INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS

Australian National Chapter

NSW Branch

2009 Seminar Series

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Water and Environment

An Integrated Hydrogeological and Geotechnical Modelling Approach to Predicting Groundwater and Surface Water Impacts of Subsidence above Longwall Mines in the Hunter Valley

29 October, 2009

Acknowledgements

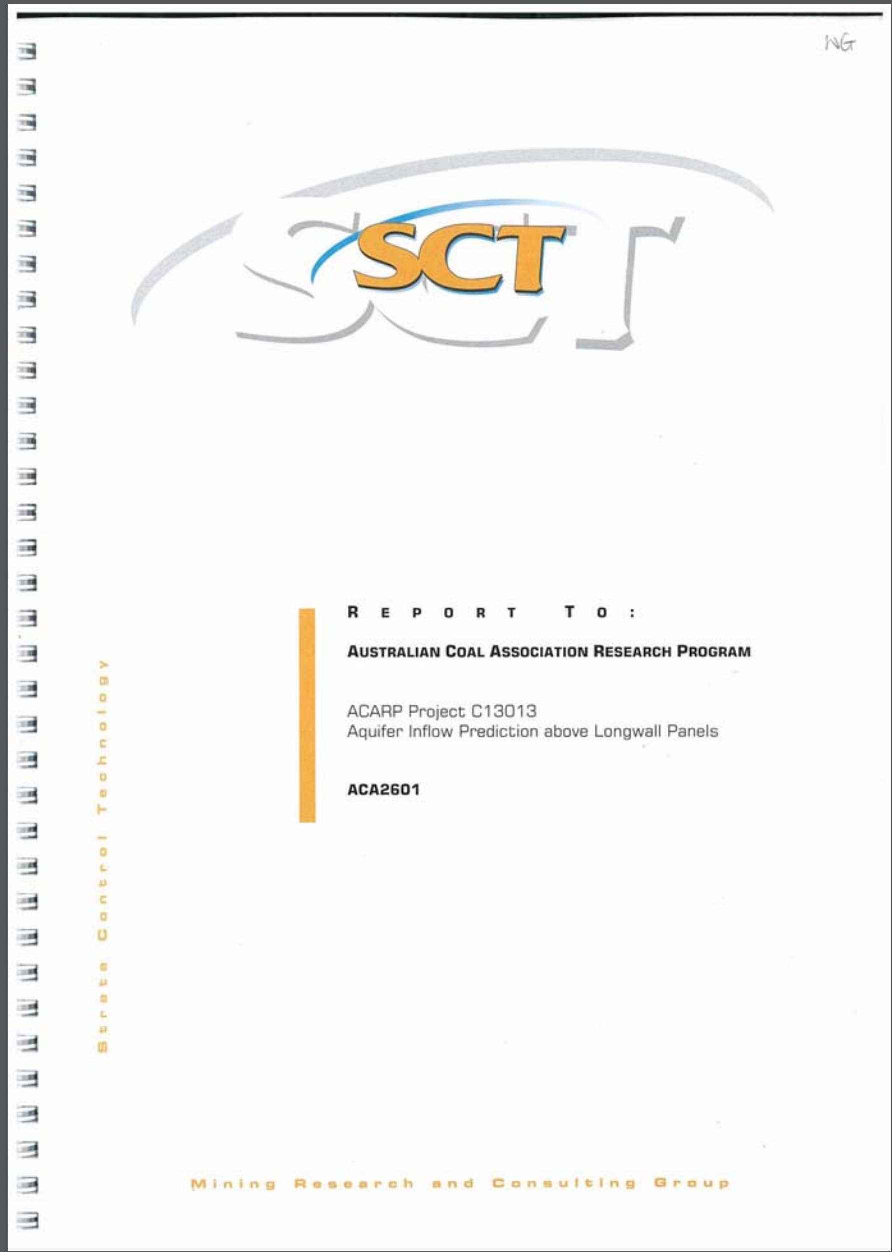
- Aquaterra
- Winton Gale, Strata Control Technology (STC)
- Ashton Coal Operations Limited (ACOL)

Overview

- Water inflows to mines
  - Two classes of inflow
    - Inflows that impact on safety, mining operations, etc
    - Inflows that impact on the environment
- Longwall mining
  - Relatively new mining approach
  - Guidelines developed from empirical data
  - Related to larger volume inflows, not low volume environmental inflows
  - Limited monitoring database of impacts (esp low volume environmental impact inflows)
  - Multi-seam longwall mining new to Hunter Valley

ACARP Study

- Australian Coal Association Research Program (ACARP) project
- ACARP Project C13013
- *"Aquifer Inflow Prediction Above Longwall Panels"*, 22 September 2008
- Author – Winton Gale, SCT Operations Pty Ltd
- Case study sites – Hunter Valley (NSW) and Bowen Basin (Queensland)


SCT

REPORT TO:

AUSTRALIAN COAL ASSOCIATION RESEARCH PROGRAM

ACARP Project C13013
Aquifer Inflow Prediction above Longwall Panels

ACA2601

Strata Control Technology

Mining Research and Consulting Group

Groundwater Flow

- Dominantly fracture flow in Permian coal measures
- Typical in situ hydraulic conductivities:
  - Rock matrix Kh and Kv very low, < 10^{-11} or 10^{-12} m/s (< 10^{-6} or 10^{-7} m/d)
  - Fracture permeability usually dominates, and commonly horizontal or bedding related
  - Rock mass Kh highly variable, but may range up to 10^{-5} m/s (1 m/d)
  - Rock mass Kv generally much lower, commonly 1 to 4+ orders lower than Kh

Groundwater Flow Around Mines

- Combined approach of geotechnical modelling and hydrogeological modelling allows consideration of both small scale and large scale aspects of the flow system
- Naturally-occurring fractures
- Longwall mining induced fractures
- Degree of interconnection of fractures is hard to determine

Factors Influencing Water Inflow to Longwall Mines

- Hydrogeology of the coal measures
- Magnitude of subsidence
- Cover depth
- Longwall panel width
- Geology (eg presence of bridging layer)
- Overburden tensile strains at water source (eg lake or alluvium aquifer)

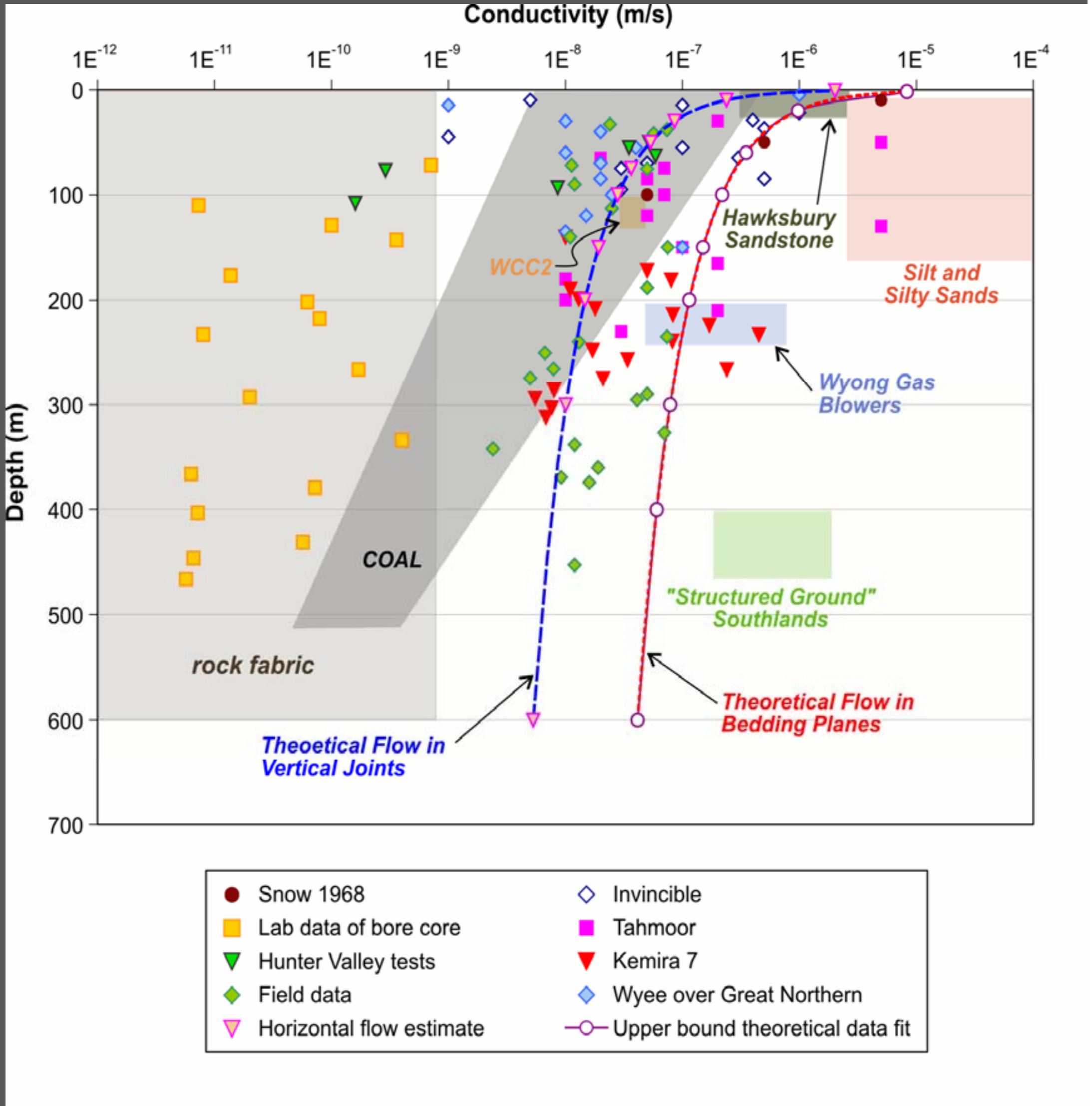


Figure 8 Examples of field measurements of hydraulic conductivity of strata.

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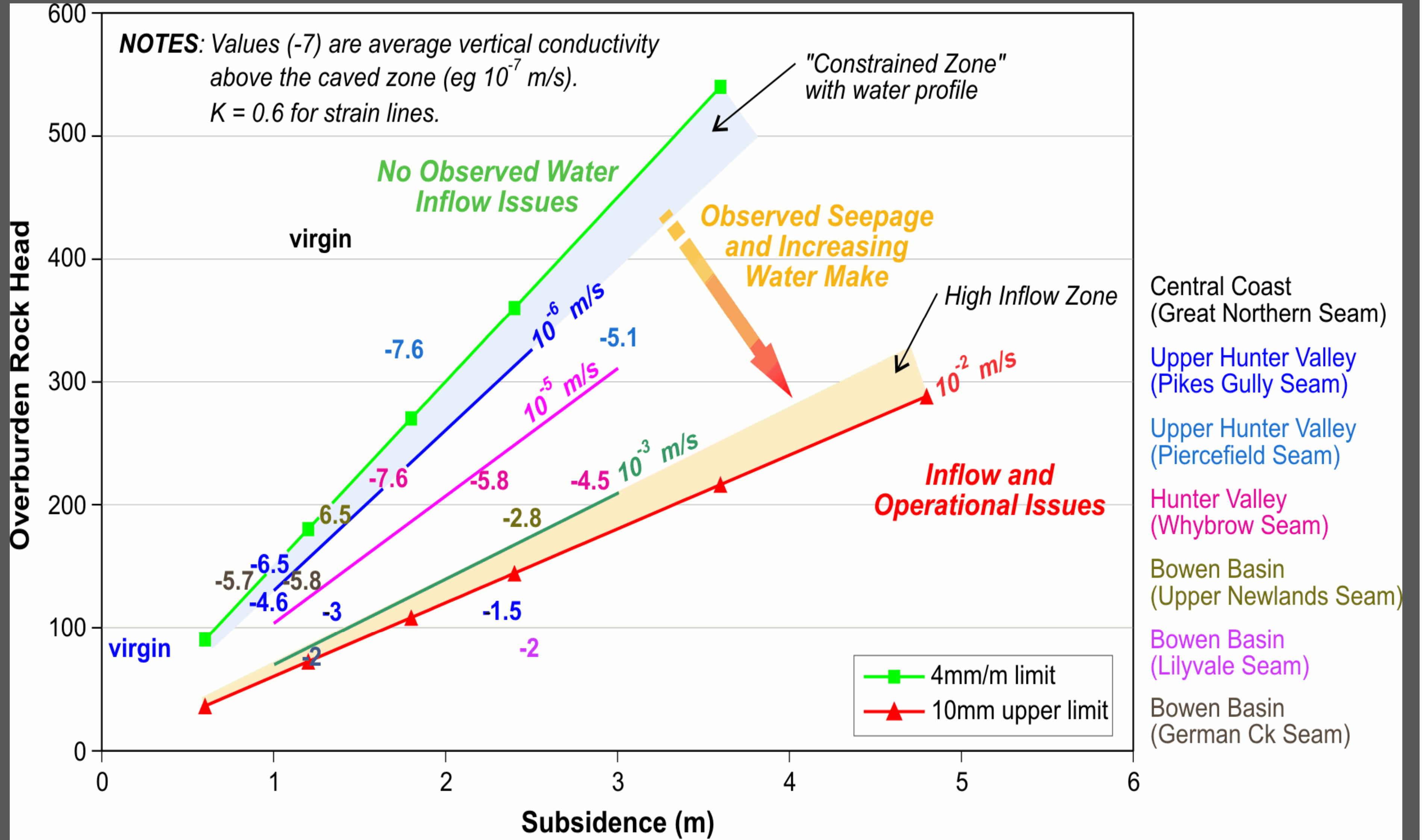
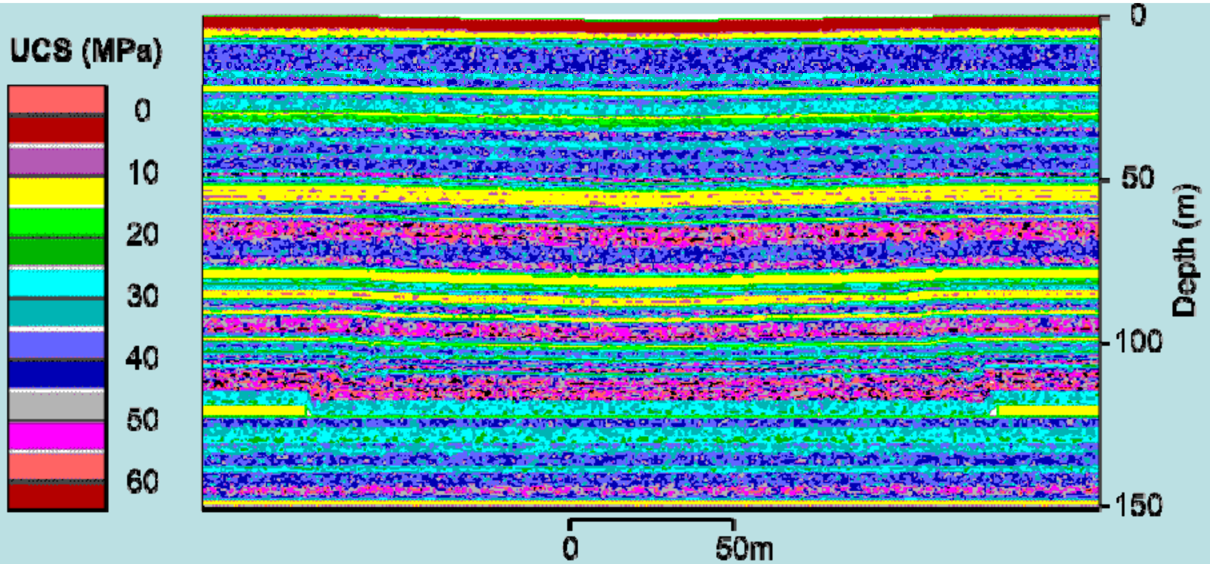


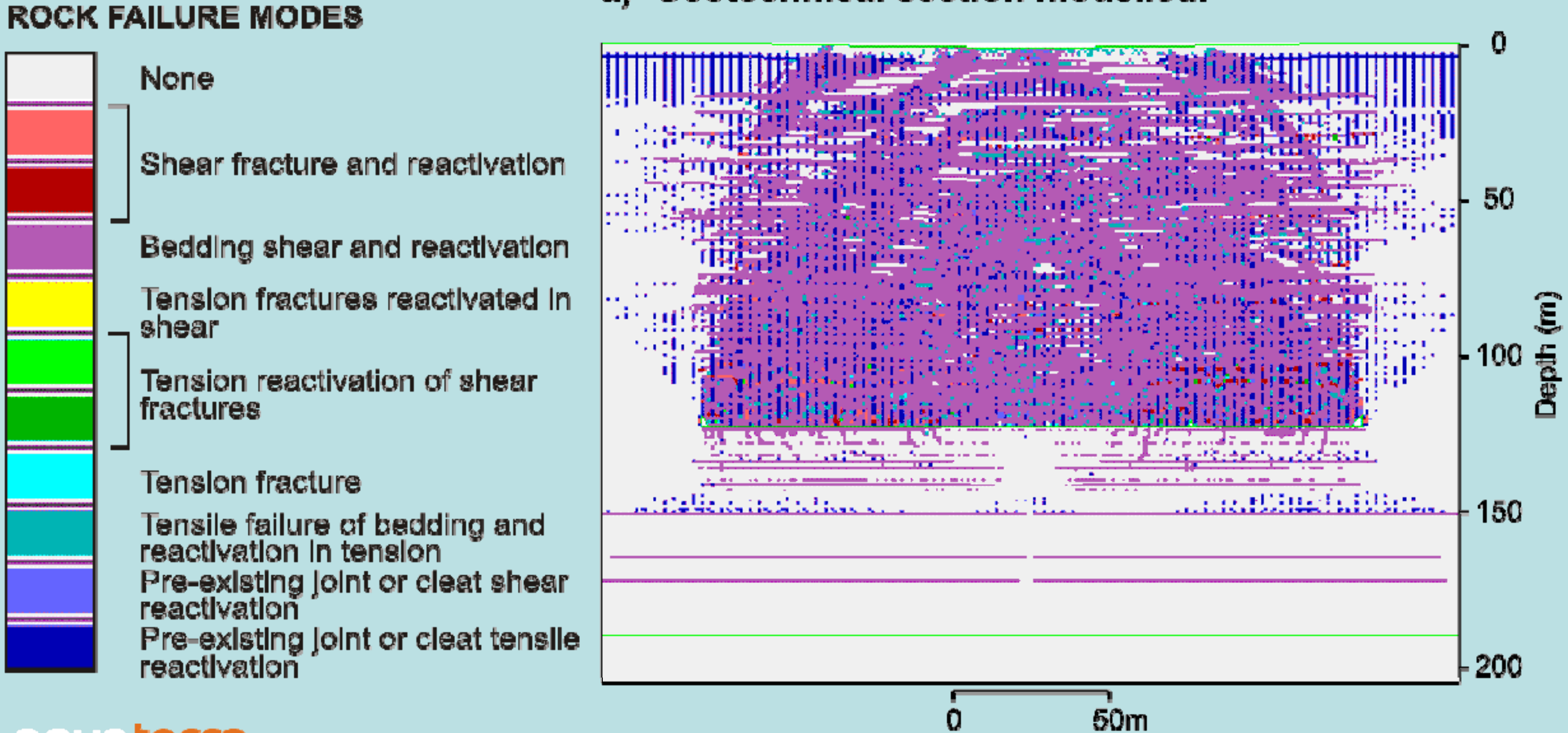
Figure S1 Average overburden conductivity characteristics relative to subsidence and depth criteria.

SCT Fracture Modelling

- FLAC modelling
- Vertical 2-D model
- 1m x 1m cell size
- Geology and fracture patterns derived from geological/geotechnical logging of drill core
- Rock strength properties from lab testing
- Apply stresses associated with longwall extraction
- FLAC Model used to predict
  - Changes to existing fractures
  - Generation of new fractures
- Hydraulic conductivity proportional to third power of aperture width



a) Geotechnical section modelled.



b) Rock fracture mode and distribution.

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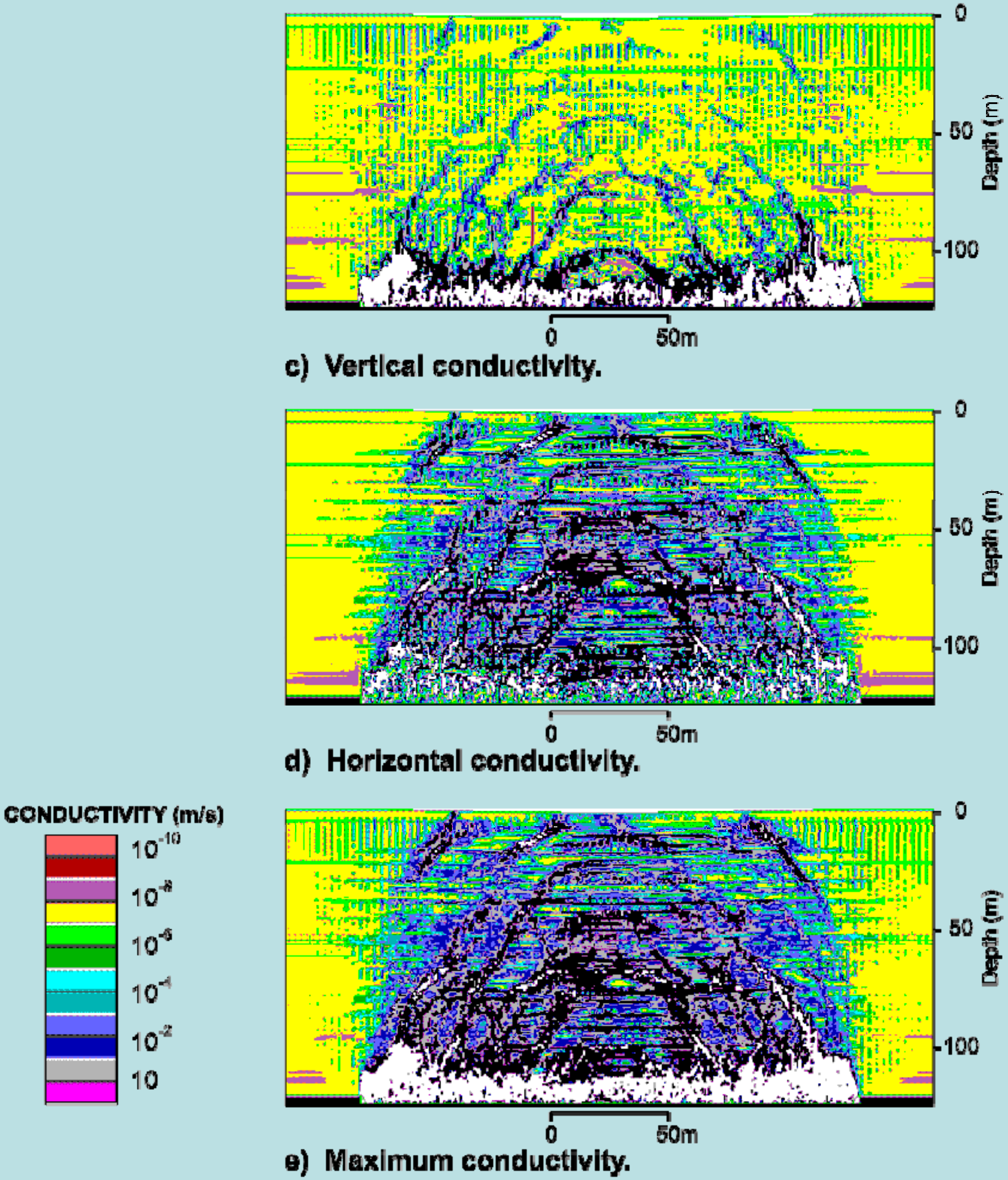

Figure S2 Fracture distribution in the model and the resultant horizontal and vertical conductivity of the elements in the model.

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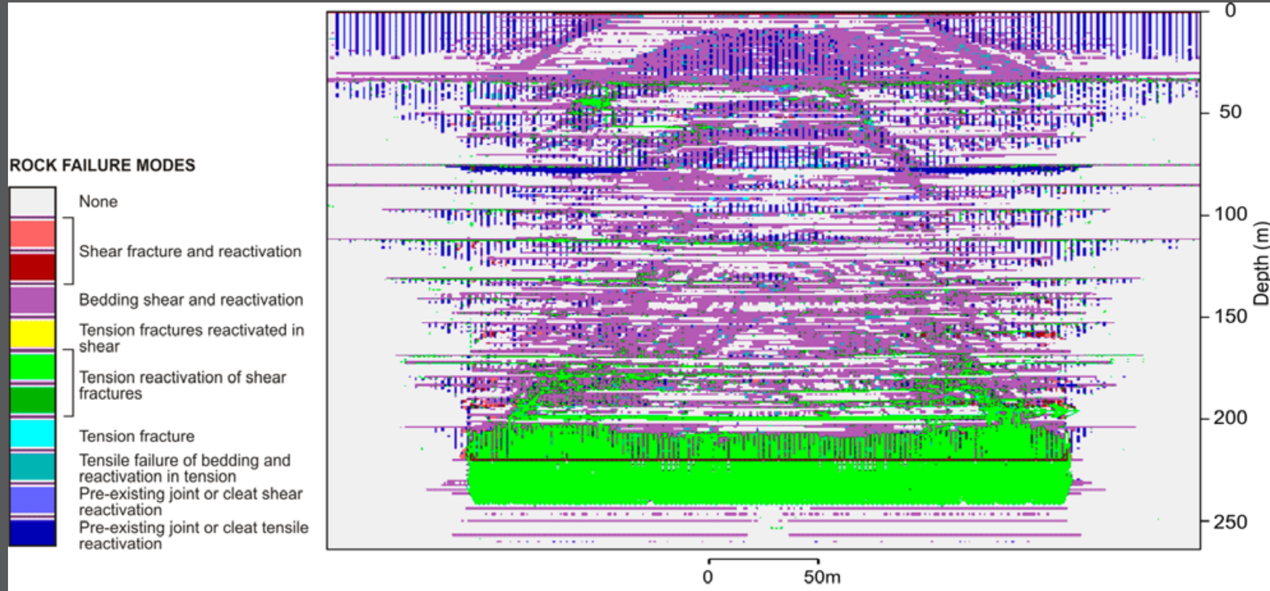
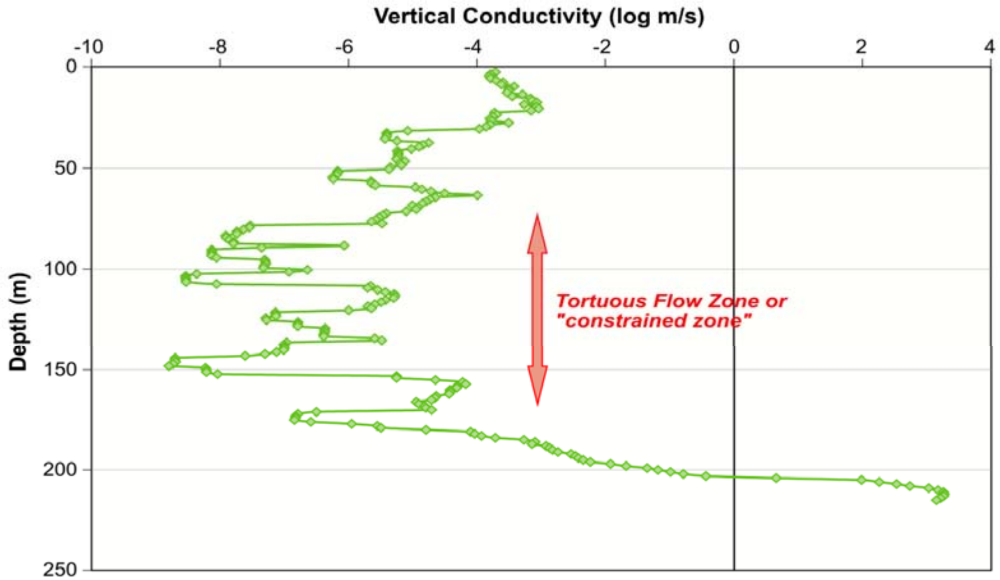


a) Panel geometry, fracture distribution and flow paths.



b) Vertical Conductivity.

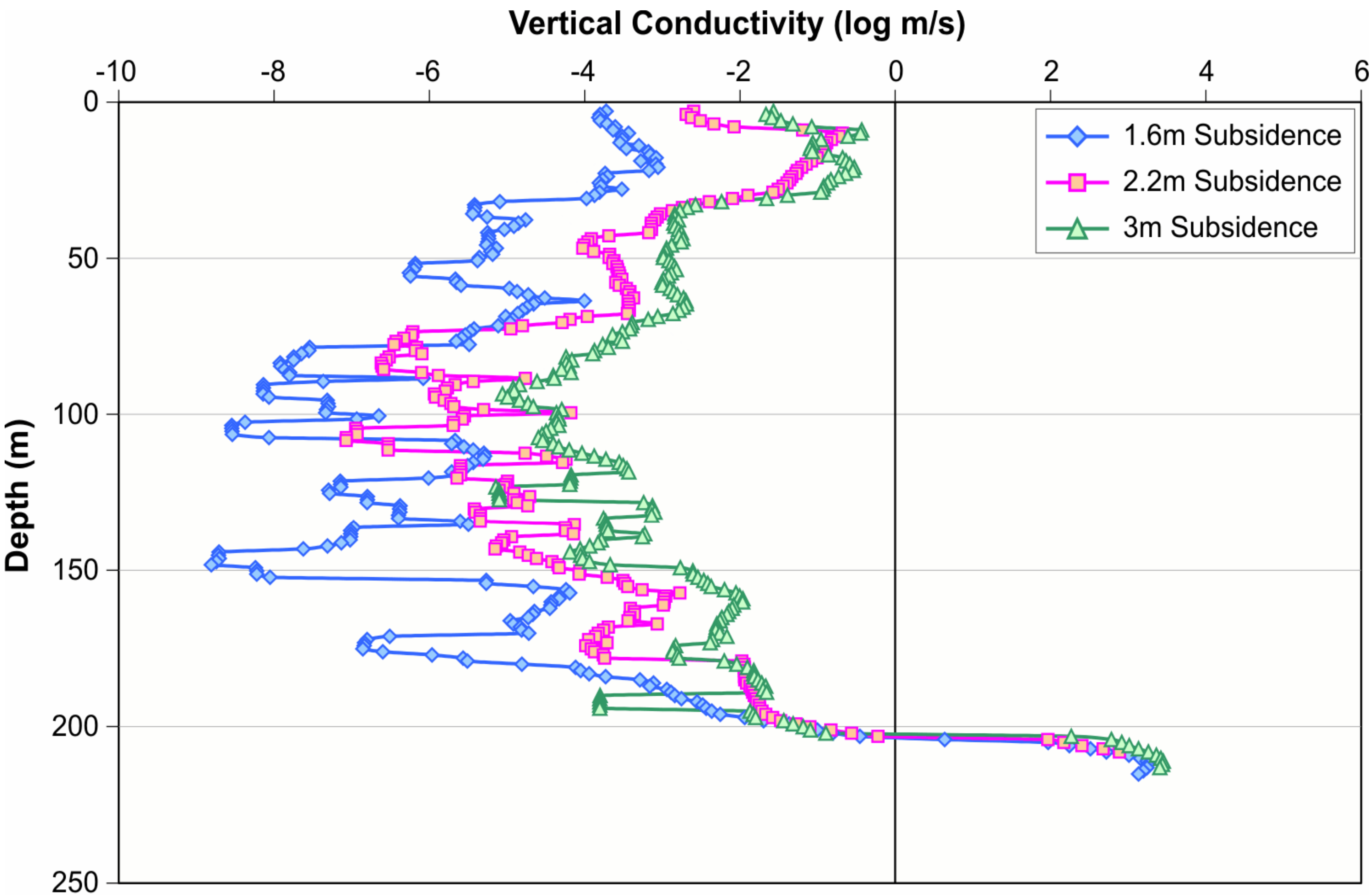


Figure 33 Conductivity changes related to increased subsidence with constant panel geometry.

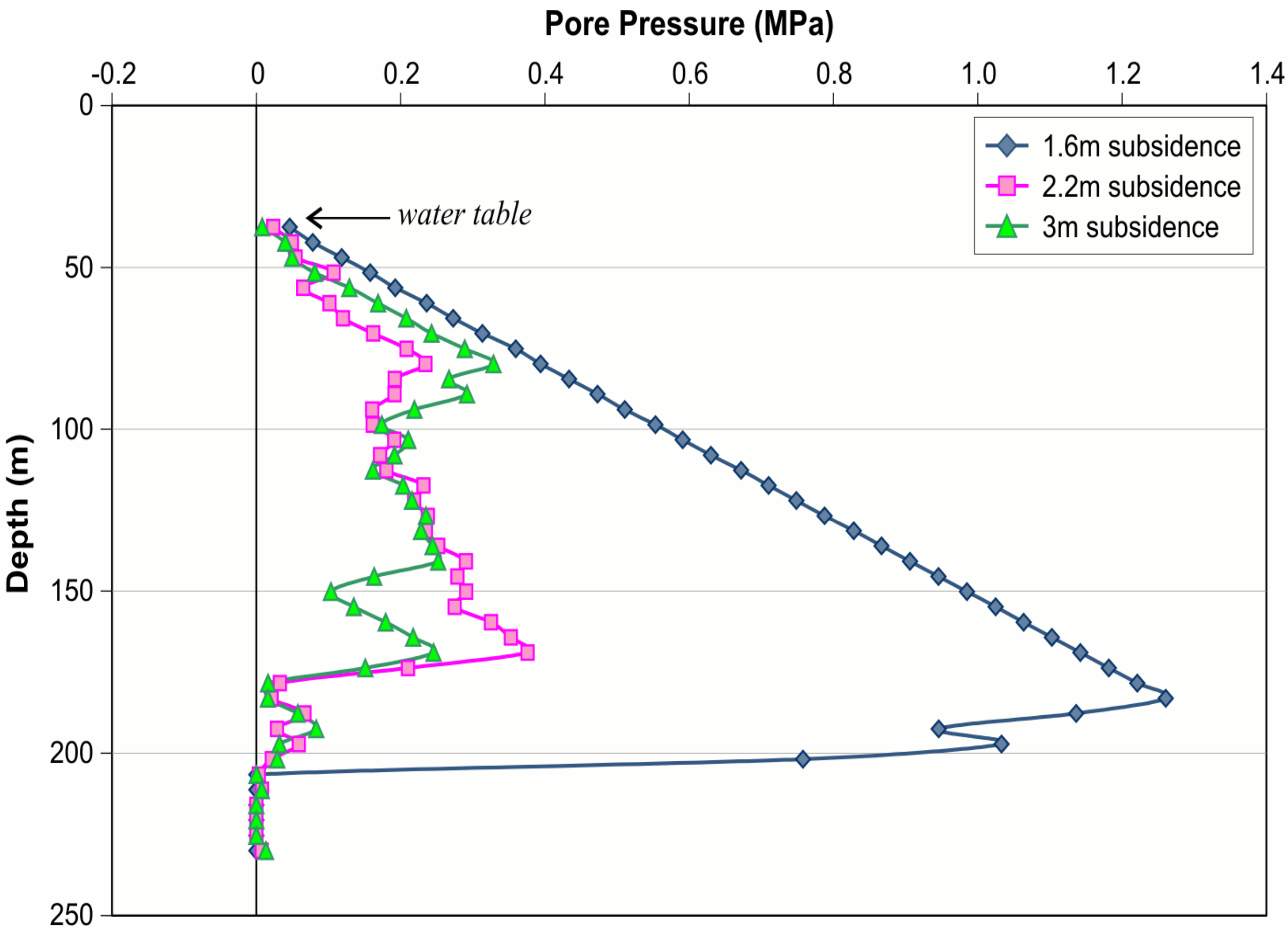


Figure 34 Pore pressure distribution for the three cases of increasing subsidence.

CASE STUDY – ASHTON PROJECT

- Ashton Coal Project
- 10km west of Singleton, Hunter Valley, NSW
- Both open cut and underground mining

CASE STUDY – ASHTON PROJECT

- Underground mine is accessed by a portal in Arties Pit

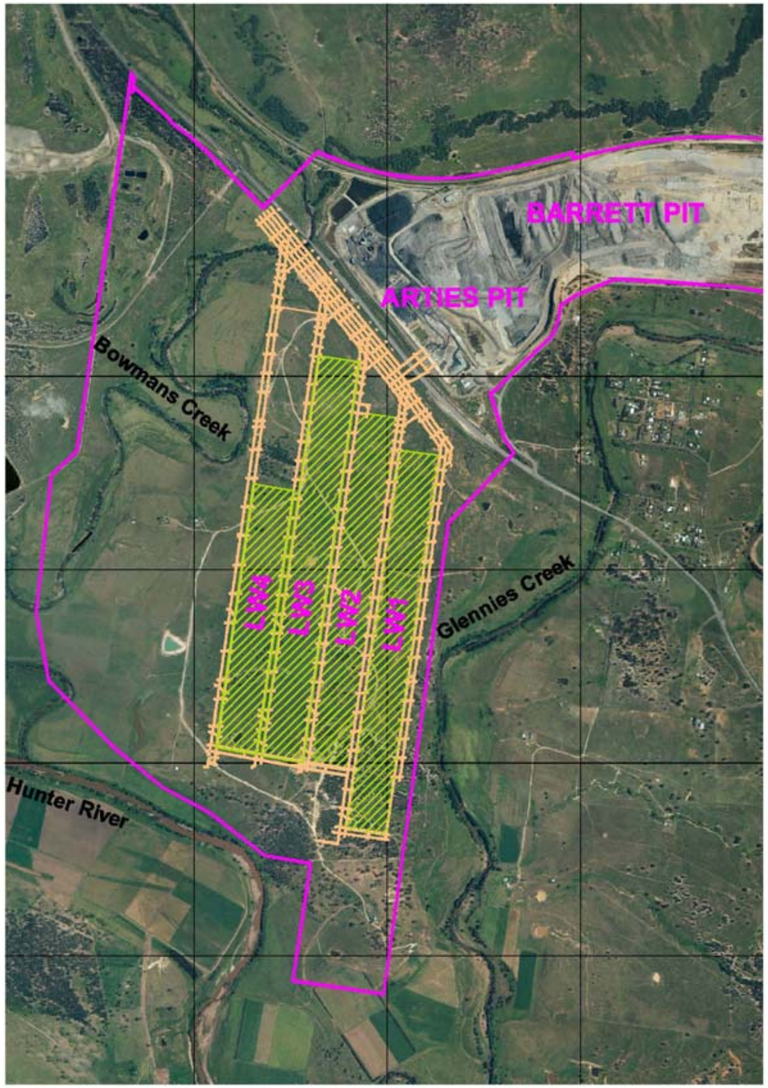
CASE STUDY – ASHTON PROJECT

- **Multi-seam longwall mining**

- Pikes Gully
- Upper Liddell
- Upper Lower Liddell
- Lower Barrett

Ashton Longwall Project

- Currently mining in LW4 of Pikes Gully Seam
- 215m wide panels, 25m chain pillars, length 2-3km
- Pikes Gully cover depth ranges from
  - 35m at northern end of LW1, to
  - 150m at southern end of LW4
- Seam extraction height 2.3m



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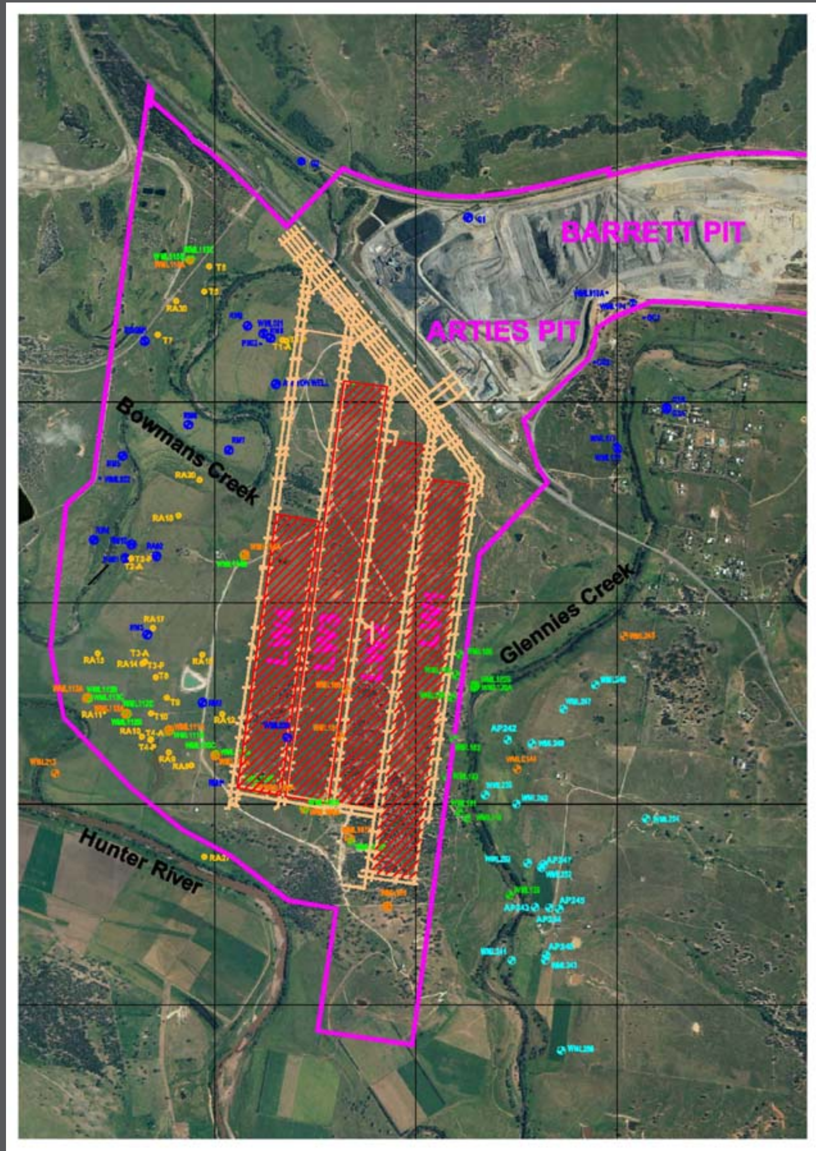
Monitoring

- Extensive piezometer network
- Multi-level vibrating wire piezometers
  - Deeper zones (mostly coal seams, some interburden horizons)
- Standpipe piezometers
  - Alluvium / colluvium
  - Weathered upper part of Permian
- Mostly outside of LW panels



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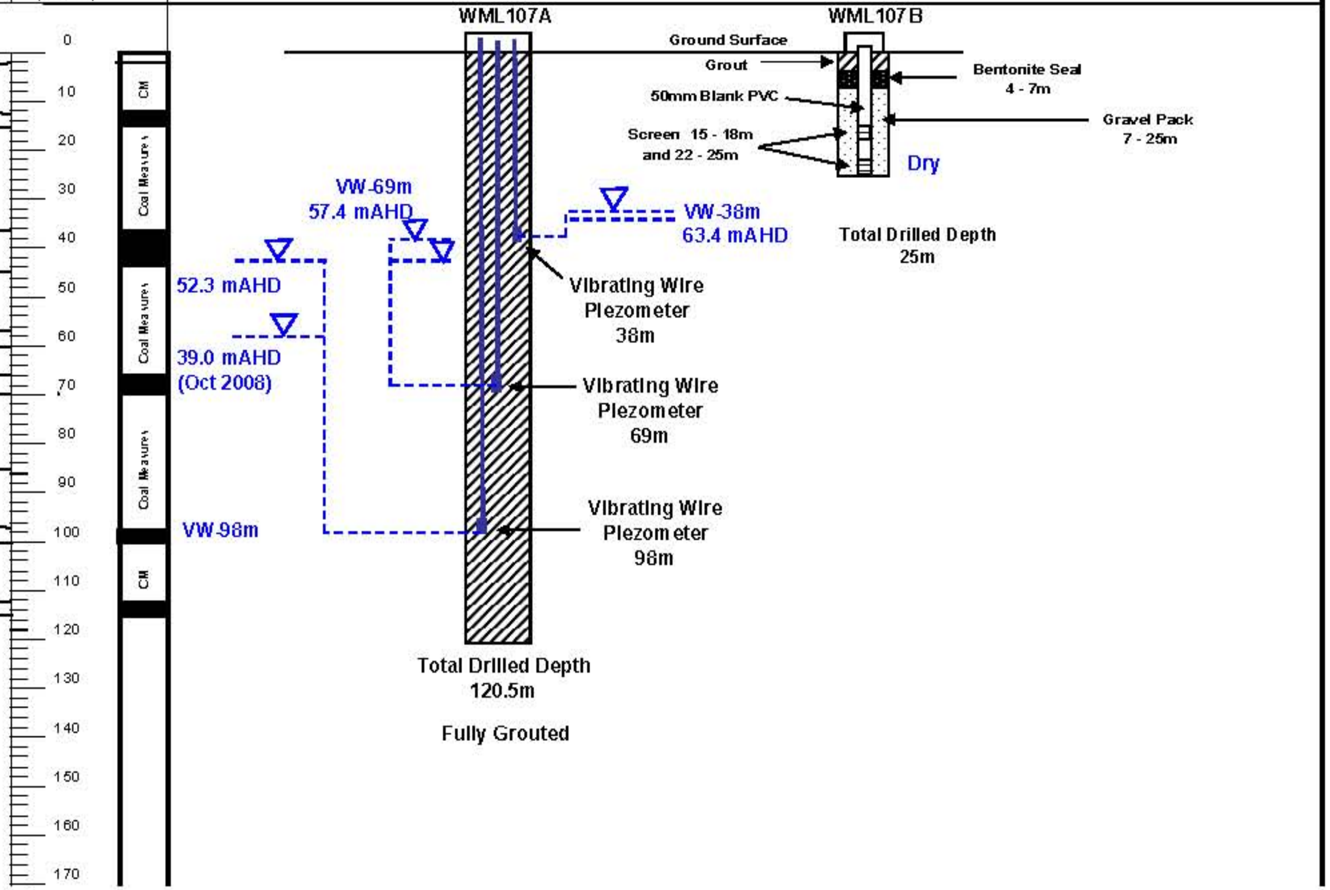
Logging Sheet

BORES: WML107A and WML107B

						Project No:	S03 (05 - 0166)
Client:	Bore:	Elevation (GL):	Elevation (TOC):	Stickup:	Drilling Contractor:	Date Started:	Date Finished:
Ashton Coal Operations Pty Ltd	WML107A	95.53 mAHD			Hunter Drilling Services	17-May-06	
Location:	WML107B	95.44 mAHD	95.70 mAHD	0.26m	Hunter Drilling Services	14-Sep-06	
Ashton Coal Project							
			Hole depths: As shown			Supervised By: R McCallum	

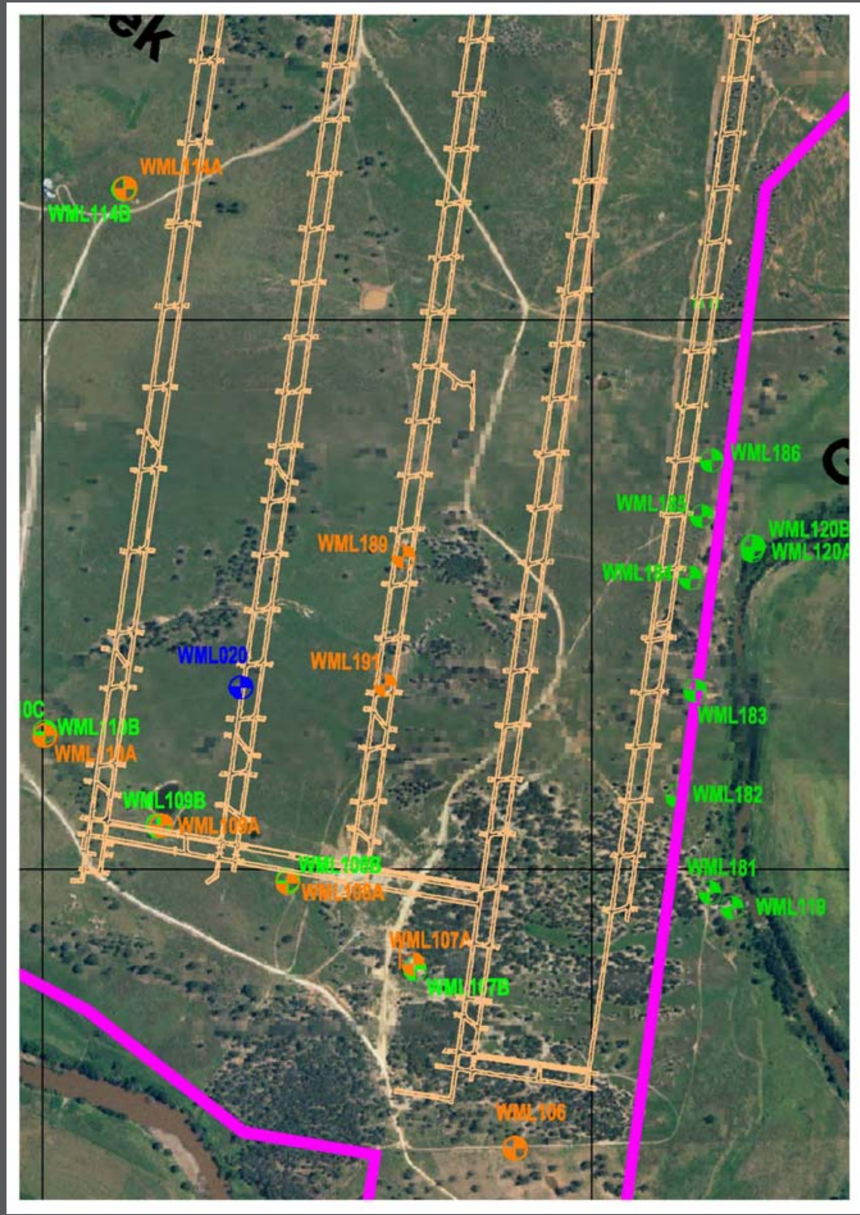
Description	Depth (metres)
Brown pebbly alluvium	
Highly weathered mudstone	
Coal	
Grey fine grained sandstone with mudstone and siltstone	
Lemington 10-14 Coal Seams	
Light grey sandstone with grey mud- and siltstones	
Matrix supported conglomerate	
Light grey sandstone with grey mud- and siltstones	
Lemington 15 Coal Seam	
Light grey sandstone with grey mud- and siltstones	
Light grey and matrix support conglomerates with sand-, silt- and mudstones	
Lemington 18-19 Coal Seams	
Light grey sandstone with mud- and siltstones, and thin coal seams.	
Pikes Gully Coal Seam	
Grey siltstone with light grey sandstone	

Well Construction Details:



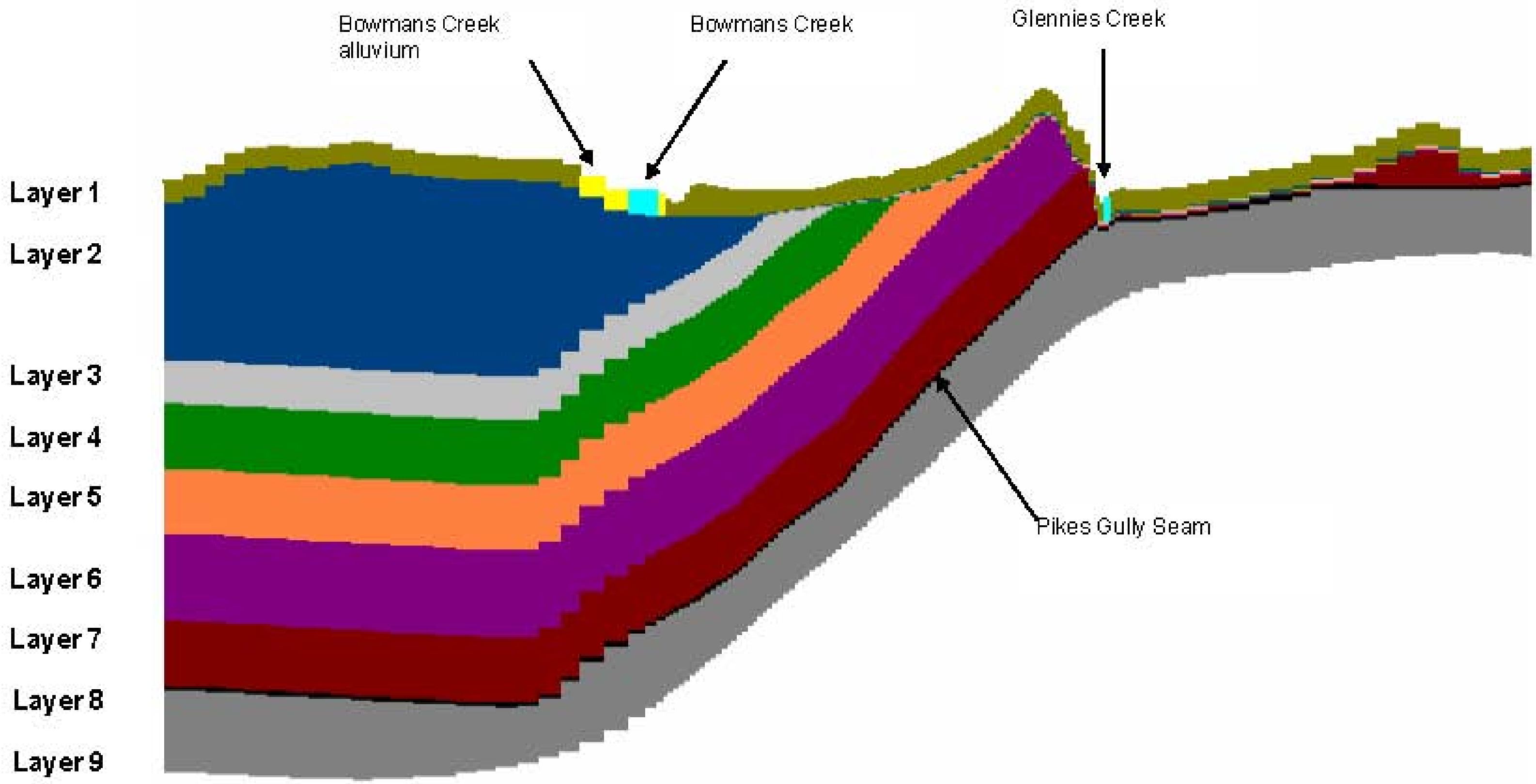
Monitoring Network

- **LIMITATION** - Virtually no monitoring inside LW panels
- Five multi-level piezometers close to LW panels
  - WML189 and WML191 – located in chain pillars between LW2 and LW3
  - WML108 located 40m outside LW3
  - WML109 located 16m inside LW4
  - WML20 (SP) located 6m inside LW3



Groundwater Modelling

- MODFLOW-SURFACT
  - Unsaturated and saturated flow
  - Unsaturated voids below (fully or partly) saturated overburden
  - Steep gradients near mine voids
  - FEFLOW considered, but run times found to be very long
- Pseudo-soil function
  - Relatively short model run times



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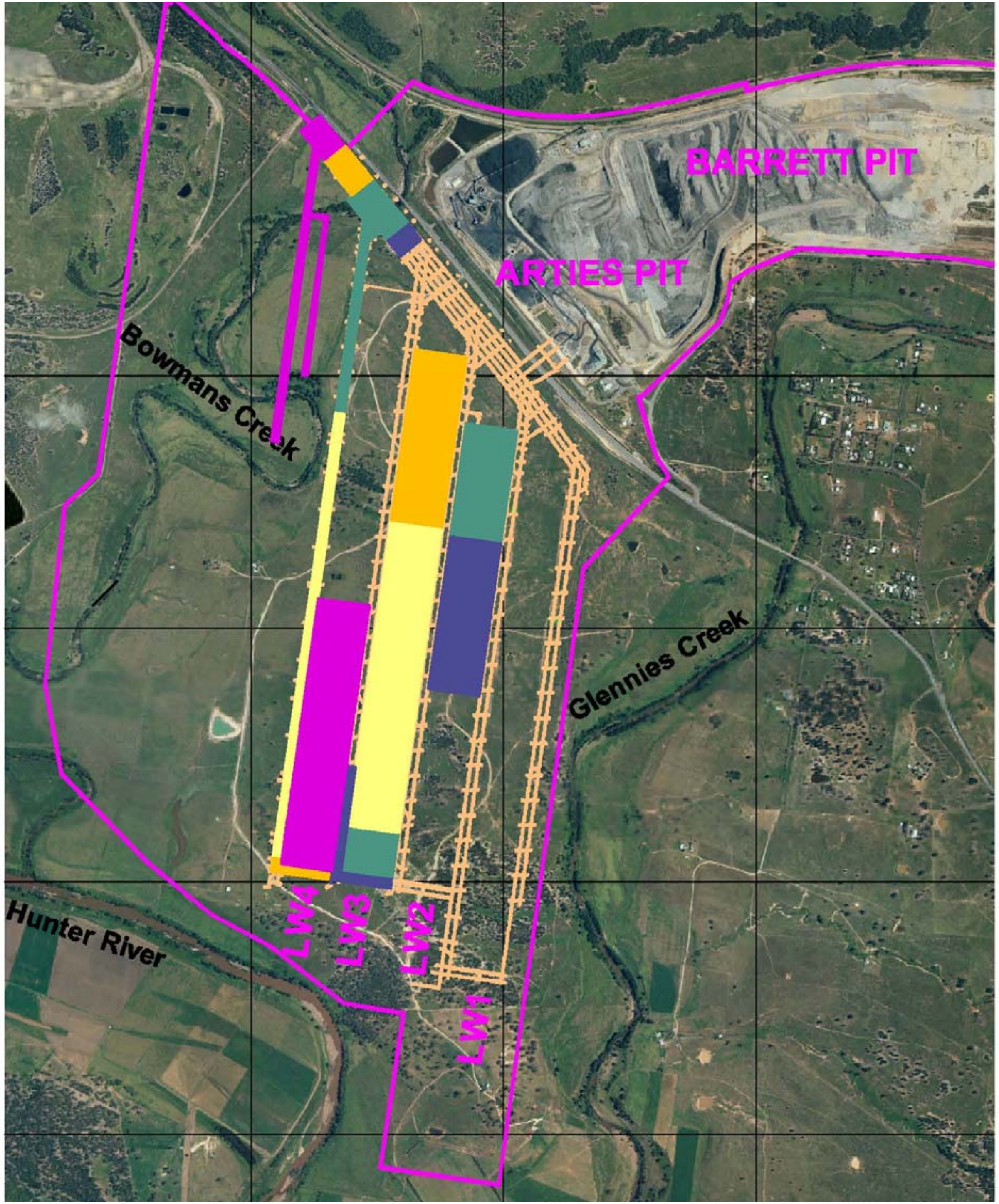
Modelled East-West Cross Section through Northing 6404460
Figure 13

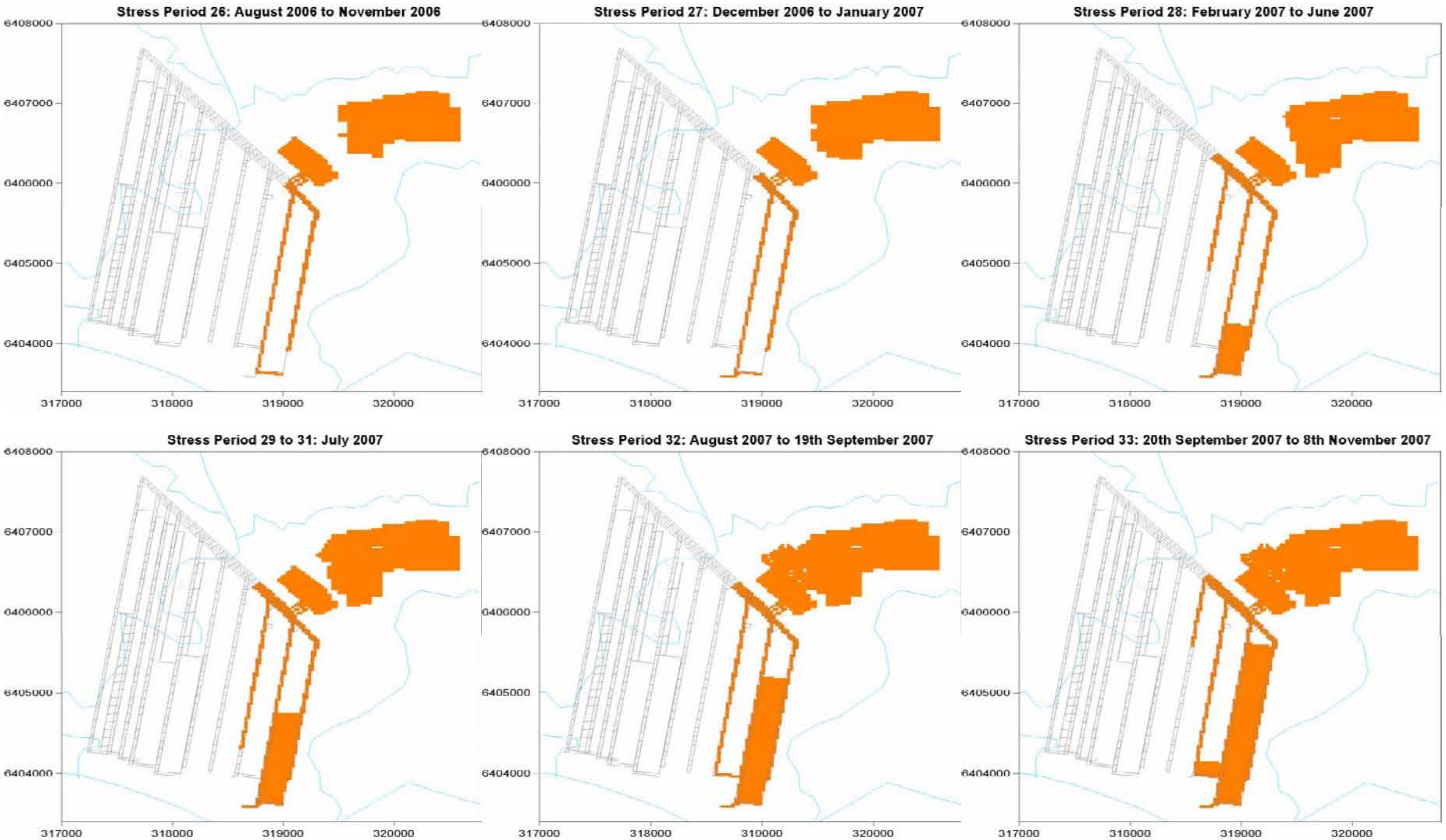
Groundwater Modelling

- Hydraulic Parameters
  - Initially derived from field permeability testing (Kh) and lab testing (Kv)
  - Subsidence affected hydraulic conductivities from SCT FLAC modelling
  - Modified during model calibration process
- Calibration
  - Monitored impacts of open cut, LW1 extraction and part of LW2
  - Calibrated against groundwater levels/heads and baseflows (seepage from alluvium)

Groundwater Modelling

- Mining simulation
  - Open cut areas set as DRAIN cells
  - UG development headings and LW areas set as DRAIN cells
  - Subsidence affected zones above LW panels modelled by increased Kh and/or Kv
- DRAIN discharges indicate dewatering rates
- Simulations run as consecutive “time slices” to allow progressive change of Kh and Kv
- 3-month stress periods


BARRETT PIT
ARTIES PIT
Bowmans Creek
Glennies Creek
Hunter River
LW4
LW3
LW2
LW1



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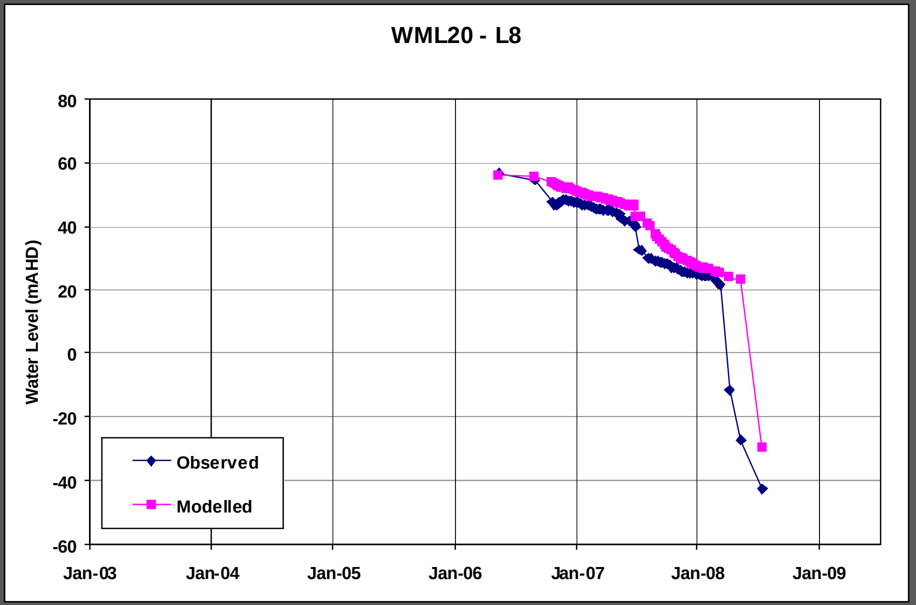
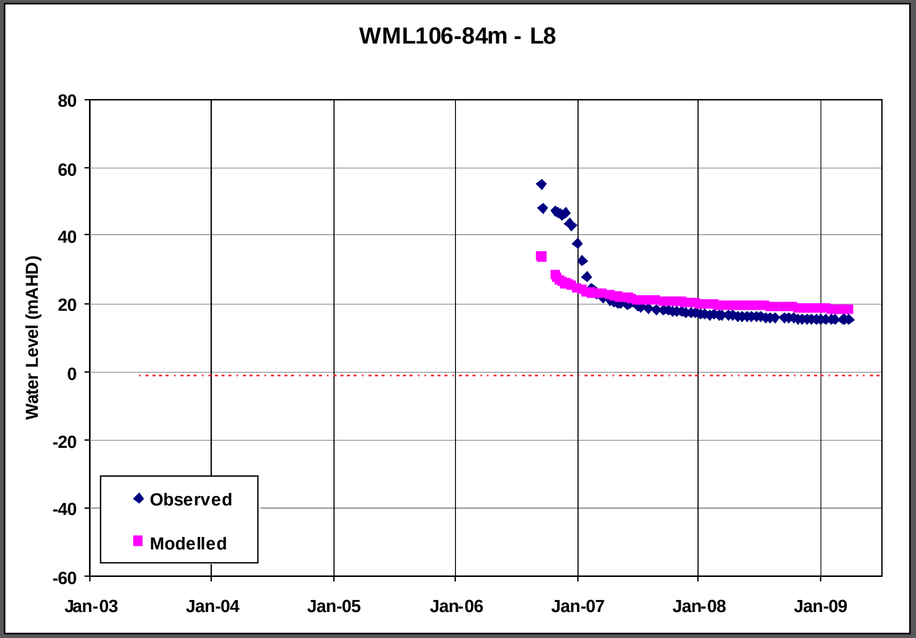
Modelled Mine Plan for Transient Calibration Period

Figure 24

Groundwater Modelling

- Hydrographs – observed vs modelled groundwater levels/pressures
- Greatest impacts in Pikes Gully Seam – Layer 8





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Groundwater Modelling

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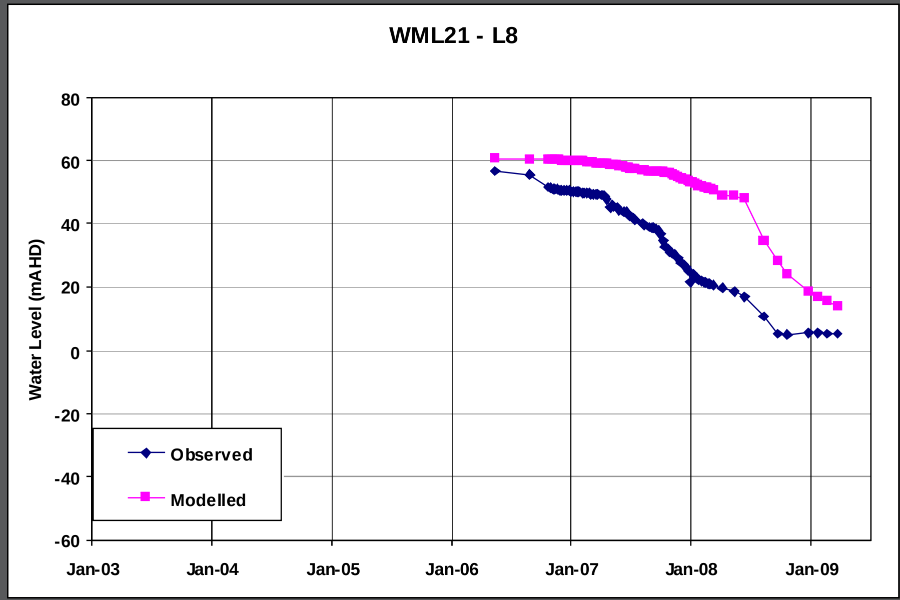
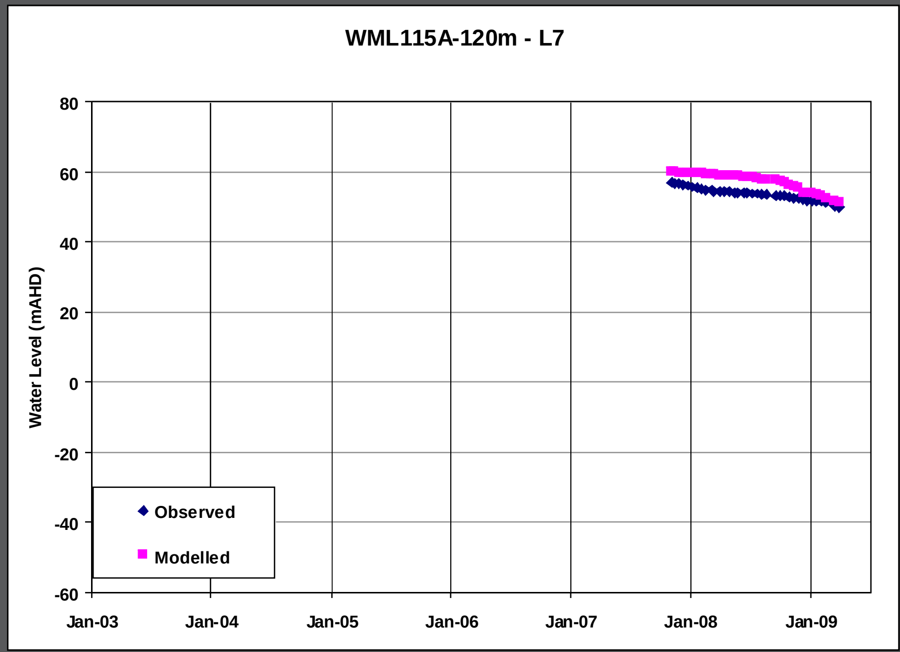
- Less impact in Layers 4-7 (Permian coal measures overburden)





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Groundwater Modelling

- Hydrographs – observed vs modelled groundwater levels/pressures
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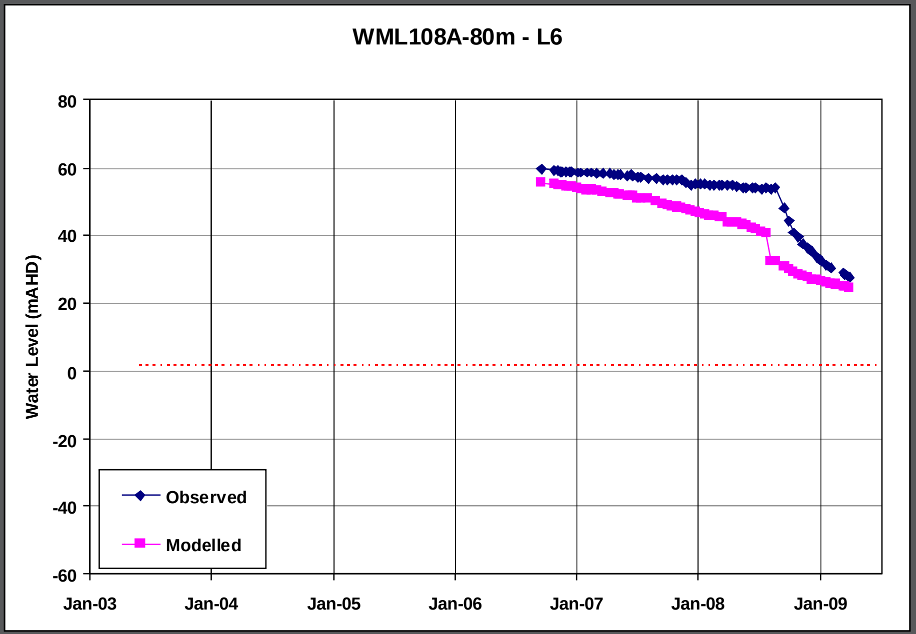
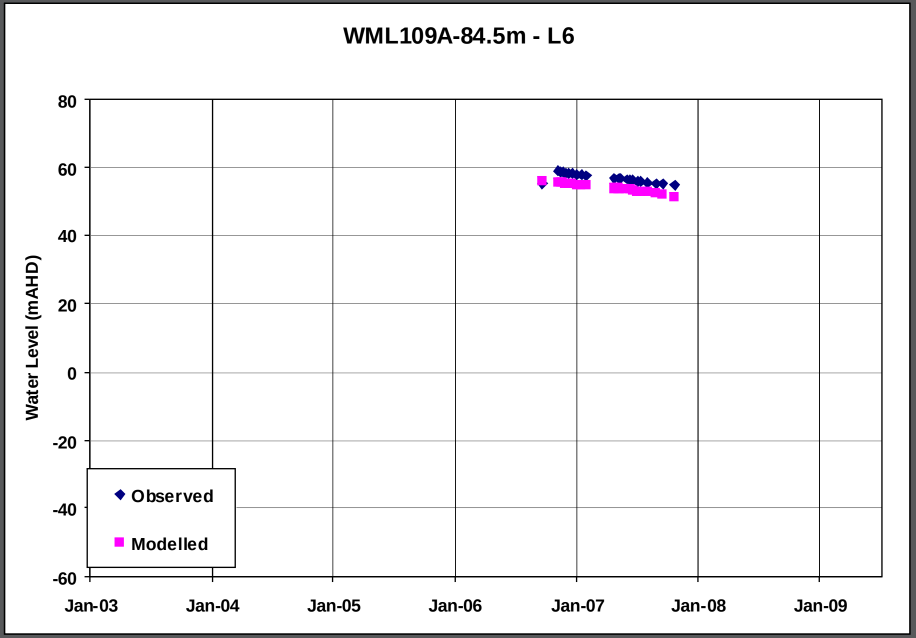
- No impact in Layer 1 (alluvium / weathered Permian) or Layer 2 (upper section of Permian overburden)





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Groundwater Modelling

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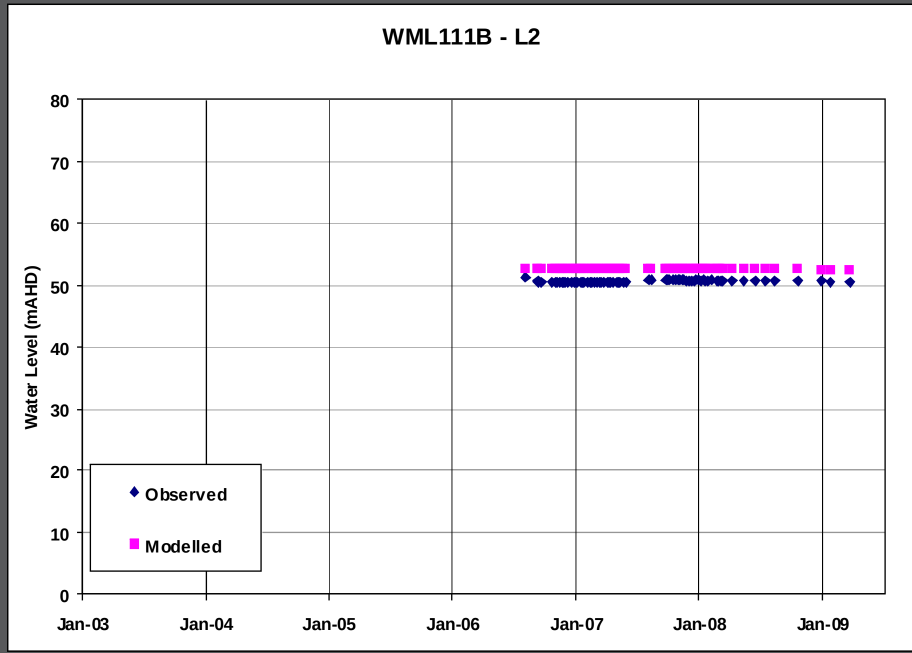
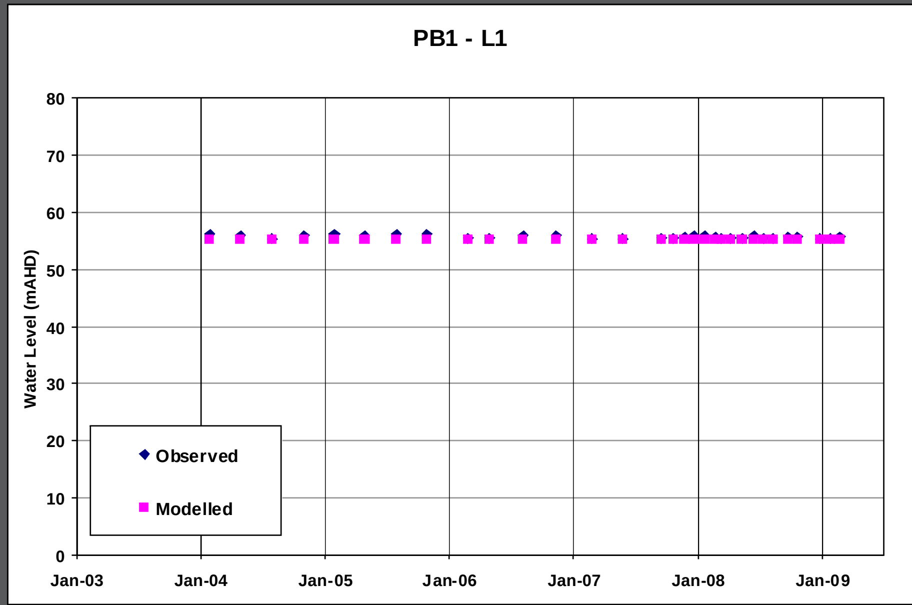
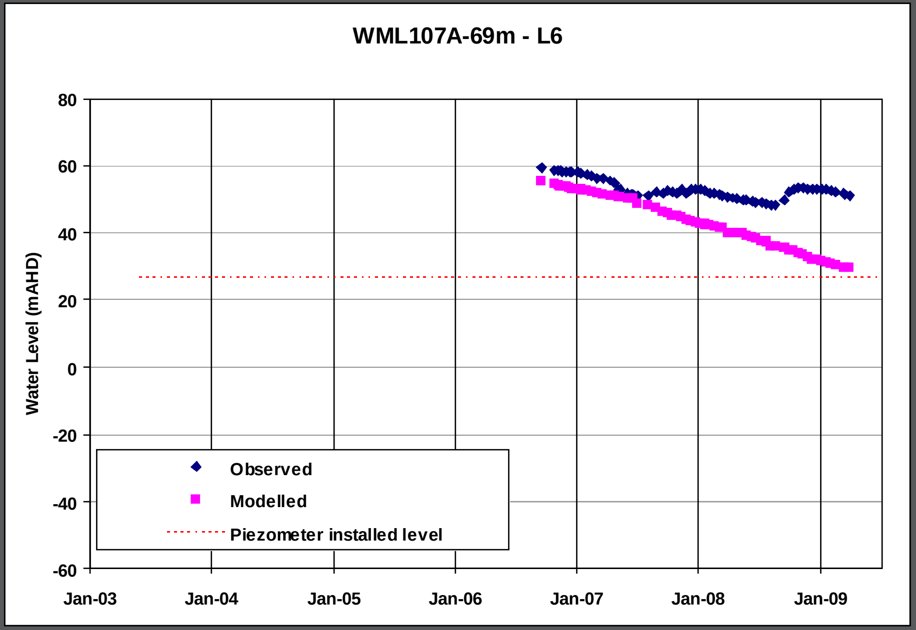
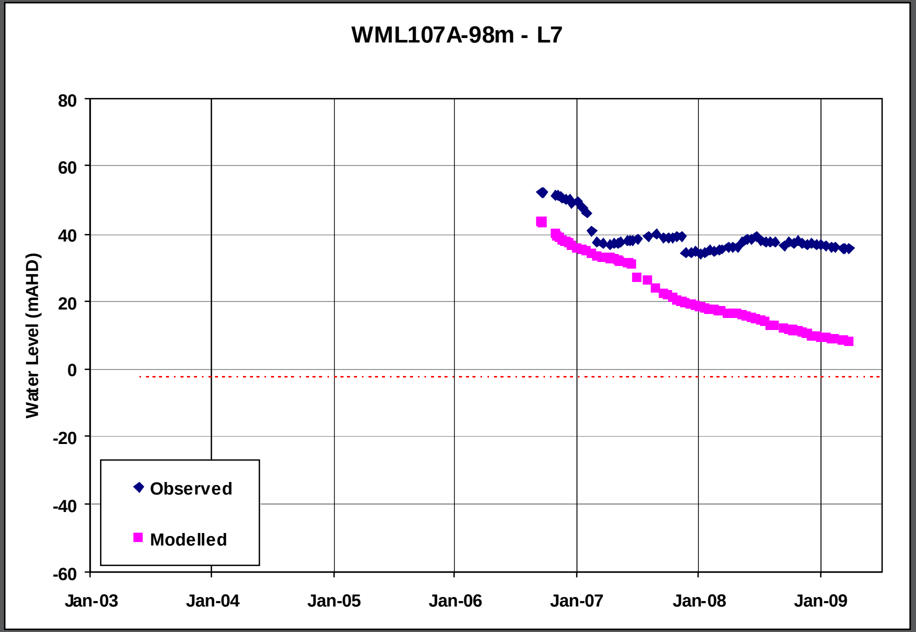




Variation from model predictions

- Less drawdown than predicted
- Partial recovery after LW extraction
- Reduction in horizontal hydraulic conductivity
  - Compaction/loading on chain pillars
  - Disruption to horizontal flow paths (ie flow parallel to bedding)
  - ?Healing of fractures





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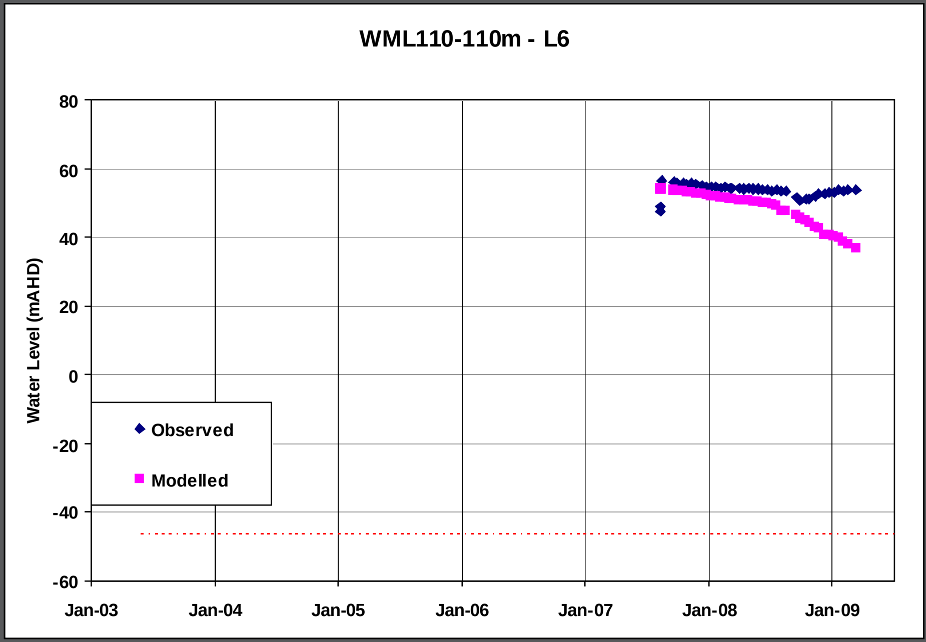

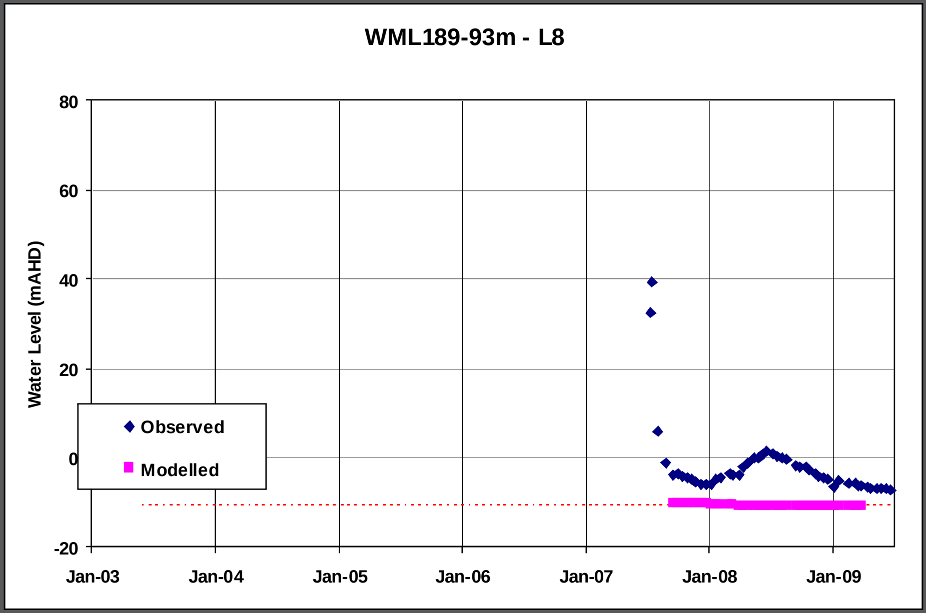

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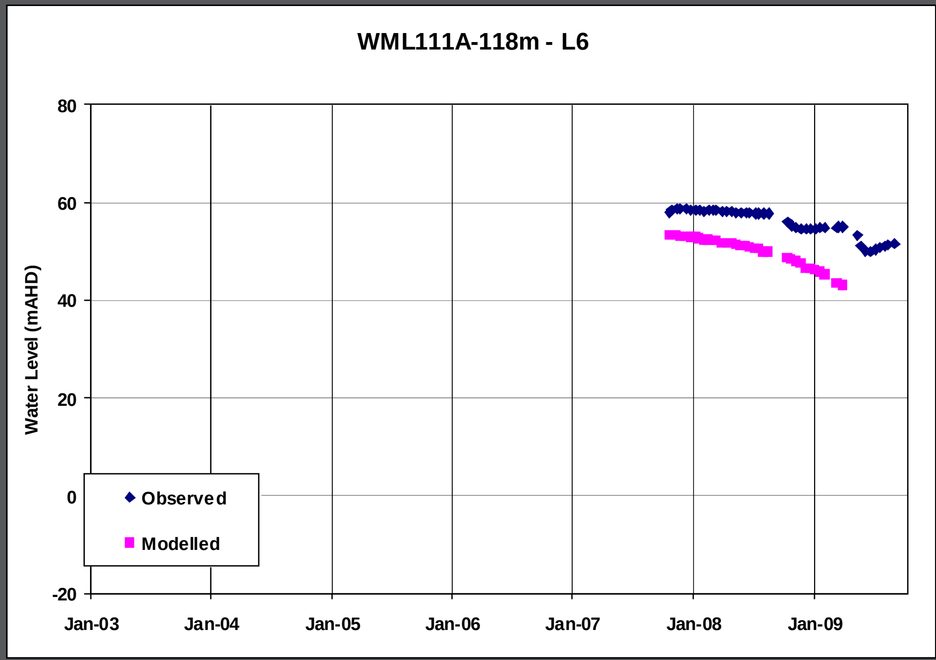

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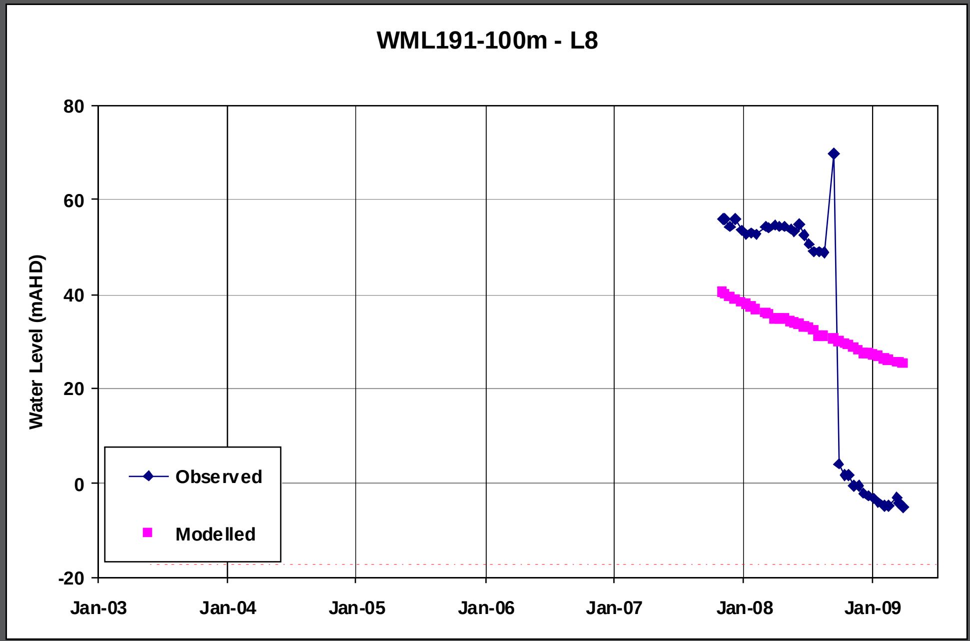
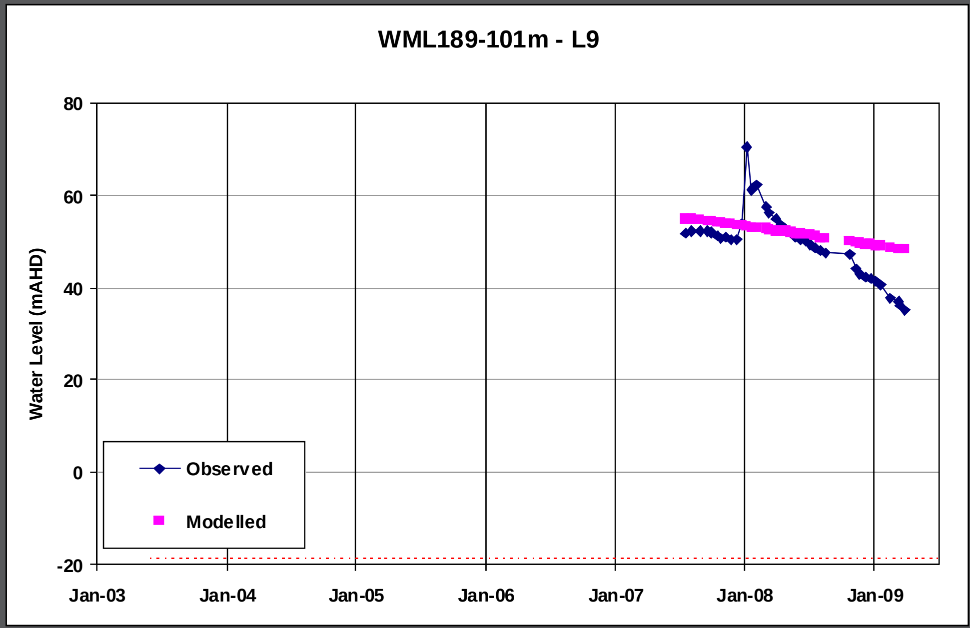
Variation from model predictions

- Rise in pressures after panel extraction, often preceding a predicted fall in pressure
  - Compaction/loading on chain pillars
  - ??





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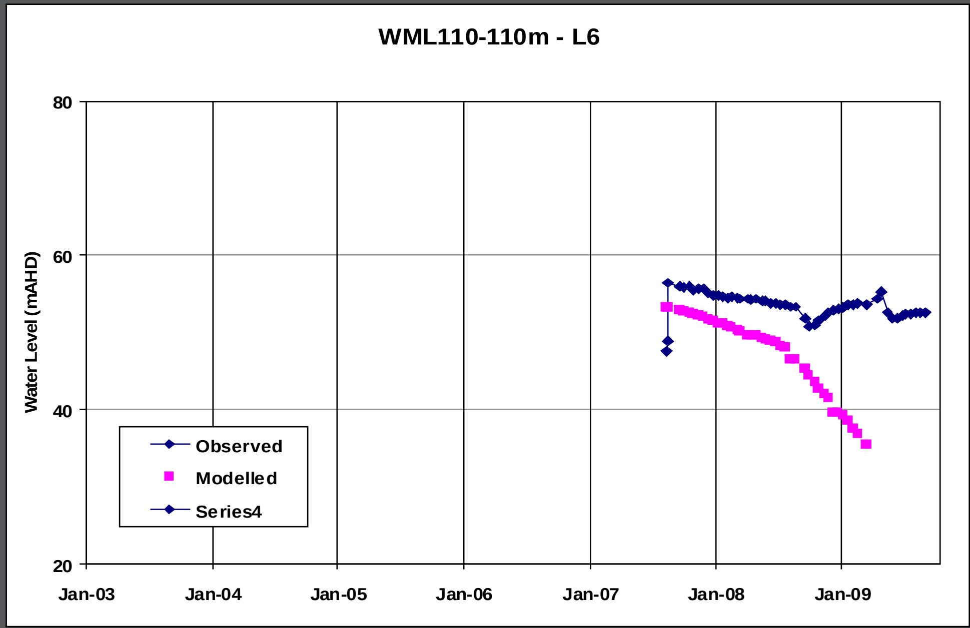

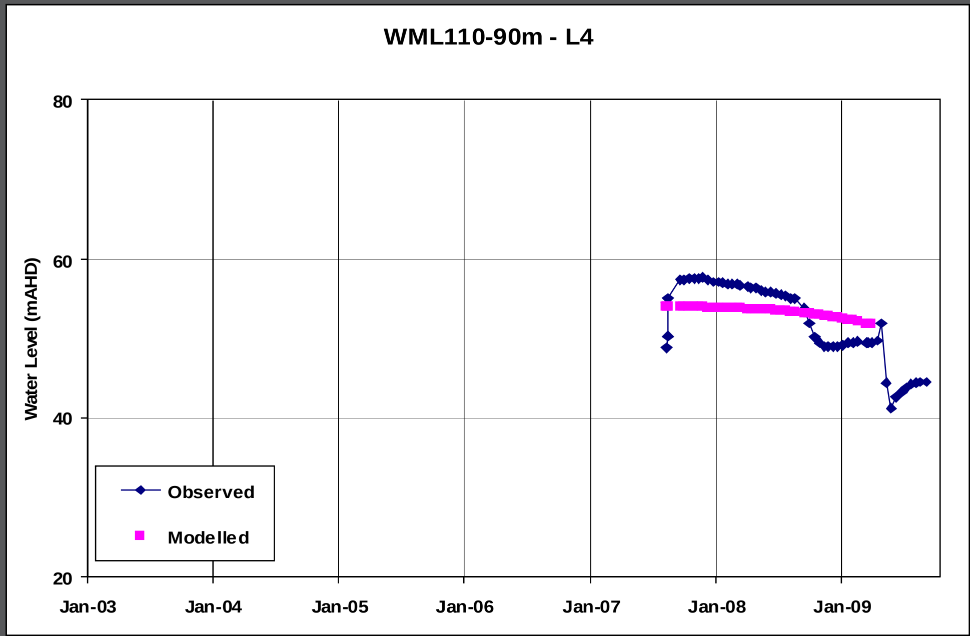

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Clogging of Fractures

- Hydraulic conductivity apparently reducing in barrier east of LW1, between LW1 and Glennies Creek alluvium floodplain
- Groundwater levels in the Pikes Gully Seam in the barrier (WML120A) rising over time
- Inflow (seepage) rate into LW1 reducing over time
- Gradient between alluvium and mine unchanged
- Therefore, permeability must be reducing, due to:
  - ?Clogging with fines
  - ?Delayed response to injection grouting

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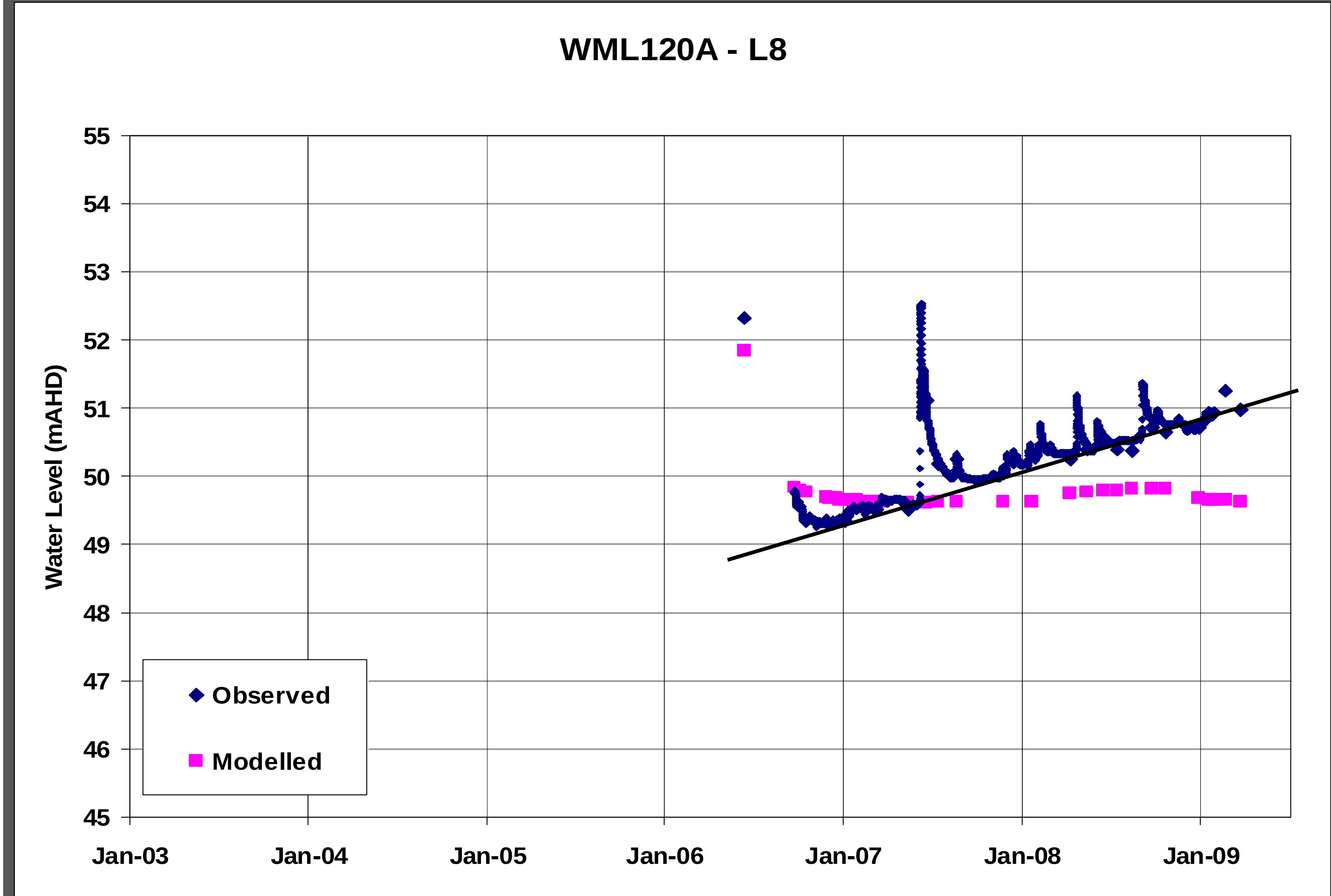

WML120A - L8
Water Level (mAHD)
55
54
53
52
51
50
49
48
47
46
45
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Observed
Modelled

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Self-Healing of Fractures Above LW1 Goaf

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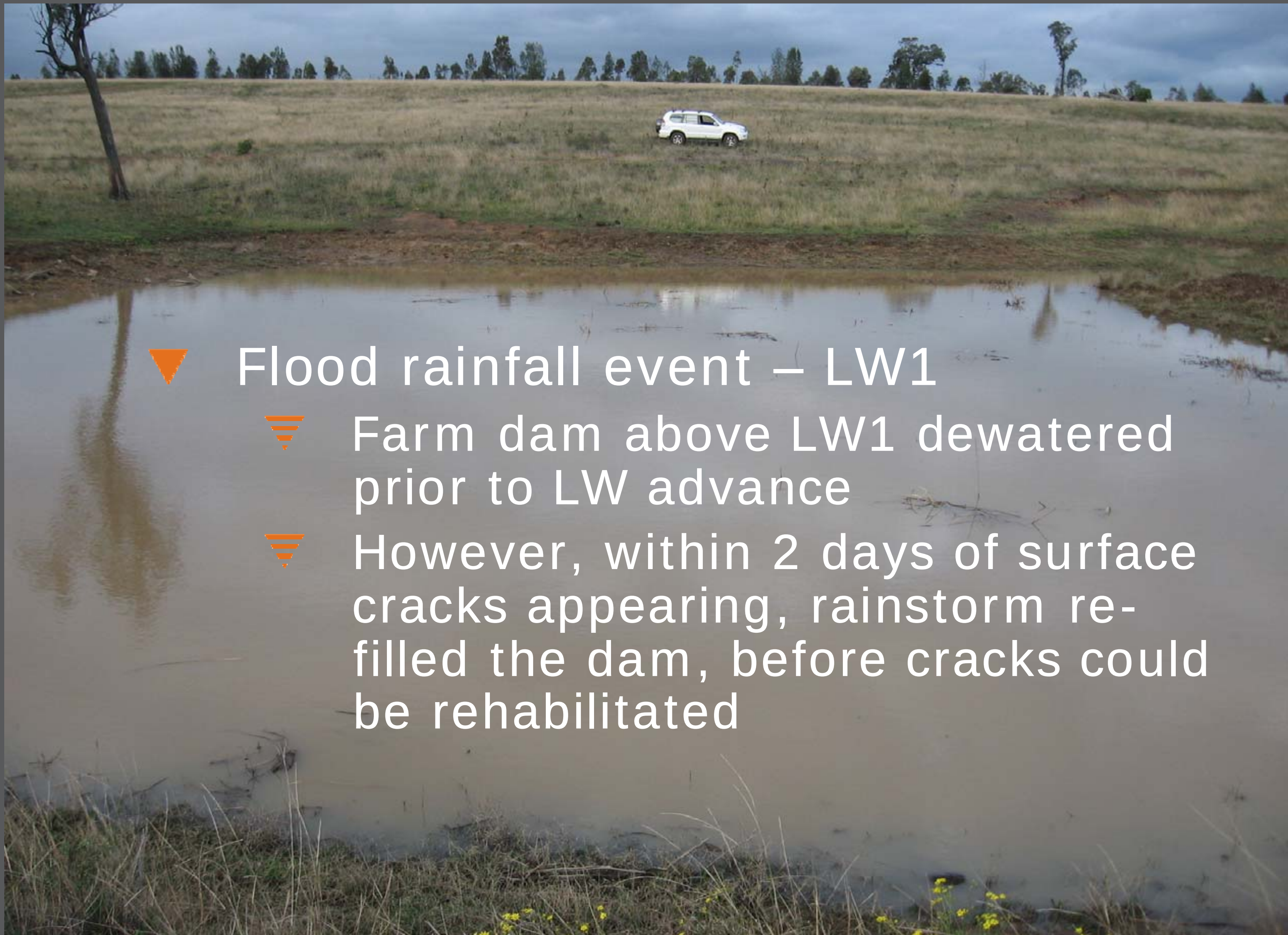
Self-Healing of Fractures Above LW1 Goaf

June 2007 flood rainfall event

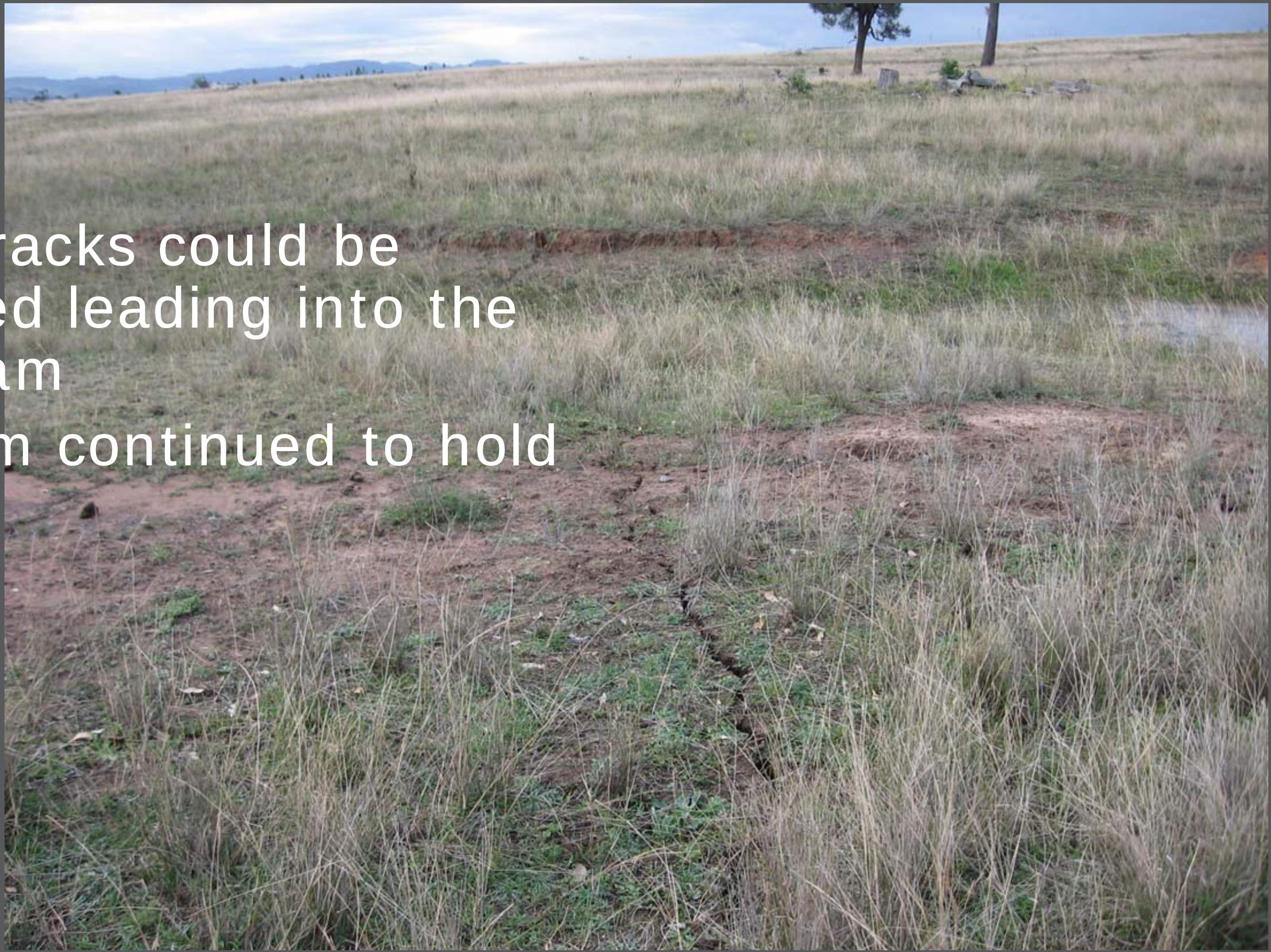
- LW1 surface fractures not yet rehabilitated
- 70m cover depth (therefore supercritical for subsidence – W/D > 3)
- Major rainfall event (?1 in 100 year event)
- Sheet runoff across open fractures
- Water observed gushing into fractures
- No increase in inflow or discolouration observed in the mine

Self-Healing Above LW1 Goaf



- Flood rainfall event – LW1
  - Farm dam above LW1 dewatered prior to LW advance
  - However, within 2 days of surface cracks appearing, rainstorm re-filled the dam, before cracks could be rehabilitated

Self-Healing Above LW1 and LW2 Goafs



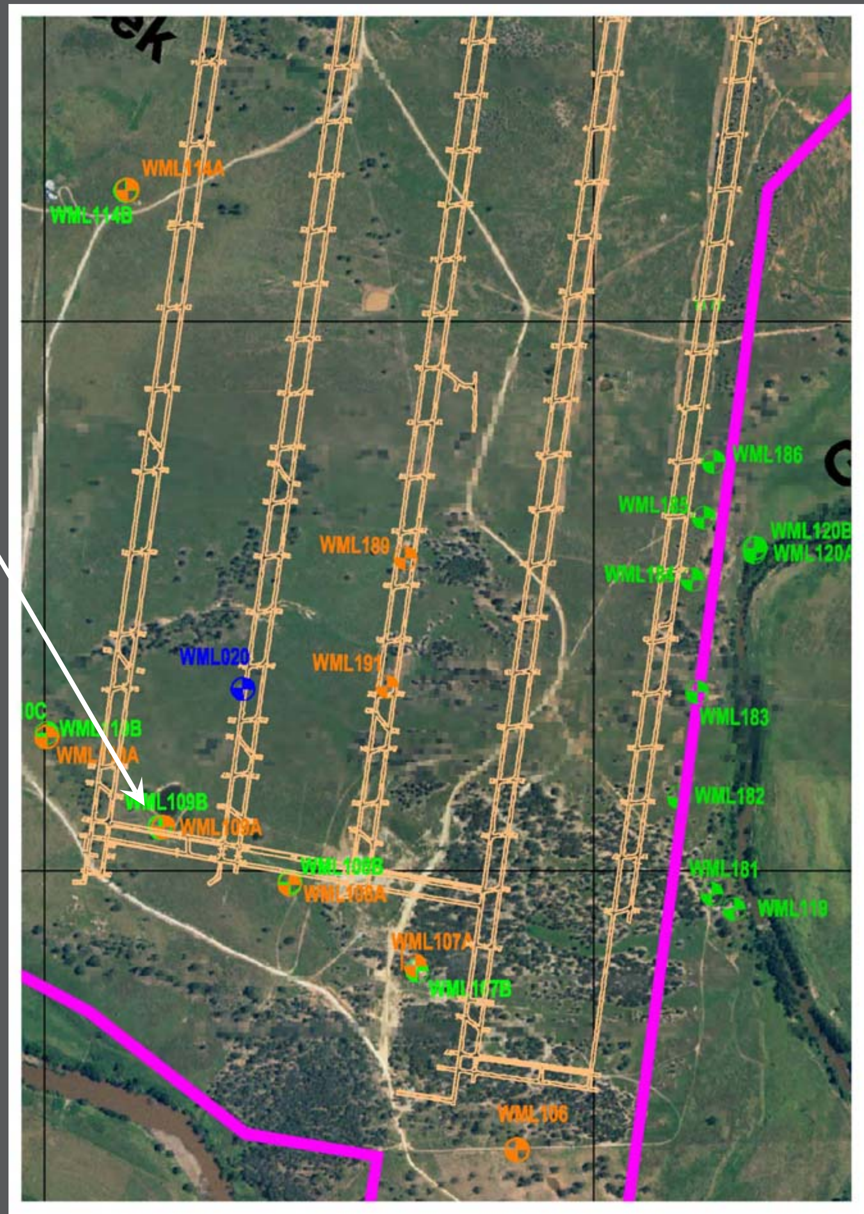
- Open cracks could be observed leading into the filled dam
- The dam continued to hold water

Self-Healing Above LW2 Goaf

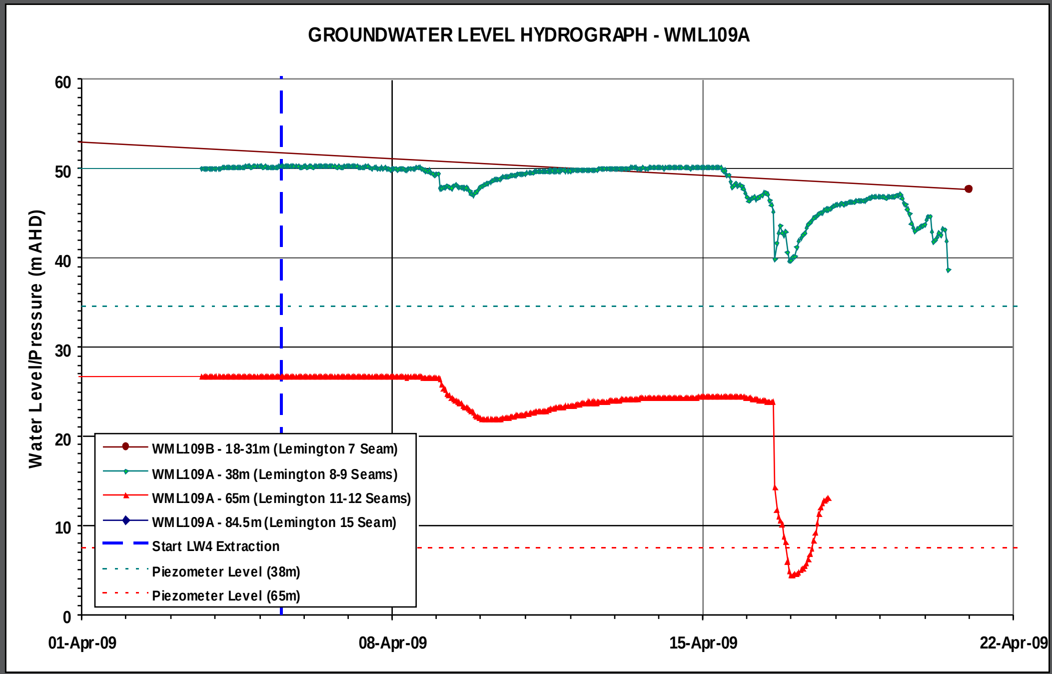
- Similar event during LW2 extraction
  - Dewatered dam filled with water
  - No apparent loss underground

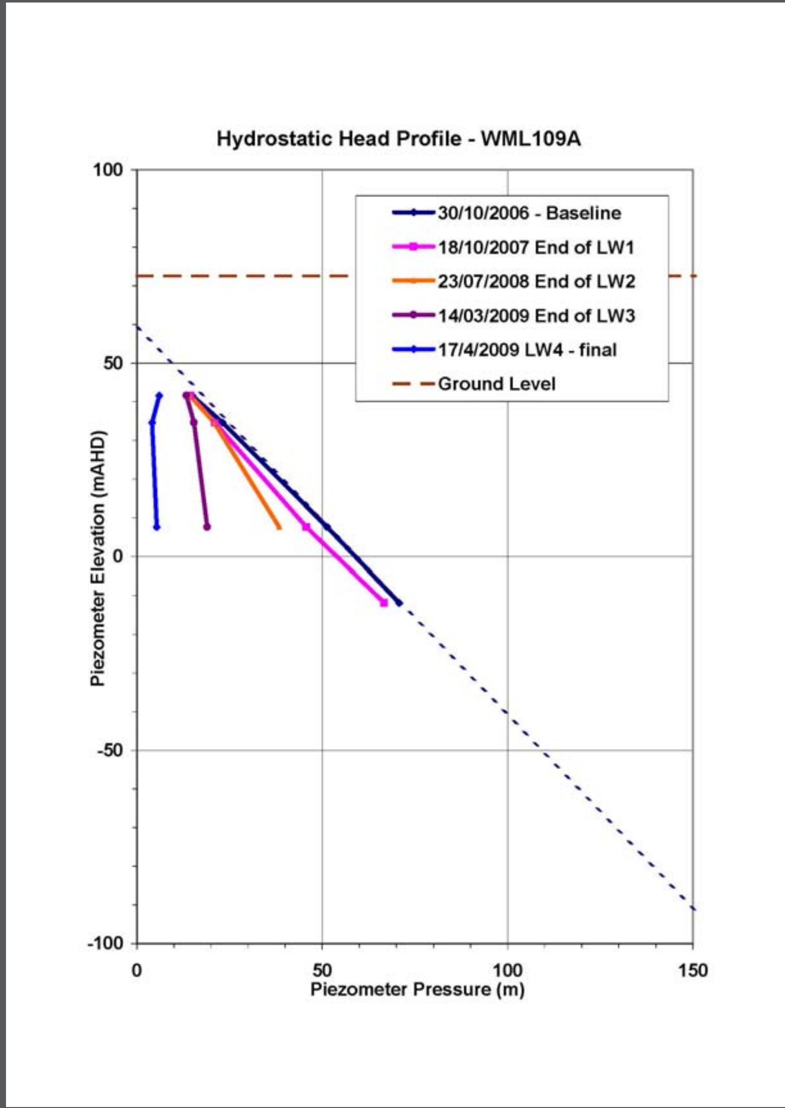
Piezometer Response Above Start of LW4

- Piezometer location 16m inside LW4
- Multi-level vibrating wire piezometer WML109 (2 levels in Permian)
- Standpipe piezometer (water level in weathered Permian – regolith)



Piezometer Response Above Start of LW4





- Vibrating wire piezometer WML109 -
  - First response after 4 days
  - Bore failed after 15 days (?cables sheared)
  - Groundwater pressures still positive

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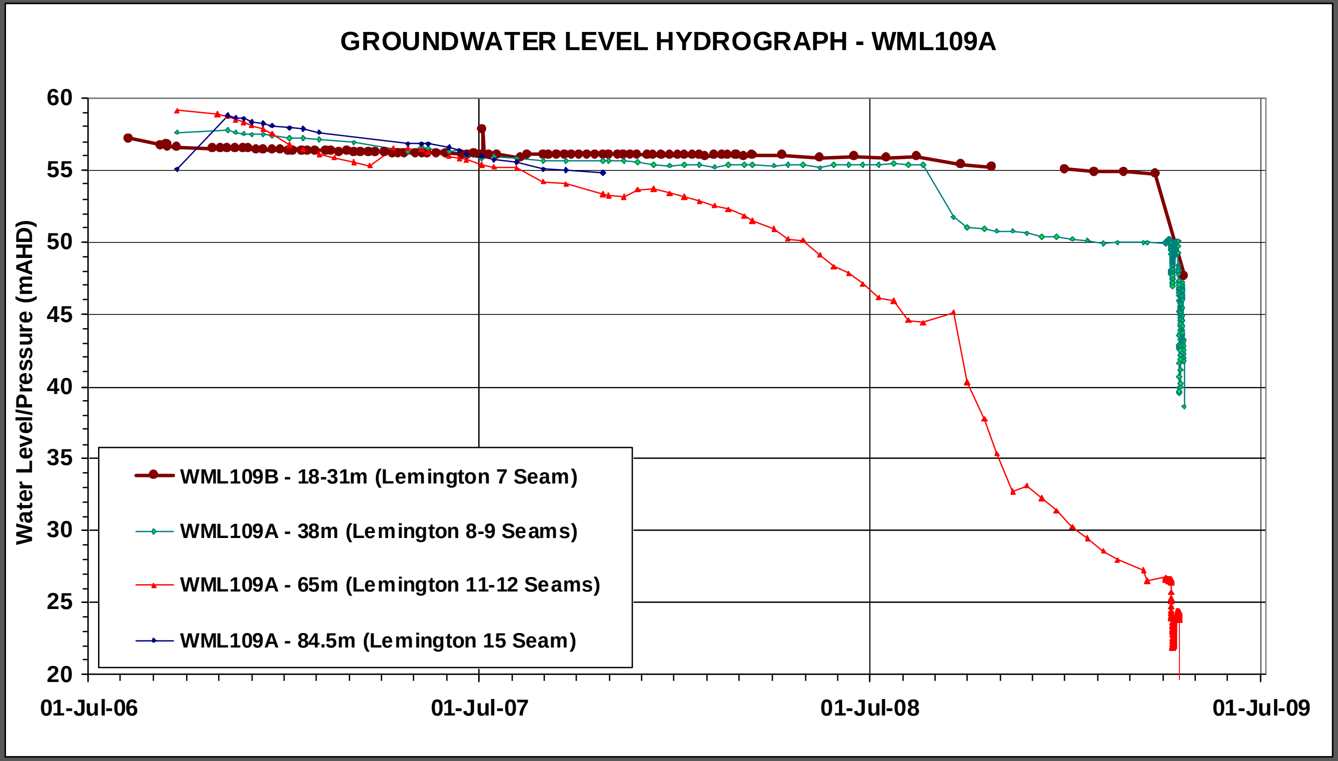
Piezometer Response Above Start of LW4

- Standpipe piezometer
  - Started sucking air into the mine, and was cemented up
  - Water level had fallen by 7m, but there was still a positive head on piezometer



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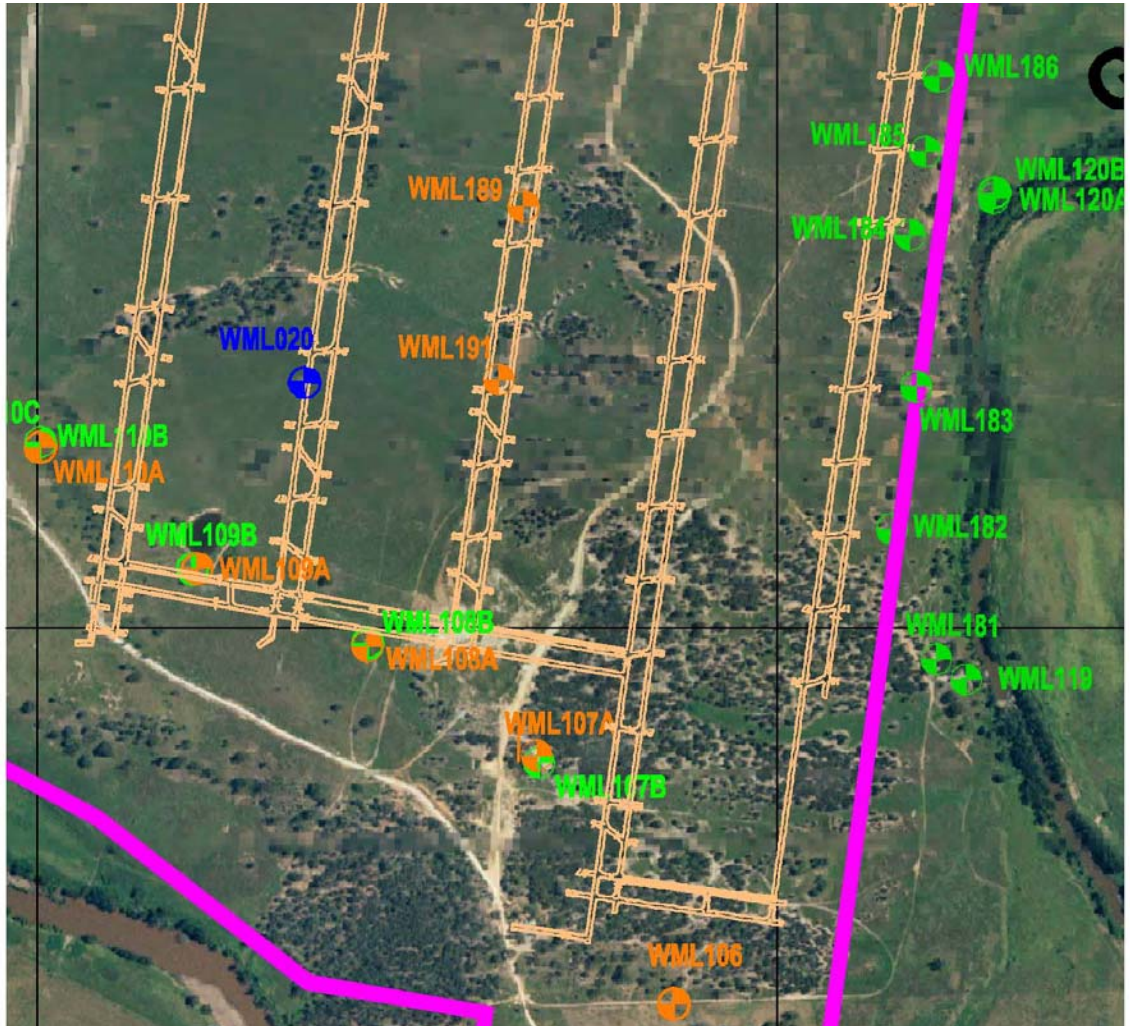
Piezometer Responses in Chain Pillars Between LW2 and LW3



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Piezometer Responses in Chain Pillars Between LW2 and LW3

- WML189
  - Responded to passage of headings between LW2 and LW3
- WML20
  - Responded to passage of headings between LW3 and LW4
- WML191
  - Did not respond to headings between LW2 and LW3
  - Did not respond to passage of LW2
  - Finally responded as LW3 passed the bore location

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Conclusions

- Model calibration showed that subsidence effects on Kv and Kh less than predicted by FLAC modelling
- Significant evidence of self-healing of fractures
- Evidence of falls in groundwater level due to changes in Sy rather than dewatering
- Suggestion that overburden Kh actually reduces around edges of LW panels
- More testing of post-longwall Kh and Kv needed