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COAL FREE SOUTHERN HIGHLAND INC.

GROUNDWATER MODELLING OF THE HUME COAL PROJECT

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EXECUTIVE SUMMARY

In 2013, Pells Consulting undertook a 3D numerical groundwater study of the (then) Hume Coal Prospect. The numerical modelling study assessed the likely impacts on regional groundwater resources from the prospective mine using a parametric approach, because specific details of the mine plan were at that time unknown. From this parametric analysis, large mine inflows and extensive drawdown was expected from the mining operations.

In March 2017, Hume Coal released a 3D numerical model study to represent impacts to groundwater from the proposed mine. Inflows to the mine and the extent of drawdown presented by Hume Coal were substantially smaller than predicted by the numerical modelling of Pells Consulting in 2013. Hume Coal advised that impacts to groundwater are minimised due to the first-workings mine plan and various “mitigation measures” that are proposed.

In this present report the Pells Consulting 2013 model was adjusted to represent the current Hume Coal first workings mine plan, including the use of bulkheads to close panels after completion. The drawdown and inflows from this proposed plan do not differ significantly from those for the previously modelled mining plan (Section 4). Hence, impacts predicted in this present report differ greatly from those presented by Hume Coal.

The Model in the EIS predicts mine inflow of 6ML per day for the mine footprint and mining process Hume proposes. The revised models in this report suggest that the inflow is likely to be about ten times this value. The sensitivity studies presented herein quantify the degree to which assumptions made in the EIS modelling lead to unreasonable computed inflow quantities.

The Model in the EIS predicts a maximum drawdown of the piezometric (groundwater) surface of up to 80m above the workings, with drawdown of greater than 2m extending a short distance beyond the mine footprint. In contrast the revised Pell 2017 models presented herein indicate drawdown of about 120m above the workings, with drawdown of 10m extending 6km to 7km beyond the mine. Again the sensitivity studies presented herein explain why there are such substantial differences, and why the predictions in the EIS are unreasonable.

The reasons for discrepancy between the Pells Consulting predictions and those by Hume Coal are examined in this report. A comparison of the models, presented in Section 2, identified the following important features of the Hume Coal model:

1. Hume Coal adopted significantly lower hydraulic conductivity values for the coal measures and for formations just above the coal workings.
2. Hume Coal adopted very low aquifer storage values
3. Hume Coal adopted very low values of ‘drain conductance’ when representing the mine in the model
4. Hydraulic Model layering adopted by Hume Coal places emphasis of the presence and continuity of a thin claystone seam above proposed workings.

The effects of these four features were tested using conceptual models, presented in Section 3 of this report. These tests confirmed that it is these four features that account for the markedly lower inflows and drawdowns presented by Hume Coal.

Insufficient justification has been found for these features:

1. Hydraulic conductivity values adopted by Hume Coal do not accord with measured values presented by Hume Coal. There is also no representation of a known productive aquifer layer within the formation.
2. Storage values adopted by Hume Coal are shown to be mathematically untenable.
3. Drain conductance values adopted by Hume Coal effectively control flows into the mine, as if it were lined with an thick, compacted impermeable clay
4. It is questioned whether sufficient evidence exists to support the representation of the claystone (interburden) adopted by Hume Coal.

Insufficient sensitivity testing was presented by Hume Coal to examine these features, notwithstanding that there is high uncertainty in these parameters, and that the parameters effectively control model outcomes.
To ensure that differing predictions were not due to errors or ill-formed modelling problems, further tests and refinement of the Pells Consulting 2013 model were made, as presented in Section 5. These included:

1. The 2013 model was updated to run in MODFLOW-SURFACT (Section 5). (compared to the previous MODFLOW 2000 solution).
2. The 2013 model was updated with various representation of model layer types, 'pseudo-soil' and unsaturated flow representations.

The wide range of parametric studies presented in this present report are considered to provide sensitivity studies that are noted to be absent in the Hume Coal study.

In summary, comparison of the numerical predictions by Pells Consulting 2013 and Hume Coal 2017 found that the proposed mine plan, and mitigation measures, do not achieve significant reduction in mine inflows and / or drawdown as compared to traditional mining techniques. Differences in predicted inflow and drawdown presented by Hume Coal arise due to parameters selected in modelling, and not to an effectiveness of the proposed mine plan.

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1 INTRODUCTION

In 2013, Pells Consulting undertook a 3D numerical groundwater study of the (then) Hume Coal Prospect. The methodology and findings were presented in Report P029.R1. At the time of that study, the specific details of the mine layout were unknown. The numerical modelling study assessed the likely impacts on regional groundwater resources from the prospective mine using a parametric approach. From this parametric analysis, we expected mine inflows of between 7 to 24ML/d for a small mine of 4.5km^2 extent, and of between 15 to 70ML/d for a larger mine of 45km^2 extent. Drawdown from the mine was predicted to be extensive – over 100m of drawdown above the mine, and drawdown of over 20m extending for 10's of kilometres from the mining operations. Two examples showing predicted drawdown from the 2013 modelling are shown in Figure 1.1 and Figure 1.2 below.

The large impacts were expected to arise from the relatively shallow depth of mining, and the nature of relatively high-yielding Hawkesbury Sandstone geological formations above the mined seam. Impacts were assessed for a range of possible mine plans and techniques. For example, the modelling included scenarios where no goafing/fracturing was incurred. In that report, we concluded:

> 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 (Pells Consulting, 2013, pg 48).

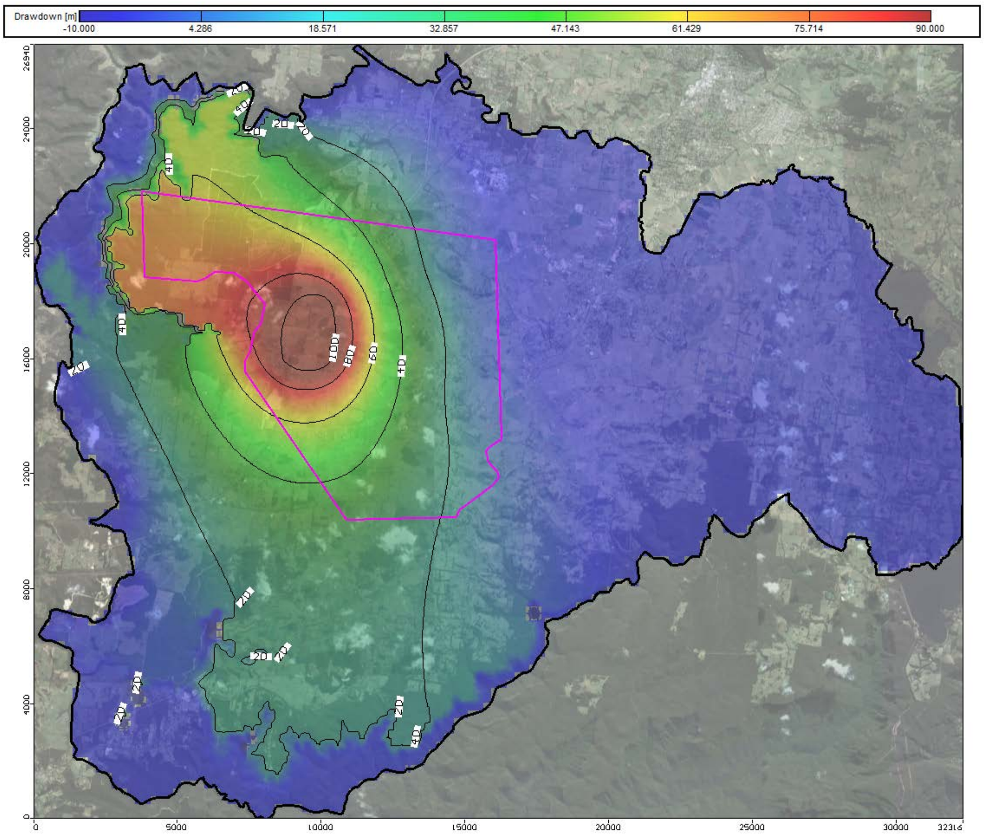


Figure 1.1 – Results from 2013 modelling, extent of drawdown after 5 years for a small 4.5km^2 mine.

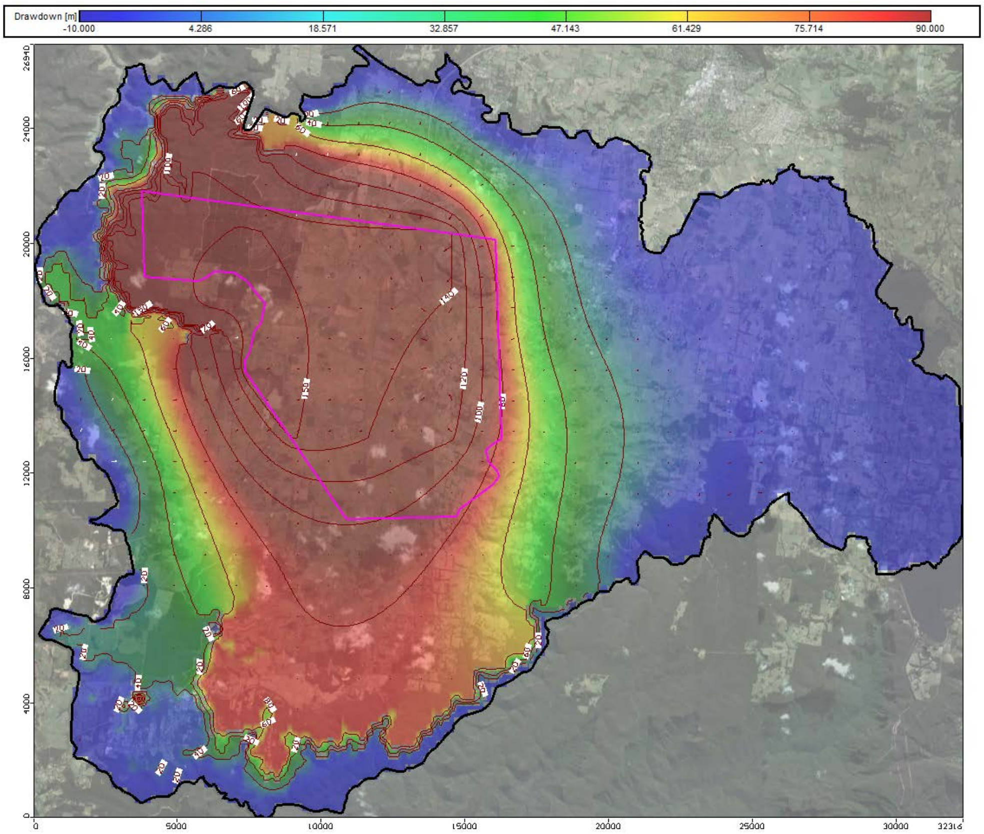


Figure 1.2 – Results from 2013 modelling, extent of drawdown after 10 years for a 45km^2 mine.

In March 2017, Hume Coal released an EIS for the Hume Coal Project (EIS), in which further details of the mine plan were provided. Hume Coal proposes to adopt a mine method comprising first workings in a 'pine feather' arrangement, and a methodology for 'plugging' of panels subsequent to extraction. A 3D numerical model was presented in the EIS, assembled to represent impacts to groundwater from this proposed mining approach. Predicted mine inflows presented in the EIS are reproduced as Figure 1.3 below. Predicted drawdown, after 17 years elapsed, are presented in Figure 1.4 (with Pells Consulting 2013 modelling boundary superimposed, to allow comparison to Figure 1.1 and Figure 1.2 above).

Inflows to the mine and the extent of drawdown presented in the EIS were both substantially smaller than predicted by the numerical modelling by Pells Consulting in 2013. For example, inflows are predicted in the EIS to peak at around 6ML/d, at a point where the mine excavation footprint is approximately 35km^2. This is less than the most conservative prediction of inflows by Pells Consulting for 4.5km^2 mine. The inflow predicted in the EIS for the mine is in the order of 40 to 70 litres per second - this is comparable to the yield from two to three existing bores[1] installed in the mine lease (Hydroilex, 2012).

Drawdown predicted in the EIS has a maximum extent of 30m, for a very limited zone around the mine, and drawdown greater than 2m extending little past the mine excavation footprint.

[1] The Rosedale bore for example, showed three horizons with yields of >20L/sec, one of which was tested to yield >40L/sec.

The reasons for discrepancy between the Pells Consulting 2013 predictions and those of the EIS are examined in this report.

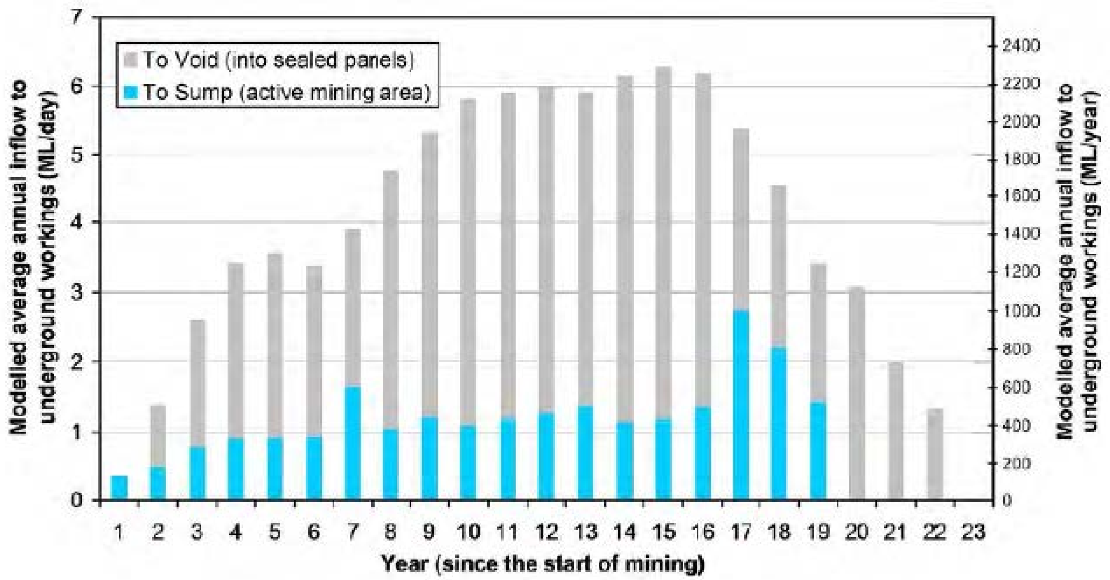


Figure 1.3 – Predicted mine inflows, Hume Coal Project EIS 2017.

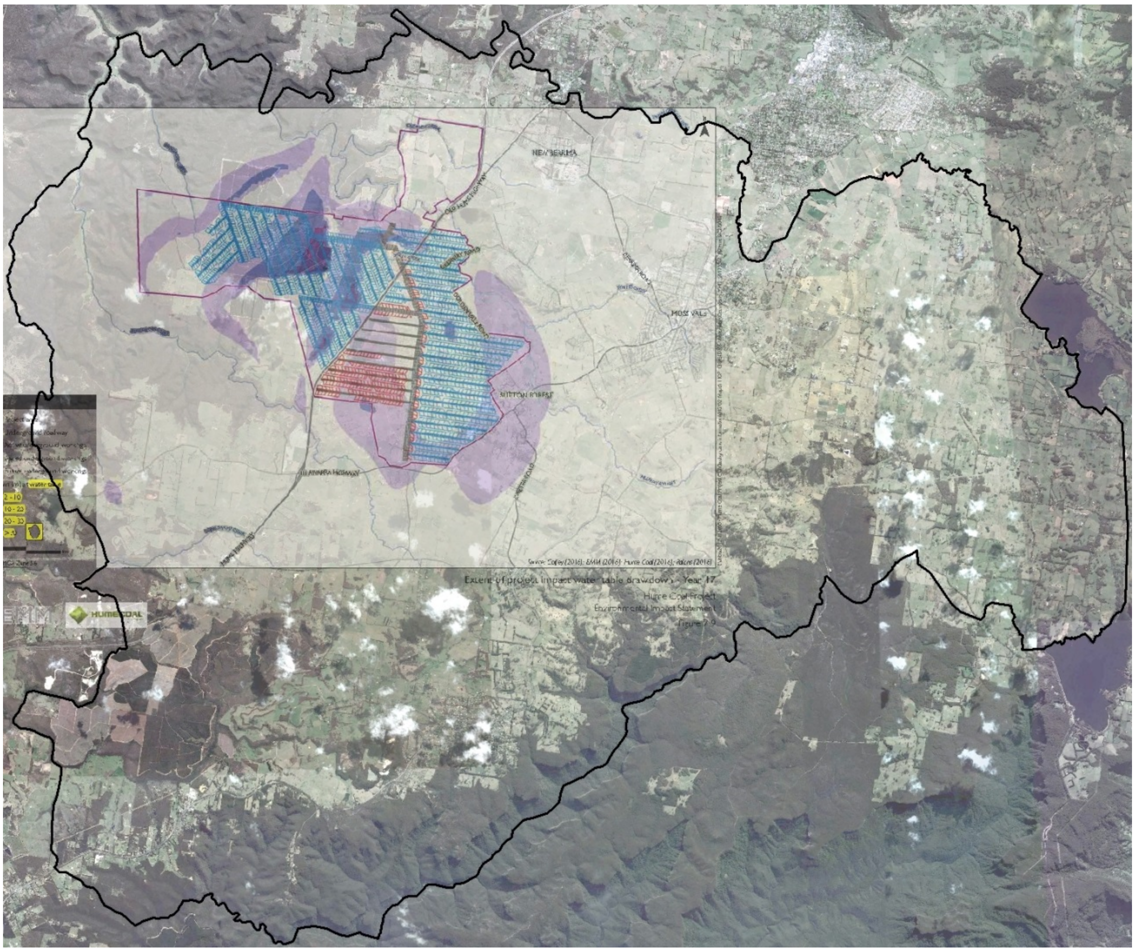


Figure 1.4 – Predicted mine drawdown, Hume Coal Project EIS 2017 (Pells Consulting 2013 modelling extents superimposed for reference)

2 COMPARISON OF GROUNDWATER MODELS

2.1 Model domain

Pells Consulting (2013) used the numerical code ‘Modflow’ for modelling, within the Visual Modflow interface, and employed the Modflow 2000 engine. The numerical model presented in the EIS also used the Modflow groundwater model within the Visual Modflow interface. Modflow-Surfact (version 3) was used as the model engine for the EIS. Modflow-Surfact has the capability to represent unsaturated flow and the user is required to selected the simulation type as either: pseudo-soil function (allowing unlimited ‘negative’ pore pressures), or; an unsaturated flow function such as van Genuchten or Brooks-Corey. Pseudo-soil simulations commonly struggle from non-convergence. Unsaturated flow simulations (van Genuchten or Brooks Corey) require input of a range of parameters, which have not been measured for rock formations within the Hume lease. The EIS does not state which simulation type was used, and if unsaturated soil modelling was indeed used, van Genuchten or Brooks-Corey parameters are not reported in the EIS.

Pells Consulting (2013) adopted a structured finite element grid, with dimensions 45m by 45m over the mine, and up to 135m by 135m elsewhere. The grid plan is presented in Pells Consulting 2013. The EIS numerical groundwater model is reported to also adopt structured finite difference grid, with slightly coarser dimensions of 50 by 50m over the mine and up to 200 by 200m elsewhere. A plan showing the grid was not provided in the EIS.

The model domains (extents) for the numerical models by Pells Consulting 2013 and the EIS are overlain in Figure 2.1. The EIS model boundaries tend to favour perceived ‘groundwater divide’ (no-flow) boundary conditions, and extends further north, including the Berrima Colliery.

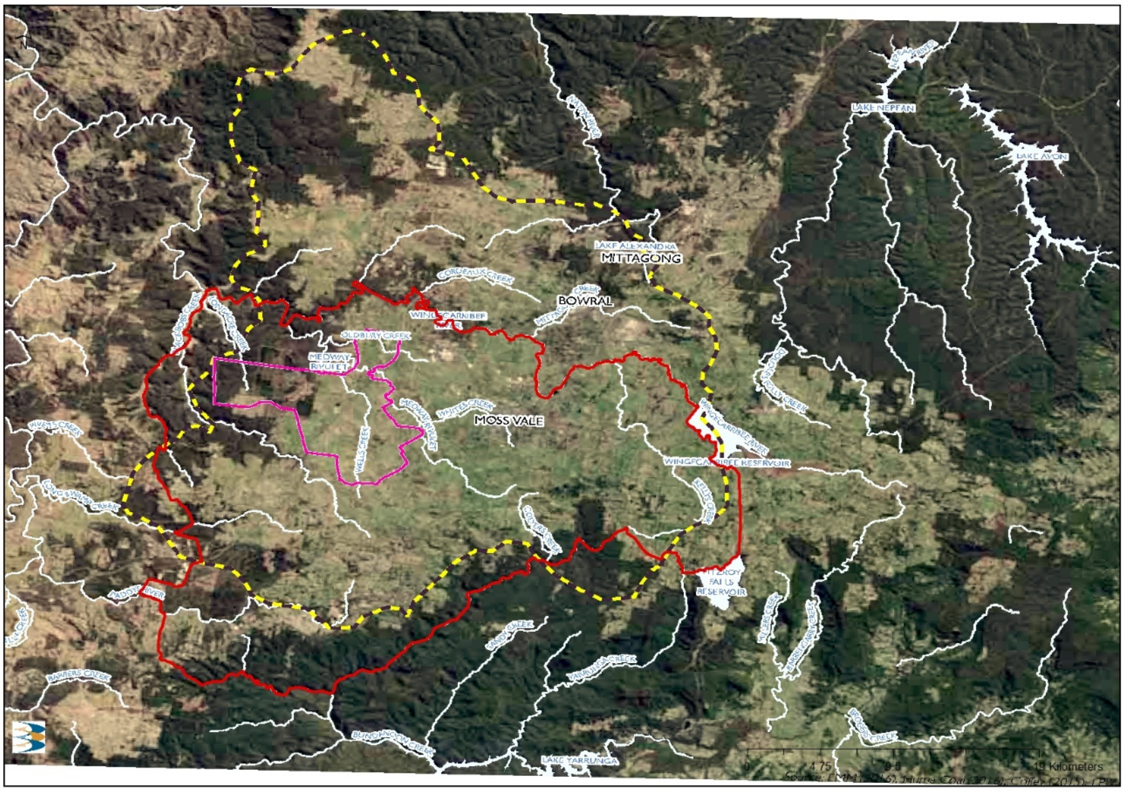


Figure 2.1 – Comparison of Modelling Domains.

2.2 Geology and model layering

The stratigraphic sequence is described in the EIS (Vol 4B, Appendix H, Page 21) as:

- Robertson Basalt (Tertiary basalt, dolerite and volcanic breccia).
- Wianamatta Group (Bringelly Shale, Minchinbury Sandstone, and Ashfield Shale) and Mittagong Formation (Triassic).
- Hawkesbury Sandstone (Triassic).
- Narrabeen Group (present only in parts) (Triassic).
- Illawarra Coal Measures (Permian).
- Shoalhaven Group (Permian)

Minor alluvium is present along the upstream reach of the Wingecarribee River.

The numerical model presented by Pells Consulting, 2013, represented: the Wianamatta Group; Hawkesbury Sandstone; Illawarra Coal Measures; the Shoalhaven Group, and a lower basal (undifferentiated) formation. The superficial Basalt formation was not included as it is of limited extent and was not considered to impact on mining effects in the dominant Hawkesbury Sandstone. The Narrabeen Group was not included because it was not present in over 90% of the borehole data available. There was also insufficient data to indicate that it had properties of significant difference to the adjacent Hawkesbury Sandstone. The alluvial formations were not included. A summary of the representation of geological formations in the model is presented in Table 1 below. Data sources used to develop model layering are also shown. It was noted that contours had to be created without the benefit of exploration borehole data from Hume Coal, although benefited from previous detailed explorations presented by Austen and Butta.

The numerical model presented in the EIS featured a similar representation to the Pells model for the Wianamatta, Hawkesbury and Shoalhaven formations. The Basalt formation was examined with a separate sub-model and the alluvium was similarly excluded. The EIS model included representation of the Narrabeen Group, and assigned more complex layering to the Illawarra Coal measures, particularly above the mined seam.

A comparison between the representation of the Pells Consulting 2013 and the EIS model is presented in Figure 2.2.

It is assumed that representation of geological sequences in the EIS model incorporated exploration borehole data from Hume Coal, although the basis for geological representation in the EIS has not been reviewed in detail at this point.

Isopachs of the Narrabeen formation presented in the EIS are reproduced in Figure 2.3. This mapping shows the formation to taper from 1m thickness north of the mine, to zero metres thickness over the centre of the mine, to being absent over the south-west of the mine. Despite the slightness of its presence, it is stated that “the interburden forms an important sequence with respect to relaxation above the seam following mining” (Appendix H, page 23). The EIS indicates that this ‘interburden’ was represented throughout the modelling domain, tapering to a minimum thickness of 0.1m.

A cross section through the EIS numerical model is presented in Figure 3.1 of Appendix H of the EIS. For comparison, a cross-section of the Pells Consulting 2013 model, at approximately the same location was also prepared. The two are presented, overlayed, in Figure 2.4 and Figure 2.5.

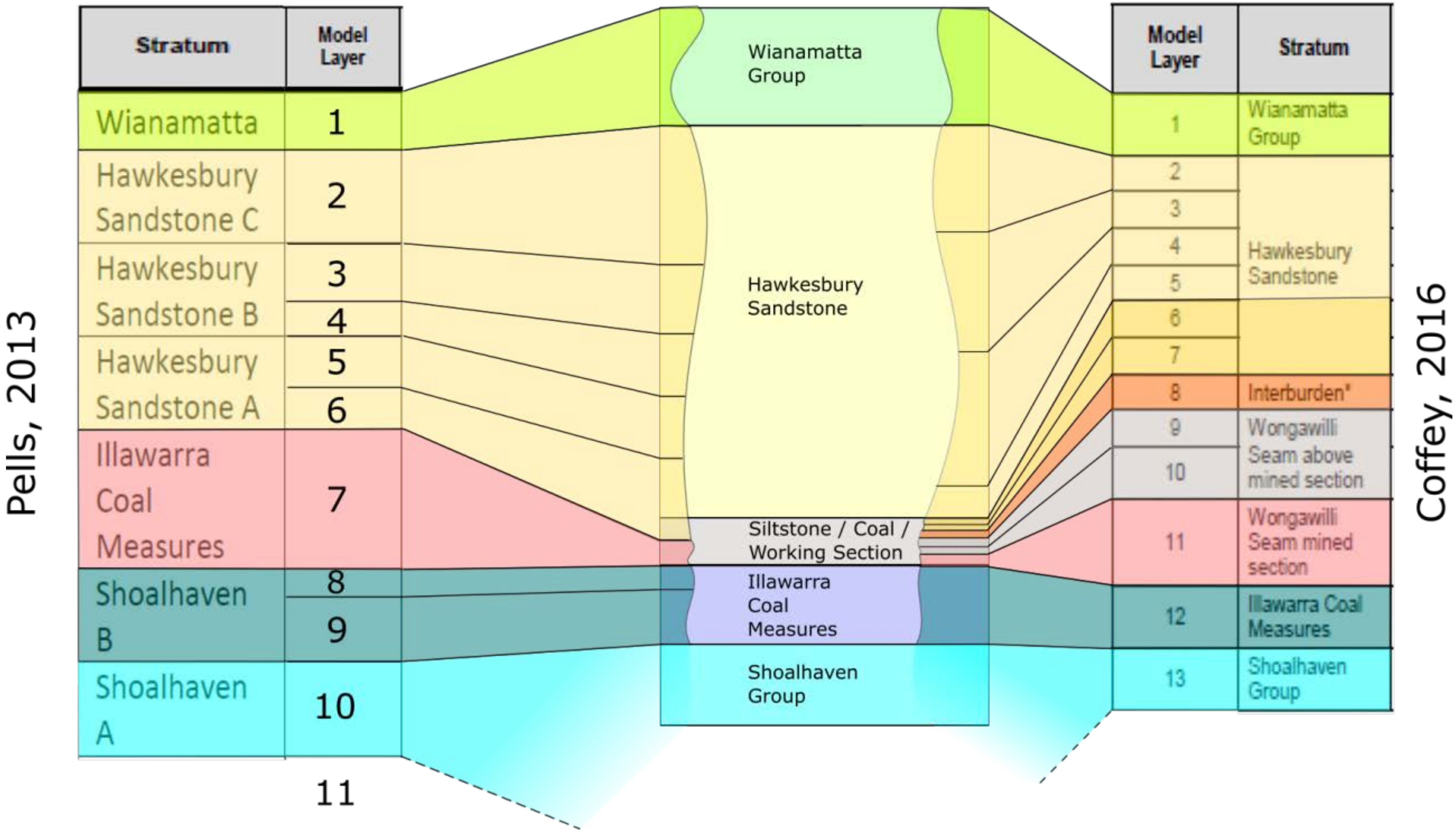


Figure 2.2 – Comparison of geological representation in models.

Table 1 – Model layers and geology data sources, Pells Consulting, 2013

Layer	Formation	Thickness	Depth to base in Hume Lease	Horizon	Data sources
				H1	Digital elevation model
1	Wianamatta	Varies	29		
				H2	Contoured from borehole data
2	Hawkesbury Sandstone C	1/3 of HSS	64		
				H3	H2 - 1/3 (H2-H7)
3	Hawkesbury Sandstone B	7/15 of HSS	80		
				H4	H3 - 7/15 (H2-H7)
4	Hawkesbury Sandstone B	7/15 of HSS	97		
				H5	H4 - 7/15 (H2-H7)
5	Hawkesbury Sandstone A	7/15 of HSS	113		
				H6	H7 + 1/5 (H2-H7)
6	Hawkesbury Sandstone A	1/5 of HSS	134		
				H7	Contours from Austen and Butta, supplemented by borehole data
7	Coal measures	Varies	140		
				H8	H7 minus isopachs from Austen and Butta
8	Shoalhaven B	5m	145		
				H9	H8 minus 5m
9	Shoalhaven B	15m	160		
				H10	H8 minus 20m
10	Shoalhaven A	80m	240		
				H11	H8 minus 100m
11	Base 1	Varies	437		
				H12	(H11 + H13)/2
12	Base 2	Varies	633		
				H13	0m AHD

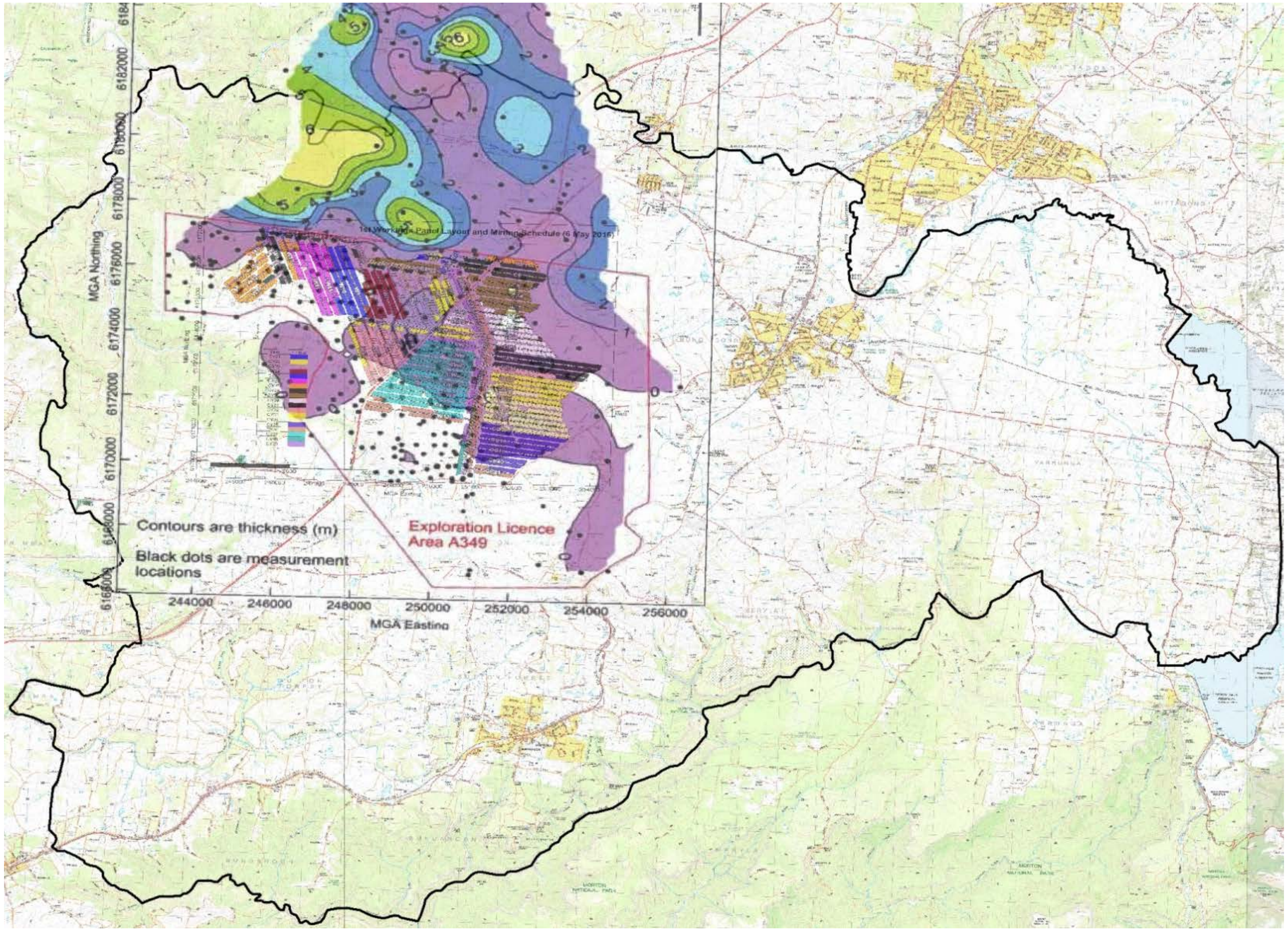


Figure 2.3 – Isopachs of 'interburden' presented in the EIS.

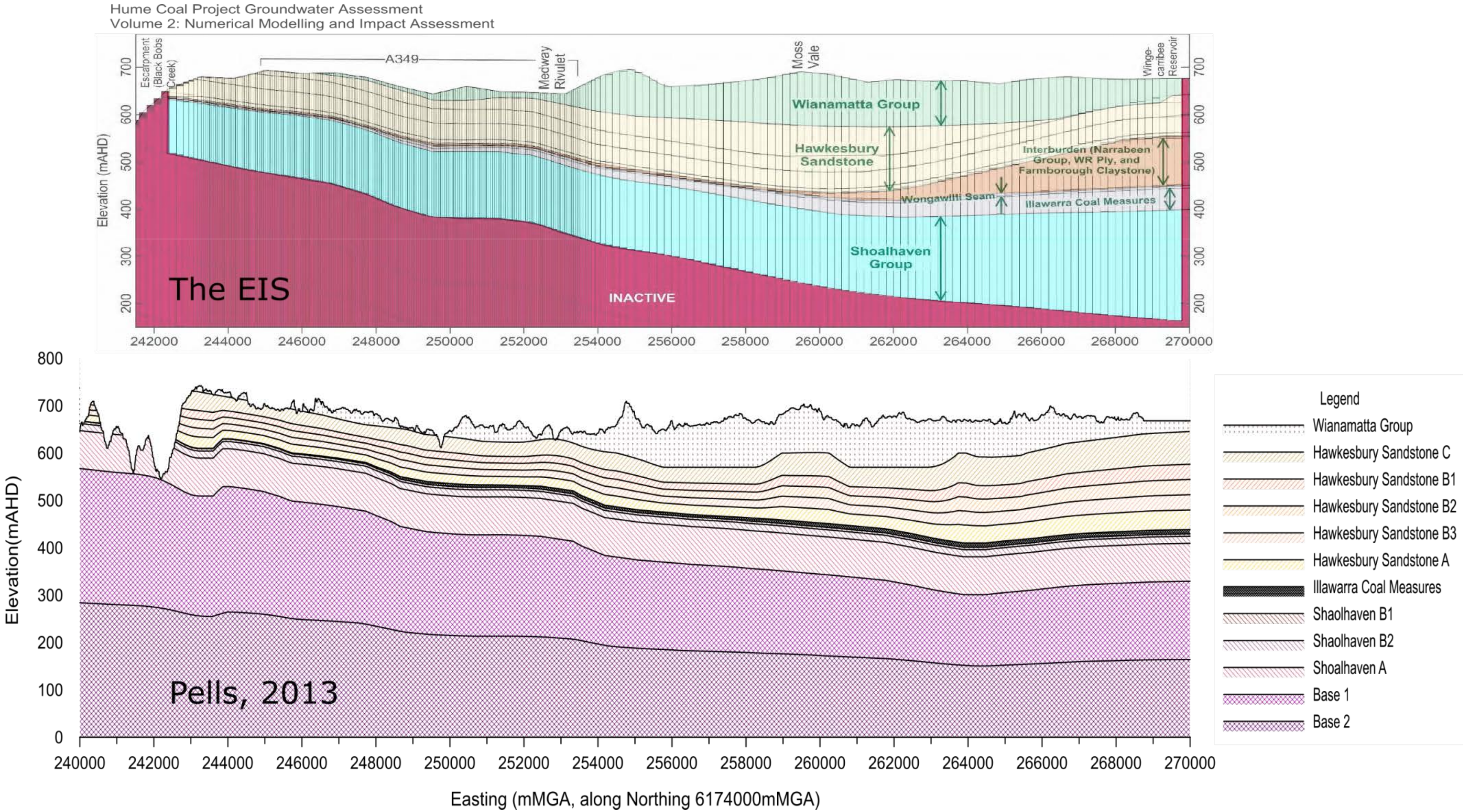


Figure 2.4 – Comparison of cross section from numerical models in the EIS (top) and Pells Consulting 2013 (bottom).

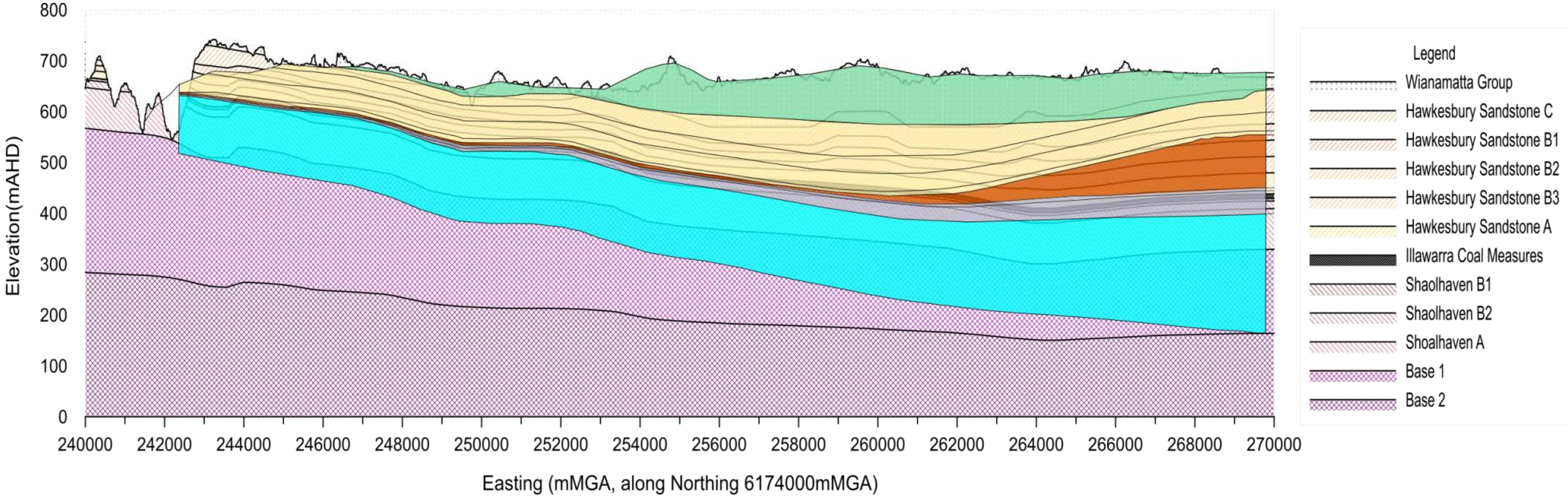


Figure 2.5 – Overlay of cross sections from numerical models in the EIS (solid colours) and Pells Consulting 2013 (hatches).

2.3 Parameters

Parameters for hydraulic conductivity adopted by Pells Consulting 2013 and in the EIS are shown in Figure 2.6. It can be seen that the choice of parameters differs greatly.

The values adopted for the Hawkesbury Sandstone by Pells Consulting 2013 reflect the advice of Hydroilex, who have extensive experience with well drilling, installation and testing within the region, including within the coal lease. The values are based on pumping test data provided by Hydroilex. In particular, experience in the region indicates a highly productive zone of the Hawkesbury Sandstone ("Hawkesbury Sandstone A") occurring at depth, just above the coal measures. Pells Consulting 2013 included representation of this zone. Values adopted for the coal measures are based on data from other sites.

The values adopted in the EIS favour a trend of decreasing permeability with depth. A productive lower layer of Hawkesbury Sandstone is not represented, with hydraulic conductivity values at depth over 100 times lower than those adopted by Pells Consulting. The choice of parameters in the EIS reflects, perhaps, a representation of decreasing permeability with increasing overburden. However, stresses from overburden is not the only process controlling permeability, as evidenced by the substantial field data of Hydroilex. It is our view that the field data from pumping tests should be taken as the dominant source of permeability measurements.

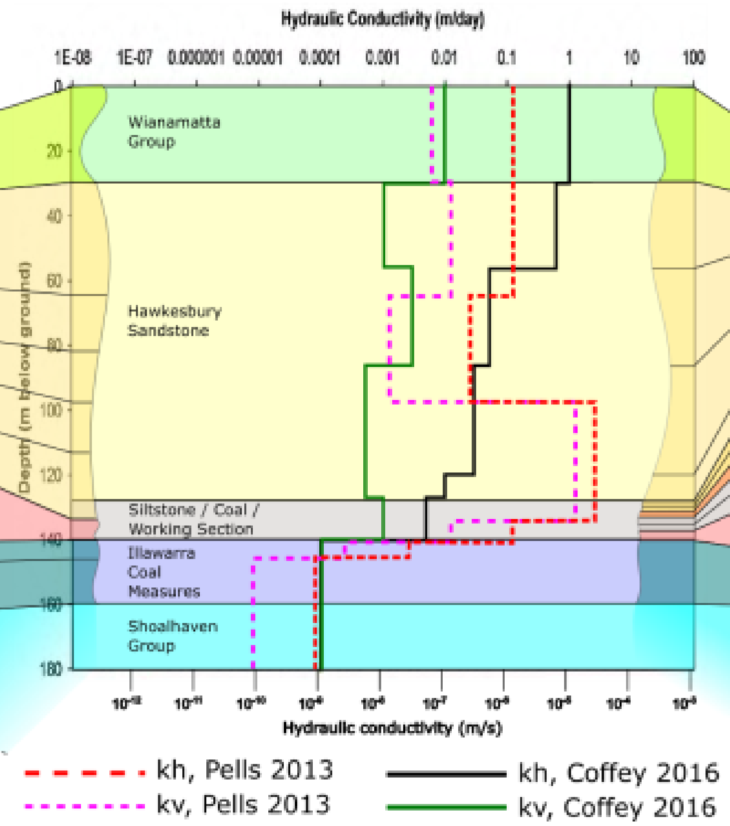
The EIS also adopts significantly lower permeability for the coal seam and for four model layers above the seam, including the 'interburden'.

The data supporting choice of hydraulic conductivity values, presented in Figure 4.5 Vol 4B, Appendix H of the EIS is reproduced in Figure 2.7. The following comments are made:

1. Not all measurements of hydraulic conductivity are equally reliable. Of these data, from pumping tests are considered to be the most reliable, followed by packer injection tests. Data from core samples reflects primary porosity (permeability of the intact substance), and are not appropriate because it is the secondary porosity (permeability of joints, faults and bedding) those determines the permeability of the formation. Edits have been made in Figure 2.7 to highlight different data sources.
2. There is a large scatter in the available data, as is typical of these measurements.
3. Packer tests tend to favour representation of horizontal hydraulic conductivity (kh). There is very little data measuring vertical hydraulic conductivity.
4. Most of the data that is available is within the Hawkesbury sandstone. There is little data for the coal seam, and none presented for the interburden. The available data for the coal seam has been shifted on Figure 2.7 to better represent the strata it pertains to.
5. Values selected in the EIS do not reflect the available data for the coal seam and layers directly above the coal seam. They are over 20 times lower.
6. The values adopted by Pells Consulting 2013 are considered to remain defensible in light of this data presented in the EIS, although it is noted that values adopted for Hawkesbury Sandstone A represents the upper range of available data.

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}	Layer
Wianamatta	1.5×10^{-6}	0.05	0.08	0.07	8000	1.59×10^{-6}	1
Hawkesbury Sandstone C	1.5×10^{-6}	0.1	0.15	0.14	6000	2.31×10^{-6}	2
Hawkesbury Sandstone B	3×10^{-7}	0.05	0.12	0.11	10000	1.52×10^{-6}	3 4
Hawkesbury Sandstone A	3×10^{-5}	0.5	0.20	0.18	8000	2.13×10^{-6}	5 6
Illawarra Coal Measures	1.5×10^{-6}	0.1	0.08	0.07	5000	2.32×10^{-6}	7
Shoalhaven B	3×10^{-8}	0.1	0.05	0.05	20000	7.16×10^{-7}	8 9
Shoalhaven A	1×10^{-9}	0.1	0.05	0.05	30000	5.52×10^{-7}	10
							11

Pells, 2013



Model Layer	Average Depth to Base in Hume Lease (mbgl)	Kh[a] (m/day)	Kv[b] (m/day)	Specific storage (m^{-1})	Specific yield	Kv/Kh	Stratum
1	30	1	0.01	1×10^{-6}	0.01	0.01	Wianamatta Group
2	56	0.6	0.001	1×10^{-6}	0.01	0.0017	Hawkesbury Sandstone
3	86	0.05	0.003	7×10^{-7}	0.008	0.06	
4	120	0.03	0.0005	7×10^{-7}	0.008	0.017	
5	127	0.01	0.0005	7×10^{-7}	0.005	0.05	
6	129	0.005	0.001	5×10^{-7}	0.005	0.2	
7	131	0.005	0.001	5×10^{-7}	0.003	0.2	
8	133	0.005	0.001	5×10^{-7}	0.003	0.2	Interburden[c]
9	135	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam above mined section
10	137	0.005	0.001	5×10^{-7}	0.003	0.2	
11	140	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam mined section
12	160	0.0001	0.0001	5×10^{-7}	0.003	1	Illawarra Coal Measures
13	250	0.0001	0.0001	5×10^{-7}	0.003	1	Shoalhaven Group

Coffey, 2016

Figure 2.6 – Comparison of hydraulic conductivity parameters adopted by Pells Consulting (2013) and in the EIS.

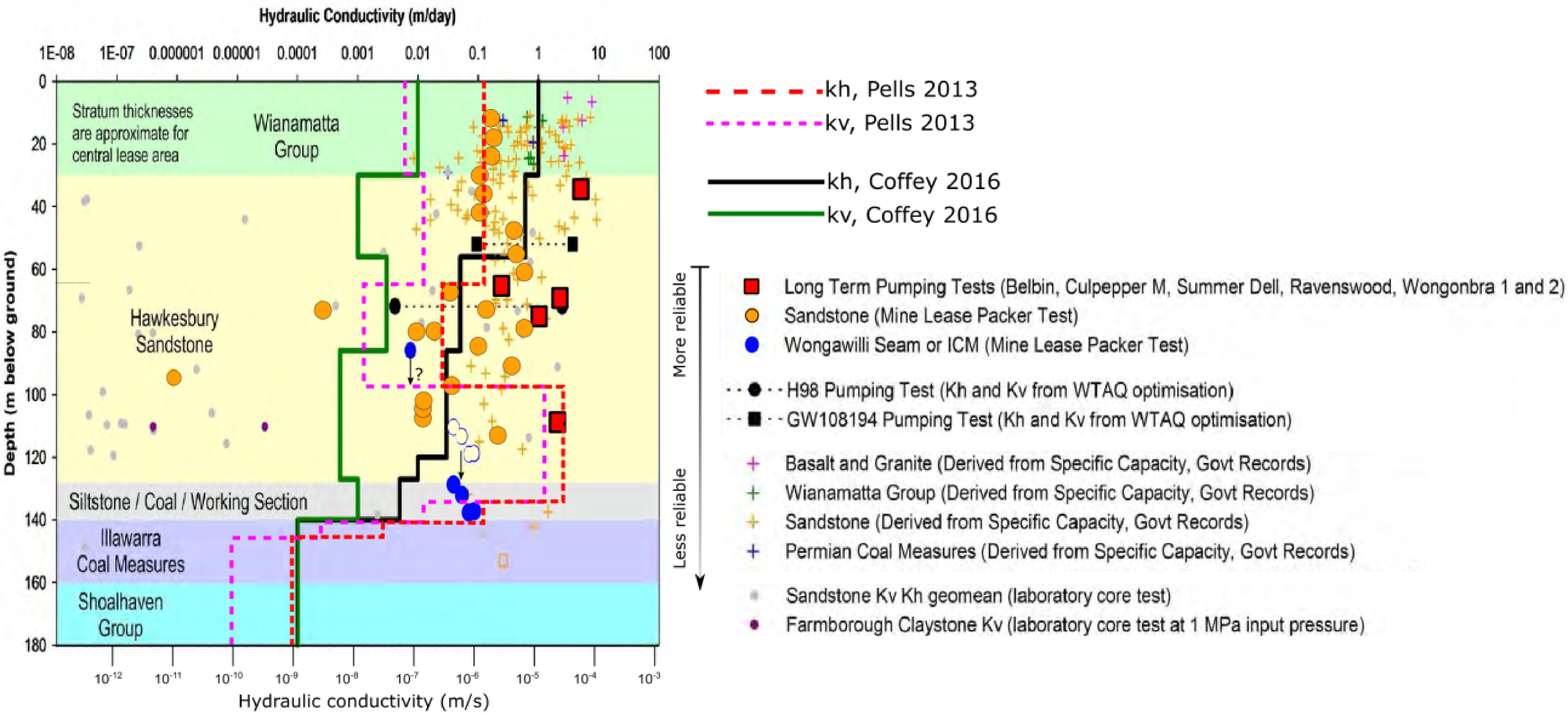


Figure 2.7 – Comparison of adopted versus observed hydraulic conductivity (from Figure 4.5, Vol 4B Appendix H of the EIS).

Hydraulic storage values adopted in the EIS are considerably lower than those adopted by Pells Consulting in 2013. Specific storage is defined according to Equation 1.

$$S_s = \text{specific storage} = \rho_w g \left[\frac{(1+\nu)(1-2\nu)}{E(1-\nu)} + n\beta\right] \qquad (1)$$

where

ρ_w = density of water (~1000kg/m^3)
g = acceleration due to gravity (9.81 m/s^2)
ν = Poisson's Ratio (typically 0.15 to 0.3)
E = Bulk Modulus (Pa)
n = porosity
β = compressibility of water (~5 x 10^{-10} Pa^{-1})

The solution to Equation 1 is plotted in Figure 2.8 below for the case of ν = 0.2 (note that ν has little influence on this solution). The region shaded in orange represents the range of possible solutions for Equation 1. Values of specific storage presented in the EIS are shown, and a 'box' on this line is drawn, representing the known range of Bulk Modulus values for these formations. It can be seen that the values of storage adopted in the EIS are mathematically impossible, requiring porosity values of less than zero. This raises questions over the validity of calibration of the EIS model.

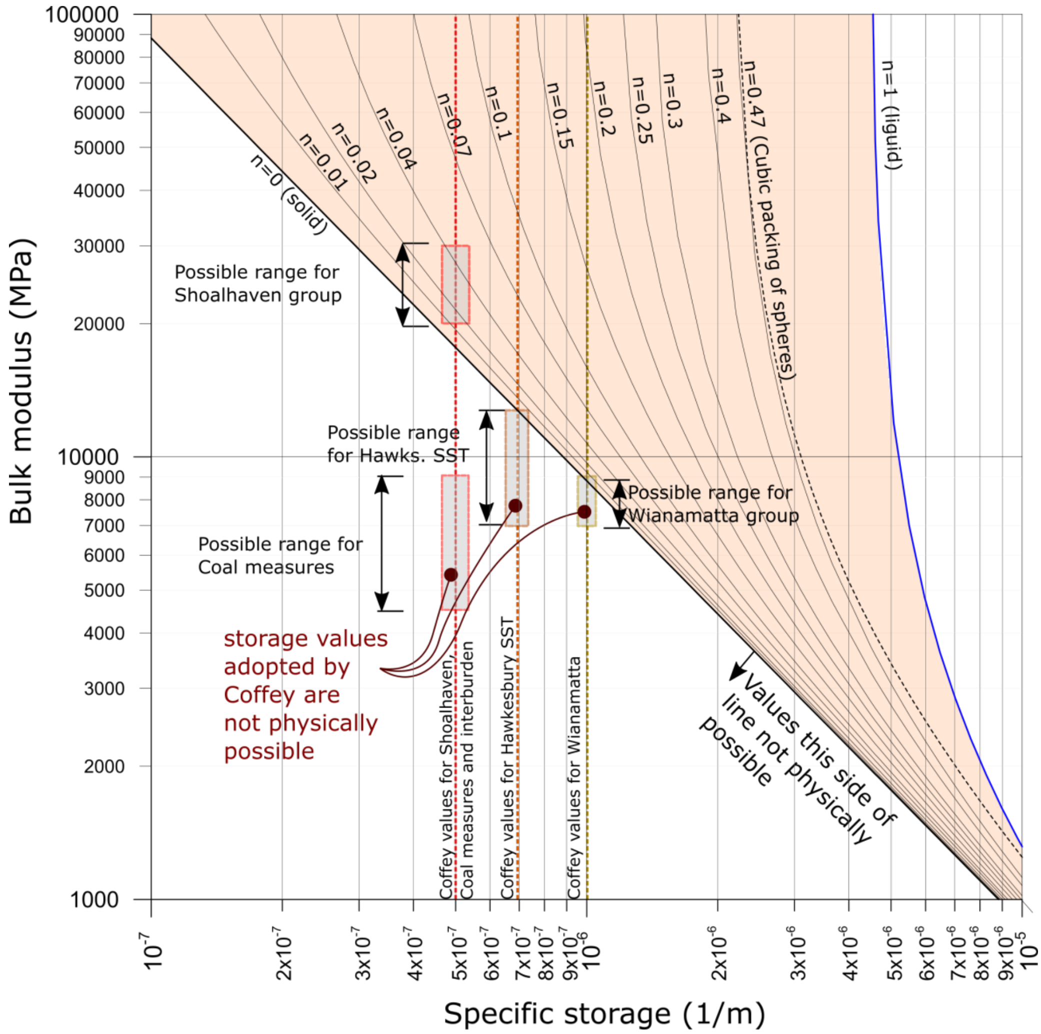


Figure 2.8 – Comparison of adopted versus theoretical storage values.

2.4 Numerical representation of the Pine Feather Mine

The EIS proposes a 'first workings' mining method, comprising mining 'panels' formed from series of 'plunge tunnels' in a 'pine feather' configuration, as illustrated in Figure 2.9 (taken from Figure 2.1 of Appendix I, Vol 4B of the EIS). Key characteristics of the proposed mine are reproduced in Table 2 (from Table 1 of Appendix I of the EIS). The proposed mining schedule is presented in Figure 2.10 (reproduced from Appendix A of Appendix I, Vol 4B of the EIS).

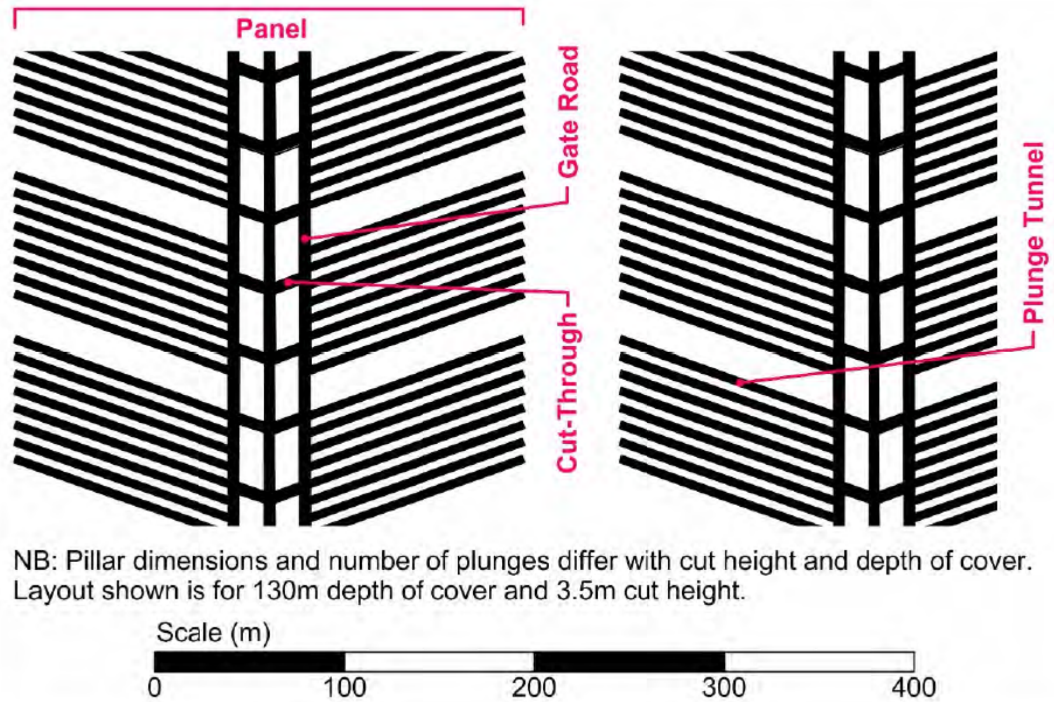


Figure 2.9 – Schematic of proposed mining method as presented in the EIS.

This mining method has been proposed for the Hume Project "as it significantly minimises groundwater impacts compared to full extraction mining." (pg 11 of Appendix I of the EIS). Strategies for minimisation (referred to in the EIS as "mitigation measures") of groundwater inflows that accompany this method are:

1. Installation of "bulkheads" used to seal panels after completion.
    a. A description in Section 5.3.1 of Appendix I states that bulkheads are to be "*placed in panel gate roads at their juncture with main headings, when the panel is complete. They are also placed at the start of main headings when the headings are no longer required*." Specific designation (eg mapping) of bulkhead locations is not given in the EIS.
    b. Panels are sealed about one week after completion (*ibid*)
2. Planned backfilling of 36% of the mined void with tailings. This co-disposal technique is stated to follow extraction of plunge tunnels, lagging by only 200 metres.
3. Injection / abstraction of water into sealed panels, depending on changing mine water requirements. This was only stated to be established for panels W6 to W18 (Section 5.2.1 of Appendix I, The EIS).

4. Selective dewatering, so that "dewatering is not undertaken where water pools down-dip of the workings" (ibid).

Table 2 – Characteristics of the proposed mine

Maximum Mining Height (m)	3.5
Typical Panel Width (m)	270
Inter-panel Distance (m)	50
Calculated Height of Desaturation (H) (m above working section roof)	2
Total extracted coal volume (ML) *	32666
Mine Life (years)	19
Method Details	Non-Caving. Spine of 3 gate roads along panel centreline. 120 m tunnels (plunges) extending from gate roads.

* 1000 m^3 = 1 ML.

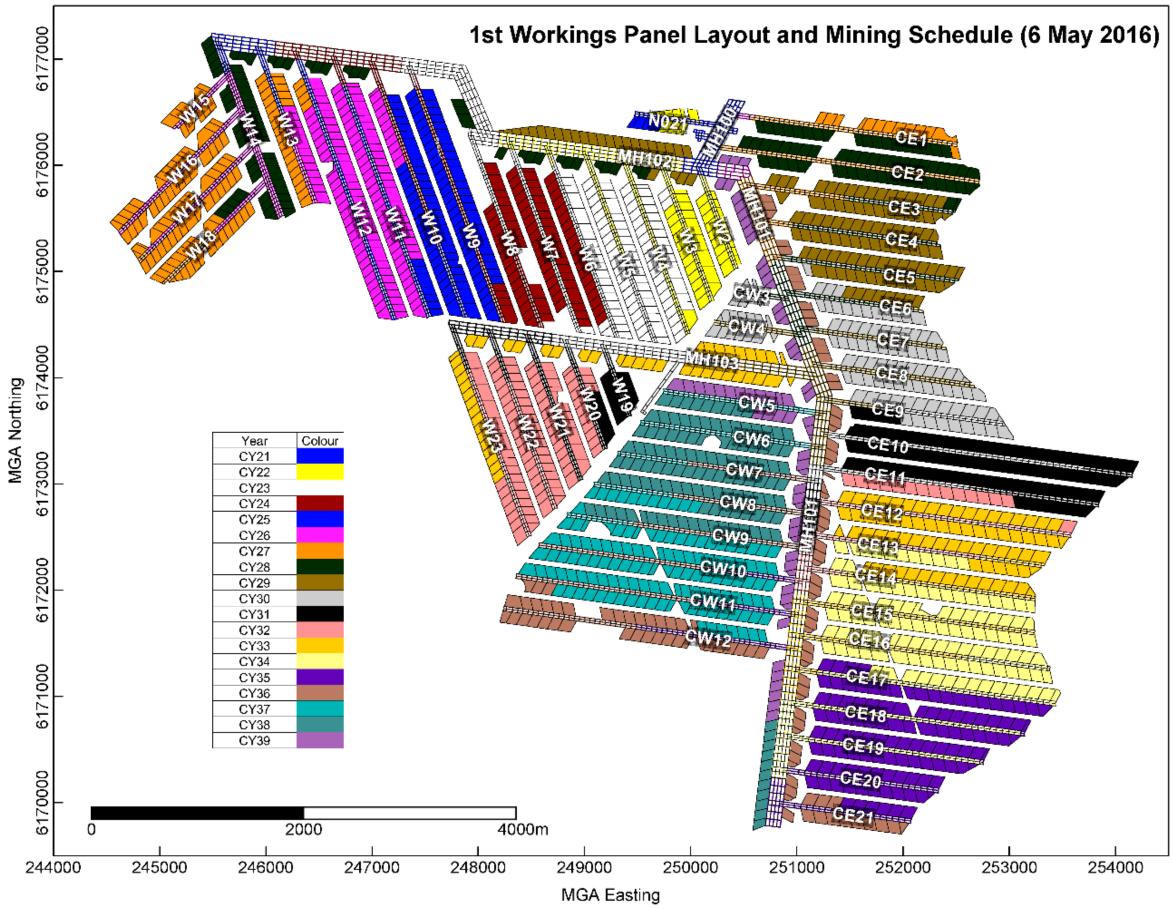


Figure 2.10 – Proposed mining schedule.

2.4.1 Simulation of the progress of mining

Numerical modelling in the EIS is described as simulating these mining strategies over a 19 year mine schedule, by turning mine 'drains' on where mining commences, and off when a panel is 'filled'.

The timing of drains being turned on and off to reflect the reality of these circumstances is complex, being a function of:

- Mine seepage inflows.
- Rate and extents of placement of tailings.
- Dip of the seam, and the nature of drainage channels formed within the workings.
- Water injections into voids and / or water withdrawals from voids, which will be managed according to the mine water balance (it was stated in Section 5.2.1 of Appendix I of the EIS that "calculation of an approximate mine water balance was required for the predictive [groundwater] simulation.")

The manner in which these circumstances were represented in modelling is described in Section 5.3.1 of Appendix I of the EIS as follows:

> During mining, drainage into the mined void is carried out using the drain mechanism (see above). To simulate the mitigation measures, the drain cells for a panel are active only for the time required for the total drained water to be equivalent in volume to the remaining void of that panel after injection behind the bulkheads and co-disposed tailings emplacement. The remaining void is calculated from a-priori schedules of injection behind bulkheads and co-disposed tailings emplacement (listed in Table 7). Predictive simulation was undertaken in an iterative fashion until the modelled total water exiting the drains for a panel was within 1% of the remaining mined volume for that panel (that is, with co-disposed tailings emplacement and injection volumes removed), and taking account of water withdrawn to satisfy water deficits. This methodology is illustrated in Figure 5.4.

It is understood then, that prior to simulation, the available volume of each 'panel' was calculated from the mine plan, but factored down to include expected filling from tailings and injected excess water. Drains in a panel were left active for the period of time required for seepage inflows to match this available volume.

It is critical to note that the time that a drain must remain open depends on the seepage inflow rate, which depends on assumed model permeability and conductance values.

Various model runs were thus repeated (it is presumed with different 'timing' of drain opening and closing) until balance was achieved. The resulting time that drains are assumed to remain open was not reported in the EIS.

If this is the case, then the groundwater model in the EIS assumes that the mine undertakes no dewatering other than to exactly match the volume of excavation.

2.4.2 Simulation of mine inflow rates

To simulate the rate of seepage into mine workings, the numerical modelling presented in the EIS assumed "nil change in the hydraulic conductivity field above the relaxed zone in the Hume Mine" (pg 15 of Appendix I of the EIS).

The mine workings were represented in the EIS groundwater modelling as 'drainage cells', with 'conductance' of 0.05m^2/day.

The term 'conductance' is adopted in Modflow to simplify the representation of flow into a drain, assuming that a certain thickness of a lining material around the drain controls flow into the drain.

The discharge into the drain is simulated according to Darcy's flow equation (Q = kiA), where the conductance represents the geometry and hydraulic conductivity of material lining the drain bed, as shown in Figure 2.11. As such, the conductance is defined according to Equation 2, and is implemented in Modflow according to Equation 3.

$$C = K\frac{\mathrm{LW}}{M} \qquad (2)$$

$$C = K\frac{\text{Cell width} \times \text{cell length}}{M} \qquad (3)$$

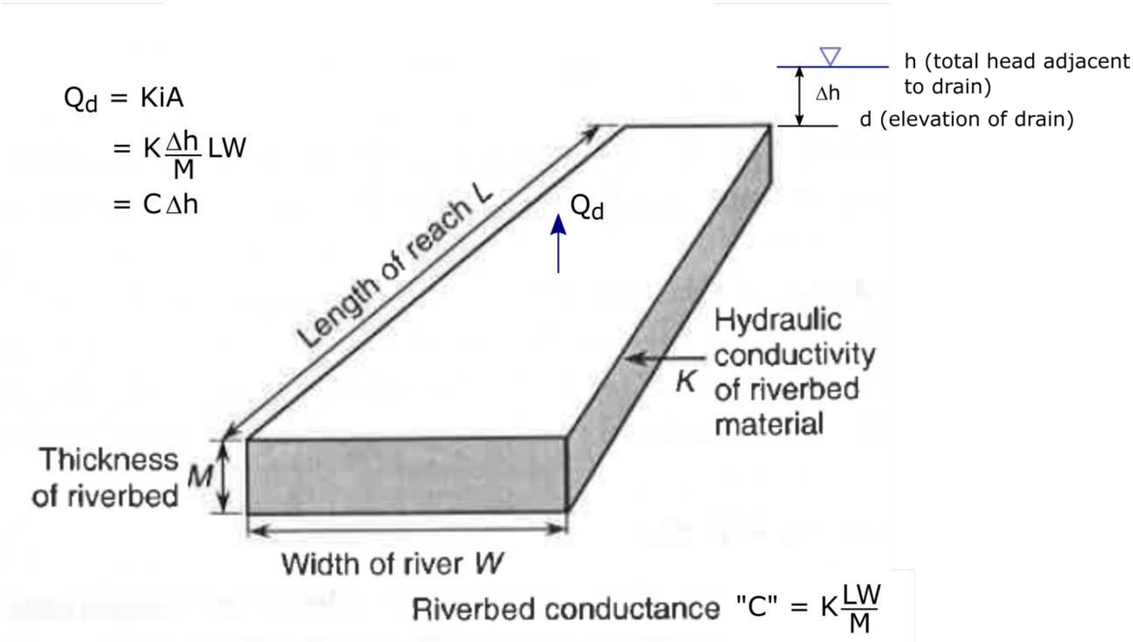


Figure 2.11 – Concept of conductance used in Modflow 'drains' (adapted from Figure 7.17 in Kresig, 2007).

The model in the EIS adopted cells of 50m by 50m above the mine workings. Hence, from Equation 3, the hydraulic conductivity represented by the choice of 'conductance' of 0.05m^2/day is given as:

$$K = \frac{0.05\ M}{50 \times 50}$$

$$= 2 \times 10^{-5}\,M \quad \text{m/d}$$

$$= 2.31 \times 10^{-10} M \quad \text{m/s} \qquad (4)$$

The value of conductance adopted in the EIS to represent mine inflows are therefore very low. Such values are indicative, for example, of mine workings being sealed, or surrounded by a thick layer of compacted clay. For example, statutory requirements for design of clay barriers for containment of contaminated waste stipulate placement of 'impermeable' clay liners, of 1 metre thickness, of material selected and placed to achieve K = 1 x 10^{-9} m/s (e.g. NSW EPA, 2015).

The conductance values adopted in the EIS are equivalent to assuming a 4 metre thick layer of such compacted clay has been constructed around all of the workings – ie a 'tanked' mine – or, in this case, that the mine void is completely backfilled with compacted clay. It is stated in the EIS that the conductance parameter "is the subject of sensitivity analyses". However, Section 5.3.2 of Appendix I of the EIS indicates that such analyses only extended to a conductance of 0.1m^2/day (i.e. a 2 metre thick clay liner).

In contrast to this, it is common practice when simulating underground mine inflows with 'drains' to adopt a high value of conductance, such as 1000m^2/day (eg; Dundon 2009; Fulton 2009; Middlemis and Fulton 2011; Fulton, 2012; Lloyd and Pavlovic 2014; Merrick et al 2014). As stated in these cited reports, an assumed high conductance causes inflows to the mine to be controlled by the formation (ie flows controlled hydraulic conductivity of the rock mass around the mine) and not an artificial representation with a liner. This was the methodology adopted in the Pells Consulting (2013) numerical model. Modellers for the EIS were evidently aware of such an approach, as it was used in other aspects of the model:

> *"remaining drainage channels were simulated using the Drain package … drain conductance was set to a high value of 1000 m^2/day, allowing the media hydraulic properties to control leakage ..."* (Section 3.2.1 of Appendix I of the EIS).

The choice of drain conductance of 0.05m^2/day to represent mine inflows in the EIS was justified as a result of calibration of the model.

2.5 Sensitivity

The EIS stated that three alternative model runs were undertaken to test the sensitivity of the model predictions to: mine drain conductance; relaxation of the formation above the workings, and; hydraulic conductivity. These are discussed in turn below. The results of sensitivity testing are subject to brief discussion in the EIS - no revised or alternative drawdown maps are presented for the scenarios.

2.5.1 Mine drain conductance

The EIS reported that the conductance of 'drain' cells to simulate mine inflows was subject to sensitivity testing. This comprised testing with values of 0.05m^2/day and 0.1m^2/day.

2.5.2 Relaxation heights

In the opening remarks to Appendix H of the EIS, it is stated that "Overburden deformation would occur as relaxation in the immediate roof over the openings, generally limited to less than 3 m into the overlying roof." Table 8 of Appendix I of the EIS indicates that sensitivity modelling tested the effects of relaxation heights of 2 and 4 metres and is discussed Section 4.3.5 of Appendix H of the EIS:

> To estimate a reasonable relaxation height, a sensitivity analysis was undertaken with the model, prior to predictive simulation, to assess the change in mine inflows for relaxation heights of 2 m and 4 m. This was applied over an area representative of the typical extent of an actively draining area at an instant in time. This analysis is reported in the sensitivity section. Results indicate an increase in inflow of 4.3% between 2 m and 4 m relaxation heights. Observational databases indicate a relaxation height of less than 2.5 m is common for first working mines. Given the small change in inflow between 2 m and 4 m heights, and the design of the Hume mine plan, the most representative relaxation height applicable over a large area of non-caving workings is considered to be 2 m, and this was adopted for predictive simulations.

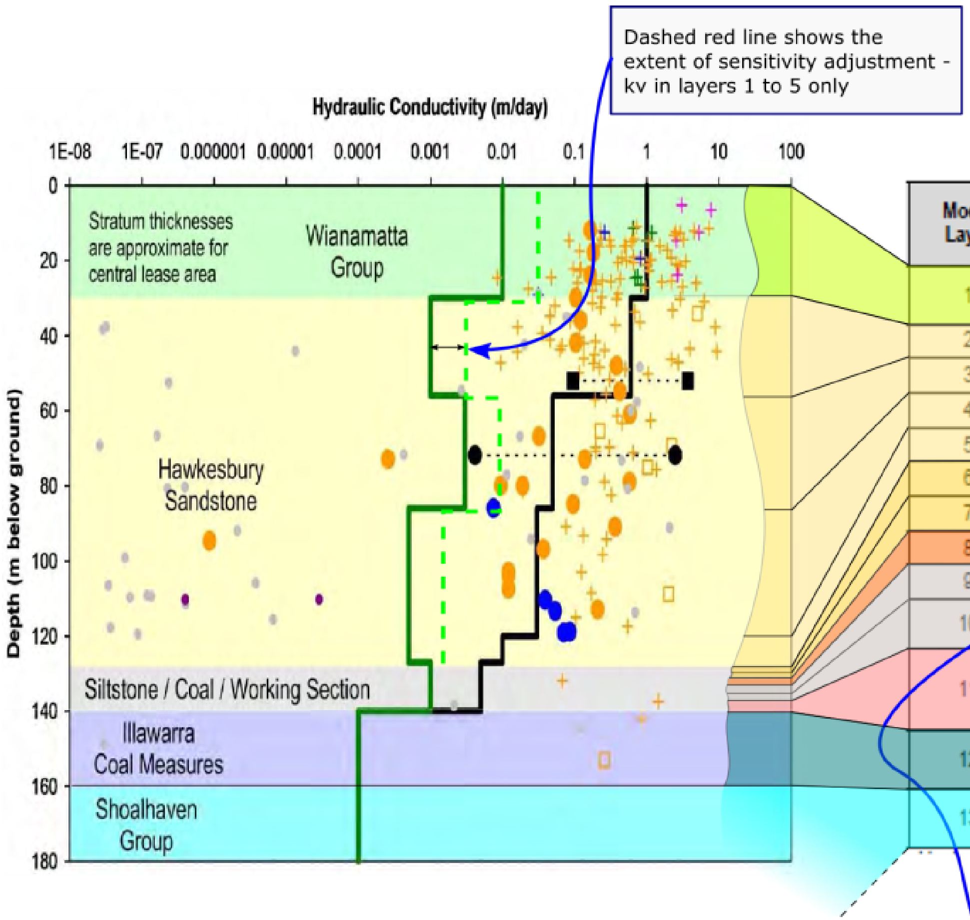
This explanation is unclear to the present writer, and raises the following questions:

- How were 'relaxation heights' represented in the model? For example, were increased hydraulic conductivity values used to represent relaxation? If so, what increase was made?
- If a relaxation height of 2 metres was adopted, why do hydraulic conductivity values presented in the EIS show no apparent increase within the vicinity of the mine? (eg see Figure 2.7 above)
- It is noted that relaxation heights of 2 to 4 metres correspond with the thickness of unworked coal measures (according to the EIS groundwater model layering), and hence relaxation is just short enough to not impact on the 'interburden'. Is there sufficient geological data to substantiate this assumption?

2.5.3 Hydraulic conductivity

Sensitivity tests on hydraulic conductivity presented in the EIS were limited to a small adjustment of vertical hydraulic conductivity in model Layers 1 to 5. This adjustment is shown graphically in Figure 2.12.

Considering the scatter in the available test data, the range of adjustment is small. The adjustment does not approach, for instance, values measured in the field by Hydroilex. It is also noted that sensitivity tests were limited to the regions where in fact there is more test data, but there is no sensitivity testing to layers 6 to 10, for which limited data exists (hence greater uncertainty).



Only these layers were adjusted

Model Layer	Average Depth to Base in Hume Lease (mbgl)	Kh[a] (m/day)	Kv[b] (m/day)	Specific storage (m^{-1})	Specific yield	Kv/Kh	Stratum
1	30	1	0.01	1×10^{-6}	0.01	0.01	Wianamatta Group
2	56	0.6	0.001	1×10^{-6}	0.01	0.0017	Hawkesbury Sandstone
3	86	0.05	0.003	7×10^{-7}	0.008	0.06	
4	120	0.03	0.0005	7×10^{-7}	0.008	0.017	
5	127	0.01	0.0005	7×10^{-7}	0.005	0.05	
6	129	0.005	0.001	5×10^{-7}	0.005	0.2	
7	131	0.005	0.001	5×10^{-7}	0.003	0.2	
8	133	0.005	0.001	5×10^{-7}	0.003	0.2	Interburden*
9	135	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam above mined section
10	137	0.005	0.001	5×10^{-7}	0.003	0.2	
11	140	0.005	0.001	5×10^{-7}	0.003	0.2	Wongawilli Seam mined section
12	160	0.0001	0.0001	5×10^{-7}	0.003	1	Illawarra Coal Measures
13	250	0.0001	0.0001	5×10^{-7}	0.003	1	Shoalhaven Group

No adjustment to the 5 layers above workings

Figure 2.12 – Illustration of the extents of sensitivity to hydraulic conductivity tested in the EIS.

3 DEMONSTRATION OF THE SIGNIFICANCE OF DIFFERENCES BETWEEN THE MODELS

3.1 Hydraulic conductivity values

A conceptual two-dimensional groundwater flow model was assembled in Geostudio 2012 (Seep/w) to demonstrate the significance of the differing hydraulic conductivity values adopted by Pells Consulting (2013) and in the EIS. The model represented a cross-section 20km wide, having model layering and media properties conforming to the EIS groundwater model, as presented in Table 3 of Appendix H of the EIS. Boundaries on the left and right hand side of the model were assigned constant head of 20m below the surface, and a nominal recharge of 5mm/annum was applied to the surface as a steady state 'initial' condition.

A mine panel was then simulated using a zero-pressure boundary condition assigned to a 250m wide region in Layer 11 (the mined seam). A transient simulation was undertaken, with the inflow to the 250m wide 'mine panel' and drawdown at two locations (one directly above the mine, at 100m below the surface, and another at 400m from the mine, 60m below the surface) being reported. The modelling was repeated for the following scenarios:

1. Media properties as per the EIS model.
2. Media properties as per the EIS model with kh and kv[2] increased by 3 times in layers 6 to 11.
3. Media properties as per the EIS model with kh and kv increased by 3 times in layers 3 to 11.
4. Media properties representing Pells Consulting 2013 parameters (fitted, as best possible, to the layering adopted in the EIS).

The model conceptualisation and results for Scenario 1, after 1 year elapsed, is shown in Figure 3.1.

The resulting inflow to the mine, for each of the above four scenarios, is presented in Figure 3.2. Drawdowns at the two locations are presented in Figure 3.3.

From Figure 3.2 it is evident that mine inflows with the EIS parameters are over 20 times smaller than those predicted using the Pells Consulting values. From Figure 3.3 it is evident that drawdowns using the EIS values are approximately halved. Hence the differences in mine inflows and drawdown between the Pells Consulting 2013 model, and that of the EIS, can be largely explained from different media properties – ie. without any differences in mine conceptualisation.

This 2D modelling concept was repeated using Modflow, as shown in Figure 3.4. It was found that the steady state conditions (before mining and after an 'infinite' period of mining) predicted by Modflow were the same as predicted by Seep/w (a slight difference in transient response was observed between the models, as Modflow simulates transient changes using Confined (Ss)/Unconfined (Sy) storage paradigm, whereas seep/w uses compressibility (m_v) and a volumetric water curve, and the two conceptualisations could not be correlated precisely). The differences in the transient simulations are presented in Figure 3.5.

Hence the Modflow conceptual model confirmed the findings of the seep/w model – ie. that the lower inflows and drawdown predicted in the EIS can be explained from different media properties, without any differences in mine conceptualisation.

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[2] kh = horizontal permeability, kv = vertical permeability.

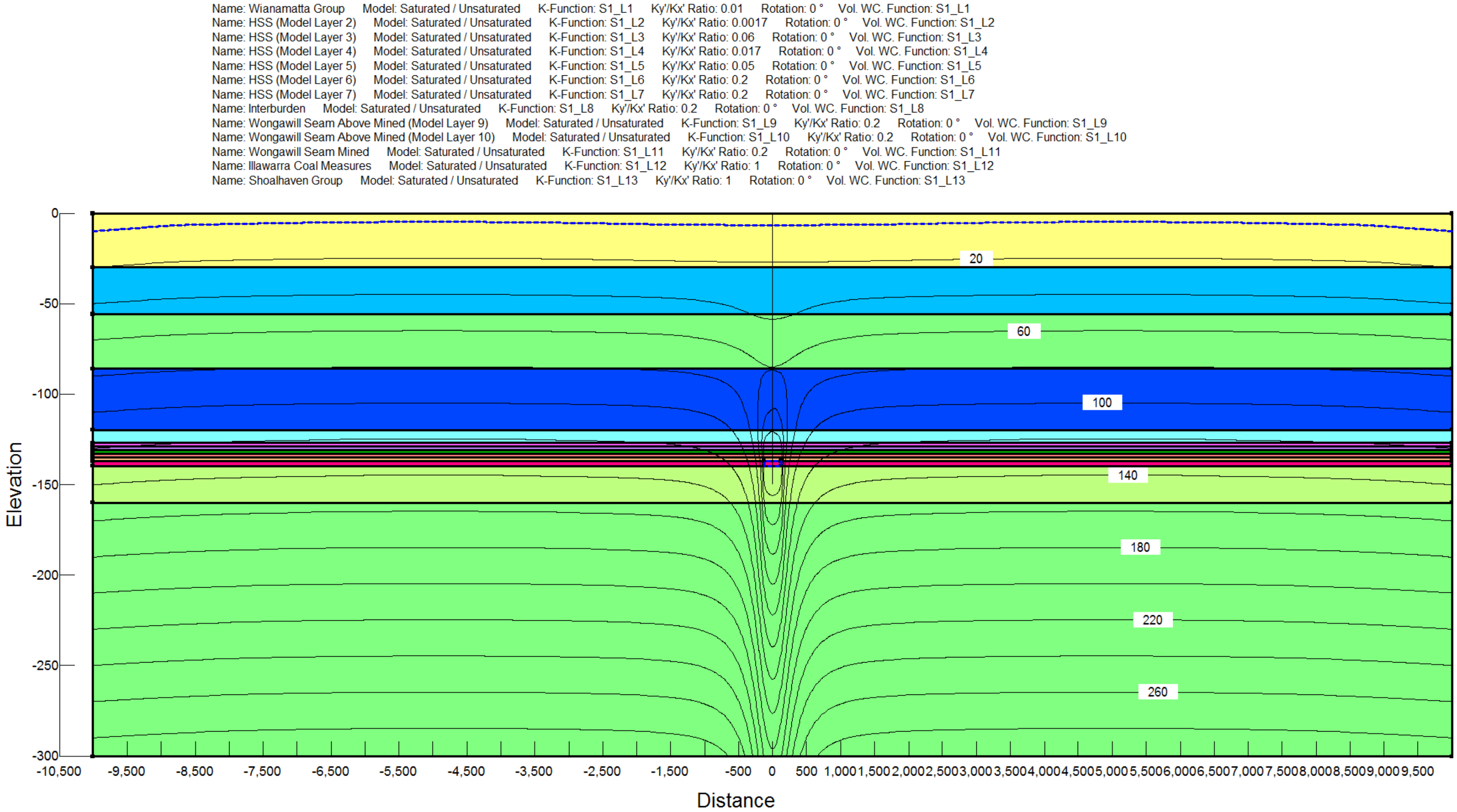

Figure 3.1 – Conceptual 2D model in Geostudio 2012 showing contours of pressure head after 1 year of mining, using EIS media properties.

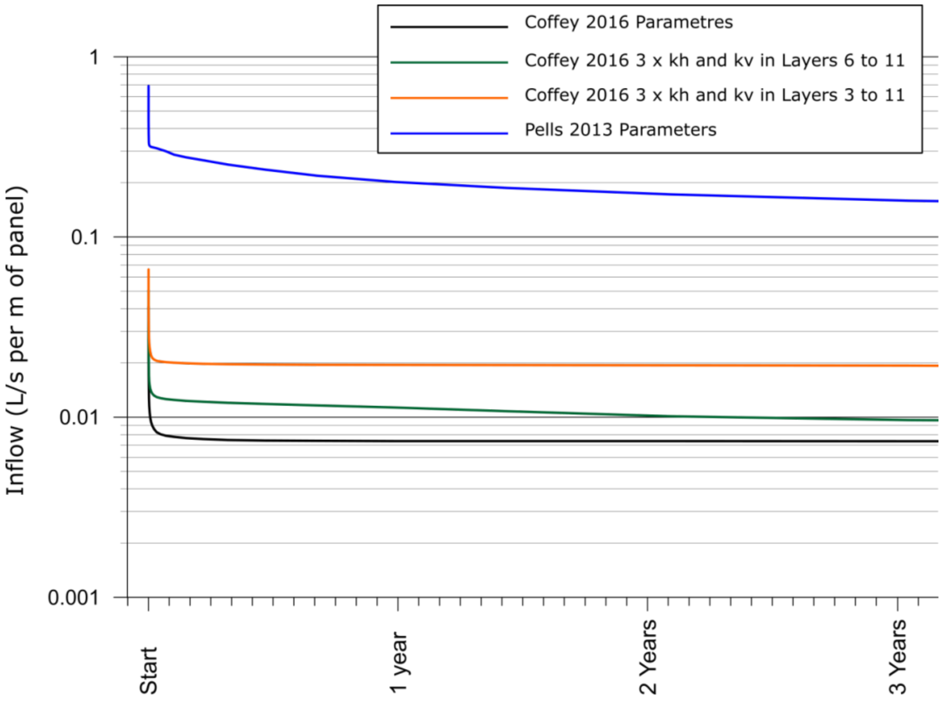

Figure 3.2 – Mine inflow versus time, conceptual 2D model in seep/w.

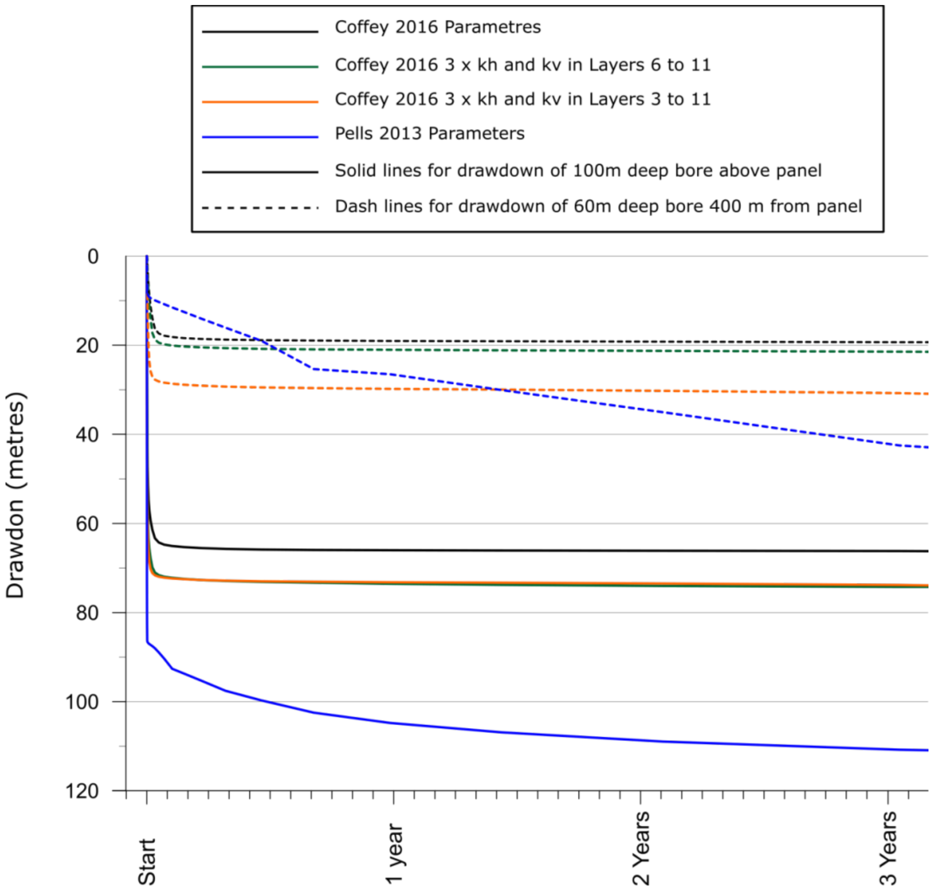

Figure 3.3 – Drawdown versus time, conceptual 2D model in seep/w.

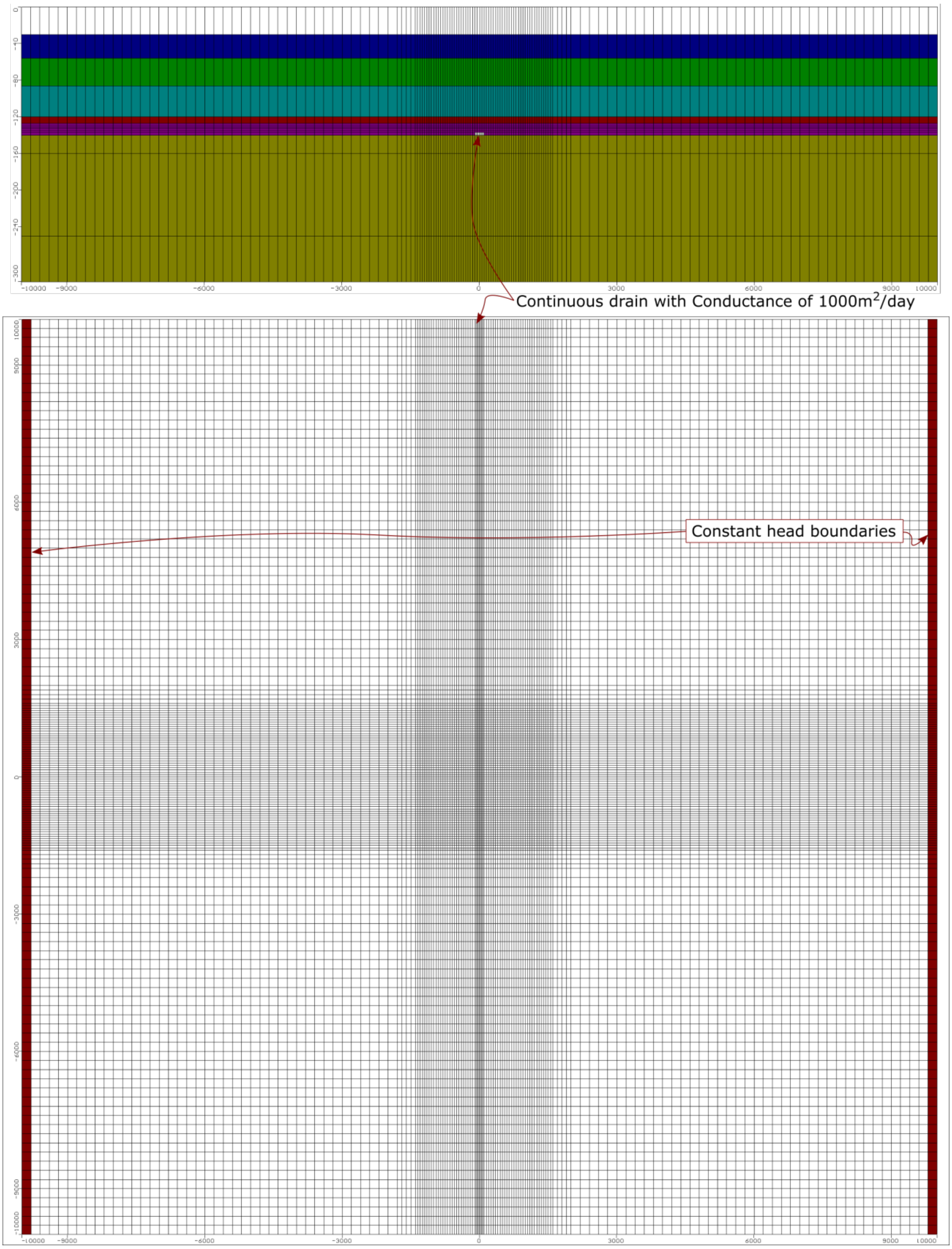

Figure 3.4 – Conceptual 2D model as established in Modflow.

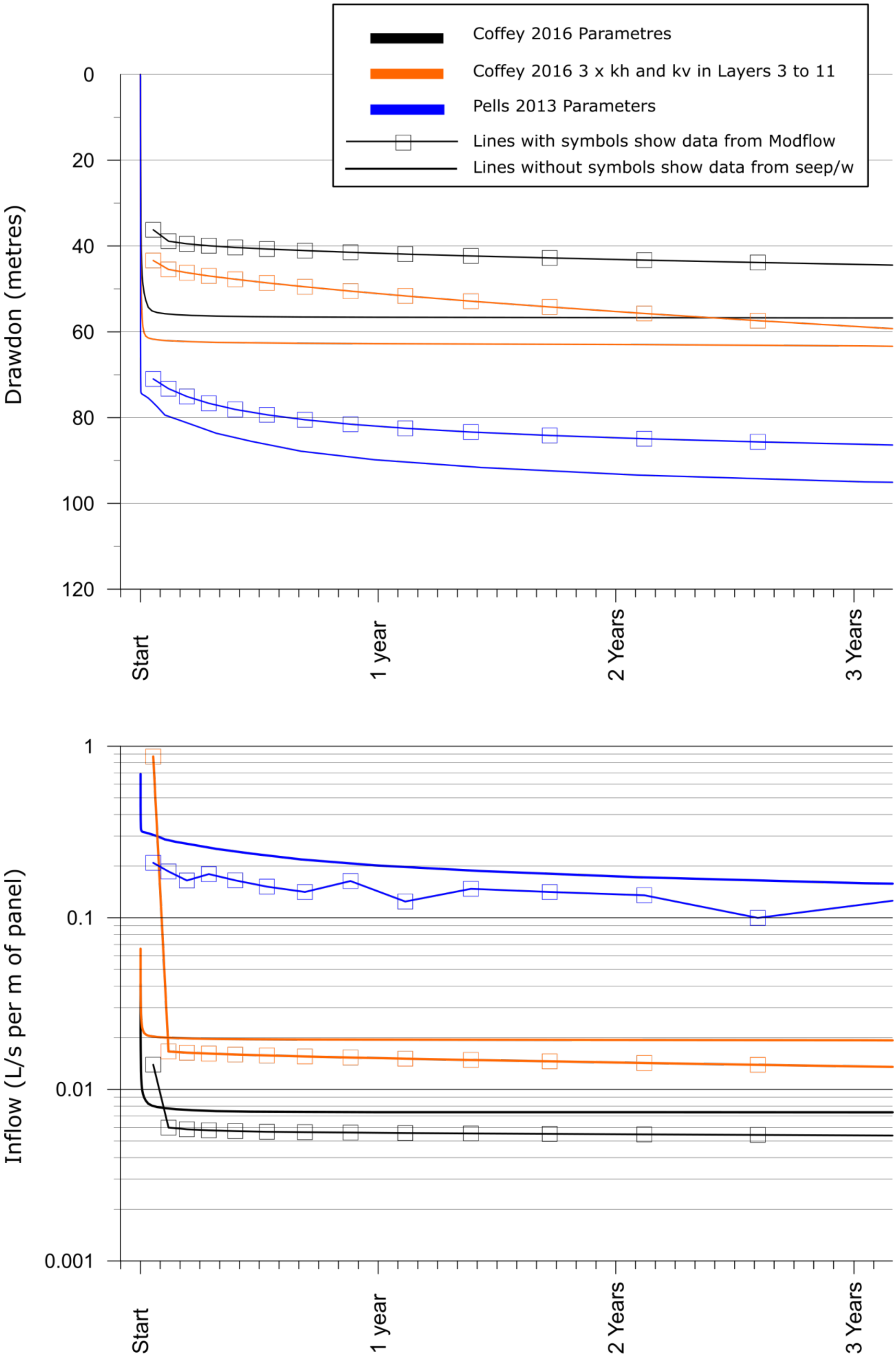

Figure 3.5 – Drawdown and inflow versus time, conceptual 2D model in Modflow and seep/w.

3.2 Mine 'conductance'

The conceptual Modflow model was then adjusted to represent 3D flows into a conceptual 2000 m long by 250 m wide panel, as shown in Figure 3.6. In the vicinity of the 'mine', the model features a 50m by 50m grid.

Scenarios 1, 3 and 4 were repeated using this 3D conceptual model, with different values of mine 'conductance'.

Plots of inflow versus conductance and drawdown versus conductance are shown in Figure 3.7 and Figure 3.8, respectively.

It can be seen that the choice of drain conductance has a large impact on the simulated inflows and drawdowns. Inflows become controlled by formation losses only when drain conductance's exceed approximately 10 m^2/day. Values of conductance of less than 10m^2/day have the effect that the drain inlet conditions control mine inflows[3].

It can be seen that the range of conductances of 0.05 and 0.1 m^2/day adopted in the EIS significantly control inflows.

This flow control also has an important effect on when the proposed mine 'bulkheads' become active. The average panel width of 270m and working height of 3.5m adopted in the EIS is indicative of a volume of 945 m^3 per metre length of panel. This void volume depends on spacing of 'plunge tunnels', but can be estimated as 150m^3 per metre if approximately 16% of the panel (in plan) are extracted from first workings[4]. The time to 'fill' these mine workings is presented in Figure 3.9, using inflow rates presented in Figure 3.7.

Simulations in the EIS assume that mine inflows are so small, that panel extraction and installation of bulkhead can be completed before the panel is inundated. It is this assumption that allows the modeller for the EIS is turn mine drains off as soon as a total inflow volume equivalent to the mine void volume is achieved. It is shown in Figure 3.9 that these inflow rates are highly sensitive to the drain conductance and hydraulic conductivity parameters assumed. Using parameters adopted by Pells Consulting, 2013 inflows exceed the mine void volume prior to placement of a bulkhead. In such as case, the criteria for when a drain gets turned 'off', depends only upon the mining program.

[3] This is like having a throttle-valve between the surrounding formation and the mine void.
[4] This value was estimated from calculation based on descriptions of pinefeather geometry described in the EIS.

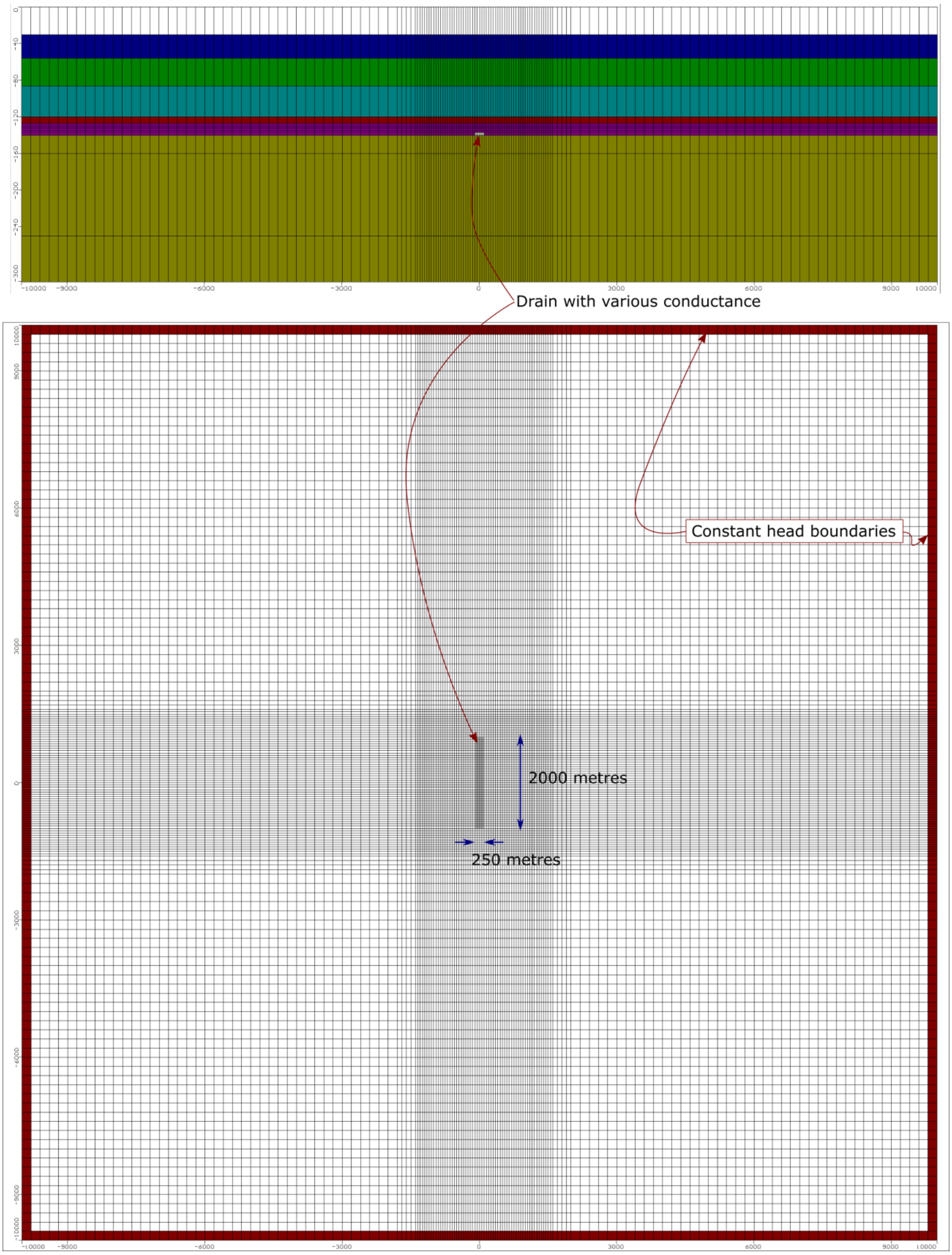

Figure 3.6 – Conceptual 3D model as established in Modflow.

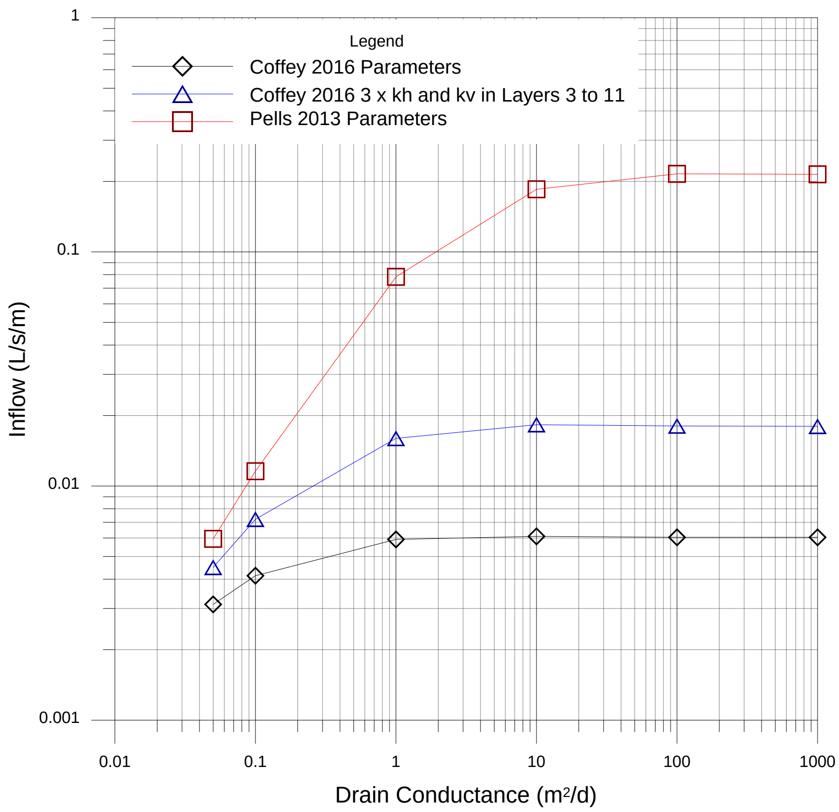

Figure 3.7 – Mine inflows versus drain conductance.

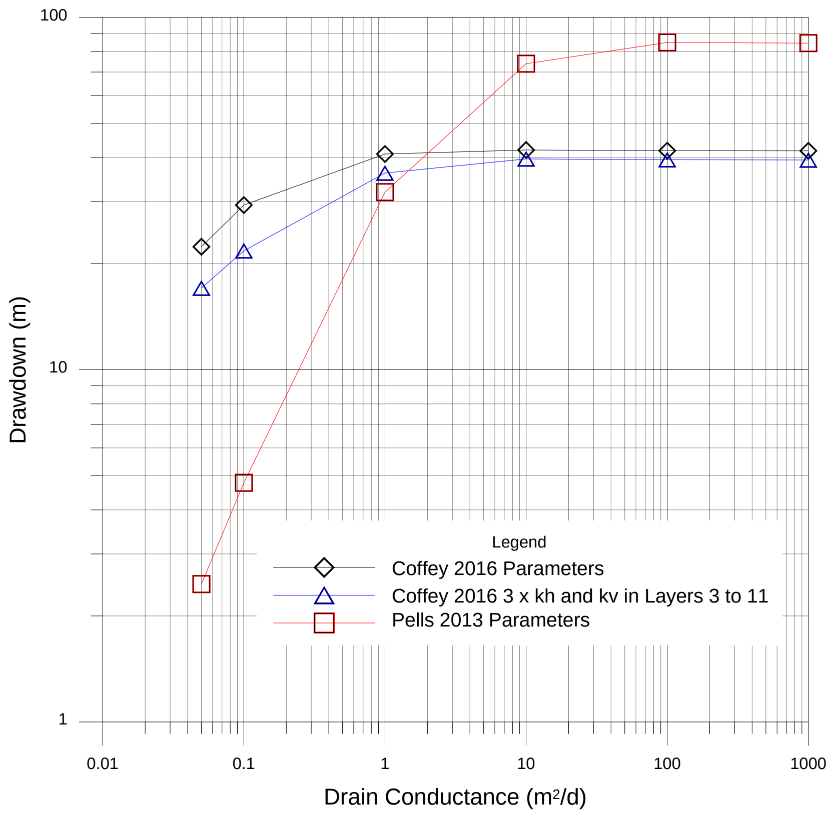

Figure 3.8 – Drawdown above mine, versus conductance.

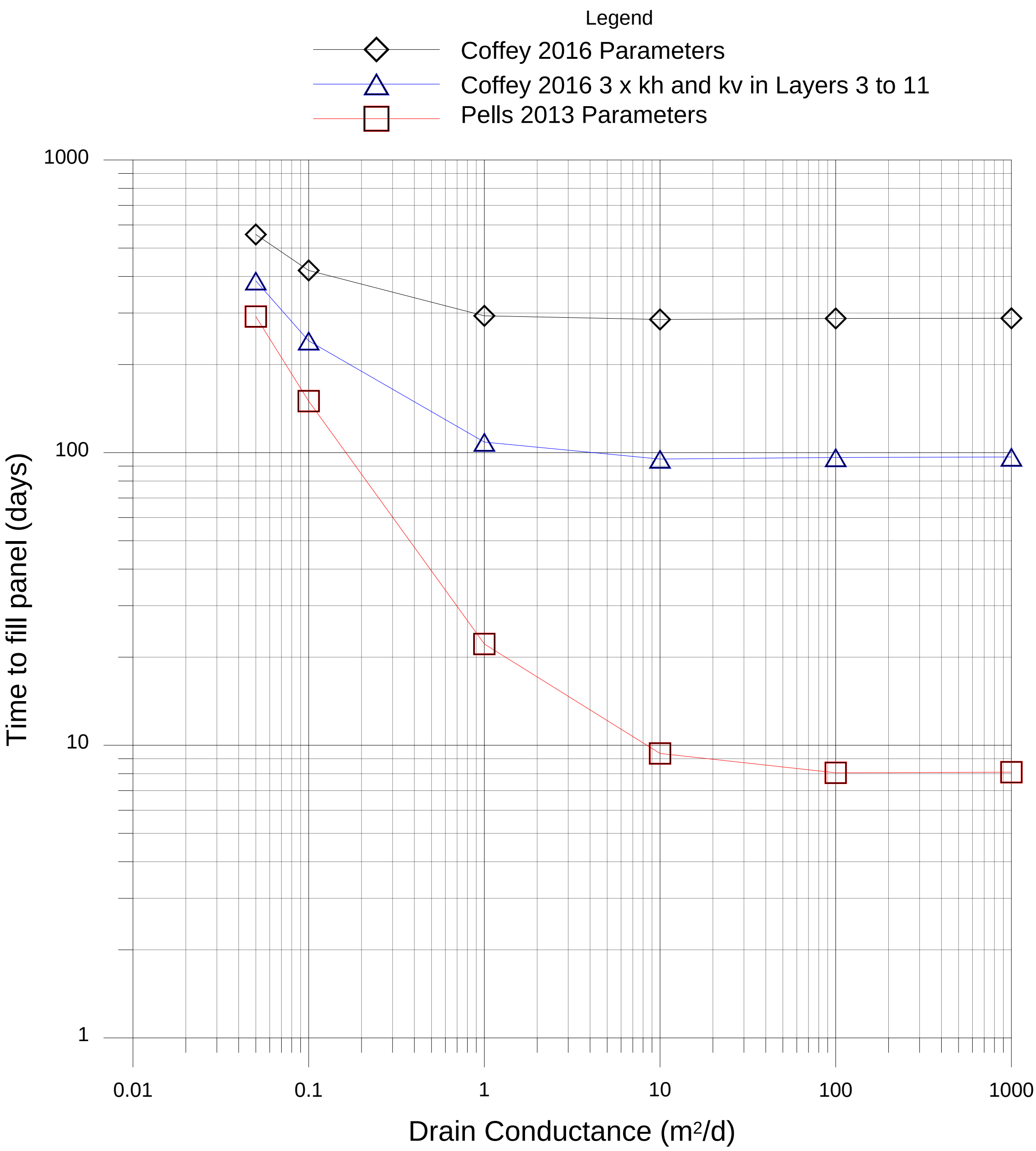

Figure 3.9 – Time to fill a panel versus conductance.

4 REPRESENTATION OF CURRENT MINE PLAN WITHIN THE PELLS CONSULTING 2013 MODEL

4.1 Adjustments made to represent new mine plan

The 3D numerical model of the Hume Lease presented in Pells Consulting 2013 was adjusted to represent the current mining plan. The previous model with 'standard' parameters was chosen (Pells Consulting, 2013). A small refinement to the grid was made so that the region with smaller (45m by 45m) cells covered the entire new mine region.

The mine was represented using drainage cells. Drains were assigned an elevation of 0.1m above the seam base. Drains became operational to reflect the onset of mining in a panel. The installation of bulkheads was assumed to cause cessation on inflow in some panels (at perceived likely bulkhead locations, based on review of the mine plan presented in Figure 2.10 above) after various years of operation (depending on the modelled scenario). The dates for turning drains on and off in the model are presented in Figure 4.1 for the case of an assumed two year period.

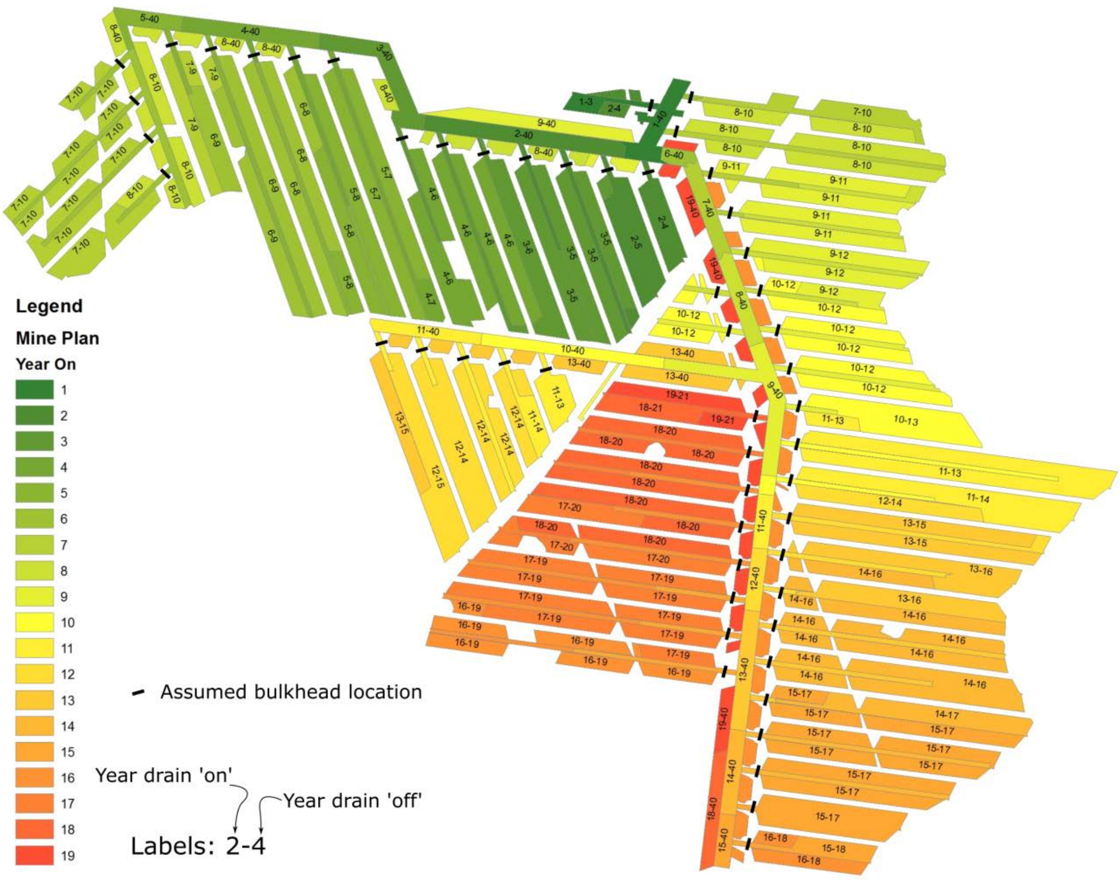

Figure 4.1 – Time to fill a panel versus conductance.

Drain cells were selected from the 45m by 45m grid as appropriate to represent each panel part. An example of the selection process for assigning cell grids for the case of a section of Panel W23 is illustrated in Figure 4.2. Each of these grids, for example, were assigned a drain cell that became active in the 13th year of mining, and inactive after the 15th year of mining.

It can be seen that the selection of 45m by 45m grids only approximates the footprint of the panel. For example, the section of panel W23 has a plan area of approximately 146,500m^2, representing a first workings area of approximately 24,000m^2 (assuming 16% extraction, in plan). The selected cells represent a plan area of 87,075m^2, hence over-representing the available open area. Assuming that the 'entry losses' to the drain occurs over a length of 0.5m, through material having the same hydraulic conductivity as the adjacent material (kv = 1.5 x 10^{-7}m/s), an appropriate conductance representing the open area of the pinefeather mine plan can be estimated as:

$$C = K \frac{\text{Cell width} \times \text{cell length}}{M} \tag{3}$$

$$= 1.5 \times 10^{-7} \frac{45 \times 45}{0.5} \frac{24000}{87075}$$

$$= 1.7 \times 10^{-4} \ \text{m}^2/\text{s}$$
$$= 14.5 \ \text{m}^2/\text{d}$$

A mine conductance of 14.5m^2/day was adopted as a baseline scenario, but sensitivity to this value was tested with multiple model runs.

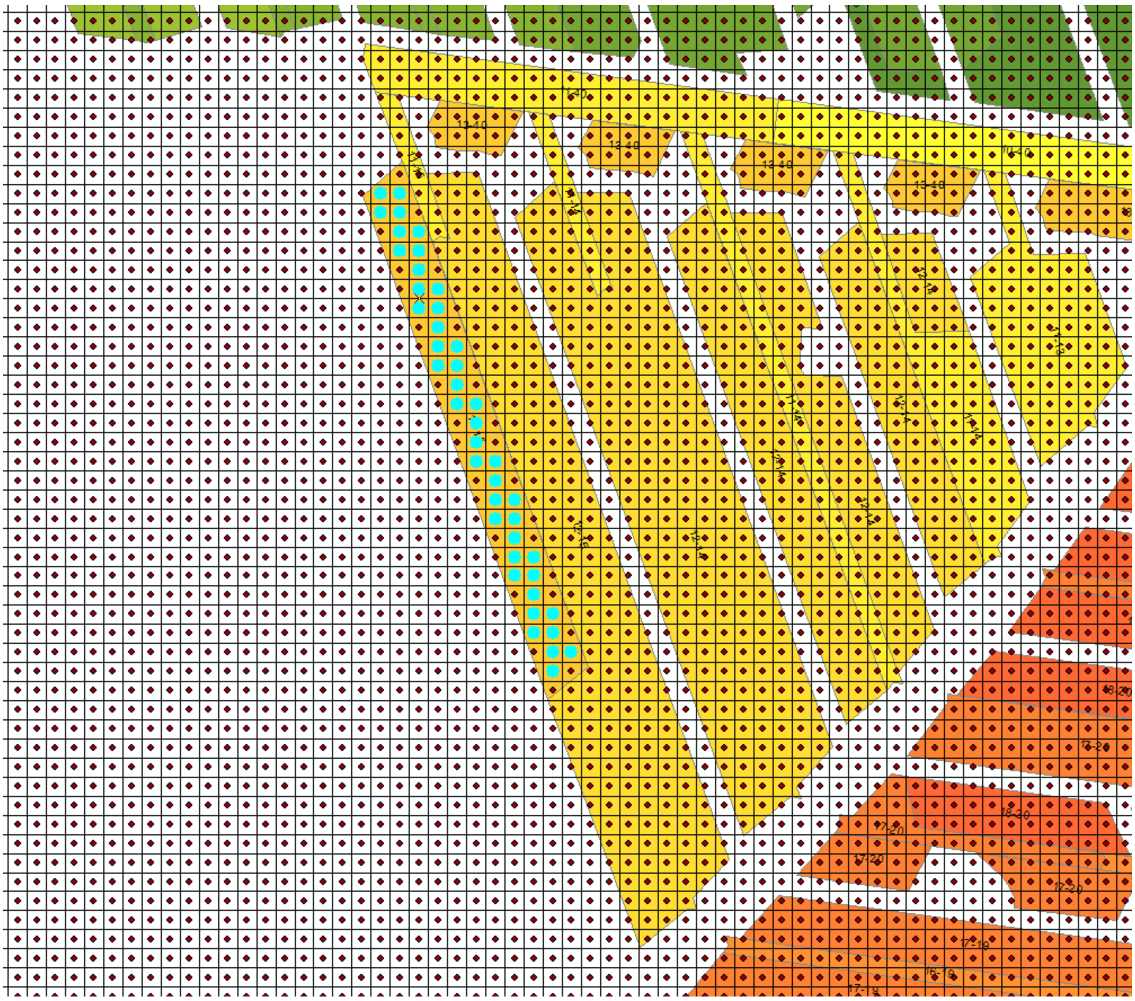

Figure 4.2 – Illustration of the drain cell definition process.

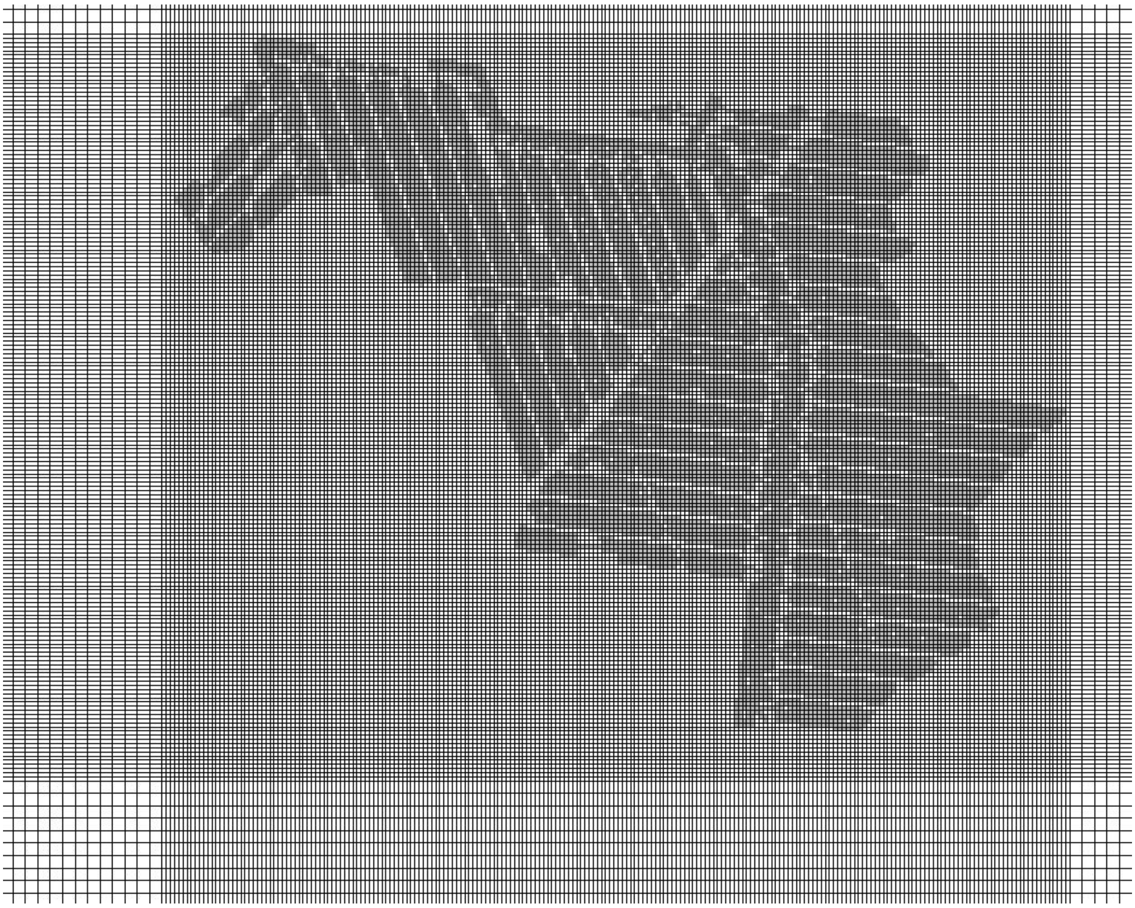

Figure 4.3 – View of mine drain-cells in Modflow

4.2 Model runs

The Pells Consulting 2013 model, with the current Hume mine plan, was run for the following scenarios:

Table 3 - Model runs for Hume Mine layout using Pells 2013 Model

Run	Engine	Solver	Hydraulic Conductivity	Storage	Mine drain conductance
1	Modflow 2000	WHS	"Median"[1.]	As per Pells and Pells 2013 [1.]	0.05 m^2/d
2					14.5 m^2/d
3					100 m^2/d

1. From Table 1 of Pells and Pells, 2013. These tables are reproduced in Section 5 below.

4.3 Results

The model was run for a simulation period of 40 years. It was assumed that all the remaining drains (ie other than those already turned off due to being located behind a bulkhead) were deactivated at year 20. The results from this simulation are presented below.

4.3.1 Inflows

Simulated mine inflows are presented in Figure 4.4. Also shown are the previous inflow predictions presented in Figure 27 of Pells and Pells 2013.

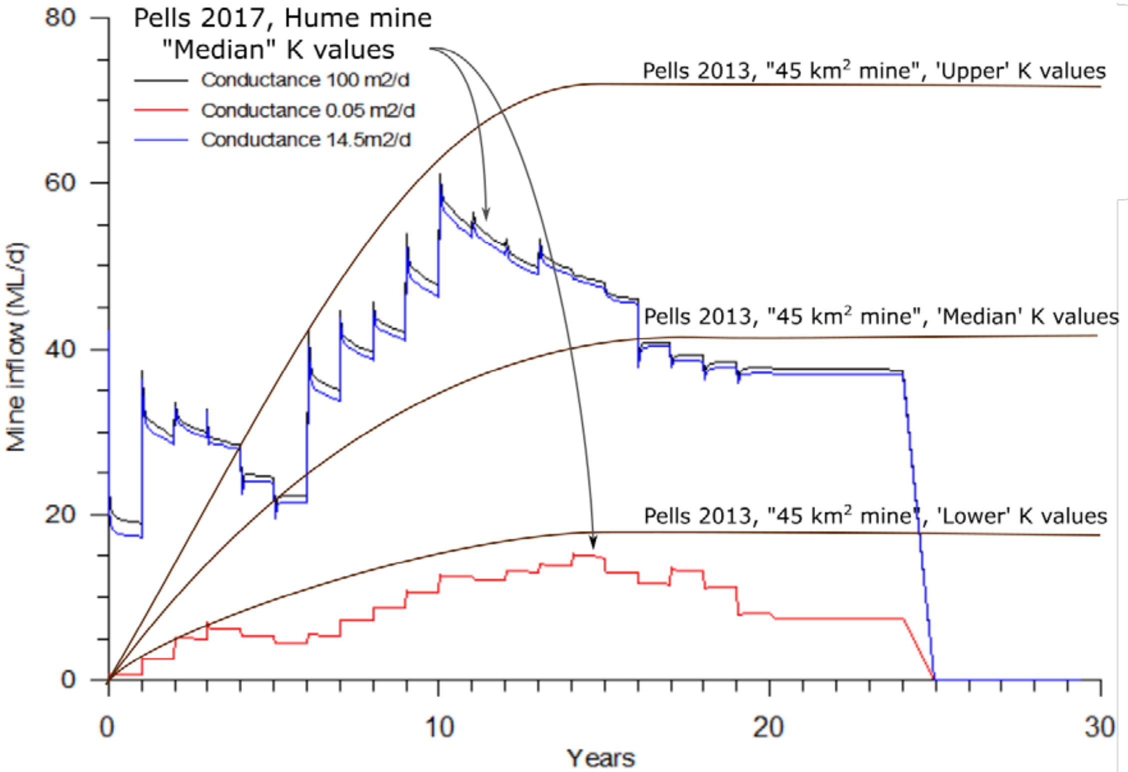

Figure 4.4 – Simulated mine inflows (note: "Median", "Upper" and "Lower" conductivity values were as presented in Tables 1 to 3 of Pells and Pells 2013)

4.3.2 Drawdown

Revised drawdown maps representing the current mine plan are presented in Figure 4.5 to Figure 4.8 below.

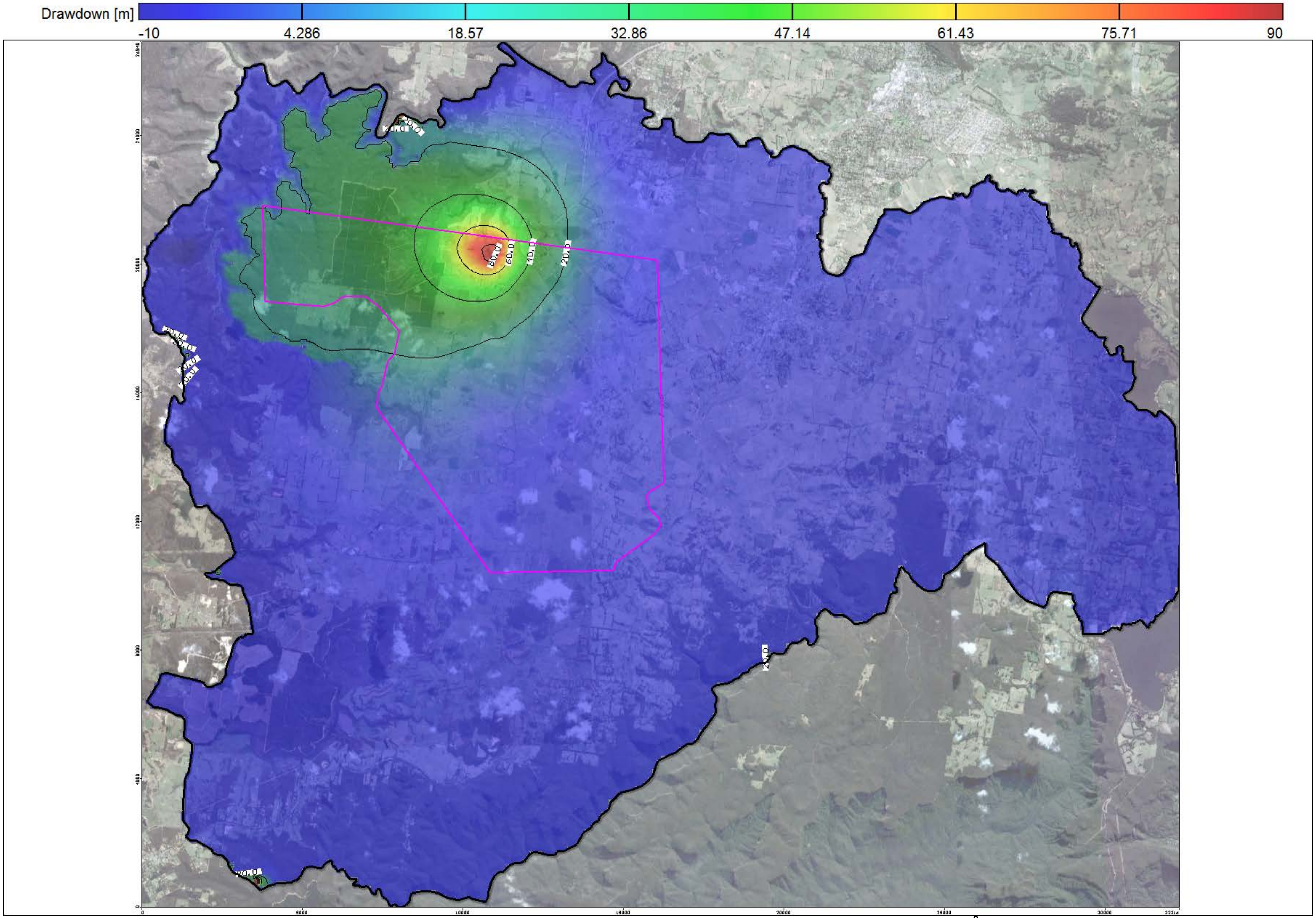

Figure 4.5 – Drawdown in Layer 4, standard values, 1 year elapsed, drain conductance 14.5m²/day

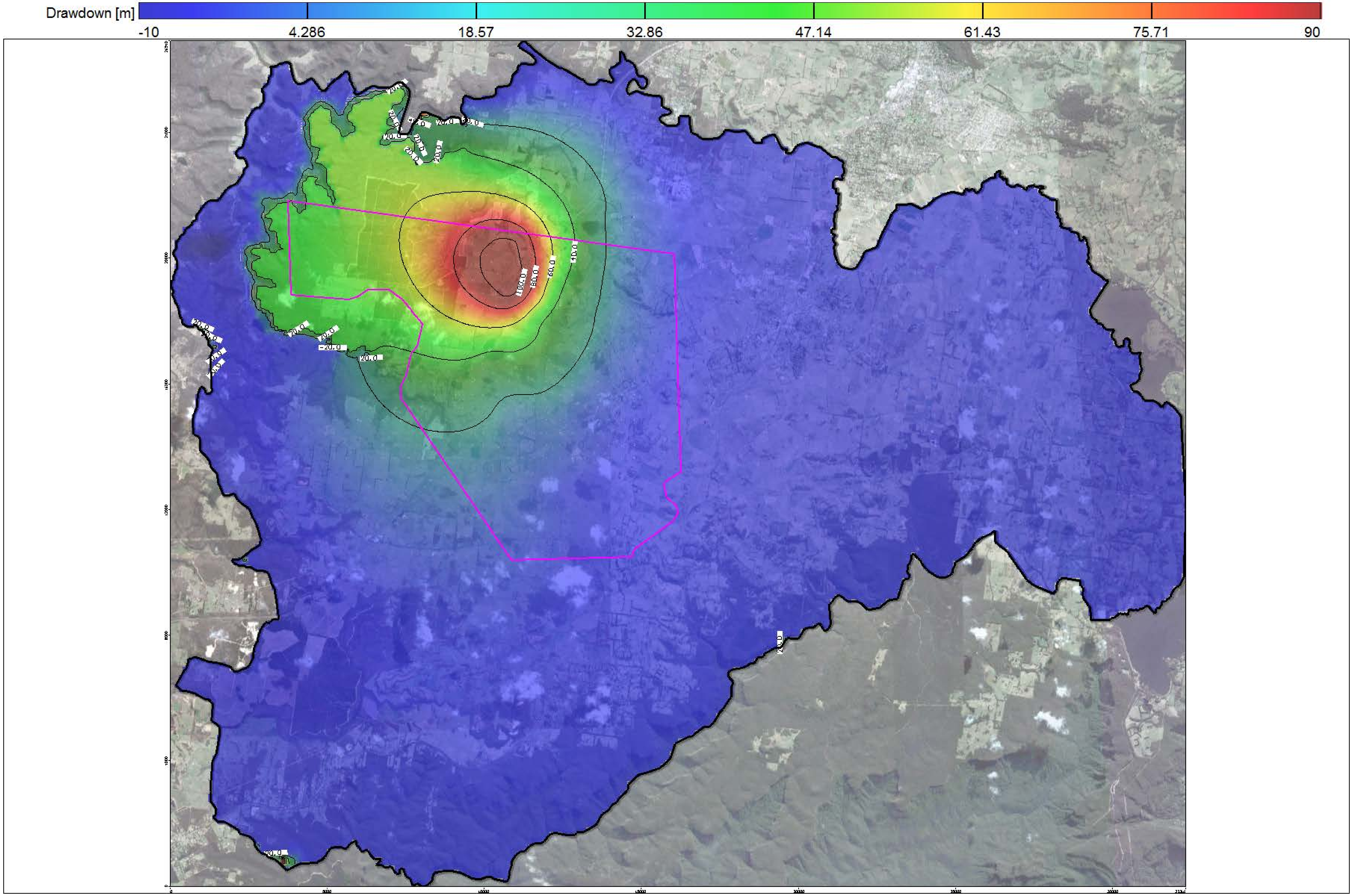

Figure 4.6 – Drawdown in Layer 4, standard values, 2 years elapsed, drain conductance 14.5m^2/day

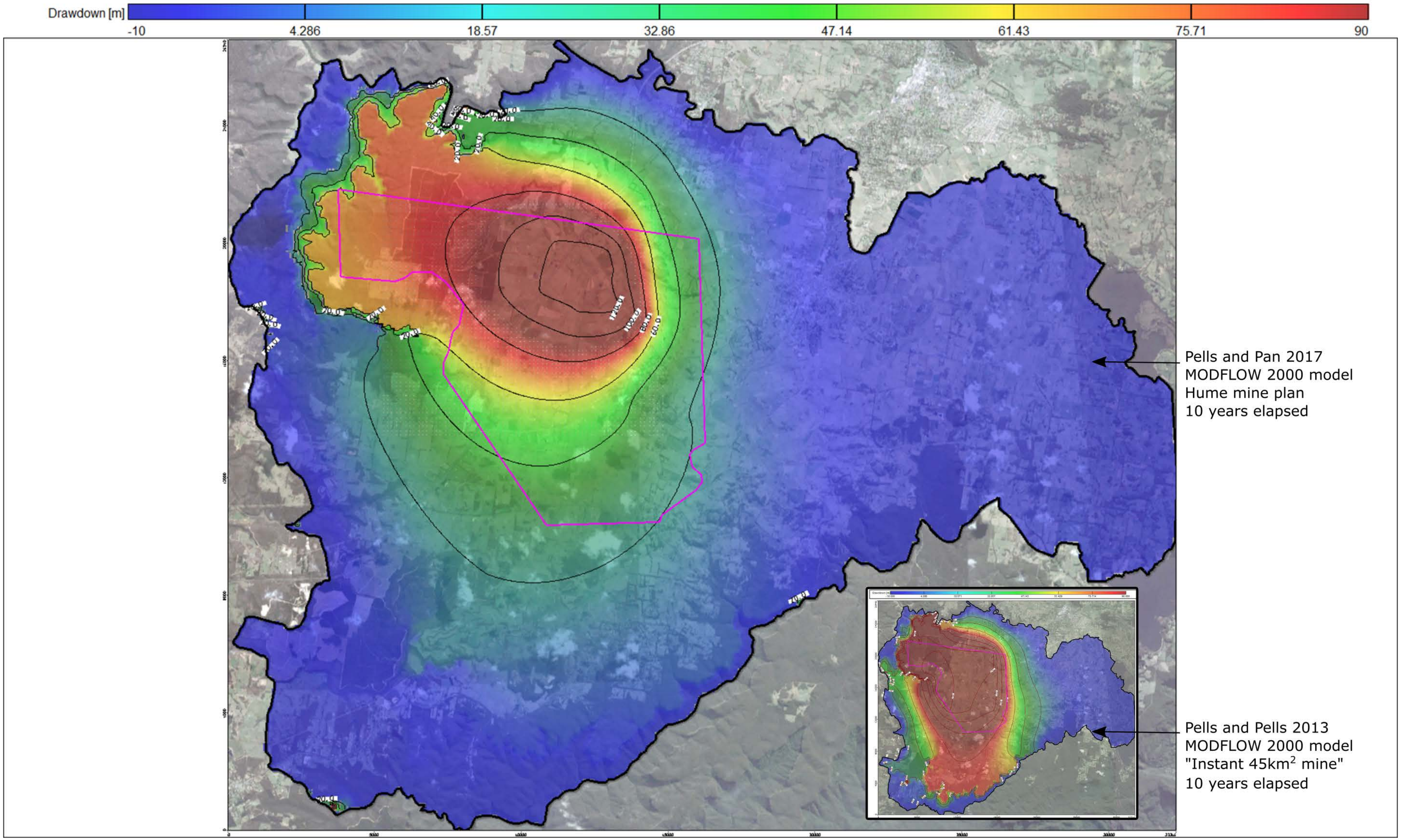

Figure 4.7 – Drawdown in Layer 4, standard values, 10 years elapsed, drain conductance 14.5m²/day.

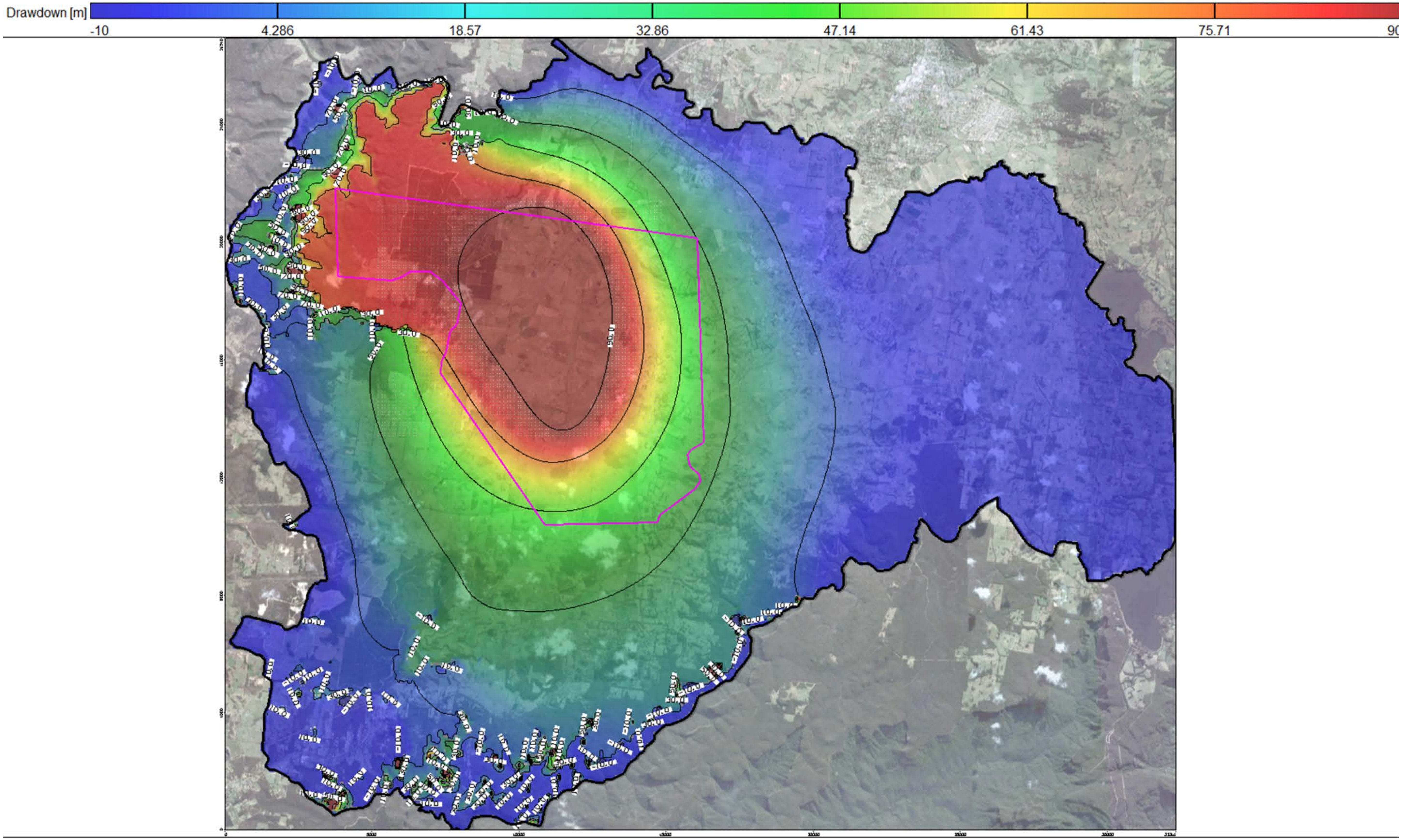

Figure 4.8 – Drawdown in Layer 4, standard values, 20 years elapsed, drain conductance 14.5m^2/day

4.4 Discussion

Figure 4.4 shows mine inflow predictions using the Pells Consulting model. It can be seen that predicted inflows for the proposed Hume 'pinefeather' mine plan are greatly reduced if the very low mine drain 'conductance' adopted in the EIS is used. As shown above, these drain conductance values used in the EIS are considered to be untenably low. If reasonable mine conductance values are used (as derived above), or if a large number is used, as per common practice (cited above) the predicted inflows to the Hume 'pinefeather' mine are much larger, and are within the range of inflows predicted by Pells and Pells 2013. Note that the inflows predicted in Pells and Pells 2013 represented a larger mine footprint of 45 square kilometres.

Hence, this demonstrates that the proposed pinefeather mine plan does not result in significant reductions in mine inflow. The smaller inflows presented in the EIS are due to the values adopted in the groundwater model (particularly mine drain conductance and formation parameters), and not due to the pine feather mine plan.

Drawdown maps presented in Figure 4.5 to Figure 4.8 above represent the proposed pine-feather mine. Predicted drawdowns in the productive Hawkesbury Sandstone layer under execution of the pine feather mine are up to 120 metres in magnitude, which is similar to the Pells and Pells 2013 prediction. The extent to drawdown under the proposed pinefeather model is reduced, although these predictions cannot be directly compared to previous drawdown maps presented in Pells and Pells 2013, as that previous model represented a larger (45km^2) mine. Nonetheless, predicted drawdown for the pinefeather mine has a magnitude 10m drawdown extending for 6 to 7 kilometres from the mine. The significantly smaller drawdown predicted in the EIS (a maximum of 80m, for a very limited zone around the mine, and drawdown greater than 2m extending little past the mine excavation footprint) arises due to modelling parameters chosen in the EIS, not due to the pine feather methodology.

5 REVISED MODELLING USING MODFLOW-SURFACT

The numerical groundwater modelling presented in The EIS adopted MODFLOW-SURFACT as the solution engine. MODFLOW-SURFACT is a proprietary code that offers some advantages over public-domain MODFLOW engines. In particular, MODFLOW-SURFACT offers alternatives for improved simulation of unsaturated flow conditions. This can be important in regions where mine effects result in drawdown to the extent that desaturation occurs.

The Pells Consulting MODFLOW models presented above, and also in Pells and Pells 2013, adopted MODFLOW 2000 as the engine. Revised modelling, presented below, adopted the MODFLOW-SURFACT engine for solutions. This was done to examine if any of the differences between predictions by Pells Consulting (above) and in The EIS could be explained by differing modelling solutions[5]. To obtain a solution using the previous MODFLOW 2000 code, many model layers in Pells Consulting (2013) were represented as 'Type 0 - confined'. Usage of the MODFLOW-SURFACT code presented below allowed model convergence with "Type 3 - unconfined / confined" conditions in all layers, which may offer better representation of drawdown where layers begin to become drawn down to the point of de-saturation. [6]

The model runs undertaken using MODFLOW-SURFACT are summarised in Table 4. A summary of which modelling results are presented in this report is given in Table 5.

Where the van Genuchten soil-water model is adopted, the model can simulate the development of matric suction, or negative pore pressures, which can arise as a geological formation becomes desaturated. This desaturation causes a reduction in hydraulic conductivity, thus affecting simulated flow conditions. The rate of reduction is defined by 'van Genuchten' parameters (after van Genuchten, 1980). There is a paucity of available data to guide suitable choice of van Genuchten parameters for fractured rock formations. The values chosen for this modelling reflect values presented in Pells and Pells 2012. Alternative values were also chosen to examine sensitivity of the prediction to adopted van Genuchten values. The reduction of hydraulic conductivity as a function of matric suction that arises from using these values is presented in Figure 5.1. Further examination of sensitivity to desaturation was also undertaken through solution of the model using a 'pseudo-soil' assumption[7].

---

[5] The EIS reported to use MODFLOW-SURFACT, but did not report which unsaturated flow solutions were adopted (ie 'pseudo-soil', van Genuchten or Brook and Corey solutions)

[6] Layer types are explain in the Visual Modflow manual as:

> Type 0 - Confined: Transmissivity and storage coefficients of the layer are constant for the entire simulation.
>
> Type 1 - Unconfined: Transmissivity of the layer varies and is calculated from the saturated thickness and hydraulic conductivity.
>
> Type 2 - Confined/Unconfined: Transmissivity of the layer is constant. The storage coefficient may alternate between confined and unconfined values.
>
> Type 3 - Confined/Unconfined: Transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity. The storage coefficient may alternate between confined and unconfined values.

[7] The 'pseudo-soil' setting allows desaturation of model cells, and development of negative pressures (matric suction), but without any change to hydraulic conductivity. The value of matric suction is unrealistic, but allows a solution to nonetheless proceed. This contrasts to standard MODFLOW solutions, which cause cells to become 'dry' and turn off when desaturated.

Table 4 – Model runs undertaken in MODFLOW-SURFACT

Scenario	Formation parameters		Mine drains		Soil-water model			
	Conductivity[1.]	Storage[2.]	Conductance[3.]	opening period[4.]	Type[5.]	α	β	SR
1	Median	Pells	14.5	1 year	VG1	0.2	3	0.01
2	Median	Pells	0.1	2 years	VG1	0.2	3	0.01
3	**Median**	**Pells**	**14.5**	**2 years**	**VG1**	**0.2**	**3**	**0.01**
4	Median	Pells	100	2 years	VG1	0.2	3	0.01
5	Median	Pells	1000	2 years	VG1	0.2	3	0.01
6	Median	Pells	14.5	5 years	VG1	0.2	3	0.01
7	Upper	Pells	14.5	2 years	VG1	0.2	3	0.01
8	Lower	Pells	14.5	2 years	VG1	0.2	3	0.01
9	Median	EIS	14.5	2 years	VG1	0.2	3	0.01
10	Median	Pells	14.5	2 years	VG2	0.6	6	0.02
11	Standard	Pells	14.5	2 years	PS	-	-	-

1. As per Pells and Pells 2013 – reproduced below
2. 'Pells' refers to storage values adopted in Pells and Pells 2013.
   'EIS' refers to storage values adopted in the EIS modelling
3. Mine conductance, as discussed in Section 3.2 and 4.1 above
4. Period elapsed from start of mining of a panel until bulkheads are installed
5. VG = van Genuchten (α, β and SR are van Genuchten parameters) ; PS = pseudo-soil

Table 5 – Results presented in this report from model runs undertaken in MODFLOW-SURFACT

Scenario	Mine inflows	drawdown maps				mass balance
		1 year	2 years	10 years	20 years	
1	✓	✓	✓	✓	✓	
2	✓					
3	✓	✓	✓	✓	✓	✓
4	✓					
5	✓					
6	✓	✓	✓	✓	✓	
7	✓			✓		
8	✓			✓		
9	✓			✓		
10	✓	✓	✓	✓	✓	✓
11	✓	✓	✓	✓	✓	✓

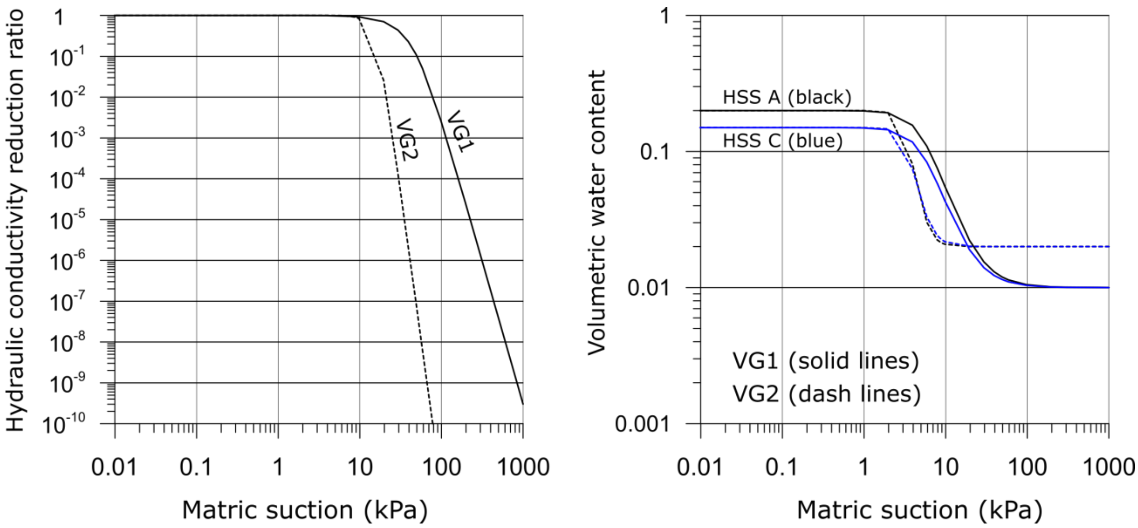

Figure 5.1 – Soil-water curves adopted in modelling (note for clarity only two examples are presented for volumetric water content)

5.1 Inflows

Predicted inflows for each of the Scenarios are presented here. The manner of presentation first requires clarification.

The numerical model was run with approximately monthly timesteps. However, to reduce computing storage requirements, many models were set to report the results only at yearly intervals. Predicted inflows for Scenario 3 are shown in Figure 5.2, showing both monthly and yearly reporting. For the monthly reporting, large peaks in the inflow coincide with a new section of mine excavation. However the magnitude of these peaks is overstated in the model, as the model represents each portion of mine to be formed instantaneously. It can be seen that yearly reporting effectively removes these steps, and is considered to provide a better representation of predicted inflows.

The following plots of predicted inflows are presented below, and adopt annual reporting:

- In Figure 5.3, Scenarios 3, 9 and 10 compare inflows with various soil functions. The tested range in van Genuchten values (VG1 – Scenario 3 vs VG2 –Scenario 10) do not affect predicted inflows significantly. The pseudo-soil function (Scenario 9) results in larger inflows.

- In Figure 5.4, Scenarios 2, 3, 4 and 5 compare inflows with various mine drain conductance. There is no difference in inflows for conductance values above the chosen value of 14.5 m^2/day, showing that formation losses control. The drain conductance of 0.1 m^2/day (the upper value in the EIS) significantly controls mine inflows, reducing flows by up to 70%.

- In Figure 5.5, Scenarios 1, 3 and 6 compare inflows with various assumed panel opening times. This timing does not greatly affect inflows, although longer times to closure do result in larger inflows, as expected.

- In Figure 5.6, Scenarios 3, 7 and 8 compare inflows with the range of hydraulic conductivity values (‘median’, ‘upper’ and ‘lower’ values, as presented in Tables 1 to 3 in Pells and Pells 2013). Larger conductivity values are associated with larger inflows, and vice versa.

- In Figure 5.7, Scenarios 3 and 9 compare inflows with the range of storage values. The very low storage values adopted in The EIS result in significantly smaller predicted inflows.

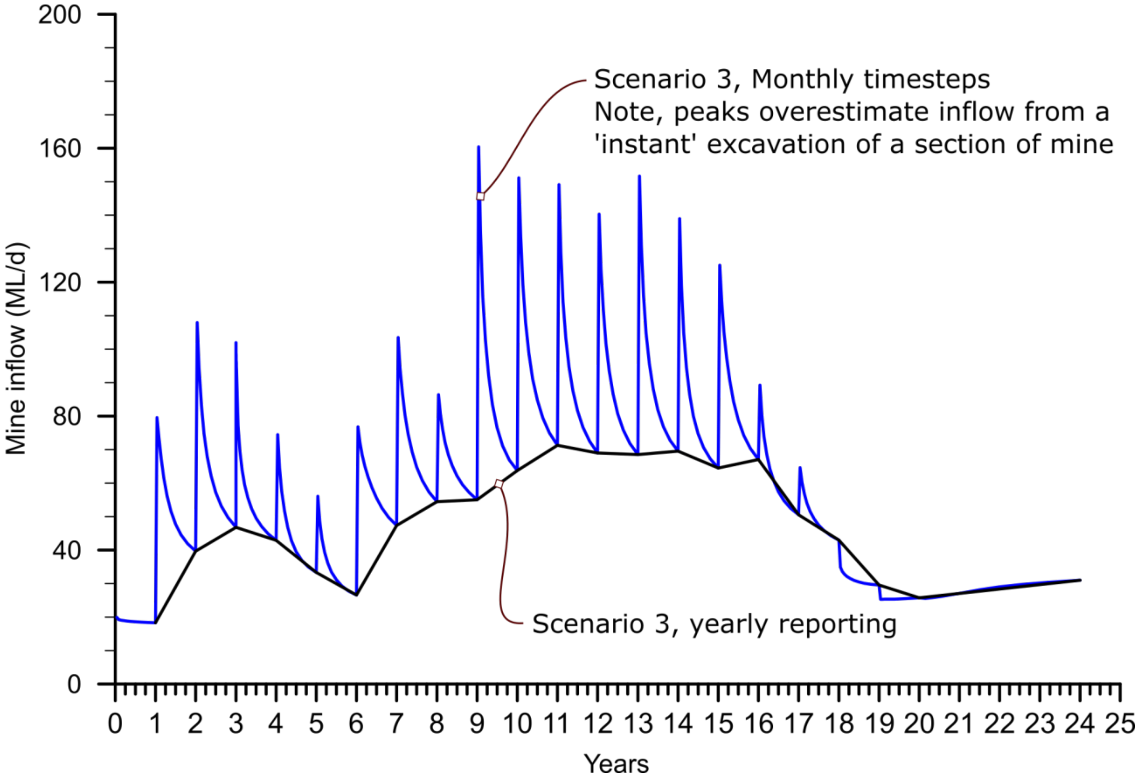

Figure 5.2 – Predicted inflow, Scenario 3, showing monthly and yearly reporting of model outputs

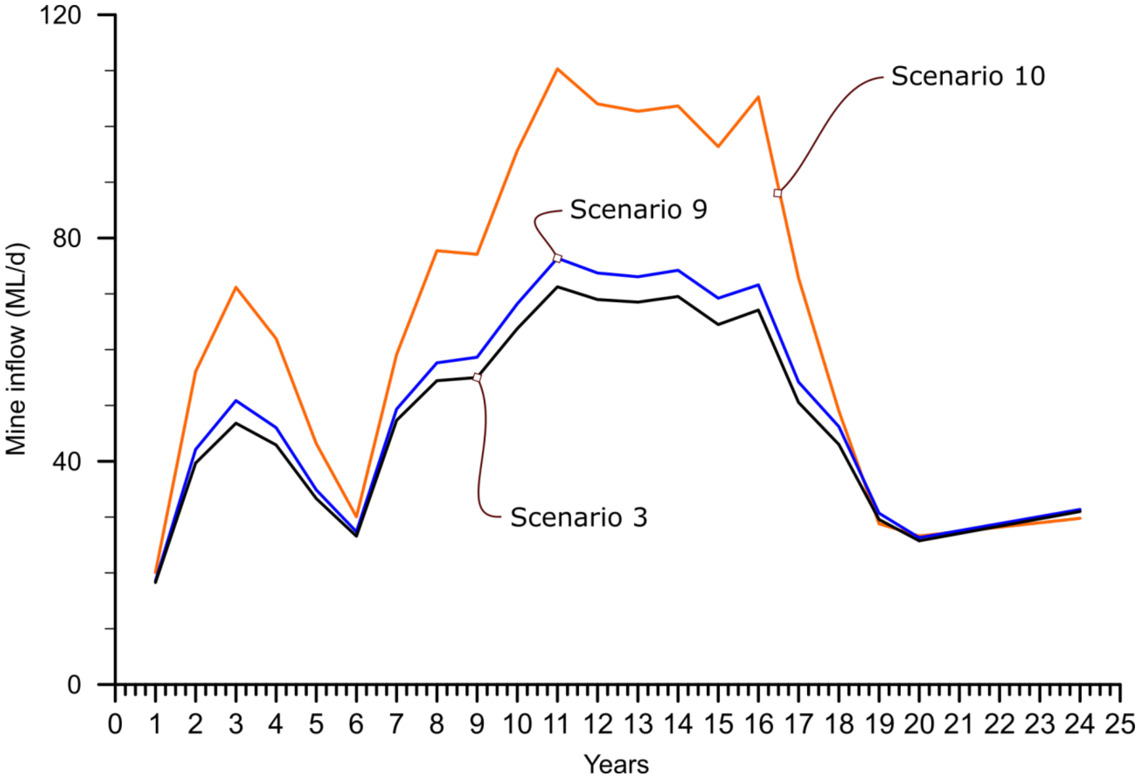

Figure 5.3 – Predicted inflow, Scenarios 3, 9 and 10, showing the effects of various soil functions

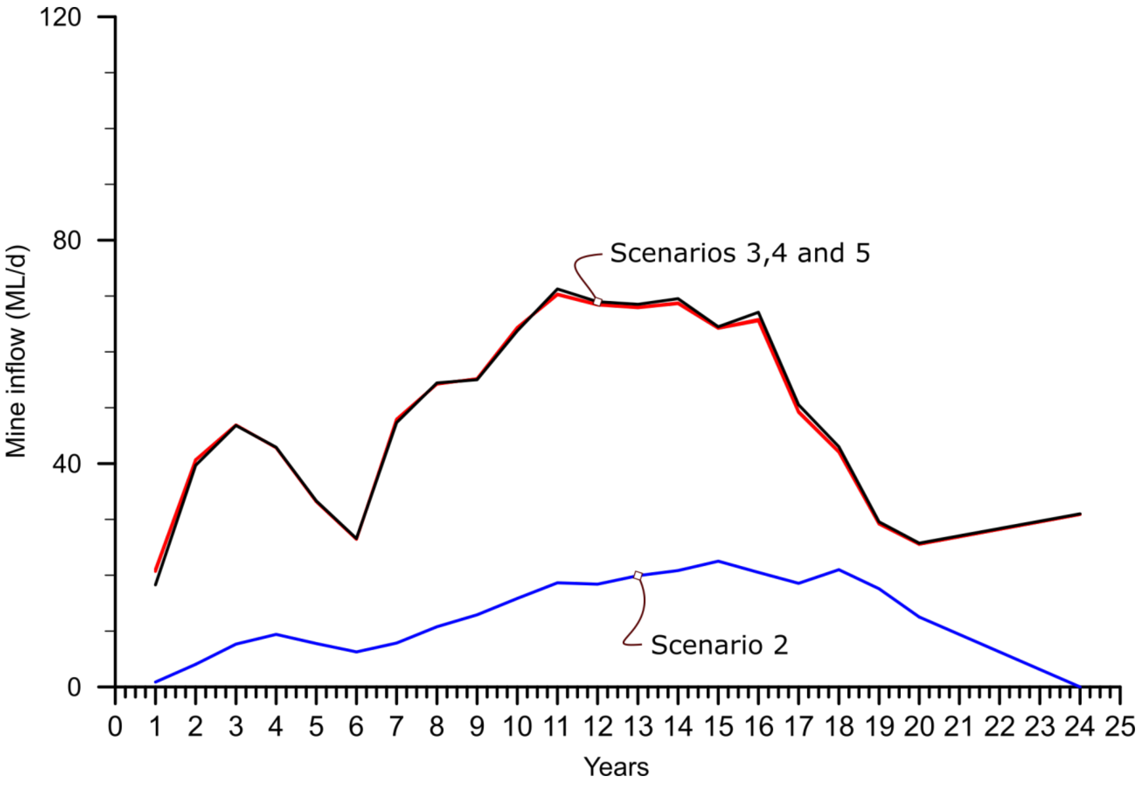

Figure 5.4 – Predicted inflow, Scenarios 2, 3, 4 and 5 showing the effects of mine drain conductance

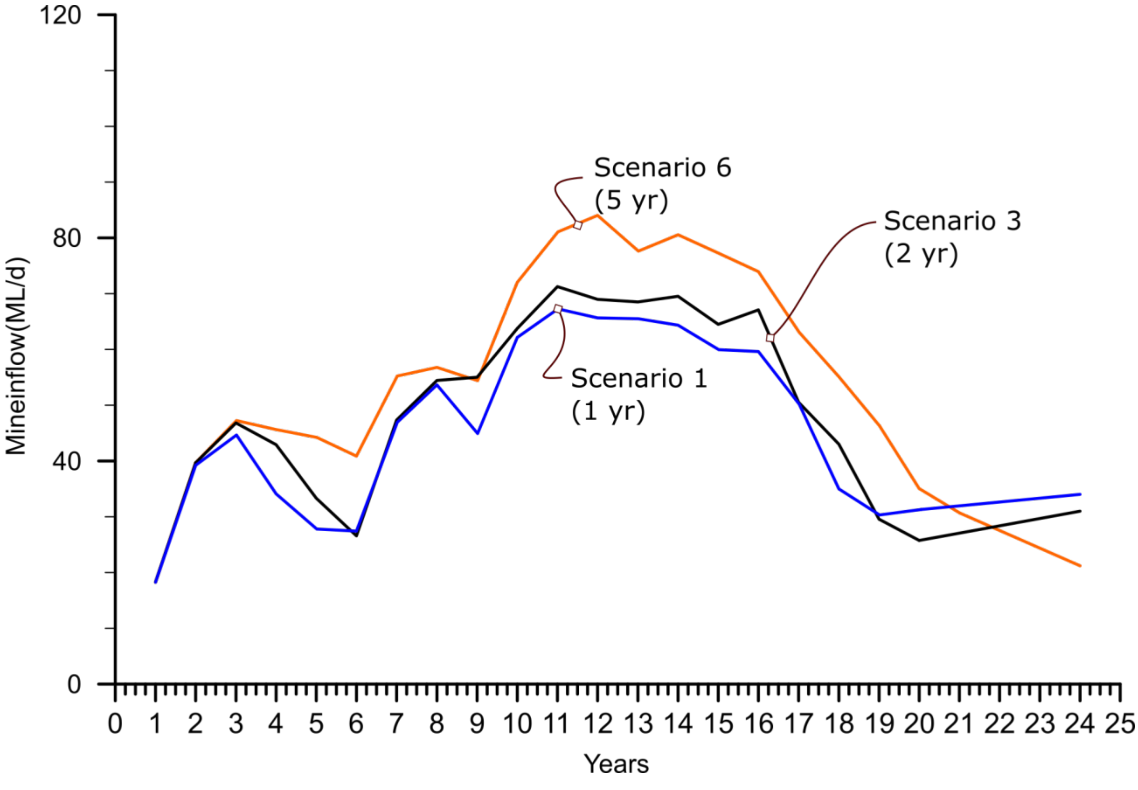

Figure 5.5 – Predicted inflow, Scenarios 1, 3 and 6 showing the effects of time to place panel bulkheads

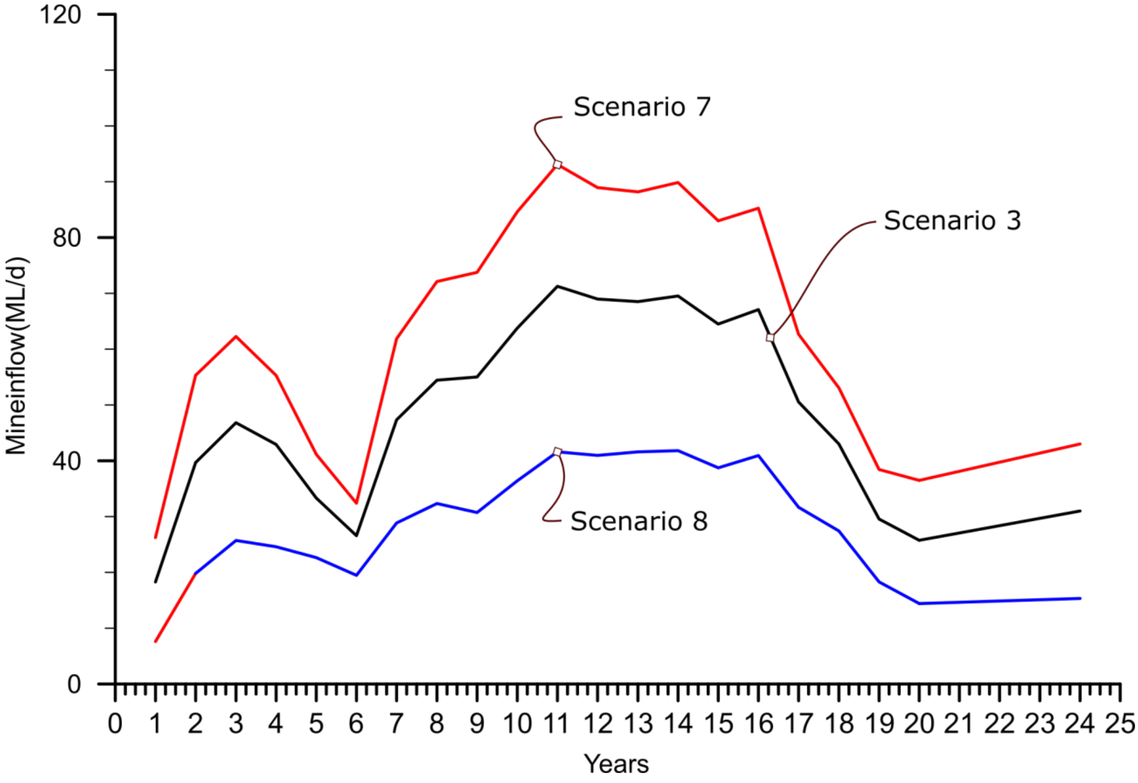

Figure 5.6 – Predicted inflow, Scenarios 3, 7 and 8 showing the effect of changes to hydraulic conductivity

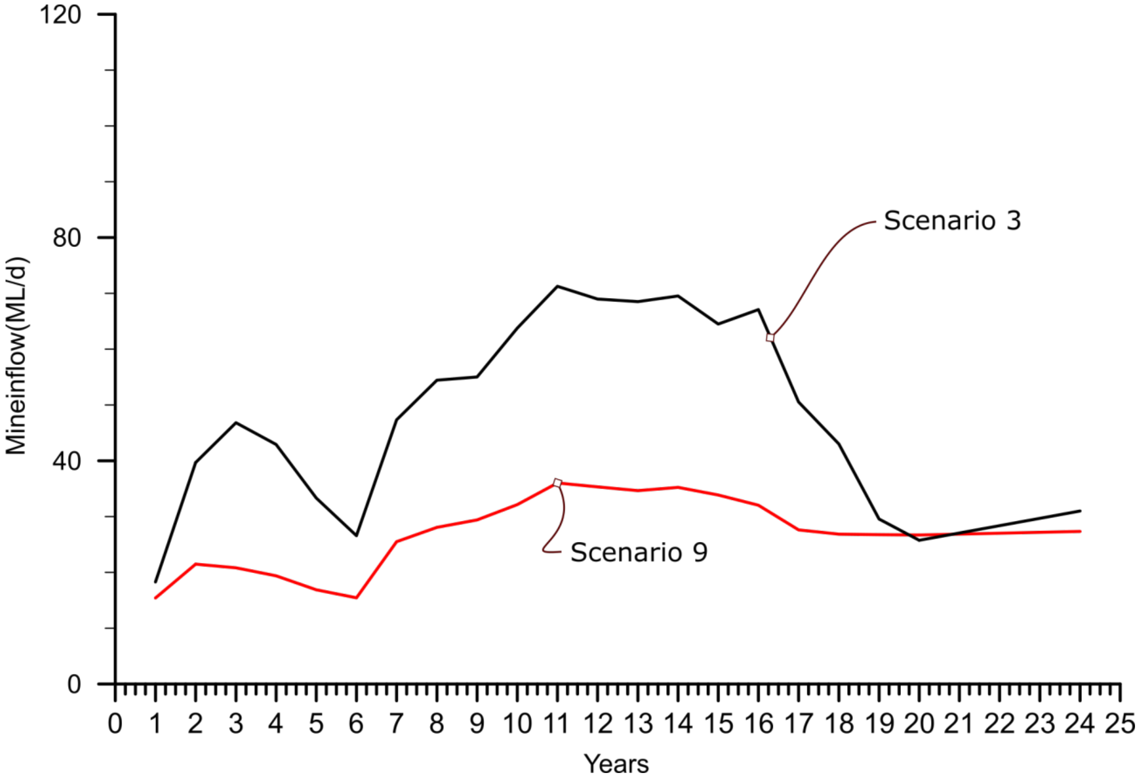

Figure 5.7 – Predicted inflow, Scenarios 3 and 9, showing the effect of changes to storage values

5.2 Drawdown

Drawdown plots are presented below.

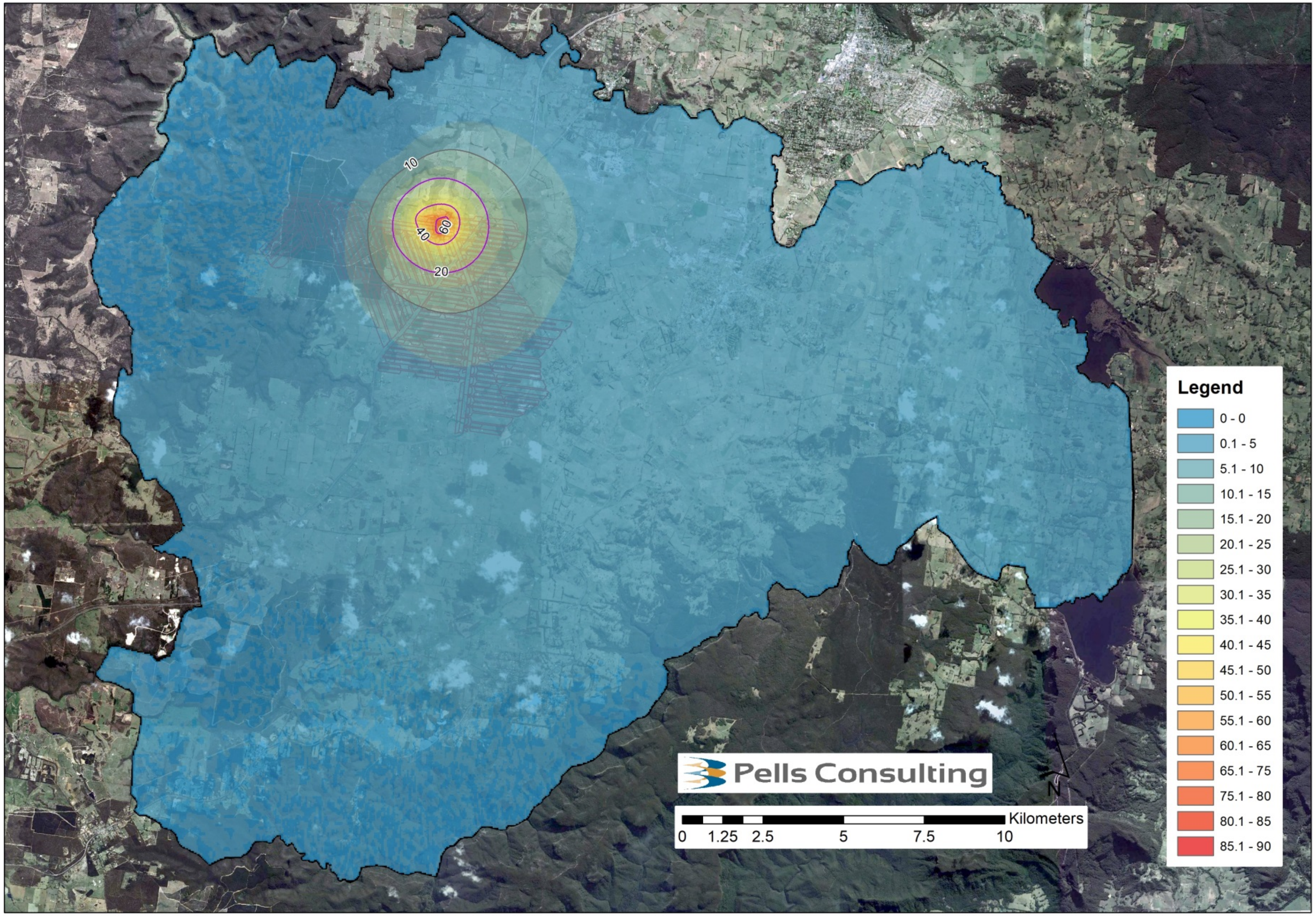

Figure 5.8 – Scenario 1. Drawdown in Layer 5. 1 yr elapsed

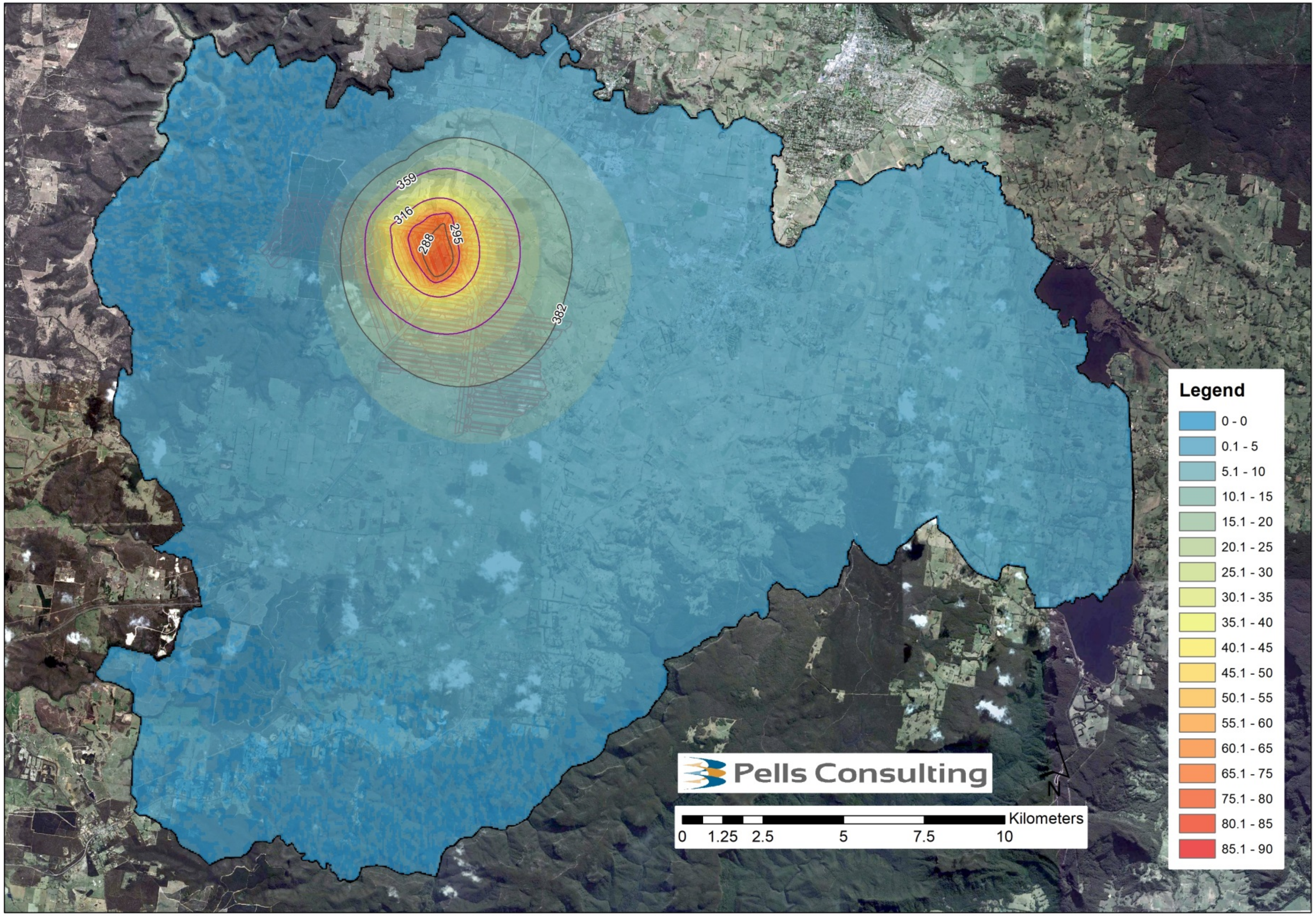

Figure 5.9 – Scenario 1. Drawdown in Layer 5. 2 yrs elapsed

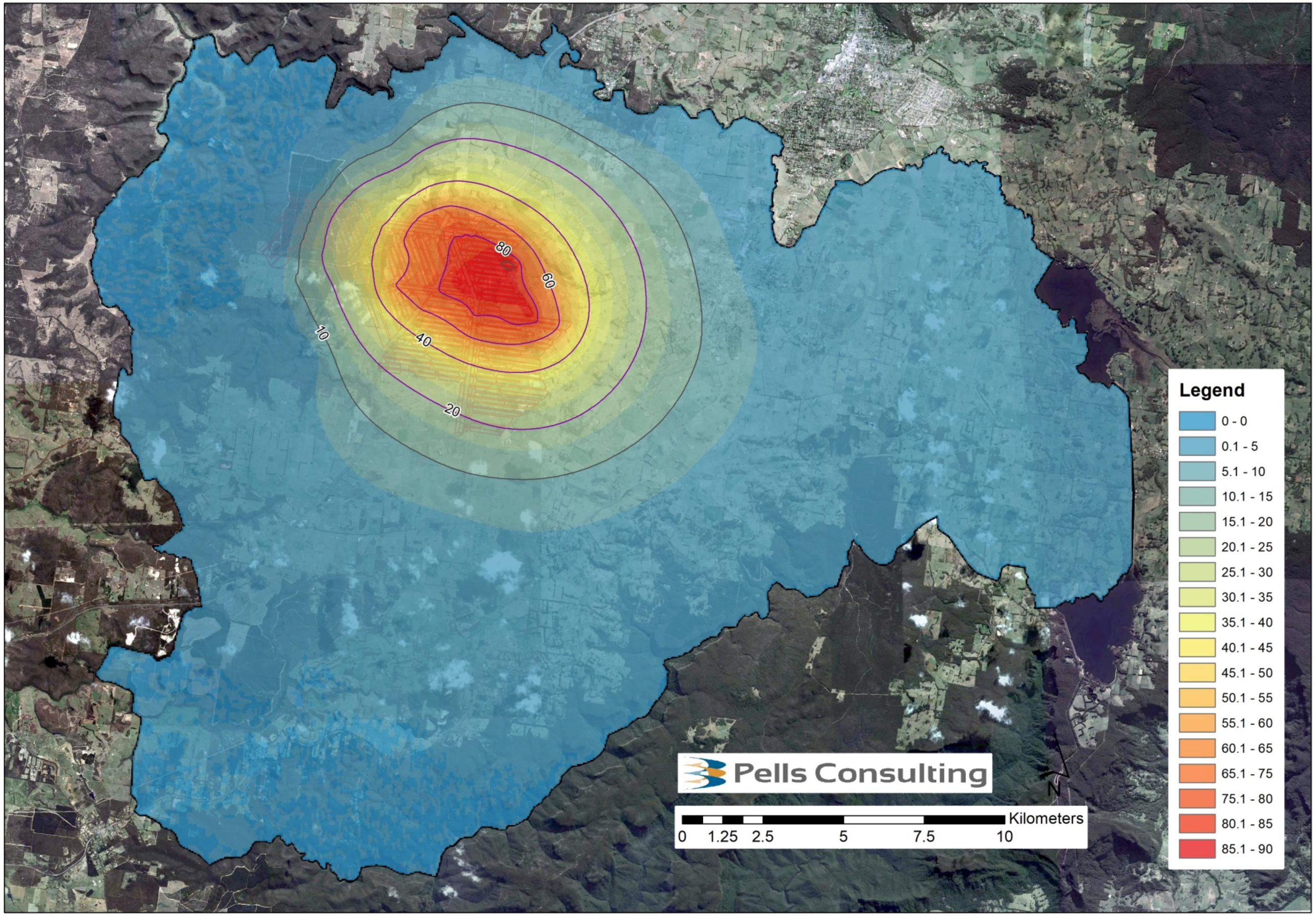

Figure 5.10 – Scenario 1. Drawdown in Layer 5. 10 yrs elapsed

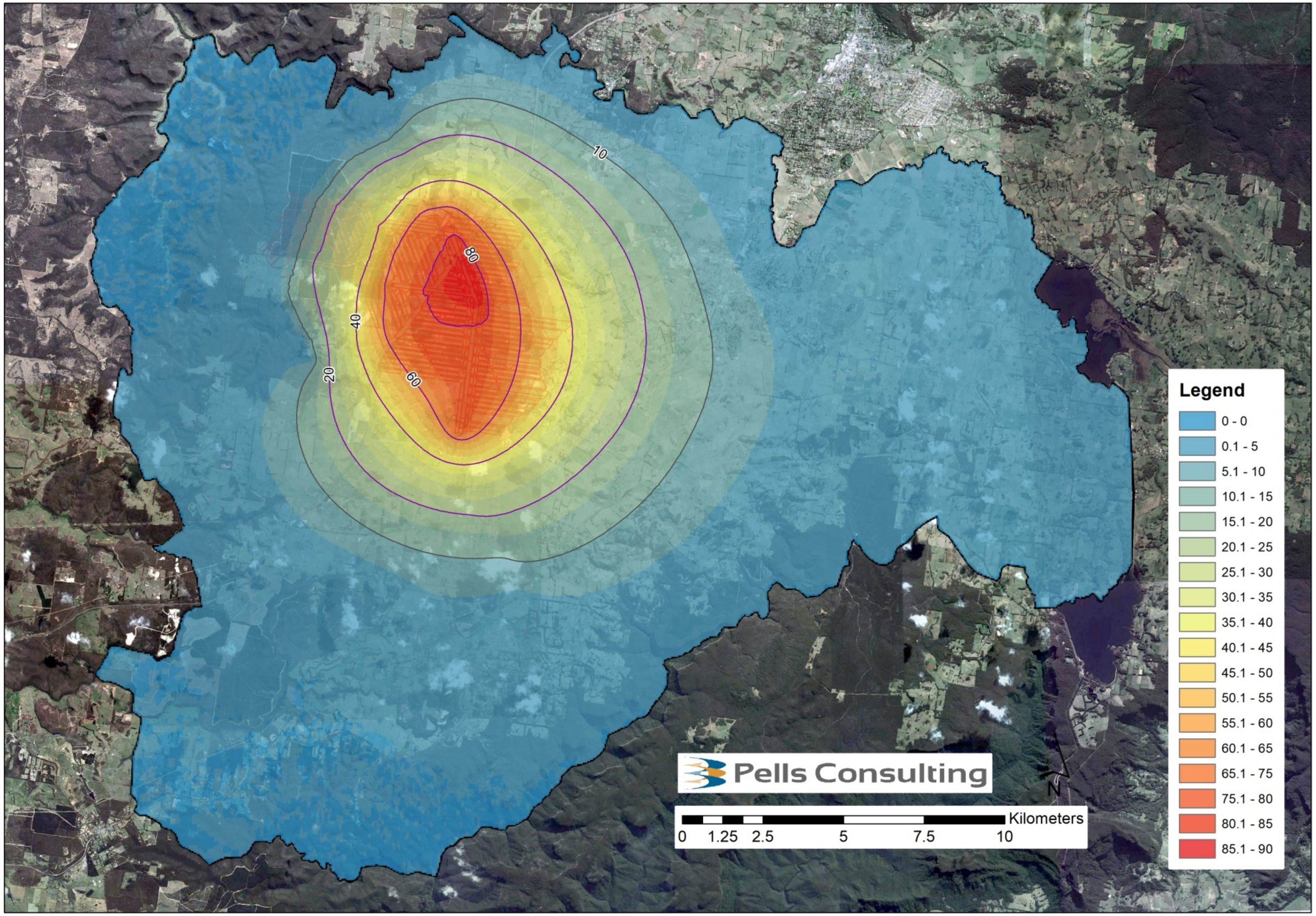

Figure 5.11 – Scenario 1. Drawdown in Layer 5. 20 yrs elapsed

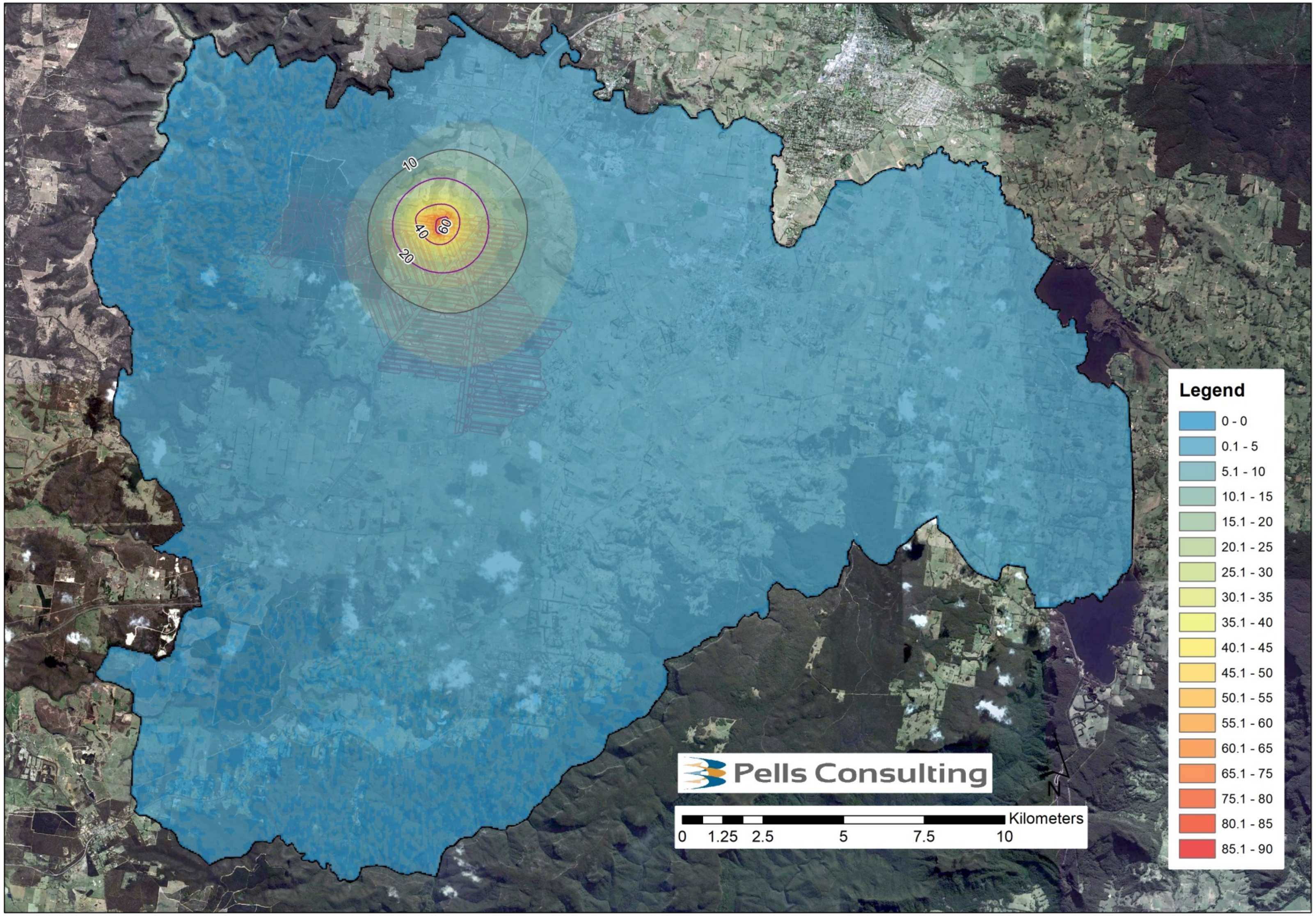

Figure 5.12 – Scenario 3. Drawdown in Layer 5. 1 yr elapsed

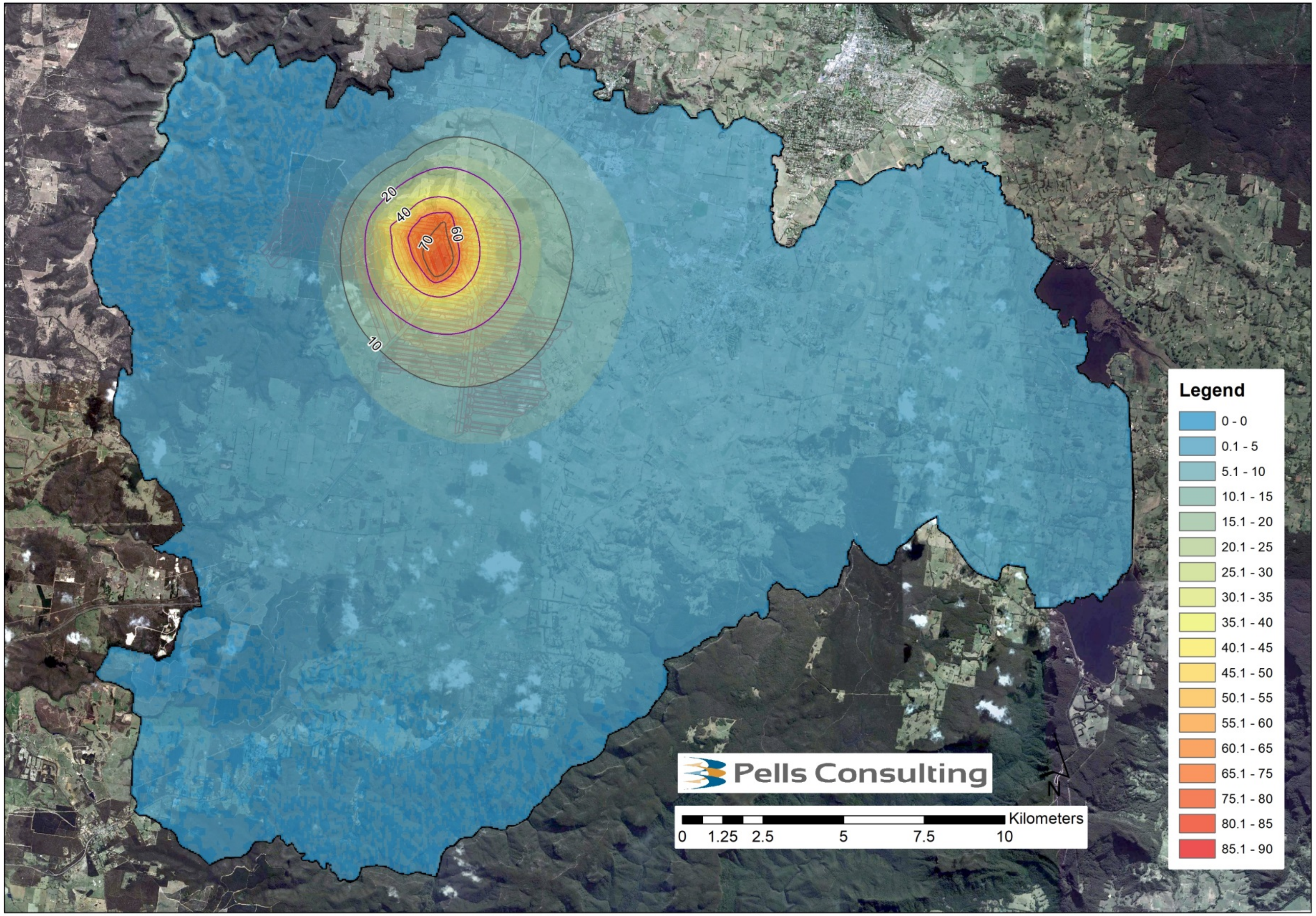

Figure 5.13 – Scenario 3. Drawdown in Layer 5. 2 yrs elapsed

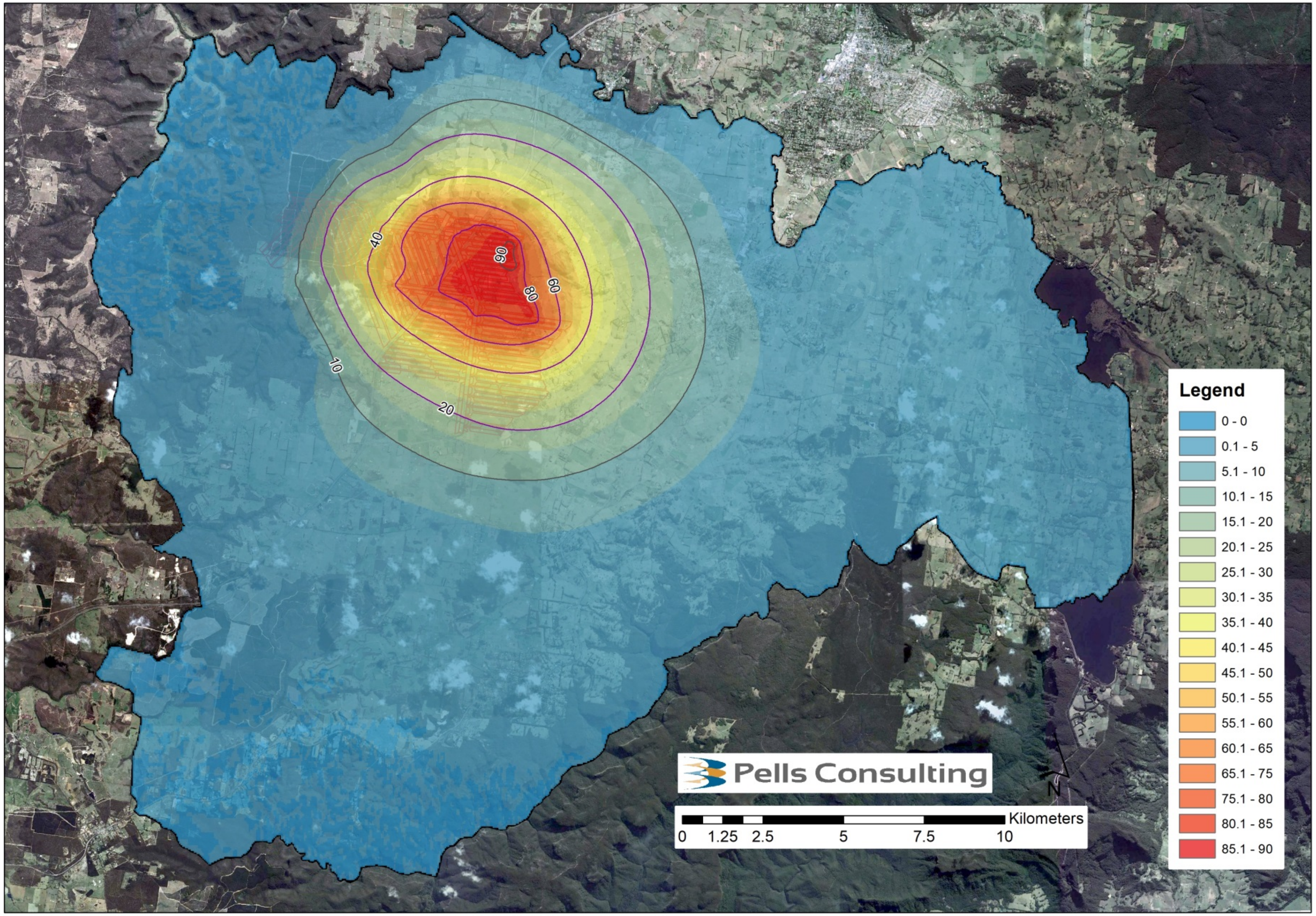

Figure 5.14 – Scenario 3. Drawdown in Layer 5. 10 yrs elapsed

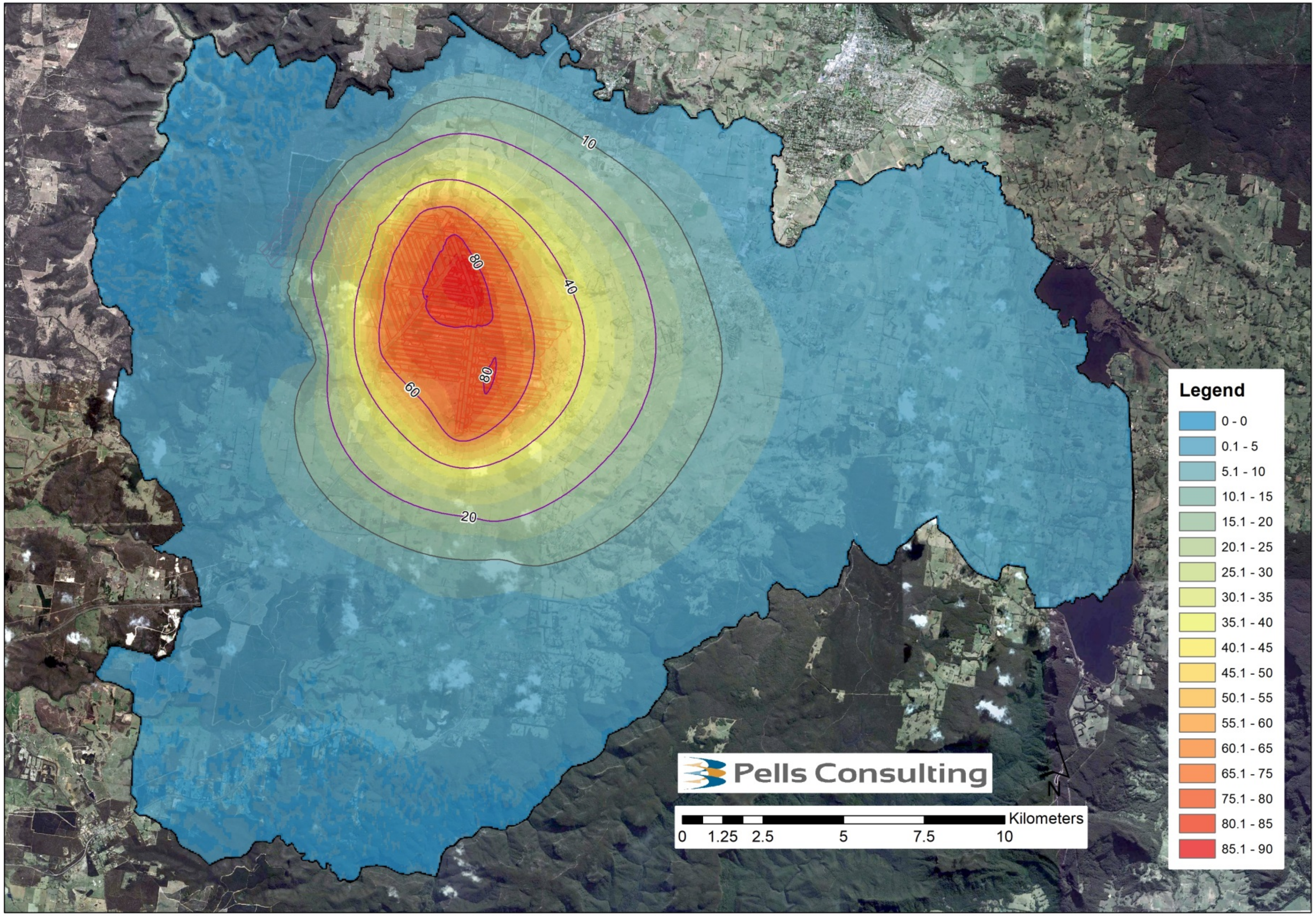

Figure 5.15 – Scenario 3. Drawdown in Layer 5. 20 yrs elapsed

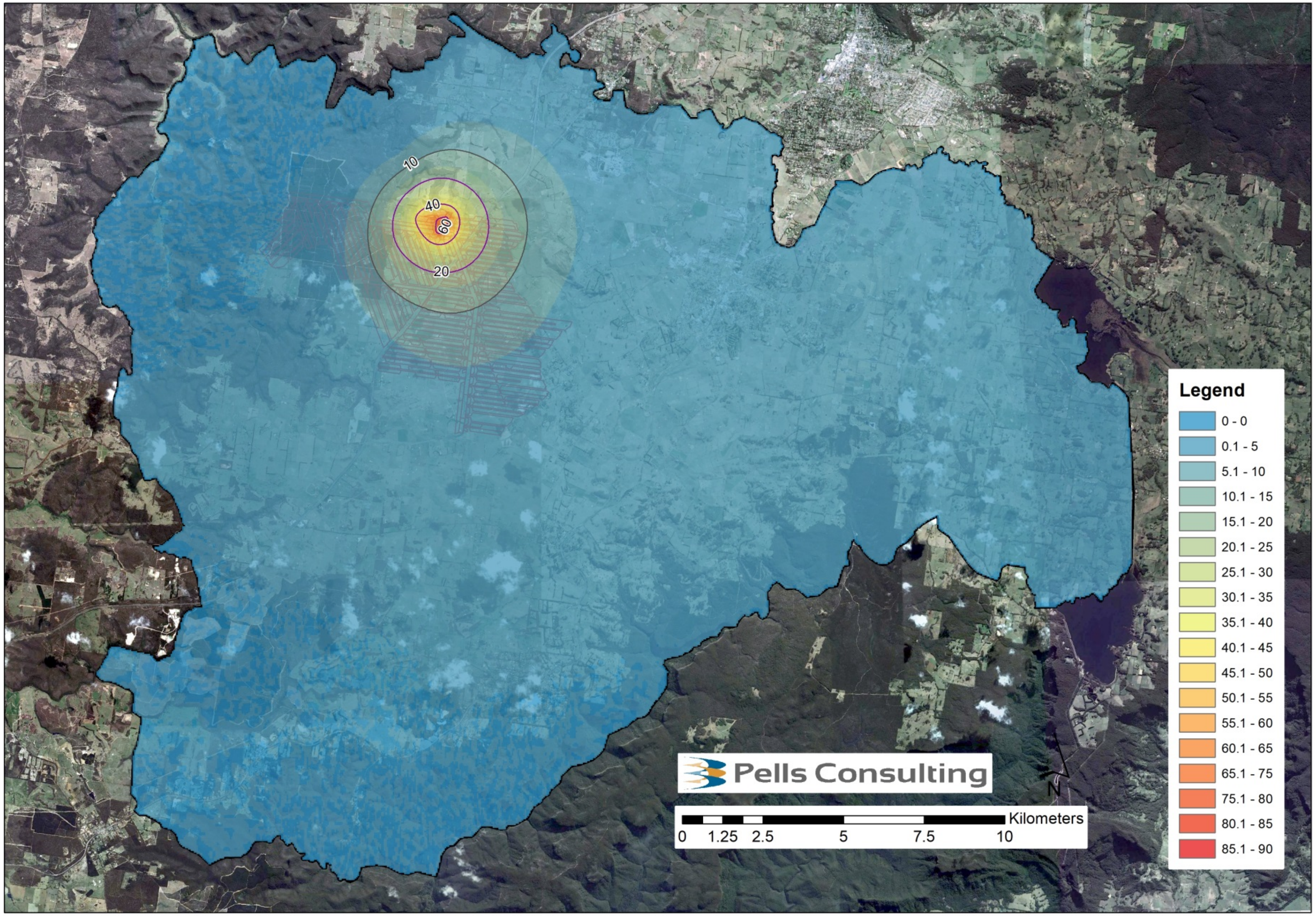

Figure 5.16 – Scenario 6. Drawdown in Layer 5. 1 yr elapsed

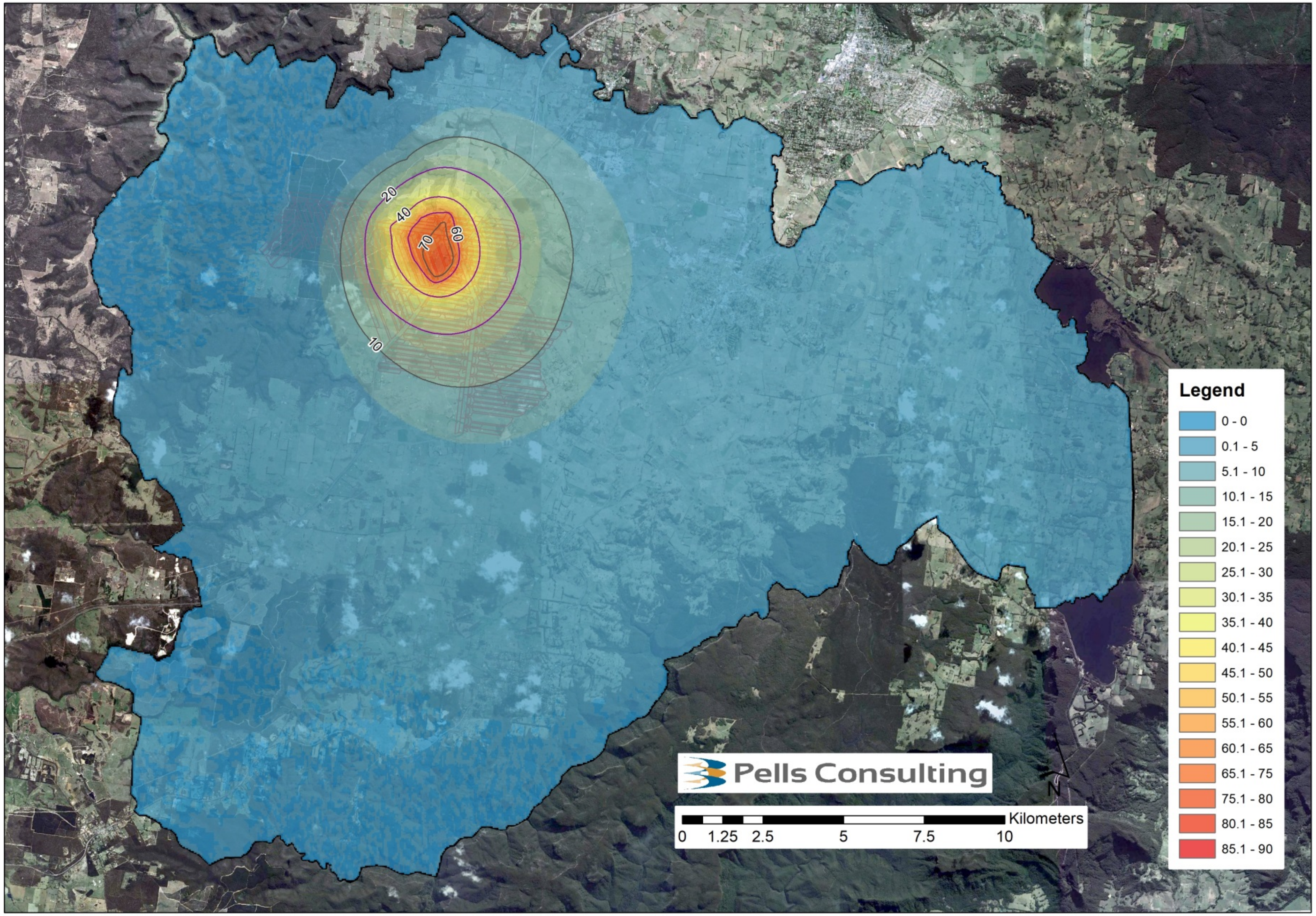

Figure 5.17 – Scenario 6. Drawdown in Layer 5. 2 yrs elapsed

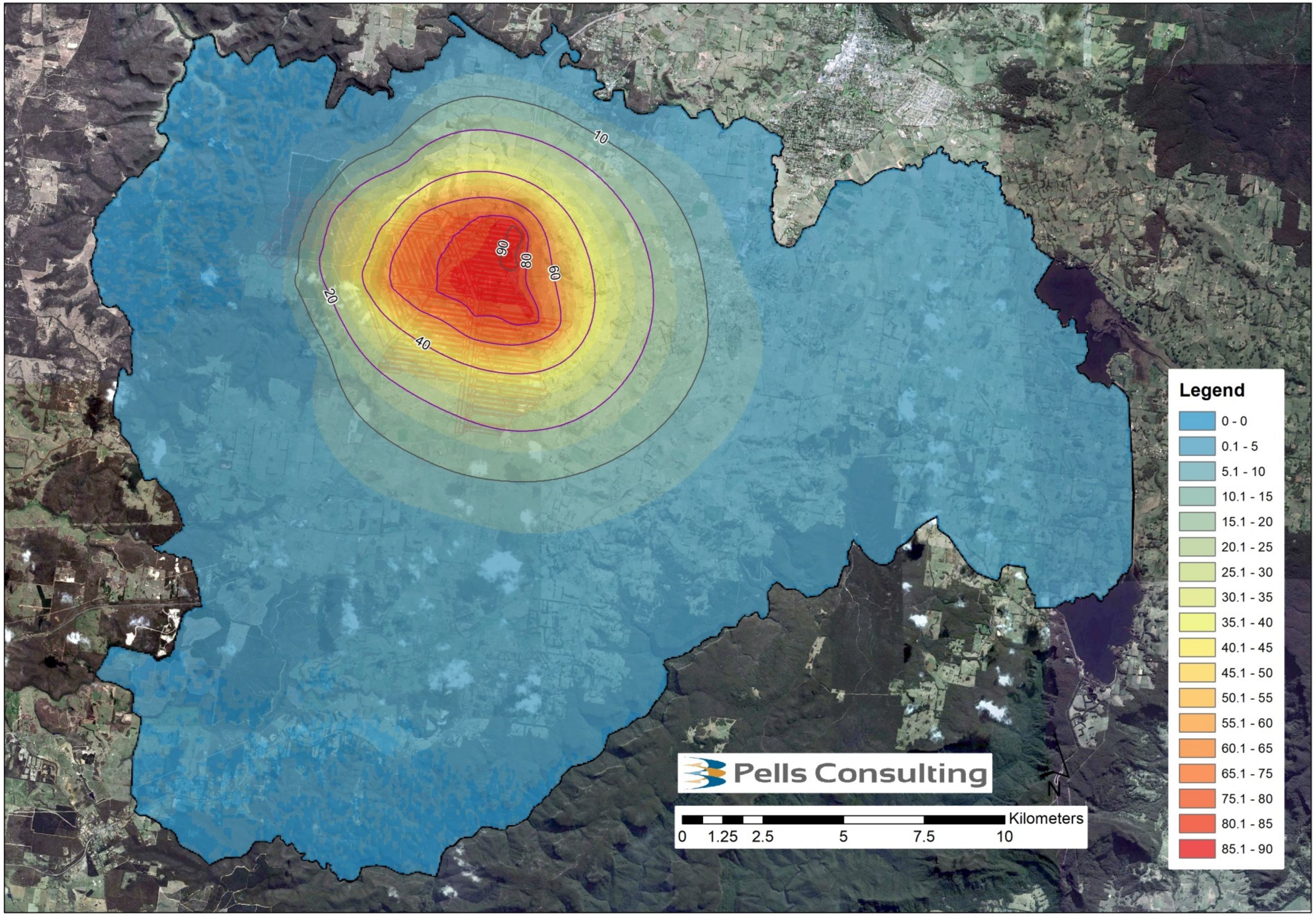

Figure 5.18 – Scenario 6. Drawdown in Layer 5. 10 yrs elapsed

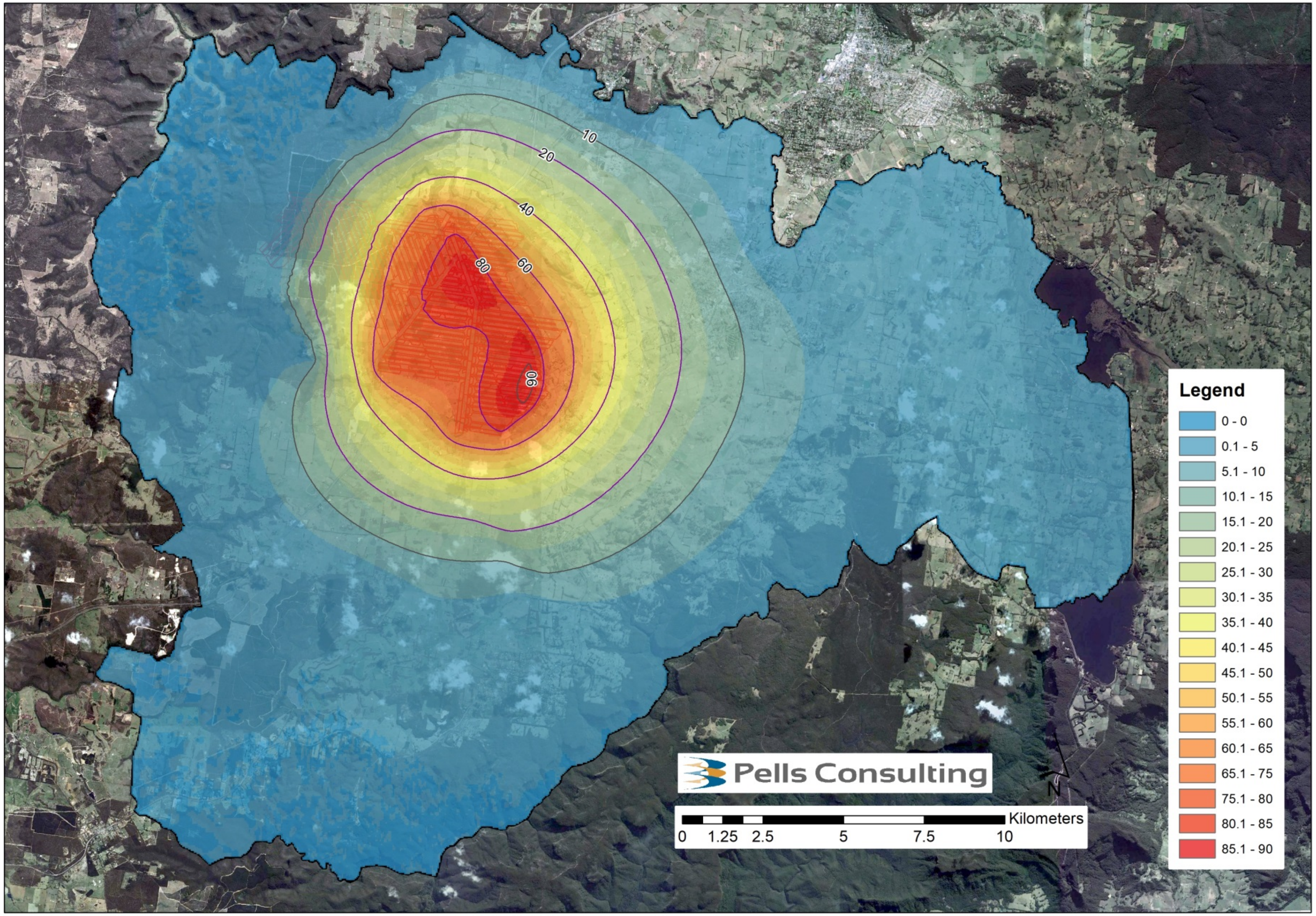

Figure 5.19 – Scenario 6. Drawdown in Layer 5. 20 yrs elapsed

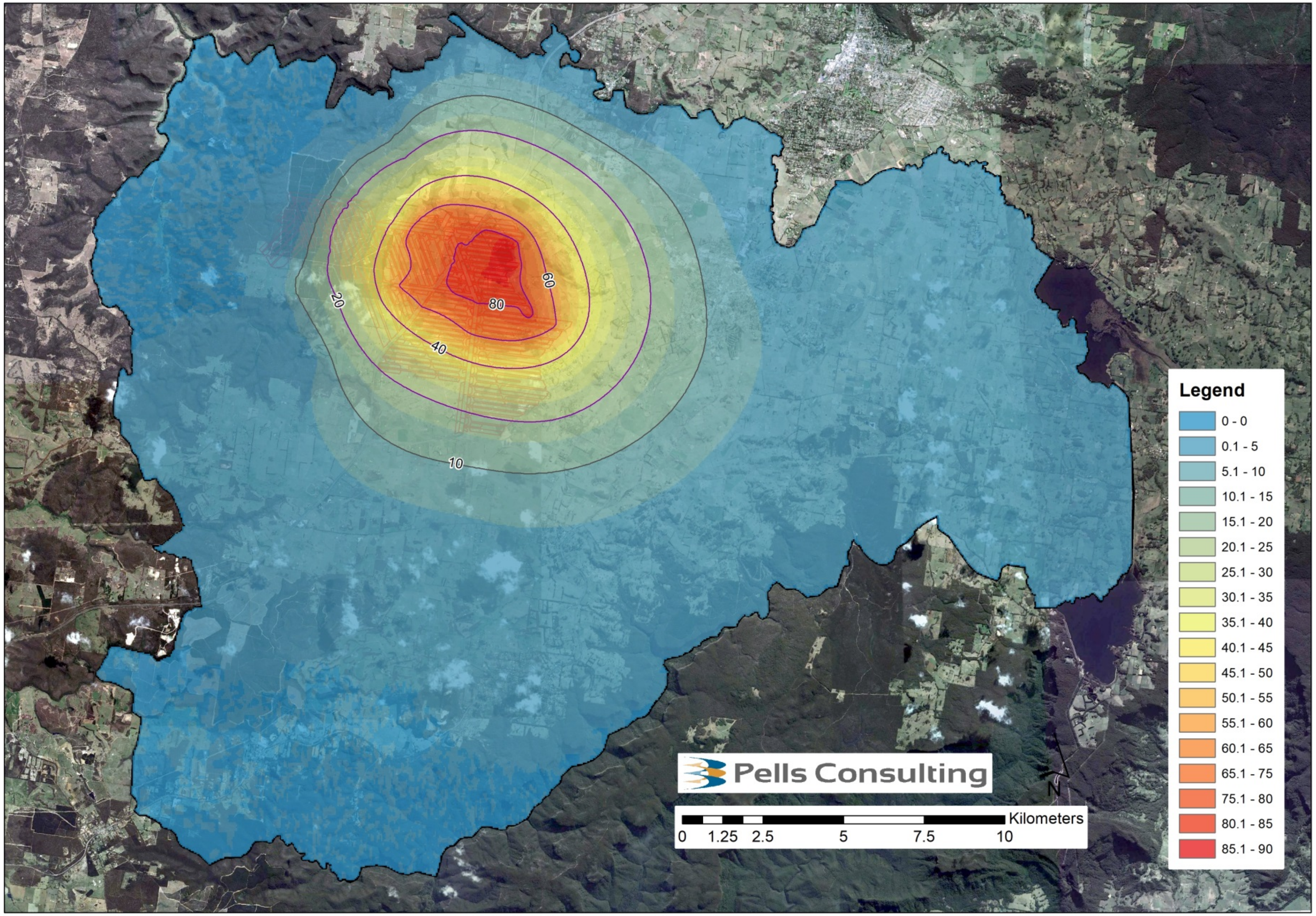

Figure 5.20 – Scenario 7. Drawdown in Layer 5. 10 yrs elapsed

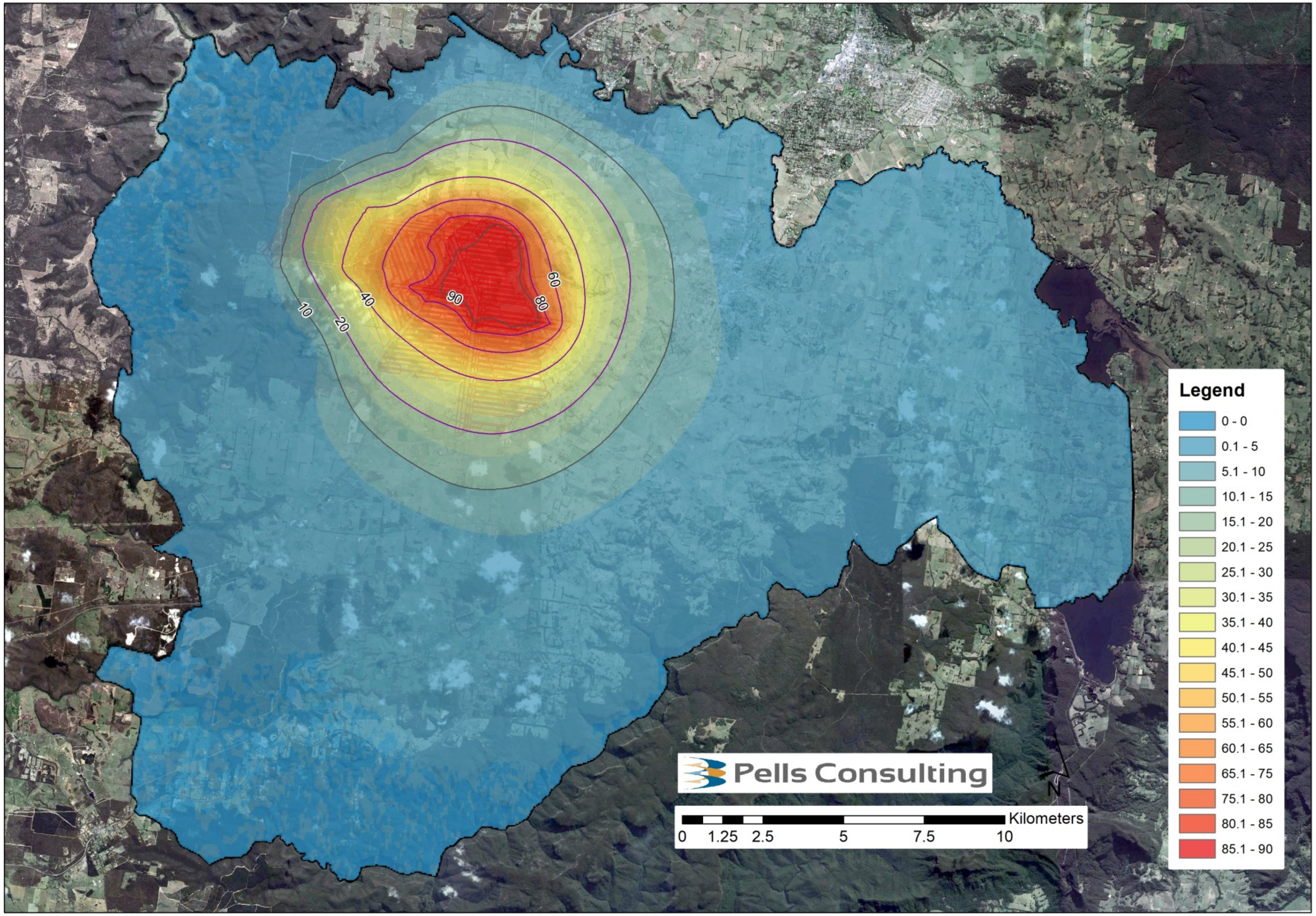

Figure 5.21 – Scenario 8. Drawdown in Layer 5. 10 yrs elapsed

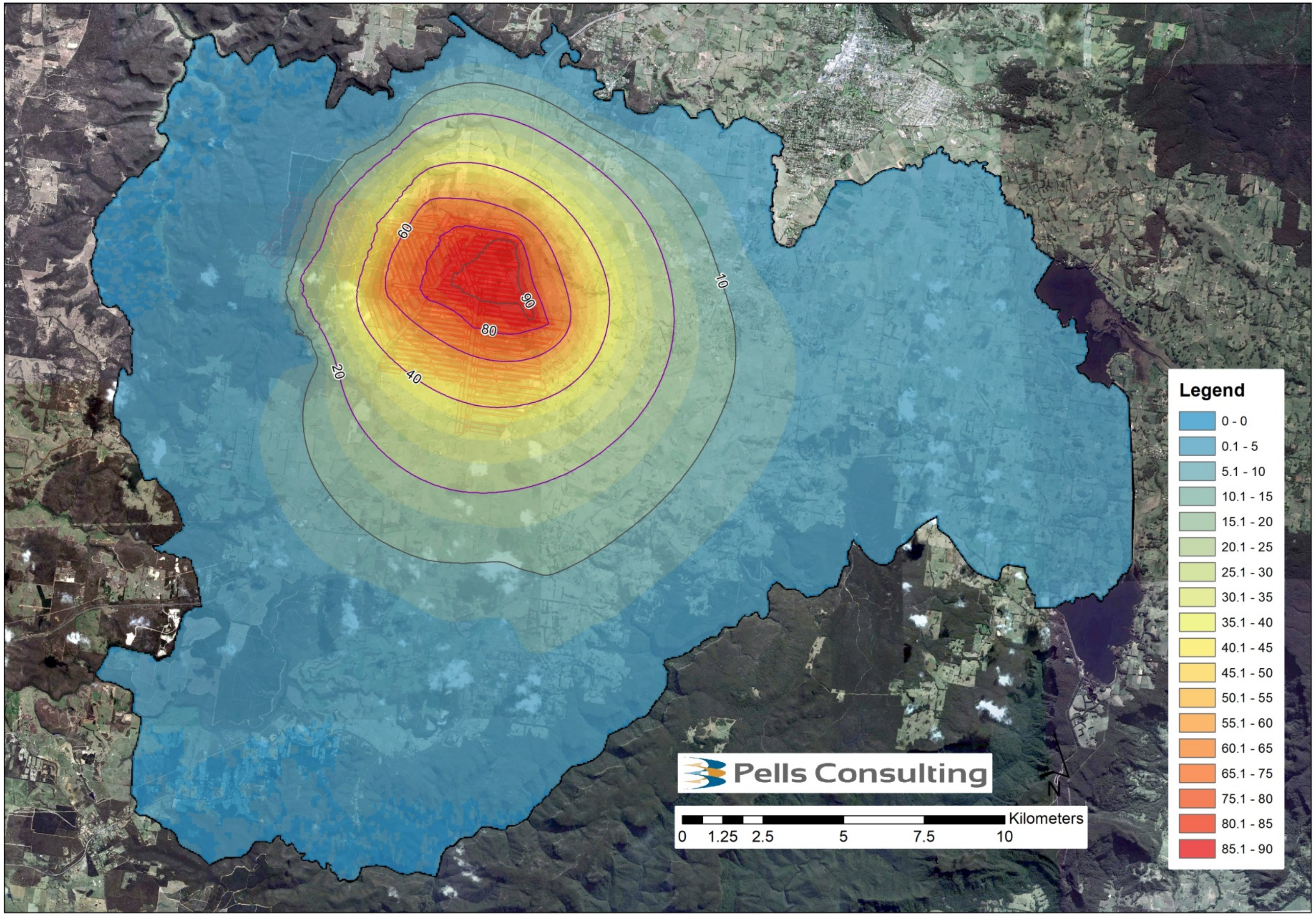

Figure 5.22 – Scenario 9. Drawdown in Layer 5. 10 yrs elapsed

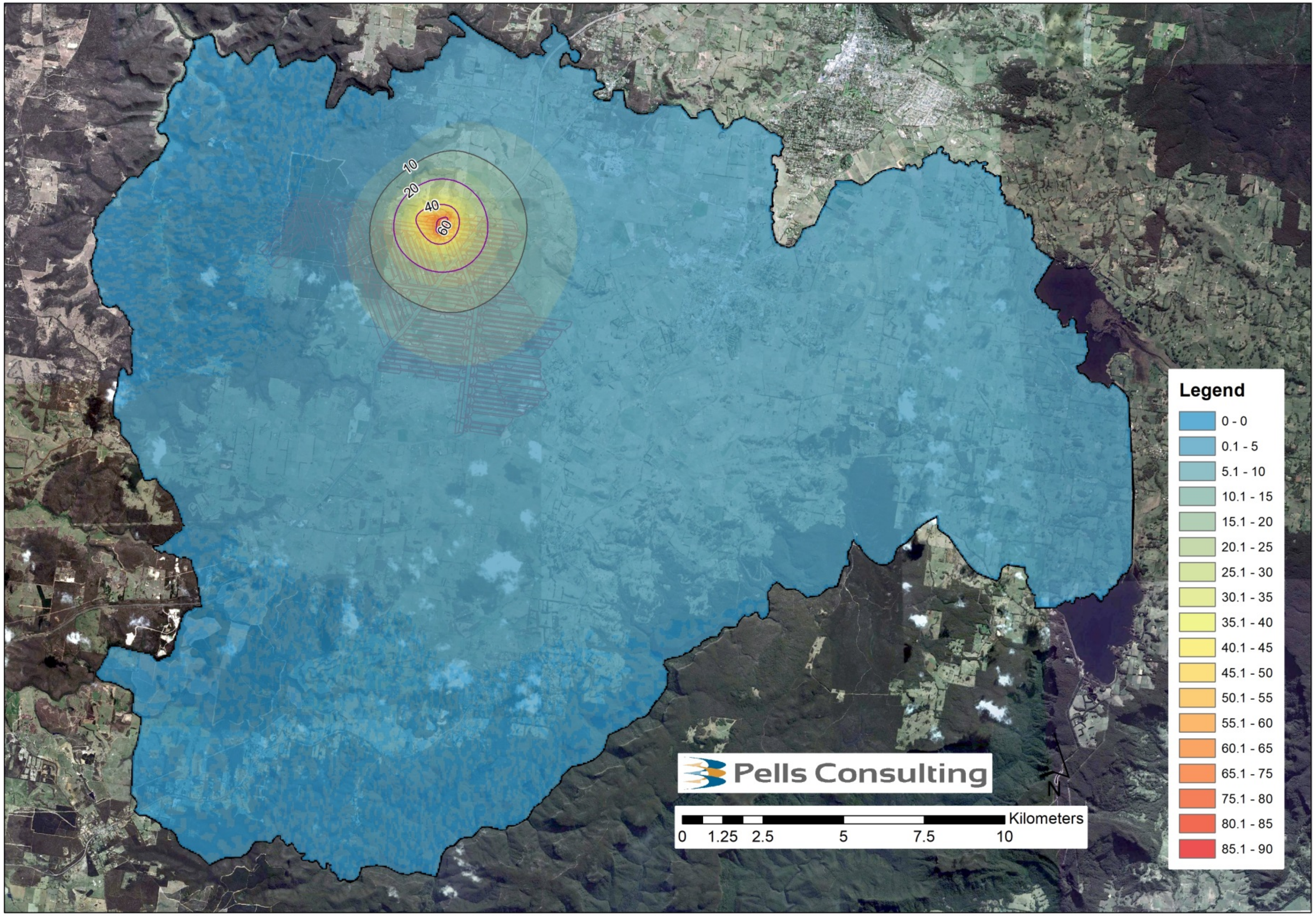

Figure 5.23 – Scenario 10. Drawdown in Layer 5. 1 yr elapsed

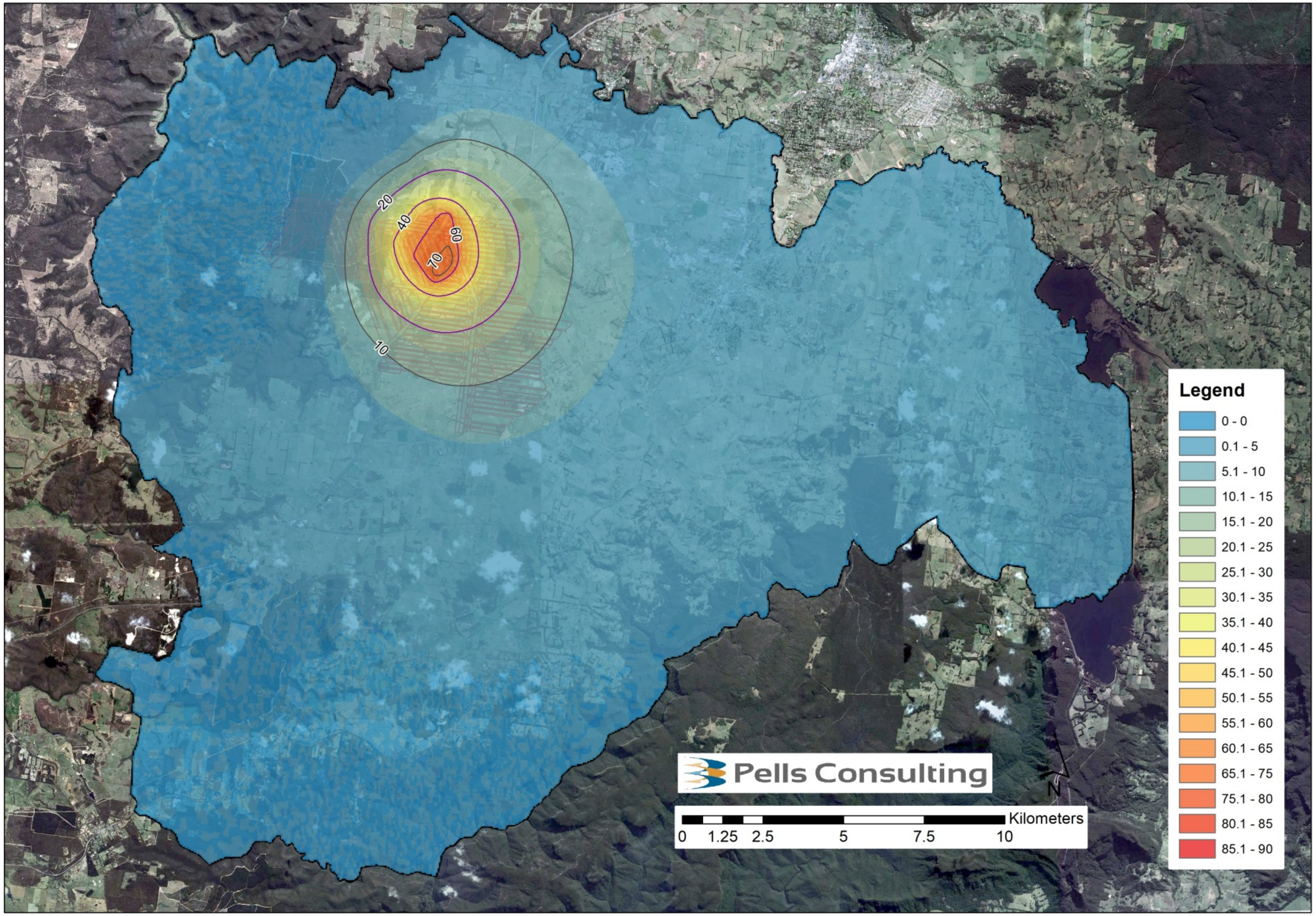

Figure 5.24 – Scenario 10. Drawdown in Layer 5. 2 yrs elapsed

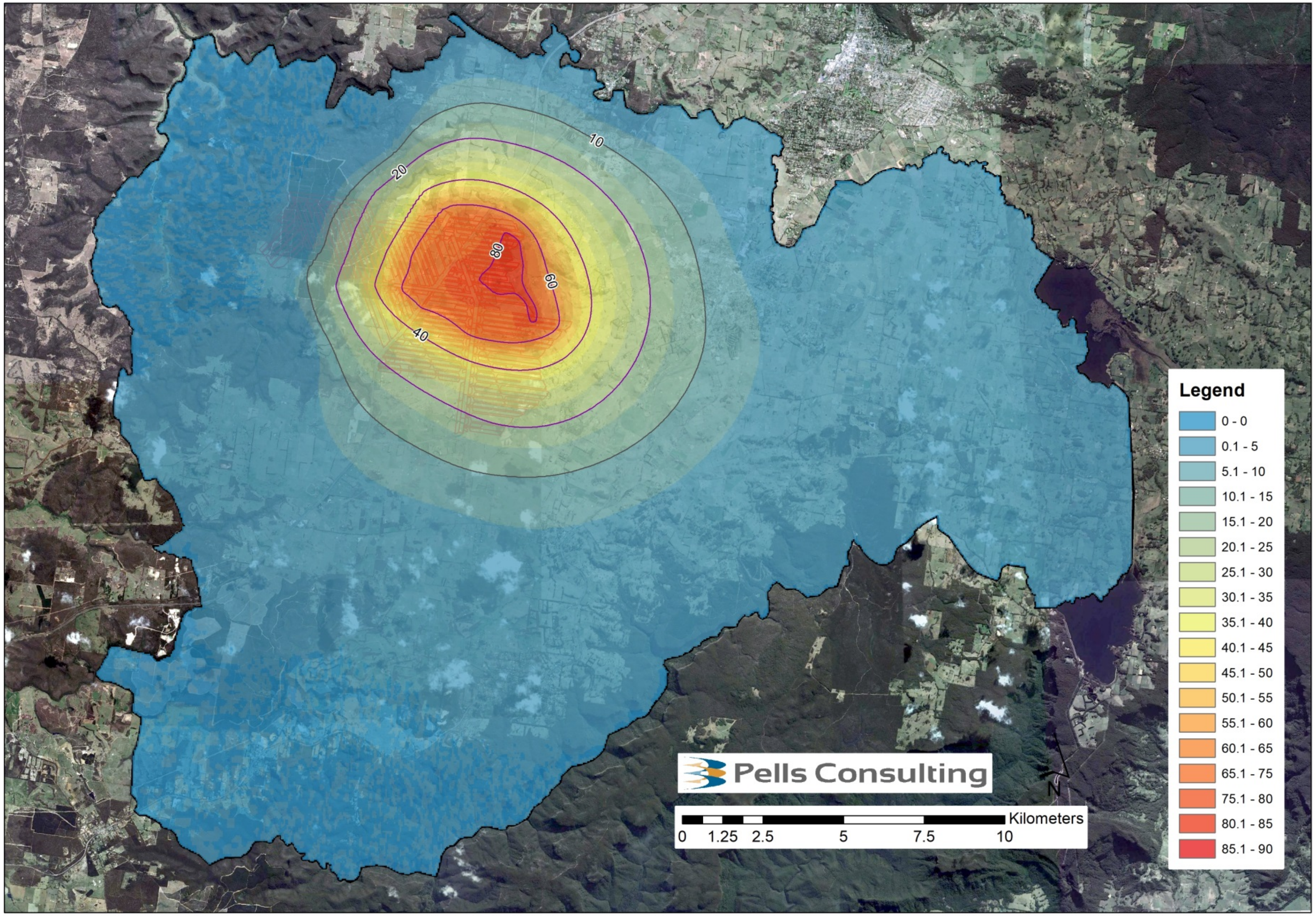

Figure 5.25 – Scenario 10. Drawdown in Layer 5. 10 yrs elapsed

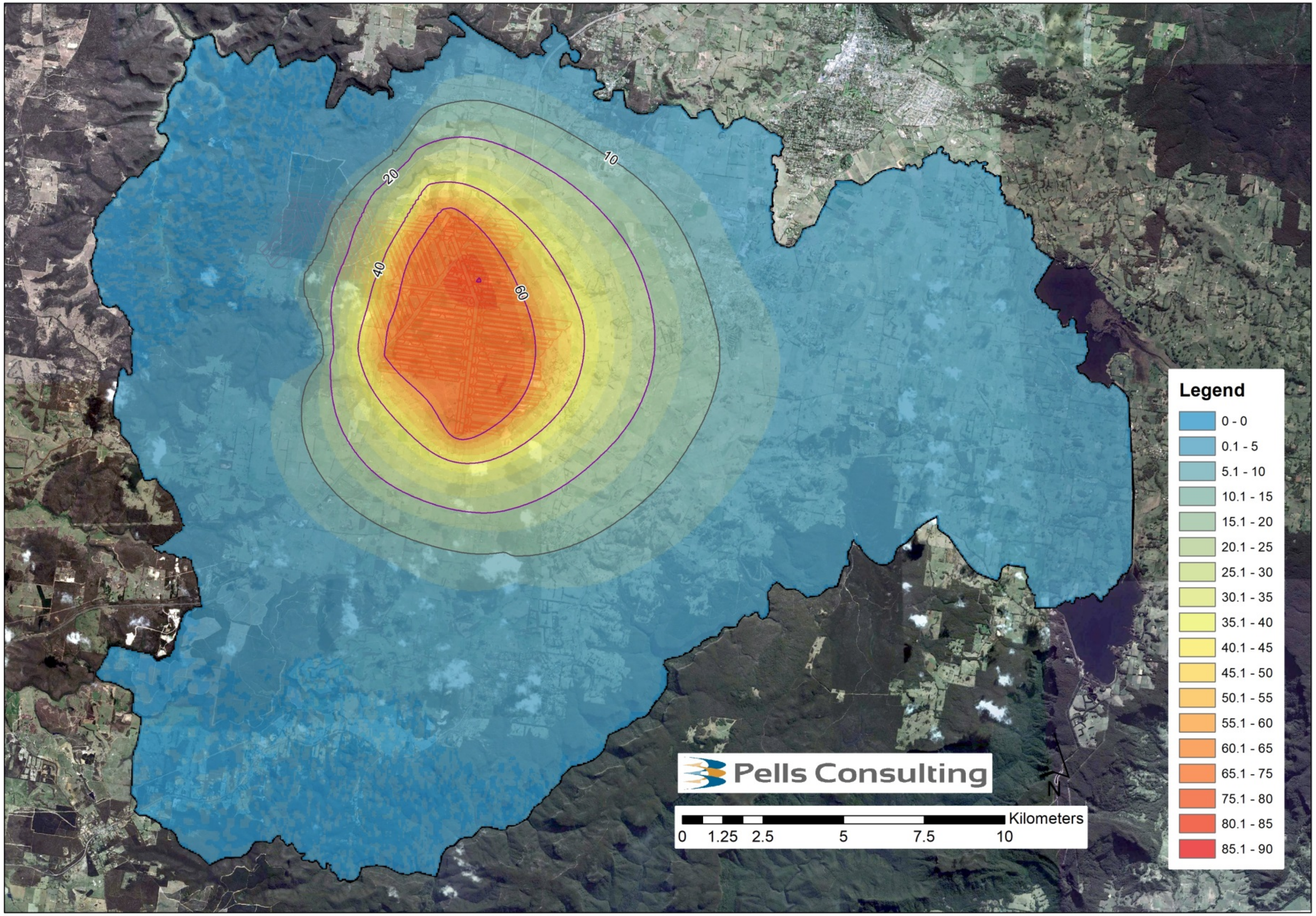

Figure 5.26 – Scenario 10. Drawdown in Layer 5. 20 yrs elapsed

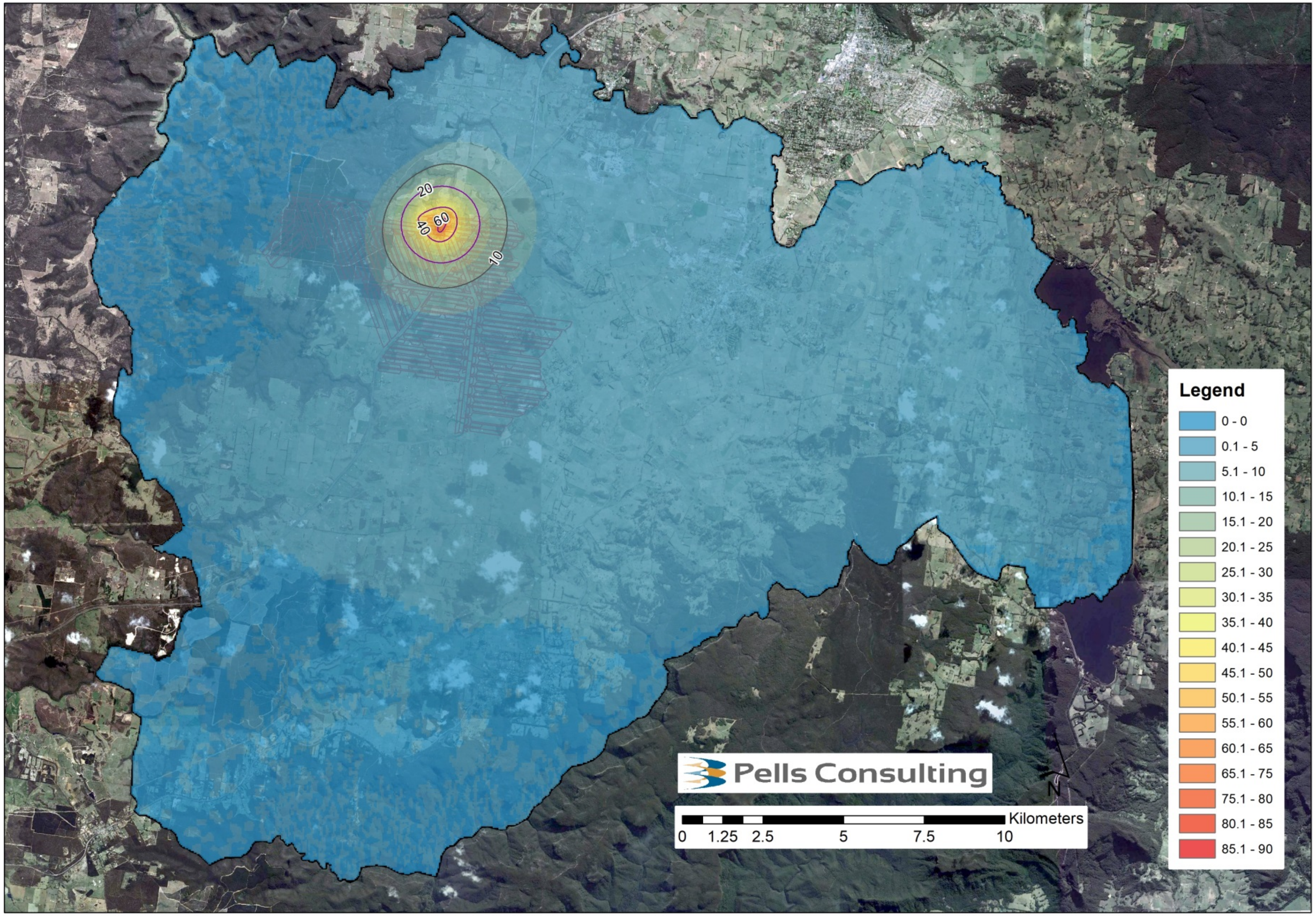

Figure 5.27 – Scenario 11. Drawdown in Layer 5. 1 yr elapsed

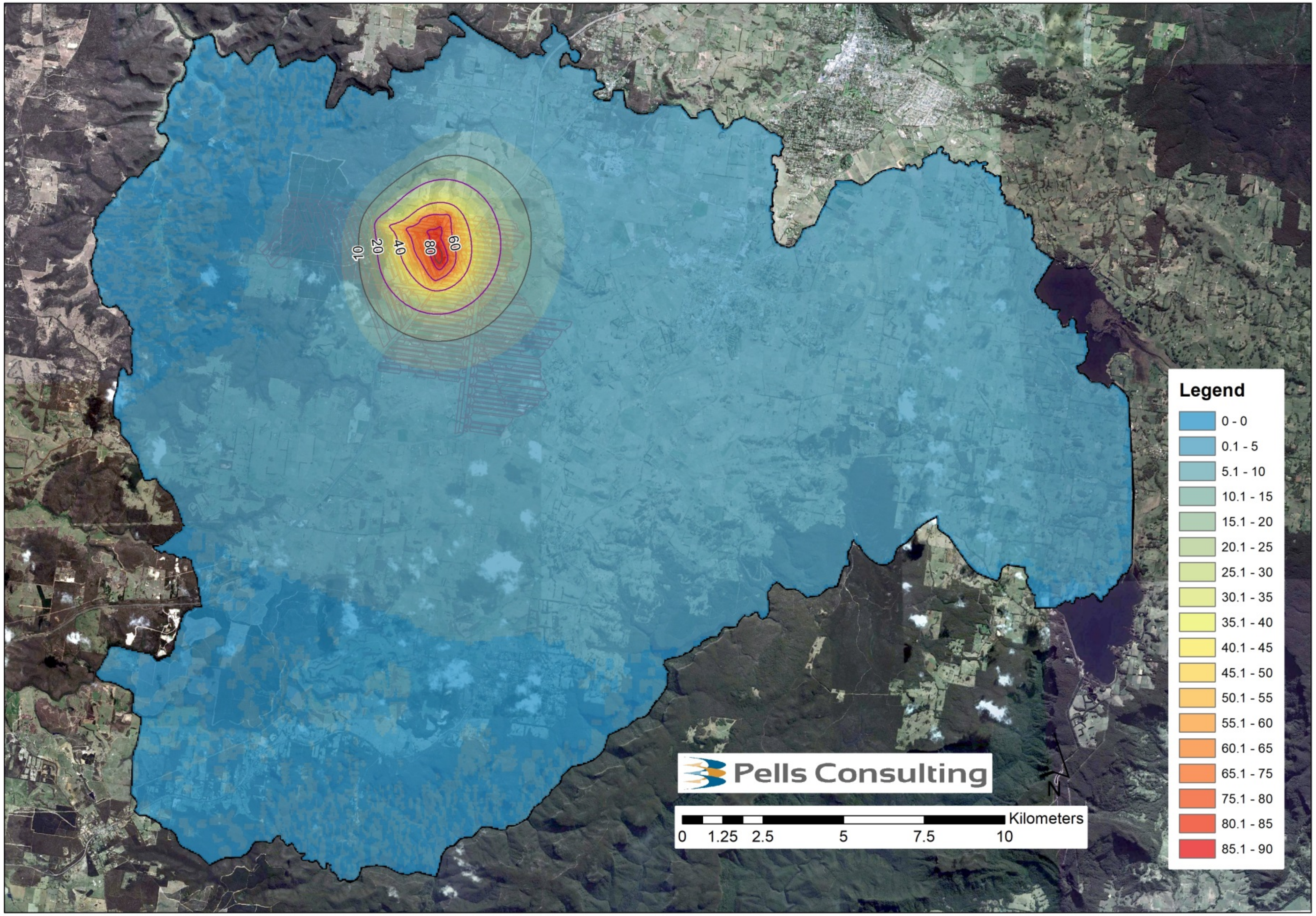

Figure 5.28 – Scenario 11. Drawdown in Layer 5. 2 yrs elapsed

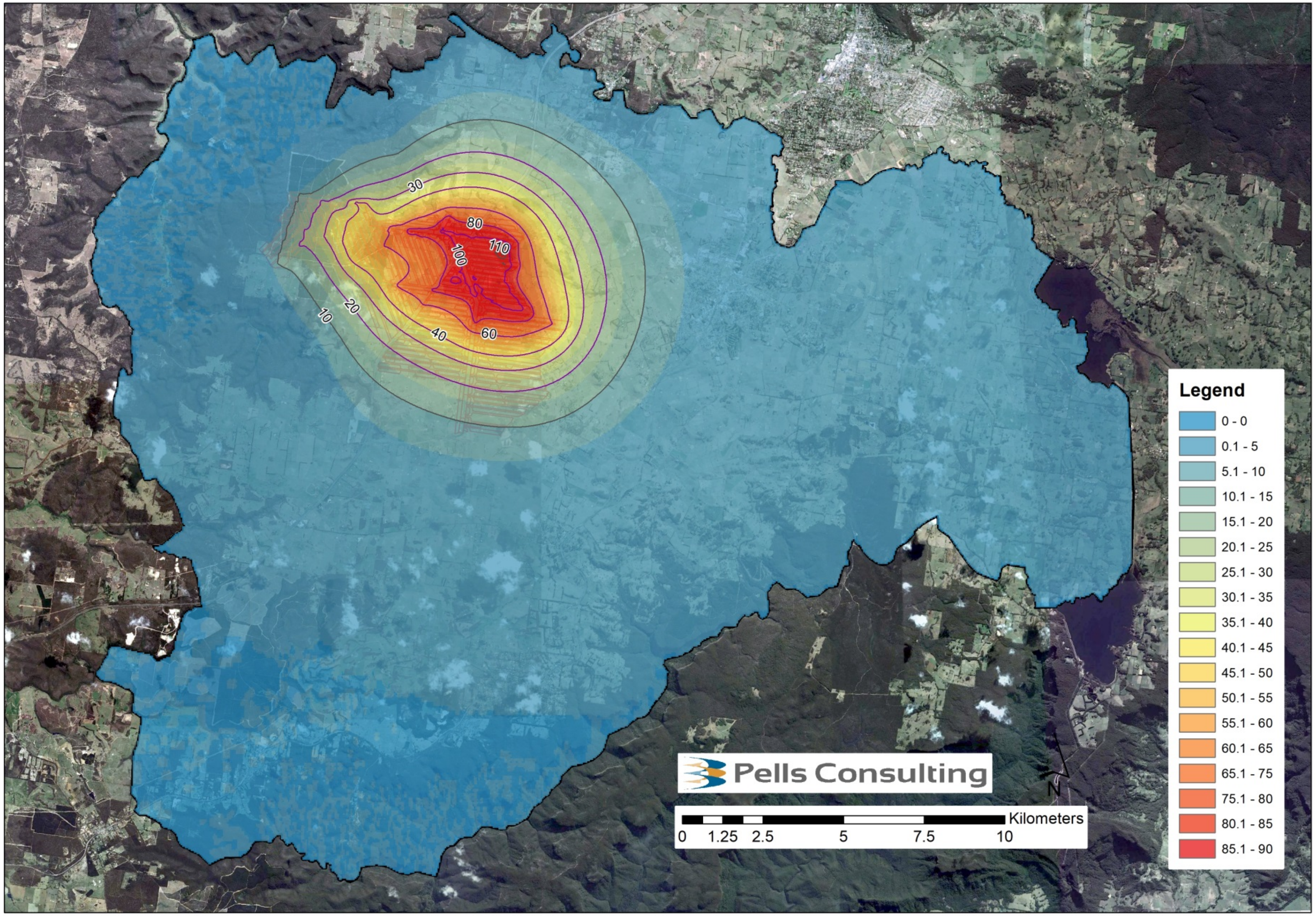

Figure 5.29 – Scenario 11. Drawdown in Layer 5. 10 yrs elapsed

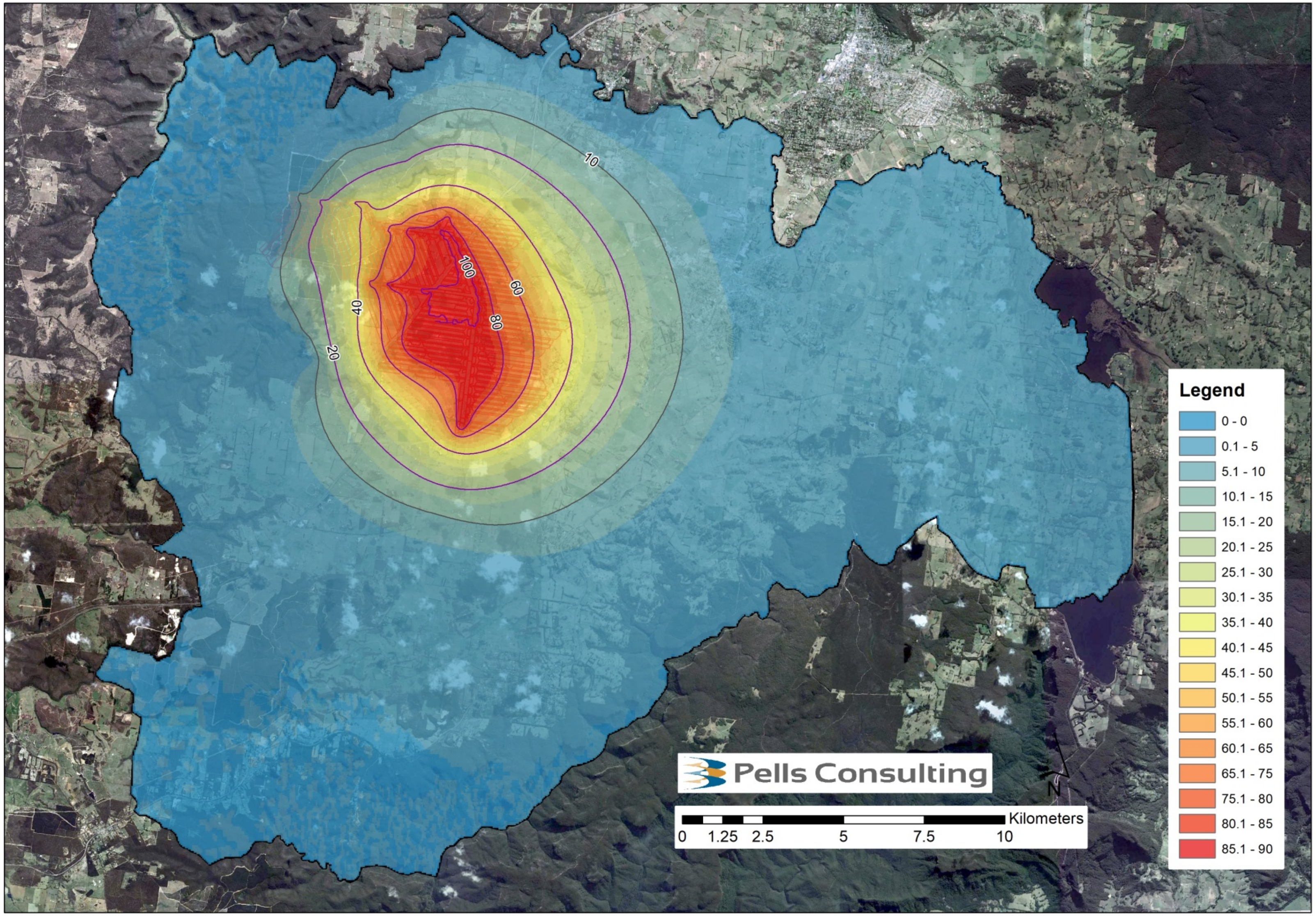

Figure 5.30 – Scenario 11. Drawdown in Layer 5. 20 yrs elapsed

5.3 Mass balance

Mass balances for selected scenarios are presented in Table 6 below.

Table 6 – Selected model mass balances

	Scenario 3				Scenario 10				Scenario 11			
Rates [m^3/day]	Steady state	Transient			Steady state	Transient			Steady state	Transient		
	Initial condition	1 year	10 Years	24 years	Initial condition	1 year	10 Years	24 years	Initial condition	1 year	10 Years	24 years
IN:												
Storage	0	13490.948	54501.215	16767.287	0	13683.4717	61447.3555	19515.0273	0	18154.7754	98065.2812	22860.3848
Constant Head	212806.953	217237.63	224058.06	224179.11	213233.906	214485.688	221076.469	221002.734	216549.031	216944.094	220112.906	222329.578
Wells	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
Recharge	38065.7812	38198.375	38241.363	38257.152	38078.5781	38145.3906	38197.3008	38209.3633	38168.0664	38192.0859	38259.9961	38276.9375
Ponded storage		0.3629	0.363	0.1964	0	0.2681	0.2943	0.1741		0.2621	0.1867	0.1595
Head dependant boundaries	0	0	0	0	0	0	0	0	0	0	0	0
Total IN	250872.734	268927.31	316801	279203.75	251312.484	266314.818	320721.419	278727.299	254717.098	273291.217	356438.37	283467.06
OUT:												
Storage	0	14.929	7774.3525	7027.1802	0	141.1417	9931.7051	8511.9746	0	2.4129	12596.7744	9276.5361
Constant Head	32195.041	32912.652	31595.725	30734.654	32292.25	32043.7324	30824.3281	30020.207	32459.6133	32398.7168	31806.0918	30975.4766
Wells	0	0	0	0	0	0	0	0	0	0	0	0
Drains	136.6099	18410.498	63876.086	31114.955	135.0499	18708.0098	68340.5391	31475.707	141.7737	20215.1875	95765.7812	29891.3008
Recharge	46613.1797	45719.887	41666.82	38344.488	46886.4961	43748.168	39936.6133	36716.9375	50124.1953	48770.6719	44330.2891	41400.2188
Ponded storage		0.041092	0.016294	0.01143	0	0.098578	0.014453	0.0093375		0.046451	0.035987	0.0077007
Head dependant boundaries	171923.672	171944.72	171940.63	171938.94	171923.922	171923.359	171919.172	171917.375	171958.188	171958.063	171956.703	171954.953
Total OUT	250868.503	269002.73	316853.63	279160.23	251237.718	266564.51	320952.372	278642.21	254683.77	273345.098	356455.676	283498.493
IN - OUT	4.231	-75.415	-52.621	43.518	74.766	-249.692	-230.953	85.089	33.328	-53.881	-17.306	-31.433
Discrepancy	0.00%	-0.03%	-0.02%	0.02%	0.03%	-0.09%	-0.07%	0.03%	0.01%	-0.02%	0.00%	-0.01%

6 SUMMARY OF FINDINGS

Numerical groundwater modelling of the Hume Coal Project presented in the EIS shows significantly smaller inflows and smaller drawdowns than predicted by numerical modelling undertaken by Pells Consulting in 2013. The EIS advises that impacts to groundwater are minimised due to the first-workings mine plan and various “mitigation measures”.

Comparison of these models presented above shows that much smaller impacts predicted in the EIS are due primarily to the parameters selected in modelling, not due to the mine plan. In particular, the values for drain conductance and hydraulic conductivity of the coal measures and formations directly above the mine adopted in the EIS are unrealistically low. As shown by the analysis presented in this report, the choice of these values cannot be supported by the available data, nor by the physics of seepage flow. These predicted impacts are also reliant on a tenuous assumption of lateral continuity of, and low permeability of, an ‘interburden’ layer.

The argument sustained in the EIS is that these values are justified through calibration. This argument is not accepted, under the following reasoning:

1. How can calibration reasonably defend the adoption of storage values that are impossibly low, such that they are outside of the mathematical framework that defines them?
2. How can calibration reasonably defend the choice of drain conductance values that are representative of a mine that is effectively lined with an impermeable layer?
3. How can calibration reasonably defend the choice of hydraulic conductivity values that are contrary to measurements?

An argument is similarly maintained in the EIS that calibration provides a reason to have such confidence in derived media values, so as to waive the requirement for reasonable sensitivity testing. This argument is also not accepted:

1. How can calibration defend a choice of zero uncertainty in horizontal hydraulic conductivity, for instance, when actual measurements show scatter over more than two orders of magnitude?
2. How can calibration defend a confidence of vertical conductivity values to within a factor of three, when there is even less certainty in measured vertical conductivity than horizontal conductivity?
3. The operational mine water balance controls the available water used to enact the “mitigation measure” of re-filling of sealed panels. How can calibration remove uncertainty in the predicted mine water balance?
4. How can calibration provide absolute confidence in conductivity values for the mine seam and layers directly above it (such as the interburden) in the absence of sufficient test data?

For numerical modelling presented in the EIS to inform upon the impacts of the proposed mining, calibration must result in physically possible storage values; it must incorporate physically reasonable representation of mine drain conductance, and; it should provide adequate defence of hydraulic conductivity values chosen for the coal measures and layers directly above the mine. It should also incorporate sensitivity testing that reflects the measured uncertainty in these parameters and uncertainty in the mine water balance.

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