



PROJECT CHINA STONE

Attachment D Additional Information on Groundwater



Australasian
Groundwater
and Environmental
Consultants Pty Ltd
(AGE)



Report on

Project China Stone

Additional Information on Groundwater - For Macmines Austasia Pty Ltd

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Project No. G1587F August 2017
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Report on

Project China Stone

Additional Information on Groundwater (For MacMines Austasia Pty Ltd)

1 Introduction

This document has been prepared by Australian Groundwater and Environmental Consultants Pty Ltd (AGE), on behalf of MacMines Austasia Pty Ltd, in response to submissions made on the Project China Stone (the project) Draft Environmental Impact Statement (draft EIS).

This document provides additional information on groundwater in response to submissions provided by the Department of Environment and Heritage Protection (EHP), Department of Natural Resources and Mines (DNRM) and the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (the IESC).

These submissions raised issues in relation to:

- baseline groundwater levels;
- conceptual groundwater regime in the vicinity of Lake Buchanan;
- sensitivity analysis; and
- subsidence effects on vertical hydraulic conductivity.

The following additional information has been provided in support of the responses to these submissions and as requested by DNRM in the groundwater meeting convened by the Office of the Coordinator-General on 21 June 2017:

- Appendix A provides hydrographs showing baseline groundwater level data collected from monitoring bores and vibrating wire piezometers (VWPs) as part of the pre-mining groundwater monitoring program described in Section 12.5.1 of the draft EIS.
- Appendix B provides a figure showing groundwater levels in the vicinity of Lake Buchanan supporting the conceptualisation of Lake Buchanan as a discharge zone for the regional groundwater table.
- Appendix C provides information on the relationship between coal seam hydraulic conductivity and its depth below surface, and the basis of the representation of coal seam conductivity in the EIS groundwater model.
- Appendix D provides figures showing the sensitivity of modelled depressurisation predictions in the Tertiary Sediments, Clematis Sandstone and Betts Creek Beds (including the target coal seams). Figures show the results of:
 - The sensitivity analysis scenarios described in Appendix B of the draft EIS Groundwater Report.
 - An additional sensitivity analysis of the effects of increasing the hydraulic conductivity values in only the coal seams (shown as 'Coal (K+)' on each figure).
 - The effects of reducing the rate at which the hydraulic conductivity of the coal seams declines with depth, coupled with an increase in the minimum hydraulic conductivity that the coal seams reduce to (shown as 'Coal (K depth)') on each figure).

- Appendix E provides a figure illustrating an example of the modelled factors applied to reflect the effects of subsidence on vertical hydraulic conductivity.
- Appendix F provides a figure showing the monitoring bores in the groundwater monitoring bore program described in Attachment 24-4 of the draft EIS.
- Appendix G provides an updated Figure B3 from the draft EIS Groundwater Report with the correct model recharge rates presented in the legend (mm/yr rather than m/yr).
- Appendix H provides the factors applied to the horizontal hydraulic conductivity values to calculate the vertical hydraulic conductivity for each model layer in the EIS. The same factors were applied to calculate the vertical hydraulic conductivity of a selected layer where changes were made to the horizontal hydraulic conductivity values during sensitivity analyses.

This report is an attachment to the Supplement to the draft EIS for the project. The Supplement of the draft EIS is Volume 6 and should be read in conjunction with the draft EIS Volumes 1 – 5 that were publicly exhibited. Together, Volumes 1 – 6 form the revised draft EIS for the project.

To the extent of any inconsistencies, the information in this attachment supersedes any information in any other volume of the draft EIS.

Appendix A **Baseline groundwater levels**

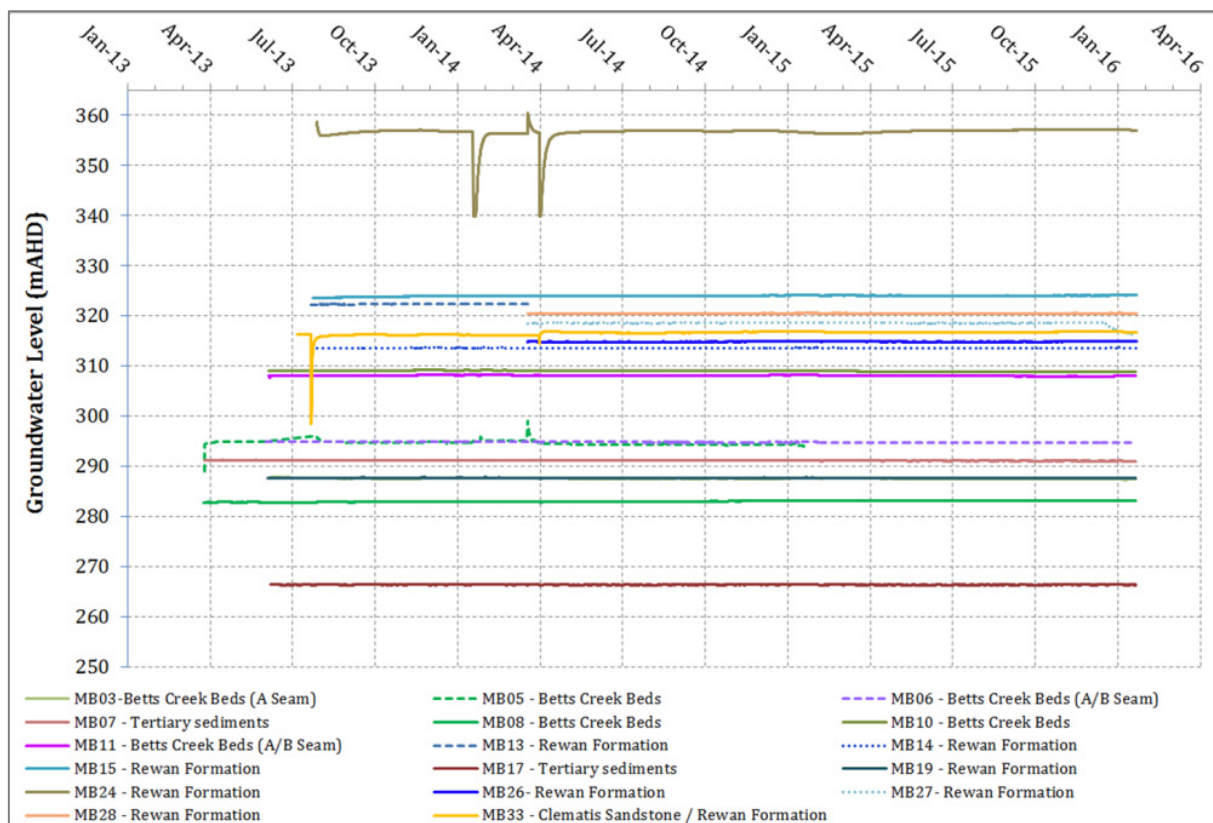


Figure A1 **Monitoring bore hydrographs**

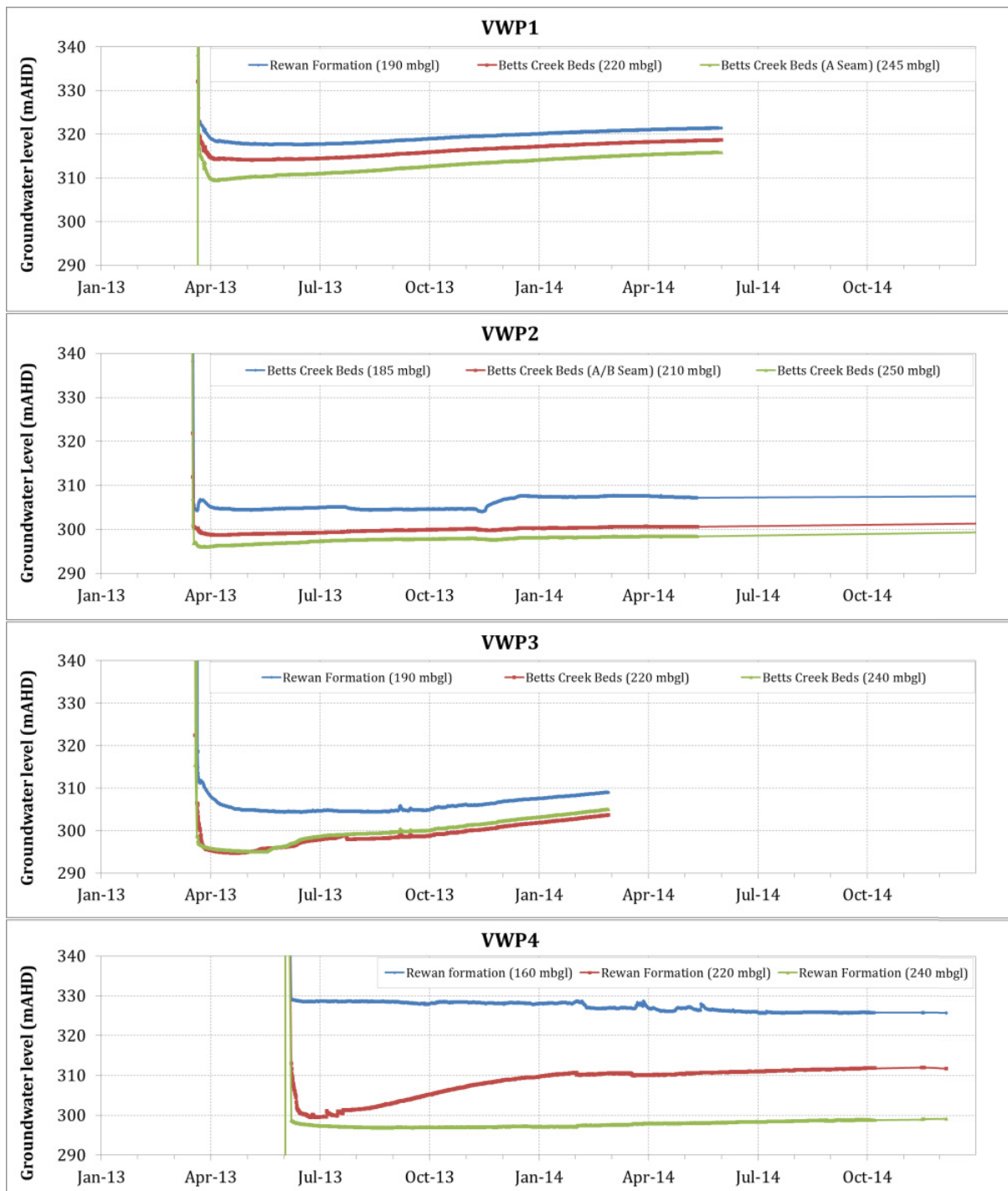
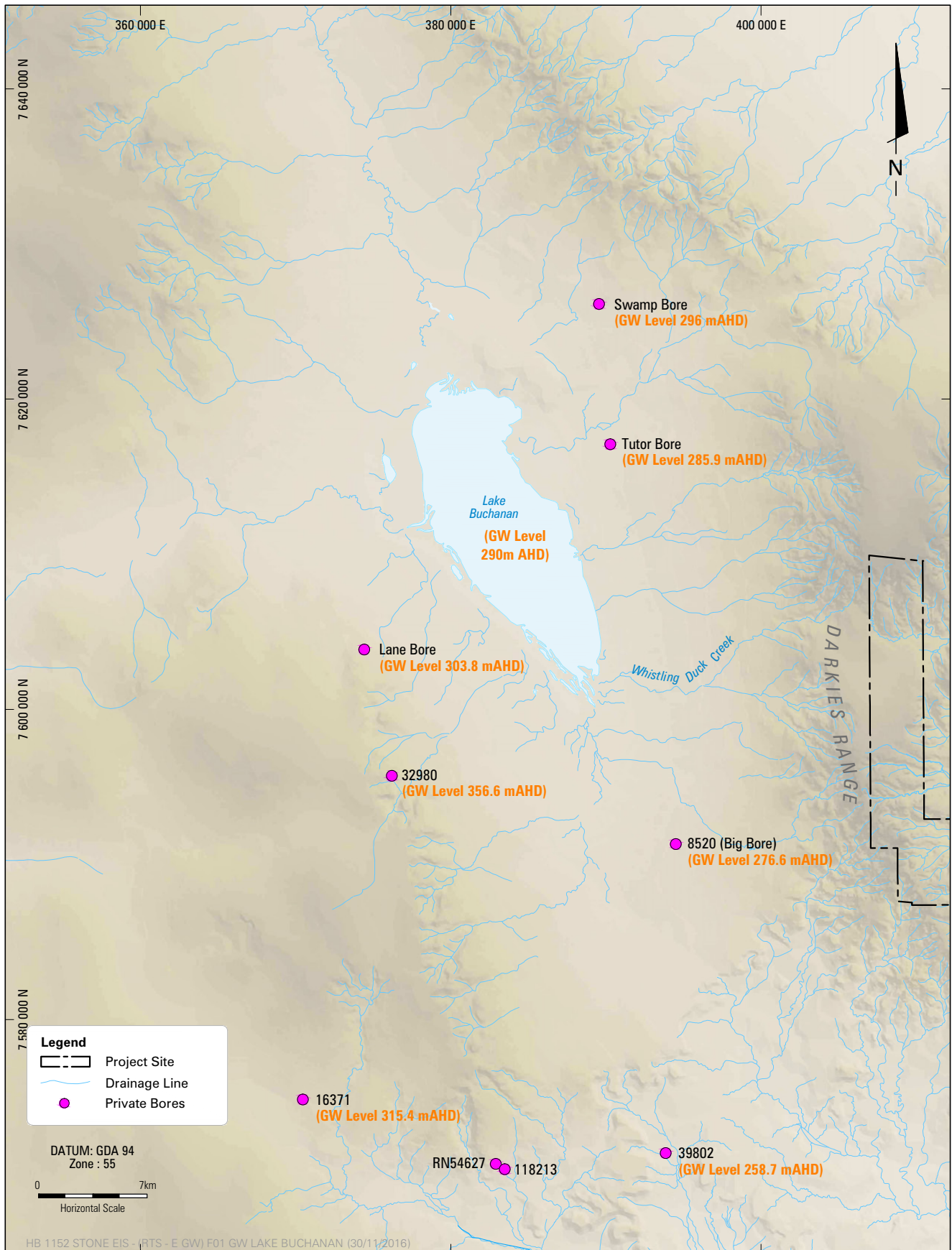


Figure A2 Vibrating wire piezometer hydrographs

Appendix B **Lake Buchanan groundwater regime**



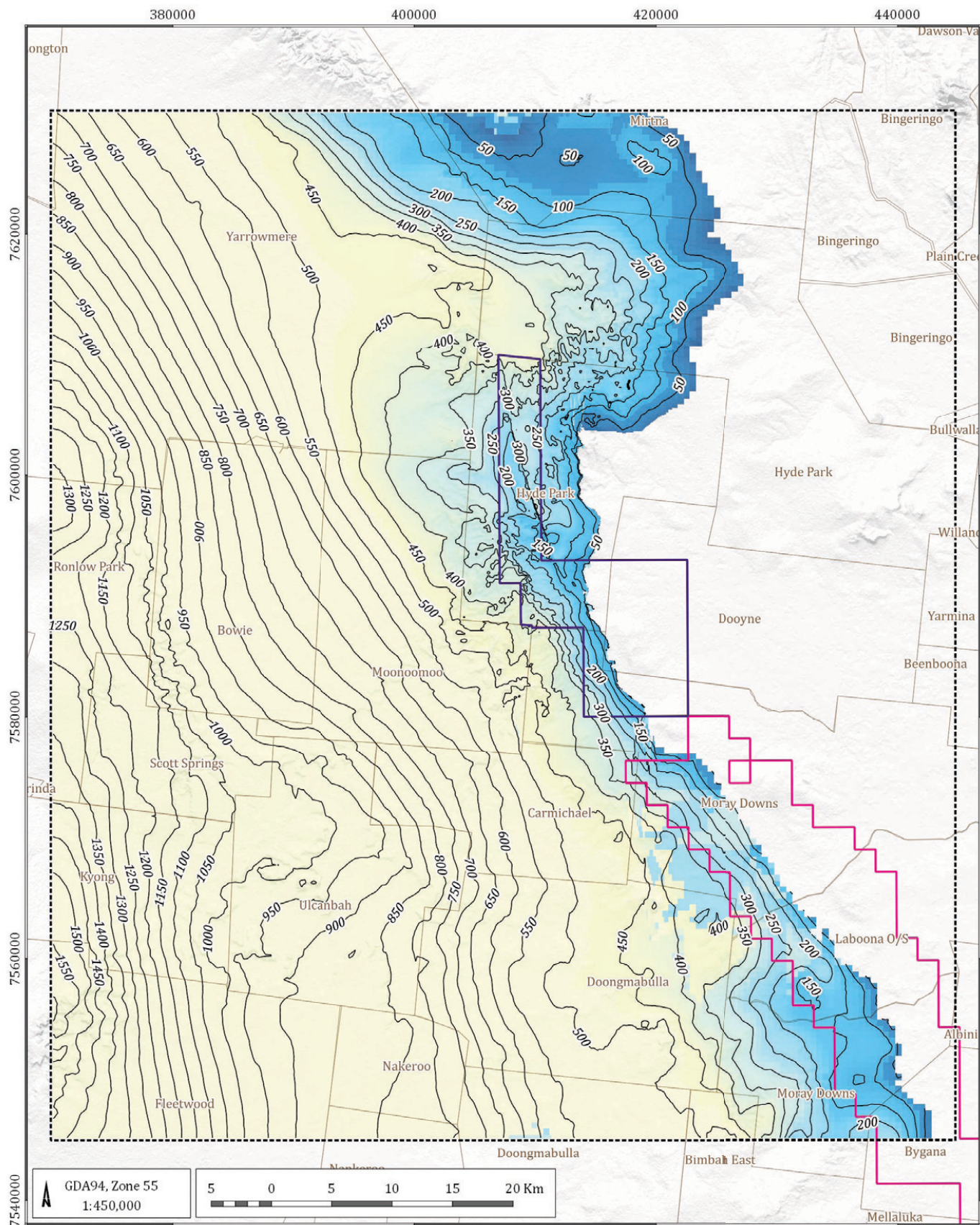
PROJECT CHINA STONE

Appendix C Coal seam hydraulic conductivity vs depth

C1 Modelled hydraulic conductivity with depth

Figures C1 to C4 show the modelled baseline hydraulic conductivity of the coal seams across the model domain along with the depth to the top of the model layer representing the top of each seam. The figures show a deepening of the coal seams towards the west, with the hydraulic conductivity only changing in the upper 400-500 m. Below this depth the hydraulic conductivity of the coal is limited to a minimum of 8.6×10^{-6} m/d.

The relationship developed to represent a decline in hydraulic conductivity with depth is provided in Section C2.



LEGEND

- Project site
- Carmichael Coal Mine Project
- Model boundary
- Pastoral station

— Depth to top of coal seam contour (m)

Hydraulic conductivity (m/day)

- 0.00001
- 0.00005
- 0.0001
- 0.0005
- 0.001
- 0.005
- 0.01
- 0.05
- 0.1
- 0.5
- 1.0

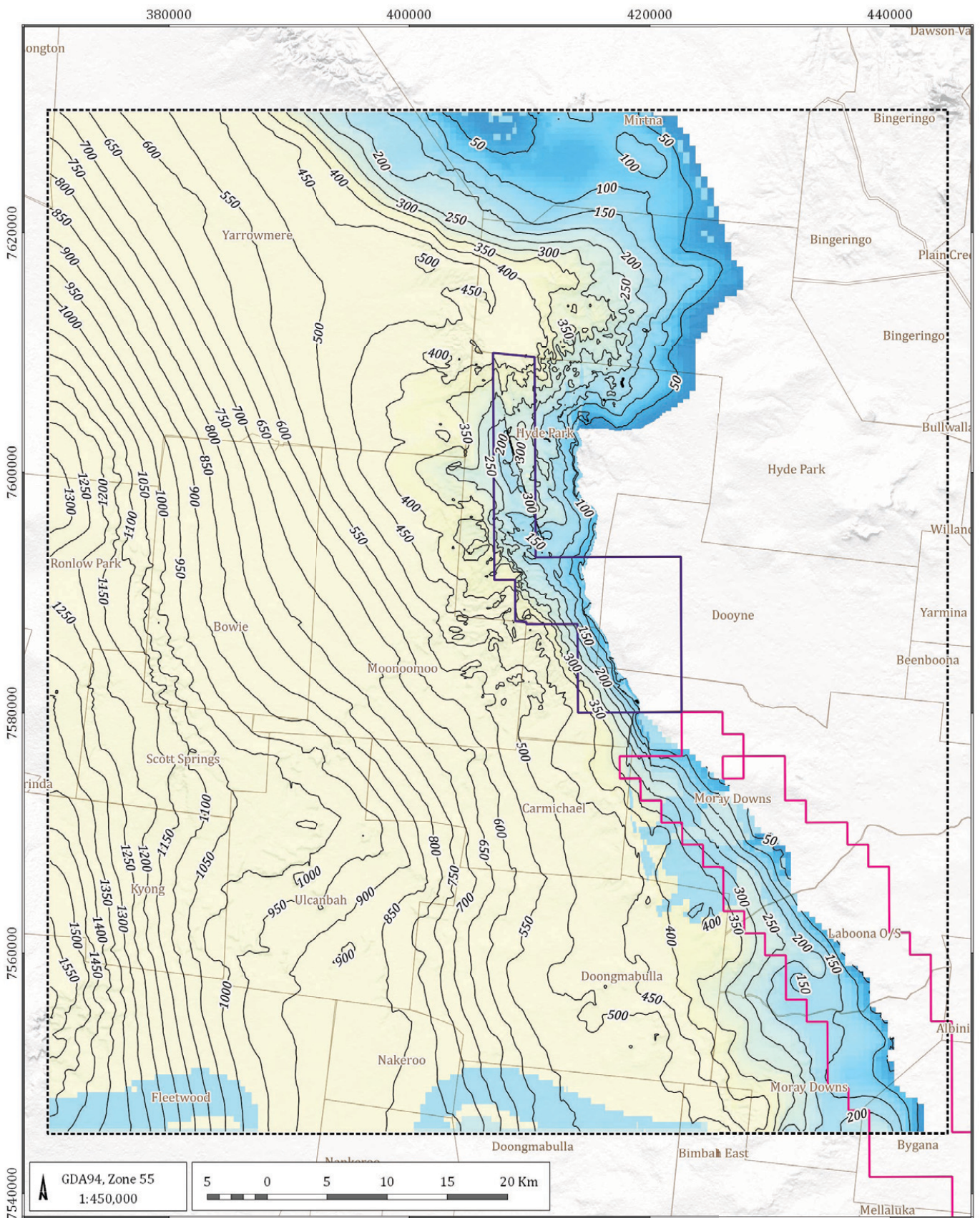
Project China Stone (G1587F)

**Horizontal hydraulic conductivity and depth to top of coal seam
A seam (layer 10)**



DATE
04/07/2017

FIGURE No:
C1



LEGEND

- Project site
- Carmichael Coal Mine Project
- Model boundary
- Pastoral station

— Depth to top of coal seam contour (m)

Hydraulic conductivity (m/day)

- 0.00001
- 0.00005
- 0.0001
- 0.0005
- 0.001
- 0.005
- 0.01
- 0.05
- 0.1
- 0.5
- 1.0

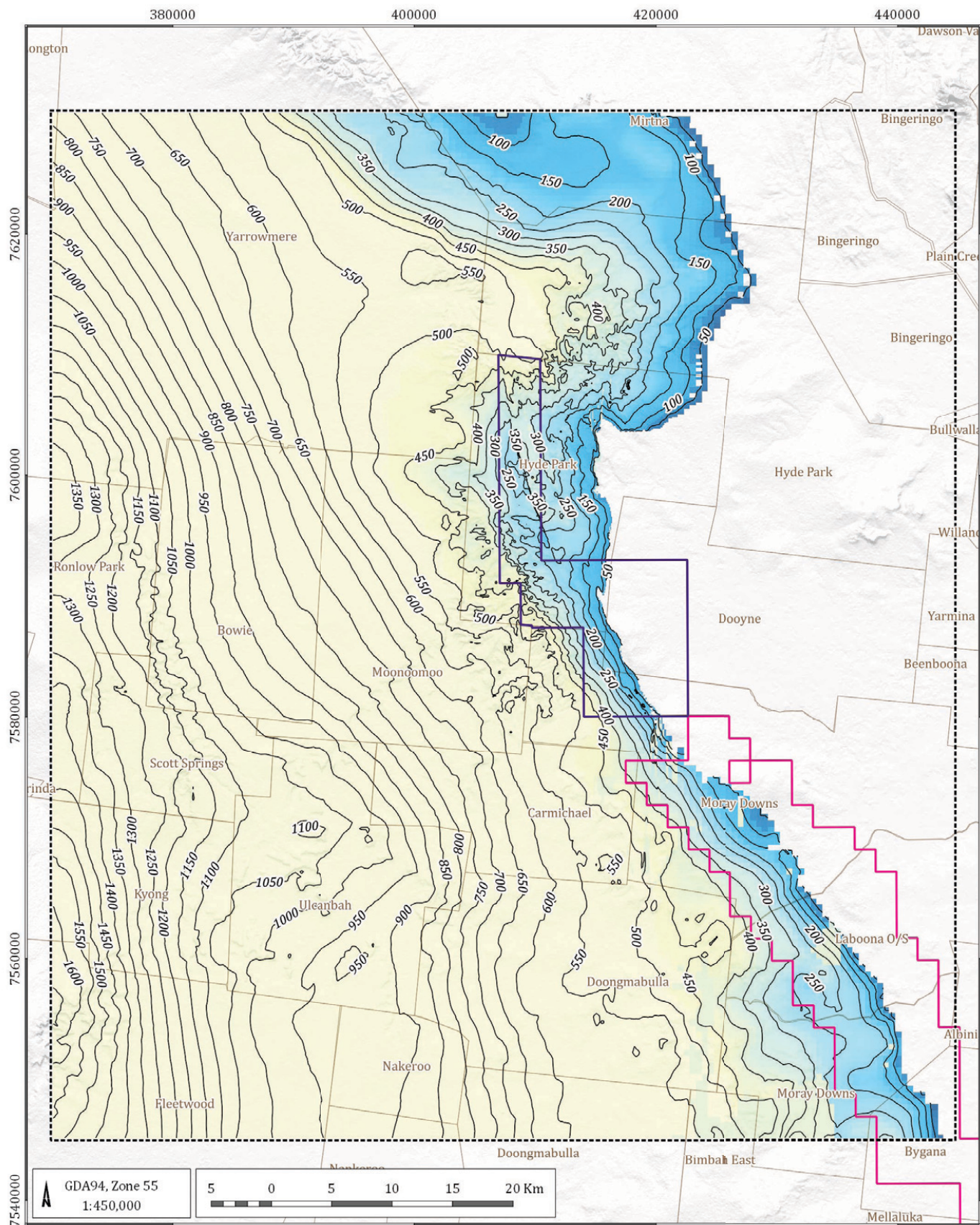
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Horizontal hydraulic conductivity and depth to top of coal seam B seam (layer 12)



DATE
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FIGURE No:
C2



LEGEND

- Project site
- Carmichael Coal Mine Project
- Model boundary
- Pastoral station

— Depth to top of coal seam contour (m)

Hydraulic conductivity (m/day)

- 0.00001
- 0.00005
- 0.0001
- 0.0005
- 0.001
- 0.005
- 0.01
- 0.05
- 0.1
- 0.5
- 1.0

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Horizontal hydraulic conductivity and depth to top of coal seam D seam (layer 16)



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FIGURE No:
C4

C2 Coal seam hydraulic conductivity with depth relationship

Mackie (2009) used data from the Hunter Valley to establish a declining relationship in coal seam hydraulic conductivity with depth (Figure C5). Measurements of hydraulic conductivity in coal were available to a depth of some 450 m below surface. There was a wide degree of scatter in the results which Mackie attributed to the brightness of the coal. The gradients plotted by Mackie indicate an order of magnitude decline in hydraulic conductivity per 180-200 m depth of cover.

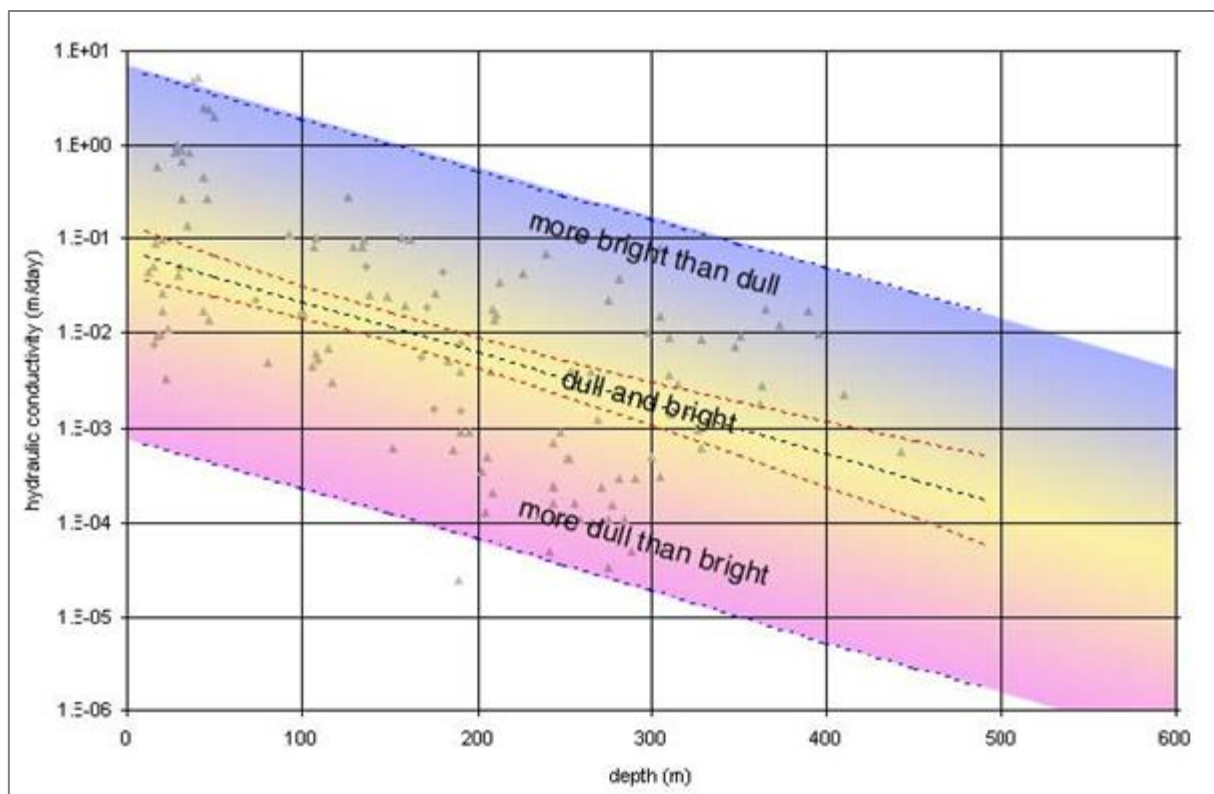


Figure C5 Simplified representation of the relationship between hydraulic conductivity and depth (Mackie, 2009¹)

A relationship of decreasing hydraulic conductivity with depth was also noted for the Walloon Coal Measures of the Surat Basin in Queensland²:

“The long term affected area (LAA) for the Walloon Coal Measures extends further in the north-east and has contracted in the south-west. The extension towards the north-east reflects an improved understanding of the spatial variation in horizontal permeability within the Walloon Coal Measures. Horizontal permeability tends to be relatively high in the north-east where the coal is close to the surface and then gradually reduce with depth towards the south-west”.

¹ Mackie, C.D., 2009. Hydrogeological characterisation of coal measures and overview of impacts of coal mining on groundwater systems in the Upper Hunter Valley of NSW. University of Technology, Sydney, January 2009.

² Department of Natural Resources and Mines, Office of Groundwater Impact Assessment. 2016. Underground Water Impact Report for the Surat Cumulative Management Area.

Results from hydraulic field testing of coal seams within the Project China Stone site and the adjoining Carmichael Project site are presented on Figure C6 along with the depth relationship developed by Mackie. Coal within the Project China Stone site is noted as being dull on geological logs, so would be expected to plot at the lower end of the hydraulic conductivity range.

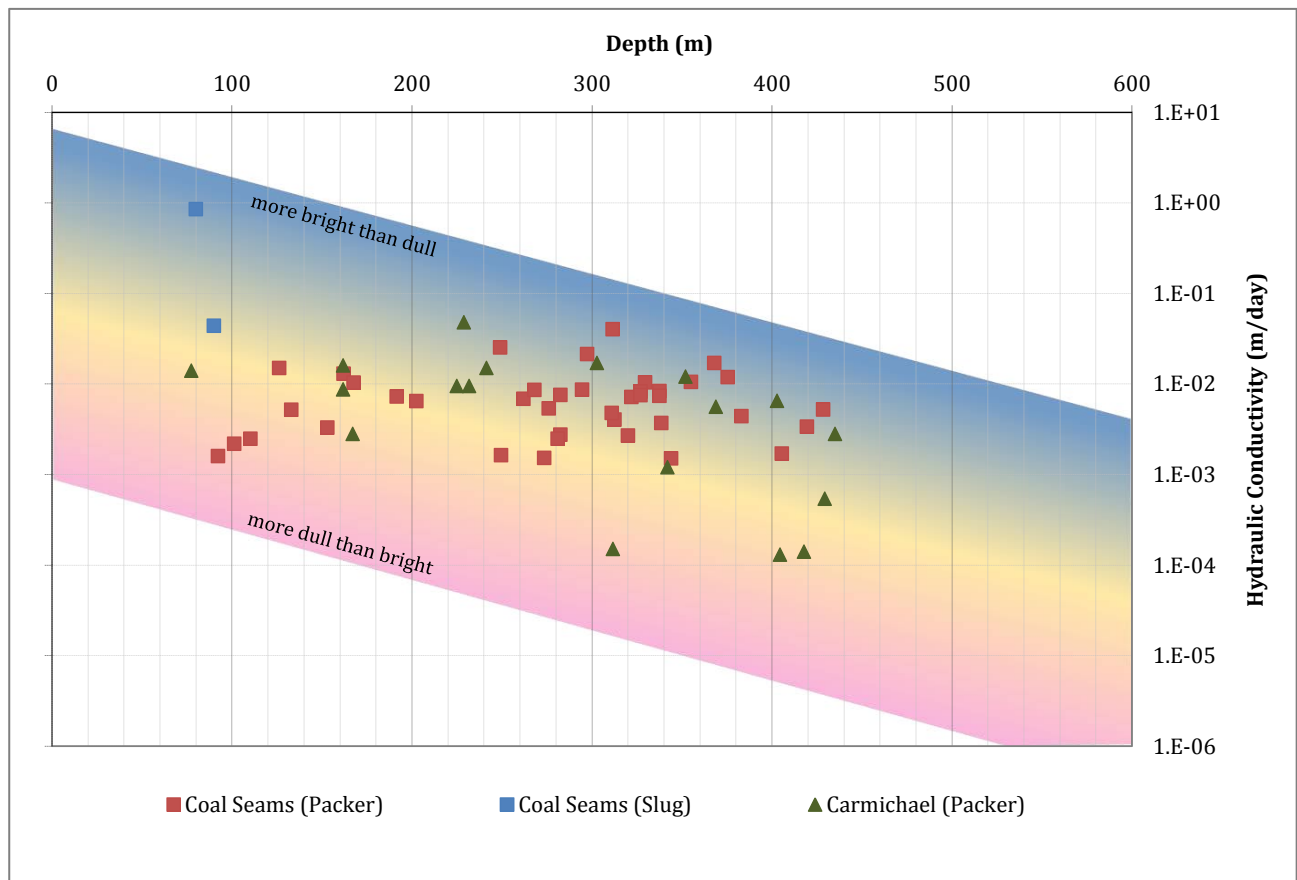


Figure C6 Field testing hydraulic conductivity data and DNRM relationship

Figure C7 shows the field testing data plus the two depth gradients used within the Project China Stone EIS numerical model to represent the hydraulic conductivity of the coal seams. The B seam was generally described as being duller than the other seams at the site (A, C, and D) so was represented with a lower hydraulic conductivity at surface. The equation used to generate the hydraulic conductivity at a specific depth is:

$$\begin{aligned} \text{Permeability at prescribed depth} \\ = \text{Hydraulic conductivity at surface} * \exp(-0.022 * \text{depth below surface}) \end{aligned}$$

Equation C1

The hydraulic conductivity at surface was set as 0.1 m/day for the B seam and 0.4 m/day for the A, C and D seams. The minimum hydraulic conductivity of the coal in any layer was limited to 8.6×10^{-6} m/d.

The sensitivity analysis of the effects of increasing the hydraulic conductivity values in only the coal seams used the same depth/permeability gradient, but with a higher surface hydraulic conductivity of 4 m/d for all coal seams, moving the slope higher on the graph. The minimum hydraulic conductivity in this scenario is therefore reached at a depth of ~ 600 metres (Figure C7).

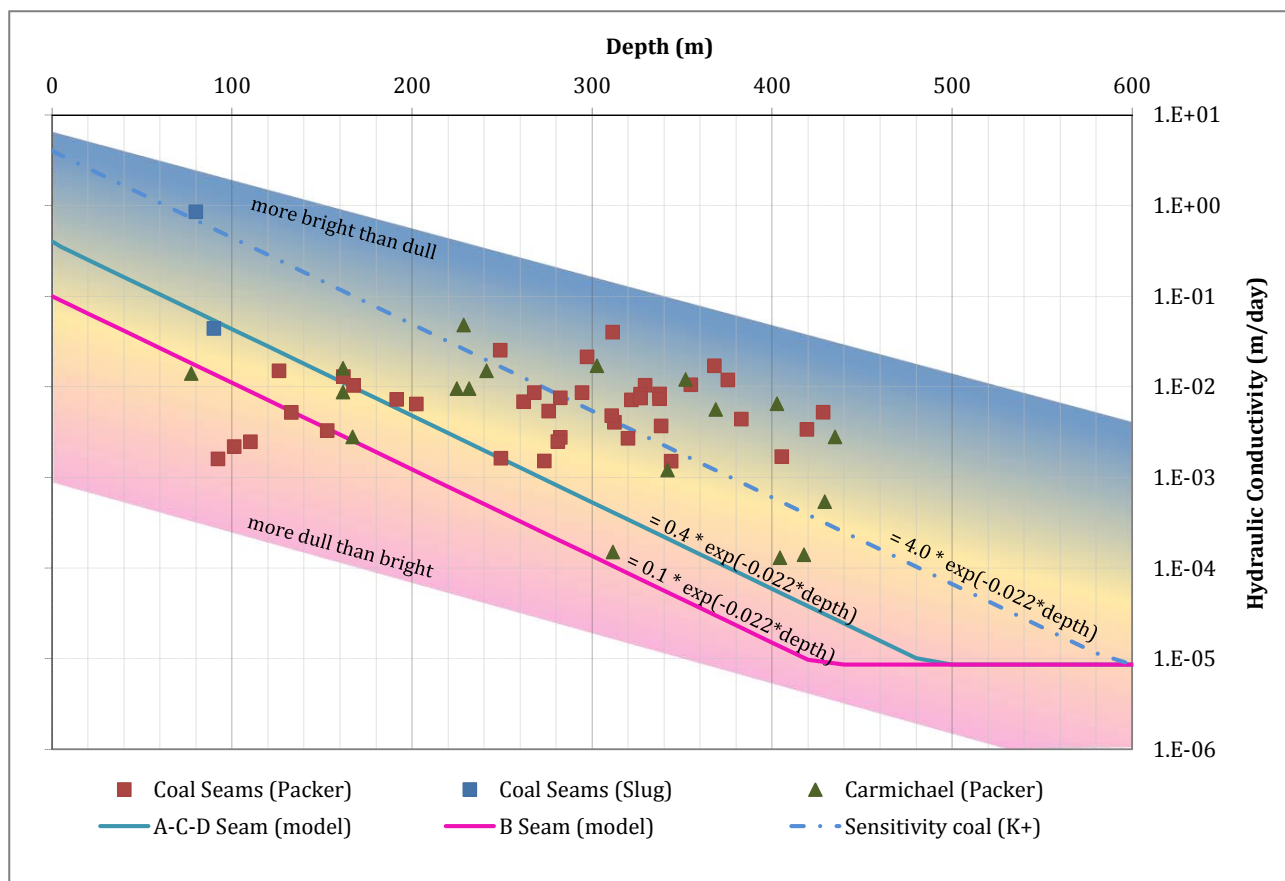


Figure C7 Field testing hydraulic conductivity data and basecase model gradient

In response to a request by the DNRM, a second sensitivity analysis on the coal permeability has been completed that uses a flatter depth gradient with the equation:

$$\begin{aligned} \text{Permeability at prescribed depth} \\ = \text{Hydraulic conductivity at surface} * \exp(-0.013 * \text{depth below surface}) \end{aligned}$$

Equation C2

The relationship is shown graphically on Figure C8.

There was no change to the surface hydraulic conductivity of the coal seams but the gradient was flattened to more closely match the gradient developed by Mackie. The minimum conductivity that the coal seams can fall to was also limited to 1.0×10^{-4} m/day to more closely match the minimum hydraulic conductivities observed during the field testing.

The effect of these changes on the zone of depressurisation within the coal seams is shown on figures included within Appendix D.

DNRM provided an alternative indicative line of best fit in the meeting on 21 June 2017 for the depth versus conductivity relationship, based on packer test data for the China Stone A seam and the Carmichael AB seams. This line is also shown in Figure C8. The gradient of the DNRM line of best fit represents an order of magnitude decline in hydraulic conductivity for approximately each 300 m depth of cover. The decline in hydraulic conductivity with depth is noticeably less than the relationship developed by Mackie, which is achieved by starting with a hydraulic conductivity that is lower at the surface than those adopted for the basecase numerical modelling.

The depth gradient adopted for the second sensitivity analysis is expected to result in a more conservative prediction of depressurisation than the DNRM best fit line for the A, C, and D seams above a depth of 500 m. This is because at the surface the modelled A, C, and D seams are more permeable by over an order of magnitude, with the difference gradually reducing to 500 m depth.

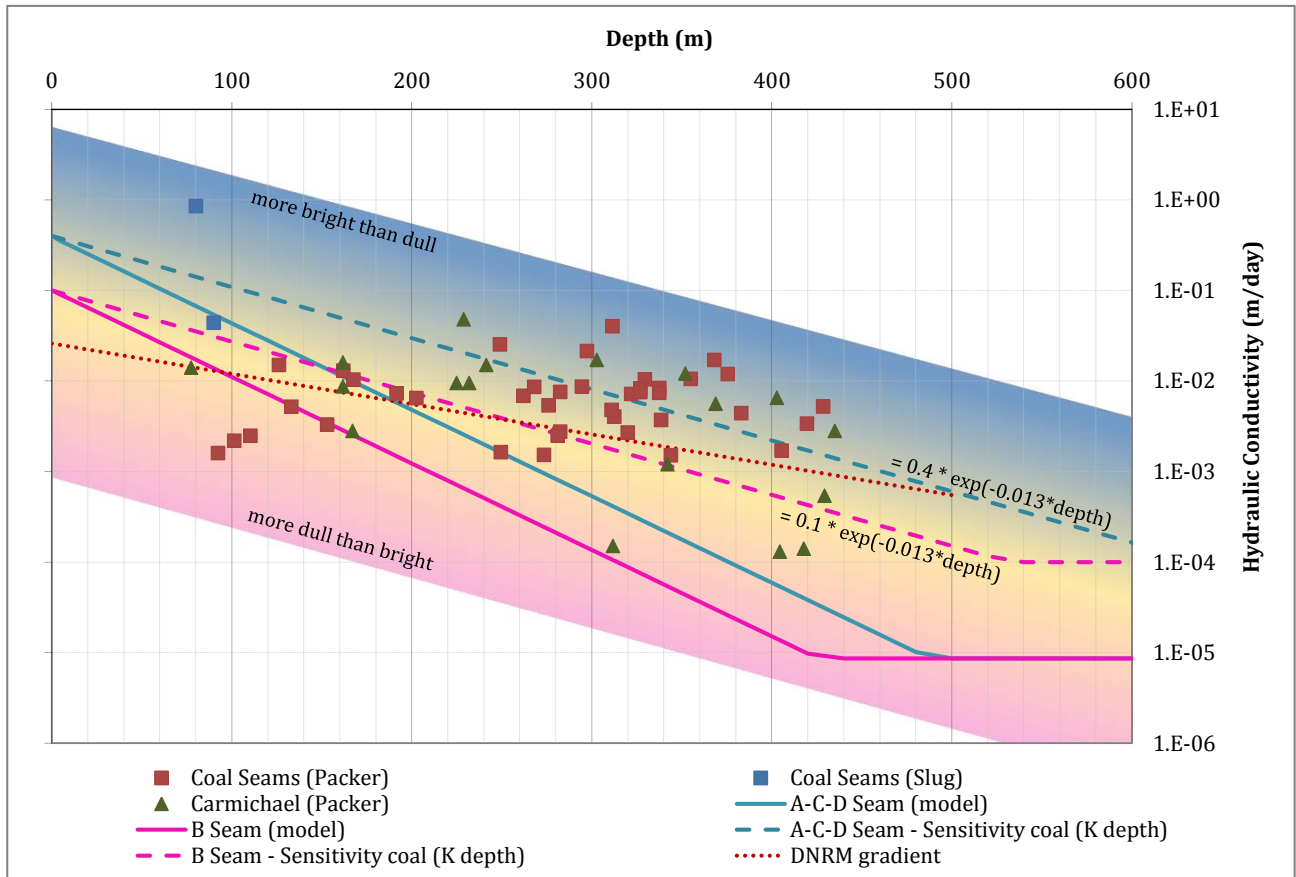
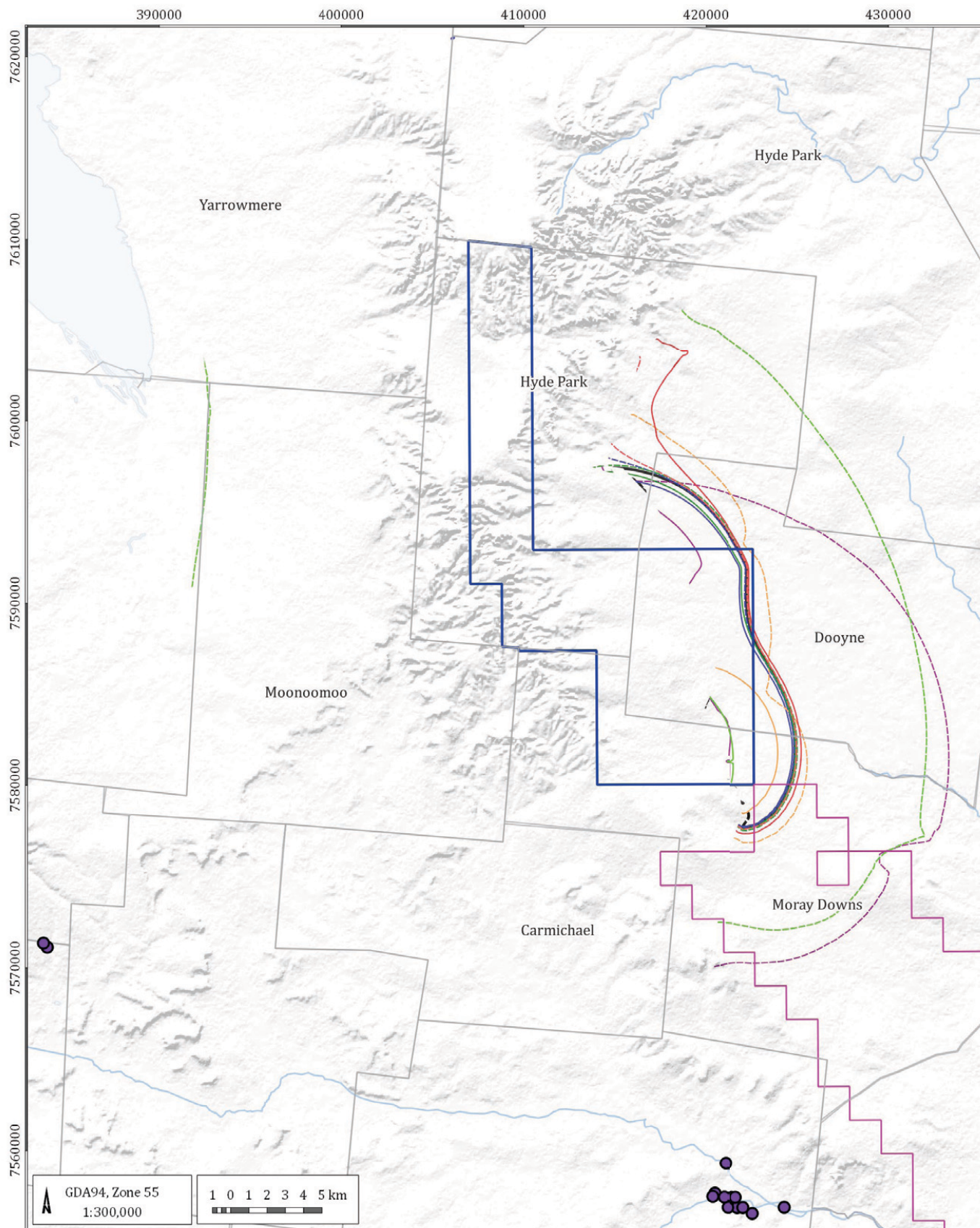


Figure C8 Reduced coal depth gradients adopted for Coal (K depth) sensitivity analysis

Appendix D **Sensitivity analysis results**



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

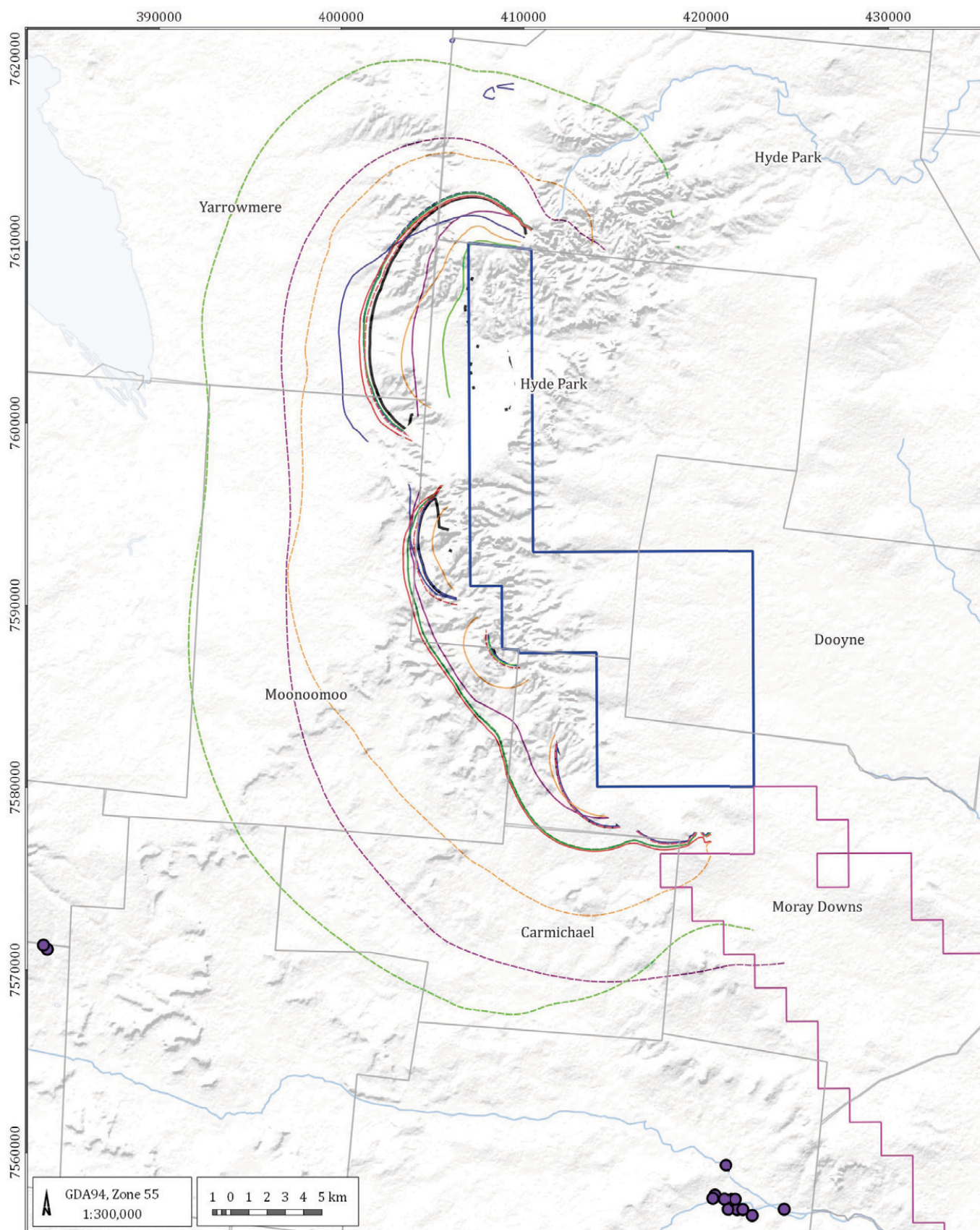
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - Tertiary sediments



DATE
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FIGURE No:
D1



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

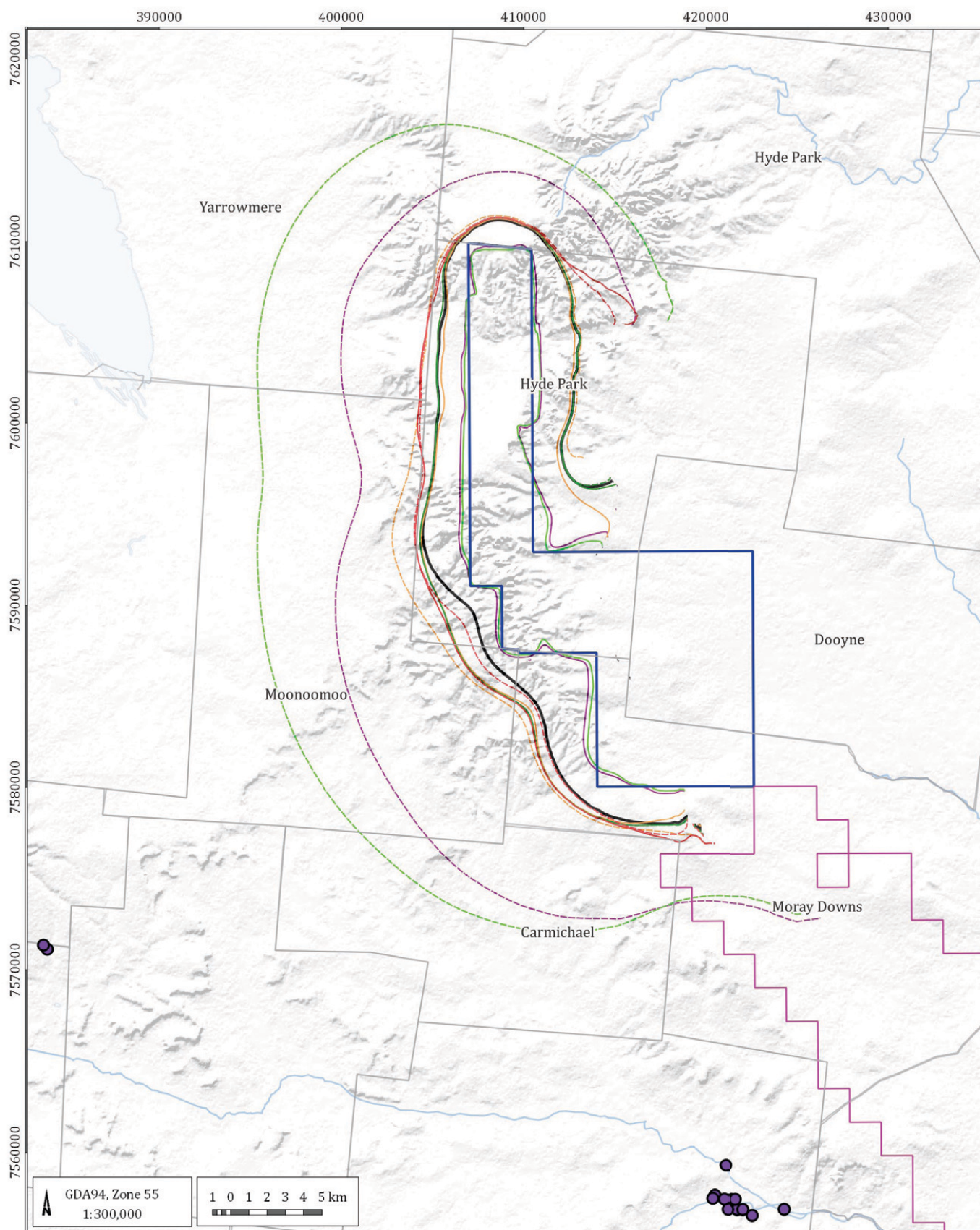
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - Clematis Sandstone



DATE
04/07/2017

FIGURE No:
D2



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

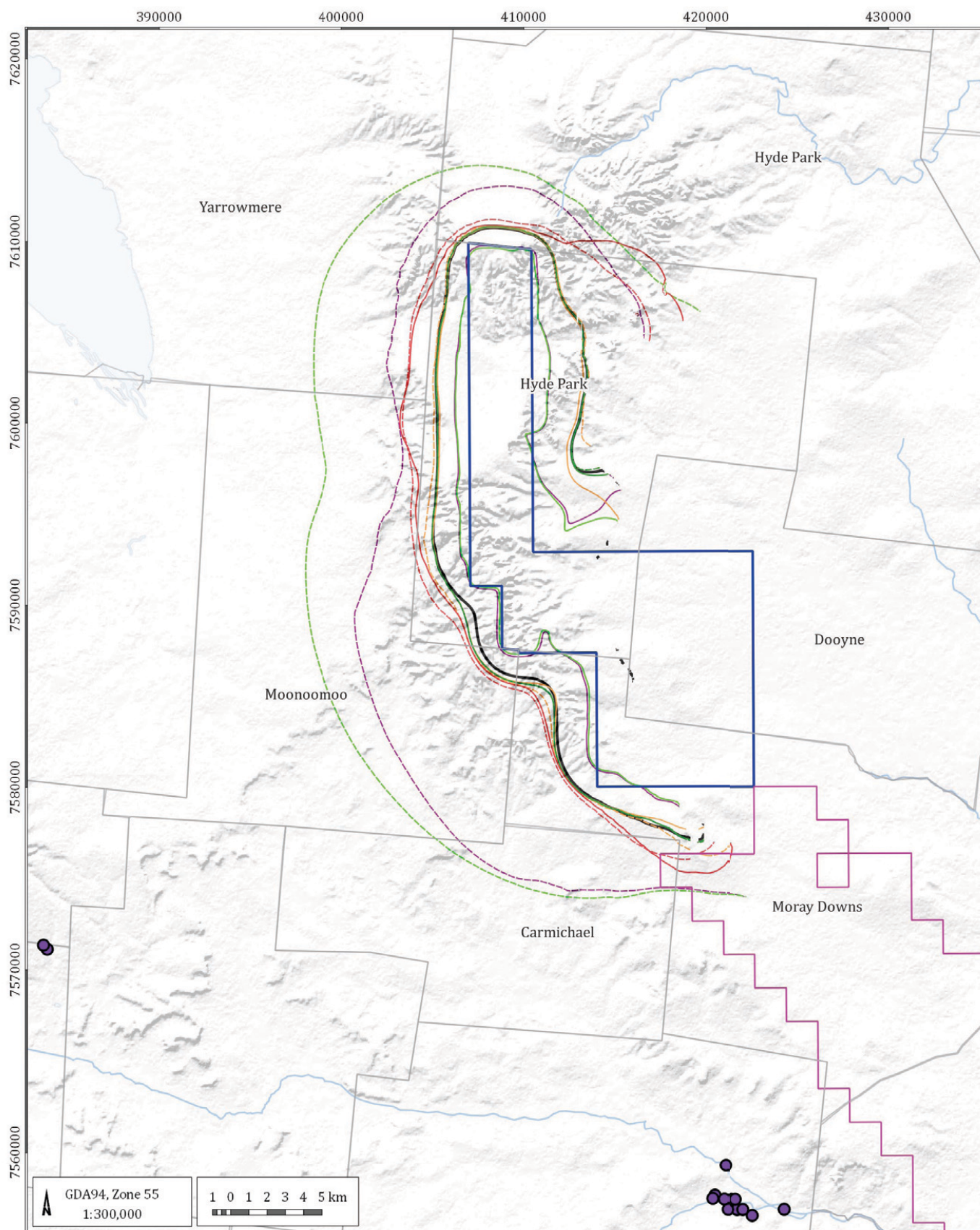
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - Permian sediments above A seam



DATE
04/07/2017

FIGURE No:
D3



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

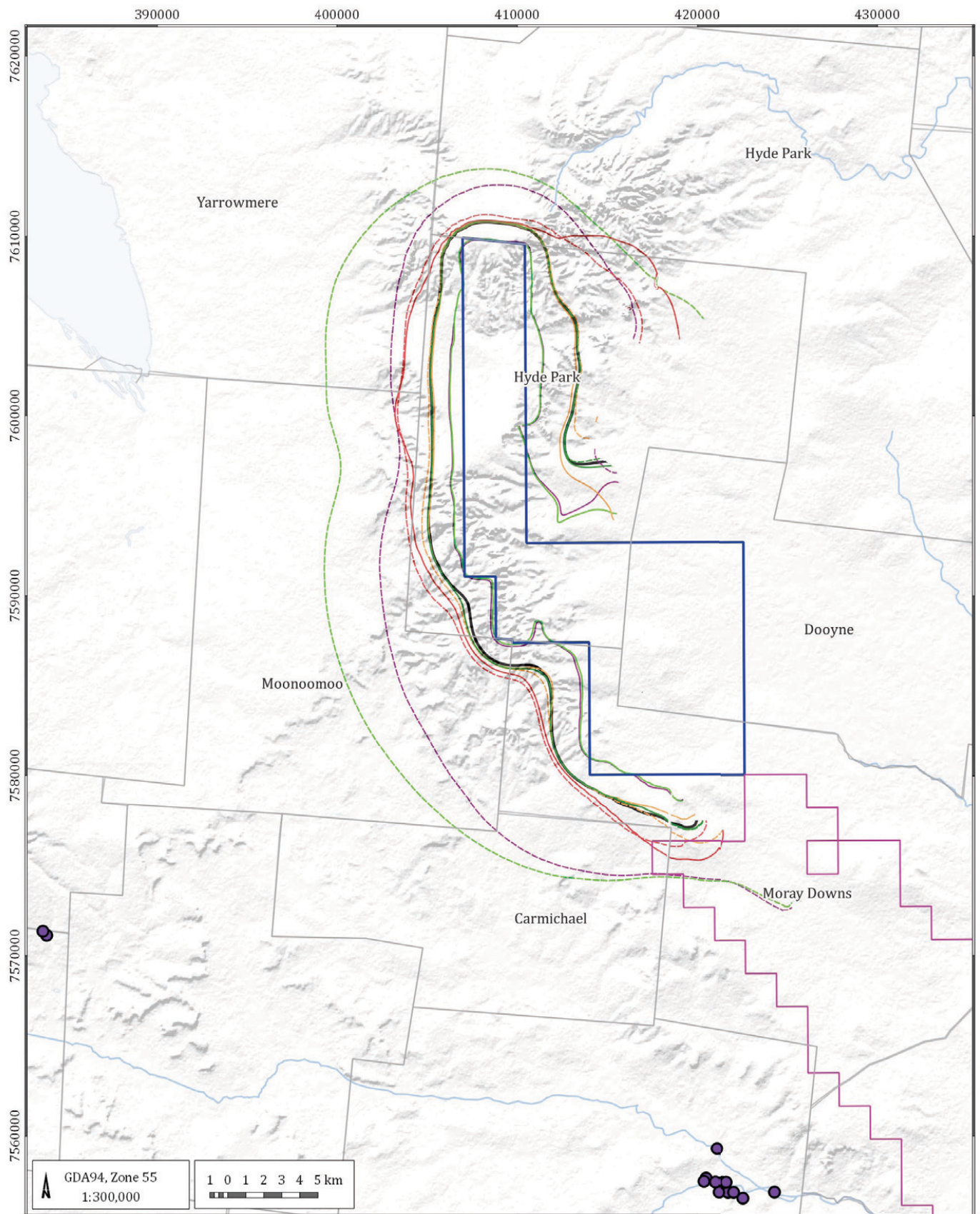
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - A seam



DATE
04/07/2017

FIGURE No:
D4



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

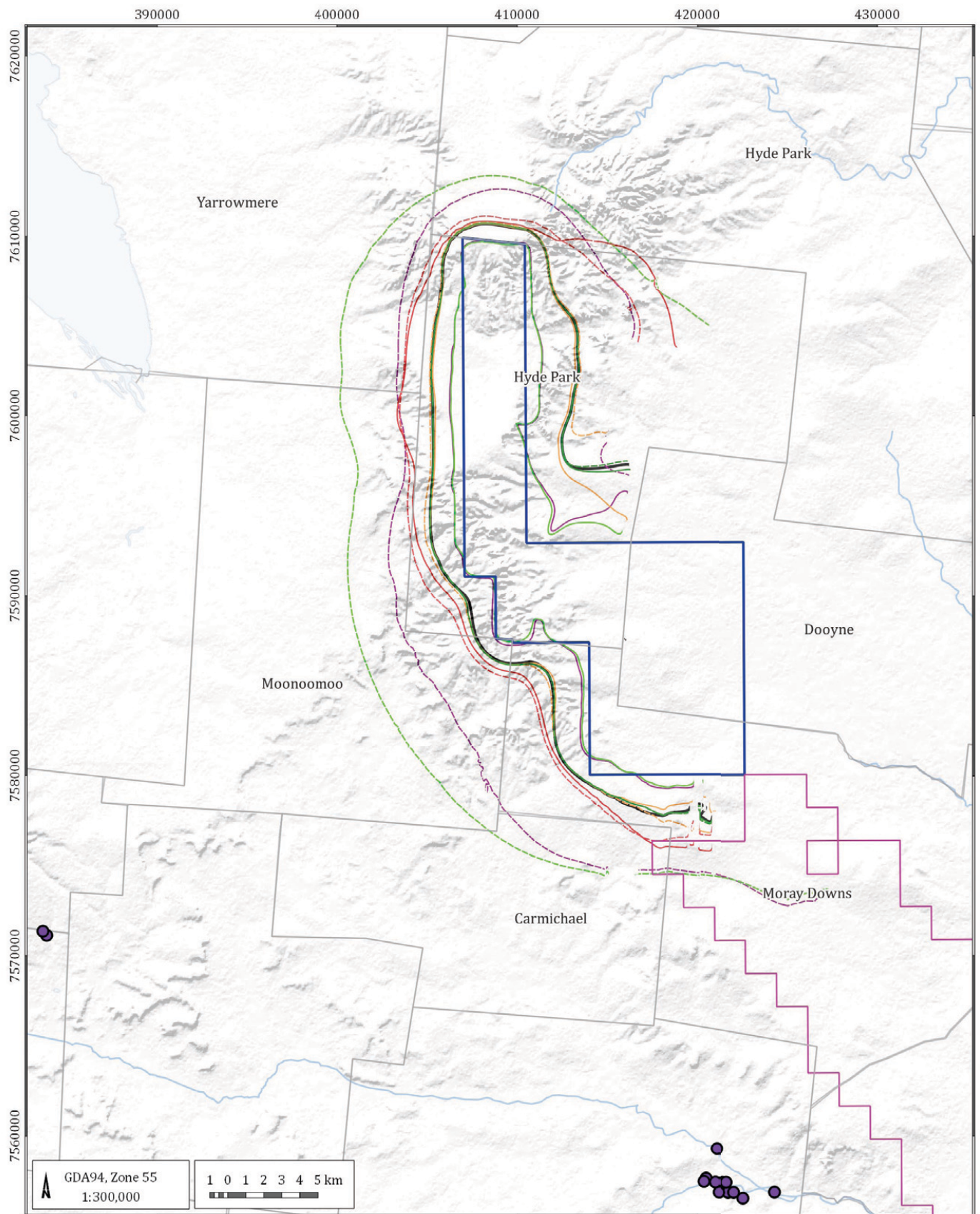
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - C seam



DATE
04/07/2017

FIGURE No:
D5



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

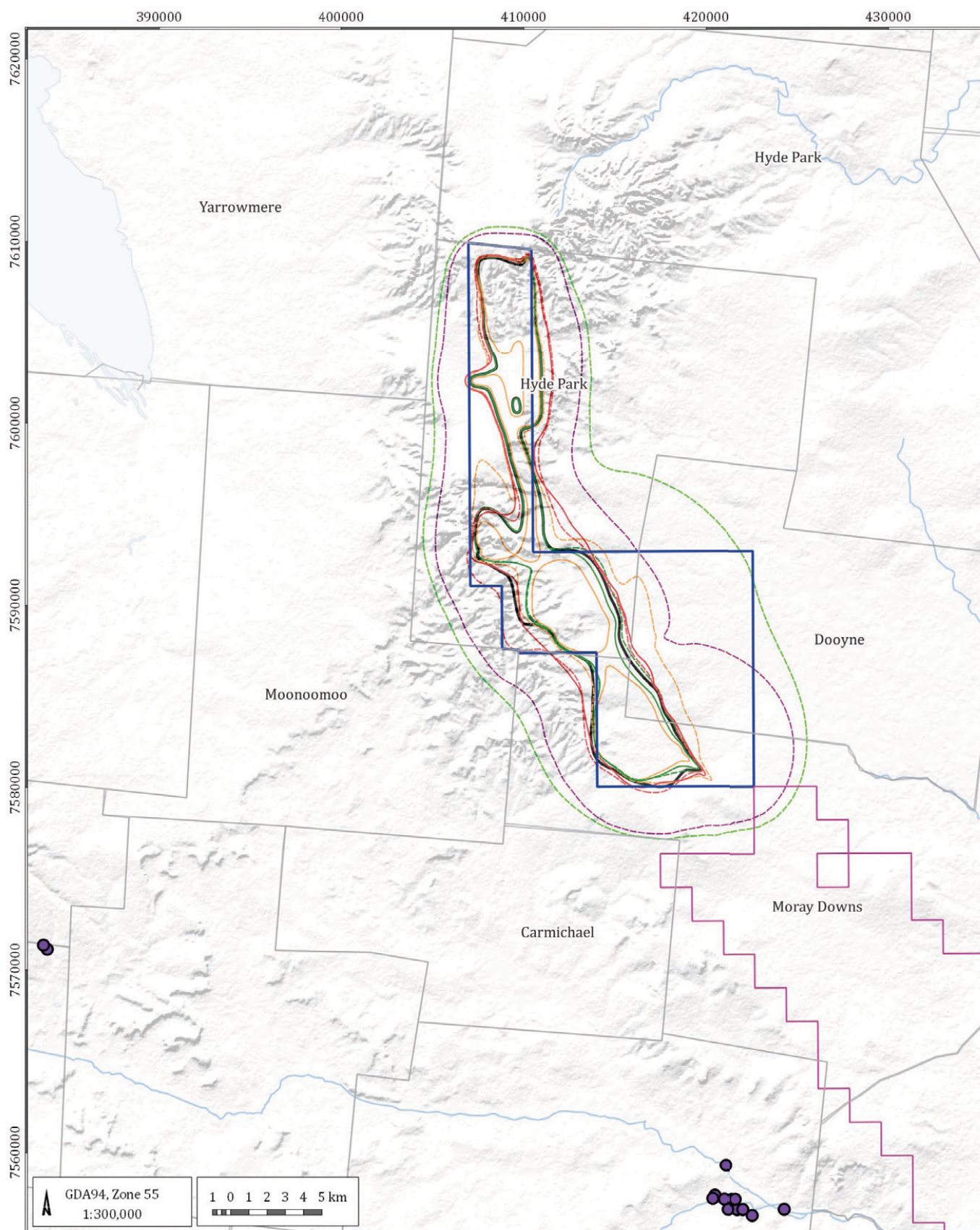
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - D seam



DATE
04/07/2017

FIGURE No:
D6



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

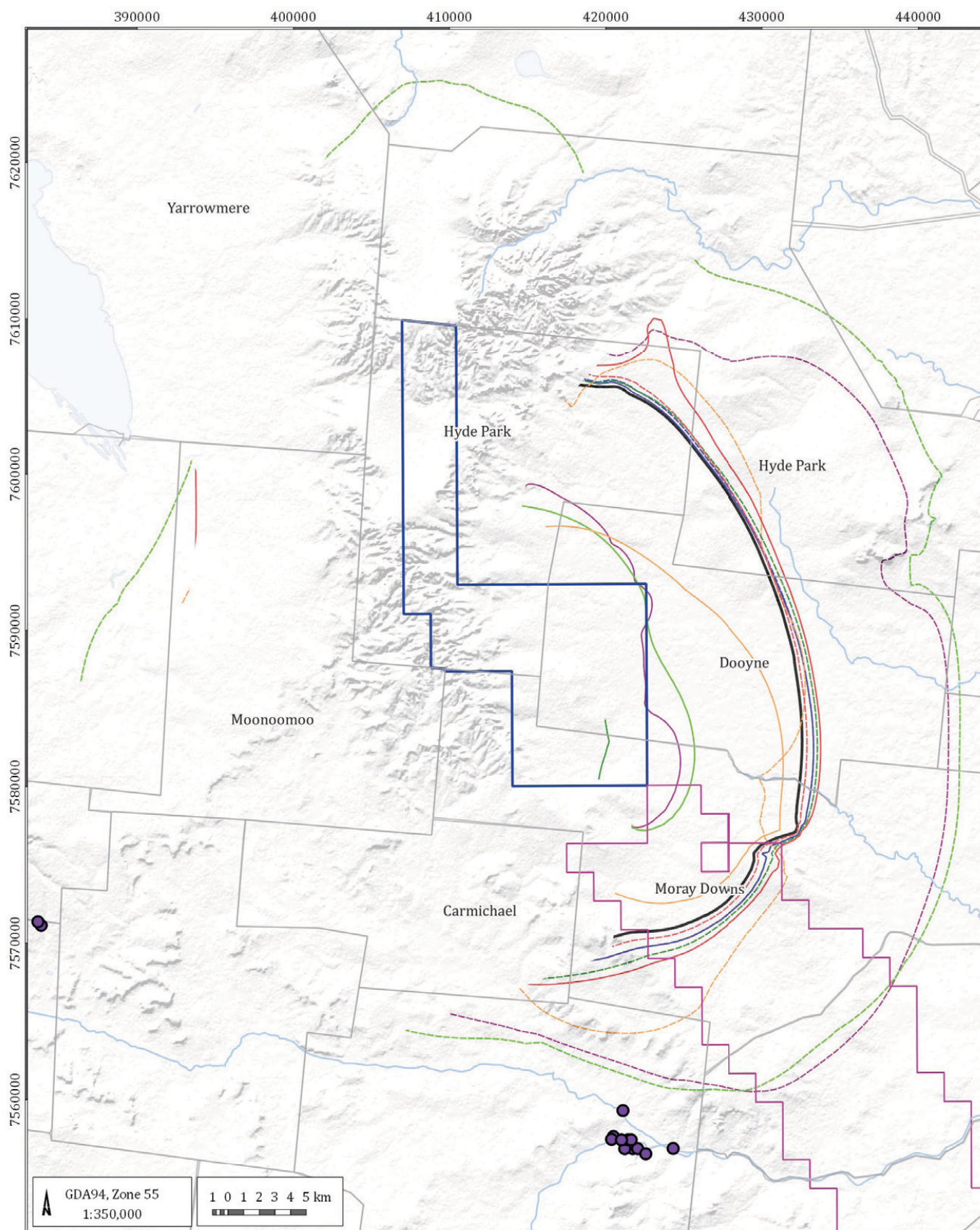
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation during mining - Permian sediments below D seam



DATE
04/07/2017

FIGURE No:
D7



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

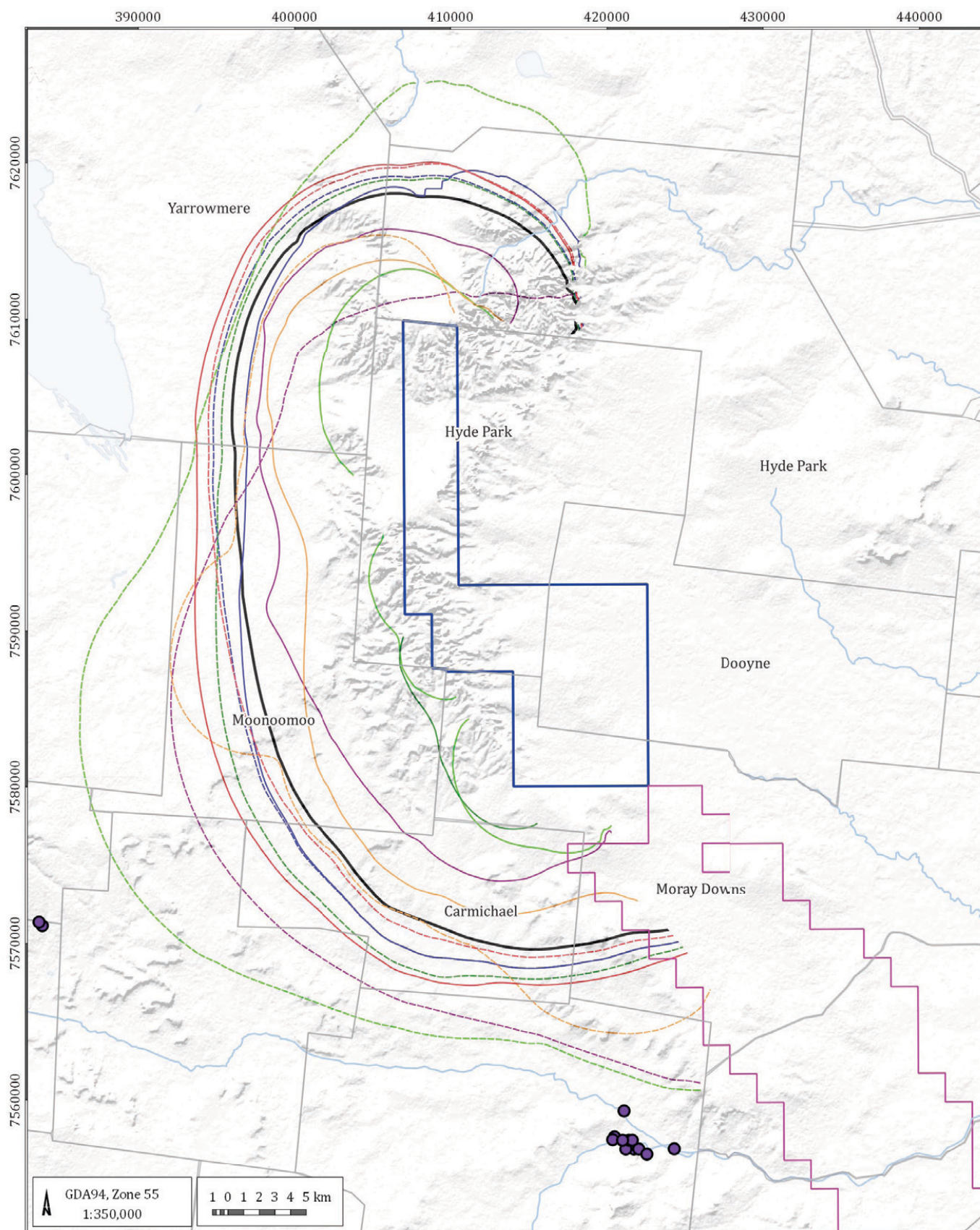
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - Tertiary sediments



DATE
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FIGURE No:
D8



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

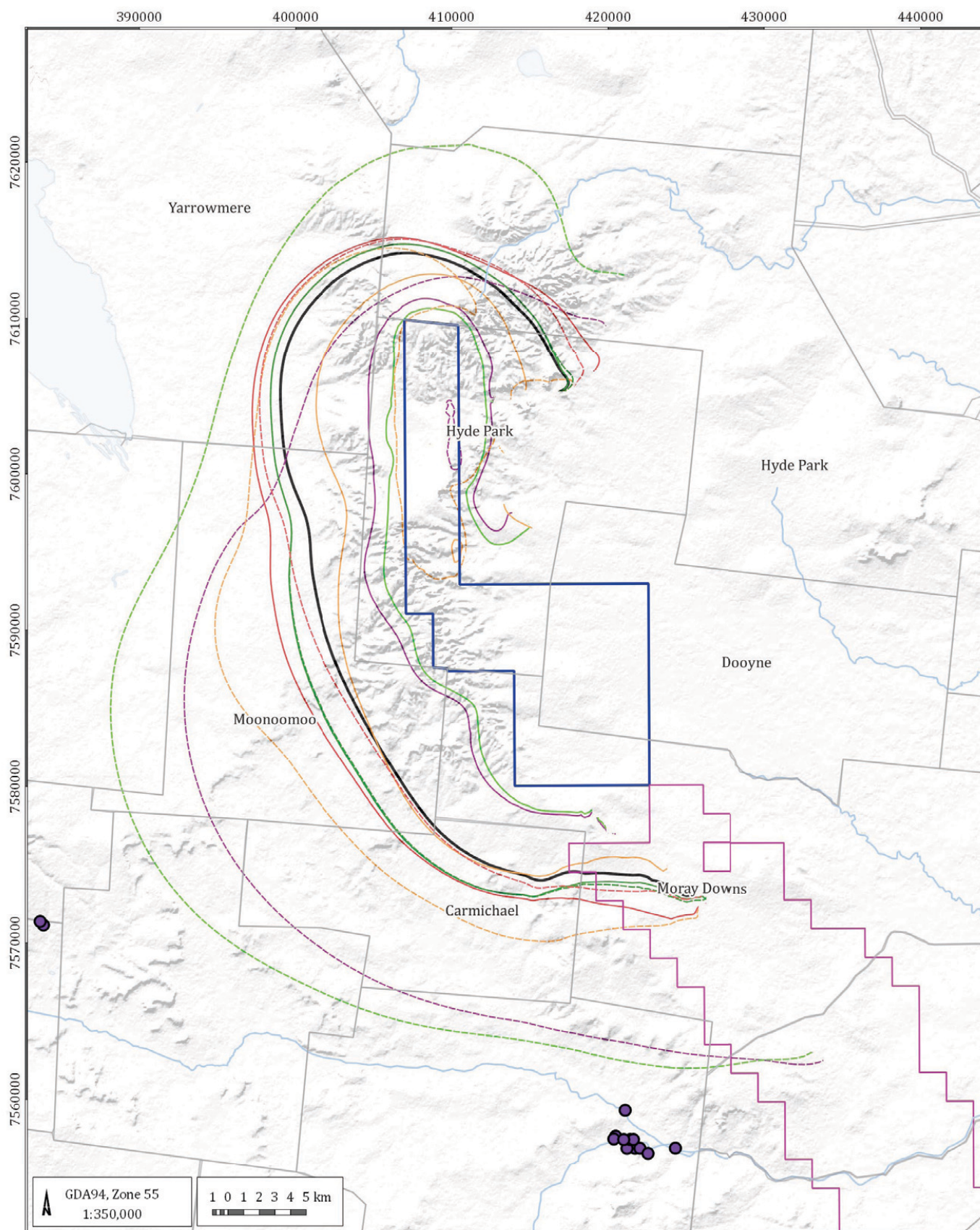
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - Clematis Sandstone



DATE
04/07/2017

FIGURE No:
D9



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

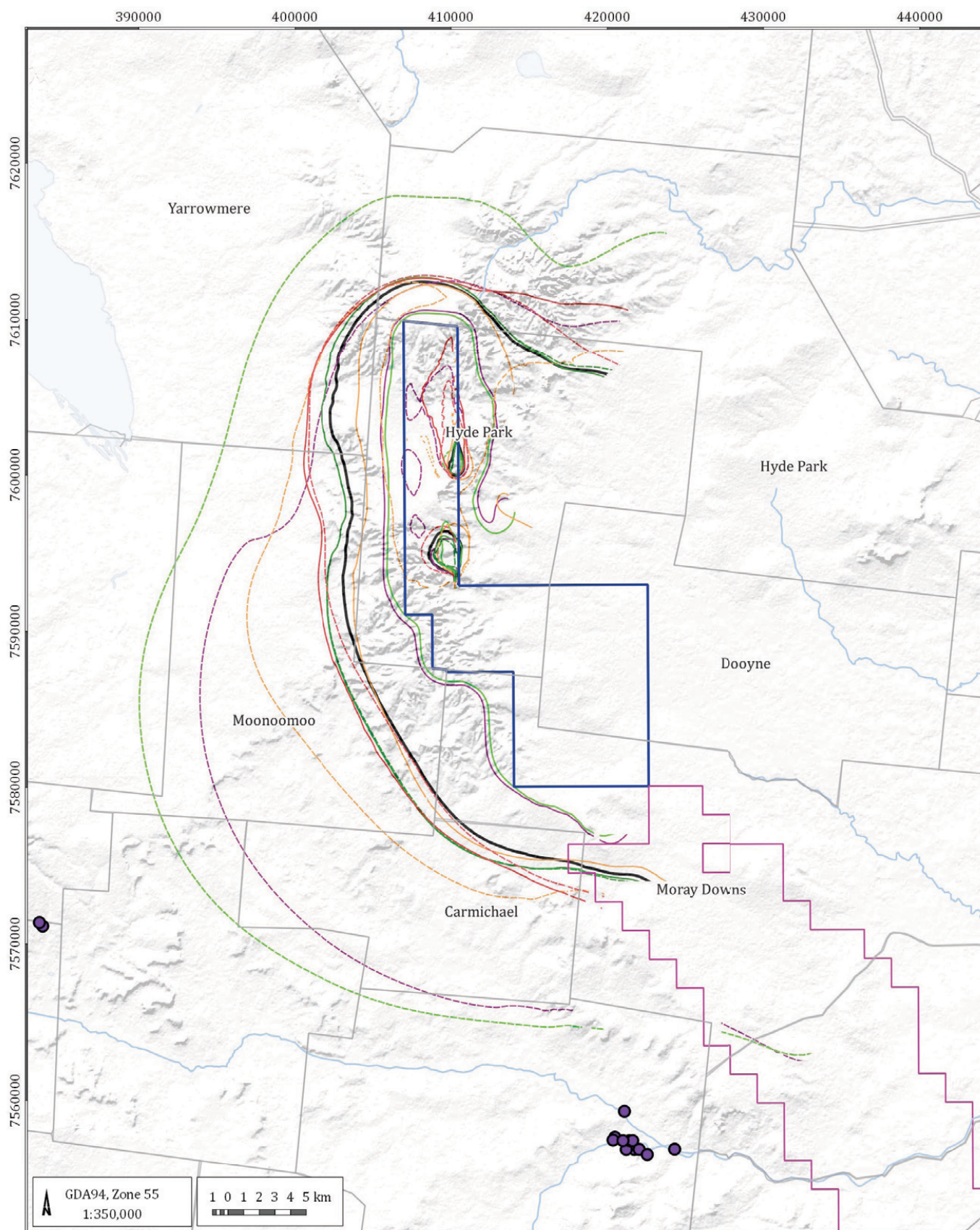
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - Permian sediments above A seam



DATE
04/07/2017

FIGURE No:
D10



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

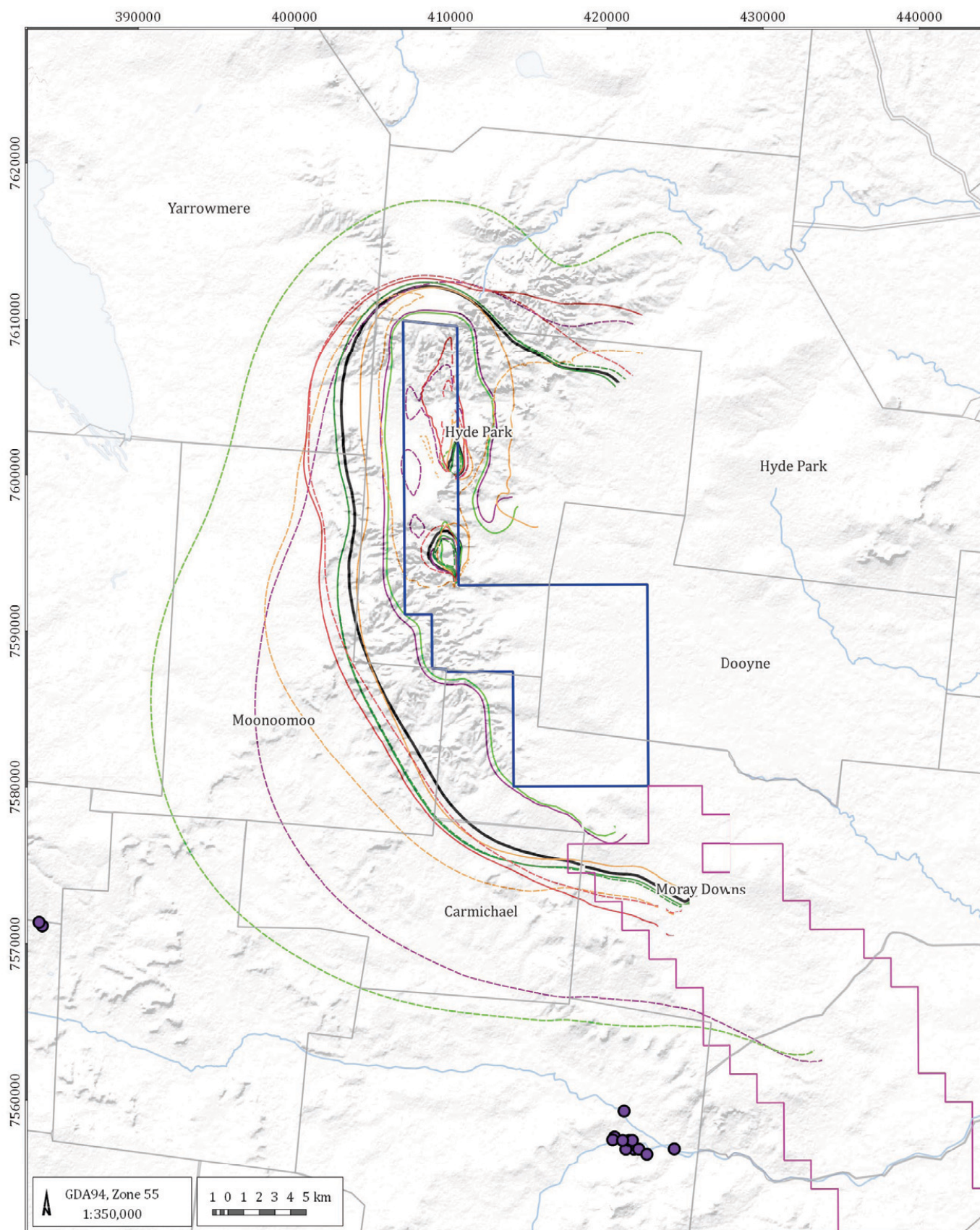
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - A seam



DATE
04/07/2017

FIGURE No:
D11



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

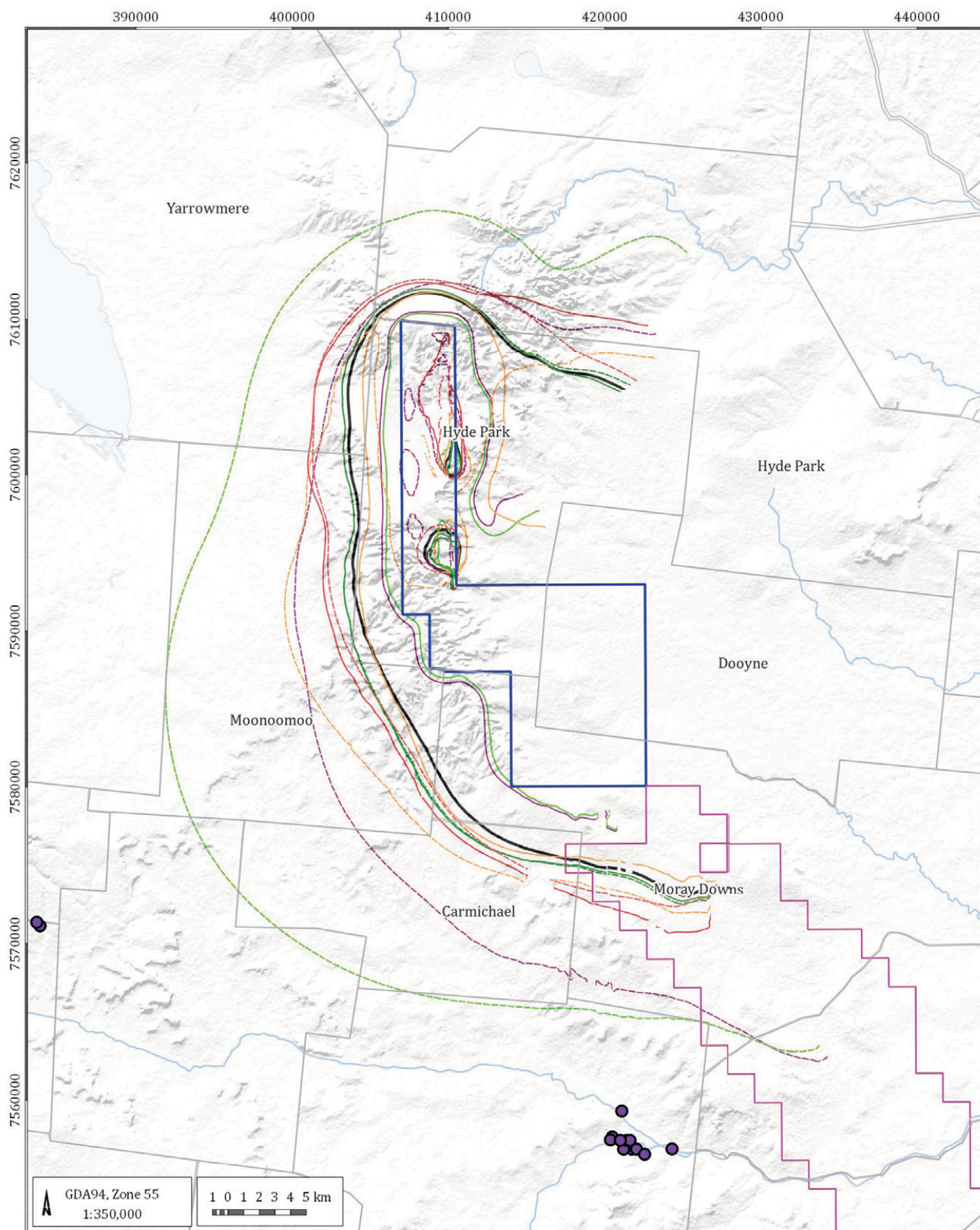
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - C seam



DATE
04/07/2017

FIGURE No:
D12



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

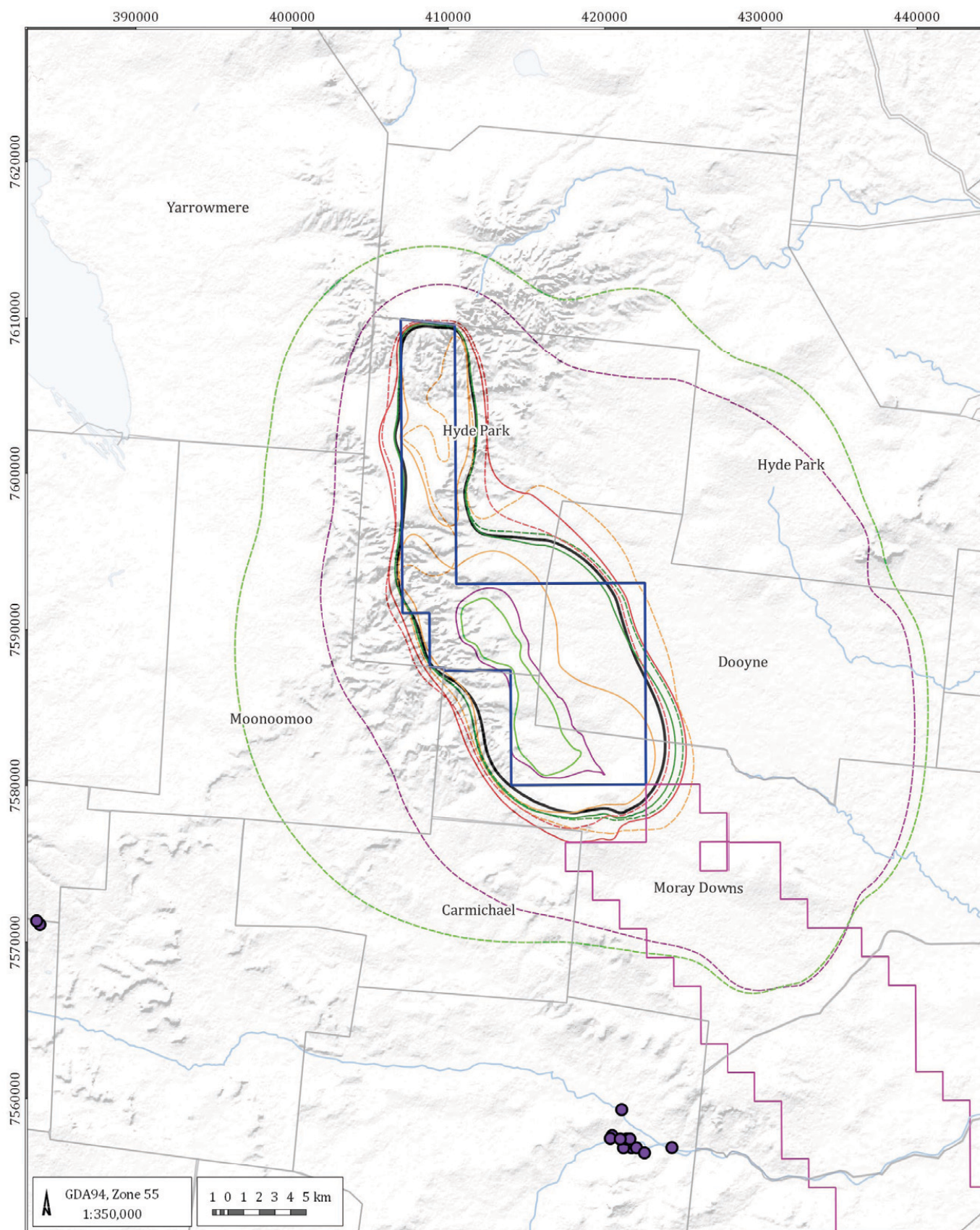
Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - D seam



DATE
04/07/2017

FIGURE No:
D13



LEGEND

- Project site
- Carmichael Coal Mine Project
- Major drainage
- Springs
- Cadastre
- Lake

Sensitivity - 1m contour

- Basecase
- Hydraulic conductivity (K) +
- Hydraulic conductivity (K) -
- Conduit fault (K/S)
- Barrier fault (HFB)
- Recharge (Rch) -
- Recharge (Rch) +
- Storage (S) -
- Storage (S) +
- Overburden (K/S/Rch) +
- Overburden (K/S/Rch) -
- Coal (K+)
- Coal (K depth)

Project China Stone (G1587F)

Sensitivity of maximum zone of depressurisation post mining - Permian sediments below D seam



DATE
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FIGURE No:
D14

Appendix E **Subsidence effects on vertical hydraulic conductivity**

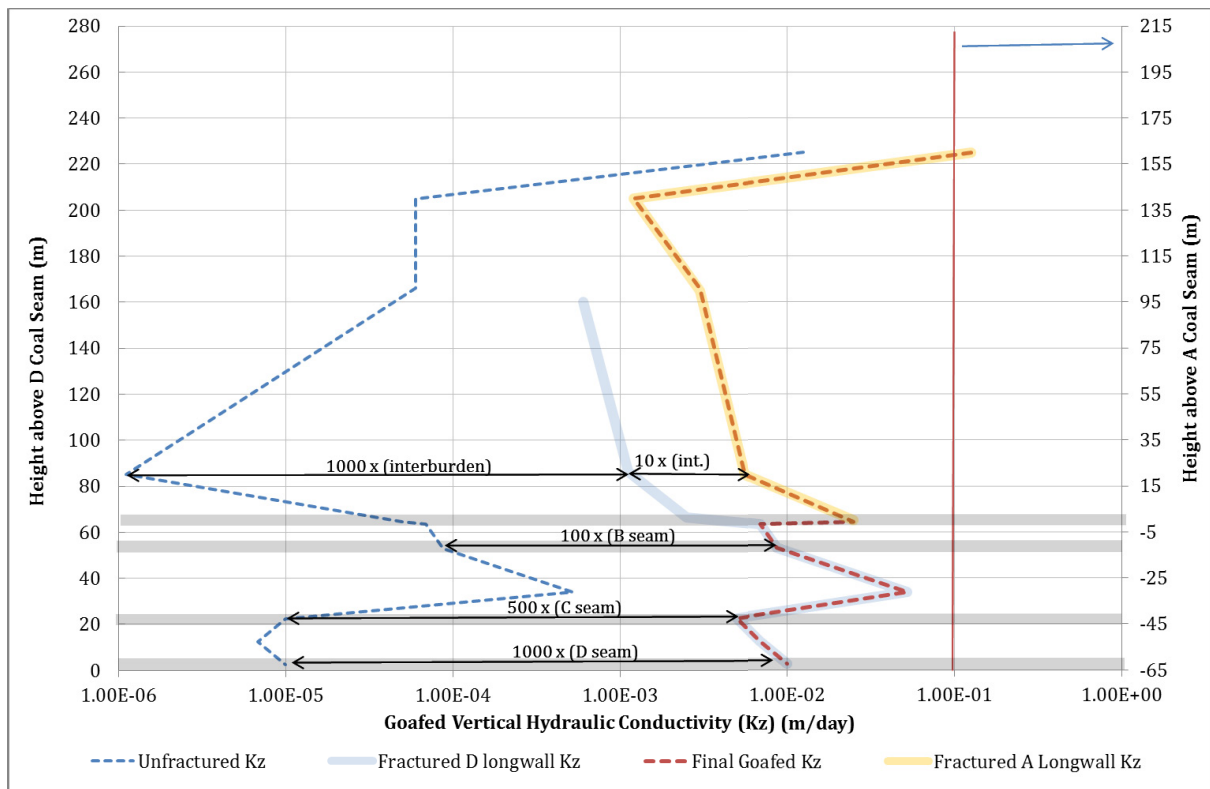
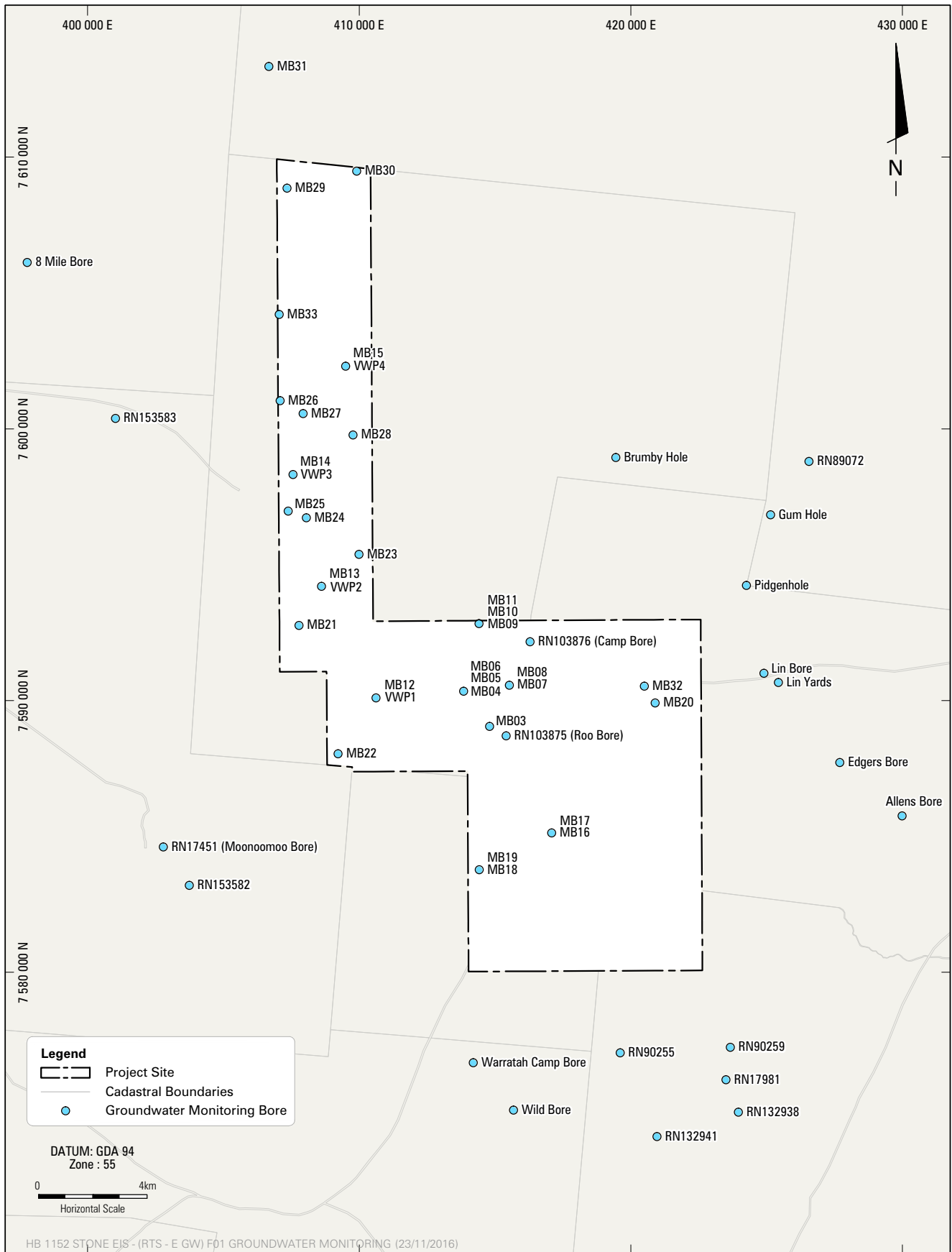


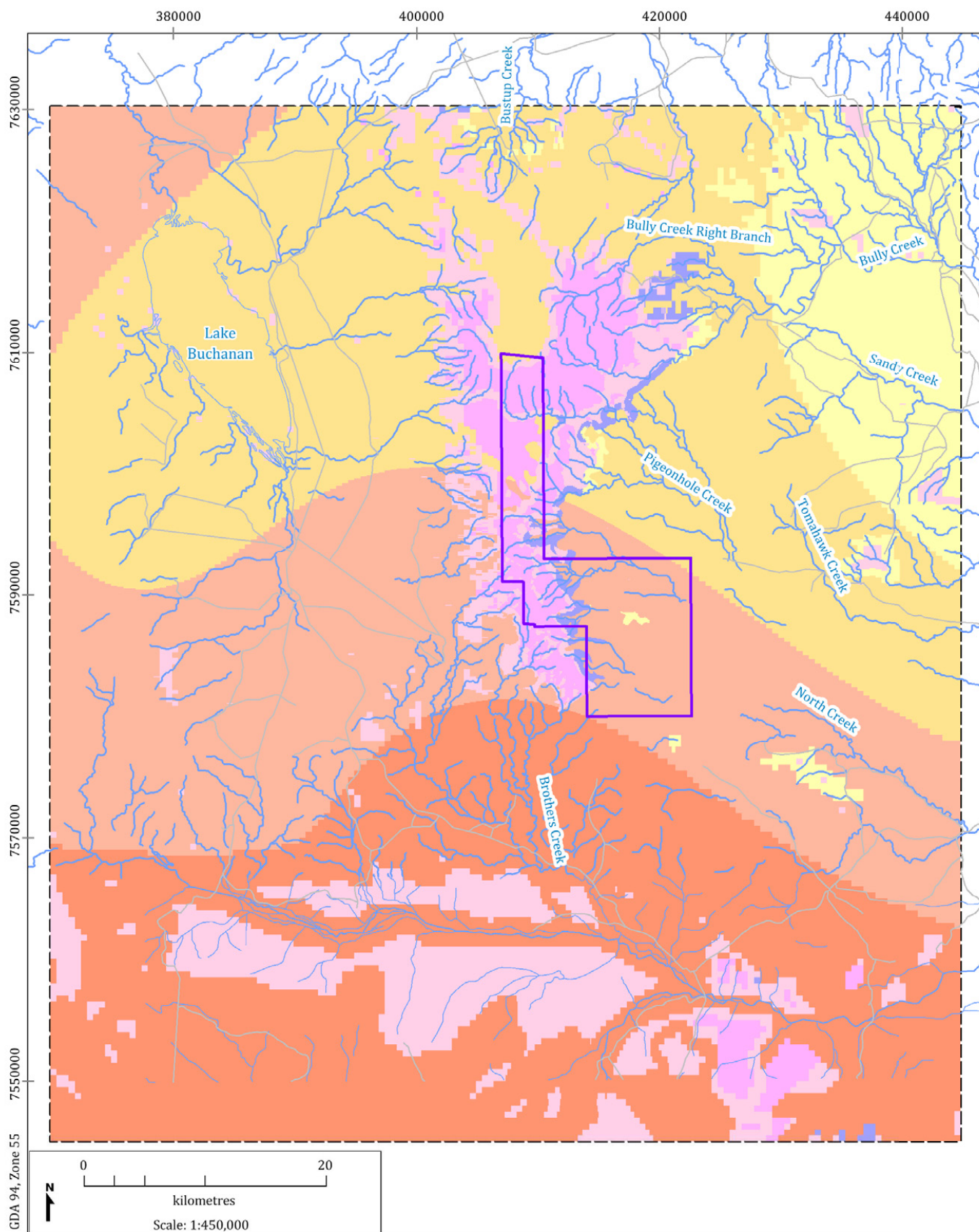
Figure E1 **Subsidence effects on vertical hydraulic conductivity**

Appendix F **Groundwater monitoring program**



PROJECT CHINA STONE

Appendix G **Updated model recharge figure (Figure B3)**



Project China Stone (G1587F)

Modelled Recharge Rates



DATE:
04/07/2017

FIGURE No:
B3

Appendix H **Vertical hydraulic conductivity multiplication factor**

The vertical hydraulic conductivity assigned to each layer in the model was a factor of the horizontal value. The factor was adjusted during calibration to optimise the match between the measured and simulated groundwater water level measurements. The multiplication factors used to calculate vertical hydraulic conductivity are shown in the table below.

Table H Vertical hydraulic conductivity multiplication factors

Layer	Geology	Multiplication factor
1	Alluvium	0.434
2	Tertiary	0.5
3	Ronlow Beds	0.242
4	Mooayameber Fm	0.5
5	Clematis Sandstone	0.251
6	Dunda Beds	0.02
7-8	Rewan Fm	0.022
9	Permian Interburden	0.01
10	AU Seam	0.5
11	Interburden	0.139
12	B Seam	0.872
13	Interburden	0.35
14	C Seam	0.1
15	Interburden	0.015
16	D Seam	0.1
17	Permian Seams/Interburden	0.5
18	Joe Joe Group	0.5