Contents

MALABAR COAL

MAXWELL PROJECT

ATTACHMENT 6

Peer Review Letters

REPORT TO:	**Malabar Coal Ltd** **PO Box R864 Royal Exchange** **SYDNEY NSW 1225**
ATTN:	**Mr Bill Dean, Malabar Coal**
Cc:	**Resource Strategies Pty Ltd**

Peer Review – Maxwell Underground Project Subsidence Assessment

(MSEC Report 986, Revision A, July 2019)

REPORT NO:	**1905/03.1 (final)**
PREPARED BY:	**BRUCE K HEBBLEWHITE**
DATE:	**11th July 2019**

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1. SCOPE OF WORK

This independent peer review report has been requested by Malabar Coal Limited, through their advising consultants, Resource Strategies Pty Ltd. The specific terms of reference for the independent peer review are to include the following tasks:

1. Review of the draft Subsidence Assessment and provision of comments
2. Review of how peer review comments have been addressed in the final version of the Subsidence Assessment
3. Provision of peer review letter describing the review undertaken.

This current report (No.1905/03.1(final)) provides the independent peer review in response to tasks (1) to (3) above.

1.1 Documentation Provided

The following documents were provided by Resource Strategies Pty Ltd for the purposes of conducting this peer review:

- MSEC Report 986, Rev. 05 (draft), May 2019: *"Maxwell Project Environmental Impact Statement – Subsidence Assessment: Subsidence predictions and impact assessments for natural and built features due to multi-seam mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, in support of the Environmental Impact Statement"*
- MSEC Report 986, Rev. A, July 2019: *"Maxwell Project Environmental Impact Statement – Subsidence Assessment: Subsidence predictions and impact assessments for natural and built features due to multi-seam mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams, in support of the Environmental Impact Statement"*
- Maxwell Project Scoping Report – Malabar Coal (August 2018)
- Maxwell Project Environmental Impact Statement – Project Description – Malabar Coal (2019)
- Maxwell Project – Conditional Gateway Certificate
- Maxwell Project – SEARs
- Maxwell Project – Regulatory input to SEARs
- Independent Expert Scientific Committee – *"Advice to decision maker on coal mining project IESC 2018-098: Maxwell Project – Expansion"*, 9 November 2018
- NSW Department of Planning & Environment: "*Peer Review*" – Draft Environmental Impact Assessment Guidance Series, June 2017.

1.2 This Report

I offer the following comments on the above MSEC subsidence assessment report, on the basis of my relevant professional qualifications, experience and background (see Summary CV in Appendix A). My background relevant to this project includes a close association with a number of different coal mining projects across NSW and internationally – from various perspectives, including mine design and audit on behalf of coal companies; and consulting/review studies on behalf of government and agencies (e.g. NSW Dept of Planning, Dept of Primary Industry and Dams Safety Committee); an earlier such study being as Chair of the Independent Expert Panel of Review into *"Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield"* (jointly for the NSW Dept of Planning & Dept of Primary Industry, 2006-2008).

I confirm that the review has been undertaken and presented in line with the NSW Department of Planning and Environment's Peer Review Guideline (draft) (2017).

I also confirm that the documentation provided, as listed above, is considered sufficient and appropriate for the purposes of carrying out this review which has been conducted in accordance with all relevant professional standards and practices. Prior to commencing the review, I was briefed by Resource Strategies Pty Ltd, in regard to the Maxwell Project, and the specific scope of this review and I am satisfied with the direction provided.

This report is structured in the form of some relevant background information; followed by specific comments on the MSEC Assessment Report (Rev. A) provided. Previous comments were provided to MSEC based on the Rev. 05 (draft) report and these have been addressed by MSEC in this final version.

In relation to this report commentary, all references and discussion relate to the Revision A version of the report. Specific comments are provided in the order they appear in the report text, and not in any order of priority or importance. Some summary factual data is reproduced for ease of reference to specific issues of subsidence management. Some issues are quite minor and are more in the form of an observational comment rather than a request for any significant alteration in the studies.

It should be noted that this review is focused on mine subsidence and related impacts which may include influence on groundwater parameters. However, detailed assessment of groundwater or related hydrogeological factors is outside of the scope for this report and is not included.

For the purposes of transparency, I declare that I have had previous associations with MSEC and some members of their staff, as individuals, in the following manner:

- Participation in various joint/collaborative research and consulting projects, and subsequent jointly-authored publications;
- Conduct of previous independent peer reviews of MSEC reports for government authorities and other third parties;
- PhD supervision for Dr James Barbato, an MSEC employee, through UNSW.

2 BACKGROUND

The following project background information has been taken from the Maxwell Project Scoping Report (Malabar, 2018). (This, and all other project-related factual information is assumed to be correct for the purposes of this review and has not been independently verified).

> *"Malabar Coal Limited (Malabar) acquired Exploration Licence (EL) 5460 and existing infrastructure within Coal Lease (CL) 229, Mining Lease (ML) 1531 and CL 395 (known as the 'Maxwell Infrastructure') in February 2018.*
>
> *As part of its acquisition of EL 5460, Malabar committed to develop the resource solely as an underground mining operation.*
>
> *EL 5460 and the Maxwell Infrastructure are located in the Upper Hunter Valley of New South Wales (NSW), east-southeast of Denman and south-southwest of Muswellbrook.*
>
> ***Overview of the Project***
> *Maxwell Ventures (Management) Pty Ltd, a wholly owned subsidiary of Malabar, is seeking consent to develop an underground coal mining operation, referred to as the Maxwell Project (the Project). The Project would involve underground coal mining within EL 5460. The requirement to construct new infrastructure would be greatly reduced as the Project would make use of the substantial facilities that already exist at the Maxwell Infrastructure location.*
>
> *The Maxwell Underground mine entry and constrained associated infrastructure would be located behind a prominent east-west ridge and therefore would not be visible from properties located along the Golden Highway.*
>
> *The Project would extract approximately 150 million tonnes of run-of-mine coal over a period of approximately 26 years.*
>
> *The Project would produce high quality coals with at least 75% of coal produced capable of being used in the making of steel (coking coals). The balance would be export thermal coals suitable for the new generation High Efficiency, Low Emissions power generators.*

The following image (Figure 1) is reproduced from the Maxwell Project Scoping Report, showing the surface topography and landscape in the vicinity of the proposed underground entry.

Figure 1. EL 5460 from above the Proposed Location of the Maxwell Underground Mine Entry
(source: Maxwell Project Scoping Report, Malabar Coal, 2018)

Figure 2 shows a map of the Hunter Valley indicating the project location to the south of Muswellbrook, located between the New England and Golden Highways, to the west of the Bayswater Power Station.

Figure 3 shows the specific proposed location of the project infrastructure and the underground mine area, overlain on an aerial photograph of the region.

2.1 Further Background

The Project Description for the Environmental Impact Statement provides further background on the Project, including the following:

> *"The Project would involve extraction of coal from four seams within the Wittingham Coal Measures using the following underground mining methods:*
>
> - *bord and pillar with partial pillar extraction in the Whynot Seam; and*
> - *longwall extraction in the Woodlands Hill, Arrowfield and Bowfield Seams.*
>
> *The annual average ROM coal production from the Project would be approximately 5.7 Mtpa, yielding an annual average of approximately 4.8 Mtpa of product coal. Underground mining activities would be undertaken 24 hours per day, seven days per week.*
>
> *The full working section of each coal seam (Table 3-1) would be extracted where practicable."*

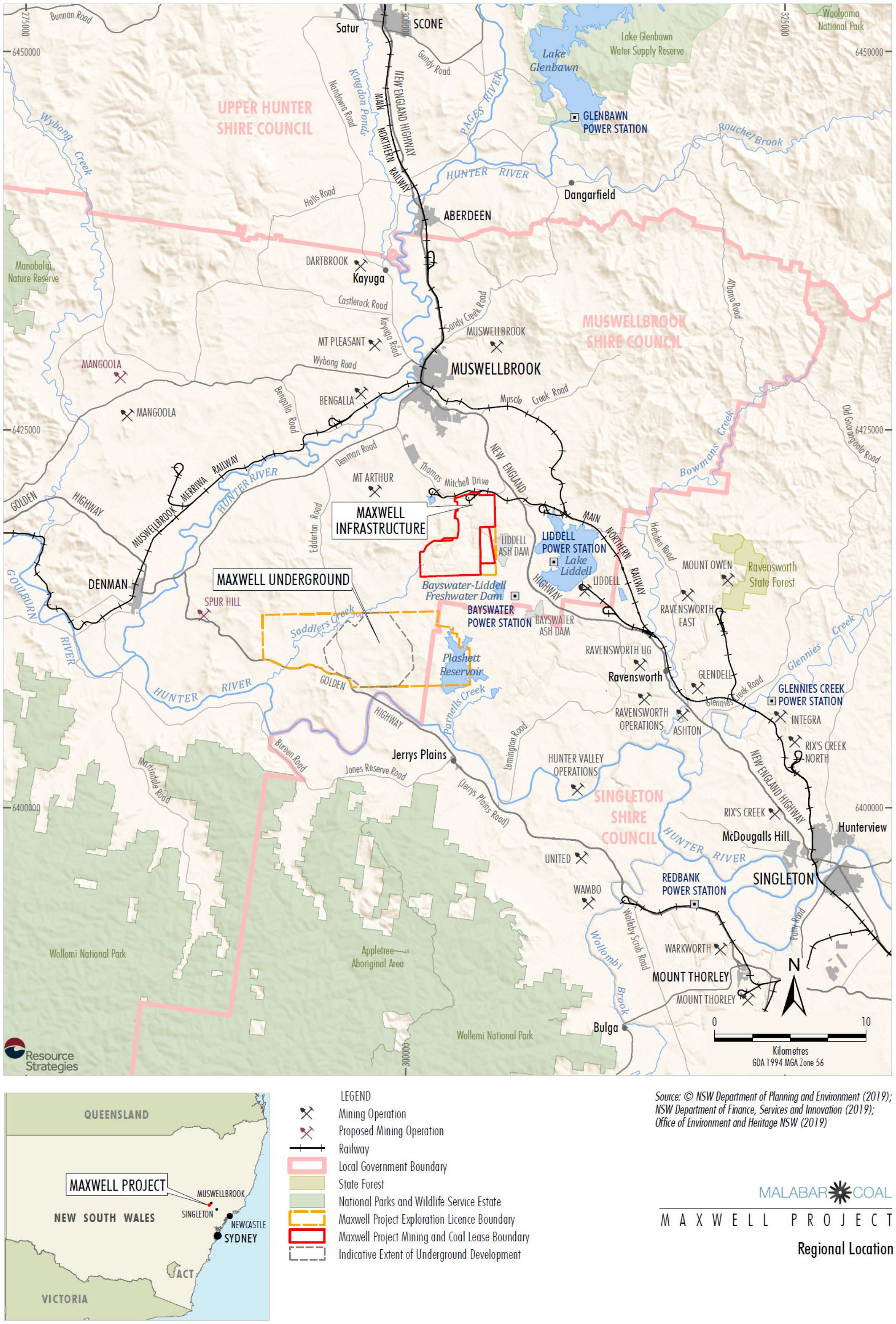

Figure 2. Maxwell Project: Regional Location
(source: Maxwell Project Environmental Impact Statement, Malabar Coal, 2019)

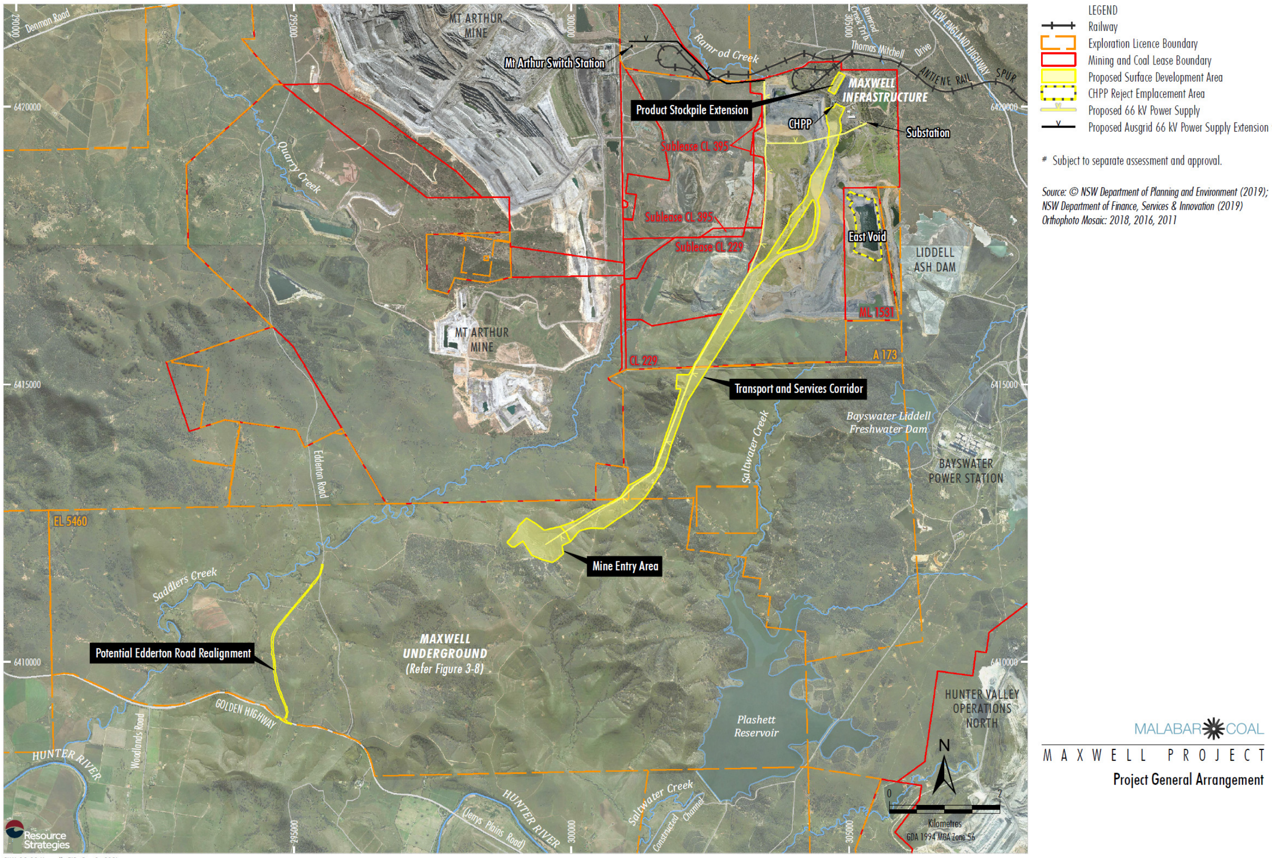

Figure 3. Maxwell Project: General Arrangement
(source: Maxwell Project Environmental Impact Statement, Malabar Coal, 2019)

Figure 4 is a generalised stratigraphic section indicating the geology and relative horizons of the target coal seams in the sequence.

Figure 5 is a simplified indicative plan for the proposed mining layouts in each of the coal seams – with bord and pillar mining proposed in the Whynot Seam, and longwalls in each of the underlying three seams.

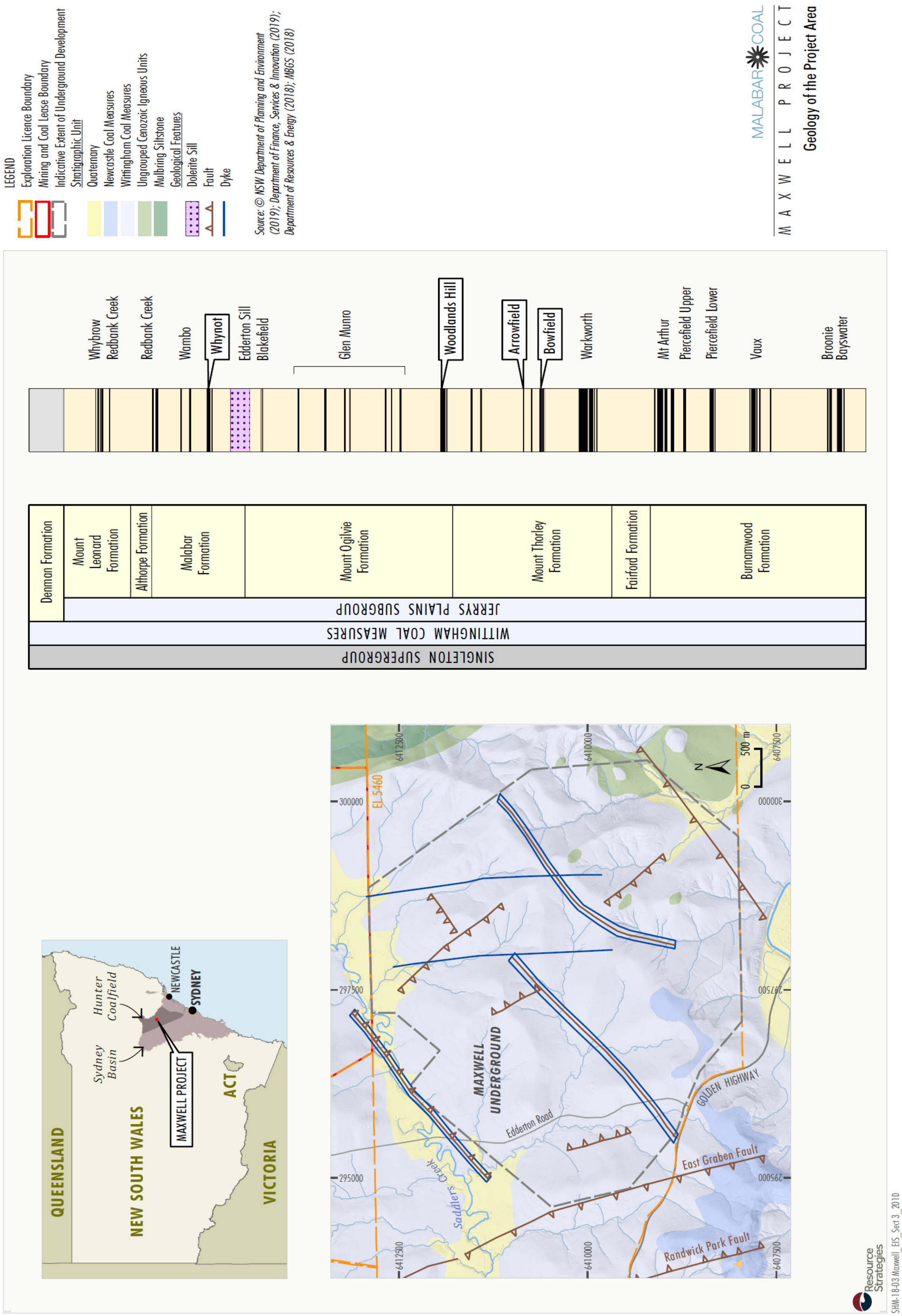

Figure 4. **Maxwell Project: Generalised lithology**
(source: Maxwell Project Environmental Impact Statement, Malabar Coal, 2019)

Figure 5. Maxwell Project: Indicative mine layouts
(source: Maxwell Project Environmental Impact Statement, Malabar Coal, 2019)

Table 1 lists the range of seam working section thicknesses and depths for the four seams proposed to be mined within the underground area.

Table 1. Seam Characteristics of the Underground Mining Area
(source: Maxwell Project Environmental Impact Statement - Project Description (Table 3-1), Malabar Coal, 2019)

Seam	Depth of Cover (m)	Working Section Thickness (m)
Whynot Seam *	40 - 180	1.3 – 2.3
Woodlands Hill Seam	125 - 365	1.7 – 3.5
Arrowfield Seam	165- 415	2.1 – 3.7
Bowfield Seam	215 - 425	2.2 – 3.3

(Secondary extraction would not occur at depths of cover less than 50m)*

The following Figures are taken from the MSEC Report, providing further detail of the proposed mine layouts within each seam (Figure 6 is an overlay of mine layouts from all four seams; whilst Figures 7, 8 9 and 10 show the layouts within each seam individually). Each of these figures also show the Study Area boundary which takes account of subsidence angle of draw (see later discussion).

Figure 11 is also taken from MSEC (2019) and is a plan shown mapped and interpreted structural geological features across the underground mining area.

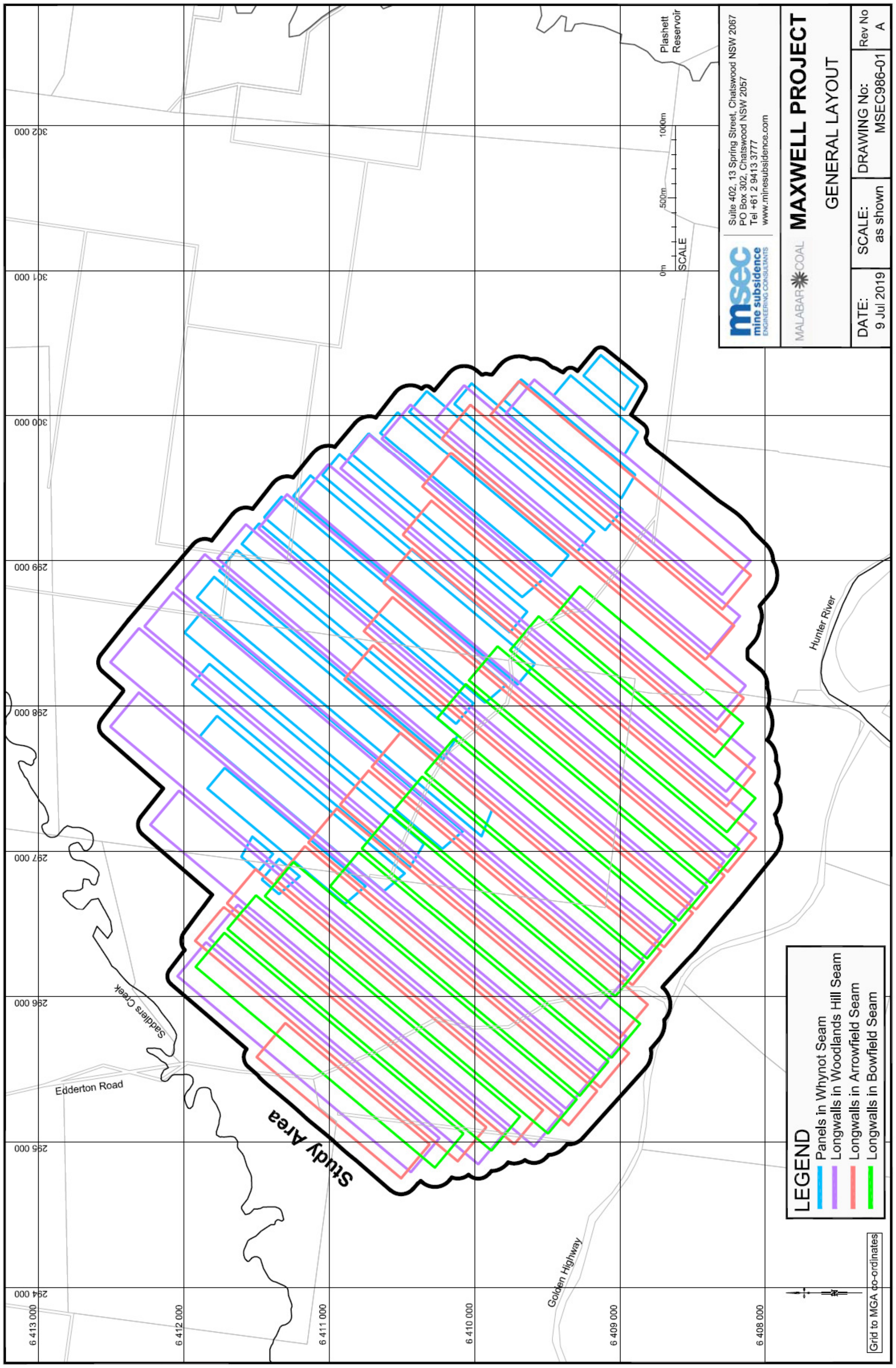

Figure 6. **Maxwell Project: Overlay of proposed mine panels**
(source: MSEC Report No. 986, Rev. A, 2019)

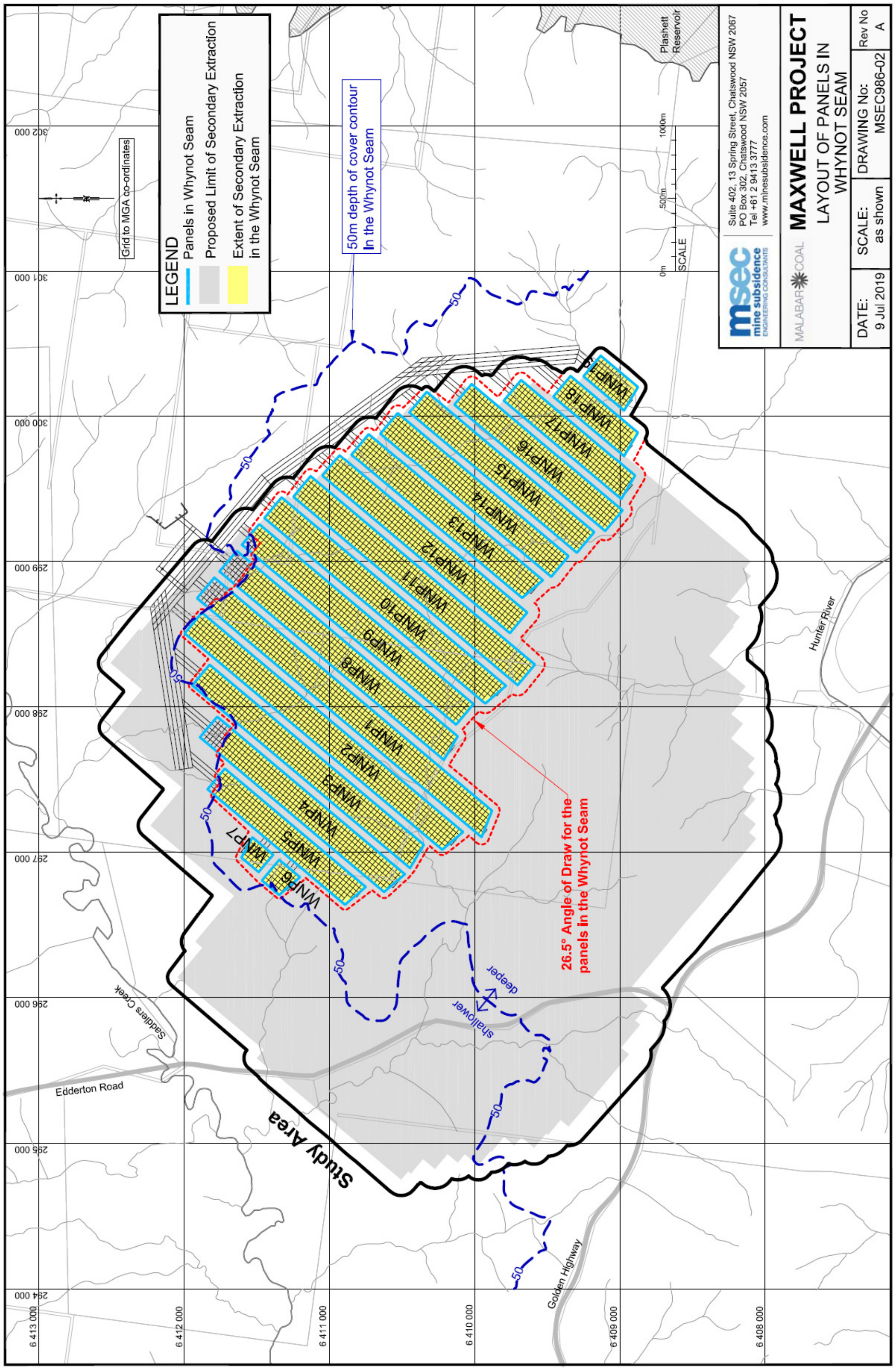

Figure 7. **Maxwell Project: Proposed Whynot Seam workings**
(source: MSEC Report No. 986, Rev. A, 2019)

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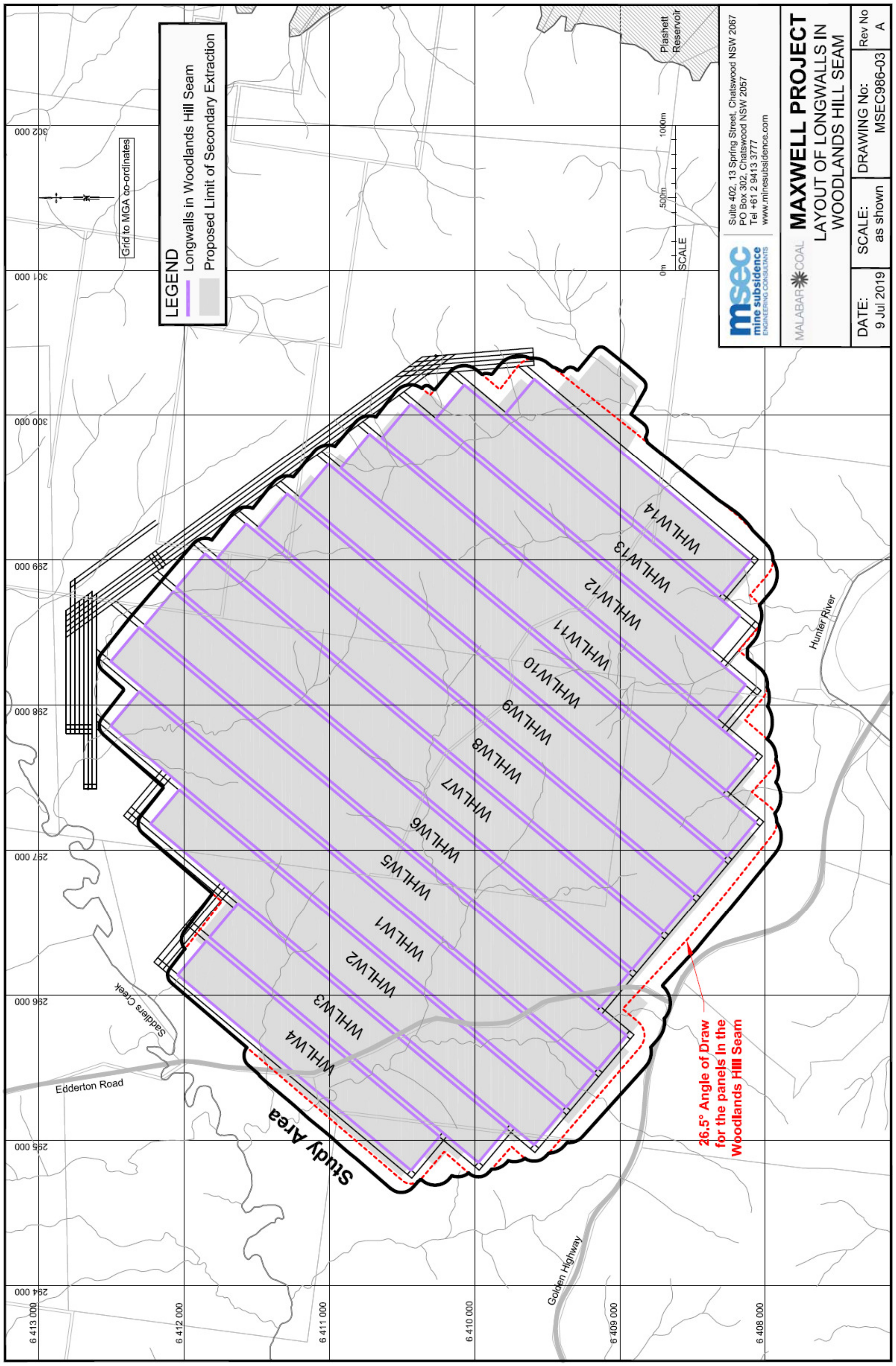

Figure 8. **Maxwell Project: Proposed Woodlands Hill Seam workings**
(source: MSEC Report No. 986, Rev. A, 2019)

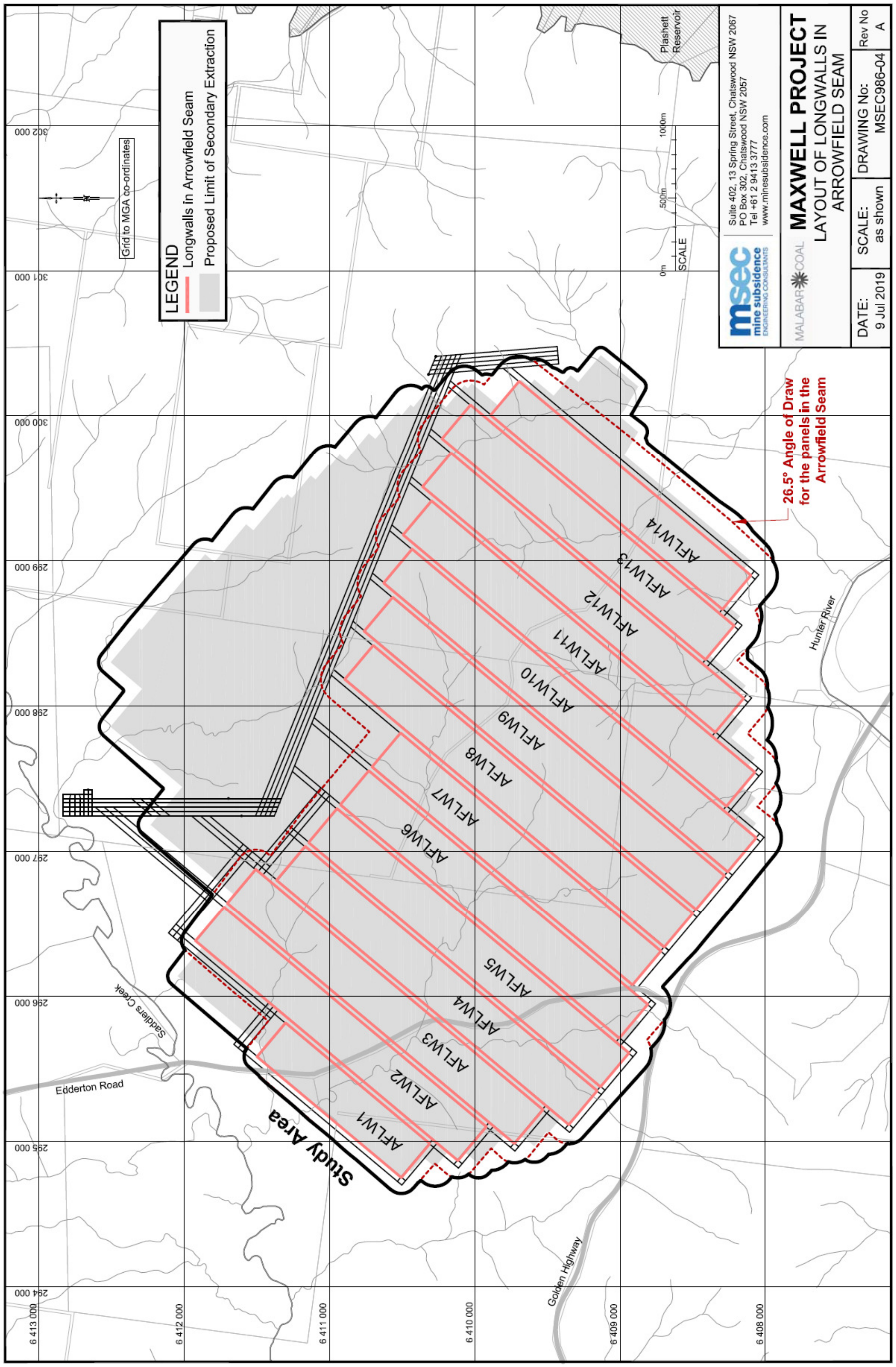

Figure 9. Maxwell Project: Proposed Arrowfield Seam workings
(source: MSEC Report No. 986, Rev. A, 2019)

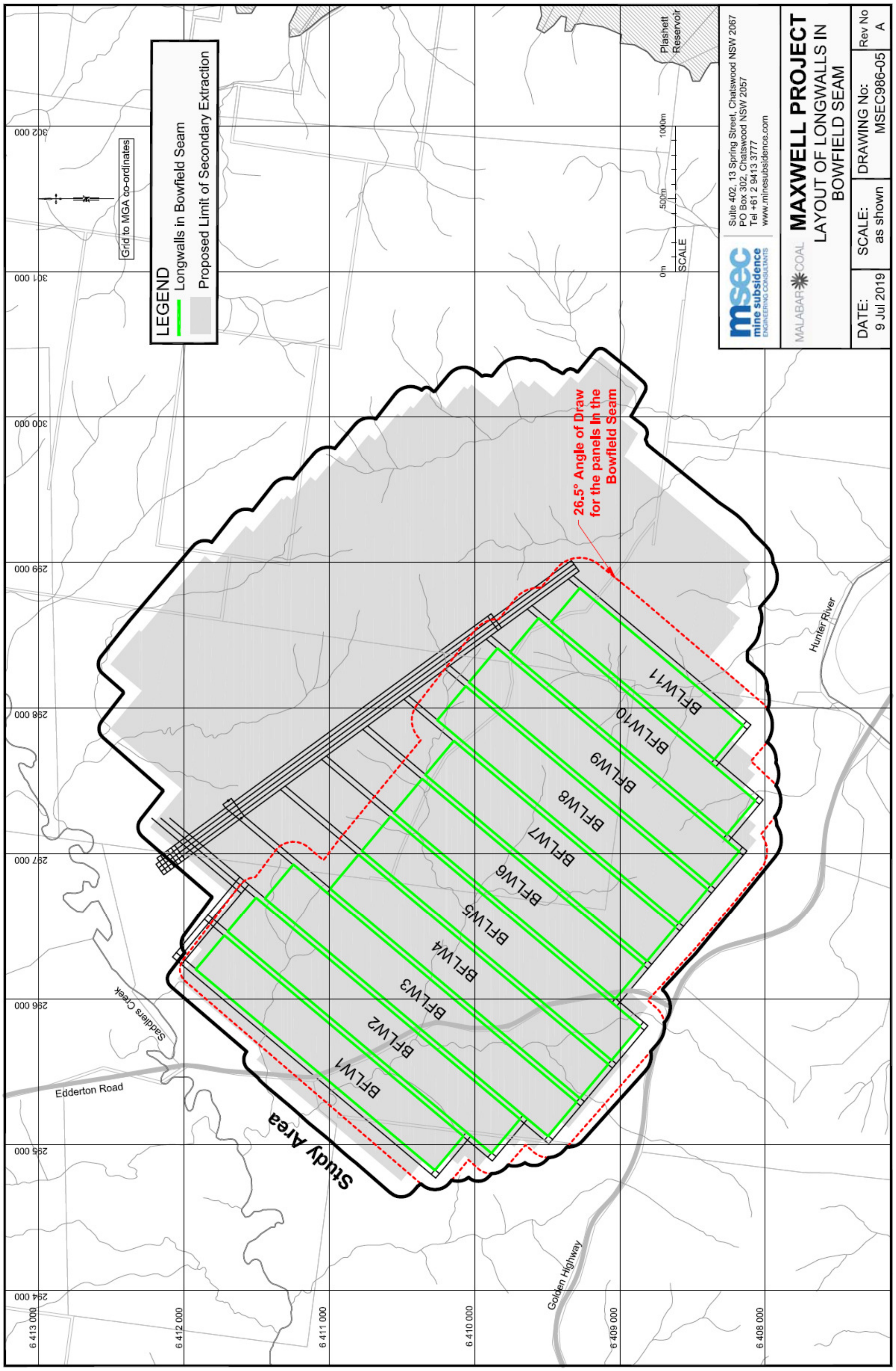

Figure 10. **Maxwell Project: Proposed Bowfield Seam workings**
(source: MSEC Report No. 986, Rev. A, 2019)

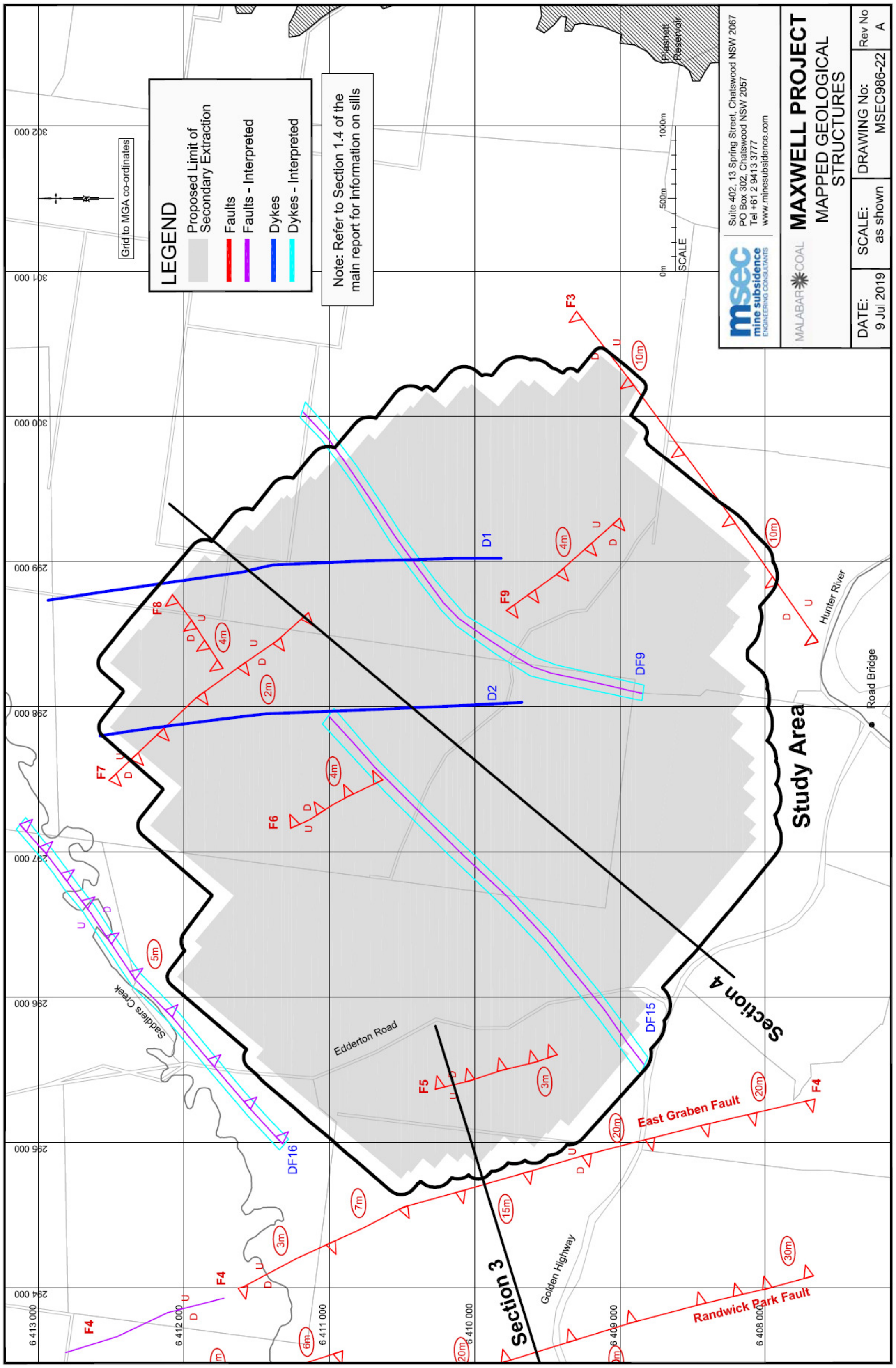

Figure 11. **Maxwell Project: Mapped and interpreted geological structures**
(source: MSEC Report No. 986, Rev. A, 2019)

3 REVIEW COMMENTS ON MSEC REPORT

The following independent review comments are provided on the MSEC Report 986, Rev. A, July 2019.

3.1 Executive Summary

1. The following is the MSEC summary of subsidence effects predicted due to the proposed underground mining in the four seams:

   "The subsidence predictions for the proposed underground mining operations have been obtained using the Incremental Profile Method. This method has been calibrated using the available single-seam and multi-seam monitoring data from the New South Wales coalfields. The maximum predicted subsidence effects due to the proposed mining in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams are:

   - *vertical subsidence of 5600 mm (58 % of the total mining height in all seams);*
   - *tilt of 50 mm/m (i.e. 5 %, or 1 in 20);*
   - *hogging and sagging curvatures of 2.0 per kilometre (km^{-1}, i.e. minimum radius of curvature of 0.5 km); and*
   - *strains typically between 10 mm/m and 20 mm/m, with localised strains greater than 20 mm/m.*

   The proposed underground mining includes both first and second workings. The first workings comprise a network of access roadways (i.e. drifts and main headings) that will be designed to remain stable for the life of the mine. The secondary workings associated with the partial pillar extraction and longwalls will result in subsidence that develops predominately above the area of secondary extraction."

2. The above predictions represent large values of subsidence effects due to the cumulative effect of subsidence created by each seam being mined. The subsidence impacts and potential consequences associated with these subsidence effects are discussed in the body of the report.

3. The Executive Summary defines the term "Study Area" as:

   > *"the surface area that is likely to be affected by the secondary extraction of the proposed panels and longwalls in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams. The extent of the Study Area has been calculated, as a minimum, as the surface area enclosed by the greater of the 26.5° angles of draw from the limits of secondary extraction in each seam and by the predicted total 20 mm subsidence contour".*

   This is therefore the area that is of greatest interest in assessing the impact of mining. It is useful to understand the variation between that contained within a 26.5° angle of draw, and that defined by the 20mm limit of vertical subsidence. To what extent do some areas of >20mm subsidence extend beyond 26.5°, and where they do, what is the effective angle of draw in such locations? Is this variation significant or not?

   The answers to these questions are provided later in the report and illustrated in Figure 2.1 which illustrates both the 26.5° limit and the 20mm subsidence limit as an overlay. It is apparent that there are only a small number of locations where there is minimal variation outside the 26.5° limit, occurring in some of the re-entrant mining geometry corners. The maximum angle of draw in such locations is understood to be no greater than 32° and the extent of such areas is minimal.

4. MSEC provides reference to the distance from the edge of mining to certain key features (such as rivers, creeks, roads etc), and also the distance outside the 26.5° angle of draw line, which effectively represents a stand-off or buffer zone. Given the comment in (3) above, this is a reasonable approach (using the 26.5° limit) and provides clear evidence of stand-off distances beyond the expected limits of vertical subsidence.

5. MSEC states *"The potential for topographic depressions to develop that may result in ponding has been modelled by Fluvial Systems (2019) based on the subsidence predictions outlined in this report. Based on this assessment, additional ponding as a result of subsidence is expected to be restricted to along existing drainage lines".*

   This finding is an important one to note, in terms of expectations of some water ponding along drainage lines. The statement is further supplemented by a comment that some surface cracking may occur in the existing drainage lines and where these cracks are significant, remedial work is recommended. This is an area that should be carefully monitored during mining, and comparisons made against the MSEC/Fluvial Systems predictions, in order to ensure that any necessary remediation can be successfully carried out, in a timely fashion.

6. Discussion in the report of the impact of subsidence on steep slopes in the area refers to cracking and compressive ridges, heaving and also erosion. In regard to the question of potential slope stability problems, MSEC states *"It is considered unlikely that the proposed mining would result in adverse impacts on the stability of the steep slopes based on the experience from the NSW coalfields. The Land Management Plan component of the Extraction Plan should include more detailed consideration of slope stability, including input from a specialist geotechnical expert.*

   The steep slopes should be visually monitored during mining. The larger surface cracking that could result in increased erosion or restrict access to areas should be remediated by infilling with soil or other suitable materials, or by locally regrading and compacting the surface".

   MSEC provides further detail on these likely impacts, in sections 5.5.3 and 5.5.4 of the report. The recommendations made by MSEC on this issue – being (1) more detailed consideration of slope stability by a specialised geotechnical engineer; and (2) visual monitoring during mining – are supported. Further to these points, there may be a need, or at least further value, in adopting a higher level of monitoring than simply visual, at least in any identified critical or high-risk slope areas (to be informed by the slope stability analysis).

7. MSEC states *"Plashett Reservoir and dam wall are located more than 2 km east of the proposed mining area. At this distance, the vertical subsidence at the reservoir and dam wall are expected to be negligible. The reservoir and dam wall could experience very small far-field horizontal movements due to the proposed mining_typically less than 25 mm, which is in the order of survey tolerance for absolute position. It is unlikely that the differential horizontal movements (i.e. strains) at the dam wall would be measurable".*

This conclusion is considered valid and appropriate. It has been shown from experience elsewhere in NSW that remote, far-field horizontal movements are commonly associated with very low levels of strain, with negligible potential for any adverse impacts.

8. It is noted with regard to groundwater impacts (on bores and groundwater resources), that the groundwater impacts are the subject of a separate report by a groundwater consultant. It is noted that this current peer review does not extend to reviewing the separate groundwater report. MSEC further notes, in regard to this and some other issues *"that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports".*

3.2 Chapter 1: Introduction

1. In discussion of the brief provided to MSEC by Malabar Coal, it is stated that it would include:

   > *"review of the proposed mining layouts in the Whynot, Woodlands Hill, Arrowfield and Bowfield Seams to identify mining geometry, surface and seam information and geological details relevant to subsidence predictions and impact assessments".*

   It is important to note here that the MSEC study is only reviewing mine layouts with respect to subsidence predictions and impact assessments. MSEC has not been tasked with any other geotechnical study, for example, of the proposed mine layouts, in particular, the bord and pillar partial extraction layouts in the Whynot Seam. Whilst such work falls outside the MSEC brief, it is an important aspect of the overall project feasibility study which may have impacts on surface subsidence. At this stage of the project it is noted that MSEC have assumed "worst case" scenarios, with respect to the subsidence effects from the bord and pillar mining.

   MSEC's treatment of bord and pillar subsidence effects are discussed in more detail in Chapter 3.

   At a later stage of the Maxwell project, more detailed consideration of the underground stability of such workings needs to be undertaken, and the subsidence predictions then re-visited. Regional stability of bord and pillar layouts (especially where partial extraction is practised) are an important consideration which could also have a significant impact on surface subsidence – due to factors such as potential inter-panel and barrier pillar instability, caving behaviour, goaf-edge control and the further, longer-term impact of multiple seam under-mining on overall, long-term pillar stability.

2. Table 1.1 from the MSEC Report is reproduced below, simply to summarise the subsidence-related SEARs and the reference to them within the MSEC Report.

Table 1.1 Secretary's Environmental Assessment Requirements (SEARs) Relating to subsidence

SEARs for subsidence	Section reference
The EIS must address the following key issues: • *Subsidence – including an assessment of the likely conventional and non-conventional subsidence effects and impacts of the development, and the potential consequences of these effects and impacts on the natural and built environment (including Edderton Road), paying particular attention to those features that are considered to have significant economic, social, cultural or environmental value;*	The maximum predicted subsidence, tilt and curvatures are summarised in Chapter 4. The predicted strains based on both conventional and non-conventional movements are summarised in Section 4.3. The assessments of the potential consequences on the natural and built features are provided in the impact assessments for each of the surface features in Chapters 5 and 6.
• *Water – including:* – *an assessment of any likely flooding impacts of the development;*	The assessment of the changes in the surface topography are provided in Sections 5.3 and 5.6. This provides the background information for the more detailed assessments undertaken by the specialist surface water consultant for the EIS.
• *Heritage – including:* – *an assessment of the potential impacts of the development on Aboriginal heritage (cultural and archaeological);* – *an assessment of the likelihood and significance of impacts on heritage items;*	The impact assessments for the Aboriginal and European heritage sites are provided in Sections 6.15 and 6.16, respectively. Further assessments are provided by the specialist heritage consultants for the EIS.
• *Hazards – including:* – *interactions with nearby prescribed dams (including the possibility of far field horizontal movements)*	Refer to Section 4.5 for the predicted far-field horizontal movements and Section 6.8 for the descriptions, predictions and impact assessments for the dam structure.

3. MSEC defines the mining geometry for the Whynot Seam bord and pillar workings, as follows:

> *"The proposed panels each comprise six rows of pillars along their lengths, as shown in Drawing No. MSEC986-02. The pillars have dimensions of 25 m by 25 m and are separated by 5 m wide development roadways.*
>
> *Malabar proposes to carry out partial extraction of the pillars within each of the proposed panels to achieve approximately 55 % to 70 % coal recovery based on both first and second workings. There are various partial extraction methods that could achieve this level of coal recovery. The final layout in the Whynot Seam would be presented by Malabar in future Extraction Plans, with subsidence predictions based on the selected pillar extraction method.*
>
> *The subsidence predictions provided in this report have been based on the extraction of the two rows of pillars adjacent to each of the barrier pillars (i.e. four rows of pillars within each panel) and leaving the two central rows of pillars unmined (i.e. central spine pillar). Small sections of the coal seam will be left as a result of the mining process, known as stooks, representing approximately 15 % of the coal for the rows of mined pillars.*
>
> *This partial extraction method achieves approximately 71% coal recovery, within each of the proposed panels, based on both first and second workings. The overall coal recovery is approximately 55 % when considering both the panels and the barrier pillars.*

The partial extraction within each of the proposed panels results in two voids between each of the barrier pillars and the central spine pillar. These two voids each have a width of 65 m. The overall width of the central spine pillar is 55 m, which is split by a 5 m wide roadway".

4. The reference above to final mine layouts for the Whynot Seam, to be presented in future Extraction Plans, confirms the need for a further iteration of the subsidence predictions once such detailed plans are developed. Such further analysis and updated predictions should also be informed by the underground regional pillar stability studies recommended in point 1 above.

5. Page 4 - The longwall panel total void widths for each of the underlying three seams are stated as 305m.

6. The chain pillar widths are 35m.

7. In relation to mining height in each seam, MSEC states *"The full seam thicknesses are proposed to be extracted, with minimum mining heights of 1.5 m in the Whynot Seam, 2.1 m in the Woodlands Hill and Arrowfield Seams and 2.4 m in the Bowfield Seam. The subsidence predictions provided in this report have been based on the variable seam thicknesses shown in Drawings Nos. MSEC986-11, MSEC986-12, MSEC986-13 and MSEC986-14, with the minimum mining heights applied".*

   Future detailed mine planning should consider proposed mining heights based on these seam thickness variations and equipment selections. For the MSEC subsidence predictions, it is stated above that variable seam thicknesses have been used, but then also states that the minimum mining heights have been applied. In the event that, where seam sections are thicker, heights greater than the minimum may be mined, updated subsidence predictions should then be made.

8. Table 1.7 also includes data on the important interburden thicknesses, as follows:

Whynot to Woodlands Hill Seam:	155m to 185m, average 165m
Woodlands Hill to Arrowfield Seam:	40m to 75m, average 50m
Arrowfield to Bowfield Seam:	20m to 45m, average 30m.

9. Figure 12 (below) is a copy of MSEC Figure 1.2, included here simply to illustrate the relative vertical configuration of the seams, relative to one another, and to the surface topography, along a typical section through the workings. This Figure also indicates three of the major faults expected to be present in the workings.

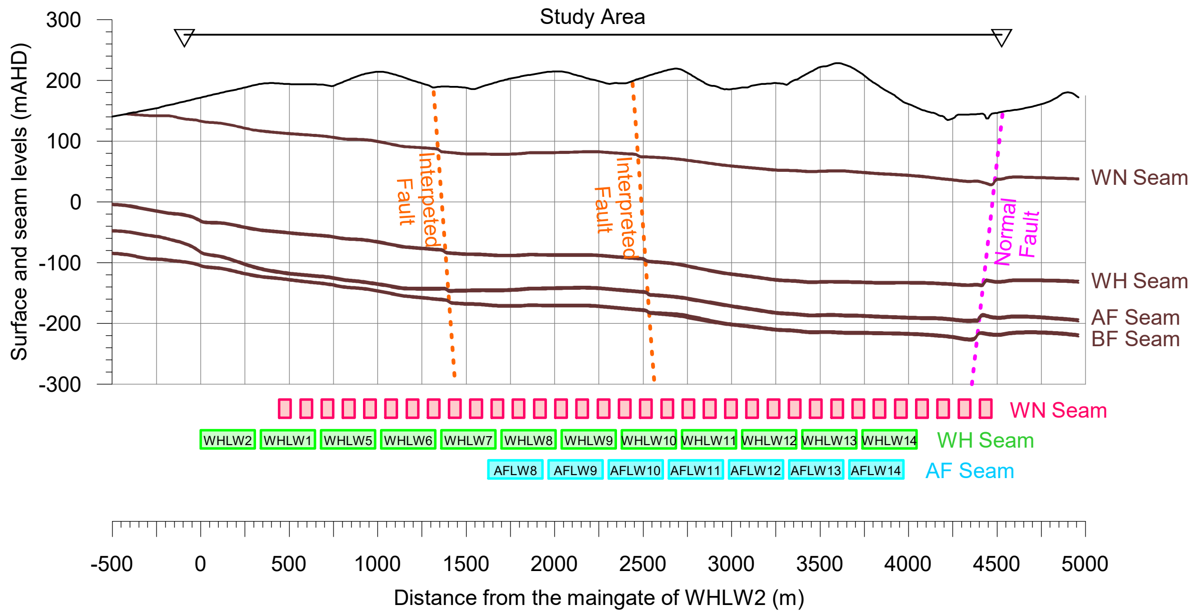

Figure 12. Maxwell Project: Surface and seam levels along Section 1
(source: MSEC Report No. 986, Rev. A, 2019)

10. Section 1.4 (pages 6 and following) discusses the geology of the area, and in particular the presence of a number of different types of faults and dykes. Detailed discussion of the impact of such structures is contained later in the MSEC Report, but it is reasonable to conclude that there may be some localised anomalous subsidence behaviour associated with mining close to, or through such structures. Such anomalous behaviour is difficult to predict.

11. Page 9 and following – The presence of dolerite sill intrusions in three of the four seams in the mining area (excluding the Woodlands Hill Seam) is discussed. Mine workings have been located to avoid the sills within each seam, but their presence in the overburden could certainly impact on both underground mining conditions and subsidence effects, with potential for delayed or anomalous subsidence in some locations. The sills are stated to be up to 20m in thickness, with strengths in excess of 180MPa. An analysis by MSEC suggests that the sills will not be strong enough to span across a full longwall panel width, but over panel edges and corners, they could certainly influence the behaviour of the overburden.

    Figure 13 is reproduced from MSEC Figure 1.4, showing the location of the sills along a particular section line (Section 4).

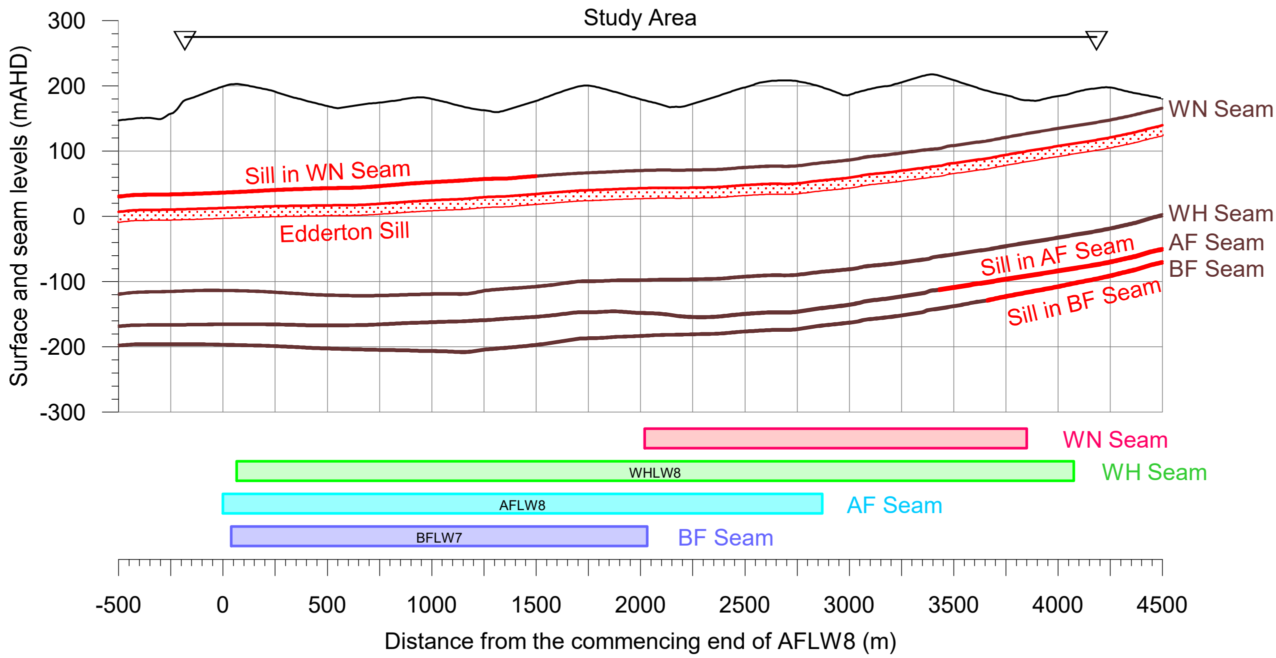

Figure 13. Surface, seam and sill levels along Section 4
(source: MSEC Report No. 986, Rev. A, 2019)

3.3 Chapter 2: Identification of Surface Features

1. This chapter summarises the full list of both natural and built features present within the Study Area above the underground mining area.

3.4 Chapter 3: Overview of Mine Subsidence and the Prediction Methods Used by MSEC

1. Section 3.2 provides an overview of conventional subsidence effects, and the associated terminology – all of which is consistent with the current state of understanding and practice.

2. Section 3.3 discusses far field horizontal movements which are normally associated with what is referred to as non-conventional subsidence behaviour. MSEC rightly points out that while such movements can be detected large distances away from the edge of mining, and well outside conventional angles of draw, they are generally associated with very low strain levels so that there is negligible adverse impact due to them.

3. Section 3.4 discusses other non-conventional subsidence effects. MSEC uses the terminology developed as part of the 2008 Southern Coalfield Inquiry. MSEC rightly states *"normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat"*. By contrast, non-conventional behaviour occurs where such conditions do not prevail. Factors which can therefore result in non-conventional behaviour include changes in geology, and variable surface topography, including

steep slopes or valleys. MSEC also includes multi-seam subsidence behaviour as non-conventional, on the basis that it is not directly predictable using conventional parameters and relationships, due to potential for multi-seam goaf interaction and larger than conventional deformations as a result.

4. Section 3.4.1 specifically then mentions anomalous behaviour – usually associated with localised changes in geology (potentially structural features) that cause localised changes and potential peaks in deformation or strain. Whilst there is an increasing capability to predict non-conventional subsidence effects, the ability to reliably and consistently predict localised anomalous behaviour is not yet possible.

5. Section 3.4.3 discusses the specific non-conventional behaviour associated with the presence of surface valleys. These result in the now commonly-observed phenomena of valley closure and valley floor upsidence or relative uplift. MSEC has been a leading group in first identifying this behaviour (originally in the NSW Southern Coalfield) and has now developed a large database of such subsidence effects and impacts, resulting in a rapidly growing capacity and reliability for predicting such phenomena.

6. Section 3.5 then describes the MSEC-developed Incremental Profile Method (IPM) for subsidence prediction. The IPM is an empirically-derived method and is therefore dependent on a large and good quality underlying database. The IPM allows for prediction of subsidence effects due to multiple mining panels in a seam – a distinct advantage over earlier empirical techniques which were only associated with single extraction panels. MSEC has invested considerable time, effort and experience into the development of this method and, based on their experience and now extensive database, MSEC has become the largest coal mine subsidence consultancy organisation involved in subsidence predictions, in Australia. There is no doubt that the IPM is the most effective method for subsidence prediction in Australia at the present time, and hence, MSEC is the leading group involved in such work.

7. MSEC lists the mines from where they have obtained subsidence data to underpin the IPM. This list is now quite extensive, including mines in all of the major NSW coalfields, as well as the Bowen Basin in Queensland. MSEC has a much larger database for the Southern Coalfield than for other areas, although the Newcastle and Hunter coalfields are included in their database and experience.

8. Within this section of the report, on page 20 MSEC then discusses the process for using the IPM for longwall mines in the Newcastle and Hunter Coalfields. This description is valid and appropriate.

9. Section 3.6.1 then discusses the calibration of the IPM for single seam operations at Maxwell. The first consideration is the bord and pillar partial extraction methods in the Whynot Seam. MSEC concludes that it is appropriate to apply the IPM since regular bord and pillar panels behave in a similar manner to longwall panels, although panel widths are usually less, and the extraction of coal within the panel is lower than for longwall, due to the presence of remnant small pillars or stooks. This is correct, although the size and extent of stooks, and hence the level of coal recovery is very dependent on the actual sequence of pillar extraction employed. As discussed earlier, this has not been discussed or evaluated in any level of detail by MSEC to date, so it is not possible to comment on this further.

10. MSEC states that the proposed panel width to depth ratios for the Whynot Seam range from 0.36 to 1.6, but average 0.65 which would be regarded as a sub-critical subsidence width. For

a panel void width of 65m and an average depth of 100m, this results in a maximum subsidence prediction of 25% to 30% of mined seam thickness, which is reasonable (assuming long-term stability of the adjacent spine and barrier pillars, as previously discussed). In the event of any subsequent pillar instability (either due to design issues, geology or effects of undermining), the level of maximum subsidence would be expected to rise, but possibly only in localised regions rather than across the whole of the workings.

11. Page 21 – There is discussion that at particularly shallow depths the panels will be supercritical (i.e. W/H ratios above 1.0 or greater), but vertical subsidence may be restricted due to spanning effects of the overlying strata. However, MSEC has used previous NSW coalfields partial pillar extraction subsidence data to calibrate the single seam predictions. It may also be important in future subsidence prediction updates to more closely analyse the near-surface geology for any regions of localised weathering or jointing which could impact (both positively and negatively) on subsidence effects due to the spanning behaviour of such overlying strata units. At this stage of the project, MSEC has adopted a "worst case" approach to this issue, for subsidence prediction, which is appropriate.

12. Page 21 – MSEC then turns to discussing the application of the IPM for single seam conditions in the Woodlands Hill Seam, where workings lie outside the extent of overlying Whynot Seam workings. Here, the depth varies between 125 m and 345 m, with an average depth of cover of 260 m. The width-to-depth ratios for these longwalls, therefore, vary between 0.88 and 2.4, with an average of 1.2. This places such panels in the critical to supercritical subsidence category and so maximum subsidence values of up to 65% of mined thickness are predicted. This is reasonable and consistent with normal IPM application for single-seam operations. MSEC notes that their experience and database for the Hunter Coalfields includes a number of nearby collieries in the same or similar coal seams, including Beltana, Blakefield South, Integra Underground, United and Wambo. Various graphs of actual versus prediction subsidence parameters are provided which demonstrate a high level of correlation and hence confidence in such predictions using the IPM and Hunter coalfield database, for single seam operations.

13. Page 26 – Section 3.6.2 then discusses calibration of the IPM for multi-seam operations. MSEC notes that subsidence in multi-seam environments generally results in higher levels of maximum subsidence (as a proportion of mining thickness) than for single seam workings. The shape of the subsidence profiles also changes as a result of both goaf and overlying pillar interaction. This is correct, although it should be noted that Australia has relatively little multi-seam mining experience, to date, when compared to single seam operations.

14. In relation to Woodlands Hill Seam longwalls beneath the overlying Whynot Seam bord and pillar workings, the following geometric parameters apply:

   – "Depth of cover to the Woodlands Hill Seam, beneath the bord and pillar panels in the overlying Whynot Seam, varies between 200 m and 365 m, with an average depth of cover of 280 m.
   – The longwall width-to-depth ratios for these longwalls, therefore, varies between 0.84 and 1.5, with an average of 1.1.
   – The proposed longwalls in the Woodlands Hill Seam are generally critical or supercritical in width where they are located beneath the bord and pillar panels in the overlying Whynot Seam (i.e. multi-seam conditions)".

15. MSEC rightly notes that *"the height of discontinuous fracturing for critical and supercritical longwalls is typically in the range of 1 to 1.5 times the longwall width above the seam roof. The height of discontinuous fracturing for the proposed longwalls in the Woodlands Hill Seam is in the range of 300 m*

to 450 m above the seam roof. The interburden thickness between the Woodlands Hill and Whynot Seams varies between 155 m and 185 m within the extents of these proposed panels and longwalls. The discontinuous fracturing due to the extraction of the proposed longwalls in the Woodlands Hill Seam, therefore, will extend up to the previously extracted bord and pillar panels in the overlying Whynot Seam. The extraction of these longwalls will remobilise the goaf and reactivate the spine and barrier pillars in the Whynot Seam. Increased vertical subsidence due to the multi-seam mining conditions is therefore expected".

This conclusion (and similar findings for the underlying seams) regarding height of fracturing and goaf interaction will have important implications for groundwater which are the subject of a separate investigation, as noted previously. The point about reactivation of the Whynot spine and barrier pillars is also noted, hence the question posed earlier about the stability of these pillars under such impacts, and if they deform significantly or fail, what additional subsidence might be expected? As has been noted above, such issues should be the subject of further analysis and new subsidence predictions once more detailed Extraction Plans for the Whynot Seam are developed, and appropriate regional pillar stability assessment has been conducted.

16. Page 26 – MSEC references the publications by Li et al (2007 and 2010) with reference to predicting the impact of multi-seam mining on maximum subsidence levels for a subsequent (second) mining horizon. The work of Li is regarded as the most up to date and appropriate at the present time in Australia and has also drawn on international experience. It is therefore appropriate to use the Li equations, but caution should be expressed that these have only been developed, to date, to predict the interaction between two mining horizons, which reflects the current Australian mining experience (as opposed to three or four seams in the case of the Maxwell project).

17. MSEC discusses the limited multi-seam experience (page 26) as follows:

    "There is limited multi-seam monitoring data from the NSW coalfields, especially where longwalls have been extracted directly beneath or above existing longwalls or panels.

    Multi-seam ground monitoring data for longwall mining beneath existing bord and pillar panels have been considered from John Darling, Kemira, Newstan, Teralba, Wyee and North Wambo Underground. Further multi-seam ground monitoring data for longwall mining beneath existing longwalls have also been considered from Blakefield South, Cumnock, Liddell, Newstan, Sigma and North Wambo Underground".

    Whilst such experience is valuable, as noted in point 13 above, it is limited and therefore the confidence levels in any prediction techniques will be lower than for similar techniques applied to single seam operations.

18. This field of multi-seam mining subsidence prediction, and the related issues associated with fracturing and goaf interaction, is one where there is a strong need for more research and development in the future to improve the understanding of behaviour, and hence further develop and refine the prediction capabilities.

19. One possible shortcoming of the Li equations that has been raised previously, is the lack of recognition of the role of interburden thickness as a variable in multi-seam subsidence prediction. It could be argued that the empirical data and related constants in the equations take this into account, but if this is the case, further caution should be exercised when applying the equations to different interburden thicknesses.

20. Table 3.1 (page 27) summarises the Australian multi-seam subsidence experience of longwall mining beneath previous workings (bord and pillar and longwall). MSEC summarises the results as follows:

 "The additional vertical subsidence measured due to the extraction of the second seam varied between 60 % and 116 % of the mining height (i.e. a_2 = 0.60 ~ 1.16). In many of these cases, however, the maximum measured vertical subsidence was localised and the values elsewhere were less than the maxima provided in the table. On average, the additional subsidence observed for these available multi-seam mining cases was around 85 % of the mining height in the second seam (i.e. a_2 = 0.85).

 The additional vertical subsidence can be greater than 100 % of the seam thickness adjacent to the chain pillars in the upper seam. The initial extraction of the first seam results in voids adjacent to the chain pillars due to the angle of break over the caving zone. The subsequent extraction in the lower seam can fail the cantilevering strata resulting in locally increased subsidence adjacent to the chain pillars. Whilst the additional subsidence due to the extraction of the lower seam can be greater than 100 % of its thickness, the total subsidence from mining both seams is less than the combined thickness of these seams.

 The total vertical subsidence measured due to the extraction of both seams varied between 63 % and 86 % of the total mining height (i.e. a_m = 0.63 ~ 0.86). On average, the total vertical subsidence measured for these available multi-seam mining cases was around 75 % of the total mining height in both seams (i.e. a_m = 0.75)".

 There is limited information on the reasons for this quite large range of behaviour (of between 60% to 116% of second seam extraction thickness for incremental subsidence and 63% to 86% of combined seam thickness for maximum total subsidence). It would be prudent to use a figure closer to the upper level of the range rather than the average, when applying the equations to a new mining region. (However, it is acknowledged that some of the peak values in this database are related to quite localised conditions and were not representative of the overall regional subsidence impacts).

21. Page 28 – MSEC now considers the multi-seam prediction for longwall mining in the Woodlands Hill Seam, beneath the bord and pillar workings in the Whynot Seam. They state:

 "The interburden thickness for the proposed longwalls in the Woodlands Hill Seam beneath the bord and pillar panels in the Whynot Seam varies between 155 m and 185 m. The multi-seam cases provided in Table 3.1 have thinner interburden thicknesses, being less than 50 m at Cumnock, Liddell, Newstan and Sigma, between 70 m and 95 m at Blakefield South and between 45 m and 120 m at the North Wambo Underground Mine.

 Whilst the interburden thickness for the proposed longwalls is greater than those for the previous multi-seam cases, these proposed longwalls are mining beneath subcritical bord and pillar panels. There is greater potential for reactivation of these workings when compared with the previous multi-seam cases, which generally comprised supercritical longwalls mining beneath supercritical longwalls and panels".

 MSEC has concluded that a total subsidence for the combined seam subsidence of 75% is reasonable, with a figure of 100% for the Woodlands Hill Seam. This latter figure is consistent with the recommendation in point 20 above.

22. Clearly, it will be very important to conduct extensive subsidence monitoring, and potentially some full section extensometry to determine vertical deformation through the overburden

section, once mining commences. A comprehensive subsidence monitoring plan will need to be developed that can inform and further refine the subsidence predictions once mining commences.

23. Figure 14 is a copy of the MSEC Figure 3.5 which illustrates the multi-seam database used for these predictions. Whilst this demonstrates a reasonable number of data points, it also clearly illustrates quite a wide range of scatter, even for the one mine, and for the one value of width/depth ratio. This further confirms that the level of confidence in the multi-seam predictions will be far less than it is with single seam predictions, at the present time. Hence a decision to use close to "worst-case" prediction factors is a prudent one, at this early stage of the project. Once actual data is gathered during operations, the understanding of multi-seam interactions will improve, as will the confidence levels for the prediction methods.

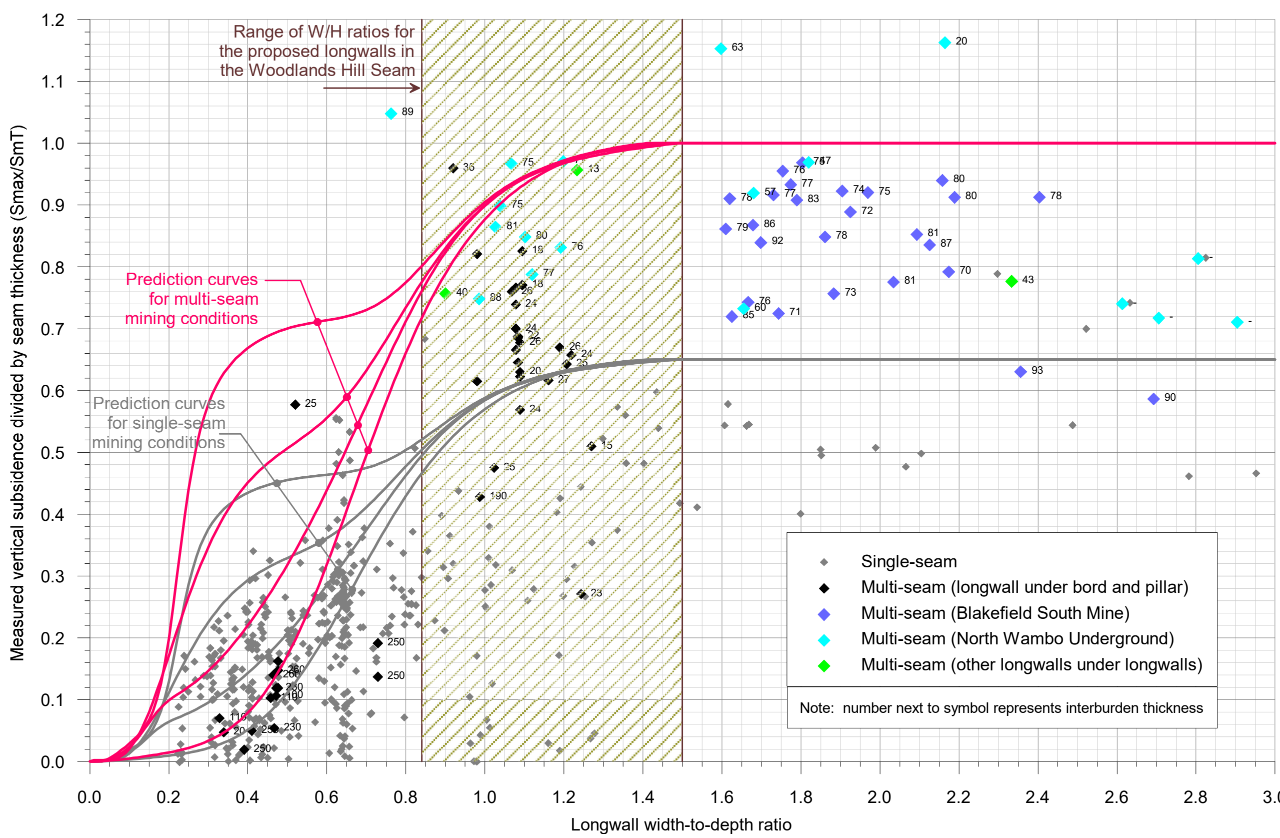

Figure 14. Maximum measured vertical subsidence versus longwall width-to-depth ratio for previous multi-seam mining cases
(source: MSEC Report No. 986, Rev. A, 2019)

24. Page 29 – MSEC then considers the multi-seam predictions for mining in the two lower seams. In these cases, mining represents longwall beneath longwall, and it is noted that panels and chain pillars are staggered, or off-set, rather than aligned. This should be advantageous in terms of overall subsidence but may contribute to some difficulties with abutment stresses at the mining horizon. Consideration of the longer-term stability of the chain pillars in each seam is also an important factor which is outside of the scope of the MSEC report, but it is an issue that needs further consideration, as part of more detailed future planning and design (which

must include pillar stability analysis and assessment of floor stability beneath each set of chain pillars).

25. MSEC determines to use a 100% factor for subsidence due to each underlying seam, as was also applied for the Woodlands Hill Seam, as they again note that fracturing and goaf interaction will occur. They state:

"The discontinuous fracturing due to the extraction of the proposed longwalls in each of the Arrowfield and Bowfield Seams will extend up to the previously extracted longwalls in the overlying seams. The extraction of these longwalls will remobilise the goaf and reactivate the chain pillars in the overlying seams. Increased vertical subsidence due to the multi-seam mining conditions is therefore expected.

The maximum predicted vertical subsidence due to the extraction of the proposed longwalls in the Arrowfield and Bowfield Seams has been based on the multi-seam prediction curves shown in Figure 3.5.

There is greater uncertainty in the predictions for the Arrowfield and Bowfield Seams since there is limited multi-seam data available for third and fourth seams. However, the proposed longwalls in the Arrowfield and Bowfield Seams are critical to super-critical in width and the maximum predicted additional subsidence represents close to 100 % of their respective seam thicknesses. The predictions of vertical subsidence for these seams are therefore considered to be conservative since the actual subsidence is limited by the available voids defined by the overall seam thicknesses".

The greater uncertainty identified with prediction of multi-seam subsidence for mining a third or fourth seam is an important recognition of the fact that there is only very limited Australian experience for such practice. The Li equations used were derived only for a two-seam scenario. Applying the same approach for the third and fourth seams is effectively assuming that only the seam immediately above the mined seam will be further or incrementally effected by the undermining. This is a plausible scenario but is not one that can be assumed without actual experience.

MSEC has made predictions for these lower seams, using a 100% factor, based on the limited available three seam database (including data from the Hunter Coalfield, from mines such as Ashton). This is considered a reasonable starting point but must only be regarded as a preliminary or first-pass prediction that would have a lower level of confidence than either the Woodlands Hill Seam multi-seam subsidence, or certainly the single seam predictions.

26. Page 30 - Section 3.7 discusses reliability of the IPM predictions. The application of the predicted subsidence effects on both natural and built features is included in the subsequent chapters, based on the IPM predictions. It is correctly noted that:

"the IPM provides site specific predictions for each natural and built feature and, hence, provides a more realistic assessment of the subsidence impacts than by applying the maximum predicted parameters at every point, which would be overly conservative and would yield an excessively overstated assessment of the potential subsidence impacts.

The prediction of strain at a point is even more difficult as there tends to be a large scatter in observed strain profiles. It has been found that measured strains can vary considerably from those predicted at a point, not only in magnitude, but also in sign, that is, the tensile strains have been observed where compressive strains were predicted, and vice versa. For this reason, the prediction of strain in this report has been based on a statistical approach, which is discussed in Section 4.3.

> *It is also likely that some localised irregularities will occur in the subsidence profiles due to near-surface geological features and multi-seam mining conditions. The irregular movements are accompanied by elevated tilts, curvatures and strains, which often exceed the conventional predictions. In most cases, it is not possible to predict the locations or magnitudes of these irregular movements. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains, including both conventional and non-conventional anomalous strains, which is discussed in Section 4.3".*

27. The above conclusions regarding the application of IPM results to the various features across the Study Area are considered valid and appropriate. MSEC has appropriately adopted a conservative, or "worst-case" approach for their predictions, at this stage of the project.

    It is particularly important to note again the potential irregularities that may result from subsidence due to multi-seam conditions which may not be straight-forward or regular and symmetrical. It is even more important to recognise that geological variations may cause further irregularities or anomalous impacts in localised areas – especially due to the identified structural features such as faults, dykes and sills.

3.5 Chapters 4, 5 and 6

The remaining chapters of the MSEC Report discuss the maximum subsidence effects predicted across the Study Area and contain the critical prediction of subsidence impacts on the range of both natural and built features.

Several of these important features have been referenced in the discussion of the Executive Summary, such as:

- The overall extent of the Study Area beyond the limits of mining;
- the issue of some ponding along drainage lines;
- impacts on steep slopes;
- Plashett Reservoir and dam wall.

It is noted that much of the Study Area is agricultural land with relatively few sensitive features that could be adversely impacted by the subsidence effects discussed. To this extent, the application of the MSEC IPM prediction methodology is considered to provide reasonable levels of confidence for subsidence prediction and impact assessment, given that "worst-case" scenarios have been adopted in the cases where greatest uncertainty exists.

It is not intended to provide any further specific commentary on these remaining chapters, as they represent the direct application of the prediction principles and methodologies that have already been discussed above. As such, the predictions in these subsequent chapters are considered appropriate, subject to the various issues and considerations discussed above, with regard to the overall prediction approach.

3.5 Overall Assessment

In regard to the issues already raised in this report, the greatest levels of uncertainty, for overall subsidence effects and impacts, are considered to relate to two main considerations:

- The stability of the partial pillar extraction bord and pillar workings in the Whynot Seam – in both the medium and longer-term, especially once undermining and potential goaf interaction occurs, and possibly destabilises the regional pillar system integrity;

- The impact of mining the underlying third and fourth seams, and their impact, not just on the seam directly above, but also on the higher-level seams (and associated goaf areas).

MSEC has clearly acknowledged each of these issues as important areas where the prediction confidence levels are reduced; and has also acknowledged that further, updated predictions will need to be made at later stages of the project, informed by more detailed mine planning, further geotechnical assessment, and subsequently by actual ground monitoring, once mining commences.

It is considered that MSEC has taken an appropriate and prudent approach to these issues in particular, in the development of their initial predictions.

It is also noted that MSEC has adequately responded to all other considerations raised following a review of the earlier Revision 5 draft report, and this is reflected in the current MSEC 986 Revision A report.

Bruce Hebblewhite
11th July 2019

APPENDIX A

Attached is a summary Curriculum Vitae for the author of this report, Bruce Hebblewhite. Bruce Hebblewhite has worked within the Australian mining industry from 1977 to the present time, through several different employment positions. Throughout this period, he has been actively involved in all facets of mining industry operations. In addition, he has visited and undertaken consulting and contract research commissions internationally in such countries as the UK, South Africa, China, New Zealand and Canada. For the majority of his 17-year employment period with ACIRL Ltd he had management responsibility for ACIRL's Mining Division which included specialist groups working within both the underground and surface coal mining sectors, and the coal preparation industry– actively involved in both consulting and research in each of these areas.

In his current employment position with The University of New South Wales, Bruce Hebblewhite is involved in undergraduate and postgraduate teaching and research, and contract industry consulting and provision of industry training and ongoing professional development programs – for all sectors of the mining industry – coal and metalliferous.

Both past and present employment positions require regular visits, inspections and site investigations throughout the Australian mining industry, together with almost daily contact with mining industry management, operations and production personnel.

<u>Disclaimer</u>

Bruce Hebblewhite is employed as a Professor within the School of Minerals & Energy Resources Engineering, at The University of New South Wales (UNSW). In accordance with policy regulations of UNSW regarding external private consulting, it is recorded that this report has been prepared by the author in his private capacity as an independent consultant, and not as an employee of UNSW. The report does not necessarily reflect the views of UNSW and has not relied upon any resources of UNSW.

SUMMARY CURRICULUM VITAE

Bruce Kenneth Hebblewhite

(Professor, Chair of Mining Engineering),
School of Minerals & Energy Resources Engineering, The University of New South Wales, &

Consultant Mining Engineer

DATE OF BIRTH 1951

NATIONALITY Australian

QUALIFICATIONS
1973: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, Univ. of New South Wales
1977: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
1991: Diploma AICD, University of New England

PROFESSIONAL MEMBERSHIPS; APPOINTMENTS; AWARDS & SPECIAL RESPONSIBILITIES
Member - Australasian Institute of Mining and Metallurgy
Member - Australian Geomechanics Society
Member – Society of Mining and Exploration Engineering (SME), USA
Member - International Society of Rock Mechanics (President – Mining Interest Group (2004 – 2011))
Emeritus Member - Society of Mining Professors (SOMP) (President (2008/09); Council Member (2006 - 2018); Secretary-General (2011-2018))
Executive Director – Mining Education Australia (July 2006 – December 2009)
Chair, Governing Board – Mining Education Australia (2015)
Member, Branch Committee – AusIMM Sydney Branch (2017-2019)

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 Northparkes Mine Accident
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries)
Expert Witness assisting NSW Mines Safety Investigation Unit – Austar Mine double fatality, April, 2014.
Member (2012 – present): Scientific Advisory Board, Advanced Mining Technology Centre, Uni. of Chile.
Trustee (2013 – present): AusIMM Education Endowment Fund
2012 Syd S Peng Ground Control in Mining Award – by SME (USA).
2017 Ludwig Wilke Award for contribution to international mining research and education (Society of Mining Professors).
2017 SME Award for Rock Mechanics (presented at 2018 SME Annual Meeting in Minneapolis, USA in Feb 2018).

PROFESSIONAL EXPERIENCE

2014 – present University of New South Wales, School of Minerals & Energy Resources Engineering
(formerly School of Mining Engineering)
Professor of Mining Engineering (p/t)

1995 - present	Principal Consultant - B K Hebblewhite Consulting
2003-2014	University of New South Wales, School of Mining Engineering Head of School and Research Director, (Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006); Professor of Mining Engineering (from 2006))
2006 – 2009	Mining Education Australia (a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide) Executive Director (a concurrent appointment with UNSW above).
1995-2002	University of New South Wales, School of Mining Engineering Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC)
1983-1995	ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation. Director of METS Pty. Limited (1990-1992) and MineRisk Management Services Pty. Limited (1991 - 1995).
1981-1983	ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs.
1979-1981	ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods.
1977-1979	ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Project Engineer for roof control and numerical modelling stability investigations.
1974-1977	Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis).

SPECIALIST SKILLS & INTERESTS

- Mining geomechanics
- Mine design and planning
- Mining methods and practice
- Mine safety and training
- Mine system audits and risk assessments
- Mining education and training

KALF AND ASSOCIATES Pty Ltd
Hydrogeological, Numerical Modelling Specialists

Maxwell Project
Groundwater Assessment
In support of an EIS
KA Peer Review

Dr F. Kalf
B.Sc., M.App.Sc. Cert., Eng. Hyd., PhD
18 July 2019

Table of Contents

Background and Key Issues

This report is the Kalf and Associates Pty Ltd (KA) peer review commissioned by Malabar Coal Limited for the HydroSimulations (HS) groundwater assessment (July 2019) in support of an EIS. The peer review has been undertaken by Dr Frans Kalf (curriculum vitae provided in Appendix A) in accordance with the NSW Department of Planning and Environment's Peer Review Guideline (draft) (2019).

Dr Frans Kalf is suitably independent, and does not have any pecuniary interest in the project, has not worked for the proponent in the last two years, has not worked or collaborated with HydroSimulations (other than in an independent peer review capacity) or worked on the assessment of the impacts of a project that may result in material cumulative impacts with the Project.

Exploration of the proposed underground mining area within licence area EL 5460 commenced in the 1940's and was then explored further between 1978 to 1982 with a further program between 1998 and 2011. In total over 950 holes have been completed along with extensive 2D and 3D seismic survey.

The proposed Maxwell Underground Area (MUA) occupies the central part of EL5460 and lies between Saddlers Creek, that is situated along a flow path just north of the MUA northern boundary and a meander of the Hunter River that lies just south of the MUA southern boundary (HS 2019).

Since the presentation of the Preliminary Groundwater Assessment in support of the Gateway Application (HS 2018), significant data, information and numerical model scope has been incorporated into the current HS (2019) report. In addition a check list of IESC requirements has also been assessed by the HS (2019) report.

The geological profile in the region is comprised mainly of hardrock coal measures with minor colluvial and alluvial deposits along ephemeral Saddlers and Saltwater Creeks (MER 2003). Saltwater Creek, lies a few kilometres east of the MUA. Saltwater Creek downstream joins the Hunter River 2 to 3 kilometres southwest of the MUA.

Underground mining is proposed from four seams in the Wittingham Coal Measures.
It includes bord and pillar methods in the shallowest Whynot Seam and longwall extraction in the remaining deeper seams (Woodlands, Arrowfield, and Bowfield) proposed over a period of 26 years.

Numerical groundwater modelling has included several scenarios that include a null (no mining); approved baseline scenario and approved plus Project case. The water balance of the model is presented in Table 5-10 (HS 2019).

Mine inflow is predicted to peak in year 12 with flows of 2.9 ML/day. Thereafter the flow decreases to an average of 2.3 ML/day.

Drawdown of the watertable at the end of the mining simulation is depicted in Figure 70 and Figure 71 (HS 2019) with and without the Project while Figures 72 to 77 show the maximum predicted depressurisation in model layers. Up to 8m maximum drawdown in the Saddlers creek alluvium is predicted and 4m in the Saltwater Creek alluvium. No drawdown greater than 2m is predicted along the Hunter River alluvium. Depressurisation of less than 20m extends about 4.7 km from the edge of the proposed underground footprint.

The cumulative influence of mining has been simulated is shown in Figures 78 to 83. The largest cumulative depressurisation occurs in the deeper coal seams limited in the northerly and easterly directions by the outcrop of the coal seams.

The modelling results indicate there are no private bores accessing the alluvial aquifers with drawdowns predicted to exceed the 'minimal harm' required by the Aquifer Interference Policy (AIP) of less than 2m drawdown.
The modelling results also indicate there would be no significant influence on identified ecosystems.

During mining there would be some mixing between shallow and deeper groundwater but these changes are likely to be of no consequence.

Peer Review Assessment

Previous Studies and Reviews

Investigations of the groundwater and surface water system were conducted in detail by MER (1998, 2001, and 2003) and AGE (2012 and 2015). Previous investigations were for an open cut in EL5460. A number of other groundwater assessments and modelling have been conducted in the region. In addition there are also numerous other mines that are or have operated in the region. The current mining proposal, the subject of this assessment, lies in an area only permitted for underground operations.

Hydrogeological and Groundwater Modelling Conceptual Description

The hydrogeological and modelling conceptual description of the region described in HS (2019) is detailed and well presented. It covers geology and its structural aspects; monitoring network; groundwater flow systems; existing groundwater influence due to mining; the various mines in the region; alluvium, Permian Coal Measures; hydraulic properties; water quality; groundwater surface interaction; groundwater use and the manner in which the model was set up to simulate the sub-surface.

HS (2019) have used the USGS MODFLOW-USG (USG) code as opposed to the more well-known MODFLOW-SURFACT (MS) code for simulation. The USG code is considered suitable and provides some distinct advantages that include variable orientation of cells, pinch outs and other features. The model mesh and associated boundary conditions in layer 1 are shown in Figure 58 (HS 2019).

In order to determine the Height of Fracturing (HoF ***H***), which establishes the zone of potential partial and/or complete drainage HS (2019) has provided estimates determined by both the Tammetta and Ditton empirical equations described in detail in Appendix J.

The modelling conceptual description is considered to be suitable.

Model Simulation Methods

For the modelling review herein the available Modelling Guideline documents (NWC 2012, MDBC 2001) content have been considered.

Layering of the EIS Maxwell groundwater model domain is shown in Figures 57 and 58 (HS 2019) and comprises 24 layers representing the strata indicated in Table 5-1 (HS 2019).

These layers are considered suitable in differentiating the influence of various units in the geological profile.

Calibrated hydraulic conductivity values and storage are listed in Table 5-7 (HS 2019).

The boundaries chosen for the model area are suitable in order to not unduly influence the drawdown extent while including any features that could be potentially influenced by mining activity. General Head Boundaries (GHB's) have been set to allow natural groundwater flow through the region which is considered suitable. It should be noted that such GHB's are not related to or influenced by mine(s) drawdown. In addition 'no flow' boundaries have also been set where required.

Depiction of the various ephemeral and perennial stream channels have been modelled using the USG 'River' package with the ability to set stage such that the creeks act either as gaining or losing streams or as ephemeral drainage channels without leakage. Stream characteristics such as dimensions and connectivity (conductance), were also determined as part of the calibration according to the report. The use of the 'River' package in the USG code is considered suitable for the modelled area.

The model uses variable gross recharge as a percentage of rainfall and evapotranspiration as input and output respectively, which is suitable, rather than application of variable net recharge.

Mining has been simulated using the 'stacked drain' approach which is considered conservative as proven in a number of past simulations conducted by another experienced modelling practitioner. This methodology simulates progressive but bulk (block) removal of strata as mining progresses.

Model simulation methods are considered to be suitable.

Model Calibration

Steady-state simulation was used to set up initial conditions and was combined with transient runs in the HS model. Manual trial and error method followed by the Parameter Estimation (PEST) code was also used.

A scattered diagram is given in Figure 62 for the steady state calibration whilst Figure 65 presents the scatter diagram for the transient calibration. The ratio of root mean square (RMS) to total head change of the transient simulation compared to the measured data was found to be 6.09%. Significant head difference at two locations of 10m (DD1004, DD1015) has been attributed to possible dyke structures but these only influence local groundwater heads.

Water balance from model simulation for transient conditions is provided in Table 5-5 (HS 2019).

The model calibration is considered to be acceptable.

Model Prediction

Model predictions are presented in Section 6 (HS 2019) showing both drawdown and depressurisation extent. Specific results are as outlined above in the Background and Summary section. The predictions as presented in the HS (2019) report are considered to be plausible.

Sensitivity

Sensitivity analysis was conducted and is described in Section 7 (HS 2019) using uncertainty analysis. This included changing the magnitude of hydraulic parameters, drain conductance and rainfall recharge, boundary conditions (GHB) and the presence of dykes within the MUA. This analysis was also examined.

Groundwater Monitoring and Mitigation

Section 10 in the report outlines management mitigation and contingency measures that include grouting and cut-off measures; sourcing additional water; licence allocations and treatment of mine water for reuse. In addition the policy of “making good” by bore enhancement by deepening; new bore construction; and piping water from another source should be applied. The analysis of fracturing (Appendix J) has indicated that there could be fracturing at the surface in parts of the proposed mining area, in particular the deeper seams extraction causing collapse of the bord pillars. Hence it would be desirable to construct a number of shallow monitoring bores along Saddlers Creek alluvium to determine the extent of any drawdown influence created due to such surface fracturing and influence on stream flow.

It is understood that the existing East Void at the Maxwell Infrastructure site would be partially backfilled. The North, South and East Voids would all remain as groundwater sinks in perpetuity with no escape of surface water or groundwater into the surrounding environment.

Conclusions

This peer review has assessed the adequacy of the hydrogeological data and the numerical model for predicting the drawdown influences of the proposed project. The hydrogeological description, conceptualisation, model design, simulations and reporting is acceptable and suitable.

The predicted effects of subsidence and vertical fracturing in the profile are considered to require additional monitoring. In particular shallow borehole monitoring along Saddlers Creek should be conducted to determine the impact of any fracturing at the surface.

The model overall is considered to be “fit-for-purpose”.(Appendix A - Model Appraisal item 9.2)

The model outcomes should be reassessed and compared with measured responses after 3 years of mining.

References

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), 2012. *Drayton South Coal Project Groundwater Impact Assessment. Prepared for Anglo American Metallurgical Coal Pty Ltd. October 2012.*

Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), 2015. *Drayton South Coal Project EIS Groundwater Impact Assessment. May 2015.*

HydroSimulations (HS.), *2019. Maxwell Project. Groundwater Assessment – in support of an EIS. Malabar Coal Limited Report HS2018/44, March.*

National Water Commission (NWC), 2012. *Australian Groundwater Modelling Guidelines. Report prepared by Barnett, B., et. al. Waterlines Report Series No 82, June.*

Mackie Environmental Research (MER), 1998. *Groundwater and surface water pre-feasibility studies. Edderton resource block. Report prepared on behalf of Saddlers Creek Coal Project.*

Mackie Environmental Research (MER), 2001*. 2001 Groundwater data collation. Report prepared on behalf of Saddlers Creek Coal Project.*

Mackie Environmental Research (MER), 2003*. Saddlers Creek Coal Project 2003 Groundwater Data Collation. May 2003. Prepared for Anglo Coal.*

Murray Darling Basin Commission (MDBC), 2001. *Groundwater Flow Modelling Guideline. Report prepared by Middlemis, H., Merrick, N., and Ross, J., Jan.*

NSW Department of Planning and Environment, 2019. *Preparing a Peer Review Report – Guidance for State Significant Projects (Draft). June 2019).*

APPENDIX A
CURRICULUM VITAE

Dr Frans Kalf

B.Sc, M.App.Sc, PhD, Cert Eng Hyd.

Dr Kalf has more than 49 years' experience in hydrogeological investigations and flow and solute transport modelling. He has a Bachelors degree in geology, Master of Applied Science in hydrogeology, certificate in Engineering Hydrology and a PhD awarded by the School of Civil and Environmental Engineering, University of NSW specialising in numerical model simulation methods that included the development of variably saturated non-linear and non-Darcy finite element code.

He was awarded a Churchill Fellowship in 1975 to study groundwater-modelling techniques in USA, and Europe. In March 2010 he was recipient of a lifetime achievement award in hydrogeology by the International Association of Hydrogeologists.

During early years with the then Department of Water Resources he was involved as a hydrogeologist with groundwater investigations of the inland drainage systems including the Namoi, Lachlan and Murrumbidgee groundwater River systems including modelling of these systems. More recently he conducted a peer review of the salinity SEMMP model for the Murray Darling Basin Authority.

Dr Kalf specialises in hydrogeological impact assessments and is a recognised expert in model simulation of groundwater systems. He pioneered the development of finite element and finite difference models in Australia in the early 70's. He has conducted studies using these methods in numerous alluvial valley groundwater systems; open pit and underground stoping, and sub-level caving inflow and impact assessments at both coal and uranium mining sites; tailings storage seepage and contaminant transport; landfill, light hydrocarbon and dense chlorinated hydrocarbon aquifer contamination, water supply assessments; evaporation basin operation, including density dependent model analysis.

He was an expert witness at the successful Cadia Gold mine and Newcrest Ridgeway EIS inquiries. He completed hydrogeological impact studies and numerical modelling of impacts for the Newcrest-Cadia and Ridgeway gold mines in NSW. In association with the Water Research Laboratory Manly Vale (WRL) he was also project manager for the complete hydrogeological investigation of the Ridgeway project which including drilling supervision and pumping tests by WRL. He was also involved in the earlier Cowal Gold Mine hearing some years ago in association with Resource Strategies.

He has conducted hydrogeological investigations for a number of coalmines since 1980 in the Hunter Valley. During the late 90's he completed a number of reports for a coal company on the hydrogeology of the site and determining the storage and inflow characteristics of the Cumnock, Liddell and Hazeldene underground workings in response to Bowmans Creek flows.

He now conducts exclusively groundwater peer reviews of predominately coal mine projects that have included: Douglas 7 area; Metropolitan, BHP Illawarra; Ashton;

Moolarben; Carrington; Duralie, Tarrawonga, Wallarah 2, Stratford, Tongara (Qld), Wards Well (Qld), Rocky Hill, Watermark, Liddell, Cobbora, Nucoal, Narrabri Coal, Vickery Coal, Bengalla, Wambo, Wallarah, Watermark, HVO South, Rocky Hill, Caroona, Hume Coal, Wilpingjong, Bylong, Warkworth, Woronora, Springvale, Dendrobium, Mt Pleasant, Warkworth. He was also recently part of a panel of three experts (hydrogeological, geotechnical and surface water) conducting a Strategy investigation into longwall mining beneath a storage reservoir. Also reviewed were two sand mining, basalt and sandstone quarry modelling projects.

He has also reviewed in 2011/2012 the hydrogeology and modelling of three major coal seam gas extraction projects in the Surat/Bowen Basin in Queensland including an underground coal gasification project also in the Great Artesian Basin in Queensland.

He has also acted as specialist advisor for a number of major consulting groups in assessing the performance and calibration of flow and solute transport models.

Dr Kalf has extensive experience at the Ranger and Jabiluka Uranium sites. The Australian government, together with a number of other experts, commissioned him to carry out a critical hydrogeological review and contaminant modelling of the proposed Jabiluka uranium mine tailings disposal. This study was prepared for and in response to a report prepared by a UNESCO delegation that visited Australia in 1998. Subsequently it included simulation and risk analyses of the closure of the Jabiluka underground mine.

From 1999 to 2010 he was the groundwater and solute transport consultant at the RioTinto/ERA Ranger uranium site

Kalf and Associates have all of the major, internationally recognised, groundwater and solute transport packages available in the public domain including numerous analytical flow, solute transport and chemical codes. Some of the major numerical model codes include SEEP/W, CTRAN/W, SUTRA, FEMWATER and 3DFEMFAT and an advanced MODFLOW package (MODFLOW-SURFACT) for treating 3D variably saturated flow, with linear and non-linear adsorption, seepage faces and radioactive decay. This code can also simulate multi-species and multi-phase (including air flow) transport and chain decay sequences (daughter products) and compressibility effects. This code has been used in the USA at major nuclear repository sites and can also simulate underground mining operations.

Dr Kalf no longer carries out groundwater modelling assignments but only conducts peer review of groundwater investigations and modelling for government and private consultants.

FRANS ROBERT PETER KALF

dewatering/inflow analysis
site contamination assessment & remediation
hydrocarbon investigations and modelling
groundwater and solute transport modelling
hydrogeological mapping
water supply studies

EDUCATION

Bachelor of Science (Geology), University of New South Wales, 1968
Post Graduate Certificate, Engineering Hydrology, UNSW 1970.
Master of Applied Science (Hydrogeology), University of New South Wales, 1973
Doctor of Philosophy (School of Civil & Environmental Engineering), UNSW 1988

PROFESSIONAL HISTORY

1991 to present	Kalf & Associates Pty Limited, Hydrogeological, and Numerical Modelling Specialists, Principal,
1989 to 1991	AGC Woodward-Clyde Pty Limited, Principal,
1980 to 1989	Australian Groundwater Consultants Pty Limited, Director and Principal Hydrogeologist
1968 to 1979	Department of Water Resources, New South Wales, Hydrogeologist

REPRESENTATIVE EXPERIENCE

DEWATERING/INFLOW ANALYSIS

- Hydrogeological, inflow and dewatering analysis and simulation for the following coal and metalliferous mines:

  Howick Coal
  Saxonvale Coal Project,
  Muswellbrook No 2,
  Eraring Coal Project,
  Mt Arthur Coal Project,
  Oaklands Coal Basin
  Muswellbrook Open Cut
  Clarence Colliery
  Boggabri Coal Project
  Woodlawn mines,
  Savage River Project,
  Batesford Limestone Quarry,

Condor Oil Shale Project,
Whangaarei Oil Refinery,
Yandicoogina and Mt Weld.
Camalco site Weipa Qld.
Century Project
Mt Newman
Queensland Cement Ltd
North Ltd mine – Lake Cowal
ERA- Jabiluka
ERA-Ranger
Newcrest –Cadia
Newcrest - Ridgeway

SITE CONTAMINATION ASSESSMENT AND REMEDIATION

- Project Director/Manager for 3-year research project to determine the effect of coal mining on the groundwater resources of the Upper Hunter Valley for NSW Coal Association.

- Quality Assurance Manager, environmental site assessment of ICI Petrochemical Complex, Botany, NSW

- Technical Adviser and Expert Witness for Wakool Brine Disposal Litigation for the Department of Water Resources

- Development of groundwater flow model to simulate movement of leachate generation potential of spent, waste oil shale on surrounding groundwater system and determination of inflow and stability of pit infill for the Condor Oil Shale Project Dimensions of final pit size of 6km x 1.5km.

- Simulation studies of contamination migration using 2D model on movement of radium and sulphate and leakage from evaporation ponds and tailings disposal pit for the Narbarlek Uranium Project. Also recommended remediation options.

- Modelled movement of interstitial water from within tailings disposal area to assess long term rate of leakage from the tailings dam for the Mary Kathleen Uranium Project. Developed saturated/unsaturated mass transport model to study movement of contaminants. Conceptual design of groundwater/surface water model to determine effect of rehabilitation studies on creek flor salinity.

- Assessment of environmental effects of organic soil extraction on surface water and groundwater system - Sutton Forest. Liaison with Dept of Water Resources.

- Assessment of pollution hazards and formulation of guidelines and pollution boundary. Dubbo City Council.

- Assessment of contamination and modelling Castlereagh Disposal site Sydney.

- Hydrogeological EIS assessments and pollution potential -Landfill sites at Young,Albury,Wingacarribee

PEER REVIEWS
Peer reviews of predominately coal mine projects that have included : Douglas 7 area; Metropolitan, BHP Illawarra; Ashton; Moolarben; Carrington; Duralie, Tarrawonga, Wallarah 2, Stratford, Tongara (Qld), Wards Well (Qld), Rocky Hill, Watermark, Liddell, Cobbora, Nucoal, Narrabri Coal, Vickery Coal, Bengalla, Watermark, Wambo, HVO South, Rocky Hill, Caroona, Hume Coal, Wilpingjong, Bylong, Warkworth, Woronora, Springvale, Dendrobium, Mt Pleasant, Warkworth. He was also recently part of a panel of three experts (hydrogeological, geotechnical and surface water) conducting a Strategy investigation into longwall mining beneath a storage reservoir. Also reviewed were two sand mining, basalt and sandstone quarry modelling projects. Also reviewed were sand mining, basalt and sandstone quarry modelling projects.

In 2011/2012 the hydrogeology and modelling of three major coal seam gas extraction projects in the Surat/Bowen Basin in Queensland including an underground coal gasification project also in the Great Artesian Basin in Queensland.

HYDROCARBON INVESTIGATIONS AND MODELLING

- Fuel/aviation gasoline spill at major Australian Airport. Investigation included specialist coring methods, monitoring bore installation, fuel volume estimation, site history, GC/MS analysis, hydrocarbon mobility determination, simulation of free phase plume movement using specialist LNAPL multi-phase simulators. Assessment of remediation options. Investigation prepared for possible litigation proceedings.

- Review of remedial strategies for petro-chemical site Queensland storage facility. Analysis of bore hole fuel thickness, groundwater flow, aquifer tests, remediation effectiveness.

- Review of jet fuel recovery system and assessment of volume extraction and proposed extraction system. Joint User Hydrant Installation Sydney Airport.

- Model simulation of effectiveness of containment wall, petrochemical site New Zealand.

- Numerous assessments of petrol station sites

- Site investigation of contamination at major chlorinated hydrocarbon site including gas surveys, monitoring bore installation, quality assurance. ICI Botany.

- Conceptual model analysis of chlorinated hydrocarbon site from deep monitoring bores.

- Development of procedures and set up and QA modelling analysis of dissolved hydrocarbon plume using 3D groundwater and solute transport models.

- Coal seam gas modelling review at two major Great Artesian Basin projects.

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELLING

- Modelling long-term (1000 and 10,000 years) analysis of both flow and solute transport at the Ranger Uranium site for Rio Tinto/ERA to develop closure options for Pit No 1 and 3. This has included possible mining and closure impacts on the Magela Creek drainage system.

- Mining and closure option groundwater impacts for Jabiluka mine NT.

- Impact modelling studies for underground Newcrest gold mining project at Ridgeway NSW /assisting in the preparation of EIS and SEE documents. Engaged as expert witness to proposed commission of inquiry 2000 for all groundwater related matters.

- Analysis of long-term groundwater dispersal of contaminants from proposed Jabiluka mine tailings repositories. Report prepared for the Australian government through Supervising Scientist NT and Environment Australia in response to UNESCO delegation visit. Report used in Australian submission in successful meeting with UNESCO in Paris 1999 to allow continuation of project.

- Simulation and risk analysis of closure of the Jabiluka mine site.

- Impact modelling studies for Cadia Newcrest gold mining project NSW /assisting in the preparation of EIS and SEE documents. Expert witness at Commission of inquiry. Development application successful.

- Flow and solute transport modelling of proposed tailings dams and expert witness at North's Cowal Gold Project Commission of Inquiry. Development application successful.

- Khon-Chi-Mun Project Thailand 1997-1998 - Development of basin-wide model and local models to determine salinisation potential for rice irrigation areas at Nong Wai, Nong Bo, Rasi Salai, Nong Han, Khon Kaen in conjunction with UTS.

- Development of combined surface storage operation and groundwater model for dam storage risk analysis and leakage for the Maranoa River Dam Project for the Queensland Water Resources Commission. Dam overlies intake beds for Great Artesian Basin with a leakage of $10km^2$ and surface catchment area of $2,000km^2$. Project Manager of field testing program to assess permeability and distribution of permeable sedimentary strata underlying proposed dam site. Testing included falling head, packer and pump out tests.

- Development and application of groundwater flow and mass transport and surface water process model to determine outflow salinity from proposed major drainage network for the Berriquin Irrigation Area. Area covered over 3,200km^2 and supported irrigation of 1,325 properties.

- Development of quasi 3D model and extraction injection system for dewatering of proposed mine for the Oakland's Coal Basin.

- Workshop for the development of fully 3D model for simulating groundwater flow in the Murray Basin in conjunction with Australian Geological Survey Organisation (formerly BMR) hydrogeological staff.

- Development of groundwater flow pit salinity model to determine long term effects on filling of open mine voids for the Hunter Valley Research Project.

- Assessment of model developed for predicting discharge and recharge behaviour for the Great Artesian Basin of Australia.

- Project Manager for development of steady state and transient state model to simulate watertable response to irrigation and develop strategies for remedial damage of possible waterlogged areas of the Leichhardt Downs for the Queensland Water Resources Commission. Regional model covered irrigation area of 100km^2. Study included review of all available permeability data, development of field program including drilling and pump testing.

- Modelling of groundwater recharge plume from disposal of 3000m^3/day treated sewage effluent from infiltration lagoons.

- Development and application of TETFLOW variably saturated model and detailed seepage analysis of open pit coal mine high wall stability in Sudan.

- Analysis of seepage from tailings dam and effect of underdrainage in Cyprus.

- Seepage analysis through tailings dam to determine possible cyanide migration through groundwater system for the Boddington tailings dam.

- Assessment of groundwater flow data at Koongara Mine for simulation in the SWIFT 3D model for the waste disposal analog for the Atomic Energy Project for the United States Nuclear Regulatory Commission.

- Conceptual design of groundwater/surface water model to determine effect of rehabilitation studies on creek flow salinity.

- Modelling of groundwater recharge plume from disposal of 30,000m^3/day treated sewerage effluent from infiltration lagoons. Assessment of environmental effects of effluent on groundwater system.

- Modelling of solute transport from ten disposal sites - South East Regions Refuse Disposal Site, Victoria.

- Development of model study to determine infiltration effects through landfill and groundwater mounding. Assessment of potential contaminant movement and compliance with environmental buffer zone - Lucas Heights Sanitary Landfill.

- Review of modelling of saturated/unsaturated flow from proposed tailings area and solute transport - Mt Keith site, W.A.

- Modelling of flow and solute transport from Castlereagh disposal site, Sydney.

- Development of methodology to model optimum extraction of gas from landfill disposal sites, Werribee, Victoria.

- Groundwater saturated/unsaturated model to determine saline water seepage from proposed evaporation pond, Mallee Cliffs, N.S.W.

- Development of conceptual modelling of flow and transport at the ICI site, Sydney.

- Liddell Coal Hydrogeological Investigation, assessing storage and flow characteristics of the underground workings at Cumnock, Liddell and Hazeldene.

- Reviews for coal mine hydrogeology and groundwater impact modelling include: Moolarben, Douglas 7, Metropolitan; BHP Illawarra; Duralie, Ashton, Carrington, Tarrawonga coal projects.

HYDROGEOLOGICAL MAPPING

- Development of hydrogeological mapping techniques on INTERGRAPH CAD computer system.

- Project Director for compilation of national groundwater database assessment and preparation of five year forward investigation program.

- Project Director for completion of Ballarat 1:250,000 hydrogeological maps and portion of Murray Basin in New South Wales.

WATER SUPPLY STUDIES

- Hydrogeological assessments, numbering over 800, for siting of bores for groundwater extraction on rural properties in New South Wales and along major inland river systems.

- Investigation, design and construction supervision of bores and wells for town and mine water supplies including Parkes, Euabalong, Forbes, Bathurst and Scone.

- Mineral water supply investigations at Dubbo and several coastal towns in New South Wales, the Yulara Village in the Northern Territory and the Fiji coral coast.

- Design and construction of several irrigation bores on rural properties in New South Wales at Hillston, Wagga and alluvial valley s of the Lachlan, Murrumbidgee.

- Site manager for investigation of recharge system near Bourke, N.S.W.

- Investigation of lake developments in Cootamundra, Leeton

- Hydrogeological investigations in the Namoi, Lachlan and Murrumbidgee alluvial groundwater systems

OTHER ACTIVITIES

Senior Lecturer, UNSW Post Graduate Hydrogeology Course (1975-1987).
Lecturer in solute transport, UNSW, 1993,1995

AWARDS

1975 Churchill Fellowship to study groundwater modelling management techniques in USA, Canada and Europe.

2010 Lifetime Achievement Award - International Association of Hydrogeologists

APPENDIX B
MODEL APPRAISAL

First Page

	ISSUES	Not applicable or Unknown				Very Good	COMMENTS
1.0	**THE REPORT**						
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very good	
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes		
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very good	
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very good	
1.5	Are the model results of any practical use?			No	Maybe	Yes	
2.0	**DATA ANALYSIS**						
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very good	
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate		
2.3	Has all relevant potential recharge data been collected and analysed?		Missing	Deficient	Adequate		
2.4	Has all relevant potential discharge data been collected and analysed?		Missing	Deficient	Adequate		
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very good	
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes	
2.7	Have consistent data and standard elevation units been used?			No	Yes		
3.0	**CONCEPTUALISATION**						
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes	
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very good	
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very good	
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No		
4.0	**MODEL DESIGN**						
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes	
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very good	
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes	
5.0	**CALIBRATION**						
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very good	
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Sufficient	
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate		
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes	
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very good	
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very good	Performance criteria have been met
6.0	**VERIFICATION**						
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very good	Verification based on ongoing monitoring
6.2	Does the reserved dataset include		Unknown	No	Maybe	Yes	

	ISSUES	Not applicable or Unknown				Very Good	COMMENTS
	stresses consistent with the prediction scenarios?						
6.3	Are there good reasons for an unsatisfactory verification?		Missing	Deficient	Adequate	Very good	
7.0	**PREDICTION**						
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very good	Climate change variability low and high rainfall
7.2	Have multiple scenarios been run for operational management alternatives?		No	Deficient	Adequate	Very good	
7.3	Is the time period for prediction comparable with the duration of the calibration period?		Missing	Greater than	Similar to	Less than	
7.4	Are the model predictions plausible?			No	Maybe	Yes	
8.0	**SENSITIVITY ANALYSIS**						
8.1	Is the sensitivity analysis sufficiently intensive for key parameters/		Missing	Deficient	Adequate	Yes	
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Yes	
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate		
9.0	**UNCERTAINTY ANALYSIS**						
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Adequate	Yes	
9.2	**Is the model 'fit-for-purpose'?**			No		Yes	