Ditton Geotechnical Services Pty Ltd
80 Roslyn Avenue Charlestown NSW 2290
PO Box 5100 Kahibah NSW 2290

DgS

Ditton Geotechnical Services

Narrabri Coal Operations Pty Ltd

Mine Subsidence Assessment for Pillar Reduction Panels CF201-CF205 (A - J) and Longwalls LW203 to LW205 at the Narrabri Underground Mine

DGS Report No. NAR-004/8

Date: 12 September 2021

ABN 43 113 858 910 ACN 124 206 962
Ph: 02 4920 9798 Mob: 0413 094074
Email: steve.dgs@westnet.com.au

12 September 2021

David Ellwood
Narrabri Coal Operations Pty Ltd
10 Kurrajong Creek Road
Baan Baa NSW 2390

DGS Report No. NAR-004/8

Dear David,

Subject: Mine Subsidence Assessment for the Proposed Pillar Reduction Panels CF201-CF205 (A - J) and Longwalls LW203 to LW205 at the Narrabri Underground Mine

This report has been prepared for submission with an Extraction Plan Application for the above mine panels.

Please contact the undersigned if you have any questions regarding this matter.

For and on behalf of
Ditton Geotechnical Services Pty Ltd

Steven Ditton
Principal Engineer & Director
BE(Civil/Hons) C.P.Eng(Civil), M.I.E.(Aust); MAusIMM
NPER 342140 RPEQ

Disclaimer

This report has been prepared for Narrabri Coal Operations Pty Ltd (NCOPL) as described in the proposal provided to them by Ditton Geotechnical Services Pty Ltd (DgS). The report has been prepared for the sole use of NCOPL for the specific development described in the report. This report shall only be presented in full and may not be used to support objectives other than those stated in the report without permission from DgS.

The services performed and advice given by DgS was based on available site information and in accordance with relevant technical standards and guidelines, the Australian Institution of Engineers Code of Ethics and Guidelines on Professional Conduct (November, 2019) and Work Health and Safety Standards.

Executive Summary

Introduction

This report presents a mine subsidence assessment in support of an Extraction Plan for the Proposed Pillar Reduction Panels CF201 - CF205 (Panels A - J) and Longwalls LW203 to 205.

The Mine is currently seeking approval for an Extraction Plan under the State Significant Development (SSD) Approval 08_0144 Conditions of Consent (Mod 7).

Mining Geometry

The proposed mining geometry would be as follows:

- The lower 4.6 m of the Hoskissons Seam (HS2) will be extracted with a nominal extraction height of approximately 4.3 m.

- Five pillar reduction panels CF201 to 205 will be orientated east-west and have two sub-panels each (A/B to I/J) in the Lower Hoskissons Seam.

- The pillar reduction panels will have cover depths ranging from 177 m to 212 m and widths ranging from 154 m to 280 m. The completed panels will have ‘critical’ to ‘supercritical’ W/H ratios of 0.80 to 1.39. The panel lengths will range from 155 m to 348 m.

- The sub-panels (production panels) will be developed on a grid of 30.5 m square pillars (solid) in the upper 3.2 m of the lower Hoskissons Seam (HS2). Second workings will ‘pocket’ every second row of pillars and increase the extraction ratio from 31% to 66%.

- The floor would then be brushed to 1.1 m depth on retreat to give a total roadway height of 4.3 m.

- The 6.5 m wide by 3.2 m high roadway and 1.1 m deep floor brushing with a width of 5.5 m effectively decreases the pillar height from 4.3 to 4.13 m.

- The longwall void widths for LW 203 to 205 range from 399.7 m to 402.9 m. The longwall panels will be 3.8 km long.

- The cover depth over the longwalls would range from 180 m to 300 m.

- The W/H for the proposed mining layout would range from 1.33 to 2.18, indicating *supercritical* subsidence behaviour.

- A five-heading mains panel is proposed between CF201-205 and LW203. The distance between the pillar reduction and longwall panels will be 266 m.

- Gate roads would be approximately 3.7 m high and 5.4 m wide. Main headings roadways would be approximately 5.4 m or 6.0 m wide.

- The proposed chain pillar geometries would be ‘squat’ with width to height ratios[1] (w/h) ranging from 7.9 to 12.7.

- The end-of-panel barriers will be 97 m to 105 m wide (solid) and designed to protect the main headings from abutment loading. The finishing ends of LW203 and 204 will be wider due to geological structure.

Surface Features

The land above the Extraction Plan Area (EP Area) is exclusively owned by Narrabri Coal Operations Pty Ltd (NCOPL). The Pilliga East State Forest covers the areas to the west.

The land within the EP Area has historically been used for livestock grazing, occasional cereal crop and an olive grove. The western area is heavily vegetated with woodland areas consisting of dry sclerophyll forest.

Topographic relief above the proposed mining area ranges from 279 m Australian Height Datum (AHD) to 340 m AHD. The surface terrain is generally flat with slopes ranging from 1^o to 5^o. Slopes increase to 10^o to 35^o in several rocky ‘hillock’ locations, including the ephemeral creeks and tributaries (or gullies), which drain the EP Area towards the north-east. The hillocks have Pilliga Sandstone exposures with local topographic relief ranging between 10 m and 15 m above the surrounding plains.

The existing surface and subsurface features within the zone of expected subsidence include the following:

- Semi-cleared, agricultural land (predominately used for grazing cattle).
- Gently undulating terrain with ephemeral watercourses associated with Kurrajong Creek and its tributaries.
- Riparian vegetation areas along the creeks.
- Steep rocky slopes up to 15 m high.
- Sub-surface groundwater aquifers at depths ranging from 5 m to 50 m (typically of poor quality).
- Two Aboriginal cultural heritage sites (‘Claremont’ and ‘Mayfield’ grinding grooves in sandstone outcrops) above CF201 (Panel B) and LW205. The sites have ‘low’ and ‘moderate’ scientific significance respectively according to **Whincop Archaeology, 2020**.

1 It is considered standard practice to adopt lowercase “w” and “h” when referring to chair pillars and uppercase “W” and “H” when referring to the longwall panels.

- One NCOPL-owned dwelling is partly constructed over chain pillars between LW204 and 205. An olive tree orchard is located south of the residence and was in poor condition at the time of inspection in 2019.
- One NCOPL-owned dwelling and machinery sheds exist above the proposed LW203 and 204 (‘Westhaven’).
- There are two NCOPL-owned residences located inside the EP Area but outside the AoD to the east of the proposed longwall and pillar reduction panels (‘Mayfield’).
- Twenty farm dams for livestock watering (D40-D50, D61-D69).
- Soil conservation (contour) banks and property fencing (post and wire).
- Two NCOPL-owned groundwater supply bores (stock and domestic) and five monitoring bores.

The surface conditions, land use and underground mining geometry in the EP Area will be similar to the completed LW101 to LW109.

Subsidence Effect Predictions

The subsidence predictions for the EP Area have been based on several empirical and calibrated analytical models of overburden and chain pillar behaviour developed in New South Wales Coalfields.

The predicted values may be occasionally exceeded (up to 5% of the time) due to discontinuous strata behaviour associated with near surface cracking, joint displacement, geological features (e.g. faults) and/or rapid changes in topography (creek beds).

The key outcomes of the results of the study are presented below:

Pillar Reduction Panels (CF201 - CF205)

- The maximum subsidence estimates due to remnant pillar crush within the panel limits after mining is completed ranges from 0.50 to 1.77 m.
- The timing of subsidence is difficult to predict and may not occur at all or years after mining is completed.
- Maximum production panel subsidence ranges from 1.42 to 1.77 m (34%h to 43%h).
- Maximum gateroad access pillar subsidence ranges from 0.50 m to 0.73 m (12%h to 18%h).
- Maximum panel tilt ranges from 14 mm/m to 36 mm/m.
- Maximum panel concave curvatures range from 0.7 per kilometre (km^{-1}) to 3.3 km^{-1} (radii of curvature 1.4 km to 0.3 km).

- Maximum panel convex curvatures range from 0.7 km^{-1} to 3.1 km^{-1} (radii of curvature 1.4 km to 0.32 km).

- Maximum panel compressive strains range from 7 mm/m to 31 mm/m.

- Maximum panel tensile strains range from 7 mm/m to 33 mm/m.

Longwall Panels (LW203 - 205)

- First maximum panel subsidence ranges from 2.54 m to 2.75 m (59%T to 64%T).

- Final maximum panel subsidence ranges from 2.65 to 2.80 m (62%T to 65%T).

- Final maximum chain pillar subsidence ranges from 0.25 m to 0.55 m (6%T to 13%T).

- Final maximum panel tilt ranges from 24 mm/m to 54 mm/m.

- Final maximum panel concave curvatures range from 0.9 per kilometre (km^{-1}) to 3.5 km^{-1} (radii of curvature 1.1 km to 0.29 km).

- Final maximum panel convex curvatures range from 0.9 km^{-1} to 3.1 km^{-1} (radii of curvature 1.1 km to 0.32 km).

- Final maximum panel compressive strains range from 9 mm/m to 35 mm/m.

- Final maximum panel tensile strains range from 9 mm/m to 31 mm/m.

Predicted Impacts - Natural Features

The results of this study indicate that the surface deformations due to mining are likely to cause the following impacts in the EP Area:

- Surface cracking and shearing within tensile and compressive strain zones. Typical crack widths in relatively ‘flat’ terrain (slopes <18°) are estimated to range from 130 mm to 320 mm, with occasional (<5% probability) cracks up to approximately 260 mm in sand or loam and approximately 640 mm in clay or rock.

- Light Detection and Ranging (LiDAR) surveys and ground truthing inspections indicate that there are approximately 0.875 ha of steep rocky slope (slope gradients 18° to 28° with heights ranging from 6 m to 12 m) within the EP Area.

- It is estimated that the steep slope would be subsided by up to 2.8 m with tilts of up to 15 mm/m and tensile/compressive strains of +/- 15 mm/m due to the transitional subsidence ‘wave’ development with a final compressive strain of 15 mm/m. Subsidence is expected to cause cracking with widths ranging from 385 mm to 770 mm, depths from 3 m to 15 m and lengths from 30 m to 100 m based on observations at Narrabri. The impact to the steep slope in the EP Area is estimated to range from 0.1% to 0.2%. The impacts are likely to be within the expected performance measure of 7%.

- General and localised slope instability (soil and rock slides) along the steep rocky slopes are considered ‘very unlikely’ to develop due to the predicted cracking and tilting.

- Surface gradients are likely to increase or decrease by up to 2.5% (+/- 1.5o) along creeks.

- Connective cracking is estimated to range from 99 m to 240 m above the proposed panels (i.e. 52% to 87% of the cover depth; 0.42 to 0.62 times the effective panel width or 37 to 56 times the effective mining heights of 4.13 m to 4.3 m).

- Direct hydraulic connection to the mine workings due to sub-surface fracturing is estimated to encroach within 27 m to 70 m depth below the surface, with the closest value occurring above the proposed LW203. It should be noted that the database of sub-surface fracturing (used for empirical modelling) contains four out of fifteen supercritical cases where seam to surface connective cracking developed and when A/H exceeded 0.8. The predicted heights of cracking for these cases were also estimated to extend to within 20 m of the surface.

- It is assessed that the A/H = 0.8 line represents the point at which there is a risk (25% probability) that the predicted connective fracture zone could interact with the surface cracking zone but also depends on the near-surface geology (see below).

- However, investigation boreholes and site observations indicate that the near-surface strata above the eastern panels (LW203 to 205) consist of weathered, thinly bedded sandstone and siltstone associated with the Purlawaugh Formation and Garrawilla Volcanics. These units are likely to shear into thinner units and ‘unlikely’ to develop deep vertical cracks that extend into the A-Zone (below 20 m depth).

- Another consideration is that Pilliga Sandstone outcrops may develop deeper cracking than the more thinly bedded Purlawaugh formation sequences. As the Pilliga Sandstone units exist only above LW204 and 205 where cover depth is > 220 m, it is considered ‘unlikely’ that A-Zone cracking would encroach within 20 m of the surface and cause a surface to seam connection in these areas.

- Based on a depth of surface cracking of 15 m and possible connectivity between the A- and B-Zones, it is assessed that there is a < 25% probability (‘unlikely’ to ‘possible’) that connective cracking could impact the surface for the proposed longwalls. It is recommended that NCOPL should continue to monitor changes in ventilation during extraction and repair surface cracks as soon as practicable.

- The Geology and Geometry Pi-Term Models predict ‘discontinuous’, or B-Zone, sub-surface fracturing is likely to interact with surface cracks (D-Zones) where cover depths are < 300 m above the 306 m wide panels and < 375 m above the wider longwalls. Creek flows could be temporarily re-routed into open cracks to below-surface pathways and re-surface downstream of the mining extraction limits in the mining area.

- Discontinuous fracturing would normally be expected to occur above the proposed mining area, causing an increase in rock mass storage capacity and horizontal permeability, without direct hydraulic connection to the workings. Groundwater levels would be lowered in the medium to long terms as a consequence of these impacts.

- A total of 7 potential ponding locations have been identified for the EP Area. The majority of potential ponding areas already exist and will probably develop laterally between 50 m to 500 m away from the watercourses. The maximum changes in pond depths are estimated to range from -0.19 m to 1.3 m[2].

- There are two farm dams (D67, 68) above CF203 (F) that may be inundated by post-mining ponding.

Predicted Impacts - Built Features

- There are twenty farm dams for livestock watering (D40-D50, D61-D69) that have been assessed in the EP Area. Eighteen dams are located within the 20 mm subsidence contour from the proposed panels and estimated to be impacted by tensile and compressive strains ranging from 3 mm/m to 15 mm/m.

- Several farm dams have already been subsided by LW101 to 109 but have not required remedial works to be undertaken. Notwithstanding, non-engineered farm dams and water storages are susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the EP Area dams (before remediation is required) will depend upon the dam wall materials, construction techniques, and foundation type. NCOPL would repair and/or re-establish the dam's function and pre-mining storage capacity (if necessary).

- The expected phases of tensile and compressive strain development may result in breaching of up to 18 dam walls or water storage areas. Loss or increase of storage areas may also occur due to the predicted tilting. Maximum tensile crack widths across dam wall or storage areas are estimated to range between 30 mm and 400 mm.

- There is one untenanted single storey weatherboard clad and timber framed residence on timber stump footings (12 m x 8.5 m) and two galvanised iron clad timber post sheds that are owned by NCOPL above LW204 ('Westhaven'). It is likely that the structure would be subsided between 1.7 m to 2.0 m by LW204 with tilts ranging from 7 mm/m to 22 mm/m, hogging and sagging curvatures of 0.2 to 0.5 per kilometre (km^{-1}) (radii of 5 kilometres [km] to 2 km) and tensile and compressive strains 2 to 5 mm/m. The building is likely to be 'moderately' to 'significantly' impacted by tilt and 'slightly' to 'moderately' impacted by curvatures and strains in accordance with **AS2870, 2011**.

- The 'Un-named' residence was recently purchased by NOCPL and is an untenanted and incomplete dwelling that is located between the LW204 and 205 chain pillars. Built features include an incomplete two-storey circular steel-framed residence with a diameter

[2] Positive values represent an increase in pond depth.

of approximately 15 m, supported on a central column. There are no other fixed features except for an olive grove to the south of the residence in a 'poor' condition (likely drought and pest animal affected). It is likely that the structure would be subsided 0.45 m by LW204 to 205 with tilts ranging from 5 mm/m to 15 mm/m, hogging curvature of 0.5 km^{-1} (radius of 2 km) and tensile strains of up to 10 mm/m. The building is likely to be 'moderately' to 'significantly' impacted by mine subsidence effects in accordance with **AS2870, 2011**.

- Domestic power and telecommunications lines to any of the existing houses are mainly pole suspended with some underground sections extending from the access roads. Management plans would require the services to be made safe during mining and repaired after mining impact (if necessary).

- Post and wire fences around the dams and along property boundaries could also be damaged and require repairs after mining.

- The unsealed gravel access roads (Red Hills, Scratch Roads) and tracks are likely to be damaged by cracking and shearing/heaving in the tensile and compressive strain zones, respectively, above the EP Area. Maximum tensile crack widths across or along roads are estimated to range between 50 mm and 420 mm. Surface 'steps' or humps due to compressive shear failures are estimated to range between 30 mm and 320 mm. Some sections of road may require re-grading or drainage remediation works after subsidence development.

- Some sections of road may also require re-grading or drainage remediation works after subsidence development. Warning signs should be erected outside the limits of mining impact.

- There are two State Survey marks that are likely to be subsided 0.01 m and 1.52 m by the EP Area panels. State Survey Marks affected by mine subsidence would be required to be relocated after mining is completed.

Predicted Impacts - Aboriginal Heritage

- There are two grinding groove sites ('Claremont GG1' and 'Mayfield GG1') located above proposed CF201(B) and LW205 respectively. These sites are located on sandstone bedrock or possibly 'loose' boulders. The quality of the grinding grooves varies from 'fair' to 'excellent'.

- The results of the impact assessment indicate that grinding grooves in bedrock are 'possible to likely' to be impacted while grinding grooves on loose boulders are 'possible to unlikely' to be impacted. Partially buried boulders may crack due to confinement of the boulder and could result in significant strain transfer into the boulder/slab.

- Impacts on isolated and scattered surface artefacts are not anticipated.

- It is assessed that the Mayfield GG1 grinding grooves are likely to be subject to tensile strains in excess of 3 mm/m and are therefore ‘likely’ to be impacted. The Claremont GG1 grinding groove site is ‘very unlikely’ to be affected by the predicted tensile strains < 1 mm/m due to the proposed mining restriction zone above CF201 (B).

- Impact management strategies for Aboriginal cultural heritage sites are presented in the Extraction Plan Heritage Management Plan (EP HMP) and have been developed in consultation with the Registered Aboriginal Parties. The Narrabri Mine Aboriginal Cultural Heritage Management Plan (ACHMP) is also applicable for the ongoing management of Aboriginal cultural values for the Narrabri Mine, including the EP Area.

Impact Management and Monitoring Strategies

A suggested program for monitoring subsidence, tilt and strain at the relevant locations has been provided for the purpose of reviewing, implementing and describing in future Extraction Plans. The use of remote LiDAR is considered an appropriate subsidence monitoring technique *in lieu* of some of the traditional ground-based subsidence survey lines.

It is recommended that the groundwater response to mining above LW109 to 111 continue to be periodically reviewed to confirm the assessed fracture zones for LW203 to 205 are still reasonable. Consideration of further borehole extensometer and Vibrating Wire Piezometer installations are suggested, as well as inspections and monitoring of underground workings and groundwater make, which should also be recorded and plotted against rainfall deficit data (when available).

Mine ventilation flows should also be monitored for possible short-circuiting detection through surface cracks.

Adaptive Management Strategies

Adaptive management strategies for the EP Area would include:

- Ongoing review of predicted subsidence impacts against observed impacts.

- Conservative longwall setback distances would be adopted in lieu of uncertain monitoring data outcomes.

- Ongoing crack mapping to improve predictions for cracking areas above future longwalls.

Table of Contents

List of Figures

List of Tables

GLOSSARY

Angle of Draw	The angle from the vertical of the line drawn between the limits of extraction at seam level to the 20 millimetre (mm) subsidence contour at the surface (it can range from 15° to 45° from the sides or ends of an extracted longwall block). The 20 mm subsidence contour is an industry defined limit and represents the practical measurable limit of subsidence due to mining. Surface impacts due to horizontal strain usually only occur within an angle of draw of 26.5°.
Anomalous Subsidence	Normally refers to unexpected subsidence effects and is usually caused by latent geological conditions (joints, faults, dykes). Measured subsidence effects are significantly higher than expected or opposite in sign (i.e. an outlier or compressive instead of tensile strain) compared to previously observed movements above longwall panels of similar geometry (cover depth, panel width and mining height).
Chain Pillar	The pillar(s) of coal left between adjacent longwall panels. This forms a barrier that allows the goaf to be sealed off and facilitates tailgate roof stability.
Compressive Strain	A decrease in the distance between two points on the surface. This can cause shear cracking or steps at the surface if > 3 millimetres per metre (mm/m). Compressive strains are usually associated with concave curvatures near the middle of the panels or where valley closure effects develop.
Confidence Limits	A term used to define the level of confidence in a predicted subsidence effect and based on a database of previously measured values.
Conventional Subsidence	Normal subsidence behaviour above a longwall panel due to the sagging of the overburden and compression of chain pillars.
Cover Depth	The depth from the surface to the mine workings roof.
Credible Worst-Case Values	The Credible Worst-Case (CWC) prediction for the subsidence effect. normally based on the Upper 95% Confidence Limit line determined from measured data and the line of 'best fit' used to calculate the mean value. The CWC values are typically 1.5 to 2 times the mean values.
Critical Width Extraction	A *critical* width extraction is one that is sufficiently wide compared to its mining depth and represents the transition from *sub-critical* to *super-critical* behaviour. Extraction widths narrower than critical extractions are termed *sub-critical*, and those larger are *super-critical*.

The *critical* width at Narrabri may range between 0.7 and 1.2 times the cover depth and is a function of the overburden geology.

Curvature The rate of change of tilt between three points (A, B and C), measured at set distances apart (usually 10 m). The curvature is plotted at the middle point or point B and is usually concave in the middle of the panel (sag) and convex near the panel edges (hog).

i.e. Curvature = (Tilt between points A and B - Tilt between points B and C)/(average distance between points A to B and B to C) and usually expressed in 1/km.

Radius of curvature is the reciprocal of the curvature is usually measured in km (i.e. Radius = 1/Curvature). The curvature is a measure of surface ‘bending’ and is usually associated with cracking.

Development Height The height at which the first workings (i.e. the main headings and gateroads) are driven, usually equal to or less than the extraction height on the longwall face.

Extraction Height The height at which the seam is mined or extracted across a longwall face by the longwall shearer.

Factor of Safety The ratio between the strength of a structure divided by the load applied to the structure. Commonly used to design underground coal mine pillars.

First Workings The tunnels or roadways driven by a continuous mining machine to provide access to the longwall panels in a mine (i.e. main headings and gateroads). The roof of the roadways is generally supported by high strength steel rock bolts encapsulated in chemical resin. Subsidence above first workings pillars and roadways is generally < 20 mm.

Goaf The extracted area that the immediate roof or overburden collapses into, following the extraction of the coal. The overburden above the ‘goaf’ sags, resulting in a subsidence 'trough' at the surface.

Horizontal Displacement Horizontal displacement of a point after subsidence has occurred above an underground mining area within the angle of draw. It can be predicted by multiplying the tilt by a factor derived for the near surface lithology at a site (e.g. a factor of 10 to 20 is normally applied for the New South Wales (NSW) Coalfields depending on cover depth).

Far-Field Displacement Horizontal displacement outside of the angle of draw, associated with movement are due to horizontal stress relief above an extracted panel of coal. Far-field horizontal displacements of up to 20 mm (measurable limit) can occur for distances of 2 to 4 times the cover depth. The strains due to these movements are usually < 1 mm/m and do not cause damage directly. Such displacements have been associated with differential movement between bridge abutments and dam walls in the Southern Coalfield, but generally have not caused significant damage.

Horizontal Strain The change in horizontal distance between two points at the surface after mining, divided by the pre-mining distance between the points.

i.e. Strain = ([post-mining distance between A and B] – [pre-mining distance between A and B])/(pre-mining distance between A and B) and is usually expressed in mm/m.

Strain can be estimated by multiplying the curvature by a factor derived for the near surface lithology at a site (e.g. a factor of 10 to 20 is normally applied in the NSW Coalfields, depending on cover depth).

Inbye An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the coal face than the reference location.

Inflexion Point The point above a subsided area where tensile strain changes to compressive strain along the deflected surface. It is also the point where maximum tilt occurs above an extracted longwall panel or where convex (hogging) curvature changes to concave (sagging) curvature.

Longitudinal Subsidence Profile Subsidence measured (or predicted) along a longwall panel or centre line.

Longwall The method of extracting a wide block or panel of coal on retreat (which will be 409 metre (m) wide for the Project, including the gateroads along each side) using a coal shearer and armoured face conveyor. Hydraulic shields provide roof support across the face and protect the shearer and mine workers.

The longwall equipment is installed along the full width of the block in an 8 to 10 m wide installation road at the starting end of the block before retreating back to the finishing end. The shields are progressively advanced across the full width of the face, as shearing continues in a sequence of backwards and forwards motions across the face.

	Depending on the geological and longwall equipment conditions, the longwall retreats at a typical rate of about 50 metres per week (m/week).
Maingate	Refers to the tunnels or roadways down the side of a longwall block which provides access for mine operations personnel, power, materials and clean air to the longwall face. It is usually located on the side of the longwall panel adjacent to unmined panels or solid coal.
Mean Values	The average value of a given subsidence effect predicted using a line of 'best fit' through a set of measured data points. The effects are usually plotted against key independent variables (e.g. panel width, cover depth or extraction height). The mean values are typically two-thirds to one-half of the credible worst-case values.
Non-conventional Subsidence	Refers to subsidence effects usually caused by mine subsidence interaction with surface topography (steep slope movements) and valleys (closure and uplift).
Outbye	An underground coal mining term used to describe the relative position of some feature or location in the mine that is closer to the mine entry point than the reference location.
Outlier	A data point well outside the rest of the observations, representing an anomaly (e.g. a measurement related to a structural discontinuity or fault in the overburden that causes a compressive strain concentration at the surface in an otherwise tensile strain field).
Panel Width	The width of an extracted area between chain pillars (i.e. void width).
Subsidence	The difference between the pre-mining surface level and the post-mining surface level after it has settled above an underground mining area.
Sub-critical Extraction	The excavation width less than the critical width ($W/H < 0.7$) and results in the lowest possible subsidence between chain pillars for the mining height. The overburden naturally spans or ‘arches’ between the chain pillars and the chain pillar compression represents a significant proportion of the total subsidence.
Super-critical Extraction	The excavation width is greater than the critical width ($W/H > 1.2$) and results in the maximum possible subsidence that can occur for the extraction height. The overburden is no longer spanning between the chain pillars.
Subsidence Effects	The measurable surface movement parameters associated with mine subsidence (i.e. subsidence, tilt, curvature, horizontal strain and displacement, valley closure and upsidence or uplift).

Subsidence Impact The observable affects to natural and built features that are caused by the subsidence effects (i.e. cracking, shearing, erosion, sedimentation, ponding rock falls, vegetation die-back).

Subsidence Control Reducing the impact of subsidence on a feature by modifying the mining layout and set back distances from the feature (normally applied to sensitive natural features that cannot be protected by mitigation or amelioration works).

Subsidence Management Plan Refers to a management plan used to define monitoring and mitigation techniques to manage mine subsidence effects and impacts for a given feature to the satisfaction of the Secretary of the Department of Planning. The management plans are prepared in consultation with relevant stakeholders and prior to the commencement of longwall extraction that would potentially lead to subsidence of the feature.

Subsidence Mitigation/ Amelioration Modifying or reducing the impact of subsidence on a feature, so that the impact is within safe, serviceable and repairable limits (normally applied to moderately sensitive man-made features that can tolerate a certain amount of subsidence).

Subsidence Reduction Potential Refers to the potential reduction in subsidence due to massive strata in the overburden being able to either ‘bridge’ across an extracted panel or have a greater bulking volume when it collapses into the panel void. The term was defined in an **ACARP, 2003** study into this phenomenon which is common in NSW Coalfields.

Tailgate Refers to the tunnels or roadways down the side of a longwall block which provides a ventilation pathway for bad or dusty air away from the longwall face. It is usually located on the side of the longwall panel adjacent to extracted panels or goaf.

Tensile Strain An increase in the distance between two points on the surface. This is likely to cause cracking at the surface if > 2 mm/m. Tensile strains are usually associated with convex (hogging) curvatures near the sides (or ends) of the panels.

Tilt The rate of change of subsidence between two points (A and B), measured at set distances apart (usually 10 m). Tilt is plotted at the mid-point between the points and is a measure of the amount of differential subsidence.

i.e. Tilt = (subsidence at point A - subsidence at point B)/(distance between the points) and is usually expressed in mm/m.

Transverse Subsidence Profile Subsidence measured (or predicted) across a longwall panel or cross line.

Valley Closure The inward (or outward) movement of valley ridge crests due to subsidence trough deformations or changes to horizontal stress fields associated with longwall mining. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and are usually visually imperceptible.

Valley Uplift The phenomenon of upward movements along the valley floors due to **Valley Closure** and buckling of sedimentary rock units. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and may cause surface cracking in exposed bedrock on the floor of the valley (or gorge).

1.0 Introduction

This report presents a mine subsidence assessment in support of an Extraction Plan (EP) for the proposed Narrabri Underground Mine Pillar Reduction Panels CF201 - CF205 and Longwalls LW203 to 205 at the Narrabri Mine, Narrabri.

The Narrabri Mine is located approximately 25 kilometres (km) south-east of Narrabri and approximately 60 km north-west of Gunnedah within the Narrabri Shire Council Local Government Area of New South Wales (NSW). The Narrabri Mine is operated by Narrabri Coal Operations Pty Ltd (NCOPL).

The Mine is currently seeking approval for an Extraction Plan under the State Significant Development (SSD) Approval 08_0144 Conditions of Consent (Mod 7) for Pillar Reduction Panels CF201-CF205 and LW203 to 205.

The report has assessed the potential impacts to natural, man-made and aboriginal heritage features within the zones of influence of the proposed mining areas based on predictions of conventional and non-conventional subsidence. The predictions have included a review of subsidence effects measured above LW101 to 109 at Narrabri Mine and the subsidence assessments provided in the Project Approval assessment reports (**DgS, 2020** and **DgS, 2021**)

The definitions of 'conventional' and 'non-conventional' subsidence are provided in the Glossary (after **Table of Contents**).

2.0 Scope of Work

The scope of work for the assessment has included the following:

- Description of the pre-mining condition of natural surface features and existing development in the EP Area.
- Overview of local geomorphology and geology (including landscape development, surface soils, rock mass lithology and structure).
- Development of predicted mine subsidence effect profiles and contours for the proposed mining areas, based on measured subsidence data for LW101 to 109.
- Predicted surface impacts (cracking, heaving, ponding, gradient changes, erosion / sedimentation).
- Predicted heights of sub-surface cracking above the proposed mining areas (connective and discontinuous).
- Natural feature impact assessments (e.g. topography, creek beds/banks, steep slopes).
- Built feature impact assessments (e.g. dwellings, buildings, farm dams, powerlines, roads, fences, contour banks and other rural infrastructure).
- Aboriginal heritage impact assessment (e.g. grinding grooves).
- Water supply and groundwater monitoring bore impact assessment (e.g. casing and screens).
- Discussion of impact remediation and adaptive management strategies to limit long-term degradation of the environment (e.g. the ongoing use of subsidence monitoring data at the Narrabri Mine to inform predictions and management measures for the EP Area).

The proposed mine plan and existing surface features are shown with cover depth contours in **Figures 1a** to **1b** with surface level and pre-mining gradient contours with surface features shown in **Figures 2a** to **2g**.

3.0 Methodology Overview

Conventional and non-conventional subsidence effects[3] have been assessed for the proposed mine workings in the EP Area.

Conventional subsidence effect predictions of maximum subsidence, tilt, curvature, strain and horizontal displacement have been estimated based on measured local data from the existing Narrabri Mine as well as the empirical models developed under Australian Coal Association Research Program (ACARP) funding (**ACARP, 2003**) and subsequently modified by DgS.

A 3-D influence function model, known as the 'Surface Deformation Prediction System' (**SDPS®**) was then calibrated to the empirical model profiles to derive the final subsidence contours for the EP Area. The subsidence effect contours associated with the subsidence contours were determined with the calculus module in Surfer12® (data contouring software).

Overall, the predictions have been prepared using the same methodology that was used to assess the previous EP for the existing Narrabri Mine LW107 to 110 (**DgS, 2017**) at the Narrabri Mine.

Subsidence monitoring data from the first six 306 m wide panels with single chain pillar rows (LW101 to 106) and three 409 m wide panels (LW107, 108A and 109) with double chain pillar rows have been reviewed. The prediction model is only modified if the measured subsidence effects exceed the predictions by more than 15% at over 5% of surveyed locations.

The maximum subsidence measured above the extracted longwalls has ranged from 53 percent (%) to 65% of the average extraction height (T) and were within the predicted values. The same methodology has been used for the proposed longwalls in the EP.

The subsidence results to-date have not identified any 'anomalous' subsidence behaviour due to the massive conglomerate or volcanic sills/dykes present in the overburden. Minor 'non-conventional' subsidence due to valley closure and uplift were observed across a Pine Creek Tributary 1 due to LW101 to 104 (which were within Stage 2 Environmental Assessment predictions [**DgS, 2009**]).

Non-conventional subsidence predictions are also included in this assessment for Kurrajong Tributary No. 1 and Kurrajong Creek.

Assessment of surface cracking, ponding and sub-surface cracking heights have been based on (i) previously observed impacts above the existing Narrabri Mine LW101 to 109, and (ii) empirical databases developed for other coalfields in NSW with similar mining geometries and geological conditions.

Sub-surface cracking height predictions have been based on reference to **Ditton and Merrick, 2014, Tammetta, 2013** and **Forster, 1995** plus existing borehole extensometer and Vibrating Wire Piezometric (VWP) data for the existing Narrabri Mine LW101 to 109.

Further details for each prediction models are given in the relevant sections that follow.

[3] see Glossary for subsidence parameter definitions.

4.0 Mining Geometry

The EP includes the approved pillar reduction panels CF201 to CF205 where the previously approved LW201 and 202 were located, and LW203 to 205 (**Figures 1a** and **1b**). The five pillar reduction panels will be extracted from north to south and the three longwalls will be extracted from south to north. The overall panel extraction sequence will occur from east to west.

4.1 Pillar Reduction Panels (CF201 to CF205)

Details regarding the proposed mining geometry for the pillar reduction panels are provided below:

- Five pillar reduction panels CF201 to 205 will be orientated east-west and have two sub-panels each (A/B to I/J) in the Lower Hoskisson Seam (see **Figure 1b**).

- The Lower Hoskissons (HS2) Seam thickness ranges from 4.3 m to 6.0 m (see **Figure 3b**).

- The panels will have cover depths ranging from 177 m to 212 m.

- The panels will have widths ranging from 154 m to 280 m and 'critical' to 'supercritical' W/H ratios of 0.80 to 1.39. The panel lengths will range from 155 m to 348 m.

- The sub-panels (production panels) will be developed on a grid of 30.5 m square pillars (solid) in the upper 3.2 m of the lower Hoskissons Seam (HS2). Second workings will 'pocket' every second row of pillars and increase the extraction ratio from 31% to 66%.

- The floor would then be brushed to 1.1 m depth on retreat to give a total roadway height of 4.3 m.

- The 6.5 m wide by 3.2 m high roadway and 1.1 m deep floor brushing with a width of 5.5 m effectively decreases the pillar height from 4.3 to 4.13 m.

- The development roadways will be 6.5 m wide with the floor brushing only 5.5 m wide.

- The north-south orientated, intra-panel (gate road) pillars will separate the production panels and include two outside rows (29.5 to 38.5 m wide x 35.1 m to 39.8 m long) and two inside rows (25 m wide x 29 m to 59 m long). Some of the two inside row pillars may also be extracted on retreat (depending on conditions) to leave residual pillar widths of 13 m.

- The inter-panel (barrier) pillars between the CF Panels will be orientated east-west and 34 m to 64 m wide after second workings. The barrier pillars will have 29.75 m deep stub headings extracted on a centre spacing of 37 m, with one lift left and right on retreat.

A summary of the pillar reduction panel geometry is presented in **Table 1A**.

Table 1A – Summary of the Proposed Pillar Reduction Panel Geometry

Panel & Sub-Panel No.	Mean Cover Depth H (m)	Panel Width W (2nd workings limits) (m)	W/H	Production Panel Pillar Geometry (solid) (m)	Mining Height T (m)	Roadway Width r (m)	E-W Inter-panel (Barrier) Pillar Mean Width x Length (m)	N-S Inter-panel (Gateroad) Outer Row Pillar Mean Width x Length (m)
	Proposed Pillar Reduction Mining Geometry (66% extraction ratio)							
CF201-A	185	272	1.47	30.5 x 30.5 (every 2nd pillar row extracted)	3.2 m (development) + 1.1 m (floor brush)	6.5 (development) 5.5 (floor brush)	56 x 348.5	*34.3 x 39.8*
CF201-B	210	273	1.30		4.3 (as above)	as above	50 x 348	*38.5 x 39.2*
CF202-C	182	235	1.29		4.3 (as above)	as above	64 x 339	*31.8 x 35.1*
CF202-D	199	199	1.00		4.3 (as above)	as above	64 x 339	*30.6 x 38.2*
CF203-E	186	199	1.07		4.3 (as above)	as above	41 x 339	*30.7 x 35.2*
CF203-F	194	236	1.22		4.3 (as above)	as above	41 x 339	*30.4 x 38.3*
CF204-G	194	236	1.22		4.3 (as above)	as above	34 x 339	*29.7 x 35.1*
CF204-H	194	199	1.03		4.3 (as above)	as above	34 x 339	*30.6 x 37.9*
CF205-I	188	188	1.00		4.3 (as above)	as above	28 x 54	*32.6 x 35.3*
CF205-J	191	287	1.50		4.3 (as above)	as above	19 x 223	*29.5 x 38.2*

italics - inter panel pillars include two outside rows of pillars (mean dimensions indicated in table) and two inside rows (25 m wide x 29 m to 59 m long with the pillar width reduced to ~13 m after 2nd workings).

4.2 Longwalls (LW203 to 205)

Details regarding the proposed mining geometry for the longwalls are provided below:

- The lower Hoskissons (HS2) Seam will be extracted with a nominal extraction height of approximately 4.3 m (**Figure 3a**).

- The longwall void widths for LW 203 to 205 range from 399.7 m to 402.9 m. The longwall panels will be 3.8 km long.

- The cover depth over the proposed longwalls will range from 185 m to 300 m.

- The W/H for the proposed mining layout would range from 1.33 to 2.18, indicating *supercritical* subsidence behaviour (*critical* W/H occurs between W/H of 0.7 and 1.2 and *supercritical* is when W/H > 1.2 - see **Glossary**).

- Three heading gate-roads are planned to be formed between LW203 and 205 with two rows of diamond-shaped chain pillars that would have minimum ‘solid’ widths ranging from 29 m to 47 m and lengths of 144 m.

- A five-heading mains panel is proposed between CF201-205 and LW203. The distance between the pillar reduction and longwall panels will be 266 m.

- Gate roads would be approximately 3.7 m high and 5.4 m wide. Main headings roadways would be approximately 5.4 m or 6.0 m wide.

- The proposed chain pillar geometries would be ‘squat’ with width to height ratios[4] (w/h) ranging from 7.9 to 12.7.

- The end-of-panel barriers will be 97 m to 105 m wide (solid) and designed to protect the main headings from abutment loading. The finishing ends of LW203 and 204 will be wider due to geological structure.

A summary of the longwall panel geometry is presented in **Table 1B**.

Table 1B – Summary of the Proposed Longwall Panel Geometry

LW #	XL #	Panel Width W (m)	Cover Depth H (m)	Extraction Height T (m)	W/H Ratio	Chain Pillar Width* w_{cp} (m)	Panel Criticality
203	6	402.9	214	4.3	1.88	2 x 29.4	Super-critical
	7	402.9	207	4.3	1.95	2 x 29.4	Super-critical
204	6	402.4	238	4.3	1.69	2 x 32.6	Super-critical
	7	402.4	244	4.3	1.65	2 x 32.6	Super-critical
205	6	399.7	263	4.3	1.52	2 x 34.6	Super-critical
	7	399.7	280	4.3	1.43	2 x 34.6	Super-critical

*** -** chain pillar height will be 3.7 m.

4 It is considered standard practice to adopt lowercase “w” and “h” when referring to chair pillars and uppercase “W” and “H” when referring to the longwall panels.

5.0 Regional Geology

The 1:100,000 geological map for this region indicates that the Narrabri Mine is situated within the Mullaley Sub-basin, which is in the northern part of the Permian-Triassic Gunnedah Basin. The rock mass bedding dips towards the west at less than 3 degrees (°).

The geological map indicates that the elevated ridges associated with the western portion of the Mining Lease Area are located within the Pilliga Sandstone, a formation within the Jurassic Surat Basin. The lithology of this unit consists of fine to coarse grained quarzitic sandstone. The eastern surface areas are located in the Purlawaugh Formation and Garrawilla Volcanics, which form the lower stratigraphy of the Surat Basin. Quaternary Alluvium exists along the creeks and watercourses to the east.

The Purlawaugh Formation comprises thinly bedded, fine grained lithic sandstone, siltstone and minor claystone. The Garrawilla Volcanics unconformably overlie the Triassic Napperby Formation and consist of basaltic flows with minor mudstone. The Napperby Formation consists of quartz-lithic sandstone over laminite and siltstone. A dolerite sill intrusion exists in the lower units of the Napperby Formation.

Underlying the above units are conglomerate and sandstone beds of the Triassic Digby Formation and the Permian Black Jack Group, which include the Hoskissons Seam and Arkarula Sandstone.

There are several north-west and north-east trending normal and reverse faults, which have throws ranging from 1 m to 5 m within the Hoskissons Seam; see **Figure 2a**.

A typical stratigraphy of the EP Area is provided in **Figure 3c**. The location of the section is shown in **Figure 4a**.

Further details of the overburden stratigraphy are presented in **Section 7.1**.

6.0 Surface Features

6.1 General

The EP Area includes exclusively land owned by NCOPL. The Pilliga East State Forest exists outside of the EP Area to the west. The land holdings have historically been used for livestock grazing and some cereal crop farming and occasional orchard farming (e.g. olive groves).

Topographic relief above the proposed mining area ranges from 279 m Australian Height Datum (AHD) to 340 m AHD. The surface terrain is generally flat with slopes ranging from 1^o to 5^o. Slopes increase to 10^o to 35^o in several rocky 'hillock' locations, including the ephemeral creeks and tributaries (or gullies), which drain the EP Area towards the north-east. The hillocks have Pilliga Sandstone exposures with local topographic relief ranging between 10 m and 15 m above the surrounding plains.

Silty sand and sandy clay surface soils to 4 m depth are present in the EP Area and are mildly to highly erosive/dispersive. The clayey soils are associated with the outcropping Garrawilla Volcanics and overlying Purlawaugh formation (**2rog Consulting, 2020**).

Sandy alluvial deposits exist along the creek channels with no rock exposures present. The channels are typically incised with steep to very steep banks between 0.5 m and 3.5 m high.

Vegetation includes several stands of native vegetation across the agricultural land use areas and riparian zones along ephemeral creeks.

The existing surface and subsurface features within the zone of expected subsidence include the following:

- Semi-cleared, agricultural land (predominately used for grazing cattle).
- Gently undulating terrain with ephemeral watercourses associated with Kurrajong Creek and its tributaries.
- Riparian vegetation areas along the creeks.
- Steep rocky slopes up to 15 m high.
- Sub-surface groundwater aquifers at depths ranging from 5 m to 50 m (typically of poor quality) (**Aquaterra, 2009**).
- Two Aboriginal cultural heritage sites ('Claremont' and 'Mayfield' grinding grooves in sandstone outcrops) above CF201 (Panel B) and LW205. The sites have 'low' and 'moderate' scientific significance respectively according to **Whincop Archaeology, 2020**.
- One NCOPL-owned dwelling is partly constructed over chain pillars between LW204 and 205. An olive tree orchard is located south of the residence and was in poor condition at the time of inspection in 2019.
- One NCOPL-owned dwelling and machinery sheds exist above the proposed LW203 and 204 ('Westhaven').
- There are two NCOPL-owned residences located inside the EP Area but outside the AoD to the east of the proposed longwall and pillar reduction panels ('Mayfield').

- Twenty farm dams for livestock watering (D40-D50, D61-D69).
- Soil conservation (contour) banks and property fencing (post and wire).
- Two NCOPL-owned groundwater supply bores (stock and domestic) and five monitoring bores.

The above features are presented in **Figures 2a** to **2f**.

6.2 Existing Subsidence Monitoring Lines

Aerial Laser Scanning (LiDAR) data has been collected over the approved longwall extraction area and used to identify the extent of steep slopes and cliffs (**Figure 2e**) and subsidence contours for all of the extracted longwalls to-date (**Figures 4b and 4c**). The measured subsidence contours were derived from the December 2009 and December 2020 LiDAR levels.

Subsidence monitoring lines have been installed above LW101 to 109 and have been used to calibrate the subsidence model for the EP Area. The survey line locations and extracted longwall areas (goafs) are also shown in **Figures 4b** and **4c**.

The subsidence lines consist of star pickets driven to refusal at 10 m spacing. The star pickets are surveyed using total station with static point control before and after mining effects. The surveys to-date indicate systematic errors between surveys ranging from -20 millimetres (mm) to +45 mm, which are mainly due to seasonal clayey soil moisture changes.

Ground-truthing of the LiDAR-based subsidence contours was conducted from the survey lines.

6.3 Definitions of Steep Rocky Slopes and Steep Slopes

Based on precedents applied in other NSW coal fields and slope descriptions in the Landslide Risk Management Guidelines prepared by the Australian Geomechanics Society (AGS) (**AGS, 2007**) the following definition of steep slopes has been adopted in this report:

"Steep Rocky Slope" - An area of land having a natural gradient ranging between 18^o and 35^o with bedrock exposures.

“Steep Slope” - An area of land having a natural gradient ranging between 18^o and 35^o with no bedrock outcrops.

There are a few steep rocky slopes and steep slopes within the 20 mm AoD from available LiDAR data (gridded to 1 m square elements) and ground truthed by a principal geotechnical engineer (**Figure 2c**). The identification, location and likely impact on the above features due to mine subsidence are discussed in the following sections.

6.4 Ground Truthing

A Principal Geotechnical Engineer inspected the EP Area (including Kurrajong Creek Tributary 1) on 3 December 2019. The features were mapped using a Suunto Compass & Clinometer and photographed with a digital camera.

LiDAR of the ground surface in the EP Area was then processed to develop a 3-D digital model of the landscape on a 1 m square grid. The location of slopes (slope and height) were ground-truthed with the mapping information and are clearly definable where slope gradients exceed 18^{o} (**Figure 2e**).

Photographs of typical surface features are presented after the text in this report.

6.5 Steep Rocky Slope Details

The south-western area of LW204 and 205 is overlain by a broad ridge 'hillocks' with several steep rocky slopes (18^{o} to 35^{o}) and exposures of Pilliga Sandstone. The strata bedding generally dips towards the south-west to west at less than 5^{o}.

By definition, there is one steep rocky slope (S12) within the EP Area above LW204 (**Figures 2c/2e**). The steep rocky slopes details are summarised in **Table 2**.

Table 2 - Steep Slopes in the EP Area

Feature No.	Easting (MGA)	Northing (MGA)	Crest RL (AHD)	LW	Slope Height Z (m)	Crest Length L (m)	Slope Width B (m)	Slope Area (ha)	Slope Gradient Z/B (o)	Aspect (Dip Direction)
S12	774598	6617576	334	204	6 - 12	377	23	0.875	23 - 28	SE-S-E

6.6 Creek Banks

Based on **Figure 2e**, there are steep to very steep incised slopes along the ephemeral watercourses in the EP Area. Kurrajong Creek No. 1 Tributary has 1 m to 3.5 m high banks that extend for 20 m to 120 m (see photos in **Appendix A**).

7.0 Sub-Surface Conditions

7.1 Stratigraphy

Reference to the borehole logs in the EP Area indicates the following stratigraphic profile:

- Pilliga Sandstone - medium cross bedded, fine to coarse grained, quartz sandstone, yellow grey, to depths ranging from 5 m to 15 m and outcropping in the western areas, overlying

- Purlawaugh Formation - interbedded sandstone and siltstone (approximately 50:50), fine to medium grained, lithic, light grey to grey, rocky outcrops to depths ranging from 76 m to 102 m over the western area only, overlying

- Garrawilla Volcanics - weathered basalt, claystone, sandstone and minor coal, orange grey to blue-green, to depths ranging from 48 m to 120 m, overlying

- Napperby Formation - interbedded sandstone and siltstone (approximately 50:50) with an intrusive dolerite sill, overlying

- Digby Conglomerate, grey-brown to depths ranging from 112 m to 294 m, overlying

- Black Jack Group, which consists of lithic sandstone, siltstone, claystone and coal with minor tuff. It is up to 70 m thick in the western part of the EP Area but is less than 40 m thick in the east due to the low angle unconformity with the overlying Digby Formations. In the eastern part of the EP Area, the unconformity truncates the Hoskissons Seam at a depth of approximately 130 m to 160 m. In the west, there is up to 20 m of Black Jack Group above the Hoskissons Seam, overlying

- Black Jack Group - Hoskissons Seam, bright and dull components with several stony bands, 2.5 m to 13 m thick, overlying

- Black Jack Group - Arkarula Formation comprising lithic sandstone.

A typical section from east to west across the EP Area is shown in **Figure 3c**. The location of the section is shown in **Figure 4a**.

Previous reviews of available borehole data suggested there may be potential subsidence reducing units in the overburden (i.e. Digby Conglomerate, intrusive dolerite sill in the Napperby Formation and basalt lava flows of the Garrawilla Volcanics).

Subsidence monitoring data, however, indicates that none of the massive strata units have reduced subsidence to-date. Subsequent predictions of maximum subsidence above the longwalls have therefore assumed the overburden would have ‘Low’ Subsidence Reduction Potential (SRP).

7.2 Immediate Mine Working Conditions

The proposed longwalls will extract the lower 4.3 m of the 4.5 to 9.5 m thick Hoskissons Seam. The seam sub-crops to the east at approximately 130 m AHD. The seam comprises low to moderate strength coal with an UCS range of 20 MPa to 40 MPa and minor carbonaceous siltstone / mudstone bands.

The immediate roof of the proposed development roads would consist of 0.2 m to 5.2 m of upper seam coal (HS1), which has similar strength coal but a higher proportion of low strength carbonaceous siltstone/mudstone (35% to 40% of roof section thickness) than the lower HS2 coal.

The Hoskisson's Seam is overlain initially by siltstone and sandstone laminite with minor mudstone with a UCS range of 33 MPa to 36 MPa. The conglomerate of the Digby Formation is greater than 30 m or so above the seam in the Mining Lease Area and has a UCS range from 21 MPa to 42 MPa.

The floor of the development roadways would consist of moderate strength, carbonaceous siltstone / mudstone and sandstone with a UCS range from 30 MPa to 45 MPa and low slaking potential.

It is assessed in **Section 9.3** that the immediate roof and floor strata conditions are within the range of the empirical database cases and may therefore be used to estimate the chain pillar subsidence reliably for the EP Area. However, in regard to the mining height of 4.3 m, it is possible in small areas that the coal roof could prematurely cave ahead of the longwall shield supports, resulting in an effective increase in mining height (and subsidence).

The regular occurrence of this type of caving may explain the 3.5 % ~ 7% increase in subsidence above LW101 to 108A to-date, based on the original single panel subsidence predictions of 58%T to 60%T that were made in the Stage 2 Environmental Assessment (**DgS, 2009**).

This would suggest an average increase in mining height of ~0.15 m to 0.3 m (i.e. an effective T of 4.45 m to 4.6 m). As discussed in **Section 9.2**, the subsidence model has been re-adjusted to allow for the observed subsidence increases to-date by adopting a single panel subsidence of 60% to 62%T.

7.3 Sub-Surface Extensometers and Vibrating Wire Piezometer

Several borehole extensometers (one or two/borehole) have been installed from the surface to monitor caving development above the starting position for LW101 to 106. The boreholes were drilled in rows at distances of 15 m to 18 m outbye of the longwall starting positions (**Figure 4d**).

The extensometer anchors were installed between 12 m and 25 m above the mine workings roof. Vertical displacement of the anchors was measured every 10 minutes with a data logger during longwall retreat. The magnitude of anchor displacement was used to infer the continuous fracture zone above the longwalls.

A borehole extensometer and VWP were installed ~300 m from the start of LW108A above the centreline on 15/2/18. The instruments were undermined in late October 2018 and provide post-mining sub-surface dilation, vertical strain and groundwater depressurisation data for fracture zone analysis for future longwalls (see **Section 10.3** for details).

8.0 Subsidence Predictions for Pillar Reduction Panels

8.1 General

The predicted worst-case or maximum subsidence above the proposed pillar reduction panels CF201 - CF205 (A - J) has been based on observed trough subsidence above Newcastle Coalfield bord and pillar panels with extraction ratios ranging from 40% to 70%.

The prediction of maximum subsidence over bord and pillar (first workings only) and pillar reduction (2^{nd} workings) panels with ‘moderate’ extraction ratios of 40% to 70% is generally difficult in Australia because survey data for collapsed cases is scarce. This has usually resulted in the need to use high extraction ratio pillar reduction panels and longwall data (extraction ratios > 85%) and adjusting the mining height for the extraction ratios to make subsidence predictions instead.

A previous subsidence study of the Newcastle CBD crush events by **Hawkins and Ramage, 2004** noted that the measured subsidence was significantly less than maximum subsidence values predicted using the longwall and total pillar reduction curve presented in **Holla, 1987** and also after adjusting for the effective mining height (which is equal to the true mining height multiplied by the panel extraction ratio); see **Figure 5a**.

The reason for the above discrepancy is considered to be caused by the fundamental differences in subsidence development mechanics between longwalls and bord and pillar or moderate pillar reduction panel workings. The former mining method results in the development of a much thicker rubble than the latter and is due to the large differences in roof span left between solid pillars or ribs in the panels after mining. The presence of remnant pillars in pillar reduction panels also reduces subsidence.

The collapsed rubble in both cases would probably be subject to the same stress and have similar stiffness properties (i.e. the strains under load would be the same), however, the rubble thickness differences would result in a proportionally greater seam roof convergence and surface subsidence to develop above a longwall. A schematic diagram, which demonstrates these fundamental differences in subsidence mechanics, is presented in **Figure 5b**.

The figure indicates that the subsidence for a longwall panel is likely to be derived from a rubble thickness that ranged from 4 to 6 times the seam thickness. However, a bord and pillar or moderate pillar reduction panel that crushes with extraction ratios of 40% to 70% would usually have lower maximum caving heights due to the reduced spans between standing pillars across the panel.

If a longwall or total extraction database is referred to, the predicted outcomes usually indicate a maximum subsidence of 0.5 to 0.65 times the effective mining height (i.e. actual mining height x pillar extraction ratio (e) above a *super-critical* [5] panel geometry). The measured subsidence above the super-critical pillar panel crushes in the Newcastle CBD have only ranged between 0.17 and 0.45 times the effective mining height; see **Figure 5c**.

It is assessed from **Figure 5c** that the maximum subsidence above partial bord and pillar panels with w/h values > 3 are likely to range between 0.35 and 0.45 times the effective mining height (h' = true mining height x extraction ratio) or 0.4h' +/- 0.05h'; see **Figure 5d**.

The predicted v. measured ranges of maximum subsidence (S_{max}) in the old mine workings are shown in **Table 3**.

Table 3 - Predicted v. Measured Subsidence for AAC & W&BI/Ferndale Mine Workings

Mine Workings	Cover Depth H (m)	Mining Height, h (m)	Extraction Ratio e (%)	Effective Mining Height h' = h.e (m)	Measured Subsidence S_{max} (m)	Predicted S_{max} 0.4h' +/- 0.05h' (mean)
New Winning	115 - 110	5.5	39	2.15	0.825 - 0.775	0.75 - 0.97 (0.86)
	77	2.5	39	0.975	*0.30*	0.34 - 0.44 (0.39)
W&BI	60	4.8	57	2.74	1.2	0.96 - 1.23 (1.10)

(brackets) - mean predictions; *italics* - measured subsidence estimated indirectly from building damage reports (**To, 1987**).

8.2 Maximum Predicted Panel Subsidence

For the proposed pillar reduction panels CF201 - CF205 at Narrabri, the maximum subsidence estimates due to remnant pillar crush within the panel limits after mining is completed is summarised in **Table 4**. The lower and upper bound limit ranges for the production panels assume an extraction ratio of 66% with a final effective pillar height of 4.13 m.

Table 4 - Predicted Maximum Subsidence for Pillar Reduction Panels CF201 - 205 (A-J)

Prediction Limit Case	Panel W/H	Mining Height h (m)	Extraction Ratio e (%)	Effective Mining Height* h' (m)	Subsidence Factor a = S_{max}/h'e	Predicted S_{max} (m)
Production Panels						
Lower Bound	0.77 - 1.48	4.3	66	4.13	0.45	1.22
Upper Bound	0.77 - 1.48	4.3	66	4.13	0.65	1.77
Gateroad Access Panels						
Lower Bound	N/A	4.3	35	4.13	0.35	0.50
Upper Bound	N/A	4.3	35	4.13	0.45	0.65

* - Effective mining height h' = (3.2 x 6.5 + 1.1 x 5.5)/6.5 = 4.13 m.

[5] Supercritical panels occur when the mined panel is wider than it is deep (W/H > 1.2 to 1.4), and usually results in complete failure of the overburden and maximum subsidence for a given mining height.

The upper and lower bound subsidence for the production panels ranges from 1.22 m to 1.77 m (0.30h to 0.43h) and from 0.50 m to 0.65 m for the Gateroad Access Panels (0.12h to 0.16h).

The potential for pillar crush to occur is discussed in **Section 8.3**.

8.3 Pillar Stability Assessment

8.3.1 General

The maximum subsidence above the proposed pillar reduction panels would depend on the stability of the remnant pillars after mining is completed. The stability of the pillars has been assessed based on consideration of the following key factors usually associated with the behaviour of pillar-roof-floor strata systems:

- Panel geometry (i.e. width, cover depth and mining height) and mining method.
- Pillar stress (σ_{pillar}) and strength (S_p).
- Pillar Factor of Safety (S_p/σ_{pillar}).
- Pillar width/height ratio (w/h).
- Bearing capacity of immediate roof and floor strata.

The probability of instability for the pillars within bord and pillar panels beneath the site have been assessed based on published cases in the Newcastle, Australian and South African Coalfields; refer to **UNSW, 1998** for data base and stability assessment methodology details.

The empirical pillar strength formulae currently used in the Australian coal industry is based on a non-linear power law, which assumes that for an FoS of 1, the pillar panel would have a Probability of Failure of 50%. The database includes ‘failed’ and ‘unfailed’ pillar panels from the South African and Australian Coal industries and is plotted in terms of pillar strength v. pillar load in **Figure 5e**.

The pillars within critical to supercritical panels were considered to be subject to the weight of the full column of rock above the pillars and half the surrounding bords. This is known in the industry as ‘full tributary area’ (FTA) loading conditions as shown in **Figure 5f**.

In **Figure 5e**, several FoS lines have been drawn through the database of 175 cases, 35% of which represent pillar panel failures. The panel failures occurred between FoS values of 0.74 and 1.66 and there is a mix of failed and unfailed cases between FoS values of 1.0 and 1.3.

It should be noted that one Australian pillar failure case in the data base was purposely subject to additional loading by progressively extracting the coal pillars beside it in order to instigate failure in the subject pillar. The additional loading is termed ‘abutment’ loading and its magnitude depends on the type and width of second workings or extracted coal or adjacent goaf development. The deflection of the overburden due to loss of pillar support in the goaf is likely to result in additional load (abutment loading) to develop on the standing pillars, as shown in **Figure 5g**. The magnitude of the stress acting on the pillars would be dependent on the cover depth, direction of loading and width of the second workings area or goaf.

The pillar width/height ratio is also a very important factor that indicates the post-yield behaviour of the pillars when they are overloaded. The w/h of the pillars in the database ranges from 0.87 to 12, with the failed 'slender' pillar panels having a w/h range between 0.87 and 5.0 plus the abutment loaded 'squat' pillar case, which had w/h of 8.16.

Pillars with w/h ratios < 3 are considered most likely to 'strain-soften' and result in rapid failure and pillar runs, whereas w/h ratios > 5 are more likely to fail slowly or squeeze, yield and then 'strain-harden'.

The two types of post-yielding behaviour have been discussed in **ACARP, 2005** and demonstrated in **Figure 5h** for pillar w/h ratios between 1 and 10. Several other studies by **Das, 1986** and **Zipf, 1999** demonstrate similar 'strain-softening behaviour of 'slender' pillars with width to height ratios < 4 insitu or < 8 in the laboratory; see **Figure 5i**. Zipf applied the w/h ratio formulae derived to determine the rate of softening or the residual modulus of the slender and squat pillars.

The above w/h ratio ranges, however, should be used as a guide only, as all pillar sizes are susceptible to 'weak' interface contacts or mid-angled structure that allow loss of confinement under load, and therefore, have the potential to modify strength and post-yield performance. There are numerous cases of pillar strength data base 'anomalies' that are caused by very low strength clay-rich beds in either the roof, floor and within the pillar.

The load acting on the pillars can also modify post-yield behaviour. A case in the US with severely overstressed pillars that would be considered 'squat' (w/h ratios of 8), resulted in sudden and complete pillar failure over a large area between two longwall goaves. A response that would normally be attributed to 'slender' pillar behaviour (**Heasley, 2008**).

8.3.2 Pillar Strength Formulae

The **UNSW, 1998** strength formula adopted in this study for square-shaped 'slender' pillars with width (w) and height (h) and a w/h < 5 is:

$S_p = 8.6\ (w\sin\theta)^{0.51}/h^{0.86}$ and θ = angle between adjacent pillar rib sides (e.g. $\theta = 90^o$ for square-shaped pillars);

The formula caters for rectangular pillars by modifying the pillar width to w_{eff} as follows:

- For pillars with w/h < 3, the length (l) of the pillar does not influence pillar strength and $w_{eff} = w\sin\theta$
- For pillars with w/h > 6 then the length of the pillar effectively increases the strength of a square pillar to $w_{eff} = w\sin\theta\ [2l/(w+l)]$
- For pillars with w/h between 3 and 6, the $w_{eff} = w[2l/(w+l)]^{(w/h-3)/3}$

A separate formula applies to 'squat' pillars with w/h > 5 as follows:

$S_p = 27.63\Theta^{0.51}(0.29((w/5h)^{2.5} - 1) + 1)/(w^{0.22}h^{0.11})$ (MPa)

where Θ = a dimensionless ‘aspect ratio’ factor or w/h ratio in this case.

8.3.3 Pillar Load Formulae

The average pillar stress (σ) for each panel was firstly considered to be due to the weight of the full column of rock above the pillars and half the surrounding bords.

σ_{FTA} = pillar load/pillar solid area = P/wl

where

P = full tributary area load of column of rock with a height, H, density, ρ, above each pillar with width, w, length, l and bord width, r;

$= (l+ r)(w + r).\rho.g.H$;

For long-term stability assessment purposes, it is considered reasonable to assume that the gateroad access and barrier pillars could also be subject to a side-on abutment load as defined in **ACARP, 1998**. Underground stress and surface subsidence monitoring around super-critical width longwall panels in the Newcastle Coalfield indicates that the additional load due to the crushing of adjacent pillars may be estimated based on an abutment angle of 21^o.

It should be noted however, that the abutment angle is known to decrease with depth as greater load is shared by adjacent goaf (if present) or increase over 21^o if strong spanning strata units are present. Values ranging between 6^o and 21^o have been measured indirectly from stress cells for deeper mines (>250 m of cover) with angles up to 90^o assumed where caving is virtually absent between extracted pillars (e.g. Teralba Conglomerate immediately above the Great Northern Seam in the Newcastle Coalfield has been observed to span over 50 m in pillar reduction panels).

Based on the borehole data for Narrabri, it is assessed that a 15 m thick bed of medium to high strength Digby Conglomerate is located approximately 4 m above the workings roof; see **Figures 5j** and **5k** respectively. Reference to the Subsidence Reduction Potential (SRP) models developed for Newcastle Coalfield Conglomerate beds (**ACARP, 2003**), indicates that the Digby Conglomerate is likely to span 44.5 m between remnant pillars (High SRP) but unlikely to span the full width of the panels (154 m to 310 m) should the remnant pillars yield (Low SRP); see **Figures 5l** and **5m**.

It is therefore assessed that a conservative abutment angle of 90^o should be adopted in the stability analysis calculations for the production pillars. An angle of 21^o is deemed appropriate for the gateroad and barrier pillars.

The distance (D) that the abutment load is likely to be distributed over adjacent pillars or solid coal may be estimated by the empirical formula presented in **Peng and Chiang, 1984**, as follows:

$D = 5.13\sqrt{H}$ = 68 m to 74 m for depths ranging from 180 m to 210 m.

The abutment load is also likely to be concentrated closer to the goaf or 'uncrushed' pillar line and calculated based on the parabolic stress distribution profile presented in **ACARP, 1998**; see **Figure 5g**.

The total increase in load/metre length (A) acting on the pillars adjacent to a crushed pillar area may be estimated as follows for a *critical* to *supercritical* panel with W/H > 2tanθ:

$A = 0.5\ \gamma\ H^2 \tan\theta$ where γ = unit weight of overburden (0.025 MPa/m)
θ = abutment angle (21^o is the default unless strong spanning units are identified)

The average stress acting on an adjacent standing pillar is then derived by multiplying 'A' by the pillar length (or width) that is perpendicular to the direction of loading plus the roadway or bord width respectively. The load is then divided by the pillar area for the total abutment stress increase increment. Depending on the geometry of the pillar and direction of abutment loading, a proportion of the abutment load (1-R) may be distributed to adjacent 'inside' pillar by the cantilevering action of the overburden, as shown by the diagram in **Figure 5g**.

The proportion, R of the abutment load, 'A' that will load a goaf edge pillar may be estimated using the formula presented in **ACARP, 1998**:

$R = 1 - [(D-w-r)/D]^3$ where D = distance that load distribution will extend from goaf edge.

w = goaf edge pillar width or dimension normal to the goaf edge.

The average pillar stress formula provided for loading from one side is as follows:

σ_{max} = pillar load/pillar area = (P+RA)/wl

The final abutment load for the gateroad and barrier pillars has been assessed as being normal to the pillar ribs that are adjacent to the goaf or crushed pillar areas.

8.3.4 Pillar Stability Analysis Results

The pillar stability analysis results for the proposed pillar reduction panels for the final second workings arrangement (pillar & floor extraction is complete).

The proposed pillars in the workings are typically located in *critical* to *super-critical* width panel of pillars that is wider than the cover depth (W/H > 1). Once every second pillar row is extracted, the remaining pillars would be subject to additional loading (i.e. side abutment loads due to unsupported spans of 44.5 m on each side of a pillar row).

The results of the average FoS for each pillar panel and the inter-panel gate-road and barrier pillars under FTA loading conditions are presented in **Tables 5A** and **5B** respectively.

Due to the relatively low FoS of the remnant pillars after second workings in the panels (1.07 to 1.23), it is considered likely that they would yield and side-on abutment loading conditions would then develop on the outer / inner gateroad and barrier pillars.

The pillar stress and FoS for the typical pillars are summarised in **Table 5B**.

Table 5A - Pillar Stability Review for FTA Loading Conditions & Max. Pillar Height

Panel	Cover Depth H (m)	Pillar Width w (m)	Pillar Length l (m)	Roadway Width b (m)	Effective Pillar Height h' (m)	Pillar w/h	e (%)	Pillar Strength S_p (MPa)	FTA Stress (MPa)	FTA FoS
Panel Pillars - Floor Brushed & Alternate Pillar Rows Extracted										
CF201-A	185	30.5	30.5	43.5	4.13	7.4	66	16.48	13.61	**1.21**
CF201-B	210	30.5	30.5	43.5	4.13	7.4	66	16.48	15.45	**1.07**
CF202-C	182	30.5	30.5	43.5	4.13	7.4	66	16.48	13.39	**1.23**
CF202-D	199	30.5	30.5	43.5	4.13	7.4	66	16.48	14.64	**1.13**
CF203-E	186	30.5	30.5	43.5	4.13	7.4	66	16.48	13.69	**1.20**
CF203-F	194	30.5	30.5	43.5	4.13	7.4	66	16.48	14.27	**1.15**
CF204-G	194	30.5	30.5	43.5	4.13	7.4	66	16.48	14.27	**1.15**
CF204-H	194	30.5	30.5	43.5	4.13	7.4	66	16.48	14.27	**1.15**
CF205-I	188	30.5	30.5	43.5	4.13	7.4	66	16.48	13.83	**1.19**
CF205-J	191	30.5	30.5	43.5	4.13	7.4	66	16.48	14.05	**1.17**
Outer Gate Pillars - Floor Brushed Only										
CF201-A	185	34.3	39.8	6.5	4.13	8.3	28	19.61	6.40	3.06
CF201-B	210	38.5	39.2	6.5	4.13	9.3	27	22.19	7.15	3.10
CF202-C	182	31.8	35.1	6.5	4.13	7.7	30	16.83	7.17	2.35
CF202-D	199	30.6	38.2	6.5	4.13	7.4	30	15.58	8.81	1.77
CF203-E	186	30.7	35.2	6.5	4.13	7.4	30	16.01	7.65	2.09
CF203-F	194	30.4	38.3	6.5	4.13	7.4	30	15.43	8.68	1.78
CF204-G	194	29.7	35.1	6.5	4.13	7.2	31	15.33	8.28	1.85
CF204-H	194	30.6	37.9	6.5	4.13	7.4	30	15.62	8.53	1.83
CF205-I	188	32.6	35.3	6.5	4.13	7.9	30	17.41	7.23	2.41
CF205-J	191	29.5	38.2	6.5	4.13	7.1	30	14.83	8.83	1.68
Inner Gate Pillars - Floor Brushed & Pillars Partially Extracted										
CF201-A	185	13	44	6	4.13	3.1	40	9.77	7.68	**1.27**
CF201-B	210	13	44	6	4.13	3.1	40	9.77	8.72	**1.12**
CF202-C	182	13	44	6	4.13	3.1	40	9.77	7.56	**1.29**
CF202-D	199	13	44	6	4.13	3.1	40	9.77	8.26	**1.18**
CF203-E	186	13	44	6	4.13	3.1	40	9.77	7.72	**1.27**
CF203-F	194	13	44	6	4.13	3.1	40	9.77	8.06	**1.21**
CF204-G	194	13	44	6	4.13	3.1	40	9.77	8.06	**1.21**
CF204-H	194	13	44	6	4.13	3.1	40	9.77	8.06	**1.21**
CF205-I	188	13	44	6	4.13	3.1	40	9.77	7.81	**1.25**
CF205-J	191	13	44	6	4.13	3.1	40	9.77	7.93	**1.23**
Inter - Panel Barrier Pillars										
CF201-A	185	55.7	348.5	6.5	3.2	17.4	10	96.34	5.16	18.65
CF201-B	210	50.0	348	6.5	3.2	15.6	12	78.09	5.93	13.16
CF202-C	182	64.3	339.5	6.5	3.2	20.1	9	128.06	5.01	25.56
CF202-D	199	63.8	339.5	6.5	3.2	19.9	9	126.05	5.48	22.99
CF203-E	186	41.3	339.5	6.5	3.2	12.9	14	54.93	5.38	10.21
CF203-F	194	40.9	339.5	6.5	3.2	12.8	14	54.00	5.62	9.61
CF204-G	194	34.0	339.5	6.5	3.2	10.6	16	39.76	5.78	6.88
CF204-H	194	34.2	339.5	6.5	3.2	10.7	16	40.12	5.77	6.95
CF205-I	188	28.0	54	6.5	3.2	8.8	18	25.34	5.71	4.44
CF205-J	191	18.7	54	6.5	3.2	5.8	24	19.54	6.31	3.10

Effective pillar height, h' = (3.2 x 6.5 + 1.1 x 5.5)/6.5 = 4.13 m; *italics* - barrier h' = (27.5 x 4.3) / 37 = 3.2 m;
Bold - Pillar FoS < 1.6 or w/h < 3 (minimum values assumed for long-term stability).

Table 5B - Pillar Stability Review for Side Abutment Loading & Max. Pillar Height

Panel	Cover Depth H (m)	Pillar Width w (m)	Pillar Length l (m)	Roadway Width b (m)	Effective Pillar Height h' (m)	Pillar w/h	Pillar Abutment Load Ratio R	Pillar Strength S_p MPa)	Pillar Stress (MPa)	FoS
Panel Pillars - Floor Brushed & Alternate Pillar Rows Extracted (FTA Loading)										
A	185	30.5	30.5	43.5	4.13	7.4	N/A	16.48	13.61	**1.21**
B	210	30.5	30.5	43.5	4.13	7.4	N/A	16.48	15.45	**1.07**
C	182	30.5	30.5	43.5	4.13	7.4	N/A	16.48	13.39	**1.23**
D	199	30.5	30.5	43.5	4.13	7.4	N/A	16.48	14.64	**1.13**
E	186	30.5	30.5	43.5	4.13	7.4	N/A	16.48	13.69	**1.20**
F	194	30.5	30.5	43.5	4.13	7.4	N/A	16.48	14.27	**1.15**
G	194	30.5	30.5	43.5	4.13	7.4	N/A	16.48	14.27	**1.15**
H	194	30.5	30.5	43.5	4.13	7.4	N/A	16.48	14.27	**1.15**
I	188	30.5	30.5	43.5	4.13	7.4	N/A	16.48	13.83	**1.19**
J	191	30.5	30.5	43.5	4.13	7.4	N/A	16.48	14.05	**1.17**
Outer Gate Pillars - Floor Brushed Only (Single Side Abutment Loading)										
A	185	34.3	39.8	6.5	4.13	8.3	0.93	19.61	11.57	1.70
B	210	38.5	39.2	6.5	4.13	9.3	0.94	22.19	13.17	1.69
C	182	31.8	35.1	6.5	4.13	7.7	0.94	16.83	12.28	**1.37**
D	199	30.6	38.2	6.5	4.13	7.4	0.94	15.58	14.51	**1.07**
E	186	30.7	35.2	6.5	4.13	7.4	0.93	16.01	12.99	**1.23**
F	194	30.4	38.3	6.5	4.13	7.4	0.95	15.43	14.10	**1.09**
G	194	29.7	35.1	6.5	4.13	7.2	0.93	15.33	14.09	**1.09**
H	194	30.6	37.9	6.5	4.13	7.4	0.95	15.62	14.00	**1.12**
I	188	32.6	35.3	6.5	4.13	7.9	0.93	17.41	12.61	**1.38**
J	191	29.5	38.2	6.5	4.13	7.1	0.95	14.83	14.14	**1.05**
Inner Gate Pillars - Floor Brushed & Pillars Partially Extracted (Single Side Abutment Loading)										
A	185	13	44	6	4.13	3.1	0.07	9.77	8.71	**1.12**
B	210	13	44	6	4.13	3.1	0.06	9.77	9.86	**0.99**
C	182	13	44	6	4.13	3.1	0.06	9.77	8.44	**1.16**
D	199	13	44	6	4.13	3.1	0.06	9.77	9.19	**1.06**
E	186	13	44	6	4.13	3.1	0.07	9.77	8.68	**1.13**
F	194	13	44	6	4.13	3.1	0.05	9.77	8.87	**1.10**
G	194	13	44	6	4.13	3.1	0.07	9.77	9.21	**1.06**
H	194	13	44	6	4.13	3.1	0.05	9.77	8.91	**1.10**
I	188	13	44	6	4.13	3.1	0.07	9.77	8.80	**1.11**
J	191	13	44	6	4.13	3.1	0.05	9.77	8.70	**1.12**
Inter - Panel Barrier Pillars (Double Abutment Loading)										
A	185	55.7	348.5	6.5	3.2	17.4	2	96.34	11.06	8.71
B	210	50.0	348	6.5	3.2	15.6	2	78.09	14.40	5.42
C	182	64.3	339.5	6.5	3.2	20.1	2	128.06	9.95	12.87
D	199	63.8	339.5	6.5	3.2	19.9	2	126.05	11.44	11.02
E	186	41.3	339.5	6.5	3.2	12.9	2	54.93	13.42	4.09
F	194	40.9	339.5	6.5	3.2	12.8	2	54.00	14.45	3.74
G	194	34.0	339.5	6.5	3.2	10.6	2	39.76	16.40	2.42
H	194	34.2	339.5	6.5	3.2	10.7	2	40.12	16.33	2.46
I	188	28	54	6.5	3.2	8.8	0.78	25.34	10.44	2.43
J	191	18.7	54	6.5	3.2	5.8	0.71	19.54	11.93	1.65

Effective pillar height, h' = (3.2 x 6.5 + 1.1 x 5.5)/6.5 = 4.13 m; *italics* - barrier h' = (30 x 4.3) / 37 = 3.14 m; **Bold** - Pillar FoS < 1.6 or w/h < 3 (minimum values assumed for long-term stability); R = Pillar load/total load, shaded - single abutment loading only.

8.3.5 Pillar Failure Likelihood

The probability of pillar failure under FTA and design abutment loading conditions in a pillar reduction panel with standing pillars, yielded pillars or second workings areas may be assessed based on **UNSW, 1998** probability of failure curve; see **Figure 5n**.

The probability of failure curve in **UNSW, 1998** was derived from a Standard Log-Normal probability density function of critical FoS values for the Australian database as follows:

$$1 - p(\text{failure}) = P(\ln(\text{FoS})/\sigma)$$

where p(failure) = probability of failure
P(.) = standard cumulative normal probability distribution
σ = standard deviation

A summary of the FoS results for the assumed pillar dimension and likely range of loading cases is provided in **Table 6**.

Table 6 - Summary of Pillar Stability Results after Mining Completed CF201-CF205

Load Scenario	Mine Workings & Pillar Type	FoS for Loading Condition	Probability of Failure (%)	Failure Likelihood (see **Figure 4a**)
FTA Loading	Panel Pillars	**1.07 - 1.27**	33.3 - 9.4	Possible to Likely
	Outer Gate Pillars	1.63 - 3.10	<0.1	Very Unlikely to Barely Credible
	Inner Gate Pillars	**1.12 - 1.29**	23.5 - 5.2	Possible to Likely
	Barrier Pillars	3.10 - 25.6	<0.0001	Barely Credible
'Side-on' Abutment Loading	Panel Pillars	**< 1**	> 50	Likely to Almost Certain
	Outer Gate Pillars	**1.05 - 1.70**	37.8 - 0.04	Possible to Very Unlikely
	Inner Gate Pillars	**0.99 - 1.13**	52.6 - 21.8	Likely
	Barrier Pillars	1.65 - 12.9	<0.1	Very Unlikely to Barely Credible

Bold - FoS < 1.6, the minimum assumed for long-term stability.

The results of the stability analysis indicate that the remnant pillars and gateroad access pillars may not crush or yield immediately after mining is completed. The timing of subsidence is difficult to predict, and it may not occur at all or until many years later. The stability of the workings will be dependent on the rate of deterioration and the effect of groundwater inundation once mining ceases. The maximum subsidence is therefore likely to range between the predicted values presented in **Section 8.1**. The presence of faults / dykes or mid-angled structure etc is expected to limit the actual pillar and floor extraction areas, and therefore reduce the subsidence over some areas.

8.4 Subsidence Effect Contour Predictions

8.4.1 General

As discussed earlier in **Section 8.1**, the maximum subsidence over crushed pillar reduction panels has been estimated based on reference to published subsidence data in the Newcastle Coalfield; see **Figures 5a, 5c** and **5d**.

The subsidence effect contours (subsidence, tilt, curvature, horizontal displacements and strains) for the various pillar instability cases have been derived using the SDPS® (Surface Deformation Prediction System). SDPS® was developed in the US Coalfields by **Karmis *et al*, 1990** based on longwall and pillar panel data.

SDPS® is an influence function-based model that may be used to estimate worst-case subsidence profiles and contours above a range of coal mine workings from longwalls to failed remnant pillars in pillar reduction panels. The influence of an extracted element of coal or standing pillar of coal is transmitted to the surface via a 3-D Gaussian (bell-shaped) function. The program allows the extraction limits of the various mining areas, intra-panel pillars and surface topography to be imported from Autocad.

The model may be calibrated to measured or predicted subsidence profiles over bord and pillar panels of known width, cover depth, mining height and panel extraction ratio. The shape of the subsidence profile may be manipulated by adjusting the influence angle and inflexion point location; see **Figure 5o** for definitions.

8.4.2 SDPS Input Parameters

In SDPS, the mine workings may be divided up into homogeneous units of similar pillar geometry, seam thickness, mining height and extraction ratio as shown in **Figure 5p**.

The following key input parameters are required for the SDPS model:

- Maximum supercritical subsidence/effective mining height ratio, $S_{max}/h' = 0.45$ for standing pillar areas with extraction ratios < 60% and $S_{max}/h' = 0.65$ for panels with extraction ratios > 60%. The maximum subsidence would also be affected by the effective mining height (h') which equals the extraction ratio multiplied by the actual mining height ($h' = h \times e$) ; see **Figure 5c**.

- Inflexion point distance/cover depth ratio, d/H; see **Figure 5q**.

- Tangent of the Influence Angle, $K_3 = \tan(\beta)$; see **Figure 5r**.

The maximum tilt, curvature and strain predictions were calculated using the longwall database empirical models presented in **Section 9.8**.

8.4.3 Results

The subsidence effect contours were derived using the calculus module in Surfer12® and empirically derived factors to estimate U95%CL values using the ACARP models.

The results are summarised in **Tables 7A & 7B** and shown graphically in **Figures 7a** to **7c**.

Table 7A - Predicted Subsidence Parameters for the Proposed Panels CF201-CF203 (A-E)

Parameter#	Predicted Mean - U95% CL				
	CF201 (A)	**CF201 (B)**	**CF202 (C)**	**CF202 (D)**	**CF203 (E)**
Maximum Production Panel Subsidence S_{max} (mm)	1.53 - 1.77	1.65 - 1.77	1.44 - 1.77	1.52 - 1.77	1.48 - 1.77
Maximum Gateroad Access Panel Subsidence S_{max} (mm)	0.50 - 0.73	0.50 - 0.73	0.50 - 0.57	0.50 - 0.57	0.50 - 0.65
Maximum Tilt T_{max} (mm/m)	15 - 22	14 - 21	16 - 24	22 - 32	21 - 31
Maximum Hogging Curvature* $+C_{max}$ (km^{-1})	0.81 - 1.63	0.68 - 1.36	0.93 - 1.86	1.37 - 2.74	1.33 - 2.67
Maximum Sagging Curvature $-C_{max}$ (km^{-1})	0.87 - 1.74	0.73 - 1.45	0.99 - 1.99	1.46 - 2.92	1.42 - 2.85
Maximum Horizontal Tensile Strain^ $+E_{max}$ (mm/m) ^	8 - 16 (32)	7 - 14 (28)	9 - 19 (38)	14 - 27 (54)	13 - 27 (54)
Maximum Horizontal Compressive Strain $-E_{max}$ (mm/m) ^	9 - 17 (34)	7 - 15 (30)	10 - 20 (40)	15 - 29 (58)	14 - 29 (58)

- tilt, curvature and strains based on mean subsidence values; * - Hogging curvature is positive; ^ - tensile strain is positive; (brackets) - discontinuous strains (2 x smooth profile strains).

Table 7B - Predicted Subsidence Parameters for the Proposed Panels CF203 - CF205 (F-J)

Parameter#	Predicted Mean - U95% CL				
	CF203 (F)	**CF204 (G)**	**CF204 (H)**	**CF205 (I)**	**CF205 (J)**
Maximum Production Panel Subsidence S_{max} (mm)	1.42 - 1.77	1.42 - 1.77	1.52 - 1.77	1.54 - 1.77	1.57 - 1.77
Maximum Gateroad Access Panel Subsidence S_{max} (mm)	0.50 - 0.65	0.50 - 0.65	0.50 - 0.65	0.50 - 0.65	0.50 - 0.65
Maximum Tilt T_{max} (mm/m)	15 - 23	15 - 23	22 - 32	24 - 36	15 - 22
Maximum Hogging Curvature* $+C_{max}$ (km^{-1})	0.91 - 1.82	0.91 - 1.82	1.37 - 2.74	1.55 - 3.11	0.78 - 1.57
Maximum Sagging Curvature $-C_{max}$ (km^{-1})	0.97 - 1.94	0.97 - 1.94	1.46 - 2.92	1.66 - 3.32	0.84 - 1.67
Maximum Horizontal Tensile Strain^ $+E_{max}$ (mm/m) ^	9 - 18 (36)	9 - 18 (36)	14 - 27 (54)	16 - 31 (62)	8 - 16 (32)
Maximum Horizontal Compressive Strain $-E_{max}$ (mm/m) ^	10 - 19 (38)	10 - 19 (38)	15 - 29 (58)	17 - 33 (66)	8 - 17 (34)

- tilt, curvature and strains based on mean subsidence values; * - Hogging curvature is positive; ^ - tensile strain is positive; (brackets) - discontinuous strains (2 x smooth profile strains).

The predicted mean and credible worst-case (U95%CL) subsidence effect results for CF201 - CF205 are summarised below:

- **Maximum Production Panel subsidence** ranges from 1.42 to 1.77 m (34%h to 43%h).
- **Maximum Gateroad Access pillar subsidence** ranges from 0.50 m to 0.73 m (12%h to 18%h).

- **maximum panel tilt** ranges from 14 mm/m to 36 mm/m.

- **Final maximum panel concave curvatures** range from 0.7 per kilometre (km^{-1}) to 3.3 km^{-1} (radii of curvature 1.4 km to 0.3 km).

- **Final maximum panel convex curvatures** range from 0.7 km^{-1} to 3.1 km^{-1} (radii of curvature 1.4 km to 0.32 km).

- **Final maximum panel compressive strains** range from 7 mm/m to 31 mm/m.

- **Final maximum panel tensile strains** range from 7 mm/m to 33 mm/m.

Note: Discontinuous movements due to cracking may double the predicted strains.

The SDPS model results indicate that the subsidence above the proposed critical width panels are expected to be lower than the maximum values predicted for supercritical panels (i.e. W/H > 1.4).

8.5 Mining Restriction Zone below the Claremont Grinding Groove Site

Assuming that the groove site cannot be removed from above CF201 (Panel B) before pillar reduction occurs, the reduction of tensile strain from 10 mm/m to 1.5 mm/m will decrease the potential for surface cracking at the Claremont Groove Site from ‘possible / likely’ to ‘unlikely’ according to the surface cracking likelihood criteria presented in *Table 24* in **DgS, 2020a**.

The minimum set back distance of 70 m to the potential goaf edge from the Claremont Groove site has been estimated to reduce the horizontal strain to 1.5 mm/m for a cover depth of 210 m or an r/H of ~0.33.

The pillars within the mining restriction zone (MRZ) will also need to remain long-term stable to achieve this out-come under side abutment loading conditions. Reference to the UNSW method indicates that the remnant pillars should be left with a maximum height of 3.2 m after pillar reduction is completed to achieve a minimum FoS of 1.6 and pillar w/h > 8. This would mean that the coal floor may not be ‘robbed’ in the MRZ.

The proposed MRZ is presented in **Figure 5s**.

An SDPS model of the proposed panels with the MRZ has also been developed to demonstrate the effectiveness of the zone to decrease the subsidence, tilt and strain at the groove site to below the likely cracking threshold values; see **Figures 8a,b,c**.

It should be noted that monitoring of strains above another panel will not necessarily provide a good indicator of the strain magnitudes if the remnant pillars are still standing. It may be several months to years before the pillars crush and full subsidence develops.

The use of mining restriction zone will therefore provide a reasonable strain and cracking control measure at the groove site.

9.0 Mine Subsidence Effect Predictions for Longwalls 203 to 205

9.1 General

Total and differential subsidence predictions have been assessed for the proposed longwalls after:

(i) each longwall block has been extracted (First Subsidence); and

(ii) mining of all of the proposed longwall panels (Final Subsidence).

The prediction methodology requires the consideration of the following:

- the SRP of the overburden and the influence of proposed mining geometry on single panel subsidence development (i.e. whether the panels are likely to be sub-critical, critical or supercritical),

- the behaviour of the chain pillars and immediate roof and floor system under double-abutment loading conditions when longwalls have been extracted along both sides of the pillars, and

- the combined effects of single panel and chain pillar subsidence to estimate final subsidence profiles and subsidence contours for subsequent environmental impact assessment.

It is known from previous assessments at Narrabri that the development of subsidence impacts will not be affected by the spanning potential of the Garrawilla Volcanics, dolerite sill or Digby Conglomerate units (i.e. the subsidence reducing potential of these units is 'low').

Subsidence predictions have therefore only considered 'Low' SRP for the worst-case scenario and measured subsidence profiles in this study.

Subsidence development above multiple longwall panels at the Narrabri Mine to-date is mostly caused by strata sag between chain pillars with a proportion of the total subsidence due to compression of the chain pillars and strata above and below them. A conceptual model of multiple longwall panel subsidence mechanics is provided in **Figure 6a**.

The multiple panel prediction is estimated by adding the strata sag or single panel subsidence to a proportion of the chain pillar subsidence. The proportion is determined based on the panel W/H ratio and goaf edge subsidence and is further discussed in **Section 9.5**.

9.2 Single Longwall Panel Subsidence and Profile Prediction Models

The single longwall panel subsidence at the Narrabri Mine was first estimated using the empirical subsidence prediction curves developed for the Newcastle Coalfield and first published in **ACARP, 2003**. The Newcastle coalfield has a wide range of geological conditions with and without massive sandstone or conglomerate strata that has reduced subsidence[6]. Data from other NSW Coalfields (Hunter Valley, Western and Southern Coalfields) and the Bowen Basin in Queensland have been added to the database by DgS over the past 14 years, with the data collected for Narrabri LW101 to 108A progressively added as well. Plots of the key geometric parameters used in the subsidence effect prediction curves (W, H, T) are plotted against Panel W/H in **Figures 6b** to **6d** to demonstrate that the Narrabri Mine longwalls are within the modified ACARP model's data base.

The full subsidence profile for a single longwall is also derived from the database using curves of 'best-fit' (spline curves) through the following key points that can be readily measured by subsidence monitoring campaigns:

- maximum panel subsidence
- inflexion point distance from ribs (point of maximum tilt)
- maximum hogging curvature location (point of maximum tensile strain)
- maximum sagging curvature location (point of maximum compressive strain)
- goaf edge subsidence
- AoD distance to 20 mm subsidence contour.

The maximum subsidence above a single longwall panel depends on the thickness and strength of strata units within the overburden (i.e. Subsidence Reduction Potential), the panel width (W), cover depth (H) and average extraction height (T) [7]. Each of the above prediction models for each parameter is presented in the following sub-sections.

The maximum subsidence (S_{max}) for a single longwall panel at 180 m to 400 m depth with 'Low' SRP overburden is summarised in **Table 8** and based on the maximum extraction height (T) of 4.3 m. The values were determined along two representative crosslines XL6 & 7 (see **Figure 1a** for their location).

Table 8 - Predicted Maximum Single Panel Subsidence for LW203 to 205

LW	XL	Panel Width W (m)	Cover Depth H (m)	W/H	Maximum Longwall Extraction Height T (m)	Single S_{max}/T* (m/m)		Single S_{max}* (m)	
						Mean	U95%CL	Mean	U95%CL
203	6	402.9	214	1.88	4.3	0.59	0.62	2.54	2.67
	7	402.9	207	1.95	4.3	0.59	0.62	2.54	2.67
204	6	402.4	238	1.69	4.3	0.59	0.62	2.54	2.67
	7	402.4	244	1.65	4.3	0.59	0.62	2.54	2.67
205	6	399.7	263	1.52	4.3	0.59	0.62	2.52	2.67
	7	399.7	280	1.43	4.3	0.59	0.62	2.54	2.67

* - Maximum subsidence limited to between 59% and 62% of extraction height T for the mean and U95%CL, respectively. Note:- m/m = metres per metre.

6 Subsidence data for cases with an absence of massive strata is also included in the database.

7 The database has been separated into four cover depth categories of 100 m, 200 m, 300 m and 400 m +/- 50m. The assessed SRP (Low, Moderate or High) is then assessed and used to estimate the range of maximum likely panel subsidence at a given W/H ratio in the appropriate depth category.

The results of the single panel spanning assessment indicate that the maximum panel subsidence for the 'non-spanning' volcanic or conglomerate units would range between 2.54 m and 2.67 m (59% to 62% T) as shown in **Figures 6e** to **6g**.

9.3 Inflexion Point Predictions

The mean inflexion point distance from the rib-side (d) or point of maximum tilt may be estimated for the proposed longwalls (LW203 to 205) as follows:

> d = H*(0.2425(W/H) +0.3097) and ranges from 78 m to 112 m for cover depths of 200 m to 290 m.

The mean distance to the peak tensile strain from the rib-side (d_t) may be estimated for the proposed longwalls (LW203 to 205) as follows:

> d_t = H*0.1643(W/H) +0.2203 and ranges from 55 m to 79 m for cover depths of 200 m to 290 m.

The mean distance to the peak compressive strain from the rib-side (d_c) may be estimated for the proposed longwalls (LW203 to 205) as follows:

> d_c = H*0.0.3409(W/H) +0.3996 and ranges from 100 m to 144 m for cover depths of 200 m to 290 m.

The databases of inflexion point distances from the goaf edge plus the peak tensile and compressive strain locations are shown in **Figure 6h**.

9.4 Goaf Edge Subsidence Prediction

The prediction models for the goaf edge subsidence predictions for the proposed longwalls are:

$$\text{Mean } S_{goe} = \text{Mean } S_{max} * 0.0875(W/H)^{-2.417}$$

$$\text{U95\%CL } S_{goe} = \text{U95\%CL } S_{max} * 0.1822\ (W/H)^{-2.237}$$

where W/H ≤ 1.2 and

The mean first goaf edge subsidence predictions for LW203 to 205 range from 0.14 m to 0.33 m. The final Upper 95% CL values range from 0.15 m to 0.34 m.

The results are presented on **Figure 6i**.

9.5 Angle of Draw Prediction

Based on the predicted maximum panel subsidence and goaf edge subsidence, the predicted mean to U95%CL AoD (to the 20 mm subsidence contour) for the proposed supercritical LW203 to 205 is estimated to range from 22^o to 43^o using the formulae below:

Mean AoD = 10.425*LN(S_{goe})+42.154

U95%CL AoD = Mean AoD + 11.8

The results are presented on **Figure 6j**.

The following U95%CL values have been adopted for the proposed longwalls:

- **Panel sides:** 43^o or 0.92H for W/H > 1.2
- **Panel ends:** 31^o or 0.6H for all W/H

The U95%CL AoD line is shown in **Figures 1a** and **1b**.

9.6 Multiple Longwall Panel Subsidence

When several panels are extracted adjacent to each other, further subsidence occurs due to the compression of the chain pillars left between the extracted panels.

The prediction of the chain pillar subsidence is based on another empirical model developed by DgS using measured subsidence data cases for a broad range of coalfield chain pillar (and longwall panel) geometries (see **Section 9.7**).

The subsidence above the chain pillars is also affected by the strength and stiffness of the strata above and below the pillars when subject to additional stress from the longwall panel extraction process. The chain pillar subsidence is estimated empirically from the total pillar stress and the longwall extraction height (**Figure 6k**).

Estimates of first and final subsidence above a given set of longwalls use this general approach. The definition of First and Final S_{max} is as follows:

First S_{max} = the maximum subsidence above a longwall panel after it is first extracted, including the effects of previously extracted longwall panels adjacent to the subject panel.

Final S_{max} = the final maximum subsidence over an extracted longwall panel after at least three more panels have been extracted, or when mining is completed.

The subsidence above chain pillars has been defined in this study as follows:

First S_p = subsidence over chain pillars after longwall panels have been extracted on both sides of the pillar for the first time.

Final S_p = the total subsidence over a chain pillar, after at least another three more panels have been extracted, or when mining is completed.

The survey data for Narrabri and other coalfields has been used to calculate the 'a' and 'b' factors for estimating the contributions of the chain pillar and goaf edge subsidence to estimate the first and final subsidence over multiple longwalls as follows:

First S_{max} = Single S_{max} + 0.5b(First $S_{p(i-1)}$)

Final S_{max} = First S_{max} + b(Final $S_{p(i)}$ - aFirst $S_{goe(i)}$)

where

$S_{p(i-1)}$ and $S_{p(i)}$ refer to previous and current chain pillars under design abutment loading respectively.

a = 0.74 and b = -0.159(W/H)+0.974 (with b_{min} =0.5 and b_{max}=1 for supercritical to sub-critical longwalls with W/H ranging from 0.3 to 3).

The U95% Confidence Limits may then be added to estimate the credible worst-case profiles for the proposed mining geometry.

9.7 Chain Pillar Stability and Subsidence Assessment

The predicted mean and U95%CL subsidence values above the proposed chain pillars (each under single abutment loading conditions) are based on the average of the longwall extraction height (T = 4.3 m). The results are summarised for representative crosslines XL6 and XL7 in **Table 4**.

The predicted first subsidence over the chain pillar pairs (S_p First) between the extracted panels LW203 to 205 is estimated to range from 0.18 m to 0.48 m for the range of pillar sizes and geometries proposed. The final subsidence over the chain pillar pairs (S_p Final) (after mining is completed) is estimated to range from 0.22 m to 0.56 m (an overall increase of between 17% and 22%); see **Figure 6k**.

Based on an abutment angle of 21°, the final vertical stress acting on the EP Area pillars is assessed to range from 13.7 MPa to 21.4 MPa, with pillar FoS values ranging from 1.78 to 1.37 for a 3.7 m pillar height. The proposed chain pillar geometries are 'squat' with a w/h range of 7.9 to 9.4 and are expected to 'strain harden' under full loading conditions.

The FoS values are within the range of previous chain pillars are within the range of previous longwall layouts. The observed subsidence above the chain pillars demonstrate that the final subsidence is unlikely to increase by more than 20% after mining is complete.

As the chain pillars are isolated between longwall goaves, which will consolidate under overburden loads, any further subsidence due to on-going chain pillar deterioration is likely to be limited to relatively low magnitudes with no further surface impacts expected.

9.8 Differential Subsidence Effects

The **ACARP, 2003** model also provides empirical estimates of maximum differential subsidence effects such as tilt, curvature and horizontal strain for a given mining geometry and maximum subsidence. These parameters are significant in that they are usually the cause of surface impact (erosion, cracking and surface heave). Ponding is caused when relatively flat surface topography is lowered by mine subsidence that is greater than the natural cross fall of an under-mined area of land.

The empirical models for estimating maximum tilt, curvature and strain are shown in **Figures 6l** to **6o** and summarised below:

- Maximum Tilt, Mean $T_{max} = 1.1187(S_{max}/W')^{1.4568}$ & U95%CL = 1.5 x Mean; see **Figure 6l**.

- Maximum Hogging Curvature, Mean $+C_{max} = 35.678(S_{max}/W'^2)$ & U95%CL = 2 x Mean; see **Figure 6m**.

- Maximum Sagging Curvature, Mean $-C_{max} = 38.075(S_{max}/W'^2)$ & U95%CL = 2 x Mean; see **Figure 6n**.

- Maximum horizontal strain (mm/m), Mean E_{max} = 10 x Mean Curvature (1/km) & U95%CL = 2 x Mean; see **Figure 6o**.

The magnitudes of the measured differential subsidence are also affected by the near surface geology and topographic relief, which can result in anomalies along the subsidence effect profiles. The anomalies are usually due to discontinuous movements along rock mass joints, faults and/or dykes during subsidence development.

It is therefore important that measured subsidence and differential subsidence profiles are reviewed regularly against the empirical models to test their reliability. If the variation between the predictions and measured values is significant (i.e. more than 5% of predictions are exceeded for a given mining geometry or the magnitudes of the predicted effects are exceeded by 15%), then the model is amended and predictions for the next longwall panels adjusted[8].

Subsequent to the predictions of maximum subsidence effects, it is also necessary to provide the spatial distribution of the mine subsidence deformations over the EP Area. The subsidence profiles described above are then used to calibrate the **SDPS®**, which uses 3-D Influence Function to generate subsidence contours. **Surfer 12®**software has then been used to generate enhanced subsidence, tilt, horizontal displacement and strain contours above the panels from the **SDPS®** output files.

9.9 Multiple Panel Subsidence Predictions for LW203 to 205

The predicted mean to U95%CL Subsidence Effects for LW203 to 205 are summarised in **Table 9**.

[8] Extraction Plans would require this review process to be undertaken for the Project and also includes a review of the predicted impacts associated with the subsidence effect predictions.

Table 9 - Predicted First and Final Maximum Subsidence Effects for LW203 to 205 (Mean & U95%CL)

LW Panel #	XL #	Panel Width W (m)	Cover Depth H (m)	Average Extraction Height T (m)	W/H Ratio	Pillar Width w_{cp} (m)	First S_{max} (m)		Final S_{max} (m)		Final Pillar S_p (m)		Max Tilt* T_{max} (mm/m)		Maximum Strain* $+E_{max}$ & $-E_{max}$ (mm/m)			
															Tensile		Compressive	
							Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Mean	U95% CL
203	6	402.9	214	4.3	1.88	2 x 29.4	2.57	2.75	2.68	2.80	0.26	0.36	34	51	15	29	16	33
	7	402.9	207	4.3	1.95	2 x 29.4	2.54	2.75	2.65	2.80	0.25	0.36	35	53	15	31	18	35
204	6	402.4	238	4.3	1.69	2 x 32.6	2.58	2.75	2.73	2.80	0.30	0.40	30	45	12	24	13	26
	7	402.4	244	4.3	1.65	2 x 32.6	2.58	2.75	2.75	2.80	0.34	0.44	29	44	11	23	12	24
205	6	399.7	263	4.3	1.52	2 x 34.6	2.58	2.75	2.75	2.80	0.38	0.48	26	39	10	20	11	21
	7	399.7	280	4.3	1.43	2 x 34.6	2.58	2.75	2.75	2.80	0.44	0.55	24	36	9	17	9	19

The predicted mean and credible worst-case (U95%CL) subsidence effect results for LW203 to 205 are summarised below:

- **First maximum panel subsidence** ranges from 2.54 m to 2.75 m (59%T to 64%T).
- **Final maximum panel subsidence** ranges from 2.65 to 2.80 m (62%T to 65%T).
- **Final maximum chain pillar subsidence** ranges from 0.25 m to 0.55 m (6%T to 13%T).
- **Final maximum panel tilt** ranges from 24 mm/m to 54 mm/m.
- **Final maximum panel concave curvatures** range from 0.9 per kilometre (km^{-1}) to 3.5 km^{-1} (radii of curvature 1.1 km to 0.29 km).
- **Final maximum panel convex curvatures** range from 0.9 km^{-1} to 3.1 km^{-1} (radii of curvature 1.1 km to 0.32 km).
- **Final maximum panel compressive strains** range from 9 mm/m to 35 mm/m.
- **Final maximum panel tensile strains** range from 9 mm/m to 31 mm/m.

As discussed above, the predicted values may be occasionally exceeded (up to 5% of the time) due to discontinuous strata behaviour associated with near surface cracking, joint displacement, geological features (e.g. faults) and/or rapid changes in topography (creek beds).

9.10 Subsidence Profile and Contour Predictions

The predicted U95%CL subsidence profiles for CF203 (E & F) and LW203 to 205 along XL6 are shown in **Figures 7a** to 7**c**.

The subsidence effect profile predictions have been derived after (i) each panel is extracted, and (ii) on the completion of mining. The profiles are based on the predicted U95%CL subsidence values for the assessment of worst-case impact scenarios.

Credible worst-case subsidence contours for the extended mining layout have been derived using the **SDPS®** program, which has been calibrated to the predicted ACARP model subsidence profiles along XL 6 and 7. The **SDPS®** and **ACARP, 2003** model outcomes are shown in **Figures 7d** to **7f** for subsidence, tilt and strain profiles along XL6.

The predicted **SDPS®** subsidence and tilt profiles were generally located within +/- 10% of the predicted modified **ACARP, 2003** model. This outcome is considered a reasonable fit considering that the **ACARP, 2003** profiles represent measured tilt profiles that are invariably affected by ‘skewed’ or kinked subsidence profiles.

The U95%CL Subsidence, tilt and horizontal strain contours have been determined with the calibrated SDPS model and are shown in **Figures 8a** to **8c** respectively.

9.11 Bearing Capacity of Roof and Floor Strata

Reference to **Pells *et al.*, 1998** indicates that the bearing capacity of sedimentary rock under an isolated, shallow footing (or pillar) is three to five times its UCS strength. Based on the estimated range of UCS values of 31 MPa and 33 MPa in the immediate floor and roof strata, respectively, the general bearing capacity of the strata is estimated to range between 93 MPa and 165 MPa.

The estimated chain pillar stresses of 13.7 MPa to 21.4 MPa give a Bearing Capacity FoS range of 4.3 to 12.

It is concluded that under stress conditions anticipated, the roof and floor strata would likely to behave elastically in regard to confined floor, but in the case where a goaf has developed on both sides of pillars and the roof strata has caved on both sides, there is some concern that the shaley coal roof may not remain as competent as the sandstone floor, without significant adjacent horizontal confinement. Some minor floor heave or localised shearing of immediate roof strata may also occur if conditions are wetter near geological structure.

9.12 Review of Measured Data v. Predictions

The predicted v. measured subsidence effects for LW101 to 109 have also been reviewed to demonstrate the robustness of the prediction models used to date.

The subsidence prediction model used in the approved LW101 to LW105 Extraction Plan had an estimated maximum subsidence of 2.44 m or 0.58T. Although the predicted values were within 15% of the measured values, with S_{max} ranging from 2.45 m to 2.75 m, the model was adjusted to reflect the actual Upper 95% Confidence Limits (U95%CLs) for subsequent panels as follows:

- Single maximum S_{max}/T has been increased to 0.62 from 0.58 (range of 0.55 to 0.62).
- First maximum S_{max}/T has been increased to 0.64 from 0.63 (range of 0.56 to 0.64).
- Final maximum S_{max}/T has been increased to 0.65 from 0.64 (range of 0.57 to 0.65).

The measured and predicted subsidence effects above LW101 to 108A are presented in **Tables 10A** and **10B**. The predicted values are the mean and the U95%CL values.

Table 10A - Summary of Measured and Predicted Subsidence Effects above LW101 to 108A

LW#	Survey Line#	Panel Width, W (m)	Cover Depth, H (m)	W/H	MG Chain Pillar Width, w_{cp} (m)	Average extraction Height, T (m)	Predicted Total Pillar Stress (MPa)	First Maximum Subsidence, First S_{max} (m)		Final Tailgate Chain Pillar Subsidence, S_p (m)		Final Maximum Subsidence, Final S_{max} (m)	
								Predicted*	Meas.^	Predicted	Meas.	Predicted	Meas.
101	CL101N	306.1	165	1.80	30.2	4.2	15.0	2.44 - 2.67	2.57	0.22 - 0.32	-	2.56 - 2.73	2.63
	CL101S	306.1	180	1.70	30.2	4.2	17.1	2.48 - 2.69	2.49	0.28 - 0.46	-	2.56 - 2.73	2.55
	XL A	306.1	160	1.91	30.2	4.2	14.5	2.44 - 2.67	2.44	0.21 - 0.31	0.175	2.56 - 2.73	2.52
102	CL102N	306.4	177	1.75	30.2	4.2	16.8	2.52 - 2.69	2.60	0.27 - 0.46	-	2.56 - 2.73	2.65
	CL102S	306.4	190	1.63	30.2	4.2	18.7	2.52 - 2.69	2.64	0.32 - 0.51	-	2.56 - 2.73	2.69
	XLA	306.4	176	1.75	30.2	4.2	16.6	2.52 - 2.69	2.56	0.27 - 0.45	0.24	2.56 - 2.73	2.63
103	CL103N	306.4	190	1.57	35.3	4.3	15.6	2.58 - 2.75	2.67	0.24 - 0.34	-	2.62 - 2.80	2.70
	CL103S	306.4	200	1.53	35.3	4.3	18.8	2.58 - 2.75	2.49	0.33 - 0.42	-	2.62 - 2.80	2.58
	XLA	306.4	190	1.57	35.3	4.3	17.6	2.58 - 2.75	2.59	0.30 - 0.39	0.23	2.62 - 2.80	2.68
104	CL104N	306.4	180	1.66	35.3	4.3	15.9	2.54 - 2.75	2.75	0.25 - 0.34	-	2.62 - 2.80	2.80
	CL104S	306.4	220	1.43	35.3	4.3	21.6	2.52 - 2.75	2.69	0.42 - 0.61	-	2.62 - 2.80	2.70
	XLA	306.4	215	1.43	35.3	4.3	21.5	2.53 - 2.75	2.49	0.42 - 0.60	0.44	2.62 - 2.80	2.62
105	CL105N	306.4	200	1.53	39.5	4.3	17.3	2.58 - 2.75	2.66	0.29 - 0.38	-	2.62 - 2.80	2.66
	CL105S	306.4	235	1.30	39.5	4.3	22.8	2.48 - 2.71	2.53	0.46 - 0.55	-	2.62 - 2.80	2.54
	XLA	306.4	240	1.30	39.5	4.3	23.2	2.46 - 2.69	2.39	0.48 - 0.57	*0.45*	2.62 - 2.80	-
106	CL106N	306.4	220	1.39	2 x 28.1	4.3	16.5	2.49 - 2.75	2.49	0.27 - 0.45	-	2.62 - 2.80	-
	XLA	306.4	255	1.20	2 x 28.1	4.3	19.7	2.45 - 2.72	2.50	0.36 - 0.55	-	2.62 - 2.80	2.61
107	CL107N	408.8	240	1.72	2 x 30.1	4.3	18.9	2.58 - 2.75	2.65	0.31 - 0.49	-	2.62 - 2.80	2.77
	XLH	408.8	245	1.72	2 x 30.1	4.3	18.4	2.58 - 2.75	2.67	0.32 - 0.51	0.18	2.62 - 2.80	2.69
108A	CL108N	408.9	280	1.47	2 x 33	4.3	21.6	2.54 - 2.75	2.52	0.39 - 0.58	-	2.62 - 2.80	-
	XLH	408.9	260	1.64	2 x 33	4.3	20.3	2.54 - 2.75	2.50	0.38 - 0.57	0.20	2.62 - 2.80	2.55
109	XLH	408.9	290	1.41	2 x 34	4.3	22.3	2.58 - 2.75	2.62	0.44 - 0.63	-	2.62 - 2.80	-

- XL = Crossline; CL = Centreline

* - Predicted values are mean to U95%CLs.

^ - Meas. – Measured. Subsidence measurements may exceed the predicted U95%CL values by up to 15% for 5% of the time (i.e. occasionally).

italics - estimated final values.

Table 10B - Summary of Measured and Predicted Subsidence Effects above LW101 to 108A

LW #	Survey Line	Final Goaf Edge Subsidence, S_{goe} (m)		AoD to 20 mm Subsidence Contour (°)		Maximum Tilt, T_{max} (mm/m)		Maximum Compressive Strain, $-E_{max}$ (mm/m)		Maximum Tensile Strain, $+E_{max}$ (mm/m)		Flat Terrain Crack Widths* (mm) (sandy or loamy soils)	
		Predicted	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Measured**
101	CL101N	0.15 - 0.33	0.31	22.4 - 42.4	23.0	46 - 70	46.3	25 - 50	15.9	23 - 46	11.4	230 - 460	100 - 200
	CL101S	0.15 - 0.33	0.11	22.4 - 42.4	13.7	41 - 62	31.1	21 - 42	15.6	20 - 39	9.2	200 - 390	100 - 200
	XLA	0.15 - 0.33	0.11-0.09	22.4 - 42.4	11 - 23.5	48 - 72	49.5 - 54.3	26 - 53	12.3 - 14.4	25 - 49	13.5 - 15.0	250 - 490	100 - 200
102	CL102N	0.15 - 0.33	0.21	22.4 - 42.4	15.5	42 - 63	42.1	22 - 43	40.4	20 - 41	19.3	200 - 410	100 - 200
	CL102S	0.15 - 0.33	0.16	22.4 - 42.4	20.6	38 - 57	29.8	19 - 38	17.2	18 - 35	7.4	180 - 350	100 - 200
	XLA	0.15 - 0.33	0.17	22.4 - 42.4	14.0	42 - 64	48.6 - 56.3	22 - 44	12.3 - 26.7	20 - 41	15.2 - 19.1	200 - 410	100 - 200
103	CL103N	0.15 - 0.34	0.25	22.4 - 42.4	23.4	39 - 59	39	19 - 38	27.9	18 - 36	14.7	180 - 360	100 - 200
	CL103S	0.15 - 0.34	0.16	22.4 - 42.4	14.0	36 - 55	30.3	17 - 35	8.5	16 - 32	9.3	160 - 320	100 - 200
	XLA	0.15 - 0.34	0.25	22.4 - 42.4	23.2	39 - 59	29.1 - 36.6	19 - 38	6.5 - 9.6	18 - 36	11.7 - 13.1	180 - 360	100 - 200
104	CL104N	0.15 - 0.34	0.18	22.4 - 42.4	19.9	42 - 64	41.7	21 - 43	35.6	20 - 40	*42.6*	200 - 400	100 - 200
	CL104S	0.15 - 0.34	0.27	22.4 - 42.4	23.4	32 - 48	31.2	14 - 29	6.7	13 - 27	8.1	140 - 300	100 - 200
	XLA	0.15 - 0.34	0.24	22.4 - 42.4	24.9	33 - 49	30.3 - 32.5	15 - 30	4.7 - 14.4	14 - 28	7.8 - 11.5	150 - 300	100 - 200

Table 10B (Cont…) - Summary of Measured and Predicted Subsidence Effects above LW101 to 108A

LW#	Survey Line	Final Goaf Edge Subsidence, S_{goe} (m)		AoD to 20 mm Subsidence Contour (°)		Maximum Tilt, T_{max} (mm/m)		Maximum Compressive Strain, $-E_{max}$ (mm/m)		Maximum Tensile Strain, $+E_{max}$ (mm/m)		Flat Terrain Crack Widths* (mm) sandy to (heavy clay/shallow rock)	
		Predicted	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Meas.**	**Predicted**	**Measured [95th-pc]**
105	CL105N	0.15 - 0.34	0.28	22.7 - 42.7	26.0	36 - 55	46.3	17 - 35	**39.9**	16 - 32	17.4	160 - 320 (640)	100 - 200
	CL105S	0.15 - 0.34	0.19	22.7 - 42.7	30.8	29 - 43	23.4	13 - 25	8.6	12 - 24	6.1	140 - 280 (560)	100 - 200
	XLA	0.15 - 0.34	0.22	22.7 - 42.7	32.5	28 - 42	25 - 28.7	12 - 29	5.2 - 9.8	11 - 23	6.7 - 7.3	140 - 270 (540)	100 - 200
106	CL106N	0.15 - 0.34	0.26	22.7 - 42.7	22.9	32 - 48	28.1	11 - 28	12.2	13 - 27	7.1	150 - 300 (600)	100 - 200
	XLA	0.15 - 0.34	0.23	22.6 - 42.7	25.3	26 - 38	27.1 - 22.6	10 - 21	9.1 - 13.2	10 - 20	8.3 - 11.5	130 - 260 (520)	100 - 200
107	CL107N	0.15 - 0.34	0.32	22.7 - 42.7	20.8	28 - 42	21.3	12 - 24	9.2	10 - 20	8.4	135 - 270 (540)	70 - 480 [460]
	XLH	0.15 - 0.34	0.29	22.7 - 42.7	40.0	28 - 42	30 - 32	12 - 23	6.4	11 - 23 (46)	7.0 - 9.9	135 - 270 (540)	10 - 600 [450]
108A	CL8N	0.15 - 0.34	0.23	22.7 - 42.7	*44.0*	22 - 33	22 - 27	9 - 18	*16.0*	8 - 17 (34)	**35.4**	115 - 230 (460)	80 - 500 [400]
	XLH	0.15 - 0.34	*0.37*	22.7 - 42.7	**>54 *(58)***	25 - 37	19 - 23	10 - 21	*5.4*	10 - 19 (38)	8.5 - 15.4	125 - 250 (500)	20 - 680 [600]
109	XLH	0.15 - 0.34	*0.31*	22.7 - 42.7	**>42**	21 - 32	30 - 32	8 - 16	*7.9*	8 - 15 (30)	5.9 - 8.9	115 - 230 (460)	10 - 650 [400]

Predicted values are mean to U95%CLs; Meas. = Measured; ***Italics*** - measured effect exceeds the predicted value by <15%;
Goaf edge subsidence, and AoD, tilt and strain measurements may exceed the predicted U95%CL values by approximately 1.15, 1.2 and 2 times, respectively, 5% of the time (i.e. occasionally). **Bold** - measured effect value exceeds prediction by more than limits indicated for the given parameter (e.g. S_{max} > 15%, T_{max} > 20% and E_{max} > 50%).
(58) - extrapolated value;* - crack width prediction method is discussed in **Section 10.2**; Note: mm/m = millimetres per metre; [95th-pc] - 95th percentile of population sample.

The results indicate the measured maximum subsidence values are within the predicted ranges.

The chain pillar subsidence model appears to be conservative, with measured values to-date plotting below the predicted mean curve in **Figure 6k**.

Less than 5% of the predicted goaf edge subsidence values and AoD predictions have been exceeded by >15% (**Figures 6i** and **6j**). It is noted however, that the exceedances have occurred above one or two of the wider longwalls, LW107 and 108A. The measured AoD to the 20 mm subsidence line also appears to show significant variation from the sides and ends of the panels as follows:

- AoD to 20 mm of subsidence from panel sides (ribs): 11° to >54° (mean of 28°)

- AoD to 20 mm of subsidence from panel ends: 13.7° to 44° (mean of 21°)

The maximum AoD of > 54° was measured along crossline H with a subsidence of 37 mm recorded at the end of the crossline after LW108. A similar outcome was measured after LW109 with a subsidence of 35 mm at a draw angle of 42°.

The AoD values for Narrabri are still within the AoD ranges observed at other deep coalfields (Southern and Western Coalfield). It is possible that the sandier soils to the west have caused the increase, including the greater abutment loading likely to have occurred over solid coal to the west. Further monitoring data is therefore required to establish the typical AoD values for the wider longwalls at Narrabri.

The following U95%CL values have therefore been adopted for the previous and proposed longwalls:

- **Panel sides:** 42.7° or 0.92H for W/H > 1.2 and increasing to 49.6° or 1.17H at a W/H = 0.9 (LW209).

- **Panel ends:** 31° or 0.6H for all W/H

The measured crack widths of 10 mm to 680 mm above LW107 to 109 have generally been within the predicted ranges (see **Section 10.2** for further details). It is understood that all cracks > 50 mm wide have been rehabilitated after active subsidence was complete and have not re-appeared.

The measured centreline subsidence profiles are shown in with the predicted subsidence effect profiles in **Figures 9a** to **9k**.

The empirical models used to estimate maximum tilt, curvature and strain are also presented with measured Narrabri Mine data in **Figures 6l** to **6o**, respectively. Points of note include:

- The maximum tilt database is satisfactorily captured by the empirical model (**Figure 6l)**.
- Convex and concave curvature models capture 90% of the database (**Figures 6m** and **6n**) with some exceedances apparent due to discontinuous behaviour (due to cracking and shear failure of the rock mass).
- Supercritical width appears to occur between 1.2H and 1.4H, based on measured tilts, curvatures and strains at the Narrabri Mine to-date.
- The Maximum Horizontal Strain = 10 x Maximum curvature for continuous or ‘smooth’ subsidence profiles. This formula also represents the mean value for the mining geometry. Discontinuous movements, such as cracking and compression heaving (uplift) or shear failures, may increase the predicted ‘smooth’ profile or mean curvature values by greater than 2 times. The U95%CL strain values may therefore be assessed from 20 times the predicted mean curvature (**Figure 6o**).

Based on the above, the measured subsidence effect profiles for crossline XLA & H are compared to the predicted subsidence, tilt, curvature and horizontal displacement and strain profiles in **Figures 9a** to **9c**.

Based on the model validation work, it is concluded that the subsidence model should produce reasonably conservative predictions for the proposed LW203 to 205.

9.13 Practical Angle of Draw to Sensitive Surface Features

The design of mining layouts that have been approved by the NSW Department of Planning, Industry and Environment have applied what are known as "practical angles of draw" (first defined in **Holla, 1985**). These are conservative angles of draw that recognise the potential variability in actual draw angles but will probably result in negligible surface impacts outside their limits.

The Southern and Western Coalfields of NSW best illustrates the limitations of the traditional use of the draw angle concept where the depth of cover typically ranges between 350 m to 500 m. Longwall mining produces angles of draw which extend for hundreds of metres beyond the edge of extraction (angles of draw to 20 mm of subsidence typically ranges from 10^o to 58^o or between 0.2 to 1.6 times the depth of cover).

More importantly, the subsidence profile outside a finite distance is mostly ‘smooth’ producing very low tilts, curvatures and strains. Numerous studies of differential subsidence (tilt, curvature and strain) outside of longwall extraction have demonstrated that potentially damaging deformations to natural and built features are unlikely to occur outside an AoD of 26.5^o (i.e. 0.5 times the cover depth). Practical angles of draw therefore provide limits to the differential movements such as tilt, curvature and strain to tolerable magnitudes, rather than attempt to limit subsidence to 20 mm.

In the NSW Coalfield's, the practical or design AoD applied to sensitive features is typically 26.5^{o} and has been applied successfully to cliff lines, waterways and sensitive archaeological sites. In some instances, an additional buffer zone has been added to the design AoD to allow for uncertainties in final mining limits and geological and/or topographical factors.

The effectiveness of the design AoD of 26.5^{o} at the Narrabri Mine can be demonstrated by reviewing the AoD to the key impact parameters of tilt, curvature and strain that have been measured to-date. Reference to **NERRDP, 1993** and **Holla and Barclay, 2000** indicate the following subsidence profile limits are appropriate for minimising impact to sensitive environmental or Aboriginal Heritage features:

- Subsidence: 50 - 100 mm.
- Tilt: 1.5 - 2 mm/m.
- Curvature: 0.05 - 0.1 per kilometre (km^{-1}) (radius of curvature > 10 km).
- Tensile Strain: 0.5 - 1.5 mm/m.
- Compressive Strain: 1 - 2 mm/m.

The limits above also take into account the survey accuracy limits for the available data.

The measured impact parameters at a 26.5^{o} AoD to the above parameters at the Narrabri Mine are summarised in **Table 10C**. Histograms of the measured subsidence, tilt and tensile strain values measured at or outside a distance equivalent to the 26.5^{o} AoD is presented in **Figures 9l** to **9n**.

It is apparent from the results in **Table 10C** that a design AoD of 26.5^{o} from the sides and ends of longwall panels to sensitive surface features is unlikely to impact a given feature.

Table 10C - Summary of Practical Angle of Draw Limits

Impact Parameter Limit	Measured Impact Parameters at or outside a 26.5o AoD		
	Crosslines	**Centrelines**	**All Data**
Subsidence (mm)	24 - 81	1 - 45	1 - 81
Tilt (mm/m)	0.1 - 0.6	0.1 - 1.2	0.1 - 1.2
Curvature (km^{-1})	0.01 - 0.1	0.01 - 0.11	0.01 - 0.11
Horizontal Tensile or Compressive Strain (mm/m)	*0.1 - 1.1*	*0.3 - 1.1*	*0.1 - 1.1*

Italics - Total Station strains are likely to be limited by survey accuracy limits of +/- 1 mm/m.

Based on measured values to-date, the AoD of 26.5^{o} (0.5 times cover depth) is considered to be an appropriate value for mine planning and impact management purposes near sensitive surface features due to the low horizontal strains (less than 1 mm/m) associated with AoD values > 26.5^{o}.

10.0 Impact Assessment for the Natural Features

10.1 General

The likely extent of the predicted subsidence, tilt and strains (i.e. subsidence effects) associated with the proposed longwall panel layout have been calculated to enable various consultant's assessments of the impacts upon and development of management strategies for the existing natural features and developments of the EP Area.

Due to the uncertainties associated with mine subsidence prediction for a given mining geometry and geology, a credible range of impact outcomes (based on probabilistic design methodologies) have been provided to assist with the development of effective subsidence management plans for the existing site features.

Discussions of likelihood of impact occurrence in the following sections generally refer to the qualitative measures of likelihood described in **Table 11**, and are based on probabilistic terms used in **AGS, 2007** and **Vick, 2002**.

Table 11 - Qualitative Measures of Likelihood

Likelihood of Occurrence	Event implication	Indicative relative probability of a single event
Almost Certain	The event is expected to occur.	90 - 99%
Very Likely	The event is expected to occur, although not completely certain.	75 - 90%
Likely+	The event will probably occur under normal conditions.	50 - 75%
Possible	The event may occur under normal conditions.	10 - 50%
Unlikely*	The event is conceivable, but only if adverse conditions are present.	5 - 10%
Very Unlikely	The event probably will not occur, even if adverse conditions are present.	1 - 5%
Not Credible	The event is inconceivable or practically impossible, regardless of the conditions.	< 1%

Notes:
+ - Equivalent to the mean or line-of-best fit regression lines for a given impact parameter presented in **ACARP, 2003**.
* - Equivalent to the worst-case or U95%CL subsidence impact parameter in **ACARP, 2003**.

The terms 'mean' and 'credible worst-case' used in this report generally infer that the predictions would be exceeded by 50% and 5% of the time, respectively, for panels with similar geometry and geology. Using lower probability of exceedance values (i.e. < 5% probability of exceedance) may result in false-positives or potentially uneconomic mining layouts (i.e. if impacts were to be over-predicted and subsidence control zones implemented based on these over-predictions).

10.2 Surface Cracking in Flat Terrain

10.2.1 General

The development of surface cracking above a longwall panel is caused by the bending of the overburden strata as it sags down into the newly created void in the coal seam. The sagging strata is supported by previously collapsed roof material (goaf), which then slowly compresses until maximum subsidence is reached.

The tensile cracks generally occur between the panel ribs (i.e. chain pillar sides adjacent to extracted panel) and the point of inflexion, which is where convex curvatures and tensile strains will develop. The point of inflexion will move inwards from the panel ribs as cover depth increases. For the proposed LW203 to 205 it will be located between 78 m and 112 m from the panel ribs. Tensile cracks can also develop above chain pillars that are located between extracted panels.

Based on reference to **ACARP, 2003**, the cracks will probably develop by the time the longwall face has retreated past a given location for a distance equal to one to two times the cover depth (170 m to 840 m at the Project).

Cracks usually develop within several days after a longwall face has retreated beneath a given location, with some of the cracks closing in the compression zone in the middle of the fully developed subsidence trough, together with new cracks developing in the tensile zones along and inside the panel sides two or three weeks later.

The cracks in the tensile strain zones would probably be tapered and extend to depths ranging from 5 m to 10 m, and possibly deeper in near surface rock exposures on steep slopes. The cracks in the tensile zone also usually occur in groups of three to five and at a spacing of 3 m to 8 m.

Cracks within compressive strain zones are generally low-angle shear cracks caused by failure and heaving of near surface strata. Some tensile type cracks can also be present due to buckling and uplift of near surface rock if present in the central zones of the panels (see **Section 10.6** regarding valley closure).

In flat terrain, surface crack widths (in mm) may be estimated by multiplying the predicted strains by 10 m or the typical peg spacing that is normally based on cover depth/20 and assuming all of the strain may concentrate at a single crack. The crack widths are expected to be wider along rocky slope crests than in flat areas with deep sandy soil cover.

Observed crack widths on steep rocky slopes in Newcastle Coalfield have been found to be a function of the measured strain and tilt, near surface lithology and topographic relief relative slope height. They are typically wider and deeper than flat terrain cracks and tend to develop on the high side of longwall panels. Compressive strain concentrations and heaving along the low side of a longwall panel is also apparent on steep slopes.

Undermining ridges can also result in surface cracks migrating up-slope and outside the limits of extraction for significant distances due to rigid block rotations. This phenomenon will depend upon the slope geometry, vertical jointing and the tilt of the slope. In steep terrain in the Newcastle Coalfield the cracks can migrate outside the limits of longwall extraction for distances up to 0.2 x cover depth (an effective draw angle of 11°).

Further discussion on estimating crack widths in flat terrain is presented in **Section 10.2.2**. Estimating crack widths on steep slopes is presented in **Section 10.4**.

10.2.2 Review of Observed Surface Cracking and Remedial Works at the Narrabri Mine

Narrabri Mine Subsidence Management Status Reports for LW101 to 104 (**NCOPL, 2015**) indicate that observed surface cracks above the 306 m wide longwalls have typically ranged from 50 mm to 100 mm wide with some cracking up to 200 mm wide. Reference to the NM Subsidence Management Status Report No. 9 (13/04/15) indicates that surface cracks observed above LW101 to LW104 have typically ranged from 50 mm to 100 mm wide, with some cracking up to 200 mm.

The surface crack width estimates for LW107 to 111 at the Narrabri Mine, ranged from 20 mm to 250 mm within the limits of extraction (**DgS, 2015**). The crack width estimates were based on the predicted range of maximum transverse tensile strains (i.e. 2 mm/m to 25 mm/m) given for the approximately 409 m wide longwall panels multiplied by the peg spacing of 10 m.

Inspections of surface cracking above LW107 and 108 (December 2019) identified the following crack impacts (**Appendix A** [**Photo 19**]):

- Two 400 mm wide x 30 m long arcuate cracks striking at 345° (north-west to south-east) and spaced at 13 m above LW107 rib side where cover depth was 240 m. The cracks could be measured to a depth of 300 mm to 600 mm with a tape measure, but likely to have extended deeper than 1 m or 2 m.

- Two East/West (280°) striking cracks with a width of 400 mm and depth of 1.5 m were observed at the north-east corner of LW108A where cover depth was 280 m.

- Several North/South orientated cracks with widths ranging from 1.0 m to 1.8 m above the chain pillars between LW107 and 108A were observed along a similarly orientated tributary of Pine Creek. The cover depth was 250 m and measured tensile strains were approximately 10 mm/m, so the development of cracks due to mine subsidence was feasible. The cracks were 800 mm deep and flat bottomed, suggesting the features were mainly formed by erosion after several storm events.

  It is considered likely that recent rains (85 mm in March, 33 mm in May and 16 mm in November 2019 according to the Turrawan weather station data at www.bom.gov.au) had eroded the cracking out to widths observed. It was noted during the pre-mining inspections that incised erosion to depths of up to 4 m is a typical of the geomorphological patterns in the terrain.

Based on the observations, it was decided to increase the crack width estimates for future longwalls by multiplying the predicted strains by an effective peg spacing of H/20 or 10 m (whichever is greater). A conservative factor of 2 has also been used to allow for strain concentration effects to estimate U95%CL values. The revised predictions are given for single flat terrain crack as follows:

Crack width, δ = maximum of H/20 or 10 m peg spacing x maximum tensile strain x strain concentration factor of 1 for cohesionless soil (i.e. sandy or loamy soil) or 2 for cohesive soil (heavy clay) or shallow bedrock.

For a cover depth of 280 m at the starting end of LW108A, the maximum predicted mean and U95%CL tensile strain of 8 mm/m and 16 mm/m respectively (see **Table 10B**). The mean and U95%CL crack widths (δ) are therefore:

mean δ = 280/20 x 8 x 1 = 112 mm (deep cohesionless soils)

mean δ = 280/20 x 8 x 2 = 224 mm (deep cohesive soils or shallow rock)

U95%CL δ = 280/20 x 16 x 1 = 224 mm (deep cohesionless soils)

U95%CL δ = 280/20 x 16 x 2 = 448 mm (deep cohesive soils or shallow rock)

As the measured tensile strain was 35 mm/m (approximately double the predicted strain) and the crack width was 400 mm in deep cohesive soils, the predicted crack width estimates are considered reasonable.

A similar result is obtained for the 400 mm wide cracking observed above LW107 with measured tensile strains of 8.4 mm/m to 9.9 mm/m. Predicted tensile strains range from 11 mm/m to 22 mm/m. Estimated crack widths are 263 mm and 525 mm for cohesionless and cohesive soils respectively.

The increased crack widths for LW107 and 108A are possibly related to (i) surface erosion and/or (ii) higher strain magnitudes due to first goafing of these panels.

The mine has established a crack monitoring register that records the width, depth and length of cracks prior to rehabilitation (refer to NOCPL Internal Memorandums - Environmental Monitoring (Subsidence Crack Repairs - Inspections between July 2017 to November 2020).

The reports indicate initial crack widths above LW107 to 109 have ranged between 10 mm to 680 mm with a median of 140 mm and 95th percentile of 500 mm. As was observed before, the photos indicate that the cracks in sands are affected by erosion with the side walls slumping and infilling the cracks to some degree. Multiple cracks in groups of two to five have also formed and in some instances have coalesced to form a wider area of surface disturbance. The slumped and coalesced cracks have ranged in width from 700 mm to 2000 mm in areas with a maximum depth of 0.5 m. The full depth of cracking in sandy areas are difficult to measure due to the side wall slumping and has ranged from 0.1 m to 2.4 m (median of 0.3 m and 95th perc. of 1.2 m). The length of cracking has ranged from 2 m to 994 m (median of 17 m and 95th perc. of 60 m).

Small potholes with diameters < 0.1 m can form where dispersive clay soils exist and 'piping' occurs into rock-head cracks near the surface. The potholes are likely to eventually link up to form a collapsed trench or depression feature above the rock-head crack after a period of time (depends on rainfall).

Histograms of measured crack geometry statistics (width, depth and length) at Narrabri (and Newcastle Coalfield) are presented in **Figures 13d** to **13f**. The data is from relatively flat terrain and supercritical longwall geometries. The results indicate similar crack widths have developed in the two mining areas. As discussed earlier, the measured crack depths at Narrabri are likely to be lower than actual depths, based on observed slumping along cracks and Newcastle observations in cohesive (clayey) soils. The Newcastle values have been used in subsequent impact assessments involving subsurface cracking interaction with surface cracking zone and steep slope impacts.

Cracks above LW101 to 109 were remediated (filled in and ploughed) after active subsidence was complete. Re-seeding of ploughed areas is only done when there is enough soil moisture present or rain to enable vegetation re-growth.

It is possible that repaired cracks in dispersive clay soil areas re-appear several years after initial repair and may need to be rehabilitated again. The application of gypsum to the soils (or equivalent non-dispersive backfill) may be required to reduce soil dispersion and sinkhole / piping re-development. Dispersion (Emerson Class) testing of soil samples should be undertaken to determine gypsum application rates (usually 8 - 13 kg/ha as a guide).

10.2.3 Predicted Effects and Impacts

Based on the predicted range of maximum transverse tensile strains for the proposed panels (i.e. 9 mm/m to 31 mm/m), surface crack widths are estimated to range from approximately 130 mm to 320 mm in cohesionless soils and from approximately 260 mm to 640 mm in cohesive soils or shallow rock.

The predicted crack widths for each longwall are given in **Table 12**.

Table 12 - Predicted Maximum Crack Widths for Proposed Panels in Flat Terrain

LW	XL	Panel Width W (m)	Cover Depth H (m)	Panel W/H	Effective Bay Length (m)	Predicted Maximum Tensile Strain (mm/m)		Predicted U95%CL Crack Width (mm)	
						Mean	U95%	Sand or Loam	Clay or Rock
CF201-CF205	6	235	182	1.29	10.0	7	31	310	620
	6	273	210	1.30	10.5	7	31	325	650
203	6	402.9	214	1.88	10.7	15	29	310	620
	7	402.9	207	1.95	10.4	15	31	320	640
204	6	402.4	238	1.69	11.9	12	24	295	590
	7	402.4	244	1.65	12.2	11	23	295	590
205	6	399.7	263	1.52	13.2	10	20	265	530
	7	399.7	280	1.43	14.0	9	17	240	480

The above crack widths are U95%CL values, which means they may be exceeded 5% of the time (by definition) due to adverse topographic or geological conditions. For example, it has been noted that in steep terrain around Newcastle, the crack widths are increased (once they occur) in direct proportion to the measured tilts causing rigid body rotation of the slopes.

Whilst this effect is unlikely to occur above CF201-CF205 & LW203 to LW205 generally, the crack widths may exceed the predicted range near the crests of steep creek banks or elevated ridges. The steep rocky slopes above LW204 and LW205 (S12) are considered likely to be impacted by surface cracking > 300 mm wide (**Section 10.4** contains further discussion on steep slope effects).

Based on the above, it is estimated that approximately 0.02 km^2 to 0.04 km^2 of the surface would be crack affected. This represents 0.13% to 0.27% of the extracted longwall area.

10.2.4 Impact Management Strategies

The practical options available for managing surface fracturing are limited to (in order of increasing impact to mining):

- Post-mining inspections the surface during subsidence development above a given panel and map crack locations and their geometry (widths, lengths, depth, photograph).
- Repair large surface cracks after subsidence development for a given longwall.
- Leave a barrier pillar or increase set-back distances from a sensitive area or restrict mining in pillar reduction panels.

Surface crack repair works such as ripping or tyning (re-seeding or filling cracks with free-draining, durable gravel into large, deep cracks) may need to be implemented around the affected areas and in particular, any ephemeral watercourses that do not infill naturally with sediment due to natural geomorphic processes. Any remediation of watercourses should be undertaken in consultation with the relevant government agencies.

Non-conventional monitoring techniques such as drone surveys for large crack location detection above the woodland areas is suggested.

Steep slope cracking impacts are discussed in **Section 10.4**.

10.3 Sub-Surface Cracking

10.3.1 General

As noted in **Li *et al.*, 2006**, 'the transmission of water through the overburden strata may [occur] via a number of mechanisms such as (i) inter-granular porosity, (ii) mining induced voids, fractures and strata dilation/bed separations and (iii) structural discontinuities/geological defects [faults and dykes]'.

The void created by extracting coal invariably results in the collapse of the immediate roof strata, which is subject to bending and shearing stresses, as the overburden tries to span the void created by mining. The extent of fracturing and shearing up through the strata is dependent on mining geometry and overburden geology.

International and Australian research on longwall mining interaction with groundwater systems indicates that the overburden may be divided into essentially four or five zones of surface and sub-surface fracturing (**Figures 10a** and **10b**). The zones are based on the **Forster, 1995** and **ACARP, 2007** models and are defined (in descending order) as follows:

- Surface Cracking Zone (D-Zone) – Unconstrained.
- Elastic Deformation Zone (C-Zone) – Constrained.
- Discontinuous or Minor Fracture Zone (B-Zone) – Constrained.
- Continuous Fracture Zone (A-Zone) – Unconstrained.
- Caved Zone (included in the A-Zone) – Unconstrained.

The prediction of connective sub-surface fracture network heights above longwall panels over the past 40 years has been based on several simple empirical models that have allowed successful mining beneath permanent water bodies such as Lake Macquarie in the Newcastle Coalfield, water supply dams in the Southern Coalfield and relatively shallow depths of cover (< 150 m) below creeks and rivers without causing surface to seam or aquifer to seam connection.

Several instances of unanticipated cracking and drainage of near-surface alluvial and confined aquifers have occurred over the years in NSW (and internationally) however and have led to further research into improving our understanding of the sub-surface crack development process and the height of fracture zone estimates above longwall and pillar extraction panels.

The research to-date has identified the following key parameters should be considered when making robust sub-surface fracture height predictions:

- Panel width (W).

- Average extraction height (T).
- Cover depth (H).
- Panel criticality (i.e. sub-critical or supercritical).
- Presence of massive sandstone or conglomerate strata that may control continuous fracture height development.
- Constrained Zone lithology and thickness required to control inter-connective cracking between surface and seam, or aquifer and seam.
- Presence of geological structure (faults/dykes/joint swarms) that have an increased level of fracturing and therefore higher secondary conductivity.

Several of the current models in use in NSW consider only one or two of the above parameters, such as W or T, because they were developed in a coalfield with a particular geometry and consistent geology, and generally provided satisfactory results. However, it is apparent that as mines are developed in other coalfields or mining geometries and/or geology changes within a coalfield, these models can significantly under-predict or over-predict the sub-surface fracture heights (if the key controlling factor or factors present at the new locations are no longer included in the simplified models).

All of the above factors have now been considered in this assessment for the EP Area using the Pi-Term empirical models (**Ditton and Merrick, 2014**). The models have been validated to measured NSW case studies with a broad range of mining geometries and geological conditions. The Pi-Term models are based on a conceptual model of the sub-surface fracturing that develops above a longwall panel with varying mining geometry and geology (**Figure 10c**).

A database of measured (interpreted) heights of A-Zone and B-Zone fracturing have been linked to several dimensionless ratios of the key parameters mentioned above. Non-linear regression techniques have been applied to derive curves of best fit with a R^2 of 0.80 for the A-Zone and 0.86 for the B-Zone (using the Geology Pi-Term Model). The R^2 value for the Geometry Pi-Term Model decreases to 0.61 (when no geological parameter is included).

The conceptual model demonstrates that longwall panel geometries and overburden geology determine the height of ‘continuous’ and ‘discontinuous’ fracturing. Continuous fractures above the mine workings tend to form up into the overburden at an angle of 12^o to 19^o from the rib sides, based on physical and numerical modelling observations and subsidence data (**Figure 10d**).

The extent of vertical fractures above the mine workings (i.e. the A-Zone) would also be dependent on the effective strata thickness that either: (i) spans the goaf, or (ii) sags down onto it with limited fracturing through the ‘beam’. The presence of ‘swelling’ clay-rich rocks in the upper, non-caved portions of the overburden are also a significant factor in limiting hydraulic connectivity between the mine workings and the surface.

A review of measured heights of A-Zone fracturing and borehole data above longwall panels in NSW and Queensland Coalfields in **Ditton and Merrick, 2014** demonstrates the overburden develops an effective strata unit thickness (t’) that limits the A-Zone at a given height above a longwall (**Figure 10d**).

The results indicate that the effective thickness of the strata units is influenced by the geology of the coalfield and the mining geometry. Ignoring this parameter may result in database bias when applying the model in different coalfields. The t' may also be calibrated to local mine site data and also allows a minimum value to be applied where no massive spanning units exist (**Section 10.3.3**).

It is therefore considered that the Geology Pi-Term Model is superior to the Geometry Pi-Term Model as the t' factor may be back-analysed to local height of A-Zone fracture height measurements once mining commences. Examples of back-calibration of the t'-factor are shown in **Figure 10e**.

Continuous sub-surface fracture height predictions (A) for LW101 to 111 and LW201 to 210 have subsequently been made based on the following empirical prediction models from several NSW Coalfields:

- Geometry Pi-Term Model ($A = 2.215W'^{0.357} H^{0.271}T^{0.372}$) (**Ditton & Merrick, 2014**).
- Geology Pi-Term Model ($A = 1.52W'^{0.4}H^{0.535}T^{0.464} t'^{-0.4}$) (**Ditton & Merrick, 2014**).
- Complete Depressurisation Height-based Model ($A = 1438 \ Ln[(4.315x10^{-5})(W.H^{0.2} T^{1.4})+0.9818]$) (**Tammetta, 2013**).
- Panel Width-based model (A = 1.0W - 1.5W) (**SCT, 2008**).
- Mining Height-based model (A = 21 - 33T) (**Forster, 1995**) and 43T (**CSIRO, 2007**).

10.3.2 Geometry Pi-Term Model

The Geometry Pi-Term Model was developed in 2013-14 in response to several concerns raised by the Bulli Seam Operations PAC in regard to large apparent differences between established prediction methods that use only one parameter in a particular coalfield (e.g. the extraction height v. panel void width models).

The Geometry Pi-Term Model considers the influence of the panel width, cover depth and extraction height on the height of continuous fracturing above a longwall panel. A dimensionally consistent product and power rule has been derived using non-linear regression analysis of measured cases. The model considers the key mining geometries and indirectly includes the influence of a wide range of geological conditions.

The Pi-Terms have been derived (by experiment) using Buckingham's Pi-Term theorem, and refer to the dimensionless ratios of key independent variables with a repeating variable of influence (the panel width) as follows:

<u>A-Zone Prediction Model</u>

Mean $A/W' = 2.215 (H/W')^{0.271}(T/W')^{0.372}$ ($R^2 = 0.61$ & root mean square error =21%)

U95%CL A/W' = Mean A/W' + a

where

a = 0.16 for *sub-critical panels (W/H < 0.7)*, 0.16 - 0.085(W/H-0.7) for *critical* and 0.1 for *supercritical* panels (0.7 < W/H < 1.4);

H = cover depth = maximum potential goaf load height;

W' = effective panel width = minimum of W and 1.4H; and

T = average extraction height.

Re-arranging the above equation in terms of A gives:

$A = 2.215W^{0.357}H'^{0.271}T^{0.372}$ +/- aW'

B-Zone Prediction Model

The heights of the B-Zone may also be estimated using a similar approach to the A-Zone methodology:

Mean B/W' = 1.621 $(H/W')^{0.55}(T/W')^{0.175}$ $R^2 = 0.86$ & rsme = 0.12W' (13%)

U95% B/W' = Mean B/W' + b

where

b = 0.16 for sub-critical panels, 0.16-0.085(W/H-0.7) for critical panels and 0.10 for supercritical panels.

Re-arranging the above equation in terms of B gives:

$B = 1.621\ W'^{0.275}H^{0.55}T^{0.175}$ +/- bW'

10.3.3 Geology Pi-Term Model

Further to the Geometry Pi-Term Model, the Geology Pi-Term Model also considers the influence of the effective strata unit thickness. The effective strata unit thickness refers to the thickness of the beam that limits the height of continuous fracturing above a longwall panel. Using a product and power rule and non-linear regression analysis of measured cases, the range of effective beam thicknesses for a given mining geometry was derived for the NSW and Queensland Coalfields (**Figure 10e**).

A-Zone Prediction Model

Mean A/W' = 1.52 $(H/W')^{0.535}(T/W')^{0.464}(t'/W')^{-0.4}$ $R^2 = 0.8$ (rmse=15%)

U95%CL A/W' = Mean A/W' + a

where

a = 0.15 for *sub-critical*, 0.15 - 0.0714(W/H-0.7) for *critical* and 0.1 for *supercritical* panels;

H = cover depth or maximum potential goaf load height;

W' = effective panel width = minimum of W and 1.4H;

T = extraction height; and

t' = effective strata unit thickness in the overburden above the A-Zone and ranges between 16 m and 54 m across the Newcastle Coalfield and includes cases with and without spanning strata units. A value of 20 m is considered a reasonable value to use when no spanning units are present. It also correlates with surface subsidence profiles and the best-fit curve through maximum strain v. curvature data of 10 (i.e. the depth to the neutral axis of bending or half the beam thickness).

Re-arranging the above equation in terms of A gives:

$$A = 1.52W^{0.4}H'^{0.535}T^{0.464}t'^{-0.4} \qquad +/- aW'$$

B-Zone Prediction Model

$$\text{Mean } B/W' = 1.873\,(H'/W')^{0.635}(T/W')^{0.257}(t'/W')^{-0.097} \qquad R^2 = 0.86 \text{ \& rmse} = 0.13W'(15\%)$$

$$\text{U95\% } B/W' = \text{Mean } B/W' + b$$

where

b = 0.15 for sub-critical panels; 0.15-0.0714(W/H-0.7) for critical panels and 0.10 for supercritical panels.

Re-arranging the above equation in terms of B gives:

$$B = 1.873\,W'^{0.205}H^{0.635}T^{0.257}t'^{-0.097} \qquad +/- bW'$$

10.3.4 Height of Depressurisation Model (Tammetta, 2013 & Tammetta, 2015)

A review of Australian and international longwall geometry and borehole piezometric data lead to a multi-variate height of full depressurisation model as described in **Tammetta, 2013** and **Tammetta, 2015**. The model focuses on the 'height of complete depressurisation' (C) above a longwall panel and correlates Vibration Wire Piezometer data with three key mining geometry parameters (cover depth [H] panel width [W] and mining height [T]) as follows:

$$C = 1438 \ln(4.315 \times 10^{-5}.W.T^{1.4}.H^{0.2} + 0.9818) \qquad \text{(mean)}$$

$$C = 1438 \ln(4.315 \times 10^{-5}.W.T^{1.4}.H^{0.2} + 0.9818) + 26 \text{ m} \qquad \text{(95\% Confidence Limit)}$$

The above equations are for a longwall centreline with chain pillar values ~ 62% of the centreline values. The influence of geology on the C value is not considered in the model.

The above model is used in the Southern Coalfield to provide conservative estimates of connective cracking above longwalls. The C height is usually more conservative than the PI-Term models mentioned earlier and has been found to give values that are similar to the B-Zone in the Ditton and Merrick models (**Hydrosimulations, 2017**). It is considered by DgS that as the Tammetta model includes all depressurisation data in both A and B Zones, then it is essentially a B-Zone horizon prediction model.

10.3.5 Panel Width-Based Models

The width-based model published in **SCT, 2008** was originally defined as a 'height of fracturing' model that did not distinguish between discontinuous and continuous zones of fracturing. The model is based on numerical Flac2-D outcomes and a FISH program that tracked tensile and compressive fracturing and bedding shear above a longwall goaf. The model is therefore likely to provide conservative estimates of the A-Zone and possibly includes the B-Zone fractures/dilated strata as well in some cases.

It is considered that, whilst the program is a reasonable attempt at predicting fracture heights numerically, the model is still a 'continuous strata model' program that is trying to model part-discontinuous and part-continuous strata behaviour. Whilst the program appears to be able to identify caving zones and zones of large displacement (i.e. the A-Zone), the predicted heights of fracturing have only been related to one parameter, the panel width, W, as follows:

A = 1.0W to 1.5W

The width-based models do not consider the effect of cover depth or extraction height; and also assume the A-Zone would continue to increase above *supercritical* panel geometries. This usually means that surface to seam connectivity would always be predicted for critical and supercritical panel widths, which is at odds with industry experience.

A review of published industry experience of *critical* and *supercritical* panels indicates that only two or three cases out of 14 (15% to 20%) or one in five *supercritical* longwalls have resulted in surface to seam connectivity (**Figure 15e**).

This outcome suggests that factors such as cover depth, extraction height and geological conditions should also be considered other than just the panel width alone when estimating heights of continuous fracturing above longwall panels. The model may therefore indicate conservative A-Zone heights in some cases and would depend on differences in extraction height, cover depth and mining geology for a given panel width.

10.3.6 T-Based Model

The height of the A-Zone fracturing has been successfully predicted from relationships established with extensometer and piezometer monitoring data above supercritical panels in the Newcastle Coalfield. A supercritical panel relationship between A and T was developed by **Forster, 1995** in the Lake Macquarie Region as follows:

A = 21T to 33T above *supercritical* panel geometries

Massive conglomerate or sandstone strata units were located at horizons where the continuous fracturing extended to in the overburden. The model has been validated against Wyee LW17 to LW23 in **Li *et al.*, 2006,** and provides a simple method by which to compare other model results. Caution is advised when making A-Zone predictions in other coalfields with less massive lithology or greater depths of cover, however, as measured heights of fracturing over 'sub-critical' and 'critical width' panels tend to increase.

The results of a study of deep borehole extensometers and piezometers by CSIRO (**ACARP, 2007**) at the Springvale Mine in the Western Coalfield indicated the A-Zone extended to 43T above the Lithgow Seam. The mining geometry included 'critical' panel widths of 265 m to 315 m, with cover depths ranging from 360 m to 380 m (W/H from 0.74 to 1.14) and an extraction height of 3.25 m. Post-mining investigation drilling and VWP data indicated a partially depressurised 'B-Zone' had developed above the longwalls, and consistent with the prediction models (which included **Ditton and Merrick, 2014** also).

10.3.7 Review of Height of Fracture Model Predictions and Borehole Extensometer and VWP Data at Narrabri Mine

As mentioned in **Section 8.3**, borehole extensometer and VWP data for LW101 to 106 and 108A has been used to estimate the measured A- and B-Zone horizons for the Narrabri Mine and compared to the predicted values.

The purpose of the extensometers above LW101 to 106 was only to measure caving heights above the longwalls after pre-conditioning (hydraulic fracturing) the massive Digby Conglomerate units. The extensometer data can therefore only be used as a guide to A- and B-Zone horizons as their location and height above the workings were limited to the face weighting zones in most cases.

A more reliable method of defining sub-surface movements has subsequently involved the installation of several multi-wired borehole extensometers into three boreholes (E108b, E108c and NC745C) located above the centreline of LW108A and approximately 300 m from the starting position of the panel (refer **Figure 4d** for monitoring locations). The boreholes were installed with four or five extensometer anchors each that targeted separate strata horizons to measure vertical displacement and strain during subsidence development.

A total of eight VWP were also installed into an adjacent borehole (P57) to measure groundwater pressure heads before and after undermining. The response of the VWPs also allowed the measured vertical strains in the extensometer to be correlated to the sub-surface fracturing horizons (A, B or C-Zones) previously discussed.

In order to allow comparison to the measured values, the predicted values for continuous (A-Zone) sub-surface fracture heights above LW101 to 111 are shown in **Figures 11a** to **11f** and summarised in **Table 13A**.

As shown in **Table 13B**, it is apparent that the Geology Pi-Term Model predicts the highest A-Zone out of the two Pi-Term models. The Tammetta Model indicates full depressurisation for all of the assessed longwalls.

Table 13A - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above LW101 to 111

LW Panels	Panel Width W (m)	Cover Depth H (m)	Average Extraction Height T (m)	Predicted Continuous Fracture Heights (A-Zone) (m)				Depth to A-Zone (m)	Height of Depressurisation C (m)	
				Geology Model		Geometry Model		Geology Model	Tammetta, 2013	
				Mean	*U95%CL*	*Mean*	*U95%CL*	*U95% CL*	*Mean*	*U95%CL*
101	306.1	165	4.2	121	144	105	128	21	327	353
	306.1	165	4.2	121	144	105	128	21	327	353
	306.1	177	4.2	129	154	110	135	23	332	358
102	306.4	180	4.2	131	156	111	136	24	333	359
	306.4	175	4.2	128	152	109	134	23	331	357
	306.4	188	4.2	137	163	114	140	25	335	361
103	306.4	195	4.3	143	170	118	145	25	349	375
	306.4	195	4.3	143	170	118	145	25	349	375
	306.4	200	4.3	146	174	120	148	26	350	376
104	306.4	180	4.3	133	158	112	137	22	343	369
	306.4	205	4.3	150	178	122	150	27	352	378
	306.4	215	4.3	157	187	125	155	28	355	381
	306.4	215	4.3	157	187	125	155	28	355	381
105	306.4	200	4.3	146	174	120	148	26	350	376
	306.4	225	4.3	162	193	128	159	32	358	384
	306.4	235	4.3	165	198	129	162	37	361	387
	306.4	235	4.3	165	198	129	162	37	361	387
106	306.4	220	4.3	160	190	127	158	30	357	383
	306.4	245	4.3	169	203	131	165	42	364	390
	306.4	255	4.3	173	208	132	168	47	367	393
	306.4	250	4.3	171	205	131	167	45	365	391
107	408.8	240	4.3	174	207	134	168	33	458	484
	408.8	270	4.3	194	232	145	182	38	416	442
	408.8	280	4.3	200	240	148	187	40	457	483
	408.8	285	4.3	204	244	150	189	41	454	480
108A	408.8	275	4.3	197	236	146	185	39	451	477
	408.8	265	4.3	190	227	143	180	38	460	486
	408.8	275	4.3	197	236	146	185	39	459	485
	408.8	290	4.3	207	248	151	192	42	465	491
108B	408.8	305	4.3	213	256	154	197	49	467	493
109	410.3	293	4.3	209	250	152	193	43	459	485
	410.3	290	4.3	207	248	151	192	42	468	494
	410.3	300	4.3	212	254	153	196	46	472	498
	410.3	305	4.3	214	256	154	197	49	470	496
	410.3	320	4.3	219	264	156	201	56	476	502
110	410.3	318	4.3	218	263	156	201	55	466	492
	410.3	310	4.3	216	259	155	198	51	475	501
	410.3	330	4.3	223	268	157	204	62	478	504
	410.3	320	4.3	219	264	156	201	56	481	507
	410.3	325	4.3	221	266	157	203	59	485	511
111	410.3	332	4.3	224	269	157	204	63	477	503
	410.3	325	4.3	221	266	157	203	59	483	509
	410.3	350	4.3	230	278	160	209	72	483	509
	410.3	360	4.3	233	282	161	211	78	492	518
	410.3	350	4.3	230	278	160	209	72	489	515

Bold - Direct hydraulic connection to the surface is considered possible if A-Horizon prediction is within 15 m of the surface. shaded - wider longwalls.

Table 13B - Summary of Sub-Surface Fracture Model Predictions (U95%CL) for the A-Zone in the Northern Area

LW	Panel Width W (m)	Cover Depth H (m)	Effective Panel Width W' (m)	Mining Height T (m)	W/H	Predicted Maximum A-Zone Height above Longwall (m)		Depth to U95%CL A-Zone	Other Models		
						Geology Pi-Term	Geometry Pi-Term	Geology Pi-Term	CSIRO 2007 (43T)	SCT, 2008 (W-1.5W)	Tammetta, 2012
101 to 106	306.1-306.4	165 - 255	231 - 306.5	4.2 - 4.3	1.2 - 1.86	**121 - 208**	105 - 168	37 - 87	181 - 185	306 - 460	327 - 393
107 to 111	408.8-410.3	240 - 360	336 - 410	4.3	1.14-1.70	**174 - 282**	134 - 211	72 - 149	185	409 - 615	472 - 535

Bold - Maximum values predicted closest to longwall performance to-date.

The results of the review indicate that the height of connective cracking above LW101 to 111 is likely to range between 121 m and 282 m (0.65H and 0.88H). The Geology model also indicates that the A-Zone could extend to within a range of 37 m to 78 m below the surface, depending on the cover depth.

The CSIRO, SCT and Tammetta model results indicate full depressurisation of the overburden and as discussed earlier are likely to give conservative results for Narrabri due to the following factors:

(i) The depressurisation heights include partial depressurisation heights (i.e. dilated strata affects in the B-Zone).

(ii) The model was developed in the Western and Southern Coalfield and does not consider 'supercritical' panel width affects.

(iii) The models do not consider geological influences on fracture connectivity in the upper reaches of the overburden (e.g. strata permeability and surface crack depth development).

Extensometer measurements above LW108A are summarised in **Table 13C** with the VWP data in **Table 13D**.

Table 13C - Summary of Measured Deep Borehole Extensometer Anchor Displacements and Vertical Strain Profiles above LW108A

Anchor No.	BH No.	Anchor Depth below Ground (m)	Anchor Location above Workings y^ (m)	Maximum Anchor Displacement or Strata Dilation Relative to Surface (mm)	Maximum Vertical Strain between Overlying Anchor & Anchor No. (mm/m)	Final Strata Dilation (mm)	Final Vertical Strain (mm/m)	Total Anchor Subsidence (mm)	Fracture Zone
13	E108b	30	245	165		5		2605	B
12	E108b	40	235	166	0.1	158	**15.3**	2758	A
11	E108b	50	225	176	1.0	19	**-13.9**	2619	A
10	E108b	60	215	215	3.9	83	6.4	2683	A
9	E108b	70	205	218	0.3	148	6.5	2748	A
8	NC745C	90	185	87	-6.6	2	-7.3	2602	A
7	NC745C	100	175	231	**14.4**	167	**16.5**	2767	A
6	NC745C	115	160	127	-6.9	0	**-11.1**	2600	A
5	NC745C	124	151	212	9.4	135	**15.0**	2735	A
4	E108c	133	142	404	**21.3**	248	**12.6**	2848	A
3	E108c	147	128	359	-3.2	220	-2.0	2820	A
2	E108c	160	115	311	-3.7	163	-4.4	2763	A
1	E108c	173	102	347	2.8	209	3.5	2809	A

^ - Cover depth to Hoskissons Seam was 275 m and panel width W=409 m (Supercritical W/H=1.49); **Bold** - Vertical strains > 8 mm/m indicate A-Zone fracturing according to database.

Table 13D - Summary of Measured Deep Borehole VWP Data above LW108A (undermined 21/10/18)

VWP No.	BH No.	Piezo Depth below Ground (m)	Piezo Location above Workings y^ (m)	Pre-Mining Pressure Head (m)	Post-Mining Pressure Head at 20/8/19 (m)	Head Loss (m)	Fracture Zone
8	P57	40	235	0.3	0	-0.3	A
7	P57	60	215	6.4	0	-6.4	A
6	P57	80	195	23.9	0	-23.9	A
5	P57	100	175	39.7	0	-39.7	A
4	P57	120	155	53.5	0	-53.5	A
3	P57	140	135	74.3	0	-74.3	A
2	P57	160	115	99.9	0	-99.9	A
1	P57	180	95	124	0	-124.0	A

An effective strata unit thickness t' = 20 m for the Geology Pi-Term Model has been back-analysed initially from assessed height of fracturing data and the maximum strain/curvature regression analysis (**Figure 6o**) for LW101 to 108A. *Note: the effective bending beam thickness at the surface is approximately twice the horizontal strain/curvature ratio of 10.*

The LW108A extensometer and VWP data provided further HoF model calibration and validation opportunities. The measured relative and total strata displacements are presented in **Figures 11g** and **11h**. **Figures 11i** and **11j** indicates several strain reversals in the deforming overburden that suggest bedding shear and dilation between strata units with beam thicknesses ranging from 20 m to 39.5 m. The strains measured between the beams are considered likely to be associated with A-Zone fracturing (i.e. > 8 mm/m) and is confirmed by complete head losses measured at the VWP locations after undermining (**Figure 11k**).

The height of connective cracking (A-Zone Horizon) is approximately equal to the U95%CL value is assessed for LW108A (i.e. 236 m above the mine workings or 39 m below the surface. It is understood that surface to seam connectivity has not been detected by NCOPL to-date based on mine ventilation records (i.e. no short-circuiting of surface airflow detected through goafed areas).

It is also apparent from the subsidence development versus longwall face distance curves for LW108A centreline (**Figure 11l**) that the overburden typically behaves in the following manner during subsidence:

- Practical subsidence deformation commences (~ 20 mm of vertical settlement) when the longwall face is approximately -0.3H inbye of the borehole (or is 80 m to the north in this case).
- Downward relative displacements and positive vertical strains (tensile) indicate the anchors are located within base of a sagging beam over the goaf due to Poisson's Ratio effect and decreasing horizontal stress.
- Upward relative displacements and negative vertical strains (compressive) indicate the anchors are located within top of a sagging beam over the goaf due to Poisson's Ratio effect and increasing horizontal stress.
- Final tensile strains indicate the anchors are located near vertical bedding separations or open cracks.
- Final compressive strains indicate the anchors are located near closing bedding separations due to goaf consolidation or vertical load increases.
- The transition from horizontal to vertical stress changes typically occurs after 50% of final subsidence and the initial strain peaks are reached and occurs when the longwall face has retreated 0.3H outbye of the borehole (or is 80 m to the south in this case).
- 95% of final subsidence and strains have usually developed when the longwall has retreated 0.7H outbye of the borehole (or 200 m to the south in this case). Based on observed retreat rates of 50 m to 70 m per week (or 7 m to 10 m per day) the majority of subsidence for a given panel takes three to 4 weeks to develop after under mining.

- The dilation of the overburden is normalised to extraction height (s_z/T) and plotted against depth over cover depth (z/H) in **Figure 11m**. The plot demonstrates that the strata between the surface and 0.6H below ground level subsided between 0.6T and 0.65T after undermining. The data is similar to patterns of movement measured in the Newcastle Coalfield above three supercritical longwall panels with a range of conglomerate unit thicknesses.
- The same data is plotted in **Figure 11n** but with distance above the mine roof and normalised to cover depth (A/H). The plot demonstrates that the strata between 0.4H and 1H above the mine workings subsided between 0.6T and 0.65T after undermining. The Newcastle data show almost full caving (~0.9T) developed to ~0.3H above the mine roof or ~8T above the mine workings (3T to 5T of caving is normally assumed).
- It is assessed that the Narrabri data indicates higher displacements and strains in the upper levels of the overburden compared to the Newcastle Coalfield cases, however the magnitude of strata dilations appear to be smaller in the lower half (that was measured). It is expected that the wider longwalls have caused a greater zone of impact, but overall have had a similar impact on the overburden as the Newcastle Coalfield cases have had.

Overall, it is considered that the measured and predicted fracture zones above LW108A align more closely with the **Ditton & Merrick, 2014** Geology model than the non-Narrabri Coalfield-based models. However, it is recommended that further monitoring of A and B Zone development above future longwalls be undertaken.

10.3.8 Continuous Sub-Surface Fracture Height Predictions (A-Zone)

The predicted values for continuous sub-surface fracture heights (A-Zone) above LW203 to 205 are summarised in **Table 14A** for the two Pi-Term Models. The **Tammetta, 2013** depressurisation height estimates are provided for comparative purposes.

The *continuous* sub-surface fracture height predictions have also been plotted against cover depth in **Figure 12a**.

Table 14A - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above the Proposed LW203 to 205

Panel	Panel Width W (m)	Cover Depth H (m)	Min-ing Height T (m)	Effective Panel Width W' (m)	Predicted Continuous Fracture Heights (A Horizon) (m)				Depth to A-Zone (m)	Height of Full Depressurisation (m)	
					Geology Model		Geometry Model		Geology Model	Tammetta, 2013	
					Mean	*U95% CL*	*Mean*	*U95% CL*	*U95% CL*	*Mean*	*U95% CL*
CF201-A	272	185	2.72	259.0	110	136	96	122	49	159	**185**
CF201-B	273	210	2.72	273.0	120	149	101	131	61	164	190
CF202-C	235	182	2.72	235.0	105	130	92	118	52	135	161
CF202-D	199	199	2.72	199.0	103	129	89	116	70	114	140
CF203-E	199	186	2.72	199.0	99	124	88	113	62	112	138
CF203-F	236	194	2.72	236.0	109	135	94	122	59	137	163
CF204-G	236	194	2.72	236.0	109	135	94	122	59	137	163
CF204-H	199	194	2.72	199.0	102	127	89	115	67	113	139
CF205-I	188	188	2.72	188.0	98	122	86	111	77	105	131
CF205-J	287	191	2.72	267.4	113	140	98	125	66	170	**196**
203	402.9	214	4.3	300	156	186	125	155	28	**455**	**481**
	402.9	207	4.3	290	151	180	122	151	27	**451**	**477**
204	402.4	238	4.3	333	172	205	134	167	33	**472**	**498**
	402.4	244	4.3	342	176	210	136	170	34	**476**	**502**
205	399.7	263	4.3	368	189	226	142	179	37	**467**	**493**
	399.7	280	4.3	392	200	240	148	187	40	**470**	**496**

Bold - Direct hydraulic connection to the surface is considered possible if A-Horizon prediction is within 15 m of the surface.

Table 14B summarises the results given in **Table 14A**.

Table 14B - Summary of Sub-Surface Fracture Model Predictions

Panel #	Panel Width W (m)	Cover Depth H (m)	W/H	Effective Panel Width W' (m) [1.4H]	Mining Height T (m)	Predicted Maximum A-Zone Height above Longwall (m)		Depth to A-Zone (m)	Height of Depressurisation (m)
						Geology Model	Geometry Model	Geology Model	Tammetta, 2013
CF201-CF205	188-287	182 - 210	1.0 - 1.5	188 - 273	2.72	99 - 149	89 - 131	49 - 70	0 - 59
LW203-LW205	356.7 - 415.4	185 - 300	0.89 - 2.31	252 - 402.2	4.3	151 - 240	122 - 187	27 - 80	454 - 502

As shown in **Table 14B**, the Geology Pi-Term Model predicts the highest A-Zone out of the two **Ditton & Merrick, 2014** models. The **Tammetta**, **2013** model indicates 'full depressurisation' of the overburden above the longwalls and CF201(A) & CF205(J) for the pillar reduction panels.

Table 15 also shows the predicted outcomes for all of the models mentioned earlier. The results show that four of the six models indicate that the A-Zone will probably develop below the surface for the proposed pillar reduction and longwall panels, with surface to seam connectivity predicted as 'likely' by the SCT and Tammetta (non-Narrabri Coalfield) models.

Table 15 - Summary of Sub-Surface Fracture Model Predictions (mean - U95%CL) v. Key Mining Parameters

A-Zone Height Prediction Model	A/H	A/W'	A/T
CF201 - CF205			
Geology Pi-Term	0.52 - 0.59	0.42 - 0.65	37 - 55
Geometry Pi-Term	0.45 - 0.66	0.37 - 0.59	32 - 48
Forster, 1995	0.27 - 0.49	0.21 - 0.48	21 - 33
CSIRO, 2007	0.59 - 0.64	0.43 - 0.62	43
SCT, 2008	**1.00 - 2.25**	**1.0 - 1.5**	**69 - 158**
Tammetta, 2013	0.56 **- 1.03**	0.56 - 0.73	39 - 72
LW203 - LW205			
Geology Pi-Term	0.72 - *0.87*	0.51 - 0.62	35 - 56
Geometry Pi-Term	0.53 - 0.73	0.38 - 0.52	28 - 44
Forster, 1995	0.32 - 0.69	0.23 - 0.49	21 - 33
CSIRO, 2007	0.66 - *0.89*	0.47 - 0.64	43
SCT, 2008	**1.43 - 2.92**	**1.0 - 1.5**	**93 - 141**
Tammetta, 2013	**1.29 - 2.67**	**1.20 - 1.91**	**105 - 126**

Bold - model predicts surface to seam connectivity is 'likely'. *italics* - model predicts connectivity is 'possible' with some values exceeding 0.8H.

As discussed in **Section 10.3.7**, the Geology Pi-Term Model gives the 'best fit' to the mining outcomes to-date for the Narrabri Mine.

It is noted however, that the database of sub-surface fracturing contains four out of fifteen supercritical cases where surface to seam connective cracking developed and when A/H exceeded 0.8 (**Figure 15d**). The predicted heights of cracking were also estimated to extend to within 20 m depth below the surface (i.e. within the limits of the surface cracking zone).

It is therefore assessed that the A/H = 0.8 ratio represents the horizon that coincides with the 25% probability of surface to seam connectivity (**Figure 12a**) with the potential interaction between the A-Zone and the surface cracking zone being the deciding factor.

Based on the Geology model, direct hydraulic-fracture connection to the mine workings is estimated to encroach within 27 m, 34 m and 40 m depth below the surface above LW203, 204 and 205 respectively. The fracturing above the pillar reduction panels is predicted to extend to within 49 m to 70 m depth.

Investigation boreholes and site observations at Narrabri indicate that the near-surface strata above the eastern panels (LW203 to 205) mainly consist of weathered, thinly bedded sandstone and siltstone associated with the Purlawaugh Formation and Garrawilla Volcanics.

These units are likely to shear into thinner units and 'unlikely' to develop deep vertical cracks that extend into the A-Zone (below 20 m depth).

Another consideration is that Pilliga Sandstone outcrops may develop deeper cracking than the more thinly bedded Purlawaugh formation sequences. As the Pilliga Sandstone units exist only above LW204 and 205 where cover depth is > 220 m, it is considered 'unlikely' that A-Zone cracking would encroach within 20 m of the surface and cause a surface to seam connection in these areas.

It is concluded that only LW203 should be considered a 'possible' or 25% probability case that connective cracking could reach the surface.

10.3.9 Discontinuous Fracturing (B-Zone)

Discontinuous fracturing would normally be expected to occur above the EP Area, causing an increase in rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings.

At the Narrabri Mine, a borehole piezometer P13 on Kurrajong Creek Tributary to the south of LW101 had a pre-mining ground water level of 5.5 m depth below the surface in the creek bed sediments. The water table was subsequently lowered by 1.5 m to 5.5 m after extraction of LW101 and 102 respectively. Further to the west, the water in the monitoring bore above LW103 dropped from 26 m below ground level to 51 m below ground level (a water table lowering of 25 m).

The Geology and Geometry Pi-Term Models predict discontinuous sub-surface fracturing is likely to interact with surface cracks (D-Zones) where cover depths are < 300 m above the 306 m wide longwall panels and < 375 m above 400 m wide longwall panels (i.e. all of the EP longwalls) (**Figure 12b**).

It is assessed that the measured lowering in water table above LW101 to 103 was consistent with 'B-Zone' cracking and strata dilation interaction only and does not indicate full depressurisation of the overburden.

Impacts associated with B-Zone fracturing include (i) potential re-routing of creek flows into open cracks to below-surface pathways, with subsequent re-surfacing down-stream of the mining extraction limits, (ii) lowering of the water table, and (iii) disruption of tree root systems.

10.3.10 Impact Management Strategies

Groundwater and surface water impact studies should consider the above uncertainties. The practical options available for controlling sub-surface fracturing are limited to:

- Monitor rainfall deficit and underground water makes or changes to ventilation during longwall mining to detect surface to seam connectivity.

- Repair surface cracks after active subsidence is complete.

- Install further borehole extensometers and piezometers to monitor the height of fracturing development for multiple 400 m wide longwalls after supercritical conditions develop (most of the subsurface fracturing prediction models consider impacts due to one or two longwalls only).

10.4 Steep Slopes

10.4.1 General

The key impacts of the predicted subsidence effects would be caused by tilting, bending and cracking of the steep slopes and minor cliff faces above the extracted longwall panels. As discussed, in **Section 10.2,** crack widths on subsided slopes are likely to be larger than those that develop in relatively flat terrain due to rotation and strain effects.

The cracks on the steep slopes are likely to develop along the high rib-side of the longwall blocks and in the vicinity of the peak tensile strains. The tensile strain profile is likely to migrate towards the high side ribs and may occur outside the limits of extraction.

Compressive strain effects such as shear failures and local 'heaving' or uplift development may occur along the low rib-side of the longwalls or along creeks. Transient cracking across and behind the longwall face may occur periodically after each goaf fall in the workings.

Previous studies of crack width estimation above longwalls in relatively ‘flat’ to moderately sloping terrain in the Newcastle Coalfield have been reasonable based on the predicted strains multiplied by 10 m to 15 m (the typical distance between survey pegs and allowing for strain concentrations) (**DgS, 2011, 2013**).

The measured crack widths in steep terrain (slopes > 18^{o}) are also influenced by the tilting of slopes and ridges of a given height. The crack width estimate should consider both longwall face and ribs-side cracking that occur during subsidence development. No tilt affect is assumed where slopes above the longwall are < 18^{o}.

10.4.2 Crack Width Model for Steep Terrain in the Newcastle Coalfield

Based on data from several end of panel reports for a Newcastle longwall mine[9] (see EIS report for further details), the following formulae have been derived and verified against measured cracks as shown in **Table 16A**:

Mean Crack width = H/20 x Mean Max Strain + Slope Height x Mean Max Tilt

U95% Crack width = H/20 x U95%CL Max Strain + Slope Height x U95%CL Max Tilt

9 Published cliff impact models for the South Coast and Western Coalfield are now out of date as they refer to length of cliff and not area of cliff. The mine from which this data was obtained was the first one to have this method of impact assessment approved by the Department of Planning (now Department of Planning, Industry and Environment). The cracking and impact prediction models developed by DgS were generally successful in predicting the observed impacts. The presence of faulting on steep slopes could result in significant step-down features and cracking to develop if undermined by a longwall.

The above formulas result in predicted values exceeding ~50% and 95% of the measured crack widths, respectively.

Table 16A - Measured Crack Widths v. Predicted Subsidence Effects Above Steep Slopes in the Newcastle Coalfield

Crack No.	Steep Slope Height (m)	Cover Depth H (m)	Measured Crack Width (mm)	Predicted Tensile Strain (mm/m)		Predicted Crack Width from Strain (mm)		Predicted Tilt (mm/m)		Predicted Crack Width from Tilt (mm)		Predicted Crack Width from Tilt & Strain (mm)	
				mean	*U95CL*	*mn.*	*U95*	*mn.*	*U95*	*mn.*	*U95*	*mn.*	*U95*
1	-	100	**200**	18	46	270	690	62	93	0	0	270	690
2	-	100	**500**	18	46	270	690	62	93	0	0	270	690
3	-	99	**100**	18	46	270	690	62	93	0	0	270	690
4	-	95	**5**	18	46	270	690	62	93	0	0	270	690
5	-	98	**150**	18	46	270	690	62	93	0	0	270	690
6	-	99	**50**	18	46	270	690	62	93	0	0	270	690
7	-	96	**50**	18	46	270	690	62	93	0	0	270	690
8	24.9	142	**500**	8.5	21	128	315	31	46	771	1,143	898	1,458
9	-	147	**300**	8.5	21	128	315	30	46	0	0	**128**	315
10	-	113	**500**	9	22	135	330	32	49	0	0	135	**330**
11	-	126	**300**	9	22	135	330	32	49	0	0	135	330
12	9.3	148	**500**	9	22	135	330	32	49	296	454	**431**	784
13	19.1	145	**1,000**	9	22	135	330	32	49	610	934	745	1,264
14	14.4	149	**300**	9	22	135	330	32	49	461	705	596	1,035
15	-	112	**300**	13	33	195	495	47	70	0	0	**195**	495
16	-	134	**300**	8.5	21.3	128	320	24	36	0	0	**128**	320
17	15.4	144	**250**	13	32	195	480	45	67	694	1,034	889	1,514
18	17.1	144	**500**	13	32	195	480	45	67	768	1,143	963	1,623
19	9.8	129	**200**	16	41	240	615	56	85	552	837	792	1,452
20	18.4	131	**1,000**	16	41	240	615	56	85	1,029	1,563	1,269	2,178
21	26.9	126	**2,500**	9	23	135	345	35	52	941	1,398	1,076	**1,743**
22	24.6	128	**1,000**	9	23	135	345	35	52	862	1,281	997	1,626
23	18.2	144	**1,000**	9	23	135	345	35	52	637	946	772	1,291
24	18.2	144	**1,000**	9	23	135	345	35	52	637	946	772	1,291
25	9.8	132	**70**	10	25.5	150	383	37	56	363	549	513	932
26	9.9	133	**150**	10	25.5	150	383	37	56	365	552	515	934
27	23.8	137	**150**	10	25.5	150	383	37	56	879	1,330	1,029	1,713
28	28.2	138	**70**	10	25.5	150	383	37	56	1,043	1,578	1,193	1,961
29	-	116	**75**	16	40	240	600	55	83	0	0	240	600
30	6.6	121	**75**	16	40	240	600	55	83	362	546	602	1,146
31	3.7	121	**60**	16	40	240	600	55	83	204	308	444	908
32	25.3	127	**2,500**	16	40	240	600	55	83	1,393	2,102	**1,633**	2,702
33	7.9	120	**100**	16	40	240	600	55	83	432	652	672	1,252
34	-	149	**200**	16.5	41	248	615	56	85	0	0	248	615
35	-	150	**300**	16.5	41	248	615	56	85	0	0	**248**	615
36	-	149	**200**	16.5	41	248	615	56	85	0	0	248	615
37	-	152	**150**	16.5	41	248	615	56	85	0	0	248	615
38	-	154	**100**	16.5	41	248	615	56	85	0	0	248	615
39	-	154	**50**	16.5	41	248	615	56	85	0	0	248	615
40	-	108	**300**	16	40	240	600	55	83	0	0	240	600
41	21.3	146	**500**	9	23	135	345	35	52	746	1,108	881	1,453
42	20.6	145	**600**	9	23	135	345	35	52	723	1,074	858	1,419

Bold - Predicted crack width exceeded by measured value.

Table 16A (Cont…) - Measured Crack Widths v. Predicted Subsidence Effects Above Steep Slopes in the Newcastle Coalfield

Crack No.	Slope Height (m)	Cover Depth H (m)	Measured Crack Width (mm)	Predicted Tensile Strain (mm/m)		Predicted Crack Width from Strain (mm)		Predicted Tilt (mm/m)		Predicted Crack Width from Tilt (mm)		Predicted Crack Width from Tilt & Strain (mm)	
				mean	*U95CL*	*mn.*	*U95*	*mn.*	*U95*	*mn.*	*U95*	*mn.*	*U95*
43	8.6	141	**300**	9	23	135	345	35	52	299	445	434	790
44	20.0	150	**400**	13	32	195	480	45	67	898	1,337	1,093	1,817
45	-	101	**150**	13	32	195	480	37	56	0	0	195	480
46	16.9	106	**500**	13	32	195	480	37	56	627	949	822	1,429
47	-	115	**35**	13	32	195	480	45	67	0	0	195	480
48	-	125	**20**	13	32	195	480	45	67	0	0	195	480
49	3.3	127	**600**	13	32	195	480	45	67	147	219	**342**	699
50	22.1	135	**1,200**	16	40	240	600	55	83	1,218	1,838	1,458	2,438
51	16.1	142	**50**	16.5	41	248	615	56	85	899	1,364	1,146	1,979
52	16.6	131	**500**	16.5	41	248	615	56	85	932	1,415	1,180	2,030
53	13.3	129	**100**	16.5	41	248	615	56	85	745	1,130	992	1,745
54	16.3	131	**70**	16.5	41	248	615	56	85	913	1,385	1,160	2,000
55	23.3	132	**1,500**	9	23	135	345	35	52	817	1,214	**952**	1,559
56	22.9	143	**500**	9	23	135	345	35	52	801	1,190	936	1,535

Bold - Predicted crack width exceeded by measured value.

The results indicate that the predicted mean values were successful in estimating greater crack widths than the measured cracks at 68% of observed crack locations (38/56). The predicted U95%CL values were successful in estimating greater crack width than the measured cracks at 96% of observed crack locations (54/56). The predicted crack widths based on strains only were successful in 41% (mean) and 68% (U95%CL) of cases, respectively. It is noted that 41% of the sites were not affected by steep slopes.

Furthermore, histograms of the measured crack widths, crack depths and crack lengths from the moderate and steeply dipping terrain in the Newcastle Coalfield for super-critical longwalls are presented in **Figures 13a** to **13c**. The measured crack statistics are summarised in **Table 16B** and demonstrate that the above parameters all increase as terrain slope increases above 18°. It is also noted that the Narrabri Mine crack widths to-date are higher than the ‘flat’ terrain crack database for Newcastle (**Figures 13d** to **13f**).

Table 16B - Surface Crack Database Summary for 'Flat' and 'Steeply Sloping' Terrain in the Newcastle and Narrabri Coalfields for Supercritical Longwall Geometries

Parameter	Statistics	Newcastle Coalfield		Narrabri Mine (LW101-109)
		'Flat Terrain' Slopes < 18°	'Steep Slopes' Slopes > 18°	'Flat Terrain' Slopes < 18°
Crack Width (m)	Minimum	0.005	0.05	*0.01*
	Maximum	**0.5**	**2.5**	***0.68***
	Median	0.15	0.5	*0.14*
	Mean	0.19	0.6	*0.18*
	U95%CL	0.48	1.9	*0.50*
	Sample size (no.)	23	33	*245*
Crack Depth (m)	Minimum	0.05	0.15	*0.1*
	Maximum	**10**	**15**	***2.4***
	Median	2	2	*0.3*
	Mean	2.4	3.5	*0.4*
	U95%CL	5	15	*1.2*
	Sample size (no.)	23	32	*201*
Crack Length (m)	Minimum	3	3	*2*
	Maximum	**50**	**100**	***994***
	Median	10	30	*17*
	Mean	15	32	*32*
	U95%CL	30	50	*60*
	Sample size (no.)	23	33	*160*

Other pertinent statistics and assumptions tied to the Newcastle Database include:

- The data was obtained above supercritical longwall panels (W/H ranged from 1.16 to 1.86).

- The cover depth ranged from 95 m to 154 m with strain and tilts measured over 10 m peg spacing.

- Cracks in flat terrain occurred in groups of two or three typically with spacing between 8 m and 12 m.

- Cracks in steep terrain tended to occur on steep slopes just below and/or behind ridge crests, and along the toe of minor cliff faces (or behind them) with a propensity to develop along persistent joints that were sub-parallel to the principal tensile strain contour.

- The impacted features were subject to either transient strain and tilt behind the retreating longwall face or final residual effects after longwall extraction, and sometimes both. The predictions are based on maximum predicted tilt and tensile strain for a given panel geometry if located within the limits of longwall extraction.

- The orientation of the feature was only used to estimate slope height relative to the longwall ribs or principal tilt and strain contours.

10.4.3 Predicted Cracking

As discussed in **Section 10.4.2**, predicting the crack widths above the EP longwalls have considered the greater cover depth relative to the Newcastle Coalfield database when estimating crack widths (i.e. cover depth ranges from 120 m to 160 m for 178 m wide longwalls in Newcastle versus 185 m to 300 m of cover for 409 m wide longwalls at Narrabri).

The formulae for crack width estimates have therefore been adjusted to include effective peg spacing of H/20 or 10 m (whichever is greater) and a strain concentration factor of 1 and 2 for mean and U95%CL values.

The predicted crack depths for the EP longwalls were estimated based on the Newcastle database and the crack lengths were based on Narrabri data.

A summary of the predicted crack widths for the steep slopes above the EP Area are presented in **Table 16C**.

Table 16C - Predicted Crack Widths on Steep Slopes above LW203 to 205

Feature No.	Slope Height Z (m)	LW	Cover Depth (m) (Slope Aspect)	Maximum Feature Subsidence (m)	Maximum Feature Strain (mm/m)	Maximum Feature Tilt (mm/m)	Crack Width from Strain (mm)	Crack Width from Tilt (mm)	Crack Width from Tilt & Strain (mm)
S12	6 - 12	204	245 (SE)	2.8	-13 to 15 (30)	10 - 15	185 (370)	120 (240)	385 (770)

S12 = Steep Rocky Slope No. 12. * - crack widths assume a single crack may develop along the upslope rib side of the given longwall beneath steep slopes > 18°. (brackets) - discontinuous strain due to cracking.

The results in **Table 16C** indicate the following cracking impacts could develop on the steep slope features inside the limits of longwall extraction:

- crack widths from 385 mm to 770 mm.
- crack depths between 3 m and 15 m.
- crack lengths from 30 m to 100 m.
- crack spacing (in groups of 2 to 3) between 8 m and 13 m.

10.4.4 Feature Impact Assessment

It is usual practice by the Department of Planning, Industry and Environment to set impact limits on minor cliff faces and steep slope areas with respect to the total area of each feature within the EP Area. The performance measures defined for steep slopes and cliffs at the Newcastle Coalfield Mine previously used as a source of cracking data is given below:

Minor environmental consequences (that is occasional rockfalls, displacement or dislodgement of boulders, collapse of overhangs, and fracturing) that in total do not impact *more than 3% of the total face area of cliffs, 5% of minor cliffs and cliff terraces, 7% of rock face features, and 7% of steep slopes.*

As discussed earlier, by definition it is assessed that there are only steep (rocky) slopes present within the EP Area. The potential impacts to the features present within the AoD to the proposed longwalls have also been estimated based on previously measured impacts of similar features in the Newcastle Coalfield.

Total impacts for the steep rocky slopes undermined by longwalls in the Newcastle Coalfield Mine previously discussed in **Section 10.4.2** are summarised in **Table 17**.

Table 17 - Measured Impacts to Landscape Features above LWA, B and C in the Newcastle Coalfield

Landscape Feature	Feature Height Range (m)	Total Project Face Area* (m^2)	Feature Length Undermined (m)	Area Undermined (m^2)	Measured Impact (m^2)	Measured Impact for Undermined Area (%)	Measured Impact in EP Area (%)	Approval Limit in EP Area (%)
Minor Cliffs	5 - 7	23,018	370	2,271	131.7	5.8	**0.57**	**5**
Rock Face Features	3 - 4	2,563	607	1,386	22.3	1.6	**0.87**	**7**
Steep Rocky Slopes	3 - 25	3,000,000	2,189	153,475	846.5	0.6	**0.03**	**7**

* - Landscape features within EP Area boundary; shaded - relevant to the EP Area at Narrabri.
Note – m^2 = square metres.

The features in **Table 17A** were subject to maximum panel subsidence of 2.2 m, tilts from 10 mm/m to 50 mm/m and tensile/compressive strains ranging from 5 mm/m to 15 mm/m. Impacts on steep rocky slopes included significant cracking that required rehabilitation after active subsidence was complete.

Hypothetically, if the Newcastle Coalfield Mine had undermined all of the Steep Slopes within the EP Area, it would have been unlikely that the approved impact limit would have been exceeded.

Impacts to steep rocky slope above LW204 at Narrabri have been estimated based on a transitional subsidence crack width of 840 mm that is sub-parallel to the longwall face and extends the full width of the undermined slope (or two 150 mm to 420 mm wide cracks spaced at 10 m apart). The slope will be located with the compressive strain zone after subsidence is completed.

The resulting percentage impact estimates to all the steep slope features due to the proposed longwall panels are summarised in **Tables 17B** and **17C**.

Table 17B - Steep Slope Cracking Impacts

Feature No.	Slope Height Z (m)	Slope Width B (m)	LW	Max Feature Subsidence (m)	Max Feature Transitional Strain (mm/m)	Final Strain (mm/m)	Max Feature Tilt (mm/m)	Predicted Impact Area* (m^2)
S12	12	23	204	2.60 - 2.80	+/- 15 (30)	-15	15	19

S = Steep Rocky Slope. * - Impact area = crack width of 840 mm develops along the full length of the steep slope; (brackets) - cracking may double predicted strains.

Table 17C - Predicted Impacts to Landscape Features

Landscape Feature*	Feature Height Range (m)	Feature Length Undermined (m)	Feature Area Undermined (m^2)	Predicted Impact Area (m^2)	Predicted Impact for Undermined Feature (%)	Assumed Approval Limit (%)
Steep Rocky Slopes	12	377	8,753	317	0.2	**7**

* - Landscape features located within 20 mm subsidence contour of proposed longwalls LW203 to LW205.

The assessed impact of 0.2% for the feature in the AoD to mining is considered to be conservative and unlikely to exceed an assumed Performance Measures of 7% of all landscape features within the AoD from the proposed longwalls.

Based on the low frequency of public (and mine site personnel) exposure along the access tracks during and after mining impacts, the risk to the personal safety due to falls or vehicle accidents associated with steep slope cracking is likely to be 'very low' and within established acceptability criteria published in the Landslide Risk Management Guidelines (**AGS, 2007**).

The likelihood of *en-masse* sliding (i.e. a landslip) of the surface terrain over basal sandstone beds tilted by subsidence has been assessed as ‘very unlikely’[10] based on observations above longwall mines with similar terrain in the Newcastle Coalfield.

It would be prudent to avoid the risk of general or local slope instability by remediating (backfilling) deep cracks after subsidence development (refer to **Section 10.4.6** for recommendations for remediation works and timing advice).

[10] Refer to landslide risk assessment terminology presented in **AGS, 2007**.

10.4.5 Erosion

The potential for 'terrain adjustment' due to cracking, erosion and deposition of soils after subsidence has also been broadly assessed.

Surface cracks on steep slopes may allow surface runoff to enter the rock mass. The seepage pathways could result in internal erosion and local instability to develop. Water pressures or concentrated flow may contribute to future instability such as reducing the effective frictional strength along the potential slide plane or contact surface. The likelihood of significant water pressures developing behind the slope faces however is low, as water is likely to drain through open joints or cracks and limit the head of water that can develop.

The rate of soil erosion is expected to increase significantly in areas with exposed dispersive/reactive soils and slopes <10° are expected to have low erosion rate increases, except for the creek channels, which would be expected to re-adjust to any changes in gradient (**Figures 14a** and **14b**) for predicted gradient changes in the EP Area of +/- 1.5^{o} (**Figure 14c**).

Erosion along the creek beds would be expected to develop above chain pillars between the panels and on the side where the gradients increase. Sediment would be expected to accumulate where gradients decrease. The extent of impact has been assessed in the Surface Water Assessment (**WRM, 2020**).

10.4.6 Impact Management Strategies

To minimise the hazards associated with steep slope instability such as increased erosion due to cracking or changes to drainage patterns after longwall extraction that is consistent with the Land Management Plan presented in Appendix I of the Extraction Plan, the management strategy should include:

- Surface slope displacement monitoring above proposed LW204 (combined with general subsidence monitoring). Cracking impacts should be visually and spatially mapped (start and end coordinates, width, depth, length, and photographed) after subsidence development has ceased. It is expected that LiDAR surveys would provide sufficient subsidence effect data after longwall extraction.

- In-filling of surface cracking to prevent excessive ingress of run-off into the slopes. It would be necessary to backfill the cracks with either durable, free-draining gravel or sand with some erosion control measures such as re-vegetation. Repairs to cracks may require additional vegetation clearing and non-conventional repair methods (due to poor access for conventional equipment). Methods such as remote pumping of sands (sluicing) and/or cementitious grout may be needed and would require environmental spill and safety management controls.

- Areas that are significantly affected by erosion after mining may need to be repaired and protected with mitigation works such as re-grading, installation of new contour banks and re-vegetation of exposed areas.

- On-going review and appraisal of any significant changes to surface slopes such as cracking along ridges, increased erosion down slopes, foot slope seepages and drainage path adjustments observed after each longwall is extracted.

10.5 Ponding and Drainage Lines

10.5.1 Predicted Effects and Impacts

Surface slopes in the elevated areas between the creeks typically range between 0.9% and 7% (0.5° to 4°) and indicate a net fall across the proposed longwall panels from 2.5 m to 10 m prior to mining. The predicted maximum panel subsidence of up to 2.8 m could therefore result in closed form depressions forming in some of the central areas of the panels with the flatter surface gradients and disrupt natural drainage pathways to watercourses and farm dams.

The potential maximum pre and post-mining ponding geometries (depth, area and volume) above the proposed panels have been summarised in **Table 18**. The Pre-mining and Post-mining pond locations are shown in **Figures 15a** and **15b**.

Table 18 - Potential Ponding Summary for EP Panels

Potential Pond No. (Dam No.)	Panel	Pre-Mining Pond Levels (m, AHD)		Maximum Pre-Mining Pond			Post-Mining Pond Levels (m, AHD)		Maximum Post-Mining Pond			Pond Area Change (ML)
		Top	Bot	Depth h(m)	Area (ha)	Vol (ML)	Top	Bot	Depth h(m)	Area (ha)	Vol (ML)	
Pillar Reduction Panels												
P19	CF201(B)	299.9	299.3	0.60	0.336	0.672	298.6	298.2	0.41	0.530	0.724	**0.052**
P20	CF203(F)	290.0	289.9	0.10	0.280	0.093	289.1	288.8	0.33	1.214	1.335	**1.242**
P21 (D67/68)	CF203(F)	289.9	289.76	0.15	0.355	0.178	289.3	288.6	0.71	1.496	3.541	**3.363**
Longwall Panels												
P13	LW203	294.9	290.2	4.70	3.565	55.85	292.5	287.5	5.0	5.020	83.667	**27.81**
P14	LW203	294.9	293.1	1.80	1.669	10.01	292.5	290.4	2.1	2.261	15.827	**5.817**
P15	LW204	299.9	299.8	0.14	0.636	0.297	297.2	297.1	0.1	0.217	0.0723	**-0.225**
P16	LW205	-	-	0.00	0.000	0.000	302.2	302.0	1.3	1.672	7.245	**7.245**

Pond Volume = Ah/3

A total of 7 potential ponding locations (P13 to P16 and P19 to P21) are assessed for the EP Area. Six of the potential ponding areas already exist along the watercourses and dams.

Existing (pre-mining) pond depths are estimated to range from 0.1 m to 4.7 m. Post-mining pond depths are estimated to range from 0.1 m to 5.0 m. Pond depths are estimated to increase by up to 1.3 m or decrease by up to 0.19 m. The maximum changes in pond volume (where positive represents an increase in pond size) are estimated to range from -0.225 ML to 27.81 ML[11]. The largest ponding increases are estimated over LW203 and LW205.

[11] The actual ponding depths, areas and volumes will also depend upon several other factors, such as rain duration, surface cracking and effective percolation rates of the surface soils along the creeks/drainage lines.

There are two dams (D67, 68) above CF203 (F) that may be inundated by post-mining ponding.

Overall, the existing ponds are expected to extend laterally from the watercourses for distances ranging from 50 m to 500 m.

10.5.2 Impact Management Strategies

An appropriate management strategy would include the on-going review and an appraisal of changes to surface drainage paths and surface vegetation in areas of ponding development after each panel is extracted (as already occurs).

Based on the post-mining surface level predictions, it is proposed that impact management strategies for the existing Narrabri Mine would be implemented in accordance with the Land Management Plan and the Extraction Plan Water Management Plan presented in Appendix I and Appendix G of the Extraction Plan respectively. Impact management measures include:

- Ponding areas located in areas with no significant vegetation and the water quality of the ponded water is non-saline to be allowed to self-correct.

- Ponding areas located in areas with significant vegetation to be assessed and remedial measures (e.g. drainage) developed and implemented in consultation with a geomorphologist.

Consideration would also be given for ponded areas for agricultural purposes (i.e., remedial measures would be developed in consultation with the land holder).

10.6 Valley Closure and Uplift

10.6.1 Predicted Effects and Impacts

Based on reference to **ACARP, 2002**, ‘valley closure’ (or opening) movements can be expected across deep valleys whenever longwalls are mined beneath them. Valley closure can also occur across broader drainage gullies where shallow surface rock is present.

When creeks and river valleys are subsided, the observed subsidence in the base of the creek or river is generally less than would normally be expected in flat terrain. This reduced subsidence is due to the floor rocks of a valley floor ‘buckling’ upwards when subject to compressive stresses generated by surface deformation. This phenomenon is termed 'upsidence' and mostly occurs in the Southern NSW Coalfields.

Survey measurements across Pine Creek Tributary 1 (Lines E-G in **Figure 3d**) in October 2014 have indicated maximum closure of 148 mm between the 30 m wide creek bank crests at Line F, with compressive strain of 6.2 mm/m and uplift of 64 mm. Lines E and G did not detect any valley closure or uplift movements in the creek above the chain pillars due to LW101 to 104. The measured movements are within the predicted range previously presented in the approved 2017 Extraction Plan (**DgS, 2017**).

As the valleys across the EP Area (characterised by the ephemeral creek lines described earlier) are very broad between crests, the development of ‘upsidence’ and closure along the creek beds above the EP Area is likely to be ‘negligible’.

10.6.2 Impact Management Strategies

The impact of upsidence and valley bending effects along the creeks associated with the existing Narrabri Mine have been monitored and managed as follows:

(i) Installation of survey lines along and across ephemeral drainage gullies and bank crests during and after longwall undermining. Surveys have been correlated with visual inspections to locate damage (cracking, uplift).

(ii) Review predictions of ‘upsidence’ and valley crest movements after each longwall.

(iii) Assess whether repairs (i.e. cementitious grouting or crushed rock) to cracking, as a result of ‘upsidence’ or gully stabilisation works are required to minimise the likelihood of long-term degradation or risks to personnel and the general public.

At this stage, no damage to the creeks as a result of valley closure or uplift has been detected based on visual inspections. It is recommended that the above measures continue to be implemented for the EP Area.

10.7 Natural Vegetation

10.7.1 Predicted Impacts and Effects

Following completion of mining in LW101, it was observed that several large trees (eucalypts in particular) were dead or highly stressed in areas within the subsidence zone and light to heavy clay soils associated with the Garrawilla Volcanics (Eco Logical Australia [**ELA], 2014**). The impact was considered to be associated with both ponding and disruption (severing) of tree roots by vertical surface cracking during mine subsidence development. Similar impacts were observed above LW102, albeit to a lesser degree than LW101 (**ELA, 2014**). Inspections of trees above LW103 identified no impact.

ELA (2014) reported that the prevailing weather conditions were also very dry at the time of extraction of LW101. Available soil moisture > 12.5% in the clay soils, which means there is water available for plant uptake, was also limited with measured moisture ranging between 4.6% and 15.2% (**ELA, 2014**).

It is likely that the combination of these dry conditions, the low depth of cover (approximately 160 m to 180 m) and cracking in heavy soil texture (sandy clay) were the contributing factors to the tree impacts observed **(ELA, 2014)**.

10.7.2 Impact Management Strategies

It is considered that any large trees (eucalypts in particular) in areas with less than 180 m depth of cover in clayey soils would be at risk of root shear leading to tree stress or death, particularly if dry climatic conditions prevail at the time of longwall extraction.

It is noted that the EP Pillar Reduction Panels (CF201(A) have a depth of cover ranging from 173 m to 211 m, which is similar to LW102, where some impact to vegetation was observed. The potential impact above CF201(A) however, should be lower than the previously proposed longwalls as the predicted subsidence is significantly reduced.

The rest of the panels in the EP Area have cover depths > 180 m, so it is not expected that dieback will occur due to mine subsidence above these areas.

The potential impacts of the proposed longwalls (203 to 205) are further discussed in the Biodiversity Development Assessment Report for the Stage 3 EIS (**Resource Strategies Pty Ltd, 2020**).

It is recommended that the condition of the trees and the soil moisture conditions (within their root systems) are monitored before and after mining along the riparian sections of Kurrajong Creek Tributary No. 1 above CF201 to CF203.

11.0 Impact Assessment for the Built Features & Heritage Sites

11.1 Water Storage Dams and Soil Conservation (Contour) Banks

11.1.1 Predicted Effects and Impacts

There are twenty farm dams for livestock watering (D40-D50, D61-D69) that have been assessed in the EP Area. The dams are nearly all located within the 20 mm subsidence contour from the proposed panels.

Several farm dams have already been subsided by LW101 to 109 but have not required remedial works to be undertaken. Notwithstanding, non-engineered farm dams and water storages are susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the EP Area dams (before remediation is required) will depend upon the dam wall materials, construction techniques, and foundation type.

The likely subsidence effects at the dams above each panel are summarised in **Table 19**.

Table 19 - Maximum Final Subsidence Effect Predictions* for the Farm Dams above the EP Area

Panel	No. Existing Dams	Cover Depth (m)	Subsidence (m)	Tilt T_{max} (mm/m)	Tensile Strain* (mm/m)	Compressive Strain* (mm/m)
CF201 (A,B)	1 (D65)	173 - 211	0.02 - 0.1	1 - 7	8 - 15	0
CF202 (C,D)	1 (D66)	176 - 202	0.1 - 1.44	4 - 28	12 - 15	0 - 35
CF203 (E,F)	0	185 - 195	0.02 - 1.48	0 - 30	0 - 22	0 - 35
CF204 (G,H)	2 (D67,68)	192 - 200	0.1 - 1.05	15 - 25	1 - 13	0 - 10
CF205 (I,J)	0	186 - 298	0.02 - 1.57	0 - 35	0 - 30	0 - 45
203	11 (D40,45-49,50,61-64)	200 - 240	0.02 - 2.80	1 - 50	3 - 15	4 - 20
204	2 (D41,44)	220 - 240	0.40 - 2.80	5 - 50	3 - 15	7 - 19
205	2 (D42,43)	250 - 260	0.40 - 2.65	15 - 30	3 - 12	7 - 19
Outside AoD	(D49,69)	120 - 300	<0.02	<1	<0.5	<0.1

* - discontinuous strains (2 x smooth profile strains).

The expected phases of tensile and compressive strain development may result in breaching of the dam walls or water losses through the floor of the dam storage areas. Loss or increase of storage areas may also occur due to the predicted tilting. Maximum tensile crack widths across dam wall or storage areas are estimated to range between 30 mm and 400 mm.

Surface ‘steps’ or heaving due to compressive shear failures are estimated to range between 30 mm and 500 mm. Impacts to windmills and fences near the dams and soil conservation (contour) banks may also occur and require repairing.

11.1.2 Impact Management Strategies

Appropriate impact management strategies consistent with the current Land Management Plan presented in Appendix I of the Extraction Plan should include the following:

(i) The development of a suitable monitoring and response plan based on consultation with stakeholders and regulatory authorities, to ensure the impacts on the dams, windmills or fences do not result in unsafe conditions or loss of access to water during and after the effects of mining.

(ii) Management of impacts would include maintaining the integrity of the dams and minimising potential downstream flooding or erosion damage and/or providing an alternate supply of water to the affected stakeholder until the dams can be reinstated to pre-mining conditions (including re-filling the dams). Threats to personnel/livestock safety should also be managed by good communication with landholders and keeping downstream areas clear until mining impacts to the dams are restored or controlled.

(iii) Damage from subsidence (i.e. cracking and tilting) can manifest quickly after mining (i.e. within hours). The management strategies would therefore need to consider the time required to respond to the impact in a controlled manner when it occurs. It would also be possible to identify the dams likely to be impacted significantly, based on their location above the mine panels and predicted subsidence contours and lower the water levels in the dams prior to undermining. This would only be necessary where downstream flooding was a concern.

(iv) Suitable responses to subsidence impacts would be to either (i) drain the dam storage area before subsidence occurs and repair the dam with an impermeable clay liner after mining, (ii) monitor the dam wall during mining and place high-capacity pumps on 24-hour stand-by during mining to draw down the storage area if the walls are significantly weakened by subsidence development and (iii) re-build a new dam after mining.

Subsidence impacts may be assumed to start to occur within a 26.5^o AoD or 0.5 times the cover depth ahead of the retreating longwall face. Full subsidence development and impacts on the dams within an actively subsiding area is likely to be 90% complete when the longwall face has retreated a distance past the dams of 1.5 times cover depth. See subsidence development v. face distance curve for LW108A centreline at two peg locations in **Figure 11l**.

Additional subsidence episodes may then occur at a subsided area when subsequent longwalls retreat past the site again, however, the extra subsidence would be unlikely to cause further cracking damage.

11.2 Access Roads

11.2.1 Predicted Effects and Impacts

The existing access roads comprise unsealed gravel carriageways that provide access across the EP Area. It is expected that they would be subsided and impacted by the panels as shown in **Table 20**.

Table 20 - Maximum Final Subsidence Effect Predictions for Access Roads

Panels	Cover Depth (m)	Subsidence (m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)	Crack Widths (mm)
CF201-CF202	180 - 210	0.02 - 1.4	0 - 28	5 - 15 (30)	0 - 28 (56)	50 - 300
LW203 to 205	180 - 300	0.1 - 2.80	33 - 61	3 - 21 (42)	3 – 27 (54)	60 - 420

(brackets) - discontinuous strains (2 x smooth profile strains).

The unsealed gravel access roads (Red Hills, Scratch Roads) and tracks are likely to be damaged by cracking and shearing/heaving in the tensile and compressive strain zones, respectively, above the EP Area. Maximum tensile crack widths across or along roads are estimated to range between 50 mm and 420 mm. Surface ‘steps’ or humps due to compressive shear failures are estimated to range between 30 mm and 320 mm. Some sections of road may require re-grading or drainage remediation works after subsidence development.

11.2.2 Impact Management Strategies

Appropriate impact management strategies to maintain access roads as “always safe” would include the following:

- Regular inspection and maintenance of the roads and access tracks during and after each longwall block is extracted.

- Repairs to road surface should be undertaken as required to allow safe passage for all vehicles.

- Local residents, forestry personnel and/or site personnel working or passing through these areas should be informed of when and where the above subsidence effects may occur, and temporary warning signs should be erected near the limits of actively subsiding areas.

Subsidence impacts may be assumed to start to occur within a 26.5^{o} AoD or 0.5 times the cover depth ahead of the retreating longwall face. Full subsidence development and impacts on the roads within an actively subsiding area is likely to be 95% complete when the longwall face has retreated a distance past the road of 0.7 times cover depth or a 35^{o} AoD.

11.3 Property Fences and Livestock

11.3.1 Predicted Effects and Impacts

The fence lines and grazing areas above the EP Area would be subject to the maximum predicted subsidence effects and cracking presented in **Table 21**.

Table 21 - Maximum Final Subsidence Effect Predictions for Fences and Livestock Grazing Paddocks

Panels	Cover Depth (m)	Subsidence* (m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
CF201-CF202	175 - 210	0.02 - 1.4	0 - 28	5 - 15 (30)	0 - 28 (56)
LW203 to 205	180 - 240	0.1 - 2.80	27 - 61	4 - 21 (42)	6 - 27 (54)

* - Subsidence range = Mean Tailgate Chain Pillar Subsidence to Maximum Panel Subsidence; (brackets) - discontinuous strains (2 x smooth profile strains).

Impact to fences is likely to include the following:

- Straining and possibly tensile failure of fencing wire strands in tensile strain zones.
- Sagging of fencing wire strands and possibly loss of fence serviceability in compressive strain zones.
- Loss of gate function in either tensile or compressive strain zones.
- Tilting of fence, gate and strainer posts, leading to the outcomes mentioned above.

11.3.2 Impact Management Strategies

The impact of subsidence on the grazing of livestock will be managed in accordance with the Land Management Plan presented in Appendix I of the Extraction Plan, and may include installation of temporary fencing around cracking or relocation of the livestock during remediation of surface cracking and damaged fences. The location and suggested methods of repair to surface cracking is discussed in **Section 10.2.4**.

11.4 Residential Dwellings and Machinery Sheds

11.4.1 Predicted Effects and Impacts

There are two NOCPL-owned properties with dwellings above the proposed LW204 (‘Westhaven’ and an un-named property).

Based on **Holla & Barclay, 2000**, and **AS2870, 2011,** ‘moderate’ to ‘significant’ damage to the existing buildings and tanks are likely where tilts > 7 mm/m and tensile or compressive strains > 4 mm/m. The severity of the damage would also be dependent on the type and geometry of each structure and whether localised ‘humps’ and ‘troughs’ develop over the goaf as it consolidates.

‘Westhaven’

There is one single storey weatherboard clad and timber framed residence (‘Westhaven’) on timber stump footings (12 m x 8.5 m) and two galvanised iron clad timber post sheds that are owned by NCOPL above LW204 (**Figure 1c** and **Appendix A**).

The buildings are in disrepair and un-tenanted.

It is likely that the structures would be subsided between 1.7 m to 2.0 m by LW204 with tilts ranging from 7 mm/m to 22 mm/m, hogging and sagging curvatures of 0.2 to 0.5 km^{-1} (radii of 5 km to 2 km) and tensile and compressive strains 2 mm/m to 5 mm/m. The building is likely to be ‘moderately’ to ‘significantly’ impacted by tilt and ‘slightly’ to ‘moderately’ impacted by curvatures and strains in accordance with **AS2870, 2011**.

Impacts to the ‘Westhaven’ buildings are likely to include high residual tilt, distortion of frames, sticking doors and windows, splitting/shearing of support posts, and loss of weather tightness and floor bearer or support. The dimension and type of building will allow significantly higher strain (> 5 mm/m) and curvature > 1 km^{-1} to occur before significant impact develops. Similar impacts are assessed for the machinery sheds, with potential collapse due to frame distortion and connection failure.

The site appears to have underground power and telecommunications running to the residence from the suspended services at the access road.

‘Un-named’ Property

An NCOPL-owned dwelling (incomplete at this stage) is located above the chain pillars between LW204 and 205 (**Figure 1a**). The partially completed circular steel-framed structure is two-storeys high with a diameter of approximately 15 m and supported on a central column. There are no other features except for an olive grove to the south that was in a poor condition (likely drought and pest animal affected).

It is likely that the structure would be subsided by 0.45 m by LW204 to 205 with tilts ranging from 5 mm/m to 15 mm/m, hogging curvature of 0.5 km^{-1} (radius of 2 km) and tensile strains of up to 10 mm/m. The incomplete building is likely to be ‘moderately’ to ‘significantly’ impacted by mine subsidence effects in accordance with **AS2870, 2011**.

Impacts to the buildings are likely to include high residual tilt, distortion of frames, sticking doors and windows, splitting/shearing of support posts, and loss of weather tightness and floor bearer or support. The dimension and type of building will allow significantly higher strain (> 5 mm/m) and curvature > 1 km^{-1} to occur before significant impact develops. Similar impacts are assessed for the machinery sheds, with potential collapse due to frame distortion and connection failure.

11.4.2 Impact Management Strategies

Based on the above, it may be assumed that only the structures 'within' the limits of longwall extraction may be 'significantly' impacted after longwall mining occurs. The structures outside the limits of longwall extraction but inside an AoD of 26.5^{o} or half the depth of cover may be 'slightly' impacted. Slight impact infers the structure may be readily repaired and 'safe to occupy', while 'significant' impact could require evacuation and reconstruction of some or all sections to the entire residence before it would be deemed 'safe to occupy' again.

A dilapidation survey of the three dwellings within the EP Area should be made by a qualified building consultant before and after mining impact, including the installation of any monitoring points for subsidence surveys if necessary. All residential dwellings within the longwall extraction limits should be made always safe by vacating before mine subsidence effects and until the necessary remediation works for re-occupation are completed.

11.5 Groundwater Supply and Monitoring Bores

11.5.1 Predicted Impacts

Water supply bores

Two water supply wells (GW022595 and GW000014) are installed over LW203 and 204, respectively, at depths ranging from 30.4 m to 122.4 m (or 108 m to 196 m above the Hoskissons Seam) (**Figure 1g**). The wells are located in aquifers associated with the Purlawaugh and Napperby Formations. Both wells are predicted to have a 'high' risk of significant subsidence impacts (**Table 22**).

Groundwater monitoring bores

Four groundwater monitoring bores (P9-P11 and P54) and are installed at depths ranging from 30 m to 348 m, or from 259 m above to 28 m below the Hoskissons Seam (**Figure 1c**).

The potential for significant well casing impact (i.e. loss of well function due to closure or rupture of casing) has been based on horizontal shear displacement and vertical strain estimates. The impacts are expected to increase with severity where wells or bores are intersected by A-Zone fracturing.

The predicted impacts to the existing groundwater monitoring bores are summarised in **Table 22**.

The groundwater monitoring bores that are located over the proposed longwall limits are predicted to have a 'high' risk of significant impact to well casing.

Bore P54 is 300 m north west of longwall extraction and has a 'low' risk of being significantly impacted by LW205. Bore P8 is located 1.2 km outside the limits of longwall mining (3.75 times the cover depth) and also has a 'low' risk of being impacted by horizontal bedding shear movements.

Table 22 - Groundwater Monitoring Wells and Impacts

Bore ID	Location	Cover to Mine Roof H (m)	Depth to Base z (m)	Base Height above Mine Roof y(m)	y/H	Predicted A-Zone Height A (m)	Predicted Well Subsidence (m)	Predicted Vertical Strain* (mm/m)	Predicted Bedding Slip / Shear^ (mm)	Impact Risk
GW000014	LW204	231	122.4	108	0.47	205	1.75	+/- 4 to 15	400	High
GW022595	LW203	226	30.4	196	0.87	194	1.1	+/- 4 to 15	400	High
P10	LW205	255	130	125	0.49	215	2.6	+/- 4 to 15	380	High
P11	LW205	255	50	205	0.80	215	2.6	+/- 4 to 15	380	High
P54	300 m NW of LW205	320	348	-28	-0.09	0	0.02	< +/-1	15	Low
P8	1.2 km west of LW205	324	65	259	0.80	0	0.0	0.0	5	Low
P9	LW203	224	30	194	0.87	194	1.6	+/- 4 to 15	400	High

* Vertical strain from extensometer data (**Figure 11j**). Tensile strains are positive. ^ **-** Shear = Tilt*t/2

11.5.2 Impact Management Strategies

Water supply bores may not be able to be reinstated above longwall extraction zones until significant groundwater recovery had occurred after mining. It is therefore likely that an alternate water source would be required after longwall mining commences in the EP Area. Additional monitoring bores may be required to replace the function of impacted monitoring bores, if necessary.

11.6 Other Rural Infrastructure

Other items of rural infrastructure within the EP Area include several aboveground water storage tanks and timber pole suspended domestic power supply and telecommunications lines. There are also small pump sheds adjacent to some of the larger farm dams or bores.

These features should be assessed for potential impacts and likely remediation works or replacement in accordance with the built feature’s management plan.

Domestic power and telecommunications lines to the existing houses would be required to be switched off during longwall mining and any impacts repaired by NCOPL.

11.7 Aboriginal Heritage

11.7.1 Description and Predicted Subsidence Effects

Aboriginal cultural heritage sites have been identified in the Aboriginal Cultural Heritage Assessment for the EP Area **(Whincop Archaeology, 2020)**. The majority of Aboriginal cultural heritage sites are isolated finds and artefact scatters.

Whincop Archaeology (2020) found that the investigation area for the Aboriginal Cultural Heritage Assessment has been impacted through historical land use practices. It is therefore reasonable to assume that most of the artefacts have been displaced as a result of previous land use activities and erosion. Based on this, **Whincop Archaeology (2020)** concludes that the impact of subsidence on surface artefact sites is likely to be minimal and, therefore, negligible. For this reason, subsidence predictions for artefact scatters and isolated artefacts are not presented in this report.

There are two grinding groove sites ('Claremont GG1' and 'Mayfield GG1') located above proposed CF201(B) and LW205 respectively. These two sites are located on sandstone bedrock or possibly 'loose' boulders (**Figures 1a/b** and **2a/b**). The quality of the grinding grooves varies from 'fair' to 'excellent'. A description of the sites is provided in **Table 23**.

Table 23 - Aboriginal Heritage Site Description

Site Name.	Site Type (No.)	LW	Description
Claremont GG1	Grinding Grooves (1)	CF201(B)	One Grinding Groove (fair condition) on what appears to be a partially buried boulder with several nearby rocks dug up and moved by farming activities (ploughing)
Mayfield GG1	Grinding Grooves (48)	LW205	Forty-eight grooves (excellent condition) in six separate clusters on sandstone bedrock. Sites are within re-generated forest to the immediate north-west of a drainage line.

Surface cracking within the boundary of an artefact site resulting from subsidence has the potential to displace soils, including archaeological deposits, and move Aboriginal objects, both of which are considered to be impacts. Moreover, if remediation of the surface was required after mining, these works could potentially impact Aboriginal cultural heritage sites.

Because of the nature of these sites (i.e. sites are hosted by rock features, which could be prone to cracking), the predicted mean and worst-case final subsidence, tilt and horizontal strain (U95%CL values) for each listed site after the proposed LW203 to 205 are presented in **Table 24**, respectively. The values were derived from the predicted subsidence effect contours (**Figures 8a** to **8c**).

Table 24 - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site Name.	Site Type (No.)	Panel	Final Subsidence (m)	Final Tilt (mm/m)	Transient & Final Horizontal Ground Strain (mm/m)^	
					Transient	Final
Claremont GG1*	Grinding Grooves (1)	CF201(B)	0.002	0.5	-	< 1
Mayfield GG1	Grinding Grooves (48)	LW205	1.16	37	2 (3)	3 (5)

^ - Tensile strain is positive; (brackets) - Discontinuous strains due to tensile cracking or compressive shearing.
* - site protected by MRZ (see **Section 8.5**).

11.7.2 Potential Impacts

The likelihood of damage occurring at the Aboriginal grinding groove sites has been assessed based on the following impact parameter criteria (**Table 25**). The criteria consider the theoretical cracking limits of rock of 0.3 mm/m to 0.5 mm/m and the 'system' slackness or strain 'absorbing' properties of a jointed, thinly bedded and highly weathered rock mass during subsidence deformation. The lack of measured observed impact (i.e. surface cracking) due to measured strains of up to 3 mm/m at several Newcastle Coalfield mines is an example of the difference between theoretical and in-situ rock mass cracking behaviour.

Table 25 – Impact Potential Criteria for Aboriginal Grinding Groove Sites

Cracking Damage Potential - Indicative Probabilities of Occurrence	Predicted 'smooth profile' Horizontal Strain (mm/m)	
	Tensile	**Compressive**
Very Unlikely (<5%)	< 1	< 2
Unlikely (5 - 10%)	1 - 3	2 - 4
Possible (10 - 50%)	3 - 5	4 - 6
Likely (>50%)	> 5	> 6
Erosion Damage Potential - Indicative Probabilities of Occurrence	**Predicted Surface Gradient Change or Tilt Increase**	
Very Unlikely (<5%)	<0.3% (<3 mm/m)	
Unlikely (5 - 10%)	0.3-1% (3 - 10 mm/m)	
Possible (10 - 50%)	1-3% (10 - 30 mm/m)	
Likely (>50%)	>3% (>30 mm/m)	

The 'Cracking Damage Potential' is considered the primary damage potential indicator and the 'Erosion Damage Potential' is an additional, secondary criterion that is relevant to features exposed to concentrated water flows along creeks or sites that have been damaged by cracking. Therefore, in cases where cracking is deemed 'possible' or 'likely' at a site, the potential for erosion damage will also be considered 'possible' or 'likely'.

The results of the impact assessment are presented in **Table 26**. Only grinding grooves in bedrock are 'likely' to be impacted as the loose boulders are 'unlikely' to crack. Partially buried boulders may still crack due to confinement of the boulder and could result in significant strain transfer into the boulder/slab.

Table 26 - Predicted Subsidence Impacts due to U95%CL Values at Aboriginal Grinding Groove Sites

Site Name.	Site Type (No. of grooves)	Location	Horizontal Strain (mm/m)^	Cracking Damage Potential*	Tilt (mm/m)	Erosion Damage Potential*
Claremont GG1*	Grinding Grooves (1)	Sandstone Bedrock	<1	Very Unlikely	<0.5	Very Unlikely
Mayfield GG1	Grinding Grooves (48)	Sandstone Bedrock	3 (5)	Likely	37	Possible

^ - Tensile strain is positive, (brackets) - transient or dynamic strains in brackets;
* - site protected by MRZ (see **Section 8.5**); # - grinding grooves are located on detached or loose boulders.

It is assessed that the Mayfield GG1 grinding grooves are likely to be subject to tensile strains in excess of 3 mm/m are therefore 'likely' to be impacted. The Claremont GG1 grinding groove site is 'very unlikely' to be affected by predicted by tensile strains < 1 mm/m due to the proposed MRZ above CF201 (B).

11.7.3 Impact Management Strategies

Impact management strategies for Aboriginal cultural heritage sites are presented in the Narrabri Mine Extraction Plan Heritage Management Plan (EP HMP) (**NCOPL, 2021**) and have been developed in consultation with the Registered Aboriginal Parties (RAPs). The Narrabri Mine Aboriginal Cultural Heritage Management Plan (ACHMP) (**NCOPL, 2019**, or its latest approved version) is also applicable for the ongoing management of Aboriginal cultural values for the Narrabri Mine, including the EP Area and will provide specific management measures for potential impacts.

11.8 Historical Heritage

A Historical Heritage Assessment was undertaken by **Niche Environmental (2020)**. No items of historic heritage were identified in the EP Area during this assessment.

11.9 Survey Control Marks

11.9.1 Potential Impacts

There are several state survey marks located in the EP Area (refer to www.maps.six.nsw.gov.au). Their location and predicted subsidence are provided in **Table 27** and **Figures 1c** and **1d**.

Table 27 - Predicted Subsidence at State Survey Marks in EP Area

Survey Mark	Easting (m)	Northing (m)	Predicted Subsidence (m)
SS43428	**774338**	**6620068**	**1.52**
SS39336	**776555**	**6619864**	**0.01**
PM74712	775775	6616586	0.00

There are two marks that are likely to be subsided 0.01 m and 1.52 m by the EP Area panels (noted in bold in **Table 27**).

11.9.2 Impact Management Strategies

State Survey Marks affected by mine subsidence would be required to be relocated after mining is completed.

11.10 Far-Field Horizontal Displacement and Strain

11.10.1 Predicted Effects and Impacts

Horizontal movements due to longwall mining have been recorded at distances well outside of the AoD in the Newcastle, Southern and Western Coalfields (**Reid, 1998**; **Seedsman and Watson, 2001**). Horizontal movements recorded beyond the AoD are referred to as far-field displacements (FFDs).

Based on a review of the above information, it is apparent that this phenomenon is strongly dependent on (i) cover depth, (ii) distance from the goaf edges, (iii) maximum subsidence over the extracted area, (iv) topographic relief and (v) the horizontal stress field characteristics (**Figure 16a**).

An empirical model for predicting FFDs in the Southern Newcastle Coalfield indicates that measurable FFD movements (> 10 mm) generally occur for distances of two to four times the cover depth (2H to 4H) as shown in **Figures 16b** and **16c**. The direction of the movement is generally towards the extracted area but can vary due to the degree of regional horizontal stress adjustment around the extracted area and the surface topography. As a result, FFD impacts at the Pit Top Area, Namoi River and are not anticipated.

Centreline and crossline horizontal strain data (normalised to cover depth) is presented in **Figures 16d** and **16e** and indicate strains are typically < 1 mm/m at an angle draw of 26.5^{o} or 0.5 times cover depth.

As surface cracking is unlikely to develop at strains < 1 mm/m, it is considered that 0.5 times cover depth is the practical limit of surface impact for the Narrabri Mine. FFD and strains generally only have the potential to damage long, linear features such as pipelines, bridges, dam walls and railway lines.

11.10.2 Impact Management Strategies

Any publicly owned surface features such as bridges or culverts within five times the cover depth (e.g. 800 m from the proposed longwalls on the eastern side of the EP Area) should be monitored for FFD movements during mining. It is understood that the Werris Creek Mungindi Railway and Kamilaroi Highway with their associated infrastructure are the only public utilities that exist to the east of the EP Area and are outside the five times cover depth range.

The deeper western side of the EP Area may affect a larger area of up to 1.5 km away, however it is understood that there are no man-made infrastructure items within this range (except a water bore at 1.2 km away from LW205).

It is therefore considered unnecessary to develop a FFD Impact Management Plan.

12.0 Monitoring Program

12.1 Subsidence Development

The development of subsidence above a longwall panel generally consists of two phases that are defined as 'primary' and 'residual' subsidence.

Primary subsidence is referred to as subsidence that is directly related to the retreating longwall face.

Residual subsidence, due to re-consolidation of goaf, represents approximately 5% to 10% of maximum final subsidence and would be ongoing for several months to years after primary subsidence ceases.

Reference to **ACARP, 2003** indicates that measurable subsidence at a given location above the longwall panel centreline is likely to commence at a distance of about 50 m to 80 m ahead of the retreating longwall face; accelerate up to 100 mm/day when the face is 0.3 times the cover depth or 50 m past the point; and decrease to <20 mm per week when the face is > 1 times the cover depth or 160 m past the point (**Figures 11j** and **17**).

Further subsidence (< 20 mm) is also likely to develop due to compression of chain pillars when adjacent panels are subsequently mined. Subsidence magnitudes usually develop at a decaying rate for each panel and usually occurs for at least two more longwalls.

Further subsidence development details in relation to sub-surface fracturing are provided in **Section 10.3.6**.

12.2 Surface Monitoring

Surface monitoring to-date has been conducted in relatively cleared grazing areas above the eastern portion of the Narrabri Mine. Future mining would be extended below natural bushland areas that would require clearing to install survey monitoring lines over LW206 to 209.

It is therefore proposed to install a new crossline along an existing road above LW203 to 209 and panel centrelines above the start and finishing ends of the panels. The centrelines would be extended out from the goaf edge limits for a maximum distance equal to the cover depth where possible. The pegs may be installed at 10 m to 15 m spacing or at 5% of the cover depth (whichever is greater).

It is also recommended that crossline H be extended to 2 times the cover depth (63^{o} angle of draw) to the west of the maingate ribs for LW 109 to 111, if possible.

The proposed survey lines would also be used to provide ground truthing information for the LiDAR results. The levelling accuracy of the LiDAR would not be able to accurately measure the angles of draw to the 20 mm subsidence contour due to the level accuracy limitations of the method (which only has +/- 0.15 m level accuracy).

The suggested monitoring program also assumes that visual inspections and mapping of surface impacts would be conducted before and after each panel is completed. Non-conventional monitoring techniques such as cliff line reflectometry and/or drone surveys of minor cliff faces and crack location detection above the woodland areas are suggested.

Subsidence and strains may be determined using total station techniques to determine 3-D coordinates, provided that the survey accuracy is suitable. Survey accuracy using Electronic Distance Measuring and traverse techniques from a terrestrial base line is normally expected to be +/- 2 mm for level and +/- 7 mm for horizontal displacement (i.e. a strain measurement accuracy of +/- 0.7 mm/m over a 10 m bay-length).

12.3 Sub-Surface Monitoring

It is noted that four deep boreholes with multilevel VWPs and several screened standpipes have been installed to the east of LW101 and directly above LW108A to monitor heights of groundwater level impacts (refer **HydroSimulations, 2015**).

It is recommended that the groundwater response to mining above LW109 to 111 continue to be periodically reviewed to confirm the assessed fracture zones for LW203 to 205 are still reasonable. Consideration of further borehole extensometer and VWP installations is recommended. It is also recommended that the last VWP be placed as close as possible to rock head or substituted with an open screened well (if the water table is still present within 50 m of the surface). The southern portion of LW 203, close to the drainage line, would be an ideal position.

Inspections and monitoring of underground workings and groundwater make should also be recorded and plotted against rainfall deficit data (when available). Ventilation input and outputs should also be monitored for possible inflow short circuiting detection through surface cracks.

12.4 Adaptive Management Strategies

Adaptive management strategies for the Project would include:

- Ongoing review of predicted subsidence impacts against observed impacts.

- Conservative longwall setback distances would be adopted in lieu of uncertain monitoring data outcomes.

- Detailed crack mapping to improve predictions for cracking areas above future longwalls.

13.0 Conclusions

The subsidence predictions for the EP Area have been based on several empirical and calibrated analytical models of overburden and chain pillar behaviour.

The subsidence effect and impact assessment predictions have been validated against data from surface and subsurface monitoring programs above LW101 to 109.

NCOPL will continue to implement an adaptive management approach to ensure Project Approval performance measures are achieved. This will include monitoring, remediation and periodic evaluation of the consequences of mining, with possible adjustment of the mining layout to achieve and maintain the required measure of performance.

The prediction methods applied in this report will allow specialist consultants to assess the potential range of impacts to a given feature in a probabilistic manner.

Impact Management Plans and strategies will continue to be developed through regular review of Trigger Action Responses and necessary mitigation measures required for the natural and built features.

14.0 References

2rog Consulting, 2020. **Narrabri Underground Mine Stage 3 Extension Project Agricultural Impact Statement**. Report for Narrabri Coal Operations Pty Ltd.

ACARP, 1998a. **Chain Pillar Design (Calibration of ALPS)**. Colwell, M., Mark, C. ACARP Report No. C6036 (October).

ACARP, 1998b. **ACARP Project No. C5024, Establishing the Strength of Rectangular and Irregular Pillars**. Galvin, J.M., Hebblewhite, B.K., Salamon, M.D.G., Lin, B.B.

ACARP, 2002. **Subsidence Impacts on River Valleys, Cliffs, Gorges and River Systems**. Project No. C9067, Waddington Kay & Associates, Report WKA110.

ACARP, 2003. **ACARP Project No. C10023, Review of Industry Subsidence Data in Relation to the Impact of Significant Variations in Overburden Lithology and Initial Assessment of Sub-Surface Fracturing on Groundwater**. Ditton, S. and Frith, R.C. Strata Engineering Report No. 00-181-ACR/1 (Sep).

ACARP, 2005. **Systems Approach to Pillar Design**. Strata Control Technologies Pty Ltd, UNSW School of Mining, Coffey Geosciences Pty Ltd. ACARP Project No. C9018. (May).

ACARP, 2007. **Hydrological Response to Longwall Mining**. CSIRO Exploration & Mining. Guo, H., Adhikary, D., Gaveva, D. Report No. C14033 (October).

AGS, 2007. **Practice Note Guidelines for Landslide Risk Management 2007**. Australian Geomechanics Society Landslide Taskforce, Landslide Practice Note Working Group.

Aquaterra (2009). **Narrabri Coal Mine Stage 2 Longwall Project Hydrogeological Assessment**. Aquaterra Consulting Pty Ltd (November 2009) Specialist Consultant Studies Compendium Volume 1, Part 2.

AS2870, 2011. **Australian Residential Slabs and Footing Design Guidelines**.

Das, 1986. **Influence of Width/Height Ratio on Post Failure Behaviour of Coal**. International Journal of Mining and Geological Engineering Vol 4.

DgS, 2009. **Narrabri Coal Mine (Stage 2) Longwall Mine Subsidence Predictions and Impact Assessment-Specialist Compendium for NCM EIS (Stage 2)**.

DgS, 2011. **Additional Mine Subsidence Impact Assessment of Steep Slopes and Cliffs above the Proposed Longwall Panels LW38 to 50 at West Wallsend Colliery**. DgS Report No. WWD-012/7 (12/09/11).

DgS, 2013. **Sub-Surface Fracture Height Review and Predictions for the Proposed Longwalls 42 to 47, 51 and 52 at West Wallsend Colliery, Killingworth**. DgS Report No. WWD-012/8 (12/08/13).

DgS, 2015. **Mine Subsidence Assessment on the Proposed 75W Modification to the Stage 2 Mining Layout at the Narrabri Mine, Narrabri**. DGS Report No. NAR-004/1 (17/08/15).

DgS, 2017. **Mine Subsidence Assessment for the Proposed LW107 to LW110 Extraction Plan at the Narrabri Mine.** DGS Report No. NAR-002/3 (08/02/17).

DgS, 2020a. **Proposed Alterations to the Narrabri Mine MOD 5 Longwalls LW109 to 120**. DgS Report No. NAR-004/5 (29/01/20).

DgS, 2020b. **Mine Subsidence Assessment for the Narrabri Underground Mine Stage 3 Extension Project**. DgS Report No. NAR-005/2 (05/07/20).

DgS, 2021. **Mine Subsidence Assessment for Proposed Pillar Reduction Panels CF201 - CF205 (A - J) at the Narrabri Underground Mine (Alterations to the MOD 7 Longwalls LW201 to 202)** DGS Report No. NAR-004/7 (17 June)

Ditton and Merrick, 2014. **A New Sub-Surface Fracture Height Prediction Model for Longwall Mines in the NSW Coalfields**. Presentation given at Australian Earth Sciences Convention, Newcastle (04/07/2014).

ELA, 2014. **Narrabri Mine Tree Health Assessment LW101 - 103**. Ecological (Australia) Pty Ltd (28/11/2014).

Forster, 1995. **Impact of Underground Coal Mining on the Hydrogeological Regime, Central Coast, NSW**. Forster, I. Published in Australian Geomechanics Society (AGS) Conference Proceedings (February), Engineering Geology of Newcastle – Gosford Region, University of Newcastle.

Hawkins G. & Ramage R., 2004. **A Synthesis of Results of Sub-Surface Investigation of Abandoned Mine Workings with Reference to the Borehole Seam Workings under Newcastle**. 6th Triennial MSTS Conference on Buildings and Structures, Maitland (November).

Heasley, 2008. **Some Thoughts on Calibrating LaModel**. The proceedings of the 27th International Conference on Ground Control in Mining, West Virginia University, WV, US.

Holla, 1985. **Mining subsidence in New South Wales 1. Surface Subsidence Prediction in the Southern Coalfield**. NSW Department of Minerals Resources: Sydney.

Holla L, 1987. **Mining subsidence in New South Wales 2. Surface Subsidence Prediction in the Newcastle Coalfield**. NSW Department of Minerals Resources: Sydney.

Holla and Barclay, 2000. **Mine Subsidence in the Southern Coalfield**. Holla, L. and Barclay, E. Department of Minerals Resources (June).

HydroSimulations, 2015. **Narrabri Mine Modification Groundwater Assessment**. HydroSimulations Pty Ltd Report No. HC2015/29 (August 2015).

HydroSimulations, 2017. **Review of Documents and Data regarding NSW DPE 'Height of**

Fracturing Study at the Dendrobium Mine'. Memorandum to South32 (25/09/17).

Karmis *et al*, 1990. **Recent Developments for the Application of the Influence Function Method for Ground Movement Predictions in the US**. US mining Science and Geotechnology. Vol 10. pp 223-245.

Li *et al.,* 2006. **A Case Study on Longwall Mining Under the Tidal Waters of Lake Macquarie**. Li, G., Forster, I., Fellowes, M. and Myors, A. 2006. Proceedings of Coal 2006 Conference, University of Wollongong.

NCOPL, 2015. **Subsidence Management Status Report No. 9** (13/04/15).

NCOPL, 2019. **Narrabri Mine Aboriginal Cultural Heritage Management Plan**. Narrabri Coal Operations Pty Ltd, 24/06/19.

NCOPL, 2021. **Narrabri Mine Extraction Plan Heritage Management Plan** (EP HMP). Narrabri Coal Operations Pty Ltd.

NERDDP, 1993. **Improved Methods of Subsidence Engineering**. P. Willey, P Hornby, S. Ditton, G. Puckett (ACIRL) and G. McNally (UNSW). NERDDP Project No. 1311 (June).

Niche Environmental, 2020. **Narrabri Underground Mine Stage 3 Extension Project Historic Heritage Assessment**. Niche Environmental Report to Narrabri Coal Operations Pty Ltd.

Pells *et al.*, 1998. **Foundations on Sandstone and Shale in the Sydney Region**. Pells, P.J.N., Mostyn, G. and Walker, B.F. Australian Geomechanics Journal.

Peng S.S. & Chiang H.S (1984). **Longwall Mining**. Wiley.

Reid, 1998. **Horizontal Movements around Cataract Dam, Southern Coalfields**. Reid, P. Mine Subsidence Technological Society 4th Triennial Conference Proceedings. Newcastle, July 1998.

Resource Strategies Pty Ltd, 2020. **Narrabri Underground Mine Stage 3 Extension Project Biodiversity Development Assessment Report**. Resource Strategies Pty Ltd Report to Narrabri Coal Operations Pty Ltd.

SCT, 2008. **Assessment of Longwall Panel Widths and Potential Hydraulic Connection to Bowmans Creek – Ashton Mine**. SCT Operations Pty Ltd Report to Ashton Coal, September.

Shepherd and Sefton, 2001. **Subsidence Impact on Sandstone Cliff Rock Shelters in the Southern Coalfield, New South**. Proceedings of 5th Triennial Conference of Mine Subsidence Technological Society.

SDPS®, 2007. **Subsidence Deformation Prediction System - Quick Reference Guide and Working Examples**. Agioutantis, Z., Karmis, M. Department of Mining and Minerals Engineering, Virginia Polytechnic Institute and State University, Virginia.

Seedsman and Watson, 2001. **Sensitive Infrastructure and Horizontal Ground Movement at Newstan Colliery**. Seedsman, R. W. and Watson, G. Mine Subsidence Technological Society 5th Triennial Conference Proceedings, Maitland, August 2001.

Tammetta, 2013. **Estimation of the Height of Complete Groundwater Drainage Above Mined Longwall Panels**. Paul Tammetta. Paper published in Groundwater Journal (Vol 51, No. 5, Sep-Oct 2013).

Tammetta, 2015. **Estimation of the Change in Hydraulic Conductivity Above Mined Longwall Panels**. Groundwater Journal, (Vol. 53, No. 1, Jan-Feb 2015)

Vick, 2002. **Degrees of Belief: Subjective Probability and Engineering Judgement**. Vick, S.G., ASCE Press.

Whincop Archaeology, 2020. **Aboriginal Cultural Heritage Assessment for the Narrabri Underground Mine Stage 3 Extension Project in the Narrabri Shire, New South Wales**.

WRM, 2020. **Narrabri Underground Mine Stage 3 Extension Project Surface Water Assessment**. WRM Water and Environment Report for Narrabri Coal Operations Pty Ltd.

UNSW, 1998**. Establishing the Strength of Rectangular and Irregular Pillars**. ACARP Project No. C5024. Galvin, J.M., Hebblewhite, B.K., Salamon, M.D.G., Lin, B.B.

Zipf, 1999. **Using a Post-Failure Stability Criterion in Pillar Design**. Proceedings of Second International Workshop on Coal Pillar Mechanics. NIOSH I.C. 9448 (June).

Appendix A - Photos of Surface Features in EP Area

(28/08/19 and 3-4/12/19)

Photo 1 - Flat Terrain above Proposed LW203 (looking south)

Photo 2 - Hillock/Steep Slope Area east of LW203 (looking south east)

Photo 3 - Kurrajong Creek Tributary No. 1 above LW203 (looking east)

Photo 4 - Kurrajong Creek Tributary No. 1 above LW204 (looking north east)

Photo 5 - Flat Terrain above LW203 to 204 (looking south)

Photo 6 - Kurrajong Creek above LW203 (looking west)

Photo 7 - Kurrajong Creek above LW203 (looking east)

Photo 8 - Farm Dam above LW203 (looking south east)

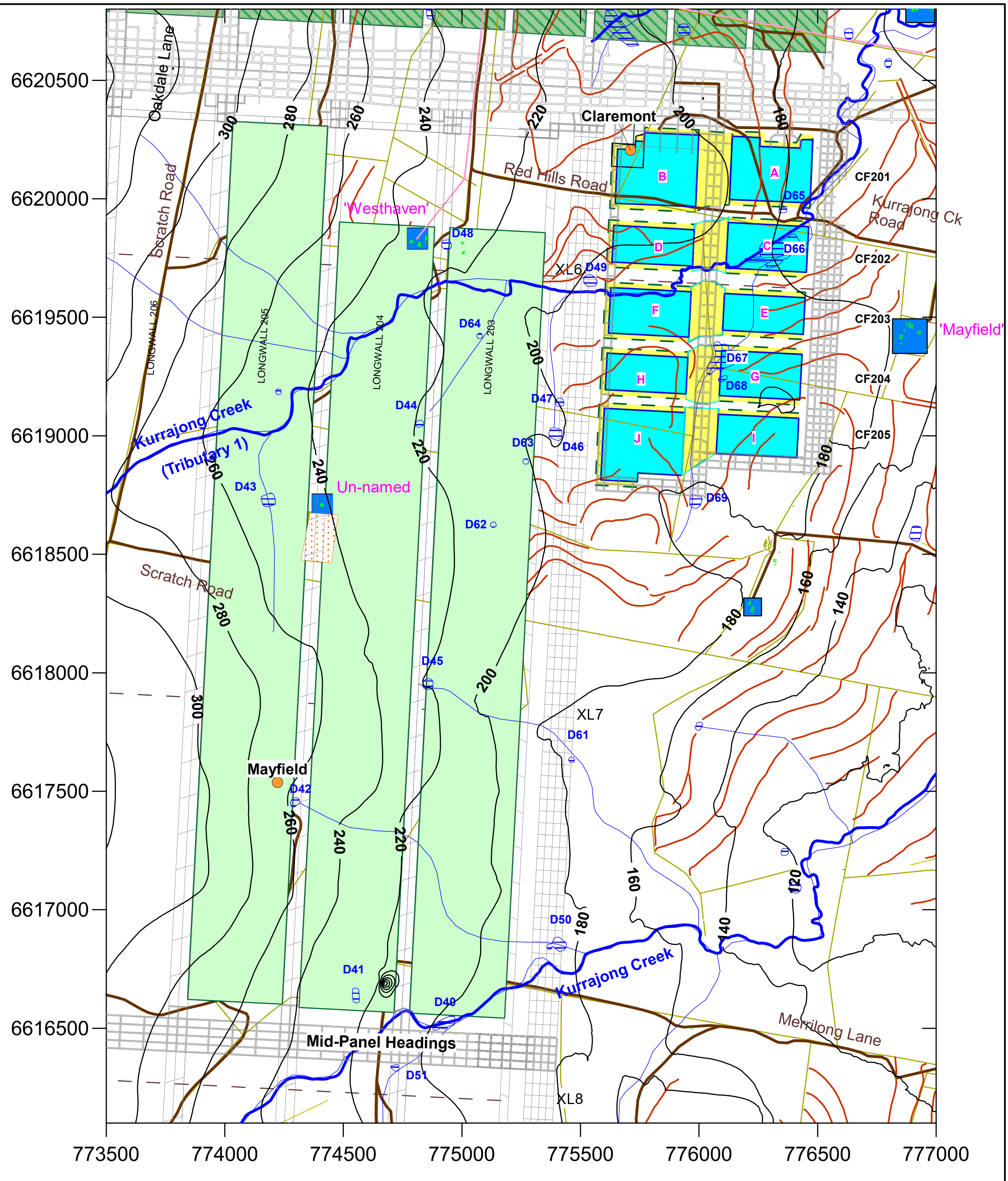
Photo 9 - Edge of Farming/Grazing Area above LW204/205 (looking west)

Photo 10 - NCOPL-Owned Residence and Farm Sheds Above LW204 ('Westhaven') (looking south)

Photo 11 - Observed Cracking along a Pine Creek Tributary above LW107 & 108A (ML1609)

Photo 12 - Remediated Cracking above LW103 & 104 (ML1609)

Photo 13 - Tree Dieback in Ponded Area (now drained) above LW101 (ML1609)

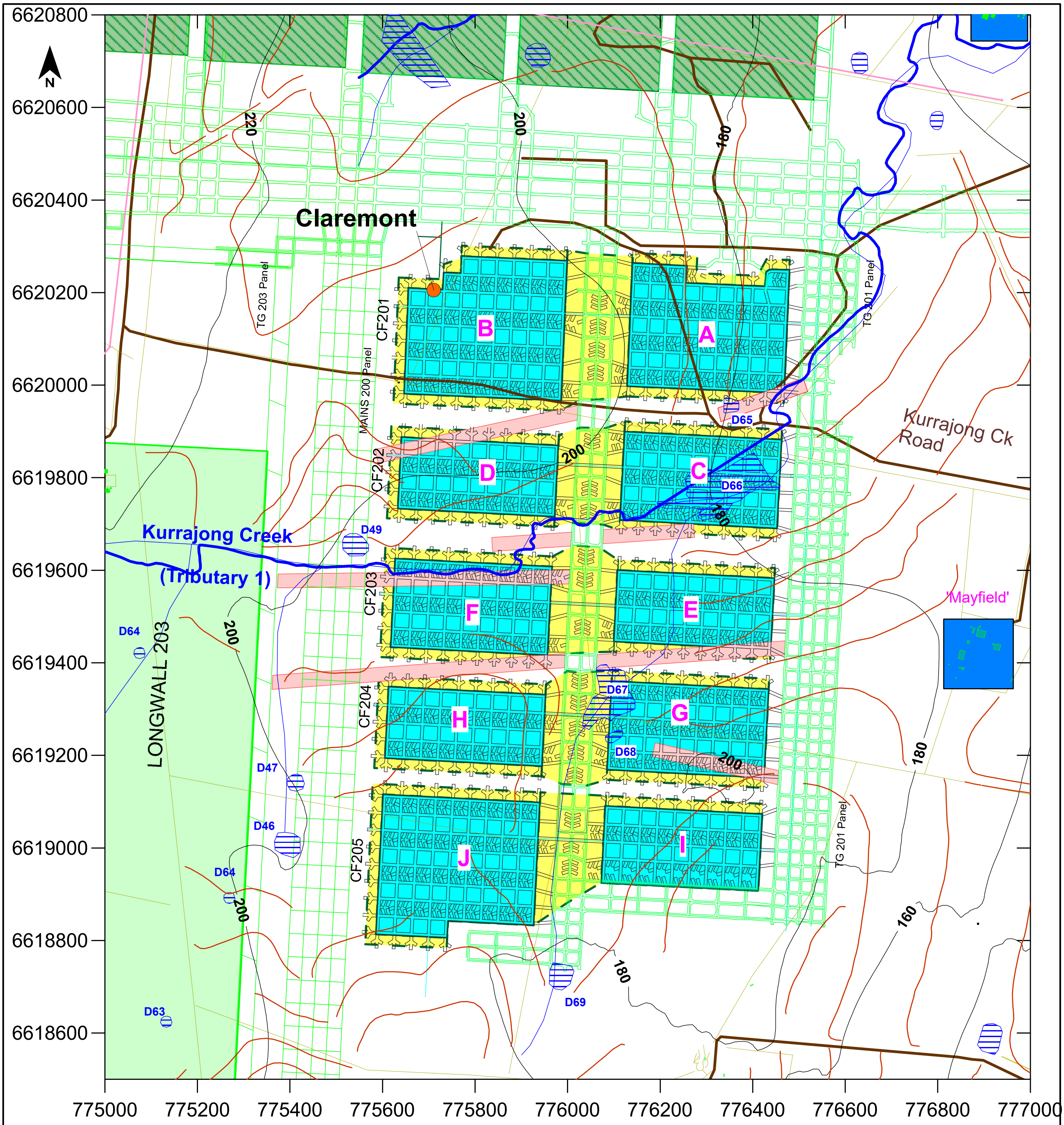


Key:

	Approved Longwalls (LW203-205)
	Extracted Longwalls (LW101-108A)
	Approved First Workings
	Proposed Pillar Reduction Panels (e = 66%)
	Proposed 2nd Workings (e=35%)
	Cover Depth Contours (m)
	Roads (unsealed)
	Fences
	Prediction Cross Lines
	Dwellings & Sheds/Tanks/Orchards
	NCO-Owned Buildings
	Ephemeral Creeks & Watercourses
	Farm Dams
	Contour Banks
	Powerlines (Domestic)
S1	Steep Rocky Slopes
	Grinding Groove Sites

DgS	Engineer:	S.Ditton
	Drawn:	S.Ditton
	Date:	01.09.21
Ditton Geotechnical Services Pty Ltd		

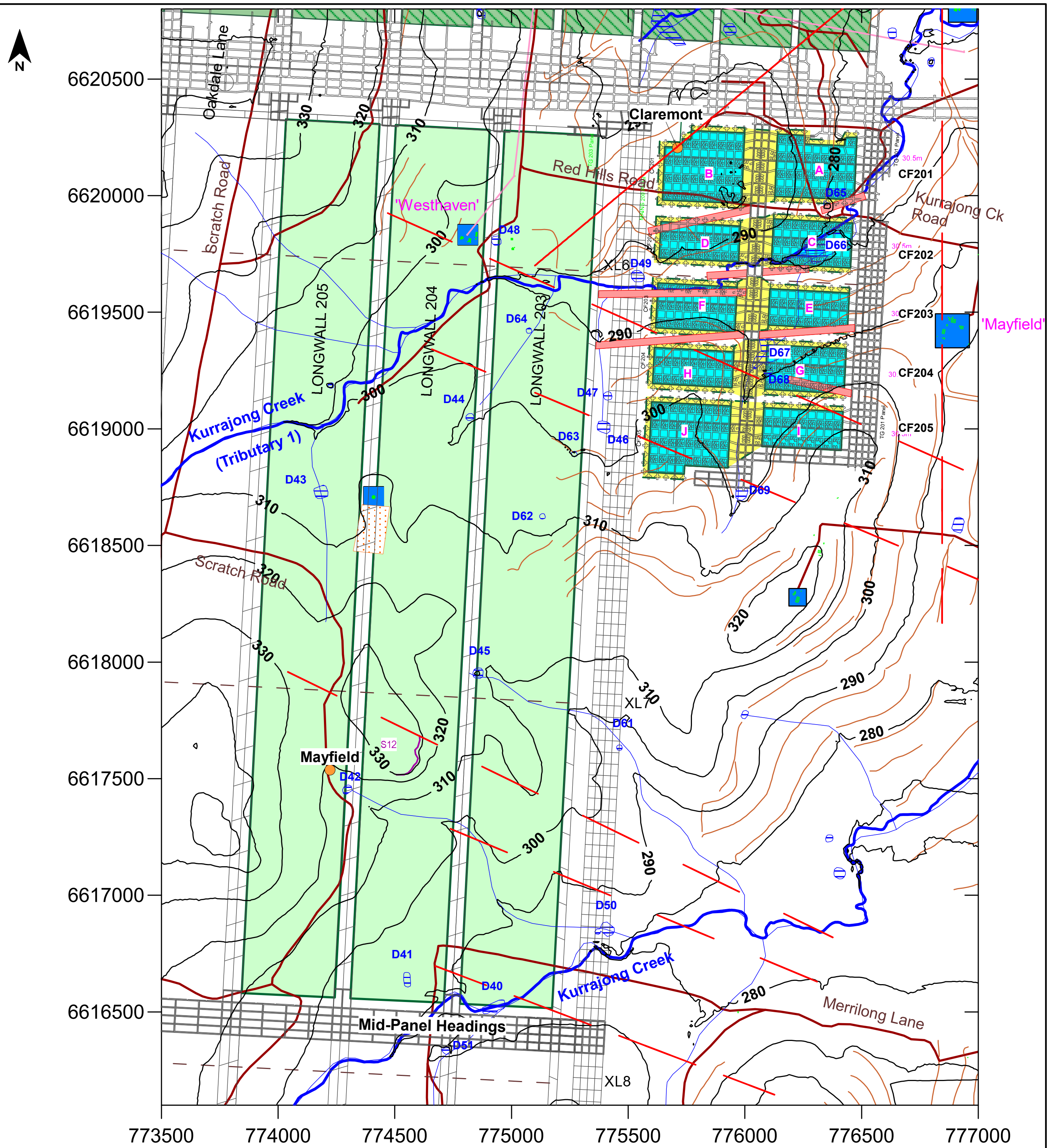
Client:	Narrabri Mine NAR-004/8
Title:	Surface Features & Cover Depth Contours to the Mine Workings Roof with the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) and Longwalls 203 to 205
Scale:	1:30,000
Figure No:	1a



Key:

Cover Depth Contours (m)	Roads (unsealed)
Approved Longwalls (LW203-205)	Pillar 'pocketing' or reduction
Extracted Longwalls (LW101-108A)	Dwellings & Sheds/Tanks
Approved First Workings	Private / NCO-Owned Buildings
Proposed Pillar Reduction Panels (e = 66%)	Powerlines (Domestic)
Proposed 2nd Workings (e=35%)	Fences
Ephemeral Creeks & Watercourses	Farm Dams
Contour Banks	Inferred Faults
Grinding Groove Site	

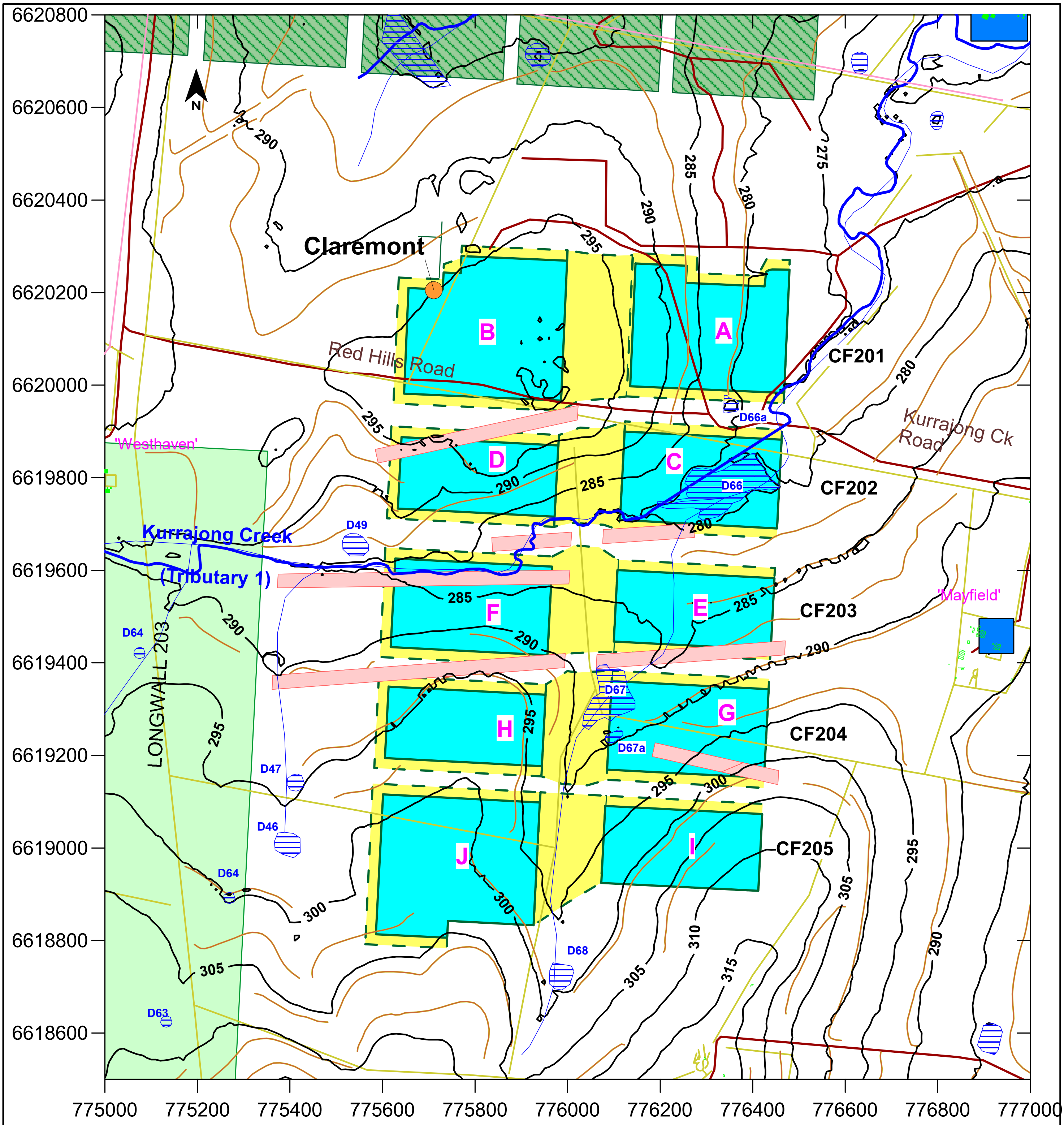
DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton	Title:	Surface Features & Cover Depth Contours to the Mine Workings Roof with the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)
	Date: 01.09.21	Scale:	1:15,000 — Figure No: 1b



Key:

Approved Longwalls (LW203-205)		Level Contours (AHD, m)		Ephemeral Creeks & Watercourses	
Extracted Longwalls (LW101-108A)		Roads (unsealed)		Farm Dams	
Approved First Workings		Prediction Cross Lines		Contour Banks	
Proposed Pillar Reduction Panels (e = 66%)		Dwellings & Sheds/Tanks/Orchards		Powerlines (Domestic)	
Proposed 2nd Workings (e=35%)		NCO-Owned Buildings		S1 Steep Rocky Slopes	
		Faults (known)		Grinding Groove Sites	

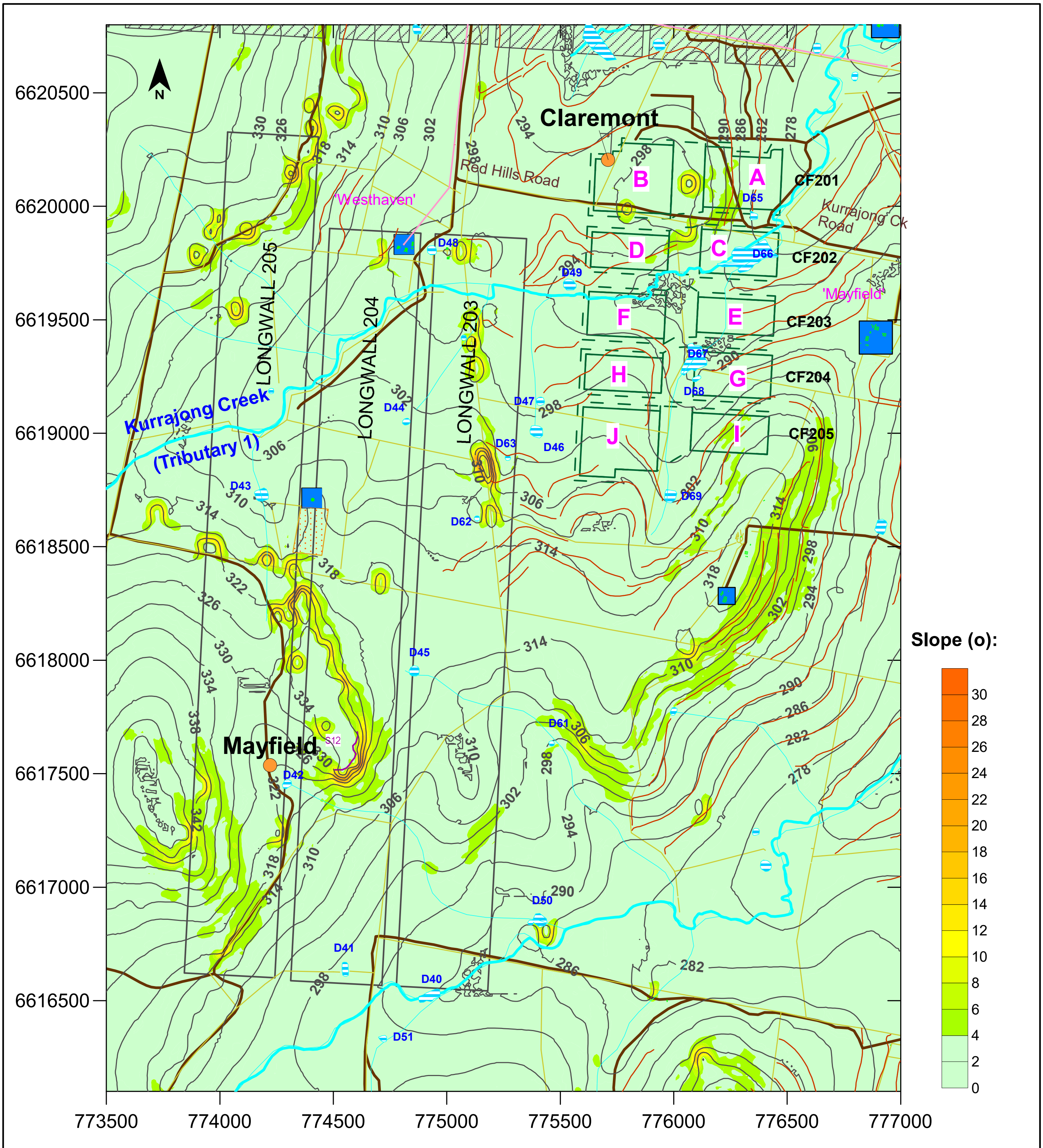
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Surface Features & Level Contours above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) & Longwalls 203 to 205	
Ditton Geotechnical Services Pty Ltd			Scale:	1:30,000	Figure No: 2a



Key:

	Surface Level Contours, AHD (m)		Roads (unsealed)		Ephemeral Creeks & Watercourses
	Approved Longwalls (LW203-205)		Pillar extraction limits		Farm Dams
	Extracted Longwalls (LW101-108A)		Dwellings & Sheds/Tanks		Contour Banks
	Proposed Pillar Reduction Panels (e=66%)		Private / NCO-Owned Buildings		Inferred Faults
	Proposed 2nd Workings (e = 35%)		Fences		Grinding Groove Site
			Powerlines (Domestic)		

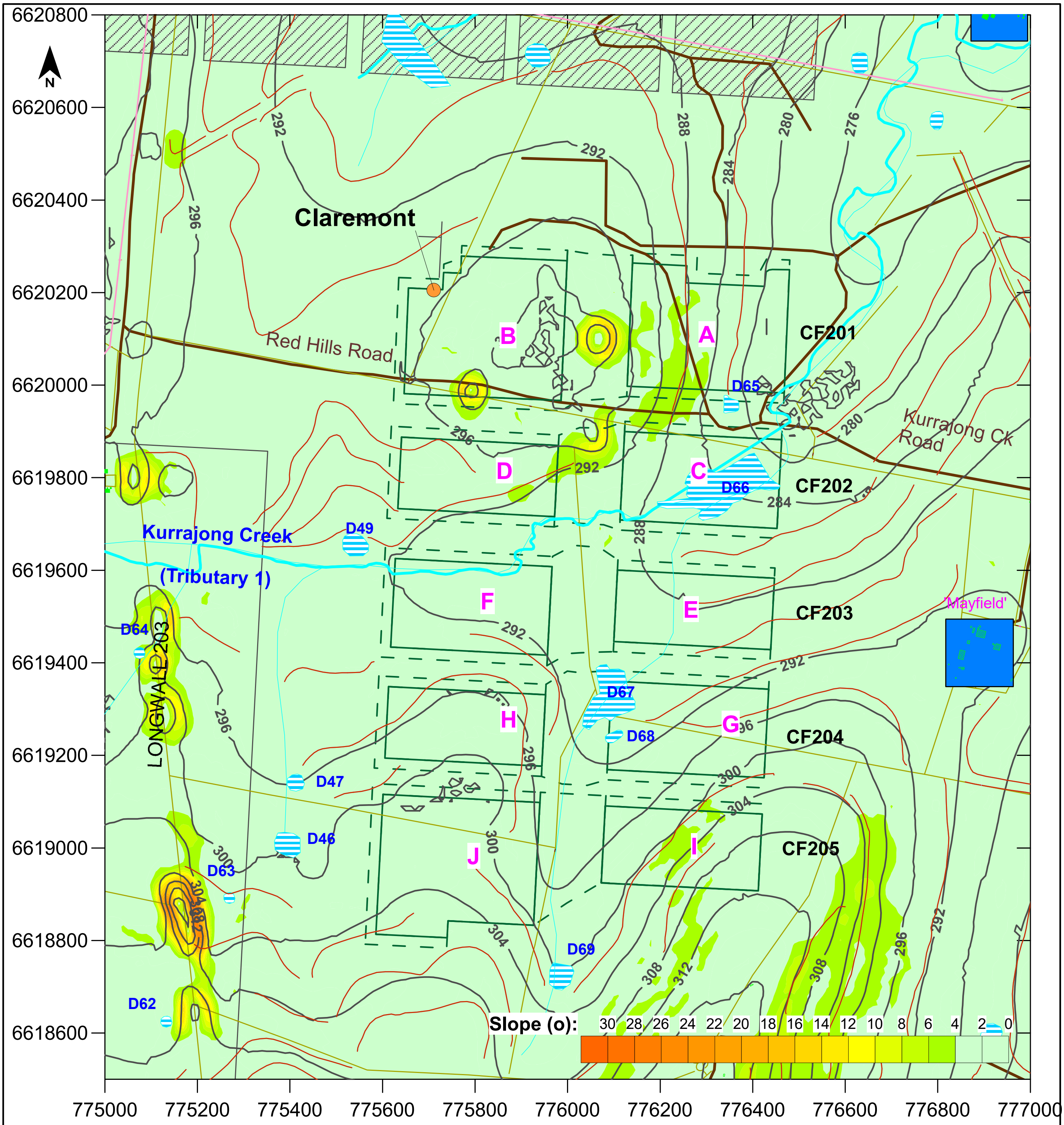
DgS Ditton Geotechnical Services Pty Ltd				
Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
Drawn:	S.Ditton			
Date:	15.07.21	Title:	Surface Features & Level Contours above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)	
		Scale:	1:15,000	Figure No: 2b



Key:

	Approved Longwalls (LW203-205)		Roads (unsealed)		Ephemeral Creeks & Watercourses
	Extracted Longwalls (LW101-108A)		Dwellings & Sheds/Tanks/Orchards		Farm Dams
A	Proposed Pillar Reduction Panels (e = 66%)		NCO-Owned Buildings		Contour Banks
	Proposed 2nd Workings (e = 35%)		Powerlines (Domestic)		Grinding Groove Site
	Level Contours (m, AHD)		Fences	S12	Steep Slopes

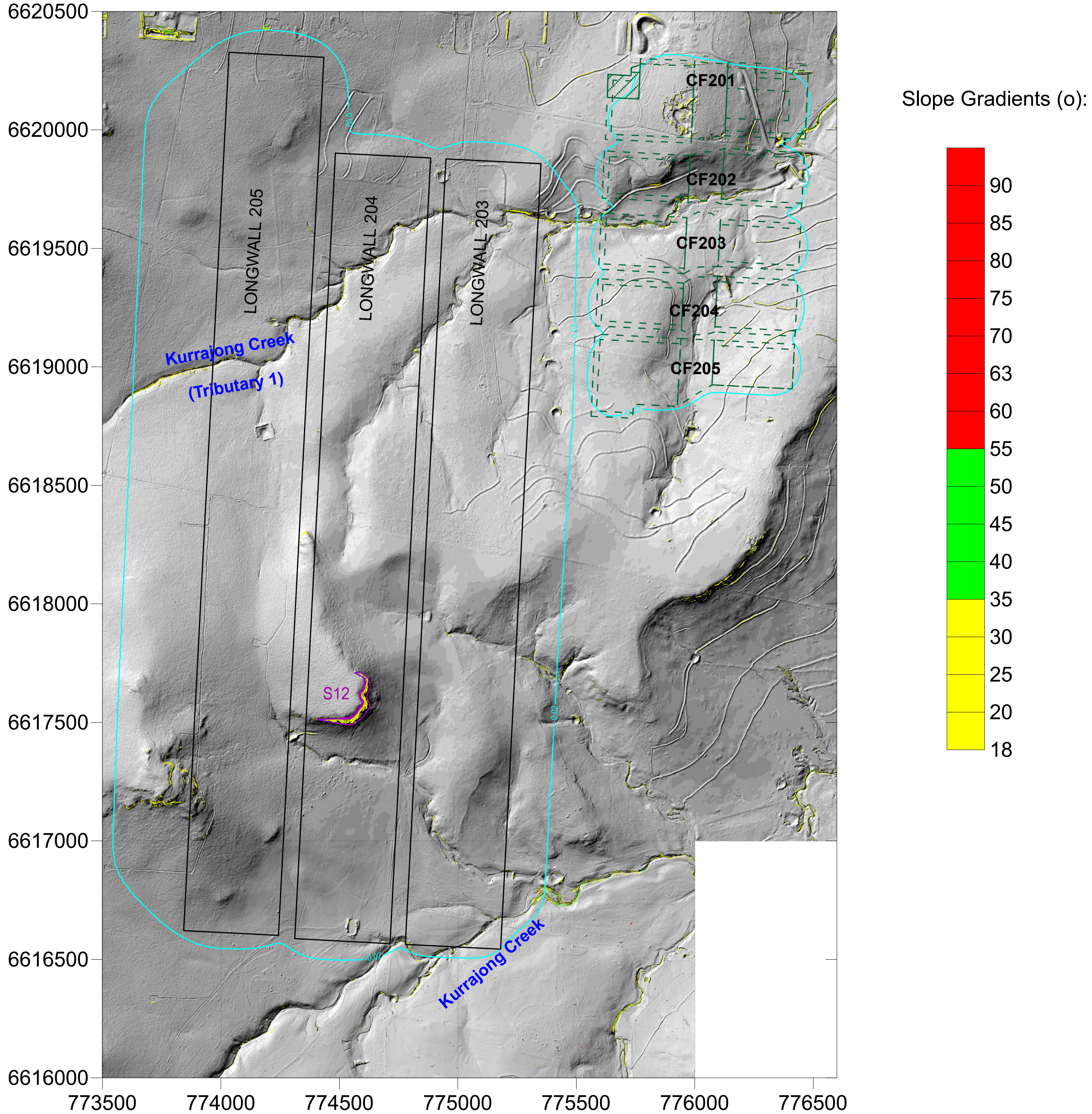
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Surface Features & Slope Gradients above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) & LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	1:30,000 — Figure No: 2c



Key:

	Approved Longwalls (LW203-205)		Roads (unsealed)		Ephemeral Creeks & Watercourses
	Extracted Longwalls (LW101-108A)		Dwellings & Sheds/Tanks		Farm Dams
A	Proposed Pillar Reduction Panels (e = 66%)		Private / NCO-Owned Buildings		Contour Banks
	Proposed 2nd Workings (e = 35%)		Powerlines (Domestic)		Grinding Groove Site
	Level Contours (m, AHD)		Fences		

DgS	Engineer: S.Ditton		Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton			
	Date: 15.07.21		Title:	Surface Features & Slope Gradients above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:15,000
			Figure No:	2d



Key:

Proposed CF201 -CF205 Limits

Proposed LW203 to 205 Limits

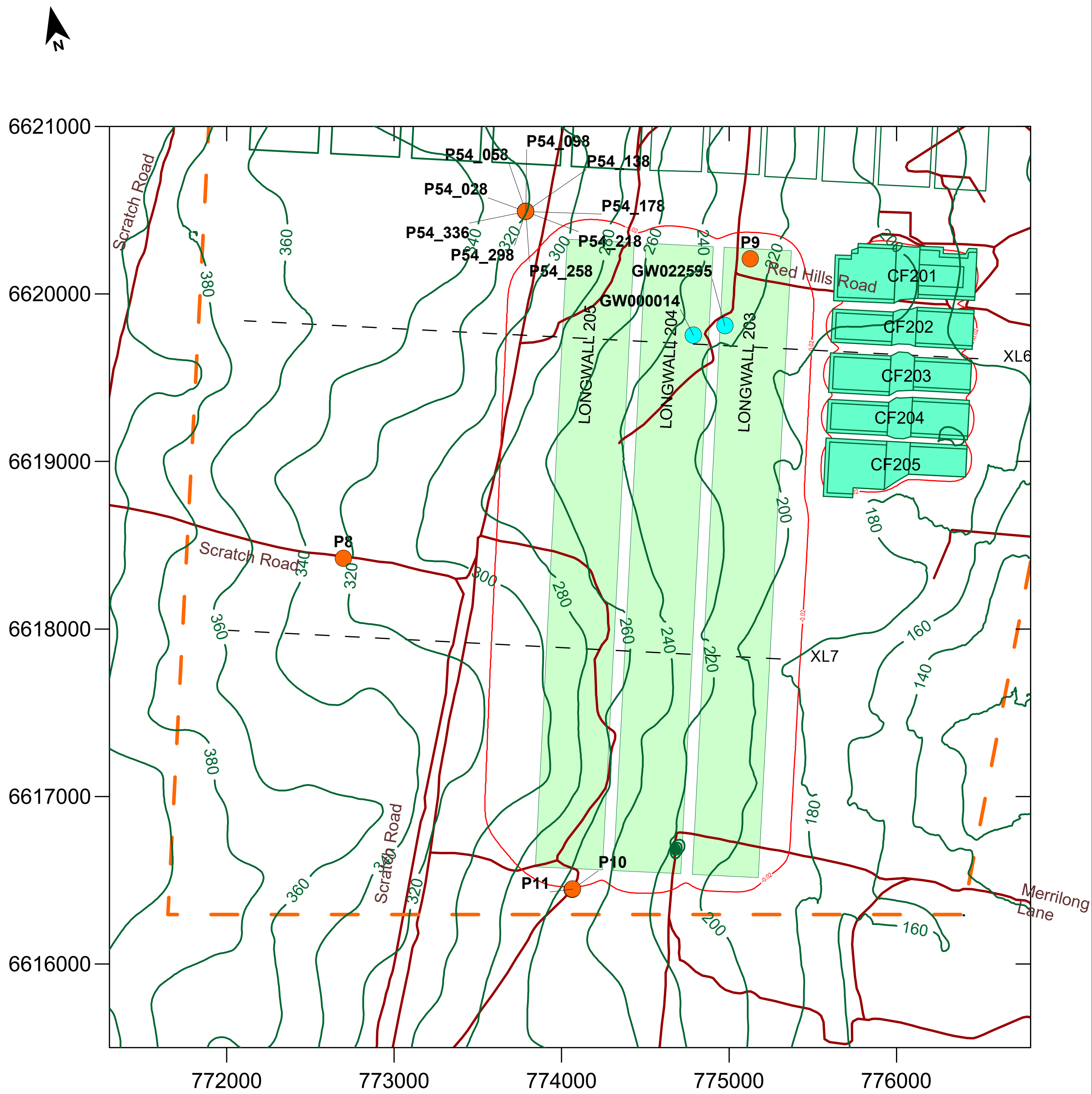
Mining Restriction Zone (CF201)

Angle of Draw to 20mm Subsidence

Steep Slope Key:

S12 - Steep Rocky Slope

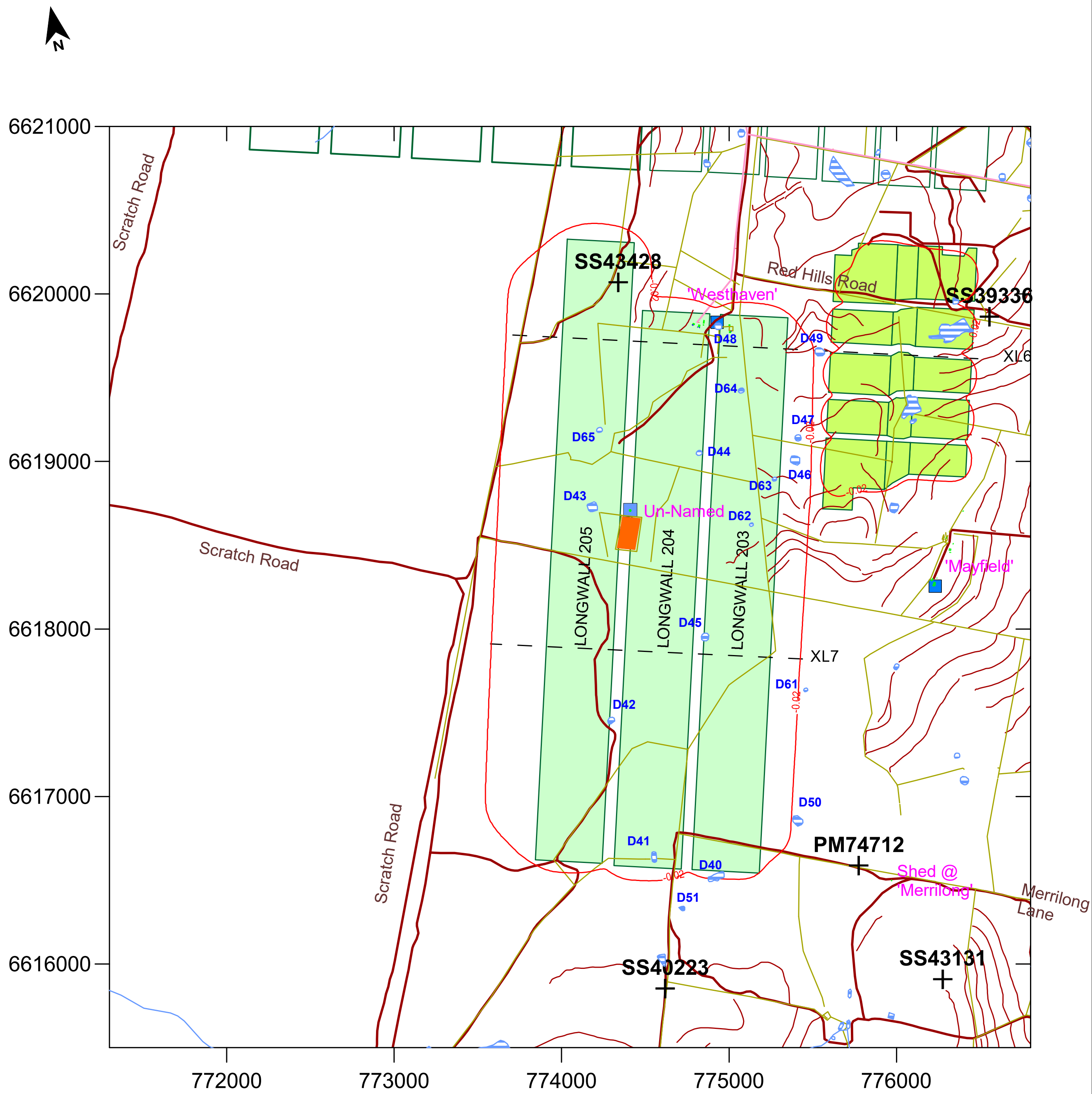
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Lidar Survey with Steep Slopes above the Extraction Plan Area
	Ditton Geotechnical Services Pty Ltd		Scale:	1:50,000
			Figure No:	2e



Key:

	Roads (unsealed)		Proposed Pillar Reduction Panels (CF201-CF205)		Cover Depth Contour (m)
	Groundwater Supply Bores		Proposed Longwall Panels (LW203 to 209)		Angle of Draw to 20mm subsidence
	Groundwater Monitoring Bores		Mining Lease 1609 Boundary		
	Subsidence Prediction Lines				

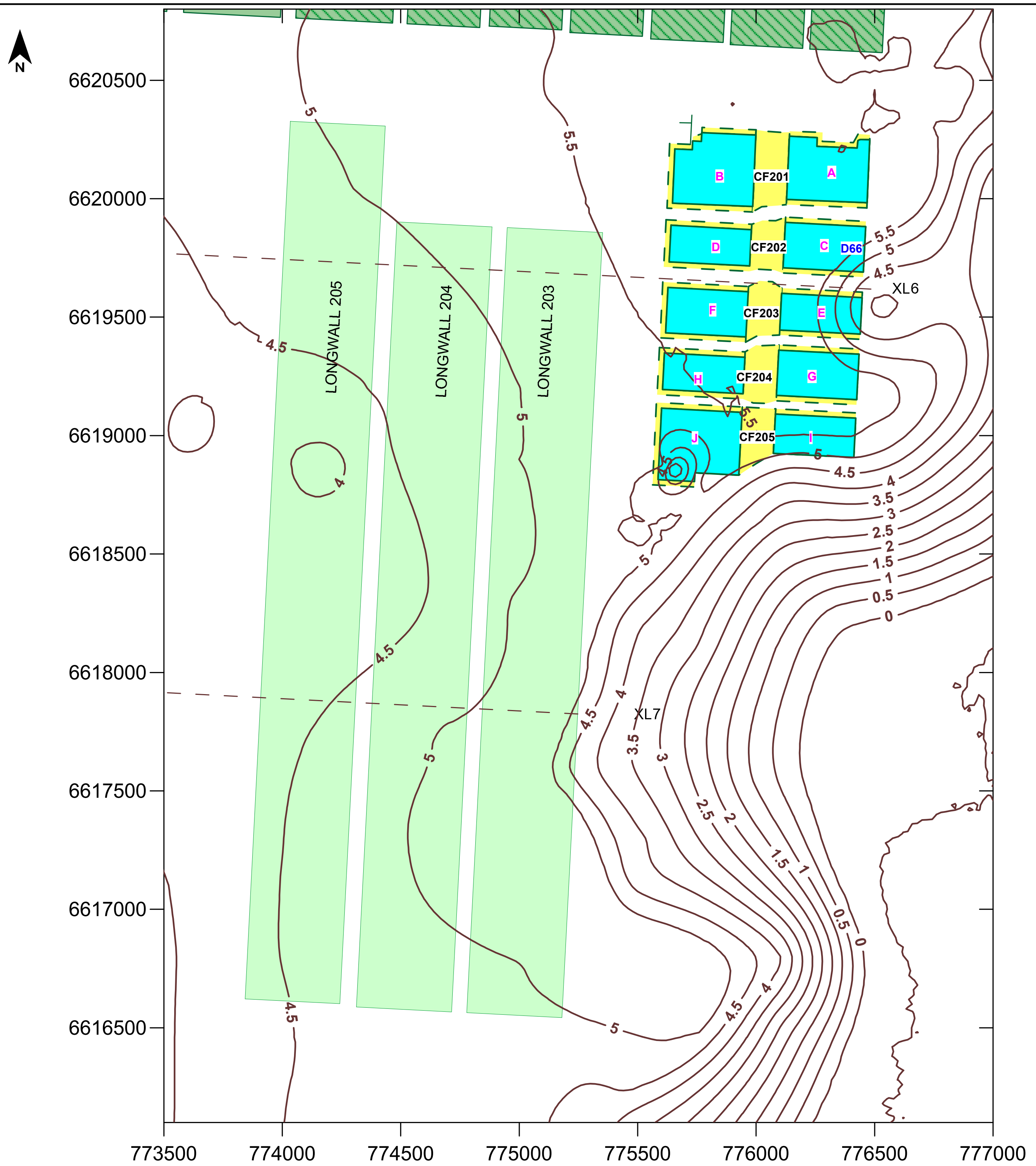
DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn: S.Ditton	Title:	Existing Groundwater Supply and Monitoring Bores above the Proposed LW203 to 205	
	Date: 15.07.21	Scale:	1:45,000	Figure No: 2f



Key:

- Roads (unsealed)
- Dwellings & Sheds/Tanks/Orchards
- NCOPL Owned
- Subsidence Prediction Lines
- Farm Dams
- Proposed CF201-CF205
- Proposed Longwalls (LW203 - 205)
- Angle of Draw to 20mm Subsidence
- Lot Boundaries/Fences
- Contour Banks
- State Survey Mark
- Powerlines (Domestic)

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	State Survey Marks above the Proposed CF201 - CF205 & LW203 to 209 at the Narrabri Mine
	Date:	15.07.21		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:45,000
			Figure No:	2g



Key:

Seam Thickness Contours (m)

Subsidence Prediction Lines

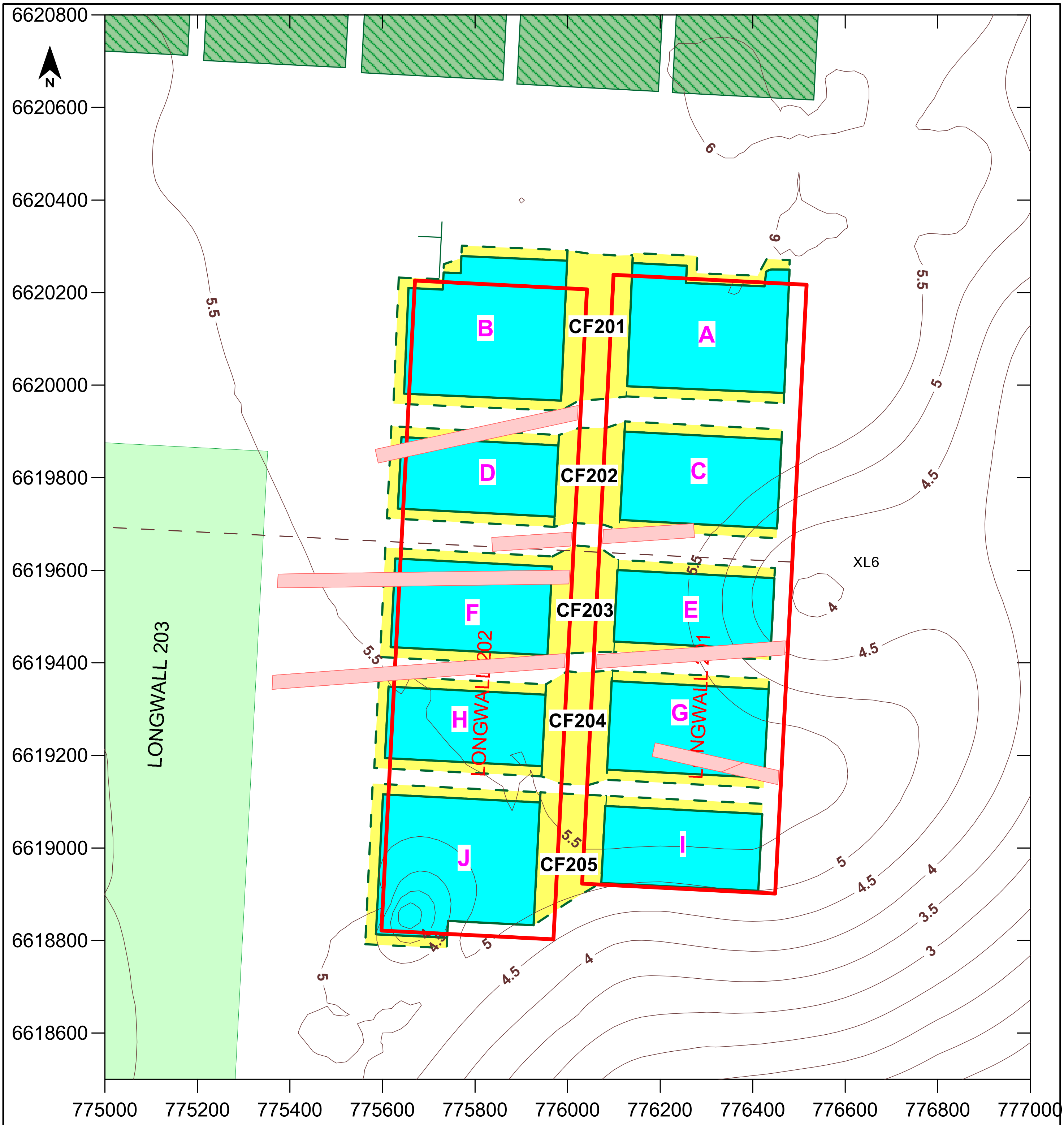
Approved Longwalls (LW203-205)

Extracted Longwalls (LW101-108A)

Proposed Pillar Reduction Panels (e = 66%)

Proposed 2nd Workings (e = 35%)

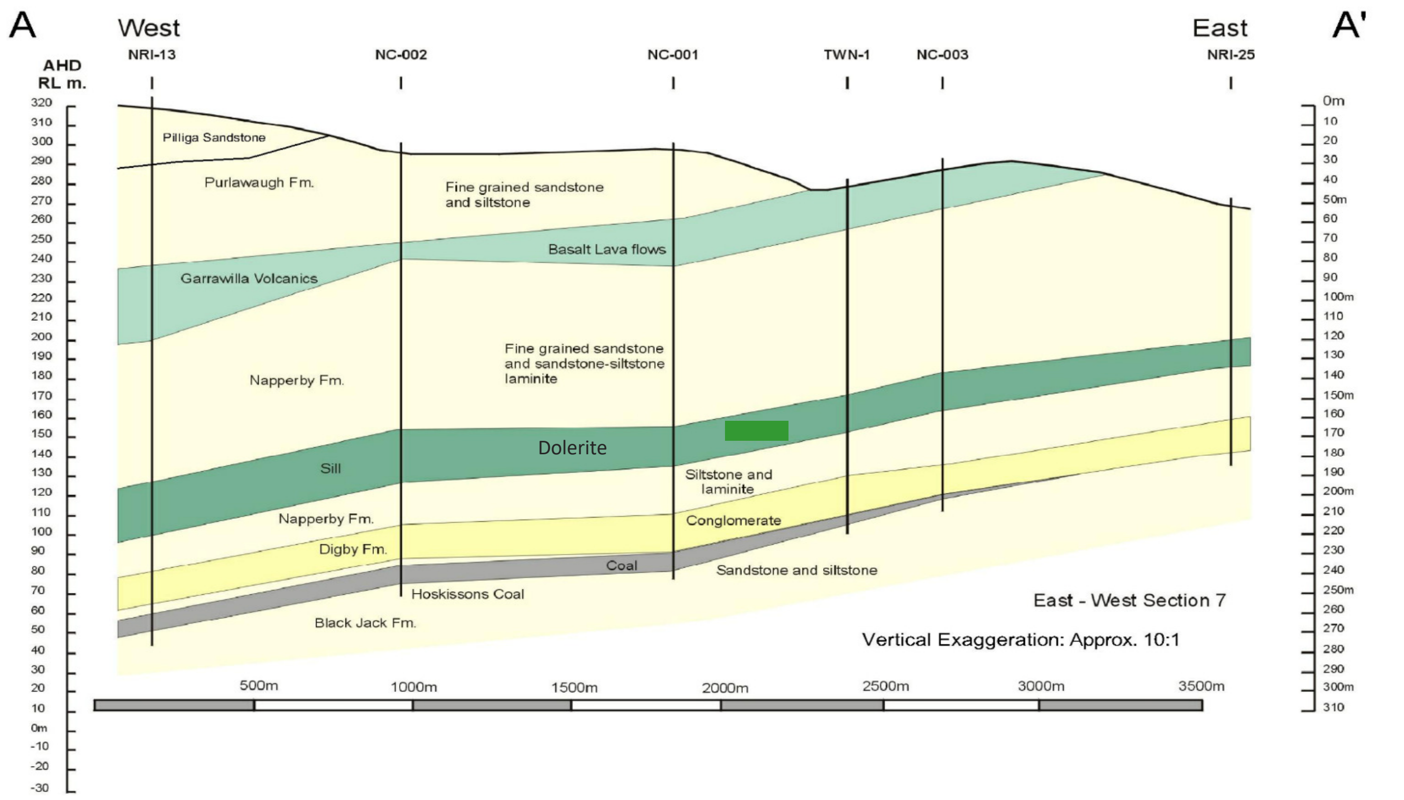
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Lower Hoskisson Seam Thickness Contours with the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) and Longwalls 203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	1:30,000
			Figure No:	3a



Key:

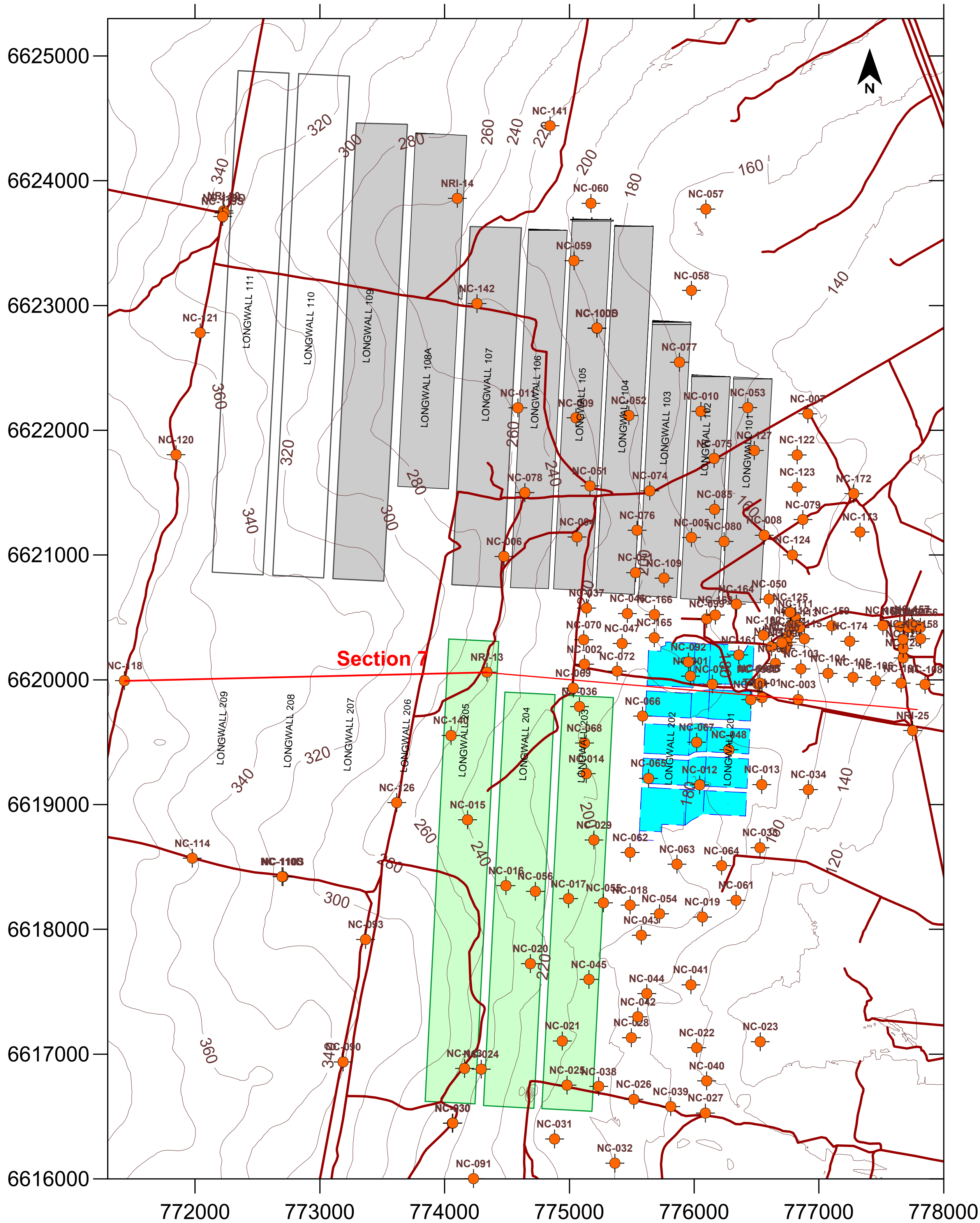
Seam Thickness Contours (m)	Inferred Faults
Approved Longwalls (LW203-205)	Subsidence Prediction Lines
Extracted Longwalls (LW101-108A)	
Proposed Pillar Reduction Panels (e = 66%)	
Proposed 2nd Workings (e = 35%)	

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Lower Hoskissons Seam Thickness Contours in the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)	
	Ditton Geotechnical Services Pty Ltd		Scale:	1:15,000	Figure No: 3b



NARRABRI COAL MINE
STRATIGRAPHY

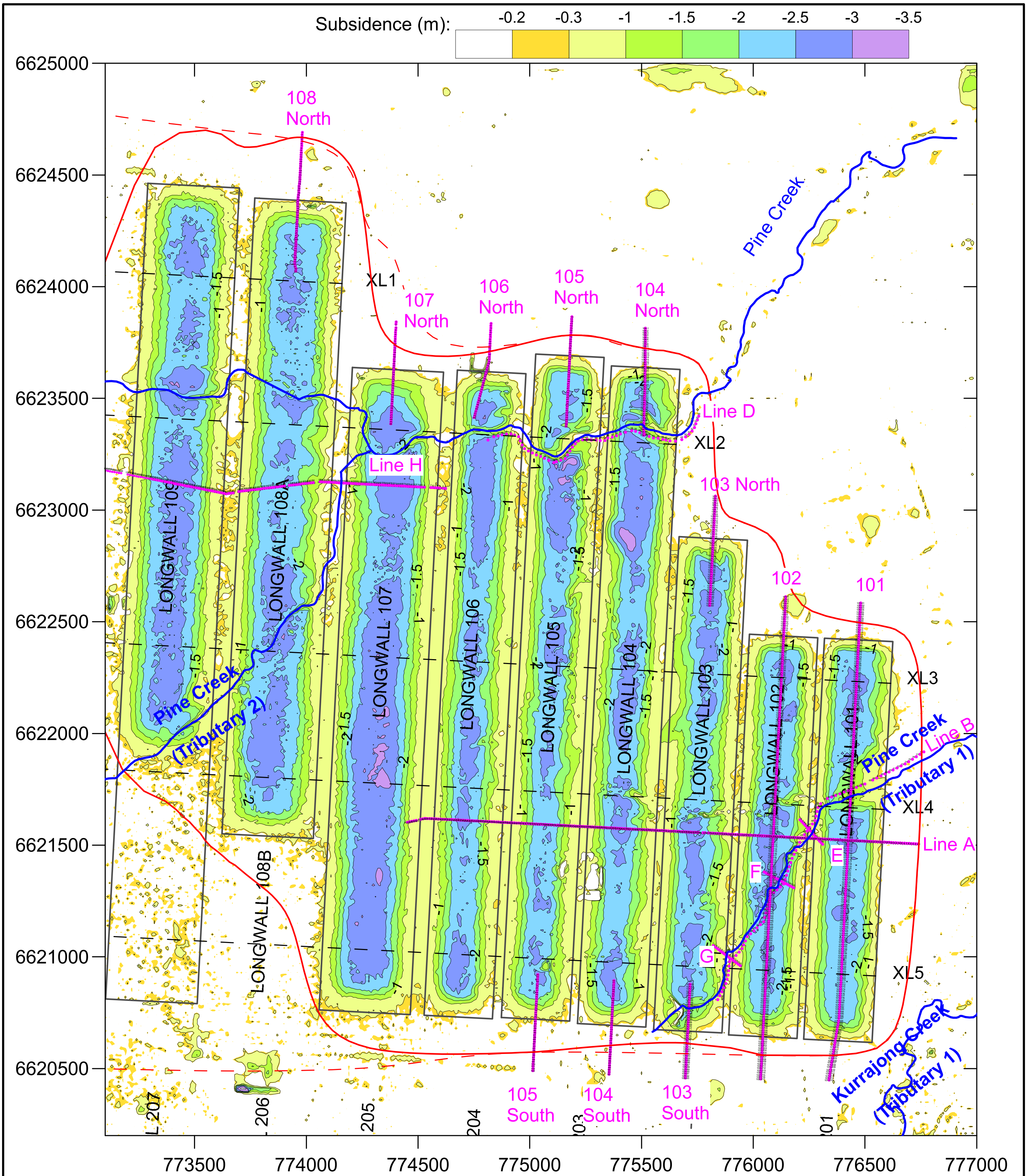
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Operations Pty Ltd		
	Drawn:	S.Ditton		NAR-004/8		
	Date:	12.09.21	Title:	Representative Section of Site Lithology: East-West Section in EP Area (see **Figure 4a** for Location)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	3c



Key:

- Cover depth contours (m)
- Roads (unsealed)
- Borehole locations
- Extracted LW101 to 109
- Approved CF 201 to CF205
- Proposed LW203 to 205
- Section 7

DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton	Title:	Borehole Locations and Cover Depth Contours above the EP Area
	Date: 15.07.21		
	Ditton Geotechnical Services Pty Ltd	Scale:	1:60,000 — Figure No: 4a



Key:

Cover Depth Contours (m)

Main Creeks

Extracted LW101 to 108A

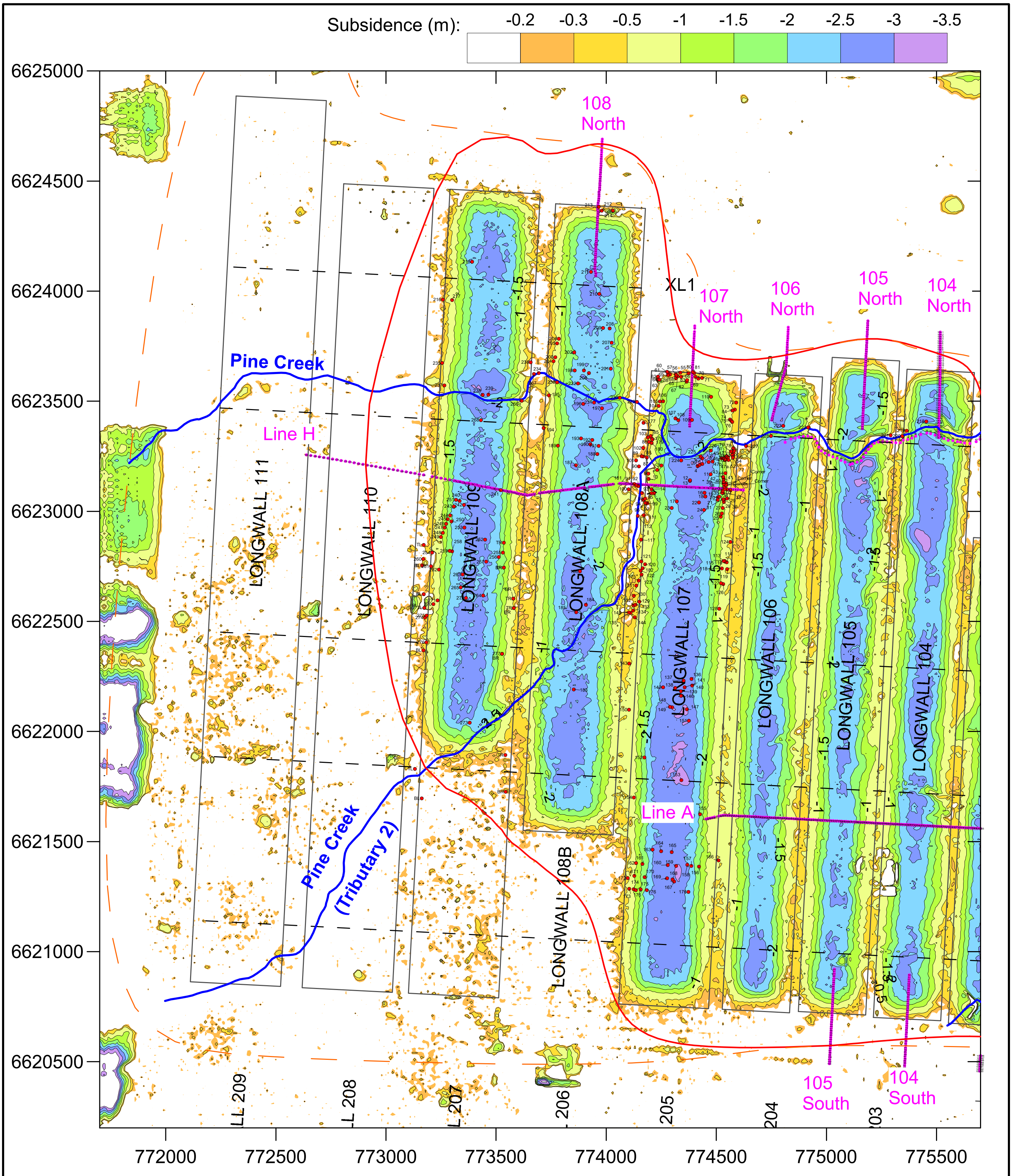
Subsidence Survey Lines

XL1 Subsidence Prediction Lines

Measured 20mm Subsidence Contour (101-108A)

Predicted Final Angle of Draw

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/4	
	Drawn:	S.Ditton			
	Date:	20.07.21	Title:	Subsidence Survey Lines with LiDAR Subsidence Contours Above the Extracted LW101 to 109 at the Narrabri Mine	
Ditton Geotechnical Services Pty Ltd			Scale:	1:25,000	Figure No: 4b



Key:

Main Creeks

LW101 to 111

Subsidence Survey Lines

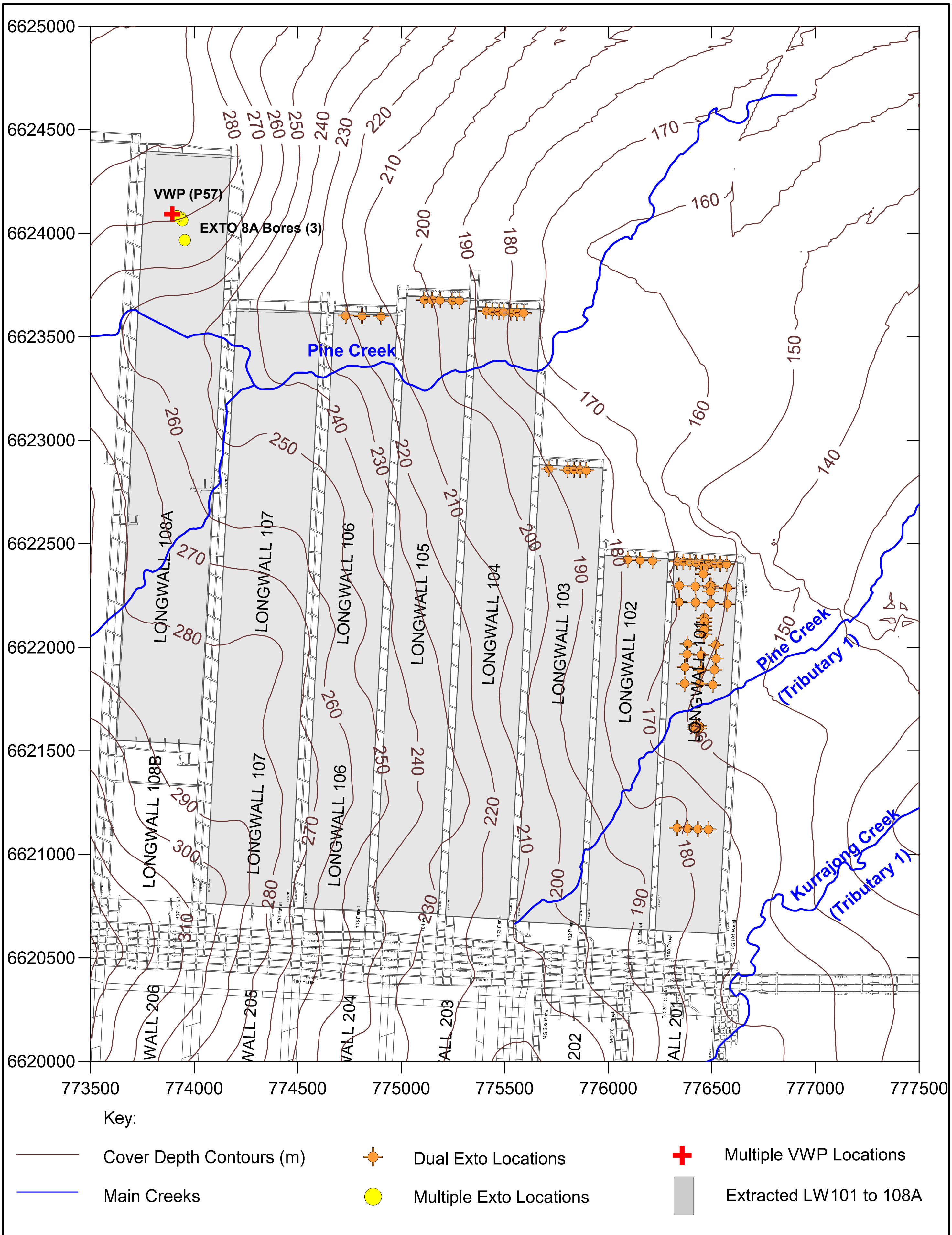
XL1 Subsidence Prediction Lines

Measured 20 mm Subsidence Contour

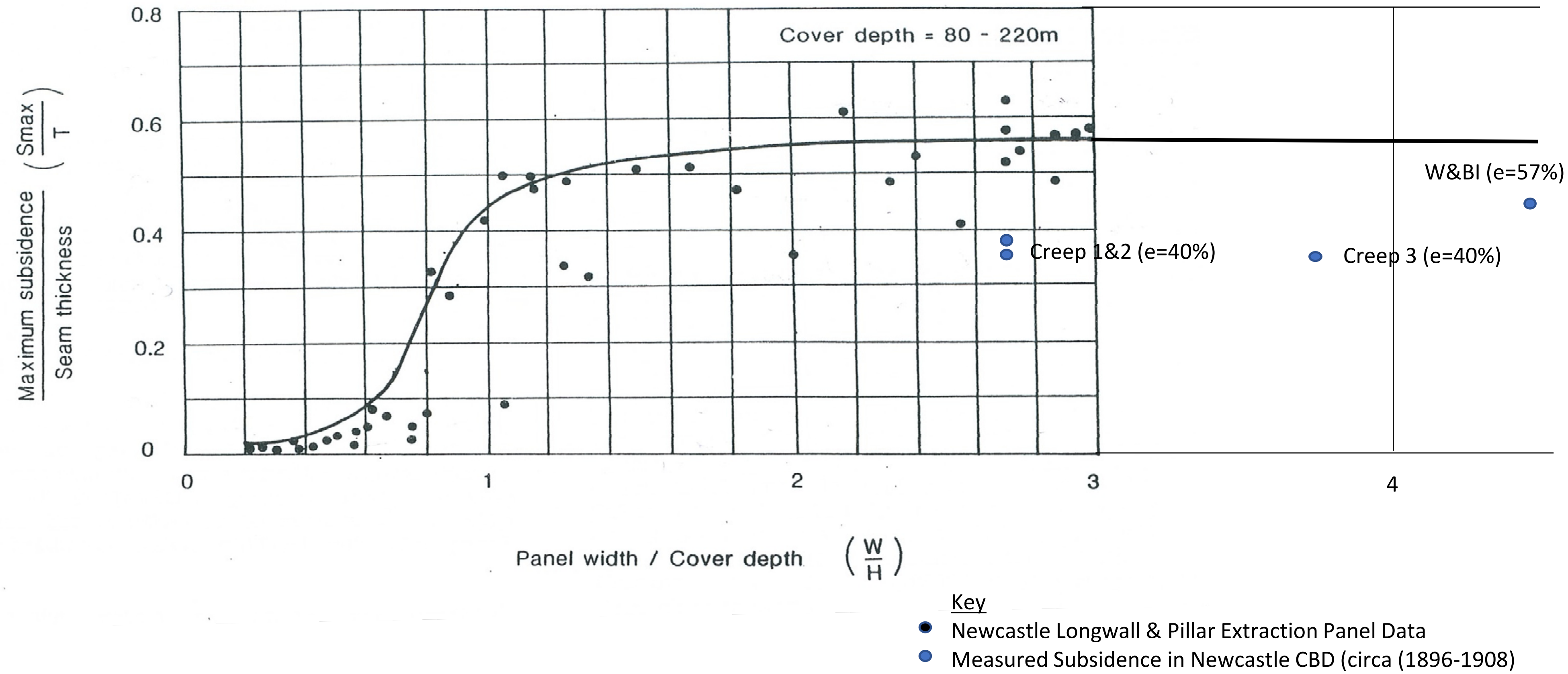
Predicted Final Angle of Draw

100 Measured crack locations

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Measured Subsidence (Lidar) & Survey Lines above LW104 to LW109 at the Narrabri Mine	
	Ditton Geotechnical Services Pty Ltd		Scale:	1:25,000	Figure No: 4c

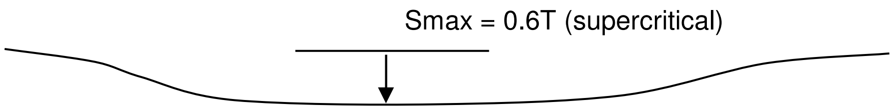


DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Borehole Extensometer Locations with Cover Depth Contours above the Extracted LW101 to 108A at the Narrabri Mine
Ditton Geotechnical Services Pty Ltd			Scale:	1:25,000
			Figure No:	4d



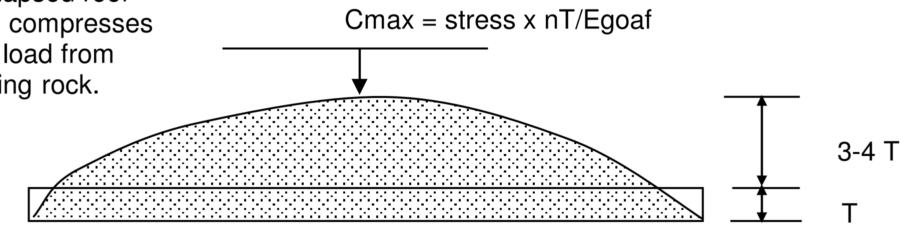
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Longwall v. Bord and Pillar Crush Subsidence data in Newcastle Coalfield (ref **Holla, 1987**)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5a

3. Seam/rubble convergence is then transferred to surface and is usually defined as a proportion (a) of the mining height (the overburden stiffness may be ignored for super-critical width panels).



a = 0.6 (but probably a function of cover depth or goaf stress)

2. Collapsed roof rubble compresses under load from overlying rock.

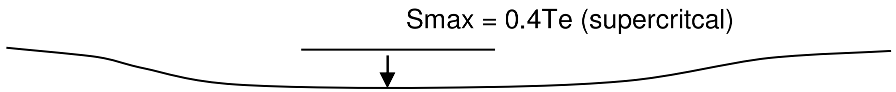


1. Coal seam is extracted and immediate roof falls into void behind face

Longwall Mining Subsidence Mechanics

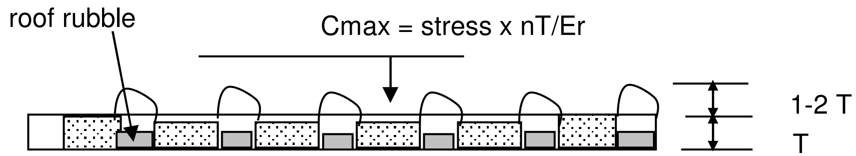
Key:
T = Mining Height.
Egoaf = Young's Modulus of collapsed roof material.
Cmax = Seam Roof convergence.
n = rubble height/mining height factor (ranges from 4 to 6).
Smax = Maximum surface subsidence.
a = subsidence factor, which relates maximum subsidence to mining thickness.

3. Seam/rubble convergence is then transferred to surface and is usually defined as a proportion (b) of the effective mining height (T x extraction ratio) The overburden stiffness may be ignored for super-critical width panels.



a = 0.4 assumed above B& P workings

2. Pillars and immediate mine roof deteriorates after mining and overburden compresses (and sometimes crushes) the remnant coal pillars and collapsed roof rubble along the bords.

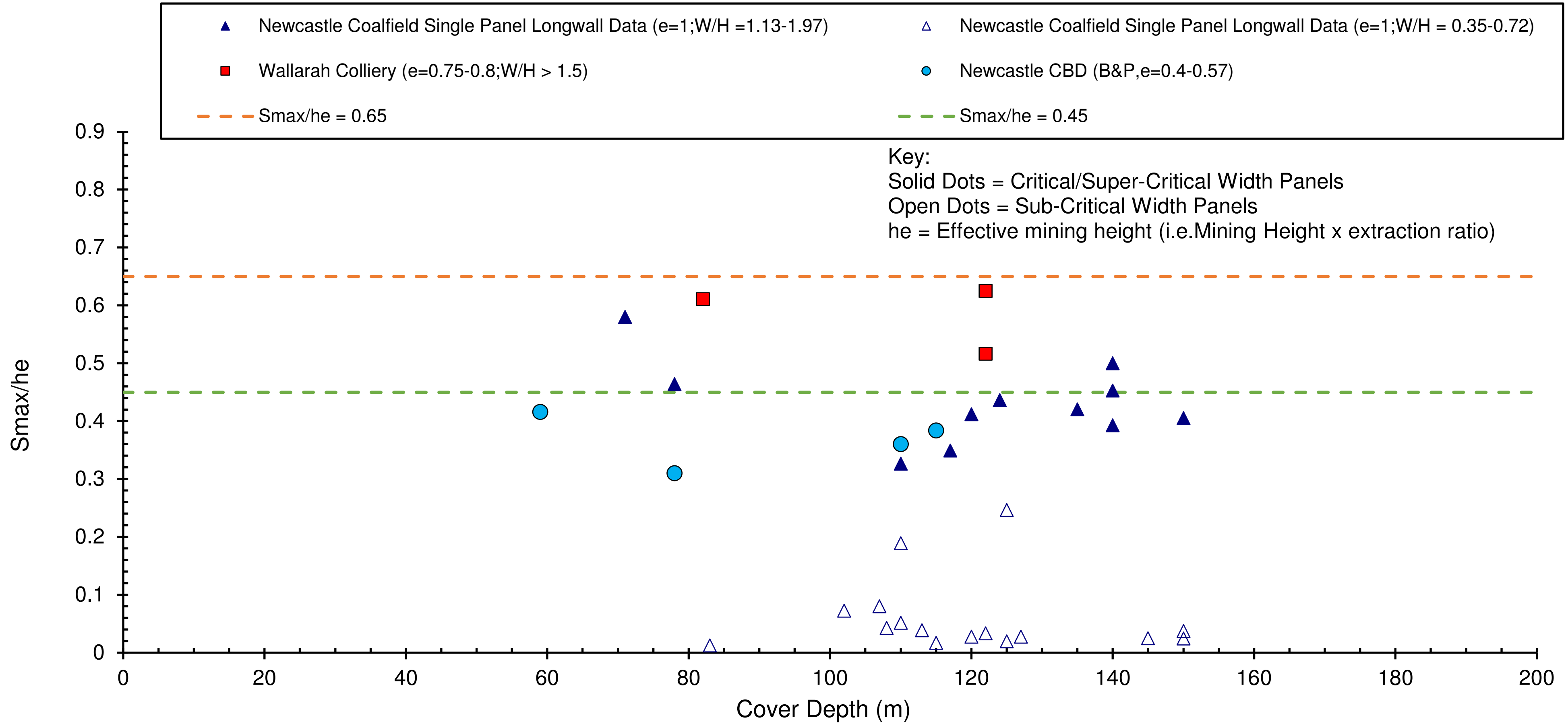


1. Bord and Pillars are formed in the coal seam.

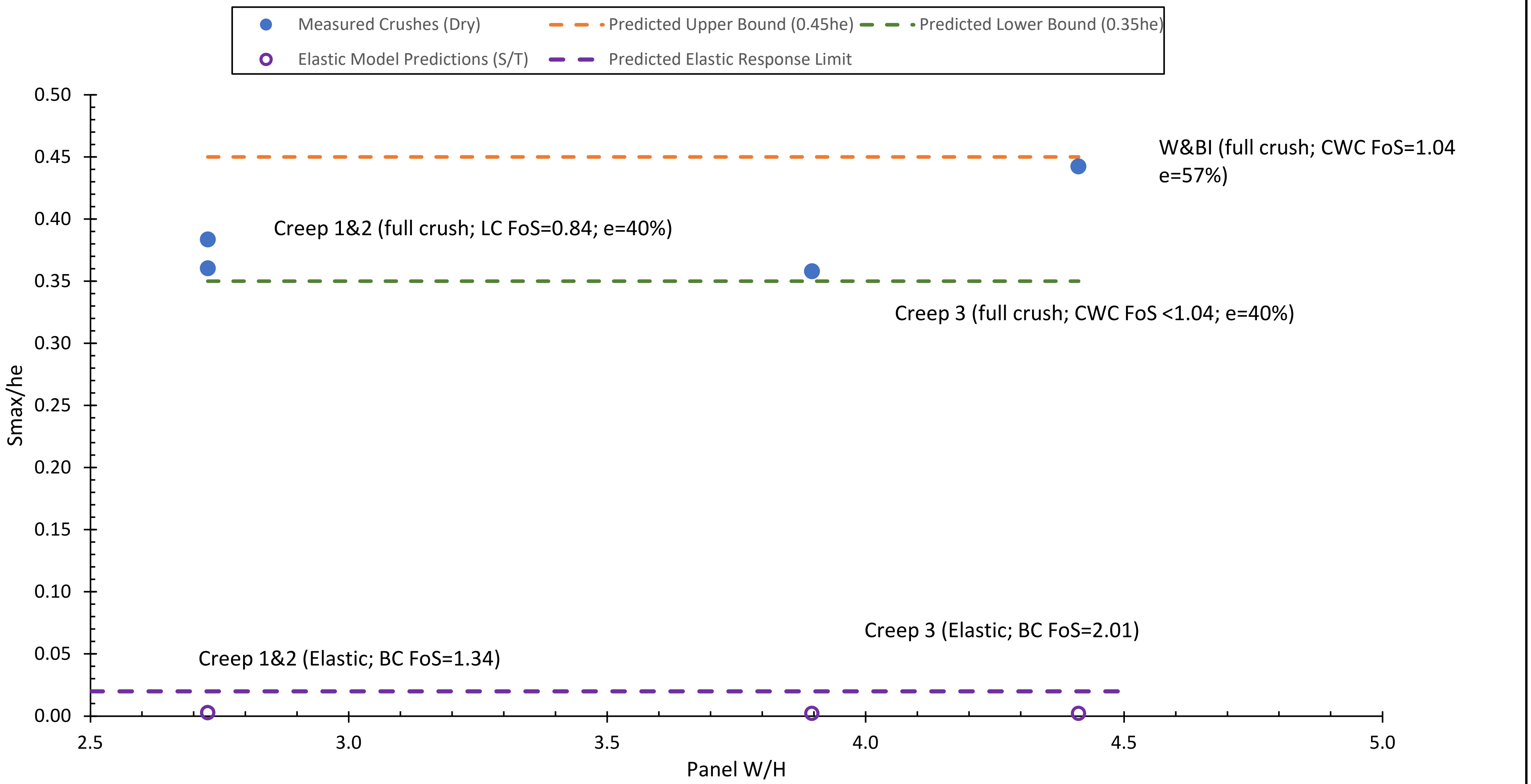
Bord and Pillar Workings Subsidence Mechanics

Key:
T = Mining Height.
Er = Young's Modulus of yielded pillar and collapsed roof material.
Cmax = Seam Roof convergence.
n = rubble height/mining height factor (ranges from 1 to 2)
Smax = Maximum surface subsidence.
a = subsidence factor, which relates maxium subsidence to mining thickness.

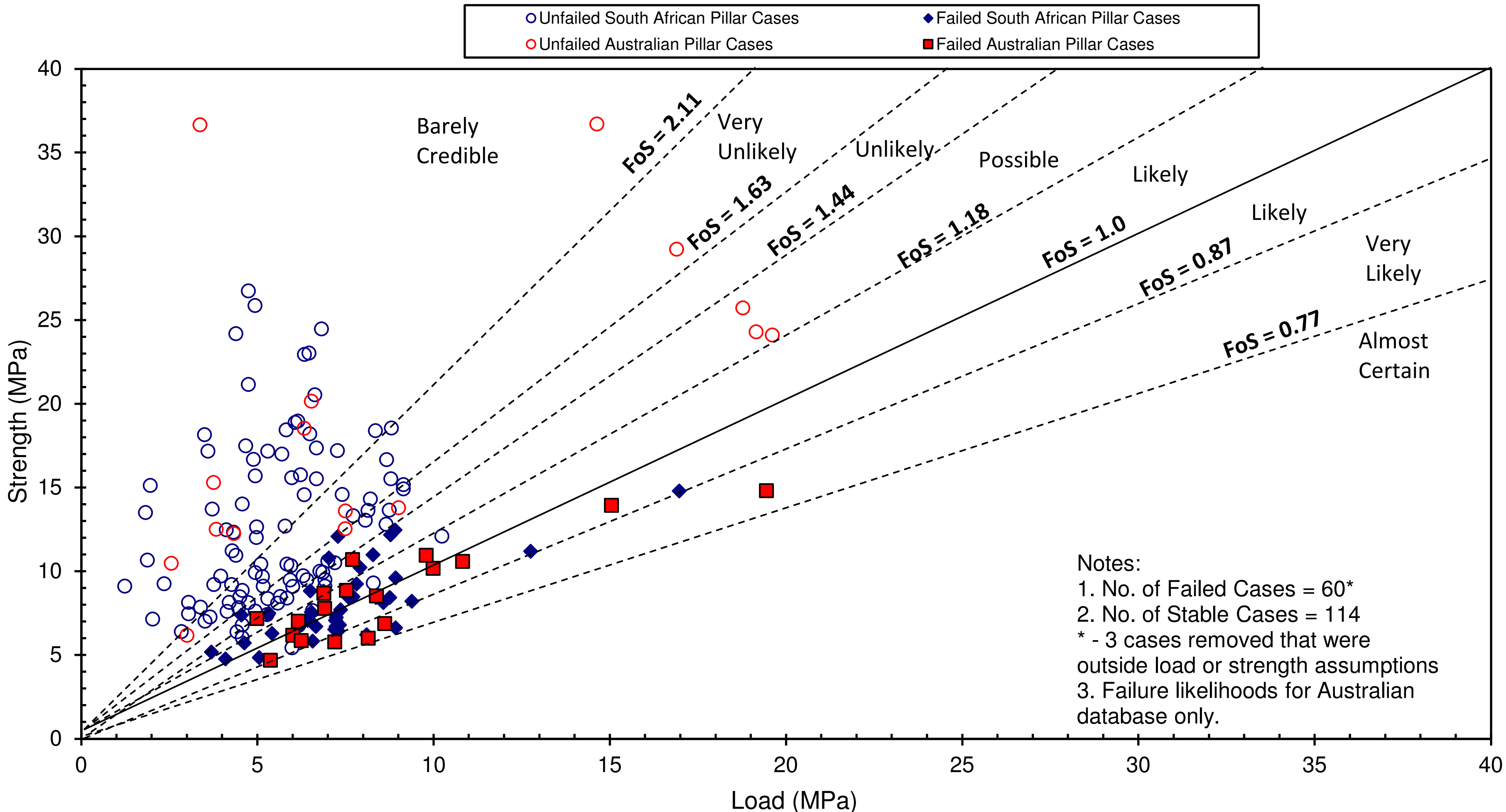
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Fundamental Differences between Longwall Subsidence Mechanics and Bord & Pillar Panels (Supercritical Width Panels Only)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	5b



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Database of Smax/he above Failed Bord and Pillar Panels in the Newcastle Coalfield			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5c	

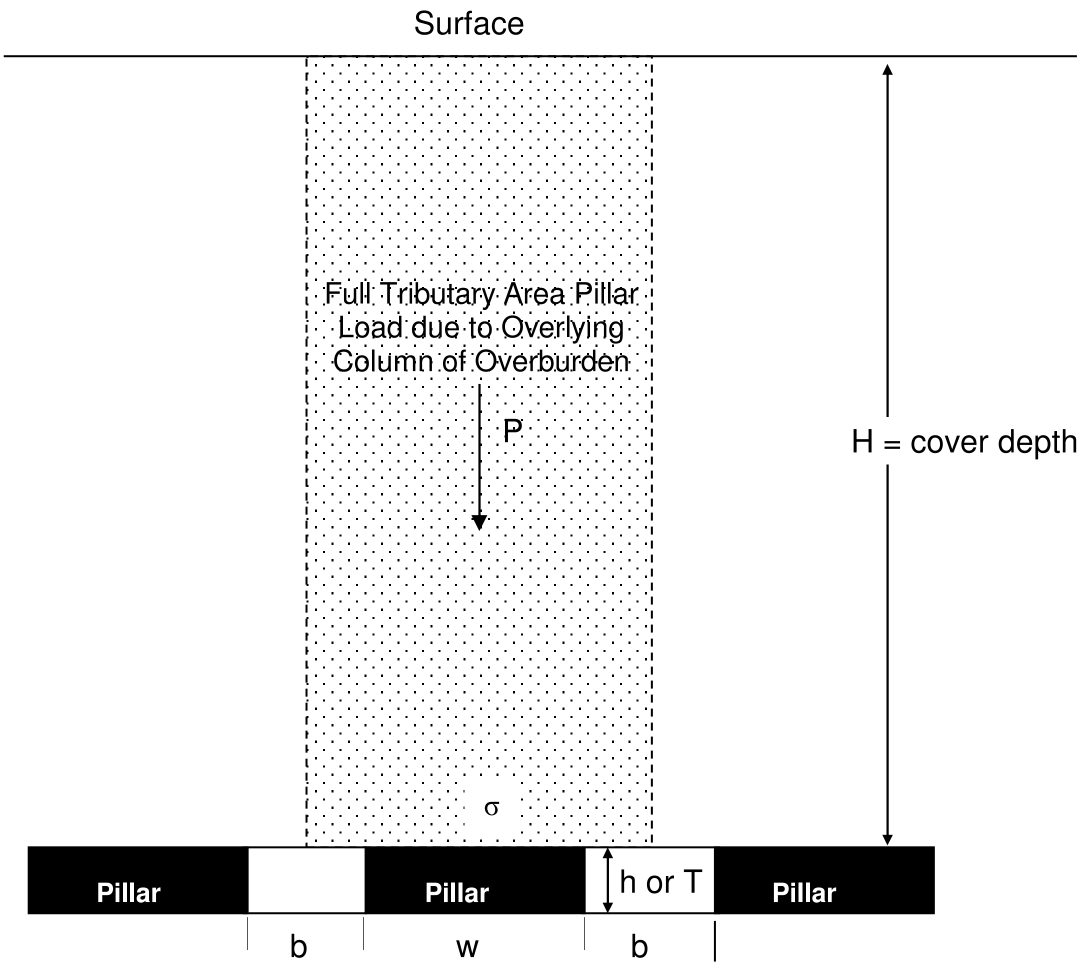


DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Maximum Pillar Crush Subsidence Prediction Model for Bord & Pillar Mine Workings with extraction ratios from 40% to 57%	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 5d



Data extracted from Salamon, *et al* 1996.

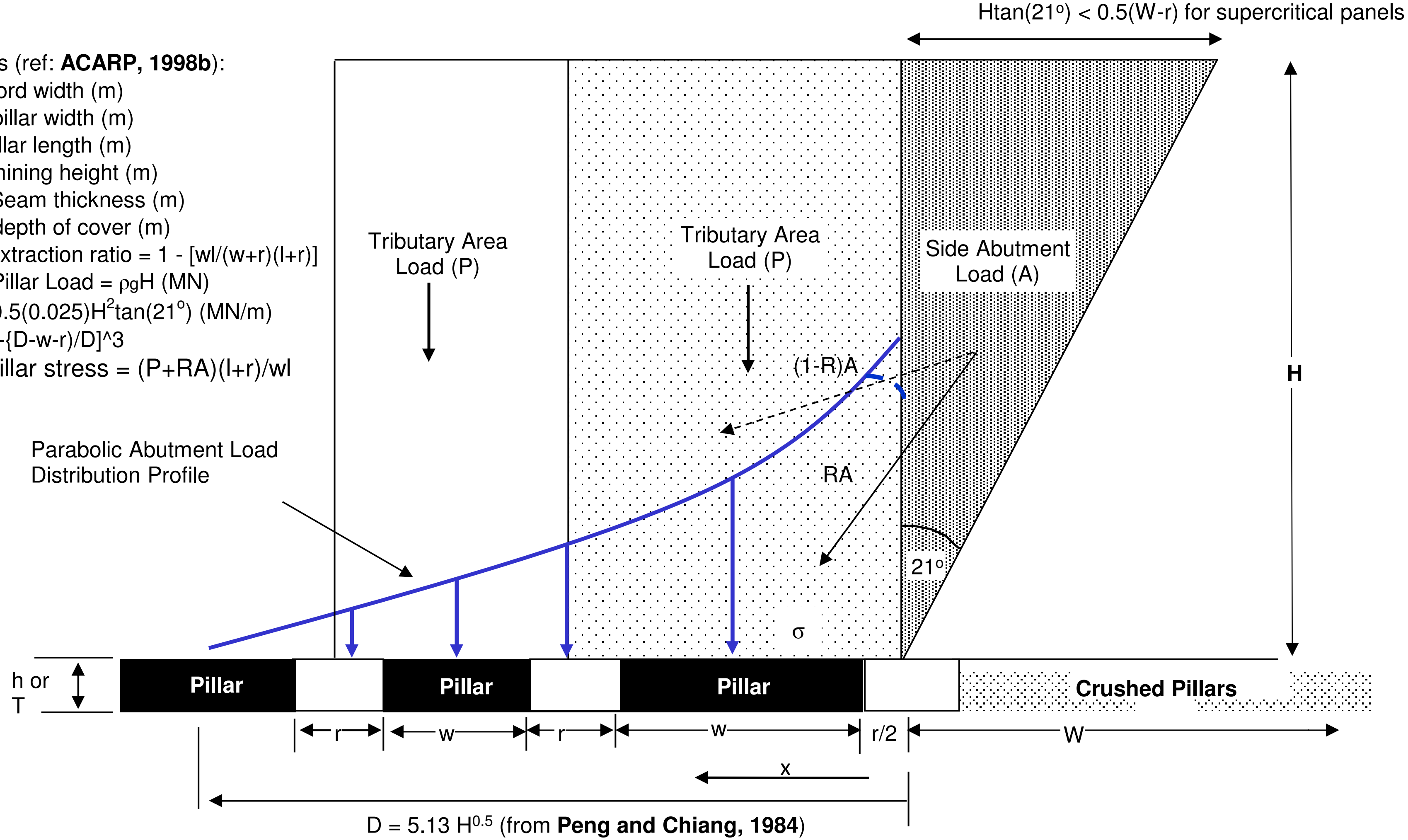
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Database of Failed and Unfailed Bord and Pillar Panels from Australian and South African Coal Mines: Pillar Strength v. FTA Load		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5e



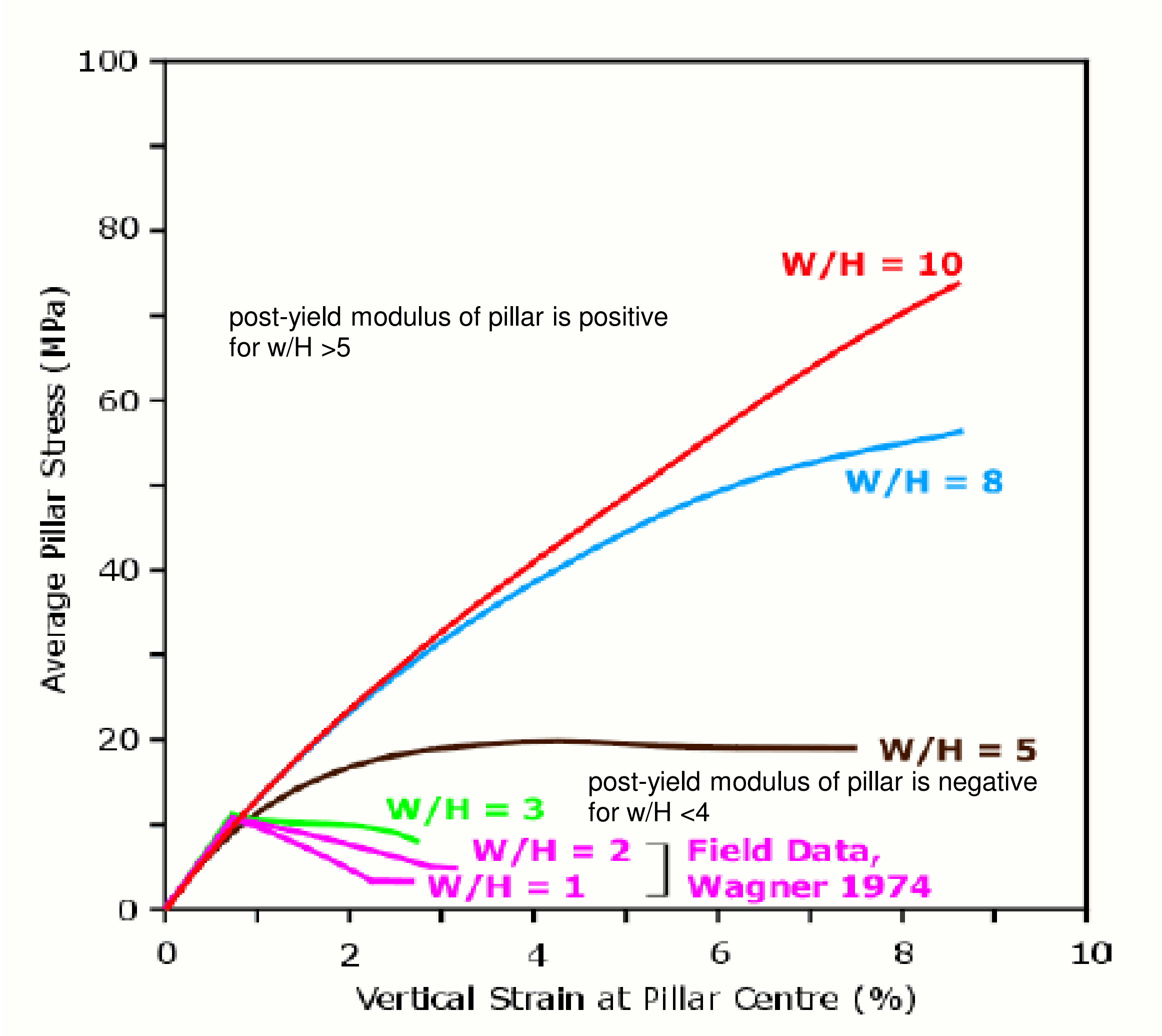
Notes:
- w = pillar width (m)
- l = pillar length
- b = bord width (m)
- r = cut-through width (m)
- h = mining height (m)
- T = Seam thickness (m)
- H = depth of cover (m)
- ρ = overburden density (t/m3)
- g = gravity acceleration = 10 m/s^2
- P = Full Tributary Area (FTA) Pillar Load = $\rho gH(w+b)(l+r)$ (MN)
- σ = FTA pillar stress = P/(wl) (MPa)
- e = extraction ratio = 1 - [wl/(w+b)(l+r)]

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine			
	Drawn:	S.Ditton		NAR-004/8			
	Date:	15.07.21	Title:	Conceptual Model of Full Tributary Area Loading			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5f	

Notes (ref: **ACARP, 1998b**):
r = bord width (m)
w = pillar width (m)
l = pillar length (m)
h = mining height (m)
T = Seam thickness (m)
H = depth of cover (m)
e = extraction ratio = 1 - [wl/(w+r)(l+r)]
P = Pillar Load = $\rho g H$ (MN)
A = $0.5(0.025)H^2\tan(21^o)$ (MN/m)
R =1-{D-w-r)/D]^3
σ= pillar stress = (P+RA)(l+r)/wl



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Conceptual Model of Abutment Load Acting on Site Pillars Due to Pillar Run Scenario
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	5g



Ref: **ACARP, 2005**

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-004/8		
	Date:	15.07.21	Title:	In-situ Pillar Stress v. Strain Behaviour for a Range of Pillar Width/Height Ratios		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5h

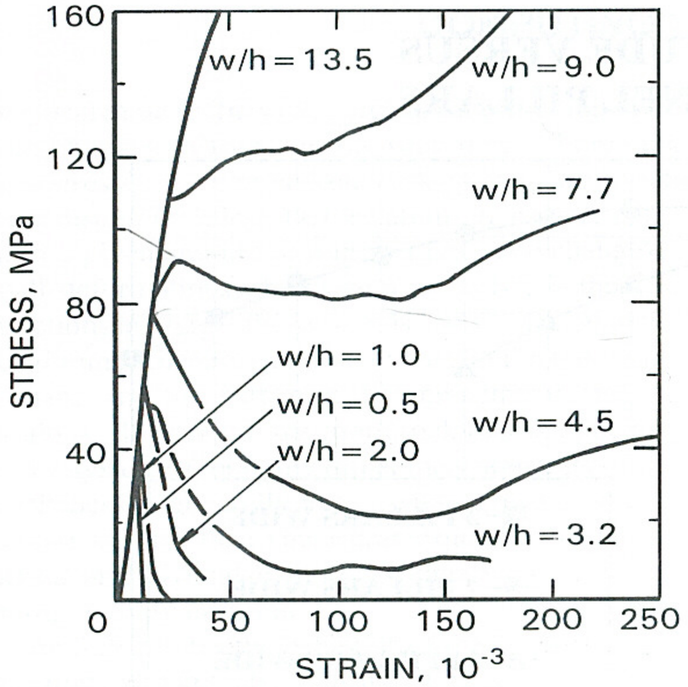


Figure 4.—Complete stress-strain curves for Indian coal specimens showing increasing residual strength and postfailure modulus with increasing w/h (after Das [1986]).

Ref: Das, **1996**

POSTFAILURE MODULUS VERSUS PILLAR WIDTH-TO-HEIGHT RATIO

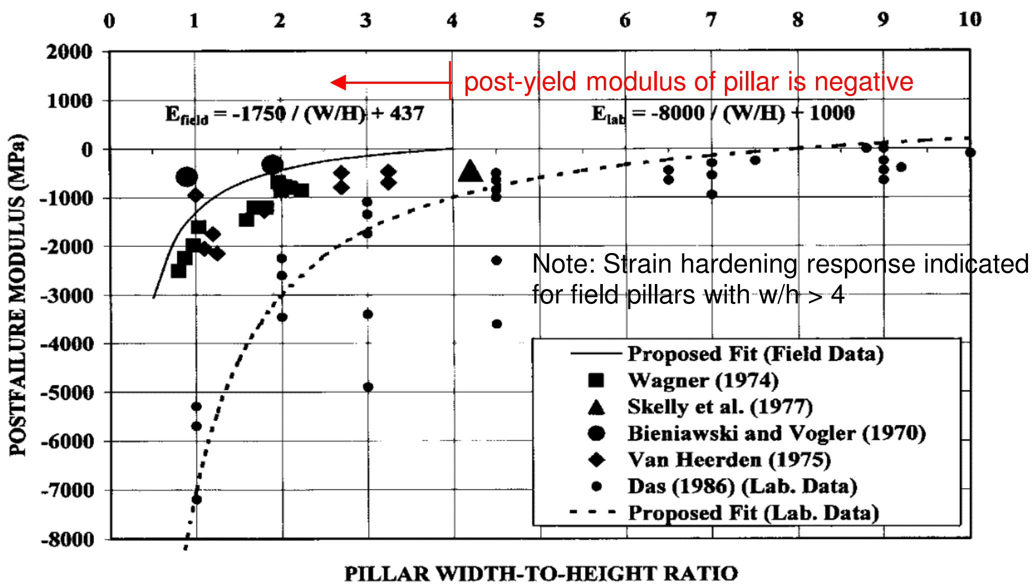
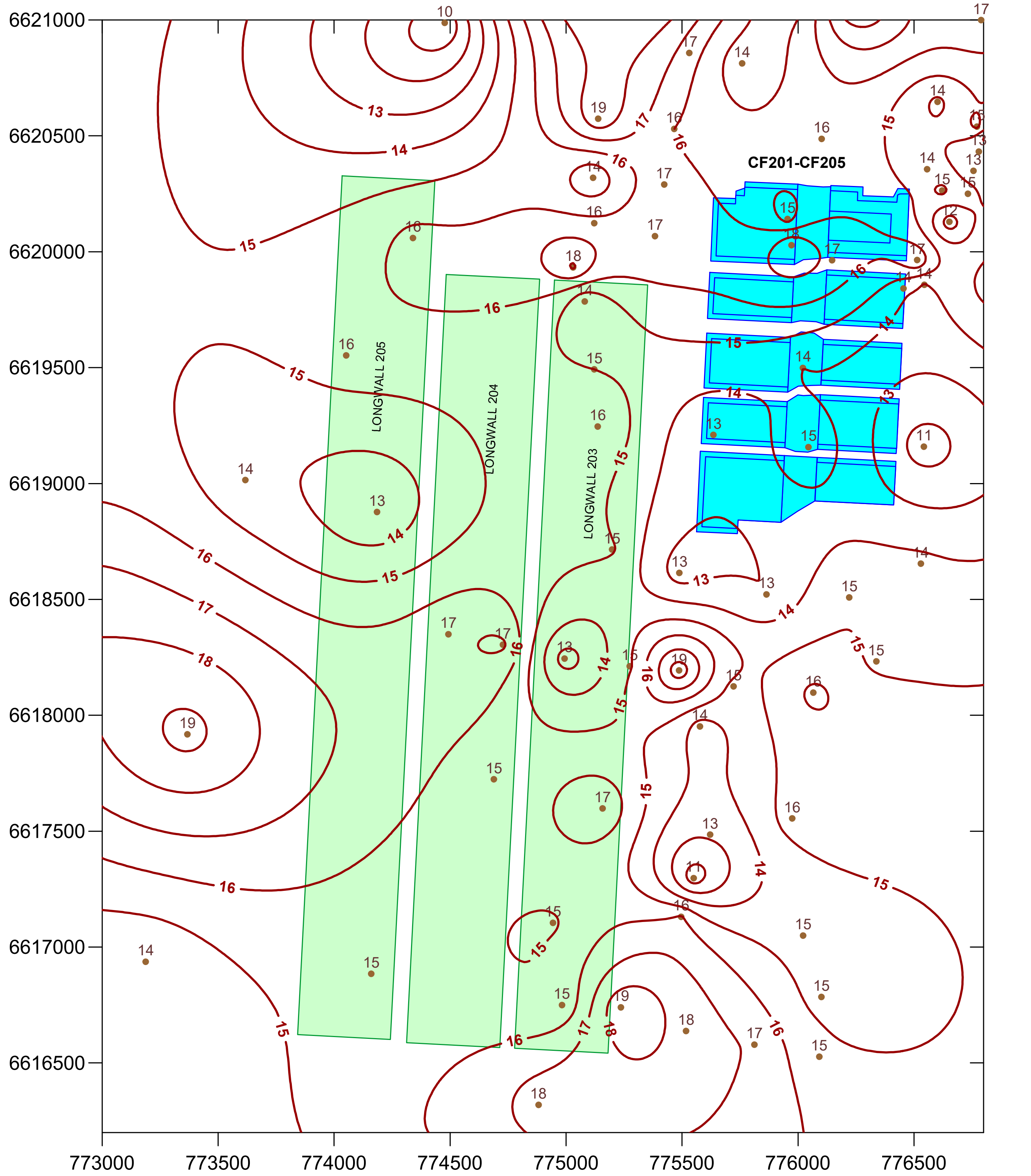


Figure 5.—Summary of postfailure modulus data for full-scale coal pillars and laboratory specimens. Also shown is proposed approximate equation for E_p.

Ref: **Zipf, 1999**

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-004/8		
	Date:	15.07.21	Title:	Post-yielded Modulus & Laboratory Stress - Strain Curves for a range of pillar w/h Ratios		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5i



Key:

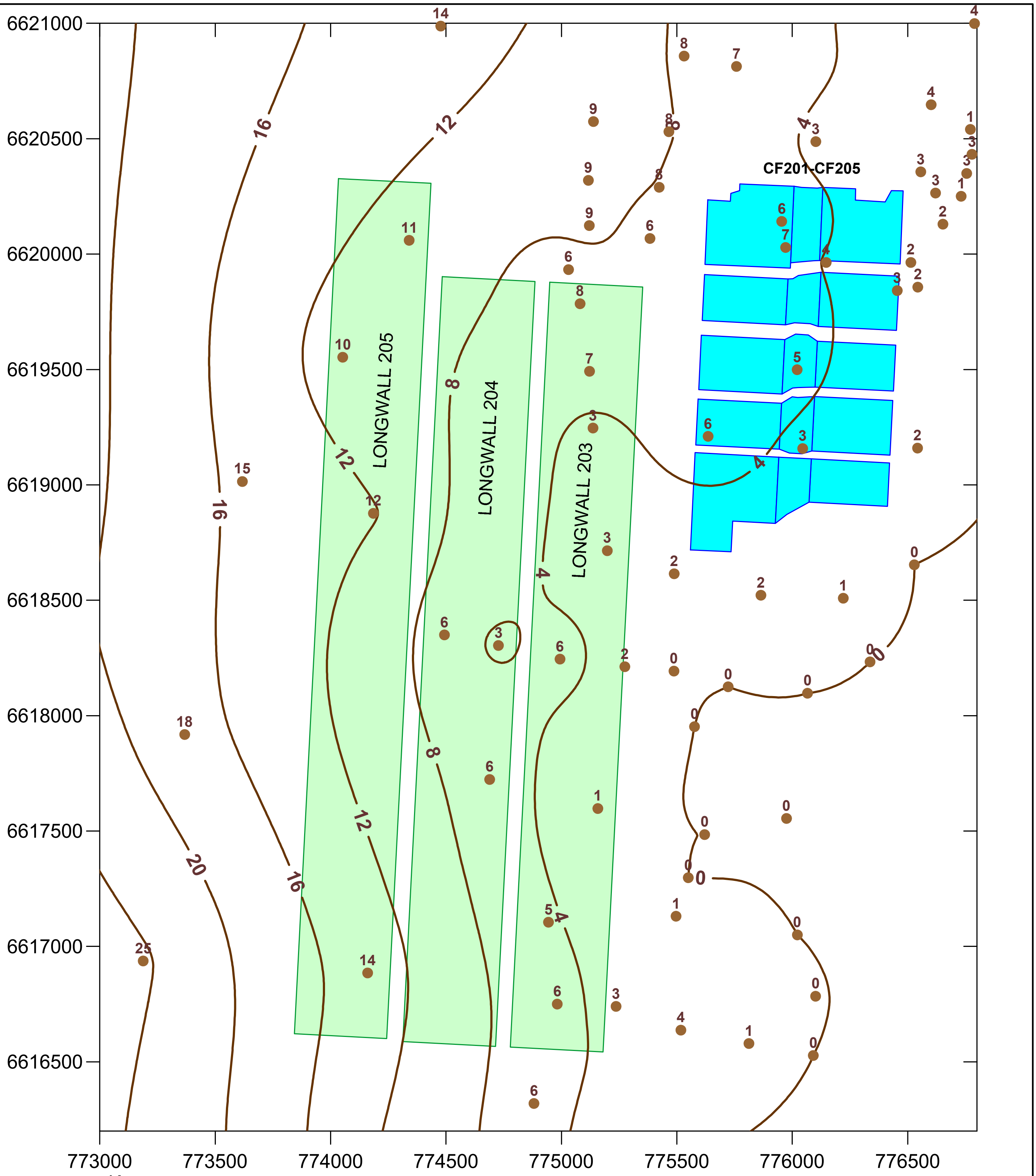
Proposed LW203 to 205

Proposed Pillar Reduction Panels (CF201-CF205)

Borehole Locations & Unit Thickness (m)

Digby Conglomerate Thickness Contours (m)

DgS Ditton Geotechnical Services Pty Ltd	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	Digby Formation Conglomerate Thickness Contours above the Proposed Pillar Reduction Panels CF201 - CF205 (A-J) and Longwalls 203 to 205
	Date:	15.07.21	Scale:	1:30,000 — Figure No: 5j



Key:

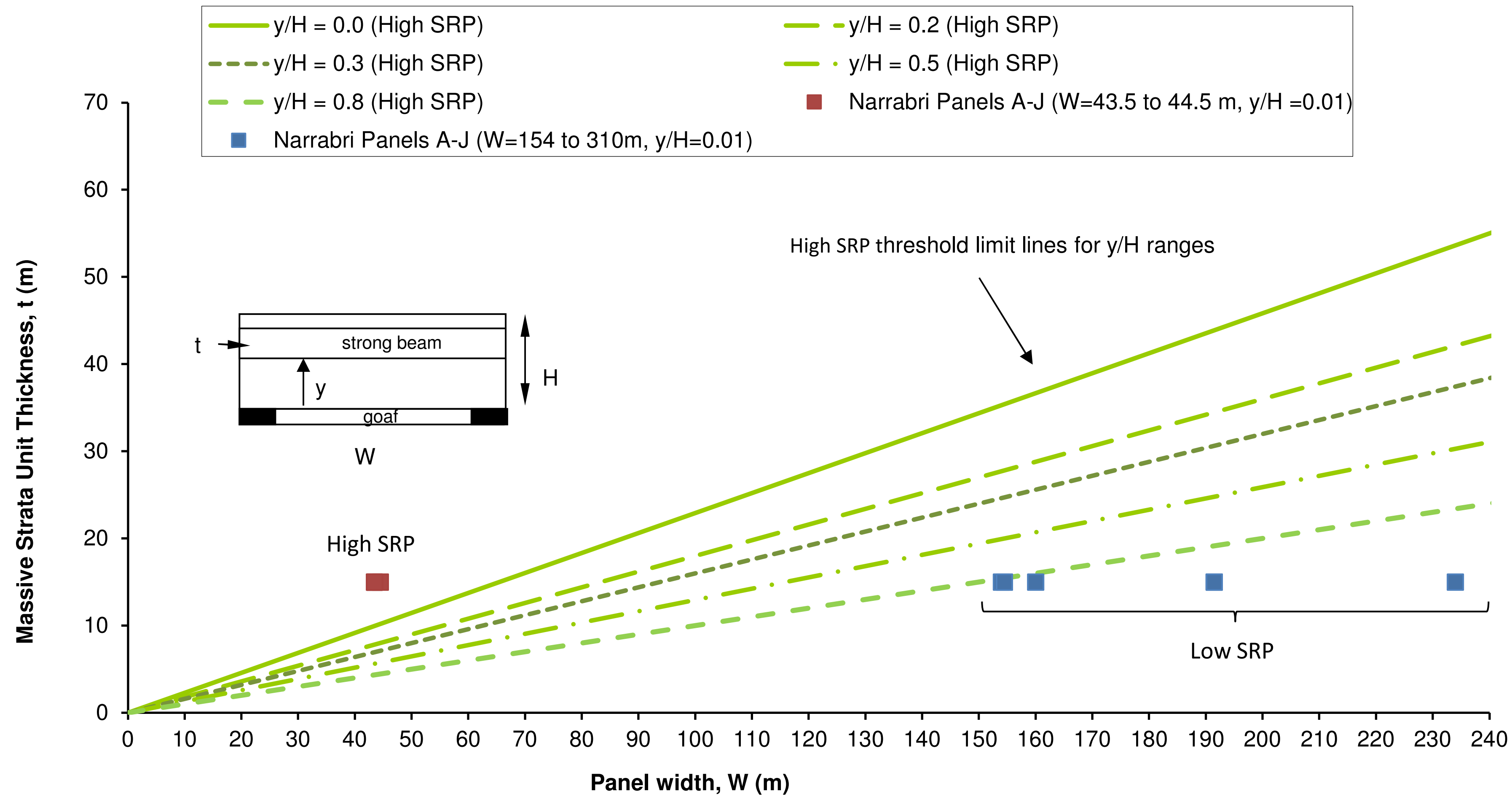
Proposed Mine Workings

Proposed Pillar Reduction Panels

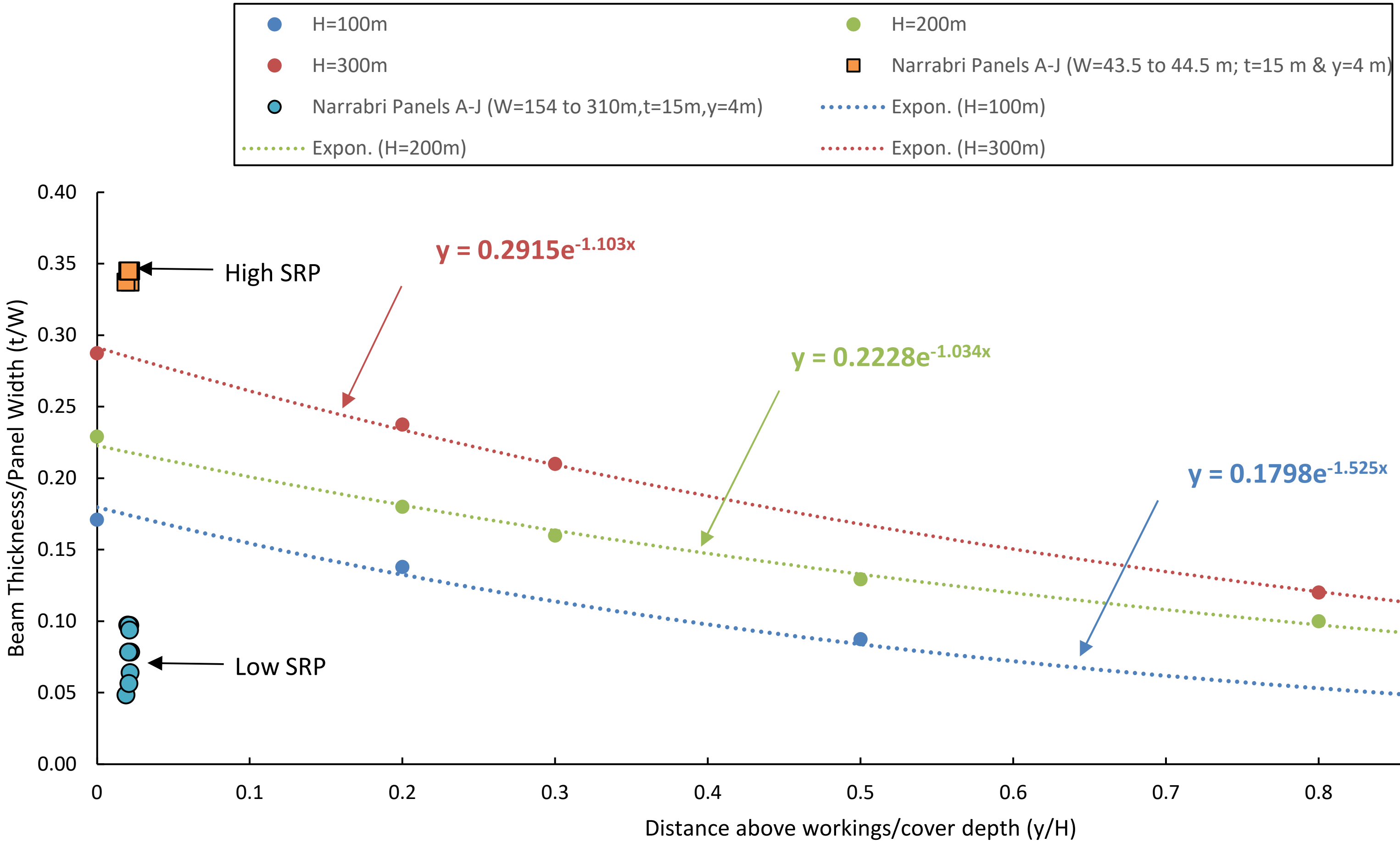
Borehole Locations & Unit Base Distance (m)

Distance to Base of Digby Conglomerate above Mine Workings Contours (m)

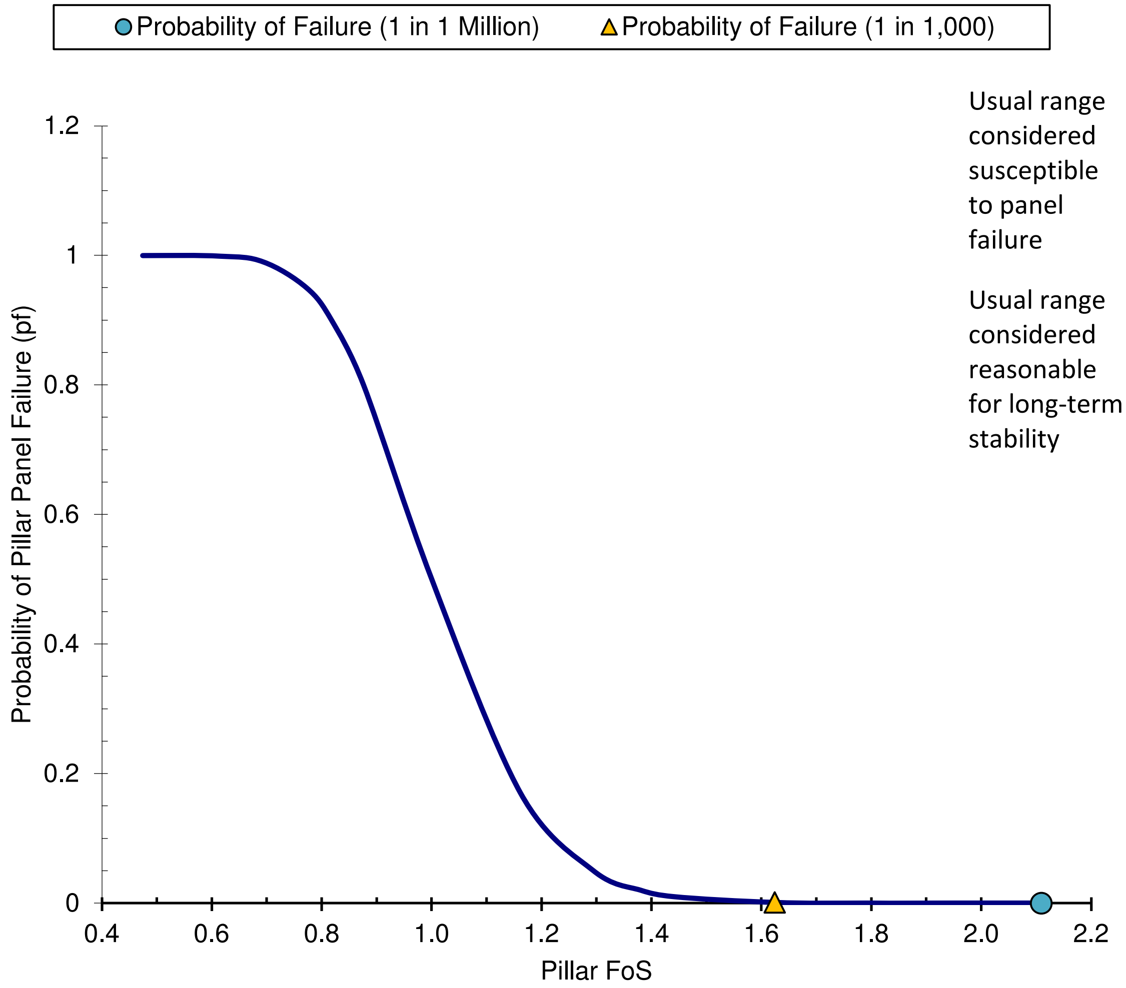
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Contours of Distance to Digby Formation Conglomerate Above the Proposed Pillar Reduction Panels CF201 - CF205 (A - J) and Longwalls 203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	1:15,000 — Figure No: 5k



DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton		
	Date: 15.07.21	Title:	Predicted Subsidence Reduction Potential of Digby Conglomerate Above Proposed Pillar Reduction Panels CF201 - CF205 (A - J) for 200 m +/-50 m Depth Category
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS — Figure No: 5I



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Minimum Digby Conglomerate Beam Thickness for High Subsidence Reduction Potential above the 44 m to 190 m Wide Spans Proposed for Panels CF201 - CF205 (A-J)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	5m



Usual range considered susceptible to panel failure

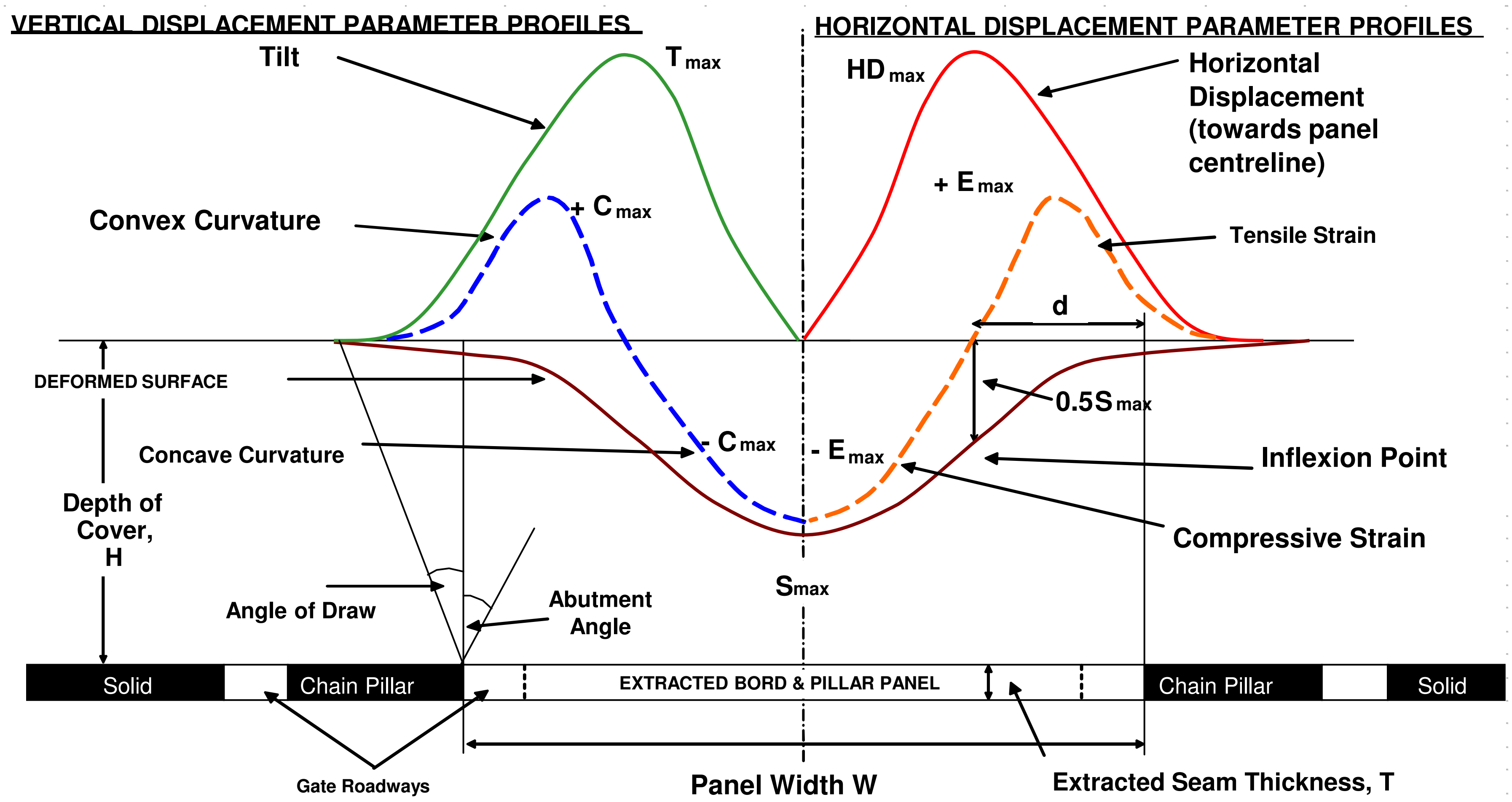
Usual range considered reasonable for long-term stability

Failure Probability (pf)			Factor of Safety
pf	**1-pf**	**lnFoS**	**FoS**
0.8	0.2	-0.13	0.87
0.5	0.5	0.00	1.00
0.1	0.9	0.20	1.22
0.05	0.95	0.26	1.30
0.02	0.98	0.32	1.38
10^{-2}	0.99	0.37	1.44
10^{-3}	**0.999**	**0.49**	**1.63**
10^{-4}	**0.9999**	**0.58**	**1.79**
10^{-5}	**0.99999**	**0.67**	**1.95**
10^{-6}	**0.999999**	**0.75**	**2.11**

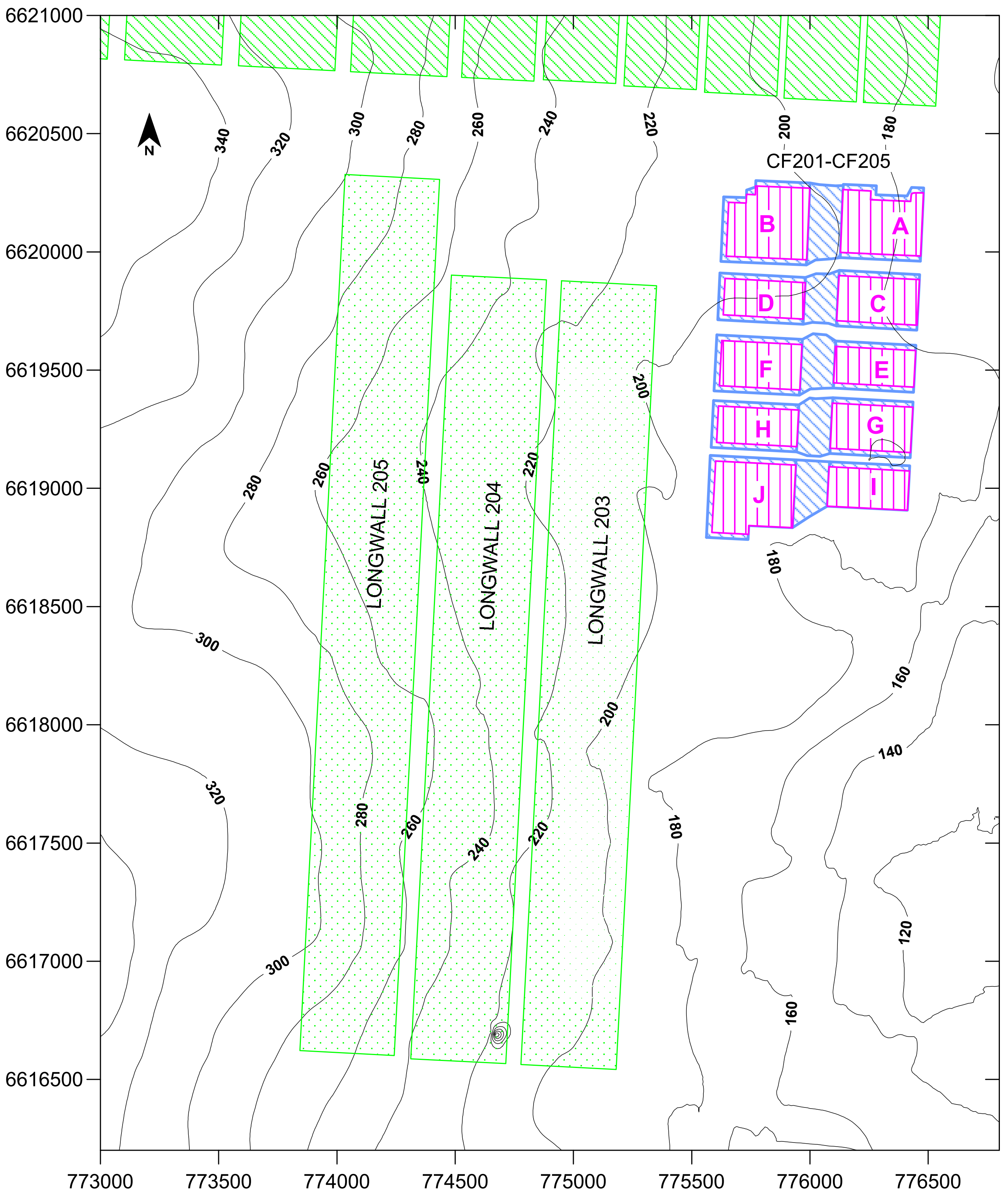
Estimated log-normal pdf parameters:

Parameter	Value
μ	1.000
sigma	0.157

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Probability of Pillar Reduction Panel Failure v. FoS under FTA or Abutment Loading Conditions
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	5n



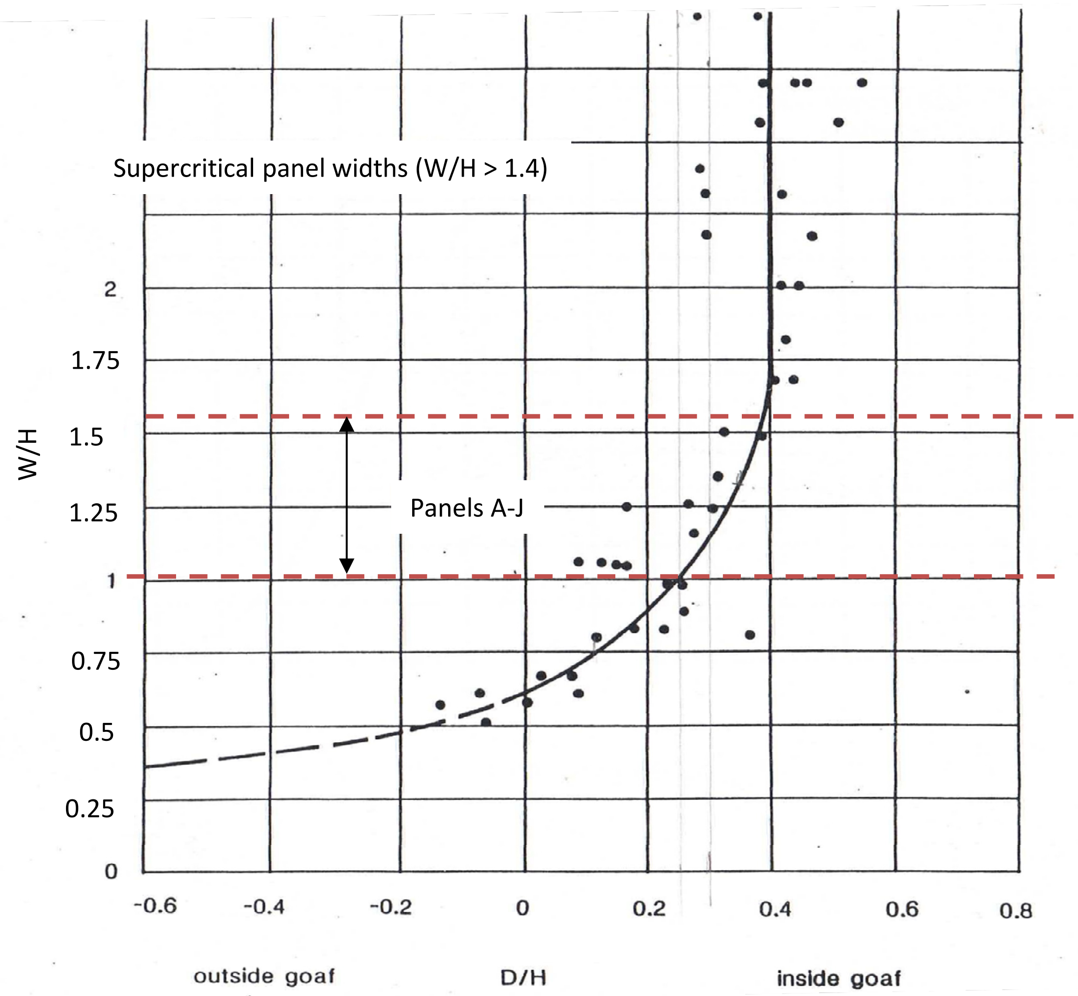
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Mine Subsidence Trough Deformation Parameters (adapted from Holla, 1987)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS Figure No: 5o



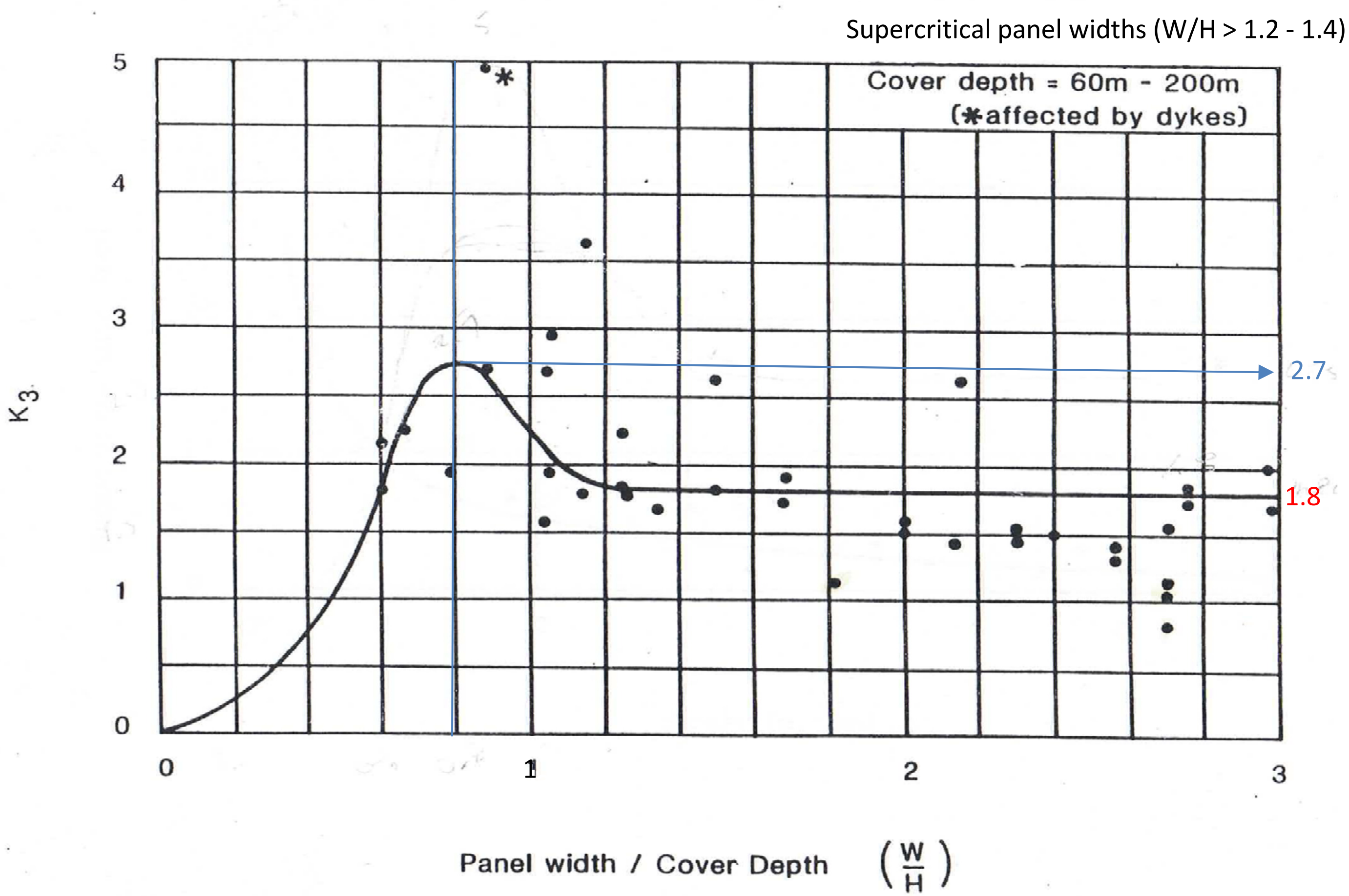
Key:

- Approved Longwalls (LW203-205)
- Extracted Longwalls (LW101-108A)
- Proposed Pillar Reduction Panels (e = 66%)
- Proposed Second Workings (e = 35%)
- Cover depth contours (m)

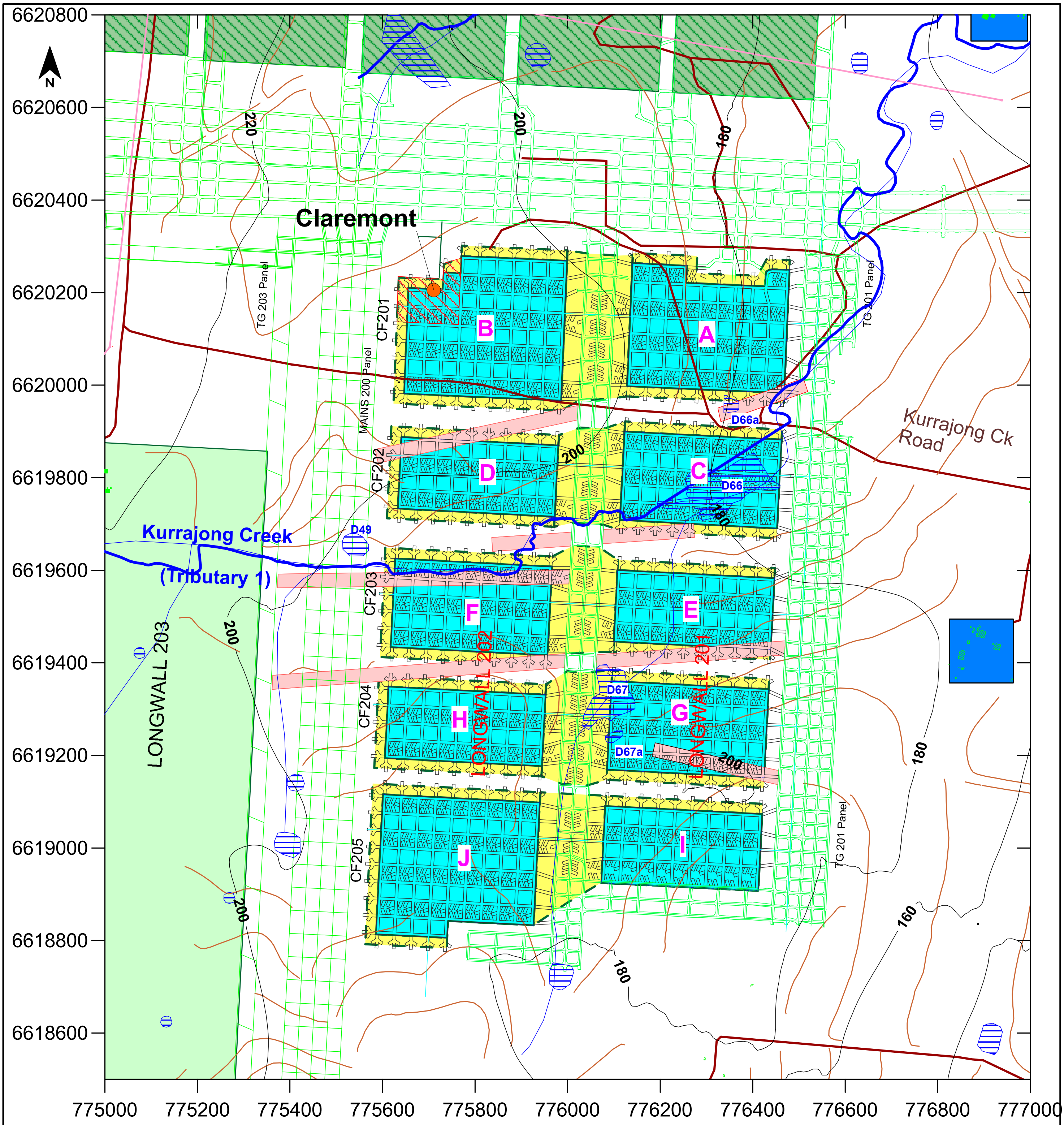
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	SDPS Panels for Proposed Pillar Reduction Panels CF201 - CF205 (A to J) & LW203 to 205
	Date:	15.07.21		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:30,000
			Figure No:	5p



DgS	Engineer: S.Ditton	Client:	Narrabri NAR-004/8	
	Drawn: S.Ditton			
	Date: 15.07.21	Title:	Inflexion point distance from mine workings limits above pillar extraction and longwall panels (**Holla, 1987**)	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 5q



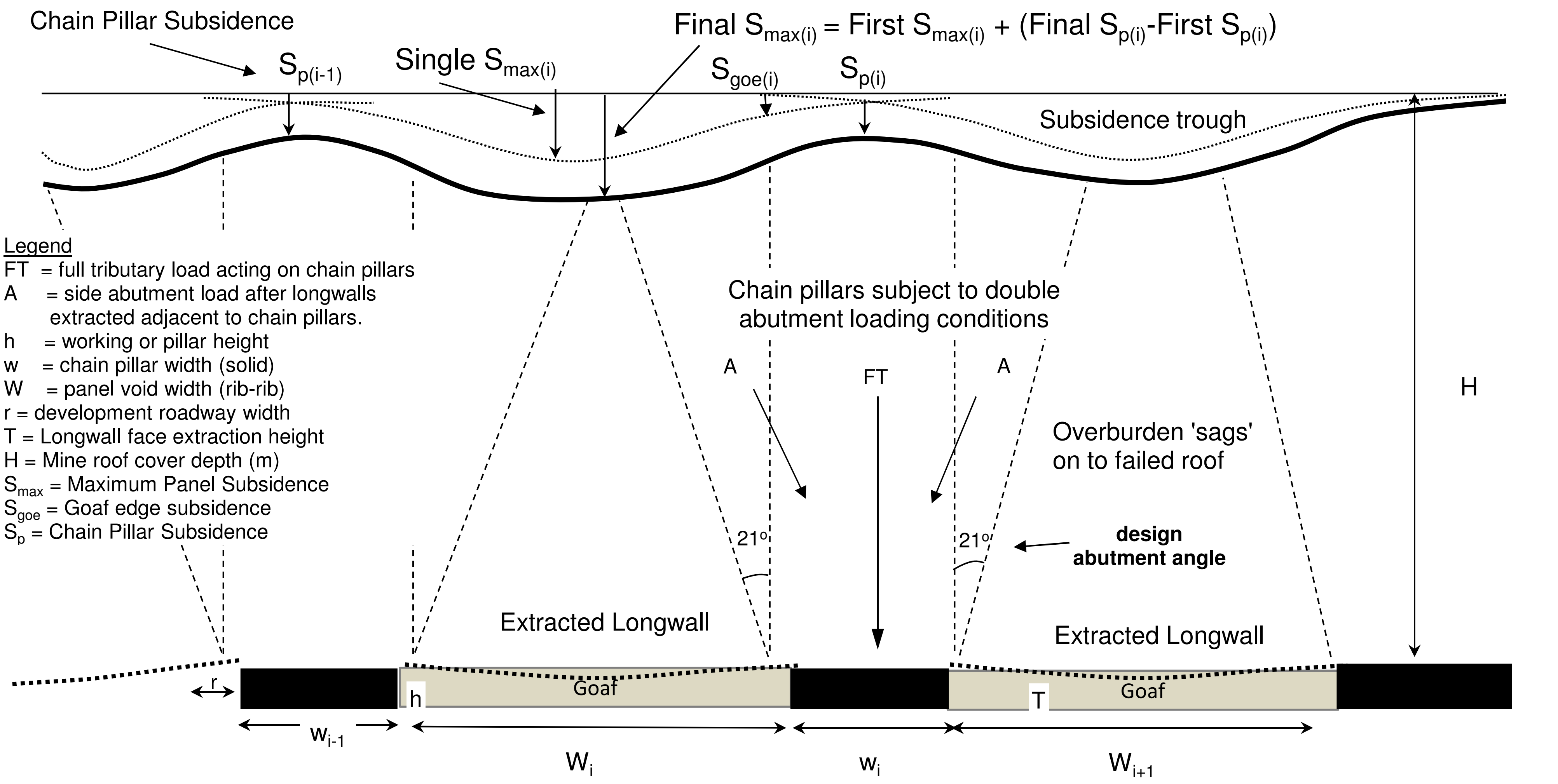
DgS	Engineer:	S.Ditton	Client:	Narrabri NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Influence Angle (K_3 = tan(beta)) above pillar extraction and longwall panels (**Holla, 1987**)		
	Ditton Geotechnical Services Pty Ltd					
			Scale:	NTS	Figure No:	5r



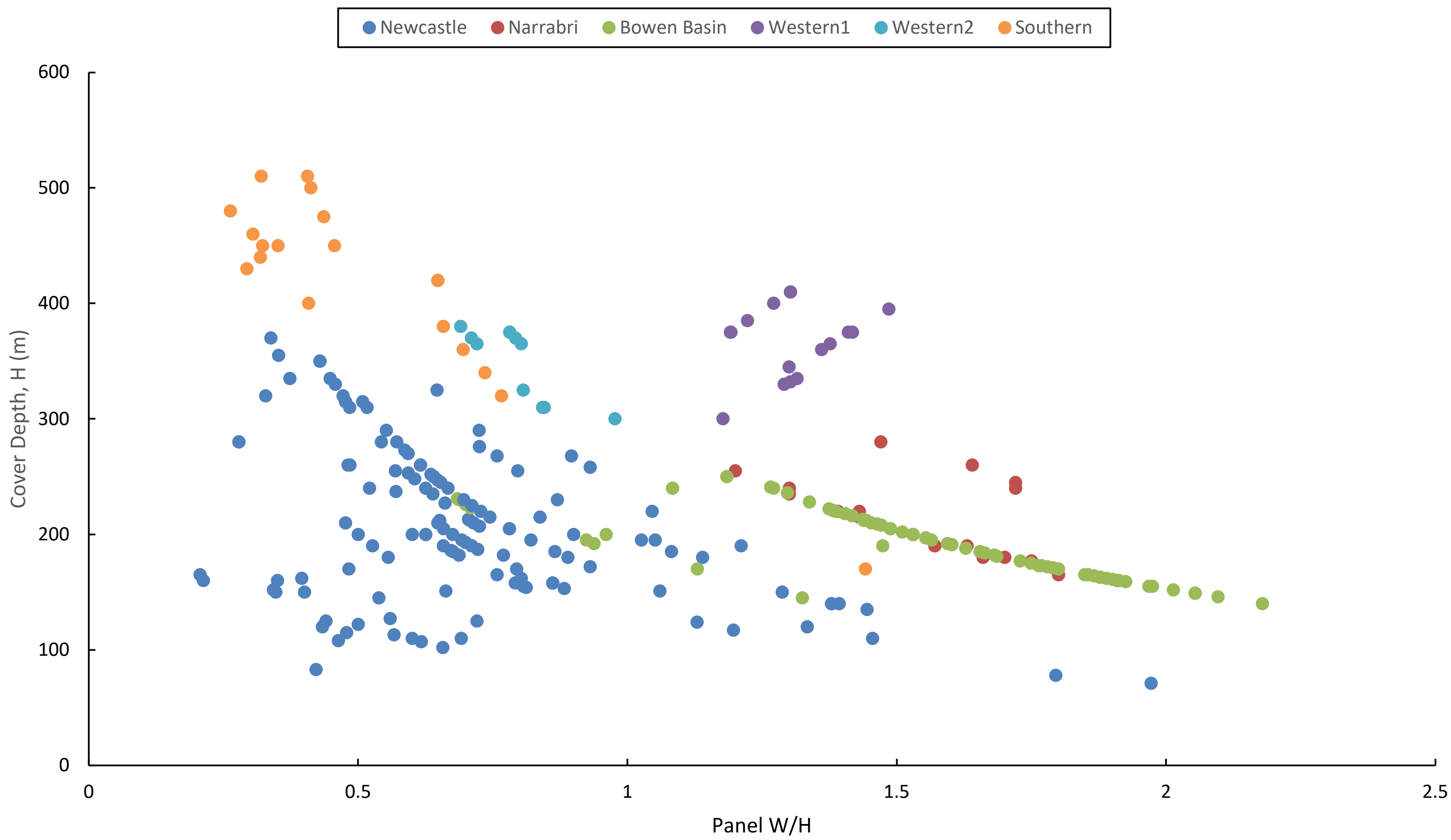
Key:

- Approved Longwalls (LW203-205)
- Extracted Longwalls (LW101-108A)
- Approved First Workings
- Proposed Pillar Reduction Panels (e = 66%)
- Proposed 2nd Workings Limits (e=35%)
- Cover Depth Contours (m)
- Mining Restriction Zone
- Pillar 'pocketing' or reduction
- Dwellings & Sheds/Tanks
- NCO-Owned Buildings
- Roads (unsealed)
- Ephemeral Creeks & Watercourses
- Farm Dams
- Contour Banks
- Powerlines (Domestic)
- Inferred Faults
- Grinding Grooves

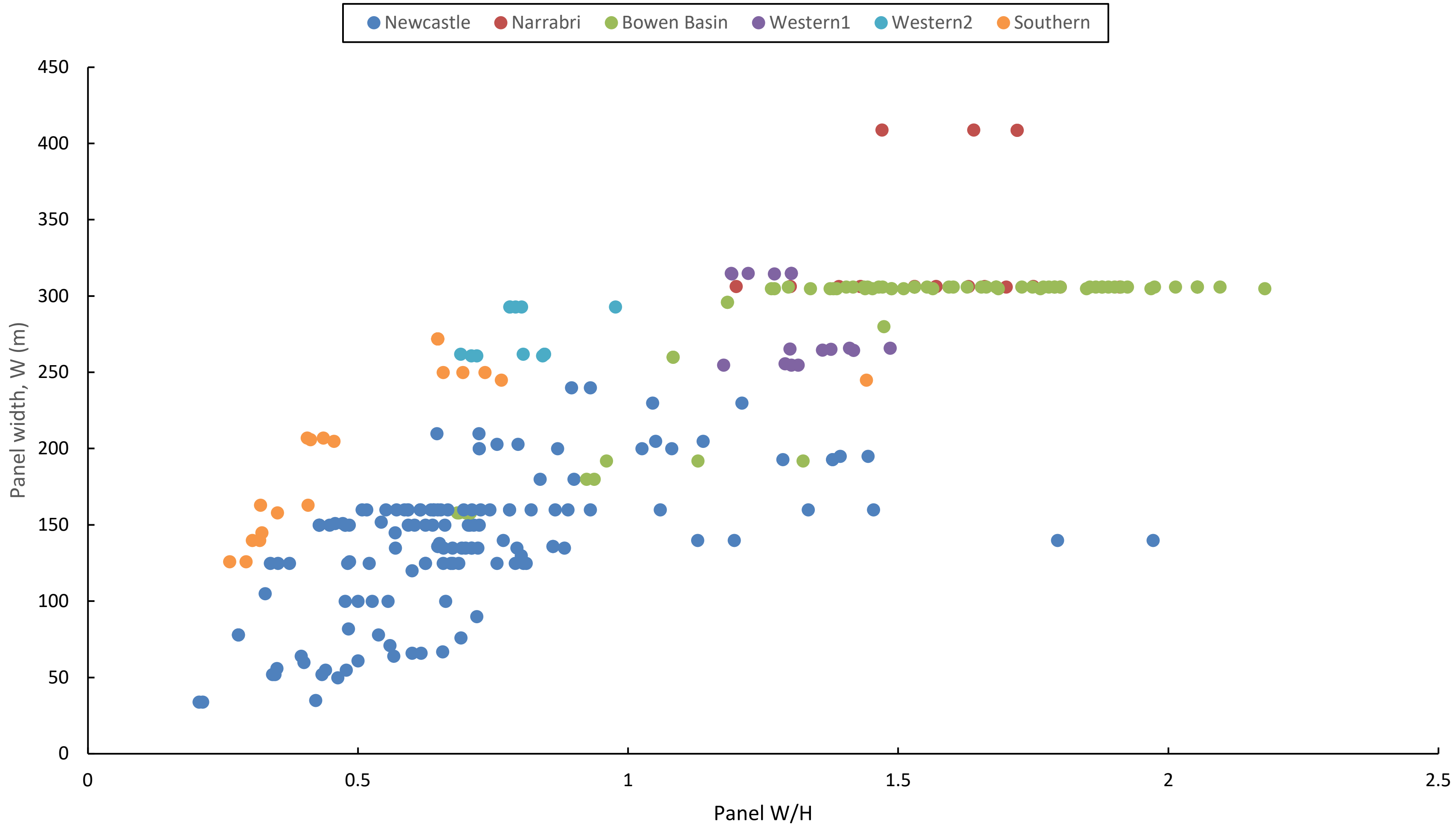
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	Proposed Pillar Reduction Panels CF201-205 (A to J) with Mining Restriction Zone to Protect Claremont Grinding Grooves from Cracking at the Narrabri Mine
	Date:	15.07.21		
Ditton Geotechnical Services Pty Ltd			Scale:	1:15,000
			Figure No:	5s



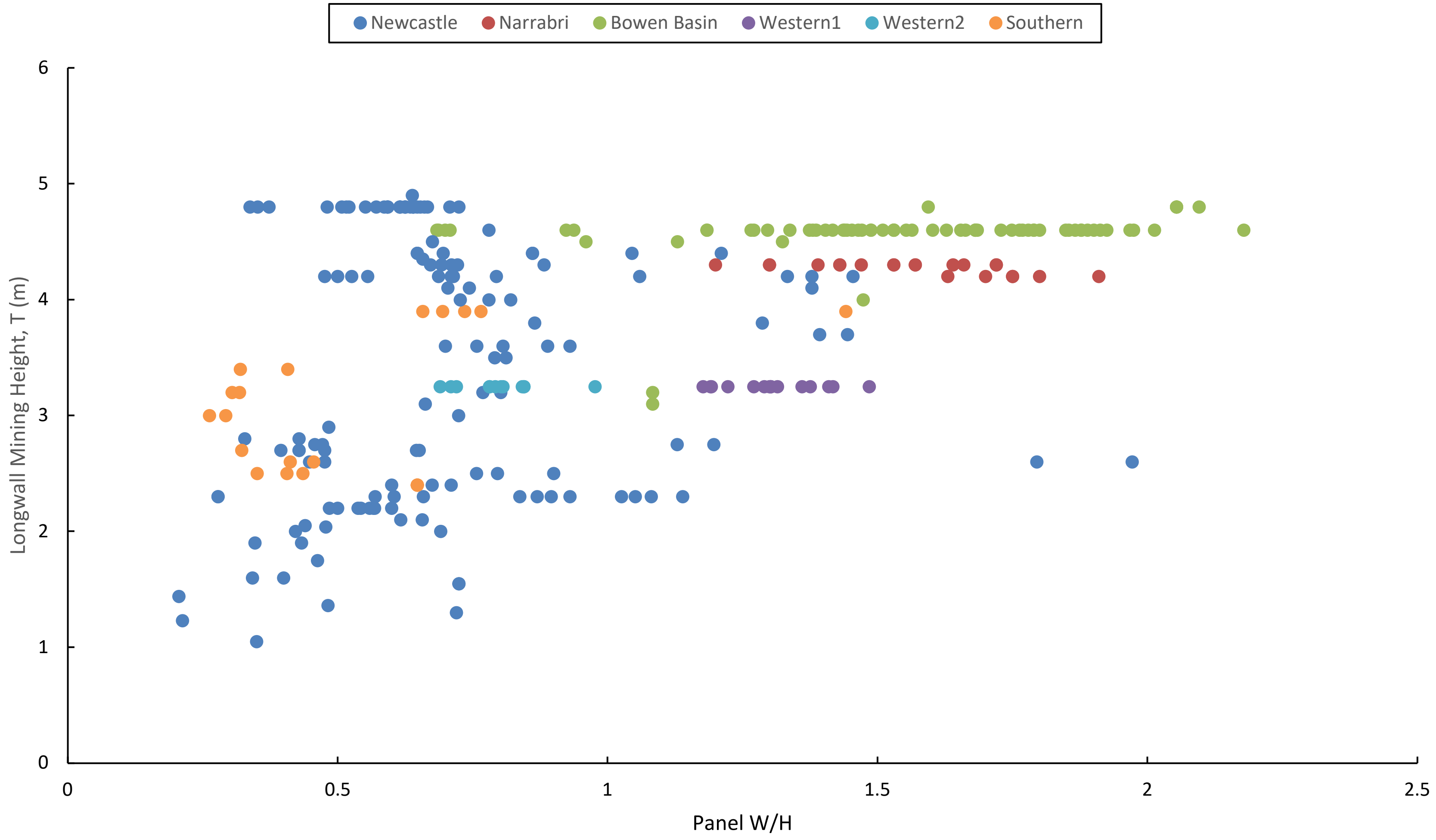
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Multiple Longwall Panel Subsidence Mechanism Concepts
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	6a



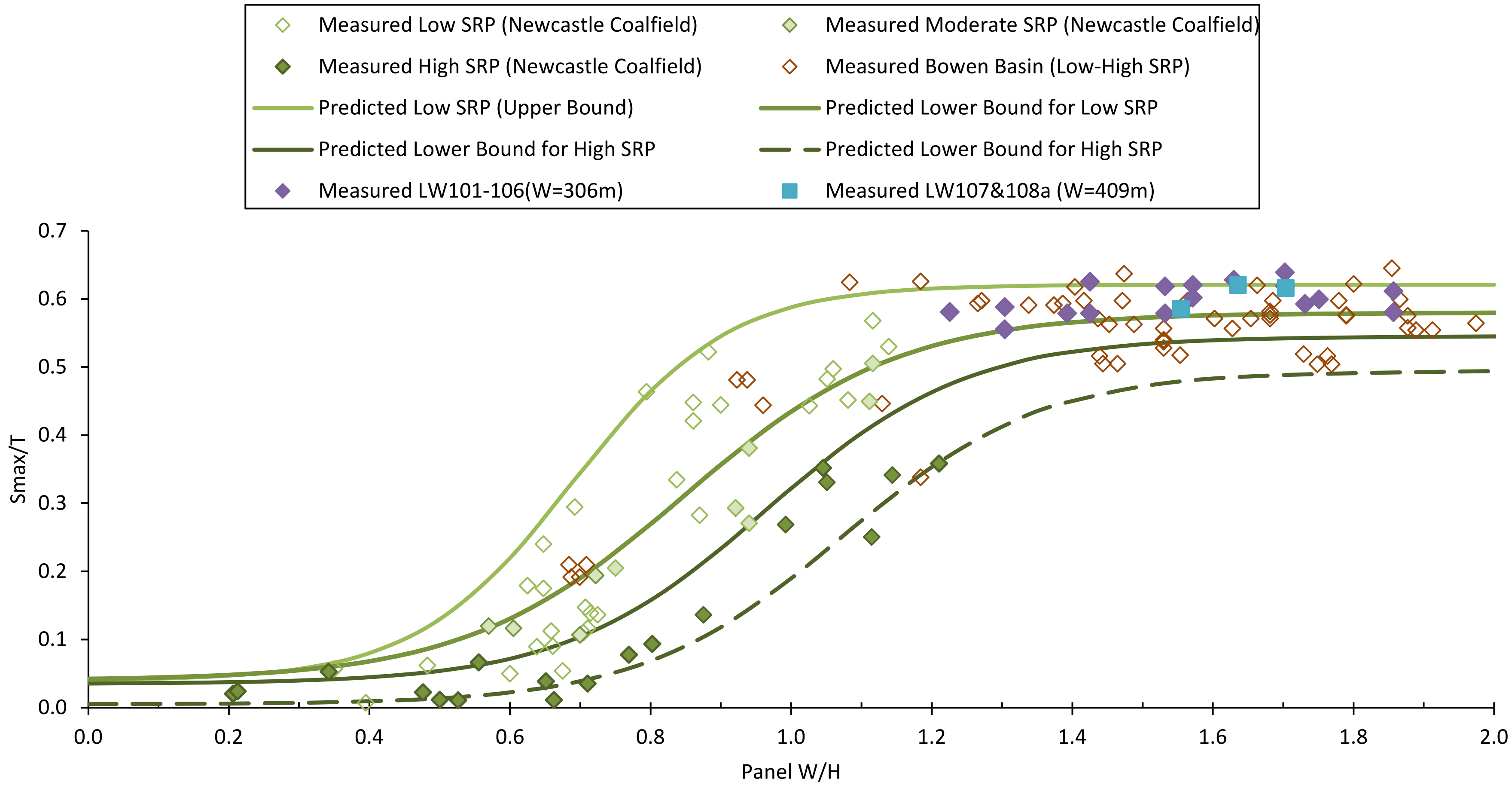
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Longwall Panel Subsidence Database of Cover Depth v. W/H			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6b	



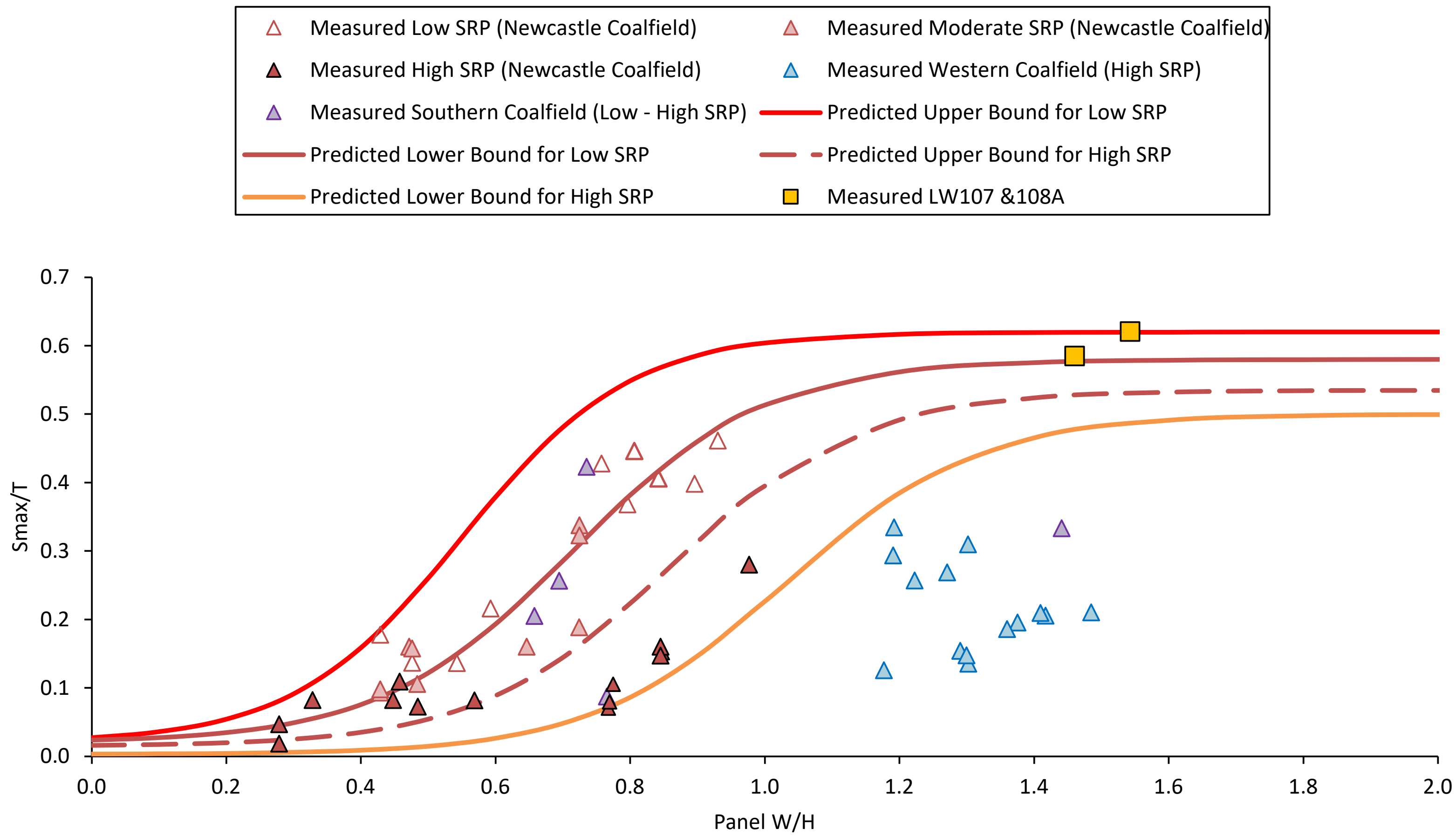
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Longwall Panel Subsidence Database of Panel Width v. W/H		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6c



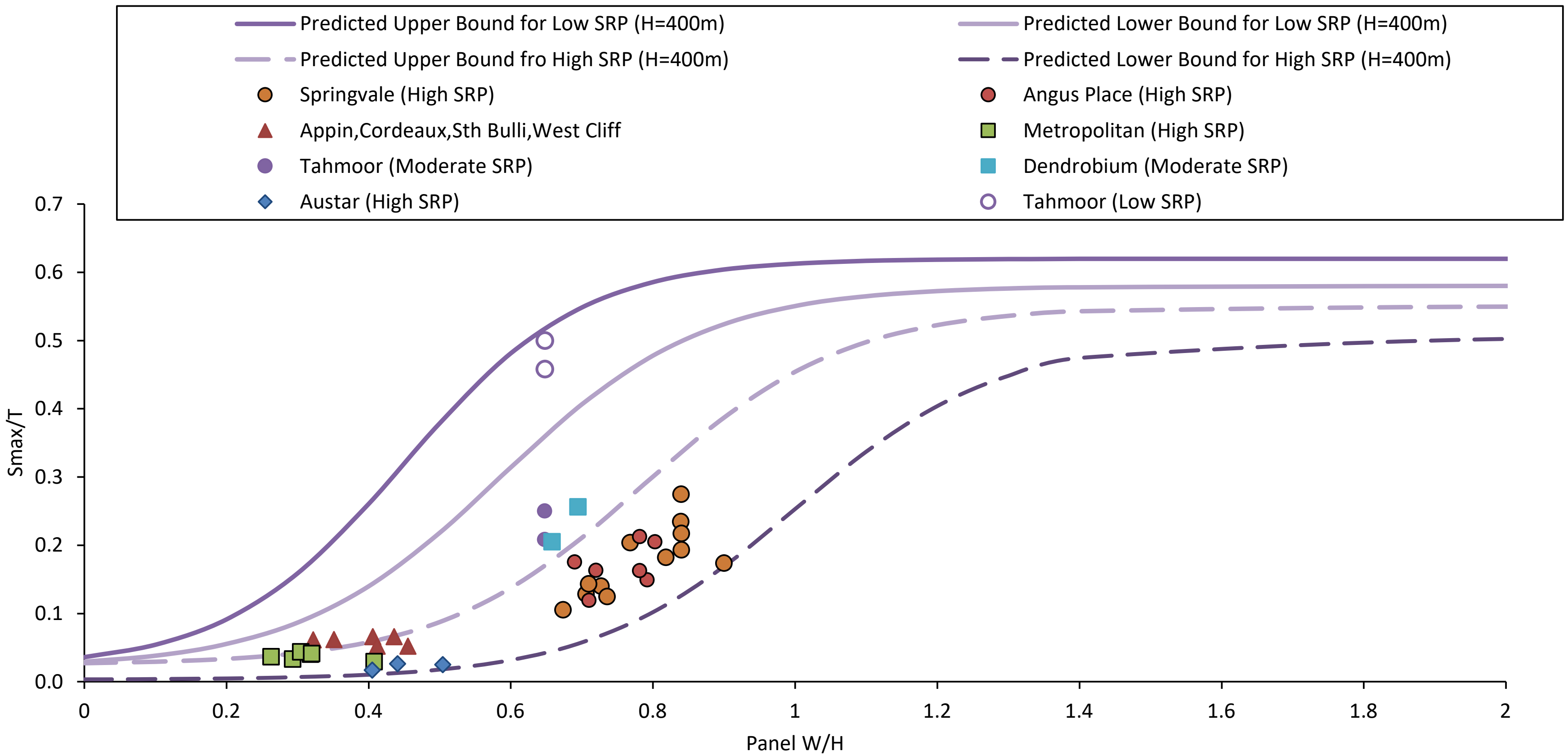
DgS	Engineer: S.Ditton	Client: Narrabri Mine NAR-004/8		
	Drawn: S.Ditton			
	Date: 15.07.21	Title: Longwall Panel Subsidence Database of Mining Height v. W/H		
	Ditton Geotechnical Services Pty Ltd	Scale: NTS	Figure No:	6d



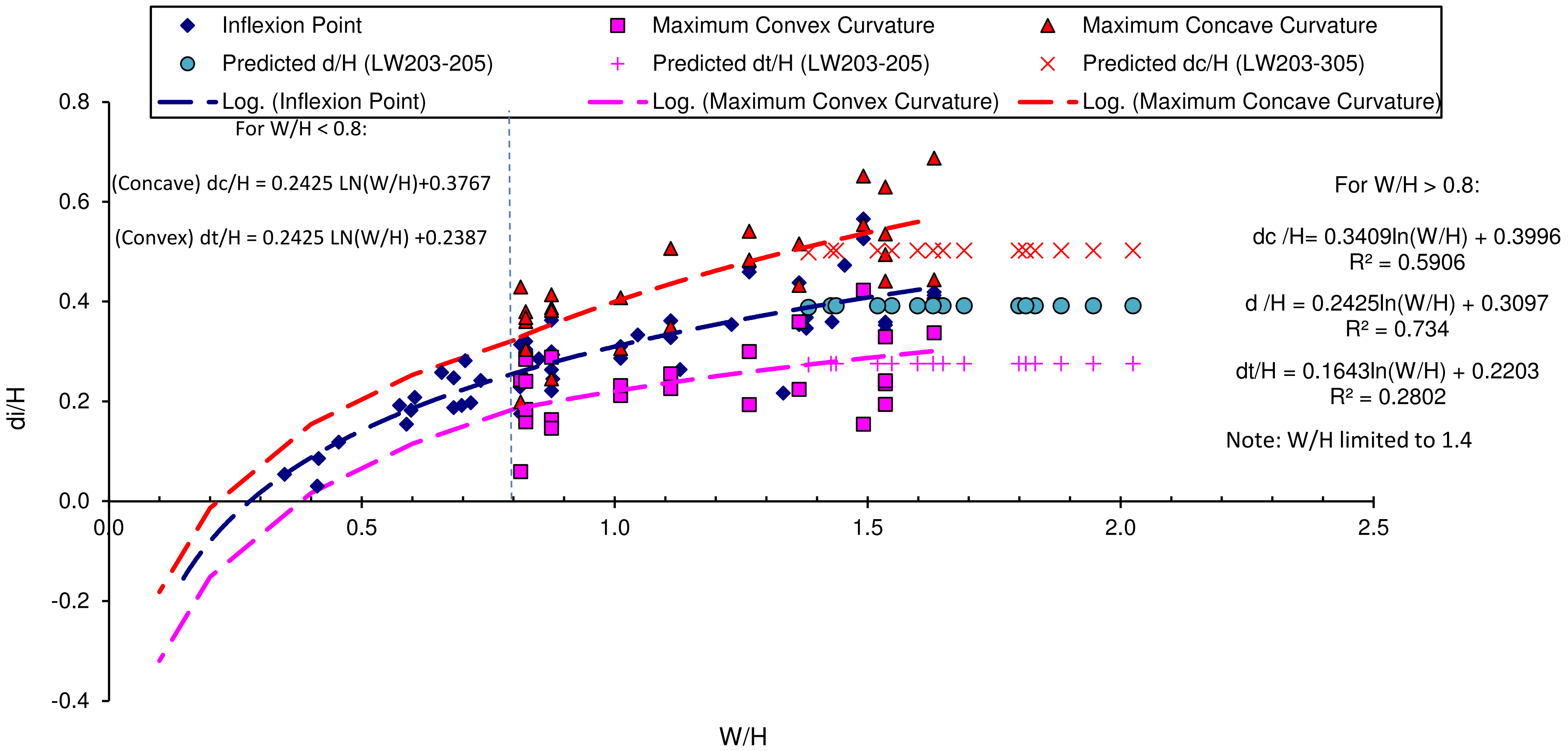
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 150 m to 250 m
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	6e



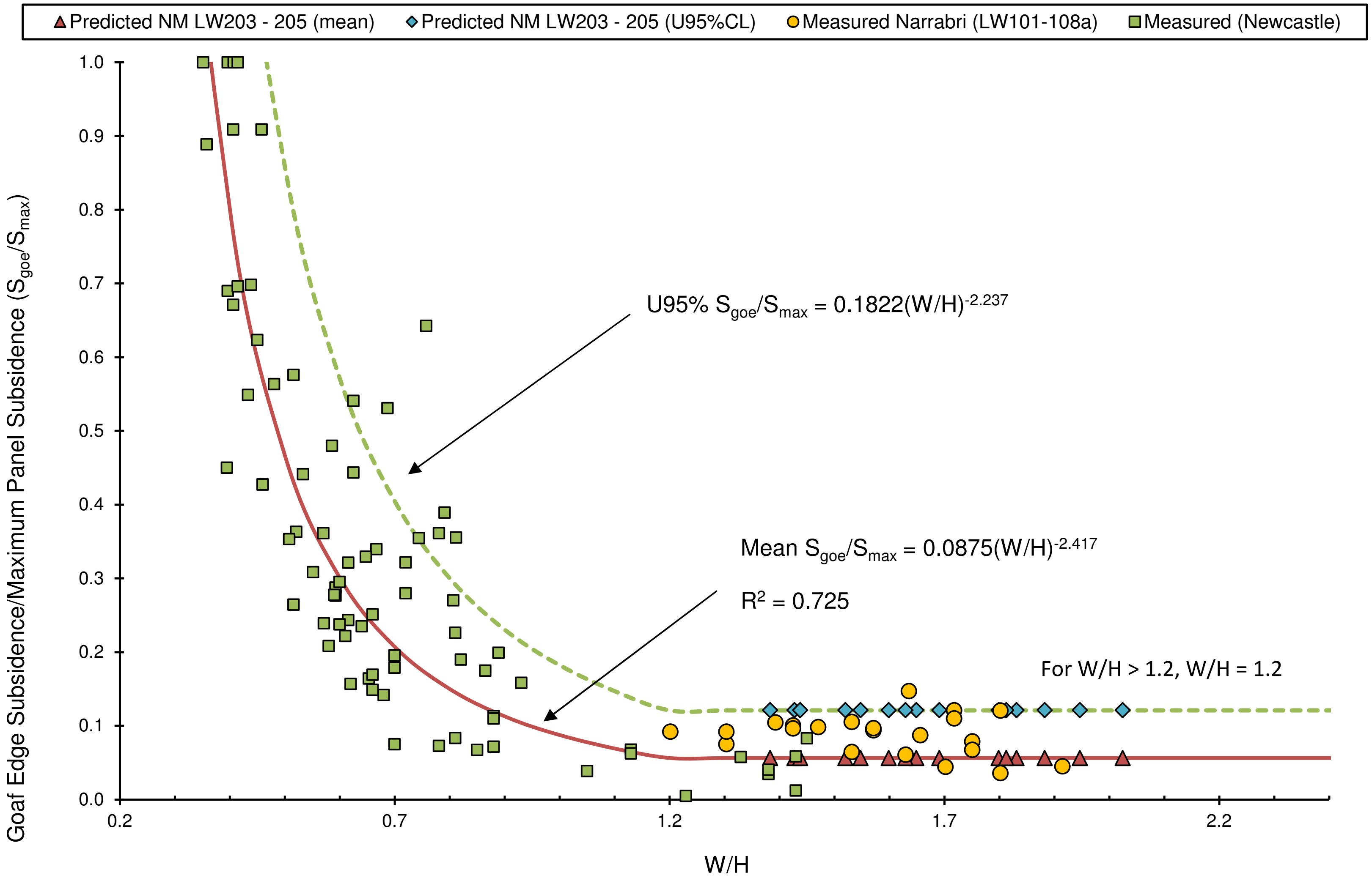
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 250 m to 350 m		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6f



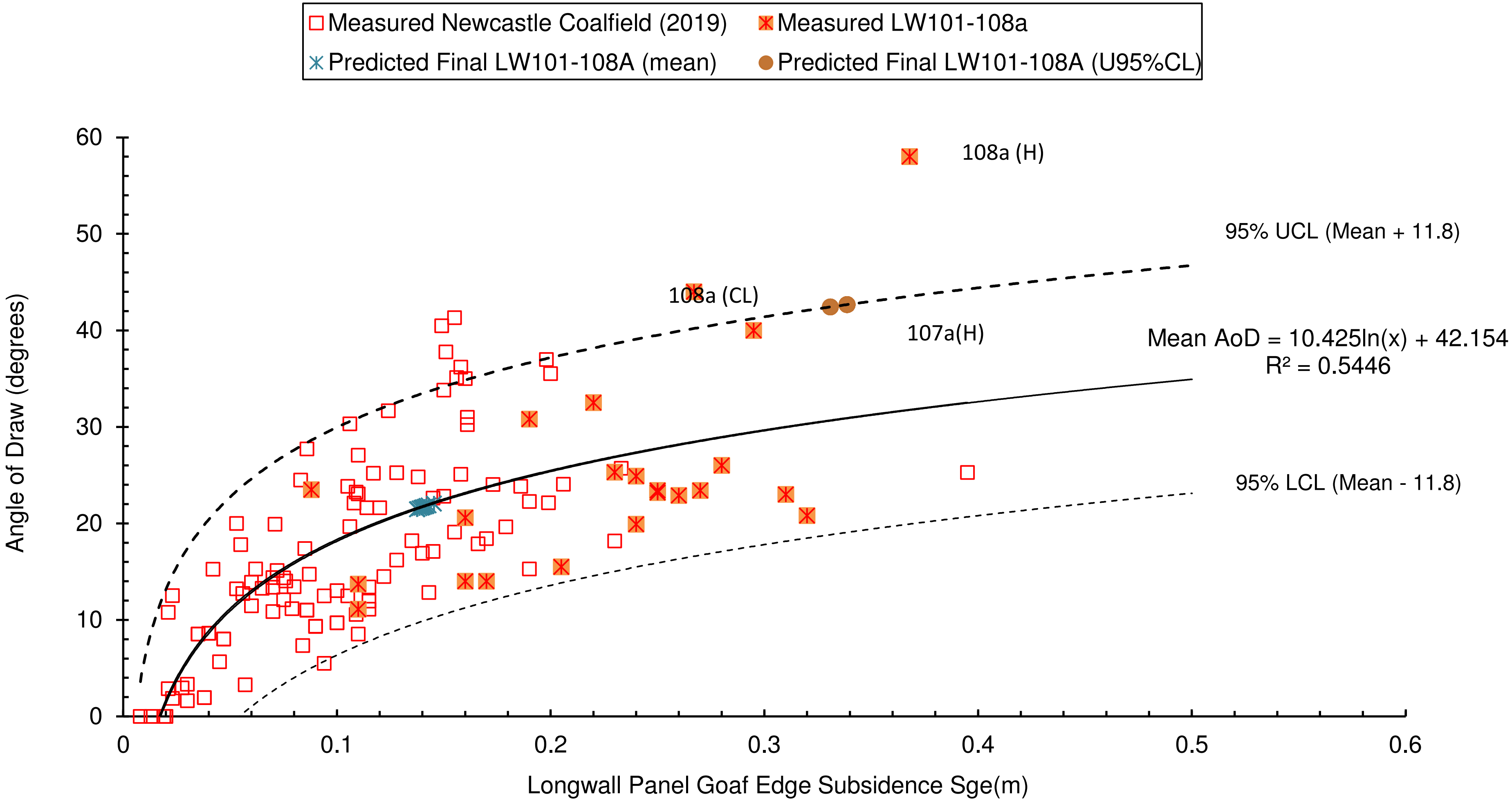
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 350 m to 500 m	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 6g



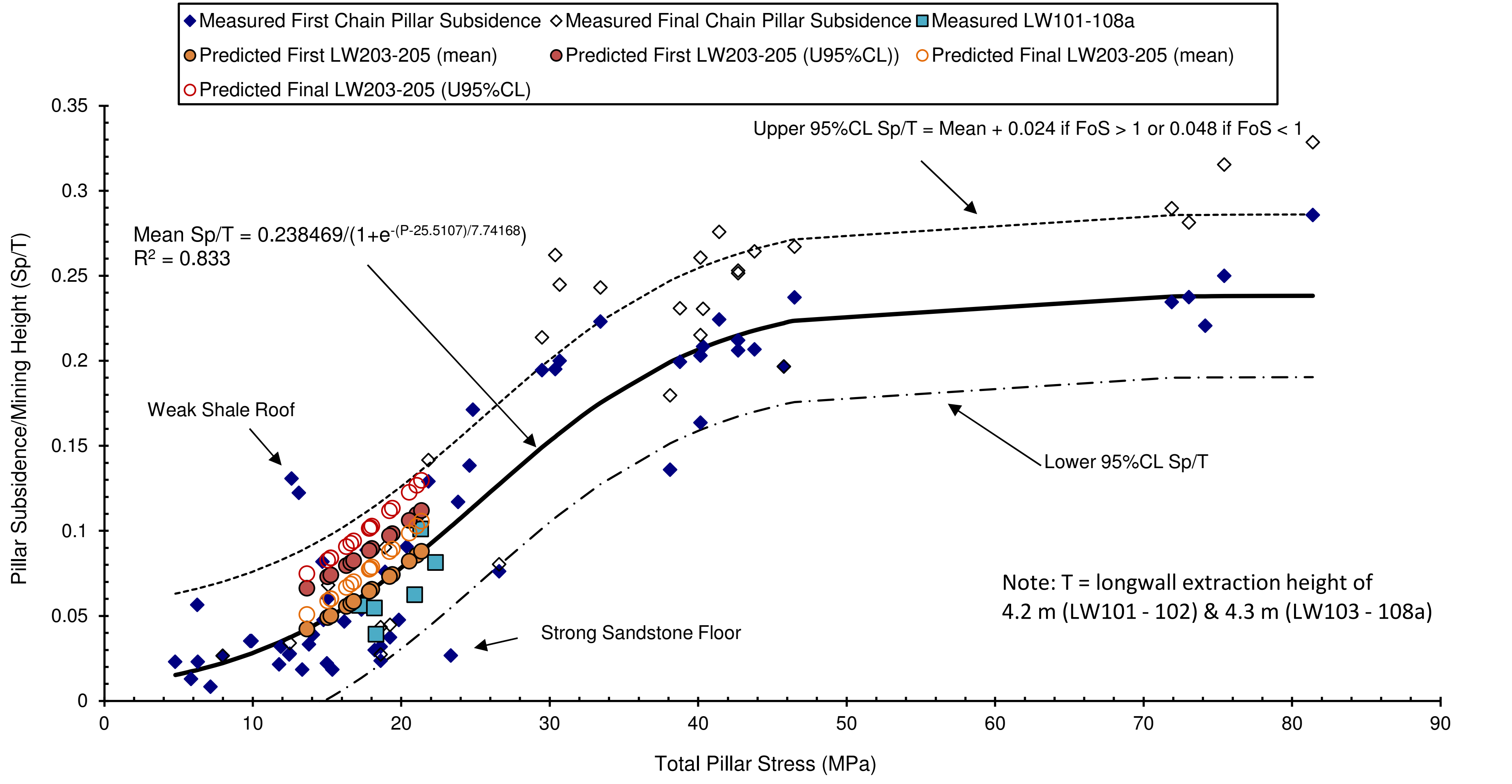
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Empirical Model for Predicting the Location of Inflexion Points and Maximum Tensile and Compressive Strain Peaks above Longwall Panels in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 6h



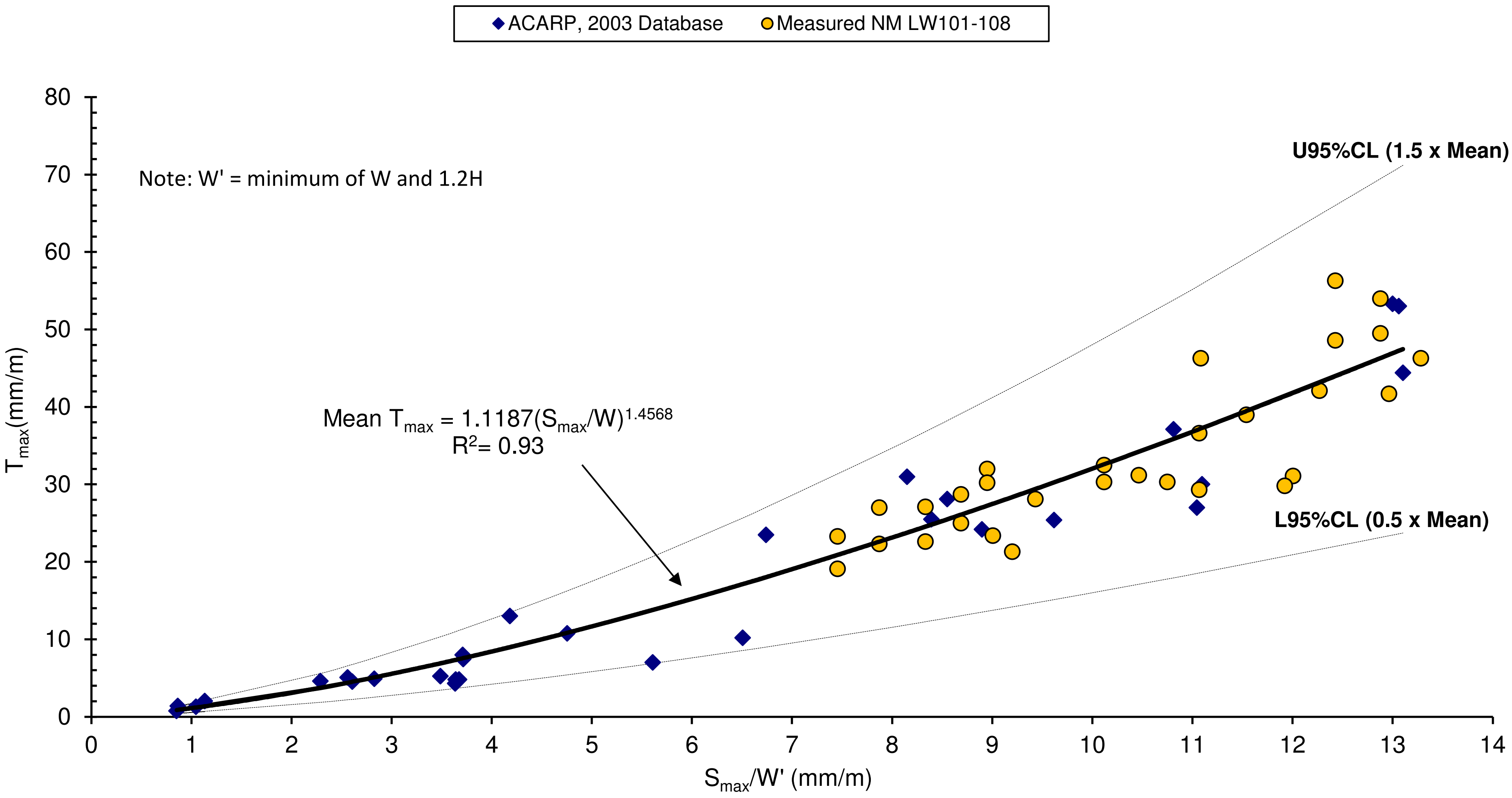
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-004/8	
	Date:	15.07.21	Title:	Empirical Model for Goaf Edge Subsidence Prediction for LW203 to 205 at the Narrabri Mine	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 6i



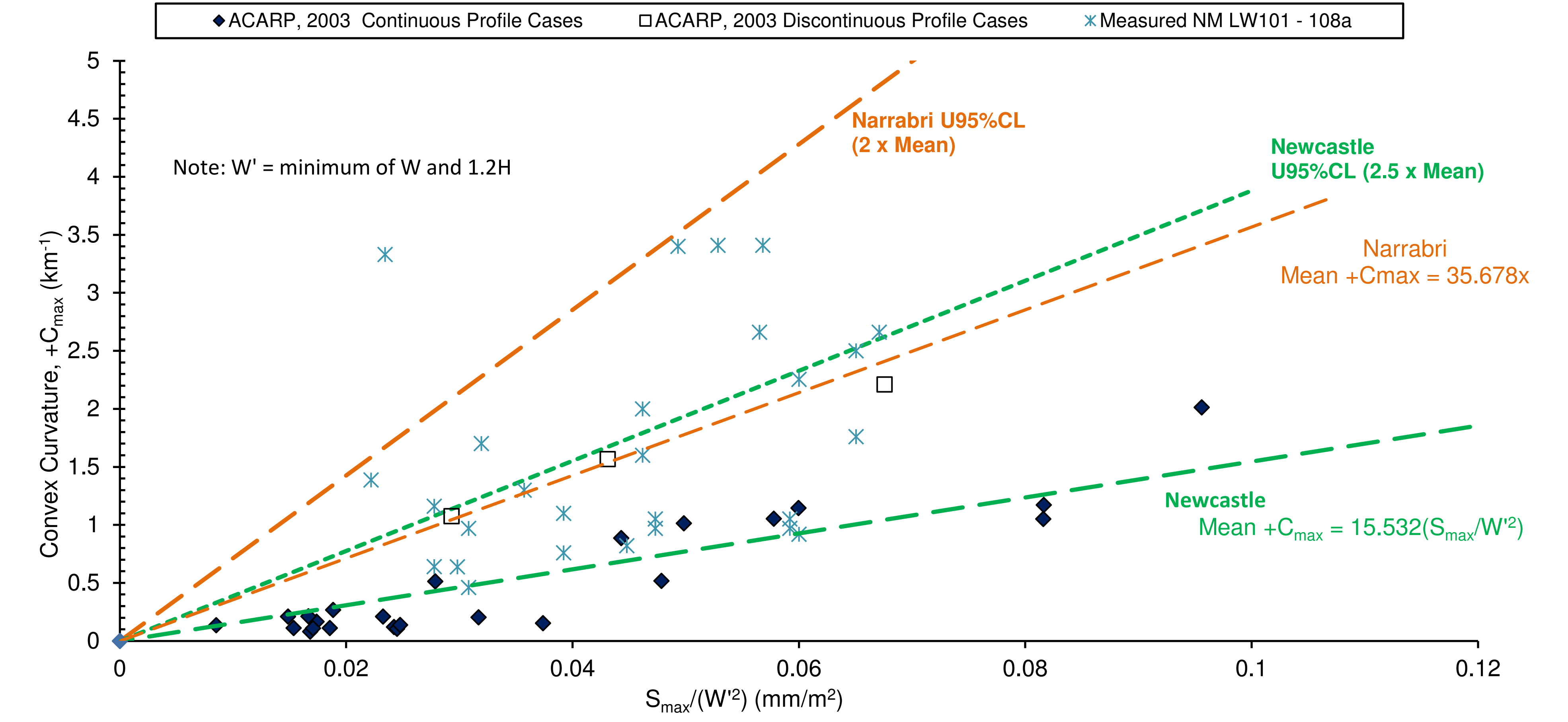
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model for Predicting the Angle of Draw to 20mm subsidence at the Narrabri Mine based on LW101 to 108a and Newcastle Coalfield Subsidence Data (2019)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6j



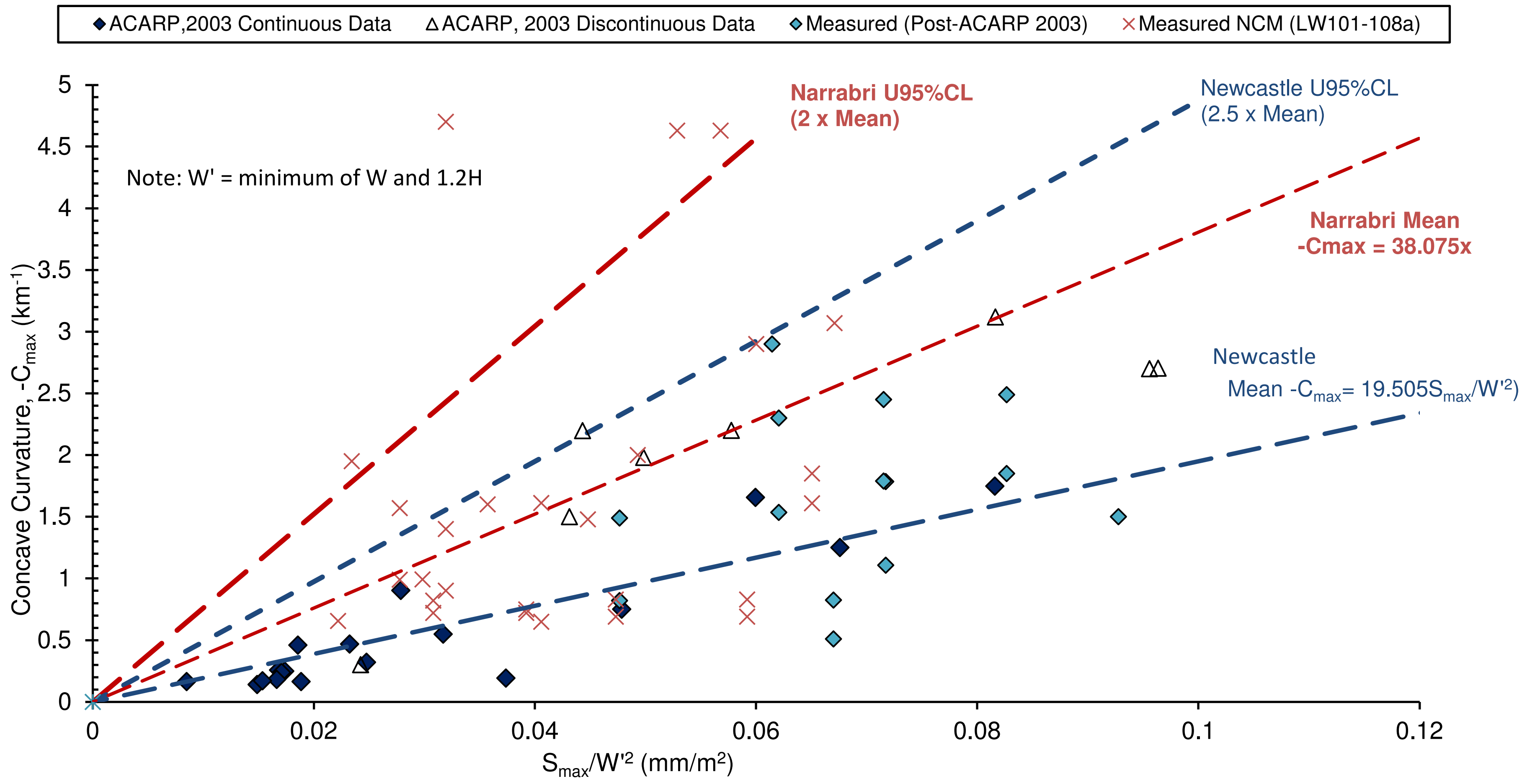
DgS	Engineer: S.Ditton		Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton			
	Date: 15.07.21		Title:	Chain Pillar Subsidence Prediction for LW203 to 205 based on the ACARP, 2003 and the Measured Outcomes for Narrabri Mine's LW101 to 108a
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	6k



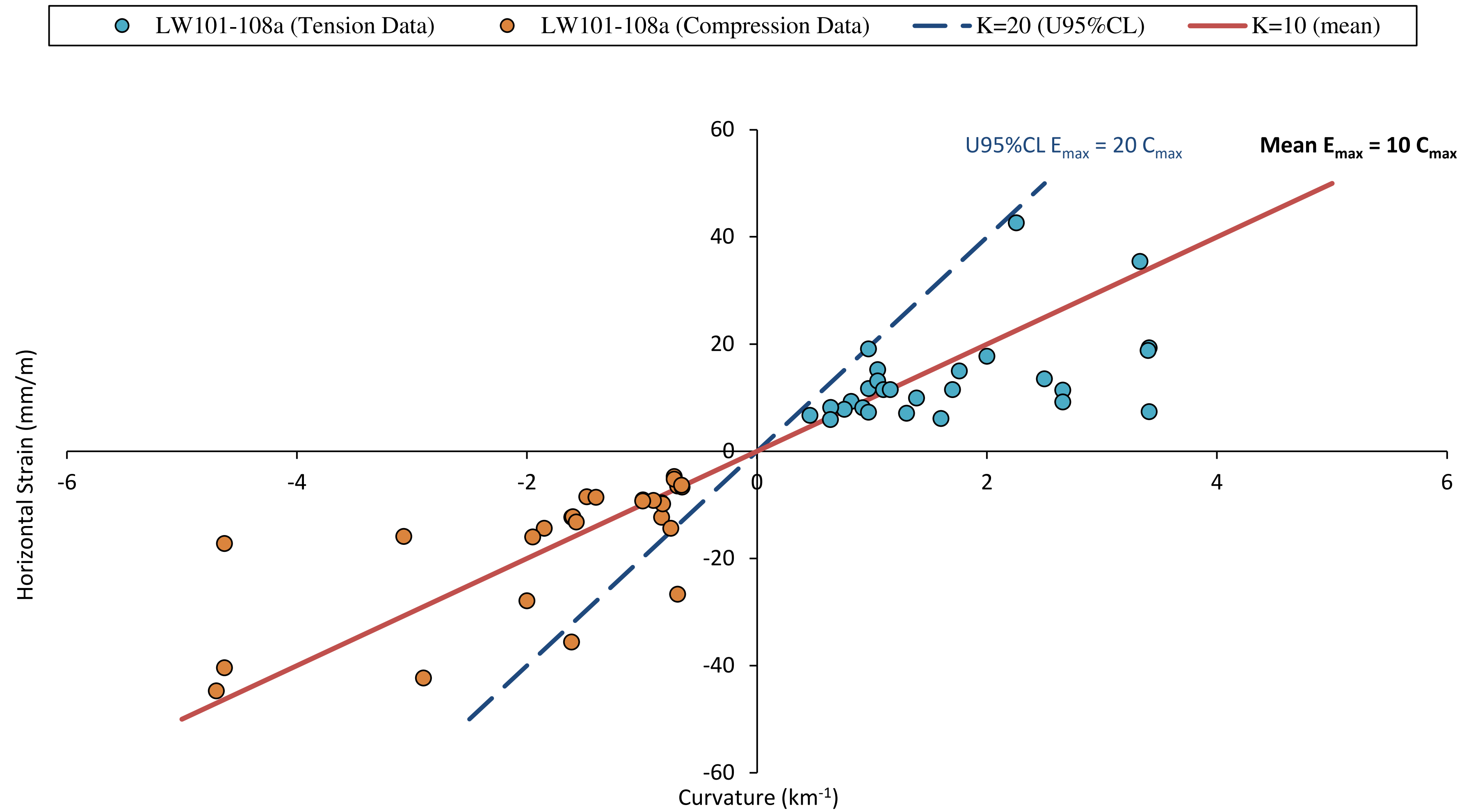
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Empirical Model of Maximum Tilt with Measured Values for LW101 to 108a			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		Figure No:	6l



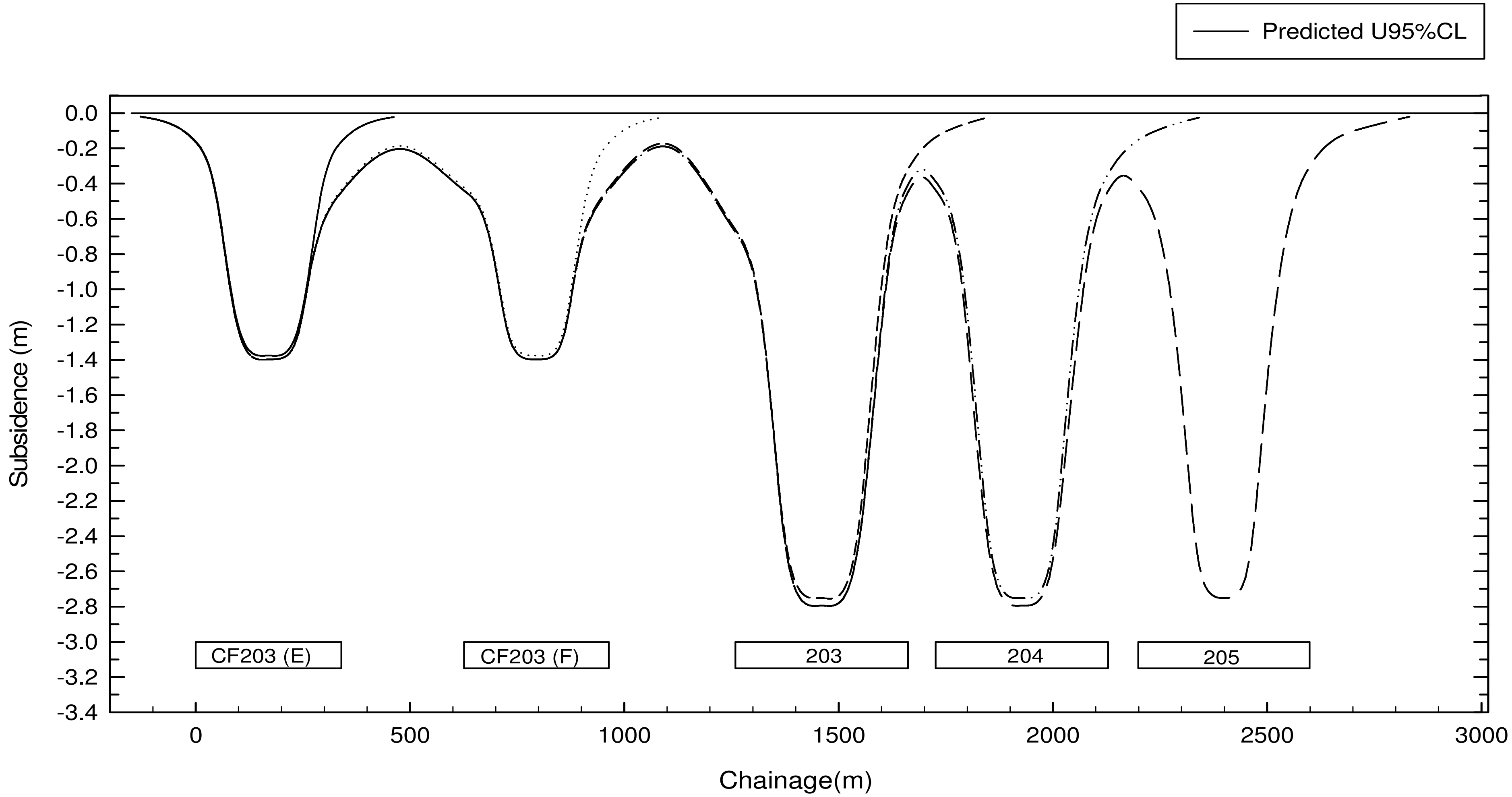
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model of Maximum Convex (Hogging) Curvature with Measured Values for LW101 to 108a		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6m



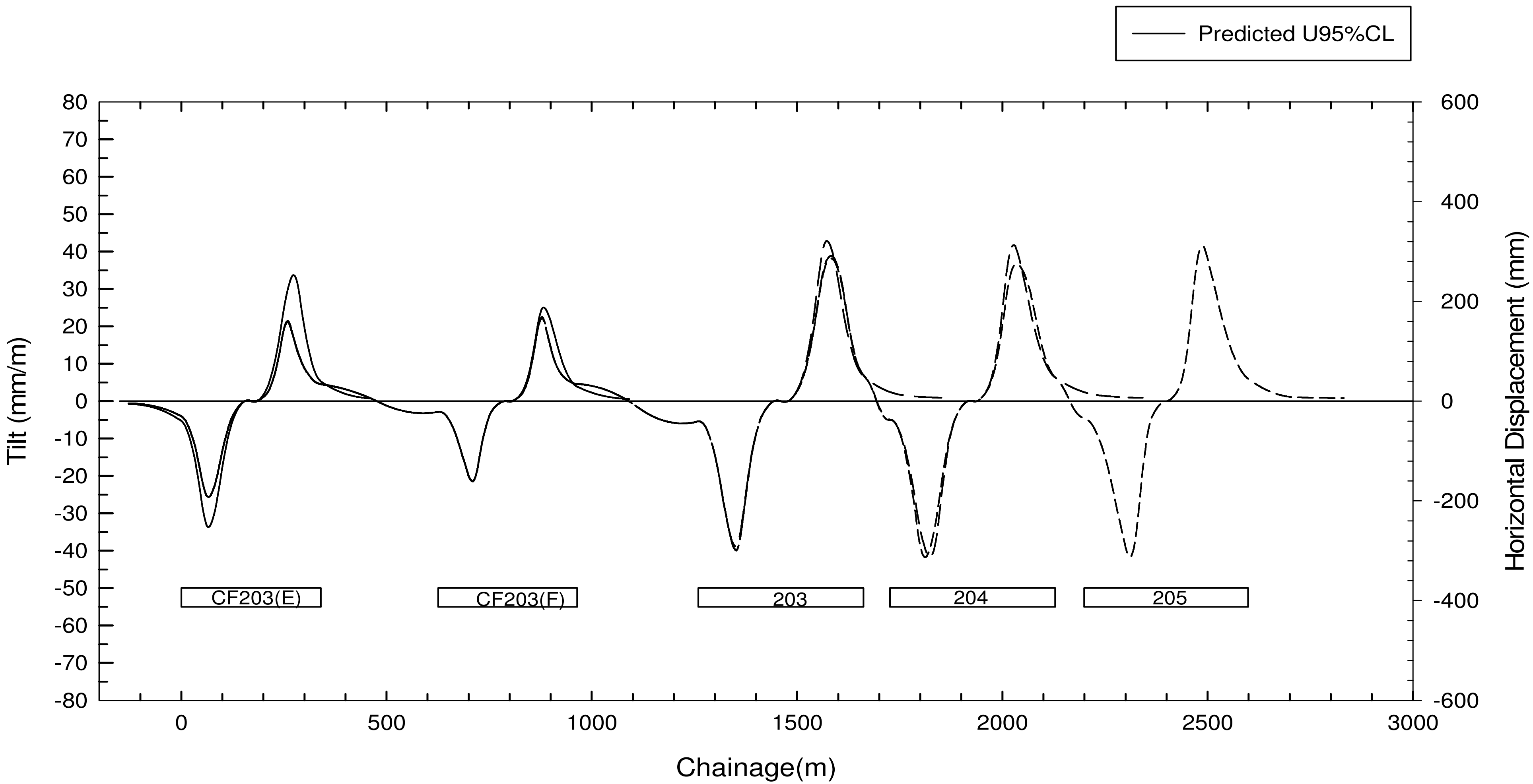
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model of Maximum Concave (Sagging) Curvature with Measured Values for LW101 to 108a (Newcastle v. Narrabri Coalfields)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6n



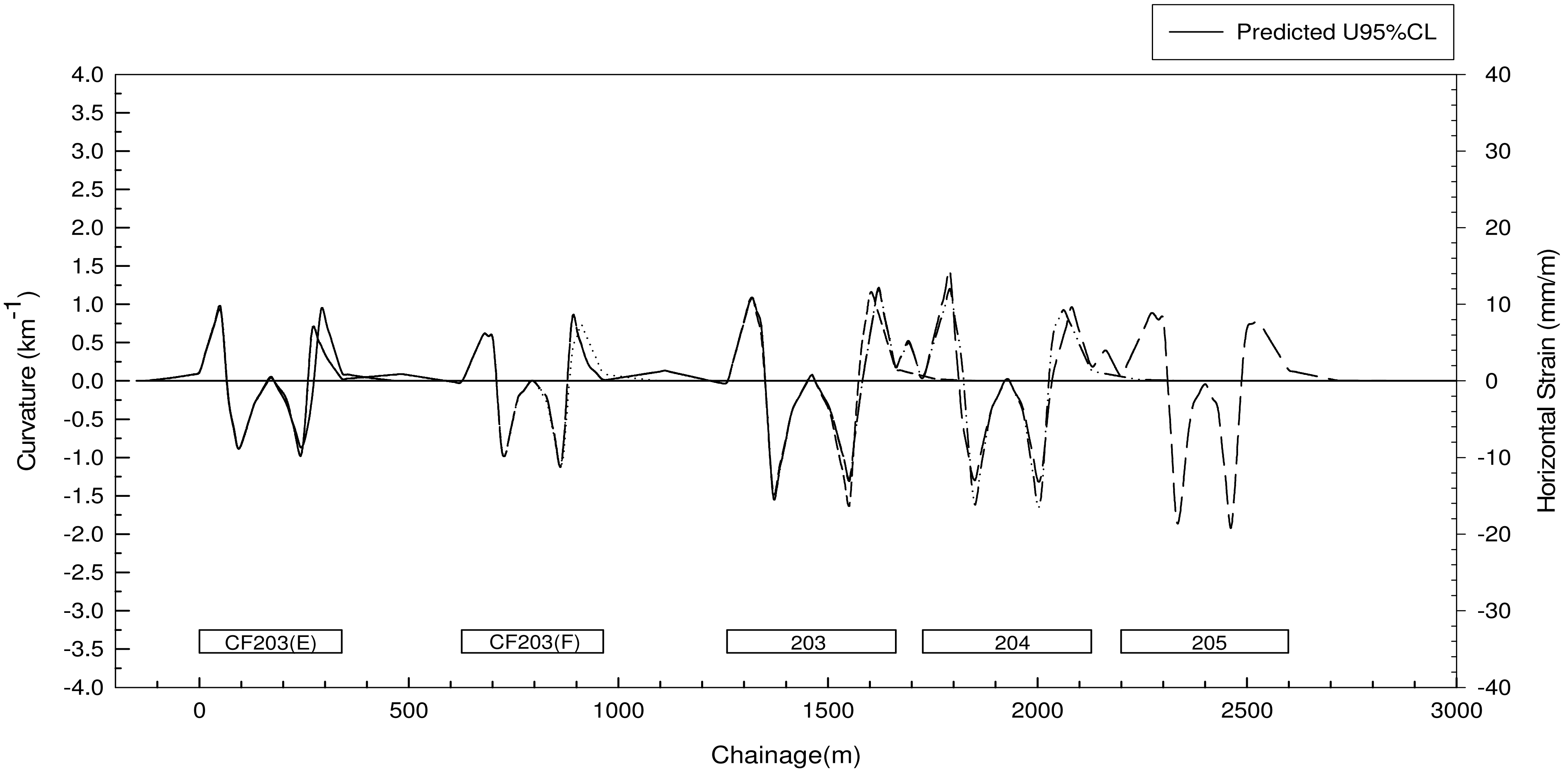
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model of Maximum Strain v. Curvature based on Measured Values for LW101 to 108a		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6o



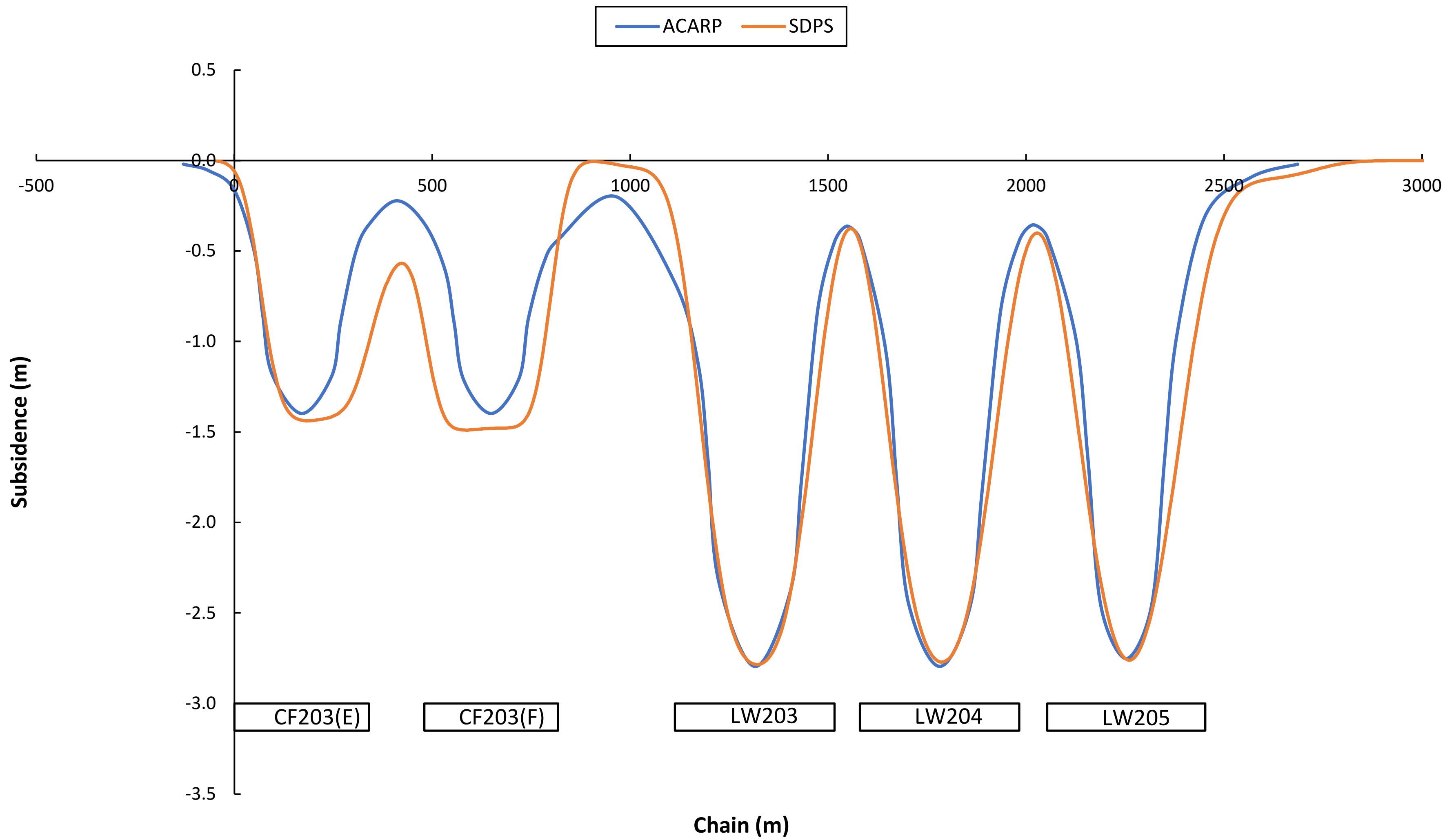
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Predicted U95%CL Subsidence Profiles along XL6 above CF203 (E&F) and LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	7a



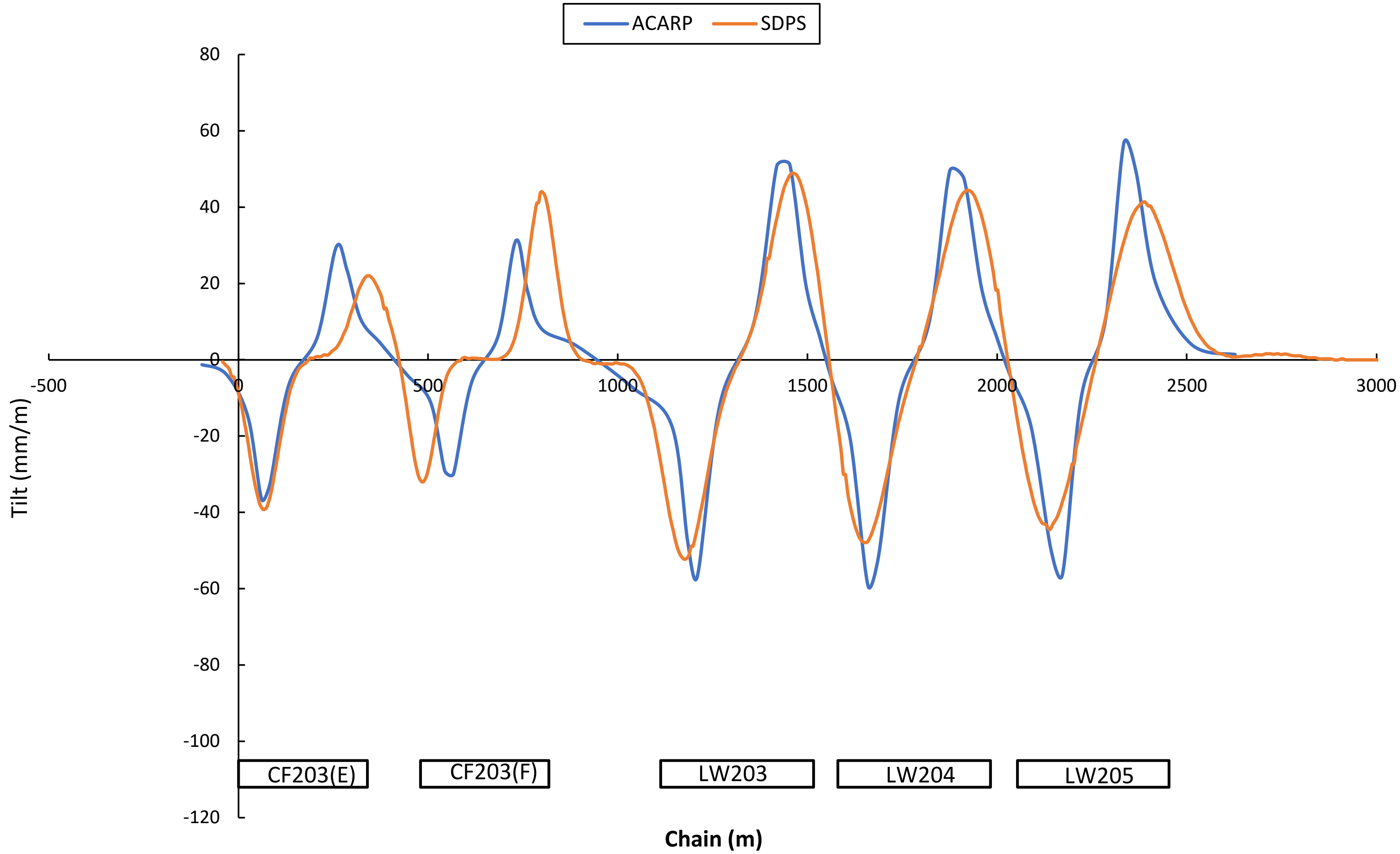
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted U95%CL Tilt & Horizontal Displacement Profiles along XL6 above CF203 (E&F) and LW203 to 205	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 7b



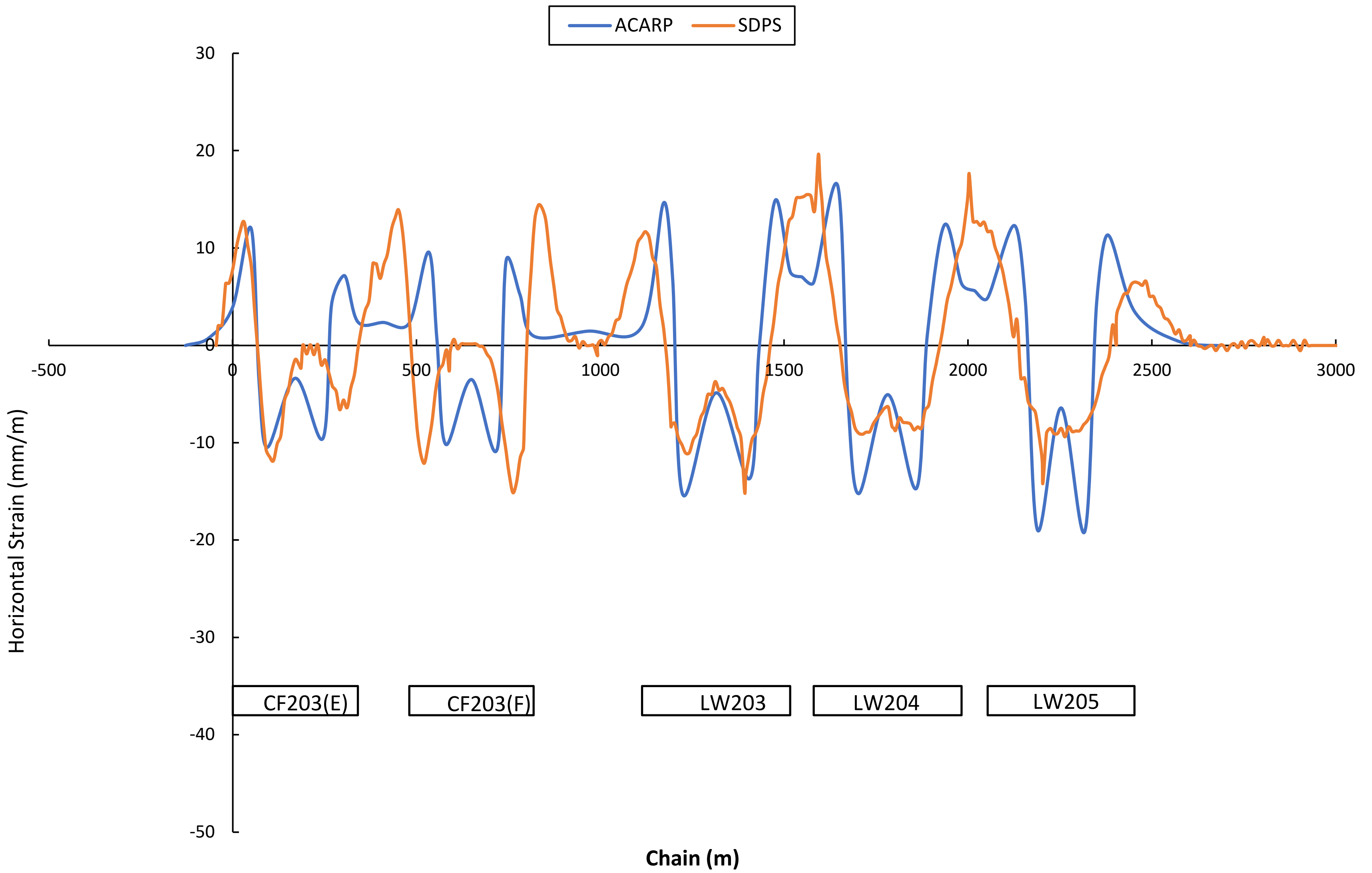
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton				
	Date:	15.11.19	Title:	Predicted U95%CL Curvature & Horizontal Strain Profiles along XL6 above CF203 (E&F) and LW203 to 205		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	7c



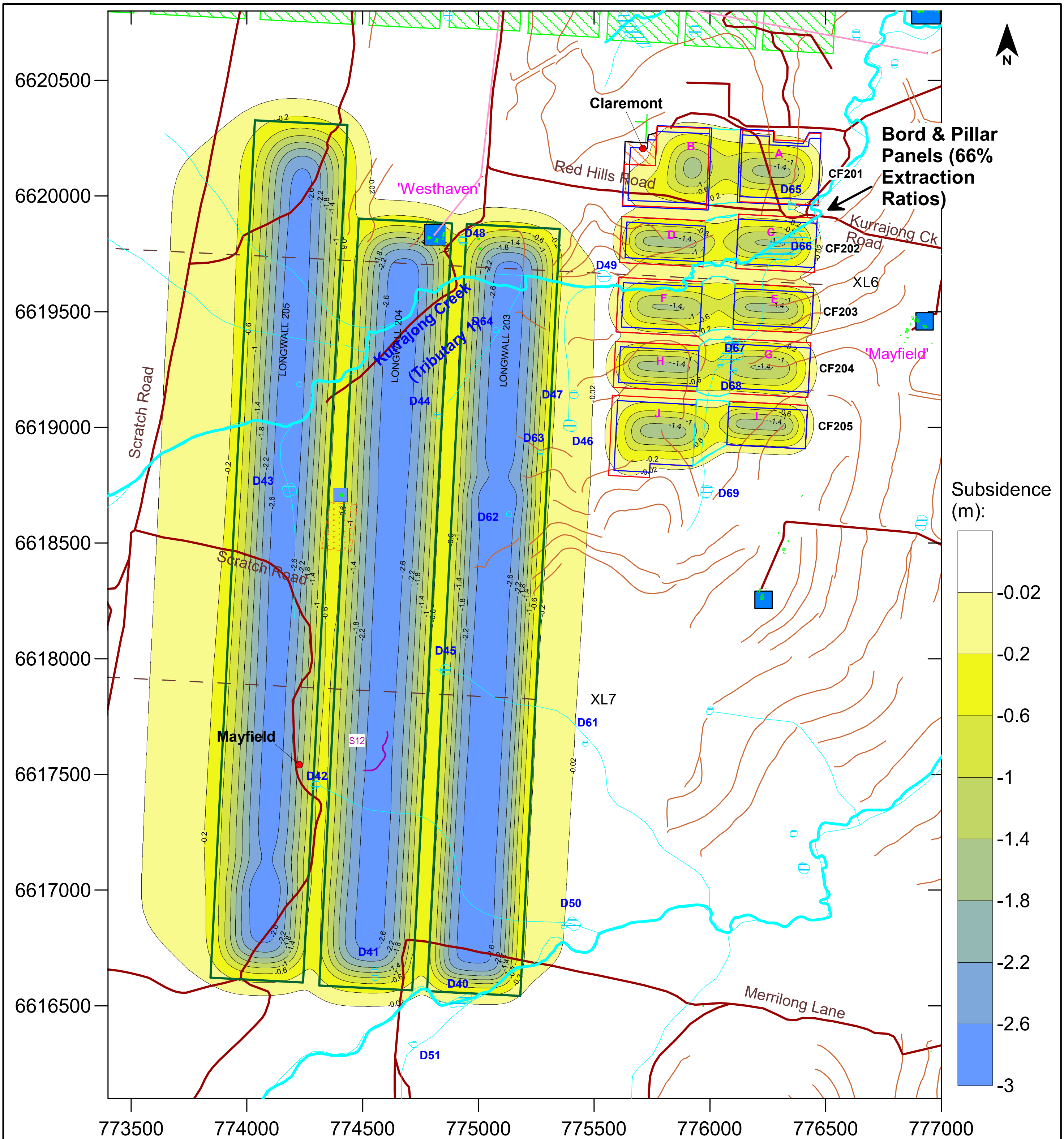
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Predicted ACARP v SDPS (U95%CL) Subsidence Profiles along XL6 above CF203(E & F) and LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 7d



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Predicted ACARP v SDPS (U95%CL) Tilt Profiles along XL6 above CF203(E & F) and LW203 to 205		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	7e



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Predicted ACARP v SDPS (U95%CL)Horizontal Strain Profiles along XL6 above CF203(E & F) and LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	7f



Key:

Approved Longwalls (LW203-205)	Prediction Cross Lines
Extracted Longwalls (LW101-108A)	Dwellings & Sheds/Tanks/Orchards
Proposed Bord & Pillar Panels (e = 66%)	NCO-Owned Buildings
Proposed Second Workings Limits (e = 35%)	Restricted Mining Zone (Long-term stable pillars)
	Grinding Groove

D48 Ephemeral Creeks & Watercourses

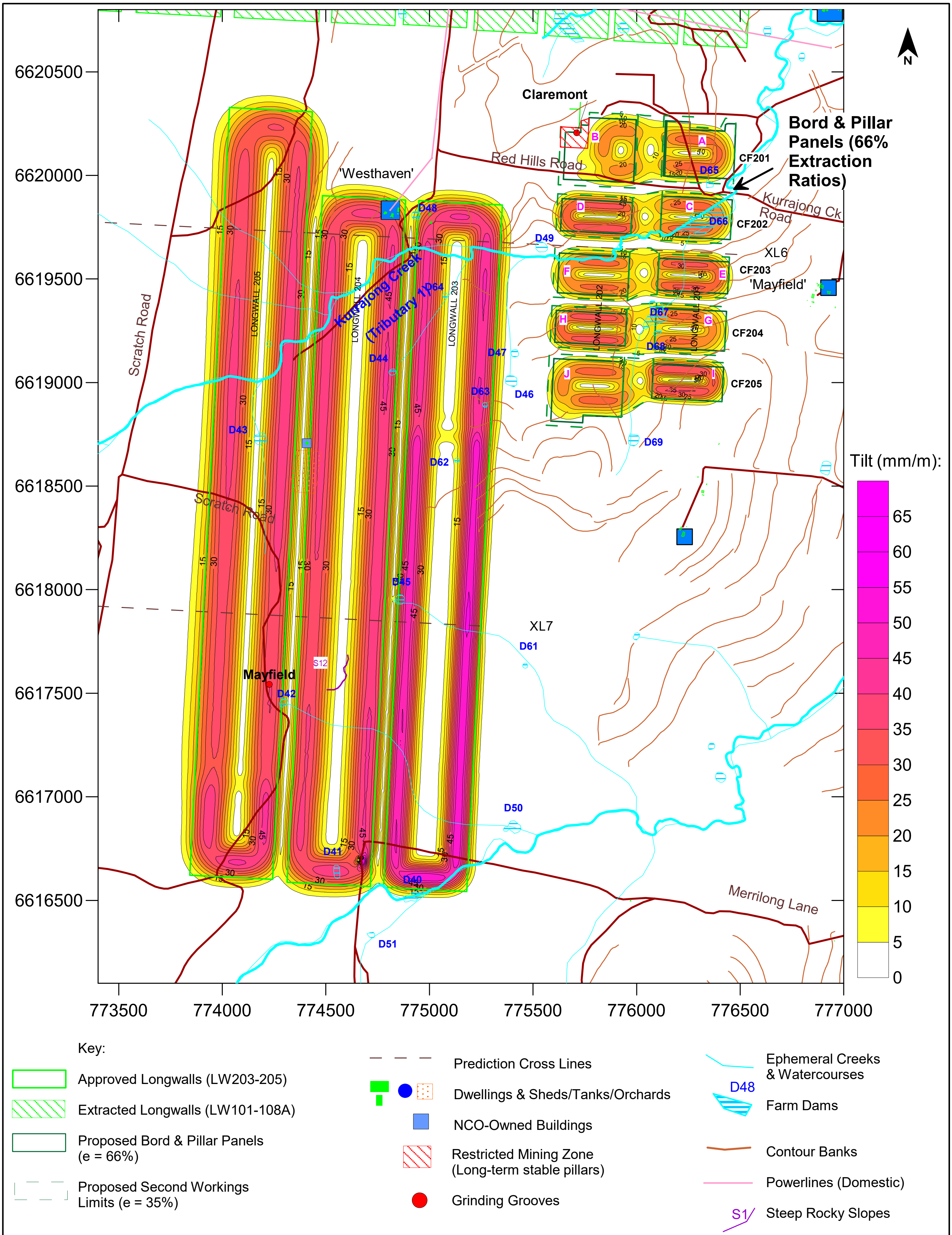
Farm Dams

Contour Banks

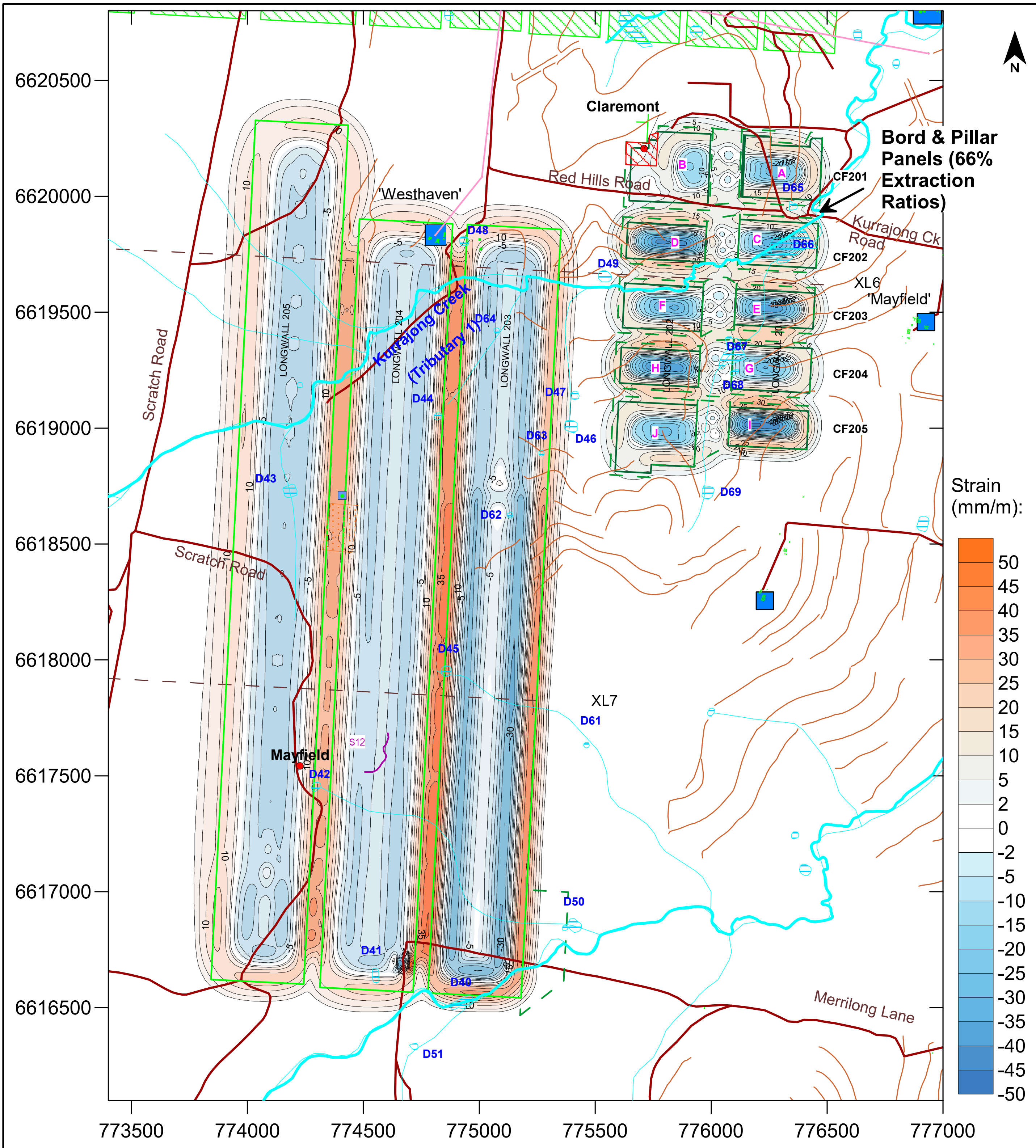
Powerlines (Domestic)

S1 Steep Rocky Slopes

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	01.09.21	Title:	Predicted U95%CL Subsidence Contours due to the Proposed Pillar Reduction Panels CF201 - CF205 (Panels A to J) & LW203 to 205
Ditton Geotechnical Services Pty Ltd			Scale:	1:30,000
			Figure No:	8a



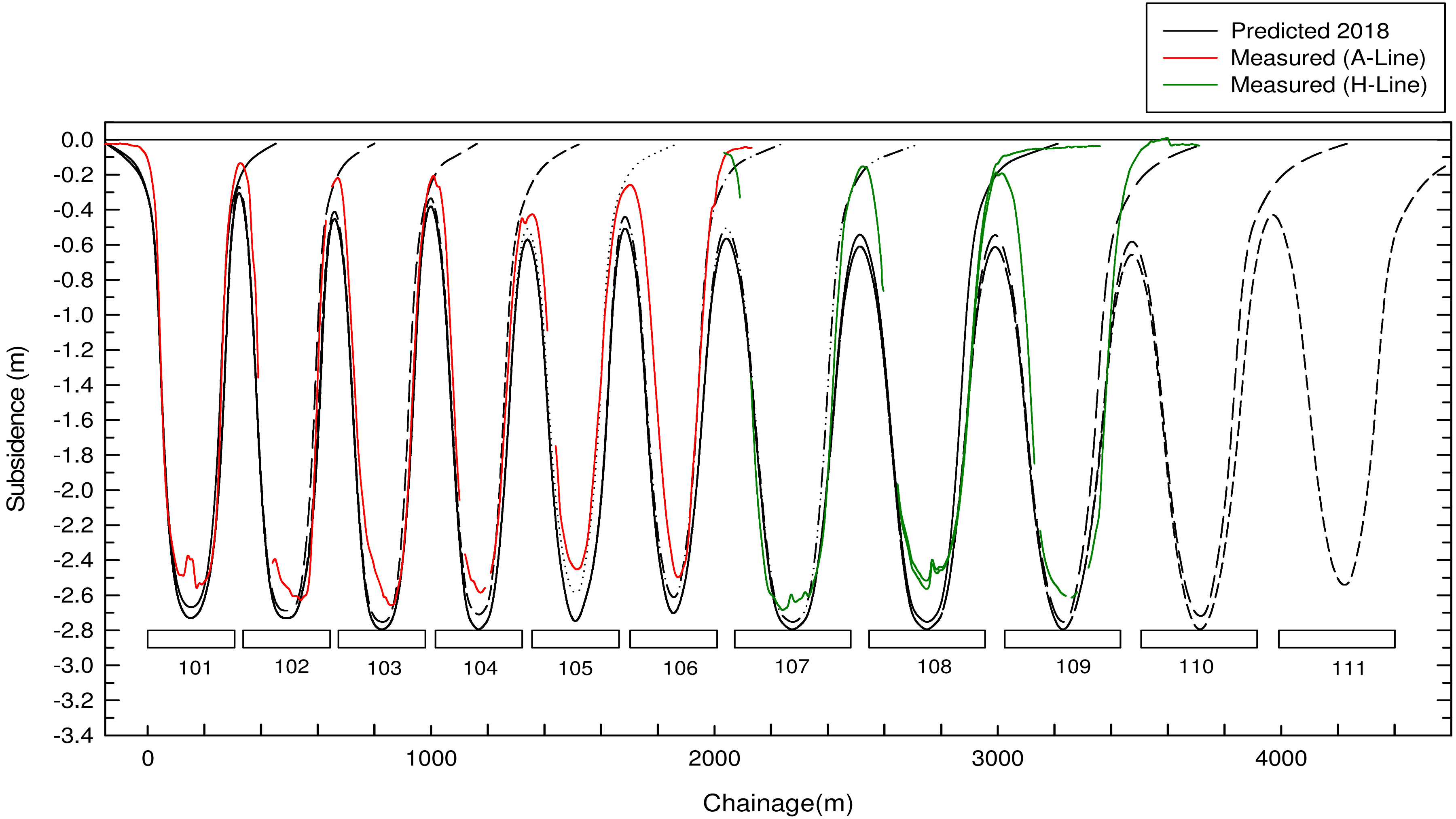
DgS	Engineer:	S.Ditton	Client: Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	
	Date:	1.09.21	Title: Predicted U95%CL Tilt Contours due to the Proposed Pillar Reduction Panels CF201 - CF205 (Panels A to J) & LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale: 1:30,000 — Figure No: 8b



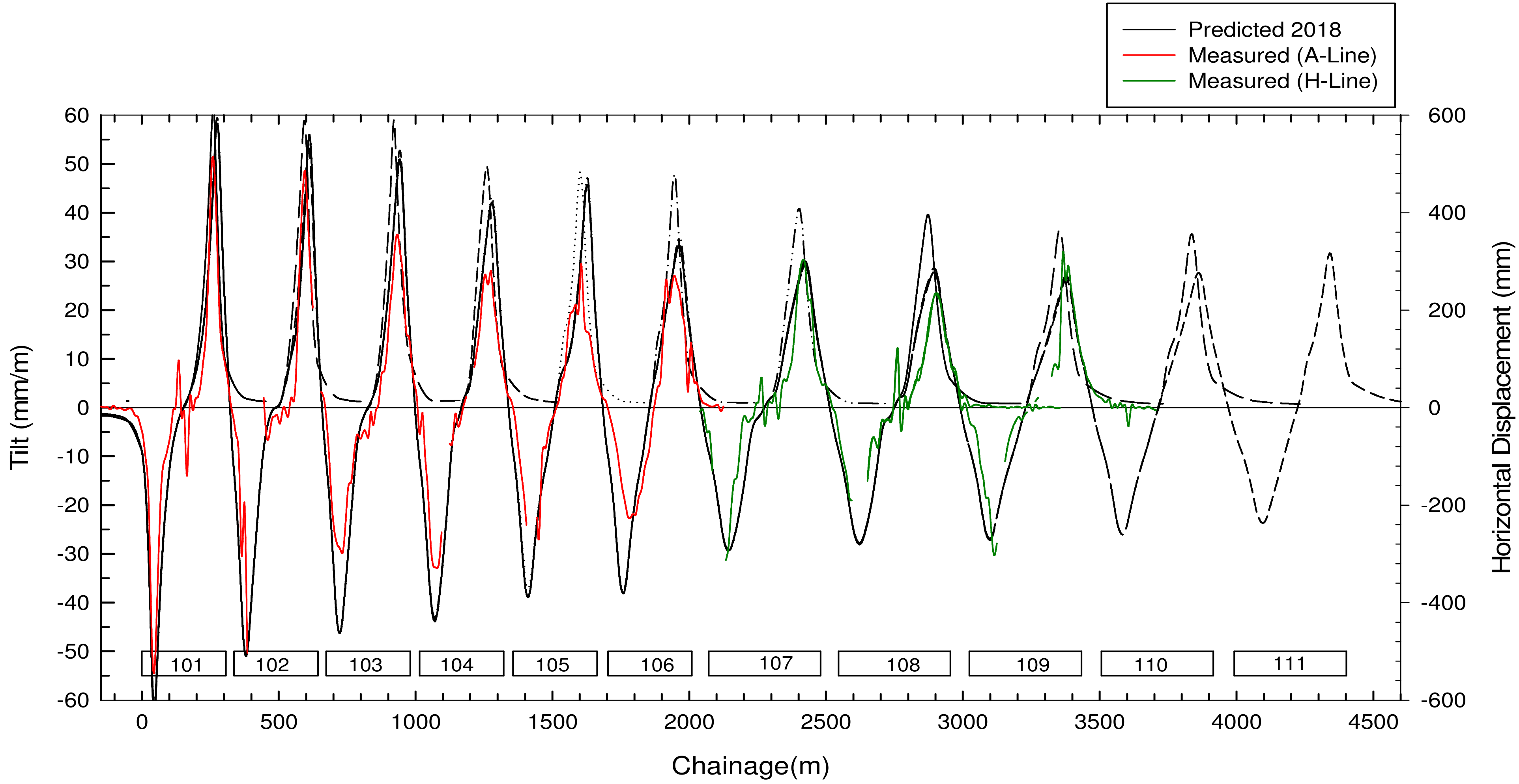
Key:

- Approved Longwalls (LW203-205)
- Extracted Longwalls (LW101-108A)
- Proposed Bord & Pillar Panels (e = 66%)
- Proposed Second Workings Limits (e = 35%)
- Prediction Cross Lines
- Dwellings & Sheds/Tanks/Orchards
- NCO-Owned Buildings
- Restricted Mining Zone (Long-term stable pillars)
- Grinding Grooves
- Ephemeral Creeks & Watercourses
- D48 Farm Dams
- Contour Banks
- Powerlines (Domestic)
- S1 Steep Rocky Slopes

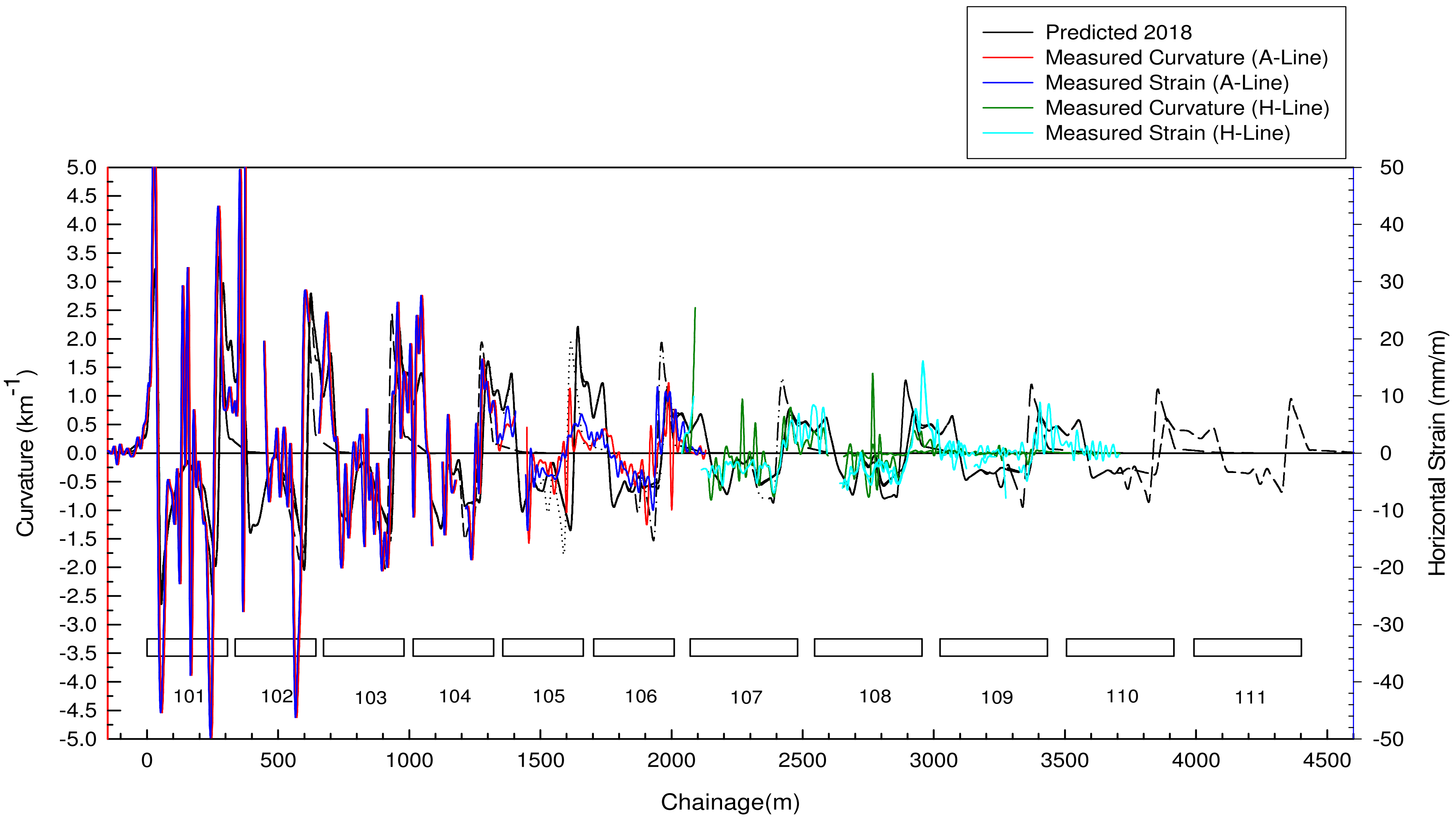
DgS Ditton Geotechnical Services Pty Ltd			
Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
Drawn:	S.Ditton	Title:	Predicted U95%CL Horizontal Strain Contours due to the Proposed Pillar Reduction Panels CF201 - CF205 (Panels A to J) & LW203 to 205
Date:	1.09.21	Scale:	1:30,000
		Figure No:	8c



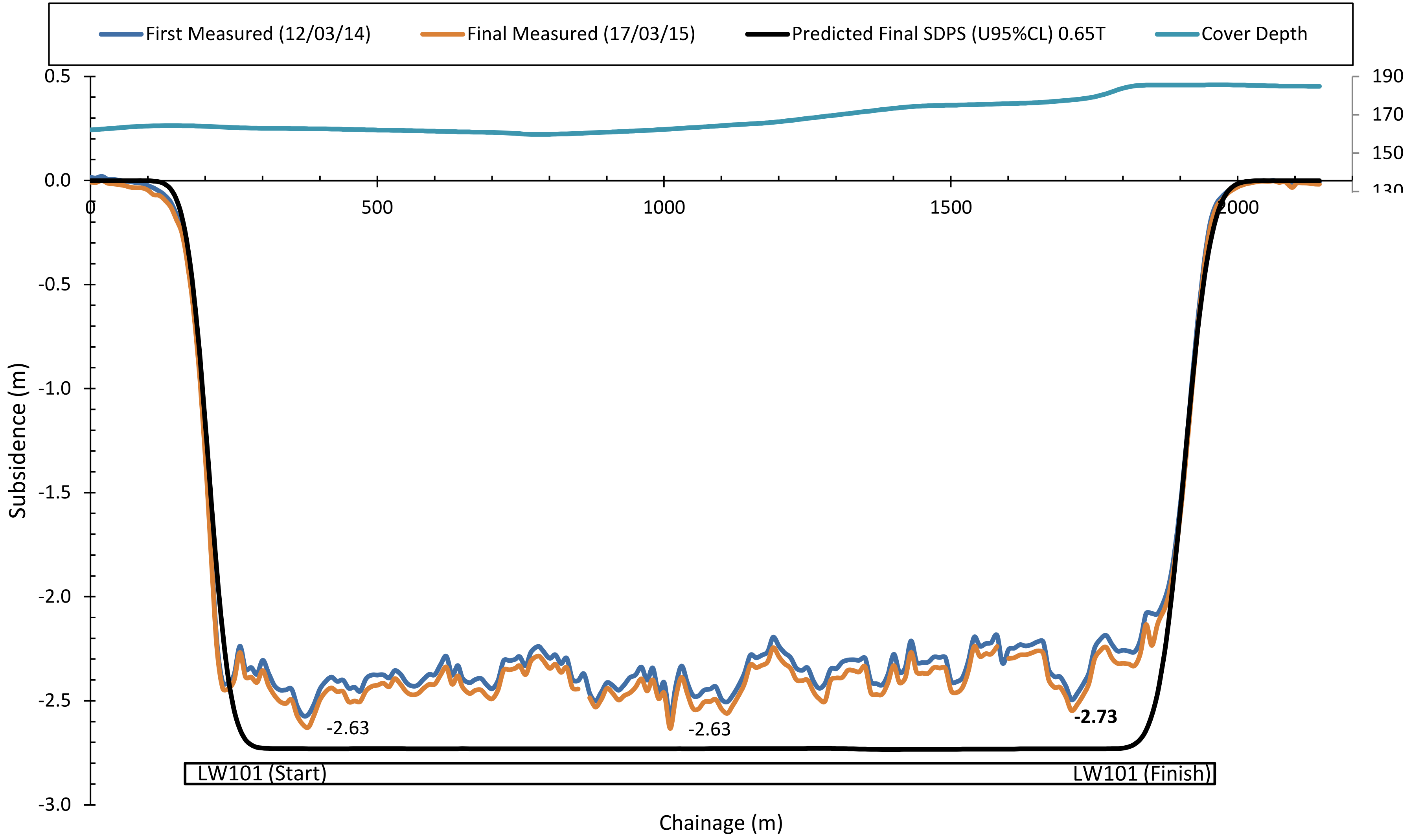
DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn: S.Ditton			
	Date: 15.07.21	Title:	Predicted U95%CL v. Measured Subsidence Profiles along XL4 & XLA/H above LW101 to 111	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 9a



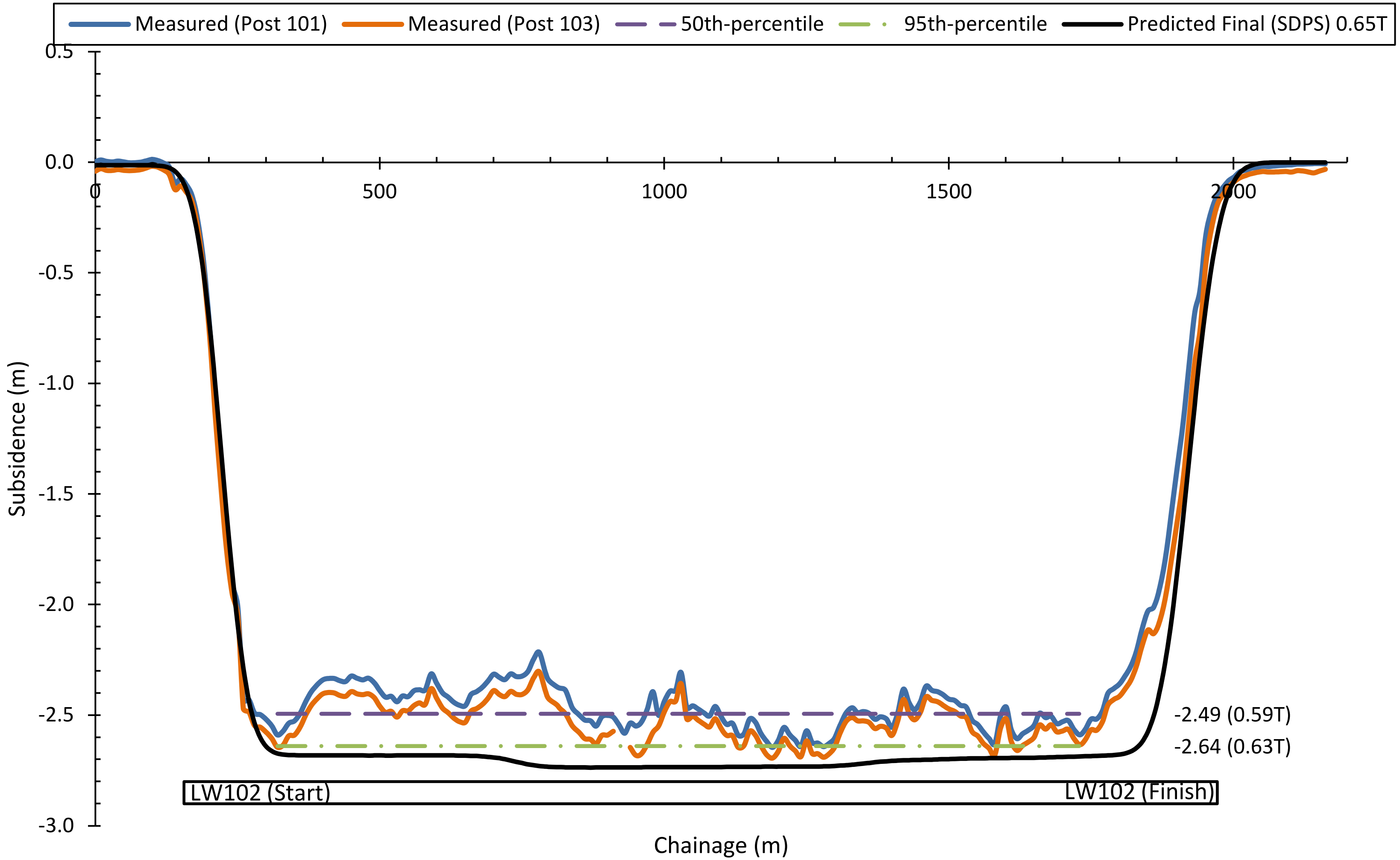
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Predicted U95%CL v. Measured Tilt & Horizontal Displacement Profiles along XL4 & XLA/H above LW101 to 111
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9b



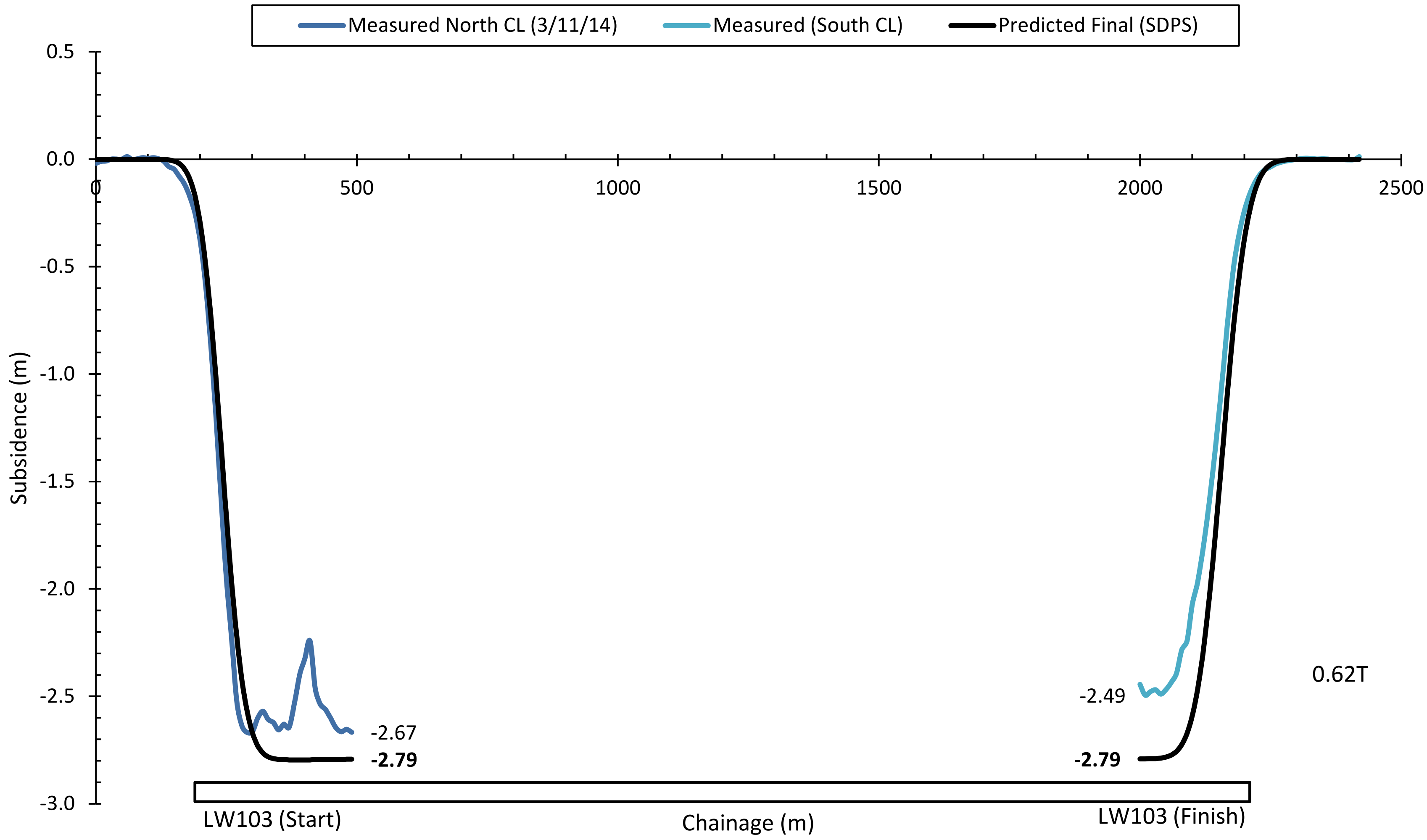
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Predicted U95%CL v. Measured Curvature & Horizontal Strain Profiles along XL4 & XLA/H above LW101 to 111
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9c



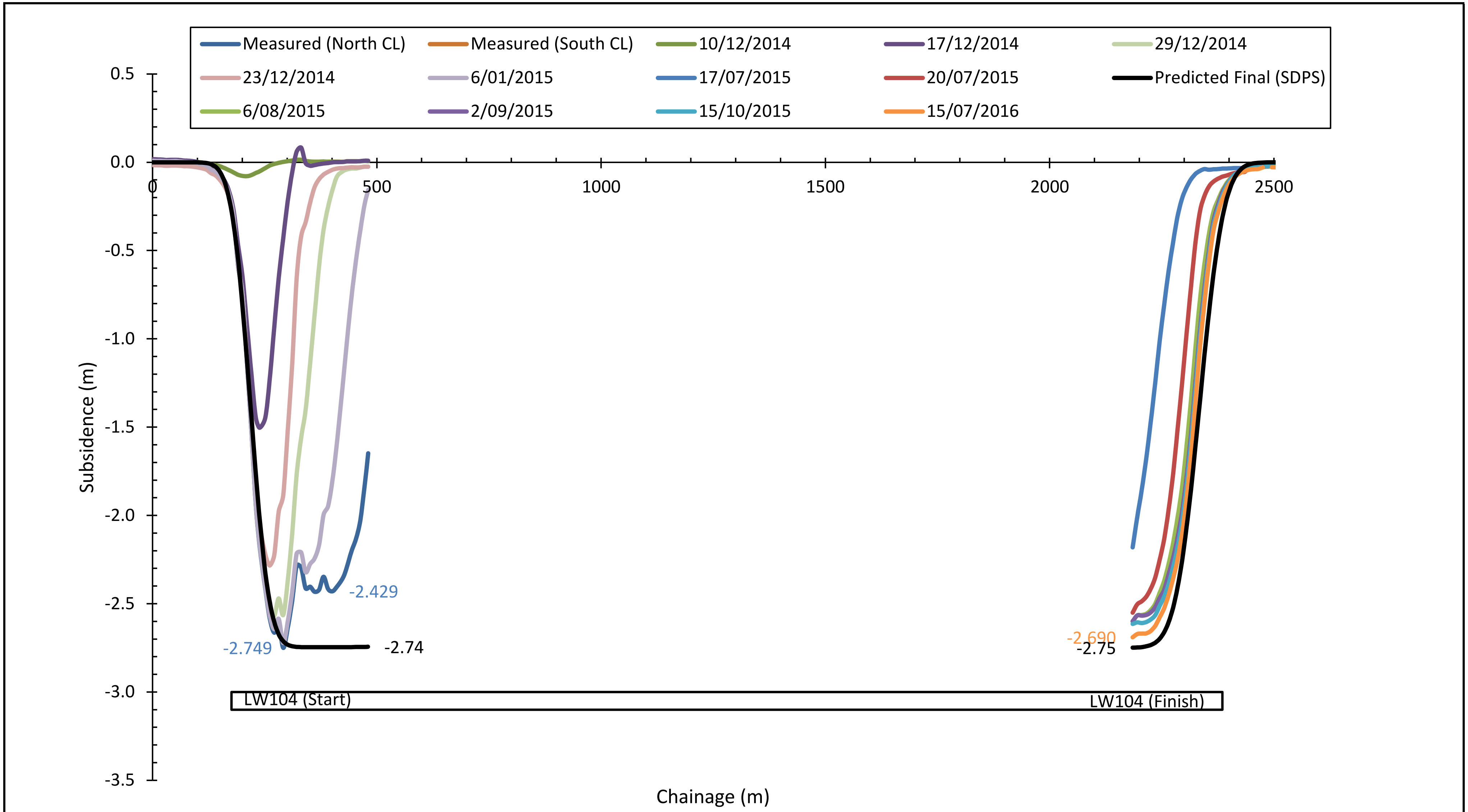
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-004/8		
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW101 Centre Line		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9d



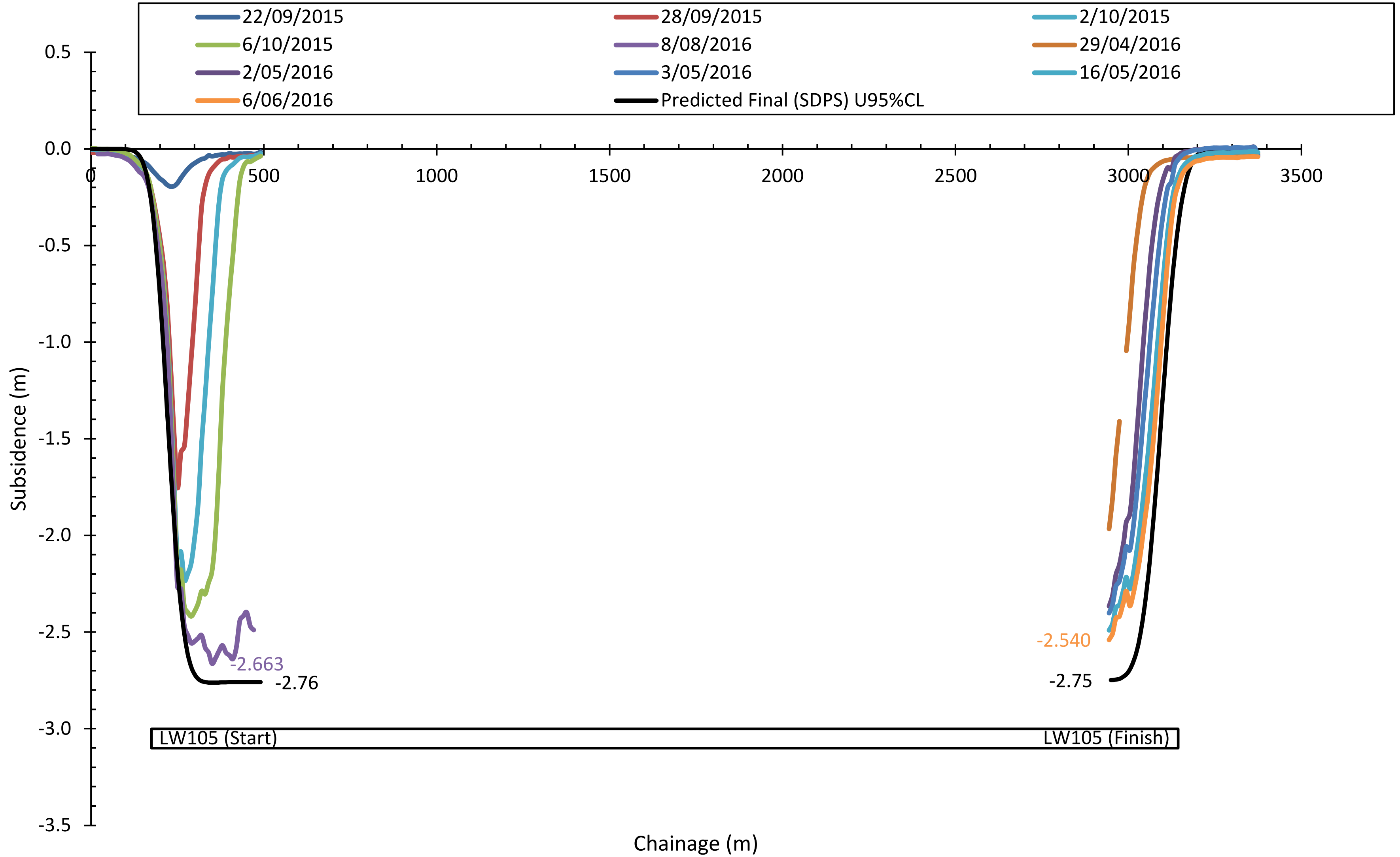
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
DgS	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW102 Centre Line		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9e



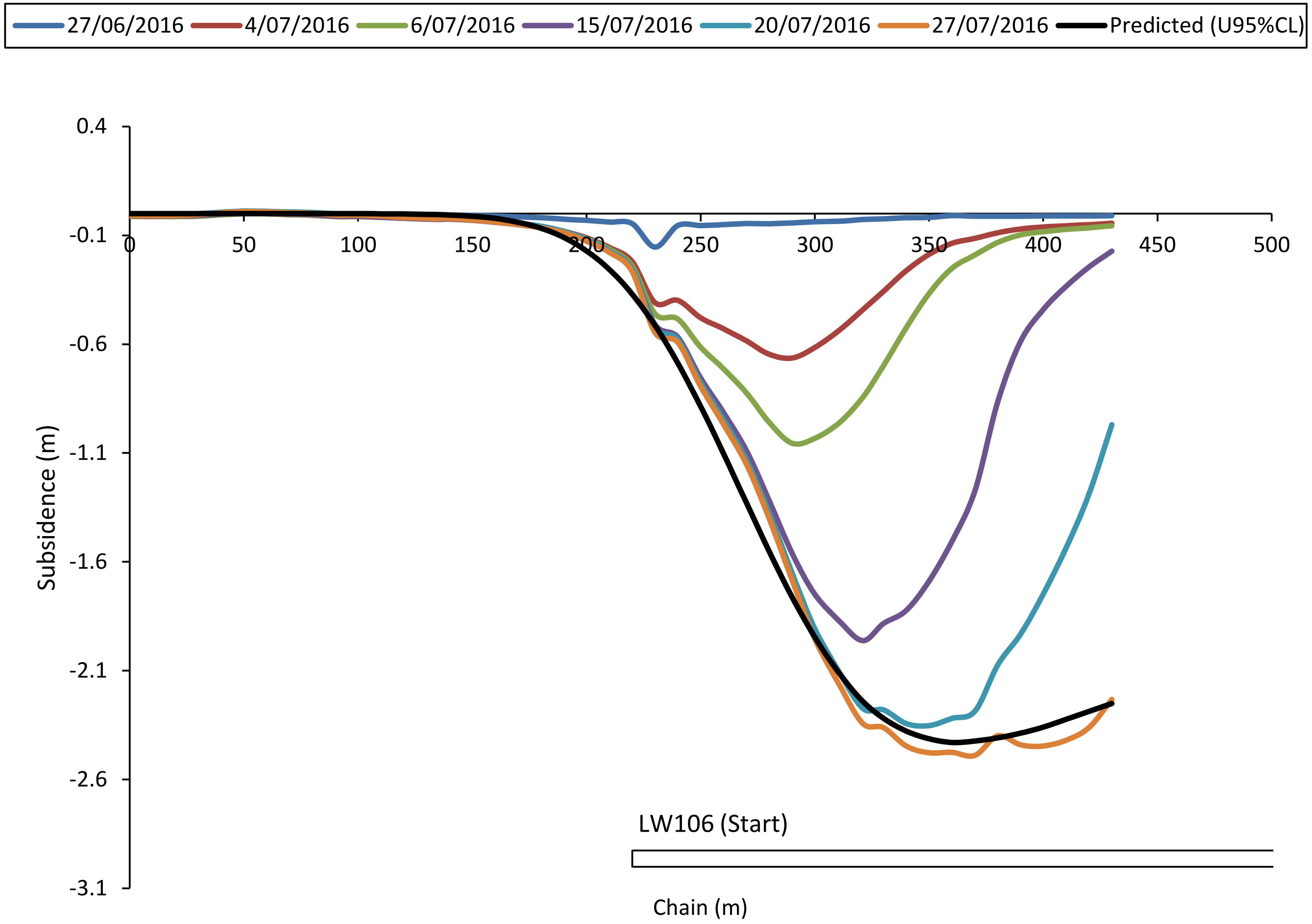
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW103 Centre Line
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9f



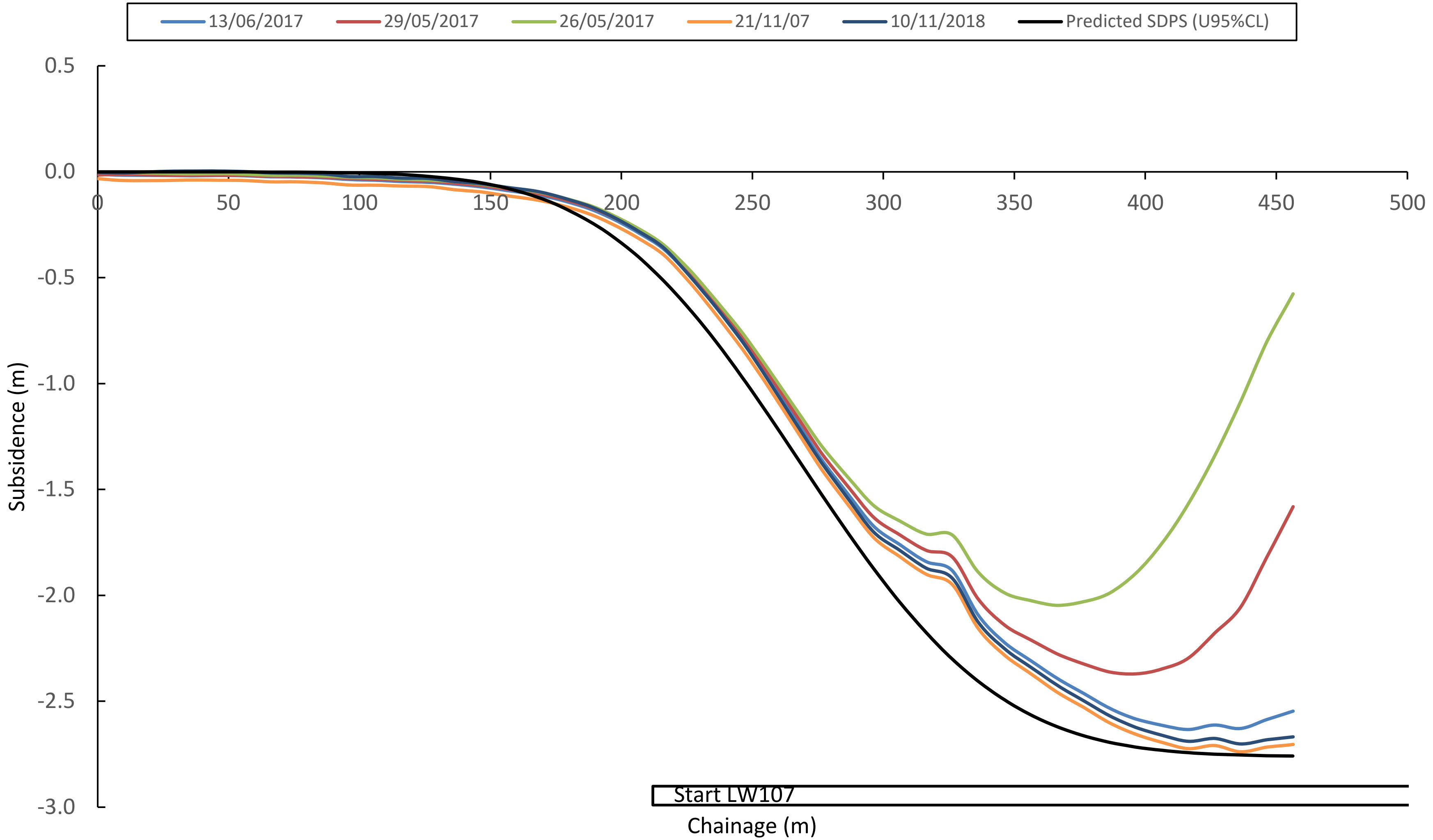
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW104 Centre Line
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9g



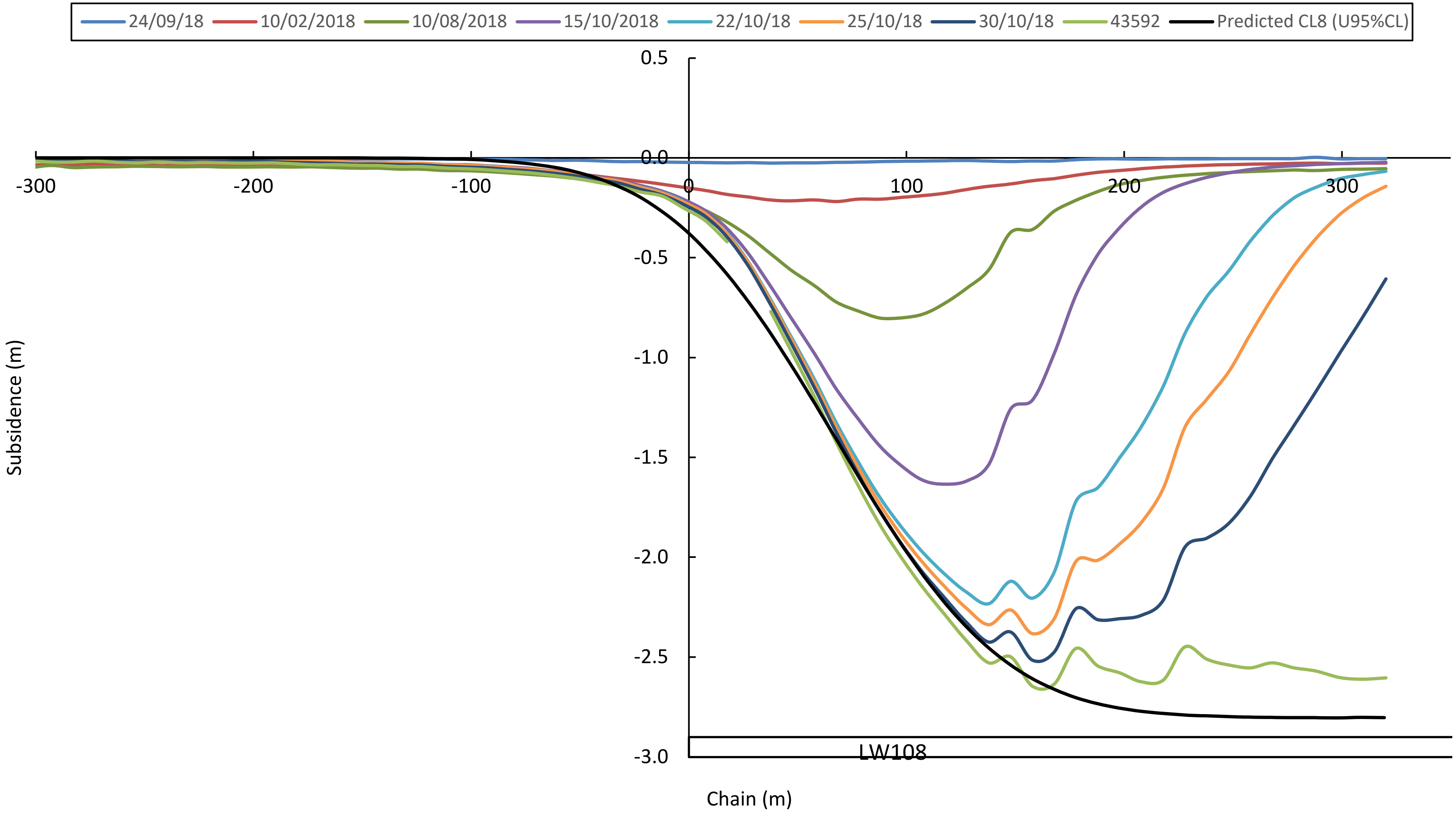
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW105 Centre Line		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9h



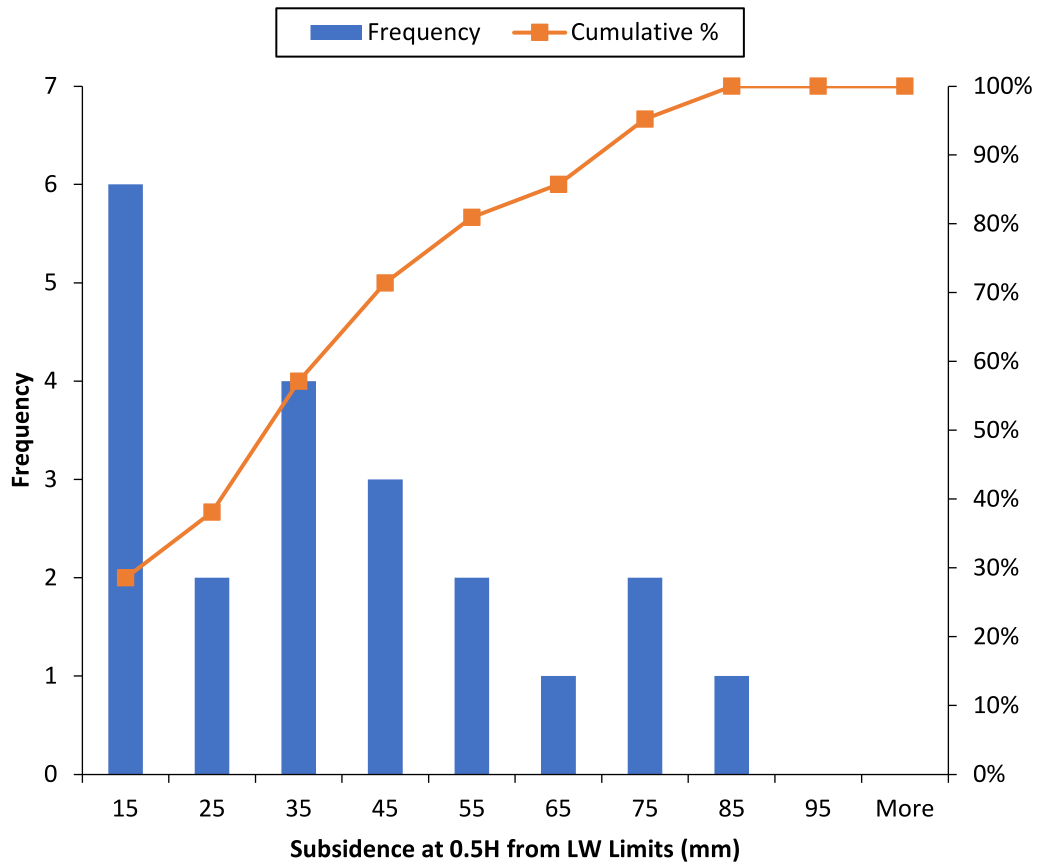
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW106 Centre Line (North)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9i



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW107 Centre Line (North)			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		Figure No:	9j



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Measured v. Predicted Subsidence along LW108 Centre Line (North)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9k

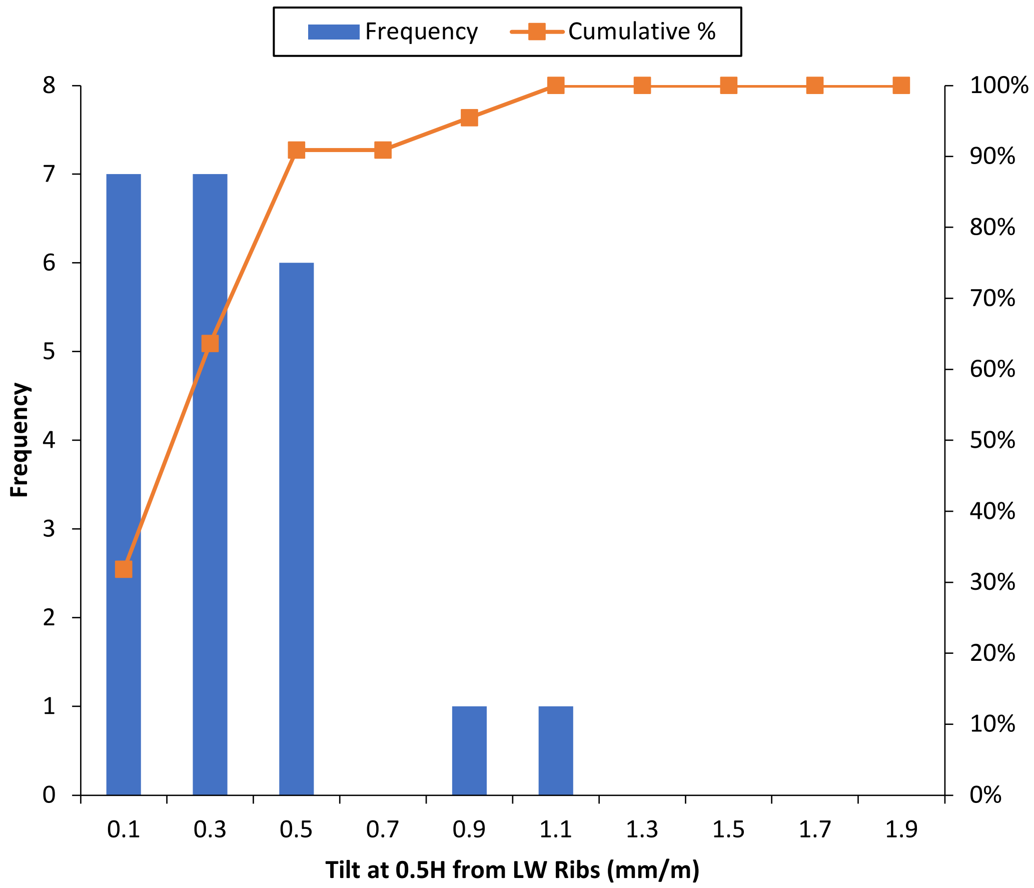


Bin	*Frequency*	*Cumulative %*
15	6	29%
25	2	38%
35	4	57%
45	3	71%
55	2	81%
65	1	86%
75	2	95%
85	1	100%
95	0	100%
More	0	100%

Statistics	
Mean	38
Standard Error	5
Median	35
Mode	4
Standard Deviation	25
Sample Variance	632
Kurtosis	-0.8
Skewness	0
Range	80
Minimum	1
Maximum	81
Sum	792
Count	21

Note: Data plotted at bin centroids

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Measured Subsidence at an Angle of Draw of 26.5^{o} outside the limits of extraction for LWs 101 to 108A
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9I

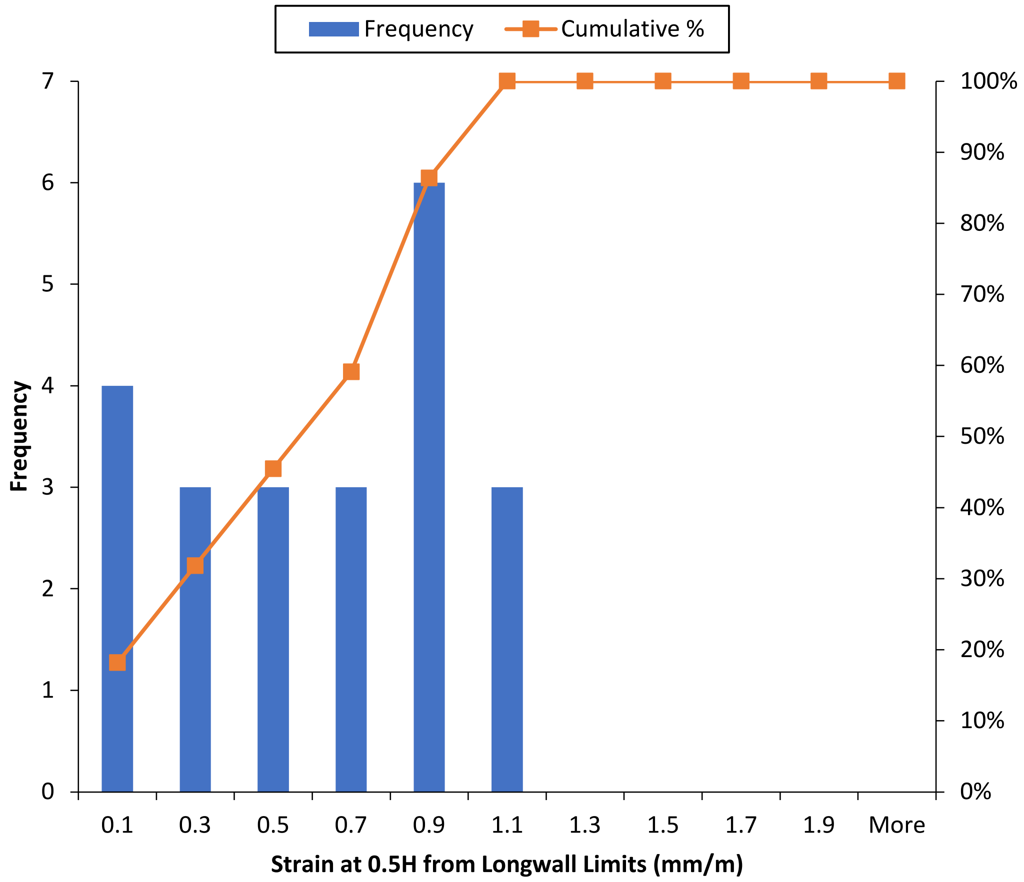


Bin	*Frequency*	*Cumulative %*
0.1	7	32%
0.3	7	64%
0.5	6	91%
0.7	0	91%
0.9	1	95%
1.1	1	100%
1.3	0	100%
1.5	0	100%
1.7	0	100%
1.9	0	100%
More	0	100%

Statistics

Mean	0.4
Standard Error	0.1
Median	0.3
Mode	0.3
Standard Deviation	0.3
Sample Variance	0.1
Kurtosis	2.6
Skewness	1.5
Range	1.1
Minimum	0.1
Maximum	1.2
Sum	8.6
Count	21.0

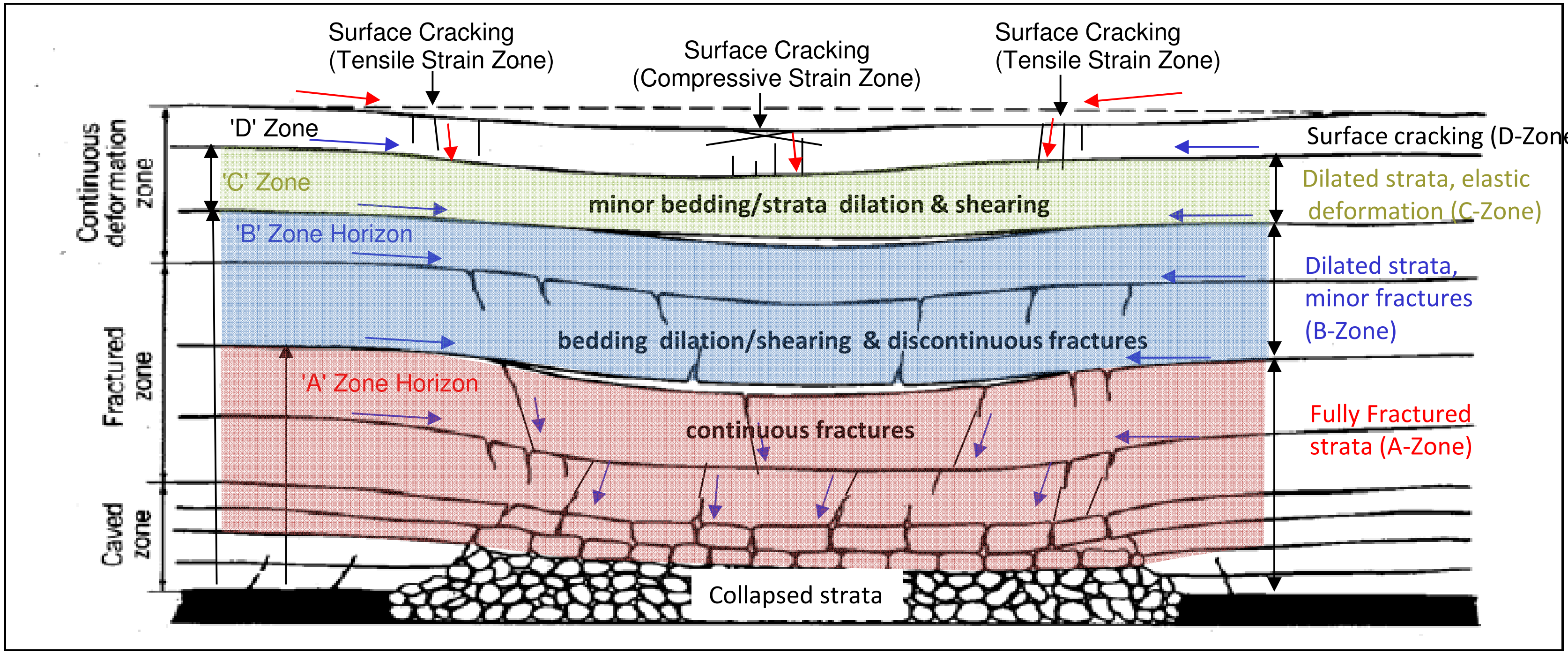
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Measured Tilt at an Angle of Draw of 26.5^{o} outside the limits of extraction for LWs 101 to 108A
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 9m



Bin	*Frequency*	*Cumulative %*
0.1	4	18%
0.3	3	32%
0.5	3	45%
0.7	3	59%
0.9	6	86%
1.1	3	100%
1.3	0	100%
1.5	0	100%
1.7	0	100%
1.9	0	100%
More	0	100%

Statistics	
Mean	0.6
Standard Error	0.1
Median	0.7
Mode	0.9
Standard Deviation	0.3
Sample Variance	0.1
Kurtosis	-1.3
Skewness	-0.1
Range	1.0
Minimum	0.1
Maximum	1.1
Sum	13.4
Count	21.0

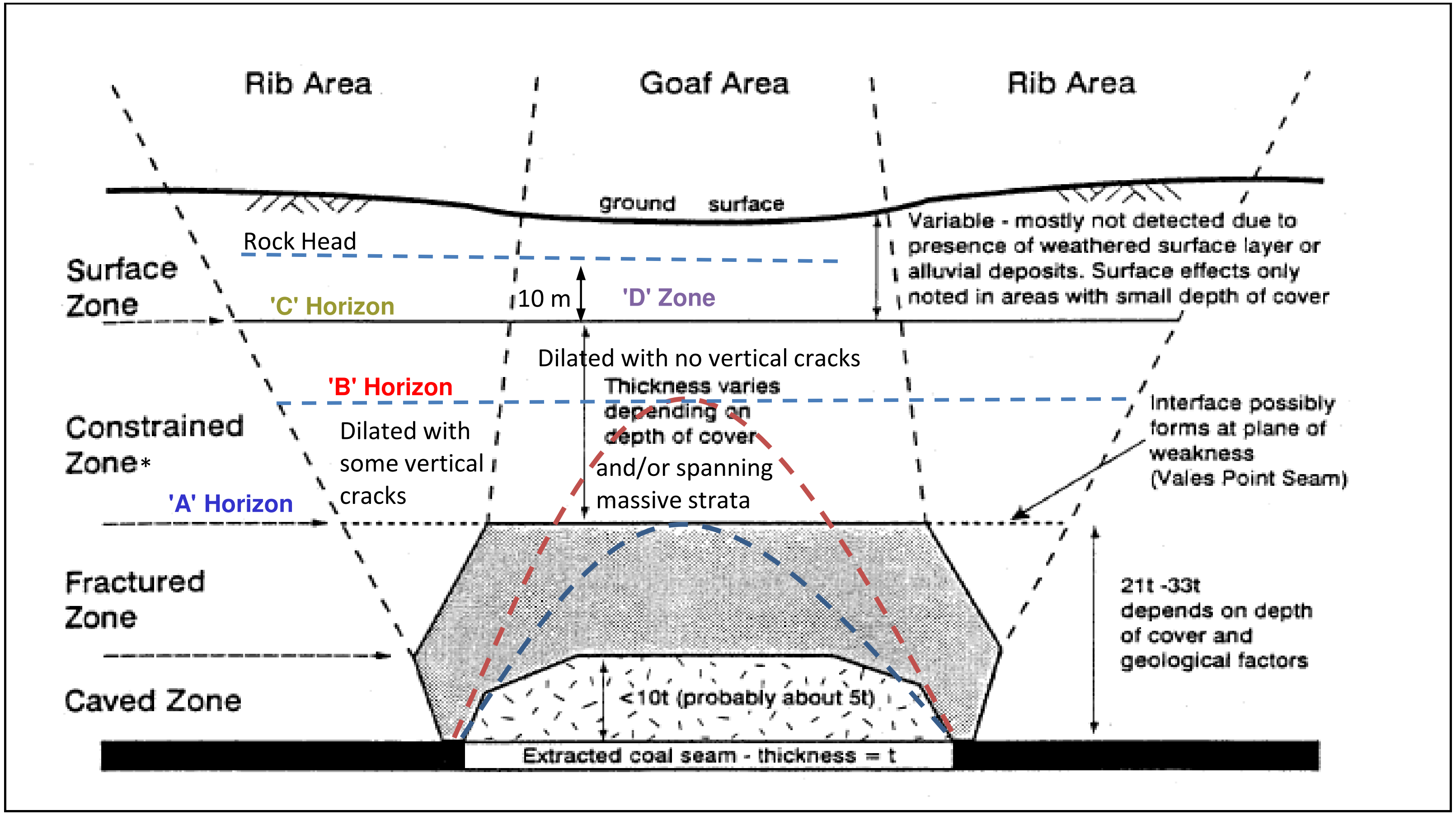
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Measured Horizontal Strain at an Angle of Draw of 26.5^{o} outside the limits of extraction for LWs 101 to 108A
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	9n



Zones in the Overburden According to Peng and Chiang (1984)

Key
'A' Horizon - Zone of Continuous Crack Connection to Workings (**Whittaker and Reddish,1989**)
'B" Horizon - Zone Of Discontinuous Crack Connection to Workings (**Whittaker and Reddish, 1989**)
→ Surface water flow path → Sub-surface water flow path

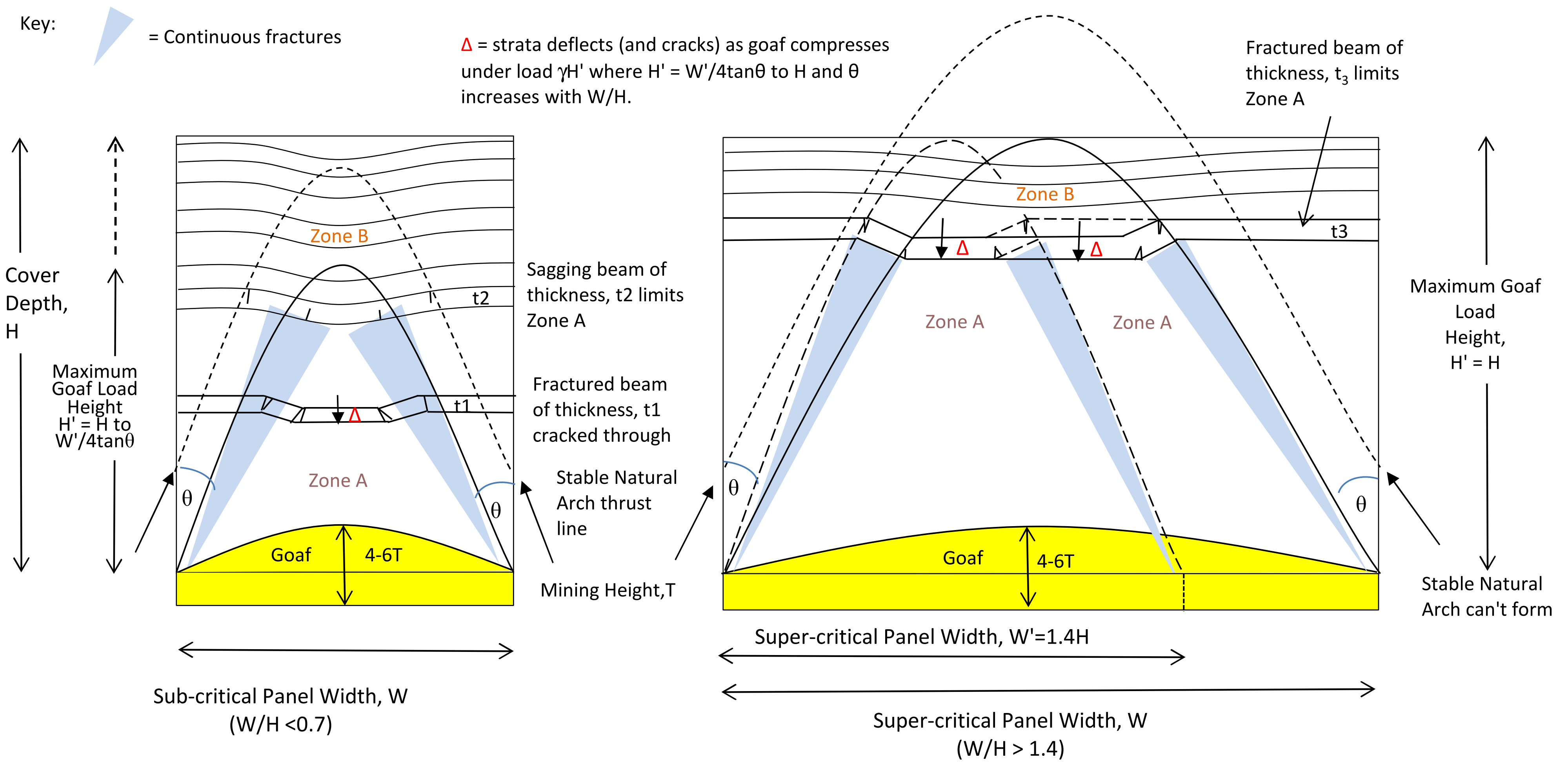
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Schematic Model of Overburden Fracture Zones Above Longwall Panels		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	10a



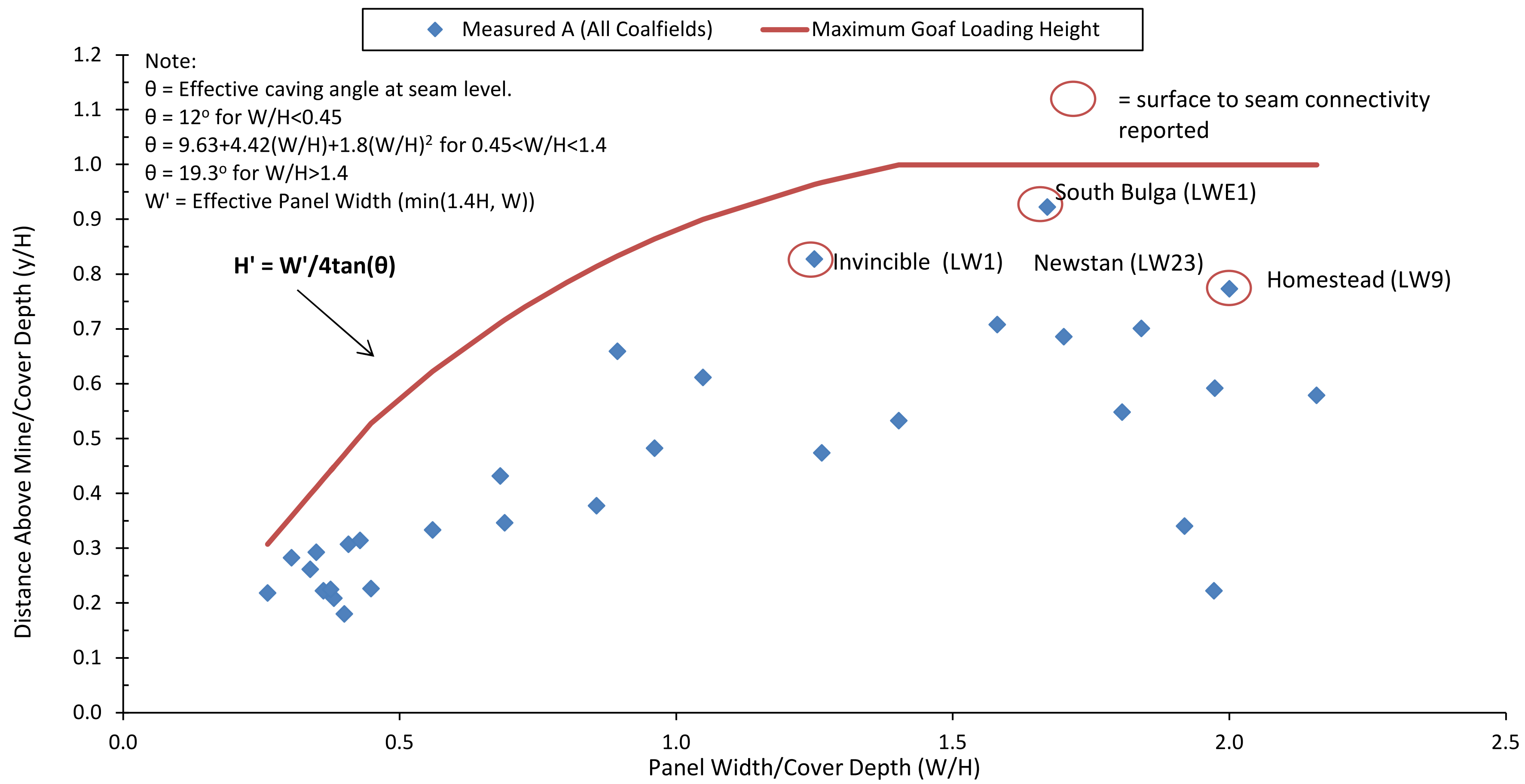
Zones in the Overburden according to Forster (1995)

* - Constrained Zone generally means B-Zone, but may include C-Zone , depending on W/H ratio and geology

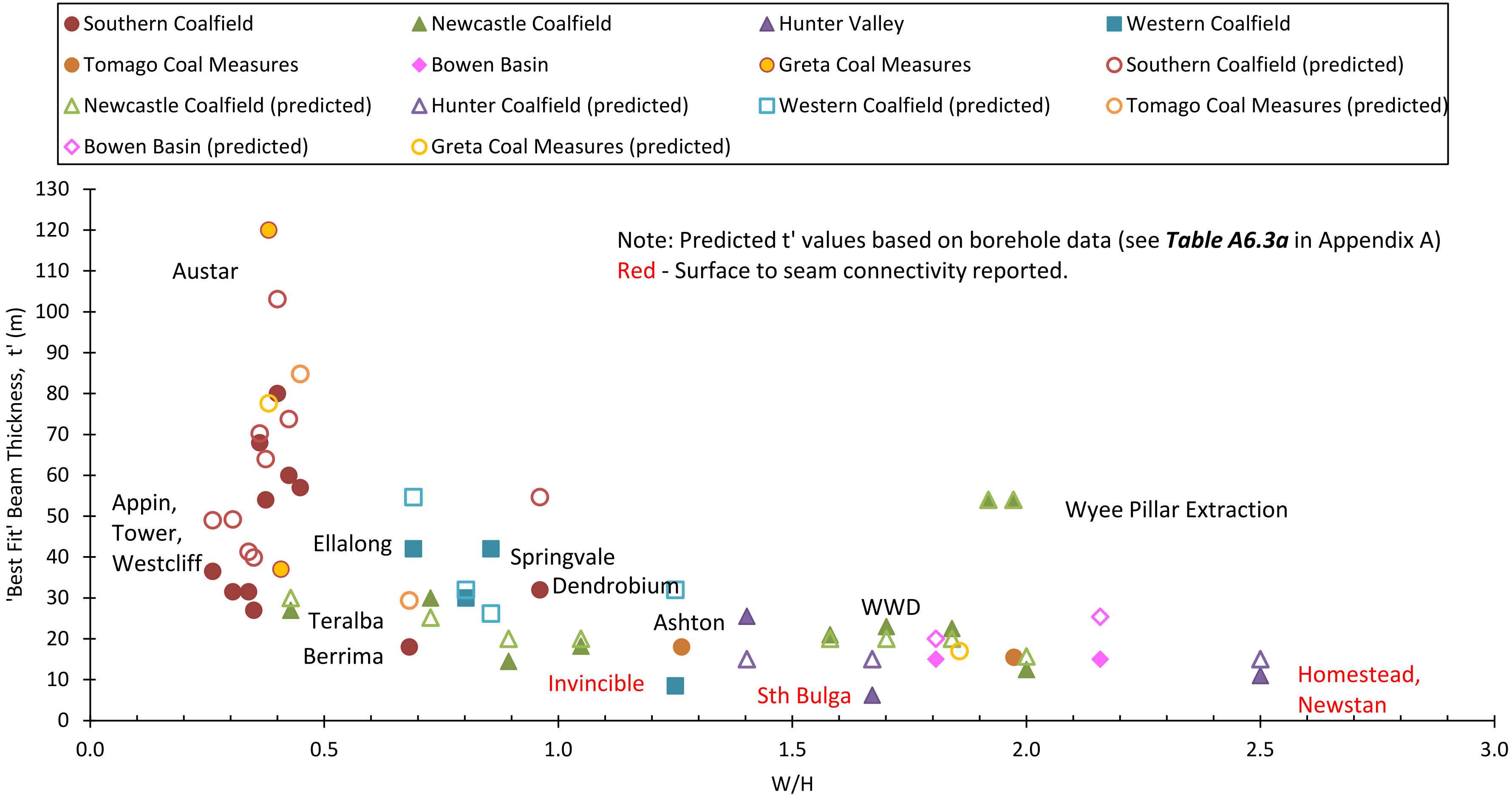
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Schematic Model of Overburden Fracture Zones in **Forster, 1995** Model (based on Piezometric Data Above High Extraction Panels in the Newcastle Coalfield)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	10b



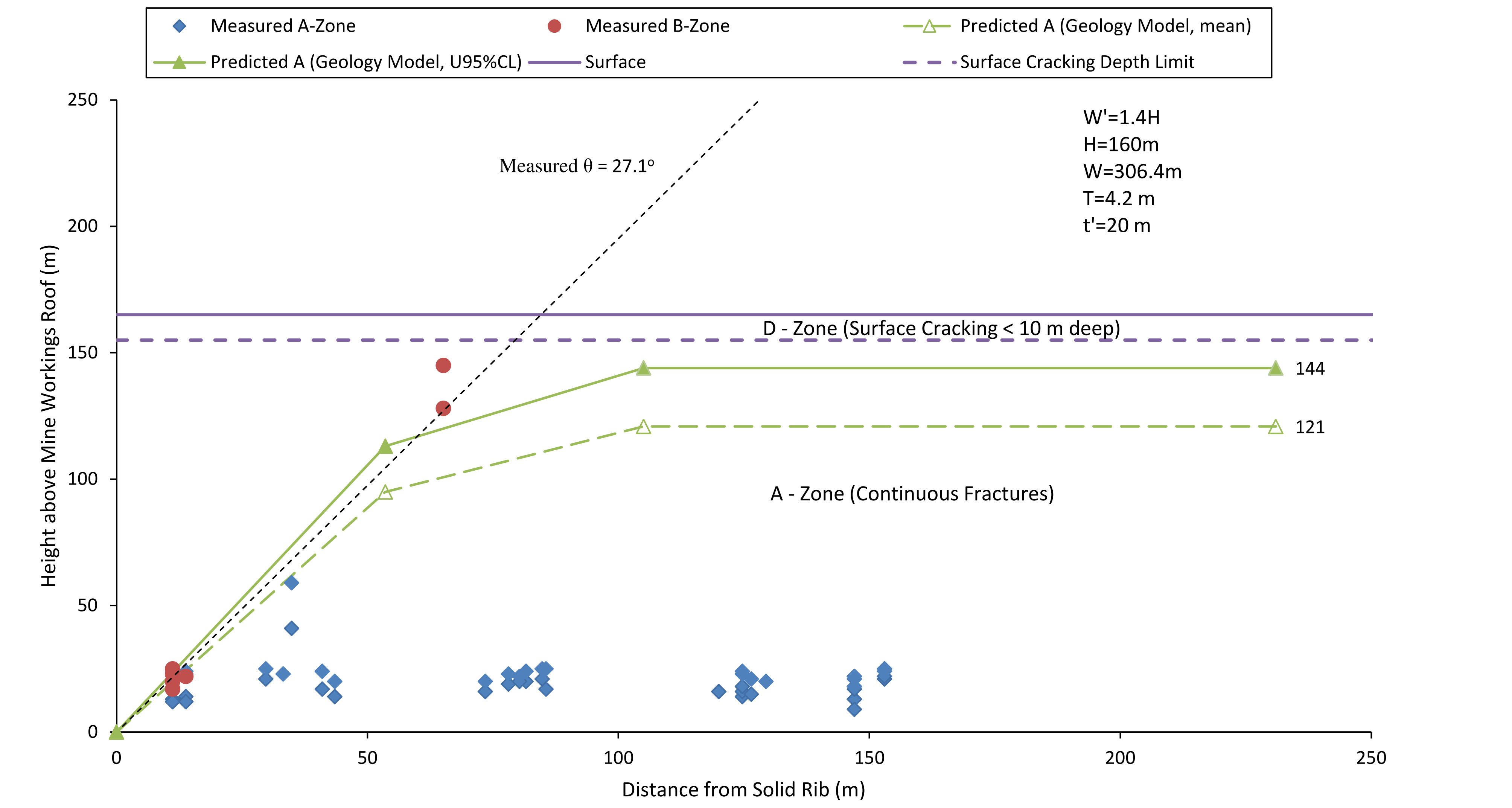
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Conceptual Model for Development of Height of Continuous Fracturing Zone for a range of Longwall Panel Geometries
	Ditton Geotechnical Services Pty Ltd			
			Scale:	NTS
			Figure No:	10c



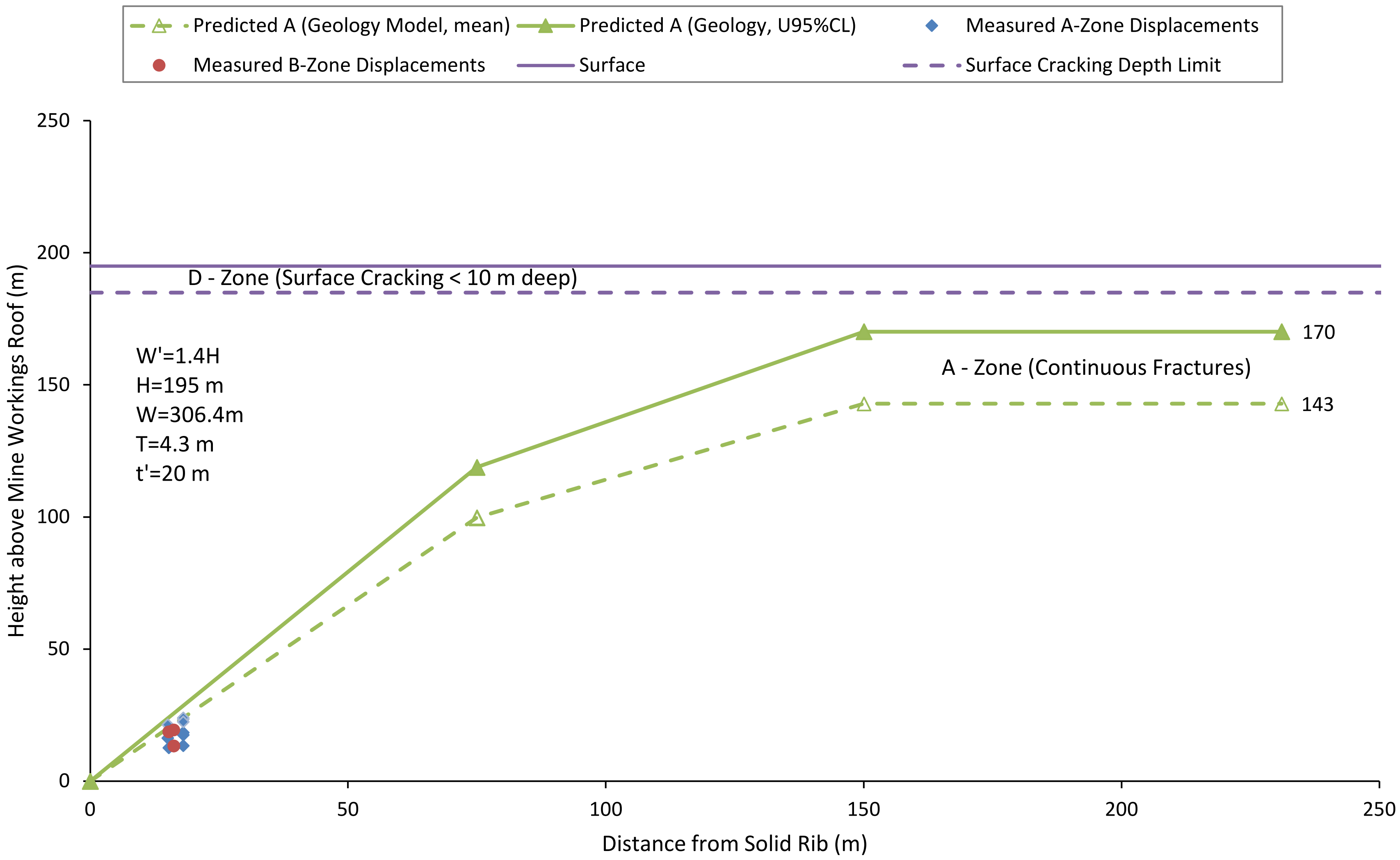
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Heights of Continuous Fracturing in NSW and QLD Coalfields with Reported Surface to Seam Connectivity Cases, caving angles and theoretical Goaf Loading Height		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	10d



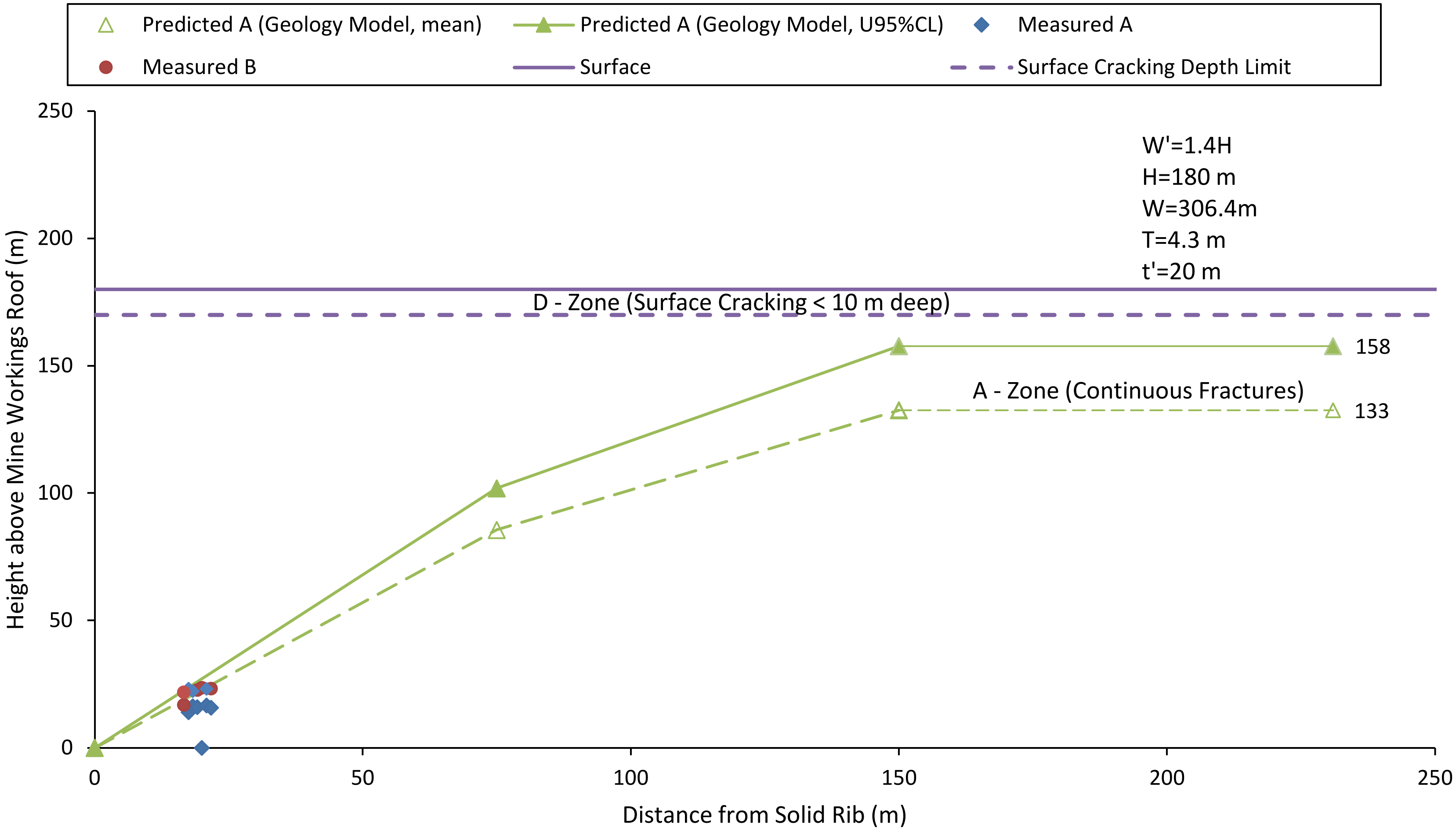
DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn: S.Ditton		
	Date: 15.07.21	Title:	Results of Back-analysis of Effective Strata Units required to Match the Observed A-Zone Heights above Longwall Panel Goafs using the Geology Pi-Term Model
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS; Figure No: 10e



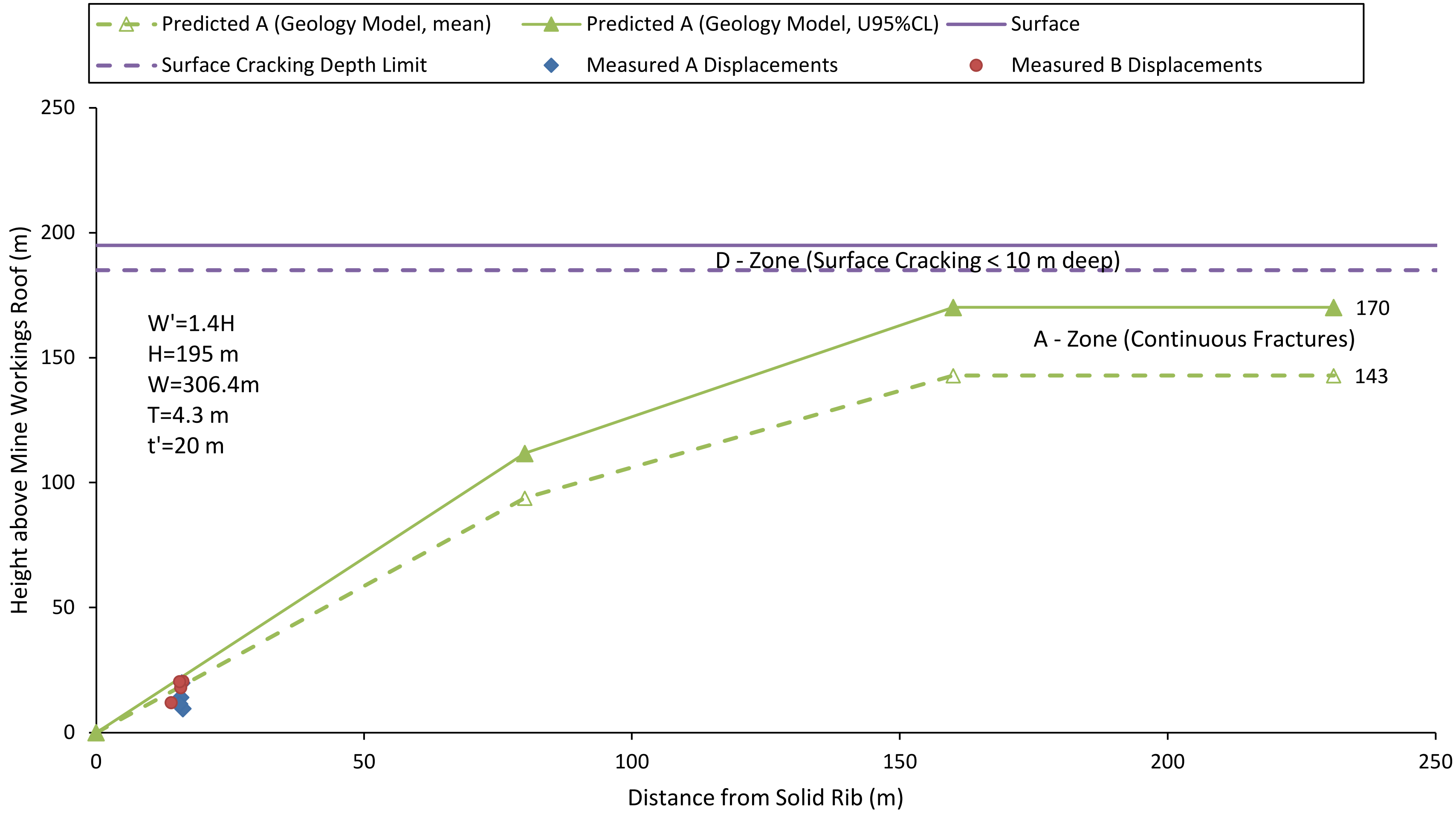
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured v. Predicted Subsurface Fracturing Above LW101 to 102 from Borehole Extensometers		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11a



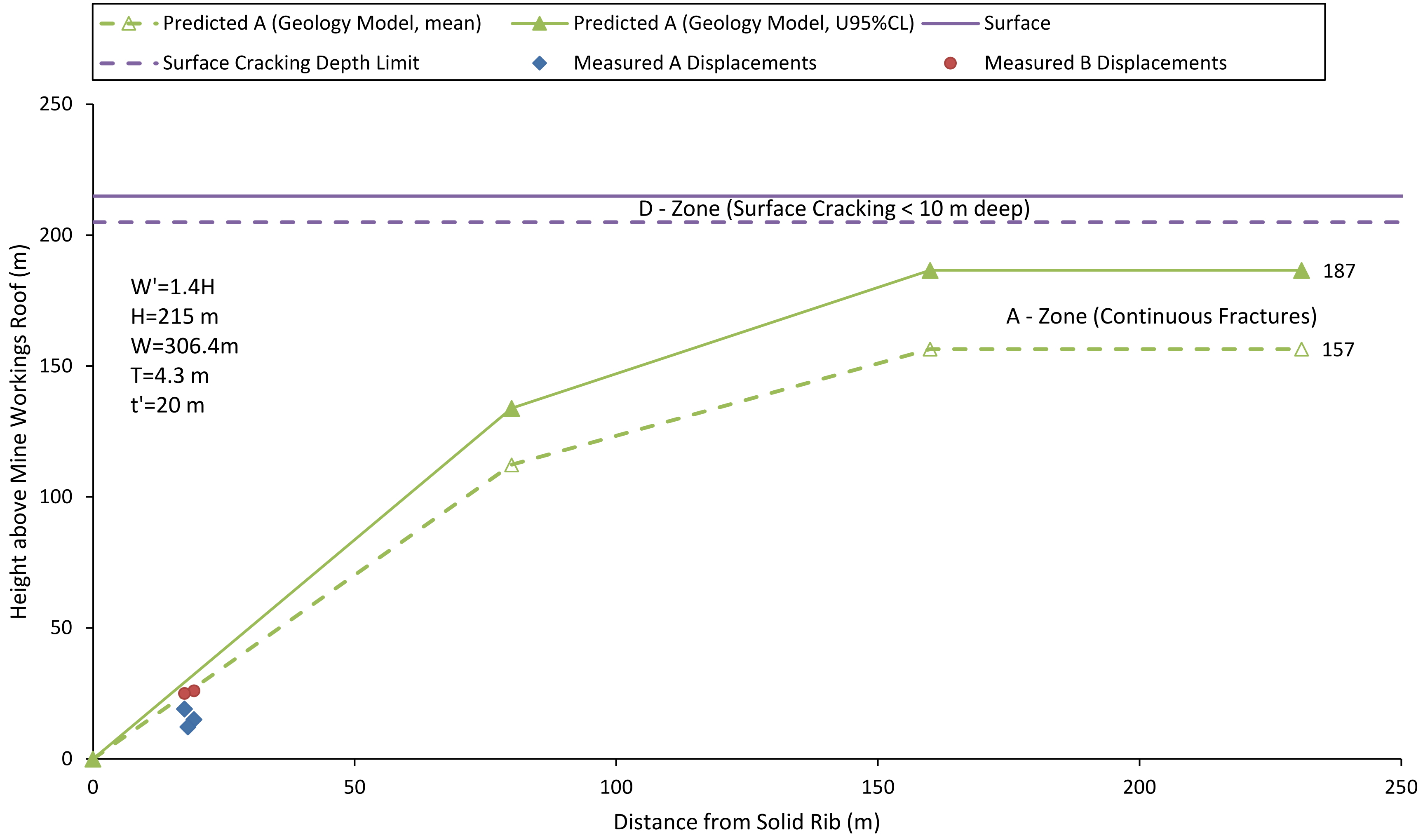
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Subsurface Fracturing Above LW103 from Borehole Extensometers		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11b



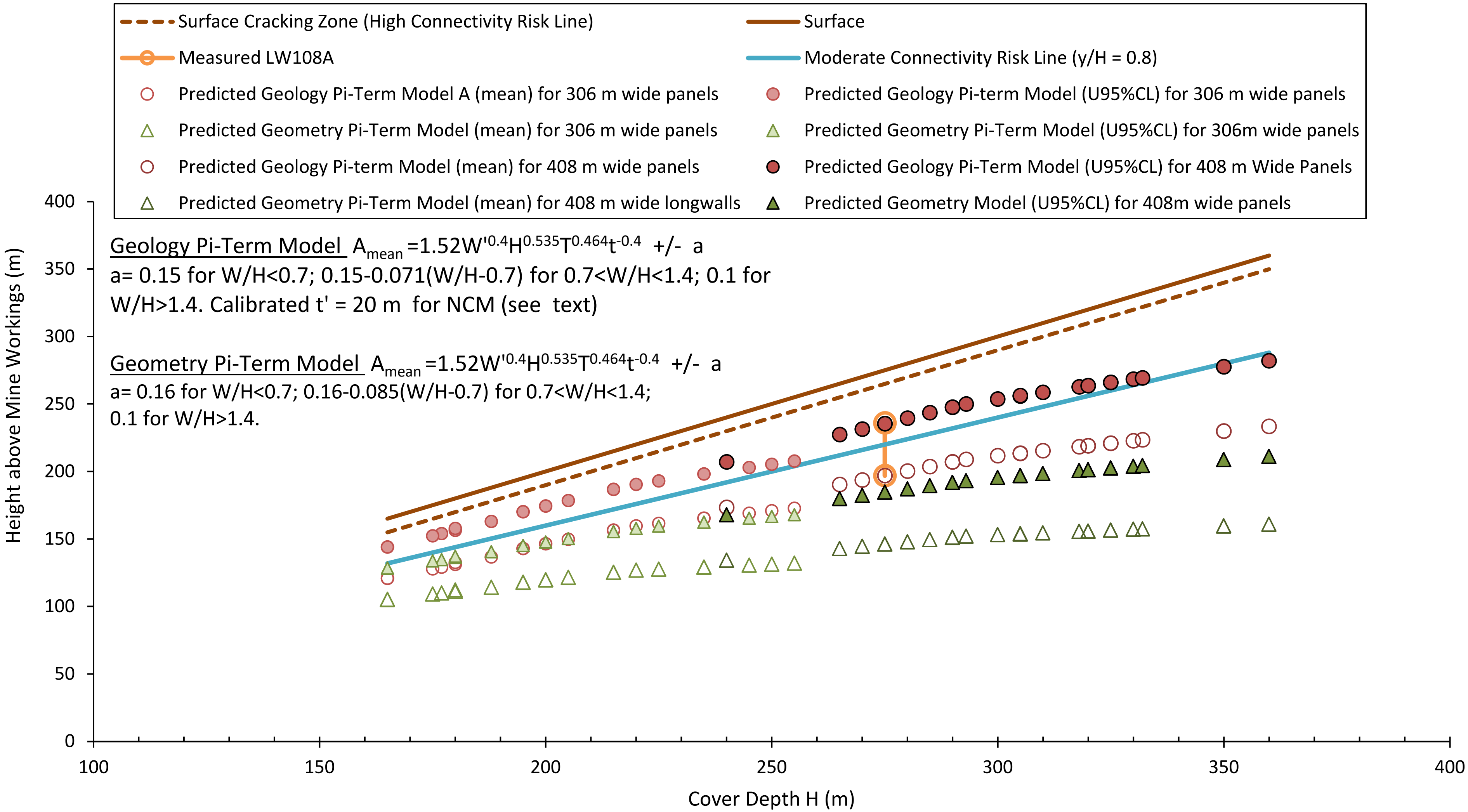
DgS	Engineer: S.Ditton	Client:	Narrabri Mine		
	Drawn: S.Ditton		NAR-004/8		
	Date: 15.07.21	Title:	Measured Subsurface Fracturing Above LW104 from Borehole Extensometers		
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No:	11c



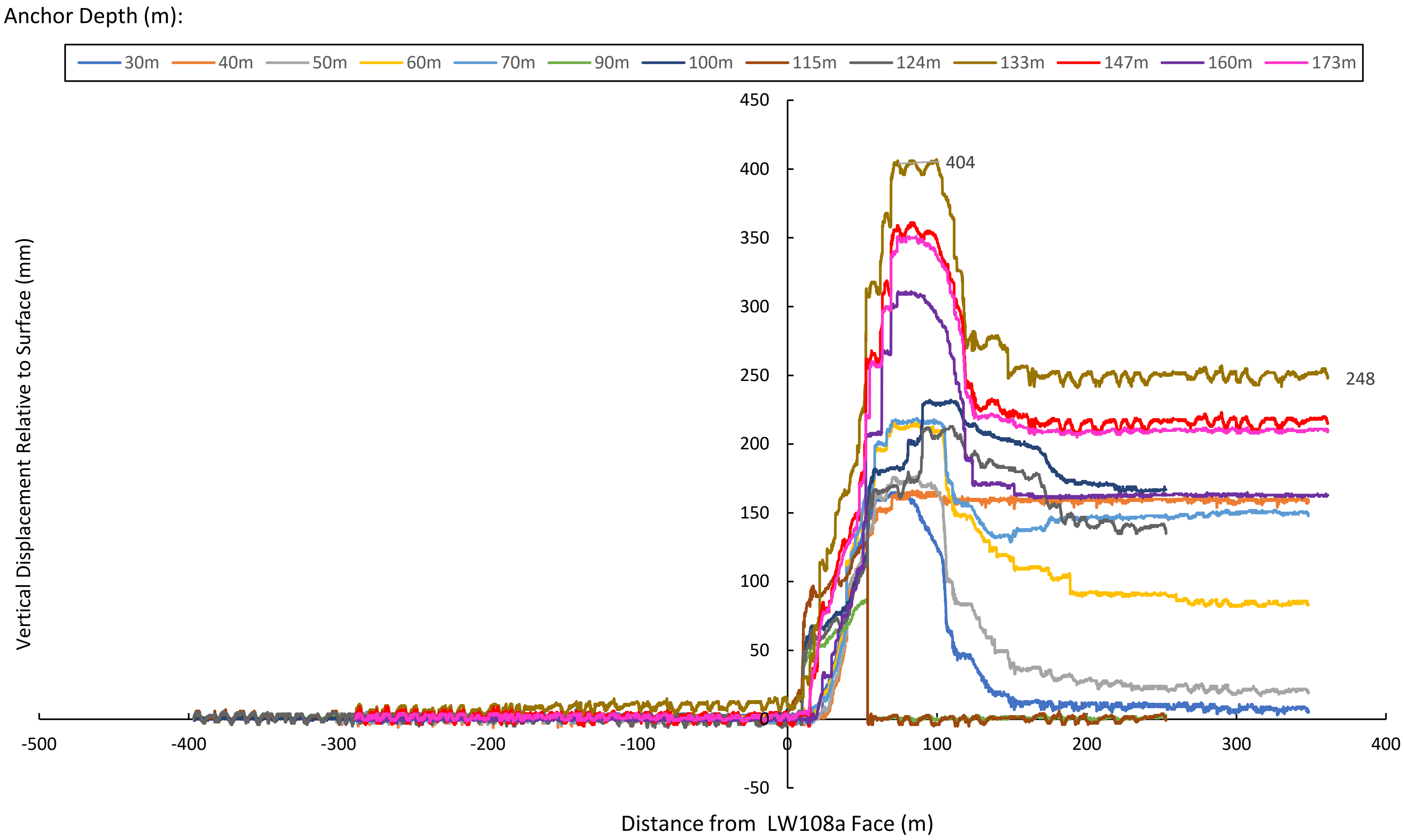
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Measured Subsurface Fracturing Above LW105 from Borehole Extensometers	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 11d



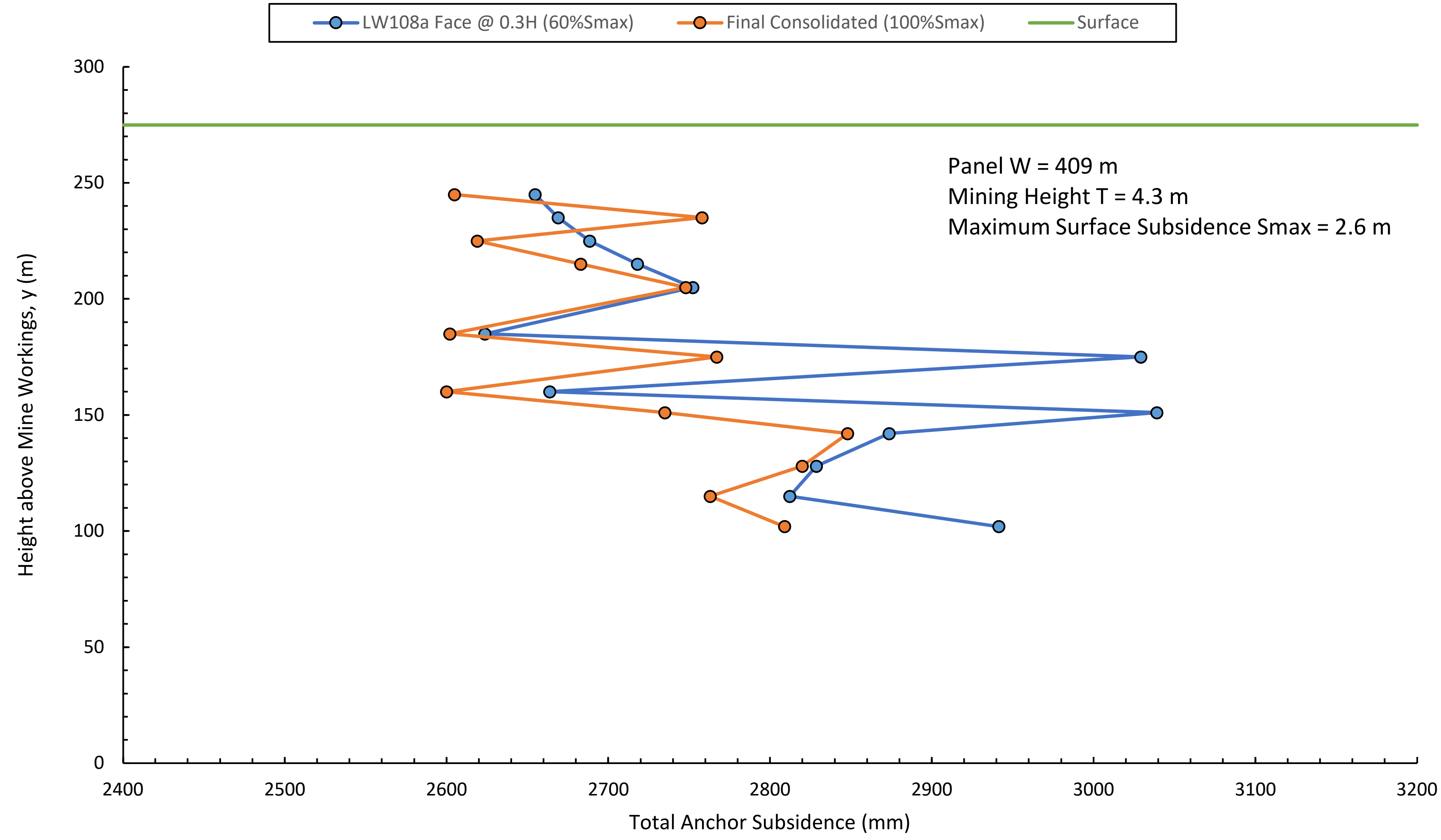
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Measured Subsurface Fracturing Above LW106 from Borehole Extensometers			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11e	



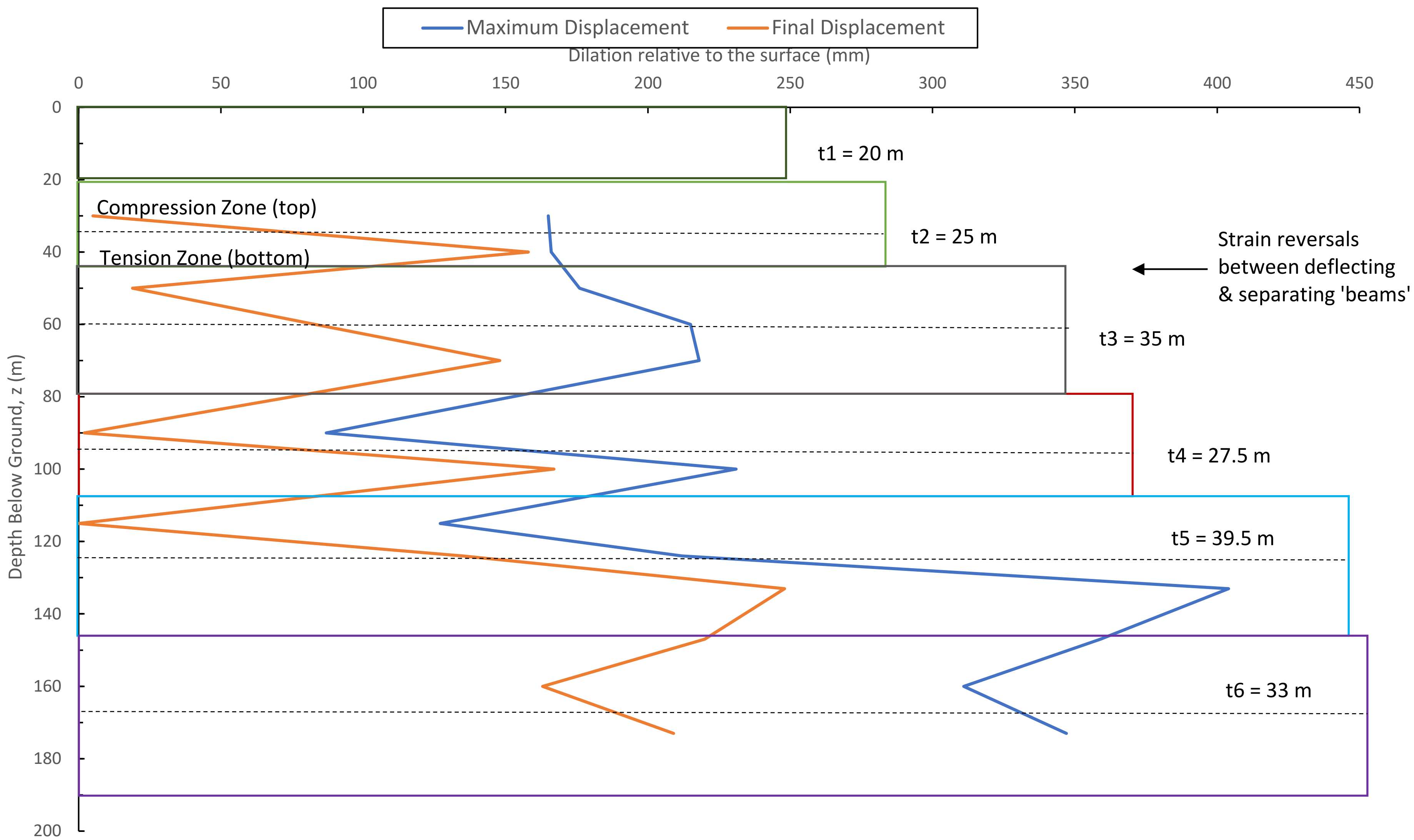
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Predicted Heights of Connective Cracking Above LW101 to 111 based on Pi-Term Models (refer **Ditton & Merrick, 2014**)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 11f



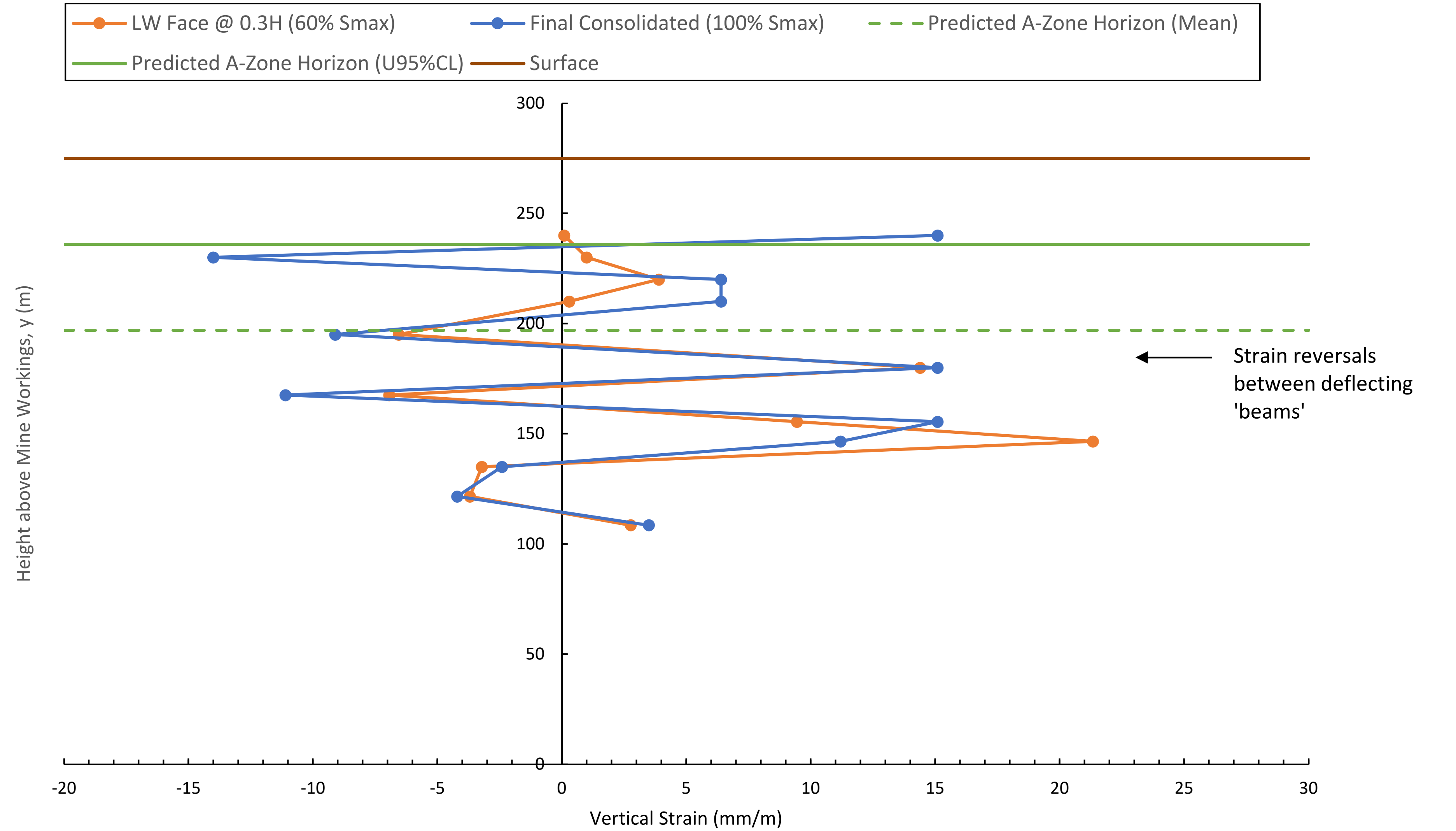
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Measured Relative Subsurface Displacements Above LW108a from Borehole Extensometers
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	11g



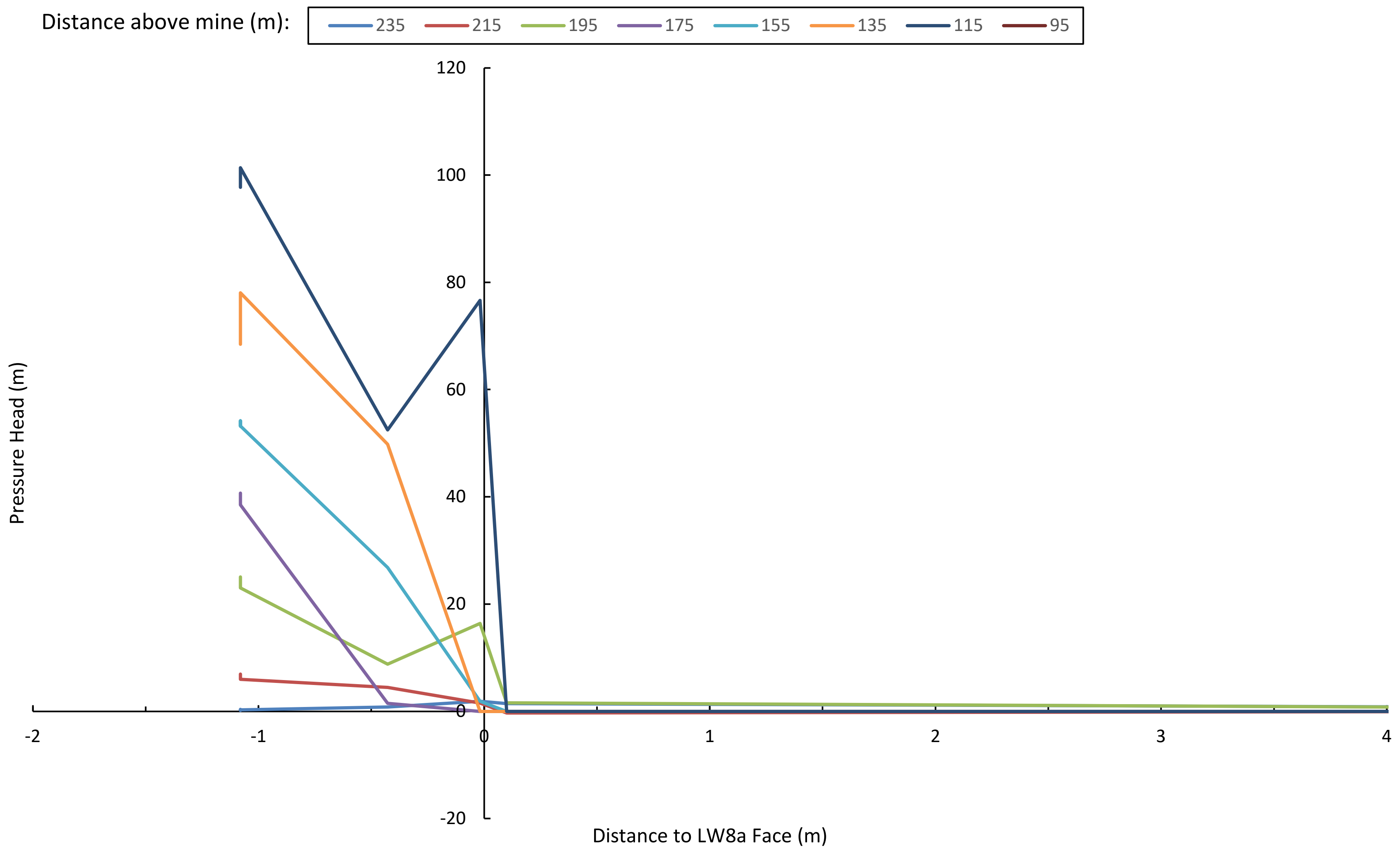
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Measured Total Subsurface Displacements Above LW108a from Borehole Extensometers
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 11h



DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn: S.Ditton			
	Date: 15.07.21	Title:	Measured Vertical Dilation Above LW108a in Borehole Extensometers with inferred deflecting beam thicknesses	
	Ditton Geotechnical Services Pty Ltd	Scale:	NTS	Figure No: 11i

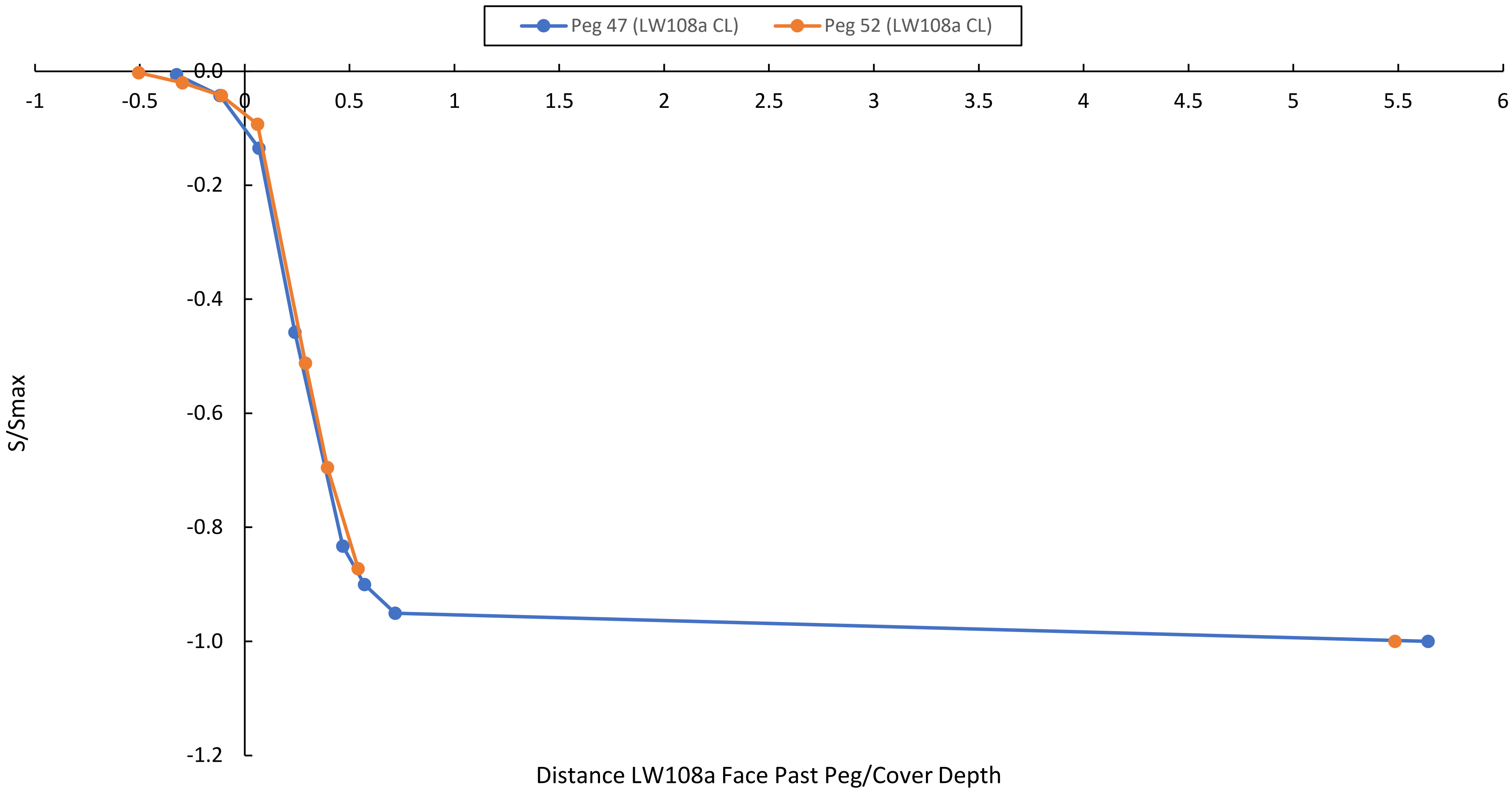


DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Subsurface Vertical Strain Above LW108a from Borehole Extensometers		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11j

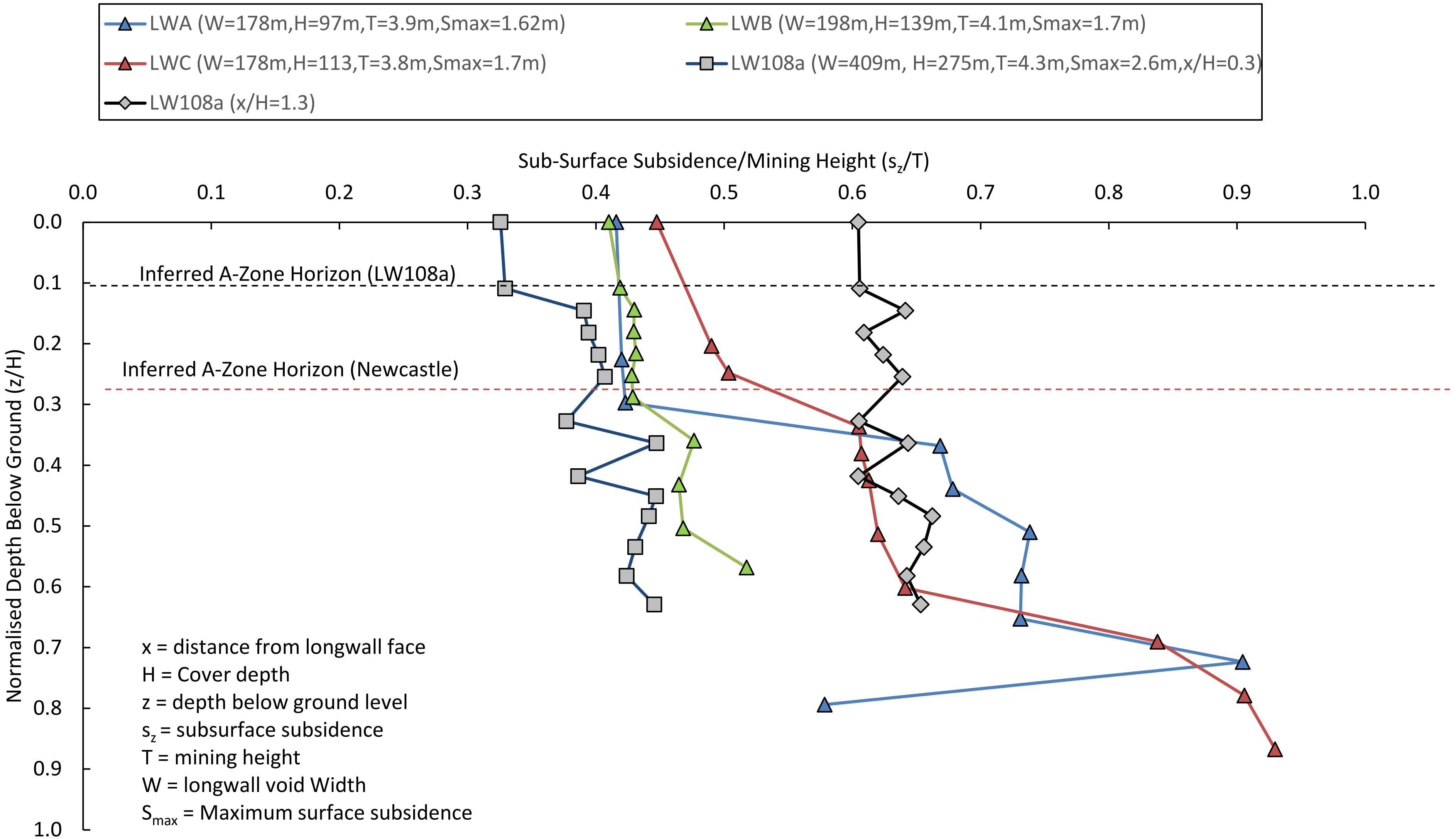


DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Measured Pressure heads in Borehole P57 relative to LW108a Face
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS

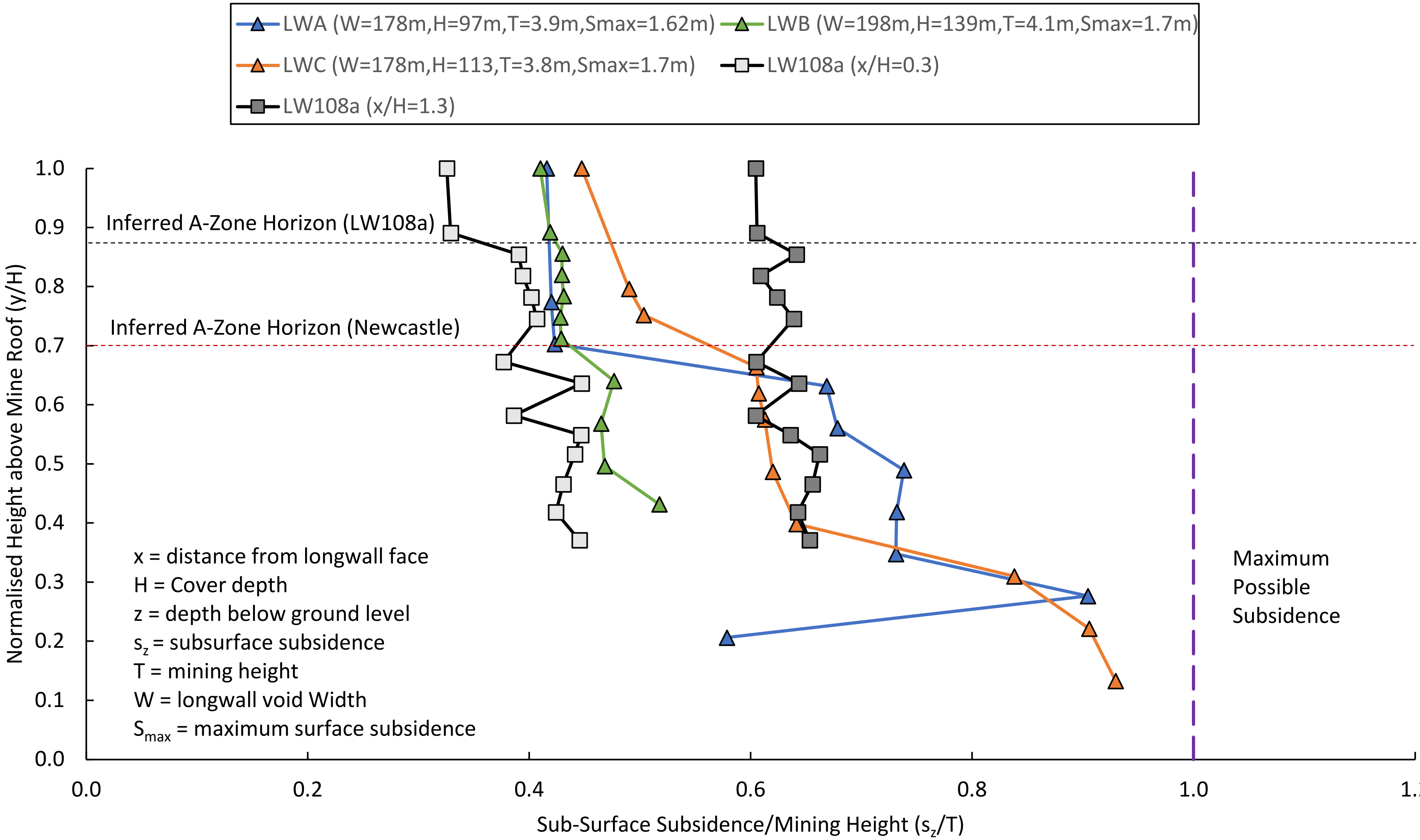
Figure No: 11k



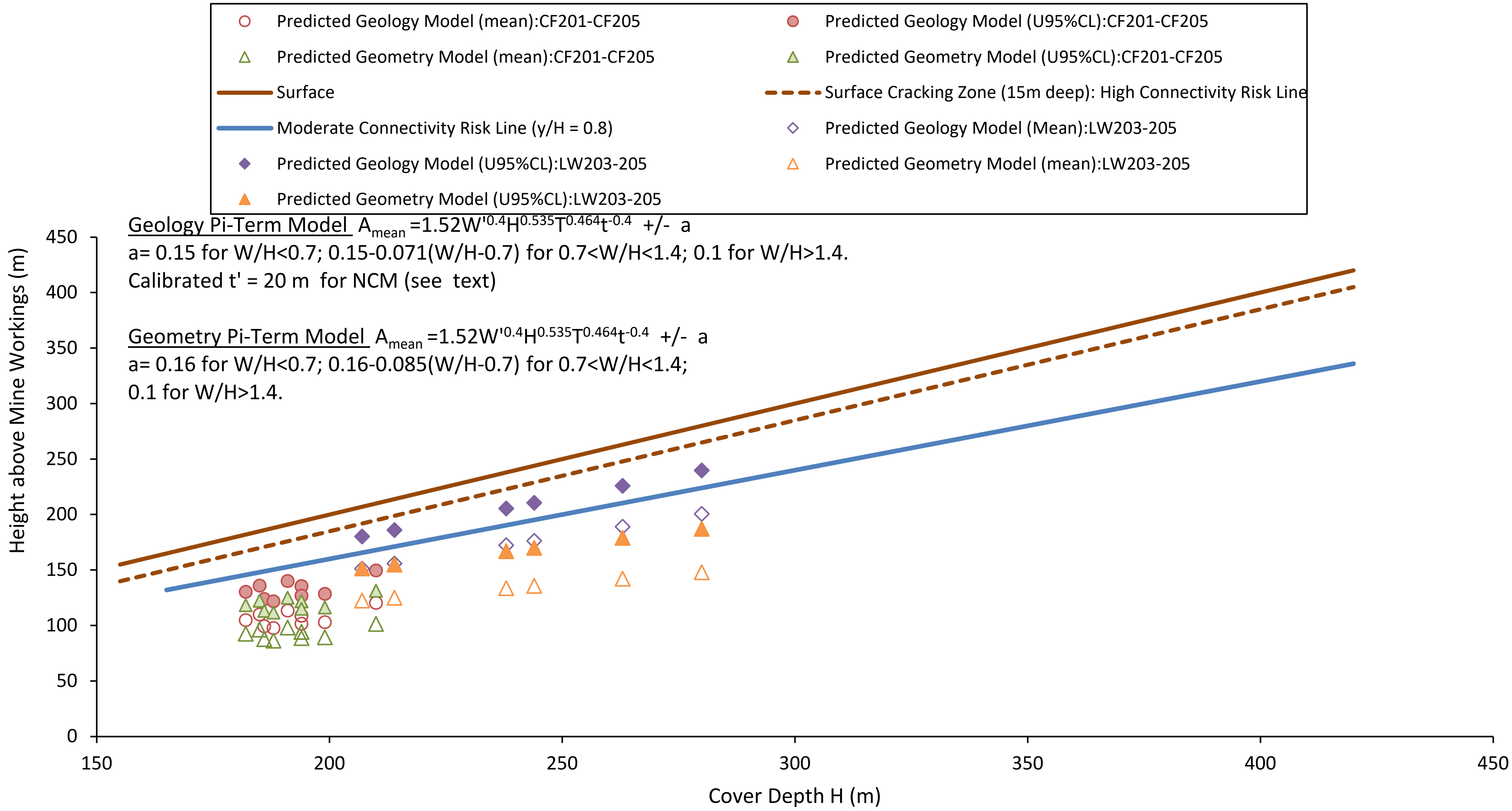
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Subsidence Development along LW108a Centreline		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11I



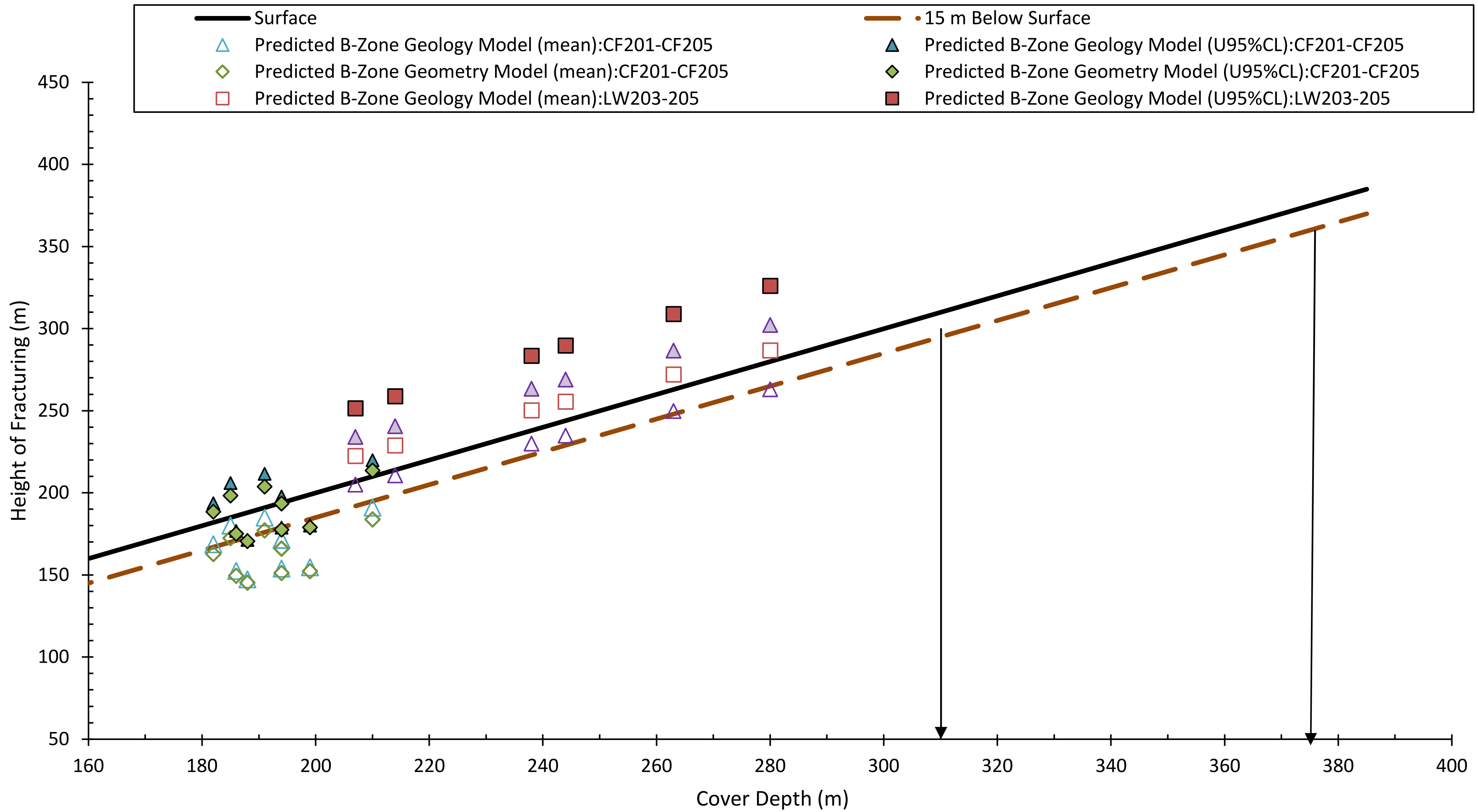
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Subsurface Strata Subsidence/Mining Height v. Depth/Cover Depth in the Newcastle Coalfield & Narrabri Mine		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11m



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Measured Subsurface Strata Subsidence/Mining Height v. Height above Mine/Cover Depth in the Newcastle Coalfield & Narrabri Mine		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11n



Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
Drawn:	S.Ditton			
Date:	15.07.21	Title:	Predicted Heights of Connective Cracking Above CF201-CF205 & LW203 to 205 based on Pi-Term Models (refer **Ditton & Merrick, 2014**)	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 12a

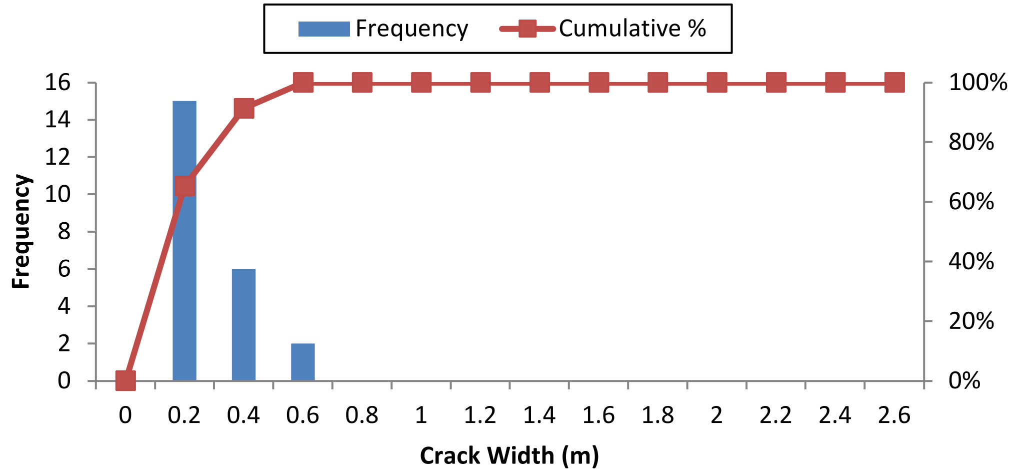


Reference: Ditton & Merrick, 2014 Sub-surface Fracture Model Outcomes

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Discontinuous (B-Zone) Sub-Surface Fracture Heights in Constrained Zone above the Proposed CF201-CF205 & LW203 to 205
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	12b

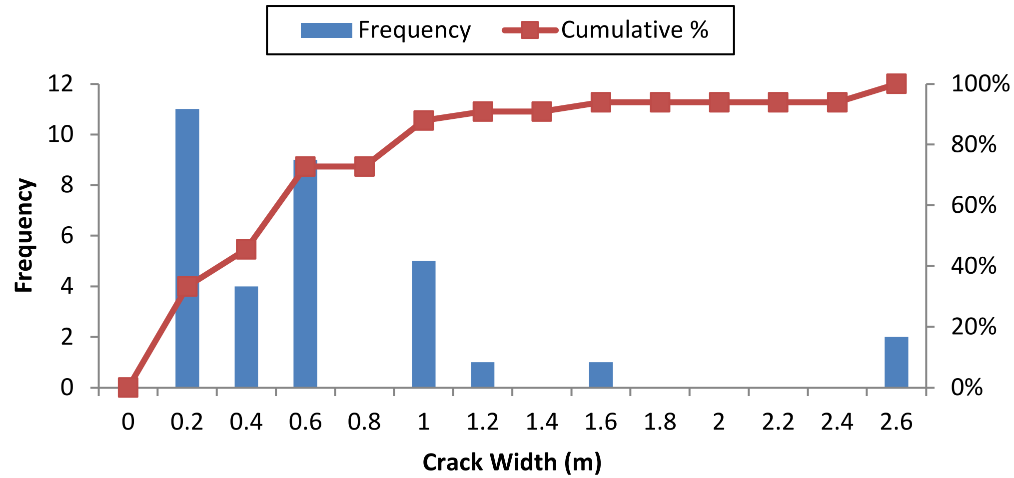
Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)
(Slopes < 18^{o})

Max	0.50	m
Min	0.01	m
Median	0.15	m
Mean	0.19	m
U95%	**0.5**	m
n	23	



Supercritical Longwalls (W/H > 1.2 + Steep Slopes)
(Slopes > 18^{o})

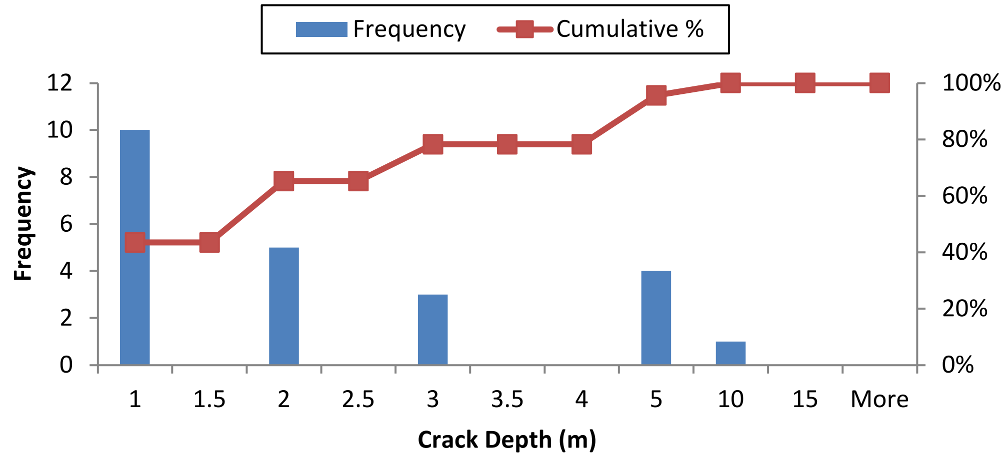
Max	2.50	m
Min	0.05	m
Median	0.50	m
Mean	0.60	m
U95%	**1.9**	m
n	33	



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-004/8		
	Date:	15.07.21	Title:	Surface Crack Width Data for Longwalls below Flat Terrain & Steep Slopes in the Newcastle Coalfield		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	13a

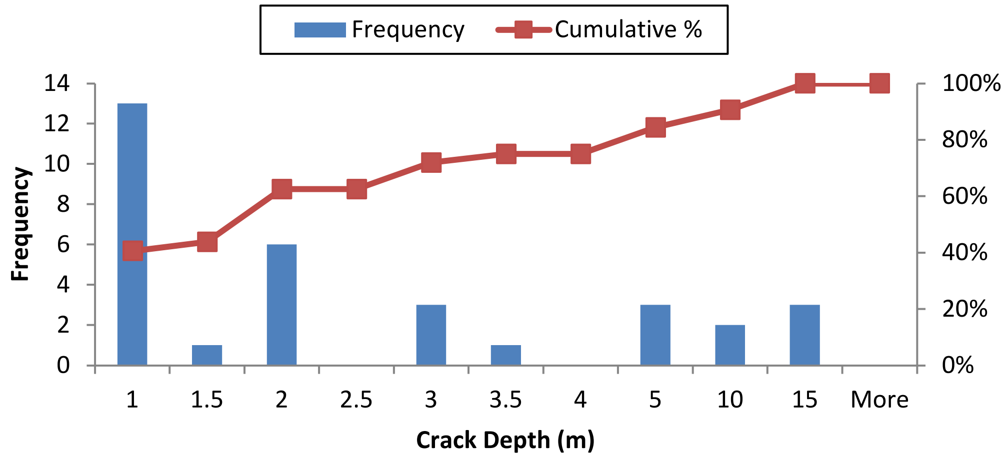
Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)
(Slopes < 18°)

Max	10	m
Min	0.05	m
Median	2.0	m
Mean	2.4	m
U95%	**5.0**	m
n	23	



Supercritical Longwalls (W/H > 1.2 + Steep Slopes)
(Slopes > 18°)

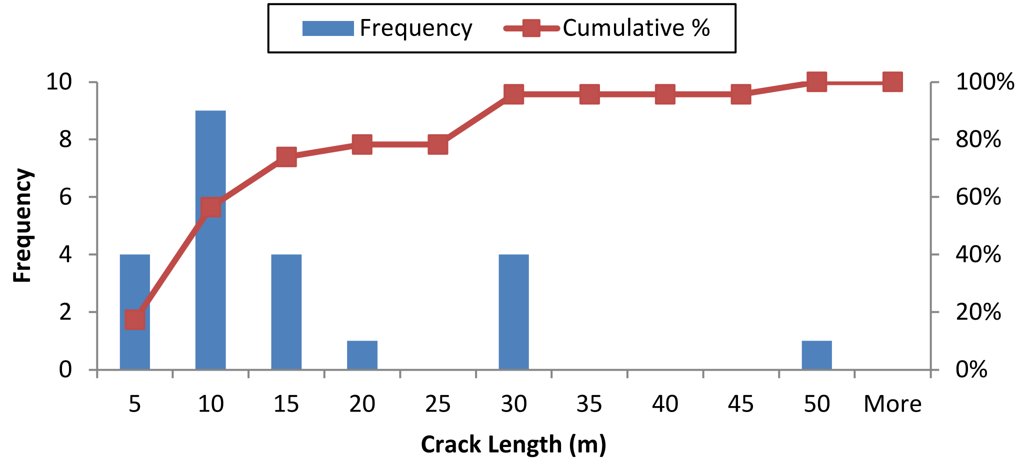
Max	15	m
Min	0.15	m
Median	2.0	m
Mean	3.5	m
U95%	**15.0**	m
n	32	



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Surface Crack Depth Data for Longwalls below Flat Terrain & Steep Slopes in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	13b

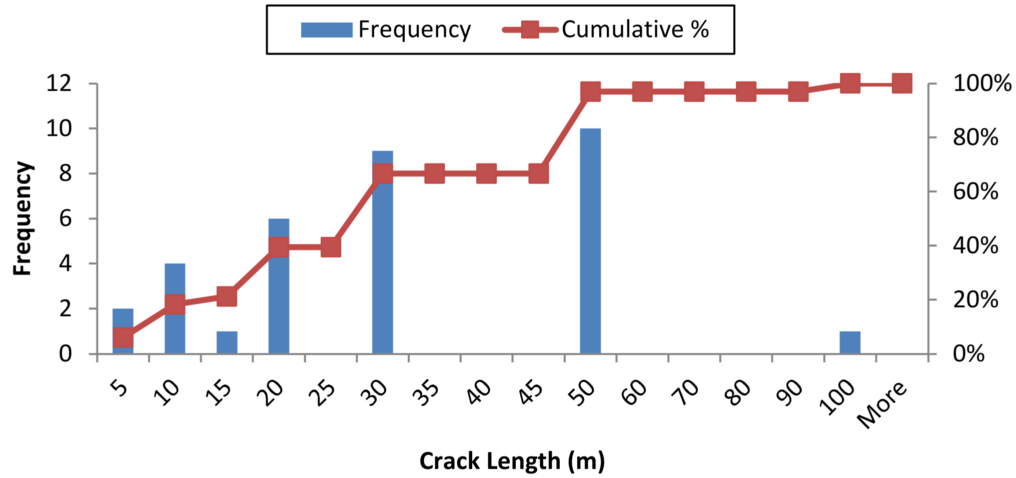
Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)
(Slopes < 18°)

Max	50	m
Min	3	m
Median	10	m
Mean	15	m
U95%	**30**	m
n	23	



Supercritical Longwalls (W/H > 1.2 + Steep Slopes)
(Slopes > 18°)

Max	100	m
Min	3	m
Median	30	m
Mean	32	m
U95%	**50**	m
n	33	



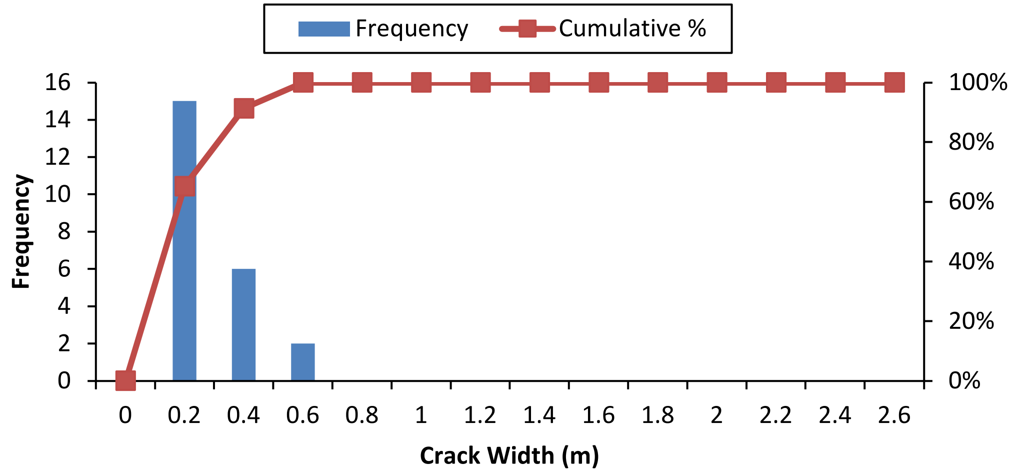
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Surface Crack Length Data for Longwalls below Flat Terrain & Steep Slopes in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	13c

NEWCASTLE COALFIELD DATA

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18^{o})

Max	0.50	m
Min	0.01	m
Median	0.15	m
Mean	0.19	m
U95%	**0.5**	m
n	23	

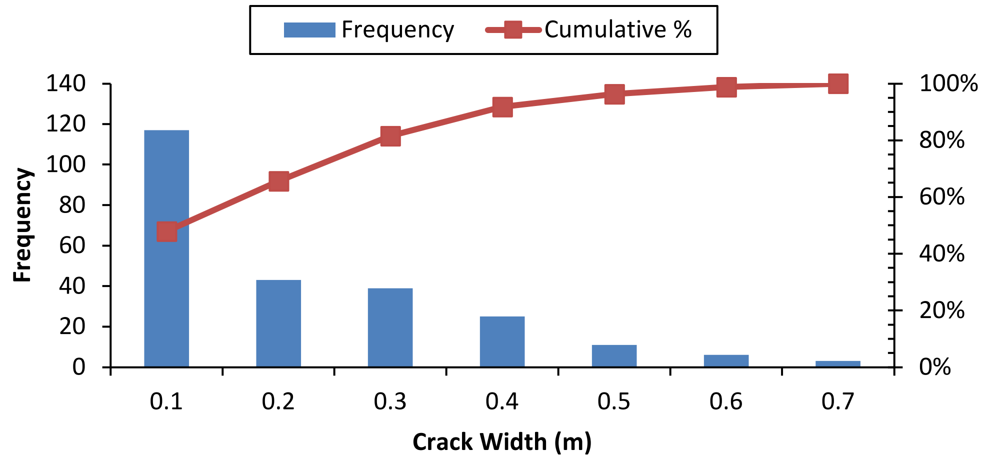


NARRABRI MINE DATA

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18^{o})

Max	0.68	m
Min	0.01	m
Median	0.14	m
Mean	0.18	m
U95%	**0.5**	m
n	245	



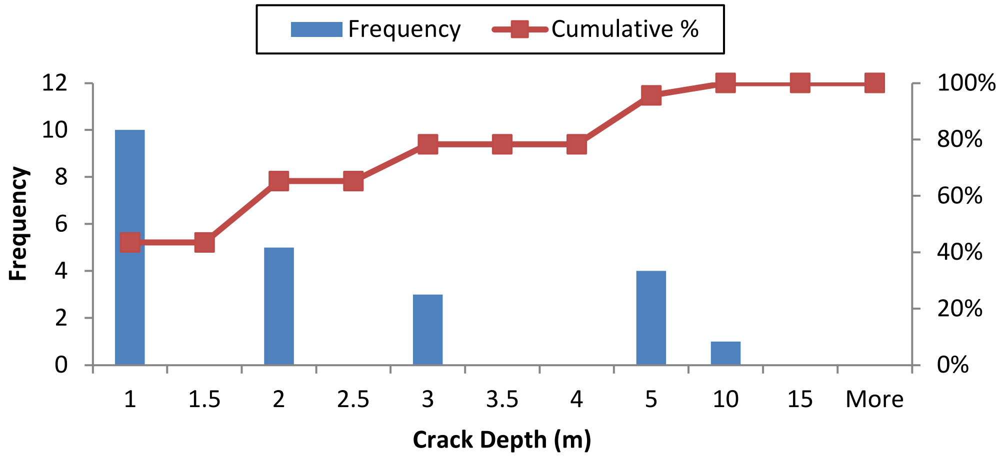
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Surface Crack Width Data for Longwalls below Flat Terrain at the Narrabri Mine (and Newcastle Coalfield)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	13d

NEWCASTLE COALFIELD DATA

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

Max	10	m
Min	0.05	m
Median	2.0	m
Mean	2.4	m
U95%	**5.0**	m
n	23	

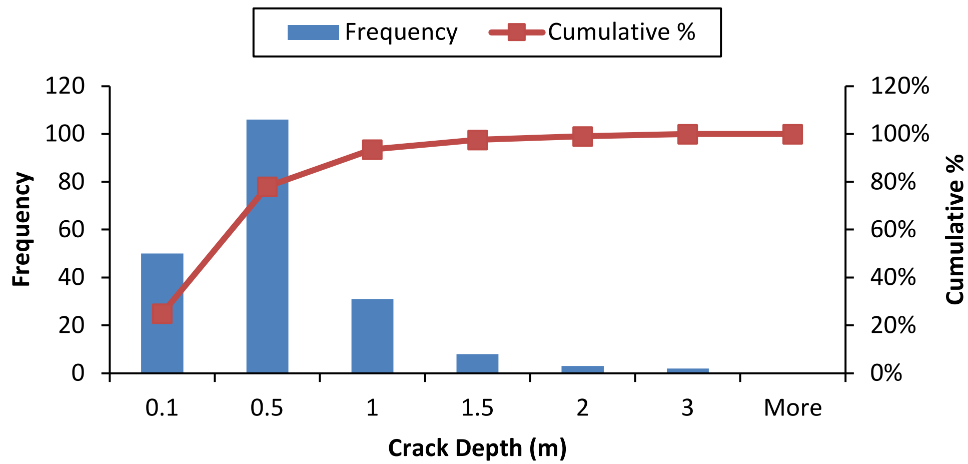


NARRABRI MINE DATA

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

Max	2.4	m
Min	0.1	m
Median	0.3	m
Mean	0.4	m
U95%	**1.2**	m
n	201	



Note: Crack depths in sands difficult to measure due to collapsing side walls.

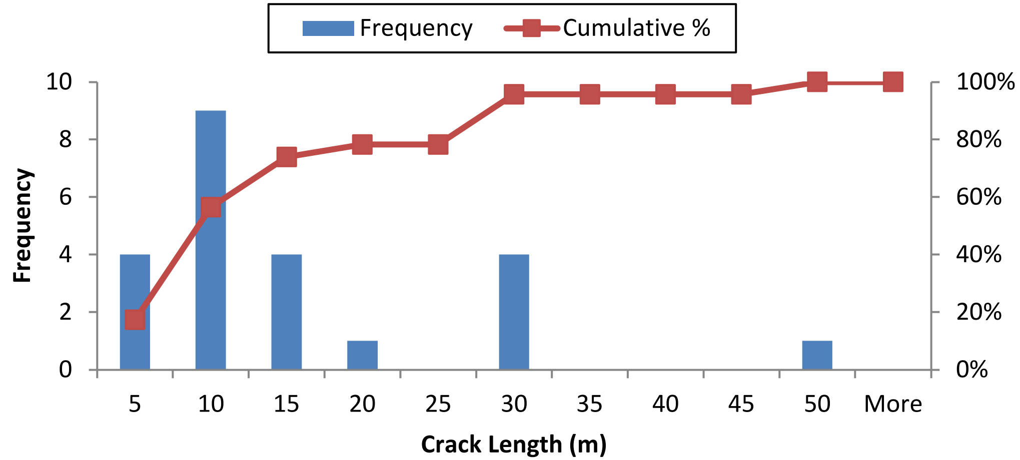
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-004/8
	Date:	15.07.21	Title:	Surface Crack Depth Data for Longwalls below Flat Terrain at the Narrabri Mine (and Newcastle Coalfield)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	13e

NEWCASTLE COALFIELD DATA

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

Max	50	m
Min	3	m
Median	10	m
Mean	15	m
U95%	**30**	m
n	23	

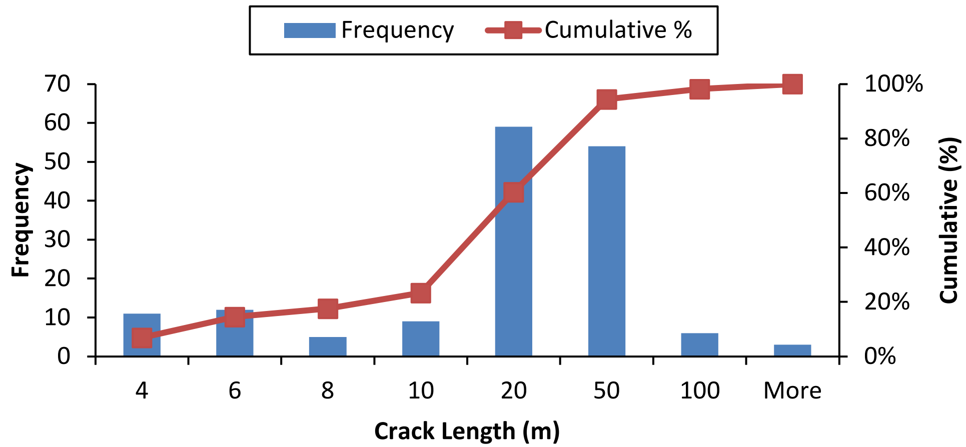


NARRABRI MINE DATA

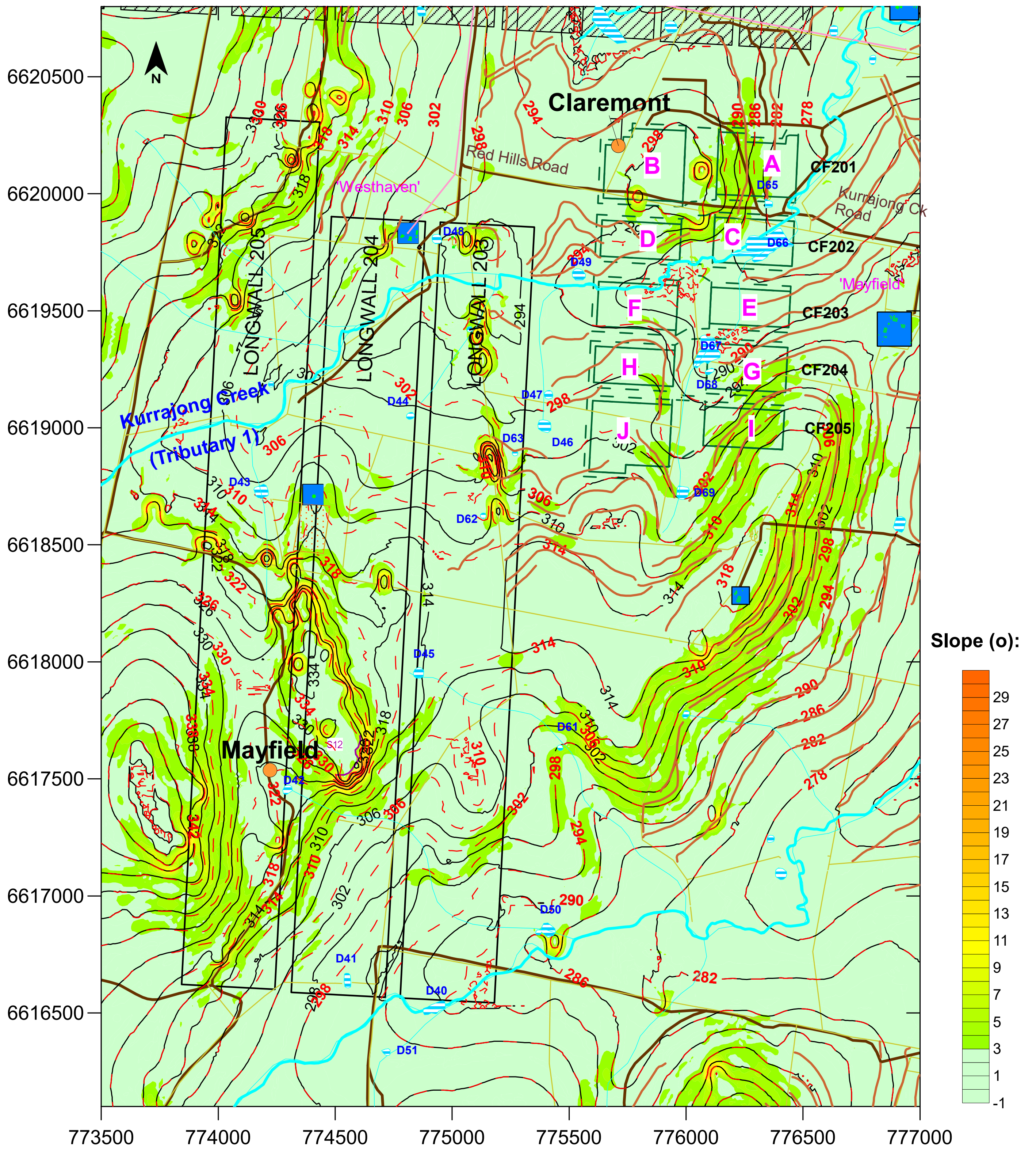
Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

Max	994	m
Min	2	m
Median	17	m
Mean	32	m
U95%	**60**	m
n	160	



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-004/8	
	Date:	15.07.21	Title:	Surface Crack Length Data for Longwalls below Flat Terrain at the Narrabri Mine (and Newcastle Coalfield)	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 13f



Key:

Approved Longwalls (LW203-205)	Roads (unsealed)
Extracted Longwalls (LW101-108A)	Dwellings & Sheds/Tanks/Orchards
A Proposed Pillar Reduction Panels (e = 66%)	NCO-Owned Buildings
Proposed 2nd Workings (e = 35%)	Powerlines (Domestic)
Post-Mining Level Contours (4m, AHD)	Fences
Pre-mining Level Contours (4m, AHD)	

Ephemeral Creeks & Watercourses

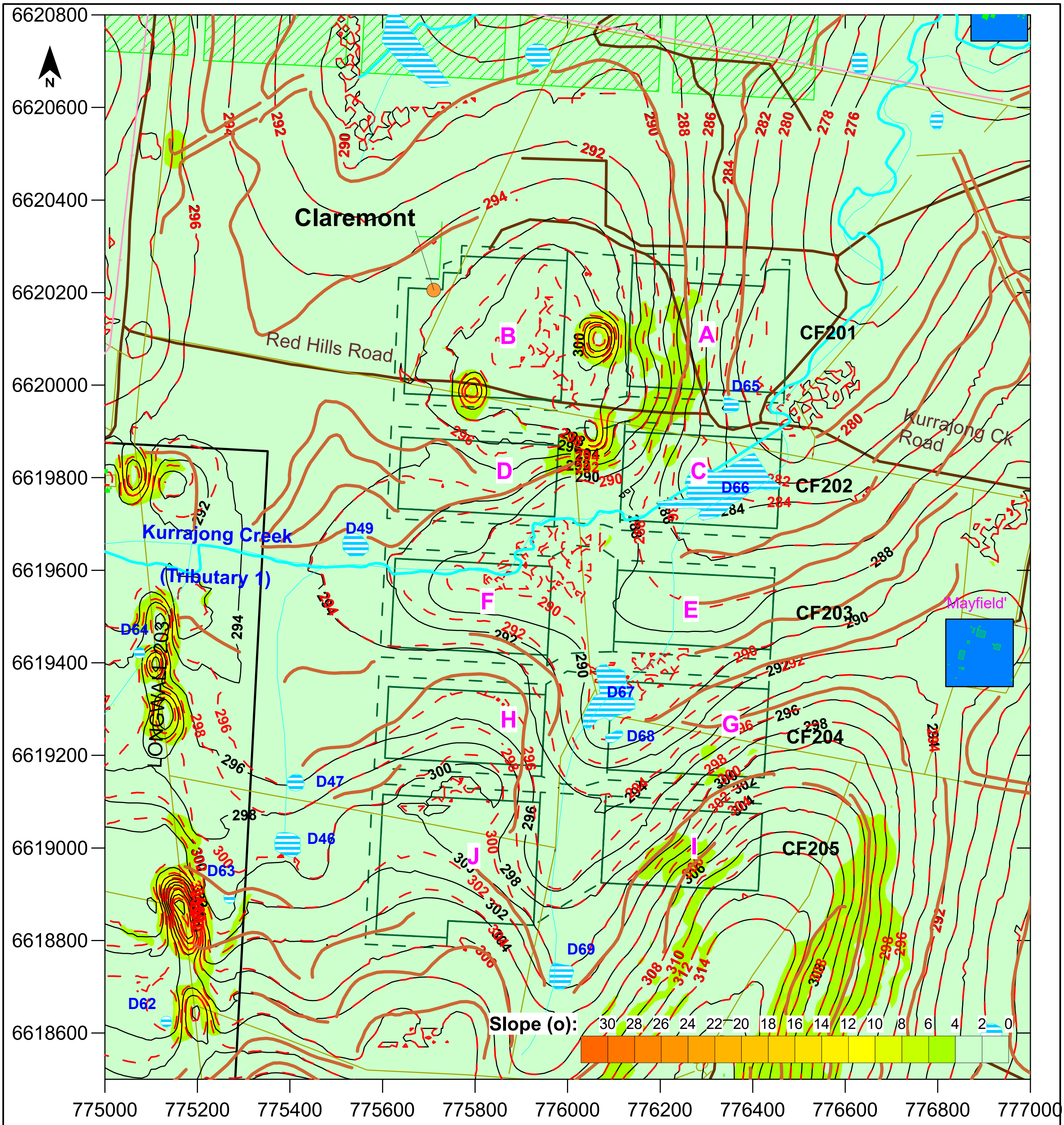
Farm Dams

Contour Banks

Grinding Groove Site

S12 Steep Slopes

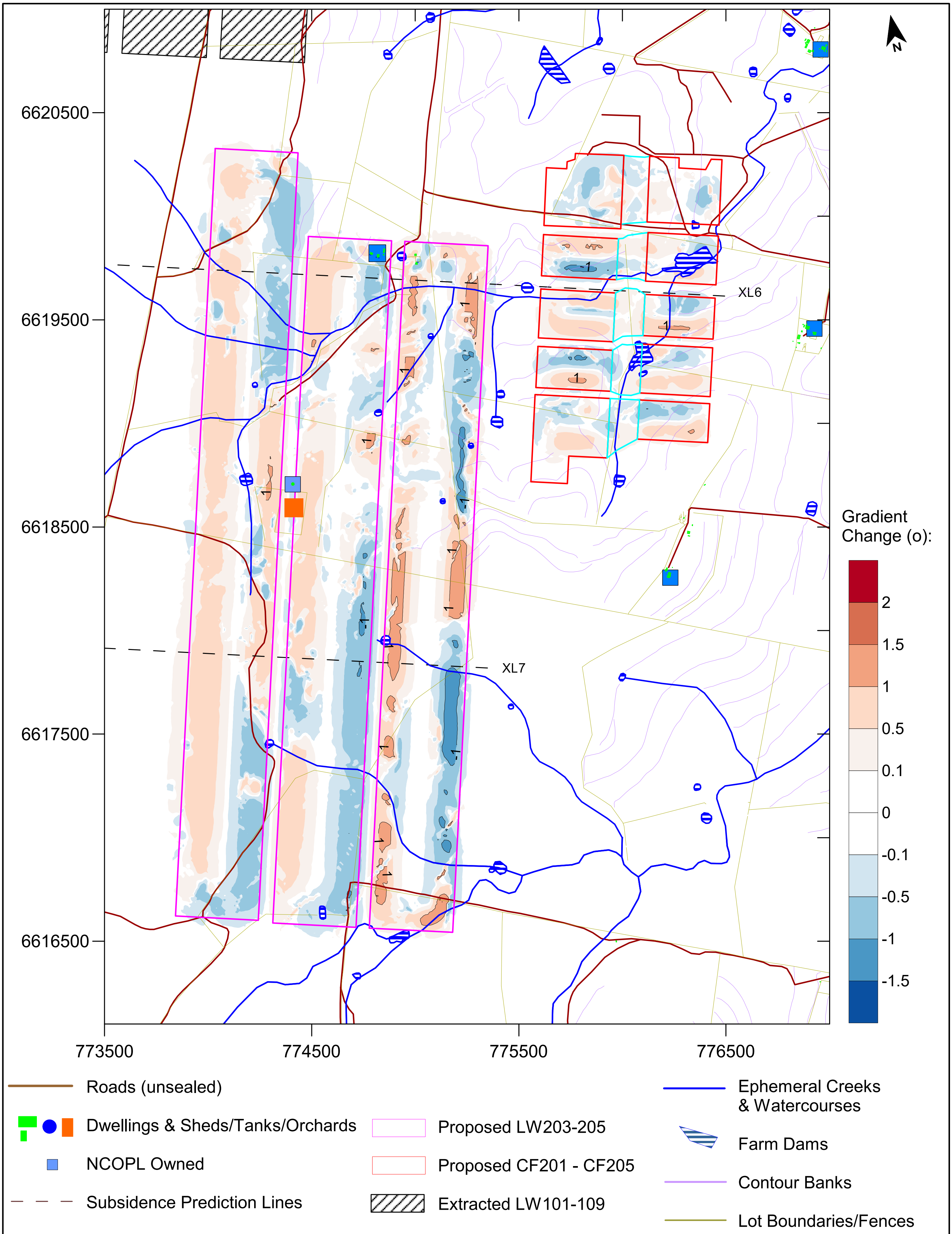
DgS	Engineer: S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn: S.Ditton			
	Date: 01.09.21	Title:	Post-Mining Surface Levels, Slope Gradients & Surface Features above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) & LW203 to 205	
	Ditton Geotechnical Services Pty Ltd	Scale:	1:30,000	Figure No: 14a



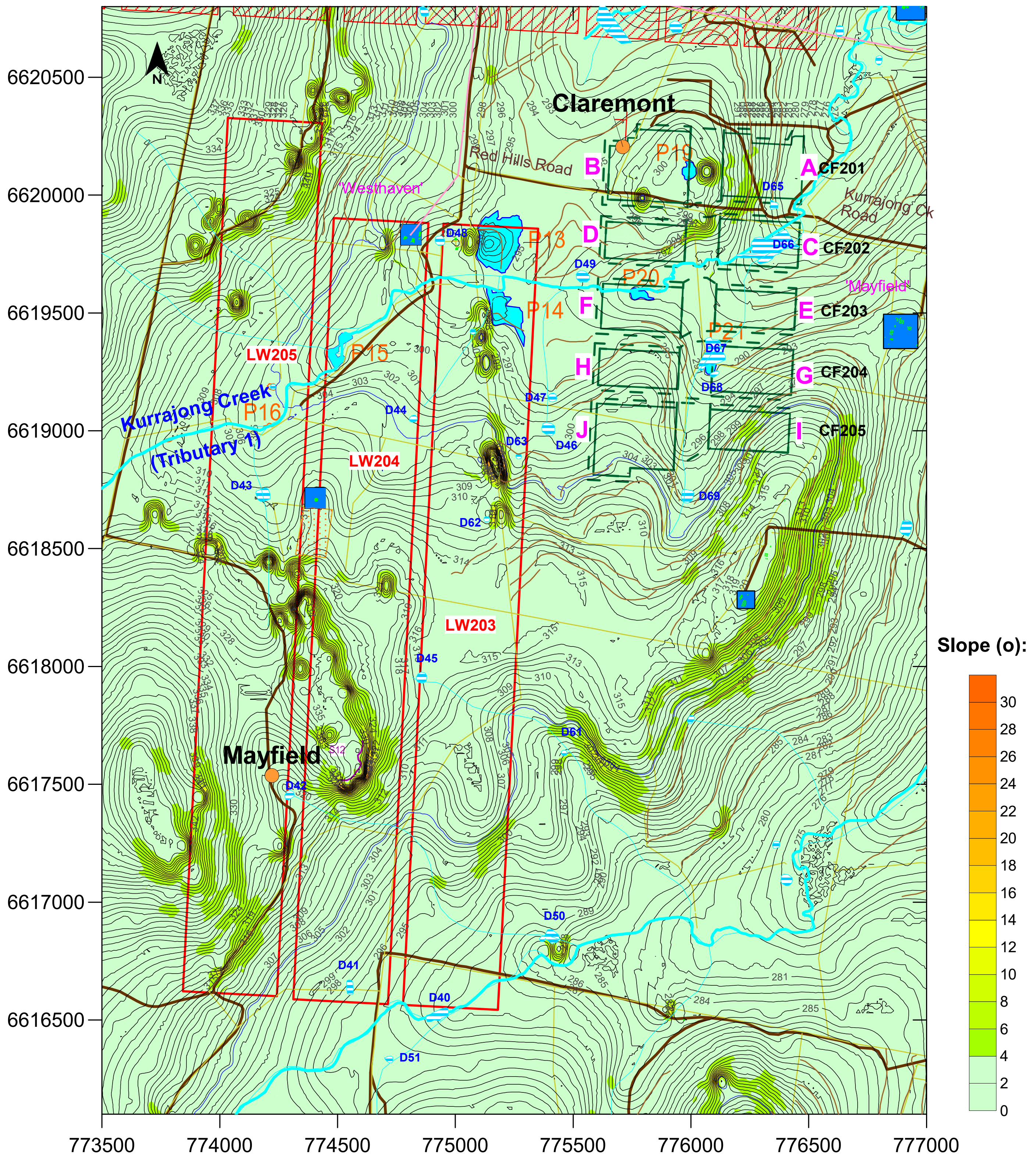
Key:

Approved Longwalls (LW203-205)	Roads (unsealed)
Extracted Longwalls (LW101-108A)	Dwellings & Sheds/Tanks
A Proposed Pillar Reduction Panels (e = 66%)	NCO-Owned Buildings
Proposed 2nd Workings (e = 35%)	Powerlines (Domestic)
Pre-mining Level Contours (2m, AHD)	Fences
Post-mining Level Contours (2m, AHD)	Ephemeral Creeks & Watercourses
	Farm Dams
	Contour Banks
	Grinding Groove Site

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	Post-mining Surface Levels, Slope Gradients & Surface Features above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)
	Date:	15.07.21		
Ditton Geotechnical Services Pty Ltd			Scale:	1:15,000 — Figure No: 14b



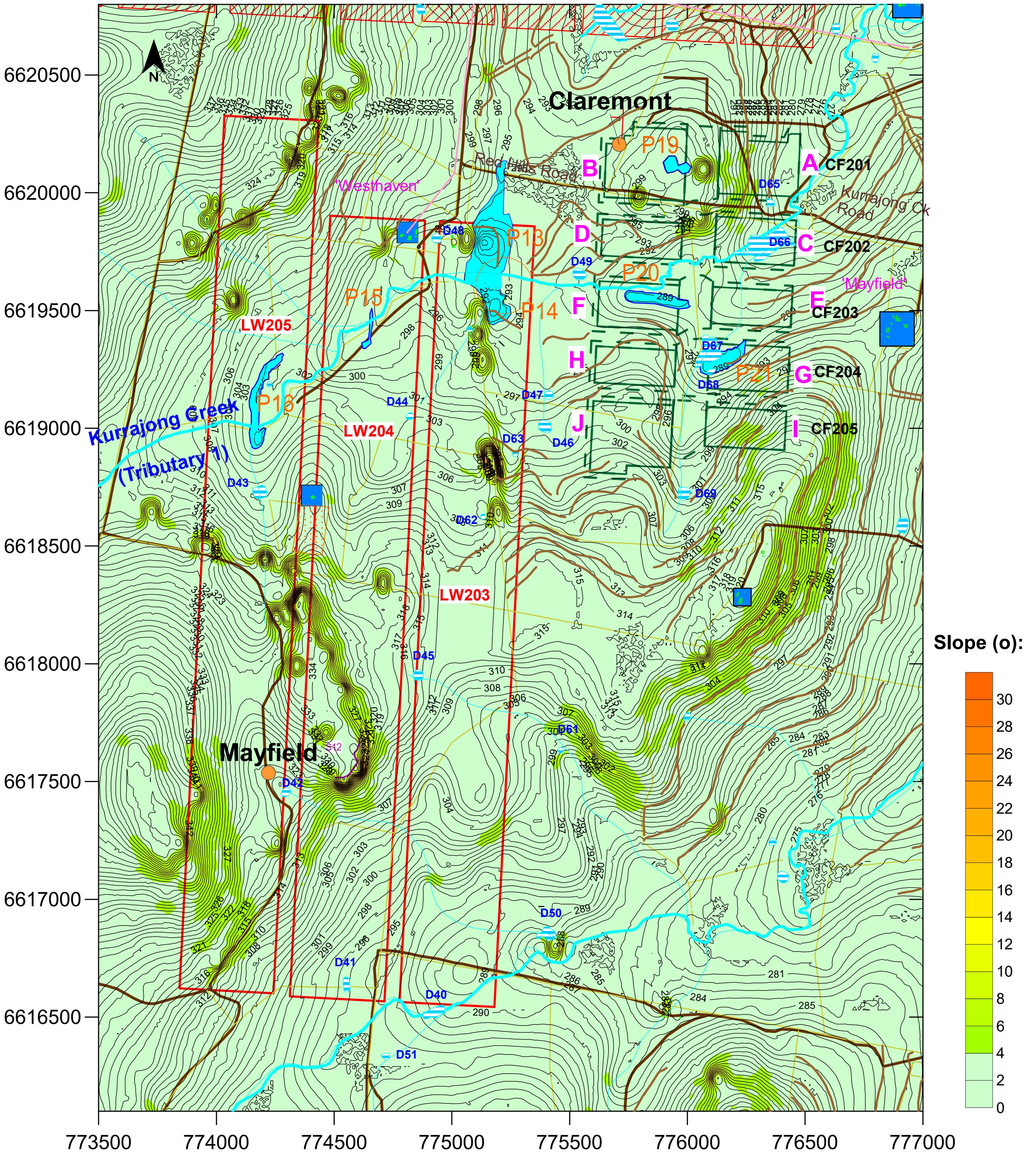
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	01.09.21	Title:	Predicted Surface Gradient Changes (degrees) due to U95%CL Subsidence Contours above the Proposed CF201-CF205 & LW203 to 205
Ditton Geotechnical Services Pty Ltd			Scale:	1:30,000
			Figure No:	14c



Key:

- Approved Longwalls (LW203-205)
- Extracted Longwalls (LW101-108A)
- A Proposed Pillar Reduction Panels (e = 66%)
- Proposed 2nd Workings (e = 35%)
- Level Contours (m, AHD)
- Roads (unsealed)
- Dwellings & Sheds/Tanks/Orchards
- NCO-Owned Buildings
- Powerlines (Domestic)
- Fences
- P14 Ponded Area
- Ephemeral Creeks & Watercourses
- Farm Dams
- Contour Banks
- Grinding Groove Site
- S12 Steep Slopes

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton	Title:	Pre-mining Surface Levels, Slope Gradients & Surface Features above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J)
	Date:	01.09.21		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:30,000
			Figure No:	15a

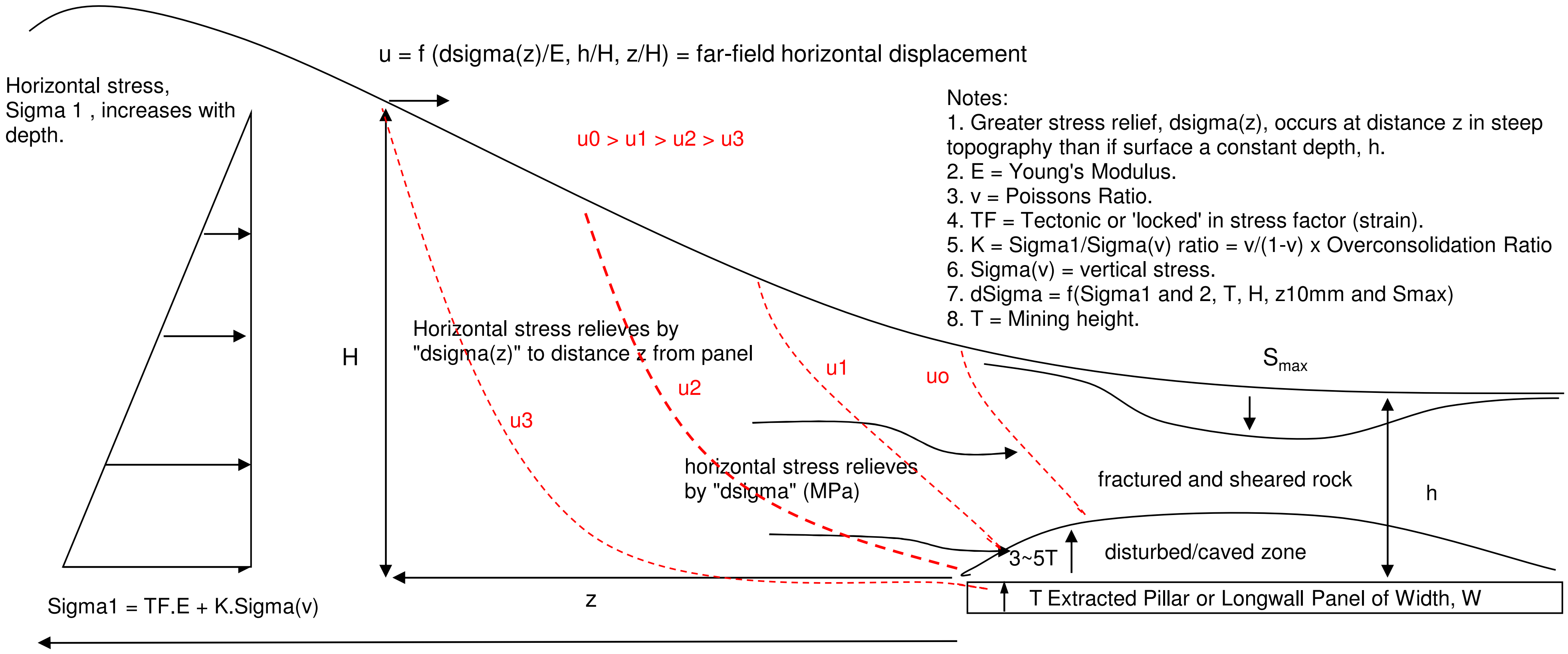


Key:

Approved Longwalls (LW203-205)	Roads (unsealed)
Extracted Longwalls (LW101-108A)	Dwellings & Sheds/Tanks/Orchards
A Proposed Pillar Reduction Panels (e = 66%)	NCO-Owned Buildings
Proposed 2nd Workings (e = 35%)	Powerlines (Domestic)
Post-Mining Level Contours (4m, AHD)	Fences
Pre-mining Level Contours (4m, AHD)	P14 Ponded Area

- Ephemeral Creeks & Watercourses
- Farm Dams
- Contour Banks
- Grinding Groove Site
- S12 Steep Slopes

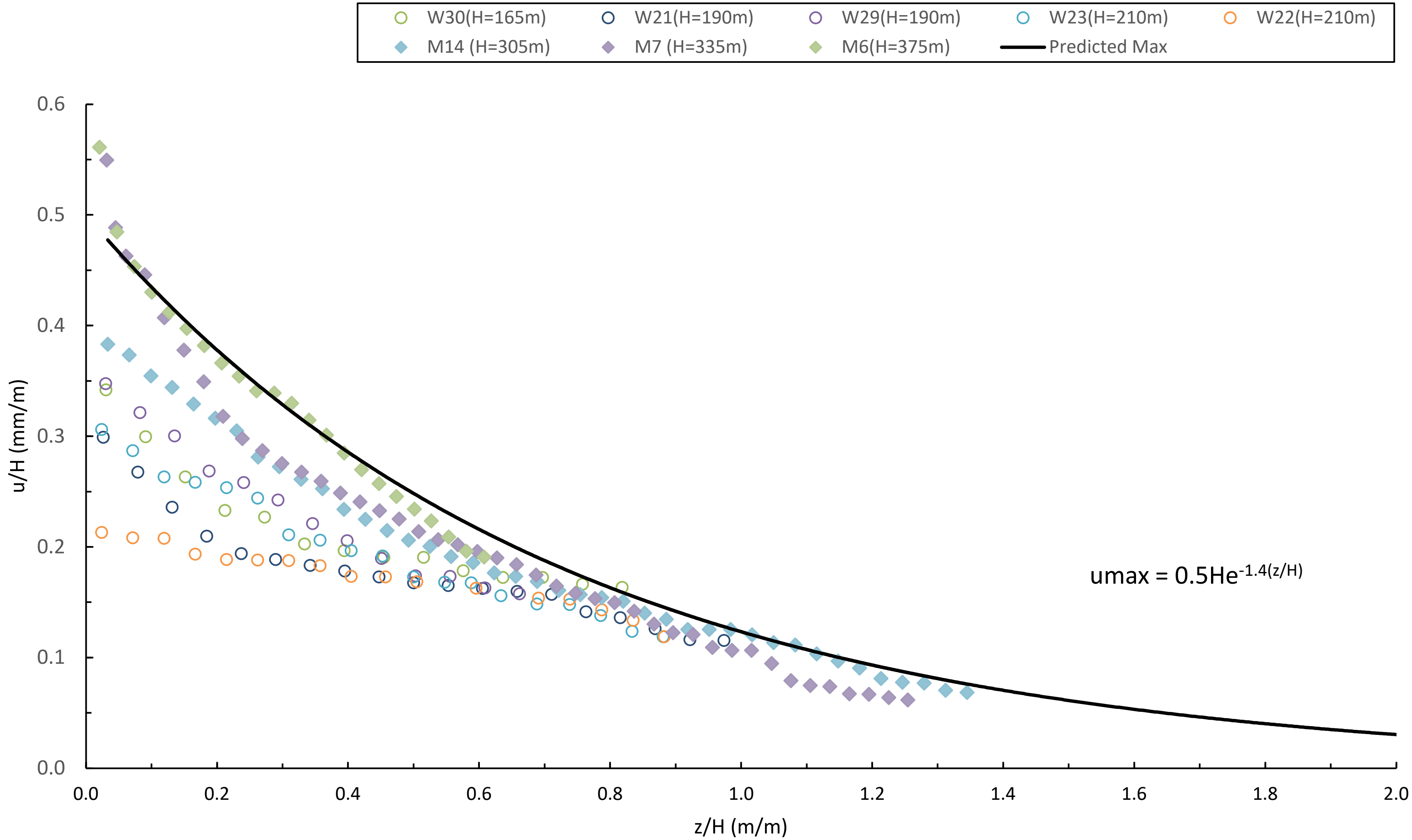
DgS Ditton Geotechnical Services Pty Ltd		Client:	Narrabri Mine NAR-004/8
Engineer:	S.Ditton	Title:	Post-Mining Surface Levels, Slope Gradients & Surface Features above the Proposed Pillar Reduction Panels CF201 - CF205 (A to J) & LW203 to 205
Drawn:	S.Ditton		
Date:	15.07.21	Scale:	1:30,000
		Figure No:	15b



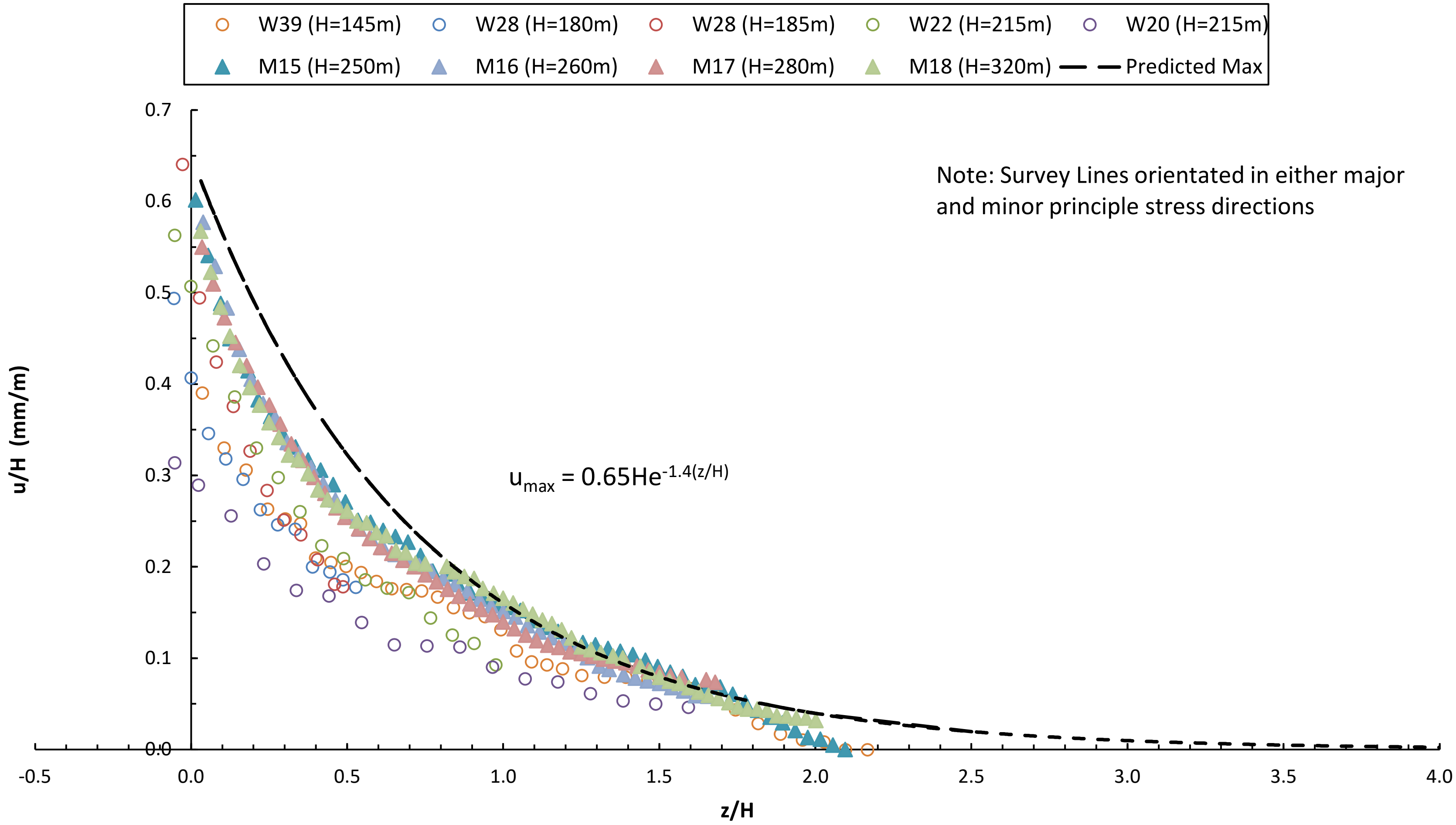
Notes:
1. Greater stress relief, dsigma(z), occurs at distance z in steep topography than if surface a constant depth, h.
2. E = Young's Modulus.
3. v = Poissons Ratio.
4. TF = Tectonic or 'locked' in stress factor (strain).
5. K = Sigma1/Sigma(v) ratio = v/(1-v) x Overconsolidation Ratio
6. Sigma(v) = vertical stress.
7. dSigma = f(Sigma1 and 2, T, H, z10mm and Smax)
8. T = Mining height.

z10mm is ~ 2 to 4 H with and without topographical effects and represents practical, measurable FFD limit of 10mm.

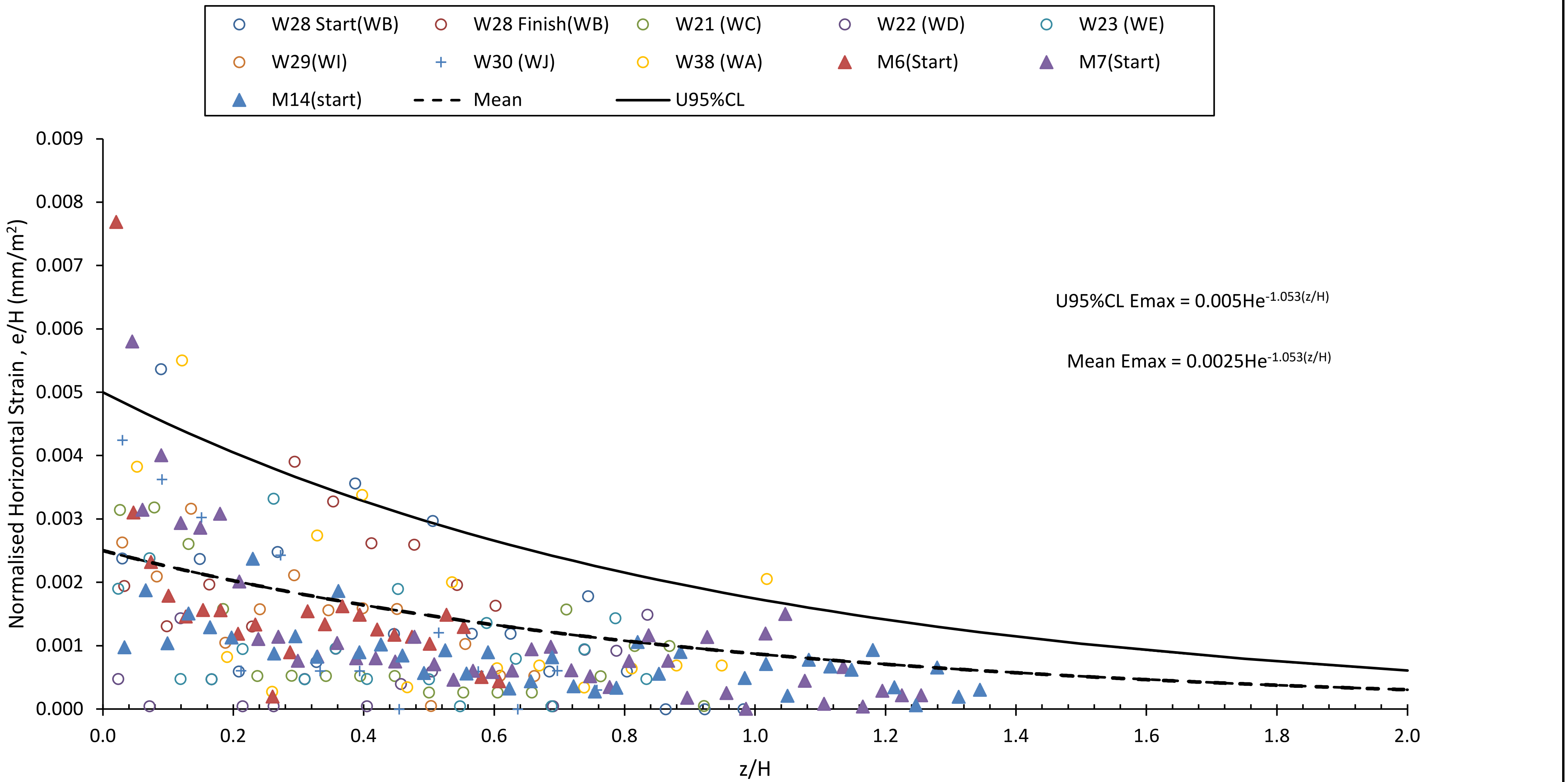
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8
	Drawn:	S.Ditton		
	Date:	15.07.21	Title:	Conceptual Model of Far-Field Displacement Outside Angle of Draw Limits from Pillar Extraction or Longwall Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 16a



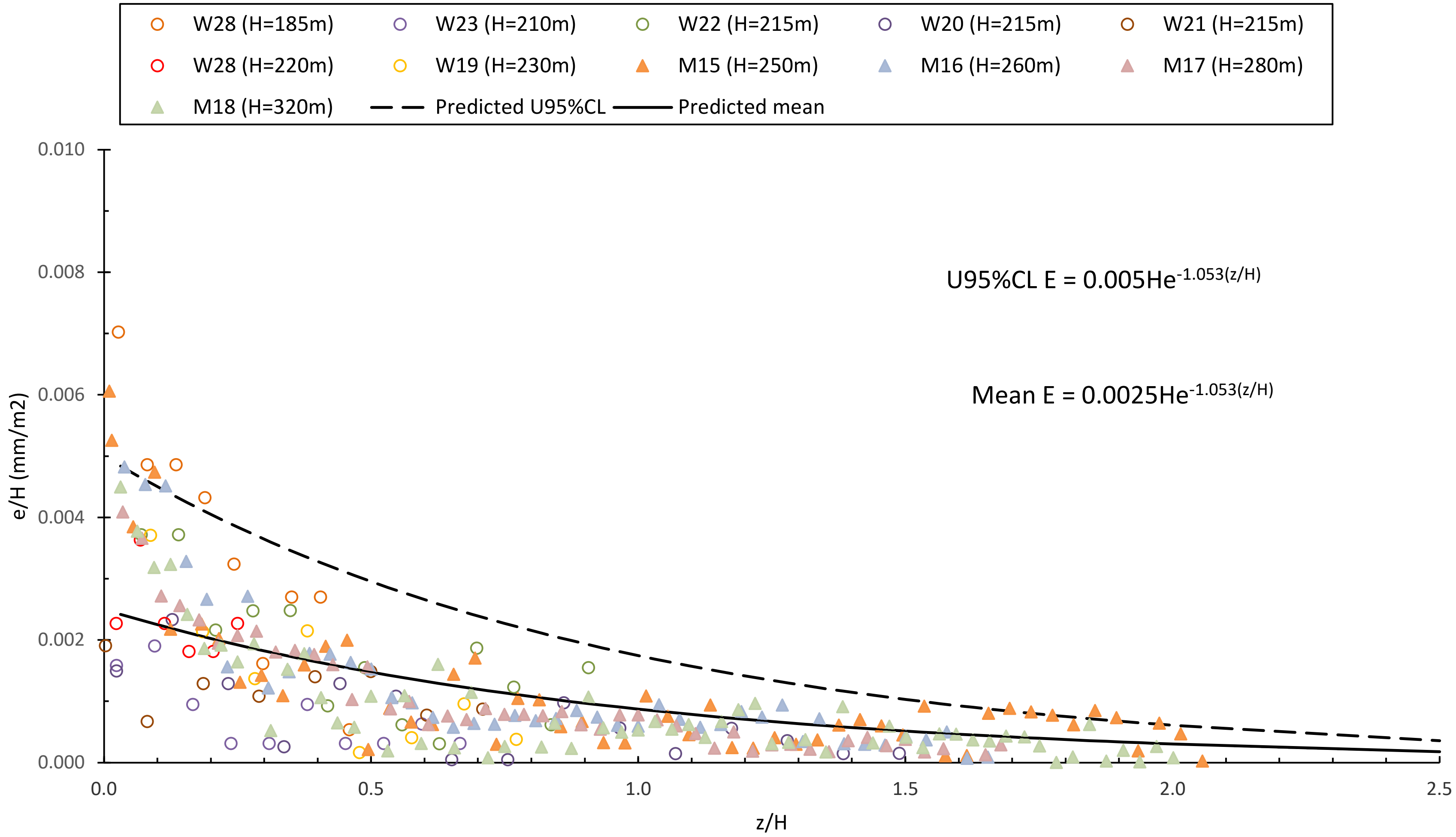
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model and Data for Horizontal Displacement Estimates around Longwalls in Southern Newcastle Coal Field: Centreline Data normalised to Cover Depth		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	16b



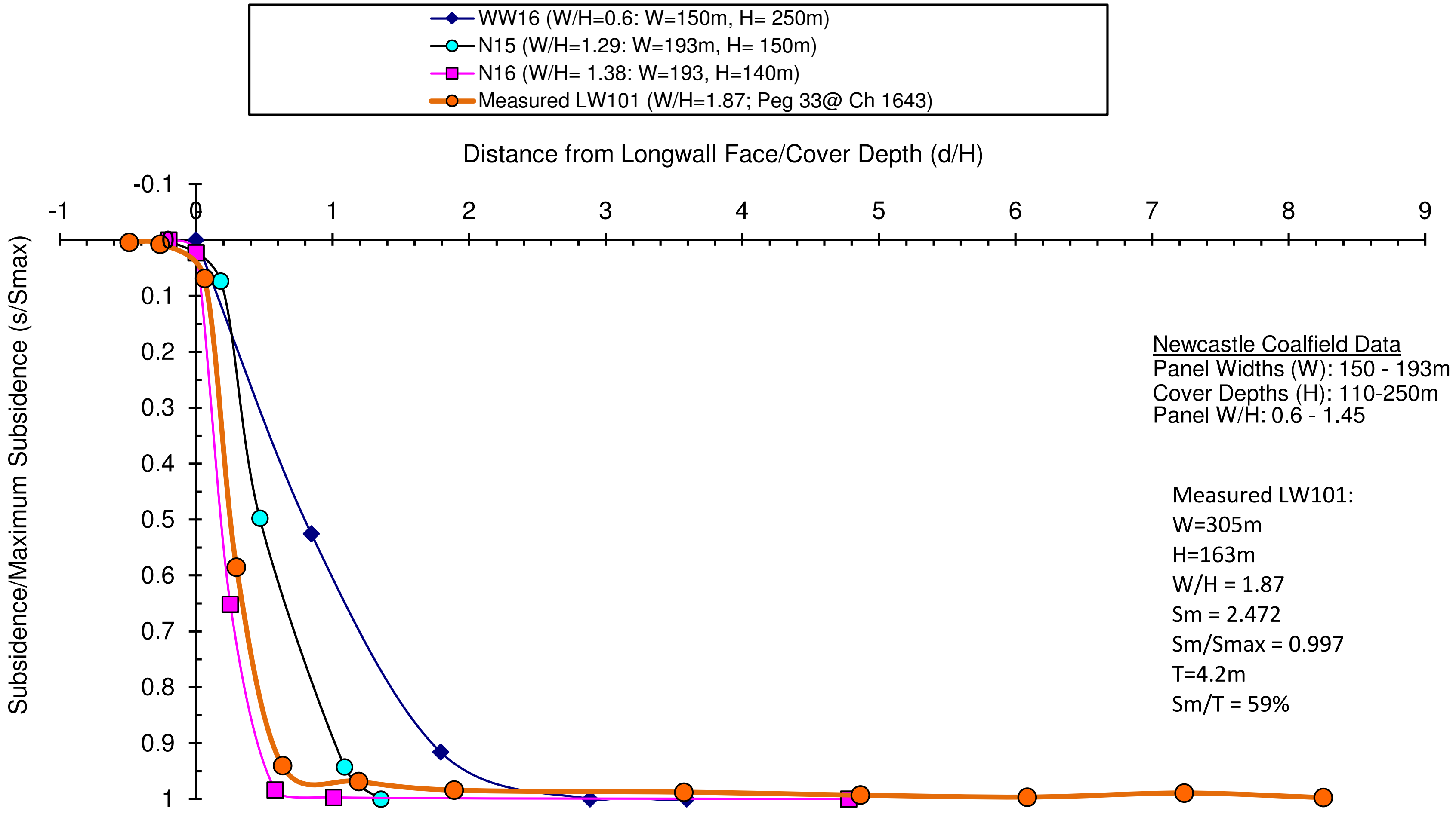
DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Model and Data for Horizontal Displacement Estimates around Longwalls in Southern Newcastle Coal Field: Crossline Data normalised to Cover Depth		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	16c



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8	
	Drawn:	S.Ditton			
	Date:	15.07.21	Title:	Empirical Model and Data for Horizontal Strain Estimates around Longwalls in Southern Newcastle Coal Field: Centreline Data	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 16d



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-004/8			
	Drawn:	S.Ditton					
	Date:	15.07.21	Title:	Empirical Model and Data for Horizontal Strain Estimates around Longwalls in Southern Newcastle Coal Field: Crossline Data			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	16e	



DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Operations Pty Ltd NAR-004/8		
	Drawn:	S.Ditton				
	Date:	15.07.21	Title:	Empirical Single Longwall Centreline Subsidence Development Prediction Model (based on Newcastle Coalfield Measurements and LW101 Data)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	17