Transient	48	Dec-06	Dec-06	Monthly					
	Transient	49	Jan-07	Jan-07	Monthly					
	Transient	50	Feb-07	Feb-07	Monthly					
	Transient	51	Mar-07	Mar-07	Monthly					
	Transient	52	Apr-07	Apr-07	Monthly					
	Transient	53	May-07	May-07	Monthly					
	Transient	54	Jun-07	Jun-07	Monthly					
	Transient	55	Jul-07	Jul-07	Monthly					
	Transient	56	Aug-07	Aug-07	Monthly					
	Transient	57	Sep-07	Sep-07	Monthly					

	Transient	58	Oct-07	Oct-07	Monthly					
	Transient	59	Nov-07	Nov-07	Monthly					
	Transient	60	Dec-07	Dec-07	Monthly					
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	Transient	62	Feb-08	Feb-08	Monthly					
	Transient	63	Mar-08	Mar-08	Monthly					
	Transient	64	Apr-08	Apr-08	Monthly					
	Transient	65	May-08	May-08	Monthly					
	Transient	66	Jun-08	Jun-08	Monthly					
	Transient	67	Jul-08	Jul-08	Monthly					
	Transient	68	Aug-08	Aug-08	Monthly					
	Transient	69	Sep-08	Sep-08	Monthly					
	Transient	70	Oct-08	Oct-08	Monthly					
	Transient	71	Nov-08	Nov-08	Monthly					
	Transient	72	Dec-08	Dec-08	Monthly					
	Transient	73	Jan-09	Jan-09	Monthly					
	Transient	74	Feb-09	Feb-09	Monthly					
	Transient	75	Mar-09	Mar-09	Monthly					
	Transient	76	Apr-09	Apr-09	Monthly					
	Transient	77	May-09	May-09	Monthly					
	Transient	78	Jun-09	Jun-09	Monthly					
	Transient	79	Jul-09	Jul-09	Monthly					
	Transient	80	Aug-09	Aug-09	Monthly					
	Transient	81	Sep-09	Sep-09	Monthly					
	Transient	82	Oct-09	Oct-09	Monthly					
	Transient	83	Nov-09	Nov-09	Monthly					
	Transient	84	Dec-09	Dec-09	Monthly					
	Transient	85	Jan-10	Jan-10	Monthly					
	Transient	86	Feb-10	Feb-10	Monthly					
	Transient	87	Mar-10	Mar-10	Monthly					
	Transient	88	Apr-10	Apr-10	Monthly					

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<tr><td rowspan="2"></td><td>Transient</td><td>89</td><td>May-10</td><td>May-10</td><td>Monthly</td><td rowspan="6"></td><td rowspan="16"></td><td rowspan="3"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Transient</td><td>90</td><td>Jun-10</td><td>Jun-10</td><td>Monthly</td></tr>
<tr><td rowspan="14">PREDICTION</td><td>Transient</td><td>91</td><td>Jul-10</td><td>Jun-11</td><td>Yearly</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>Transient</td><td>92</td><td>Jul-11</td><td>Jun-12</td><td>Yearly</td><td rowspan="8">Water Storage (DRN Cells)</td></tr>
<tr><td>Transient</td><td>93</td><td>Jul-12</td><td>Jun-13</td><td>Yearly</td></tr>
<tr><td>Transient</td><td>94^</td><td>Jul-13</td><td>Jun-14</td><td>Yearly</td><td rowspan="5">Open Cut</td><td rowspan="11">Open Cut</td></tr>
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<tr><td>Transient</td><td>96</td><td>Jul-15</td><td>Jun-16</td><td>Yearly</td></tr>
<tr><td>Transient</td><td>97</td><td>Jul-16</td><td>Jun-17</td><td>Yearly</td></tr>
<tr><td>Transient</td><td>98</td><td>Jul-17</td><td>Jun-18</td><td>Yearly</td></tr>
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<tr><td>Transient</td><td>103</td><td>Jul-22</td><td>Jun-23</td><td>Yearly</td></tr>
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<tr><td>Recovery</td><td>Transient</td><td>105</td><td></td><td></td><td>200 Years</td><td>Back-filled</td><td>Open Void</td><td>Back-filled</td><td>Open Void</td><td>Open Void</td></tr>
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^ The Project period runs from stress period 94 to stress period 104

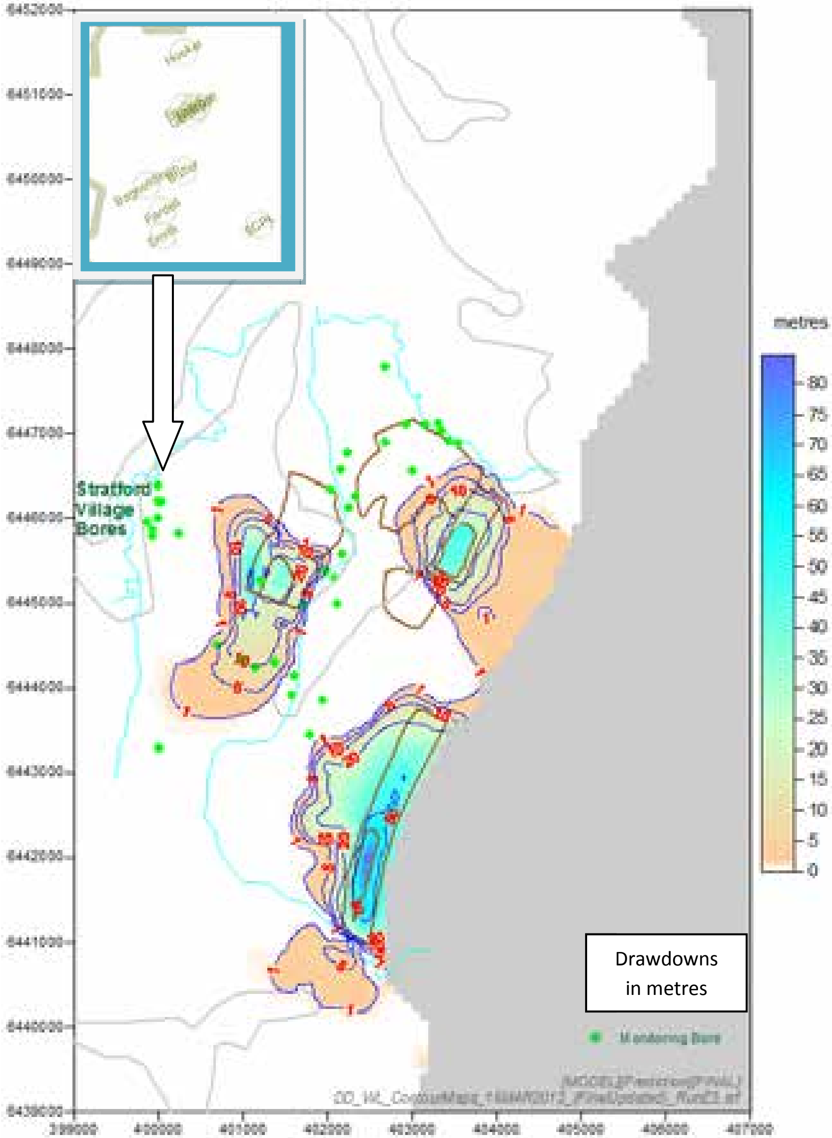
ATTACHMENT AD

Predicted Groundwater Drawdown (m) Contour Maps for Layers 2, 3, 5, 7 and 11 from 2013 to 2024:

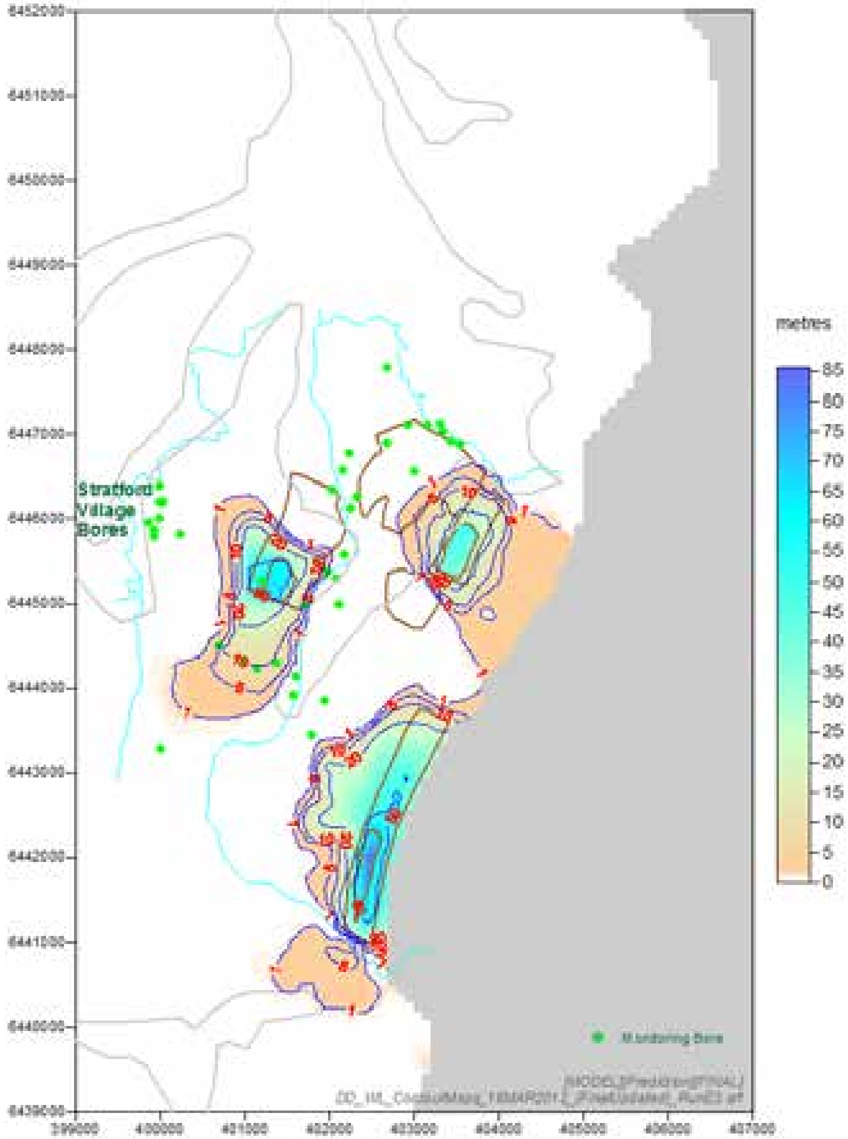
(1) Project Only

(2) Cumulative Projects

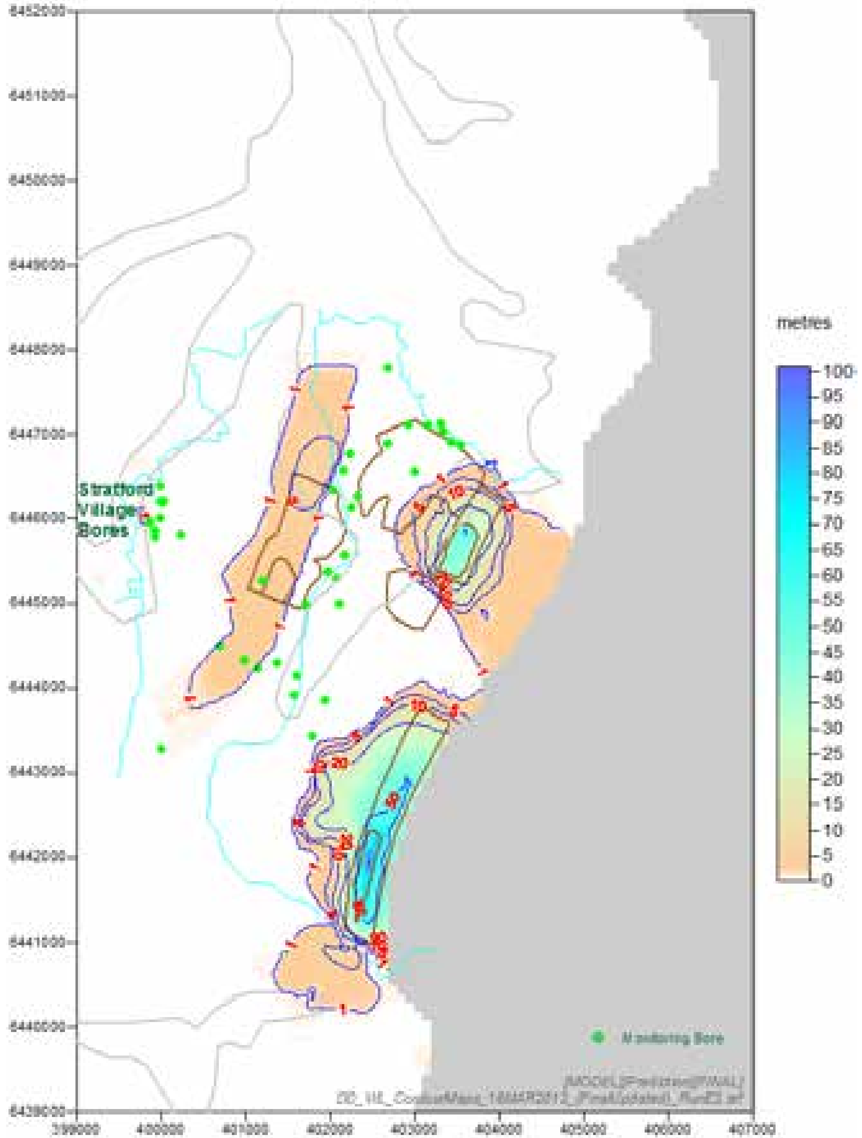
PROJECT ONLY - LAYER 2



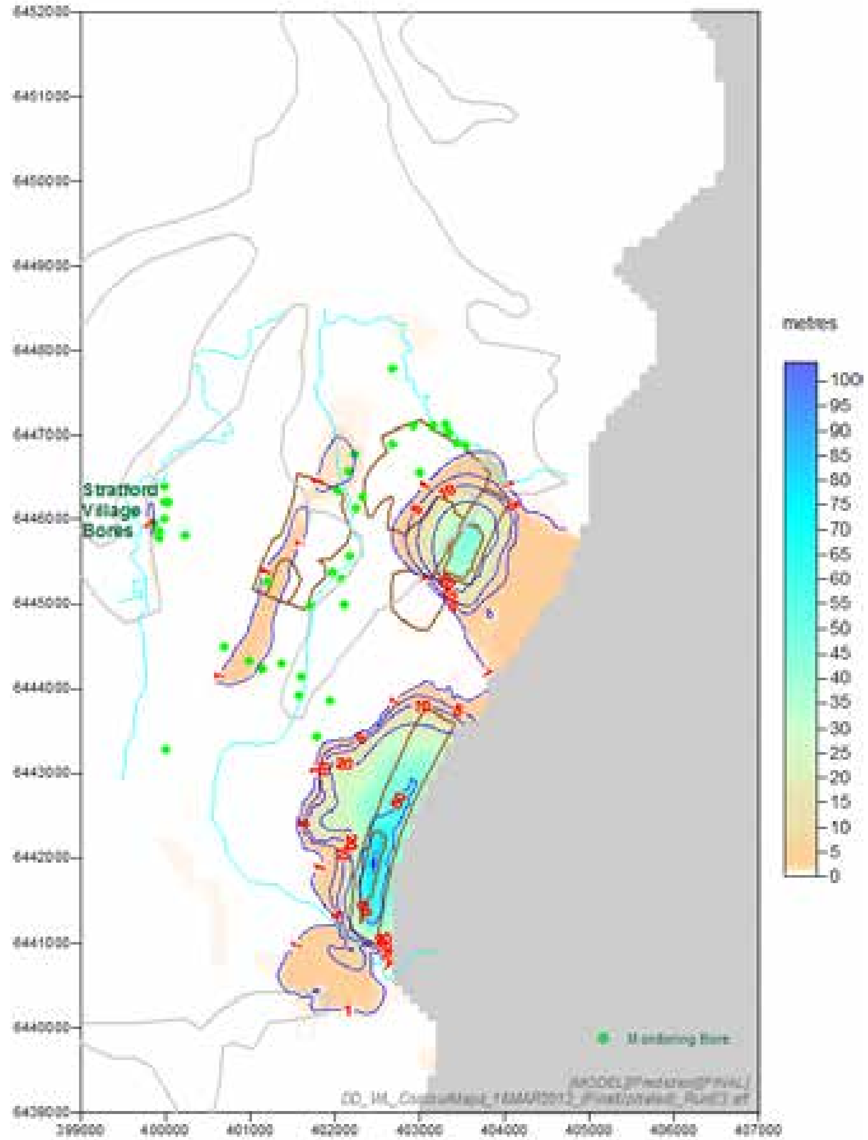
PROJECT ONLY - LAYER 3



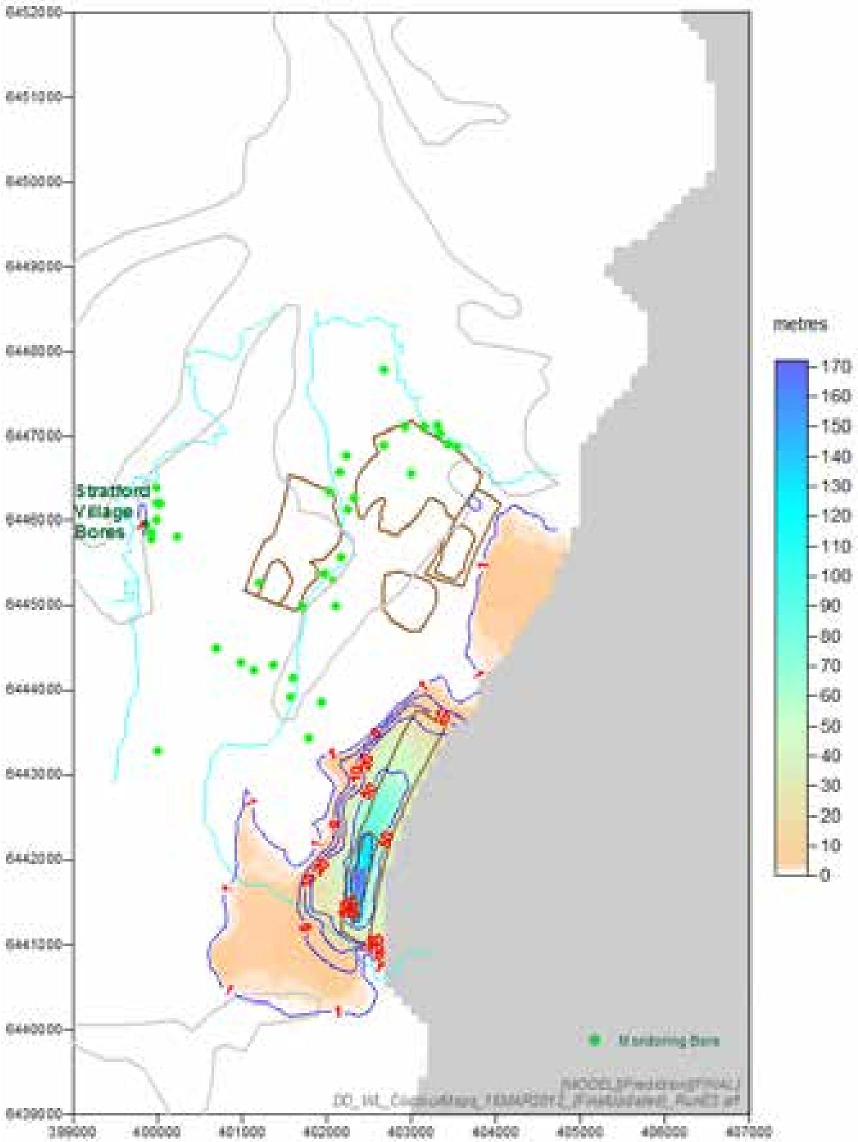
PROJECT ONLY - LAYER 5



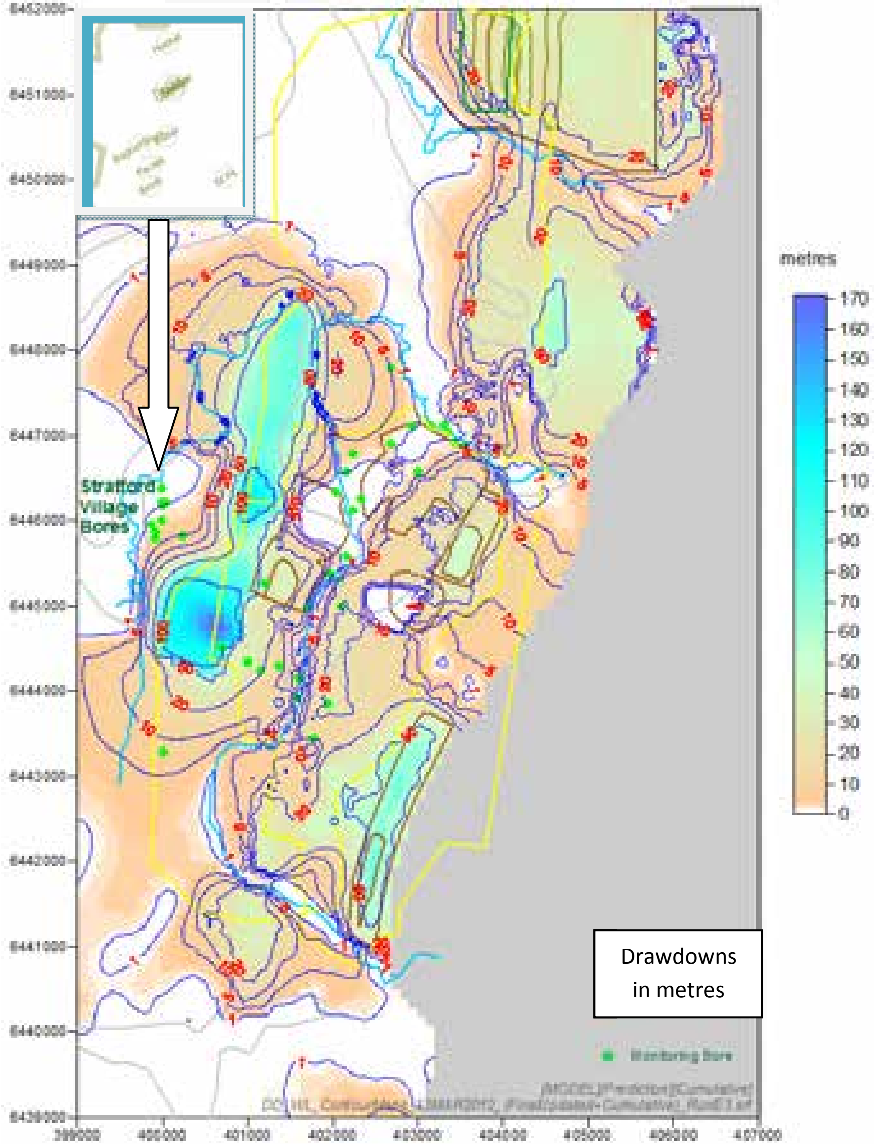
PROJECT ONLY - LAYER 7



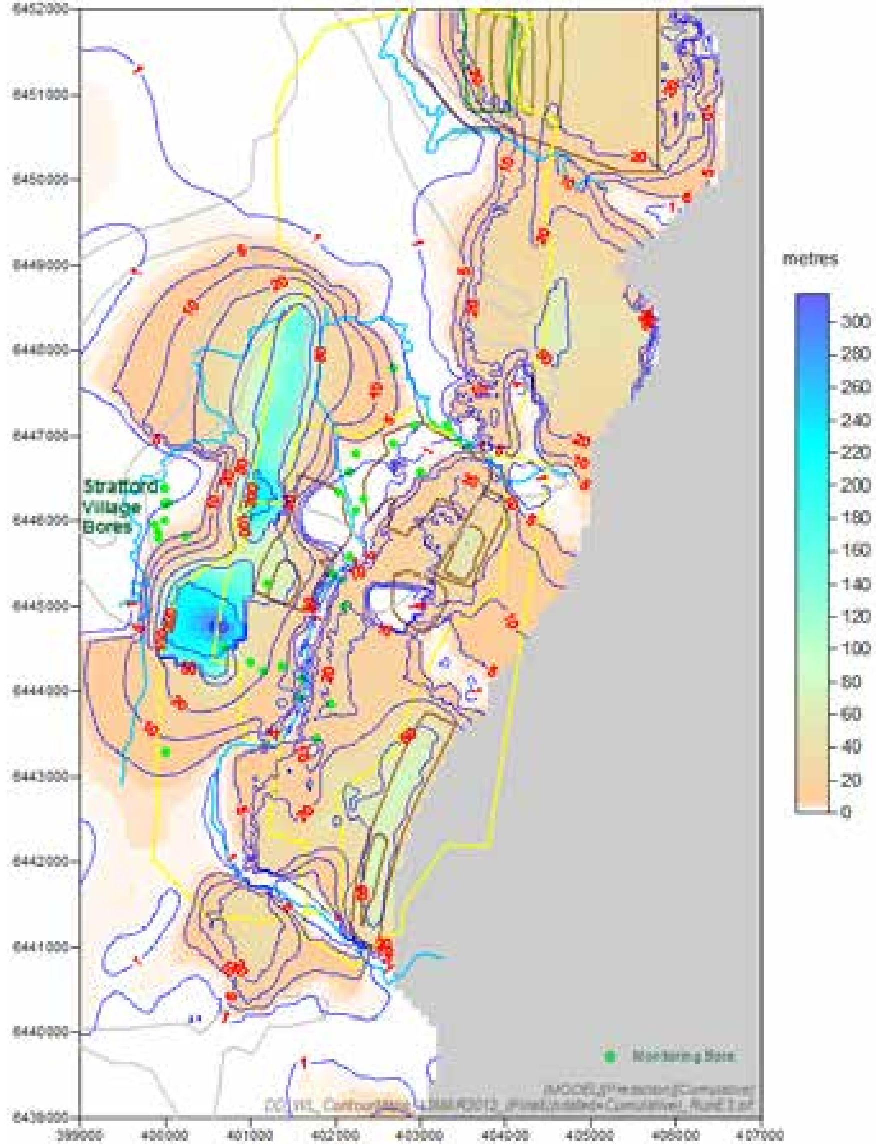
PROJECT ONLY - LAYER 11



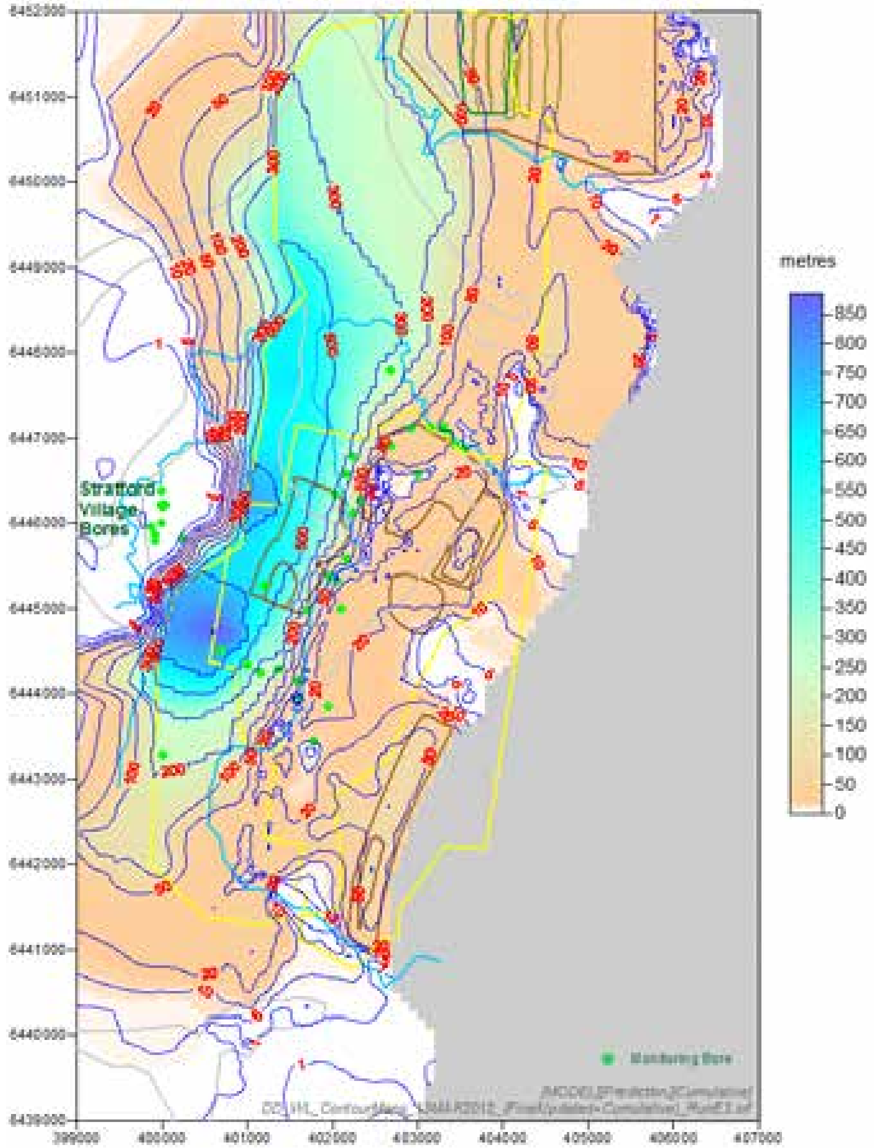
CUMULATIVE PROJECTS - LAYER 2



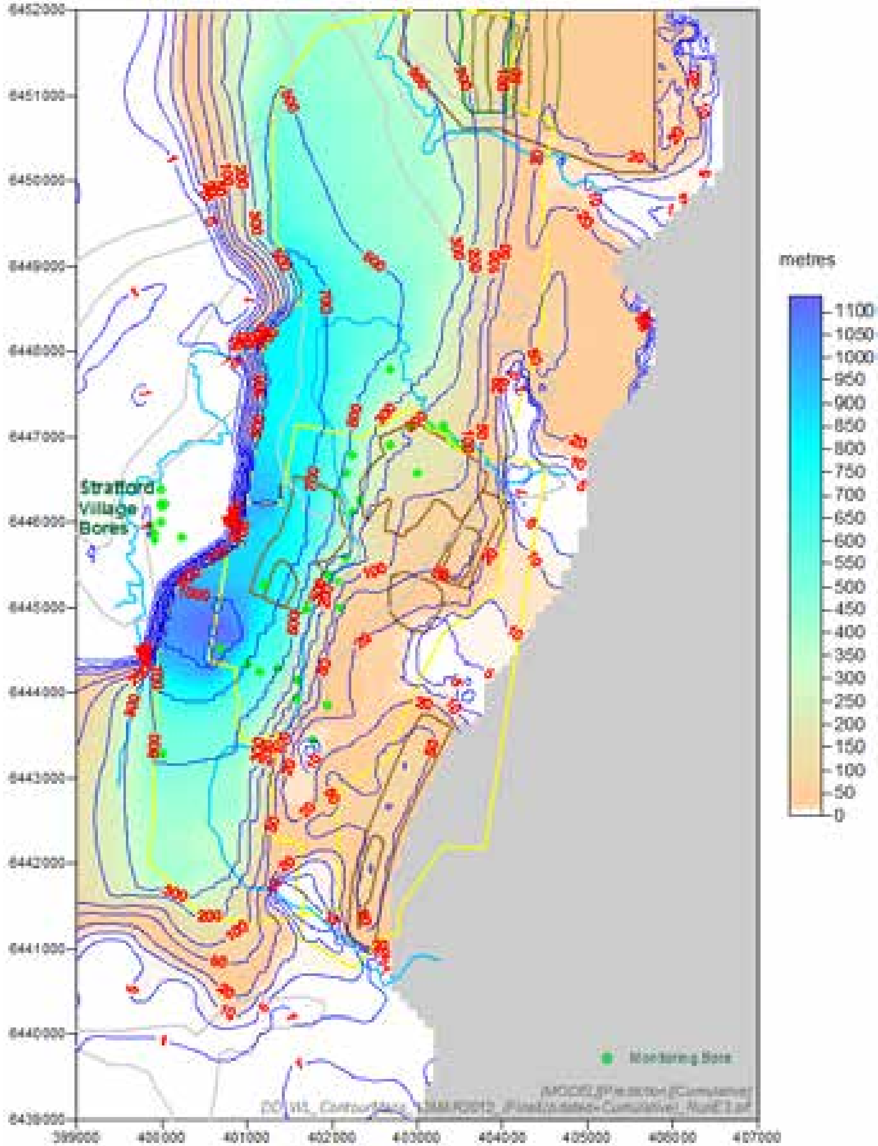
CUMULATIVE PROJECTS - LAYER 3



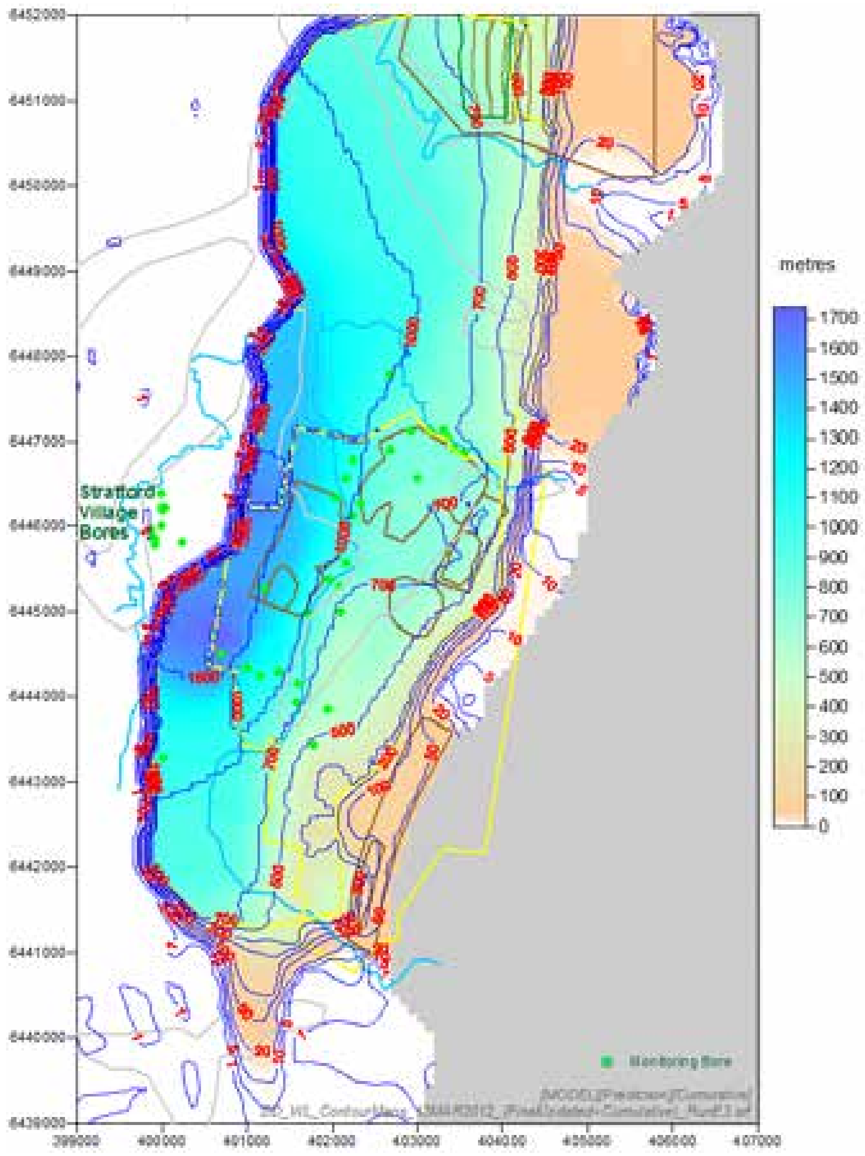
CUMULATIVE PROJECTS - LAYER 5



CUMULATIVE PROJECTS - LAYER 7



CUMULATIVE PROJECTS - LAYER 11



ATTACHMENT AE

Schoeller Diagrams

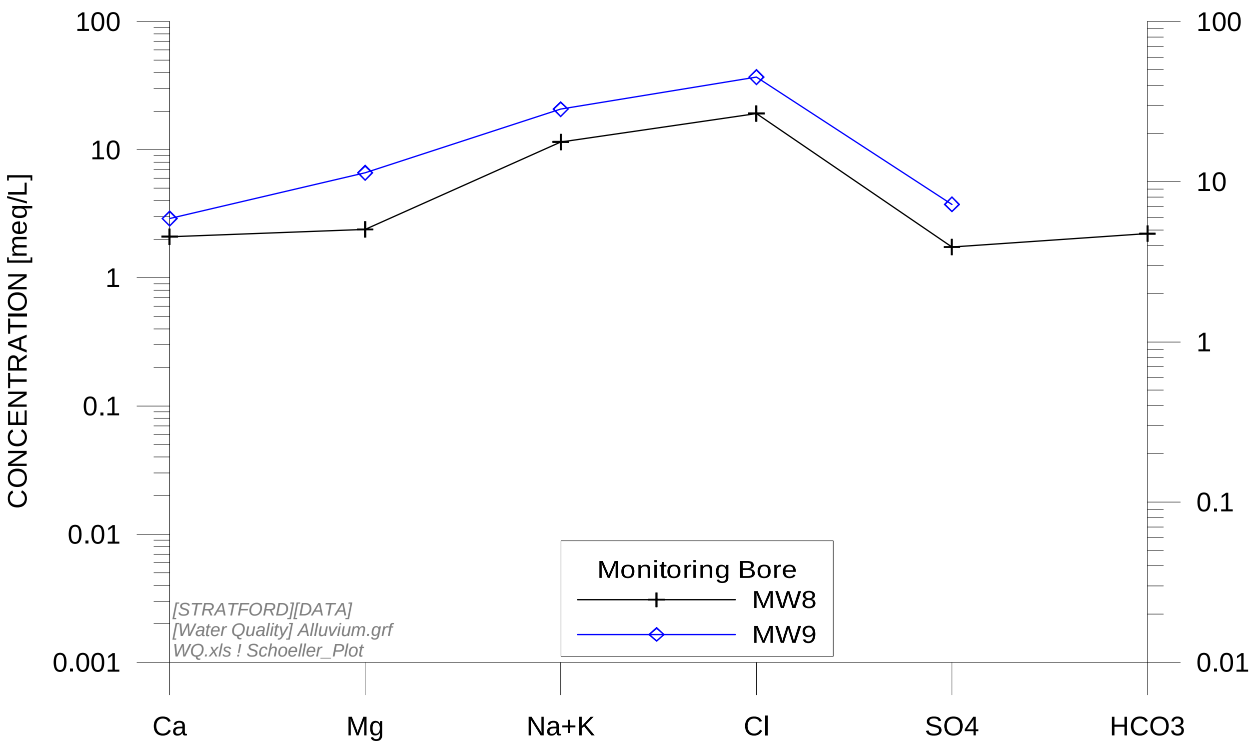


Figure AE-1. Schoeller diagram for major ions in alluvium/regolith

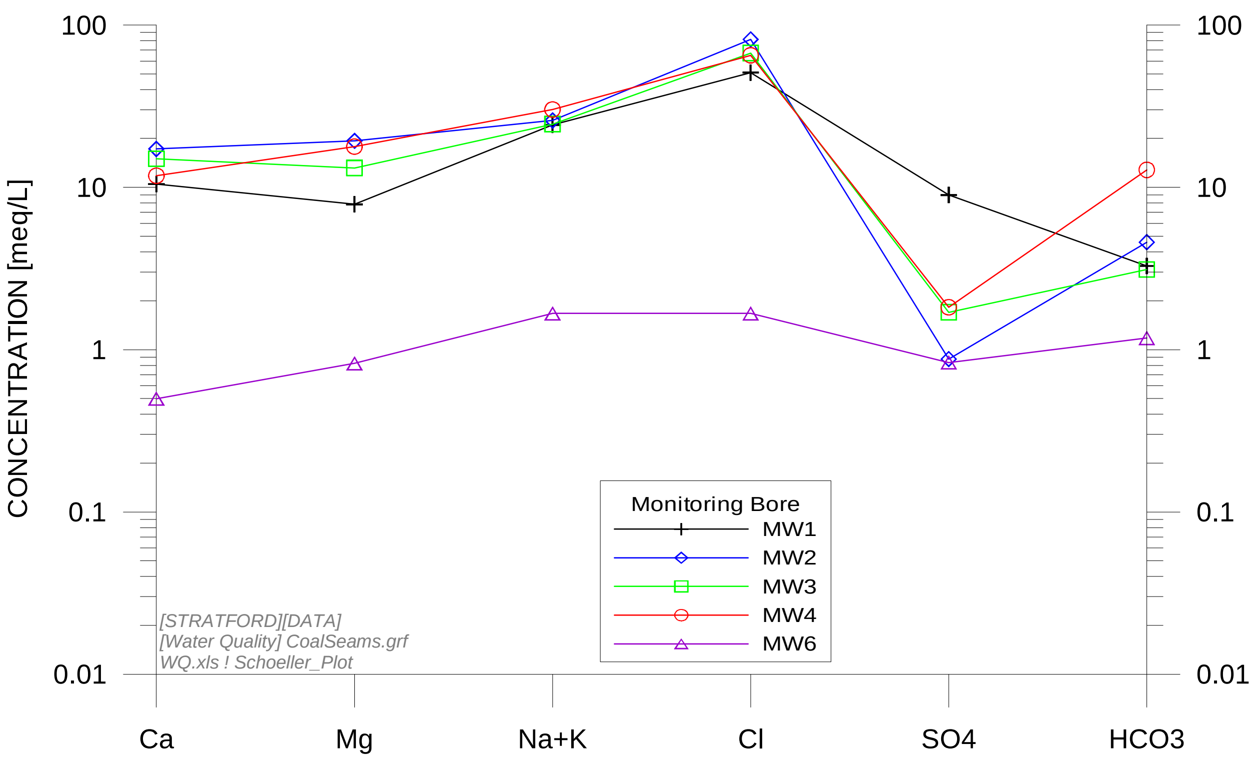


Figure AE-2. Schoeller diagram for major ions in coal seams

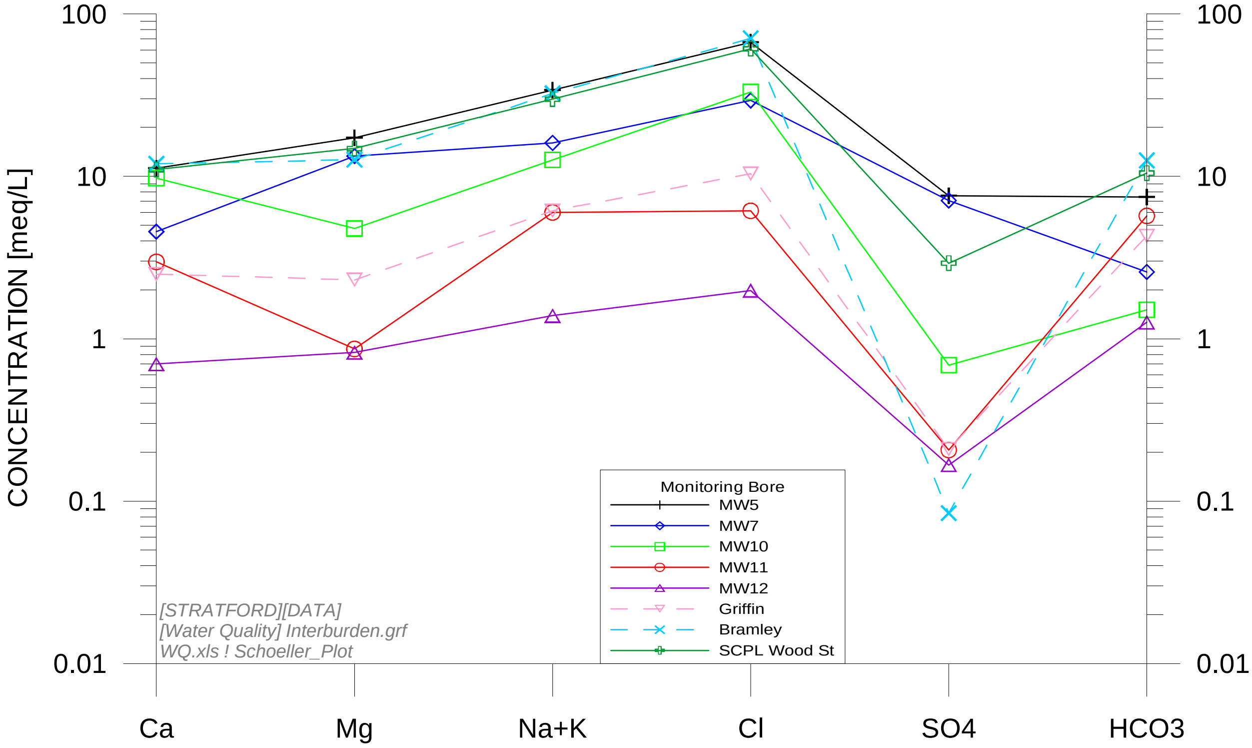


Figure AE-3. Schoeller diagram for major ions in interburden

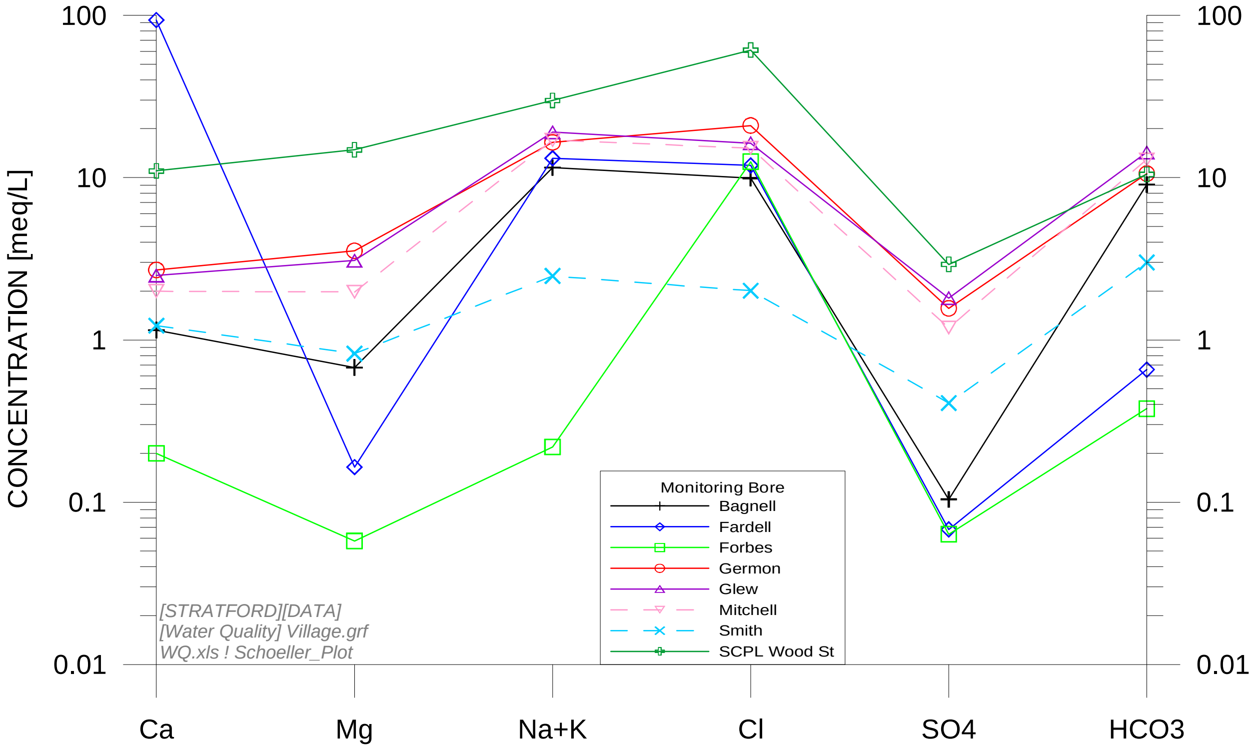
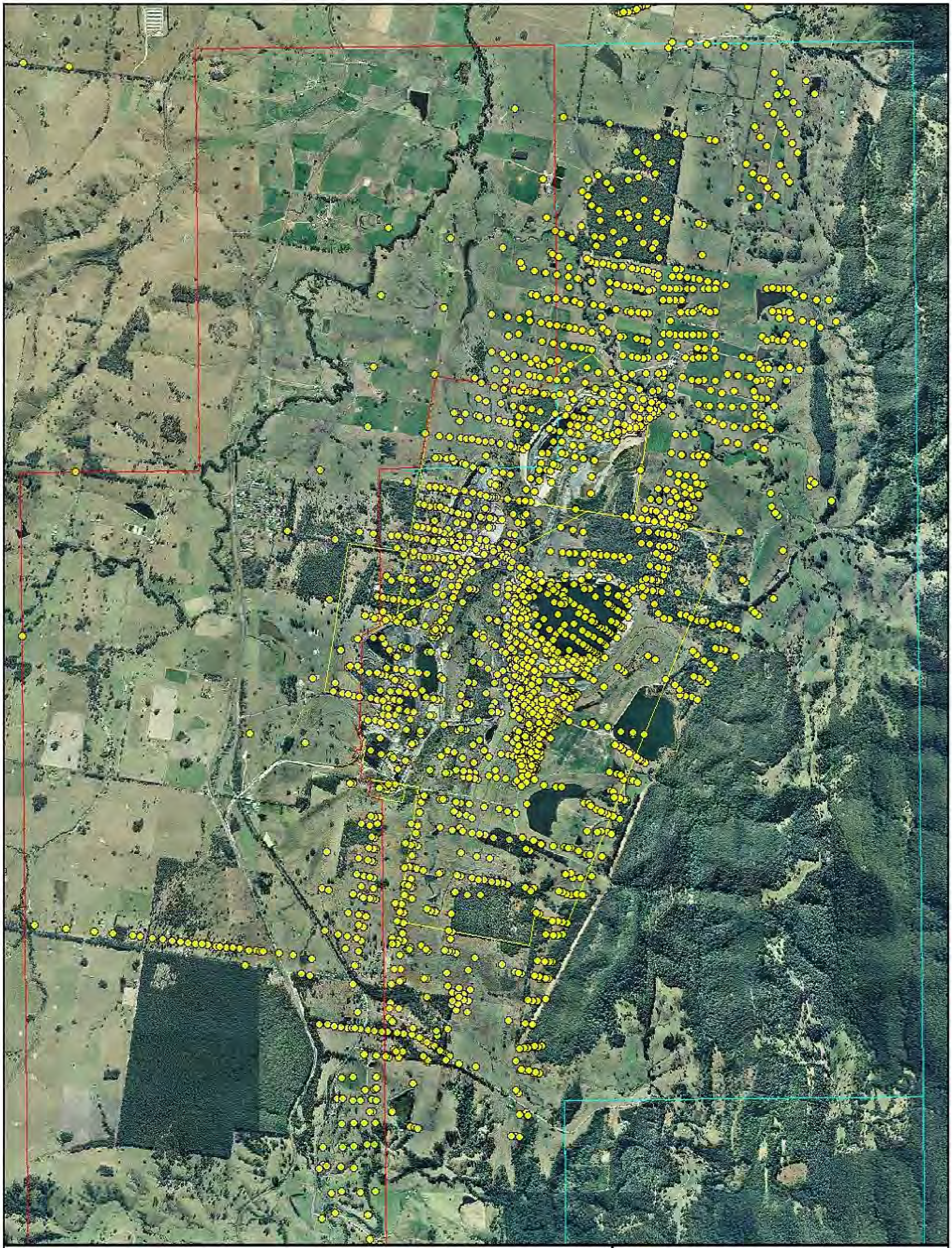


Figure AE-4. Schoeller diagram for major ions in interburden at Stratford Village

ENCLOSURE 1

Geological Logs Plan

A copy of individual drill logs shown on the enclosed figure can be provided upon request from environment@gcl.com.au



Scale: 1cm = 600m

GLOUCESTER COAL

ALL HOLES DRILLED WITHIN EXPLORATION LEASES (NORTHERN SECTION, 10M OR DEEPER)

13/06/2012