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THREE DIMENSIONAL GROUNDWATER MODEL OF HUME COAL PROSPECT, SOUTHERN HIGHLANDS NSW

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1 INTRODUCTION

This report presents a three dimensional groundwater model established to assess probable impacts from underground coal mining in the Hume Coal prospect in the Southern Highlands of NSW. The study was commissioned by the Southern Highlands Coal Action Group, who arranged for a peer review of the work to be undertaken by the Water Research Laboratory of the University of NSW. The initial peer review made recommendations for additional analyses which are incorporated in this report.

As shown in Figure 1, the area falls within the Southern Highlands Groundwater Resource as defined and detailed in a report by the NSW Department of Infrastructure, Planning and Natural Resources in 2004[1] **(Pritchard report)**. That report notes as follows:

> "The groundwater resource that underlies much of the Southern Highlands is extracted from aquifers within the Hawkesbury Sandstone formation. <u>This groundwater resource is highly valued for its good quality and high yielding supplies.</u>"

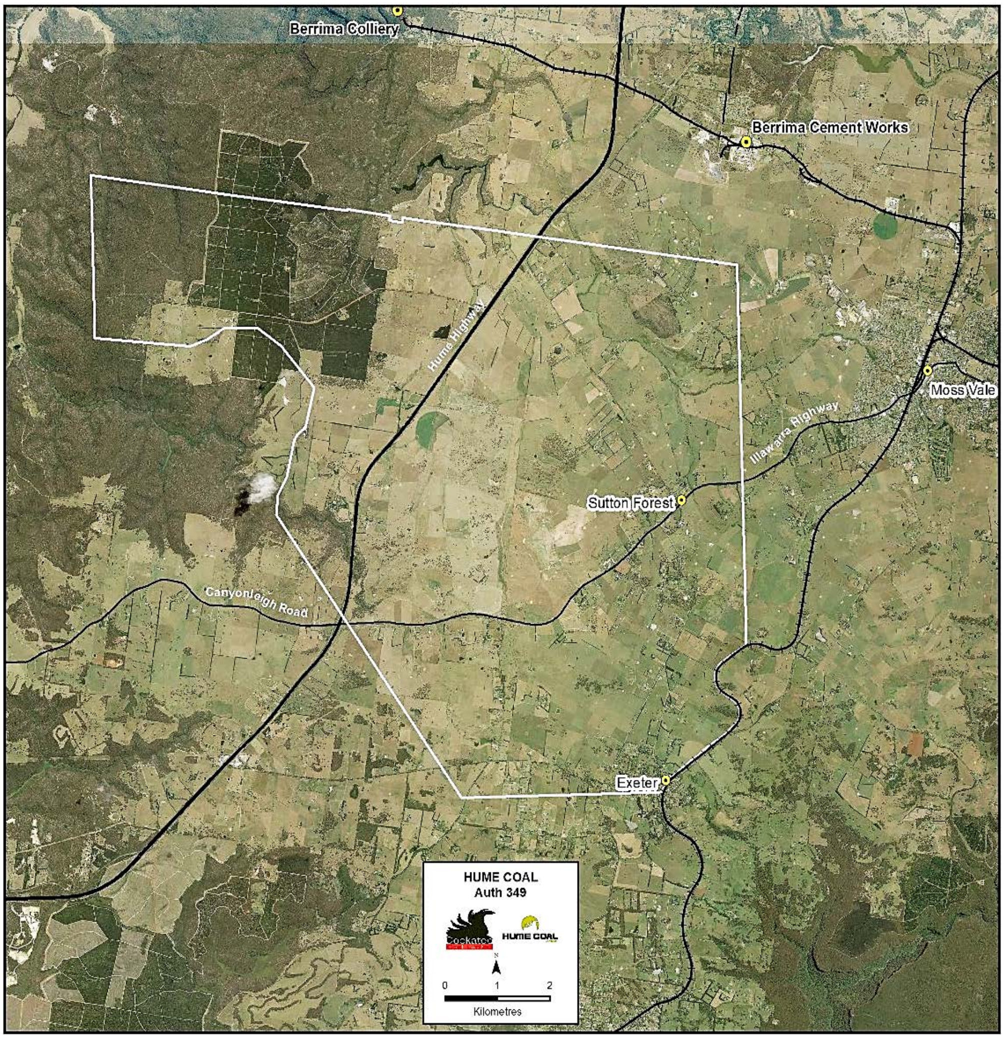

Figure 1 – Bounds of Hume Coal Authorisation 349 (April 2013)

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[1] Pritchard, Hehir and Russell (2004). "A review of the status of the groundwater resources in the Southern Highlands, NSW. NSW Dept, Infrastructure, Planning and Natural Resources, may 2004.

The Conclusions to the Pritchard report include the following important comments:

"During the formulation of this report, other issues became evident:

- declining water levels within some of the department's monitoring bores up to in excess of 10 metres;
- parts of the study area are likely to have reached their sustainable limit for access to the groundwater resource;
- lack of knowledge on actual water extraction (i.e. volumes, rates, timing) from licensed bores, particularly high yield bores;
- limited understanding of the linkages between the groundwater resource and the dependent ecosystems within study area;

Figure 2 shows the NSW Office of Water summary of airlift bore yields in the area covered by this report. The yields from the Hawkesbury Sandstone in this area are the highest in this Formation within the Sydney Basin,

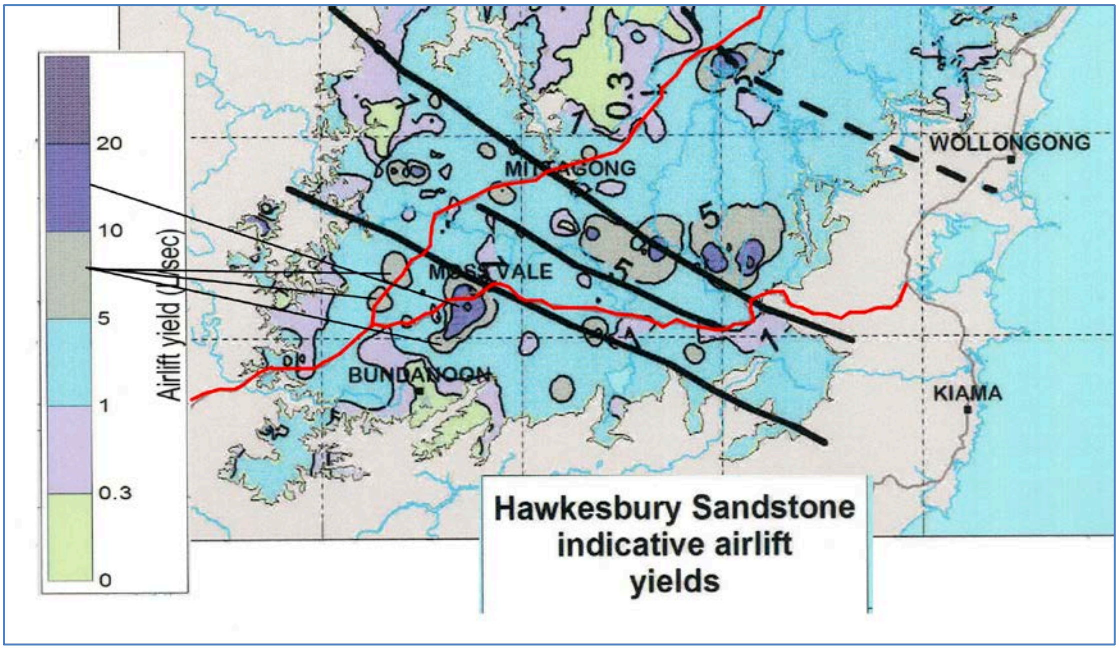


Figure 2 – NSW Office of Water, Yields in the Hawkesbury in Moss Vale area

For this study we have drawn on the substantial geological database available through the Geological Survey of NSW covering coal exploration in the area up to 1982 (223 boreholes), and in the database of the NSW Office of Water (82 bores selected). In addition Mr John Lee of Hydroilex has provided detailed stratigraphic and water bore pump testing data from 28 bores installed by his firm and held in his files. Most of these data are not available in the NSW Office of Water database.

It is understood that Hume Coal have completed additional exploration boreholes in the area, and possibly some groundwater investigations comprising bore testing and piezometer installation. However, no data from this work have been made available through the community consultative process, and therefore have been unavailable for inclusion in this study.

At the time of this study Hume Coal had not provided details of the location of the proposed mine within the Authorisation area, nor of the method of mining. However, they had indicated a proposal to extract up to 4.1 million tonne per annum (mta), and that they would seek to reduce surface subsidence impacts. Therefore, from knowledge of modern coal mining practice, it is reasonable to assume that mining could comprise short longwall faces, with two operating simultaneously so as to produce the required yield. It is also reasonably easy to designate, approximately, the likely mining areas based on published isopachs of the Wongawilli Seam and published contours of coal quality. However, it is important to note that the precise details of the mine layout and mining method are not critical to the groundwater study, because the key factor is the complete groundwater depressurisation at coal seam level over an area governed by the mine extraction rate and the likely mined thickness, assumed to be about 3m.

The length of longwall faces does impact on the extent to which rock is fractured above the extracted seam, but that variable is covered in this study by considering both no fracturing (as if extraction were by bord-and-pillar workings), and fracturing above a nominal 100m longwall face.

2 PREPARATION OF THE MODEL

2.1 Model Domain

The coal exportation lease, Authorisation 349, current at the time of this report is presented in Figure 1.

As shown in Figures 3 and 4, the groundwater model domain covers an area substantially greater than Authorisation 349. The boundaries of the model were set about 10 km away from the locations of probable mining. The model boundaries were chosen to be substantially defined by surface hydraulic features, namely:

- Wingecarribee River along the northern boundary (Figure 5 and Figure 6),
- Wingecarribee and Fitzroy reservoirs along the eastern boundary,
- Black Bob’s creek along the western boundary, and
- Bundanoon Creek (“the Grand Canyon”) along the southern boundary (see Figure 7).

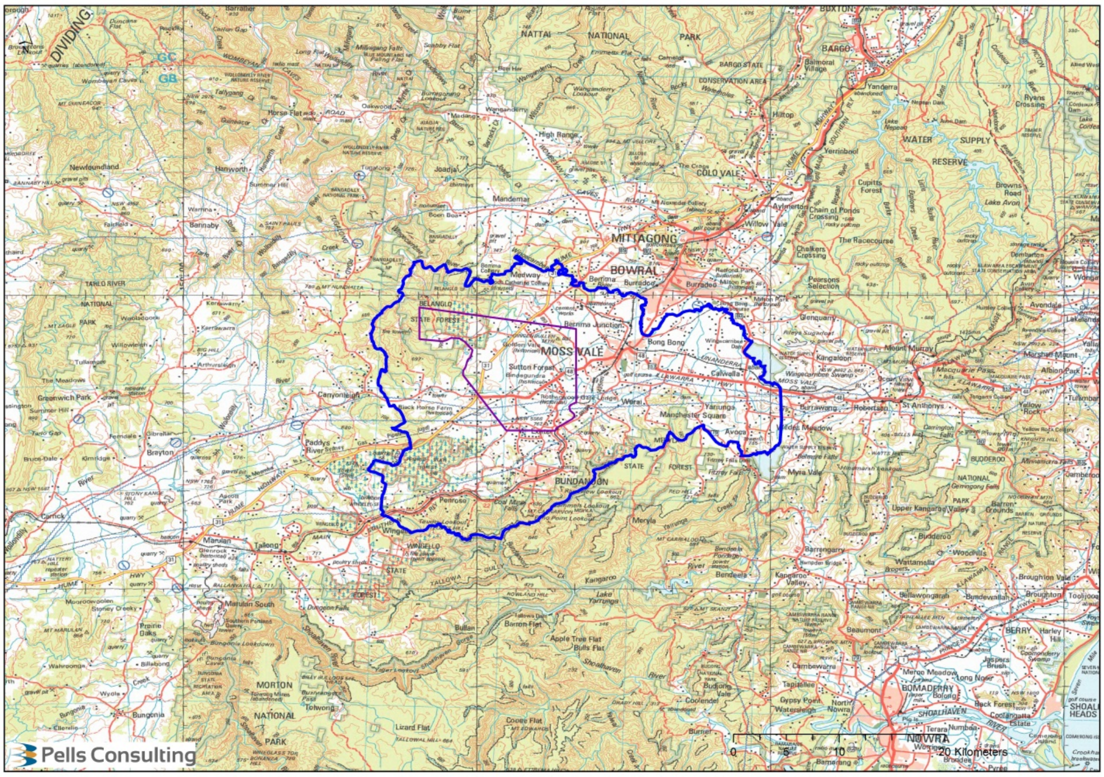


Figure 3 – Model Boundary over 1:250,000 Topographic Sheet

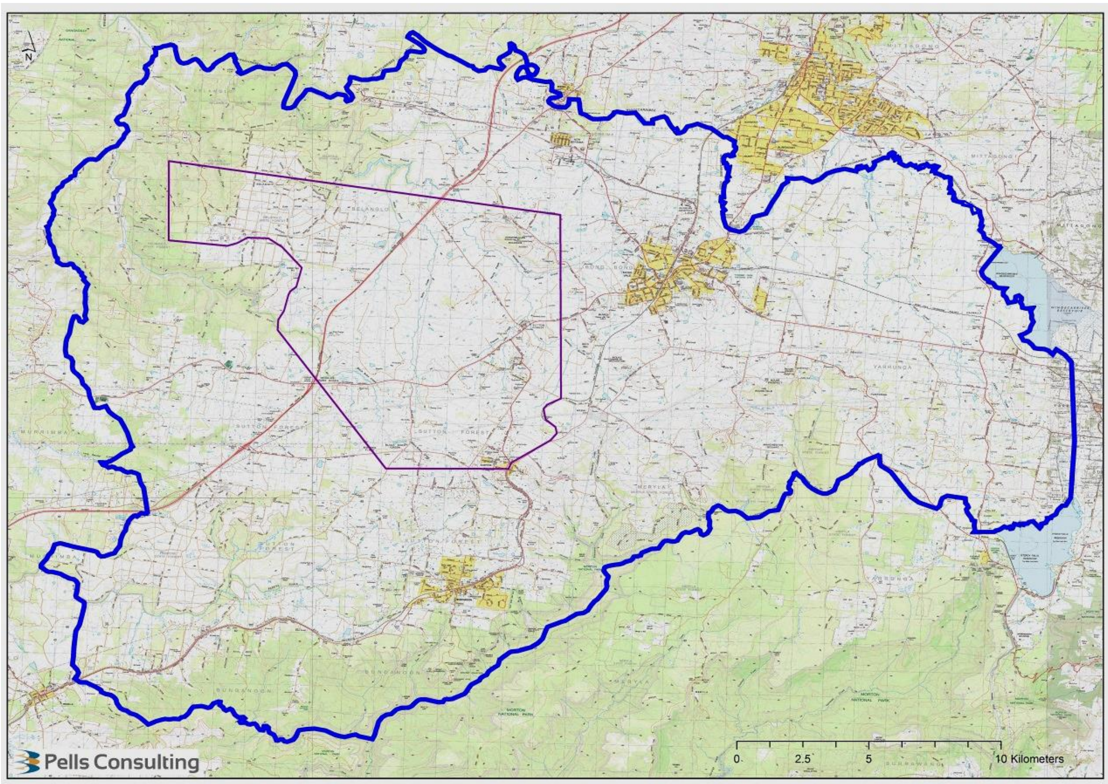


Figure 4 - Model Boundary over 1:25,000 Topographic Sheet

Figure 5 - Wingecarribee River North east of Moss Vale, viewing upstream to the east.

Figure 6 - Wingecarribee River just downstream of Wingecarribee dam, viewing downstream to the west

Figure 7 - Bundanoon Creek, near Bundanoon (Grand Canyon)

2.2 Surface Topography

A digital elevation model of surface topography (at approximately 28.7 m grid resolution) was provided to Pells Consulting, as shown in Figure 8.

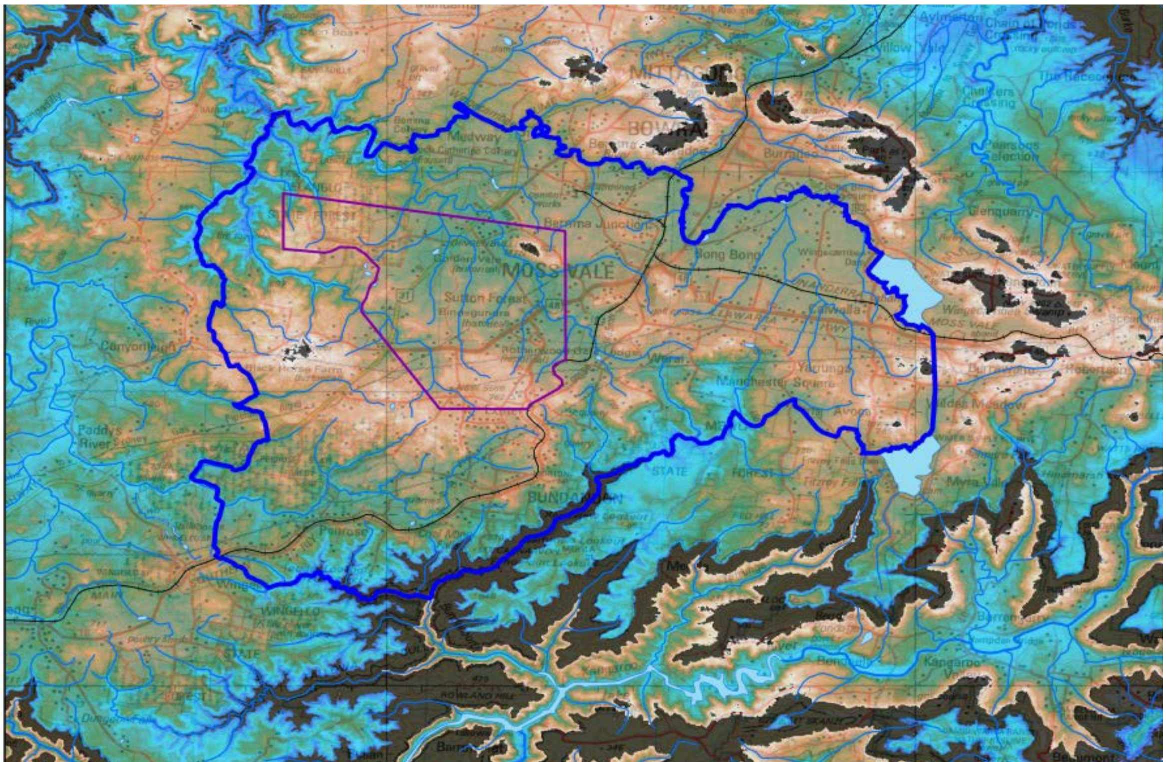


Figure 8 – Digital Elevation Model of Surface Topography

The site is located at the divide between the Nepean and Shoalhaven catchments as shown in Figure 9. The Nepean catchment flows to the north, to Lake Burragorang (Warragamba Dam). The Shoalhaven catchment flows south from the study area towards Lake Yarrunga (Tallowa Dam).

Authorisation 349 is entirely in the Warragamba catchment.

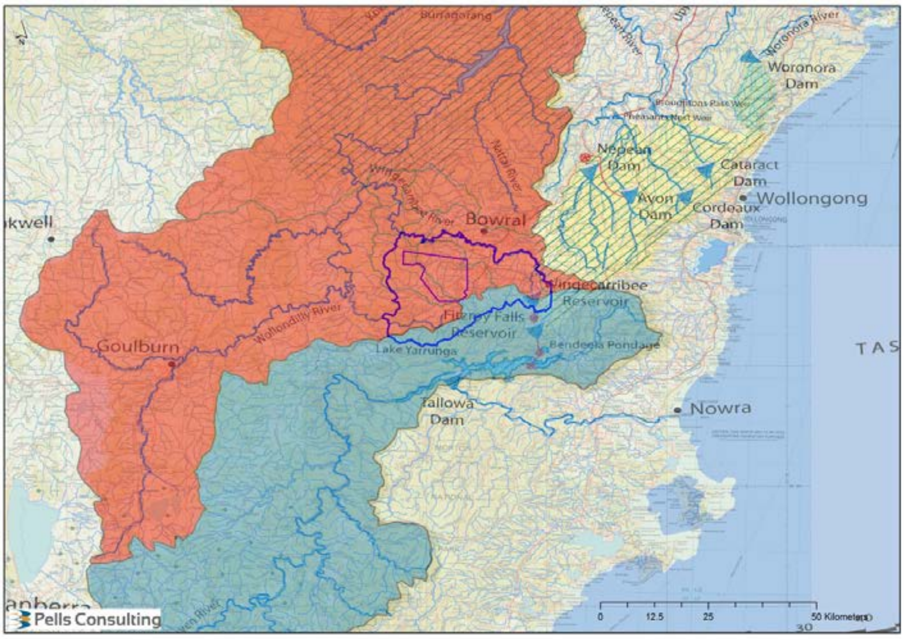


Figure 9 – Regional surface water catchments

2.3 Interpreted Geology and Stratigraphy

The stratigraphy of the area is shown in Figure 10.

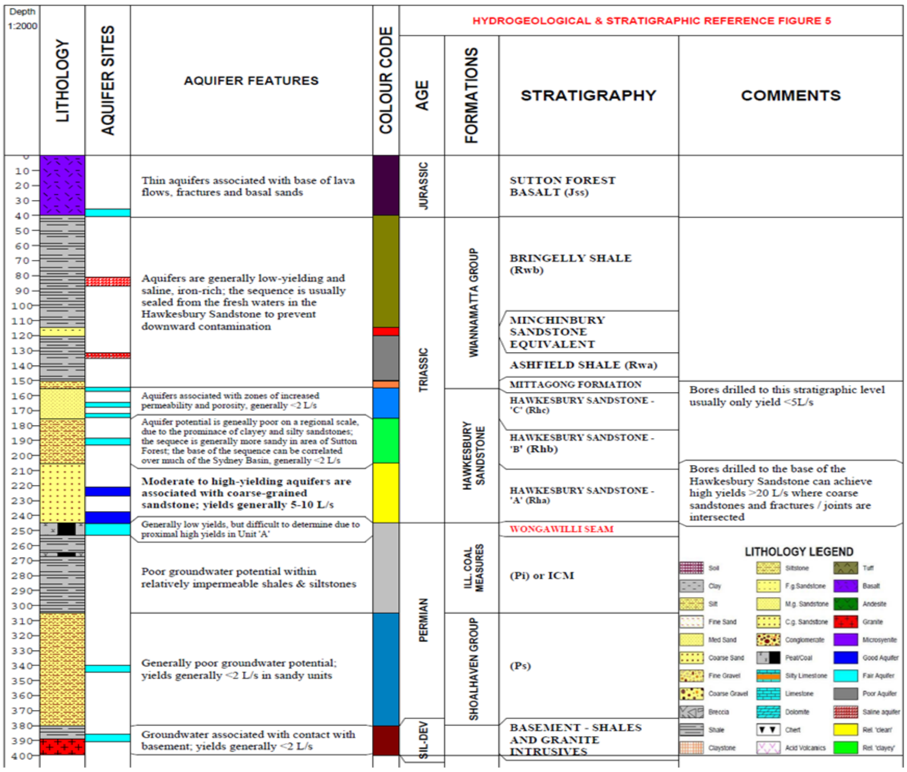


Figure 10 – Stratigraphic Sequence and Hydrogeology (provided by J Lee of Hydroilex)

The key feature of the stratigraphy, which makes Authorisation 349 very different from the Southern Coalfields in the Picton, Appin and Wollongong area, is that here the Hawkesbury Sandstone directly overlies the Wongawilli Seam[2]. We have examined most of the borehole records from the pre-1985 investigations of the area (more than 200 boreholes) and found direct contact between the Hawkesbury Sandstone and the Wongawilli Coal Seam in more than 90% of the holes. This is consistent with the conclusions of McElroy Bryan in 1980.

Relevant contours and isopachs of the units comprising the model were derived from the following source data:

- 216 exploration boreholes by Austen & Butta and Bellambi Coal, drilled prior to 1982 (see Figure 11).
- 28 groundwater bores installed, logged and tested by Hydroilex (see Figure 11).
- 82 selected groundwater bores on the NSW Office of Water (NOW) database (see Figure 11).
- 7 boreholes in the Belanglo area drilled by Hume Coal (see Figure 11).
- Contours and isopachs of stratigraphy prepared by McElroy Bryan and Associates, for Austen & Butta Ltd (see Figure 12 and 13)
- Geological mapping by the geological Survey of NSW from 1973 and onwards (see Figure 4)
- Geological cross sections prepared by Hydroilex (see Figure 5 and 16A to 16D)

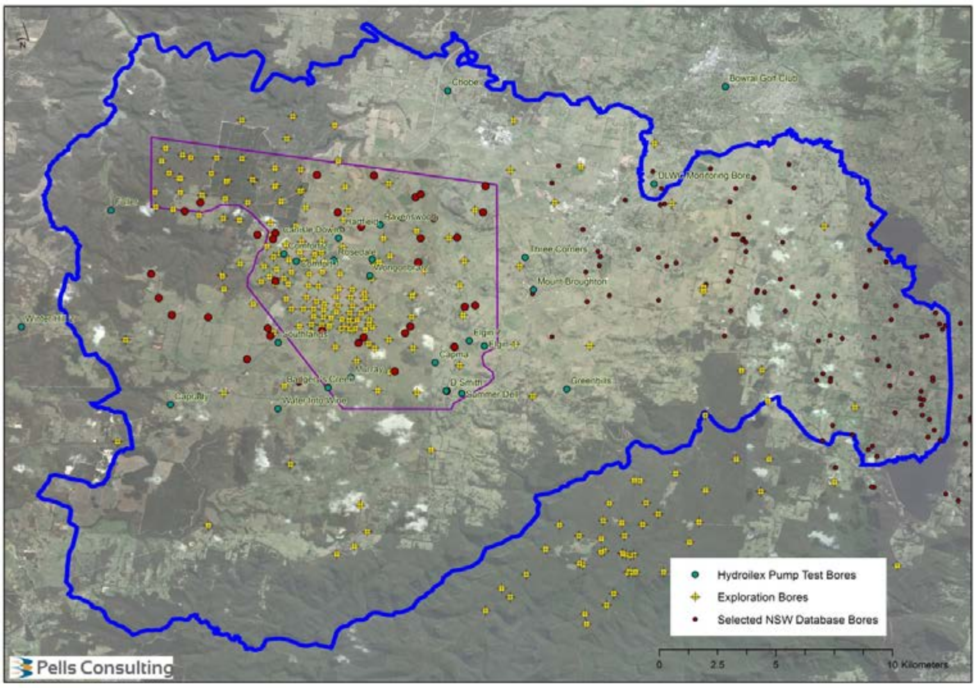


Figure 11 – Bores Used in Development of Contours and Isopachs

[2] The Bulli and Balgownie Seams, that overly the Wongawilli Seam in the Appin/Wollongong area, are absent in the Sutton Forest Moss Vale area, as too is the Narrabeen Formation, except for some thin, isolated remnants.

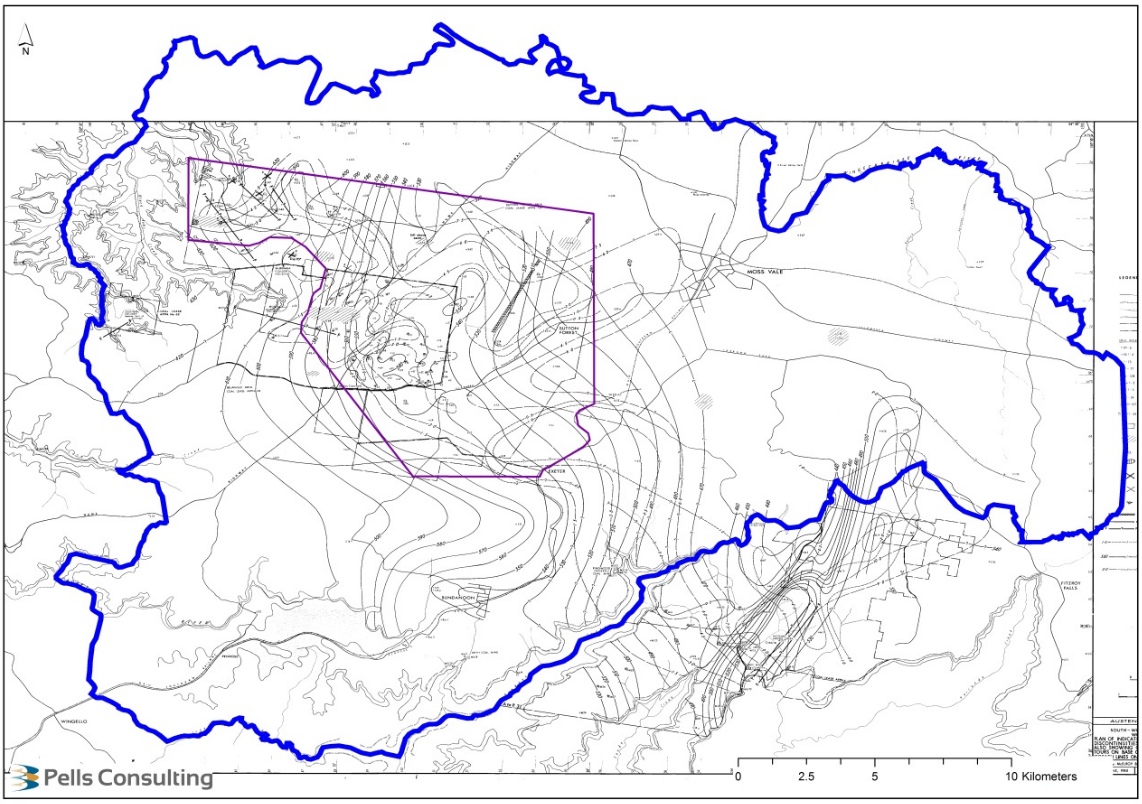


Figure 12 – Stratigraphic Contours by Austen & Butta, 1982

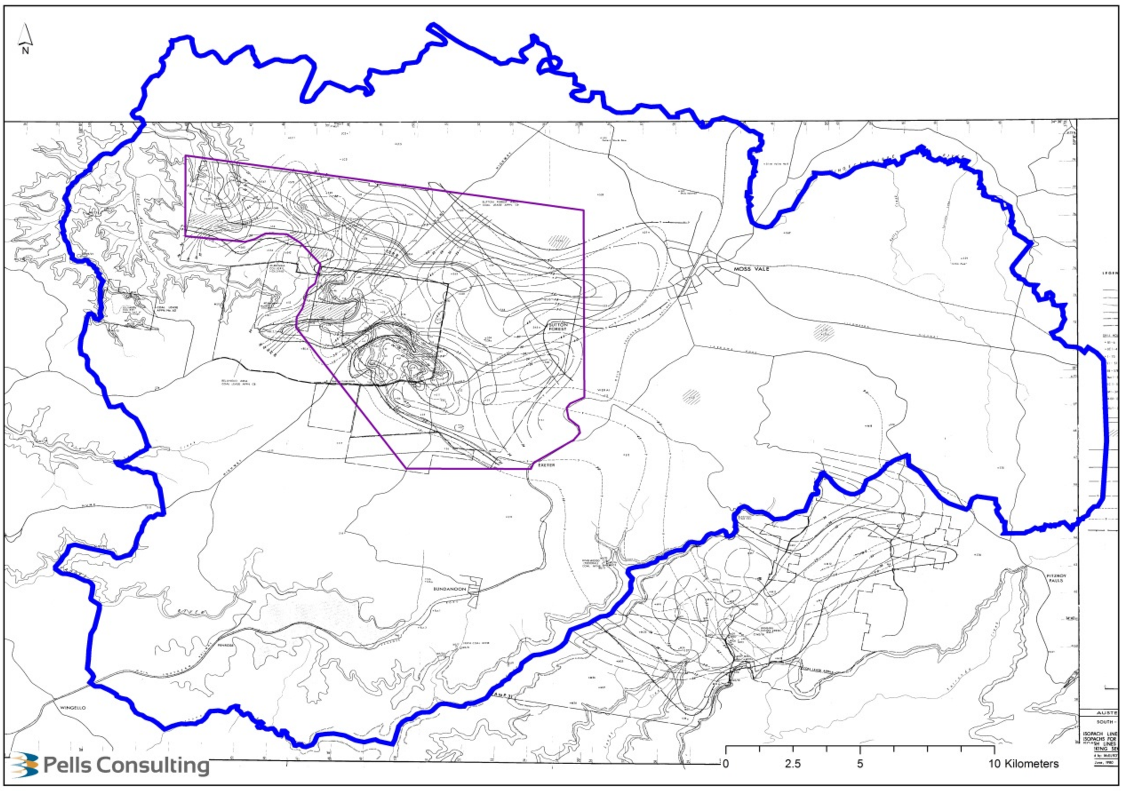


Figure 13 – Isopachs of Wongawilli Seam by Austen & Butta, 1982

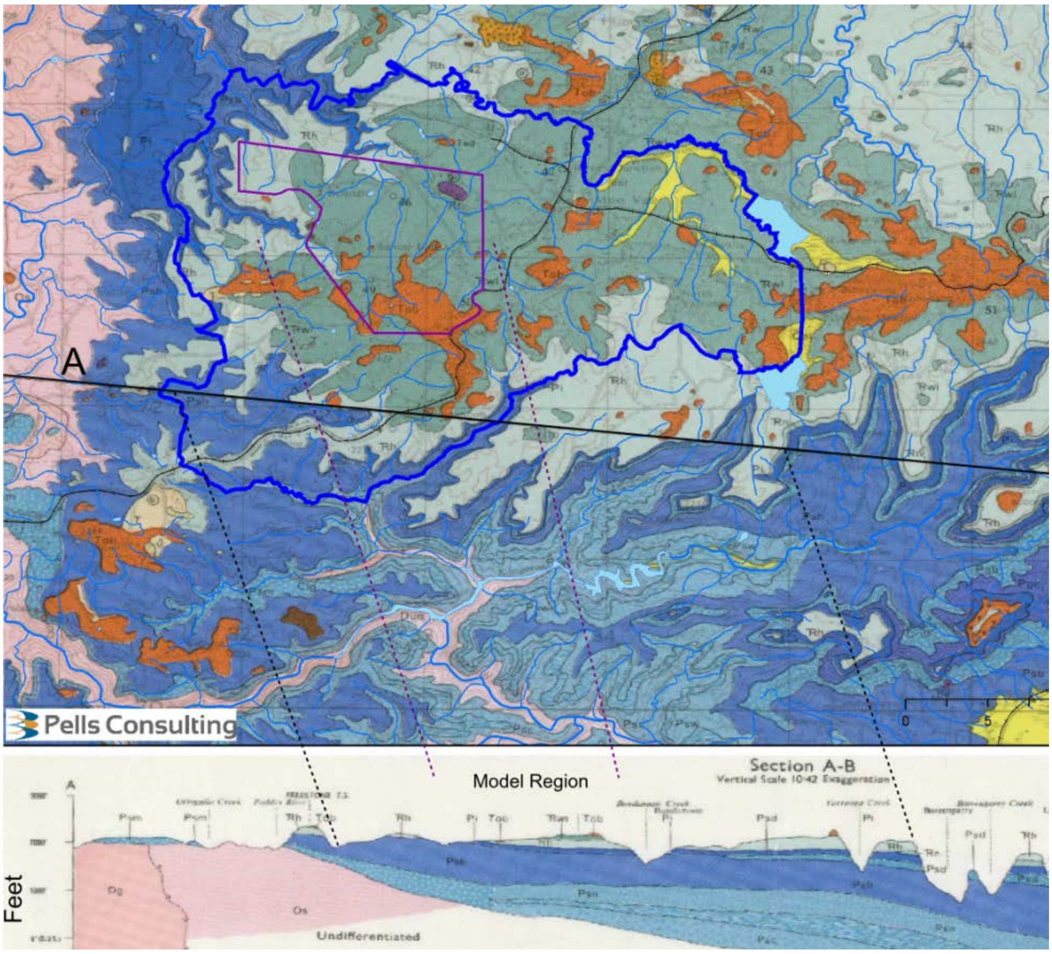


Figure 14 – Extract from Wollongong 1:250000 Geological Sheet

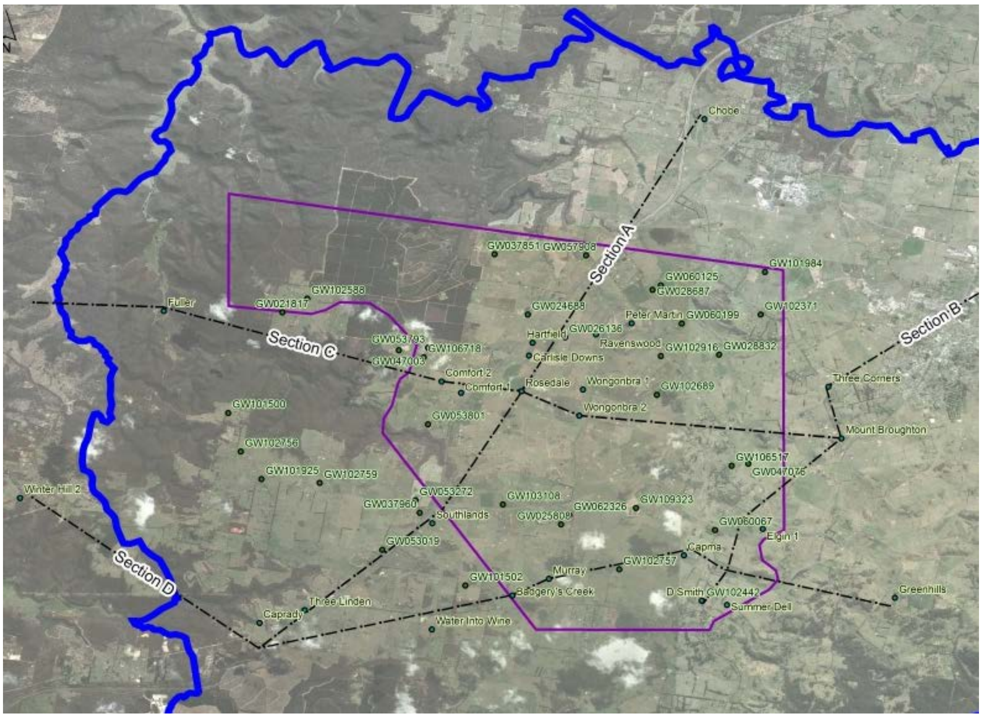


Figure 15 – Locations of Cross Sections Prepared by Hydroilex

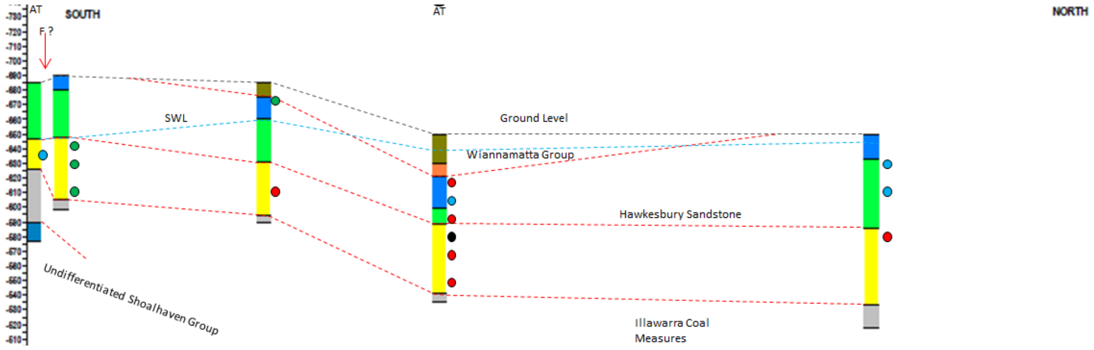


Figure 16A – Cross Section A

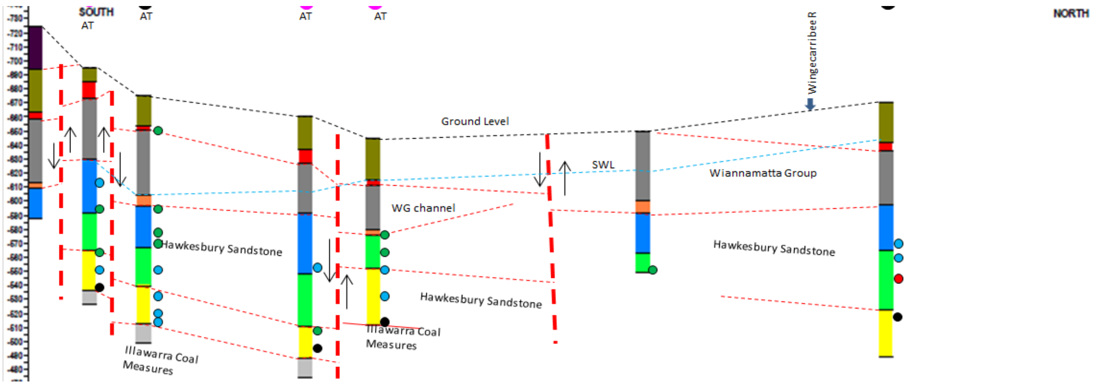


Figure 16B– Cross Section B

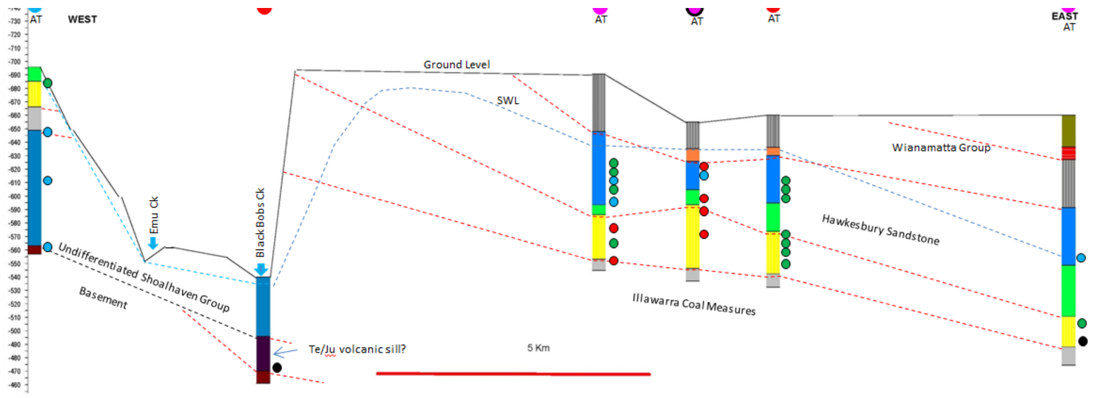


Figure 16C – Cross Section C

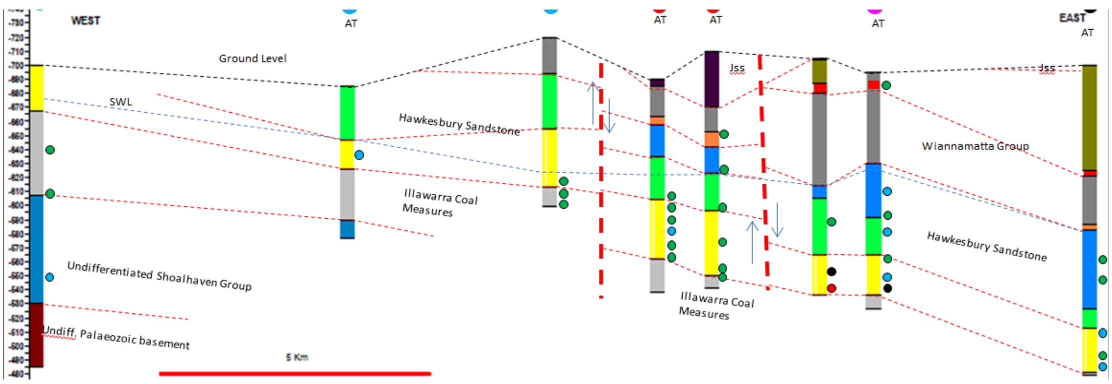


Figure 16D – Cross Section D

Contours were produced by digital and hand contouring techniques, of:

- the top surface of the Wongawilli Seam,
- the base of the Hawkesbury Sandstone (in 90% of the bores the logging shows this to be the same as the top of the Wongawilli coal seam),
- the base of the Wianamatta Shale.

Figures 17 and 18 are examples of the process of developing the contours and isopachs by combining the various data sources, initially by hand and subsequently with GIS software.

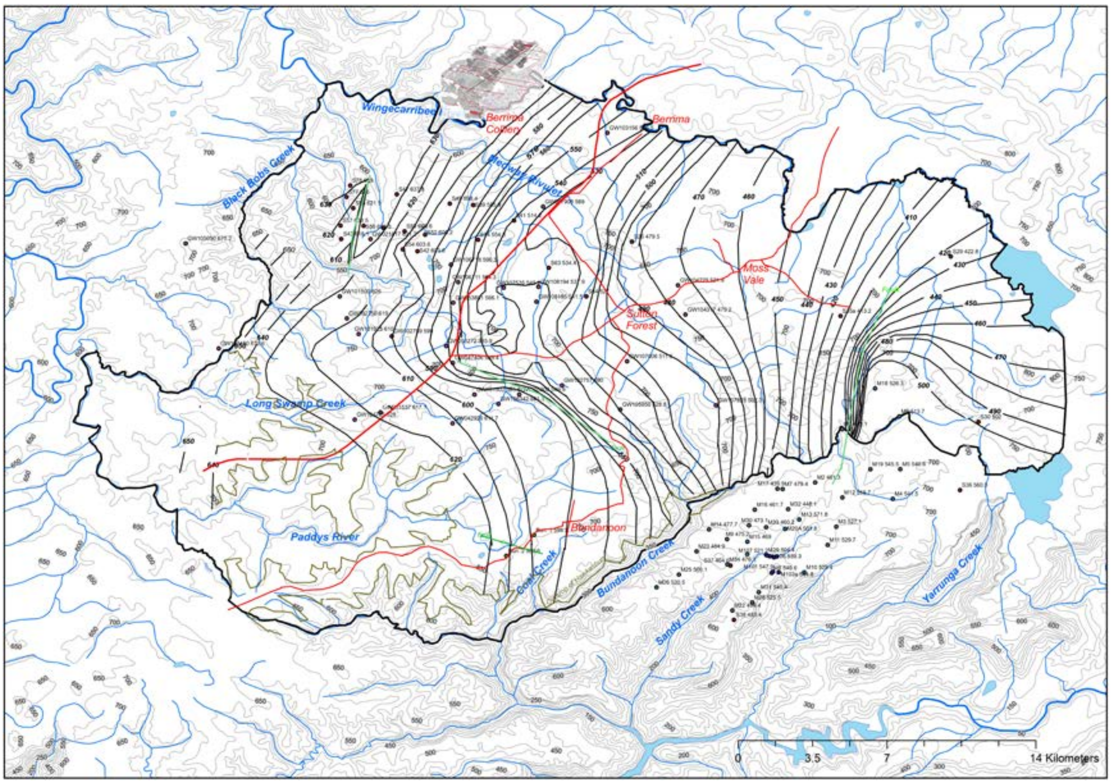


Figure 17 - Initial preparation of contours on base of the Wongawilli Seam.
(As noted in the Introduction, these contours had to be created without the benefit of exploration borehole data from Hume Coal)

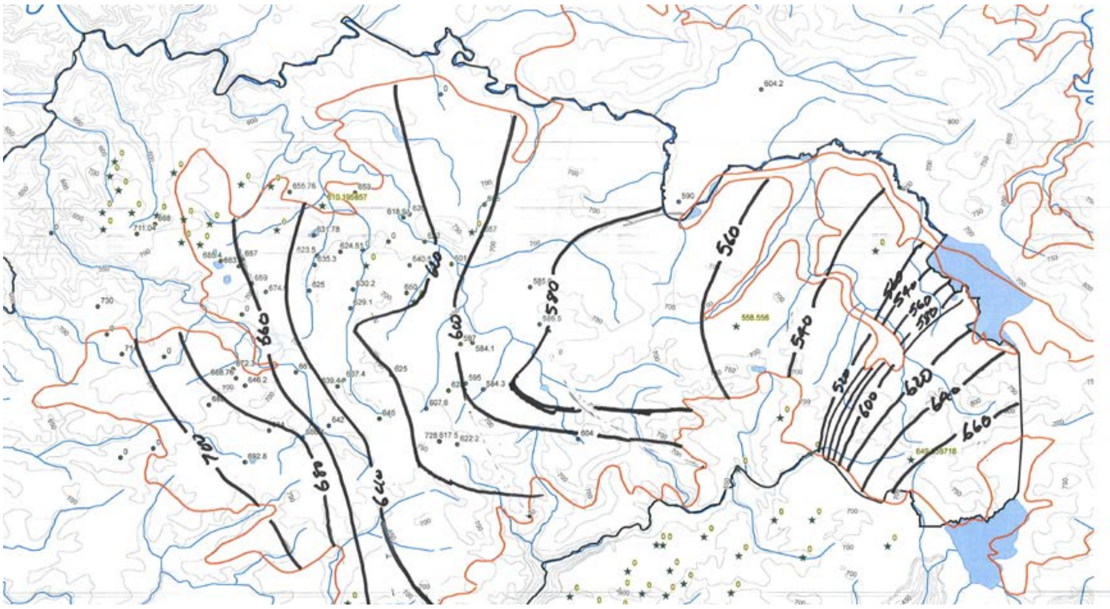


Figure 18 - Contours on the base of the Wianamatta Formation

2.4 Hydrogeologic Parameters

The model comprises the following horizons:

- Wianamatta Shale
- Hawkesbury Sandstone
- Illawarra Coal Measures (Wongawilli Seam and any rock between the seam and the base of the Hawkesbury Sandstone)
- Shoalhaven Formation
- Base

From analyses of test data from 28 bores in the area, John Lee of Hydroilex has divided the Hawkesbury Sandstone into three hydrogeological horizons, namely:

- Hawkesbury C: upper horizon of moderately high mass-permeability
- Hawkesbury B: central horizon of relatively low mass-permeability
- Hawkesbury A: basal horizon of high permeability.

Pump-test transmissivity data were analysed by Pells Consulting to interpret equivalent horizontal coefficients of permeability (hydraulic conductivity) for the basal horizon; with design parameters being based on log mean values[3]. The adopted values are given in Table 1.

Design parameters for the other two horizons in the Hawkesbury Sandstone, and for the other Units in the model, were derived from a combination of the Hydroilex pump test data and insitu permeability test data from the southern coalfields and the greater Sydney region, as published in Pells (1993) and Pells and Pells (2012).

[3] Mostyn G." A statistical approach to characterising the permeability of a mass." 4th Int Cong Applications of Probability in Soil and Structural Engineering, Florence, 1983

Groundwater modelling scenarios were tested with the hydraulic conductivity for Layers 1 to 6 were increased and decreased by a factor of 1.67 for 'upper' and 'lower' scenarios, respectively, so as to represent a total range in hydraulic conductivity by a factor of 5. Anisotropy shown in Table 1 was maintained in all cases (see Tables 2 and 3)

The ranges were used to represent uncertainties in the hydraulic conductivity values and to demonstrate model sensitivity to these, values.

Table 1 – Hydrogeological parameters – median (or best estimate) case

Layer	Formation	Horizontal Hydraulic Conductivity "k_h" $m.s^{-1}$	Anisotropy "k_v/k_h"	Porosity	Specific Yield "S_y"	Modulus MPa	Specific Storage m^{-1}
1	Wianamatta	1.5×10^{-6}	0.05	0.08	0.07	8000	1.59×10^{-6}
2	Hawkesbury Sandstone C	1.5×10^{-6}	0.1	0.15	0.14	6000	2.31×10^{-6}
3	Hawkesbury Sandstone B	3×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}
4	Hawkesbury Sandstone A	3×10^{-5}	0.5	0.20	0.18	8000	2.13×10^{-6}
5	Illawarra Coal Measures	1.5×10^{-6}	0.1	0.08	0.07	5000	2.32×10^{-6}
6	Shoalhaven B	3×10^{-8}	0.1	0.05	0.05	20000	7.16×10^{-7}
7	Shoalhaven A	1×10^{-9}	0.1	0.05	0.05	30000	5.52×10^{-7}
8	Base	5×10^{-10}	0.1	0.05	0.05	35000	5.05×10^{-7}

Table 2 – Hydrogeologic parameters – upper case

Layer	Formation	Horizontal Hydraulic Conductivity "k_h" $m.s^{-1}$	Anisotropy "k_v/k_h"	Porosity	Specific Yield "S_y"	Modulus MPa	Specific Storage m^{-1}
1	Wianamatta	2.5×10^{-6}	0.05	0.08	0.07	8000	1.59×10^{-6}
2	Hawkesbury Sandstone C	2.5×10^{-6}	0.1	0.15	0.14	6000	2.31×10^{-6}
3	Hawkesbury Sandstone B	5×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}
4	Hawkesbury Sandstone A	5×10^{-5}	0.5	0.20	0.18	8000	2.13×10^{-6}
5	Illawarra Coal Measures	2.5×10^{-6}	0.1	0.08	0.07	5000	2.32×10^{-6}
6	Shoalhaven B	5×10^{-8}	0.1	0.05	0.05	20000	7.16×10^{-7}
7	Shoalhaven A	1×10^{-9}	0.1	0.05	0.05	30000	5.52×10^{-7}
8	Base	5×10^{-10}	0.1	0.05	0.05	35000	5.05×10^{-7}

Table 3 – Hydrogeologic parameters – lower case

Layer	Formation	Horizontal Hydraulic Conductivity "k_h" $m.s^{-1}$	Anisotropy "k_v/k_h"	Porosity	Specific Yield "S_y"	Modulus MPa	Specific Storage m^{-1}
1	Wianamatta	5×10^{-7}	0.05	0.08	0.07	8000	1.59×10^{-6}
2	Hawkesbury Sandstone C	5×10^{-7}	0.1	0.15	0.14	6000	2.31×10^{-6}
3	Hawkesbury Sandstone B	1×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}
4	Hawkesbury Sandstone A	1×10^{-5}	0.5	0.20	0.18	8000	2.13×10^{-6}
5	Illawarra Coal Measures	5×10^{-7}	0.1	0.08	0.07	5000	2.32×10^{-6}
6	Shoalhaven B	1×10^{-8}	0.1	0.05	0.05	20000	7.16×10^{-7}
7	Shoalhaven A	1×10^{-9}	0.1	0.05	0.05	30000	5.52×10^{-7}
8	Base	5×10^{-10}	0.1	0.05	0.05	35000	5.05×10^{-7}

Table 4 gives the adopted changes to hydraulic conductivity, and storage, due to fracturing and disturbance of the rocks above an assumed short-longwall mining scenario.

Table 4 – Hydrogeologic parameters above longwalls

Layer	Formation	Increase in "k_h" $m.s^{-1}$	Anisotropy "k_v/k_h"	Porosity	Specific Yield "S_y"	Modulus MPa	Specific Storage m^{-1}
1	Wianamatta	× 10	0.25	0.15	0.14	7500	1.98×10^{-6}
2	Hawkesbury Sandstone C	× 5	0.2	0.2	0.18	5000	2.86×10^{-6}
3	Hawkesbury Sandstone B	× 100	0.25	0.25	0.23	8000	2.35×10^{-6}
4	Hawkesbury Sandstone A	× 1000	0.75	0.4	0.36	5000	3.76×10^{-6}

2.5 Boundary Conditions

The perimeter of the chosen model terrain is bounded by rivers or creeks. The groundwater was assumed to reflect the river stage at these locations. The river stage was interpreted from the digital terrain model, 1:25,000 topographic sheets and aerial photographs as the values shown around the model perimeter in Figure 19. A constant head boundary was assumed in accordance with these values (linearly varying along the model boundary between the values shown) to act around the perimeter of the model domain.

Standing water levels (in metres below ground) as reported in the NSW groundwater database, were obtained from 885 bores within and around the model domain (see Figure 19). These levels were reduced to a level in metres AHD by assuming the following:

- that the bore collar was equivalent to the ground surface level at the bore location, as taken from the digital terrain model.
- The levels reflect groundwater conditions at a screen location assumed at 5m above the base of the bore.
- The measured depth to water was taken as an indication of the regional water levels regardless of long term or seasonal variation.

These assumptions were used to provide a large dataset of water levels, but it is acknowledged that there is significant uncertainty in the values. It is also acknowledged that NSW groundwater database measurements are subject to limited quality control. It is considered that the data are indicative only of the regional long term groundwater conditions, and are likely to be subject to a scatter generally within +/- 20 m, but in some cases larger.

Contours of the water table were produced from this bore data and the perimeter river stages, as shown in Figure 19.

For modelling purposes recharge was chosen as a value, for each scenario, that resulted in a steady state water table elevation that matched, on average, the water level data given in Figure 19.

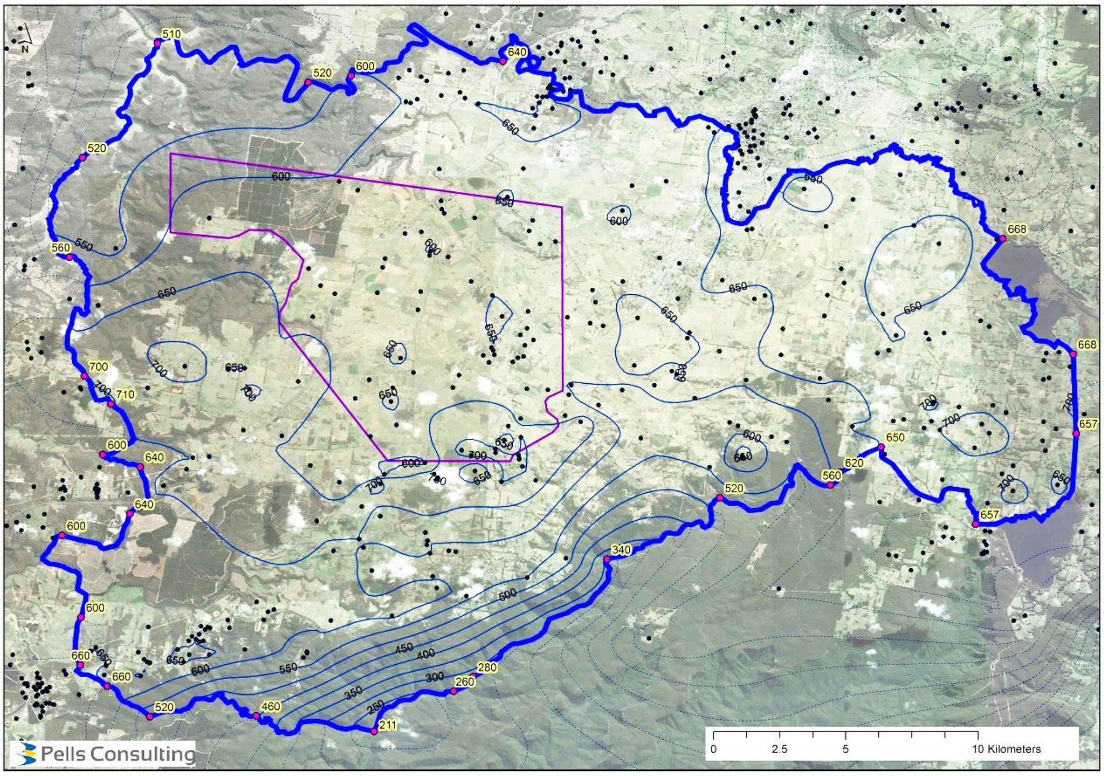


Figure 19 – Interpreted River Stages, Bores with SWL Readings and Interpreted Initial Groundwater Head Contours

2.6 Numerical Modelling Framework

The groundwater model was assembled using Visual Modflow™ software by Schlumberger (http://www.swstechnology.com).

Stratigraphic layers assembled in Visual Modflow, based on the data presented above, are represented in 3D in Figure 20.

The stratigraphy used in the model assumed 8 layers, constructed according to the following parameters:

- Hawkesbury Sandstone unit is defined between contours of the base of the Wianamatta and top of the Illawarra Coal measures.
- Hawkesbury Sandstone subdivided into three layers:
  - Hawkesbury Sandstone Layer C taken 30% of the thickness of the total Hawkesbury Sandstone
  - Hawkesbury Sandstone Layer A taken as 25% of the thickness of the total Hawkesbury Sandstone
  - The remained comprising Hawkesbury Sandstone Layer B
- Base of the Shoalhaven B at 30 m below base of the Illawarra Coal measures
- Base of the Shoalhaven A at 100 m below base of the Illawarra Coal measures
- Base of the model at 0 m AHD.

A finite difference grid assembled over the model domain comprised cells approximately 270 m x 270 m around the periphery, but refined by a factor of 3 (ie approximately 90 m x 90 m) in the vicinity of the mine (see Figure 21).

The following simplifications in the model are therefore noted:

- No geological structures are included in the model[4]
- Only drilling logs from Hydroilex provide interpretation of discrete units of the Hawkesbury sandstone, and these data points were not considered to be dense enough to provide the basis for individual contouring of these layers. The thicknesses chosen to represent regions of the Hawkesbury Sandstone (A, B, and C) are considered to under-represent the extent of highly productive layer A and over-represent the thickness of the relatively low mass-permeability central region.

Inclusion of geological structures and increasing the thickness of the Hawkesbury Sandstone 'A' horizon would result in larger inflows to the mine and more widespread impacts to groundwater from the mining activities. As such, the modelling concepts employed here are considered to be representative of conditions that are skewed in under-prediction of the impacts to groundwater from the proposed mine.

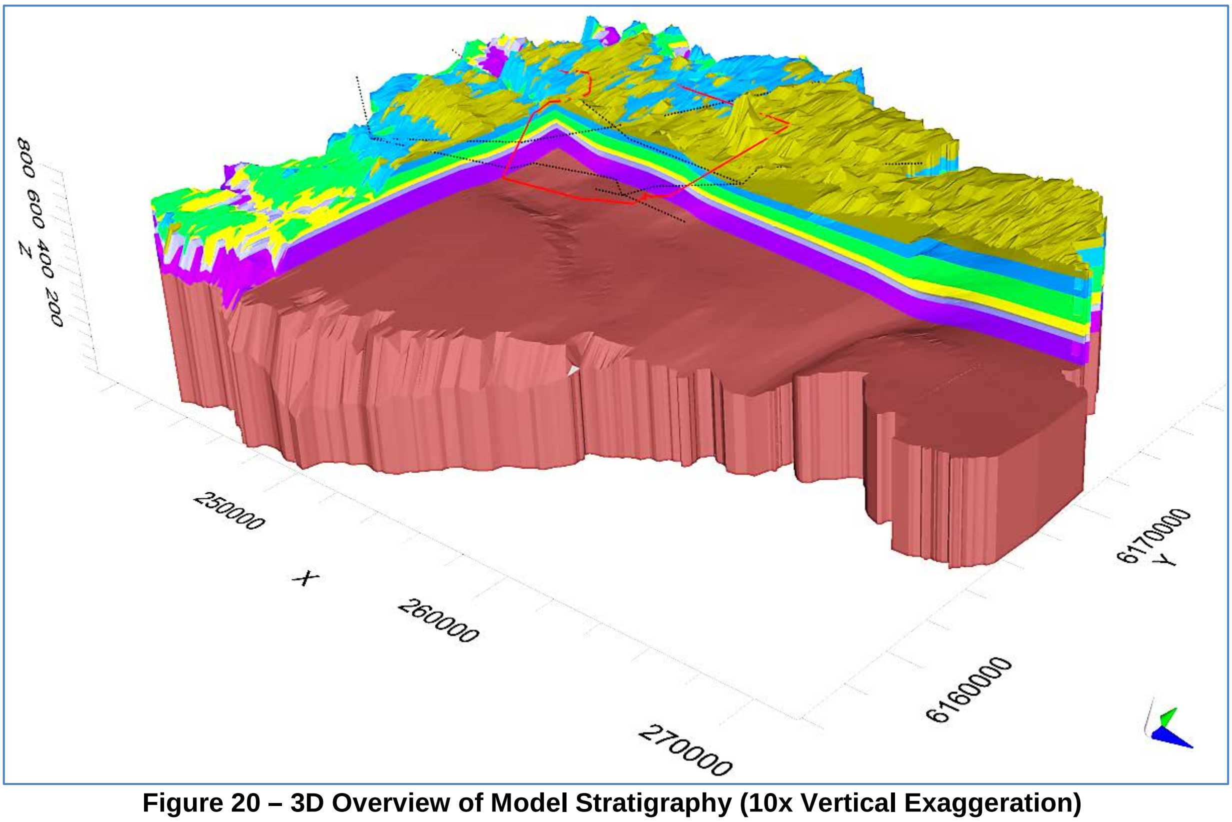


Figure 20 – 3D Overview of Model Stratigraphy (10x Vertical Exaggeration)

[4] Versions of MODFLOW currently available commercially cannot practically incorporate high angle faults, either as near vertical conduits (open, or rubble filled faults) or as near vertical barriers (clay filled fault surfaces). This is because the current finite-difference grid structure cannot practically support the level of refinement required to incorporate these features. A new version (MODFLOW-USG) promises to allow better modelling of such features by using tetrahedral elements and an unstructured grid, and is expected to be available in October 2013.

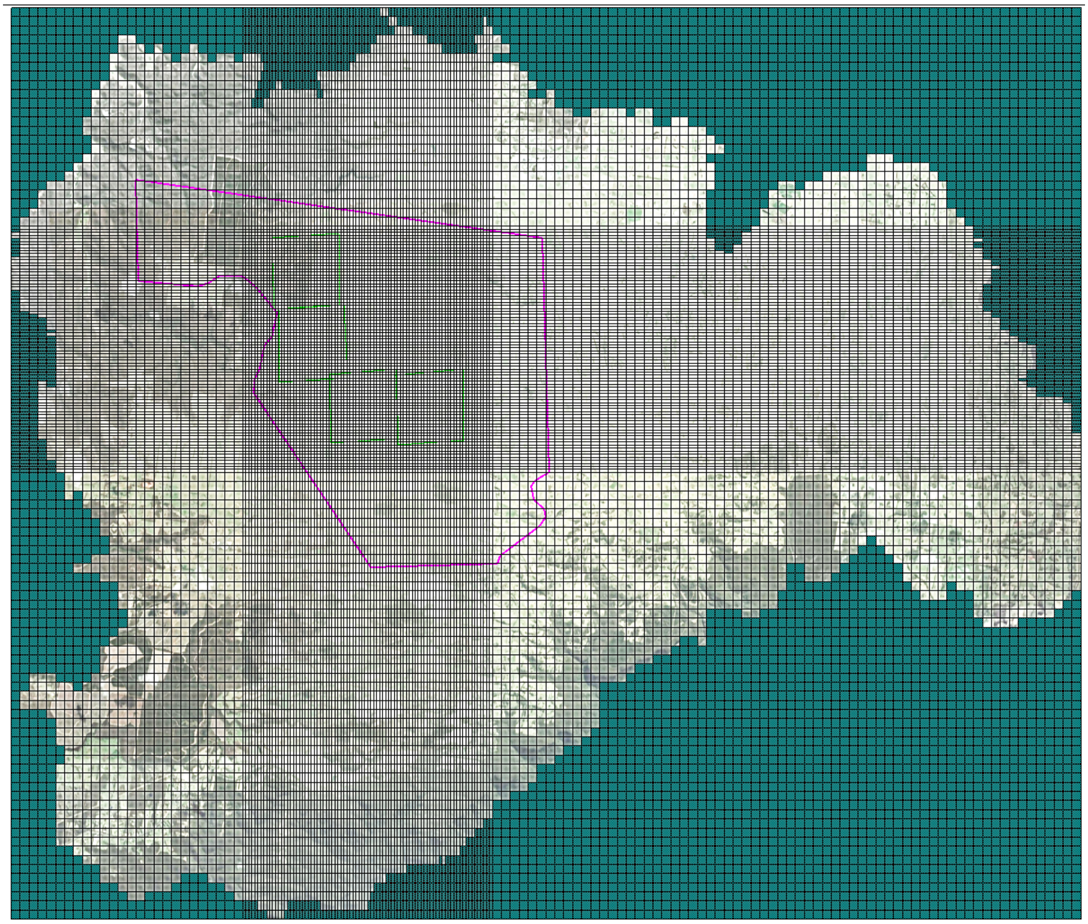


Figure 21 – Plan of Model Grid

3 SIMULATIONS

3.1 Mining Location and Operations

The actual location of mining proposed by Hume Coal is not known.

The modelling approach was therefore structured to provide an analysis of:

- a generic initial (first 2 to 7 years) of mining, and
- a separate analysis of the subsequent effects from a larger mine.

The area of the mine footprint can be estimated as:

$$A = R.T = \frac{TY}{t\gamma e}$$

Where:
A = mine area in km^2
R = rate of mine area growth (km^2/year)
T = time, in years
Y = coal extraction yield (Mt/year)
t = average thickness of the coal seam, in metres
γ = density in coal, in tonnes per m^3
e = extraction footprint ratio (eg, roadways, access etc)

A range of mining development rates are presented in Table 5 assuming a coal thickness of 2.5 to 3.5 m, γ of 1.4 to 1.6 t.m^{-3}, coal extraction yield of 1.2 to 4.1 Mt/year and extraction ratio of 0.4 to 0.6. It is noted that a prefeasibility study presented by Hume Coal states an expected yield ("Y") of 4.1 Mt/year.

Table 5 – Expected range of mining progress

Yield "Y" Mt/year	Coal seam thickness "t" m	Coal Density "γ" kg/m^3	extraction ratio "e" -	Rate of growth of mine area "R" km^2/year
4.1	2.5	1.4	0.4	2.9
	3	1.5	0.5	1.8
	3.5	1.6	0.6	1.2
3	2.5	1.4	0.4	2.1
	3	1.5	0.5	1.3
	3.6	1.6	0.6	0.9
2	2.5	1.4	0.4	1.4
	3	1.5	0.5	0.9
	3.5	1.6	0.6	0.6
1.2	3	1.5	0.5	0.5
	3.1	1.5	0.6	0.4
	3.6	1.6	0.7	0.3

From the analysis in Table 5 it is shown that a mine growth rate of between 1.2 and 2.9 km^2/year is expected for the stated 4.1 Mt/year yield. However, it is acknowledged that initial mining periods may be slower. Computed rates of mine expansion are shown in Figure 22 for "R" values of 0.3, 0.6, 1.2 and 2.9.

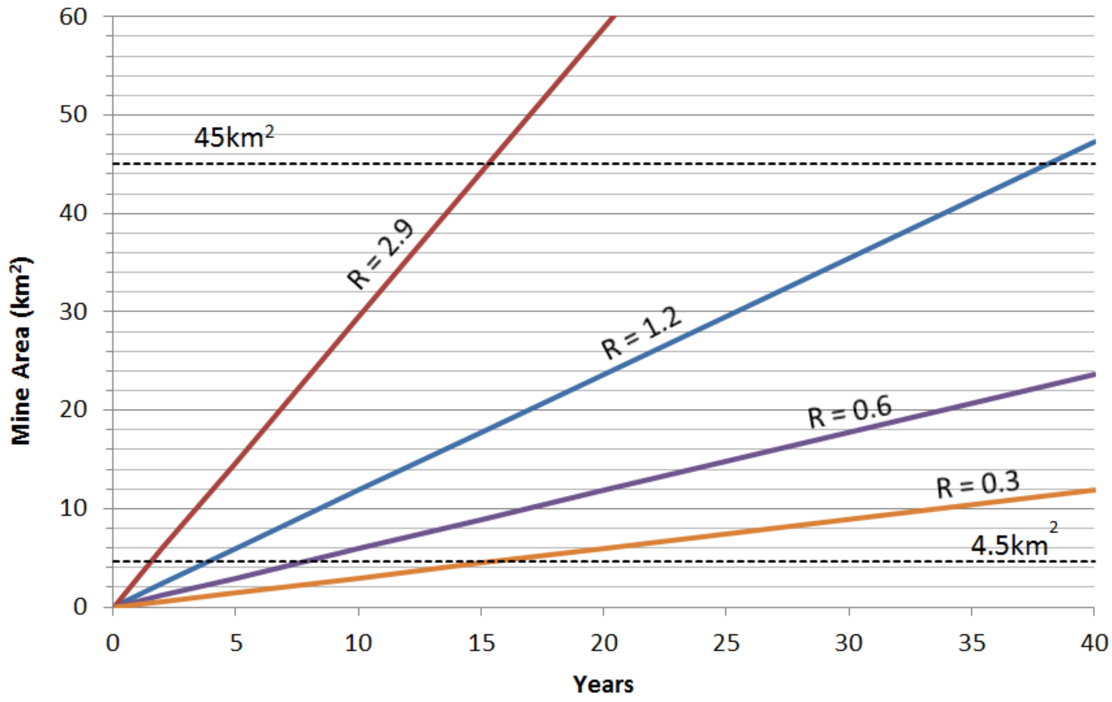


Figure 22 – Various rates of mine footprint expansion

A mine footprint area of approximately 4.5 km^2 was considered suitable to represent an initial 3-10 year mine (it was assumed that mine progress errs to the slower side of predictions in the initial period).

It was clear from coal isopach data; the locations of faults, and; coal quality data that mining would most likely include the 4.5 km^2 locations marked No. 1 to. 4 in Figure 23. For modelling of the initial phase, area No.1 was used.

An assumed larger mining area of 45 km^2 (shown with a grey outline in Figure 23) was also incorporated in model simulations, which was considered representative of a 20 to 40 year mine life.

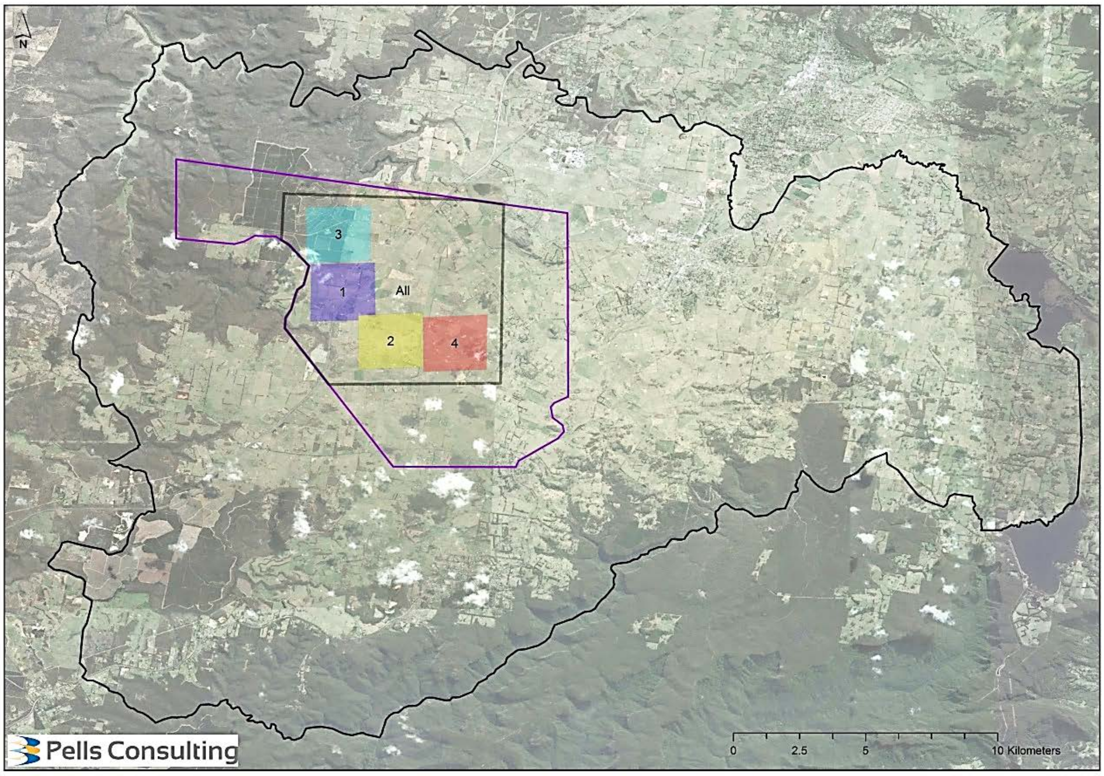


Figure 23 – Anticipated Mine Location Options

3.2 Modelling Approach

It was considered too speculative to model, sequentially, the development of a 45 km^2 mine, because the layout is not known. The larger 45 km^2 mine was modelled by simultaneous one-off introduction of the mine within the model. That is, the entire mine is assumed to be formed 'suddenly' within the model. This 'sudden' introduction produces unrealistic estimates of mine inflow in the first instance but, over time, the inflow and drawdown pattern converges to a proper figure.

However, an initial mining phase was modelled *sequentially* to allow examination of the early effects of mining. A sequentially expanding mine footprint was modelled for the 4.5 km^2 mine (marked No. 1 in Figure 23) to examine groundwater effects over the early period of mining. The model cells in the vicinity of mining have dimensions approximately 90m by 90m. The mining within an initial area was simulated to advance in the form of strips 180 m wide (2 cells), advancing at a rate of 90 m (1 cell forward) in 20, 10, 5 and 2 days to represent the possible mine expansion rates presented in Table 6 .

The initial (4.5 km^2) mine was then also modelled using the 'sudden' introduction of boundary conditions, as used for the larger mine. Comparison of the results demonstrated that the 'sudden' approach was indeed suitable for representation of effects to groundwater that occurred after the initial mining phase, as discussed below.

This initial area is small enough to be considered 'generic'. That is, the calculated groundwater drawdowns and inflows from this area are considered to be adequately representative of such an initial mining phase placed in any likely location within the lease boundary.

Table 6 – Modelled development rates for initial phase of mining

Rate of growth of mine area "R" km^2/year	Elapsed days between each 90 m x 180 m panel advance
0.3	20
0.6	10
1.2	5
2.9	2
Instant	0

The approach to modelling was therefore as follows:

1. The model was established using the stratigraphy and boundary conditions described above, and the hydraulic parameters presented in Table 1.
2. The model was used to establish a pre-mining condition in steady state
    a. A constant recharge value was assumed across the model domain and the model was run in steady state.
    b. Step a. was repeated until an appropriate replication of the regional water table was simulated in steady state. This was taken as the pre-mining condition for the assumed hydraulic parameters. The recharge values chosen for pre-mining conditions for each of the three assumed hydraulic conductivity cases are presented in Appendix A.1.
3. Using the established pre-mining condition as a starting point, an initial (4.5 km^2) region was modelled in 5 different scenarios, where the mine was introduced sequentially at the 5 rates shown in Table 6.
4. The 'instantaneous' scenario was then repeated, but with the assumptions for altered hydraulic conductivity and storage parameters introduced above the mine.
5. Again using the established pre-mining condition as a starting point, the model was then run in a transient condition, with an assumed 45 km^2 mining region represented with sudden introduction of drainage boundary conditions, and with altered hydraulic conductivity and storage parameters introduced above the mine.
6. The outputs of the transient models were interrogated to report drawdown of the regional water table and total mine inflows over time.

7. Steps 1. to 5. were then repeated with ‘upper’ and ‘lower’ values for hydraulic conductivity, presented in Table 2 and Table 3, respectively.

In each case, the effects of mining were simulated by introducing a ‘drain’ boundary condition within the Illawarra Coal measures with an invert 0.1 m above the base of the Illawarra Coal measures. A nominal high conductance of 1000 m^2/day was used to ensure flow into the drains was limited by formation losses, not drain entry losses.

This modelling protocol is not tailored to model existing conditions with accuracy, but rather to simulate changes to existing conditions that are introduced from proposed mining activities.

4 FINDINGS

4.1 Inflow Discharges

Inflows to the mine for the case of the initial mine, as reported by the model are presented in Figure 24 below. This includes plots for the 5 rates of development presented in Table 6. It can be seen that mine inflows for the simulated ‘instant’ mine provide an envelope that is approached, over time, by mines that include sequential development. These alternative simulation methods show good agreement once the assumed mining program is reached.

Hence, inflows from a simulated ‘instant’ mine are considered representative of actual inflows from the time that the mine area is reached. For example, if the mine progresses according to the “R = 0.6 km^2/year” scenario, and 4.5 km^2 is achieved after 8 years, the curve from the “instant mine” from 8 years onwards is considered valid. If it progresses more slowly (ie R = 0.3 km^2/year), taking 15 years to achieve 4.5 km^2, the “instant mine” curve is valid from that time on.

In Figure 25 plots of the initial 4.5 km^2 mine are again shown, but this time including the assumed changes in hydraulic conductivity and storage above the mine due to fracturing and subsidence. It is seen that the modelled fracturing causes a moderate increase in mine inflows.

Inflows to the mine for the case of the larger 45km^2 mine, as reported by the model are presented in Figure 26. Based on the analysis presented above, it is considered that the curves in Figure 26 are representative of inflows from the time that a 45 km^2 mine area is reached. The interpreted enveloped for mines with progress rates “R” of 0.6 and 2.9 km2/year are thus presented in Figure 27. That is, inflows for a 45 km^2 mine of 20 to 70 ML/day are predicted. The range of inflow values are directly related to the values of hydraulic conductivity assumed.

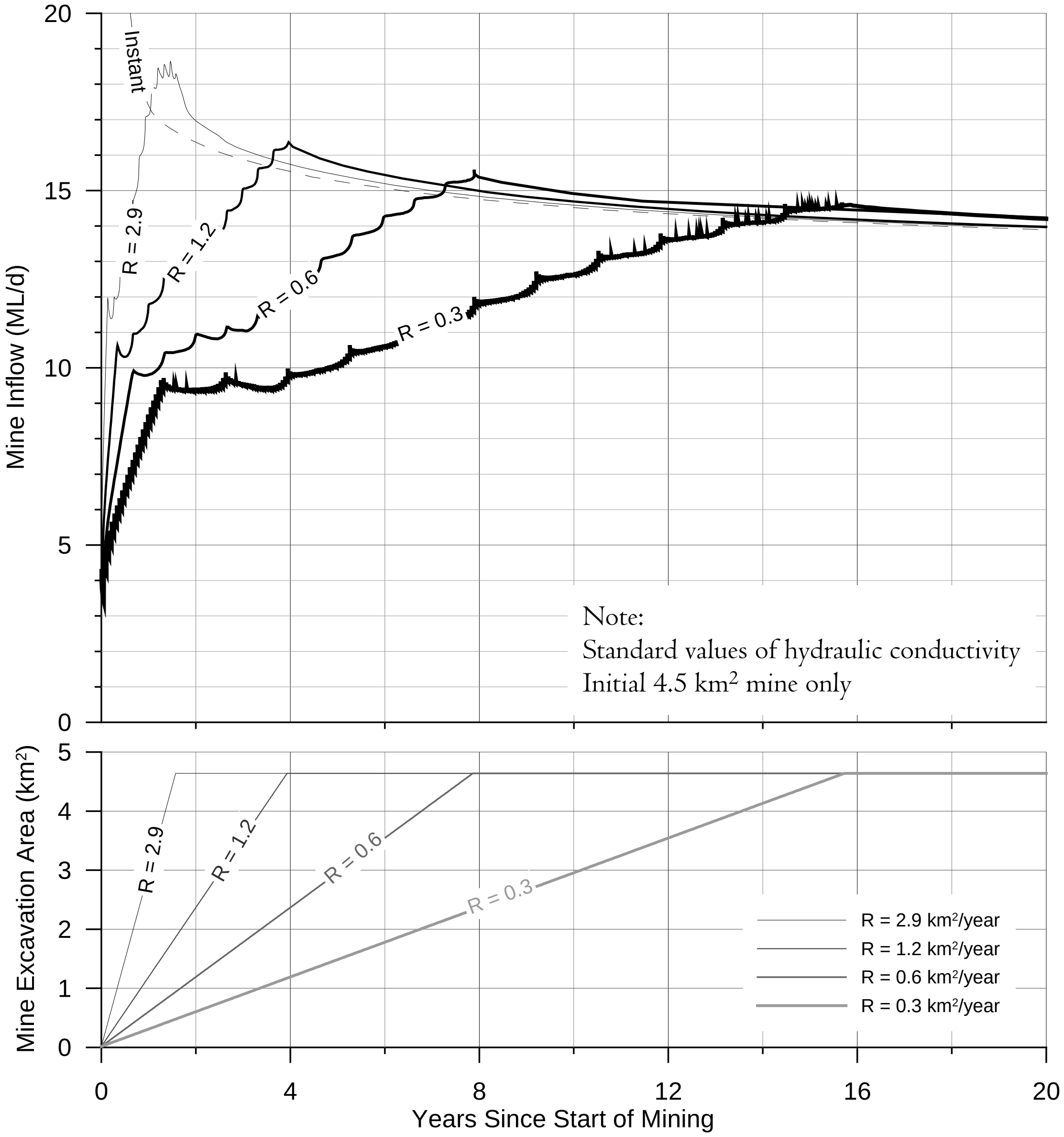


Figure 24 - Effect of mining rates on simulated inflows, initial (4.5 km^2) mining phase, standard hydraulic conductivity values

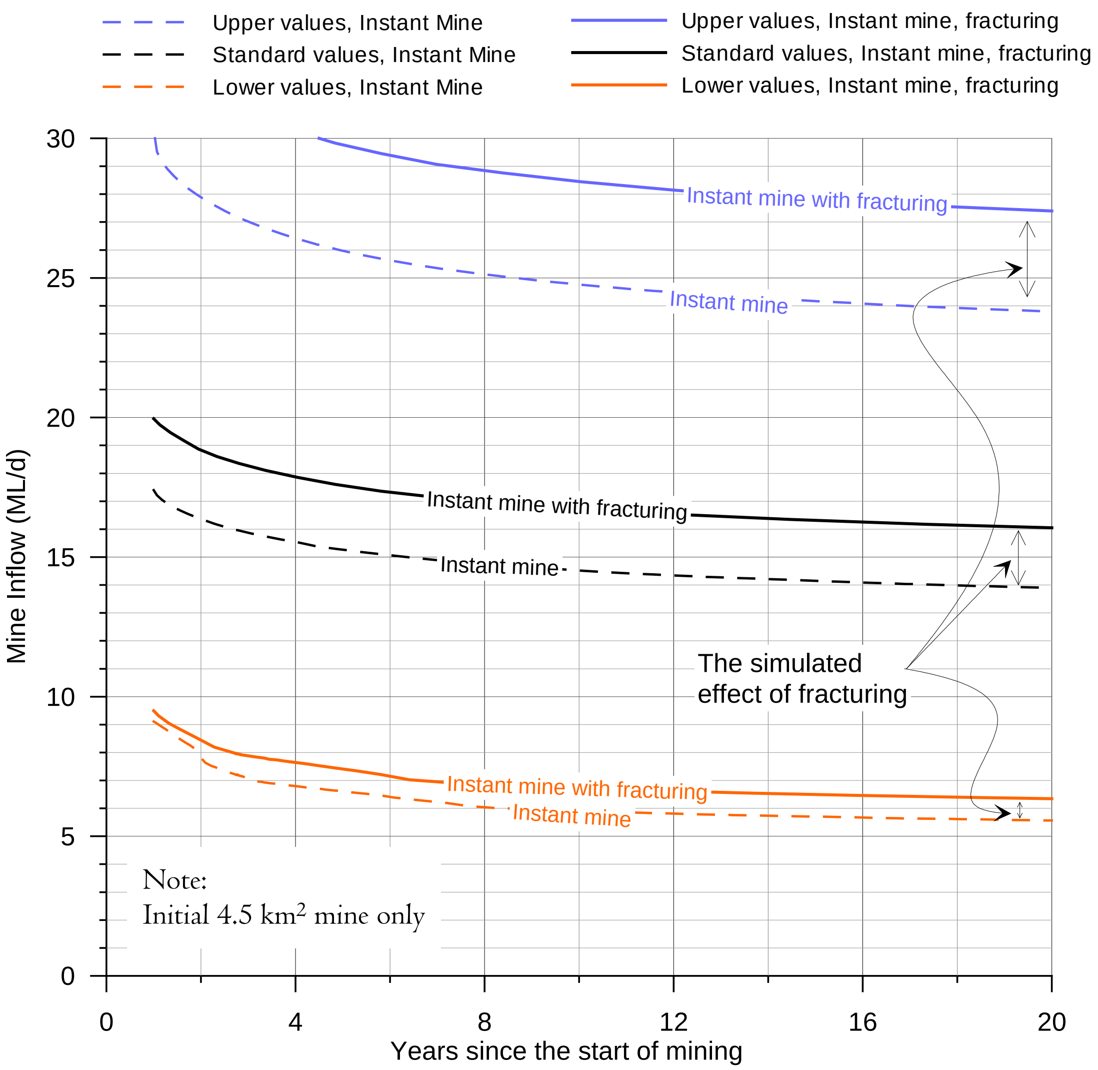


Figure 25 - Effect of simulated fracturing of overburden on inflows, initial (4.5 km^2) mining phase

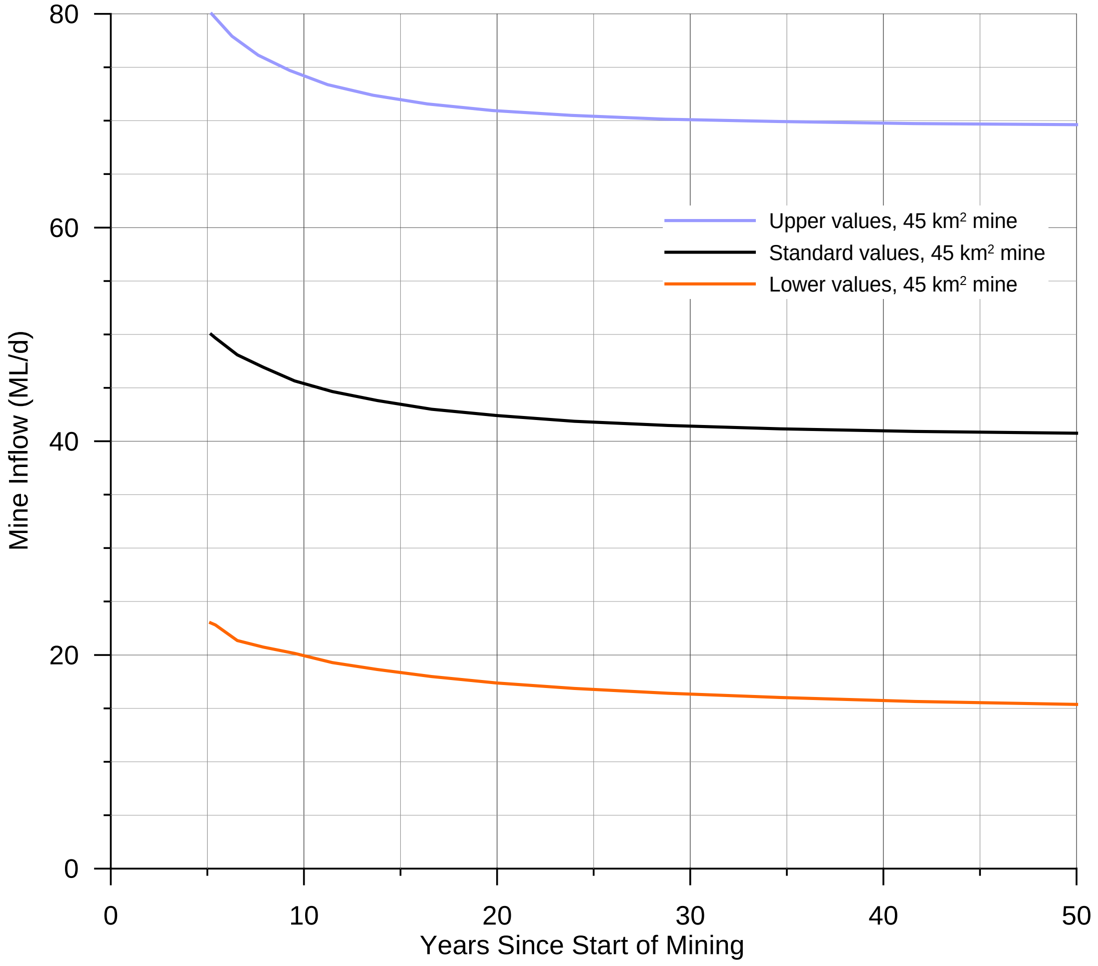


Figure 26 – Predicted inflows, larger (45 km^2) mining phase with fracturing assumed

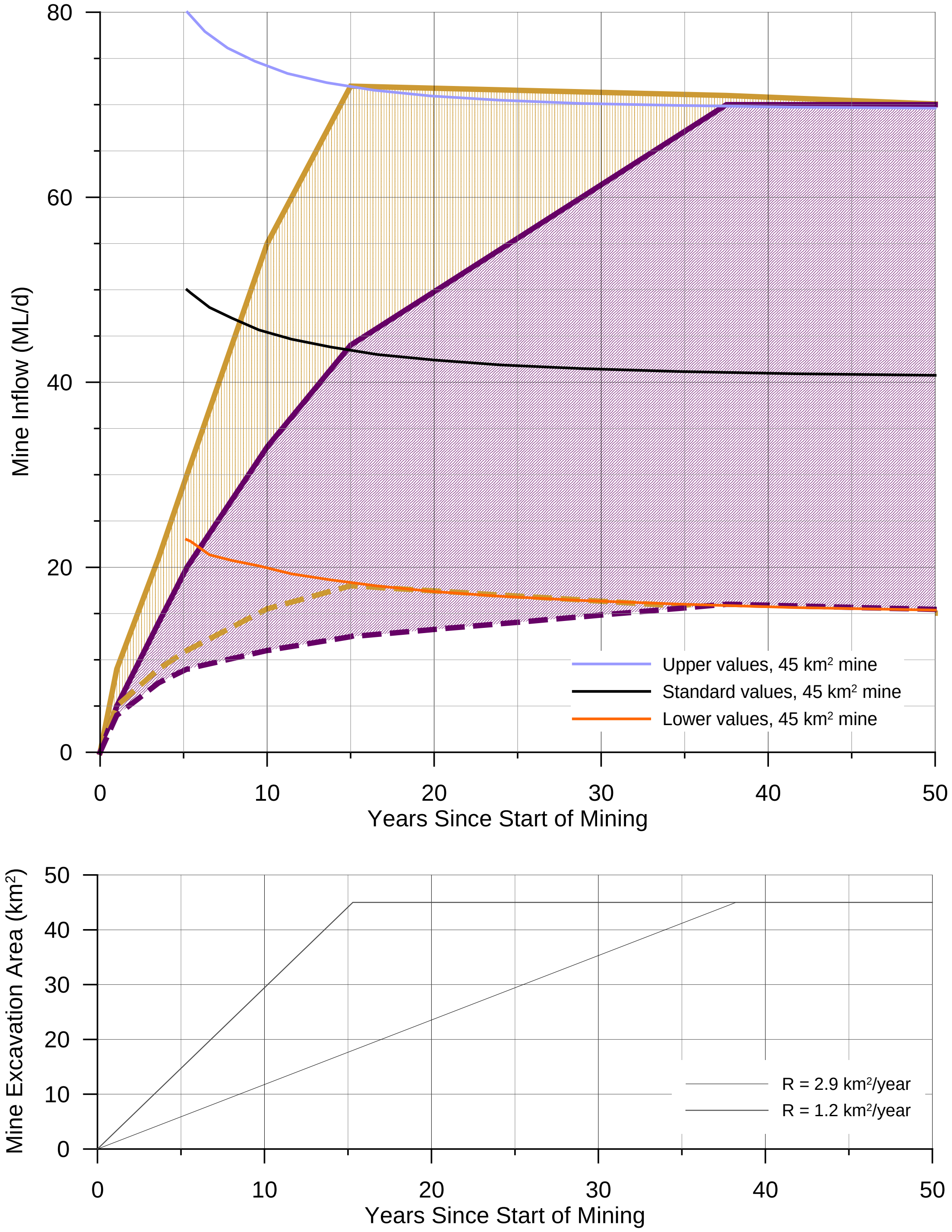


Figure 27 – Postulated inflows over the mining phase for a mine that ceases at 45 km^2

4.2 Depressurisation and Drawdown of Water Table

Drawdown was calculated across the model domain as the difference between the initial pre-mining groundwater condition, and the groundwater condition following mining. This was done at every timestep of mining.

Maps showing drawdown within Layer 4 (the productive horizon of Hawkesbury Sandstone above the Illawarra Coal measures) are presented, for 'standard' aquifer characteristics in Figure 28 to Figure 35 below. Drawdowns in adjacent layers can be provided on request, but are generally similar to those in Layer 4. Selected drawdown maps for higher and lower aquifer characteristics are included in Appendix A.

In Figure 28 to Figure 31 are presented maps for periods of 2 months, 1, 2, and 5 years since the start of mining for the case of the 'initial' 4.5 km^2 mine, without fracturing from settlement, and with a mine area progressing at a rate ("R" – see Table 5 and Table 6) of 1.2 km^2/year. In such a case, the 4.5 km^2 extent is reached after approximately 5 years and remains static thereafter.

Secondly, maps produced for period 10 and 40 years since the start of mining, including fracturing from settlement are presented, based on the larger (45 km^2) sized mine.

Drawdown develops across the model region over time, as a result of both the ongoing dewatering, and the increasing mine area. Drawdown is observed to develop towards the northern and southern boundaries, as in these locations the boundary heads are lower than the mine. In other regions (the eastern and western boundaries), the assumed constant head conditions are higher than the mine, and hence the groundwater level is maintained from inflows along these boundaries.

In all cases, due to the shallow depth of mining and the higher permeability strata, depressurisation above the mining region causes groundwater at all levels to move down to the mining seam – a distance of about 120 metres. This means, for example, that the standing water level of any bores located above the mine, would decrease by this amount. The extent of drawdown decreases with distance from the mine.

While the long term drawdown is similar for each condition, the assumed hydraulic conductivity and storage values affect the rate at which drawdown occurs, and the mine inflow discharge under which is occurs.

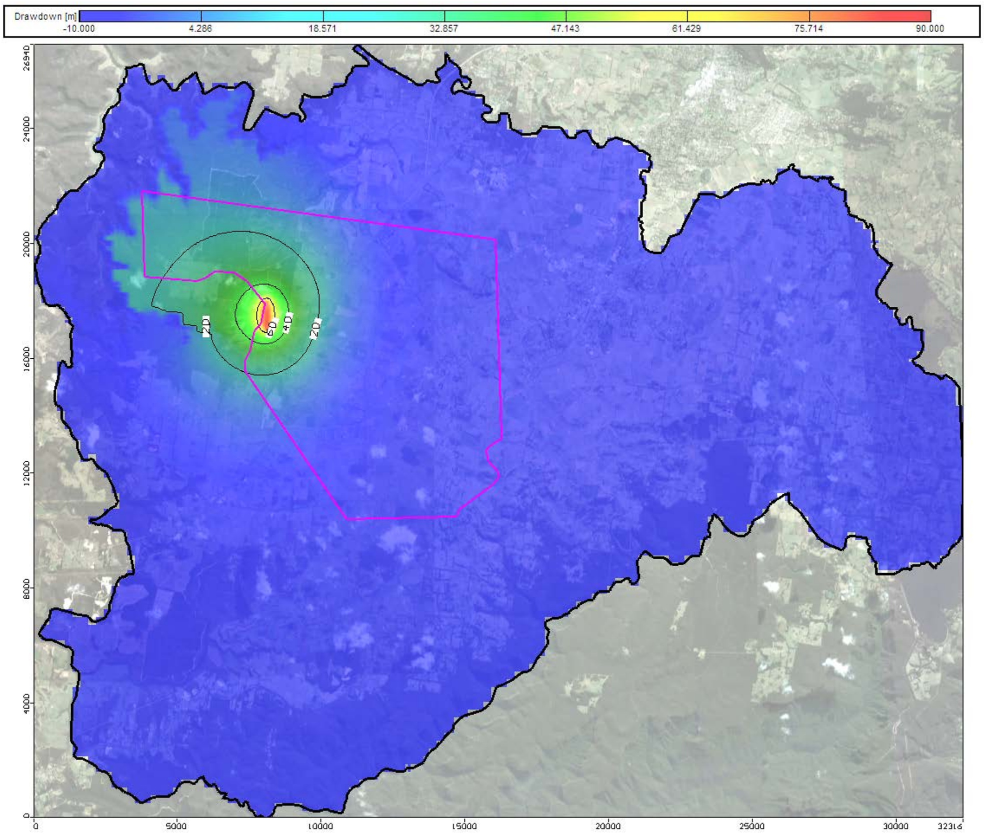


Figure 28 – Drawdown in Layer 4, standard values, Mine rate R=1.2, 2 months elapsed.

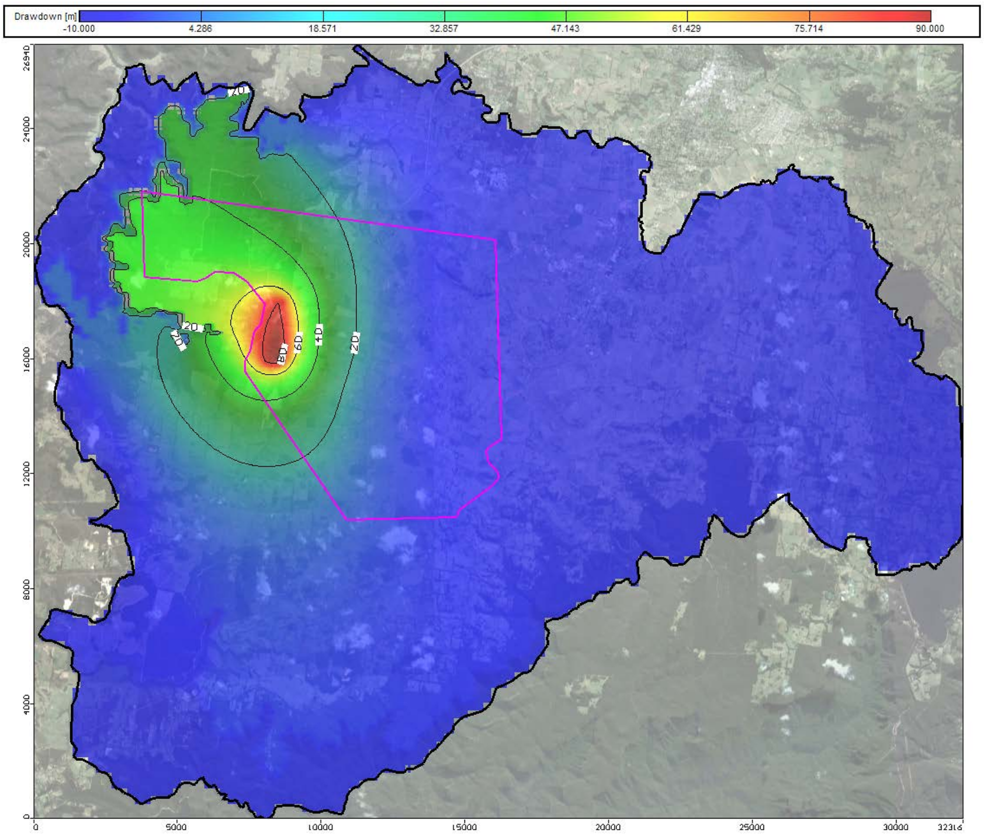


Figure 29 – Drawdown in Layer 4, standard values, Mine rate R=1.2, 1 year elapsed.

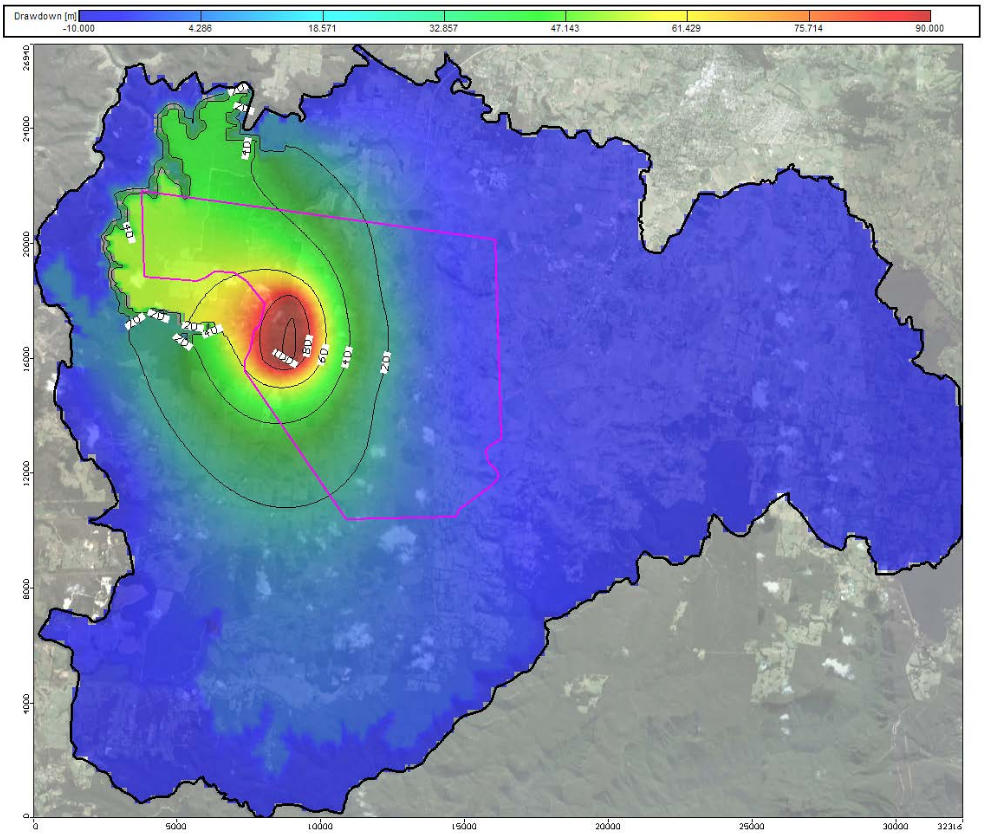


Figure 30 – Drawdown in Layer 4, standard values, Mine rate R=1.2, 2 years elapsed.

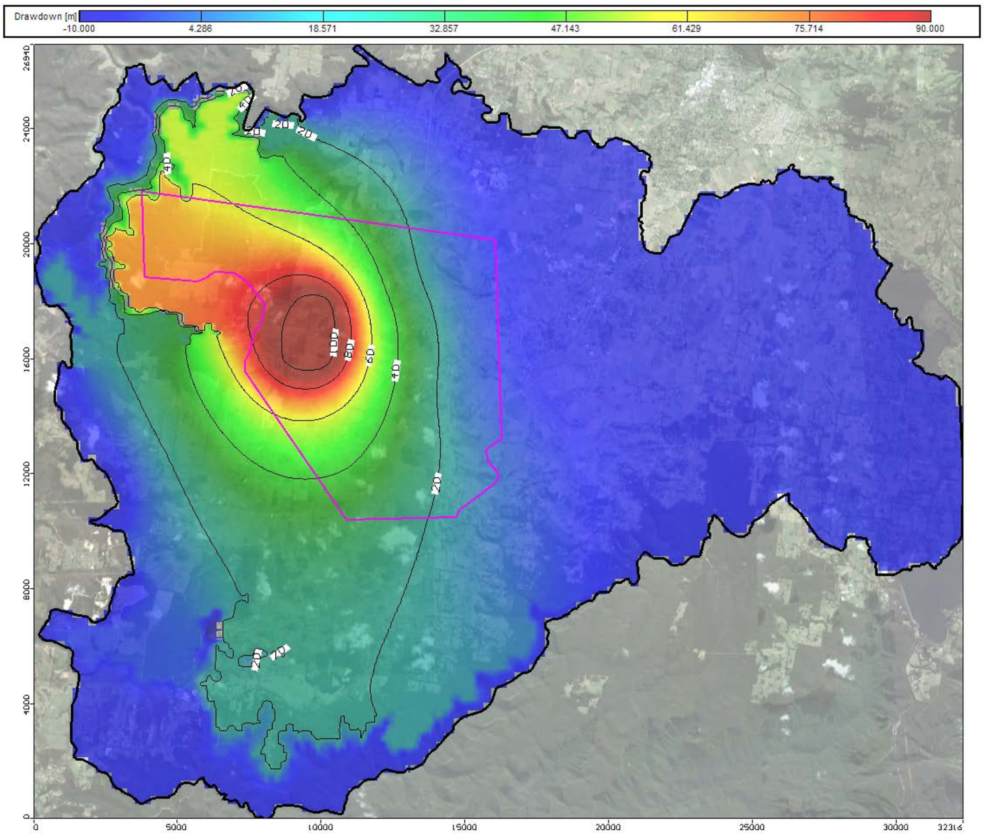


Figure 31 – Drawdown in Layer 4, standard values, Mine rate R=1.2, 5 years elapsed.

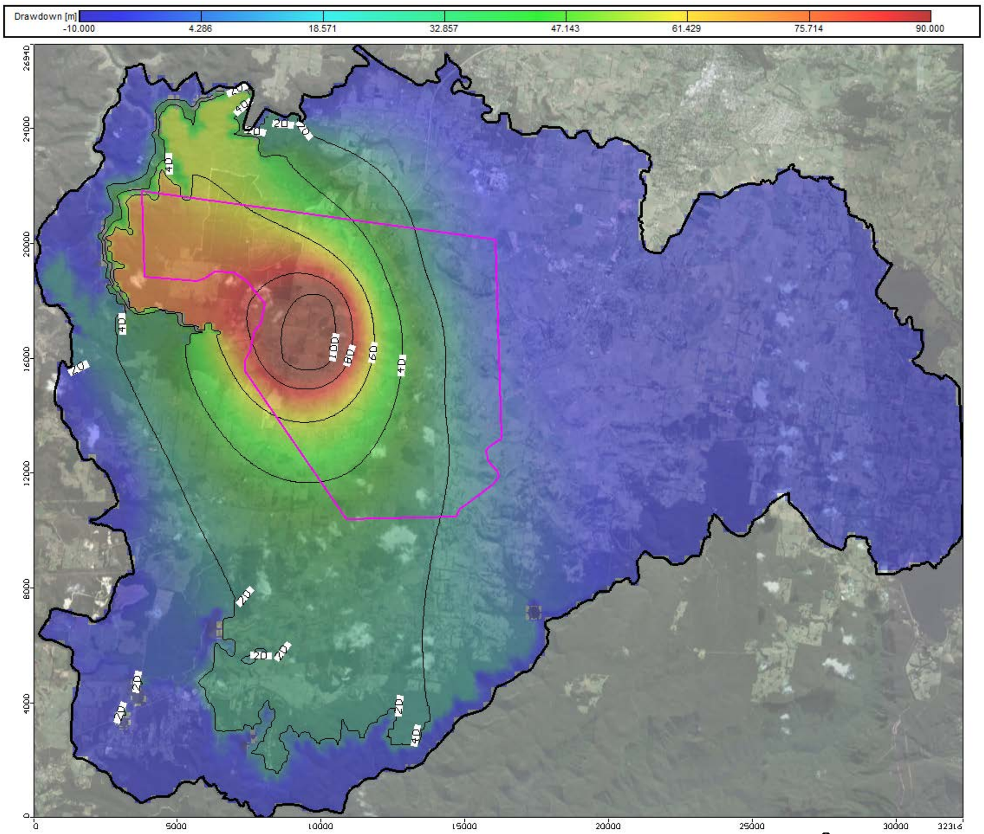


Figure 32 – Drawdown in Layer 4, standard values, Instant 4.5 km² min, 5 years elapsed.

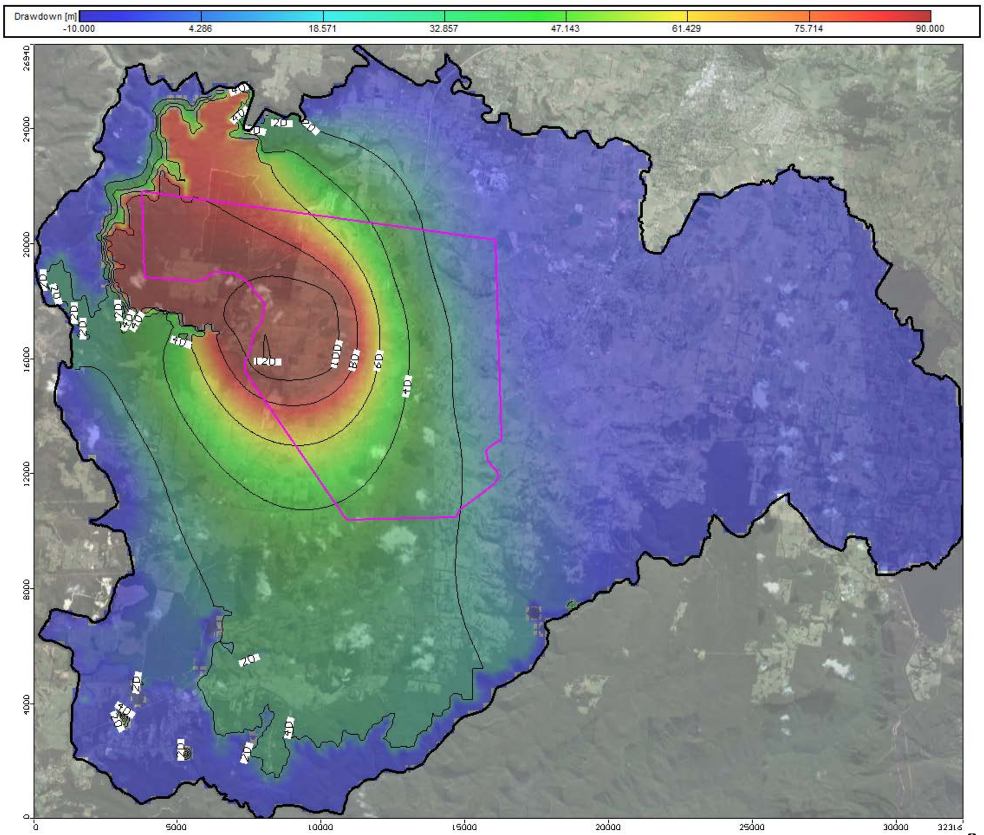


Figure 33 – Drawdown in Layer 4, standard values with fracturing, Instant 4.5 km² min, 5 years elapsed.

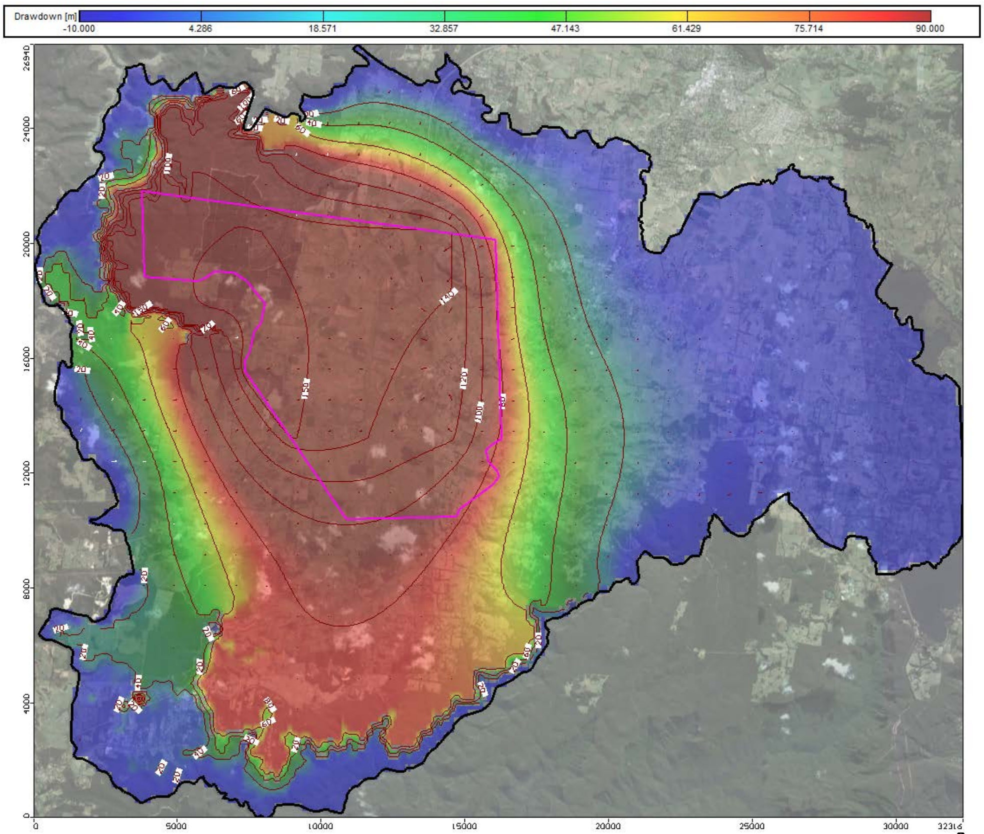
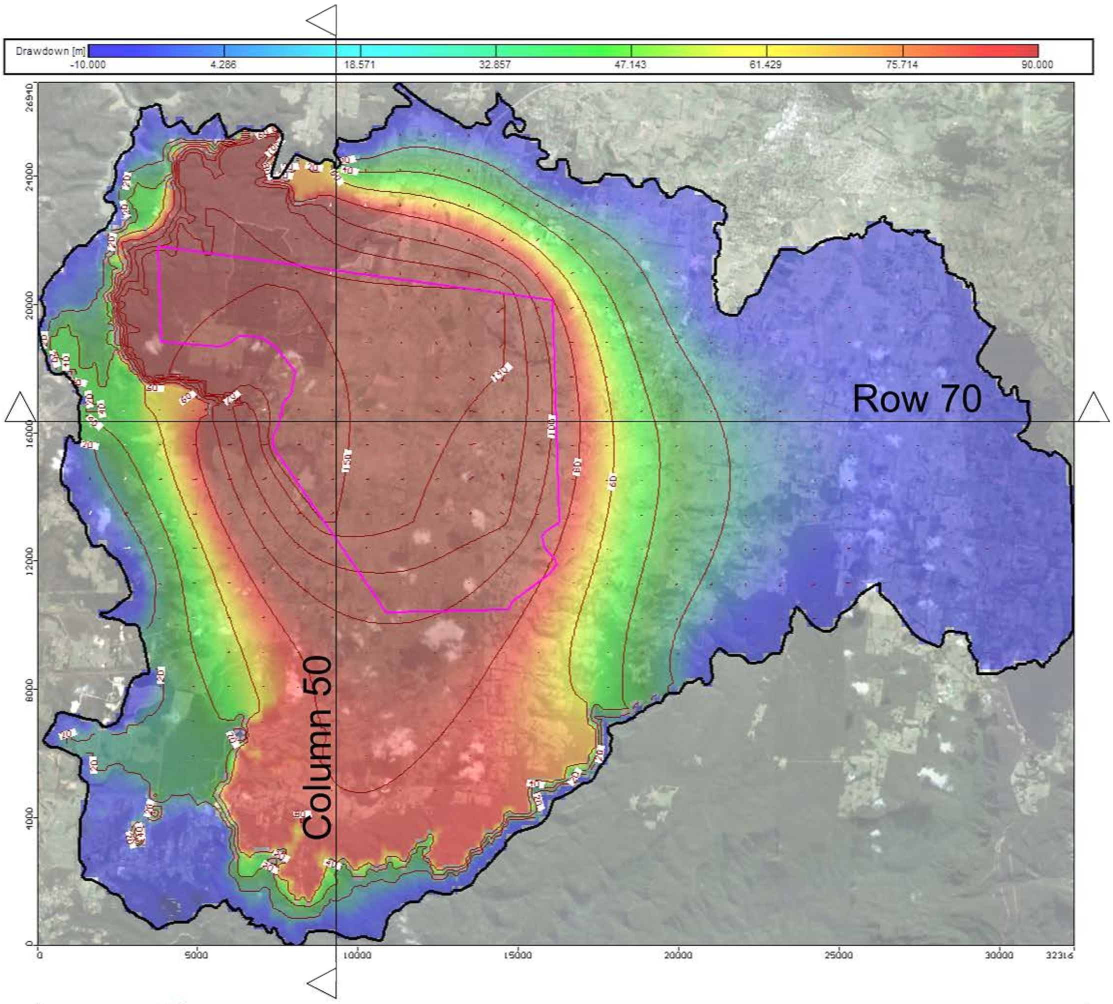
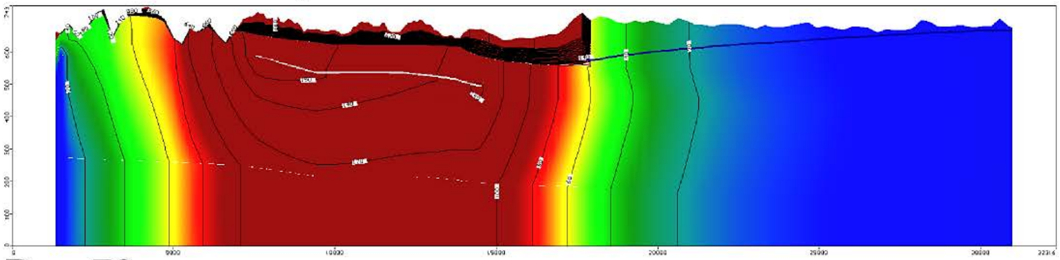


Figure 34 – Drawdown in Layer 4, standard values with fracturing, Instant 45 km^2 mine, 10 years elapsed.





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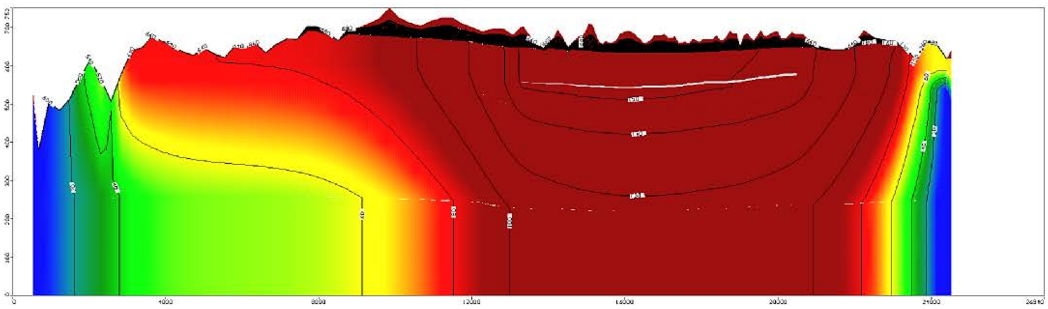


Column 50

Figure 35 – Drawdown in Layer 4, standard values with fracturing, Instant 45 km^2 mine, 40 years elapsed.

5 MODEL VALIDATION AND TESTING

Following an independent peer review of the numerical groundwater model presented above, a number of further tests were undertaken to validate the performance and robustness of the numerical model. Specifically, the recommendations and adopted responses are as summarised below:

1. Refinement of the model grid in the north western and southern perimeter of the model for better representation of steep vertical gradients in these locations (see Figure 36).
    a. *It was decided simply to double the resolution of the entire model. This was chosen as it also allowed for verification of the adequacy of the original model grid.*
2. Refinement of model layering, by splitting the original model layer 3 (Hawkesbury Sandstone Unit B) in three layers and original model layer 8 into two layers. The purpose of this was again to improve the resolution of vertical flow around the perimeters and into the mine (see Figure 37 and Figure 38).
    a. *The refinement of layering above the mine was used as an opportunity to rectify the representation of Hawkesbury Sandstone Unit C, increasing its thickness to better represent data presented in Figure 14 to Figure 18. As such, the entire Hawkesbury Sandstone geology is represented in 5 layers: 1 for Unit C and 2 for each of Units B and A.*
3. Replacement of the assumed constant head boundaries in the original layers 7 and 8 with general head boundaries which reflected flow out of the model. For example, general head boundaries in the southern region of the model were established to reflect expected south-bound flow to lower elevations of Tallowa Dam (see Figure 39).
4. Insertion of ‘drain’ nodes around the perimeter of outcropping of original model layer 4 (the Hawkesbury Sandstone Unit A) to represent a seepage face (see Figure 40).
5. It was anticipated that the changes in Points 1. to 4. above would require increased recharge to support appropriate simulation of existing groundwater conditions.
6. It was also suggested that the transient response of the model be tested against selected pumping test results.

These changes were implemented, and were run using the ‘standard’ values of hydraulic conductivity and storage (see Table 1). The 45 km^2 `instant mine’ was also re-run with the new changes. Each change is described below.

5.1 Refinement of model grid and layering

The finite difference grid assembled over the model domain was refined such that it comprised cells approximately 135 m x 135 m around the periphery, but refined by a factor of 3 (ie approximately 45 m x 45 m) in the vicinity of the mine.

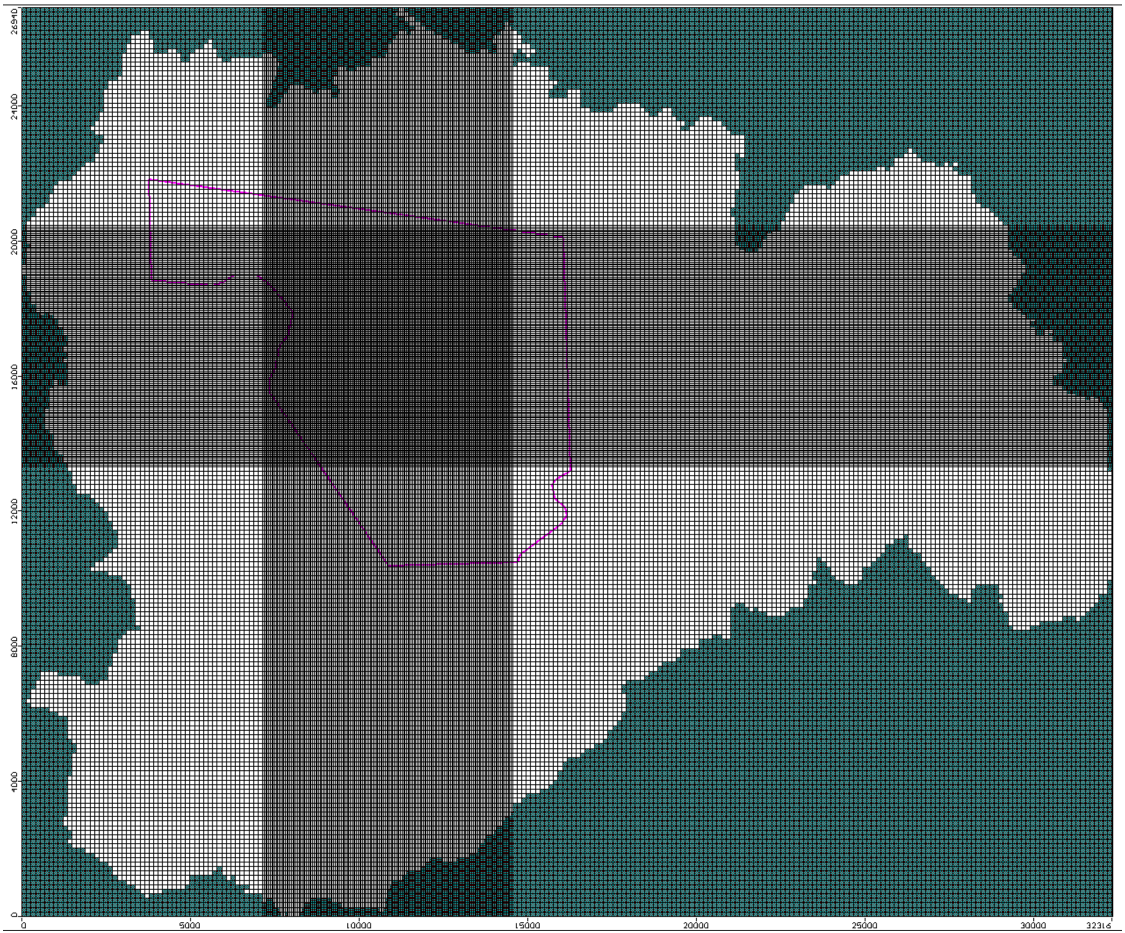


Figure 36 – Refined model grid (350 columns, 306 rows)

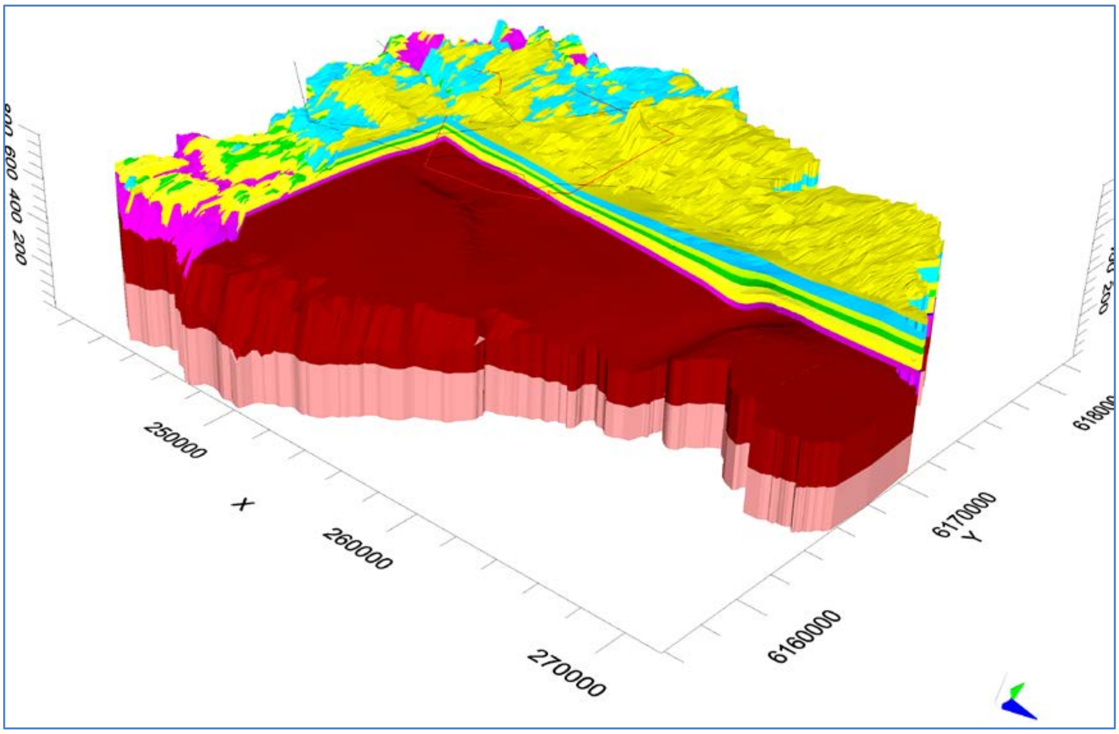


Figure 37 – 3D Overview of Refined Model Stratigraphy (10x Vertical Exaggeration)

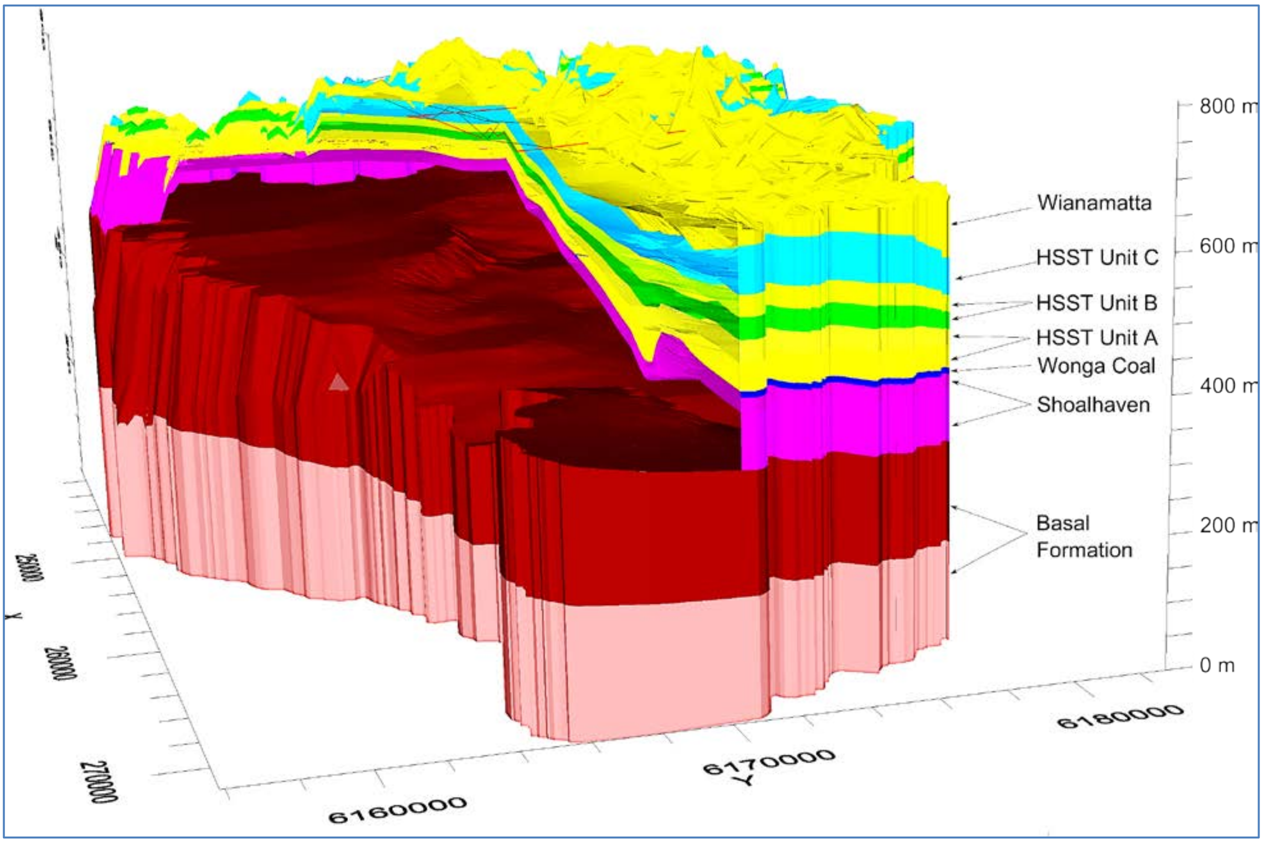


Figure 38 – 3D Overview of Refined Model Stratigraphy (20x Vertical Exaggeration)

The mapping of recharge was recalculated over the refined grid, and the `assumed value' was repeatedly adjusted until an appropriate replication of the regional water table was simulated in steady state. An approximate match (see Figure 58, in Appendix A) was found with a recharge value of 8 mm/a (Figure 59). This is less than the value of 11 mm/a used in the unrefined grid, but was mapped more extensively so resulted in a similar net value of recharge.

In the first instance, the model with the refined grid and refined layering was run without any changes to the original boundary conditions, and the thickness of Hawkesbury Sandstone Unit A was left unchanged from the original assumptions. This was done so the effects of the grid and layer refinement could be examined alone.

The replication of steady state conditions from the refined-grid model are shown in Figure 58. The drawdown conditions for an 'instant' 45 km^2 mine are shown in Figure 63 and Figure 64, and mine inflow conditions are compared to the original calculations in Figure .

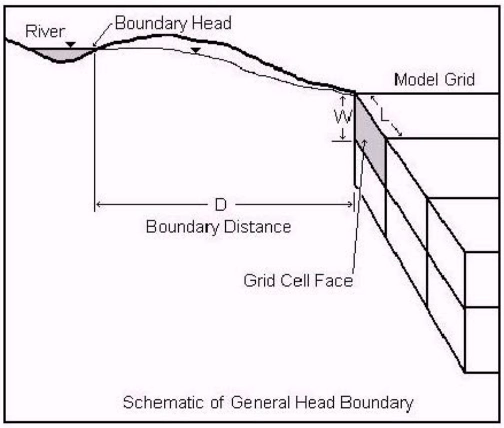
It can be seen that the refinement of the grid and layering, alone, resulted in little changes to the model outcomes. This shows that the original model grid was of sufficient resolution to assess of the effects on groundwater from the proposed mining.

5.2 Refinement of model boundary conditions

The model boundary conditions were refined by converting constant head boundaries, at depth, into general head boundaries to reflect regional deeper groundwater flow gradients away from the model domain. The parameters used for the general head boundaries were based on the distances and gradients shown in Figure 39, and by adopting a 'conductance' ('C'), for each grid cell, determined from the area of outer face of each grid and using the horizontal hydraulic conductivity relevant to each layer. The function of the general head boundary as summarised in the user manual for *Visual Modflow* is reproduced below:

General head boundaries:

Flow into or out of a cell from an external source is provided in proportion to the difference between the head in the cell and the reference head assigned to the external source. The application of this boundary condition is intended to be general, as indicated by its name, but the typical application of this boundary conditions is to represent heads in a model that are influenced by a large surface water body outside the model domain with a known water elevation. The purpose of using this boundary condition is to avoid unnecessarily extending the model domain outward to meet the element influencing the head in the model. As a result, the General Head boundary condition is usually assigned along the outside edges of the model domain. This scenario is illustrated in the following figure:



$$C = (LW)\,\frac{K}{D}$$

Where:

- C is the conductance
- (LxW) is the surface area of the grid cell face exchanging flow with the external source/sink
- K is the average hydraulic conductivity of the aquifer material separating the external source/sink from the model grid
- D is the distance from the external source/sink to the model grid

The primary differences between the General-Head boundary and the Constant Head boundary are:

- the model solves for the head values in the General-Head grid cells whereas the head values are specified in Constant Head cells.
- the General-Head grid cells do not act as infinite sources of water whereas Constant Head cells can provide an infinite amount of water as required to maintain the specified head.

Such general head boundaries were used around the perimeter of the model at depths below the surface. That is, in the refined model, a constant head simulated the stage of the river at the surface, and general head boundaries reflected regional scale outflow from the perimeter of the model at depths lower than the bounding rivers.

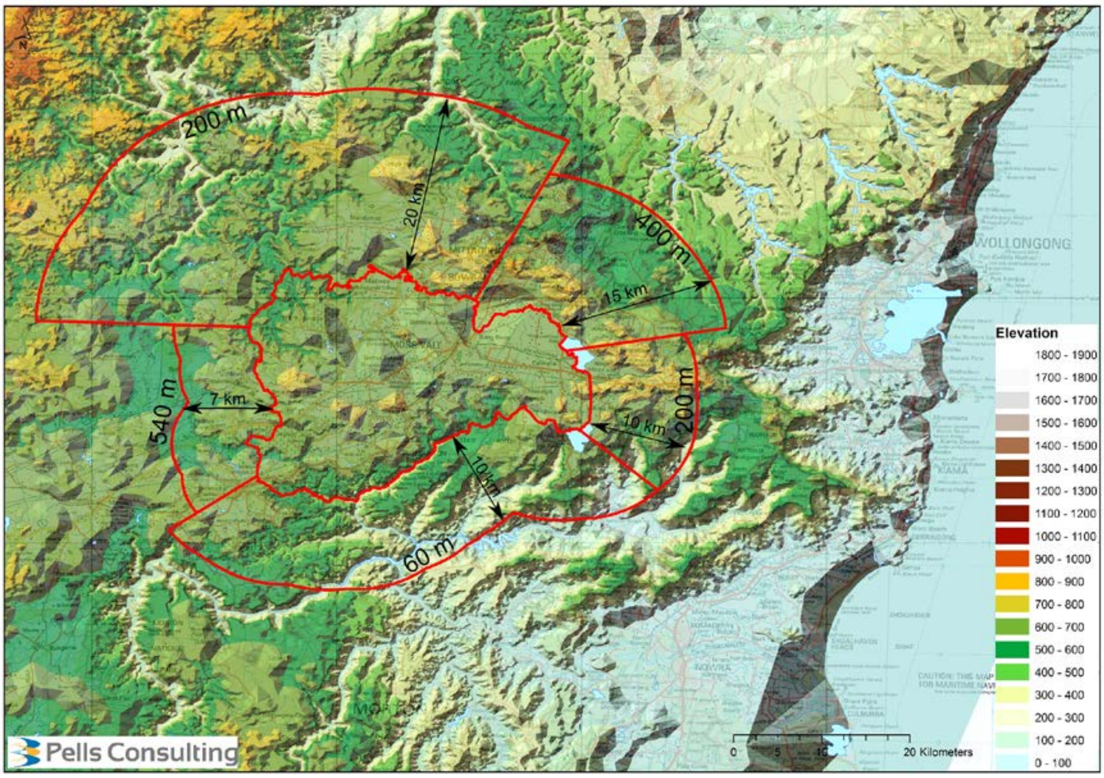


Figure 39 – Concept of General head boundaries applied to Layers 6 to 11

A series of drain nodes were also placed along the perimeter of outcropping of the (new) layer six (ie lower layer of Hawkesbury Sandstone Unit A), at locations as shown in Figure 40. This was done to represent a seepage face along these steep regions. This drainage node was assigned a nominal conductance of 1.5 m/day, which was found to simulate a reasonable value of flow. Higher values of conductance resulted in little further drainage outflow, indicating that flow through the drains was limited by formation losses not drain losses.

A significantly larger value of recharge of 50 mm/annum was then required, in conjunction with these modified boundary conditions, to provide a steady-state approximation of regional groundwater levels. The match to regional groundwater levels is shown in Figure 60 and the refined recharge map is shown in Figure 61 (both in Appendix A). It should be noted that various complements of boundary and recharge conditions could be chosen (for example, a recharge of 30 mm/a with drainage conductance of 0.4 m/day also produced an acceptable outcome), and the chosen values simply represent one possible scenario.

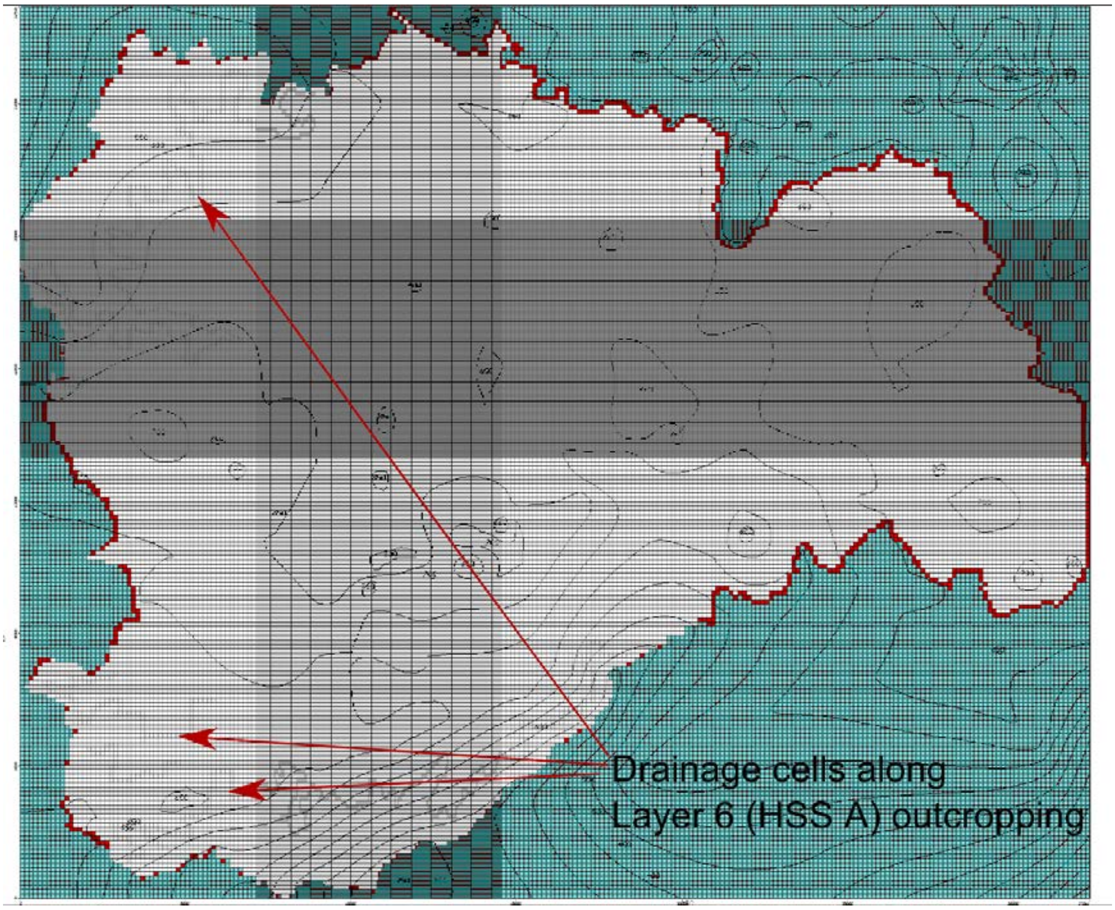


Figure 40 – Drainage cells placed to simulate seepage face

Predicted mine inflows from the original and refined models are shown in Figure 41. It can be seen that the refinement of boundary conditions has a large impact on the predicted inflows. The predicted inflows for standard hydraulic conductivity values are approximately doubled. This is because the larger recharge value of 50 mm/a and because of the increased thickness (ie transmissivity) of the Hawkesbury Sandstone Unit A.

The assessed drawdown from the refined model after 10 and 40 years, assuming an 'instant' 45 km^2 mine, is shown in Figure 64 and Figure 65. The larger recharge value adopted for the refined model has the effect of slightly reducing the extent of drawdown (see Figure 34 and Figure 35).

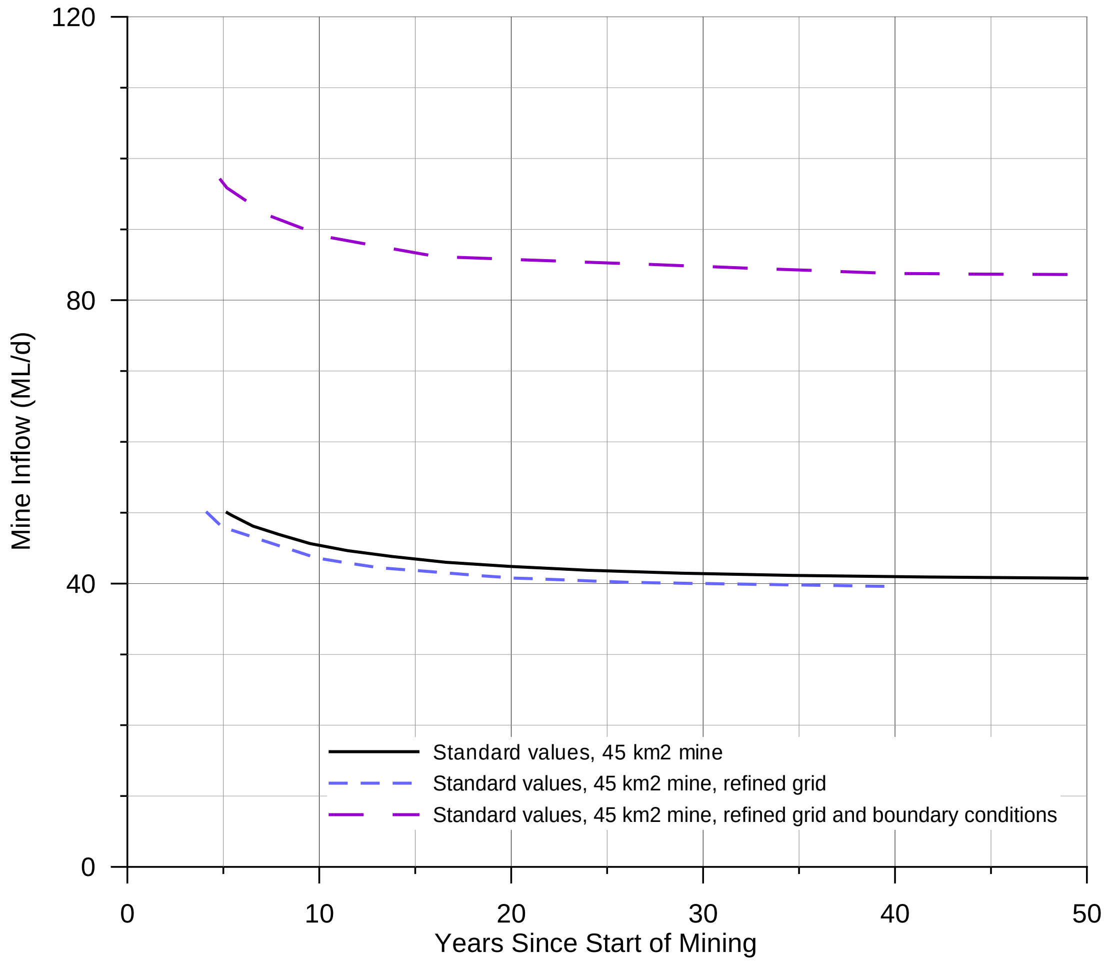


Figure 41 – Mine inflows, refined models versus original model

5.3 Validation against pumping tests

The groundwater model presented herein was established to assess the effects of mining, rather than to assess existing groundwater conditions. As such, it is agreed that validation of the model is best done by assessing its response to stresses, rather than trying to match existing conditions.

Data from four selected pumping tests, undertaken by Hydroilex within the model domain, were used to validate the response of the model. It is noted, however, that these pumping tests only recorded drawdown within the pumping bore, and no separate monitoring bores were used. As such, it is recognised that the pumping tests represent highly localised stresses which are not necessarily simulated with accuracy by the regional-scale model, for two reasons:

1. The model grid is too coarse to represent high-gradient flows and well losses into the bore[5]. The model reports only one water level per cell, and the smallest cells (in the refined model) of approximately 45 m x 45 m would reflect the average drawdown over that cell area, which should be significantly less than the drawdown level in the bore. To account for this, a correction was applied as discussed below with reference to Figure 42.

[5] A local grid refinement (LGR) can be used to address this; however, the LGR MODFLOW engine is not available within the version of *Visual Modflow* used.

2. The local conditions of the bore, such as localised fracturing encountered by the bore, may have significant impacts on the yields, but are not represented in the model. For example, two bores installed by Hydroilex to identical depth and specification, cited within 700 metres from each other, (Wongonbra 1 and Wongongra 2) achieved markedly different assessed yields.

Hence, the simulation of pumping test data, as requested by the independent peer review, is considered to be only an approximate validation procedure.

Consider the schematic of flow to a pumping well shown in Figure 42. The groundwater model considers only one water level in the entire cell in which that well is located and does not consider well losses. As such the level predicted by the model should fall somewhere between the drawdown at the outer face of the bore (S_{skin}) and the drawdown at a radius that reflects the cell size ($S_{model\ cell}$). As the grid size decreases, this level would more closely reflect the drawdown in the well.

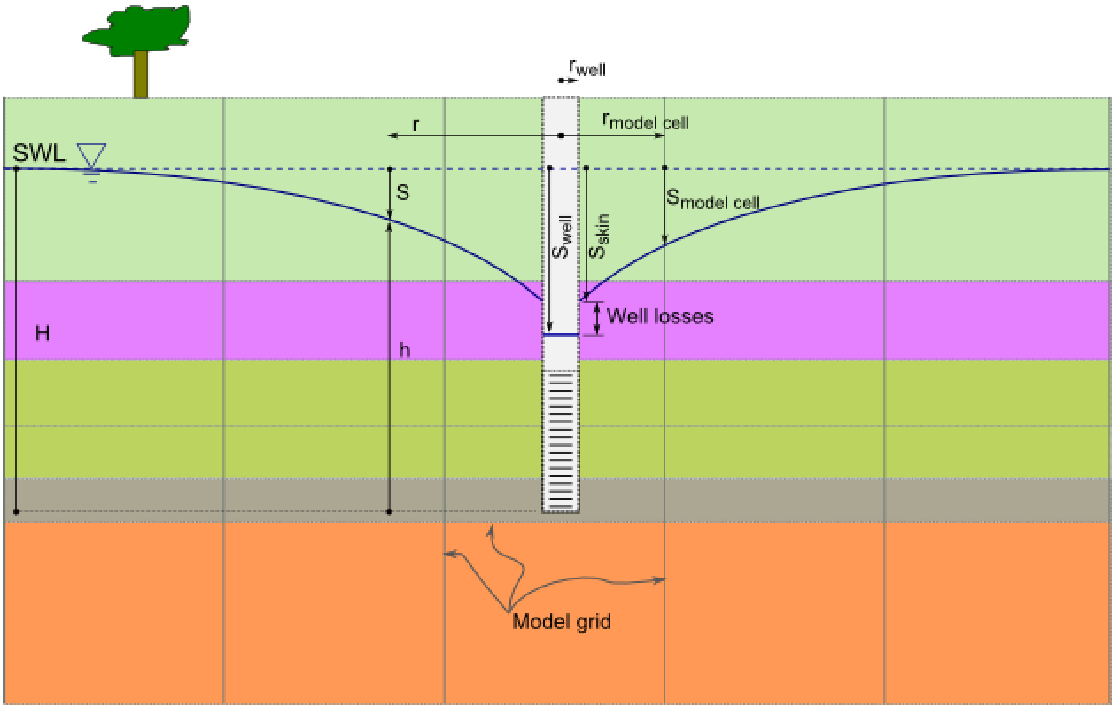


Figure 42- Schematic of flow to a pumping well

Assuming a well efficiency of 80% (Kresig, 2007), the drawdown at the well face (`S_{skin}') can be estimated as:

$$S_{skin} = 0.8 S_{well} \quad (1)$$

The drawdown at the perimeter of the cell that the well is cited is can be approximated by radial flow theory:

$$(h_{model\ cell})^2 = (h_{skin})^2 - \frac{Q}{\pi k} ln\left(\frac{r_{model\ cell}}{r_{well}}\right) \quad (2)$$

Where: $h_{skin} = H - S_{skin}$

$h_{model\ skin} = H - S_{model\ skin}$

Q = pumping well discharge

K = effective hydraulic conductivity for the layers

$r_{model\ skin}$ = $= \sqrt{row\ width\ x\ column\ width/\pi}$

The locations of pumping test bores used are shown in Figure 43, and key parameters are shown in Table 7.

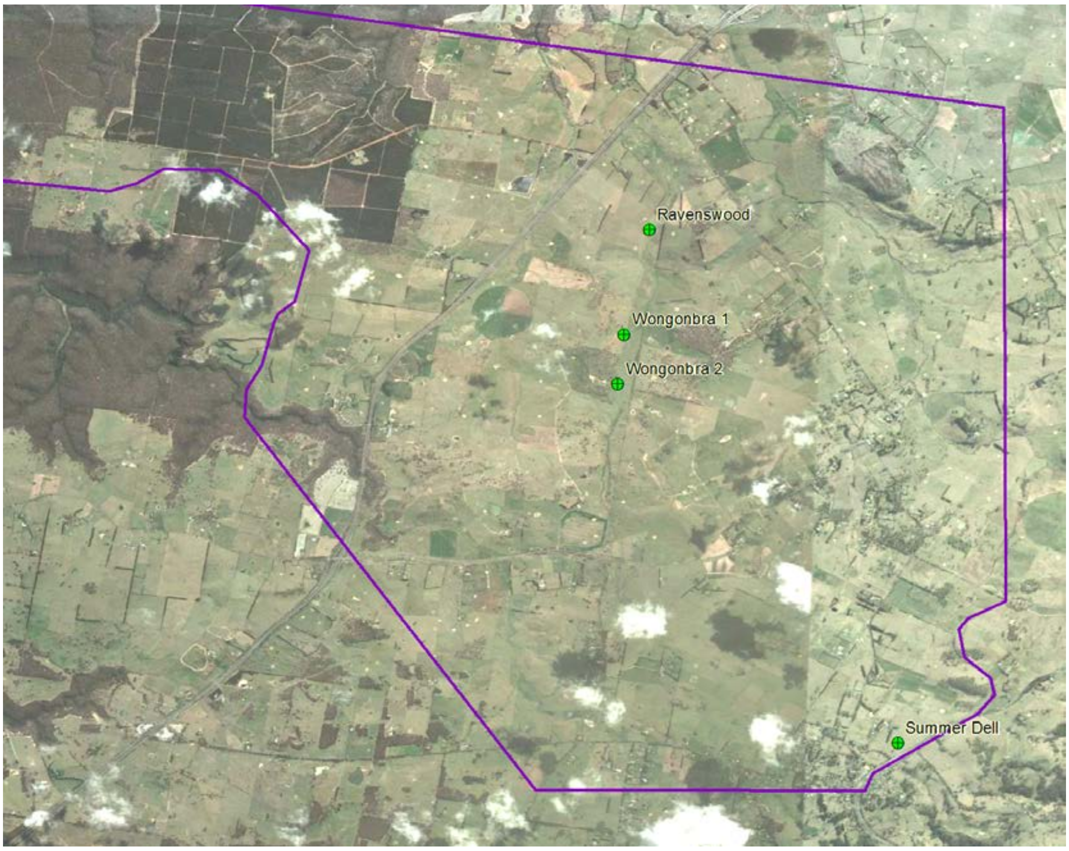


Figure 43 - Pump testing bore locations

Table 7 – Pump test data

Name	Depth m	SWL mBGL	Q L/s	S_{well} m	H m	Original Model			Refined Model		
						K_{eff}	r_{cell}	S_{cell}	K_{eff}	r_{cell}	S_{cell}
Summer Dell	169	72.6	11.4	16.4	96.4	9.8E-06	152	-1.9	1.5E-05	76	4.1
Ravenswood	108	15.8	9.2	20.1	92.2	5.5E-06	51	-3.3	1.5E-05	25	9.3
Wongonbra 1	121.5	24.5	17.8	15.7	97.0	8.7E-06	51	-8.7	1.5E-05	25	1.0
Wongonbra 2	126	26.5	8.3	52.5	99.6	8.8E-06	51	27.6	1.5E-05	25	34.1

The simulated drawdown curves are compared to the field-recorded drawdown curves in Figure 45 to Figure 47. Also shown on these figures are the interpreted drawdown levels at the well outer face and at the edge of the model cell that the well is cited in.

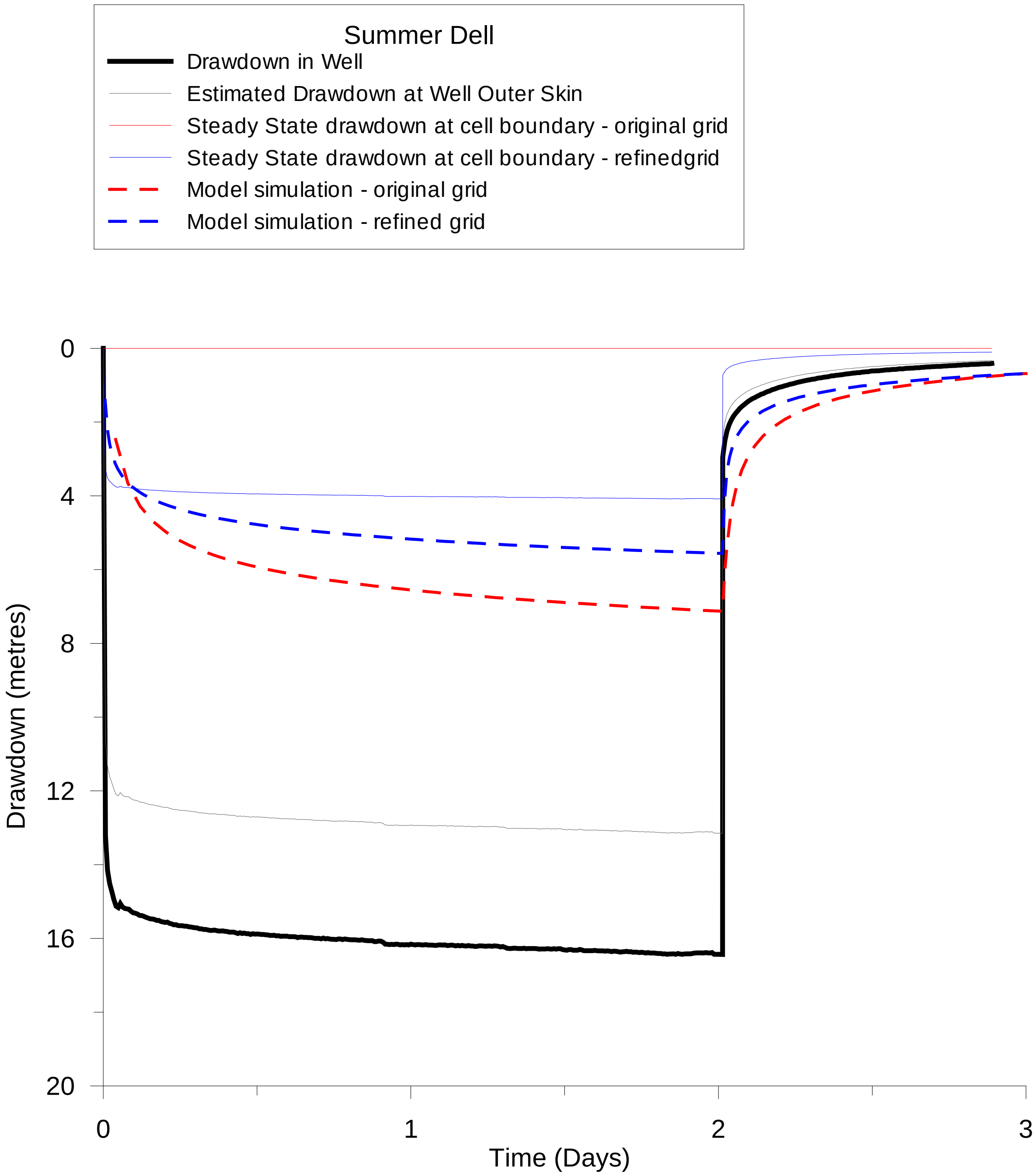


Figure 44 – Pump test at `Summer Dell'

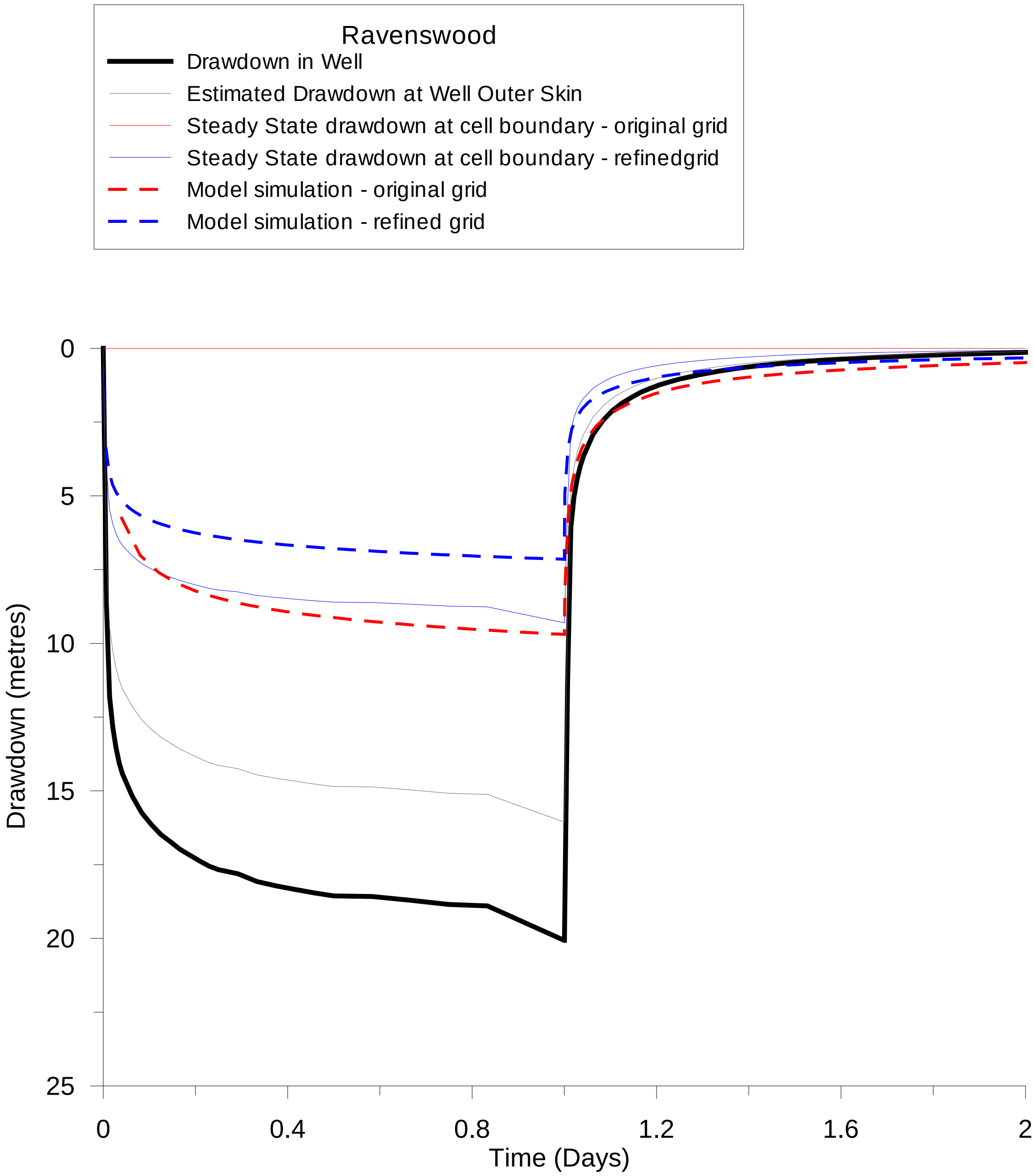


Figure 45 – Pump test at Revenswood

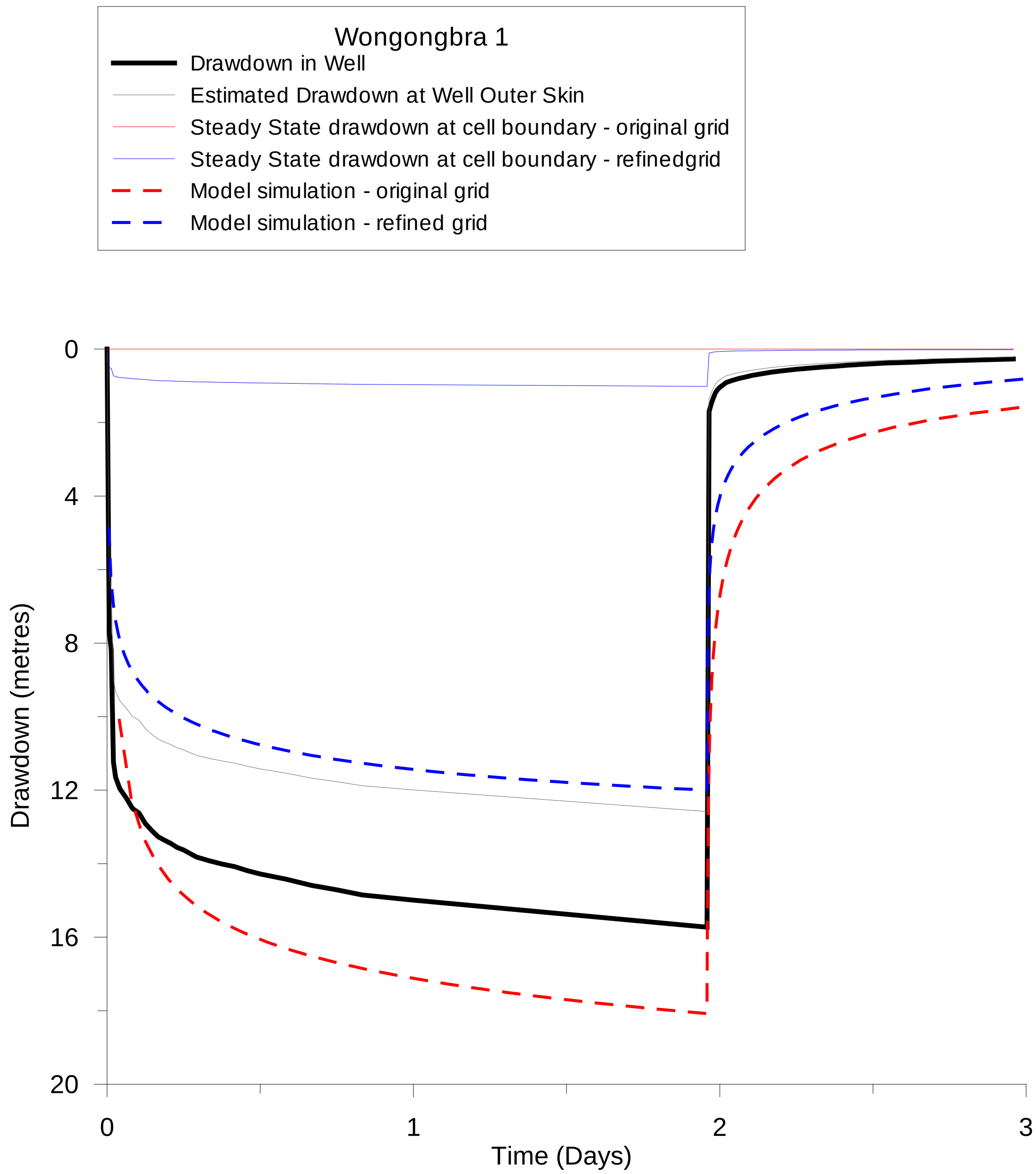


Figure 46 - Pump test at Wongonbra 1

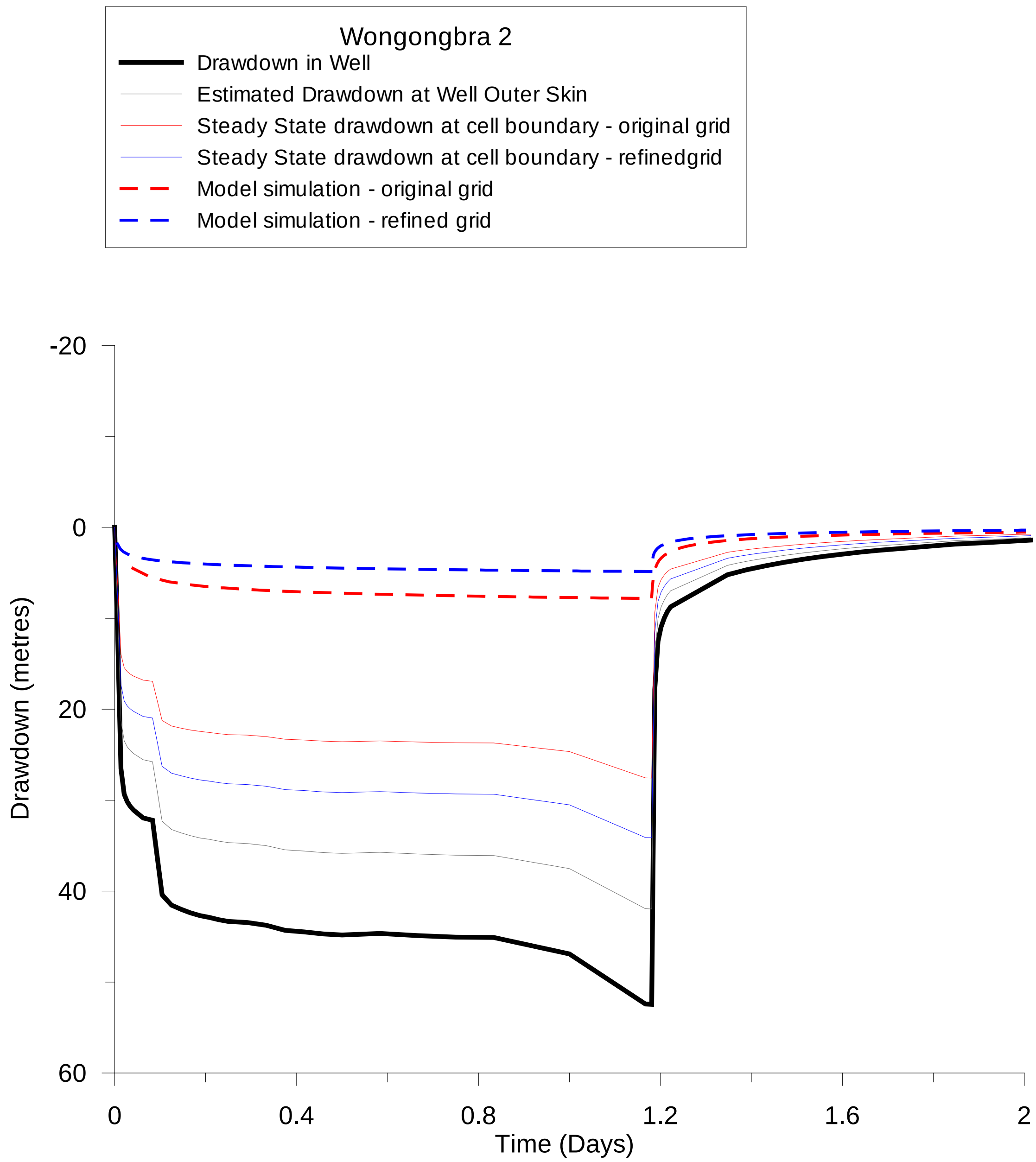


Figure 47 - Pump test at Wongonbra 2

Within the limitations of having pump tests with no externally located piezometers, and a model grid that is too coarse for simulating the true bore diameter, it is considered that the comparisons, presented in Figures 44 to 47, provide support for the hydraulic conductivity values used for the Hawkesbury Sandstone in the 3D model.

6 CONCLUSIONS

6.1 Key Variables – mine inflow

All complex 3D groundwater models of the kind presented here, involve many variables in the form of the hydrogeological horizons that make up the model, the hydraulic conductivity and storage characteristics of those horizons, and the boundary conditions, both around the perimeter of the modelled area , and of the simulated mine.

The sensitivity studies undertaken with this model show that the dominant factors affecting mine inflow are:

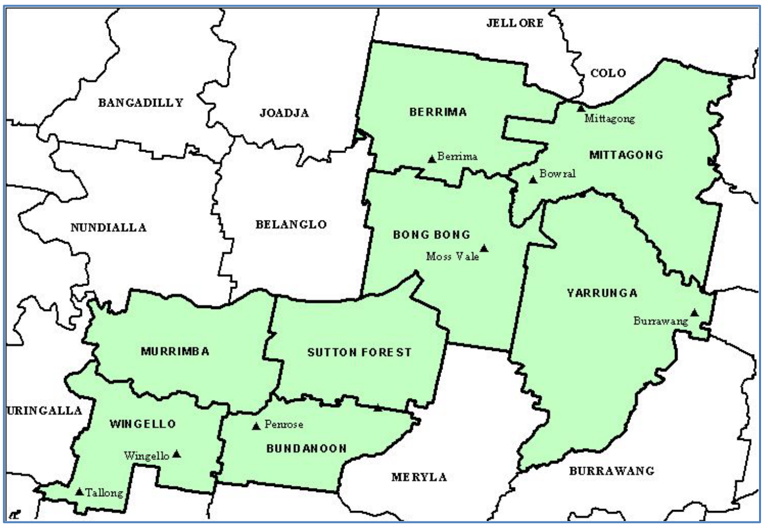
- the adopted hydraulic conductivity values, and
- the adopted perimeter boundary conditions, which impact on the surface recharge needed to give a reasonable match with what is known about the natural groundwater regime.

Fracturing of the Hawkesbury Sandstone above the workings is a secondary effect, so the method of mining is of little consequence. Conversely nothing meaningful can be achieved in reducing mine inflows, and groundwater drawdown, by altering the mining method.

Adopting boundary conditions consistent with the recommendations of the peer review leads to an average recharge of 50mm/annum. With the boundary conditions initially adopted the recharge over the area above the mine (for median permeability parameters) is 11mm/annum.

These recharge figures may be considered in the light of discussion in the Pritchard report that gives an average annual rainfall of 982mm, and suggests a recharge of 5% for "exposed sandstone" and 0.5% for non-exposed sandstone. This equates to **49mm/annum** for exposed sandstone and **5mm/annum** for non-exposed sandstone.

The Pritchard report also indicates the exposed sandstone area in Sutton Forest (see their Figure reproduced below) as 8% and in Bong Bong as 1.1% (values are not given for Belanglo and Meryla).



Pritchard Report Figure 1

Therefore it is considered that the recharge conditions matched with our initial boundary conditions may be a better representation of reality than the 50mm/annum needed to accompany the modified boundary conditions.

We consider therefore that Figure 26 gives the most likely range of mine inflows, but they could be higher.

6.2 Key Variables – Depressurisation and Drawdown

Depressurisation of the strata above and around the mine, and drawdown of the water table are not sensitive to the model perimeter boundary conditions.

Depressurisation and drawdown rates are higher for higher conductivity values, but the hydrogeology of the area, with the Hawkesbury Sandstone mostly directly overlying the Wongawilli coal seam, means that rapid and complete drawdown occurs above the mine within the life of the mine, and substantial drawdown eventually occurs over most of Authorisation 349.

It is reasonable to expect that most groundwater bores in the area will lose all or most of their current yields. This is fully consistent with observations of groundwater drawdown at the Berrima Colliery which is just north of the modelled area.

Yours faithfully

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BE(Civil) Hons, MEngSc

7 REFERENCES

McElroy Bryan and Associates (1980) South-West Coal Project, Geological Summary Report.

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Visual MODFLOW 2011.1 User's Manual, Schlumberger Water Services.

APPENDIX A

MODEL DATA

A.1 ORIGINAL MODEL

A.1.1 Selection of recharge - pre-mining conditions

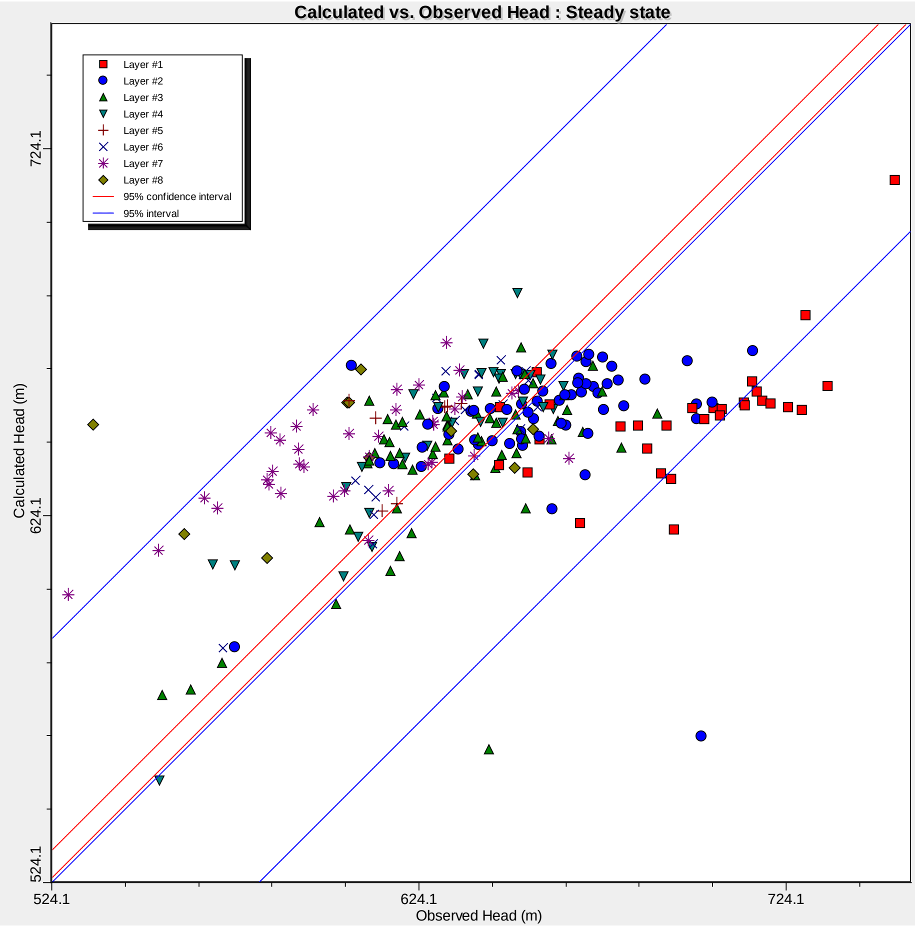

Figure 48 – Calibration of pre-mine, Upper Values

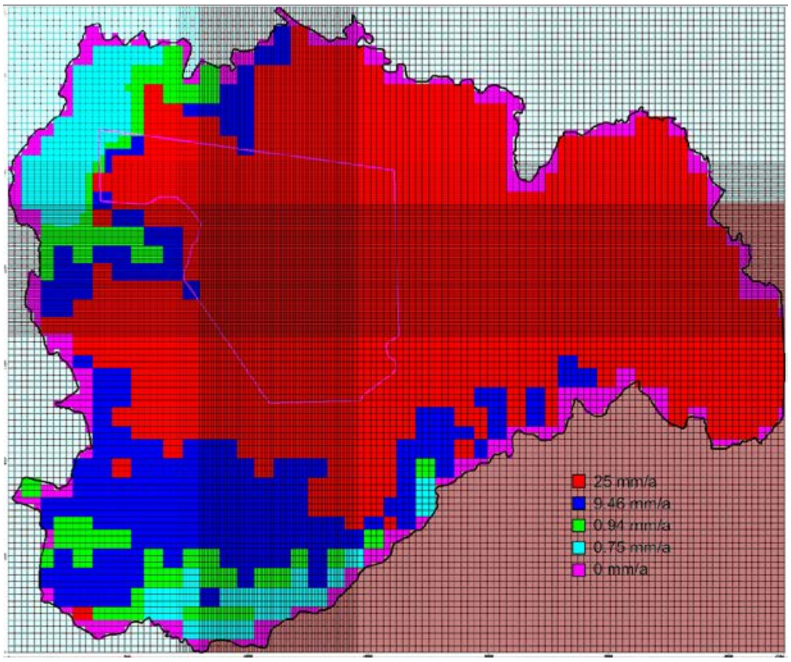

Figure 49 – Recharge Values used with Upper Values of Hydraulic Conductivity

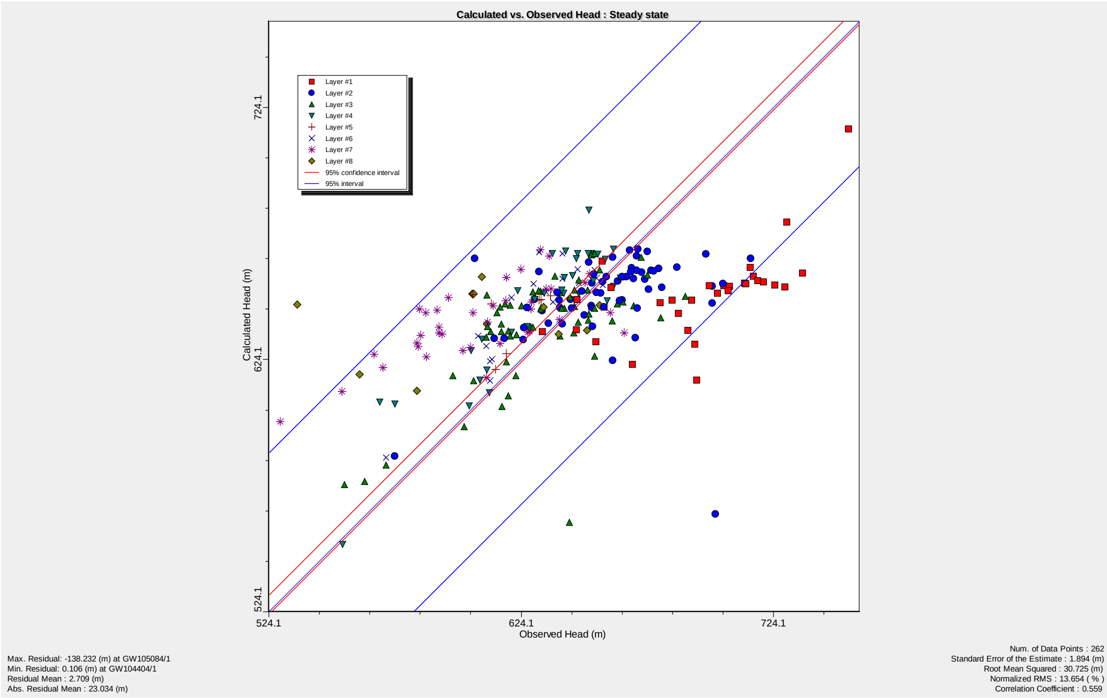

Figure 50 – Calibration of pre-mine, Median Values

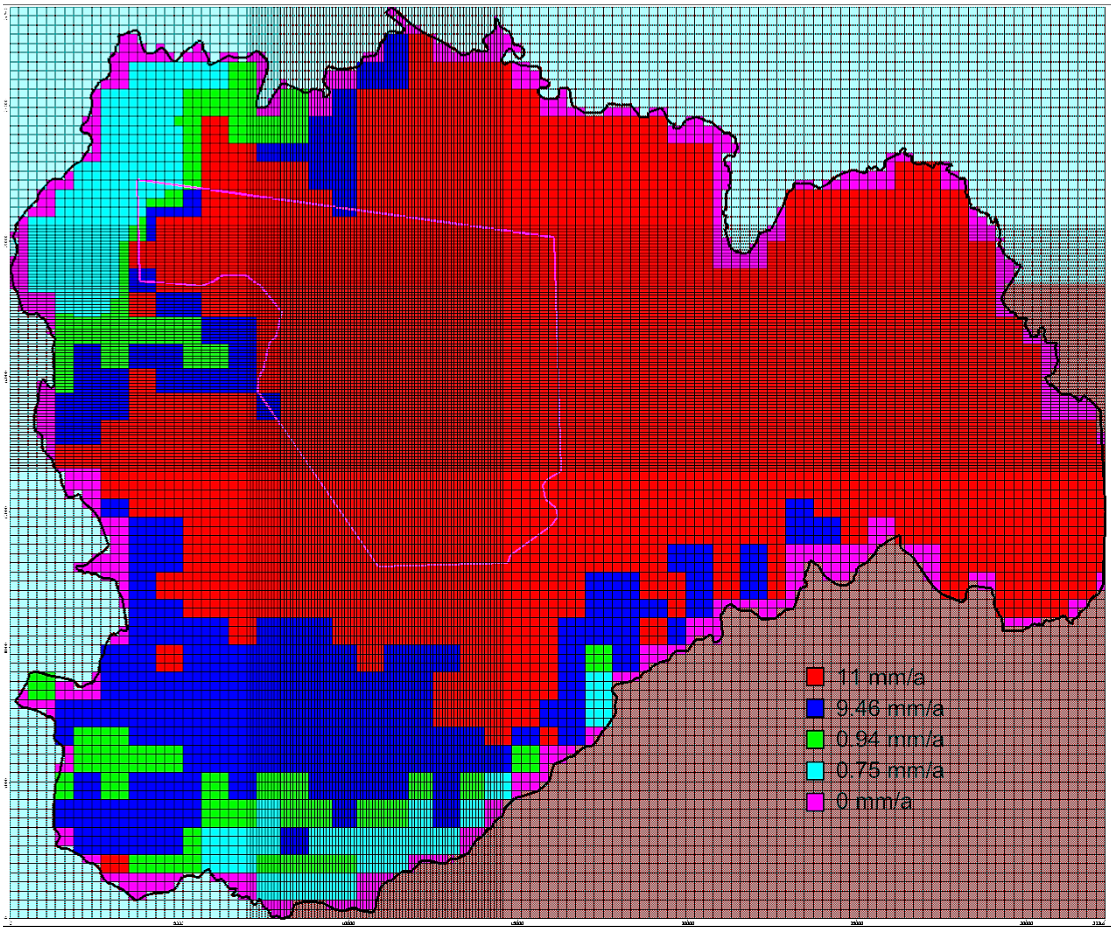

Figure 51 – Recharge Values used with Median Values of Hydraulic Conductivity

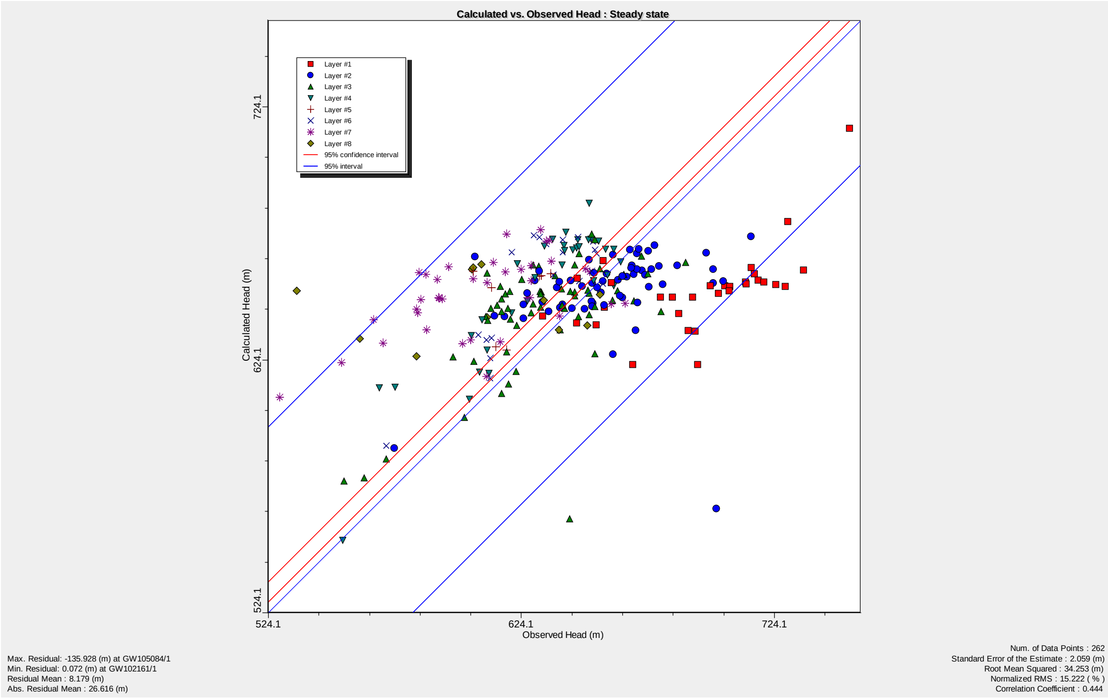

Figure 52 – Calibration of pre-mine, Lower Values

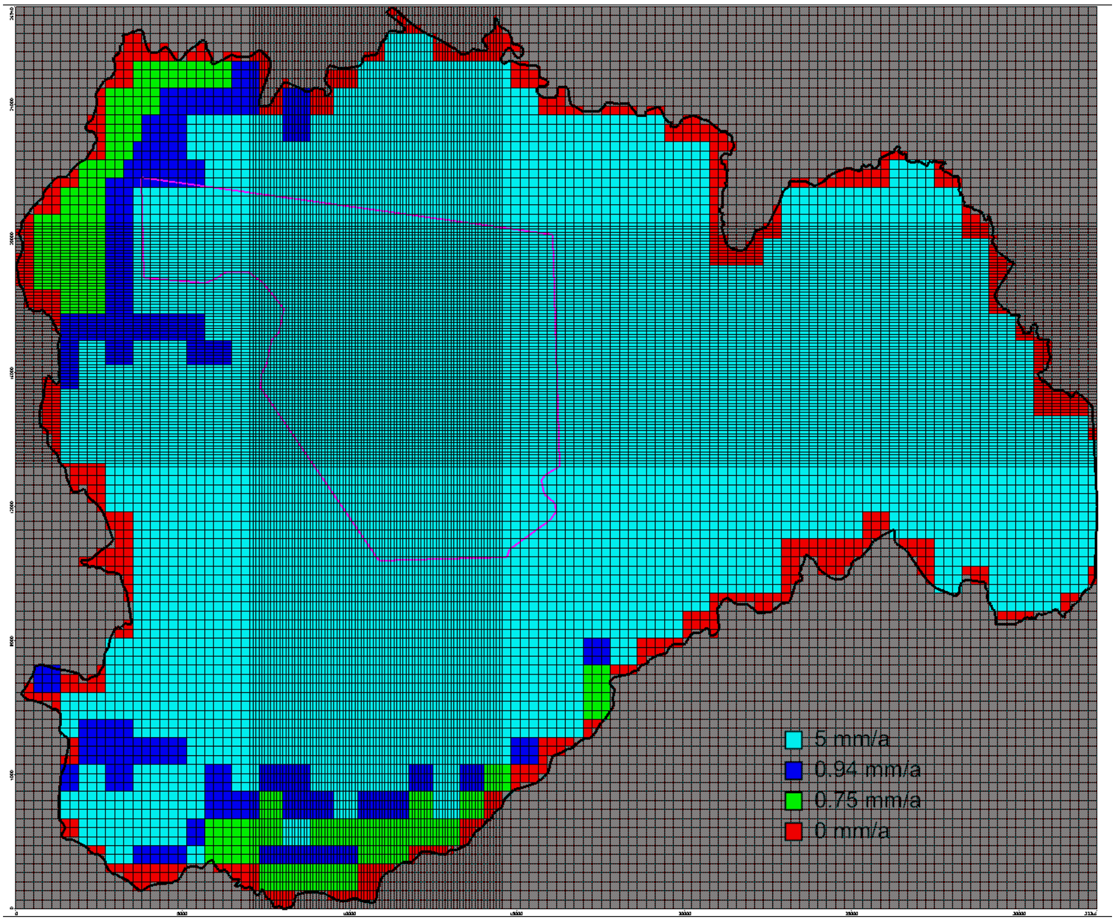

Figure 53 – Recharge Values used with Lower Values of Hydraulic Conductivity

A.1.2 Additional Drawdown Maps

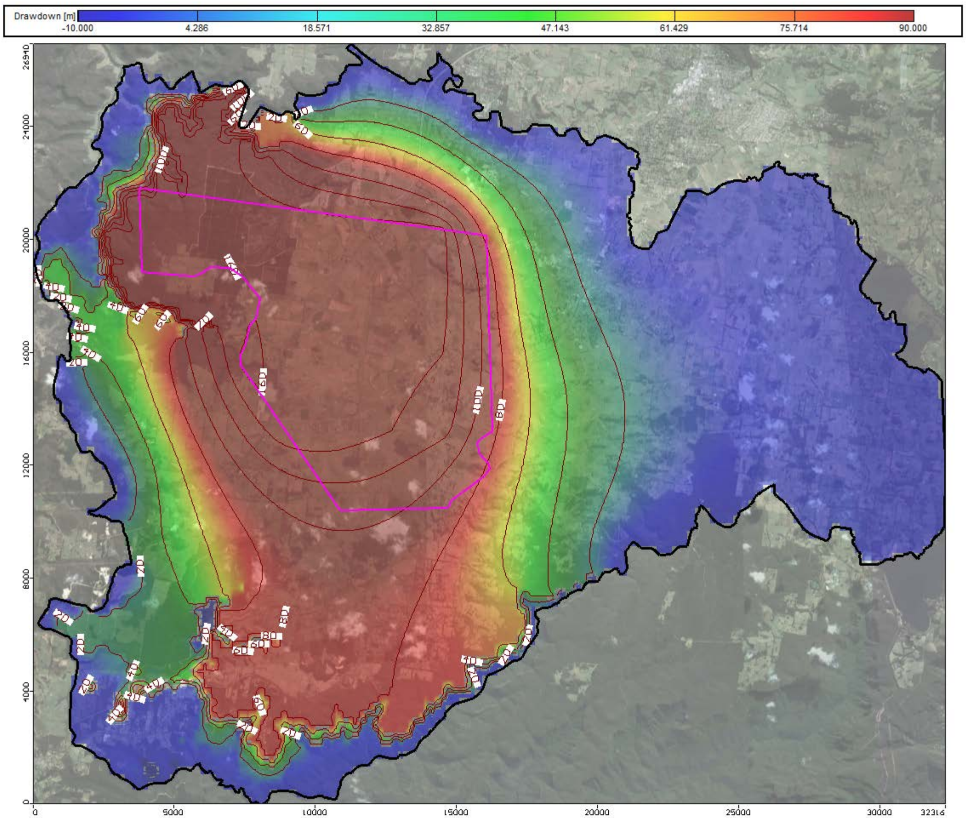

Figure 54 – Drawdown in Layer 4, higher values with fracturing, Instant 45km^2 mine, 10 years elapsed

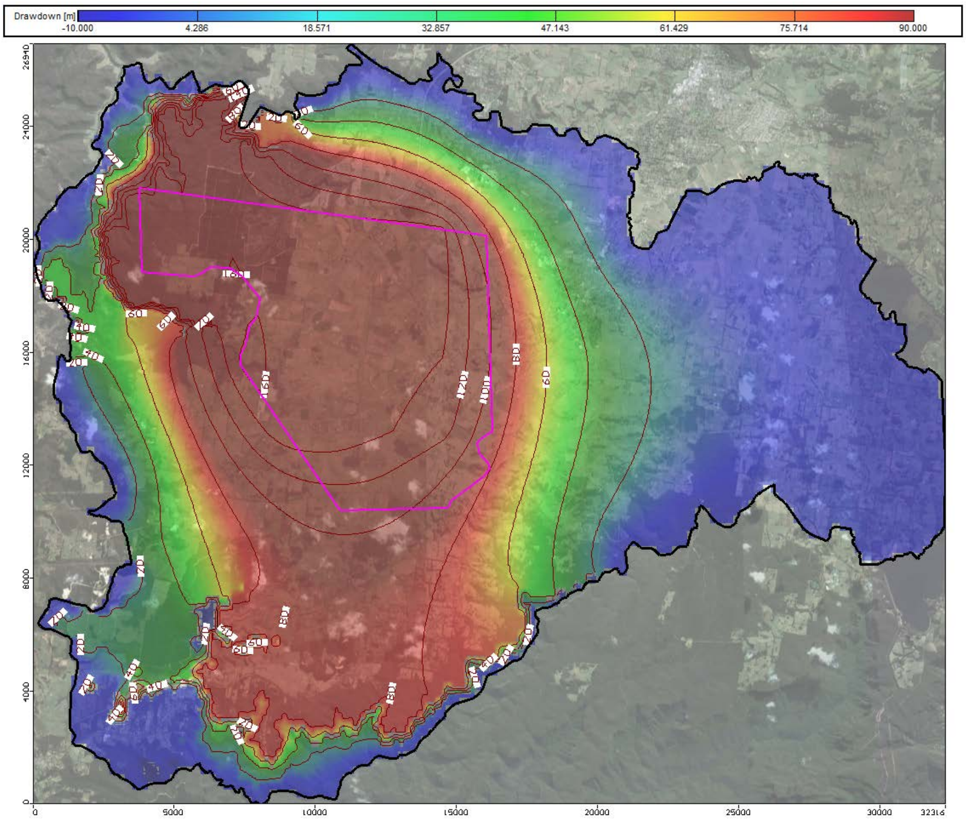

Figure 55 – Drawdown in Layer 4, higher values with fracturing, Instant 45km^2 mine, 40 years elapsed,

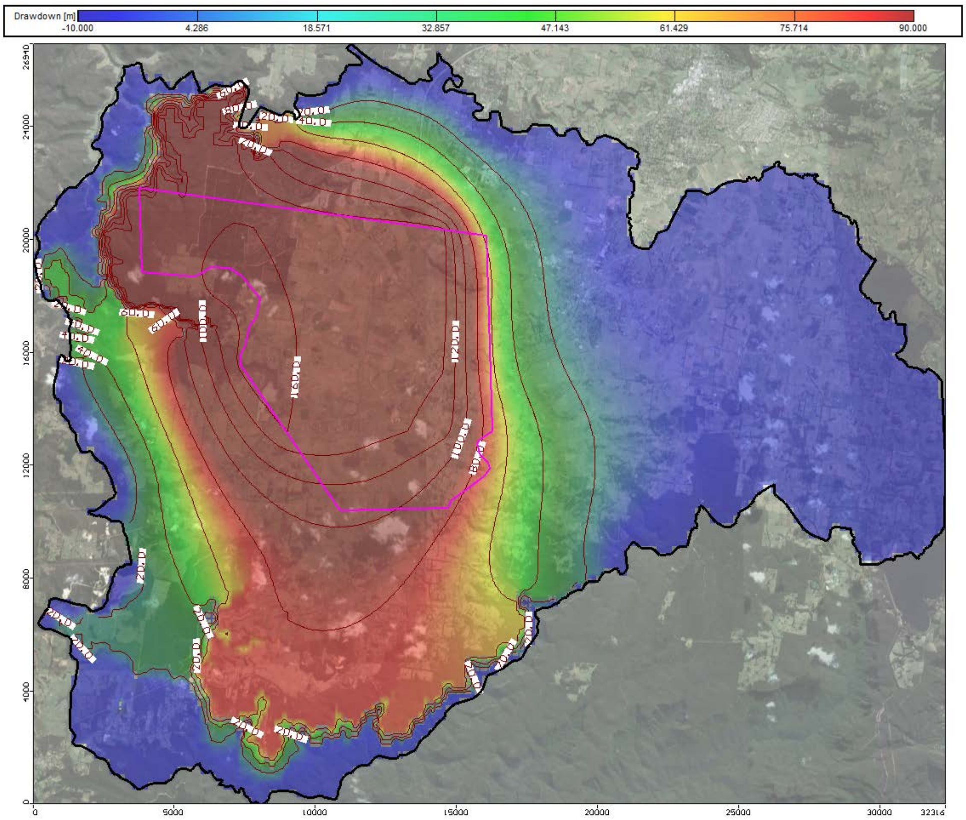

Figure 56 – Drawdown in Layer 4, lower values with fracturing, Instant 45km^2 mine, 10 years elapsed

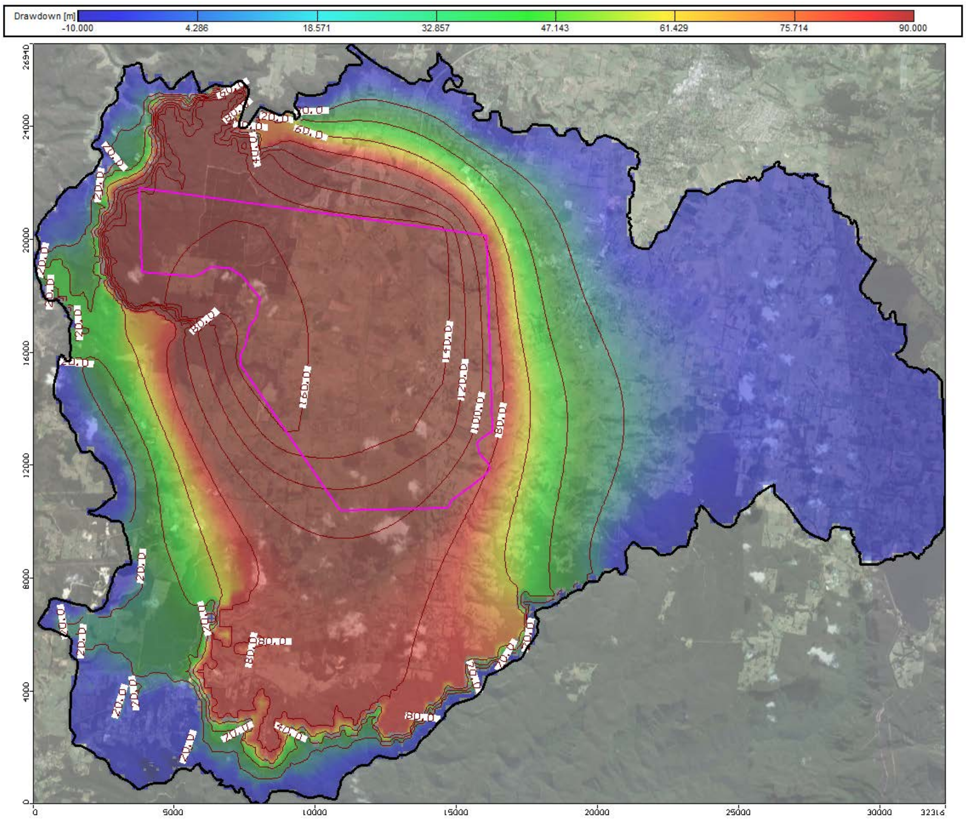

Figure 57 – Drawdown in Layer 4, lower values with fracturing, Instant 45km^2 mine, 40 years elapsed

A.2 REFINED MODEL

A.2.1 Selection of recharge - pre-mining conditions

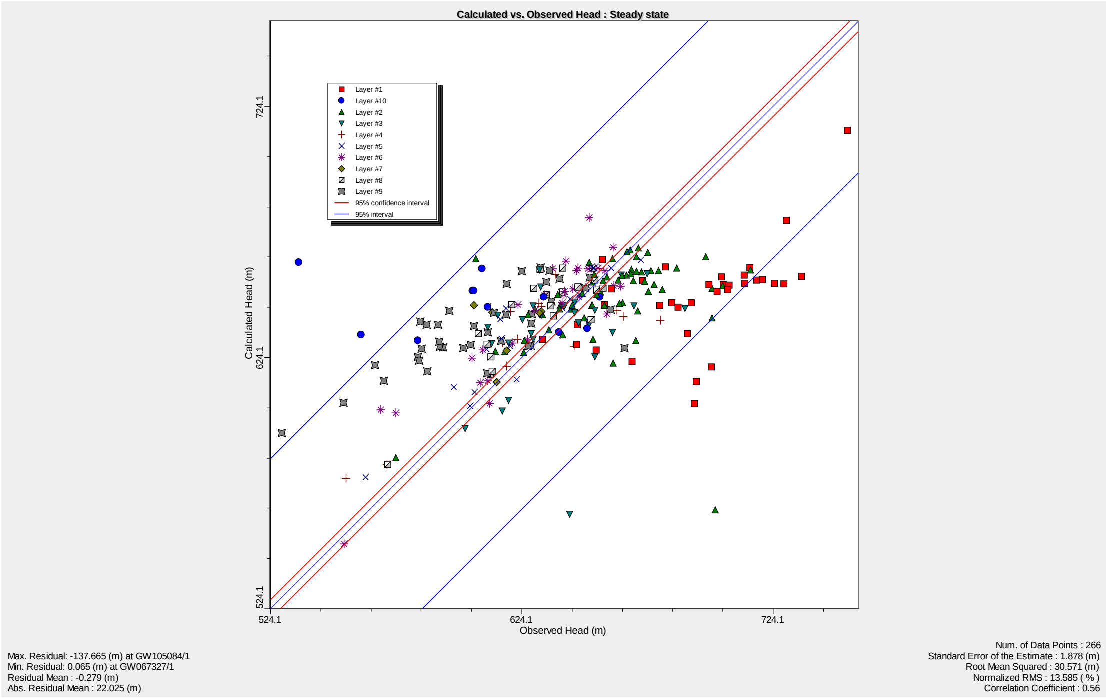

Figure 58 – Calibration of pre-mine values, standard values, refined grid

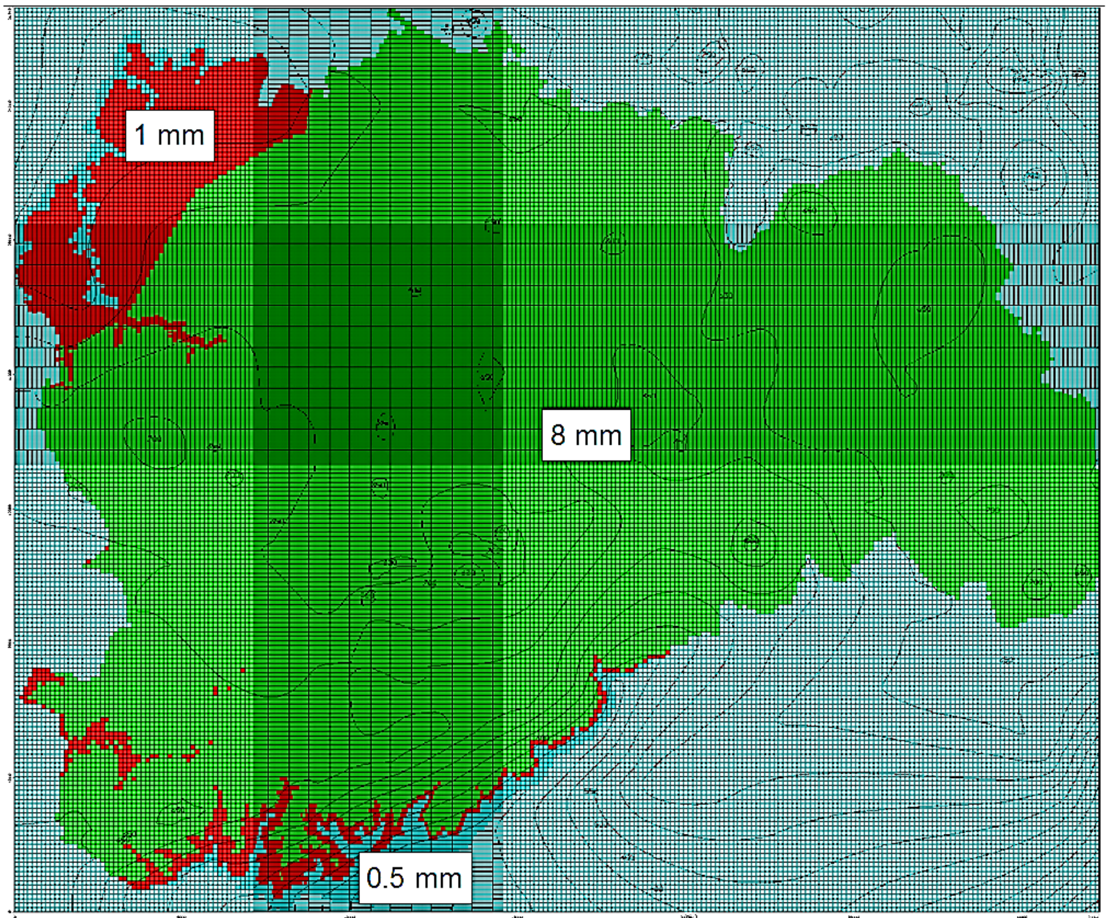

Figure 59 – Recharge map, standard values, refined grid

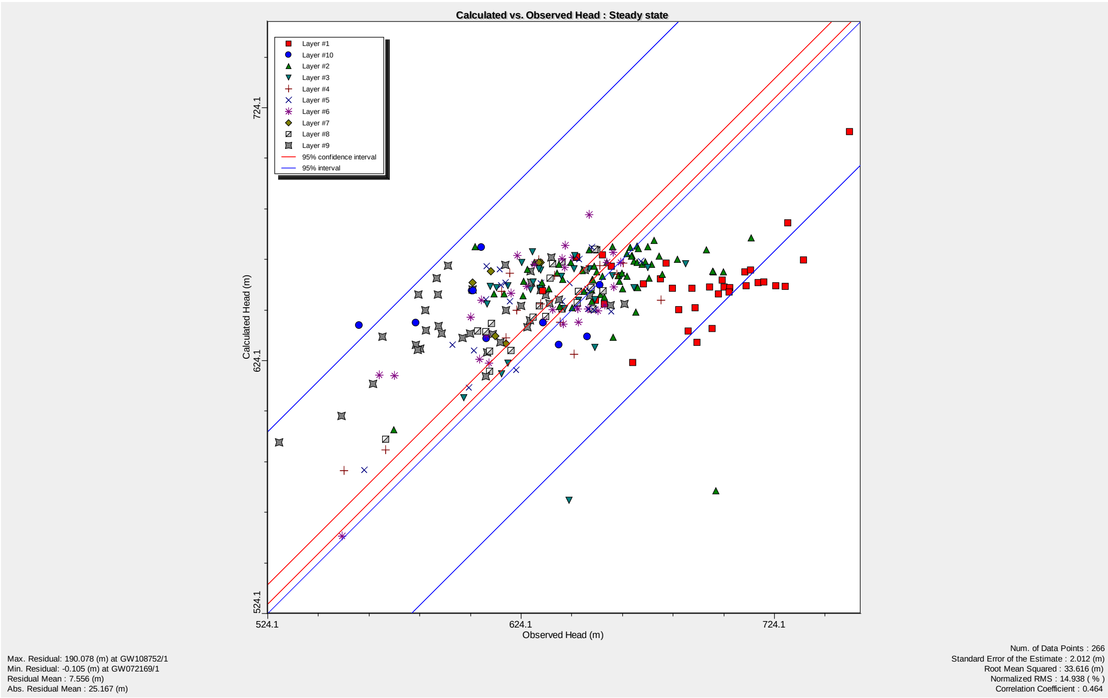

Figure 60 – Calibration of pre-mine values, standard values, refined model (refined grid and revised boundary conditions)

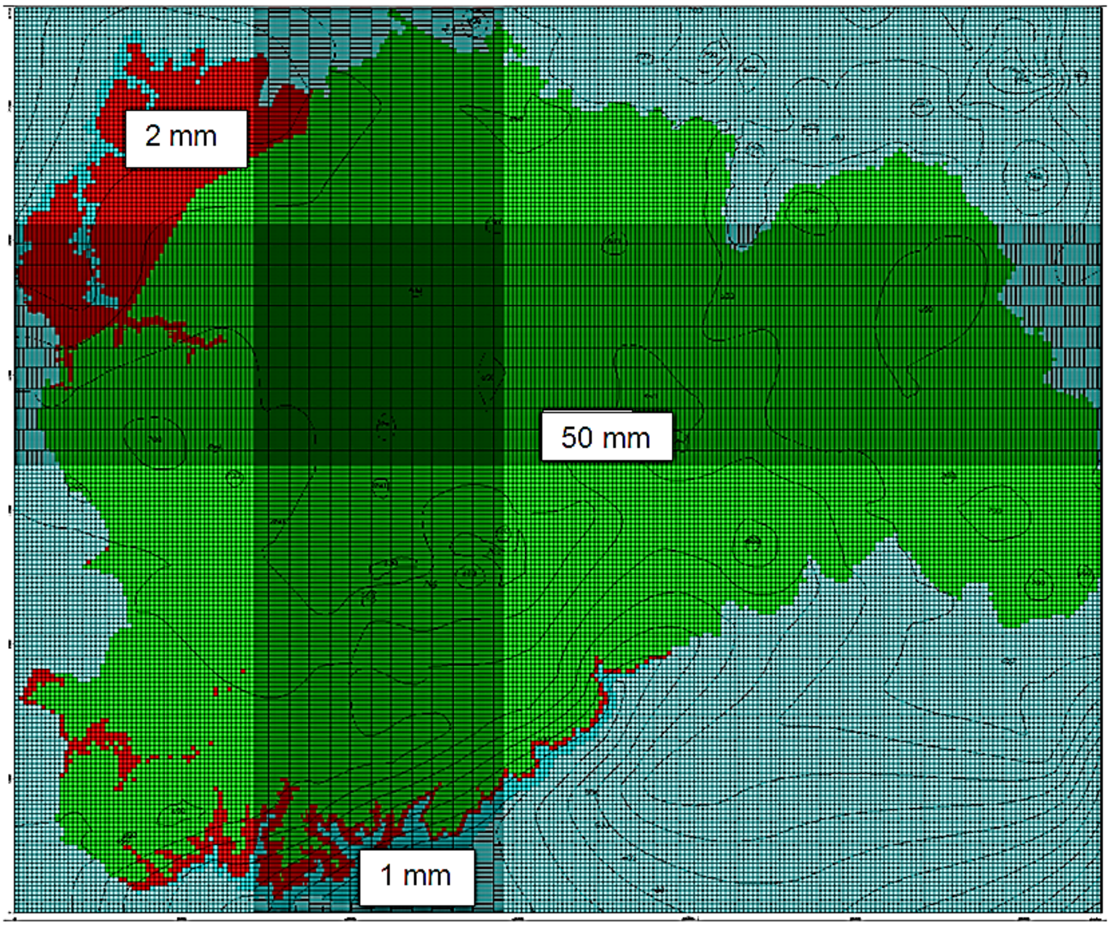

Figure 61 – Recharge map, standard values, refined model (refined grid and revised boundary conditions)

A.2.2 Drawdown Maps

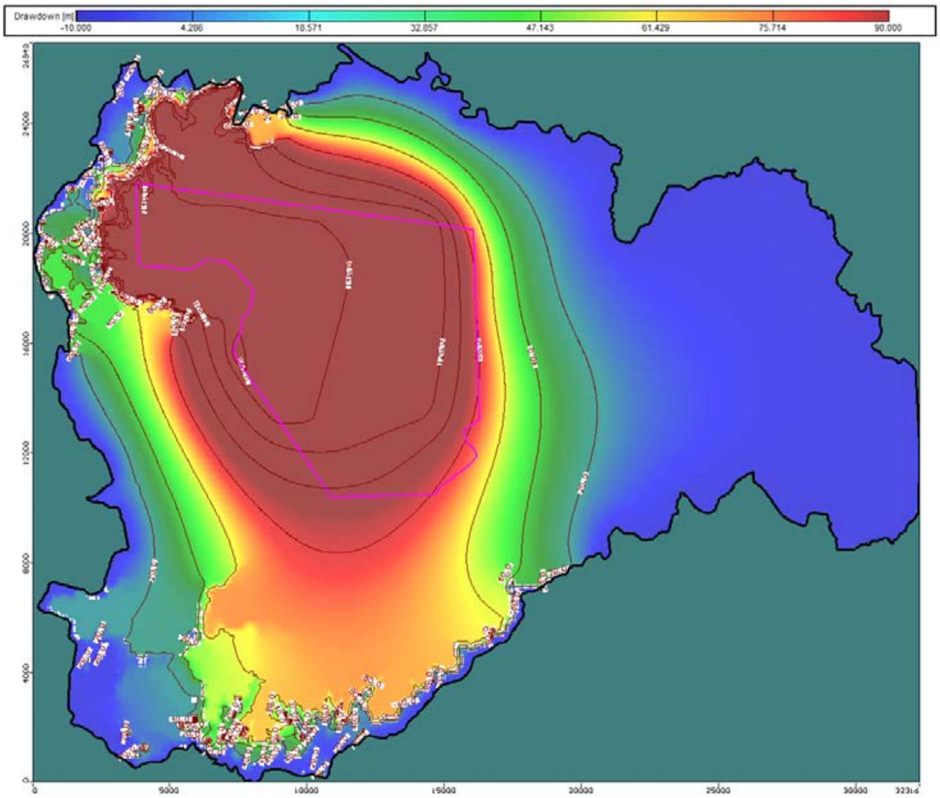

Figure 62 – Refined grid only, drawdown in Layer 6, standard values with fracturing, Instant 45km^2 mine, 10 years elapsed

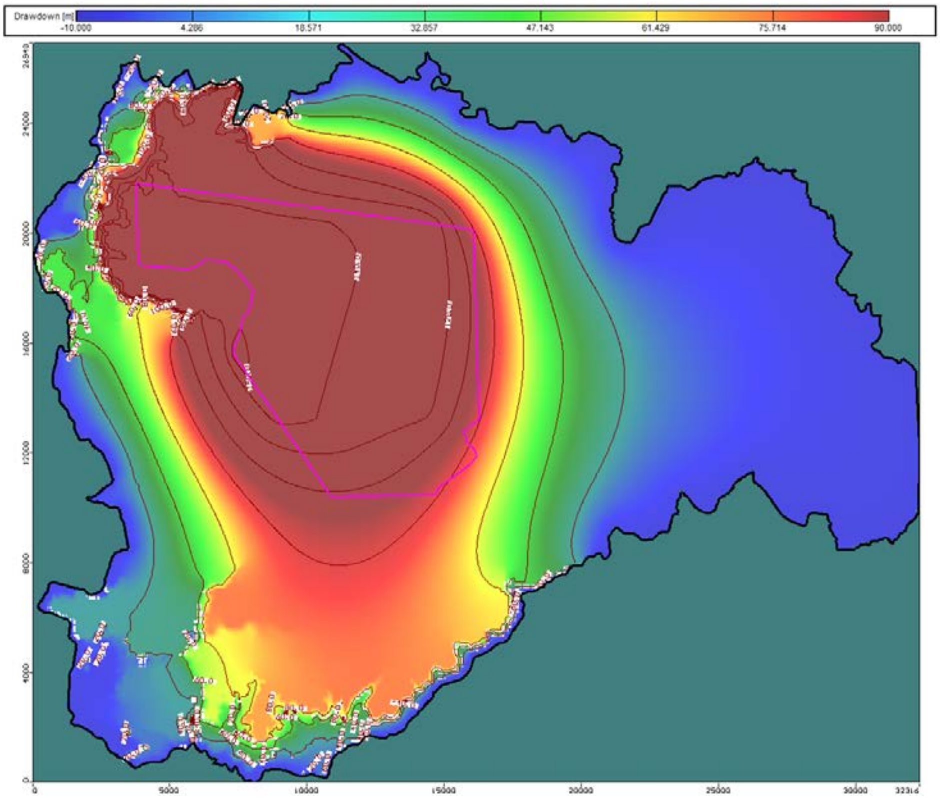

Figure 63 – Refined grid only, drawdown in Layer 6, standard values with fracturing, Instant 45km^2 mine, 40 years elapsed

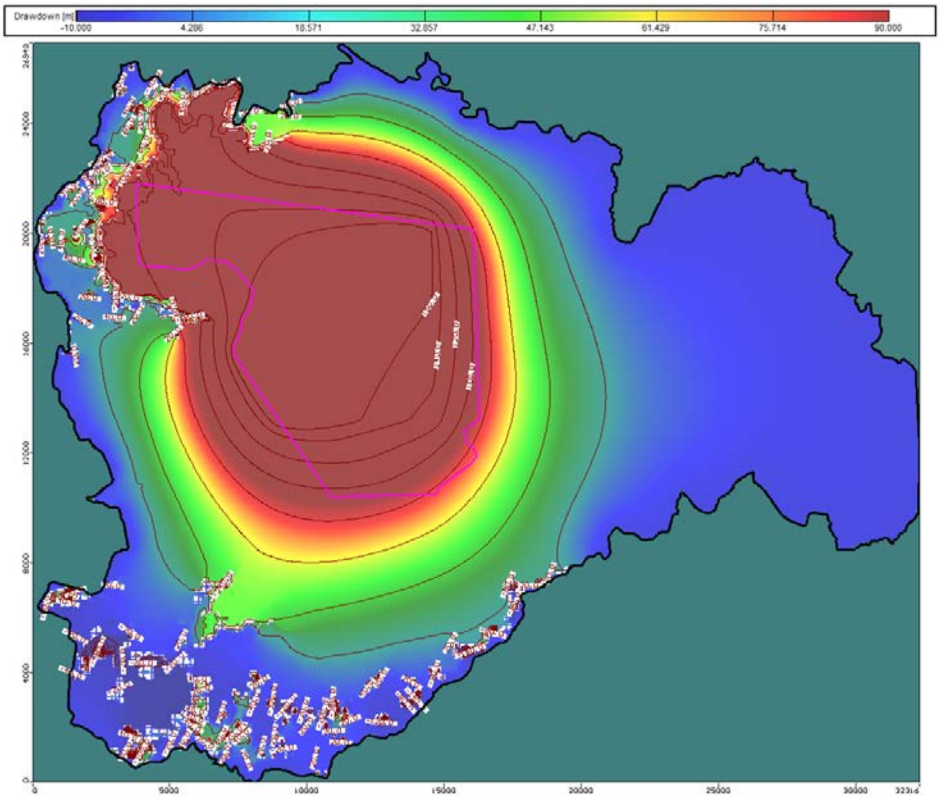

Figure 64 – Refined model, drawdown in Layer 6, standard values with fracturing, Instant 45km² mine, 10 years elapsed

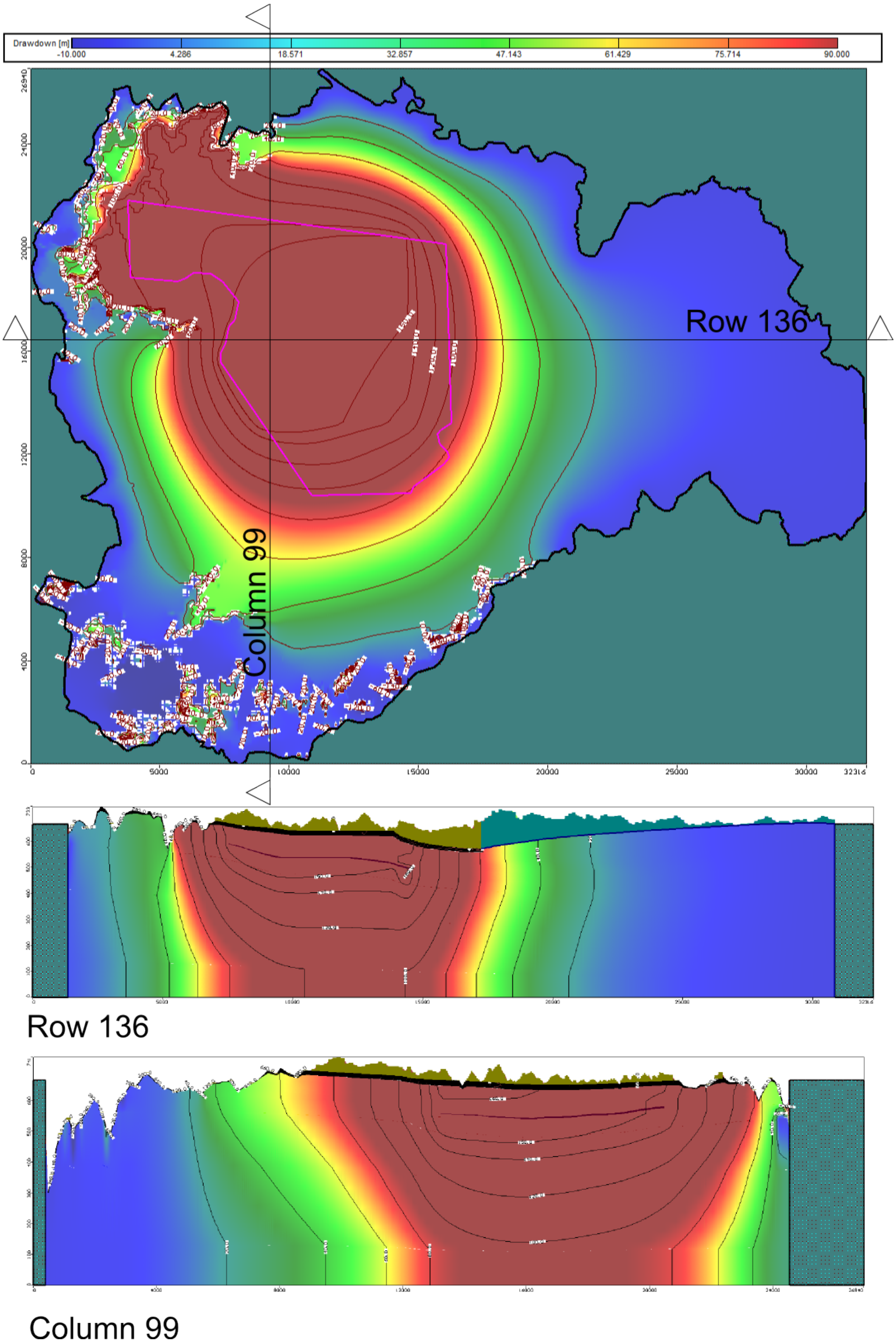

Figure 65 – Refined model, drawdown in Layer 6, standard values with fracturing, Instant 45km² mine, 40 years elapsed

APPENDIX B

SELECTED MODEL MASS BALANCE CALCULATIONS

Table 8 – Mass Balance for Pre-mining conditions (steady state)

Rates for Time Step Report [m^3/day]	Original Model			Refined Grid	Refined Model
	High	Standard	Low	Standard	Standard
IN:					
Storage	0	0	0	0	0
Constant Head	35881	23083.37	6996.044	26088.3984	39493.3594
Wells	0	0	0	0	0
Drains	0	0	0	0	0
MNW	0	0	0	0	0
LAKE SEEPAGE	0	0	0	0	0
Recharge	26625.11	13173.68	6253.294	10721.7109	39296.7305
ET	0	0	0	0	0
River Leakage	0	0	0	0	0
Stream Leakage	0	0	0	0	0
General-Head	0	0	0	0	0
Total IN	62506.11	36257.05	13249.34	36810.1094	78790.0938
OUT:					
Storage	0	0	0	0	0
Constant Head	62506.22	36256.56	13249.23	36810.1055	68873.5703
Wells	0	0	0	0	0
Drains	0	0	0	0	9686.9209
MNW	0	0	0	0	0
LAKE SEEPAGE	0	0	0	0	0
Recharge	0	0	0	0	0
ET	0	0	0	0	0
River Leakage	0	0	0	0	0
Stream Leakage	0	0	0	0	0
General-Head	0	0	0	0	229.6101
Total OUT	62506.22	36256.56	13249.23	36810.1055	78790.1016
IN - OUT	-0.1094	0.4883	0.1094	0.0039062	-0.0078125
Discrepancy	0%	0%	0%	0%	0%

Table 9 – Mass Balance, Selected 4.5 km^2 mine scenarios

Cumulative Volumes Report [m^3]	Original Model Standard Values, Rate `R'=1.2		Original Model Standard Values, Instant with fracturing	
	Day 1	5 years	Day 1	5 years
IN:				
Storage	4315.8896	16321787	317953.7812	21706956
Constant Head	23083.1777	46837344	23084.8906	46960152
Wells	0	0	0	0
Drains	0	0	0	0
MNW	0	0	0	0
LAKE SEEPAGE	0	0	0	0
Recharge	13173.6826	24616916	13173.6826	23308504
ET	0	0	0	0
River Leakage	0	0	0	0
Stream Leakage	0	0	0	0
General-Head	0	0	0	0
Total IN	40572.75	87776048	354212.375	91975608
OUT:				
Storage	171.1024	105503.7969	155.0763	686545.1875
Constant Head	36256.4766	62101468	36254.6875	55881432
Wells	0	0	0	0
Drains	4271.4883	25611260	317928.0938	35408088
MNW	0	0	0	0
LAKE SEEPAGE	0	0	0	0
Recharge	0	0	0	0
ET	0	0	0	0
River Leakage	0	0	0	0
Stream Leakage	0	0	0	0
General-Head	0	0	0	0
Total OUT	40699.0664	87818232	354337.875	91976064
IN - OUT	-126.3164	-42184	-125.5	-456
Discrepancy	-0.31%	-0.05%	-0.04%	0%

Table 10– Mass Balance, Selected 45 km^2 mine scenarios

Cumulative Volumes Report [m^3]	Original Model									Refined Grid			Refined Model		
	High			Standard			Low			Standard			Standard		
	Day 1	10 Years	40 Years	Day 1	10 Years	40 Years	Day 1	10 Years	40 Years	Day 1	10 Years	40 Years	Day 1	10 Years	40 Years
IN:															
Storage	6642510	1.22E+08	1.71E+08	4120558	90570376	1.48E+08	16348564	79147632	1.44E+08	482873.3438	1.07E+08	1.58E+08	5280848	1.87E+08	2.42E+08
Constant Head	36201.68	2.31E+08	1.17E+09	422095.2	1.43E+08	7E+08	113379.8	41370344	2.02E+08	491.1352	1.62E+08	7.16E+08	184778.1	8.07E+08	3.25E+09
Wells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drains	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MNW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAKE SEEPAGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recharge	26625.11	90044024	4.04E+08	203421	45774940	2E+08	97028.45	21833894	95482656	201.842	38693508	1.57E+08	65552.11	2.45E+08	9.54E+08
ET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
River Leakage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stream Leakage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General-Head	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total IN	6705337	4.43E+08	1.74E+09	4746075	2.79E+08	1.05E+09	16558972	1.42E+08	4.41E+08	483566.3125	3.07E+08	1.03E+09	5531178	1.24E+09	4.44E+09
OUT:															
Storage	31.0394	332823.3	402209.7	8384.281	246965.9	371236.7	74.3276	159694.6	524708.4	546.6006	4082301	4980098	10541.6	8204242	10007354
Constant Head	61813.56	1.42E+08	6.06E+08	503111.7	87411008	3.65E+08	196310.9	32200142	1.33E+08	693.1396	95539032	3.74E+08	55562.75	1.45E+08	5.46E+08
Wells	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drains	6643412	3.01E+08	1.13E+09	4234474	1.92E+08	6.83E+08	16362272	1.1E+08	3.07E+08	482354.8438	2.07E+08	6.52E+08	5293444	4.43E+08	1.39E+09
MNW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAKE SEEPAGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Recharge	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ET	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
River Leakage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stream Leakage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
General-Head	0	0	0	0	0	0	0	0	0	0	0	0	171971.9	6.42E+08	2.5E+09
Total OUT	6705257	4.43E+08	1.74E+09	4745970	2.79E+08	1.05E+09	16558657	1.42E+08	4.41E+08	483594.5938	3.07E+08	1.03E+09	5531521	1.24E+09	4.44E+09
IN - OUT	80	1024	-256	104.5	-1024	-2304	315	-208	-992	-28.2812	-64	2304	-343	1280	3584
Discrepancy	0%	0%	0%	0%	0%	0%	0%	0%	0%	-0.01%	0%	0%	-0.01%	0%	0%