A photograph of an underground mine tunnel. The walls are dark, jagged rock. Numerous metal rock bolts are drilled into the rock face. A large, curved metal structure, possibly a conveyor or part of a tunneling machine, is visible in the foreground. The lighting is dramatic, highlighting the textures of the rock and metal.

Appendix A

Subsidence
Assessment

Narrabri Underground Mine Stage 3 Extension Project

Environmental Impact Statement

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



Narrabri Coal Operations Pty Ltd

Mine Subsidence Assessment for the Narrabri Underground Mine Stage 3 Extension Project

DGS Report No. NAR-005/2

Date: 5 July 2020



5 July 2020

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

DGS Report No. NAR-005/2

Dear David,

**Subject: Mine Subsidence Assessment for the Narrabri Underground Mine Stage 3
Extension Project**

This report has been prepared in accordance with the brief for the above project.

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



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 Environmental Impact Statement for the proposed Narrabri Underground Mine Stage 3 Extension Project (the Project) at the Narrabri Mine.

The Project includes the extension of Longwalls (LW) 203 to 209 (which start in Mining Lease [ML] 1609 and extend into Mining Lease Applications [MLAs] 1 and 2). The new LW210 is located to the east of LW203 in MLA 1.

Longwall mining impacts within ML 1609 are approved, however, additional surface infrastructure is required to facilitate the Project. Furthermore, the Project would increase the current mining tenements by approximately 3,789 hectares (ha) and includes eight extended or new longwall blocks (LW203 to LW210).

Mining Geometry

The proposed mining geometry would be as follows:

- The lower 4.5 m of the Hoskissons Seam would be extracted with a nominal extraction height of approximately 4.3 m.
- The longwall void widths for LW 203 to 209 would range from approximately 399.7 m to 409.2 m. The previously approved longwall panels would be extended to the south by 6.1 km to 6.4 km giving total panel lengths ranging from 9.80 km to 10.26 km.
- The proposed longwall panel LW210 would be approximately 415 m wide and have a length of 3.93 km.
- The cover depth over the longwalls would range from 180 m to 420 m.
- The W/H for the proposed mining layout would range from 0.97 to 2.3, indicating *critical* to *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 to 209 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.
- Four and five heading mains panels are proposed between LW202 and 203 and between LW203 and 210. The total separation distances between the longwall panel voids would be 299 m and 222 m respectively.
- 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 m wide.
- The proposed chain pillar geometries would be ‘squat’ with width to height ratios¹ (w/h) ranging from 7.9 to 12.7.

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.

Surface Features

The surface conditions, land use and underground mining geometry in the Project Area would be similar to the completed LW101 to LW108A and approved LW109 to 111 and 201 to 209 in ML 1609.

The land use above the Project Area includes private land holdings and land owned by Narrabri Coal Operations Pty Ltd (NCOPL) over the eastern side of the site. The Pilliga East State Forest covers the western side. The eastern land 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 longwalls ranges from 290 metres (m) Australian Height Datum (AHD) to 400 m AHD. The surface terrain is generally flat with slopes of 1 degree (°) to 5°. Slopes increase to 10° to 35° in several of the ephemeral creeks and tributaries associated with Kurrajong Tributary 1, and Kurrajong and Tulla Mullen Creek Tributaries 1 to 3, which drain the Project Area towards the north-east and east. There are also several ridges and hillocks with steep rocky slopes between 15° and 40° and minor cliffs up to 12 m high above LW204 to 209. The ridges and hillocks have Pilliga Sandstone exposures with local topographic relief ranging between 10 m to 30 m above the surrounding plains.

Built features inside the Project Area include three dwellings with machinery sheds (now disused) inside the predicted angle of draw and six dwellings outside the likely zone of influence. Several unsealed access roads, farm dams, post and wire fences and contour banks are also present.

Subsidence Effect Predictions

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

The key outcomes of the results of the study are presented below for the proposed LW203 to 210:

- (i) First and Final maximum panel subsidence is likely to range between 2.40 m and 2.80 m (56 percent [%] to 65% of the extraction height).
- (ii) Maximum chain pillar subsidence is estimated to range between 0.20 m and 0.75 m for an average pillar height of 4.0 m under vertical stresses ranging from 13.6 megapascal (MPa) to 28.5 MPa. Pillar Factor of Safety values of 2.21 to 1.33 are estimated for a 3.7 m pillar height.
- (iii) Strain-hardening of the 'squat' pillars, due to core confinement and load sharing to adjacent goaf materials within the extracted panels, will result in eventual cessation of subsidence to within the ranges indicated.
- (iv) Maximum panel tilts are estimated to range from 17 millimetres per metre (mm/m) to 58 mm/m.

- (v) The maximum tensile strains are expected to range from 6 mm/m to 38 mm/m.
- (vi) The maximum compressive strains are also expected to range from 6 mm/m to 40 mm/m.
- (vii) The final goaf edge subsidence is predicted to range between 140 millimetres (mm) to 660 mm.
- (viii) Based on the predicted maximum panel subsidence and goaf edge subsidence, the predicted mean to Upper 95% Confidence Limit (U95%CL) AoD (to the 20 mm subsidence contour) for the proposed supercritical LW203 to 208 and 210 is estimated to range from 22° to 43°. For the critical LW209 ($0.9 < W/H < 1.2$) the AoD prediction ranges from 25° to 50°.

Based on the predicted range of maximum transverse tensile strains for the proposed LW203 to 210 (i.e. 6 mm/m to 38 mm/m), surface crack widths are estimated to range from approximately 100 mm to 350 mm in cohesionless soils (average of 240 mm) and from approximately 200 mm to 700 mm in cohesive soils or shallow rock (average of 480 mm).

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 Project Area:

- Surface cracking and shearing within tensile and compressive strain zones. Typical crack widths in relatively ‘flat’ terrain (slopes $< 18^\circ$) are estimated to range from 100 mm to 200 mm, with occasional ($< 5\%$ probability) cracks up to approximately 350 mm in sand or loam and approximately 700 mm in clay or rock.
- Light Detection and Ranging (LiDAR) surveys and ground truthing inspections indicate that there are approximately 15.1 ha of steep rocky slope (slope gradients 18° to 35° with heights ranging from 6 m to 26 m), 674 m or 3,003 square metres (m^2) of rock face features (cliffs between 2 m and 5 m high and > 20 m long) and 374 m or 3,621 m^2 of minor cliff (cliffs between 5 m and 10 m high and > 20 m long) within the Project Area.
- It is estimated that approximately 7.5 ha of steep slope would be subsided by up to 2.8 m. Subsidence is expected to cause cracking with maximum widths ranging from 440 mm to 920 mm, depths from 3 m to 15 m and lengths ranging from 30 m to 100 m based on observations in the Newcastle Coalfield. The impact to the total length of steep slope in the Project Area is estimated to range from 0.3% to 0.7%. The impacts are likely to be within the expected performance measure of limiting rock falls to a probability of $< 7\%$ within the Project Area.
- Approximately 371 m length or 513 m^2 face area of rock face features would be subsided by up to 2.8 m. Potential rock falls effecting 0.3% to 4.4% of the cliff faces in the Project Area are estimated. Crack widths due to tilt and strain are estimated to range between 350 mm to 380 mm with depths and lengths similar to the steep slopes. The impacts are likely to be within the expected performance measure limiting rock falls to $< 7\%$ within the Project Area.

- Approximately 124 m length or 378 m² face area of minor cliff would be subsided by up to 2.8 m with potential rock falls effecting 0.6% to 1.4% of the cliff faces. Crack widths due to tilt and strain is estimated to range between 410 mm to 470 mm with depths and lengths similar to the steep slopes. The impacts are likely to be within the expected performance measure limiting rock falls to < 5% within the Project Area.
- General and localised slope instability (soil and rock slides) along the minor cliffs and 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% (+/- 1.5°) along creeks.
- Connective cracking is estimated to range from 133 m to 282 m above the proposed panels (i.e. 62% to 88% of the cover depth; 0.51 to 0.77 times the effective panel width or 31 to 69 times the extraction height of 4.3 m).
- Direct hydraulic connection to the mine workings due to sub-surface fracturing is estimated to encroach within 22 m to 118 m depth below the surface, with the closest value occurring above the proposed LW210. 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 therefore 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 and 210) 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 to 209 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 18 potential ponding locations are assessed for the Project Area. The majority of potential ponding areas already exist and would develop further along the watercourses and likely to remain 'in-channel'. The maximum changes in pond depths are estimated to range from -0.1 m to 0.9 m (average of 0.6 m)².

Predicted Impacts - Aboriginal Heritage

- Aboriginal heritage sites have been identified in the Project Area. There are three sites of grinding grooves located along drainage lines above proposed LW205 and 210 on sandstone bedrock and boulders. The quality of the grooves vary from poor to excellent. There are also several areas with artefact scatters / individual artefact finds above LW203 to 206.
- The results of the impact assessment indicate that grinding grooves in bedrock are 'possible to likely' to be impacted while 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.
- Impact management strategies for Aboriginal cultural heritage sites are presented in the Aboriginal Cultural Heritage Management Plan (ACHMP) and have been developed in consultation with the Registered Aboriginal Parties. The Narrabri Mine ACHMP would be updated to incorporate the findings of the Aboriginal Cultural Heritage Assessment for the Project.

Predicted Impacts - Built Features

- There is one 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**.

² Positive values represent an increase in pond depth.

- A privately-owned incomplete dwelling is located between the LW204 and 205 chain pillars. Built features include an incomplete two-storey circular steel-framed residence with a diameter 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**.
- Impacts to the ‘Westhaven’ and the privately-owned 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 would allow significantly higher strain ($> 5 \text{ mm/m}$) and curvature $> 1 \text{ km}^{-1}$ to occur before significant impact develops. Similar impacts are assessed for the machinery sheds, with potential collapse due to frame distortion and connection failure.
- There is one further NCOPL-owned dwelling above the eastern goaf edge of LW210 (‘Yarranabee’). The dwelling is a secondary residence (cottage) on Yarranabee and consists of a single storey 20 m x 12 m weatherboard-clad timber-framed structure with slab on ground footings with adjoining 8 m x 8 m garage and carport. A 3.5 m diameter concrete water tank is located behind the garage. It is likely that the structure would be subsided between 135 mm to 90 mm by LW210 with tilts ranging from 4 mm/m to 0.5 mm/m, hogging curvature of 0.2 km^{-1} (radius of 5 km) and tensile strains of up to 3 mm/m. The building is likely to be ‘slightly’ impacted by mine subsidence effects in accordance with **AS2870, 2011**.
- Impacts to the ‘Yarranabee’ dwelling are likely to consist of cracking to concrete slabs $< 2 \text{ mm}$ wide and internal plasterboard wall and ceiling panels of $< 5 \text{ mm}$ wide, distorting of gutters requiring re-adjustment and tilting, and possible cracking of the tank footing slab and walls.
- Domestic power and telecommunications lines to the existing houses (except the one private landholder) 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).
- There are 41 farm dams that are located within the AoD from the proposed LW203 to 210. Twenty-four farm dams exist outside the limits of subsidence effect to the south of the proposed longwalls but within MLA 1. There are also nine farm dams located within the Project Area that are likely to have their inflow affected by upstream ponding above LW203 to 205.

- Several dams have already been subsided at the Narrabri Mine by LW101 to 108A but have not required remedial works to be implemented. Experience has shown that non-engineered farm dams and water storages would be susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques, and foundation type. NCOPL would repair and/or re-establish the dam's function and pre-mining storage capacity (if necessary) in consultation with the landholder. Repairs to the dams may therefore be required after mining LW203 to 210.
- 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 and tracks are likely to be damaged by cracking and shearing/heaving in the tensile and compressive strain zones respectively above the proposed longwall panels. Maximum tensile crack widths across or along roads are estimated to range between 60 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 also require re-grading or drainage remediation works after subsidence development. Warning signs should be erected outside the limits of mining impact.

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.

Non-conventional monitoring techniques such as cliffline reflectometry and/or drone surveys of minor cliff faces and crack location detection above the woodland areas are suggested.

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 210 are still reasonable. Consideration of further borehole extensometer and Vibrating Wire Piezometer installations are recommended, 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.

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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°.
Anomaly	Normally refers to unexpected subsidence effects and is caused by latent geological conditions (joints, faults, dykes) and results in a higher than expected subsidence effect or outlier 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	<p>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).</p> <p>Compressive strains are usually associated with concave curvatures near the middle of the panels or where valley closure effects develop.</p>
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	<p>A <i>critical</i> width extraction is one that is sufficiently wide compared to its mining depth and represents the transition from <i>sub-critical</i> to <i>super-critical</i> behaviour. Extraction widths narrower than critical extractions are termed <i>sub-critical</i>, and those larger are <i>super-critical</i>. The <i>critical</i> width at Narrabri may range between 0.7 and 1.2 times the cover depth and is a function of the overburden geology.</p>
Curvature	<p>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).</p> <p>i.e. $\text{Curvature} = (\text{Tilt between points A and B} - \text{Tilt between points B and C}) / (\text{average distance between points A to B and B to C})$ and usually expressed in 1/km.</p> <p>Radius of curvature is the reciprocal of the curvature is usually measured in km (i.e. $\text{Radius} = 1/\text{Curvature}$). The curvature is a measure of surface ‘bending’ and is usually associated with cracking.</p>
Development Height	<p>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.</p>
Extraction Height	<p>The height at which the seam is mined or extracted across a longwall face by the longwall shearer.</p>
Factor of Safety	<p>The ratio between the strength of a structure divided by the load applied to the structure. Commonly used to design underground coal mine pillars.</p>
First Workings	<p>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.</p>
Goaf	<p>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.</p>
Horizontal Displacement	<p>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).</p>

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	<p>The change in horizontal distance between two points at the surface after mining, divided by the pre-mining distance between the points.</p> <p>i.e. Strain = $([\text{post-mining distance between A and B}] - [\text{pre-mining distance between A and B}]) / (\text{pre-mining distance between A and B})$ and is usually expressed in mm/m.</p> <p>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).</p>
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	<p>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.</p> <p>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.</p>



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	The measurable surface movement parameters associated with mine.

Effects	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. $\text{Tilt} = (\text{subsidence at point A} - \text{subsidence at point B}) / (\text{distance between the points})$ 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

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).

NCOPL is seeking a new Development Consent under the State Significant Development provisions of Part 4 of the NSW *Environmental Planning and Assessment Act 1979* for the Narrabri Underground Mine Stage 3 Extension Project (the Project). This Subsidence Assessment forms part of the Environmental Impact Statement (EIS), which has been prepared to accompany the Development Application for the Project.

The Project includes the extension of Longwalls (LW) 203 to 209 (which start in Mining Lease [ML] 1609 and extend into the Mining Lease Applications [MLAs] 1 and 2) and the new LW210. Longwall mining impacts in ML 1609 are approved; however, additional surface infrastructure is required to facilitate the Project.

The Project would result in the extension of the mine life to 2044, and development of supporting surface infrastructure. Run-of-mine coal production would occur at a rate of up to 11 million tonnes per annum, consistent with the currently approved limit.

A detailed description of the Project is provided in Section 2 in the Main Report of the EIS.

2.0 Background

2.1 Proposed Project

The Project includes the extension of the currently approved LW203 to 209 in the Hoskissons Seam by 6.1 km to 6.4 km towards the south into MLAs 1 and 2. In addition, a 3.7 km long longwall (LW210) is proposed to the east of the extended longwalls within MLA 1. Altogether, including, and in the vicinity of the Angle of Draw (AoD) for the proposed LW203 to 210 represent the Project Area. The Project would increase the current mining tenements by 3,789 hectares (ha).

The sequence and extraction direction would be subject to further detailed mine planning, however, would generally be as follows:

- The modified LW203 to 209 panels would be extracted from east to west.
- The additional longwall to the east of LW203 (LW210) would be extracted after LW209.
- Due to underground horizontal stress conditions, LW203 to 209 would be retreated from north to south to avoid the major principal stress concentrating at the maingate (i.e. the north-east to south west orientated major principle stress will notch at the tailgate).
- LW210 will be extracted from south to north for operational reasons and likely to be in the ‘stress shadow’ of LW203.
- Sufficient width barrier pillars would protect the mains from additional longwall stresses.

The surface conditions, land use and mining geometry within MLAs 1 and 2 would be similar to the currently approved mining layouts within ML 1609 (LW101 to 111 and 201 to 209).

The Narrabri Mine has recently completed LW108A under the existing Extraction Plan Approval for LW107 to 110. The first six longwall panel voids were 306 metres (m) wide and the remaining five panels in the “100 series” are approximately 409 m wide. The longwall extraction height has ranged from 4.2 m to 4.3 m to date. Additional subsidence data has been included in this assessment since the Extraction Plan Approval for LW107 to 110 in 2017 (refer to **Ditton Geotechnical Services Pty Ltd [DgS], 2017**). This data has been reviewed and used to calibrate subsidence predictions for the Project.

The proposed mine plan and existing surface features are shown with cover depth (H) contours in **Figures 1a to 1h**. Surface level and pre-mining gradient contours with surface features are shown in **Figures 2a to 2c**.

Further details on mining geometry and surface features are presented in **Sections 5 and 7**.

2.2 Secretary's Environmental Assessment Requirements

In regard to this subsidence assessment, the EIS must address the following specific matters:

Subsidence – including an assessment of the likely **conventional** and **non-conventional** subsidence effects and impacts of the development, and the potential consequences of these effects and impacts on the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental value, taking into consideration:

- recorded regional and historic subsidence levels, impacts and environmental consequences.
- the potential extent of fracturing of the strata above the longwall panels; and
- the implementation of a comprehensive subsidence monitoring program which is capable of detecting vertical, horizontal and far-field subsidence movements.

Land – including:

- an assessment of the likely impact of the development on landforms (topography), including...:
- the potential subsidence impacts on cliffs, rock formations and steep slopes; and
- the long-term geotechnical stability of any new landforms;

...

Water – including:

...

- an assessment of potential flooding (addressed by others) and ponding impacts of the development;

...

Heritage – including an assessment of the likely Aboriginal and historic heritage (cultural and archaeological) impacts of the development;

Hazards - including an assessment of the likely risks to public safety, paying particular attention to potential subsidence risks...;

Rehabilitation and Final Landform – including an assessment of the likely economic impacts of the development, paying particular attention to:

...

- an assessment of the likely impacts of the development on existing landforms and topography, including justification of the final landform design and its long-term geotechnical stability;

- *a detailed description of the progressive rehabilitation measures that would be implemented for the development and how this rehabilitation would integrate with the final landform of the mine;*
- *a detailed description of the proposed rehabilitation and mine closure strategies for the development, including rehabilitation objectives, performance standards and completion criteria.*

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

3.0 Scope of Work

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

- Site inspections of the Project Area (conducted on 28/08/19 and 3 to 4/12/19).
- Description of the existing land use as context for the subsidence assessment.
- Identification and description of the pre-mining condition of natural surface features and existing development.
- 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 LW203 to 210, based on measured subsidence data for LW101 to 108A.
- Predicted surface cracking/deformations, ponding and sub-surface fracturing.
- Predicted heights of sub-surface cracking above the proposed longwalls (connective and discontinuous).
- Natural feature impact assessments (e.g. landforms [topography]; cliffs, rock formations, and steep slopes; geotechnical stability of new landforms; flooding and ponding; Aboriginal and historic heritage [cultural and archaeological]; and rehabilitation and final landform).
- Built feature impacts (e.g. dwellings, buildings, farm dams, powerlines, roads, fences, contour banks and other rural infrastructure).
- Discussion of impact remediation and adaptive management strategies (e.g. the ongoing use of subsidence monitoring data at the Narrabri Mine to inform predictions and management measures for the Project) to limit long-term degradation of the environment.

4.0 Methodology Overview

Conventional and non-conventional subsidence effects³ have been assessed for the proposed longwalls in the Project Area.

Conventional subsidence effect predictions of maximum longwall panel and chain pillar 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’ (2017) (SDPS[®]) was then calibrated to the empirical model profiles to derive the final subsidence contours for the Project 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 Extraction Plan 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 two 409 m wide panels (LW107 and 108A) with double chain pillar rows have been reviewed. Where necessary, the prediction model was updated to capture the measured subsidence effects as described below.

The maximum subsidence measured above the extracted 306 m wide panels (i.e. LW101 to 106) ranged from 53 percent (%) to 65% of the average extraction height (T). These values were not significantly different to the wider panels (i.e. 409 m wide LW107 and 108A) due to their critical to supercritical geometry (void width to cover depth ratio $[W/H > 1.2]$) and twin rows of inter-panel barrier pillars. Therefore, the same methodology can be used for the Project and similar predicted subsidence can be expected for the Project with 409 m wide longwall panels.

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 ML 1609 Stage 2 Environmental Assessment predictions [DgS, 2009]).

Non-conventional subsidence predictions are also included in this assessment for Kurrajong Tributary, Kurrajong Creek and Tulla Mullen Creek Tributaries 1 to 3.

³ see Glossary for subsidence parameter definitions.

The potential impacts to natural and built features have been estimated from predicted ‘credible worst-case’ mine subsidence and surface level contours derived from Light Detection and Ranging (LiDAR).

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 108A, 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 108A.

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

5.0 Mining Geometry

As part of the Project, the currently approved LW203 to 209 would be extended towards the south (**Figure 1a**). An additional longwall (LW210) would be added to the east of LW203 (**Figure 1b**). The longwall extraction sequence is proposed to generally occur from east to west.

Further details regarding the proposed mining geometry for the Project are provided below:

- The lower 4.5 m of the Hoskissons Seam would be extracted with a nominal extraction height of approximately 4.3 m (**Figures 3a and 3b**).
- The longwall void widths for LW 203 to 209 would range from approximately 399.7 m to 409.2 m. The previously approved longwall panels would be extended to the south by 6.1 km to 6.4 km giving total panel lengths ranging from 9.80 km to 10.26 km.
- The proposed longwall panel LW210 would be approximately 415 m wide and have a length of 3.93 km.
- The cover depth over the longwalls would range from 180 m to 420 m.
- The W/H for the proposed mining layout would range from 0.97 to 2.3, indicating *critical* to *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 to 209 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.
- Four and five heading mains panels are proposed between LW202 and 203 and between LW203 and 210. The total separation distances between the longwall panel voids would be 299 m and 222 m, respectively.
- 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 m wide.
- The proposed chain pillar geometries would be ‘squat’ with width to height ratios⁴ (w/h) ranging from 7.9 to 12.7.

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.



6.0 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 Project 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 quartzitic 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.

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

There are several north-west to south-west and north-east to north-west trending normal and reverse faults, which have throws ranging from 1 m to 5 m within the Hoskissons Seam.

7.0 Surface Features

7.1 General

The Project includes private land holdings and land owned by NCOPL over the eastern side of the site, with the Pilliga East State Forest covering the western side. The eastern land has historically been used for livestock grazing and some cereal crop farming and occasional orchard farming (e.g. olive grove). The western area is heavily vegetated with woodland areas consisting of dry sclerophyll forest associated with the Pilliga East State Forest (**Figures 1a and 1b**).

Topographic relief above the proposed longwalls ranges from 290 m Australian Height Datum (AHD) to 400 m AHD. The surface terrain is generally flat with slopes 1° to 5°. Slopes increase to 10° to 35° in several of the ephemeral creeks and tributaries (or gullies), which drain the Project Area towards the north-east and east. There are also several ridges with steep rocky slopes between 15° and 40° and minor cliffs up to 12 m high above LW204 to 209. The ridges and hillocks have Pilliga Sandstone exposures with local topographic relief ranging between 10 m to 30 m above the surrounding plains (**Figures 2a and 2b**).

Silty sand and sandy clay surface soils to 4 m depth are present in the Project Area and are mildly to highly erosive/dispersive. The clayey soils are associated with the outcropping Garrawilla Volcanics and overlying Purlawaugh formation, which exist mainly in MLA 1. Sand and clayey sand soils associated with the Pilliga Sandstone cover the majority of MLA 2 (**2rog Consulting, 2020**).

Sandy alluvial deposits exist along the creek channels with no rock exposures evident. The channels are typically incised with steep to very steep banks between 0.5 m to 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 features within the zone of expected subsidence include the following:

- Gently undulating terrain with ephemeral watercourses associated with Kurrajong Creek and its tributaries and Tulla Mullen Creek tributaries.
- Semi-cleared, agricultural land (predominately used for grazing cattle).
- Forested areas of the Pilliga East State Forest and adjacent margin.
- Steep rocky slopes up to 30 m high and minor sandstone cliffs or rock face features ranging from 2 m to 12 m high (i.e. Pilliga Sandstone exposures).
- Sub-surface groundwater aquifers at depths ranging from 5 m to 50 m (typically of poor quality) (**Aquaterra, 2009**).
- Two Aboriginal cultural heritage sites above LW205 and 210 (grinding grooves in sandstone outcrops) of ‘moderate’ and ‘low’ scientific significance, respectively (**Whincop Archaeology, 2020**).

- One privately-owned dwelling is partly constructed above LW204 and 205 chain pillars. An olive tree orchard is located south of the residence and, at the time of inspection, was in poor condition.
- One NCOPL-owned dwelling and machinery sheds exists above the proposed LW203 and 204 and one single storey NCOPL-owned dwelling is located above the Tailgate goaf edge of LW210 and can be accessed from Yarrabee Road.
- There are four privately-owned residences inside the Project Area that are located well outside the AoD to the east and south of the proposed longwall panels.
- Sixty-five farm dams for livestock watering (D1 - D65), which includes 41 dams that are within the AoD.
- Yarrabee Road and several unsealed rural access roads (including Scratch Road).
- Soil conservation (contour) banks and property fencing (post and wire).
- Two NCOPL-owned groundwater supply (stock and domestic) and five monitoring bores.
- Two Santos-owned groundwater monitoring boreholes (LW204).

The built features for the Project are also presented in **Figures 1c** and **1d** respectively. The Aboriginal Heritage site locations are shown in **Figures 1e** and **1f** and the groundwater supply and monitoring well locations are shown in **Figures 1g** and **1h**.

7.2 Existing Subsidence Monitoring Lines

Subsidence monitoring lines have been installed above LW101 to 108A and have been used to calibrate the subsidence model for the Project Area. The survey line locations and extracted longwall areas (goafs) are shown in **Figure 3d**.

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.

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 2c**). Ground-truthing of the LiDAR contours was conducted at Bulga Hill, Rocky Outcrop with Caves and Kurrajong Creek Tributary 1 (**Section 7.4**).

7.3 Definitions of Steep Slopes and Cliffs

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 definitions of cliff and steep slopes have been adopted in this report:

- "Cliff" - A continuous rock face greater than 20 m in length having a minimum height of 10 m and slope greater than 55°.
- "Minor Cliff" - Either (i) a continuous rock face greater than 20 m in length having a minimum height of 5 m to 10 m and a slope greater than 55° or (ii) a discontinuous rock face less than 20 m in length having heights greater than 10 m and slopes greater than 55°.
- "Rock Face Feature" - Either (i) a continuous rock face greater than 20 m in length with a height of 2 m to 5 m and slope greater than 55° or (ii) a discontinuous rock face less than 20 m in length having heights between 5 m and 10 m with slopes greater than 55°.
- "Steep Rocky Slope" - An area of land having a natural gradient ranging between 18° and 35° with numerous continuous rock outcrops with lengths greater than 20 m and heights greater than 5 m or discontinuous rock outcrops or rock face features with lengths less than 20 m, heights less than 5 m and slopes greater than 55°.
- "Steep Slope" - An area of land having a natural gradient ranging between 18° and 35° with nil to occasional rock outcrops (typically creek banks). Only steep slopes with overall heights greater than 5 m considered in the stability assessment.

The steep slopes and cliff faces within the 20 mm AoD have been identified from available LiDAR data (gridded to 1 m square elements) and ground truthing 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.

7.4 Ground Truthing

A Principal Geotechnical Engineer inspected the buildings, roads, creeks, steep slopes and cliffs at several locations above the Project Area (including Bulga Hill, Rocky Outcrop with Caves and 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 Project Area was then processed to develop a 3-D digital model of the landscape on a 1 m square grid. The location of cliff faces (length, slope and height) were ground-truthed with the mapping information and are clearly definable where slope gradients exceed 55° (**Figure 2c**).

Photographs of typical surface features are presented after the text.

7.5 Steep Rocky Slope and Cliff Face Descriptions

The south-western areas of LW204 to 209 are overlain by several broad ridges with steep, rocky slopes (18° to 35°) and minor sandstone cliffs up to 12 m high consisting of Pilliga Sandstone. The strata bedding generally dips towards the south-west to west at less than 5°. The incised slopes along the watercourses are discussed in **Section 7.6**.

Definitions of the cliff face and steep slope types present on the site are provided in **Section 7.3**. There are no 'Cliffs' present (by definition) in the Project Area. By definition, there are sixteen steep rocky slopes (S1 to S16) within the Project Area, two of which have eight 'minor' cliff faces (C1-C8) from 5 m to 12 m high and twelve rock face features (R1 to R12) from 2 m to 5 m high (Bulga Hill and Rocky Outcrop with Caves). There are two minor cliff sections at Bulga Hill between 10 m and 12 m high that are approximately 15 m long each (C3 and C5).

The minor cliff faces are sub-rounded to sheer, with faces sloping from 63° to 70°. The exposed strata on the minor cliff faces and steep rocky slopes consist of blocky, medium cross bedded quarzitic sandstone beds of low to medium strength (Unconfined Compressive Strength [UCS] ranges from 5 to 25 megapascals [MPa]). Small to large sandstone boulders (0.5 m to 3 m side dimensions) and weathered sandstone exposures form steep, rocky talus slopes below the minor cliff faces.

Cliff face development appears to have been controlled by the dominate sub-vertical joint sets (striking north-west, north-south, east-west and north-east). Finer grained sandstone units are present between the stronger units and have eroded more rapidly resulting in overhang development (with spans of 3 m to 4 m) and subsequent block release. On the western facing minor cliff faces, honeycomb weathering patterns in the sandstone have developed due to wind erosion.

The steep rocky slopes, rock face features and minor cliff faces identified within the Project Area from the longwalls are shown in **Figures 1a** and **1b** and summarised in **Table 1**.

7.6 Creek Banks

Based on **Figure 2c**, there are steep to very steep incised slopes along the ephemeral watercourses in the Project Area. Kurrajong Creek Tributary has 1 m to 3.5 m high banks that extend for 20 m to 120 m. Similar conditions exist along the Kurrajong Creek and the three Tulla Mullen Creek Tributaries (see **Appendix A [Photos 3, 4, 6 & 7]**).

Table 1 - Steep Slopes and Minor Cliff Faces in the Project Area

Feature No. (Photo#)	Easting	Northing	Crest RL	LW	Slope Height Z (m)	Crest Length L (m)	Slope Width B (m)	Slope Gradient Z/B (o)	Aspect (Dip Direction)
C1 (#13)	772870	6612859	358.1	207	6 - 8	35	3	63 - 69	SE
C2	772869	6612888	358.8	207	5	20	2.5	63	E
R1(#14)	772868	6612922	360.7	207	2 - 5	24	1.25	63 - 70	E
R2	772862	6612973	362.1	207	2 - 3	74	1.5	63 - 70	E
R3	772829	6612828	354.6	207	2 - 3	49	1.5	63 - 70	SE
S1	772829	6612852	368.0	207	8 - 22	450	32	35	E-SE
C3	773339	6610184	393.0	206	6 - 11	98	3 - 5	63 - 70	SW-W
C4 (#12)	773282	6610302	391.2	206	5 - 8	69	2.5 - 3	63 - 70	SW
C5	773408	6610183	398.2	206	5 - 12	66	2 - 5	63 - 70	NE
C6	773477	6610148	400.7	206	5 - 8	27	3.0 - 4.0	63 - 70	NE
C7	773412	6610092	392.8	206	5 - 6	33	2.5 - 3.0	63 - 70	SW
C8	773577	6610227	372.7	206	5 - 6	27	2.5 - 3.0	63 - 70	NE
R4	773219	6610319	383.0	206	2 - 4	41	1.0 - 2.5	63 - 70	SW
R5(#11)	773214	6610377	386.0	206	2 - 4	72	1.0 - 2.5	63 - 70	NE
R6	773282	6610335	390.0	206	2 - 5	74	1.0 - 2.5	63 - 70	SW
R7	773344	6610236	385.0	206	2 - 4	37	1.0 - 2.0	63 - 70	W
R8	773419	6610168	399.4	206	2 - 5	21	1.0 - 2.5	63 - 70	NE
R9	773478	6610142	400.0	206	2 - 5	60	1.0 - 2.9	63 - 70	NE
R10	773454	6610060	396.3	206	2 - 3	36	1.0 - 1.5	63 - 70	SW
R11	773502	6610056	398.0	206	2 - 4	33	1.0 - 2.3	63 - 70	SE
R12	773610	6610175	371.3	206	2 - 4	153	1.0 - 2.3	63 - 70	E
S2(#10)	773319	6610261	385.0	206	16 - 20	987	18 - 30	34 - 39	NE-SE-W
S3	773541	6610030	378.0	206	12 - 26	491	24 - 37	26 - 33	SE
Other Hills & Ridges (unnamed)									
S4	774377	6612858	344	204	8	38	21	21	NE
S5	774342	6612544	342	204	6	54	15	22	SE
S6	773922	6611057	357	205	8	40	18	24	SE
S7	772273	6610390	388	208	6 - 14	490	52	19	SE-E
S8	772442	6610171	376	208	6 - 16	484	35	25	SE

Table 1 (Cont...) - Steep Slope and Minor Cliff Faces in the Project Area

Feature No. (Photo#)	Easting	Northing	Crest RL	LW	Slope Height Z (m)	Crest Length L (m)	Slope Width B (m)	Slope Gradient Z/B (o)	Aspect (Dip Direction)
S9	772541	6611564	365	208	6	48	12.5	26	SE
S10	771940	6612378	383	209	6 - 8	103	15	28	SE-E-NW
S11	771636	6611963	384	209	6 - 8	198	20	22	SE
S12	774598	6617576	334	204	6 - 10	235	21	26	SE-S-E
S13	772987	6616760	356	207	5 - 10	210	25	21	SE
S14	773247	6620355	357	207	5 - 8	48	16	26	N-NW
S15	771826	6612824	371	209	5 - 7	74	19	20	SE-E
S16	772412	6615446	348	208	18	246	29	32	SE

Feature No. Key: C = Minor Cliff Face; R = Rock Face feature; S = Steep Rocky Slope.

8.0 Sub-Surface Conditions

8.1 Stratigraphy

Reference to the borehole logs in the Project 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 Project 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 Project, 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 Project Area is shown in **Figure 3c**.

Clayey to sandy red brown to yellow white soils exist over the Project Area to depths ranging from 1 m to 4 m.

Previous reviews of available borehole data (**Figures 4a** and **4b** show their location) 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).

8.2 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 (**Figures 3a** and **3b**). 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, 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 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 Project 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 9.2** 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 Project. 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 ML 1609 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.

8.3 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 4c**).

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 (**Section 10.3**).

9.0 Mine Subsidence Effect Predictions

9.1 General

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 5a**.

The multiple panel prediction is estimated by adding the strata sag or single panel subsidence to the chain pillar subsidence. Other factors also affect the multiple panel predictions and are discussed in the following sub-sections.

9.2 Single Longwall Panel Subsidence 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 subsidence⁵. 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 13 years, with the data collected for Narrabri LW101 to 108A progressively added as well. Plots of key subsidence prediction parameters used in the subsidence effect prediction curves are plotted against Panel W/H in **Figures 5b to 5d**.

The full subsidence profile for a single longwall is derived 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. SRP), the panel width (W), cover depth (H) and average extraction height (T)⁶.

⁵ Subsidence data for cases with an absence of massive strata is also included in the database.

⁶ 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.

It was identified during the **ACARP, 2003** project, that the observed maximum subsidence (normalised to the longwall extraction height) for a given panel geometry ratio (W/H), generally increases with cover depth. The subsidence cases were subsequently divided into several cover depth groups to enable the SRP due to the overburden geology to be assessed.

The relevant subsidence prediction curves and database cases for the Narrabri Mining Lease cover depth ranges are shown in **Figures 6a, 6b** and **6c**. The curves presented are DgS modifications of the original **ACARP, 2003** model curves also.

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

The goaf edge subsidence is a function of the panel W/H and the maximum panel subsidence. The goaf edge subsidence is a function of the maximum panel subsidence and W/H ratio. The ratio of the goaf edge to maximum panel subsidence follows a decaying power law and ranges from 1.0 to 0.1 for subcritical to supercritical panel geometries as shown in **Figure 6e**.

The AoD to the 20 mm of subsidence contour is the surface area that could be affected by mining of the Project longwalls. The AoD has been derived from the longwall database of measured draw angles for the Newcastle Coalfield and Narrabri Mine longwalls (**Figure 6f**). The data indicates the AoD is correlated with the goaf edge subsidence. Subsidence movements beyond the extent of the AoD to the 20 mm subsidence contour would be negligible and would be less than, or similar to, movements associated with the natural wetting and drying of surface soils.

9.3 Multiple Longwall Panel Subsidence Profile Prediction Models

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.

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 from the total pillar stress and the longwall extraction height and pillar development height (**Figure 6g**).

Multiple-panel subsidence profiles are then determined by the **ACARP, 2003** model by adding a proportion of the predicted final chain pillar subsidence less the first goaf edge subsidence.

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.

First S_{\max} for the Narrabri Mine longwalls have been predicted by adding 50% of the previous panels chain pillar subsidence to the single panel subsidence prediction. The Final S_{\max} is then determined by adding a further 70% of the predicted final subsidence over the chain pillars for the current panel after subsequent longwalls are extracted less the first goaf edge subsidence for the panels:

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

$$\text{Final } S_{\max} = \text{First } S_{\max} + 0.7 * (\text{Final } S_{p(i)} - 0.5 * \text{First } S_{goe(i)})$$

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

First and Final Subsidence profiles for each panel may then be estimated based on the maximum panel subsidence, the chain pillar subsidence, goaf edge subsidence and angle of draw for each case. The U95% Confidence Limits may also be added to estimate to derive the credible worst-case profiles for the proposed mining geometry.

9.4 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 expected location of the maximum differential subsidence effects above a longwall panel after mining occurs are shown in **Figure 6h**. The prediction models are verified against Narrabri Mine data (**Section 9.5**).

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 adjusted⁷.

Subsequent to the predictions of maximum subsidence effects, it is also necessary to provide the spatial distribution of the mine subsidence deformations over the Project 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.

9.5 Review of Measured Data v. Predictions

The subsidence prediction model used in the approved LW101 to LW106 Extraction Plan (**DgS, 2015a**) 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 2A** and **2B**. The predicted values are the mean and the U95%CL values.

⁷ 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 2A - 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	2.60
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	-	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 2B - 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 2B (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
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)	100 - 200
	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)	400
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)	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)	-

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.

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 6g**. Based on these outcomes, the mean values have been adopted for the estimated U95%CL profiles at the Narrabri Mine.

Less than 5% of the predicted goaf edge subsidence values and AoD predictions have been exceeded by >15% (**Figures 6e** and **6f**). 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 inferred AoD of > 54° was measured along crossline H with a subsidence of 37 mm recorded at the end of the crossline (after LW108A). The AoD to 20 mm of subsidence was linearly extrapolated to give the observed draw angle of 58° (**Figure 6i**). The accuracy of the estimate is questionable and should be checked against subsequent profiles that extend far enough out from the longwall limits.

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 has 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.

At this stage, the following U95%CL values have 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 and tensile strains above LW101 to 108A have also exceeded the predicted values at these locations and warrants further review when more data becomes available. Further discussion on crack width estimates are given **Section 10.2**.

The measured centreline subsidence profiles are shown with the predicted subsidence effect profiles in **Figures 7a** to **7h**.

The empirical models used to estimate maximum tilt, curvature and strain are also presented with measured Narrabri Mine data in **Figures 8a to 8d**, respectively. Points of note include:

- The maximum tilt database is satisfactorily captured by the empirical model (**Figure 8a**).
- Convex and concave curvature models capture 90% of the database (**Figures 8b and 8c**) 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 8d**).

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**. The updated subsidence effect contours for LW101 to 111 are shown in **Figures 9d to 9f**.

Based on the model validation work, it is concluded that the subsidence model should produce reasonably conservative predictions for the proposed LW203 to 210. Further review of surface impacts and subsidence effects above the wider longwalls are recommended.

9.6 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° to 58° 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° (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° 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° at the Narrabri Mine can be demonstrated by reviewing the AoDs to the key impact parameters of tilt, curvature and strain that have been measured to-date. Reference to **National Energy Research Development and Demonstration Program (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° AoD to the above parameters at the Narrabri Mine are summarised in **Table 7**. Histograms of the measured subsidence, tilt and tensile strain values measured at or outside a distance equivalent to the 26.5° AoD is presented in **Figures 9g to 9i**.

It is apparent from the results in **Table 2C** that a design AoD of 26.5° from the sides and ends of longwall panels to sensitive surface features is unlikely to impact a given feature.

Table 2C - 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)	<i>0.1 - 1.1</i>	<i>0.3 - 1.1</i>	<i>0.1 - 1.1</i>

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° (0.5 times cover depth) is considered to be an appropriate value for mine planning and impact management purposes near sensitive surface features (such as Bulga Hill) due to the low horizontal strains (less than 1.1 mm/m) associated with AoD values > 26.5°.

9.7 Subsidence Effect Predictions for LW203 to 210

9.7.1 General

Total and differential subsidence predictions have been assessed across the Project Area after:

- (i) each longwall block has been extracted; and
- (ii) mining of all of the proposed longwall panels.

The assessment 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.

As mentioned previously, it is considered that the development of subsidence impacts would not be affected by the spanning potential of the Garrawilla Volcanics, dolerite sill or Digby Conglomerate units and the subsidence above the chain pillars between the panels (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 for LW101 to 108A (**Section 9.2**).

In regard to the proposed mining geometries for LW203 to 210 and the subsidence model database, a comparison is made between each key parameter in Table 2D and **Figures 5b to 5d**. The table indicates that the prediction model database parameters generally bracket the proposed mining geometry.

Table 2D - Summary of Subsidence Model Geometry & Geology Ranges

Parameter	Proposed LW203 to 210	Modified ACARP, 2003
Panel Width, W (m)	401.2- 415.4	34 - 409
Cover Depth, H (m)	180 - 420	50 - 510
Panel W/H Ratio	0.9 - 2.3	0.2 - 6.8
Longwall Extraction Height, T (m)	4.3	1.05 - 4.8*
Gateroad Development Height, h (m)	3.7	2.0 - 3.8
TG Chain Pillar Width, w (m)	29 to 47	16 - 55
TG Chain Pillar Width/Pillar Height Ratio (w/h)	7.9 - 12.7	7.5 - 15
TG Chain Pillar Width/Cover Ratio, (w/H)	0.12 - 0.14	0.06 - 0.38
Massive Strata Unit Thickness t (m) (conglomerate and sandstone)	10 - 25	5 - 60
Strata SRP	Low - Moderate	Low - High

* - includes 62 out of 136 cases from Newcastle Coalfield and 8 cases from Narrabri with mining heights > 4 m.

It is therefore assessed that the subsidence predictions for the proposed longwalls should be reasonably accurate with minimal extrapolation required outside the model data sets.

The outcomes of the subsidence assessment are presented in the following sections.

9.7.2 Maximum Single Panel Subsidence

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 3** and based on the **maximum** extraction height (T) of 4.3 m. The values were determined along five representative crosslines XLs 6 to 10 (**Figures 1a** and **1b** show their location).

The results of the single panel spanning assessment indicate that the maximum panel subsidence for the ‘no spanning’ volcanic or conglomerate units would range between 2.04 m and 2.67 m (48% to 62% T) as shown in **Figures 10a** to **10c**.

The single panel subsidence values predicted above would be used with the chain pillar and goaf edge subsidence to estimate the multi-panel subsidence in the following sections.

9.7.3 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) and the development height (h=3.7 m) or $T_{av} = 4.0$ m. The results are summarised for representative crosslines XL6 to XL10 in **Table 4**.

The predicted first subsidence over the chain pillar pairs (S_p First) between the extracted panels LW203 to 209 is estimated to range from 0.17 m to 0.65 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 0.20 m to 0.75 m (an overall increase of between 11% and 17% between first and final subsidence values); see **Figure 10d**.

Based on an abutment angle of 21° , the final vertical stress acting on the Project Area pillars is assessed to range from 13.7 MPa to 28.5 MPa, with pillar FoS values ranging from 2.21 to 1.33 for a 3.7 m pillar height. The proposed chain pillar geometries are ‘squat’ with a w/h range of 7.9 to 12.7 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. Based on the probability of failure criteria described in **ACARP, 1998a**, the pillars may not be considered to be long-term stable with FoS values ranging between 1.3 and 1.6 in some locations.

However, as the chain pillars are isolated between longwall goaves, which have consolidated 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.

The predicted final subsidence values given in **Table 4** are therefore long-term post-mining values for the pillars.

Table 3 - Predicted Maximum Single Panel Subsidence for LW203 to 210

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
	8	402.9	199	2.02	4.3	0.59	0.62	2.54	2.67
	9	402.9	224	1.80	4.3	0.59	0.62	2.54	2.67
	10	402.9	220	1.83	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
	8	402.4	222	1.81	4.3	0.59	0.62	2.54	2.67
	9	402.4	247	1.63	4.3	0.59	0.62	2.54	2.67
	10	402.4	260	1.55	4.3	0.59	0.62	2.53	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
	8	399.7	250	1.60	4.3	0.59	0.62	2.54	2.67
	9	399.7	278	1.44	4.3	0.59	0.62	2.54	2.67
	10	399.7	289	1.38	4.3	0.59	0.62	2.52	2.67
206	6	399.7	297	1.35	4.3	0.58	0.62	2.48	2.67
	7	399.7	312	1.28	4.3	0.56	0.62	2.42	2.63
	8	399.7	285	1.40	4.3	0.59	0.62	2.54	2.67
	9	399.7	304	1.31	4.3	0.57	0.62	2.45	2.67
	10	399.7	305	1.31	4.3	0.57	0.62	2.45	2.66
207	6	402.2	330	1.22	4.3	0.55	0.62	2.36	2.57
	7	402.2	318	1.26	4.3	0.56	0.62	2.40	2.62
	8	402.2	320	1.26	4.3	0.56	0.62	2.40	2.61
	9	402.2	321	1.25	4.3	0.56	0.62	2.39	2.61
	10	402.2	319	1.26	4.3	0.56	0.62	2.40	2.61
208	6	401.2	352	1.14	4.3	0.53	0.61	2.28	2.50
	7	401.2	323	1.24	4.3	0.55	0.62	2.38	2.60
	8	401.2	346	1.16	4.3	0.53	0.62	2.30	2.51
	9	401.2	340	1.18	4.3	0.54	0.62	2.32	2.53
	10	401.2	356	1.13	4.3	0.53	0.61	2.27	2.48
209	6	409.2	365	1.12	4.3	0.49	0.62	2.26	2.48
	7	409.2	346	1.18	4.3	0.51	0.62	2.32	2.54
	8	409.2	380	1.08	4.3	0.48	0.61	2.22	2.43
	9	409.2	376	1.09	4.3	0.49	0.61	2.23	2.44
	10	409.2	400	1.02	4.3	0.47	0.61	2.12	2.33
210	9	415.4	184	2.26	4.3	0.59	0.62	2.54	2.67
	10	415.4	180	2.31	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.

Table 4 - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model

LW	XL	Panel Width W (m)	Cover Depth H (m)	Chain Pillar Pair Widths w (m)	Pillar Height (m)		Chain Pillar Stress (MPa)	Pillar FoS under SA Loading Conditions	S _p First* (m)		S _p Final* (m)	
					T _{av}	h			Mean	U95%	Mean	U95%
203	6	402.9	214	2 x 29.4	4.0	3.7	15.3	1.57	0.20	0.39	0.24	0.43
	7	402.9	207	2 x 29.4	4.0	3.7	15.0	1.60	0.20	0.39	0.24	0.43
	8	402.9	199	2 x 29.4	4.0	3.7	13.6	1.76	0.17	0.27	0.20	0.30
	9	402.9	224	2 x 29.4	4.0	3.7	16.3	1.47	0.22	0.41	0.27	0.46
	10	402.9	220	2 x 29.4	4.0	3.7	16.6	1.45	0.23	0.42	0.27	0.47
204	6	402.4	238	2 x 32.6	4.0	3.7	16.8	1.62	0.23	0.33	0.28	0.38
	7	402.4	244	2 x 32.6	4.0	3.7	17.9	1.52	0.26	0.45	0.31	0.50
	8	402.4	222	2 x 32.6	4.0	3.7	15.2	1.78	0.20	0.30	0.24	0.34
	9	402.4	247	2 x 32.6	4.0	3.7	18.0	1.51	0.26	0.45	0.32	0.51
	10	402.4	260	2 x 32.6	4.0	3.7	19.4	1.40	0.30	0.49	0.36	0.55
205	6	399.7	263	2 x 34.6	4.0	3.7	19.2	1.53	0.29	0.48	0.35	0.54
	7	399.7	280	2 x 34.6	4.0	3.7	21.0	1.40	0.34	0.53	0.41	0.60
	8	399.7	250	2 x 34.6	4.0	3.7	17.8	1.65	0.26	0.35	0.31	0.41
	9	399.7	278	2 x 34.6	4.0	3.7	20.5	1.43	0.33	0.52	0.39	0.59
	10	399.7	289	2 x 34.6	4.0	3.7	21.4	1.37	0.35	0.54	0.42	0.61
206	6	399.7	297	2 x 37.1	4.0	3.7	22.0	1.47	0.37	0.56	0.45	0.64
	7	399.7	312	2 x 37.1	4.0	3.7	22.6	1.43	0.39	0.58	0.47	0.66
	8	399.7	285	2 x 37.1	4.0	3.7	20.8	1.56	0.34	0.53	0.40	0.59
	9	399.7	304	2 x 37.1	4.0	3.7	22.1	1.46	0.37	0.57	0.45	0.64
	10	399.7	305	2 x 37.1	4.0	3.7	22.1	1.46	0.37	0.57	0.45	0.64
207	6	402.2	330	2 x 38.6	4.0	3.7	25.0	1.33	0.46	0.65	0.55	0.75
	7	402.2	318	2 x 38.6	4.0	3.7	22.6	1.51	0.39	0.58	0.47	0.66
	8	402.2	320	2 x 38.6	4.0	3.7	23.8	1.44	0.42	0.62	0.51	0.70
	9	402.2	321	2 x 38.6	4.0	3.7	23.6	1.45	0.42	0.61	0.50	0.69
	10	402.2	319	2 x 38.6	4.0	3.7	24.2	1.42	0.44	0.63	0.52	0.71

Table 4 (Cont...) - Predicted Chain Pillar Subsidence based on Modified ACARP, 2003 Empirical Model

LW	XL	Panel Width W (m)	Cover Depth H (m)	Chain Pillar Pair Widths w (m)	Pillar Height (m)		Chain Pillar Stress (MPa)	Pillar FoS under SA Loading Conditions	S _p First* (m)		S _p Final* (m)	
					T _{av}	h			Mean	U95%	Mean	U95%
208	6	401.2	352	2 x 47.1	4.0	3.7	23.8	1.97	0.42	0.52	0.51	0.60
	7	401.2	323	2 x 47.1	4.0	3.7	21.2	2.21	0.35	0.44	0.42	0.51
	8	401.2	346	2 x 47.1	4.0	3.7	24.0	1.96	0.43	0.53	0.52	0.61
	9	401.2	340	2 x 47.1	4.0	3.7	23.4	2.00	0.41	0.51	0.50	0.59
	10	401.2	356	2 x 47.1	4.0	3.7	25.4	1.84	0.47	0.57	0.57	0.67
209	6	409.2	365	1 x 47.1	4.0	3.7	24.6	1.90	N.A.	N.A.	N.A.	N.A.
	7	409.2	346	1 x 47.1	4.0	3.7	22.7	2.07	N.A.	N.A.	N.A.	N.A.
	8	409.2	380	1 x 47.1	4.0	3.7	26.2	1.79	N.A.	N.A.	N.A.	N.A.
	9	409.2	376	1 x 47.1	4.0	3.7	25.8	1.82	N.A.	N.A.	N.A.	N.A.
	10	409.2	400	1 x 47.1	4.0	3.7	28.5	1.65	N.A.	N.A.	N.A.	N.A.
210	9	415.4	184	<i>195</i>	4.0	3.7	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	10	415.4	180	<i>195</i>	4.0	3.7	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

SA = Single abutment loading applies to each chain pillar in three heading gate roads; * - The chain pillars referred to in the above table are on the maingate side of panels. *Italics* - total barrier width (includes pillars of varying width); Pillar FoS based on the gateroad development height, h. Chain pillar subsidence based on average between development height and maximum longwall extraction height (i.e. $T_{av} = (T + h)/2$)

9.7.4 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 28.5 MPa give a Bearing Capacity FoS range of 3.3 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.

Further review of pillar stability and subsidence during the mining of LW109 to 111 is therefore recommended.

9.7.5 Goaf Edge Subsidence Prediction

Based on the modified **ACARP, 2003** model, the mean final goaf edge subsidence predictions for LW203 to 210 range from 0.14 m to 0.28 m for the proposed longwalls. The final Upper 95% CL values range from 0.34 m to 0.66 m.

The results are presented on **Figure 10e**.

9.7.6 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 208 and 210 is estimated to range from 22° to 43°. For the critical LW209 ($0.9 < W/H < 1.2$) the AoD prediction ranges from 25° to 50°.

The results are presented on **Figure 10f**.

Based on the above and as discussed in **Section 9.5**, the following U95%CL values have been adopted for the 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 U95%CL AoD line is shown in **Figures 1a** and **1b**.

9.7.7 Multiple Panel Subsidence Prediction

Based on the predicted maximum single panel, chain pillar and goaf edge subsidence values derived from the **ACARP, 2003** model, the mean and worst-case (U95%CL) first and final maximum multi-panel subsidence predictions (and associated impact parameters) are summarised in **Table 5** for representative crosslines (XLs 6 to 10) for the proposed LW203 to 210.

The predicted U95%CL values may be exceeded occasionally (<5% of the time) due to local discontinuous strata movements (i.e. tensile cracking or compressive shearing) associated with geological structure or topographic interaction.

The predictions have included the outcomes of the subsidence data review presented in **Section 9.2**.

The predicted mean and credible worst-case (U95%CL) subsidence effect results for LW203 to 210 are summarised below:

- **First maximum panel subsidence** ranges from 2.40 m to 2.75 m (56%T to 64%T).
- **Final maximum panel subsidence** ranges from 2.54 to 2.80 m (59%T to 65%T).
- **Final maximum chain pillar subsidence** ranges from 0.27 m to 0.75 m (5%T to 17%T).
- **Final maximum panel tilt** ranges from 17 mm/m to 58 mm/m.
- **Final maximum panel concave curvatures** range from 0.60 km⁻¹ to 4.03 km⁻¹ (radii of curvature 1.7 km to 0.25 km).
- **Final maximum panel convex curvatures** range from 0.56 km⁻¹ to 3.78 km⁻¹ (radii of curvature 1.79 km to 0.26 km).
- **Final maximum panel compressive strains** range from 6 mm/m to 40 mm/m.
- **Final maximum panel tensile strains** range from 6 mm/m to 38 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).

9.7.8 Subsidence Profile Predictions

The predicted U95%CL subsidence profiles for LW203 to 209 panels are presented along XL6 (**Figures 11a to 11c**) with LW203 to 210 along XL10 (**Figures 11d to 11f**).

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.

Table 5 - Predicted First and Final Maximum Subsidence Effects for LW203 to 210 (Mean & U95%CL)

LW #	XL #	Panel Width W (m)	Cover Depth H (m)	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)			
				Max	Mean			Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Tensile		Compressive	
																Mean	U95% CL	Mean	U95% CL
203	6	402.9	214	4.3	4.0	1.88	2 x 29.4	2.57	2.75	2.61	2.80	0.24	0.42	33	49	14	28	15	30
	7	402.9	207	4.3	4.0	1.95	2 x 29.4	2.54	2.75	2.57	2.80	0.24	0.41	34	51	15	30	16	32
	8	402.9	199	4.3	4.0	2.02	2 x 29.4	2.54	2.75	2.55	2.80	0.20	0.29	35	53	16	32	17	34
	9	402.9	224	4.3	4.0	1.80	2 x 29.4	2.58	2.75	2.62	2.80	0.27	0.44	31	46	13	26	14	28
	10	402.9	220	4.3	4.0	1.83	2 x 29.4	2.57	2.75	2.62	2.80	0.27	0.45	32	48	13	27	14	29
204	6	402.4	238	4.3	4.0	1.69	2 x 32.6	2.58	2.75	2.62	2.80	0.28	0.37	28	42	11	23	12	24
	7	402.4	244	4.3	4.0	1.65	2 x 32.6	2.58	2.75	2.62	2.80	0.31	0.49	27	41	11	22	12	23
	8	402.4	222	4.3	4.0	1.81	2 x 32.6	2.58	2.75	2.62	2.80	0.24	0.33	31	47	13	26	14	28
	9	402.4	247	4.3	4.0	1.63	2 x 32.6	2.58	2.75	2.62	2.80	0.32	0.49	27	40	11	21	11	23
	10	402.4	260	4.3	4.0	1.55	2 x 32.6	2.58	2.75	2.62	2.80	0.36	0.54	25	37	10	19	10	21
205	6	399.7	263	4.3	4.0	1.52	2 x 34.6	2.58	2.75	2.62	2.80	0.35	0.53	24	37	9	19	10	20
	7	399.7	280	4.3	4.0	1.43	2 x 34.6	2.58	2.75	2.62	2.80	0.41	0.59	22	33	8	17	9	18
	8	399.7	250	4.3	4.0	1.60	2 x 34.6	2.58	2.75	2.62	2.80	0.31	0.40	26	40	10	21	11	22
	9	399.7	278	4.3	4.0	1.44	2 x 34.6	2.58	2.75	2.62	2.80	0.39	0.57	23	34	8	17	9	18
	10	399.7	289	4.3	4.0	1.38	2 x 34.6	2.58	2.75	2.62	2.80	0.42	0.60	21	32	8	16	8	17
206	6	399.7	297	4.3	4.0	1.35	2 x 37.1	2.58	2.75	2.62	2.80	0.45	0.62	20	31	7	15	8	16
	7	399.7	312	4.3	4.0	1.28	2 x 37.1	2.58	2.75	2.62	2.80	0.47	0.64	19	29	7	13	7	14
	8	399.7	285	4.3	4.0	1.40	2 x 37.1	2.58	2.75	2.62	2.80	0.40	0.58	22	33	8	16	9	17
	9	399.7	304	4.3	4.0	1.31	2 x 37.1	2.58	2.75	2.62	2.80	0.45	0.63	20	30	7	14	8	15
	10	399.7	305	4.3	4.0	1.31	2 x 37.1	2.58	2.75	2.62	2.80	0.45	0.63	20	30	7	14	7	15
207	6	402.2	330	4.3	4.0	1.22	2 x 38.6	2.54	2.75	2.62	2.80	0.60	0.73	18	26	6	12	6	13
	7	402.2	318	4.3	4.0	1.26	2 x 38.6	2.58	2.75	2.62	2.80	0.50	0.65	19	28	6	13	7	14
	8	402.2	320	4.3	4.0	1.26	2 x 38.6	2.56	2.75	2.62	2.80	0.55	0.69	18	28	6	13	7	14
	9	402.2	321	4.3	4.0	1.25	2 x 38.6	2.58	2.75	2.62	2.80	0.54	0.68	18	27	6	13	7	13
	10	402.2	319	4.3	4.0	1.26	2 x 38.6	2.58	2.75	2.62	2.80	0.56	0.70	18	28	6	13	7	14

Table 5 (Cont...) - Predicted First and Final Maximum Subsidence Effects for LW203 to 210 (Mean & U95%CL)

LW #	XL #	Panel Width W (m)	Cover Depth H (m)	Extraction Height T (m)		W/H Ratio	Pillar Width, w_{ep} (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)			
				Max	Mean			Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Mean	U95% CL	Tensile		Compressive	
																Mean	U95% CL	Mean	U95% CL
208	6	401.2	352	4.3	4.0	1.14	2 x 47.1	2.51	2.74	2.62	2.80	0.55	0.60	17	26	6	12	6	12
	7	401.2	323	4.3	4.0	1.24	2 x 47.1	2.58	2.75	2.62	2.80	0.45	0.50	18	27	6	12	7	13
	8	401.2	346	4.3	4.0	1.16	2 x 47.1	2.51	2.74	2.62	2.80	0.55	0.60	17	26	6	12	6	12
	9	401.2	340	4.3	4.0	1.18	2 x 47.1	2.53	2.75	2.62	2.80	0.53	0.58	17	26	6	12	6	12
	10	401.2	356	4.3	4.0	1.13	2 x 47.1	2.49	2.72	2.62	2.80	0.61	0.66	17	26	6	12	6	12
209	6	356.7	365	4.3	4.0	1.12	1 x 40.6	2.47	2.71	2.62	2.80	-	-	17	25	6	11	6	12
	7	356.7	346	4.3	4.0	1.18	1 x 40.6	2.50	2.73	2.62	2.80	-	-	17	25	6	11	6	12
	8	356.7	380	4.3	4.0	1.08	1 x 40.6	2.43	2.67	2.62	2.80	-	-	17	25	6	11	6	12
	9	356.7	376	4.3	4.0	1.09	1 x 40.6	2.44	2.67	2.62	2.80	-	-	17	25	6	11	6	12
	10	356.7	400	4.3	4.0	1.02	1 x 40.6	2.40	2.64	2.62	2.80	-	-	17	25	6	11	6	12
210	9	415.4	184	4.3	4.0	2.26	<i>221.3</i>	2.54	2.75	2.54	2.79	-	-	38	57	18	36	19	39
	10	415.4	180	4.3	4.0	2.31	<i>221.3</i>	2.54	2.75	2.54	2.79	-	-	39	58	19	38	20	40

* - Predicted tilt and strains are 'smooth' to 'discontinuous' profile values (mean to U95%CL); subsidence, tilt and strain measurements may exceed the predicted U95%CL values by up to 1.15, 1.2 and 2 times, respectively, 5% of the time (i.e. occasionally or at the starting ends of the panels due to first goafing effects); *italics* - includes barrier pillars, gateroad pillars and mains pillars.

SDPS[®] versus **ACARP, 2003** model outcomes are presented in **Figures 12a to 12c** for subsidence, tilt and strain profiles along XL6 and **Figures 12d to 12f** for XL10.

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.

9.7.9 Prediction of Subsidence Effect Contours

Credible worst-case subsidence contours for the extended mining layout have been derived using the **SDPS[®]** program from the predicted subsidence profiles along XLs 6 to 10. The **SDPS[®]** model was calibrated to the predicted subsidence profiles to within 10%.

The outcome of the **SDPS[®]** model calibration exercise is summarised in **Table 6**.

Table 6 - SDPS[®] Model Calibration Summary

Input Parameters	Value
Panel No.s (refer to Figures 1a and 1b)	203 - 210
Panel Void Width, W (m)	401.2 - 415.4
Cover Depth, H (m)	180 - 420
Average Extraction Height, T (m)	4.3
W/H range	0.95 - 2.31
SRP	Low
Maximum Final Panel Subsidence (U95%CL), S_{max} (m)	2.80
S_{max}/T for Panels	0.65
Solid Chain Pillar Widths (m)	2 x 29.4 to 2 x 47.10
Gate Road Heading and Cut-through Widths (m)	5.4
Chain Pillar Pair Subsidence (m)	0.2 - 0.83
Calibration Results for Best Fit Solution to the Modified ACARP, 2003 Model Predictions[^]	Optimum Values
Influence Angle (tan[beta])	1.8 - 1.5
Influence Angle (°)	56 - 61
Supercritical Subsidence Factor for Panels and Pillars (S_{max}/T)	65
Distance to Inflexion Point from Rib-sides (m)	35 - 126
Inflexion Point Location (d) from Rib-side/Cover Depth (H): d/H	0.25 - 0.39

[^] - These values provide best fit to Modified **ACARP, 2003** profiles only and are due to the effect of calibrating **SDPS** to multiple panels with compressing chain pillars (i.e. they should not be used other than for **SDPS** input values).

The results of the analysis indicate that the majority of the predicted tensile and compressive **SDPS[®]** strains fell within +/- 50% of the modified **ACARP, 2003** model predictions. This result is also considered reasonable in the context that the **ACARP, 2003** model represents measured profile data that includes strain concentration effects such as cracking and shearing.

As mentioned earlier, this ‘discontinuous’ type of overburden behaviour can increase ‘smooth’ profile strains by two to four times locally. The predicted worst-case subsidence effects provided in this study should encapsulate approximately 95% of the measured values if the model is calibrated to a representative range of data for a given mining geometry in similar geological conditions.

Predictions of final subsidence contours (U95%CL) for the northern end of LW203 to 209 are shown in **Figure 13a**. Predictions of final subsidence contours (U95%CL) for the southern end of LW203 to 209 and LW210 are shown in **Figure 13b**.

Associated subsidence effect contours of principal tilt and horizontal strain have been subsequently derived using the calculus module provided in **Surfer12[®]** and the predicted subsidence contours. The outcomes are shown in **Figures 13c, 13d** (tilt) and **13e, 13f** (strain) for the above longwall panel areas respectively.

The pre-mining surface levels above the proposed LW203 to 210 are shown in **Figures 14a** and **14b**. The predicted post-mining surface levels have been generated from the pre-mining surface level and subsidence contours and are shown in **Figures 14c** and **14d**.

Subsidence impacts to the natural and built surface features within the Project Area are assessed in **Section 10**.

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 Project 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 7**, and are based on probabilistic terms used in **AGS, 2007** and **Vick, 2002**.

Table 7 - 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 fractures 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 209 it would be located between 40 m and 102 m from the panel ribs. Tensile cracks can also develop above chain pillars that are located between extracted panels.

The compressive shear fractures or 'heaving' zones (if they occur) will generally develop in the central area above the longwall panel and inside the inflexion points. 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 two or three and at a spacing of 8 m to 12 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 the modified ML 1609 Mining Layout at the Narrabri Mine, ranged from 20 mm to 250 mm within the limits of extraction (DgS, 2015b). 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.

Recent 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.
- North/South orientated cracks to a depth of 800 mm with widths ranging from 1.0 m to 1.8 m above the chain pillars between LW107 and 108A along a similarly orientated tributary of Pine Creek. The cover depth was 250 m and measured tensile strains were approximately 10 mm/m. 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.

It was therefore 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 2B**). The mean and U95%CL crack widths (δ) are therefore:

mean δ = $280/20 \times 8 \times 1 = 112$ mm (deep cohesionless soils)

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

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

U95%CL δ = $280/20 \times 16 \times 2 = 448$ 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. However, more cracking geometry data (width, depth, length and spacing) is required to allow the median and 95th percentiles to be estimated more confidently.

Cracks in cleared areas above LW101 to 107 have been 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.

10.2.3 Predicted Effects and Impacts for LW203 to 210

Based on the predicted range of maximum transverse tensile strains for the proposed LW203 to 210 (i.e. 6 mm/m to 38 mm/m), surface crack widths are estimated to range from approximately 100 mm to 350 mm in cohesionless soils (average of 240 mm) and from approximately 200 mm to 700 mm in cohesive soils or shallow rock (average of 480 mm).

The predicted crack widths for each longwall are given in **Table 8**.

Table 8 - Predicted Maximum Crack Widths for Proposed LW203 to 210 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
203	6	402.9	214	1.88	11	14	28	346	692
	7	402.9	207	1.95	10	15	30	324	648
	8	402.9	199	2.02	10	16	32	302	605
	9	402.9	224	1.80	11	13	26	308	616
	10	402.9	220	1.83	11	13	27	318	635
204	6	402.4	238	1.69	12	11	23	290	580
	7	402.4	244	1.65	12	11	22	295	591
	8	402.4	222	1.81	11	13	26	273	546
	9	402.4	247	1.63	12	11	21	266	533
	10	402.4	260	1.55	13	10	19	292	584
205	6	399.7	263	1.52	13	9	19	263	526
	7	399.7	280	1.43	14	8	17	250	500
	8	399.7	250	1.60	13	10	21	247	494
	9	399.7	278	1.44	14	8	17	232	464
	10	399.7	289	1.38	14	8	16	260	520
206	6	399.7	297	1.35	15	7	15	234	468
	7	399.7	312	1.28	16	7	13	225	450
	8	399.7	285	1.40	14	8	16	219	438
	9	399.7	304	1.31	15	7	14	208	417
	10	399.7	305	1.31	15	7	14	228	456
207	6	402.2	330	1.22	17	6	12	214	428
	7	402.2	318	1.26	16	6	13	213	426
	8	402.2	320	1.26	16	6	13	197	394
	9	402.2	321	1.25	16	6	13	204	409
	10	402.2	319	1.26	16	6	13	203	406
208	6	401.2	352	1.14	18	6	12	202	405
	7	401.2	323	1.24	16	6	12	204	407
	8	401.2	346	1.16	17	6	12	205	409
	9	401.2	340	1.18	17	6	12	201	402
	10	401.2	356	1.13	18	6	12	201	402
209	6	409.2	365	1.12	18	6	11	198	395
	7	409.2	346	1.18	17	6	11	207	414
	8	409.2	380	1.08	19	6	11	204	408
	9	409.2	376	1.09	19	6	11	193	387
	10	409.2	400	1.02	20	6	11	212	425
210	9	415.4	184	2.26	9	18	36	210	420
	10	415.4	180	2.31	9	19	38	224	447

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 LW203 to 210 generally, the crack widths may exceed the predicted range near the crests of steep creek banks or elevated ridges. The rocky outcrops with caves above LW207 are considered likely to be impacted by surface cracking > 200 mm wide (**Section 10.4** contains further discussion on steep slope effects).

The potential cracking-affected areas has been estimated from:

- the combined surface area above the Project Area longwalls of around 30 square kilometres (km²)
- surface crack widths are likely to develop in pairs around the interior longwall limits, and
- an average single crack width of 240 mm and 480 mm in sand or clay/rock respectively.

Based on the above, it is estimated that approximately 0.04 km² to 0.08 km² of the surface would be crack affected. This represents 0.13% to 0.27% of the extracted longwall area.

This prediction range may be further refined with detailed crack mapping over future longwall panels, including in the current mining areas for LW109 to 111 and LW201 to 202.

10.2.4 Impact Management Strategies

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

- Regularly inspect the surface during subsidence development above a given panel and map crack locations and their geometry (widths, lengths, depth, shape).
- 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 limit mining to first workings (e.g. Bulga Hill bat colony, which is currently protected from subsidence impact with a 26.5° set-back distance from LW205 and 206 finishing points).

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.

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 15a and 15b**). 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 Project Area using the Pi-Term empirical models (**Ditton and Merrick, 2015**). 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 15c**).

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° to 19° from the rib sides, based on physical and numerical modelling observations and subsidence data (**Figure 15d**).

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, 2015** demonstrates the overburden develops an effective strata unit thicknesses (t') that limits the A-Zone at a given height above a longwall (**Figure 15d**). 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 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.

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 ($A = 1438 \ln[(4.315 \times 10^{-5})(W H^{0.2} T^{1.4}) + 0.9818]$) (**Tammetta, 2015**).
- 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 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).

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:

A-Zone Prediction Model

$$\text{Mean } A/W' = 2.215 (H/W')^{0.271} (T/W')^{0.372}$$

$$R^2 = 0.61 \text{ (root mean square error [rmse]=21\%)}$$

$$U95\%CL \ A/W' = \text{Mean } A/W' + a$$

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:

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

B-Zone Prediction Model

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

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

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

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:

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

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 15e**).

A-Zone Prediction Model

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

$$\text{U95\%CL } A/W' = \text{Mean } A/W' + a$$

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:

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

B-Zone Prediction Model

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

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

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:

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

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:

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

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

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:

$$A = 1.0W \text{ to } 1.5W$$

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 **Figures 4a to 4c** 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 16a to 16f** and summarised in **Table 9A**.

As shown in **Table 9B**, 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.

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 9C** with the VWP data in **Table 9D**.

Table 9A - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above LW101 to 111 and LW201 and 202 (ML1609)

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

Table 9A (Cont...) - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above LW101 to 111 and LW201 and 202 (ML1609)

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
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
201	417.4	183	4.3	135	160	113	139	23	458	484
202	372.1	192	4.3	141	168	117	144	24	416	442

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 9B - 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)
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.

Table 9C - 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 9D - 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 8d**) 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 16g** and **16h**. **Figures 16i** and **16j** 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 16k**).

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 16l**) 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 16m**. 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 16n** 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 ($\sim 0.9T$) developed to $\sim 0.3H$ above the mine roof or $\sim 8T$ 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 is undertaken above future approved longwalls in ML1609 (LW109 to 111 and 201 and 202) and proposed LW203 to 210.

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 210 are summarised in **Table 10A** 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 17a**.

Table 10B summarises the results given in **Table 10A**.

As shown in **Table 10B**, the Geology Pi-Term Model predicts the highest A-Zone out of the two **Ditton & Merrick, 2014** models. The Tammetta model indicates ‘full depressurisation’ of the overburden.

Table 10A - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above the Proposed LW203 to 210

LW Panel	Panel Width W (m)	Cover Depth H (m)	Mining 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
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
	402.9	199	4.3	279	146	173	119	147	26	447	473
	402.9	224	4.3	314	163	194	129	160	30	455	481
	402.9	220	4.3	308	160	191	127	158	29	455	481
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
	402.4	222	4.3	311	161	192	128	159	30	464	490
	402.4	247	4.3	346	178	213	137	171	34	476	502
	402.4	260	4.3	364	187	223	141	178	37	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
	399.7	250	4.3	350	180	215	138	173	35	460	486
	399.7	278	4.3	389	199	238	147	186	40	467	493
	399.7	289	4.3	400	205	246	150	191	43	473	499
206	399.7	297	4.3	400	208	250	151	193	47	478	504
	399.7	312	4.3	400	214	257	153	198	55	481	507
	399.7	285	4.3	399	204	244	150	189	41	472	498
	399.7	304	4.3	400	211	253	152	195	51	478	504
	399.7	305	4.3	400	211	254	152	196	51	480	506
207	402.2	330	4.3	402	221	267	156	203	63	506	532
	402.2	318	4.3	402	217	261	155	200	57	503	529
	402.2	320	4.3	402	217	262	155	200	58	501	527
	402.2	321	4.3	402	218	262	155	200	59	503	529
	402.2	319	4.3	402	217	261	155	200	58	503	529

Table 10A (Cont...) - Summary of Predicted Sub-Surface Fracturing Heights (A-Zone) above the Proposed LW203 to 210

LW Panel	Panel Width W (m)	Cover Depth H (m)	Mining 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
208	401.2	352	4.3	401	229	276	159	208	76	486	512
	401.2	323	4.3	401	218	263	155	201	60	499	525
	401.2	346	4.3	401	227	274	158	206	72	501	527
	401.2	340	4.3	401	224	271	157	205	69	501	527
	401.2	356	4.3	401	230	278	159	209	78	504	530
209	356.7	365	4.3	357	222	269	154	202	96	517	543
	356.7	346	4.3	357	216	261	151	198	85	512	538
	356.7	380	4.3	357	227	275	155	205	105	518	544
	356.7	376	4.3	357	226	273	155	204	103	518	544
	356.7	400	4.3	357	234	282	158	209	118	524	550
210	415.4	184	4.3	258	135	161	114	139	23	457	483
	415.4	180	4.3	252	133	158	112	137	22	452	478

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

Table 10B - Summary of Sub-Surface Fracture Model Predictions

LW	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 Pi-Term	Geometry Pi-Term	Geology Pi-Term	Tammetta, 2013
203 to 210	356.7 - 415.4	180 - 400	0.89 - 2.31	252 - 402.2	4.3	133 - 282	112 - 209	22 - 118	447 - 550

Table 11 also shows the predicted outcomes for all of the models mentioned earlier for further comparison. The results demonstrate that only the Geology Pi-term model indicates the A-Zone will develop below the surface for the proposed longwalls, with surface to seam connectivity predicted by all of the non-Narrabri Coalfield models.

Table 11 - 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
Geology Pi-Term	0.62 - 0.88	0.51 - 0.73	31 - 69
Geometry Pi-Term	0.62 - 0.78	0.37 - 0.56	26 - 51
Forster, 1995	0.23 - 0.84	0.22 - 0.56	21 - 33
CSIRO, 2007	0.46 - 1.03	0.45 - 0.73	43
SCT, 2008	1.02 - 3.46	1.0 - 1.5	93 - 145
Tammetta, 2013	1.29 - 2.67	1.20 - 1.91	105 - 126

Bold - preferred prediction model based on calibration outcomes with mine site data.

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. The model predicts that the height of connective cracking above LW203 to 210 is likely to range between 133 m and 299 m (62% to 88% of the cover depth; 0.51 to 0.73 times the effective panel width and 31 to 69 times the proposed extraction height of 4.3 m) (**Table 11**).

Based on the Geology model, direct hydraulic connection to the mine workings due to sub-surface fracturing above the panels is estimated to encroach within 22 m to 153 m depth below the surface across the Project Area.

It is noted that the database of sub-surface fracturing contains four out of fifteen supercritical cases where seam to surface 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 of the surface.

The predicted mean A/H ratio is < 0.8 for all of the proposed panels, whereas the U95%CL A/H ratio exceeds 0.8 for all panels except LW208 and 209. It is therefore assessed that the A/H = 0.8 ratio represents the horizon that coincides with the U75% CL line (**Figure 17a**).

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 ('possible') that connective cracking could reach the surface for the proposed longwalls.

However, investigation boreholes and site observations at Narrabri indicate that the near-surface strata above the eastern panels (LW203 and 210) 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 to 209 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.

10.3.9 Discontinuous Fracturing (B-Zone)

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

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

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 Project longwalls) (**Figure 17b**). All of the non-Narrabri Coalfield models predict the height of full depressurisation will reach the surface for the proposed longwalls (**Table 11**).

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 single longwalls only or a given W/H ratio).

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, 2011a, 2013b**).

The measured crack widths in steep terrain (slopes > 18°) 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°.

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 mine⁸ (**DgS 2011b, 2012, 2013a, 2013c**), the following formulae have been derived and verified against measured cracks as shown in **Figures 14e to 14h** in **Table 12**:

Mean Crack width = 15 x Mean Max Strain + Slope Height x Mean Max Tilt

U95% Crack width = 15 x U95%CL Max Strain + Slope Height x U95%CL Max Tilt

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

⁸ 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.

Table 12 - 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)	
				<i>mean</i>	<i>U95CL</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>
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

Table 12 (Cont...) - 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)	
				<i>mean</i>	<i>U95CL</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>
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
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

Table 12 (Cont...) - 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)	
				<i>mean</i>	<i>U95CL</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>	<i>mn.</i>	<i>U95</i>
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 14i to 14k**. The measured crack statistics are summarised in **Table 13** 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 lie within the ‘flat’ terrain crack database for Newcastle.

Table 13 - Surface Crack Database Summary for ‘Flat’ and Steeply Sloping Terrain in the Newcastle Coalfield for Supercritical Longwall Geometries

Parameter	Statistics	Newcastle Coalfield		Narrabri Mine (LW101-108A)
		‘Flat Terrain’ Slopes < 18°	‘Steep Slopes’ Slopes > 18°	‘Flat Terrain’ Slopes < 18°
Crack Width (m)	Minimum	0.005	0.05	<i>0.05</i>
	Maximum	0.5	2.5	0.4
	Median	0.15	0.5	<i>0.15</i>
	Mean	0.19	0.6	<i>0.2</i>
	U95%CL	0.48	1.9	<i>0.4</i>
	Sample size (no.)	23	33	<i>>6</i>
Crack Depth (m)	Minimum	0.05	0.15	<i>0.3</i>
	Maximum	10	15	1.5
	Median	2	2	<i>1.0</i>
	Mean	2.4	3.5	<i>1.0</i>
	U95%CL	5	15	<i>1.5</i>
	Sample size (no.)	23	32	<i>>6</i>
Crack Length (m)	Minimum	3	3	<i>2</i>
	Maximum	50	100	30
	Median	10	30	<i>20</i>
	Mean	15	32	<i>16</i>
	U95%CL	30	50	<i>30</i>
	Sample size (no.)	23	33	<i>>6</i>

Italics - statistics based on a small sample of observations by DgS and from end of panel report commentary by NCOPL personnel.

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 10.2**, predicting the crack widths above the Project's longwalls has 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 240 m to 420 m of cover for 409 m wide longwalls at the Project).

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 and lengths for the Project were estimated based on the Newcastle database.

A summary of the predicted crack widths for the steep slopes and minor cliff faces above the Project Area are presented in **Table 14**.

Table 14 - Predicted Credible Worst-Case (U95%CL) Crack Widths on Steep Slopes and Minor Cliff Faces

Feature No.	Slope Height Z (m)	LW	Slope Aspect	Final Panel Subsidence (m)	Maximum Feature Subsidence (m)	Maximum Feature Tensile Strain (mm/m)	Maximum Feature Tilt (mm/m)	Crack Width from Strain (mm)	Crack Width from Tilt (mm)	Crack Width from Tilt & Strain (mm)
Rocky Outcrop with Caves										
C1	7	207	SE	2.8	2.67	7.5	30	256	210	466
C2	5	207	E	2.8	2.66	7.5	30	257	150	407
R1	4	207	E	2.8	2.65	7.5	30	258	120	378
R2	3	207	E	2.8	2.61	7.5	30	258	90	348
R3	3	207	SE	2.8	2.46	7.5	30	257	90	347
S1	22	207	E-SE	2.8	2.44	7.5	30	259	660	919
Bulga Hill										
C3	10	206	SW-W	2.8	<0.02	<0.5	<1	0	0	0
C4	8	206	SW	2.8	<0.02	<0.5	<1	0	0	0
C5	12	206	NE	2.8	<0.02	<0.5	<1	0	0	0
C6	8	206	NE	2.8	<0.02	<0.5	<1	0	0	0
C7	6	206	SW	2.8	<0.02	<0.5	<1	0	0	0
C8	6	206	NE	2.8	<0.02	<0.5	<1	0	0	0
R4	4	206	SW	2.8	<0.02	<0.5	<1	0	0	0
R5	4	206	W	2.8	<0.02	<0.5	<1	0	0	0
R6	5	206	NE	2.8	<0.02	<0.5	<1	0	0	0
R7	4	206	W	2.8	<0.02	<0.5	<1	0	0	0
R8	5	206	NE	2.8	<0.02	<0.5	<1	0	0	0
R9	5	206	NE	2.8	<0.02	<0.5	<1	0	0	0
R10	3	206	SW	2.8	<0.02	<0.5	<1	0	0	0
R11	4	206	SE	2.8	<0.02	<0.5	<1	0	0	0
R12	4	206	E	2.8	<0.02	<0.5	<1	0	0	0
S2.1	20	206	NE	2.8	<0.02	<0.5	<1	0	0	0
S2.2	20	206	NE	2.8	<0.02	<0.5	<1	0	0	0
S2.3	20	206	SE	2.8	<0.02	<0.5	<1	0	0	0

Table 14 (Cont...) - Predicted Credible Worst-Case (U95%CL) Crack Widths on Steep Slopes and Minor Cliff Faces

Feature No.	Slope Height Z (m)	LW	Slope Aspect	Final Panel Subsidence (m)	Maximum Feature Subsidence (m)	Maximum Feature Tensile Strain (mm/m)	Maximum Feature Tilt (mm/m)	Crack Width from Strain (mm)	Crack Width from Tilt (mm)	Crack Width from Tilt & Strain (mm)
S2.4	20	206	SW	2.8	<0.02	<0.5	<1	0	0	0
S2.5	20	206	SW	2.8	<0.02	<0.5	<1	0	0	0
S2.6	20	206	W	2.8	<0.02	<0.5	<1	0	0	0
S3	26	206	SE	2.8	<0.02	<0.5	<1	0	0	0
Other Hills & Ridges (unnamed)										
S4	8	204	NE	2.8	2.45	11.0	40	295	320	615
S5	6	204	SE	2.8	2.60	11.0	40	295	240	535
S6	8	205	SE	2.8	0.82	9.0	34	264	272	536
S7	14	208	SE-E	2.8	2.06	7.5	28	307	392	699
S8	16	208	SE	2.8	0.12	7.5	28	288	448	736
S9	6	208	SE	2.8	0.77	7.5	28	270	168	438
S10	8	209	SE-E-NW	2.8	2.16	8.0	32	326	256	582
S11	8	209	SE	2.8	0.42	8.0	32	340	256	596
S12	10	204	SE-S-E	2.8	2.60	12.0	44	294	440	734
S13	10	207	SE	2.8	1.95	7.0	30	244	300	544
S14	8	207	N-NW	2.8	0.70	7.0	28	252	224	476
S15	7	209	SE-E	2.8	2.05	8.0	32	318	224	542
S16	18	208	SE	2.8	1.70	7.0	28	246	504	750

C = Minor Cliff Face; R = Rock Face feature; S = Steep Rocky Slope. * - crack widths assume a single crack may develop along the upslope rib side of the given longwall beneath steep slopes > 18°.

The results in **Tables 13** and **14** indicate the following cracking impacts could develop on the steep slope features inside the limits of longwall extraction:

- 410 mm to 470 mm cracks on Minor Cliff faces.
- 350 mm to 380 mm cracks on Rock Face features.
- 440 mm to 920 mm cracks on Steep Rocky Slopes.

As discussed earlier, the depth, length and spacing of cracks may be estimated from the Newcastle and Narrabri Mine data bases. In summary:

- The crack depth is likely to range between 3 m and 15 m.
- The crack length is likely to range from 30 m to 100 m.
- The crack spacing (in pairs) is likely to range from 8 m to 13 m.

The results in **Table 14** indicate that any cracking impacts to Bulga Hill are considered negligible.

10.4.4 Feature Impact Assessment

As well as cracking, there is potential for direct subsidence of minor cliff faces and rock face features to accelerate natural weathering processes, such as the release of rock wedges or blocks (i.e. rock falls). 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 Project 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 minor cliff faces, rock face features and steep (rocky) slopes present within the Project Area. The potential impacts to the features present within the AoD to the proposed longwalls have been estimated based on previously measured impacts of similar features in the Newcastle Coalfield.

Total impacts for the minor cliff faces, rock face features and steep slopes undermined by the three longwalls in the Newcastle Coalfield Mine previously discussed in **Section 10.4.2** are summarised in **Table 15**.

Table 15 - Measured Impacts to Landscape Features above LWA, B and C in the Newcastle Coalfield

Landscape Feature	Feature Height Range (m)	Total Project Face Area* (m²)	Feature Length Undermined (m)	Area Undermined (m²)	Measured Impact (m²)	Measured Impact for Undermined Area (%)	Measured Impact in Project Area (%)	Approval Limit in Project 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 Slopes	3 - 25	3,000,000	2,189	153,475	846.5	0.6	0.03	7

* - Landscape features within PA boundary.

Note – m² = square metres.



It should be noted that the Newcastle Coalfield Mine successfully extracted a further five longwalls (total of eight longwalls) below similar features without exceeding the impact predictions. The features 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 included cracking, release of rock wedges and toppling failures. Several overhangs with spans of up to 3 m or 4 m were impacted by cracking and bedding shears but did not collapse. At some locations, interaction with conjugate mid-angled joint sets or cracking on steep slopes, resulted in ‘stepped’ subsidence profiles with depths ranging from 100 mm to 300 mm occurring on several undermined ridges.

Hypothetically, if the Newcastle Coalfield Mine had undermined all of the Minor Cliff faces in the Project Area with similar impacts occurring each time, then it would have been possible to exceed the 5% impact limit. It would have been ‘very unlikely’, however, that the limits for the Rock Face Features and Steep Slopes would have been exceeded if all of these features were undermined.

Based on the above analysis, a similar analysis technique has been completed for the minor cliff faces and rock face features in the Project Area.

The expected area of impact was assumed to equal the rate noted for the Newcastle Coalfield mine example. The worst-case area of impact was determined by using a joint spacing of 3 m to 4 m and assuming a crack develops every 10 m along the undermined cliffs, as well as the opening of sub-parallel joints or fresh cracking occurs along the minor cliff faces.

It is estimated, by probability, that there could be a rock fall from the upper 3 m of minor cliff of at least 3 m or 4 m after undermining. This represents an impact rate of 9 m² to 12 m² every 10 m length of subsided minor cliff face. For the rock face features, it is considered that the impact rate would be 50% of the minor cliff rate or 4.5 m² to 6 m²/10 m.

Impacts to steep rocky slopes have been estimated based on a maximum sub-parallel crack width of 500 mm would extend the full length of each undermined slope (or two 500 mm wide cracks spaced at 10 m for half the slope length).

The resulting percentage impact estimates to all of the steep slope features due to the proposed longwall panels are summarised in **Tables 16A** and **16B**.

Table 16A - Steep Slope and Minor Cliff Face Cracking or Rock Fall Impacts

Feature No.	Slope Height Z (m)	LW	Final Panel Subsidence (m)	Max Feature Subsidence (m)	Max Feature Tensile Strain (mm/m)	Max Feature Tilt (mm/m)	Predicted Impact for Undermined Area (%) Newcastle - Project	Predicted Impact Area (m ²)	
								Newc ⁷	Project
Rocky Outcrop with Caves									
C1	7	207	2.8	2.67	7.5	30	5.8 - 11.2	15.5	32
C2	5	207	2.8	2.66	7.5	30	5.8 - 11.2	6.5	18
R1	4	207	2.8	2.65	7.5	30	1.6 - 10.8	1.6	11
R2	3	207	2.8	2.61	7.5	30	1.6 - 10.8	4.0	33
R3	3	207	2.8	2.46	7.5	30	1.6 - 10.8	2.6	22
S1	22	207	2.8	2.44	7.5	30	0.5 - 1.5	96	225
Bulga Hill									
C3	10	206	2.8	<0.05	<1	<1	0	0	0
C4	8	206	2.8	<0.05	<1	<1	0	0	0
C5	12	206	2.8	<0.05	<1	<1	0	0	0
C6	8	206	2.8	<0.05	<1	<1	0	0	0
C7	6	206	2.8	<0.05	<1	<1	0	0	0
C8	6	206	2.8	<0.05	<1	<1	0	0	0
R4	4	206	2.8	<0.05	<1	<1	0	0	0
R5	4	206	2.8	<0.05	<1	<1	0	0	0
R6	5	206	2.8	<0.05	<1	<1	0	0	0
R7	4	206	2.8	<0.05	<1	<1	0	0	0
R8	5	206	2.8	<0.05	<1	<1	0	0	0
R9	5	206	2.8	<0.05	<1	<1	0	0	0
R10	3	206	2.8	<0.05	<1	<1	0	0	0
R11	4	206	2.8	<0.05	<1	<1	0	0	0
R12	4	206	2.8	<0.05	<1	<1	0	0	0
S2.1	20	206	2.8	<0.05	<1	<1	0	0	0
S2.2	20	206	2.8	<0.05	<1	<1	0	0	0
S2.3	20	206	2.8	<0.05	<1	<1	0	0	0
S2.4	20	206	2.8	<0.05	<1	<1	0	0	0

Table 16A (Cont...) - Steep Slope and Minor Cliff Face Cracking or Rock Fall Impacts

Feature No.	Slope Height Z (m)	LW	Final Panel Subsidence (m)	Max Feature Subsidence (m)	Max Feature Tensile Strain (mm/m)	Max Feature Tilt (mm/m)	Predicted Impact for Undermined Area (%) Newcastle - Project	Predicted Impact Area (m ²)	
								Newc ⁷	Project
S2.5	20	206	2.8	<0.05	<1	<1	0	0	0
S2.6	20	206	2.8	<0.05	<1	<1	0	0	0
S3	26	206	2.8	<0.05	<1	<1	0	0	0
Other Hills & Ridges (unnamed)									
S4	8	204	2.8	2.45	11.0	40	0.5 - 1.5	4.7	19
S5	6	204	2.8	2.60	11.0	40	0.5 - 1.5	4.8	27
S6	8	205	2.8	0.82	9.0	34	0.5 - 1.5	4.3	20
S7	14	208	2.8	2.06	7.5	28	0.5 - 1.5	145.1	245
S8	16	208	2.8	0.12	7.5	28	0.5 - 1.5	0	0
S9	6	208	2.8	0.77	7.5	28	0.5 - 1.5	3.7	24
S10	8	209	2.8	2.16	8.0	32	0.5 - 1.5	9.6	51.5
S11	8	209	2.8	0.42	8.0	32	0.5 - 1.5	23.5	99
S12	10	204	2.8	2.60	12.0	44	0.5 - 1.5	30.1	117.5
S13	10	207	2.8	1.95	7.0	30	0.5 - 1.5	31.1	105
S14	8	207	2.8	0.70	7.0	28	0.5 - 1.5	4.7	24
S15	7	209	2.8	2.05	8.0	32	0.5 - 1.5	8.2	37
S16	18	208	2.8	1.70	7.0	28	0.5 - 1.5	46.2	123

C = Minor Cliff Face; R = Rock Face feature; S = Steep Rocky Slope. * - crack widths assume a single crack may develop along the upslope rib side of the given longwall beneath steep slopes > 18°.

Table 16B - Predicted Impacts to Steep Landscape Features

Landscape Feature	Feature Height Range (m)	Total Project Face Area* (m²)	Feature Length Undermined (m)	Area Undermined (m²)	Predicted Impact Area (m²)	Predicted Impact for Undermined Features (%)	Predicted Impact in Project Area (%)	Assumed Approval Limit in Project Area (%)
Minor Cliffs	5 - 12	3,621	375	996	50 - 58	5.8 - 11.2	1.4 - 1.6	5
Rock Face Features	3 - 5	3,003	674	1598	26 - 132	1.6 - 10.8	0.9 - 4.4	7
Steep Slopes	6 - 26	151,349	4,196	98,188	540 - 1,117	0.5 - 1.5	0.4 - 0.7	7

* - Landscape features within AoD of proposed longwalls.

The assessed range of impact for the features in the AoD to mining is considered to be conservative and unlikely to exceed the assumed Performance Measures of 5% to 7% of all features within the AoD from the proposed longwalls. The hazards associated with the impacts would include the development of unstable rock wedge or overhang conditions and deep cracking that would require safety measures (such as fencing) to be installed and/or remediation if possible (**Section 10.4.6**).

Based on the frequency of existing natural cliff face rock falls and the degree of public exposure (utilisation) of the access tracks, the risk to the public due to rock falls associated with natural cliff face instability is likely to be 'very low' and fall within established acceptability criteria published in the Landslide Risk Management Guidelines (**AGS, 2007**).

The increase in rock fall probability associated with mine subsidence is 'unlikely' to increase this risk level to beyond acceptable criteria and can be managed by the landscape subsidence management plans.

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'⁹ 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 cracks after subsidence development (refer to **Section 10.4.6** for recommendations for remediation works timing advice).

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 wedge sliding along bedding planes by (i) increasing the pressure acting on the sliding wedge and (ii) 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 $<10^\circ$ 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 18a** and **18b**) for predicted gradient changes in Project Area ($\pm 1.5^\circ$). **Figures 18c** and **18d** show the gradient changes in terms of percentage ($\pm 2.5\%$).

⁹ Refer to landslide risk assessment terminology presented in **AGS, 2007**.

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 future minor cliff and steep slope instability such as rock falls or increased erosion due to cracking or changes to drainage patterns after longwall extraction that is consistent with the Land Management Plan (**Eco Logical Australia [ELA], 2017**) (or its latest approved version), the management strategy should include:

- Surface slope and cliff face displacement monitoring will be required above proposed LW204 to 209 (combined with general subsidence monitoring). Each feature should be named and monitored after subsidence development has ceased. It is expected that LiDAR surveys would provide a general overview of terrain conditions after longwall extraction, however, it would also be necessary to install reflectors along minor cliff faces at 10 m to 15 m spacing for remote surveys and/or run a series of remote drone surveys to record changes in cliff face impacts before and after mine subsidence.
- 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 dental concrete or cementitious grouting in areas exposed to runoff, potential instability. Repairs to cracks behind or along the toe of minor cliff faces 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.

Pre-mining surface levels and likely ponding locations are shown in **Figures 19a** and **19b**. Post-mining surface level and pond locations are shown in **Figures 19c** and **19d**. The potential maximum and net ponding depths above the proposed panels after mining have been summarised in **Table 17**.

A total of 18 potential ponding locations (P1 to P18) are assessed for the Project Area. The majority of potential ponding areas already exist and would further develop along the watercourses after mining and likely to remain in channel.

Existing (pre-mining) pond depths are estimated to range from 0.2 m to 3.2 m. Post-mining pond depths are estimated to similarly range from 0.25 m to 3.2 m. The maximum changes in pond depth (where positive represents an increase in pond depth) are estimated to range from -0.1 m and 0.9 m (average of 0.6 m)¹⁰.

There are also nine dams (D11, 12, 16-18, 20-22 and 24) that may have their inflows affected by upstream ponding due to the proposed longwalls (**Figures 19c** and **19d**).

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 (if they occur) after each longwall is extracted (as occurs for the existing Narrabri Mine).

Based on the post-mining surface level predictions, consistent with the existing Narrabri Mine, it is proposed that impact management strategies for the existing Narrabri Mine would be implemented in accordance with the Land Management Plan (**ELA, 2017**) and the Extraction Plan Water Management Plan (**NCOPL, 2017**) (or their latest approved versions). Impact management measures include (**NCOPL, 2017**):

- 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 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.

Table 17 - Potential Ponding Summary after LW203 to 210

Potential Pond No. (Figures 19a and 19b)	LW Panel	Pre-Mining Pond Levels (m, AHD)		Maximum Pre-Mining Pond Depth, h(m)	Post-Mining Pond Base RL (m, AHD)		Maximum Post-Mining Pond Depth, h(m)	Post-Mining Pond Change* $\Delta h(m)$	No. of Farm Dams Possibly Affected by Ponding (Dam No.s)
		Top	Bot		Top	Bot			
P1	209	-	-	0	315.9	315.4	0.5	0.5	0
P2	207	-	-	0	304.8	304.3	0.5	0.5	1 (D12)
P3	206	303.0	300.8	2.2	301.0	298.7	2.3	0.1	0
P4	204	293.5	292.5	1.0	291.0	289.9	1.1	0.1	1 ((D11)
P5	203	302.0	301.0	1.0	301.0	299.9	1.1	0.1	1 (D24)
P6	210	292.3	291.8	0.5	290.9	289.8	1.1	0.6	0
P7	210	295.0	291.8	3.2	293.1	289.9	3.2	0.0	1 (D17)
P8a	210	301.4	298.3	3.1	298.7	295.5	3.2	0.1	1 (D16)
P8b	210	298.7	295.6	3.0	295.9	292.9	3.0	0.0	1 (D15)
P9	210	293.0	292.8	0.2	291.8	291.0	0.8	0.6	2 (D21, D24)
P10	203	299.4	300.1	0.7	297.7	297.1	1.6	0.9	0
P11	204	306.1	305.7	0.4	304.3	303.3	1.0	0.6	0
P12	210	297.1	295.6	1.5	295.0	293.3	1.4	-0.1	2 (D18, D22)
P13	203	288.2	287.9	0.3	286.0	285.2	0.8	0.5	0
P14	204	292.5	291.9	0.6	290.0	289.3	0.7	0.1	0
P15	205	300.5	299.3	1.2	298.1	296.8	1.3	0.1	0
P16	205	299.0	298.7	0.3	296.5	296.1	0.4	0.1	0
P17	206	303.4	302.0	1.4	301.7	300.0	1.7	0.3	0
P18	207	-	-	-	308.3	308.1	0.2	0.2	0

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 along cliffs and sides of 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 buckling upwards when subject to compressive stresses generated by surface deformation. This phenomenon is termed ‘upsidence’ and in most cases in the Newcastle and Southern NSW Coalfields, the observed ‘upsidence’ has extended outside steep sided valleys and included the immediate cliff faces and the ground beyond them.

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 Project Area (characterised by the ephemeral creeklines described earlier) are very broad between crests, and there is a lack of thick, massive beds of conglomerate and/or sandstone units along the creeks/valleys, the development of ‘upsidence’ and closure along the creek beds above LW203 to 210 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 Project.

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 (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) 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 noted that the Project longwalls (LW203 to 210) have a higher depth of cover than LW101, with the lowest depth of cover ranging from 180 m to 200 m above LW203 and 210 along the eastern edges of the Project Area. This depth of cover is similar to LW102 where some impacts to vegetation were observed, but to a lesser extent than LW101 (ELA, 2014).

It is therefore considered that any large trees (eucalypts in particular) in areas with less than 180 m depth of cover in clayey soils above LW210 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. This potential impact is considered in the Biodiversity Development Assessment Report for the Project (Resource Strategies Pty Ltd, 2020).

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 41 farm dams that have been assessed in the Project Area that are located within the AoD from the proposed LW203 to 210 (**Figure 19d**). Twenty-four dams exist outside the limits of subsidence effect to the south and east of the Project Area longwalls. There are also nine farm dams located within the Project Area that are likely to have their inflow affected by upstream ponding above LW203 to 205.

Several farm dams have already been subsided by LW101 to 108A but have not required remedial works to be implemented. Notwithstanding, non-engineered farm dams and water storages are susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence, therefore these potential impacts are considered further below.

The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques, and foundation type.

The predicted worst-case subsidence deformations (subsidence, tilt and horizontal strain) at the dams within the limits of longwall extraction are based on **Figures 13a, 13b, 13c, 13d, 13e and 13f**. The likely subsidence effects at the dams above each longwall are summarised in **Table 18**.

Table 18 - Maximum Final Subsidence Effect Predictions* for the Farm Dams above the Project Area

LW	No. Existing Dams	Cover Depth (m)	Subsidence (m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
203	22	200 - 240	0.02 - 2.80	1 - 50	3 - 15	4 - 20
204	8	220 - 240	0.40 - 2.80	5 - 50	3 - 15	7 - 19
205	2	250 - 260	0.40 - 2.65	15 - 30	3 - 12	7 - 19
206	1	270 - 280	1.20 - 2.80	2 - 40	3 - 9	4 - 12
207	1	290 - 295	1.0 - 1.60	25 - 35	3 - 7	3 - 10
210	7	165 - 195	0.38 - 2.80	3 - 67	8 - 20	10 - 27
Outside AoD	24	120 - 300	<0.02	<1	<0.5	<0.1

* - Refer to **Figures 13a-b, 13c-d and 13e-f** for specific predictions at each dam.

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 300 mm.

Surface 'steps' or heaving due to compressive shear failures are estimated to range between 30 mm and 300 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 (ELA, 2017) (or its latest approved version) 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 agistees 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.
- (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 or (iii) re-build a new dam after mining.

Subsidence impacts may be assumed to start to occur within a 26.5° 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 16j**.

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 private access roads comprise unsealed gravel carriageways that provide access across the Project Area. It is expected that they would be subsided and impacted by LW203 to 210 as shown in **Table 19**.

Table 19 - Maximum Final Subsidence Effect Predictions for Access Roads above LW203 to 210

LW	Cover Depth (m)	Subsidence (m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)	Crack Widths (mm)
203 to 210	180 - 400	0.1 - 2.80	33 - 61	3 - 21	3 - 27	60 - 420

The unsealed gravel access roads and tracks are likely to be damaged by cracking and shearing/heaving in the tensile and compressive strain zones, respectively, above the Project longwalls in **Figures 13e** and **13f**. Maximum tensile crack widths across or along roads are estimated to range between 60 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 also require re-grading or drainage remediation works after subsidence development. Yarranabee Road would not be impacted by the Project.

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° 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° AoD (**Section 10.3.6**).

11.3 Property Fences and Livestock

11.3.1 Predicted Effects and Impacts

The fence lines and grazing areas above the Project Area would be subject to the maximum predicted subsidence effects and cracking presented in **Table 20**.

Table 20 - Maximum Final Subsidence Effect Predictions for Fences and Livestock Grazing Paddocks above the Project Area

Cover Depth (m)	Subsidence* (m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
180 - 240	0.1 - 2.80	27 - 61	4 - 21	6 - 27

* - Subsidence range = Mean Tailgate Chain Pillar Subsidence to Maximum Panel Subsidence.

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 would be managed in accordance with the current Land Management Plan (ELA, 2017) (or its latest approved version) 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 three properties with two dwellings above the proposed LW204 and one dwelling just east of LW210.

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 untenanted.

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 ($> 5 \text{ mm/m}$) and curvature $> 1 \text{ km}^{-1}$ 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.

Private Landholder dwelling

A privately-owned dwelling (incomplete at this stage) is located above the chain pillars between LW204 and 205 (**Figure 1c**). The partially completed structure is a two-storey steel circular frame only 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 private landholder 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 private landholder 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 ($> 5 \text{ mm/m}$) and curvature $> 1 \text{ km}^{-1}$ to occur before significant impact develops. Similar impacts are assessed for the machinery sheds, with potential collapse due to frame distortion and connection failure.

Yarranabee

There is one NCOPL-owned dwelling ('Yarranabee') above the eastern goaf edge of LW210 (**Figure 1d** and **Appendix A**). Note this is a secondary dwelling (cottage) and not the main residence on Yarranabee.

The dwelling is a single storey 20 m x 12 m size weatherboard-clad timber framed structure with slab on ground footings with adjoining 8 m x 8 m garage and carport. A 3.5 m diameter concrete water tank is located behind the garage and collects rainwater from the gutters (**Appendix A**).

It is likely that the ‘Yarranabee’ dwelling would be subsided between 135 mm to 90 mm by LW210 with tilts ranging from 4 mm/m to 0.5 mm/m, hogging curvature of 0.2 km^{-1} (radius of 5 km) and tensile strains of up to 3 mm/m. The building is likely to be ‘slightly’ impacted by mine subsidence effects in accordance with **AS2870, 2011**. Impacts are likely to consist of cracking to concrete slabs < 2 mm wide and internal plasterboard wall and ceiling panels of < 5 mm wide, distorting of gutters requiring re-adjustment and tilting and possibly cracking of the tank footing slab and walls.

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° 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 Project 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 21**).

Groundwater monitoring bores

Seven groundwater monitoring bores are installed at depths ranging from 30 m to 348 m, or from 259 m above to 28 m below the Hoskissons Seam (**Figures 1g and 1h**). Two of the monitoring bores are operated by Santos on land owned by NCOPL above LW204. The Santos monitoring bores (TULPRNAP01 and TULPRDGY02) target the Digby Conglomerate and Napperby Formation, and have depths of approximately 131 m and 218 m, respectively.

It is expected that the majority of wells could be impacted by horizontal shear movements at strata unit boundaries or vertical tensile strains due to bedding parting separation. The impacts are expected to increase with severity where wells or bores are intersected by A-Zone fracturing. Bores located outside the limits of longwall mining (and within the AoD) or above chain pillars (e.g. the two Santos bores) are still at risk to horizontal bedding shear movements. The potential for significant well casing impact (i.e. loss of well function due to closure or rupture of casing) have been based on horizontal shear displacement and vertical strain estimates.

The predicted impacts to the existing groundwater monitoring bores are summarised in **Table 21**.

It is predicted that groundwater monitoring bore P54 has a low risk of being significantly impacted by sub-surface movements after LW206 is extracted. The remaining groundwater monitoring bores that are located over the proposed longwall limits are predicted to have a 'moderate' to 'high' risk of significant impact to well casing.

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 Project 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 Project 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 Project (**Whincop Archaeology, 2020**). The majority of Aboriginal cultural heritage sites are isolated finds and artefact scatters.

Table 21 - 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 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	150 m north LW206 start	320	348	-28	-0.09	0	0.02	< +/-1	30	Low
P8	LW208	324	65	259	0.80	263	2.7	+/- 4 to 15	340	High
P9	LW203	224	30	194	0.87	194	1.6	+/- 4 to 15	400	High
TULPRDG Y02	LW204	243	218	25	0.10	210	0.6	+/- 4	130	Moderate
TULPRNAP 01	LW204	244	131	113	0.46	210	0.6	+/- 4	130	Moderate

* Vertical strain from extensometer data (Figure 16j). Tensile strains are positive. [^] - Shear = Tilt*t/2

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.

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 located along drainage lines above proposed LW205 and 210 on sandstone bedrock and boulders (**Figures 1e** and **1f**). The quality of the grinding grooves vary from deteriorated to good (**Whincop Archaeology, 2020**). A description of the sites is provided in **Table 22**.

Table 22 - Aboriginal Heritage Site Description

Site No.	Site Type (No.)	LW	Description
Mayfield GG01	Grinding Grooves (48)	LW205	48 grooves (fair to good condition) in six clusters on sandstone bedrock, within regenerated forest to the immediate north-west of a drainage line.
Longsight GG01	Grinding Grooves (2)	LW210	Two grooves (deteriorated condition) on separate sandstone boulders within a drainage line.

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 210 are presented in **Table 23**, respectively. The values were derived from **Figures 13a** to **13f**.

Table 23 - Predicted Subsidence Effects at Aboriginal Heritage Sites

Site No.	Site Type (No.)	LW	Final Subsidence (m)	Final Tilt (mm/m)	Transient & Final Horizontal Ground Strain (mm/m) [^]	
					Transient	Final
Mayfield GG01	Grinding Grooves (48)	LW205	1.16	37	2 (3)	3 (5)
Longsight GG01	Grinding Grooves (2)	LW210	2.60	19	8 (12)	-19 (-29)

[^] - Tensile strain is positive; (brackets) - Discontinuous strains due to tensile cracking or compressive shearing.

11.7.2 Potential Impacts

The likelihood of damage occurring at the sites has been assessed based on the following impact parameter criteria (**Table 24**). 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.

If necessary, the dimensions of grinding groove sites and the orientation of natural jointing and mining panels proposed, may also be factored into the assessment of the criteria for individual sites (refer to **Shepherd and Sefton, 2001**).

Table 24 – Impact Potential Criteria for Aboriginal Heritage 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 25**. 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 25 - Predicted Subsidence Impacts due to U95%CL Values at Aboriginal Heritage Sites

Site No.	Site Type (No. of grooves)	Location	Horizontal Strain (mm/m) [^]	Cracking Damage Potential*	Tilt (mm/m)	Erosion Damage Potential*
Mayfield GG01	Grinding Grooves (48)	Sandstone Bedrock	3 (5)	Possible to Likely	37	Possible
Longsight GG01	Grinding Grooves (2)	Sandstone Boulders	-19 (-29)	Possible to Unlikely [#]	19	Unlikely

[^] - Tensile strain is positive, (brackets) - transient or dynamic strains in brackets;

* - see **Table 24** for Impact Potential definitions; # - grinding grooves are located on detached or loose boulders.

11.7.3 Impact Management Strategies

Impact management strategies for Aboriginal cultural heritage sites are presented in the Narrabri Mine Aboriginal Cultural Heritage Management Plan (ACHMP) (NCOPL, 2019) (or its latest approved version) and have been developed in consultation with the Registered Aboriginal Parties (RAPs). The Narrabri Mine ACHMP (NCOPL, 2019) would be updated to incorporate the findings of the Aboriginal Cultural Heritage Assessment for the Project and provide specific management measures for potential impacts from the Project.

11.8 Historical Heritage

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

11.9 Survey Control Marks

11.9.1 Potential Impacts

There are several state survey marks located in the Project Area (refer to www.maps.six.nsw.gov.au). Their location and predicted subsidence are provided in **Table 26** and **Figures 1c** and **1d**.

There are five marks that are likely to be subsided by between 0.04 m and 1.52 m by the Project longwalls (noted in bold in **Table 26**).

Table 26 - Predicted Subsidence at State Survey Marks in Project Area

Survey Mark	Easting (m)	Northing (m)	Predicted Subsidence (m)
SS43428	774338	6620068	1.52
SS39336	776555	6619864	0.04
SS43131	776277	6615908	0.00
PM74712	775775	6616586	0.00
SS40223	774619	6615852	1.25
SS43435	772289	6614993	0.49
SS40222	774987	6611883	0.08
SS1632	773608	6610115	0.00
TS6958BAAN	773491	6610100	0.00

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 20a**).

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 20b** and **20c**. 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 and the Namoi River are not anticipated.

Centreline and crossline horizontal strain data (normalised to cover depth) is presented in **Figures 20d** and **20e** and indicate strains are typically < 1 mm/m at an angle draw of 26.5° 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 Project 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 Project Area and are outside the five times cover depth range.

The deeper western side of the Project 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. 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 16j and 21**).

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° AoD) 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 VWP's 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 210 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).

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.
- Early warning monitoring campaigns to confirm appropriate set-back distances from defined subsidence control zones (i.e. Bulga Hill).
- 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 Project have been based on several empirical and calibrated analytical models of overburden and chain pillar behaviour.

The subsidence prediction model has been refined by using measured values above the existing LW101 to LW108A at the Narrabri Mine. The predicted values for the proposed longwalls are as follows:

- Single maximum panel S_{\max}/T of 0.62.
- First maximum panel S_{\max}/T of 0.64.
- Final maximum panel S_{\max}/T of 0.65.
- Supercritical width appears to occur at 1.2H instead of 1.4H, based on measured tilts and strains to-date.

It is considered that the development of subsidence impacts would not be reduced by the spanning potential of the Garrawilla Volcanics, dolerite sill or Digby Conglomerate units. Subsidence predictions have therefore only considered 'Low' SRP for the worst-case scenario.

The key outcomes of the results of the study are presented below for the proposed LW203 to 210:

- (i) First and Final maximum panel subsidence is likely to range between 2.40 m and 2.80 m (56% to 65% of the extraction height).
- (ii) Maximum chain pillar subsidence is estimated to range between 0.20 m and 0.75 m (5% to 17%T) under vertical stresses from 13.6 MPa to 28.5 MPa. Pillar FoS values of 2.21 to 1.33 are estimated for a 3.7 m pillar height.
- (iii) Strain-hardening of the 'squat' pillars, due to core confinement and load sharing to adjacent goaf materials within the extracted panels, would result in eventual cessation of subsidence to within the ranges indicated.
- (iv) Maximum panel tilts are estimated to range from 17 mm/m to 58 mm/m.
- (v) The maximum tensile strains are expected to range from 6 mm/m to 38 mm/m.
- (vi) The maximum compressive strains are also expected to range from 6 mm/m to 40 mm/m.
- (vii) The final goaf edge subsidence is predicted to range between 140 mm to 660 mm.
- (viii) 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 208 and 210 is estimated to range from 22° to 43°. For the critical LW209 ($0.9 < W/H < 1.2$) the AoD prediction ranges from 25° to 50°.

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

- Based on the predicted range of maximum transverse tensile strains for the proposed LW203 to 210 (i.e. 6 mm/m to 38 mm/m), surface crack widths are estimated to range from approximately 100 mm to 350 mm in cohesionless soils (average of 240 mm) and from approximately 200 mm to 700 mm in cohesive soils or shallow rock (average of 480 mm).
- LiDAR surveys and ground truthing inspections indicate that there are approximately 15.1 ha of steep rocky slope (slope gradients 18° to 35°), 3,003 m² of rock face features (cliffs between 2 m and 5 m high and > 20 m long) and 3,621 m² of minor cliff (cliffs between 5 m and 10 m high and > 20 m long) within the potential AoD zone around the proposed longwalls.
- It is estimated that approximately 7.5 ha of steep slope that are 6 m to 22 m high would be subsided by up to 2.8 m. Subsidence is expected to cause cracking with maximum widths ranging from 440 mm to 920 mm, depths from 3 m to 15 m and lengths ranging from 30 m to 100 m based on observations in the Newcastle Coalfield. The impact to the total length of steep slope in the potential subsidence zone is estimated to range from 0.3% to 0.7%. The impacts are likely to be within the expected performance measure limiting crack widths to <7% within the potential AoD zone.
- Approximately 371 m length or 513 m² face area of Rock Face Features would be subsided by up to 2.8 m. Potential rock falls effecting 0.3% to 4.4% of the cliff faces in the Project Area are estimated. Crack widths due to tilt and strain are estimated to range between 350 mm to 380 mm with depths and lengths similar to the steep slopes. The impacts are likely to be within the expected performance measure limiting rock falls to < 7% within the Project Area.
- Approximately 124 m length or 378 m² face area of minor cliff would be subsided by up to 2.8 m with potential rock falls effecting 0.6% to 1.4% of the cliff faces. Crack widths due to tilt and strain is estimated to range between 410 mm to 470 mm with depths and lengths similar to the steep slopes. The impacts are likely to be within the expected performance measure limiting rock falls to <5% within the Project Area.
- General and localised slope instability (soil and rockslides) along the minor cliff faces lines and steep rocky slopes are considered ‘very unlikely’ to develop due to the predicted cracking and tilting caused by LW203 to LW210.
- Surface gradients are likely to increase or decrease by up to 2.5% (+/- 1.5°) along creeks.
- Connective cracking is estimated to range from 133 m to 282 m above the proposed longwall panels (i.e. 62% to 88% times the cover depth; 0.51 to 0.73 times the effective panel width or 31 to 69 times the extraction height of 4.3 m).
- Direct hydraulic connection to the mine workings due to sub-surface fracturing is estimated to encroach within 22 m to 118 m depth below the surface, with the closest cracking zone occurring above the proposed LW210.

- The database of sub-surface fracturing cases contains four out of fifteen supercritical cases where connective cracking developed for a $y/H > 0.8$. The $y = 0.8H$ horizon represents the 75% Confidence Limit Horizon which indicates that there would be a 25% probability that this point would be exceeded.
- However, investigation boreholes and site observations at Narrabri indicate that the near-surface strata above the eastern panels (LW203 and 210) 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 to 209 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 10 m to 15 m and possible connectivity between the A- and B-Zones, the potential for connective cracking is considered ‘unlikely’ to ‘possible’ based on the review of the borehole extensometer and mining performance data for LW101 to 108a.
- 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 < 375 m above the wider longwalls (i.e. LW203 to 210). Creek flows could be re-routed into open cracks to below-surface pathways and re-surface downstream of the mining extraction limits in the Project 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.
- Aboriginal cultural heritage sites have been identified in the Project Area. There are two sites of grinding grooves located along drainage lines above proposed LW205 and 210 on sandstone bedrock and boulders. The number and quality of the grooves vary from poor to excellent. There are also several areas with artefact scatters/individual finds above LW203 to 206.
- The results of the impact assessment indicate that grinding grooves in bedrock are ‘possible to likely’ to be impacted while grooves on loose boulders are ‘possible to unlikely’ to be impacted. Impact management strategies for Aboriginal cultural heritage sites are presented in the ACHMP for the Narrabri Mine and have been developed in consultation with the RAPs. The Narrabri Mine ACHMP would be updated to incorporate the findings of the Aboriginal Cultural Heritage Assessment and specific management measures for the Project.

- There is one single storey weatherboard clad and timber framed residence on timber stump footings and two galvanised iron clad timber post sheds above LW204 on ‘Westhaven’, which is owned by NCOPL. 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**.
- A privately-owned property is located between LW204 and 205 chain pillars. Built features on the property include a partially completed two-storey circular steel-framed residence with a diameter of approximately 15 m and supported on a central column. There are no other fixed features (i.e. power and telecommunications lines).

The property also contains an olive grove to the south of the partially built dwelling in a poor condition at the time of inspection (likely drought and pest animal affected). The building is likely to be ‘moderately’ to ‘significantly’ impacted by mine subsidence effects in accordance with **AS2870, 2011**.

- Impacts to the incomplete private dwelling 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 structure would allow significantly higher strain ($> 5 \text{ mm/m}$) and curvature $> 1 \text{ km}^{-1}$ to occur before significant impact develops. Similar impacts are assessed for the machinery sheds, with potential collapse due to frame distortion and connection failure. Management measures would be developed prior to impact with the objective of having the structure in an always safe condition.
- There is one NCOPL-owned dwelling above the eastern goaf edge of LW210 on Yarrabee. The building is likely to be ‘slightly’ impacted by mine subsidence effects in accordance with **AS2870, 2011**.
- Impacts to the ‘Yarrabee’ dwelling are likely to consist of cracking to concrete slabs $< 2 \text{ mm}$ wide and internal plasterboard wall and ceiling panels of $< 5 \text{ mm}$ wide, distorting of gutters requiring re-adjustment and tilting and possibly cracking of the tank footing slab and walls.
- A suspended powerline with telecommunications runs to the house from Yarrabee Road. It is unlikely the services would be impacted by mining.
- Domestic power and telecommunications lines to the existing dwellings on ‘Westhaven’ and ‘Yarrabee’ are mainly pole suspended with some underground sections extending from the access roads. Management plans would be developed prior to impact with the objective of having the infrastructure in an always safe condition.
- There are 41 farm dams that are located within the AoD from the LW203 to 210. Twenty-four dams exist outside the limits of subsidence effect to the south of the proposed longwalls. Nine of the farm dams located above MLA 1 are likely to have their inflow affected by LW203 to 205.

- Several dams have already been subsided by the existing LW101 to 108A at the Narrabri Mine but have not required remedial works to be implemented. Non-engineered farm dams and water storages would be susceptible to surface cracking and tilting (i.e. storage level changes) due to mine subsidence. The tolerable tilt and strain values for the dams would depend upon the materials used, construction techniques and foundation type. NCOPL would repair and/or re-establish the dam's function and pre-mining storage capacity (if necessary) in consultation with the landholder. Repairs to the farm dams may therefore be required after mining LW203 to 210.
- The unsealed gravel access roads and tracks are likely to be damaged by cracking and shearing/heaving in the tensile and compressive strain zones, respectively, above the proposed longwall panels. Maximum tensile crack widths across or along roads are estimated to range between 60 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 also require re-grading or drainage remediation works after subsidence development. Yarrabee Road would not be impacted by the Project.
- Post and wire fences around the dams and along property boundaries could also be damaged and require repairs after mining.

A suggested program for monitoring subsidence, tilt and strain at the relevant locations has been provided for the purpose of implementing and reviewing 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.

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.

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 210 are still reasonable. Consideration of further borehole extensometer and VWP installations is recommended, 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). Ventilation input and outputs should also be monitored for possible inflow short circuiting detection through surface cracks.

14.0 References

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Appendix A - Photos of Project Area Surface Features
(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 above LW203 (looking east)



Photo 4 - Kurrajong Creek Tributary above LW204 (looking north east)



Photo 5 - Flat Terrain above LW203 to 204 (looking south)



Photo 6 - Kurrajong Creek above LW203 to 204 (looking west)



Photo 7 - Kurrajong Creek above LW203 to 204 (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 - Steep Rocky Slopes (S2) at Bulga Hill above LW206



Photo 11 - Rock Face Feature (R5) at Bulga Hill above LW206



Photo 12 - Minor Cliff (C4) at Bulga Hill above LW206



Photo 13 - Minor Cliff (C1) at the 'Rocky Outcrop with Caves' above LW207



Photo 14 - Rock Face Feature (R1) at the 'Rocky Outcrop with Caves' above LW207



Photo 15 - Pilliga East State Forest above LW206 & 205 (looking north-east from Bulga Hill)



Photo 16 - Pilliga East State Forest above LW207 & 208 (looking north-west from Bulga Hill)



**Photo 17 - NCOPL-Owned Residence and Farm Sheds Above LW204 ('Westhaven')
(looking south)**



**Photo 18 - NCOPL-Owned Residence and Garage Above LW210's Eastern Rib
(‘Yarranabee’) (looking east)**



**Photo 19 - Observed Cracking along a Pine Creek Tributary above LW107 & 108A
(ML1609)**



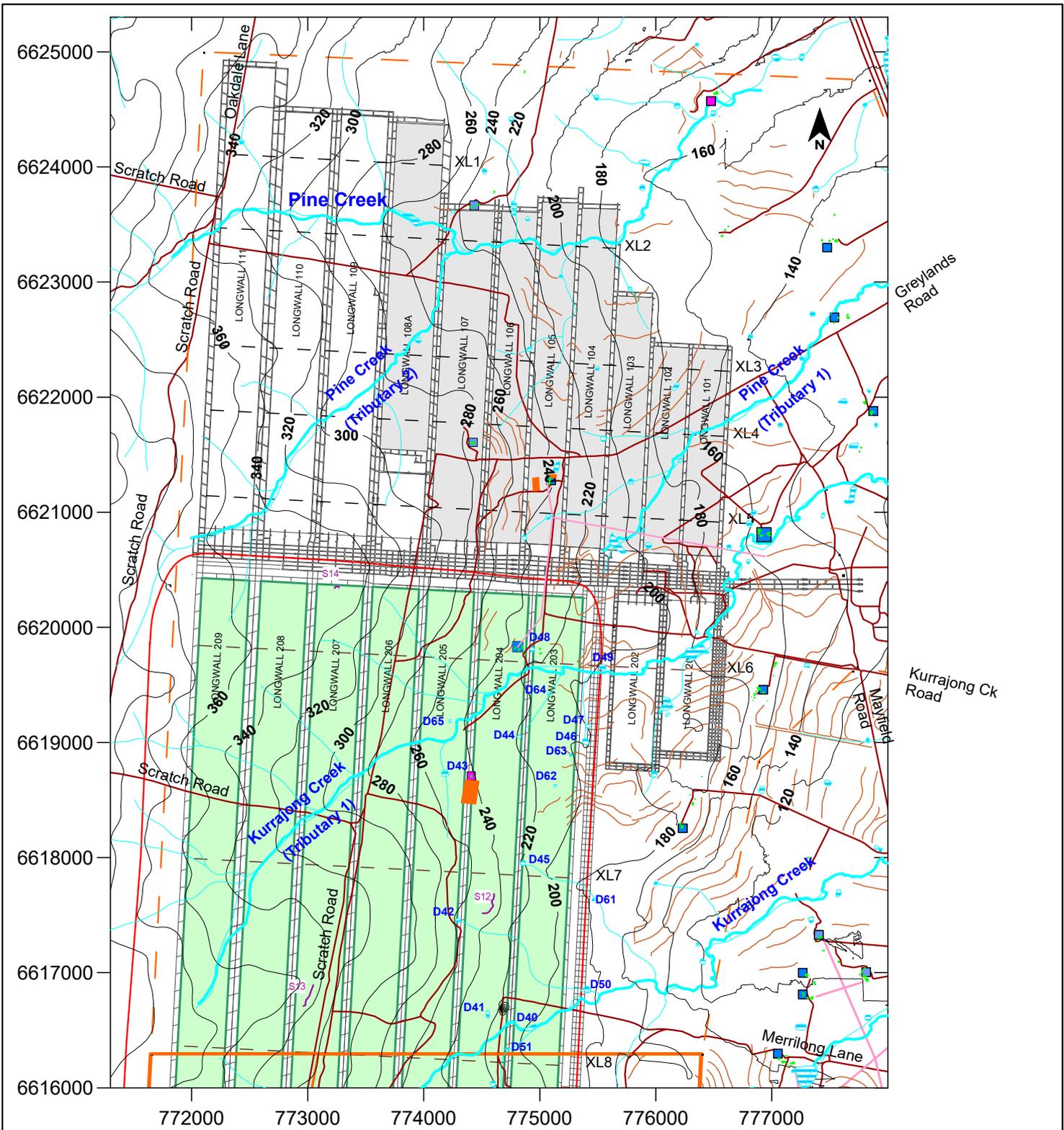
Photo 20 - Remediated Cracking above LW103 & 104 (ML1609)



Photo 21 - Tree Dieback in Poned Area (now drained) above LW101 (ML1609)



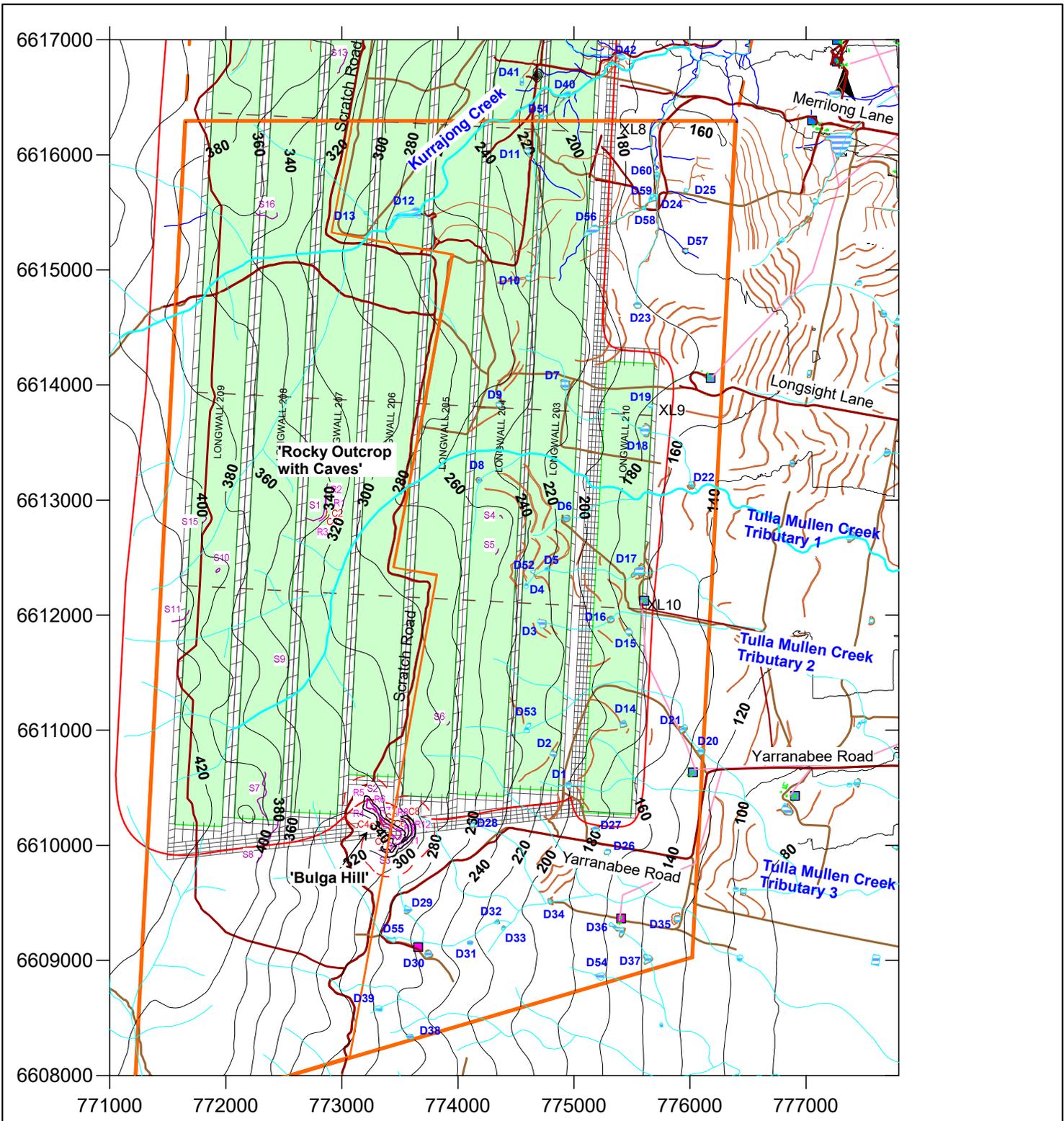
Figures



Key:

- Cover Depth Contours (m)
- Roads (unsealed)
- Proposed Longwalls (LW203-209)
- Approved Longwalls (LW108B-111, 201-202)
- Extracted Longwalls (LW101-108A)
- - - Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- - - Prediction Cross Lines
- Angle of Draw to 20mm Subsidence
- Dwellings & Sheds/Tanks/Orchards
- Dwellings (Private / NCO-Owned)
- Ephemeral Creeks & Watercourses
- Farm Dams (D40-D51, D61-D65)
- Contour Banks
- Powerlines (Domestic)
- C1/R1/S1 Minor Cliffs, Rock Faces & Steep Rocky Slopes

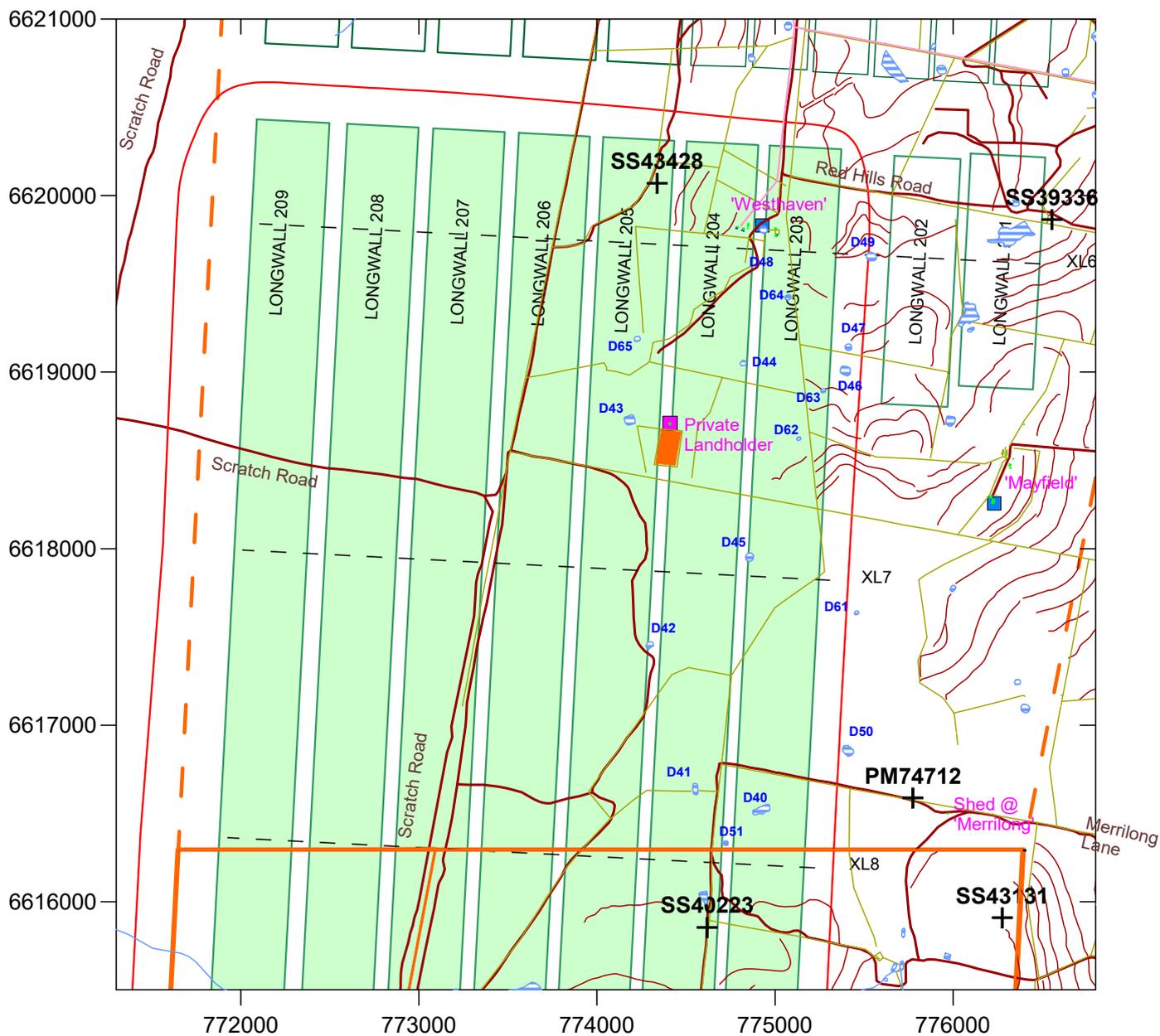
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	Drawn:	S.Ditton	Title:	Surface Features & Cover Depth Contours to the Mine Workings Roof for the Proposed LW203 to 209 in Mining Lease 1609 for The Project (see Figure 1b also)
	Date:	15.10.19	Scale:	1:60,000
	Ditton Geotechnical Services Pty Ltd		Figure No:	1a



Key:

- Cover Depth Contours (m)
- Roads (unsealed)
- Dwellings & Sheds/Tanks/Orchards
- Dwellings (Private/NCO-Owned)
- Proposed Longwalls (LW 203-210)
- - - Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- - - Prediction Cross Lines
- Angle of Draw to 20mm Subsidence
- - - Bulga Hill Buffer Zone Limits
- Ephemeral Creeks & Watercourses
- ▨ Farm Dams (D1-D39,52-60)
- Contour Banks
- Powerlines (Domestic)
- C1/R1/S1 Minor Cliffs, Rock Faces & Steep Rocky Slopes

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton	Title:	Surface Features & Cover Depth Contours to the Mine Workings Roof for the Proposed LW203 to 210 in the Mining Lease Application Areas 1 and 2 for The Project (see Figure 1a also)	
	Date:	15.10.19	Scale:	1:60,000	Figure No:
	Ditton Geotechnical Services Pty Ltd				1b



Key:

- Roads (unsealed)
- Dwellings & Sheds/Tanks/Orchards
- Dwellings (Private / NCOPL Owned)
- Subsidence Prediction Lines
- Farm Dams (D40-D51, D61-D65)
- Approved LW101 - 111, 201 - 202
- Proposed Longwalls (LW203 - 209)
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Angle of Draw to 20mm Subsidence
- Lot Boundaries/Fences
- Contour Banks
- State Survey Mark
- Powerlines (Domestic)

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 01.12.19

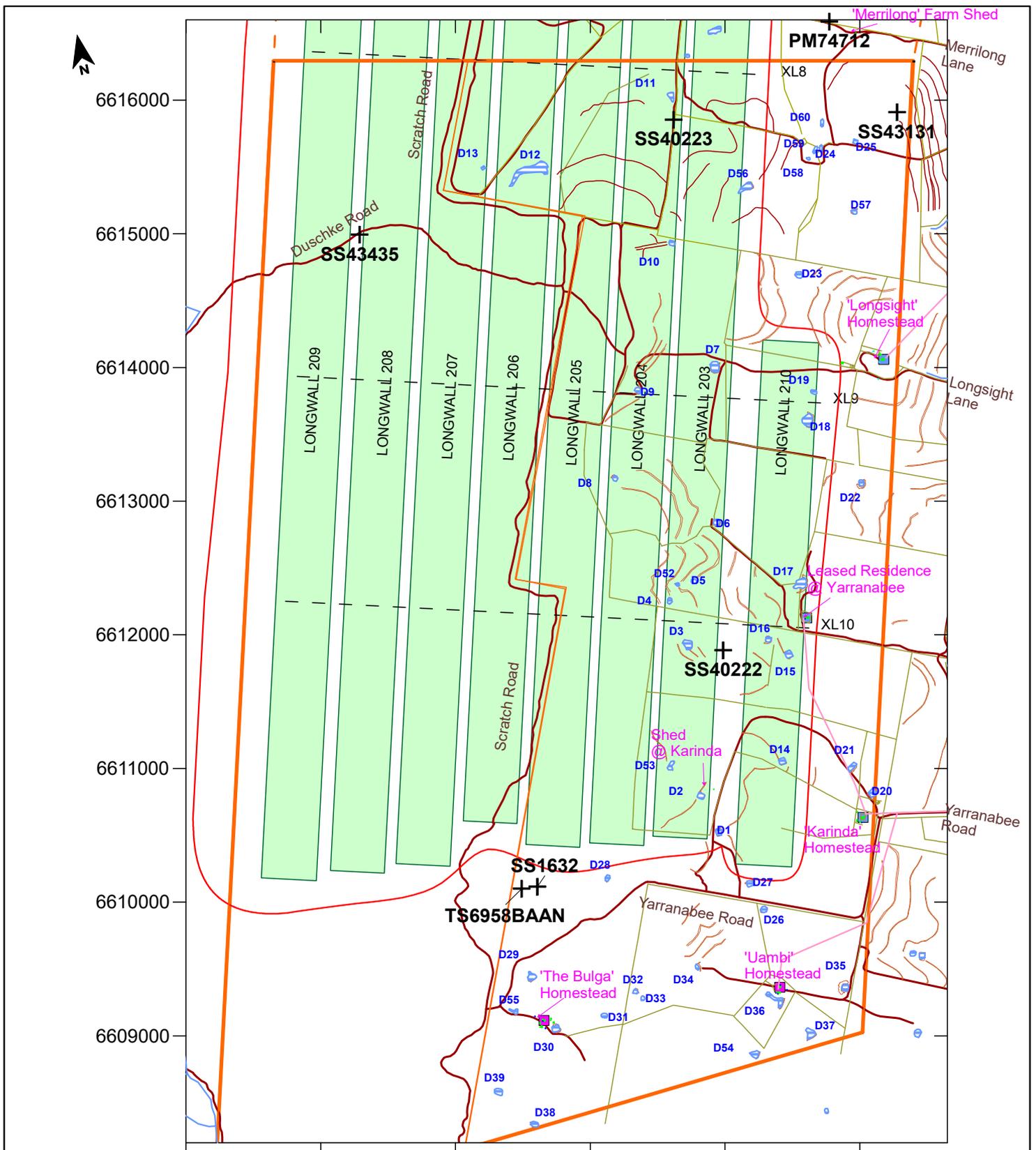
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 Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

Title: Built Features above the Proposed LW203 to 209 in Mining Lease 1609 for the Project

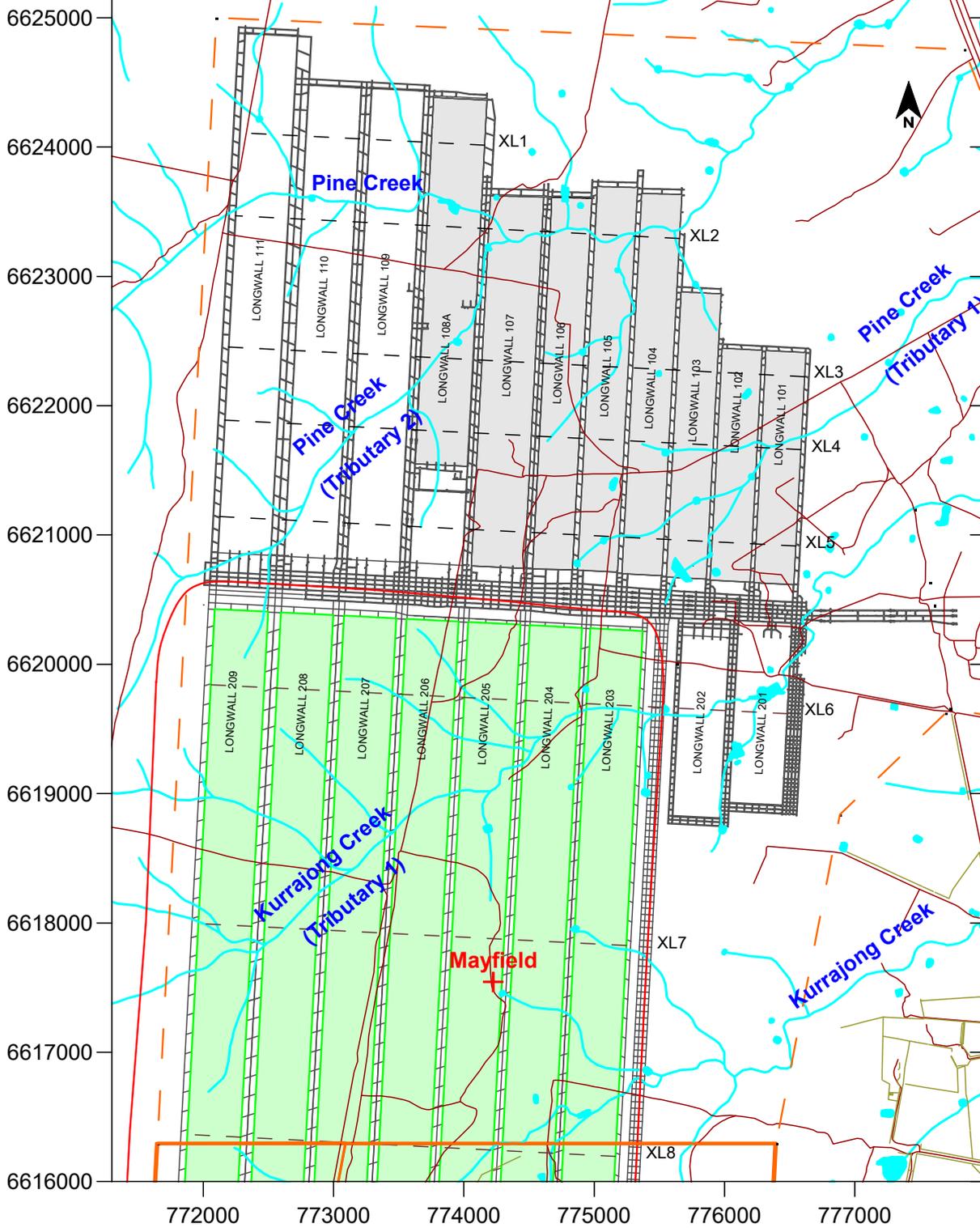
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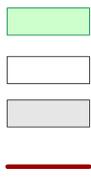


- Key:
- Roads (unsealed)
 - Proposed Longwalls (LW203 - 210)
 - Dwellings & Sheds/Tanks/Orchards
 - Mining Lease 1609 Boundary
 - Dwellings (Private / NCOPL Owned)
 - Mining Lease Application Areas 1 & 2 Boundaries
 - Subsidence Prediction Lines
 - Angle of Draw to 20mm Subsidence
 - Lot Boundaries/Fences
 - Powerlines (domestic)
 - Contour Banks
 - State Survey Mark
 - Farm Dams (D1-D39,52-60)

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton			
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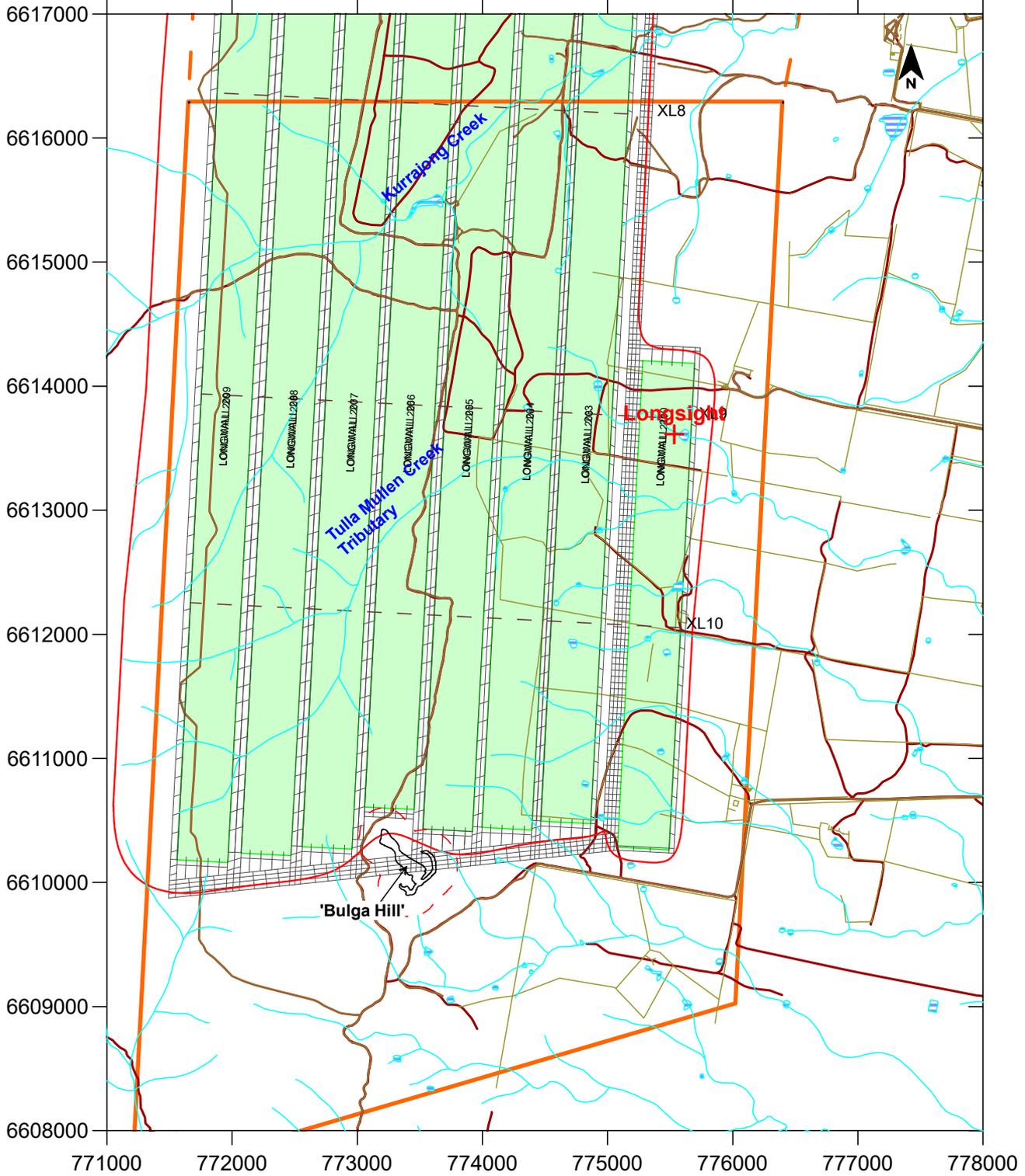


- Proposed Longwalls (LW203 to 209)
- Approved Longwalls (LW109 to 111, 201 & 202)
- Extracted Longwalls (LW101 to 108A)
- Roads (unsealed)

- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Subsidence Prediction Cross Lines
- Lot Boundaries / Fences
- Angle of Draw to 20mm subsidence

- Ephemeral Creeks & Watercourses
- Grinding Groove Locations

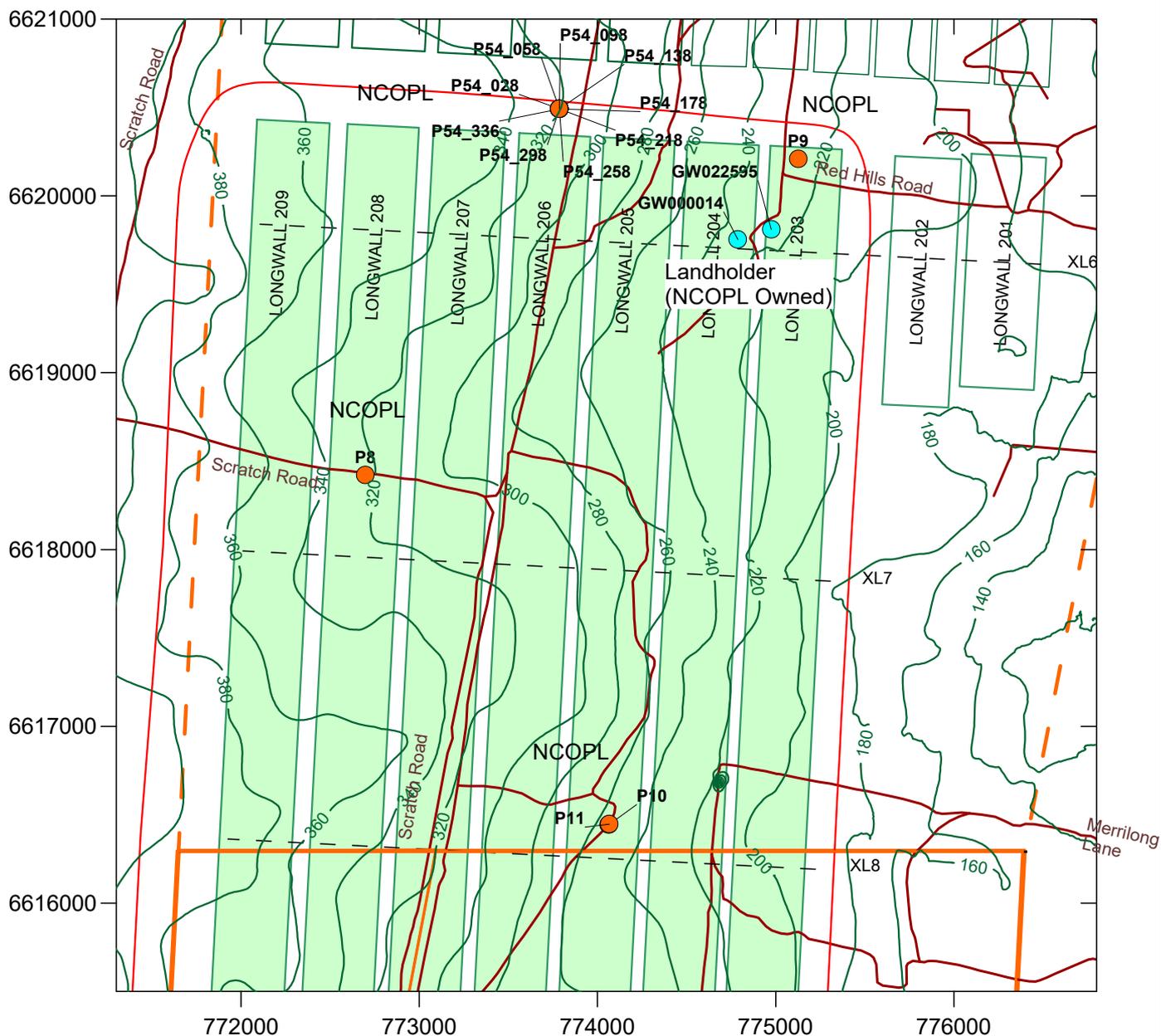
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	Date:	15.10.19	Scale:	1:60,000	Figure No:	1e
	Ditton Geotechnical Services Pty Ltd					



Key:

- Proposed Longwalls (LW203 to 210)
- Roads (unsealed)
- Angle of Draw to 20mm subsidence
- Bulga Hill Buffer Zone
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Subsidence Prediction Lines
- Lot Boundaries / Fences
- Ephemeral Creeks & Watercourses
- + Grinding Groove Locations

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton	Title:	Aboriginal Heritage Sites above the Proposed LW203 to 210 in MLA Areas 1 & 2	
	Date:	15.10.19	Scale:	1:60,000	
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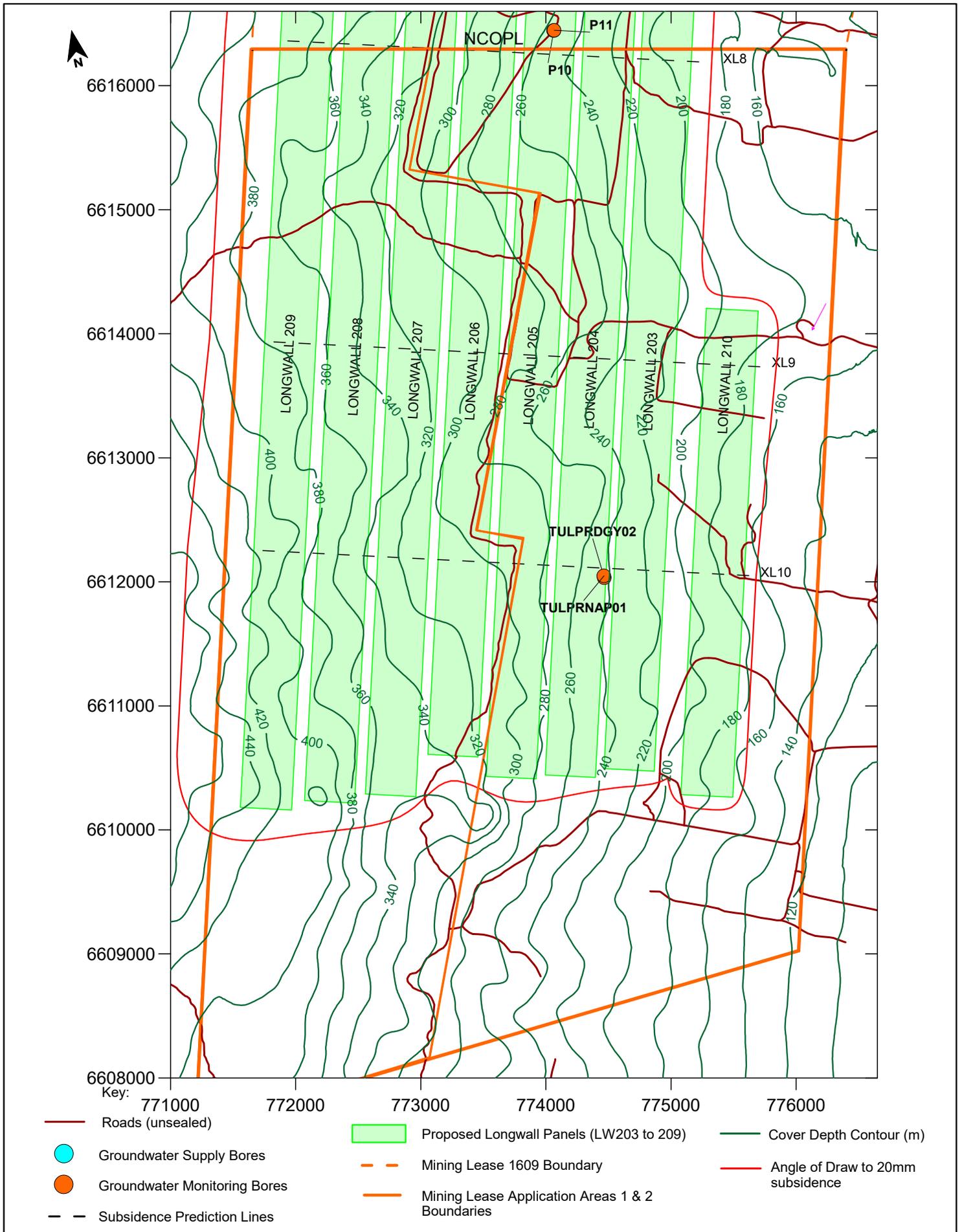


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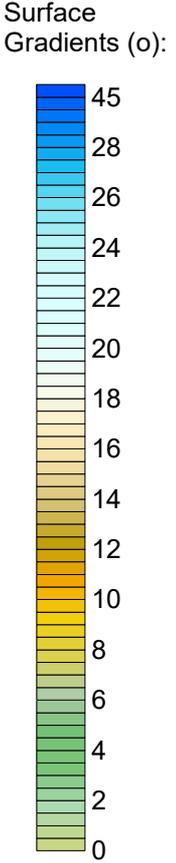
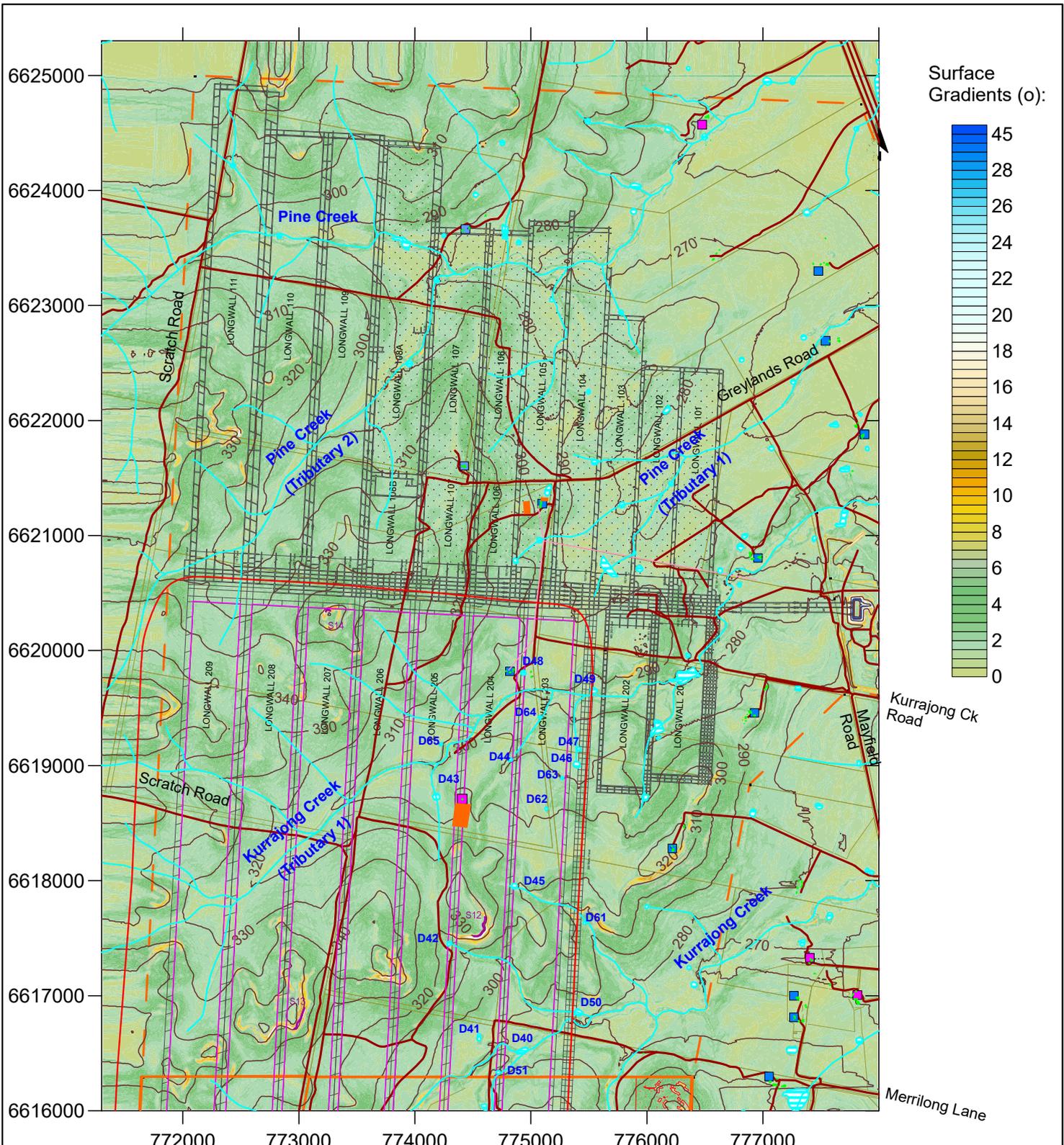
- Roads (unsealed)
- Groundwater Supply Bores
- Groundwater Monitoring Bores
- - Subsidence Prediction Lines
- Proposed Longwall Panels (LW203 to 209)
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Cover Depth Contour (m)
- Angle of Draw to 20mm subsidence



DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Existing Groundwater Supply and Monitoring Bores above the Proposed LW203 to 209 in ML1609		
	Date:	01.12.19				
	Ditton Geotechnical Services Pty Ltd			Scale:	1:45,000	Figure No:



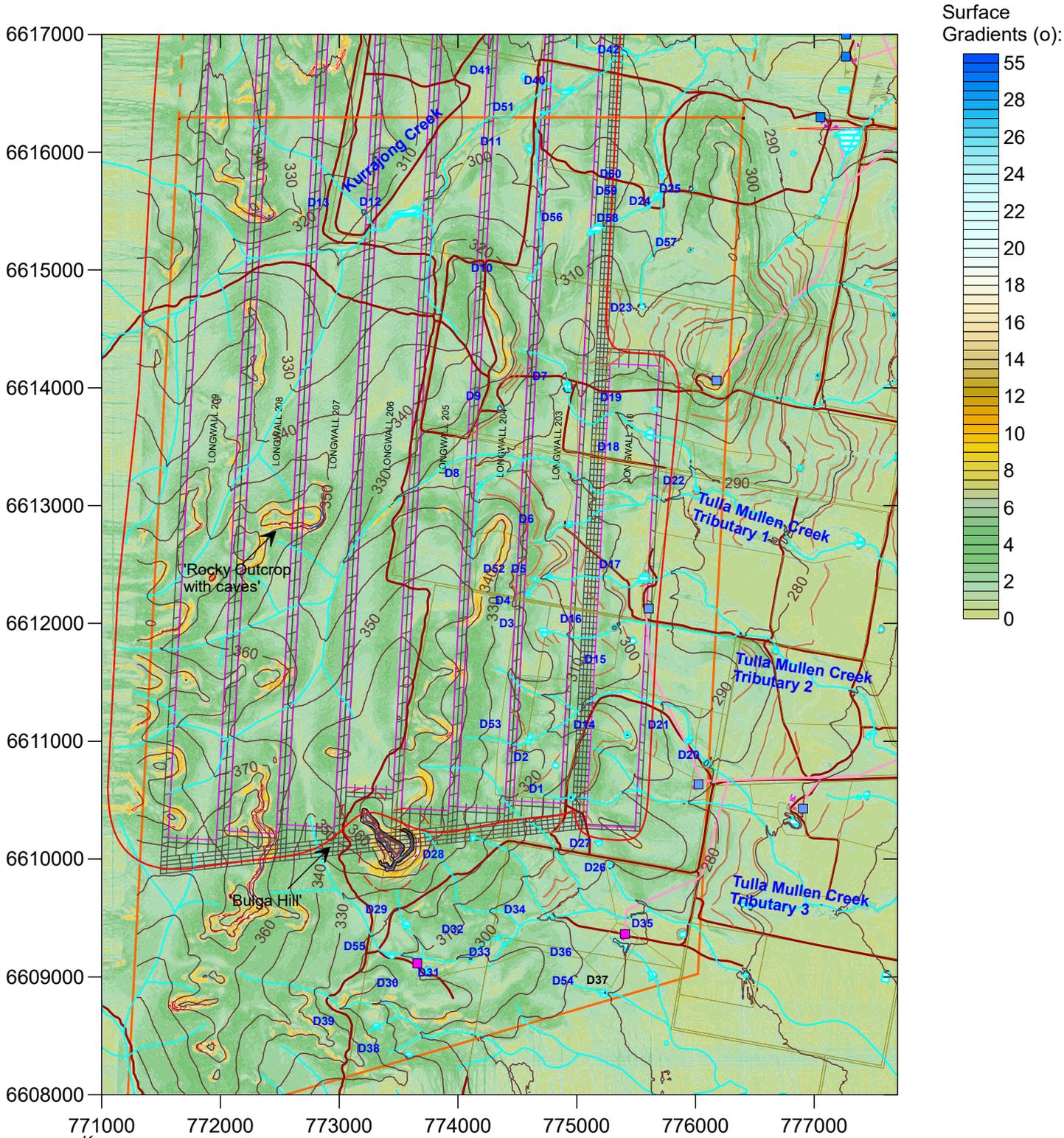
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Existing Groundwater Supply & Monitoring Bores above the Proposed LW203 to 210 in MLA Areas 1 & 2		
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	Ditton Geotechnical Services Pty Ltd					



Key:

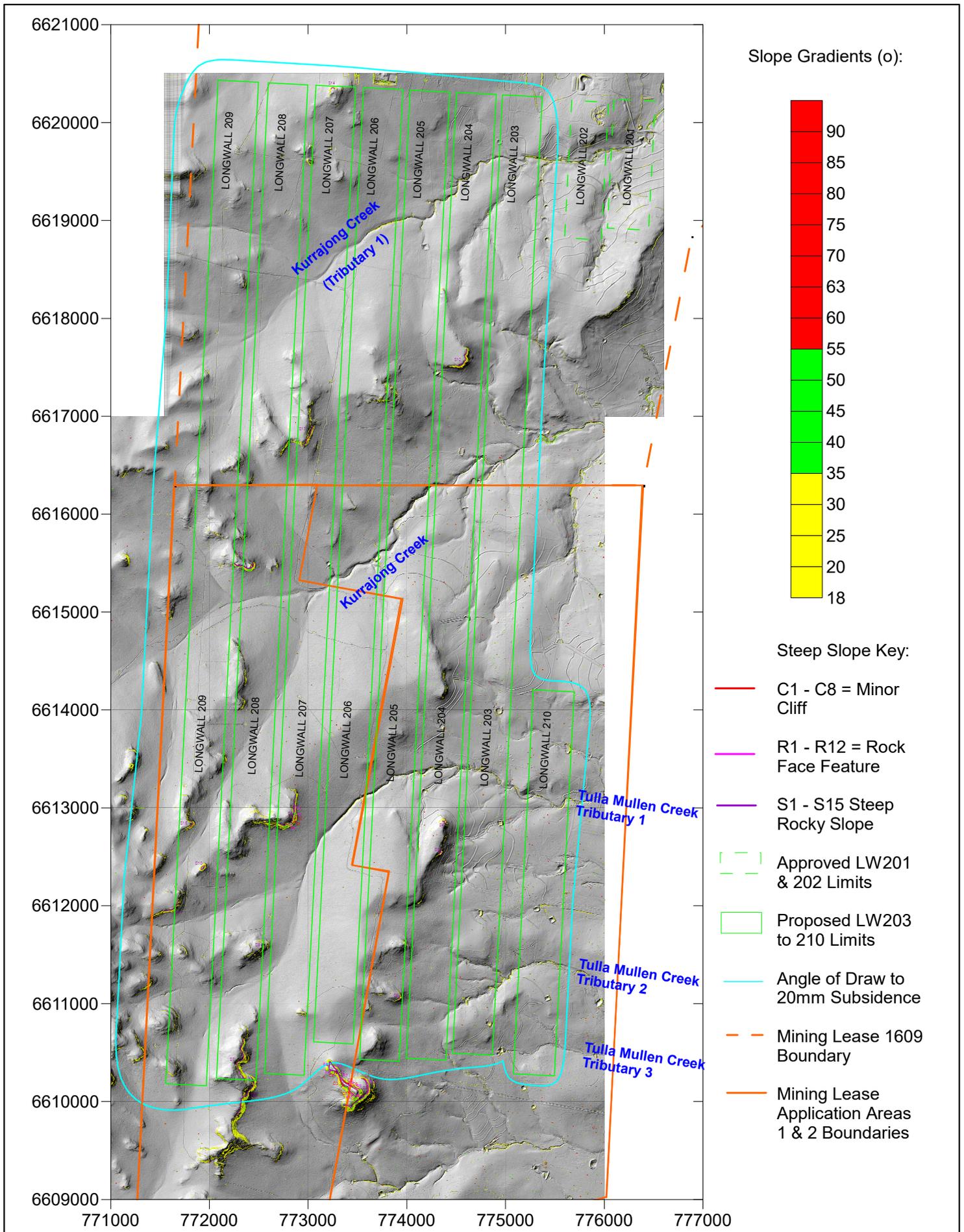
- Surface Level contours (m)
- Approved LW109 to 111 & 201 to 202
- Extracted LW101 to 108A
- Proposed LW203 - 209
- Angle of Draw to 20mm subsidence
- Ephemeral Creeks & Watercourses
- Dwellings (Private/NCO-Owned)
- Lot Boundaries/Fences
- Roads (unsealed)
- Powerlines (Domestic)
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Farm Dams (D40-D51, D61-D65)
- Minor Cliffs, Rock Faces & Steep Rocky Slopes
- Dwelling/Shed/Tank/Orchard

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Surface Level Contours with Surface Features above the Proposed LW203 to 209 in ML1609		
	Date:	20.03.20	Scale:	1:60,000	Figure No:	2a
	Ditton Geotechnical Services Pty Ltd					

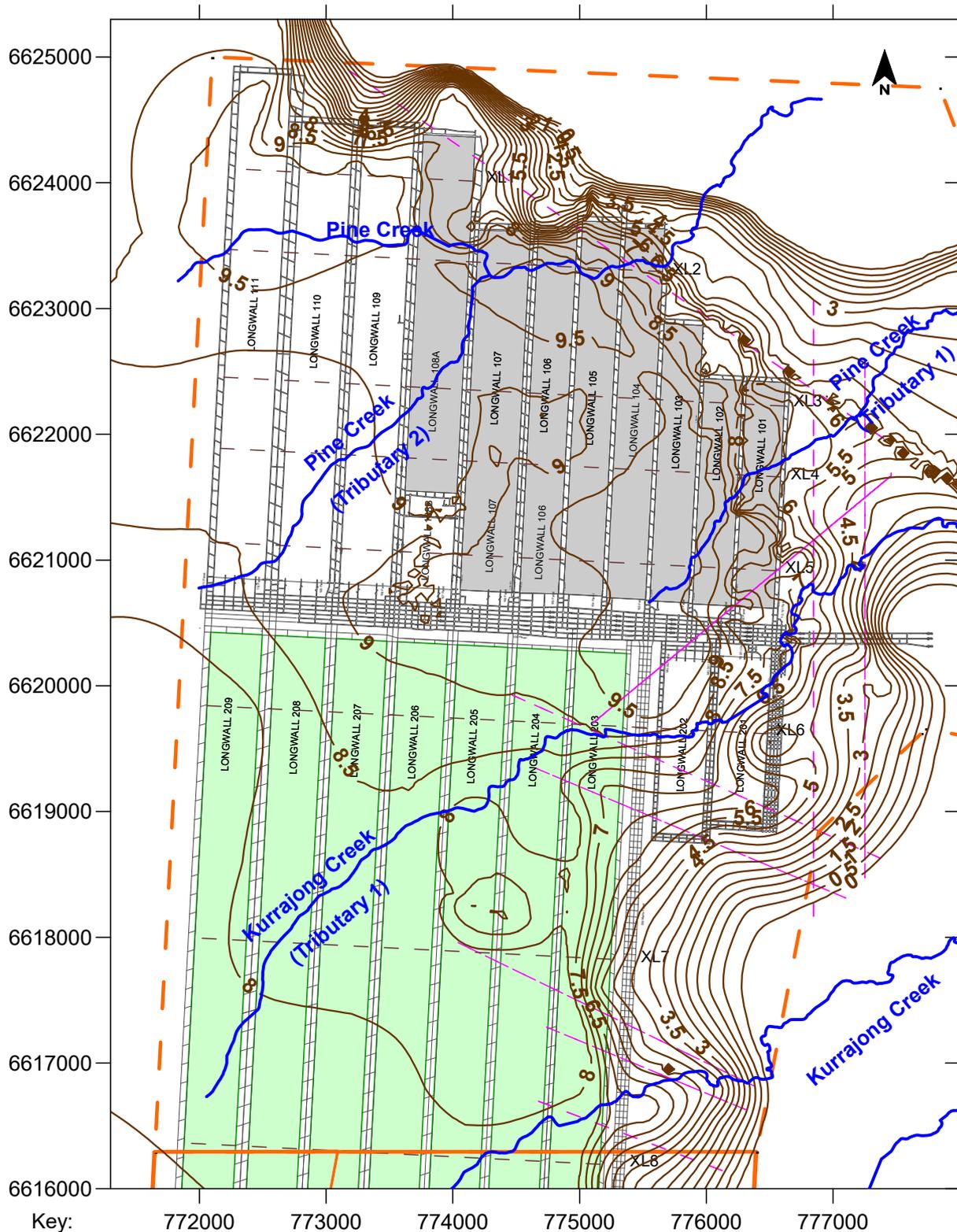


- Key:
- Surface Level contours (m)
 - Ephemeral Creeks & Watercourses
 - Mining Lease 1609 Boundary
 - Proposed LW203 - 210
 - Existing Dwellings (Private/NCO-Owned)
 - Mining Lease Application Areas 1 & 2 Boundaries
 - Angle of Draw to 20mm subsidence
 - Lot Boundaries/Fences
 - ▽ Farm Dams (D1-D39, D52-60)
 - Roads (unsealed)
 - Suspended Powerlines (11kV)
 - C1/R1/S1 Minor Cliffs, Rock Faces & Steep Rocky Slopes

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Surface Level Contours with Surface Features above the Proposed LW203 to 210 in MLA Areas 1 & 2		
	Date:	20.03.20	Scale:	1:60,000	Figure No:	2b
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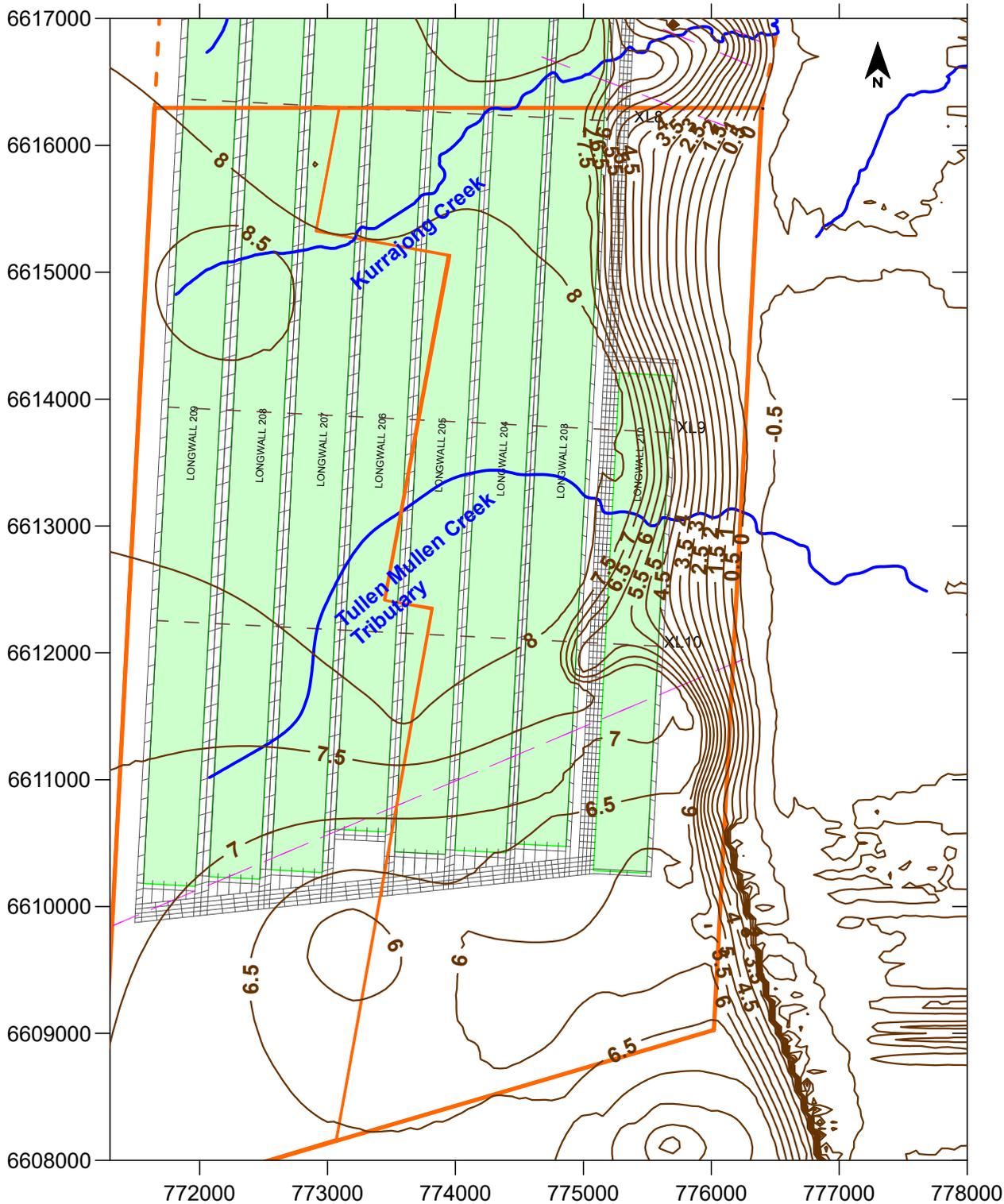


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	31.12.19	Title:	Lidar Survey with Steep Slopes & Minor Cliffs above Mining Lease 1609 and Mining Lease Application Areas 1 & 2 for the Project	
	Ditton Geotechnical Services Pty Ltd			Scale:	1:50,000



- Hoskissons Seam Thickness contours (m)
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Extracted LW101-108A
- Approved LW109 to 111 & LW201 to 202
- Proposed LW203 to 210
- Main Creeks
- Faults
- Subsidence Prediction Lines

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Hoskissons Seam Thickness Contours in ML1609		
	Date:	15.10.19	Scale:	1:60,000	Figure No:	3a
	Ditton Geotechnical Services Pty Ltd					



Key:

- Hoskissons Seam Thickness contours (m)
- Subsidence Prediction Lines
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Proposed LW203 to 210
- Main Creeks
- Faults

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.10.19

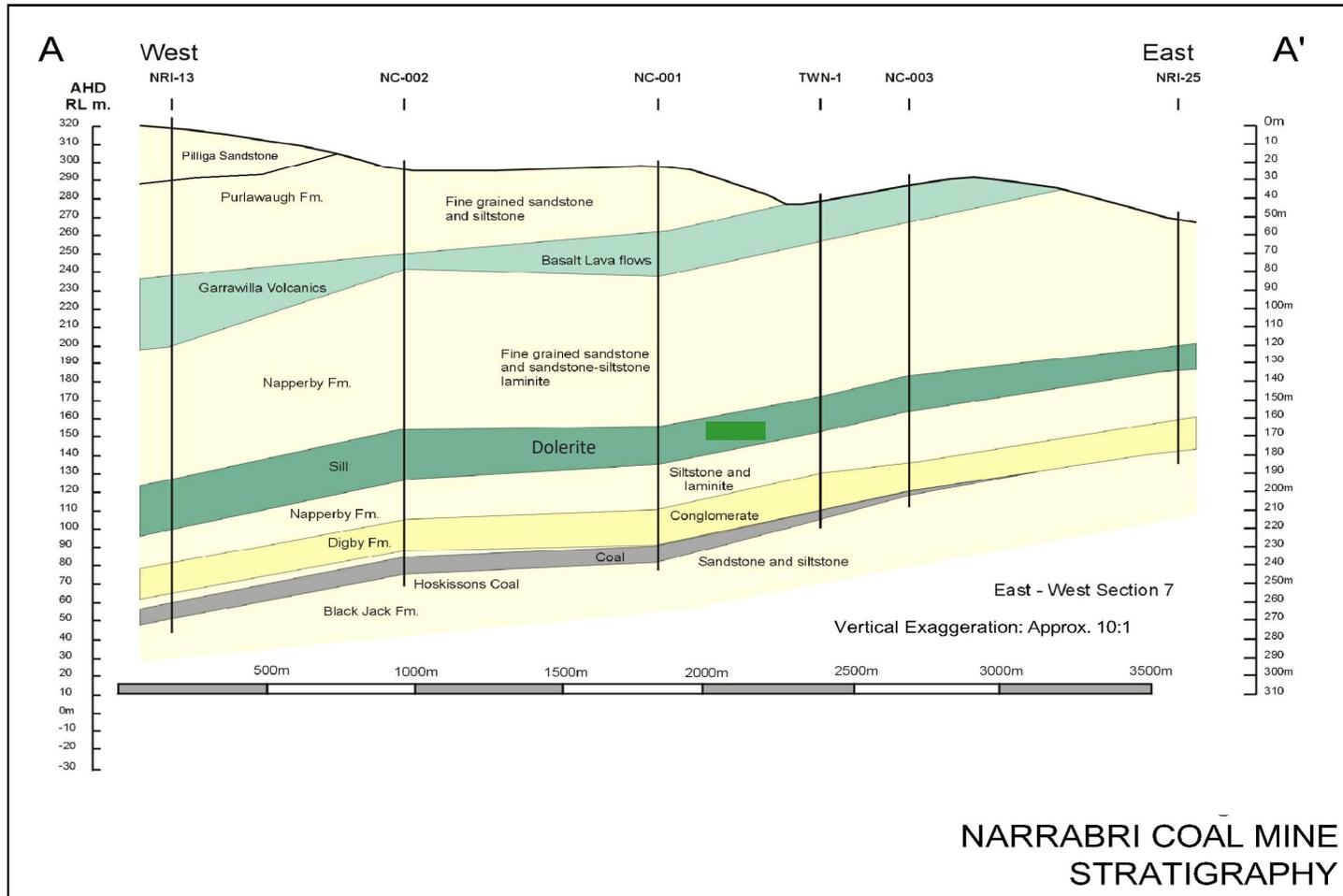
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Client: Narrabri Mine
 NAR-005/2

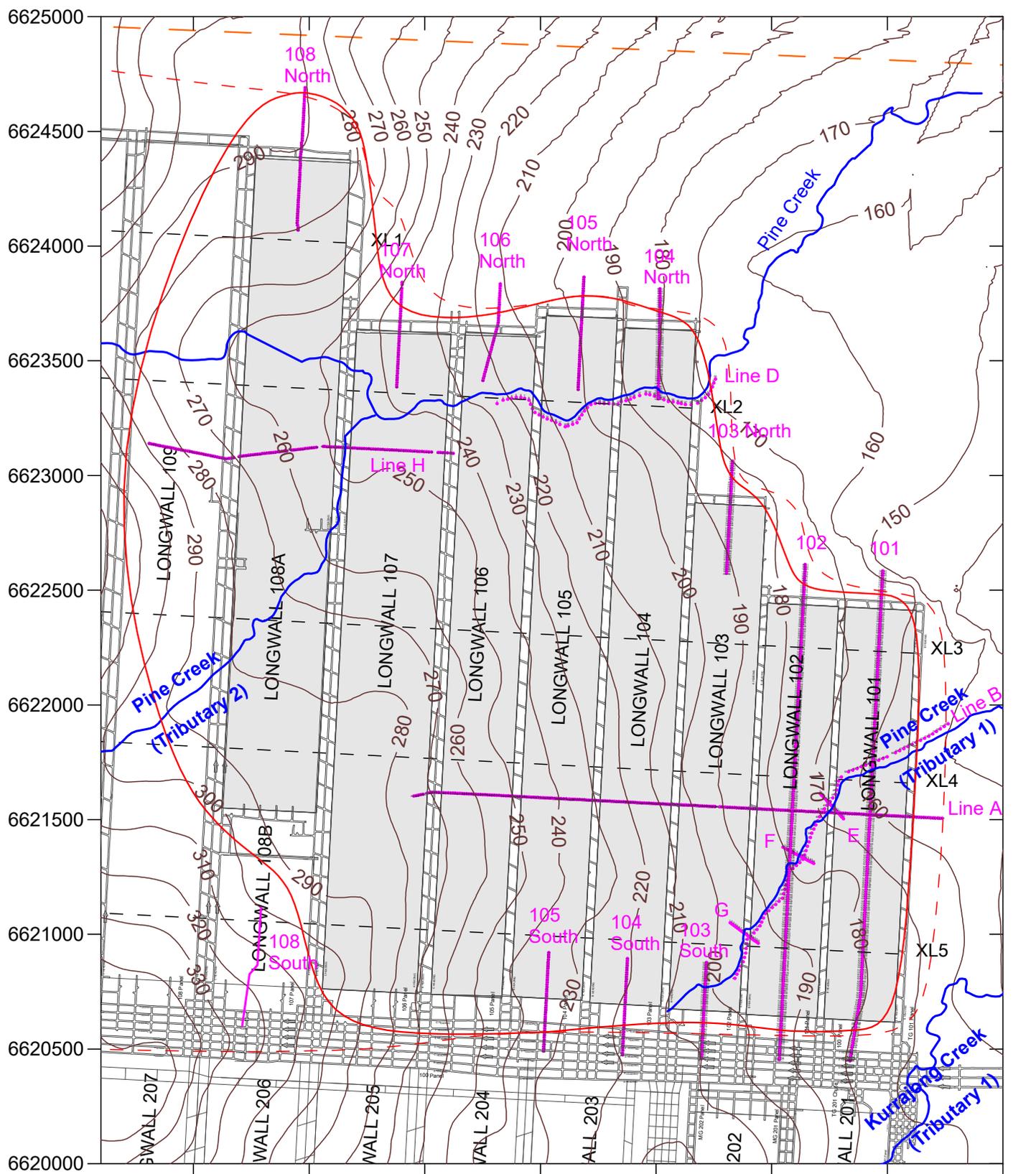
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Figure No: 3b



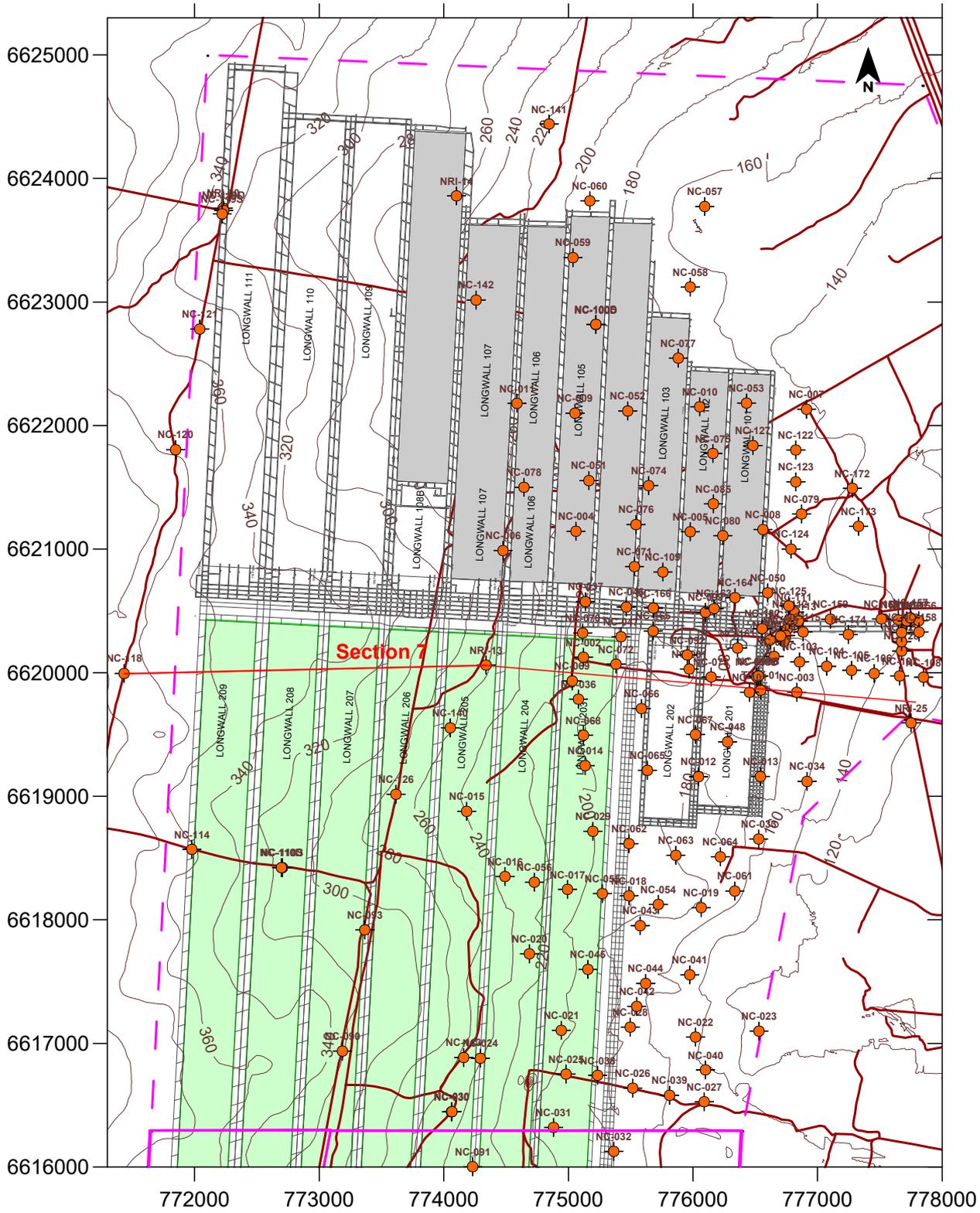
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	Date:	15.10.19	Title:	Representative Section of Site Lithology: East-West Section in Project Area (see Figure 4a for Location)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	3c



Key:

- Cover Depth Contours (m)
- Subsidence Survey Lines
- Measured Angle of Draw (101-108A)
- Main Creeks
- XL1 - - - Subsidence Prediction Lines
- Predicted Final Angle of Draw
- █ Extracted LW101 to 108A
- Mining Lease 1609 Boundary

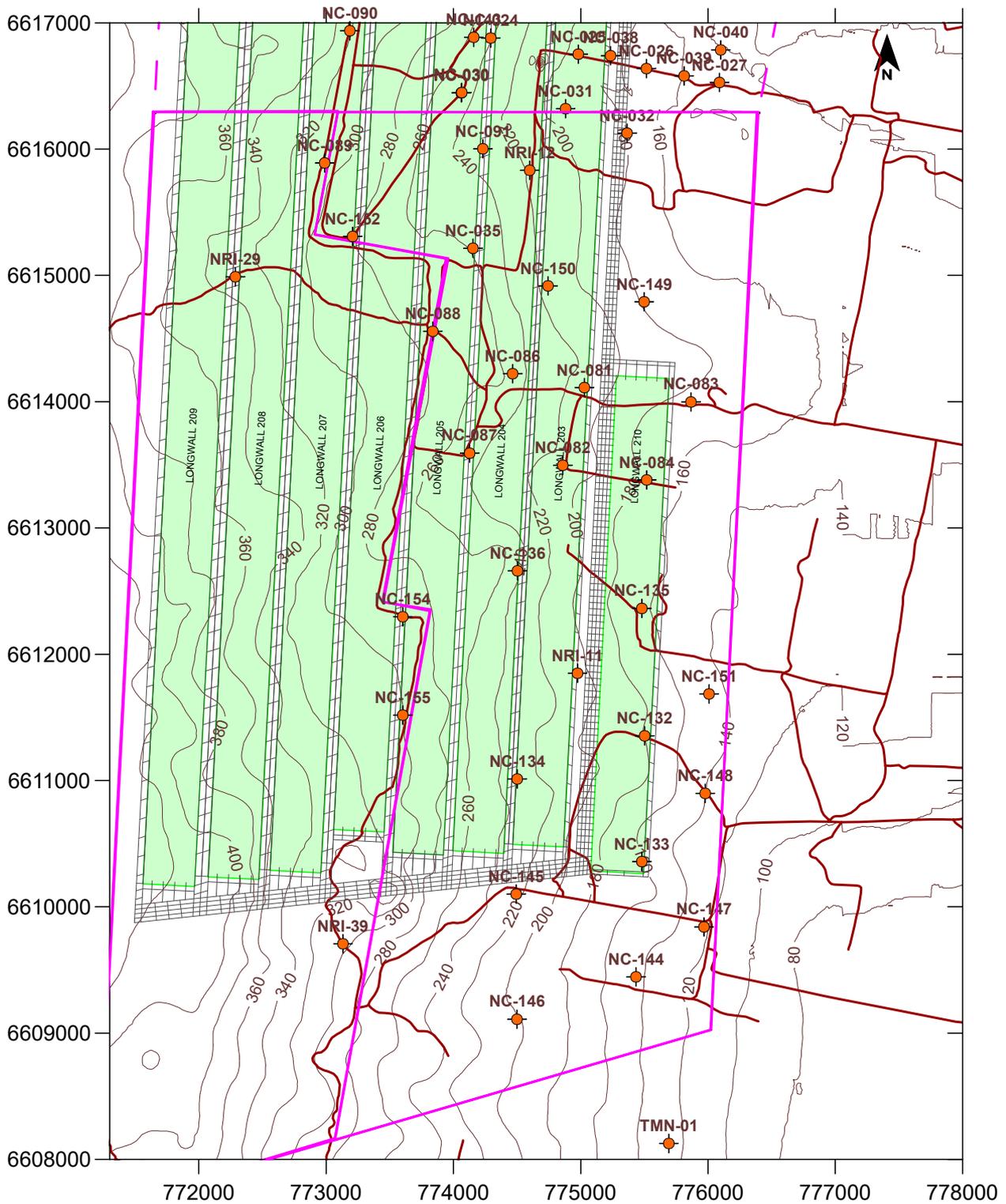
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	Drawn:	S.Ditton	Title:	Subsidence Survey Lines with Cover Depth Contours Above the Extracted LW101 to 108A in ML1609	
	Date:	20.03.20	Scale:	1:25,000	
	Ditton Geotechnical Services Pty Ltd			Figure No:	3d



Key:

- Cover depth contours (m)
- Roads (unsealed)
- Borehole locations
- █ Extracted LW101 to 108A
- █ Approved LW109 to 111 & 201 to 202
- █ Proposed LW203 to 210
- - - Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Section 7

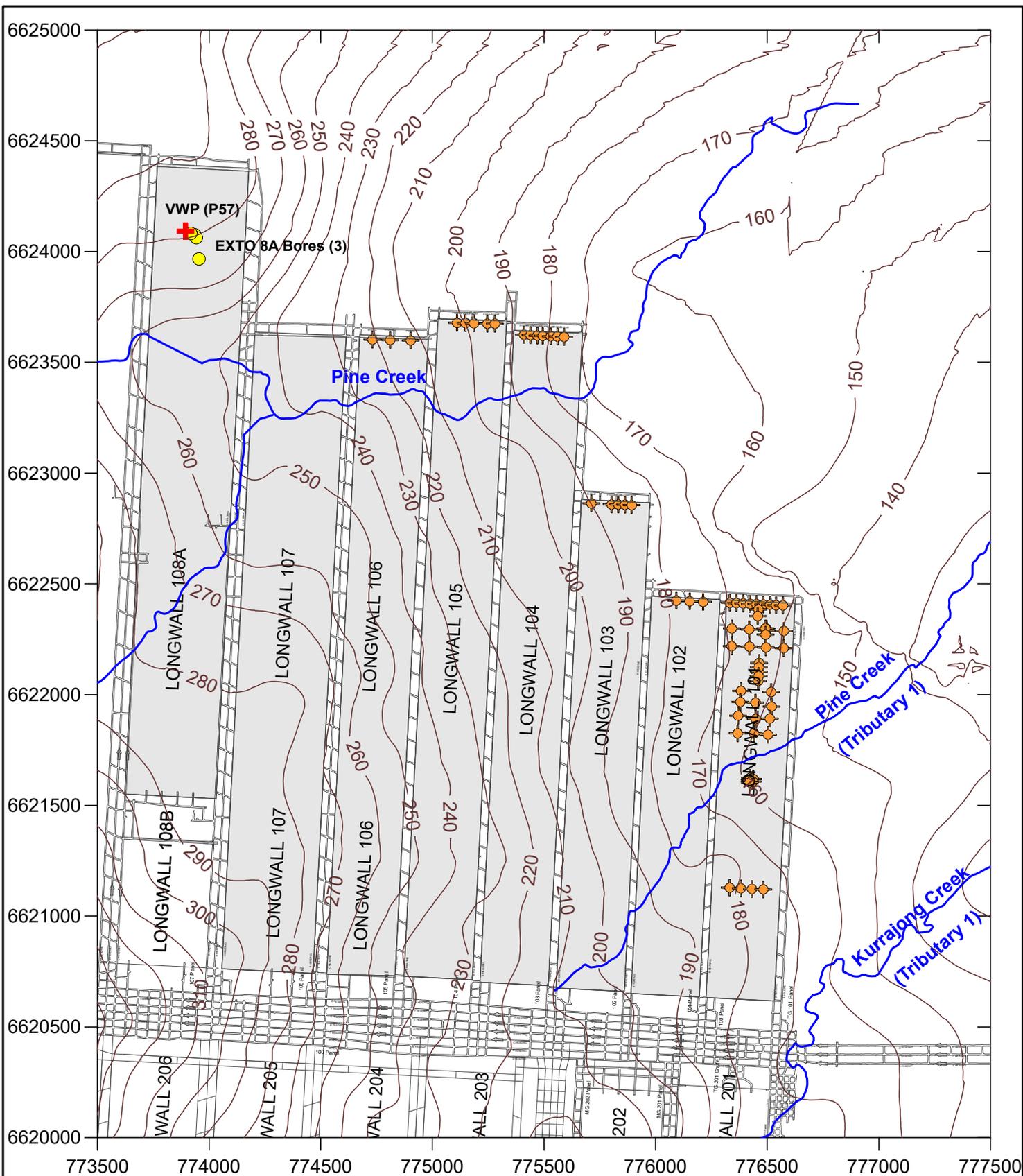
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Borehole Locations and Cover Depth Contours above the Proposed LW203 to 209 in ML1609		
	Date:	15.10.19	Scale:	1:60,000	Figure No:	4a
	Ditton Geotechnical Services Pty Ltd					



Key:

- Cover depth contours (m)
- Roads (unsealed)
- ⊕ Borehole locations
- █ Proposed LW203 to 210
- - - Mining Lease 1609 Boundary
- █ Mining Lease Application Areas 1 & 2 Boundaries

 DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton	Title:	Borehole Locations and Cover Depth Contours above the Proposed LW203 to 210 in MLA Areas 1 & 2	
	Date:	15.10.19	Scale:	1:60,000	Figure No:
	Ditton Geotechnical Services Pty Ltd				4b



Key:

- Cover Depth Contours (m)
- Main Creeks
- Multiple Exto Locations
- Dual Exto Locations
- Multiple VWP Locations
- Extracted LW101 to 108A



Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 1.11.19

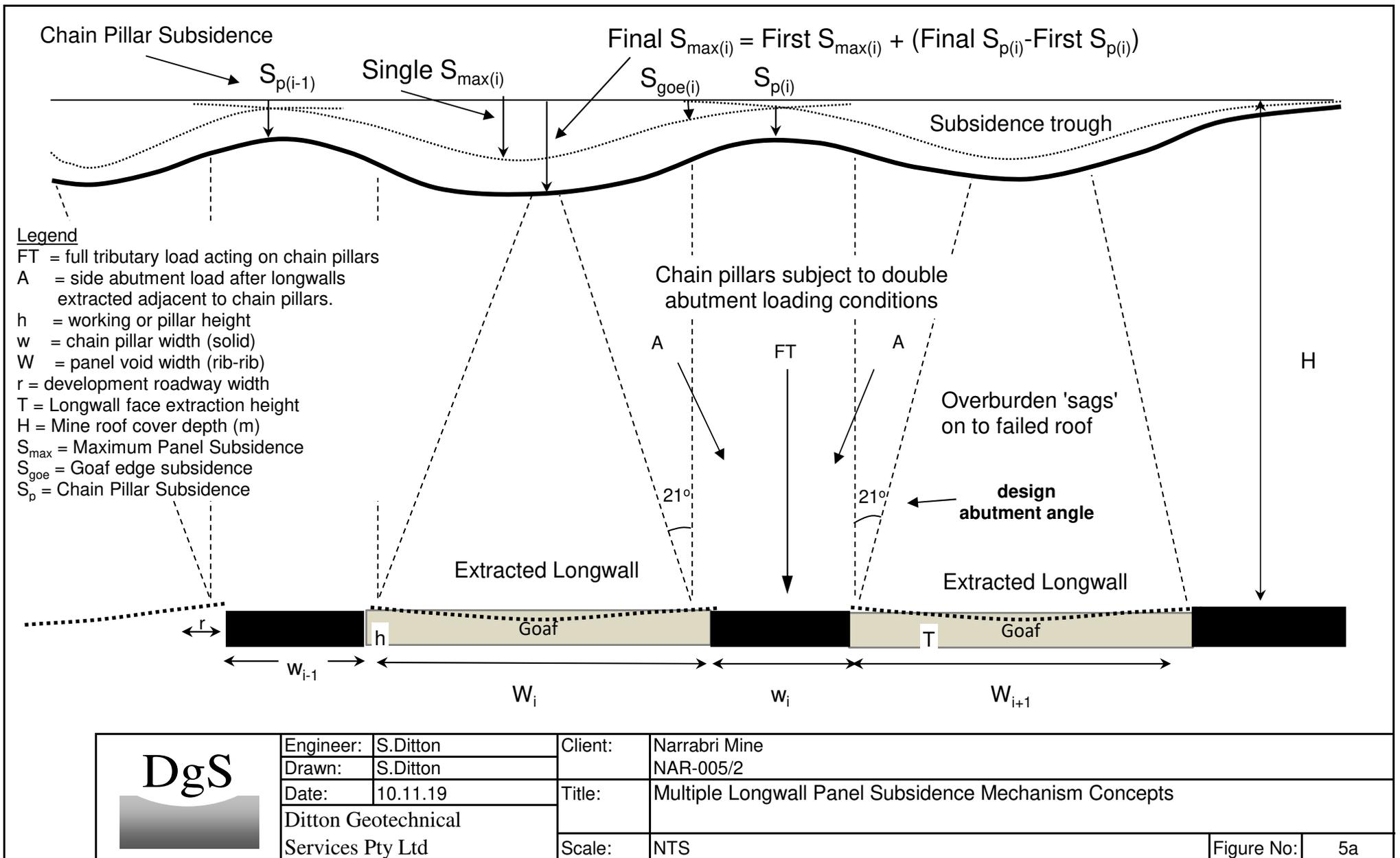
Ditton Geotechnical Services Pty Ltd

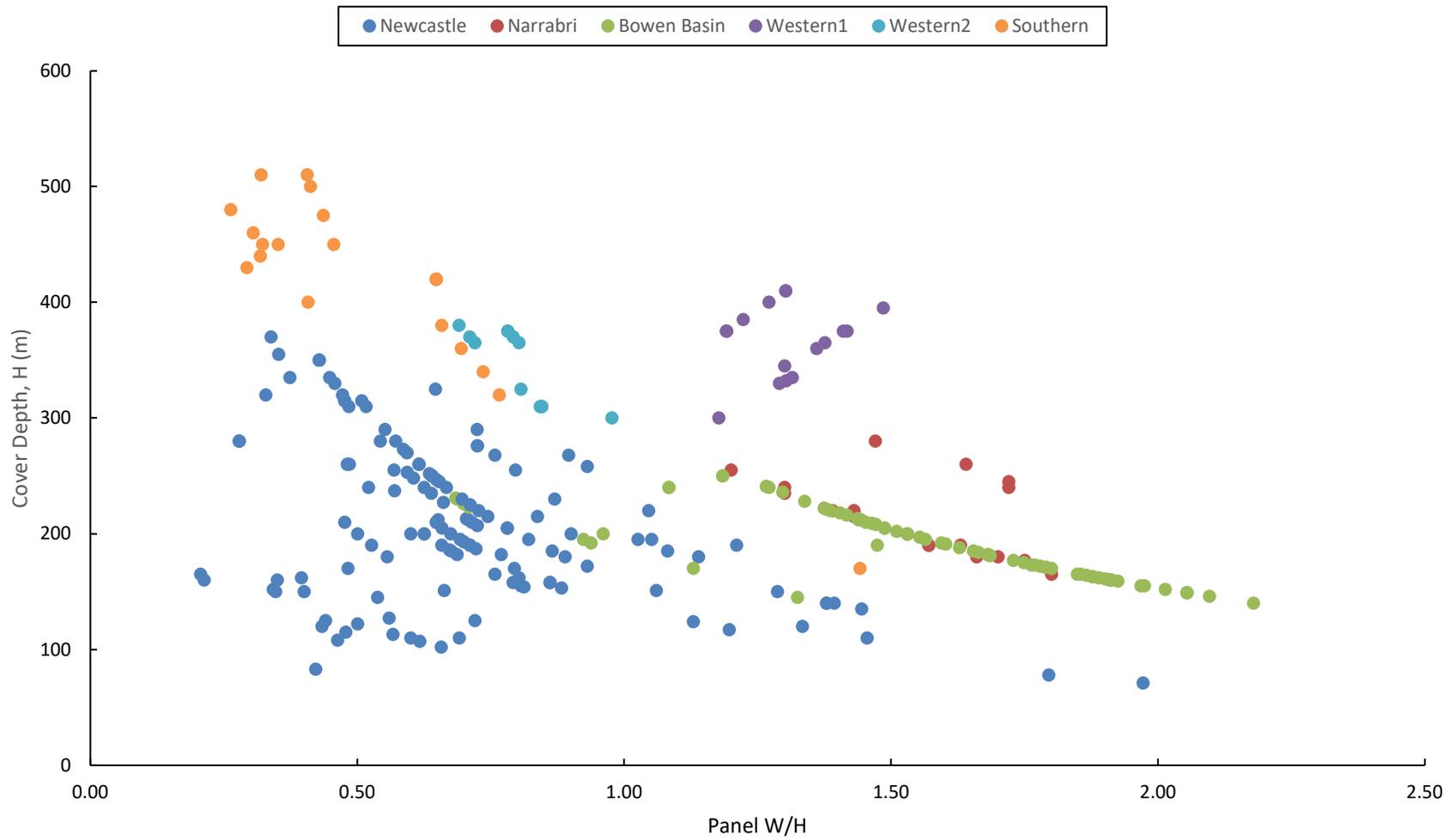
Client: Narrabri Mine
 NAR-005/2

Title: Borehole Extensometer Locations with Cover Depth Contours above the Extracted LW101 to 108A in ML1609

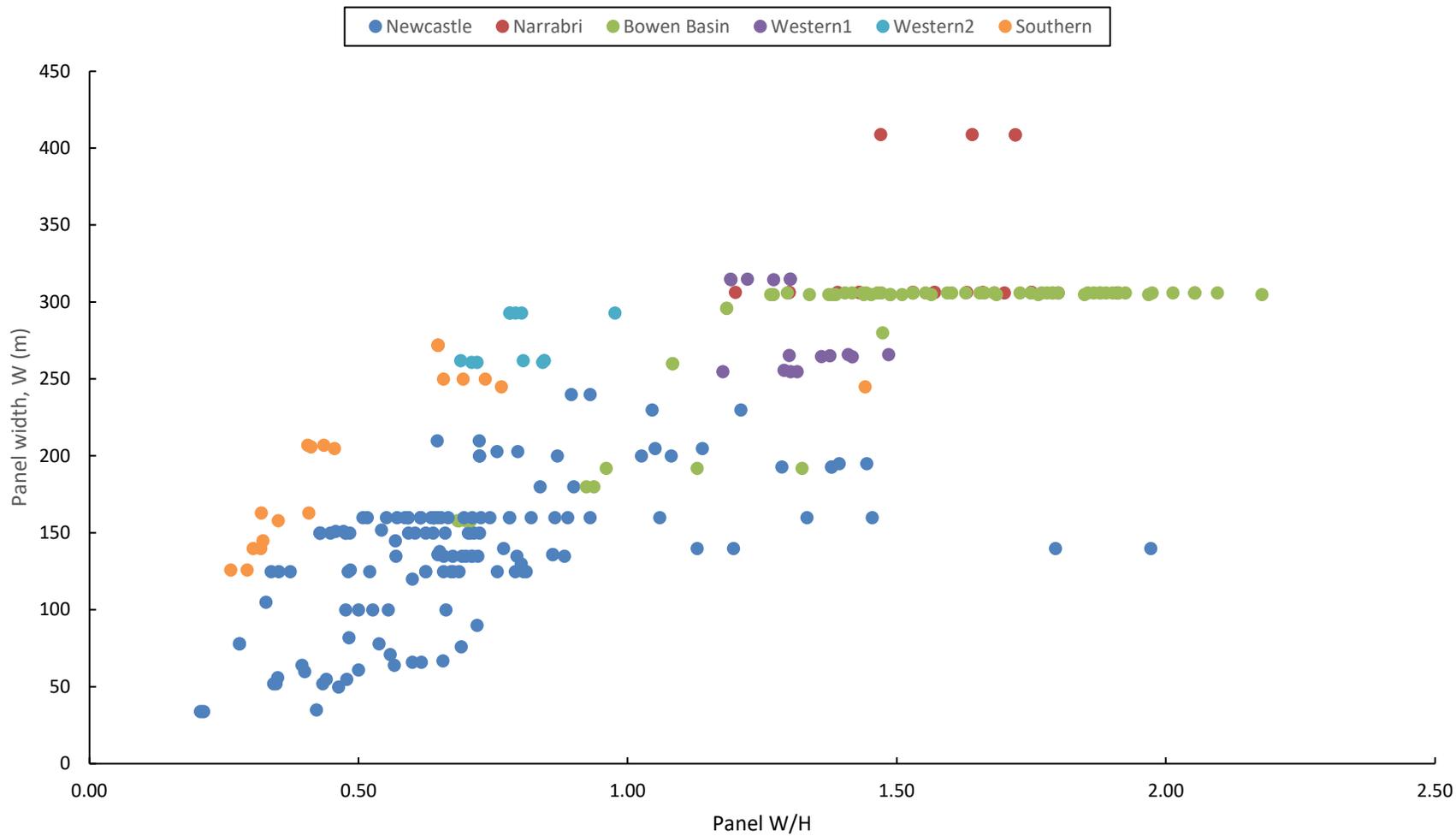
Scale: 1:25,000

Figure No: 4c

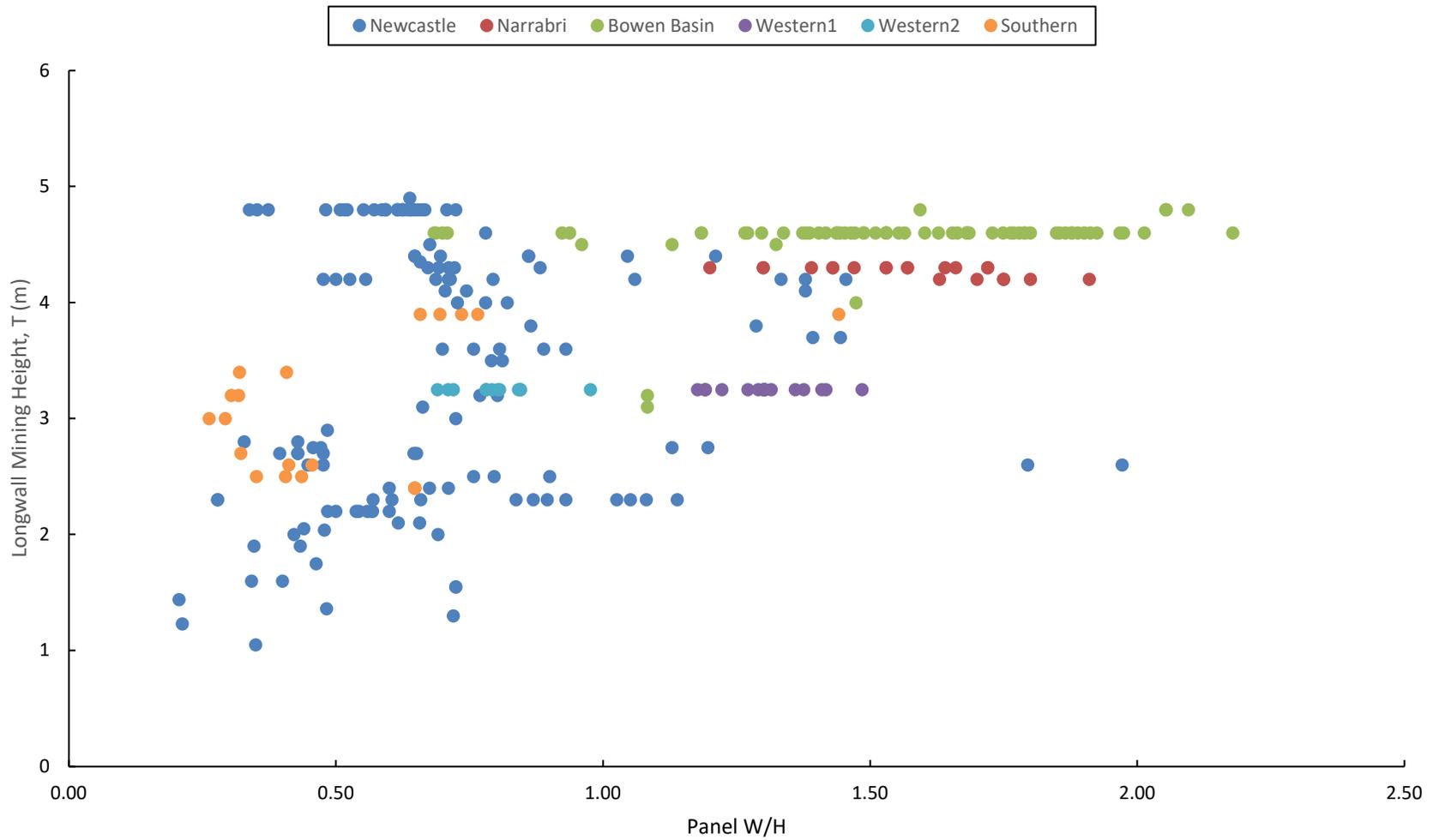




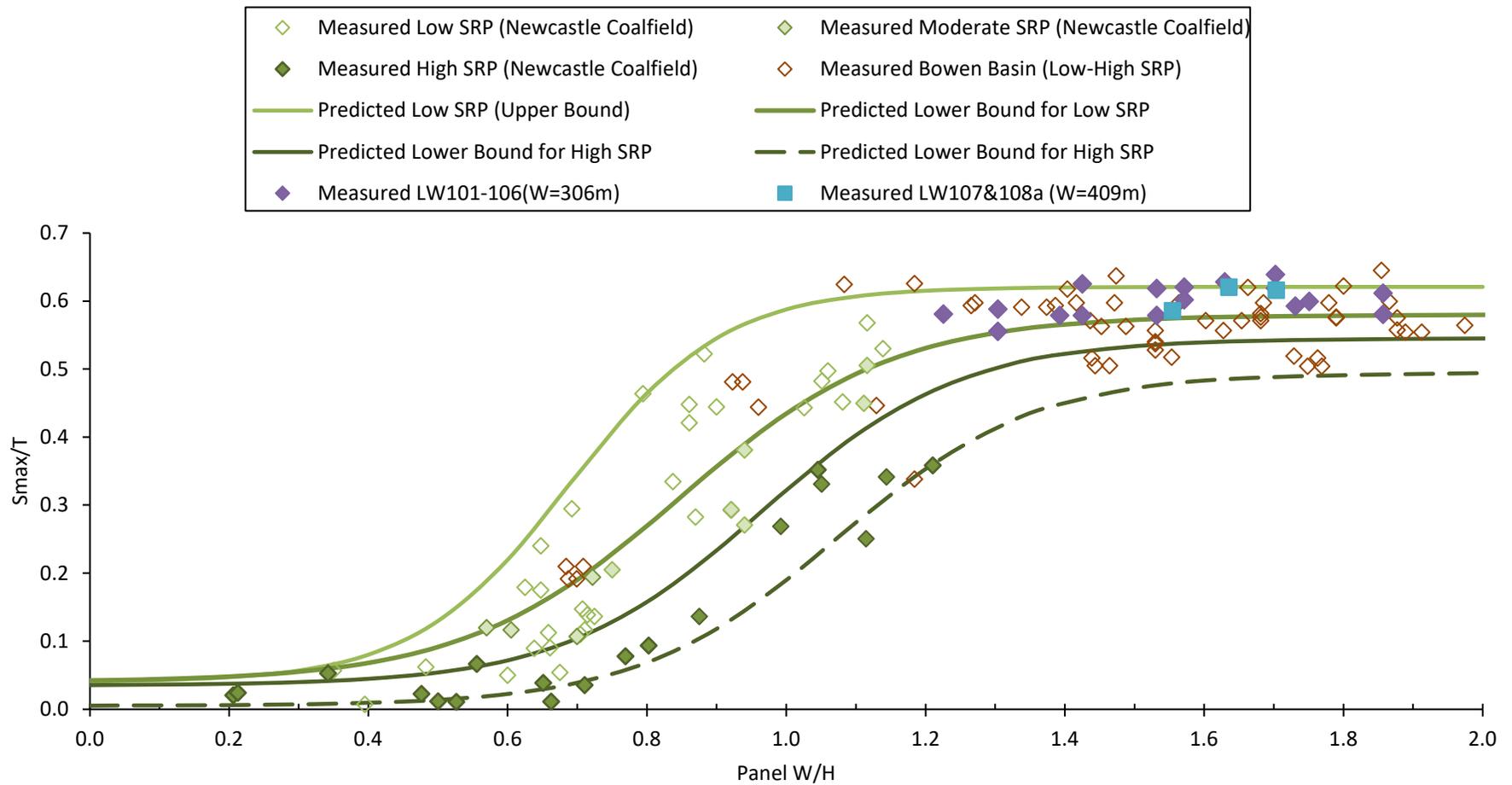
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.06.20	Title:	Longwall Panel Subsidence Database of Cover Depth v. W/H	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



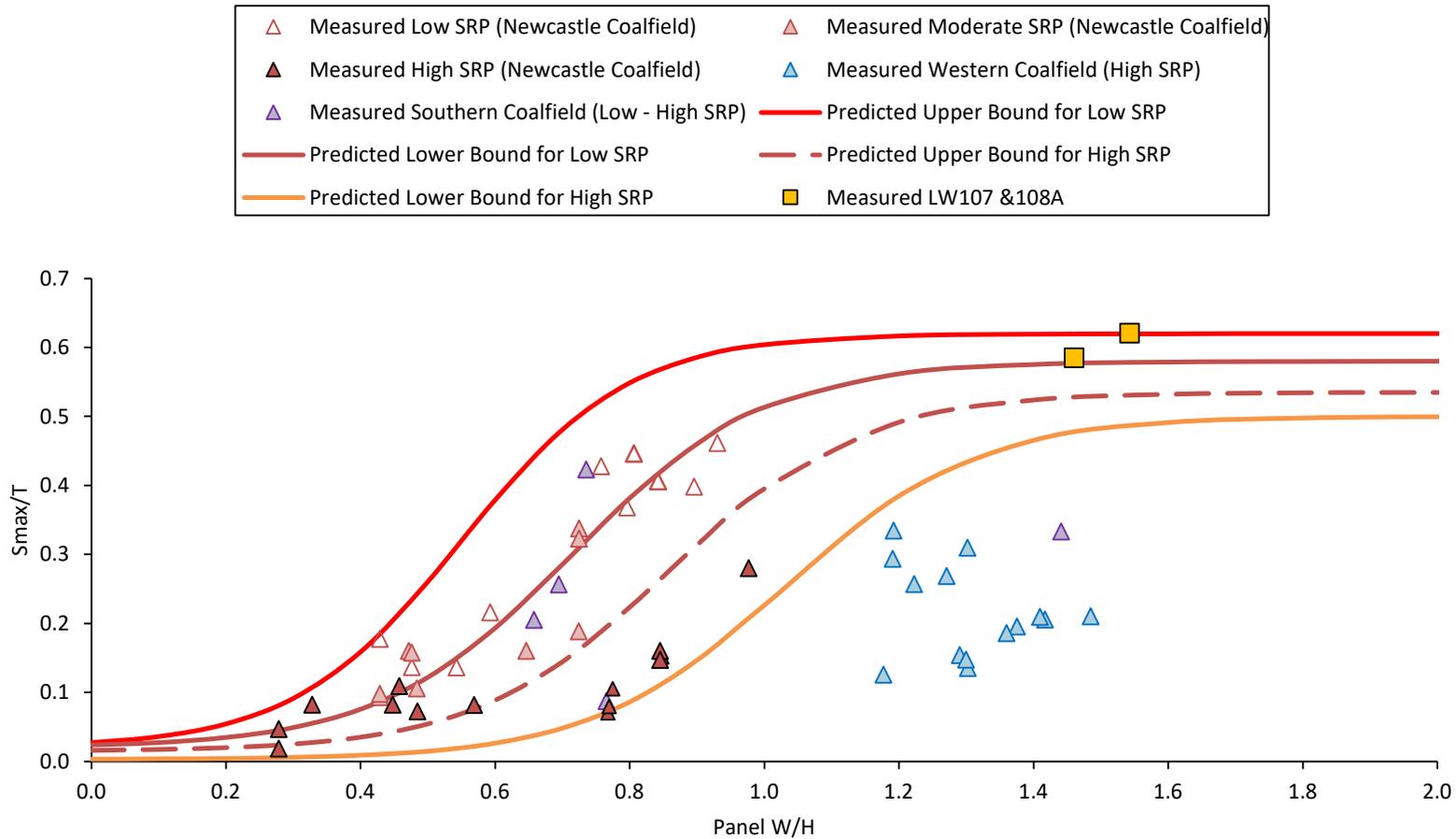
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.06.20	Title:	Longwall Panel Subsidence Database of Panel Width v. W/H	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



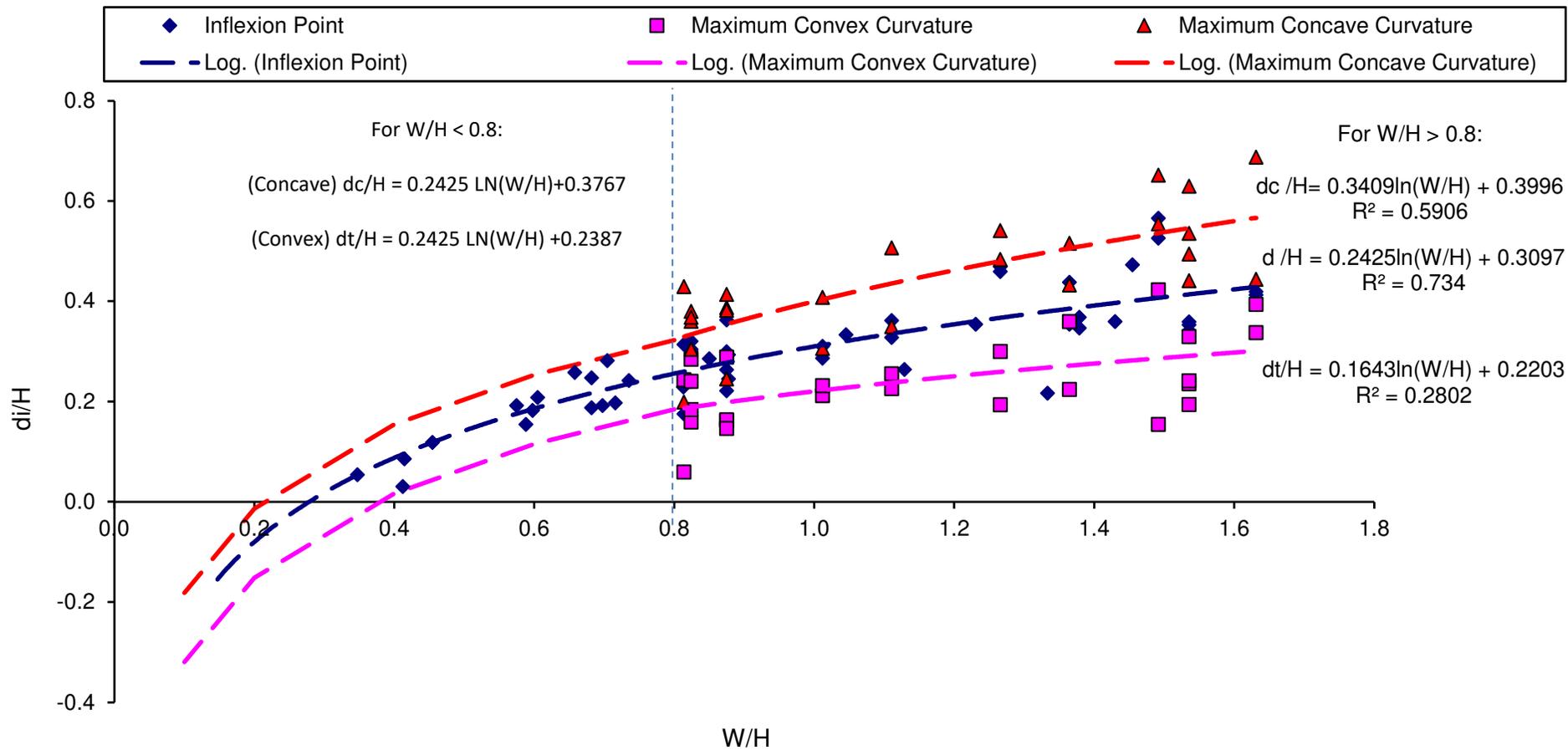
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.06.20	Title:	Longwall Panel Subsidence Database of Mining Height v. W/H	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



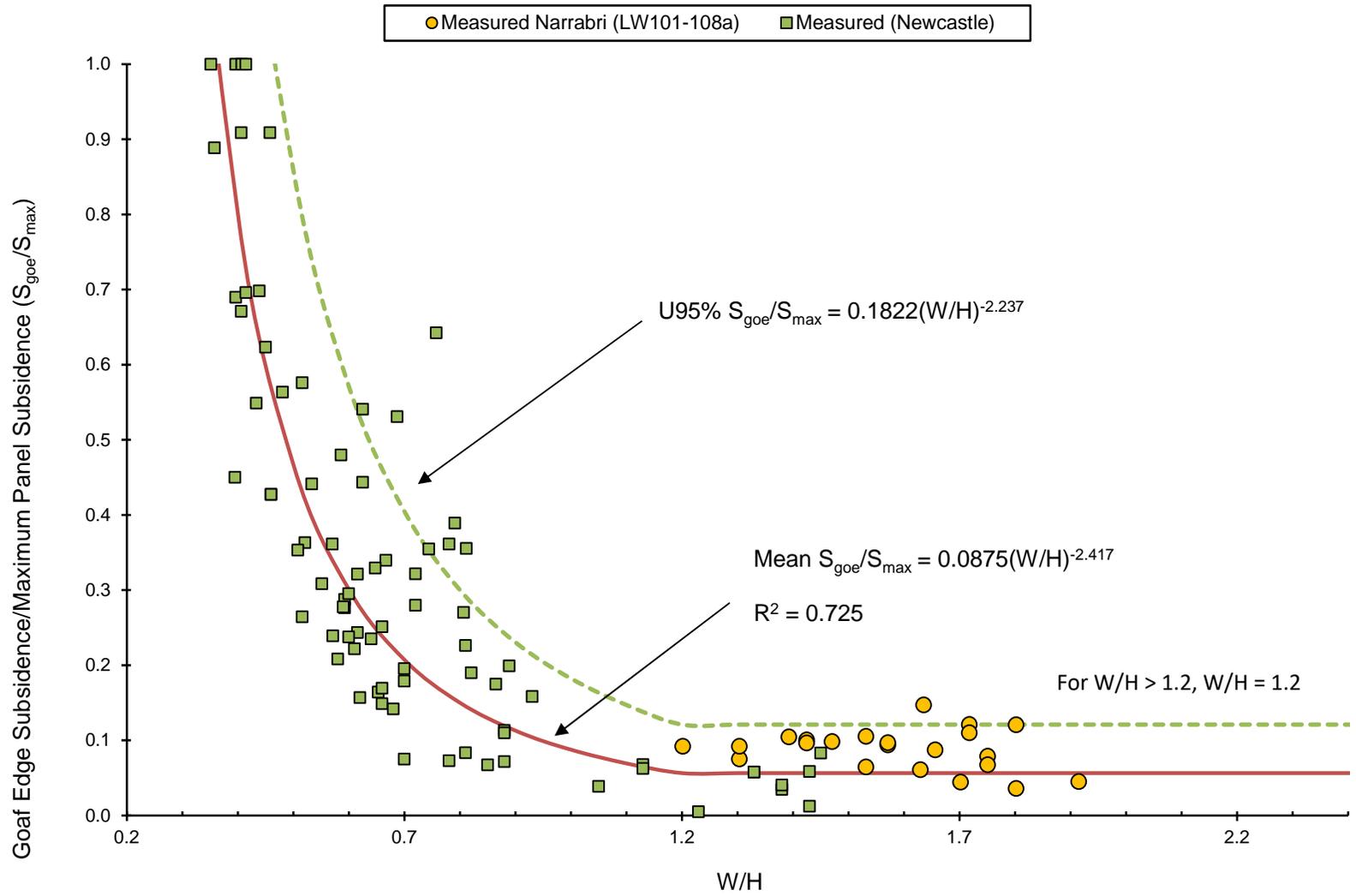
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	01.11.19	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 150 m to 250 m	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



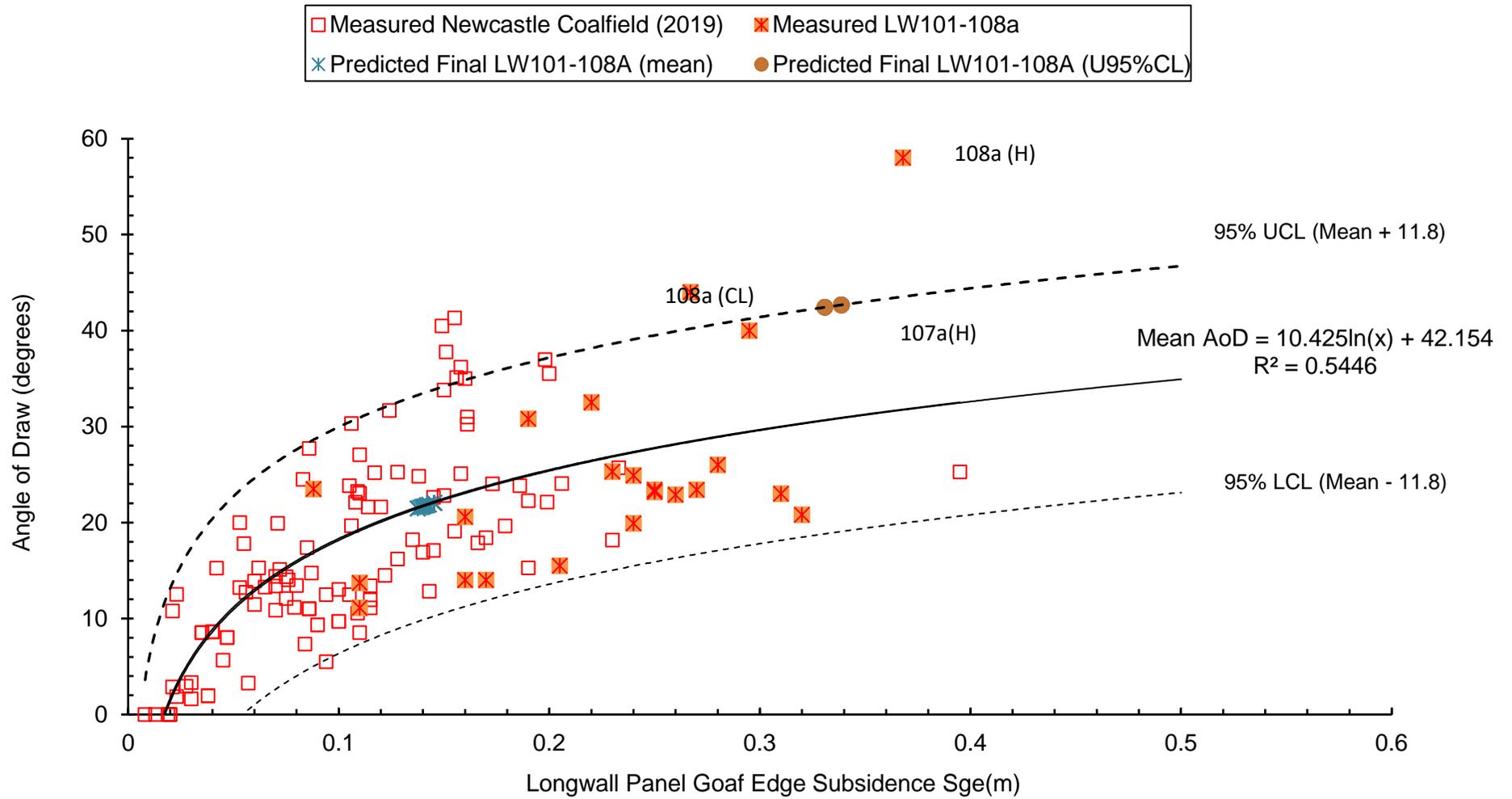
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	01.11.19	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 250 m to 350 m	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



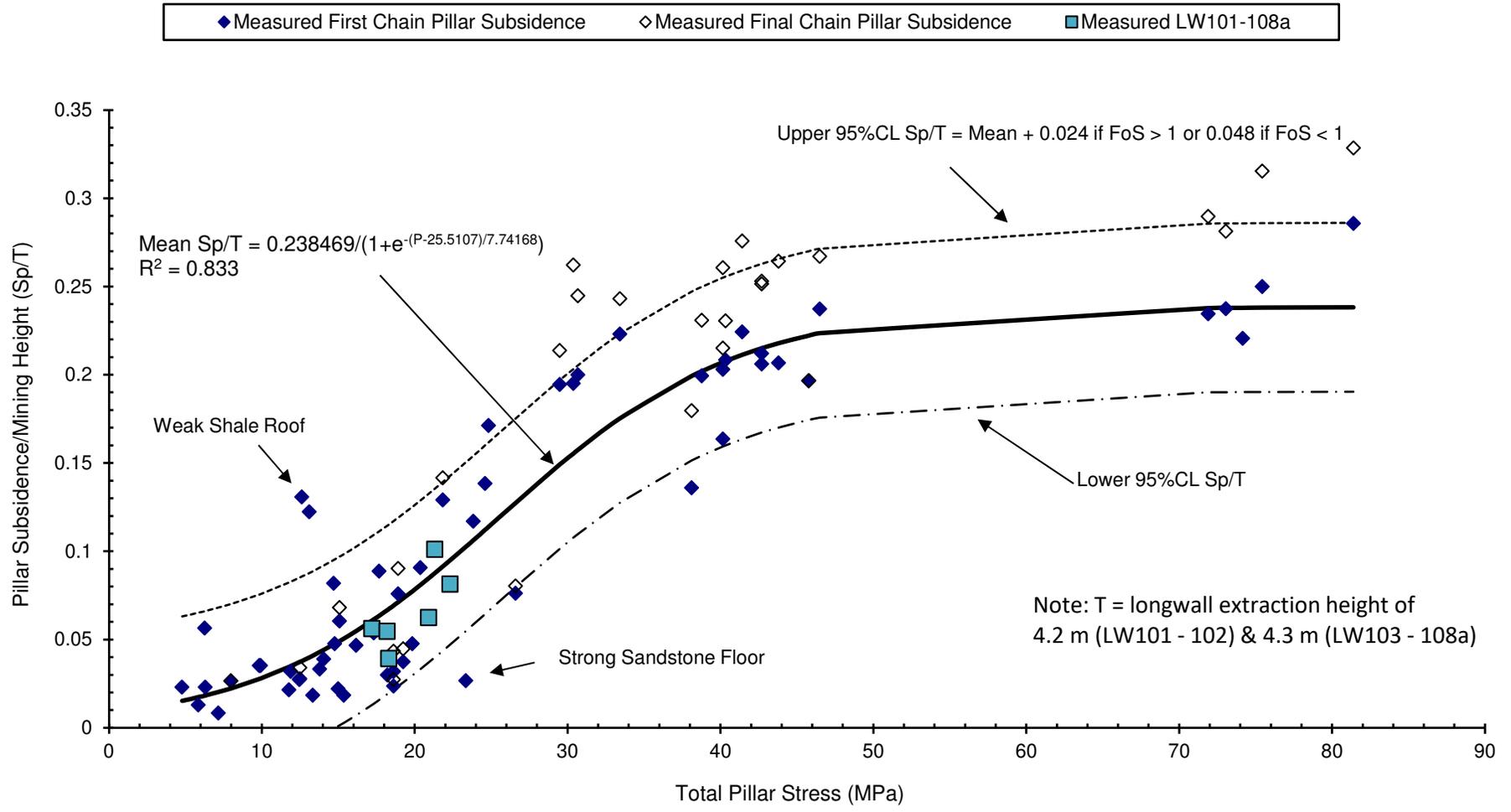
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.06.20	Title:	Empirical Model for Predicting the Location of Inflexion Points and Maximum Tensile and Compressive Strain Peaks above Longwall Panels in the Newcastle Coalfield	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
				Figure No:	6d



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	Title:	Empirical Model for Goaf Edge Subsidence Prediction Above the Narrabri Mine's LW101 to 108A at the Narrabri Mine	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



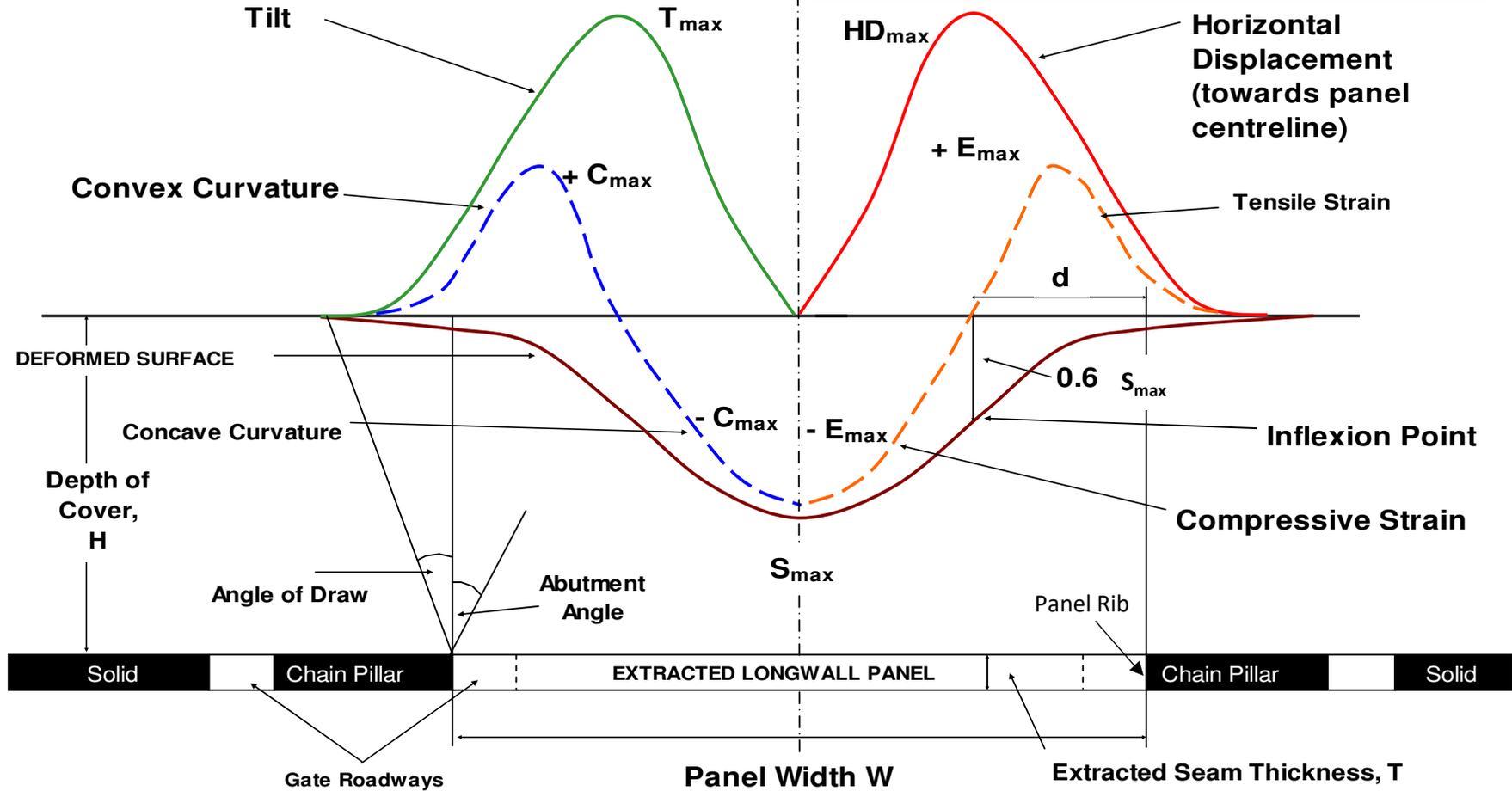
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.06.20	Title:	Empirical Model for Predicting the Angle of Draw to 20mm subsidence at the Narrabri Mine based on LW101 to 108a and Newcastle Coalfield Subsidence Data (2019)	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	20.06.20	Title:	Chain Pillar Subsidence Prediction Model 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:	6g

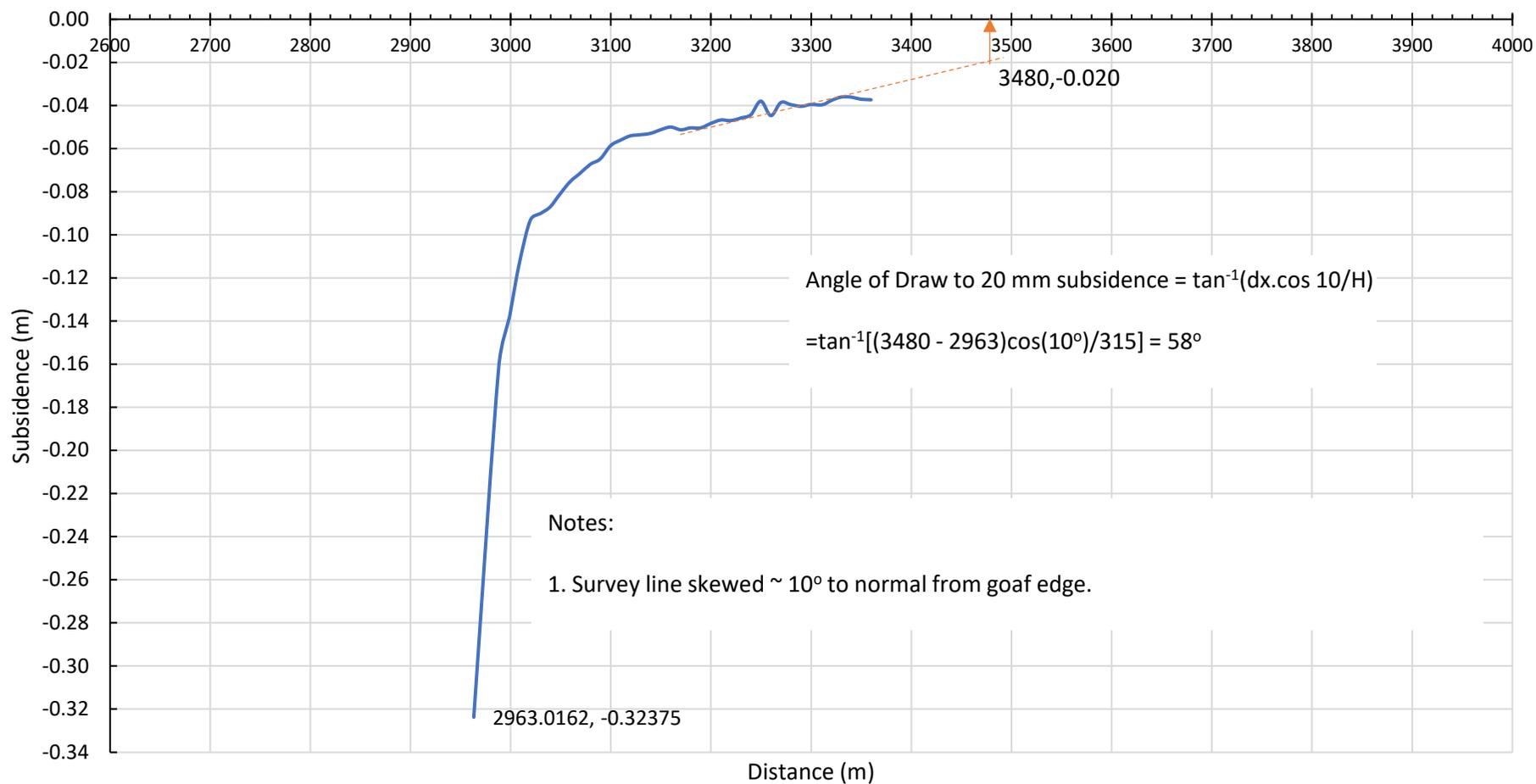
VERTICAL DISPLACEMENT PARAMETER PROFILES

HORIZONTAL DISPLACEMENT PARAMETER PROFILES

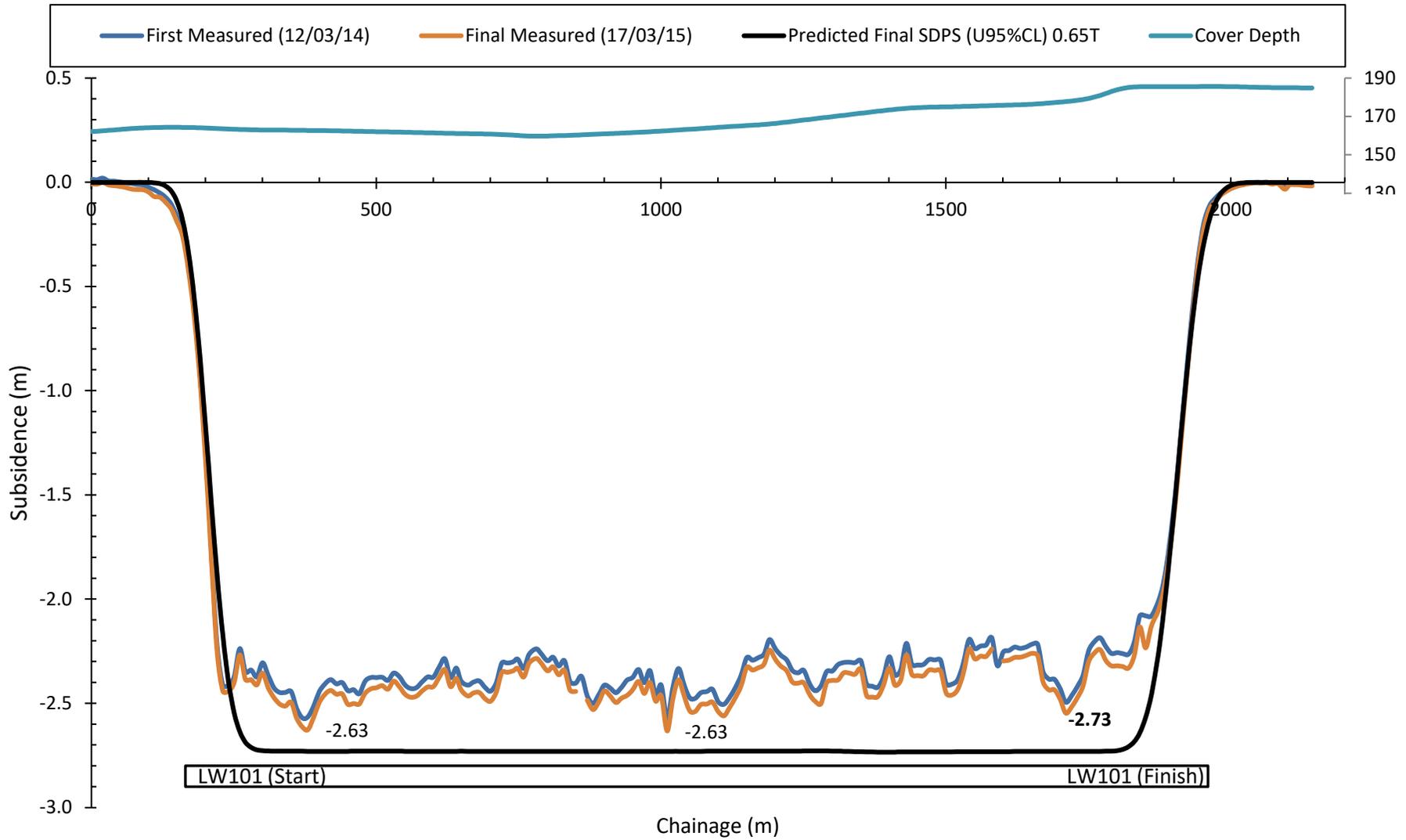


	Engineer:	S.Ditton	Client:	Narrabri Mine	Figure No:	6h
	Drawn:	S.Ditton		NAR-005/2		
	Date:	01.08.19	Title:	Mine Subsidence Trough Deformation Parameters (adapted from Holla, 1987)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		

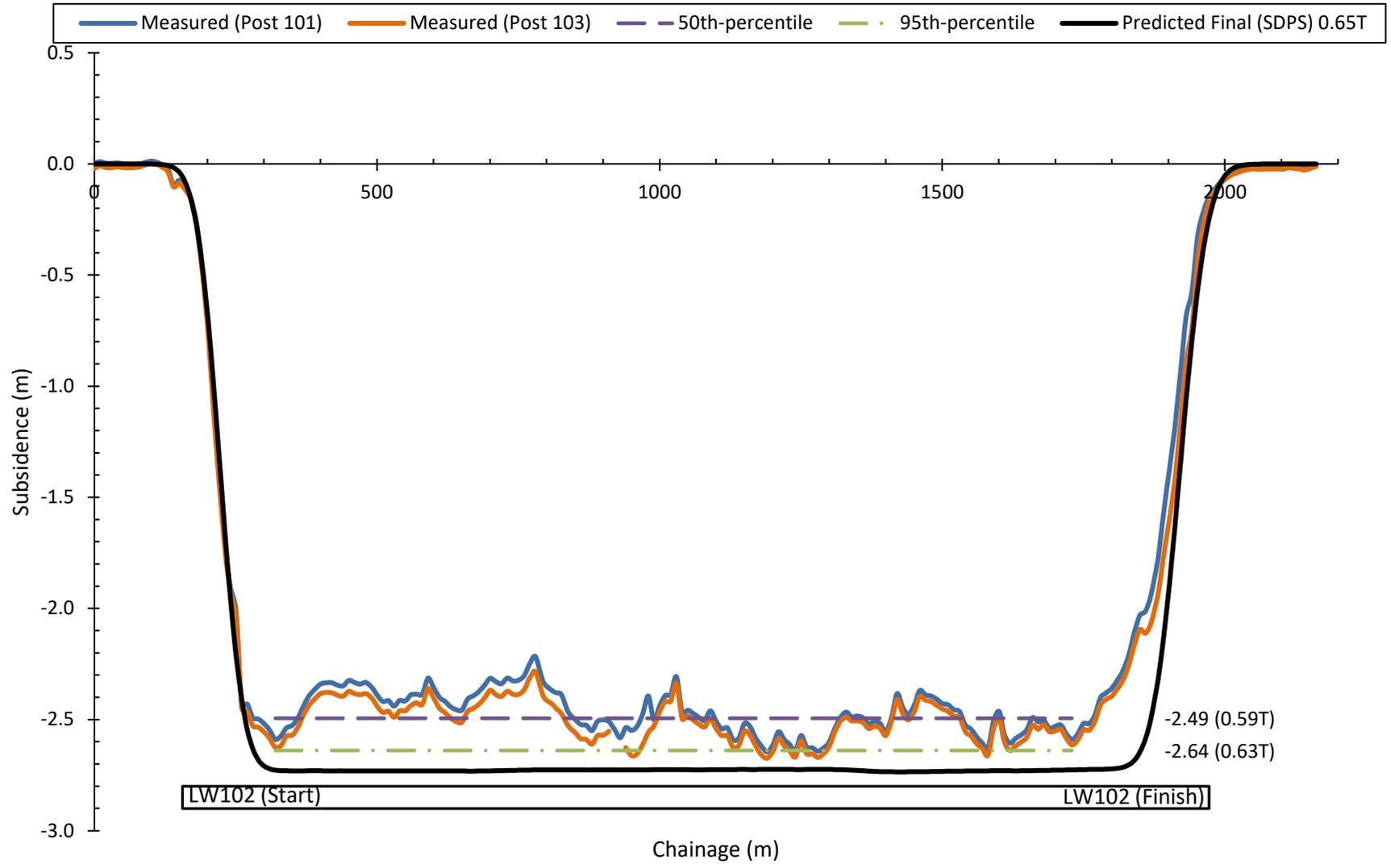
Line H AoD



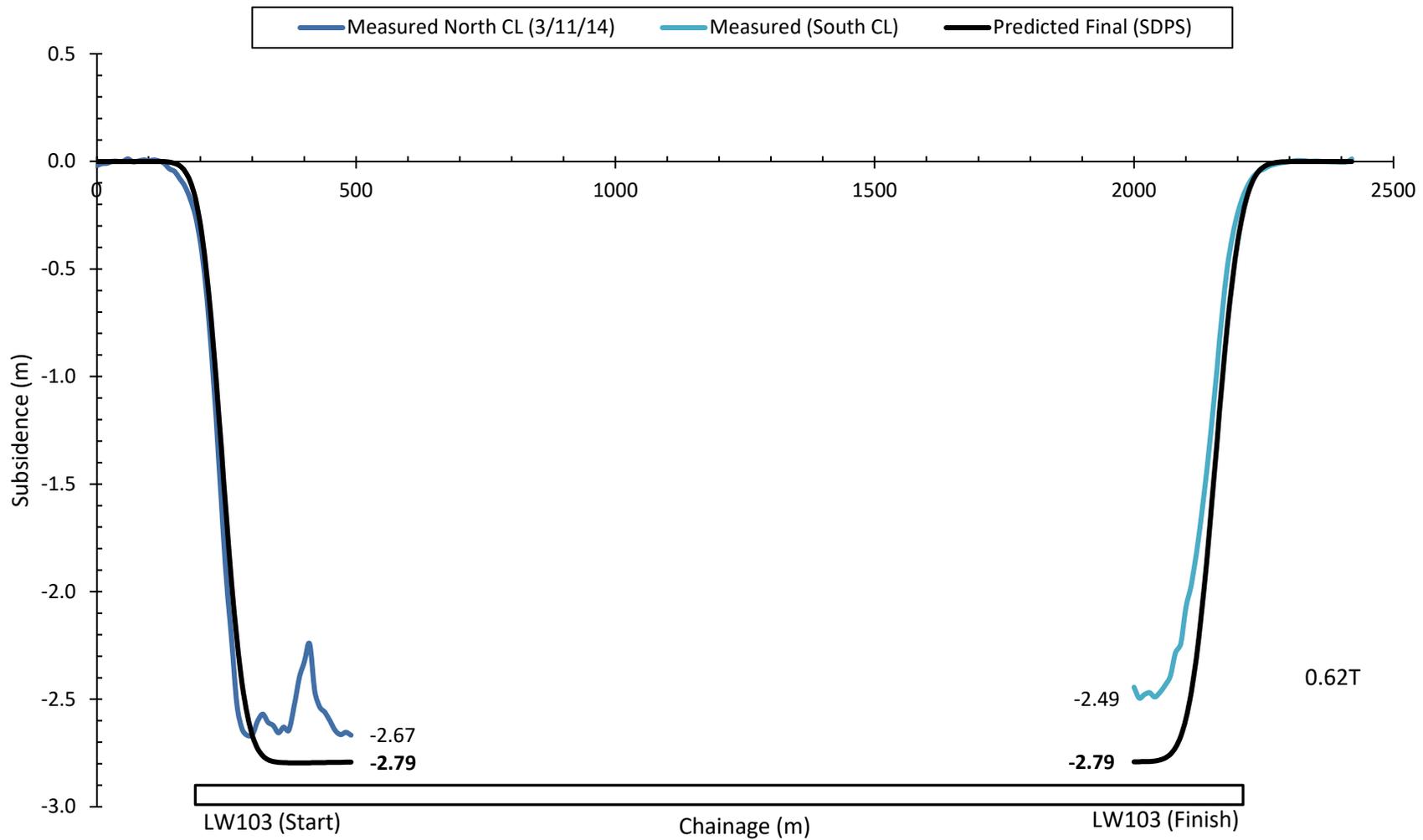
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.06.20	Title:	Empirical Model for Predicting the Angle of Draw to 20mm subsidence at the Narrabri Mine based on LW101 to 108a and Newcastle Coalfield Subsidence Data (2019)	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



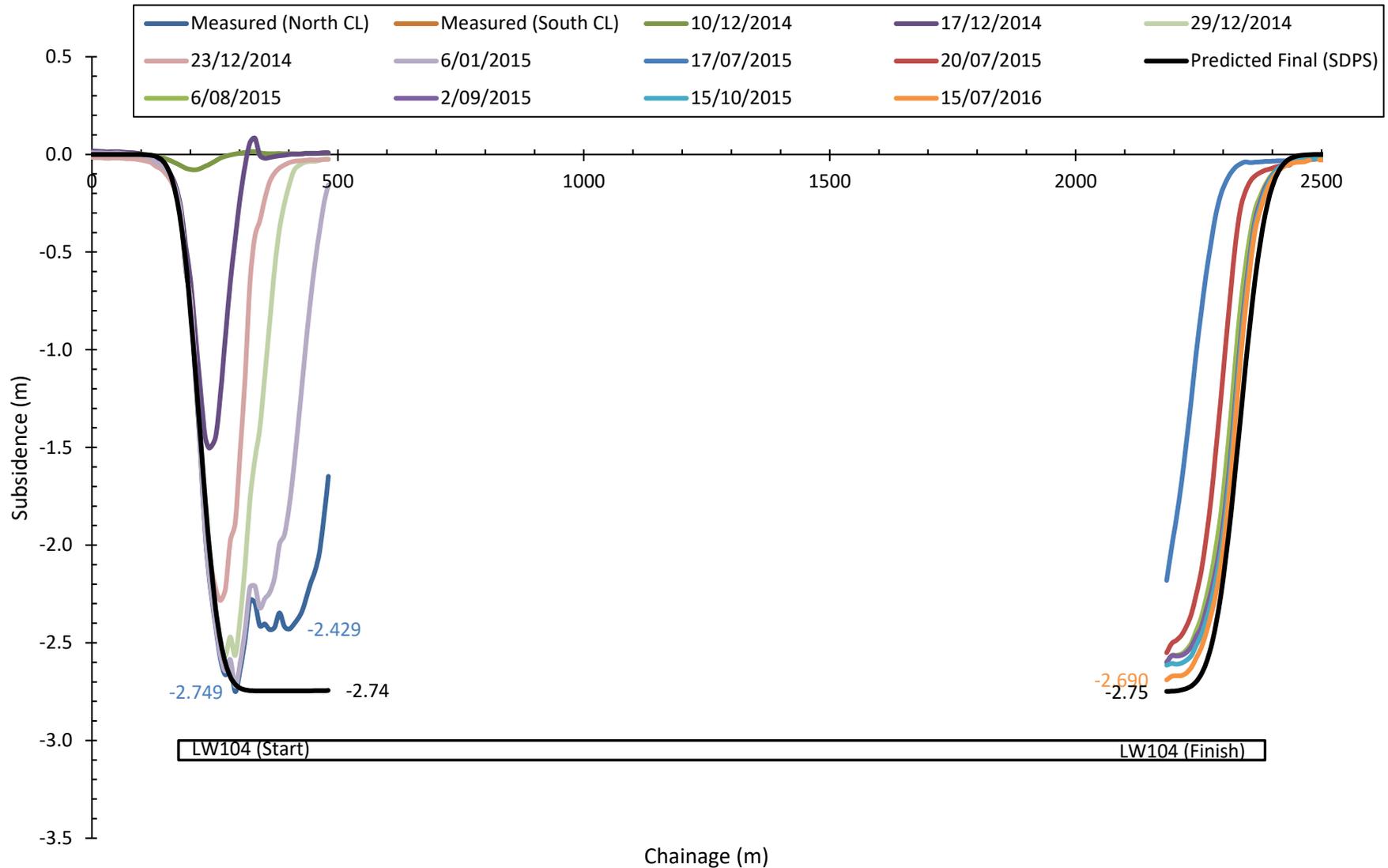
	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-005/2		
	Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW101 Centre Line		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		
					Figure No:	7a



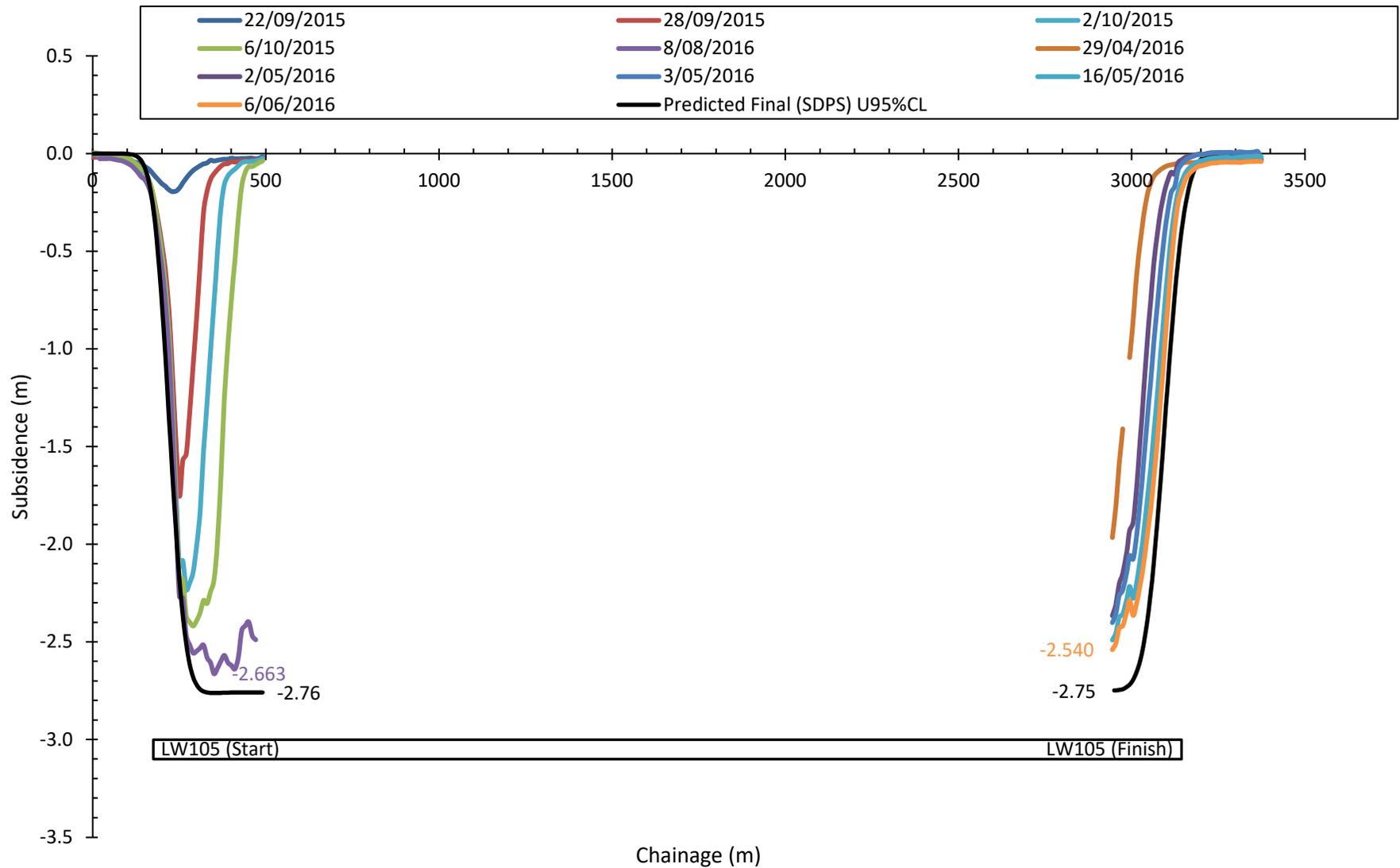
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW102 Centre Line	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	7b	



Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW103 Centre Line	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	7c

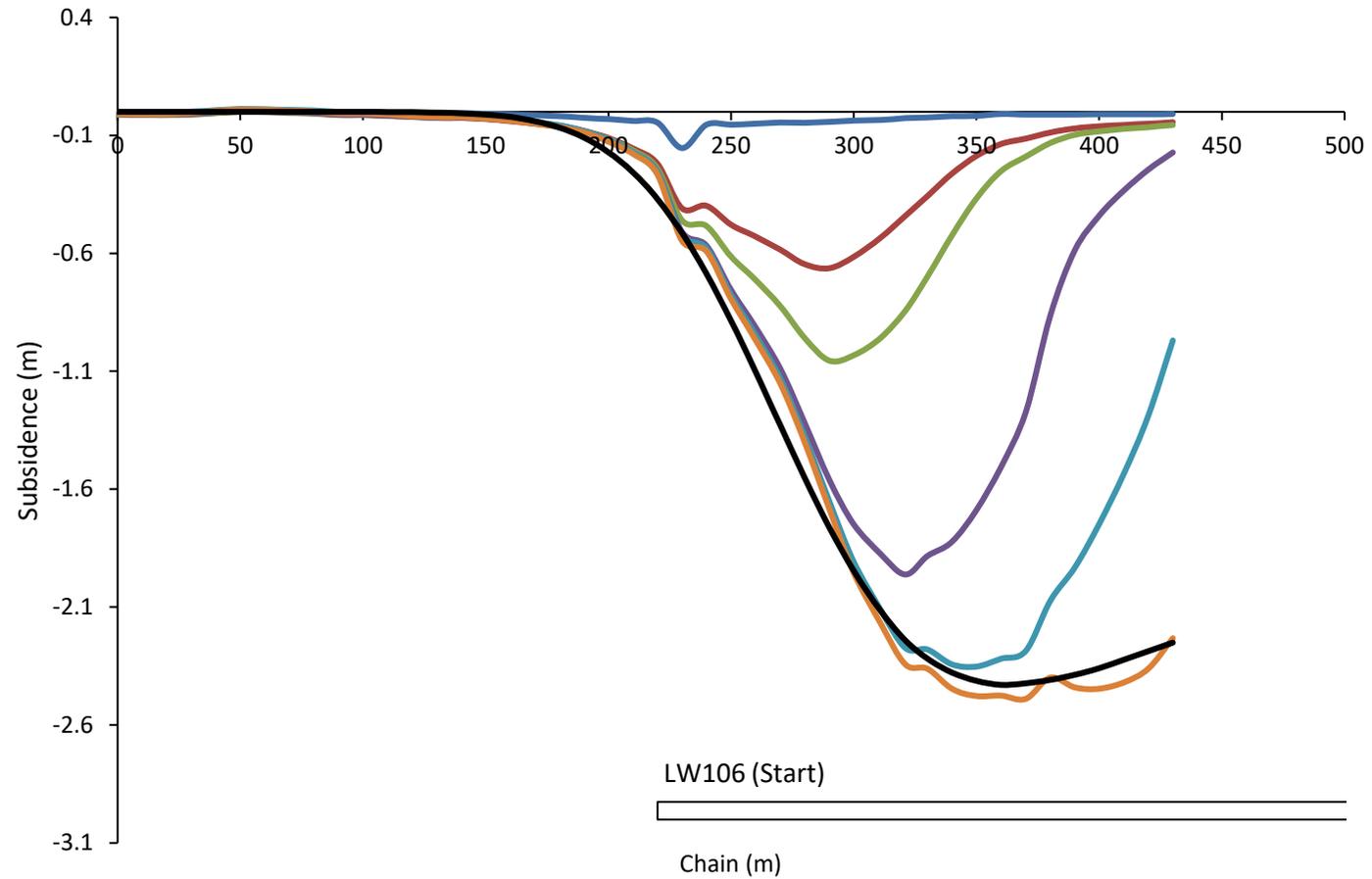


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW104 Centre Line	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	7d	

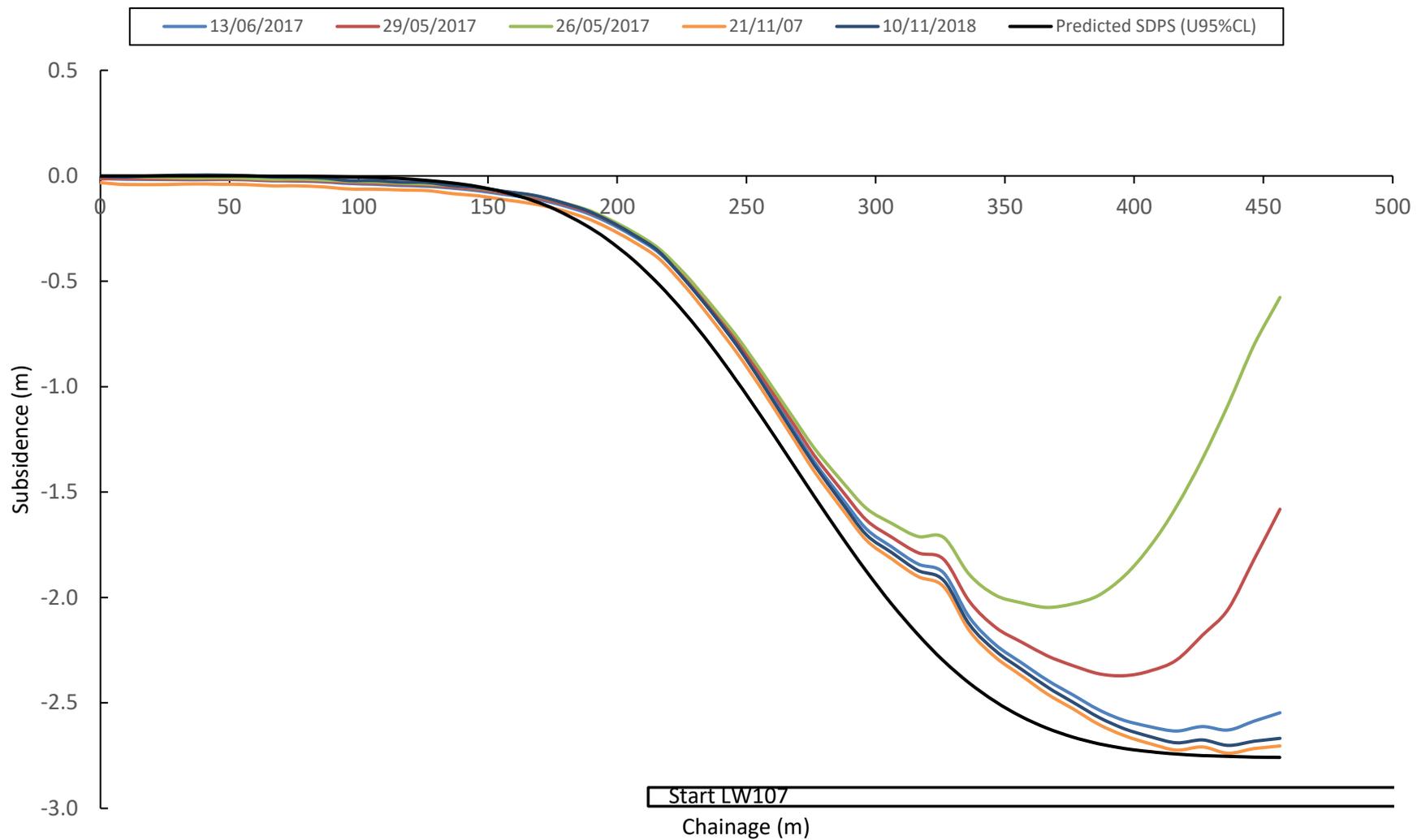


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW105 Centre Line	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	7e	

— 27/06/2016
 — 4/07/2016
 — 6/07/2016
 — 15/07/2016
 — 20/07/2016
 — 27/07/2016
 — Predicted (U95%CL)

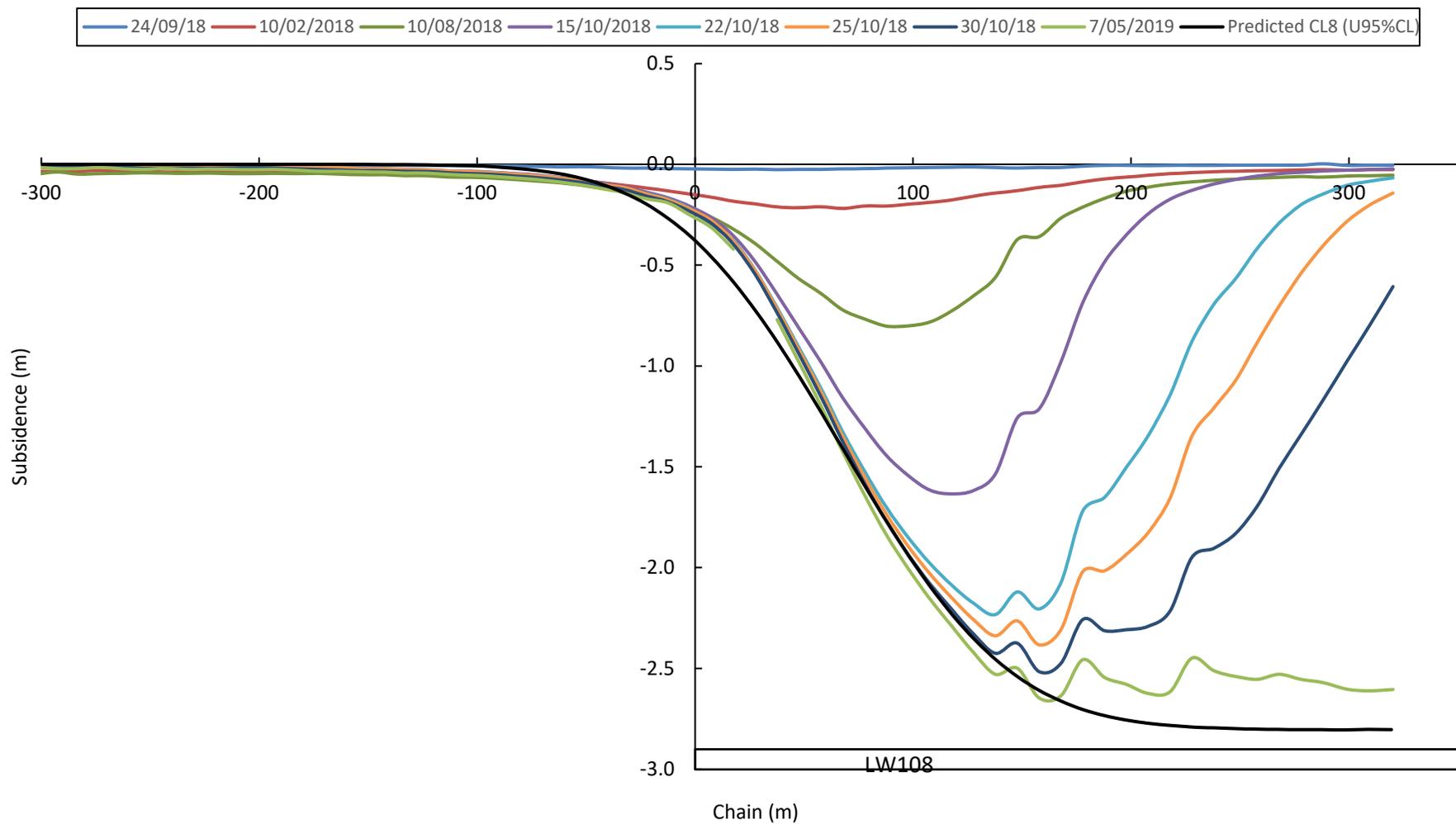


Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	10.11.19	Title:	Measured v. Predicted Subsidence along LW106 Centre Line (North)	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	7f



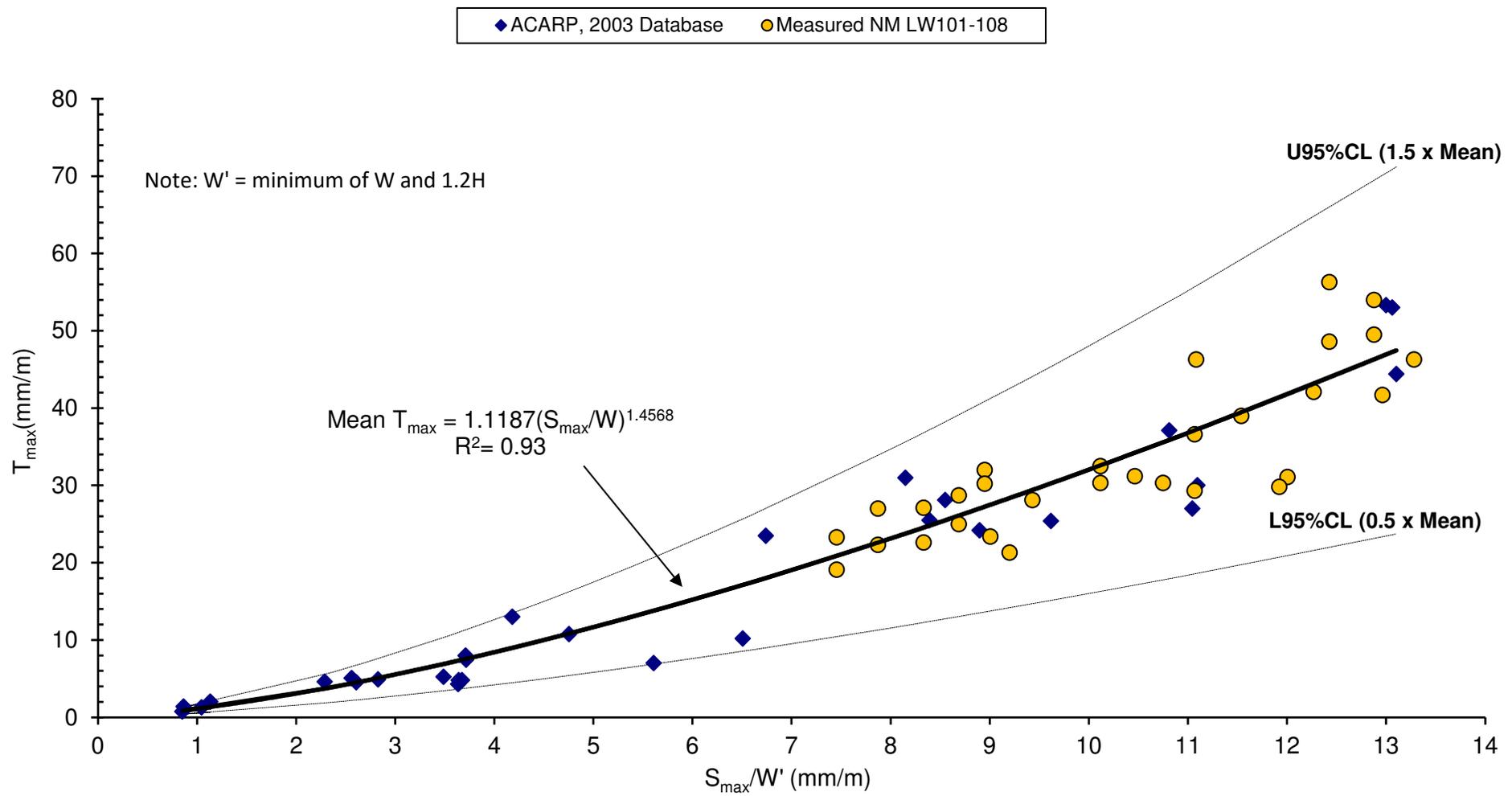
Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 10.11.19
 Ditton Geotechnical
 Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2
 Title: Measured v. Predicted Subsidence along LW107 Centre Line (North)
 Scale: NTS
 Figure No: 7g

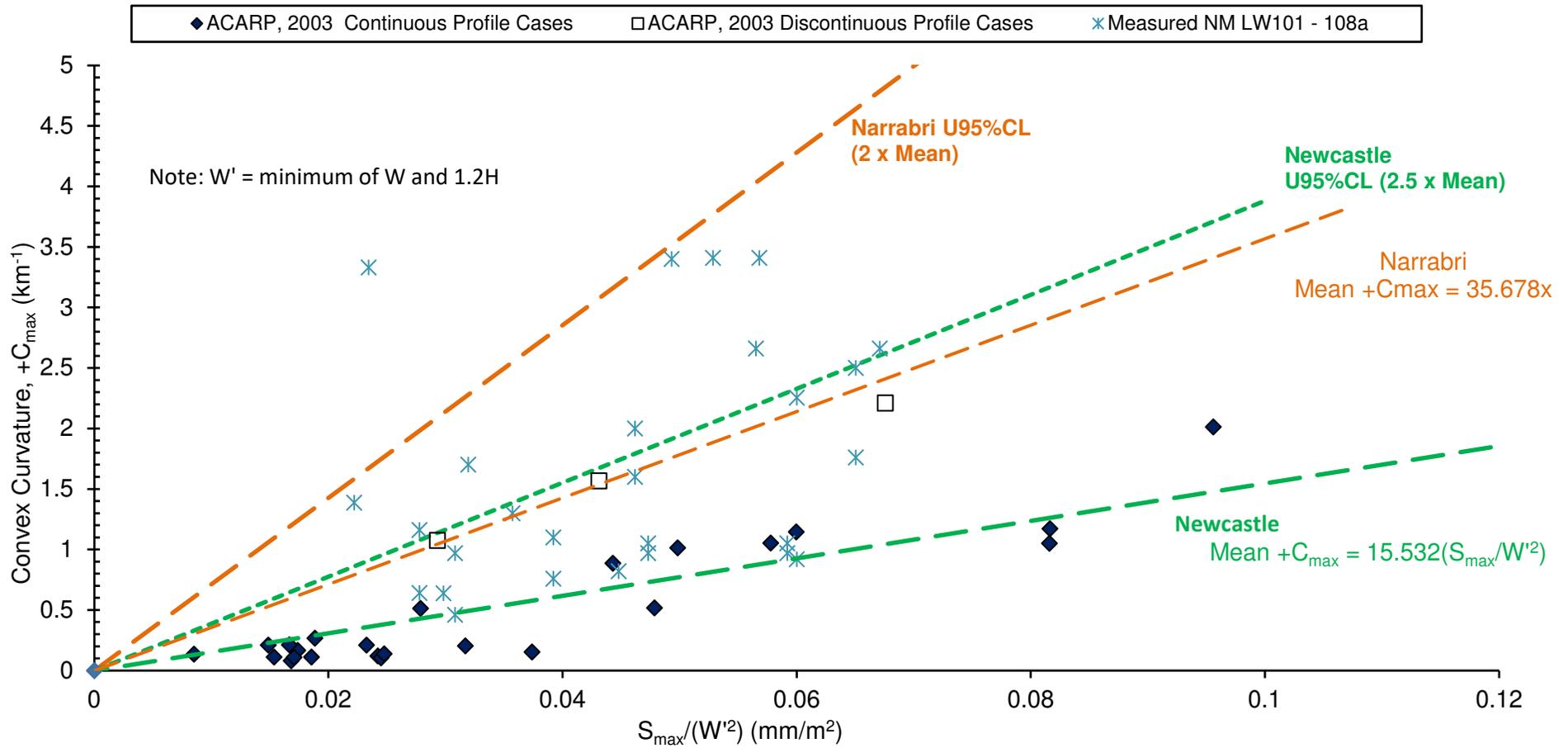


Engineer:	S.Ditton
Drawn:	S.Ditton
Date:	10.11.19
Ditton Geotechnical Services Pty Ltd	

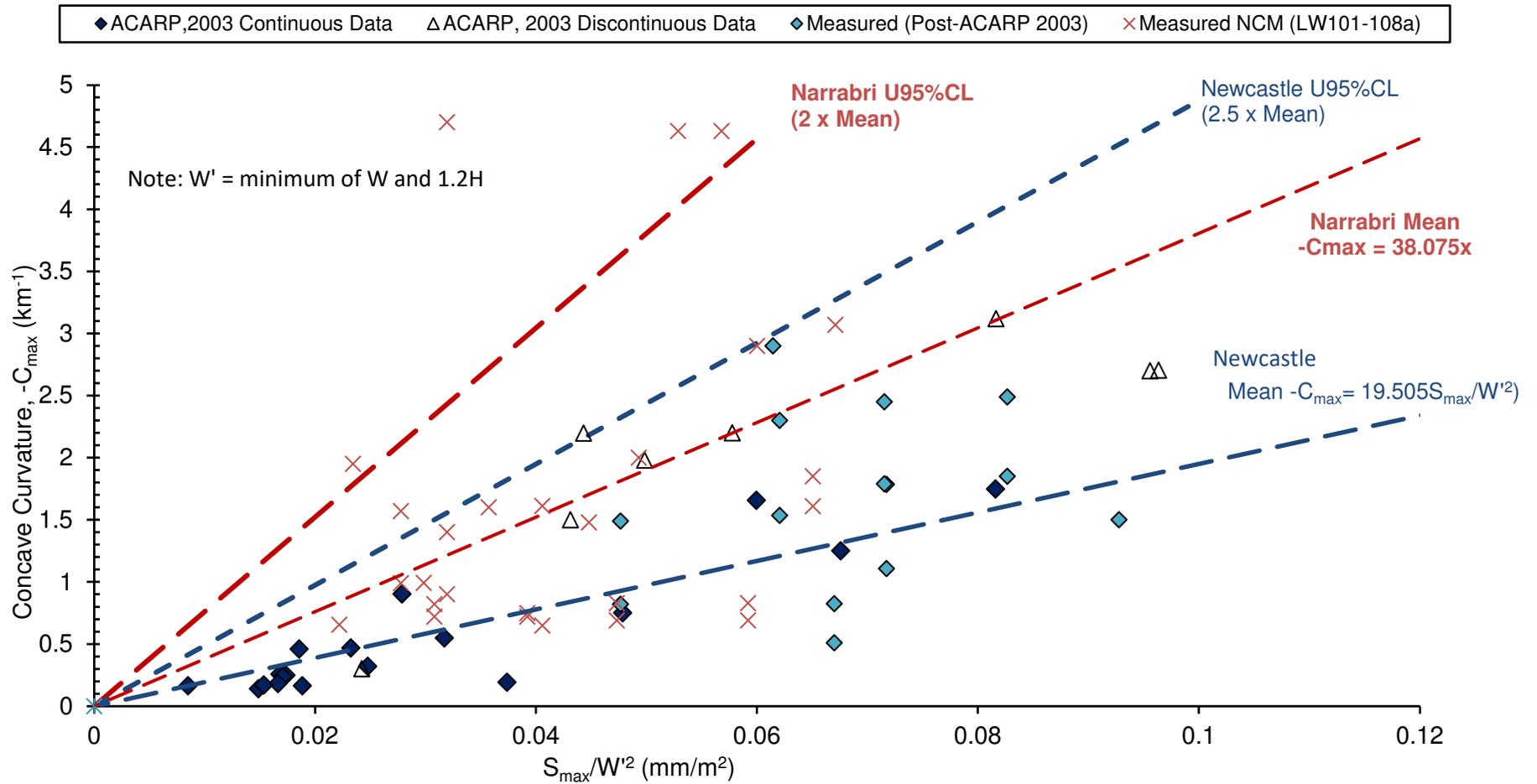
Client:	Narrabri Mine NAR-005/2	
Title:	Measured v. Predicted Subsidence along LW108 Centre Line (North)	
Scale:	NTS	Figure No: 7h



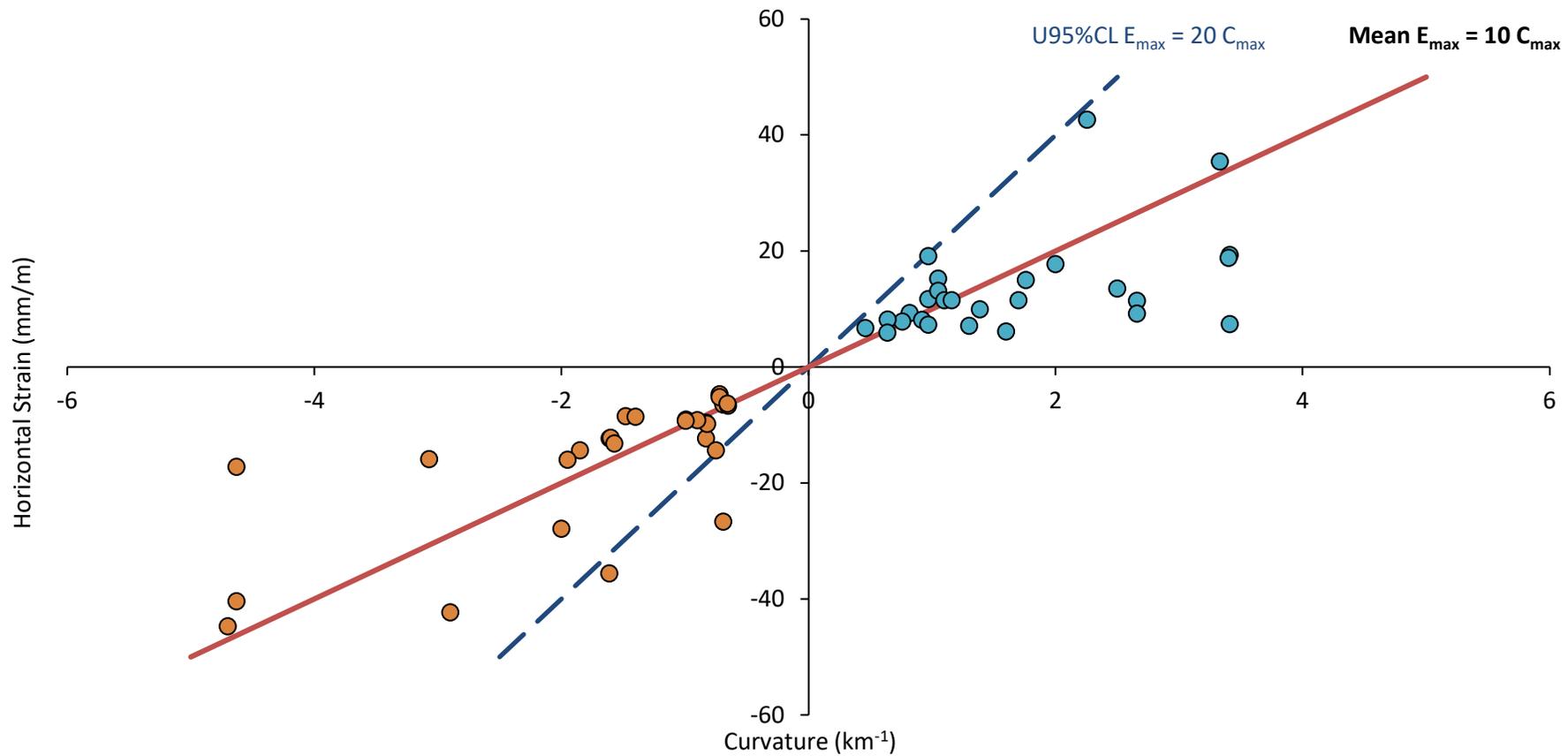
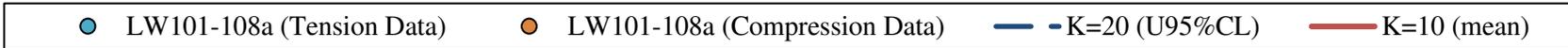
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	Title:	Empirical Model of Maximum Tilt with Measured Values for LW101 to 108a	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



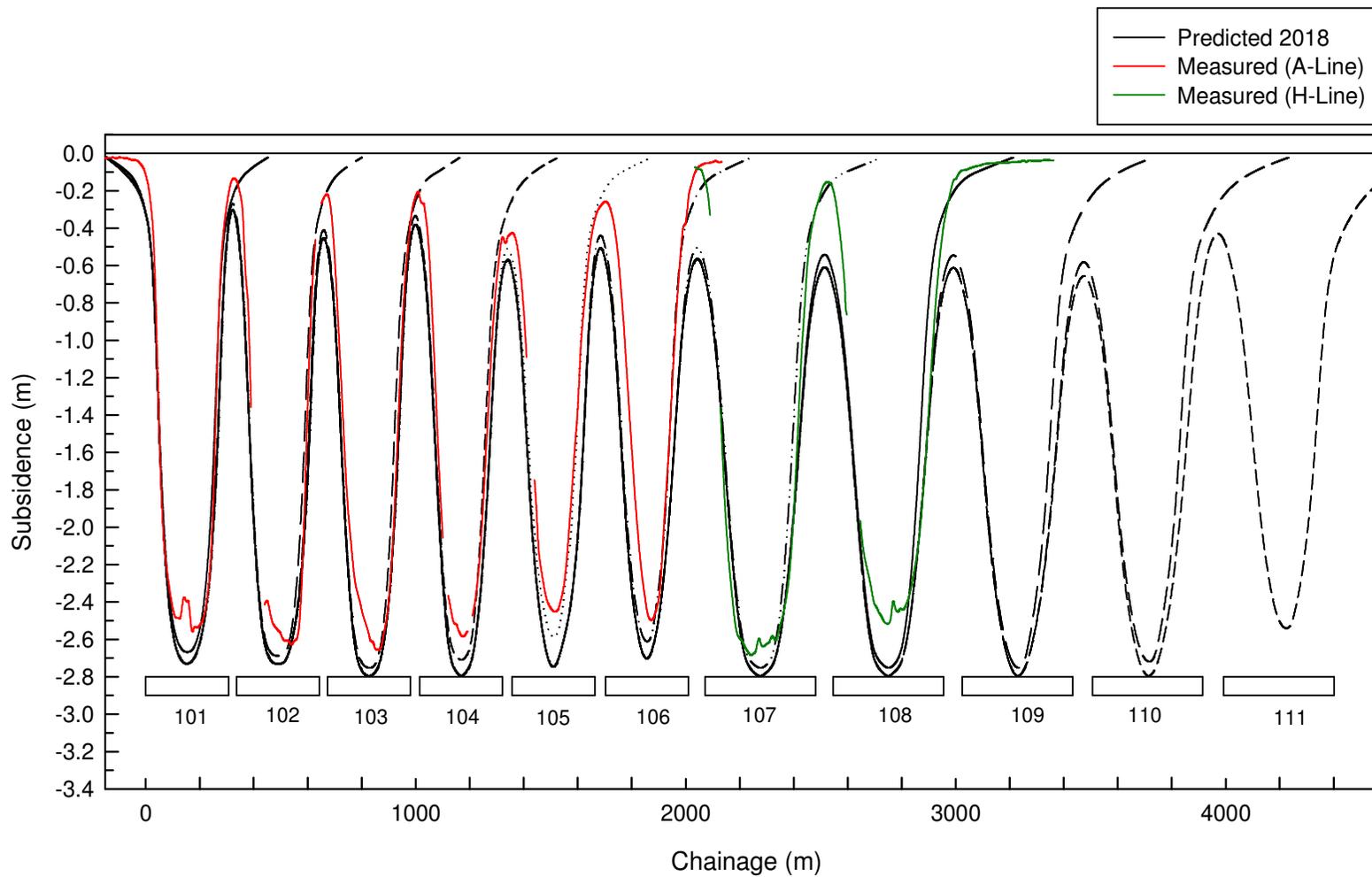
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	Title:	Empirical Model of Maximum Convex (Hogging) Curvature with Measured Values for LW101 to 108a	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



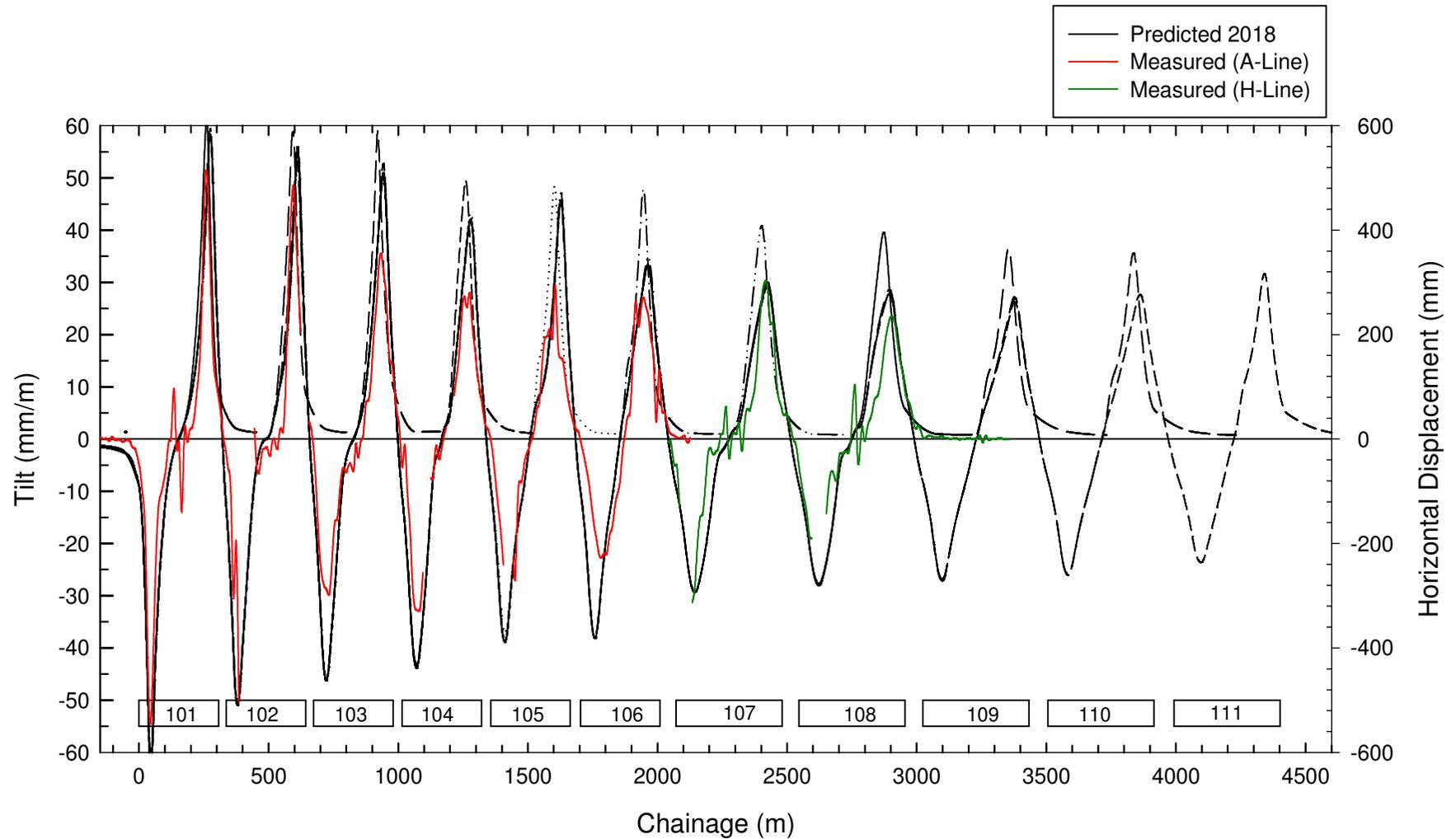
	Engineer:	S.Ditton	Client:	Narrabri Mine	Figure No:	8c
	Drawn:	S.Ditton		NAR-005/2		
	Date:	1.11.19	Title:	Empirical Model of Maximum Concave (Sagging) Curvature with Measured Values for LW101 to 108a (Newcastle v. Narrabri Coalfields)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		



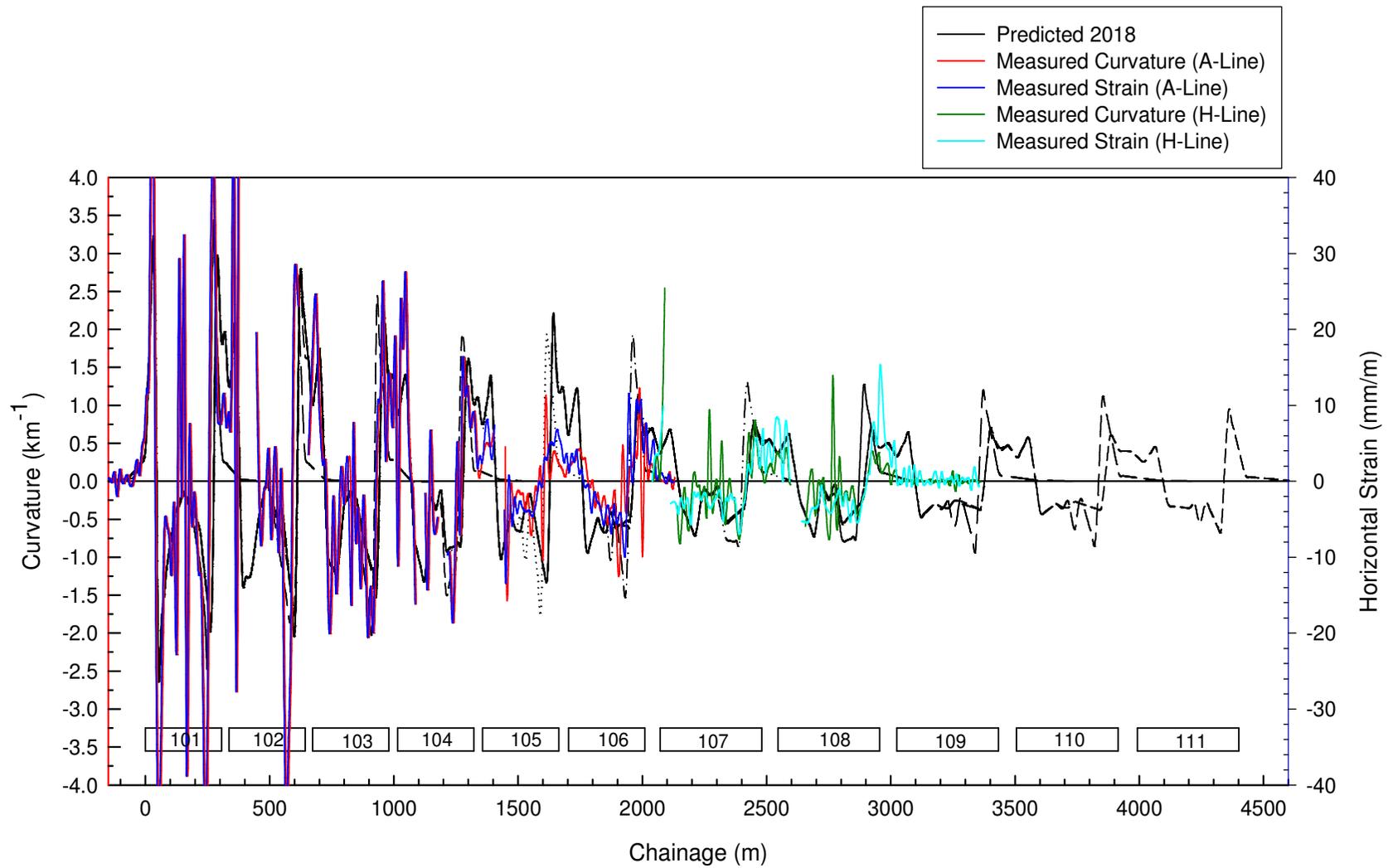
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	Title:	Empirical Model of Maximum Strain v. Curvature based on Measured Values for LW101 to 108a	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	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:

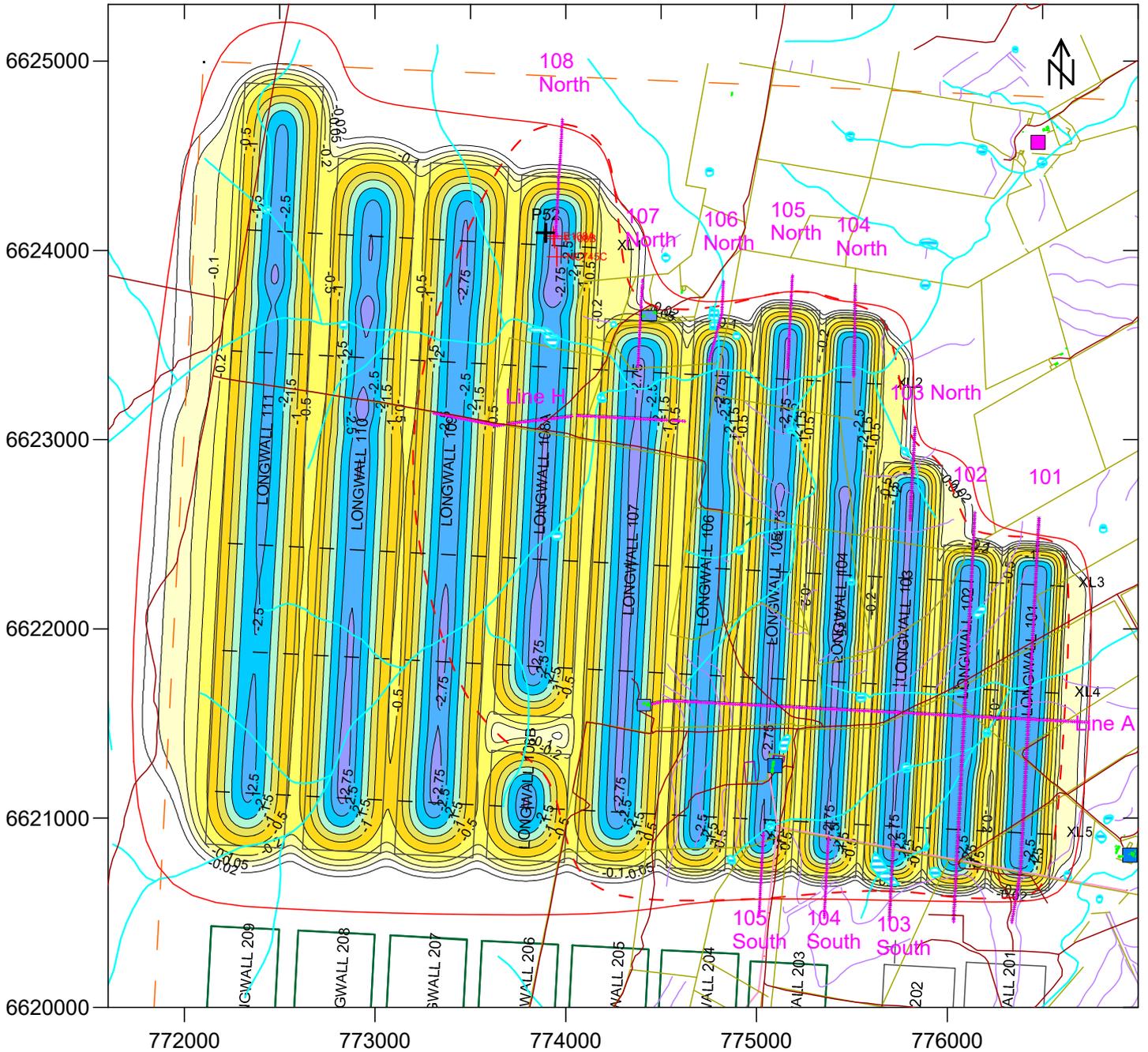


Engineer: S.Ditton	Client: Narrabri Mine NAR-005/2
Date: 1.11.19	Title: Predicted U95%CL v. Measured Tilt & Horizontal Displacement Profiles along XL4 & XLA/H above LW101 to 111
Ditton Geotechnical Services Pty Ltd	Scale: NTS
	Figure No: 9b



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	1.11.19	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:

Subsidence (m): -0.02 -0.05 -0.1 -0.2 -0.5 -1 -1.5 -2 -2.5 -2.75 -3



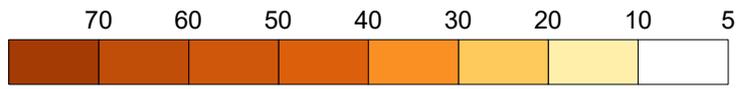
Key:

- Proposed LW203 to 209
- Subsidence contours (m)
- Approved LW101-111 & 201-202
- Survey Lines
- + Borehole Exts + VWP
- Subsidence Prediction Lines
- ML1609 Boundary
- Measured 20mm subsidence contour (LW101-108A)
- Predicted 20mm Subsidence Contour
- Roads (unsealed)
- ~ Ephemeral Creeks / watercourses
- Dwellings (Private/NCO-Owned)
- Lot Boundaries/Fences
- Farm Dams
- Powerlines (Domestic)
- Contour Banks

	Engineer: S.Ditton	Client: Narrabri Mine NAR-005/2
	Drawn: S.Ditton	
	Date: 15.10.19	Title: Predicted U95%CL Final Subsidence Contours for the Approved LW101 to 111 in ML1609
	Ditton Geotechnical Services Pty Ltd	Scale: 1:40,000



Tilt (mm/m):



Key:

- Tilt contours (mm/m)
- Roads (unsealed)
- Dwellings (Private/NCO-Owned)
- Measured 20mm Subsidence Contour (LW101-108A)
- Proposed LW203 - 209
- Approved LW101-111 & 201-202
- ML1609 Boundary
- Lot Boundaries/Fences
- Powerlines (Domestic)
- Contour Banks
- Prediction Lines
- Ephemeral Creeks & Watercourses
- Farm Dams
- Predicted 20mm Subsidence Contour

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19

Ditton Geotechnical
 Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

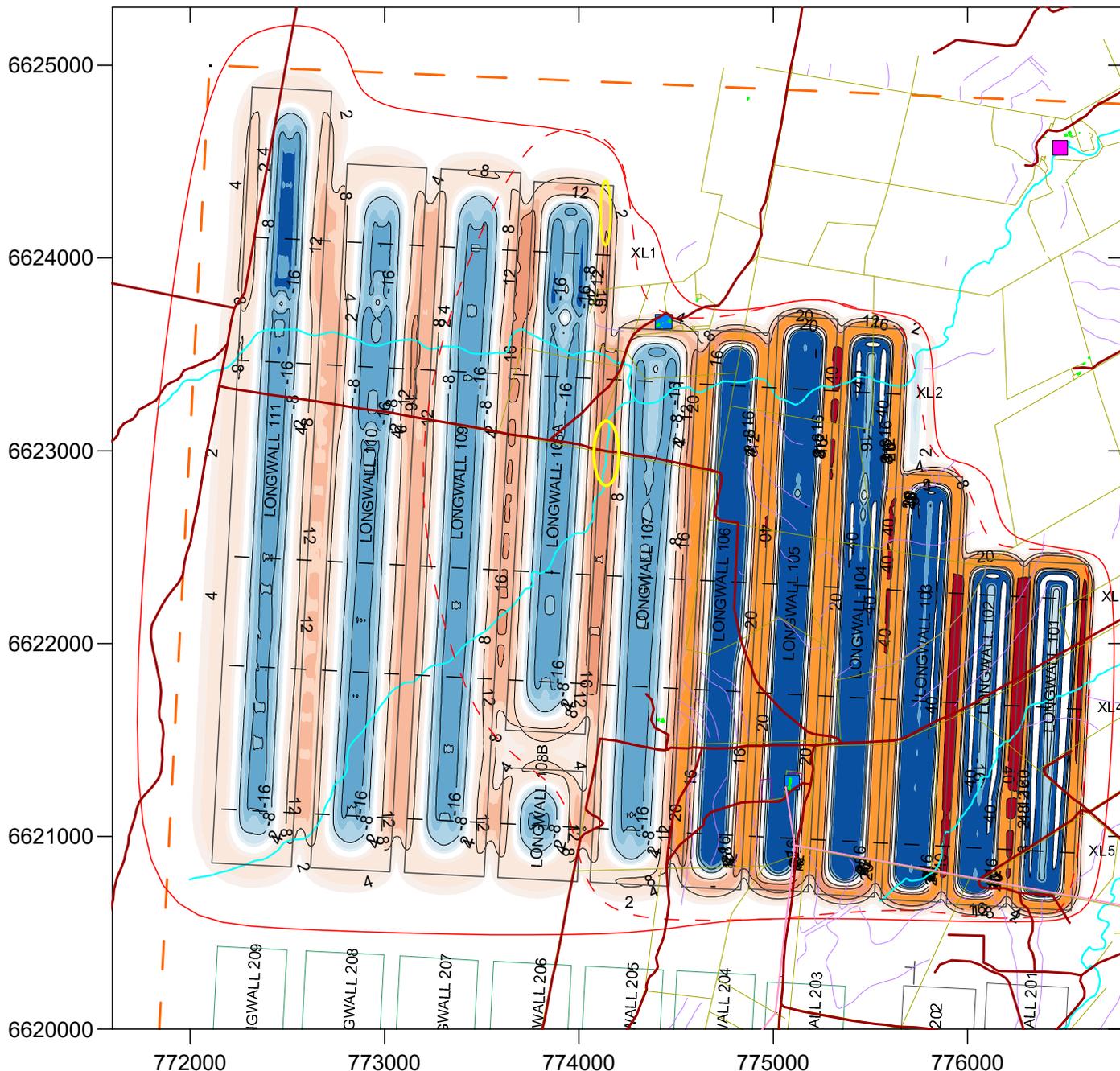
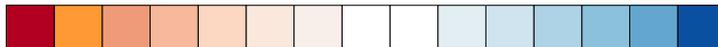
Title: Predicted Tilt Contours (U95%CL) above the Approved LW101 to 111 in ML1609

Scale: 1:60,000

Figure No: 9e



Strain (mm/m): 40 20 16 12 8 4 2 0 -2 -4 -8 -12 -16 -20 -40



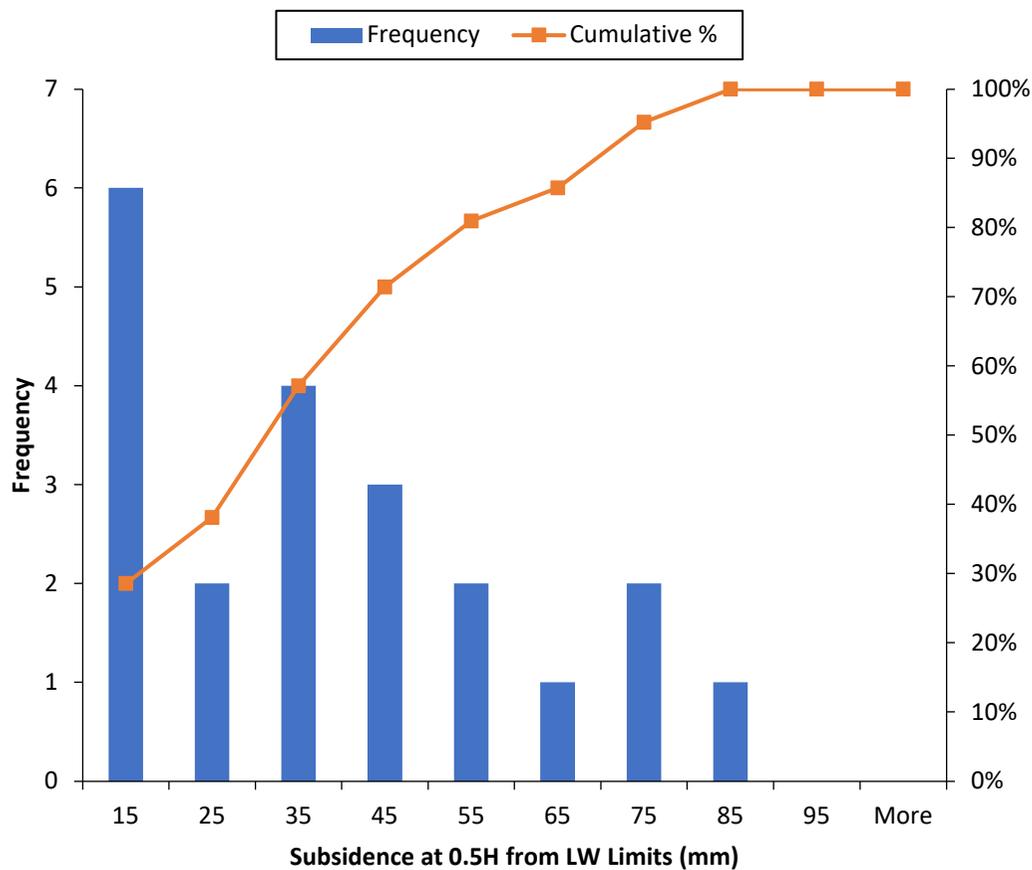
Key:

- | | | | | | |
|--|--|--|------------------------------|--|---------------------------------------|
| | Strain contours (mm/m) | | Approved LW101-111 & 201-202 | | Ephemeral Creeks & Watercourses |
| | Roads (unsealed) | | Proposed LW203 - 209 | | Farm Dams |
| | Dwellings (Private/NCO-Owned) | | ML1609 Boundary | | Predicted 20mm Subsidence Contour |
| | Measured AoD to 20mm subsidence (LW101-108A) | | Lot Boundaries/Fences | | Observed Crack Locations (Post-LW108) |
| | Strain Prediction Lines | | Powerline (Domestic) | | Contour Banks |

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19
 Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine NAR-005/2
 Title: Predicted Horizontal Strain Contours (U95%CL) above the Approved LW101 to 111 in ML1609
 Scale: 1:40,000
 Figure No: 9f

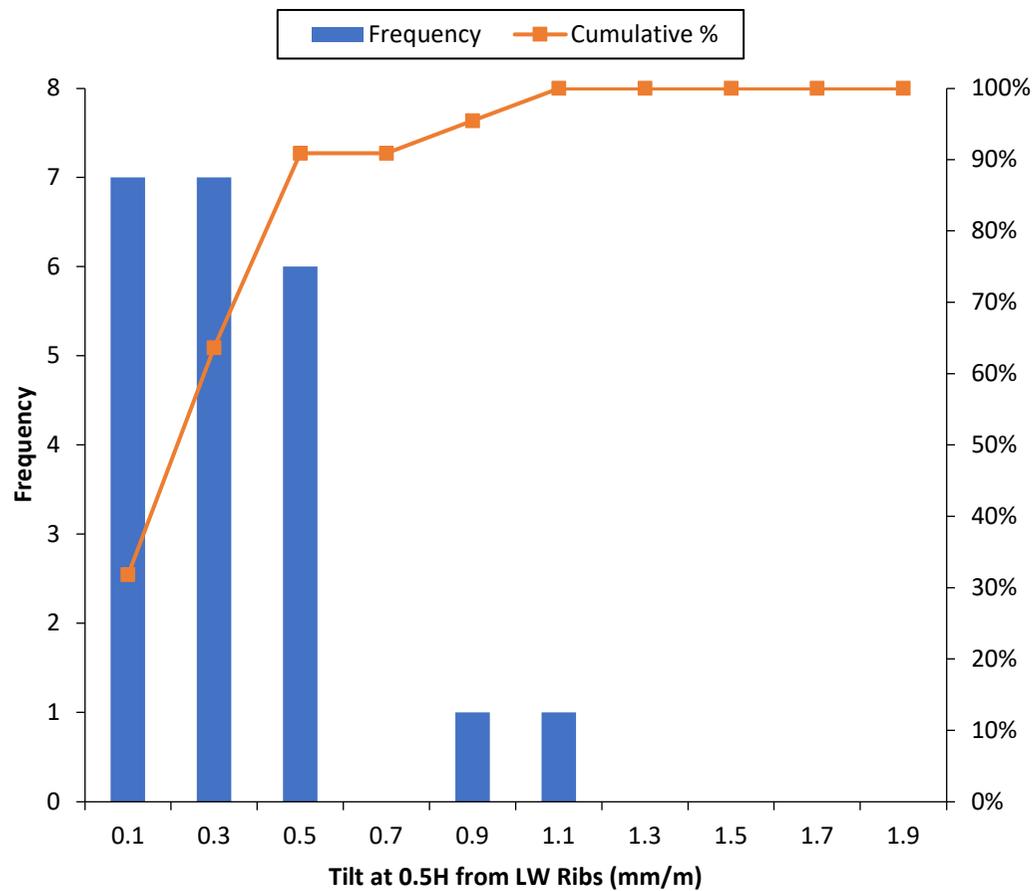


Bin	Frequency	Cumulative %
15	6	29%
25	2	38%
35	4	57%
45	3	71%
55	2	81%
65	1	86%
75	2	95%
85	1	100%
95	0	100%
More	0	100%

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

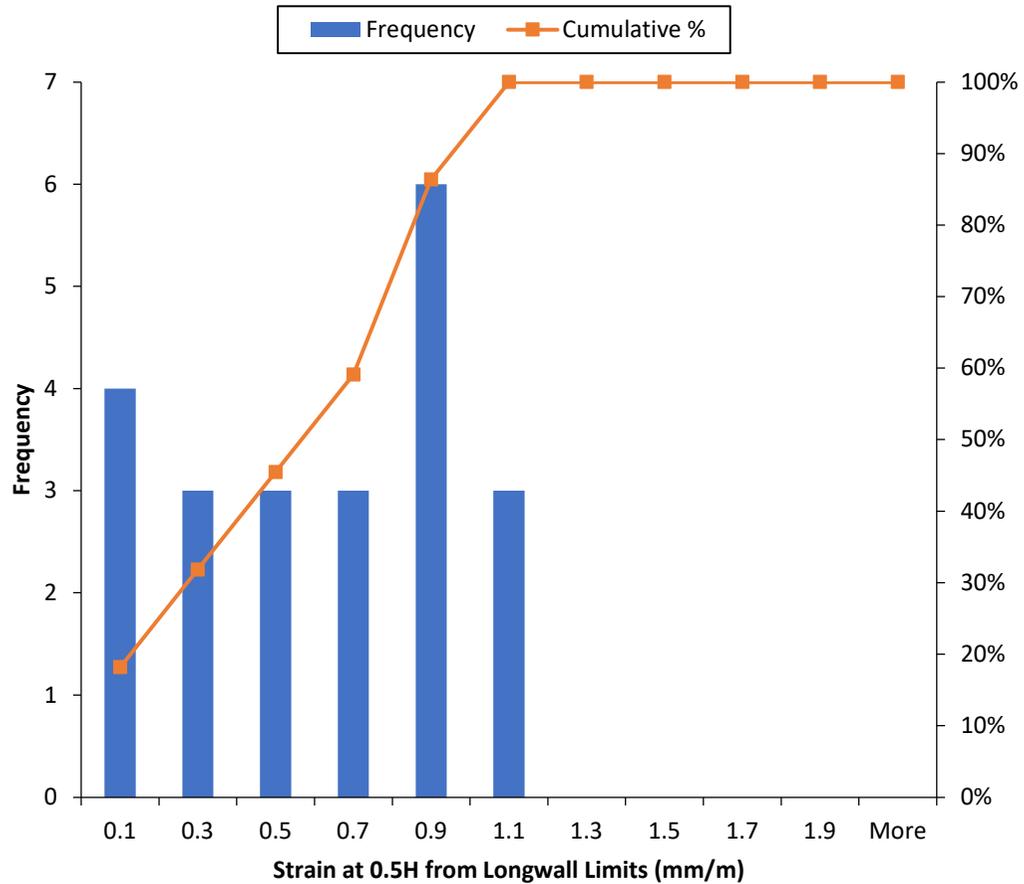
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.06.20	Title:	Measured Subsidence at an Angle of Draw of 26.5° outside the limits of extraction for LWs 101 to 108A	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
				Figure No:	9g



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

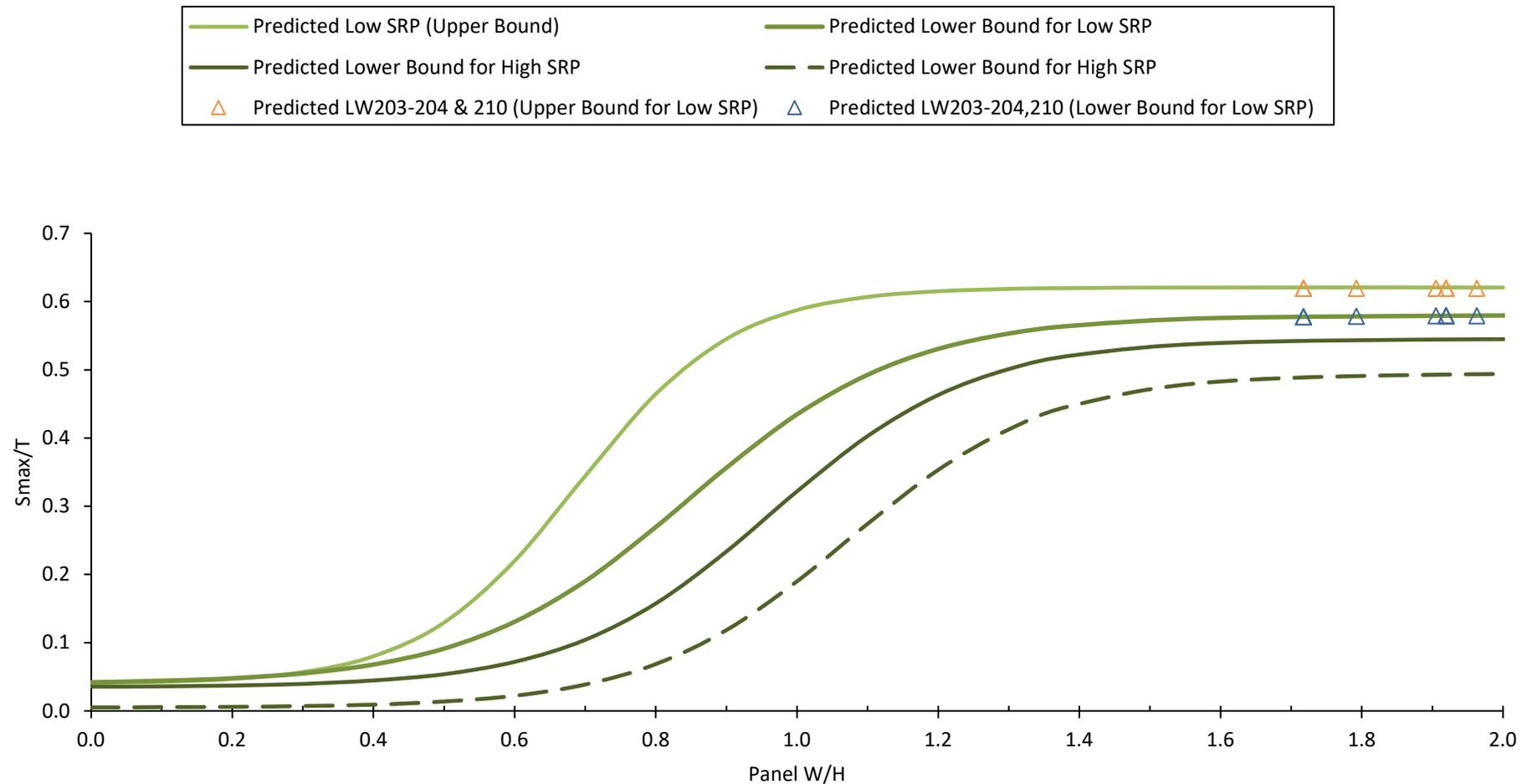
	Engineer: S.Ditton	Client: Narrabri Mine NAR-005/2
	Drawn: S.Ditton	
	Date: 25.06.20	Title: Measured Tilt at an Angle of Draw of 26.5° outside the limits of extraction for LWs 101 to 108A
	Ditton Geotechnical Services Pty Ltd	
Scale: NTS	Figure No: 9h	



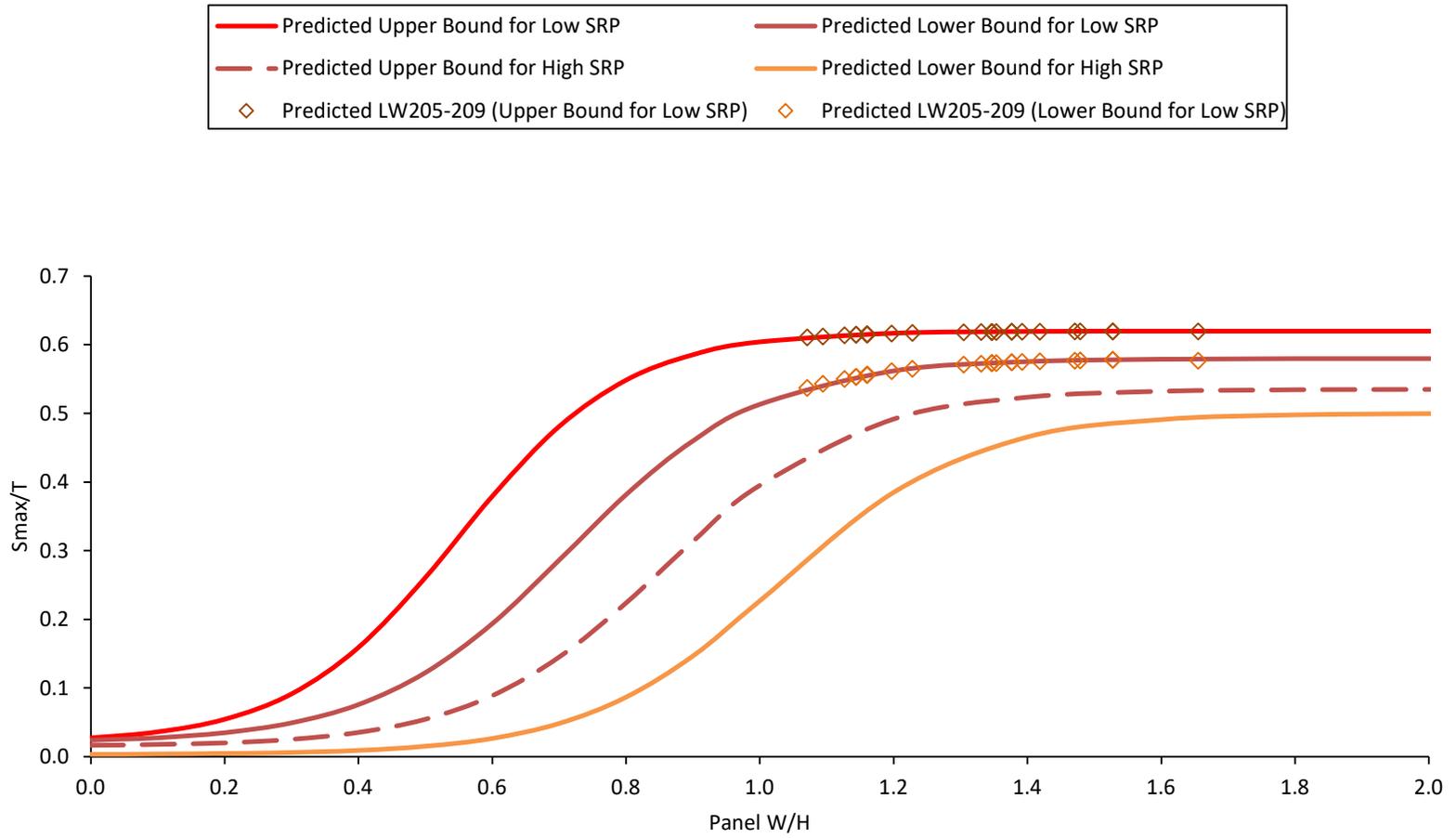
<i>Bin</i>	<i>Frequency</i>	<i>Cumulative %</i>
0.1	4	18%
0.3	3	32%
0.5	3	45%
0.7	3	59%
0.9	6	86%
1.1	3	100%
1.3	0	100%
1.5	0	100%
1.7	0	100%
1.9	0	100%
More	0	100%

<i>Statistics</i>	
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

	Engineer: S.Ditton	Client: Narrabri Mine NAR-005/2
	Drawn: S.Ditton	
	Date: 25.06.20	Title: Measured Horizontal Strain at an Angle of Draw of 26.5° outside the limits of extraction for LWs 101 to 108A
	Ditton Geotechnical Services Pty Ltd	
Scale: NTS		Figure No: 9i



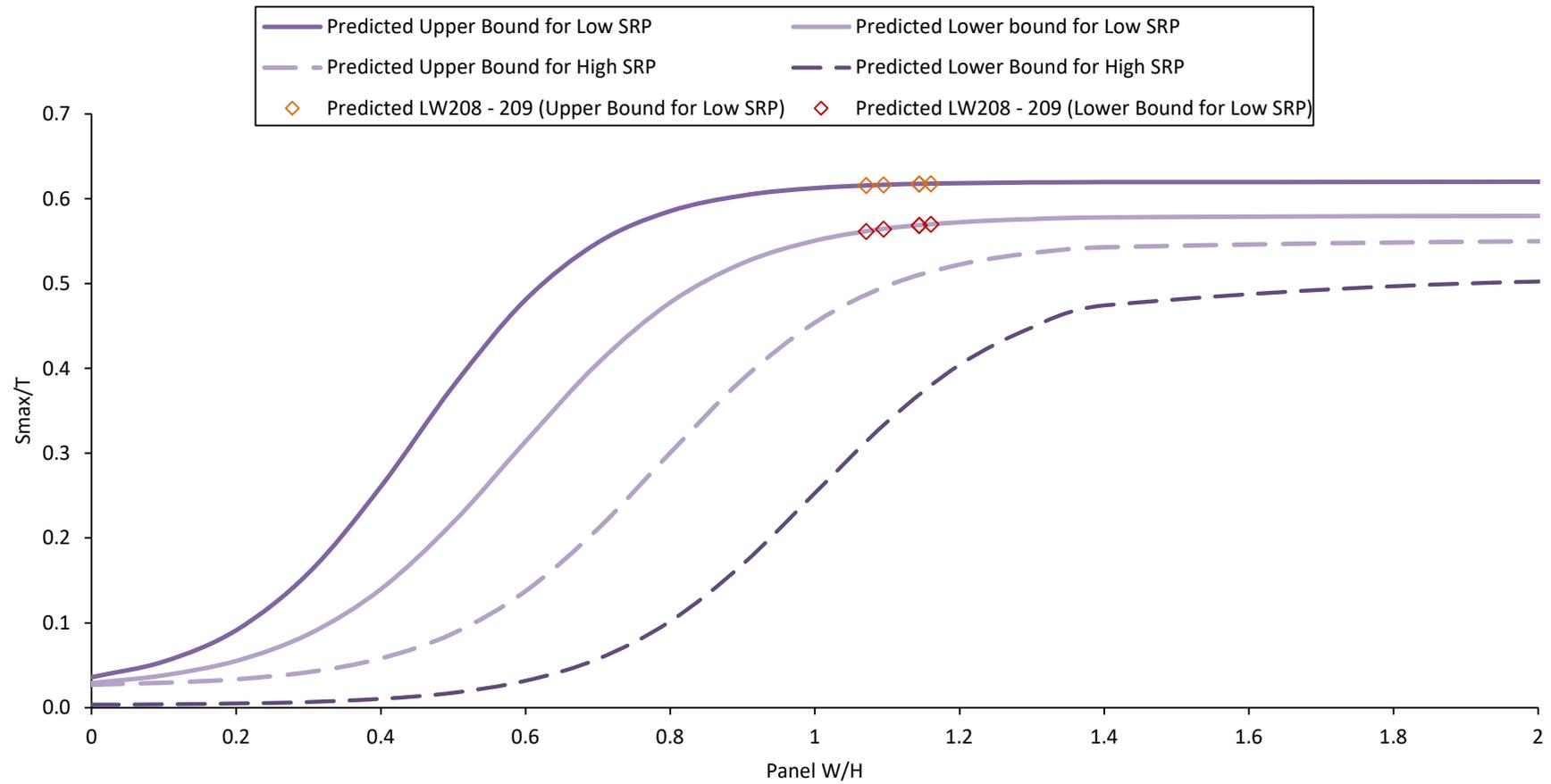
	Engineer:	S.Ditton	Client:	Narrabri Mine	Figure No:	10a
	Drawn:	S.Ditton		NAR-005/2		
	Date:	01.11.19	Title:	Prediction Model for Maximum Single Panel Subsidence above the Proposed LW203 to 210 with Cover Depths ranging from 150 m to 250 m		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		



DgS



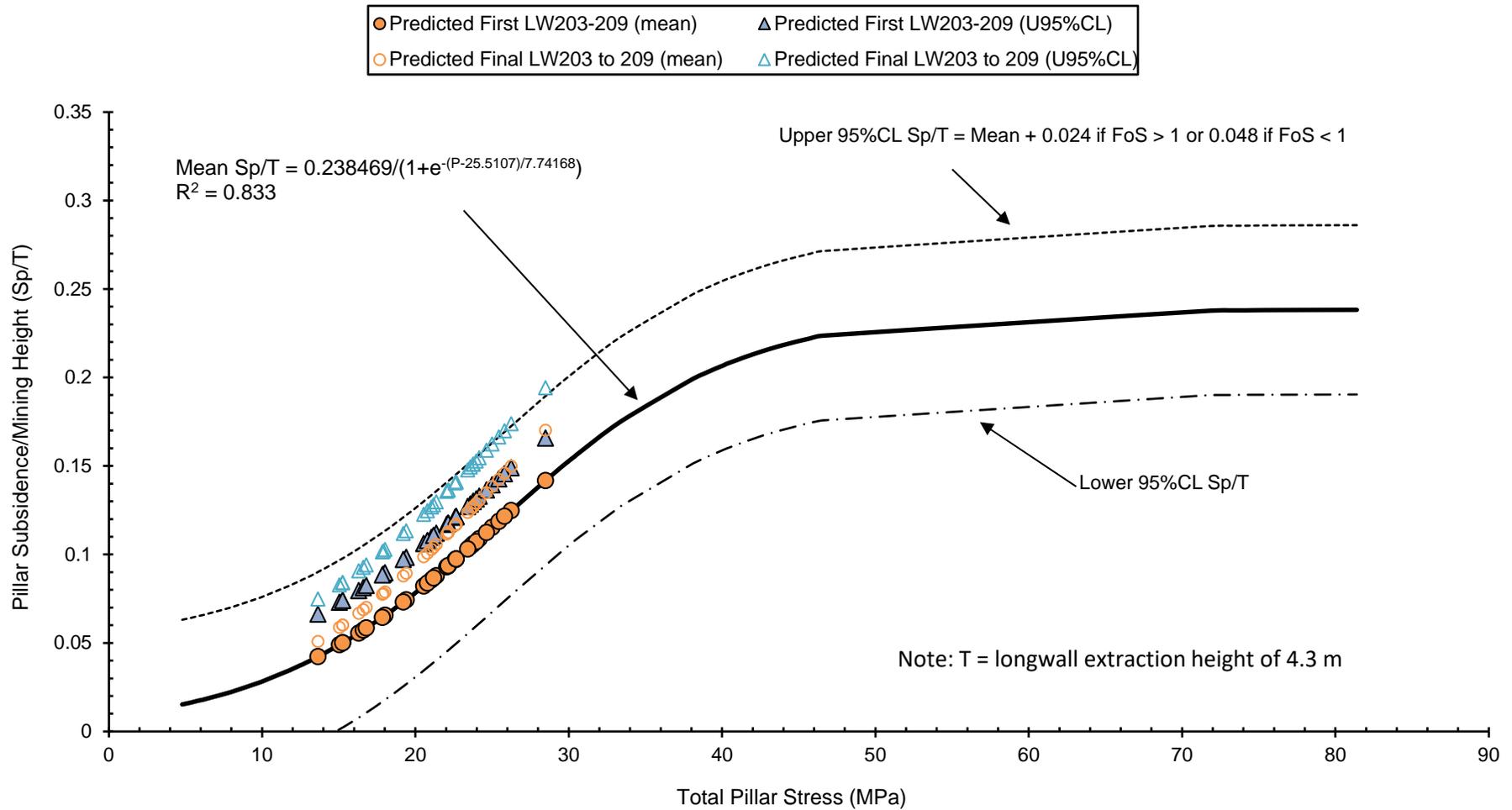
Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	01.11.19	Title:	Prediction Model for Maximum Single Panel Subsidence above the Proposed LW205 to LW209 with Cover Depths ranging from 250 m to 350 m	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 10b



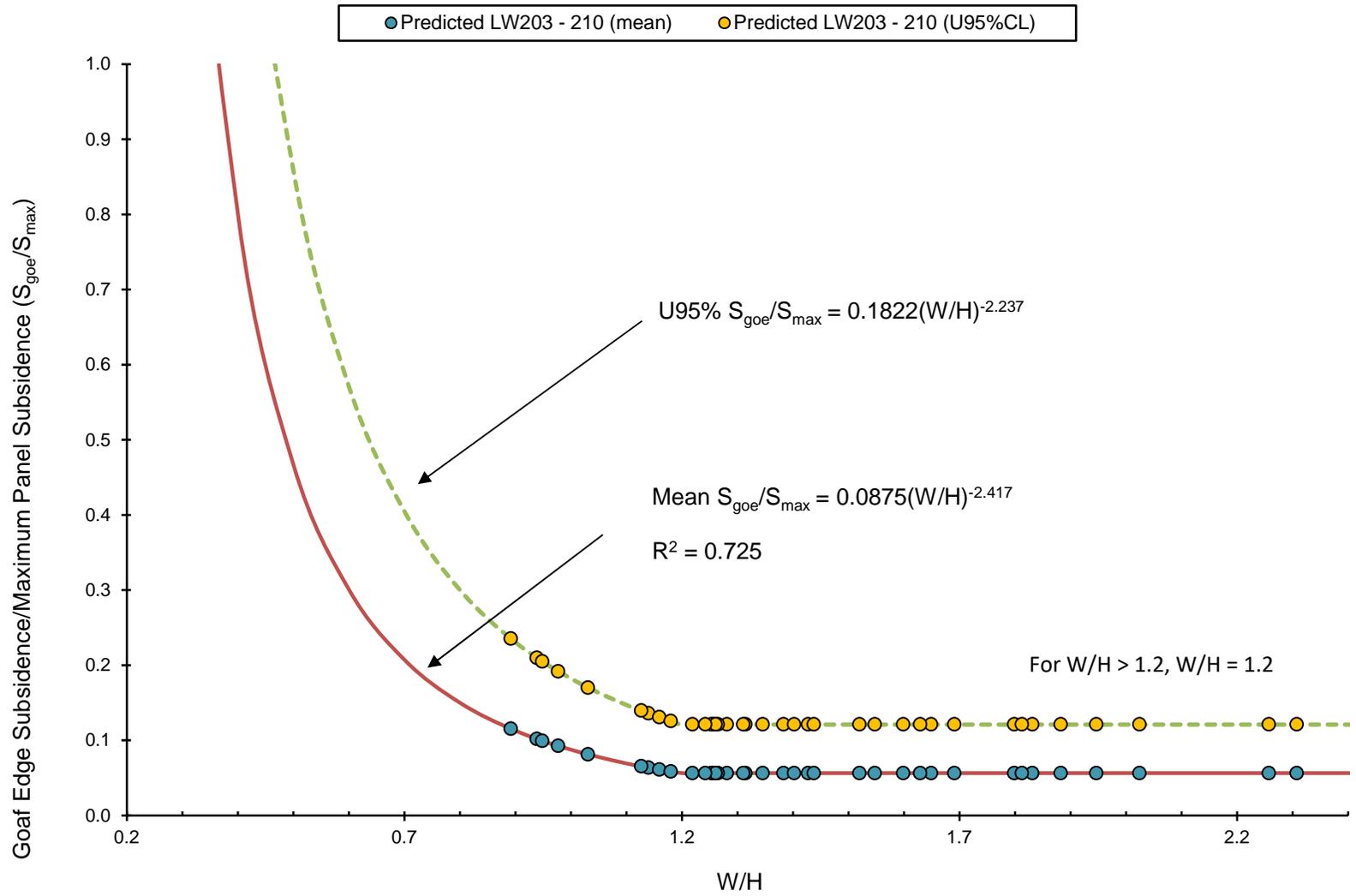
DgS



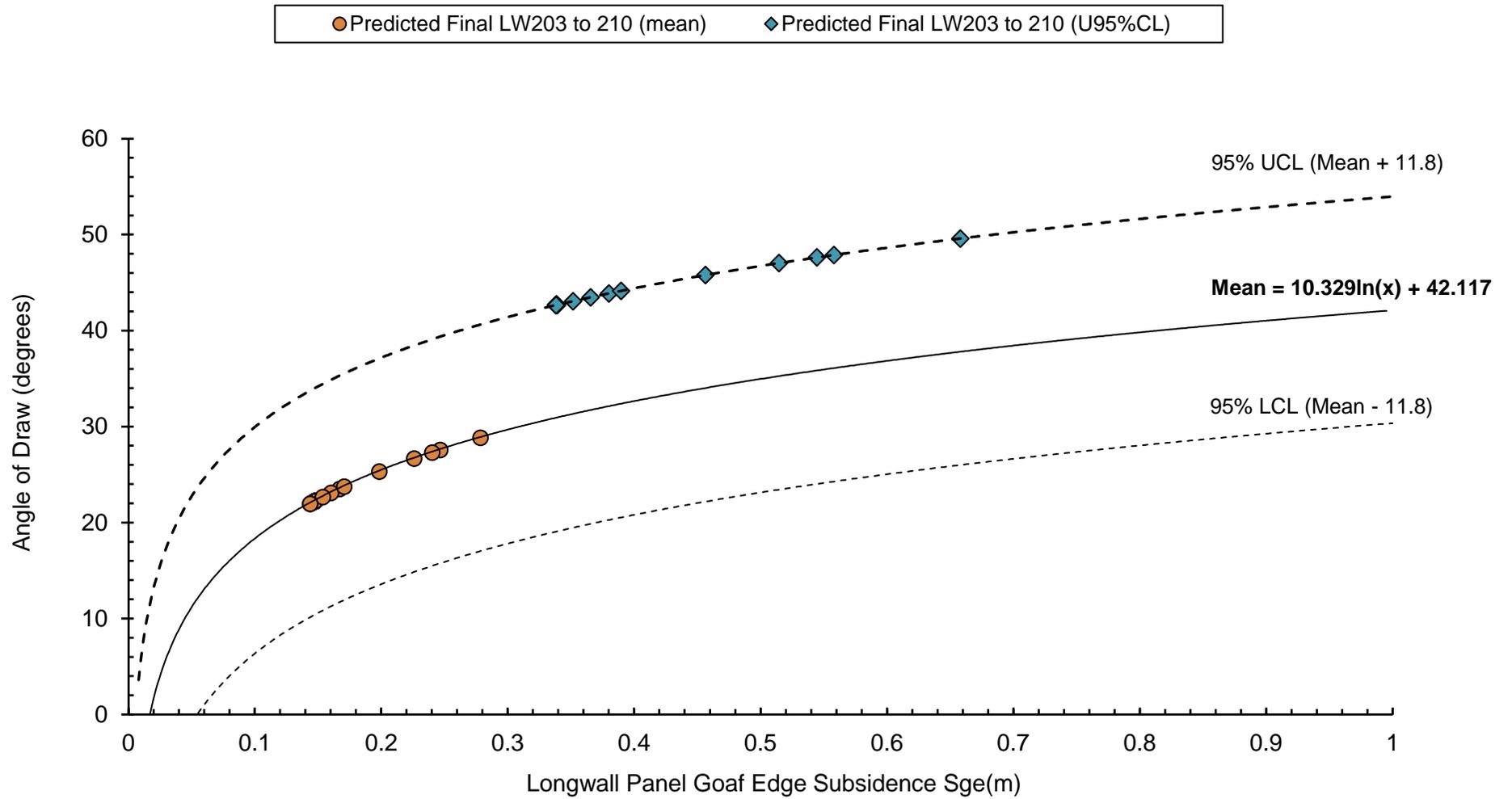
Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	01.11.19	Title:	Prediction Model for Maximum Single Panel Subsidence with Cover Depths ranging from 350 m to 500 m	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 10c



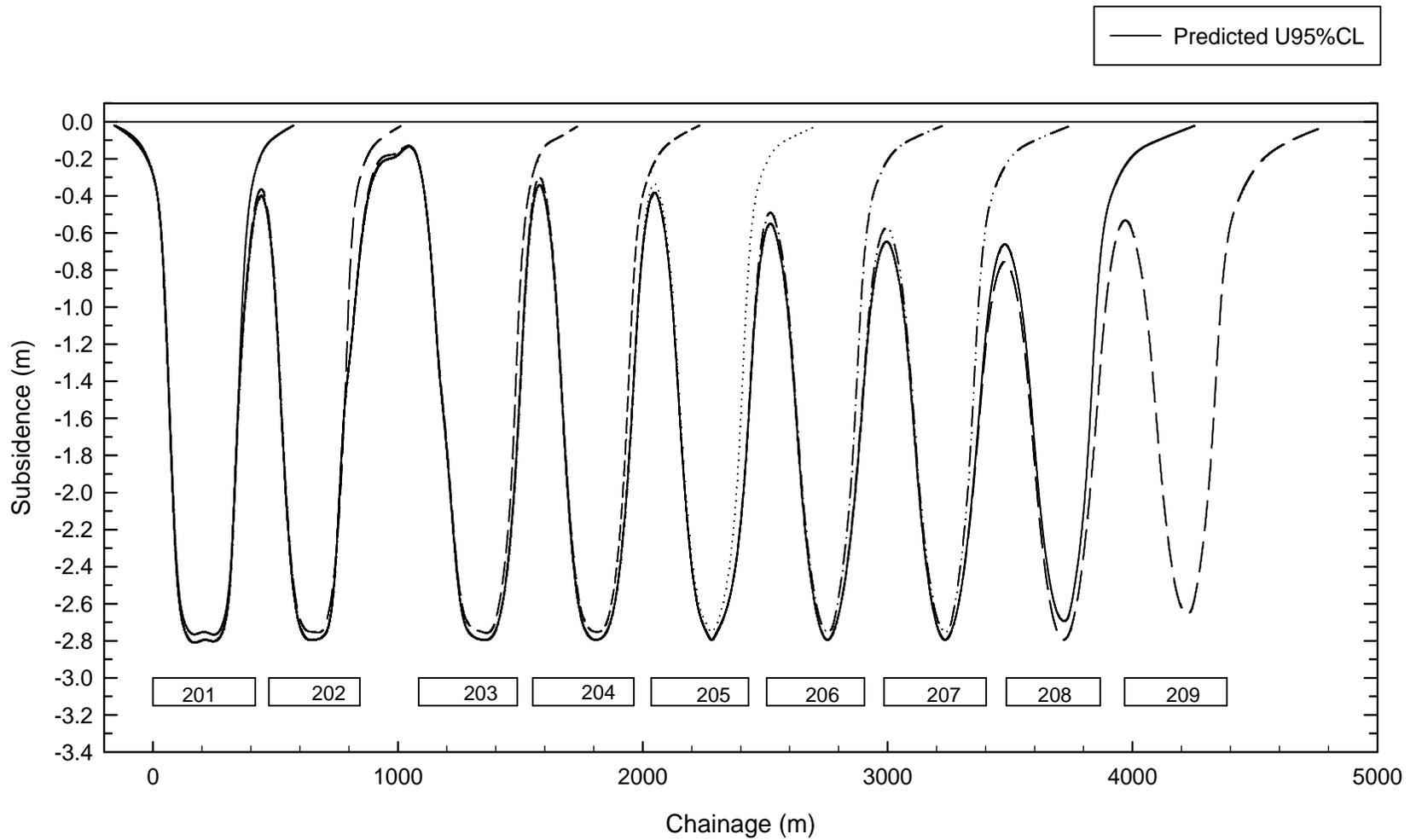
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	20.06.20	Title:	Predicted First and Final Chain Pillar Subsidence for the Proposed LW203 to 209	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



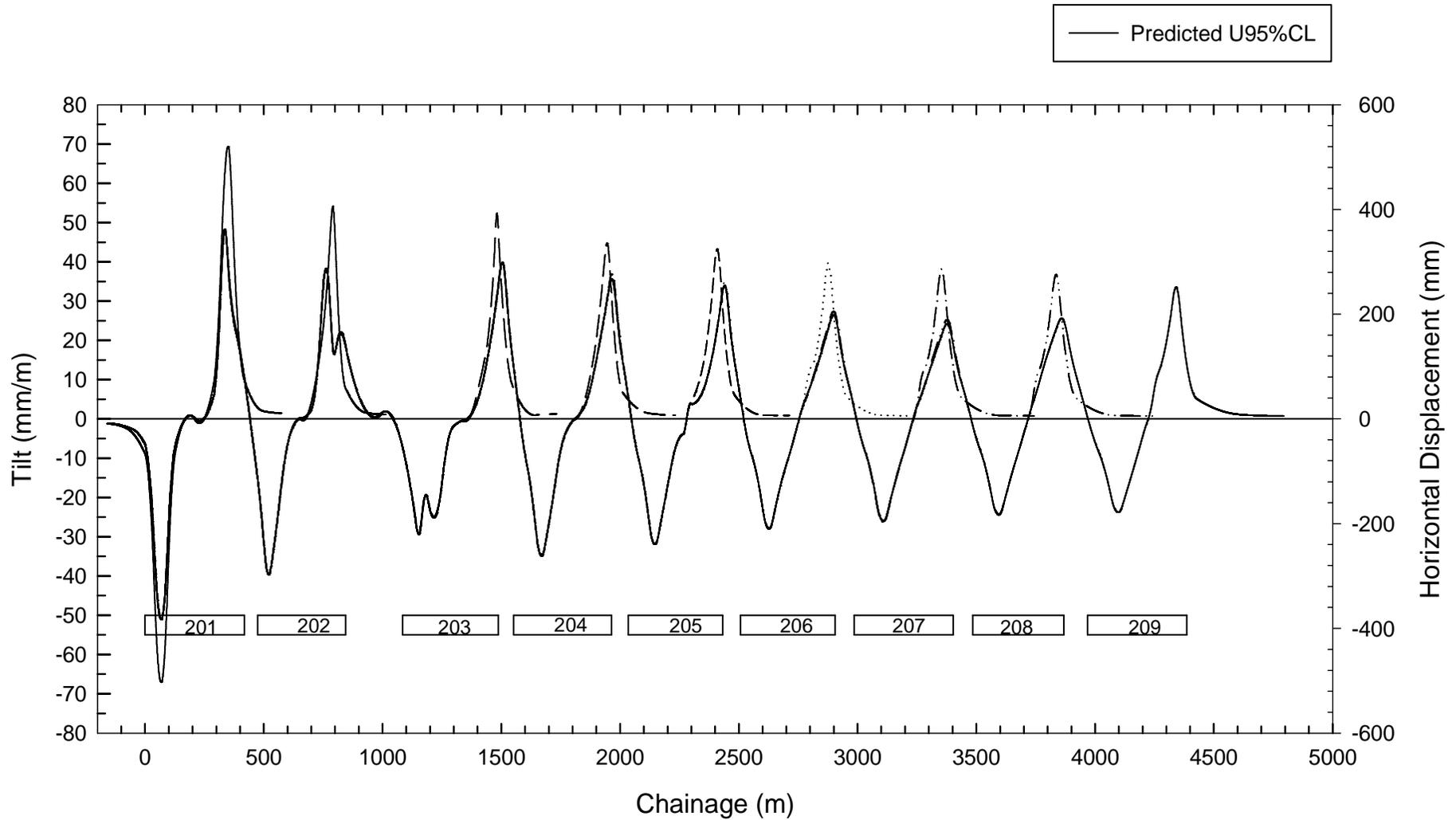
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	20.06.20	Title:	Predicted Goaf Edge Subsidence for the Proposed LW203 to 210 at the Narrabri Mine	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.06.20	Title:	Predicted Angle of Draw to 20mm subsidence for the Proposed LW203 to 210 at the Narrabri Mine	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

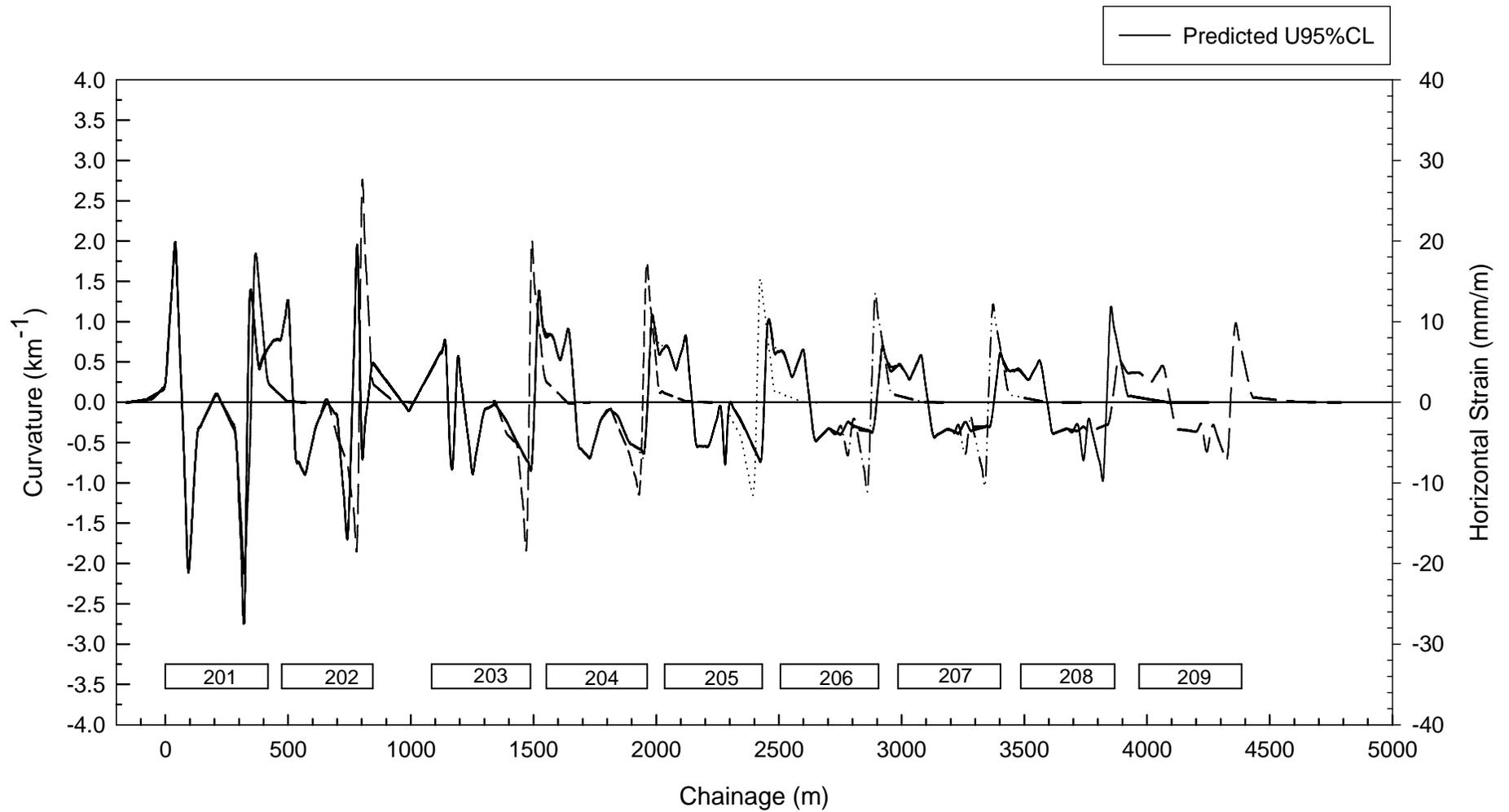


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted U95%CL Subsidence Profiles along XL6 above the Approved LW201 to 202 and the Proposed LW203 to 209 in ML1609	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

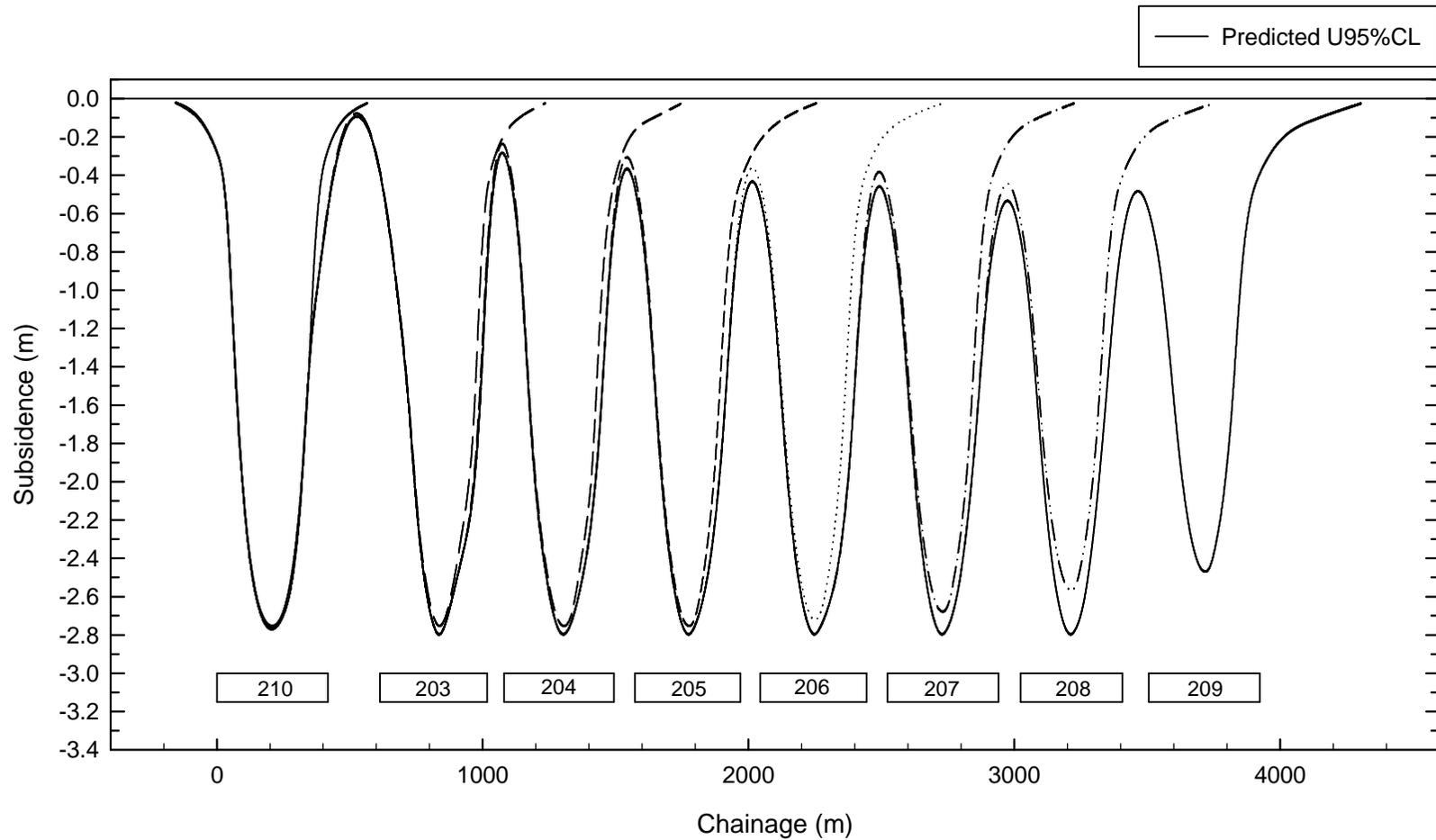


Engineer:	S.Ditton
Drawn:	S.Ditton
Date:	15.11.19
Ditton Geotechnical Services Pty Ltd	

Client:	Narrabri Mine NAR-005/2		
Title:	Predicted U95%CL Tilt Profiles along XL6 above the Approved LW201 to 202 and the Proposed LW203 to 209 in ML1609		
Scale:	NTS		Figure No: 11b

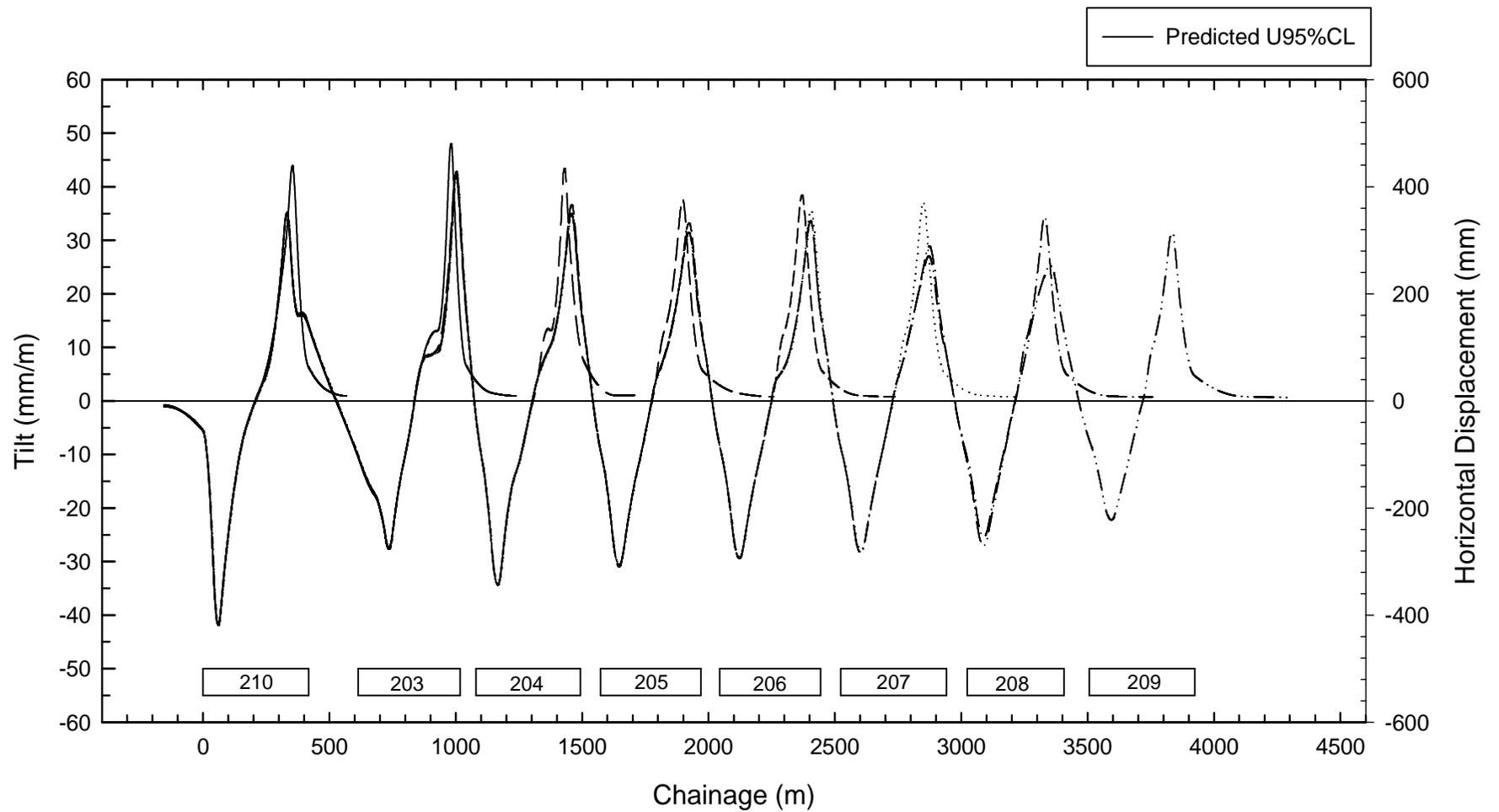


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted U95%CL Curvature Profiles along XL6 above the Approved LW201 to 202 and the Proposed LW203 to 209 in the ML1609	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

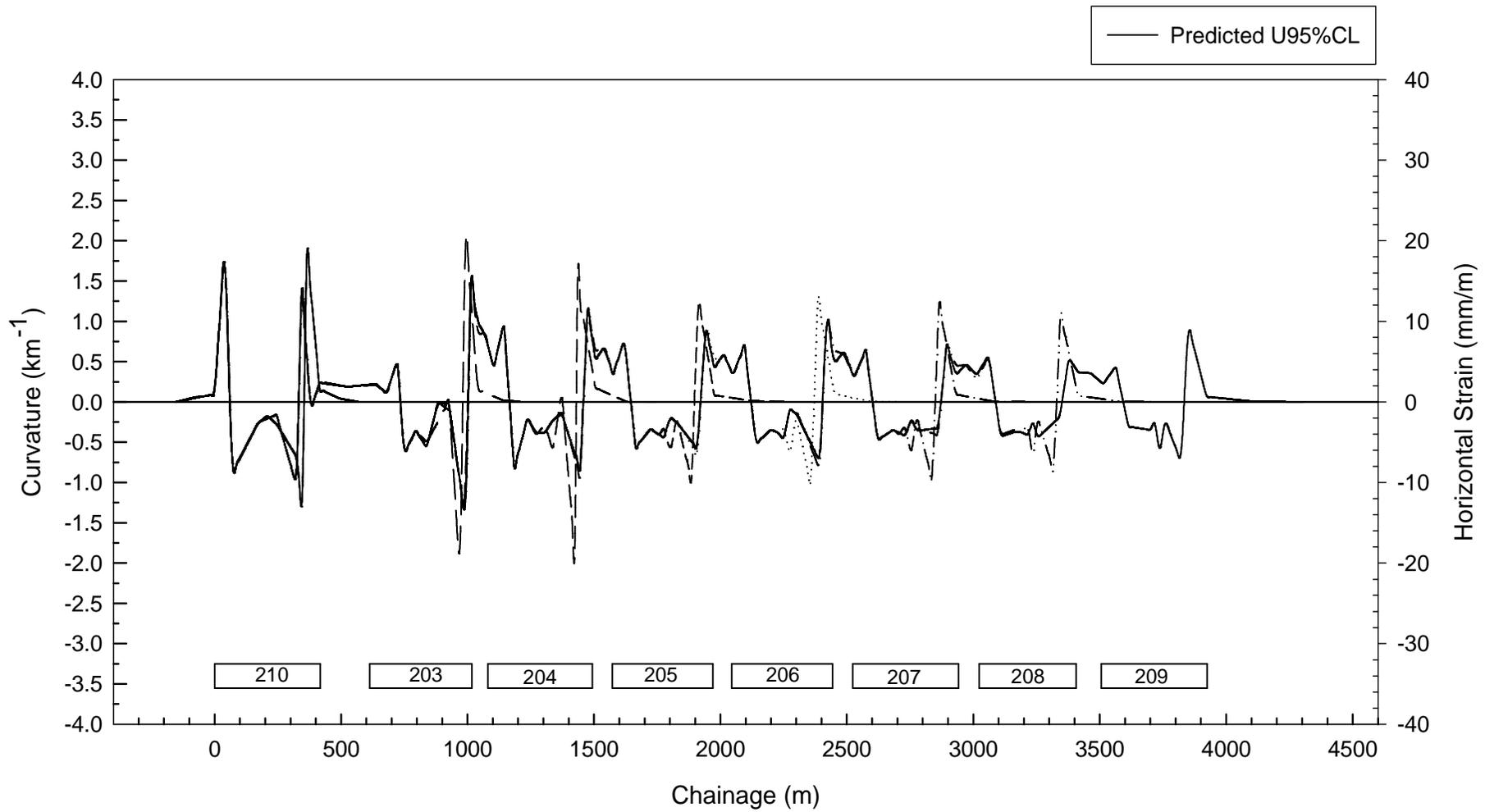


Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19
 Ditton Geotechnical
 Services Pty Ltd

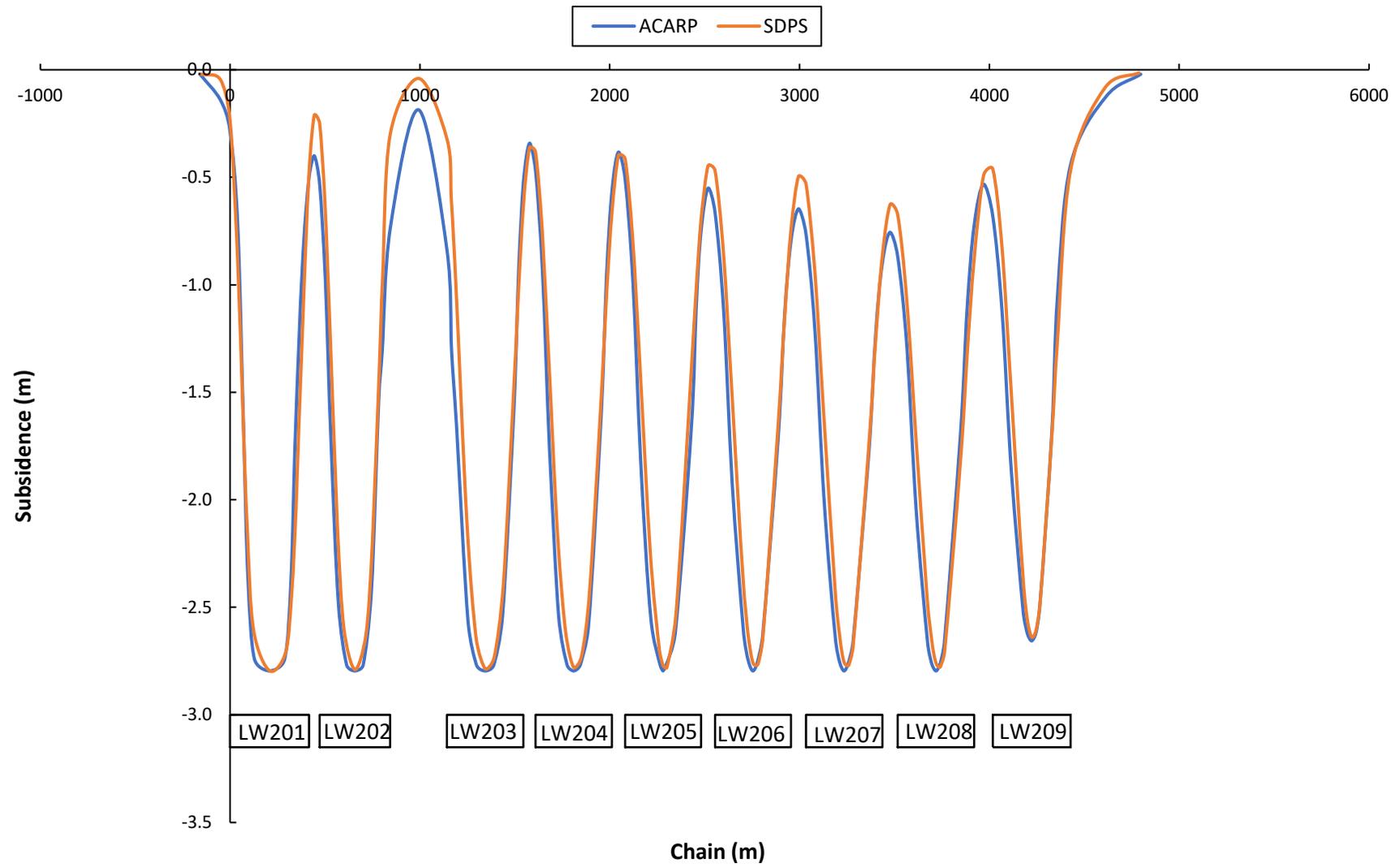
Client:	Narrabri Mine NAR-005/2	
Title:	Predicted U95%CL Subsidence Profiles along XL10 above the Proposed LW203 to 210 in MLA Areas 1 & 2	
Scale:	NTS	Figure No: 11d



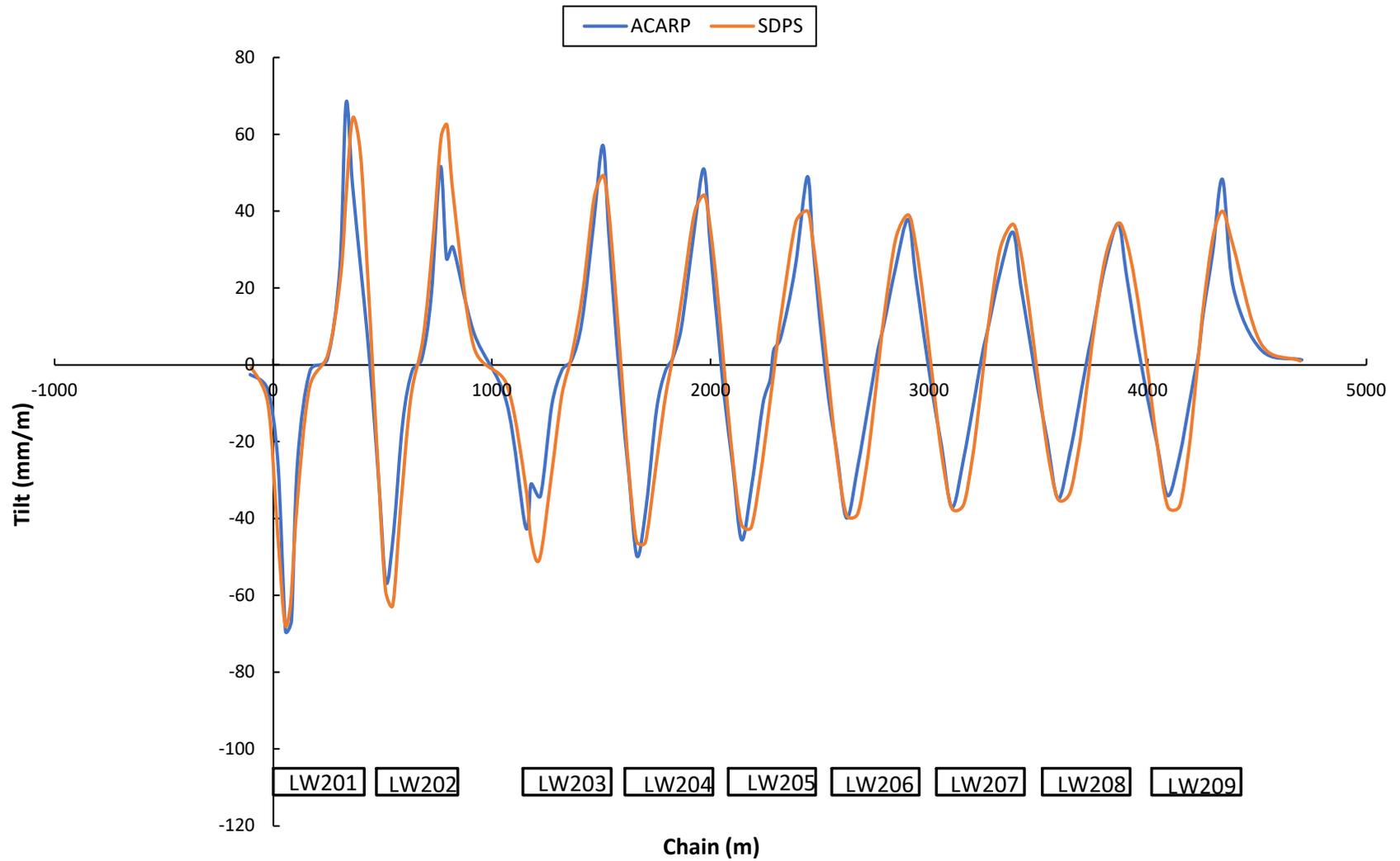
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted U95%CL Tilt Profiles along XL10 above the Proposed LW203 to 210	
	Ditton Geotechnical Services Pty Ltd			in MLA Areas 1 & 2	
			Scale:	NTS	Figure No: 11e



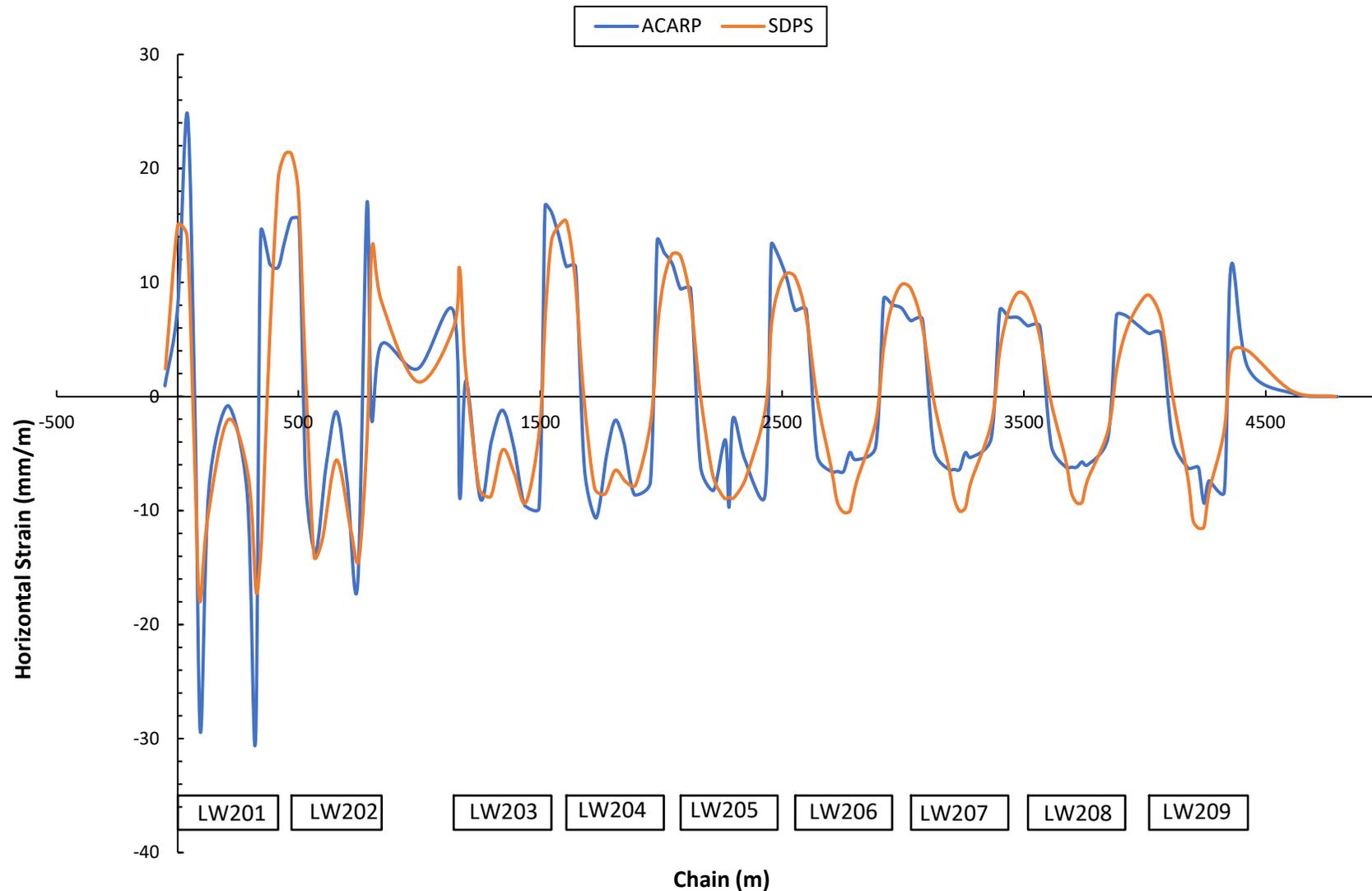
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted U95%CL Curvature Profiles along XL10 above the Proposed LW203 to 210	
	Ditton Geotechnical Services Pty Ltd			in MLA Areas 1 & 2	
			Scale:	NTS	Figure No: 11f



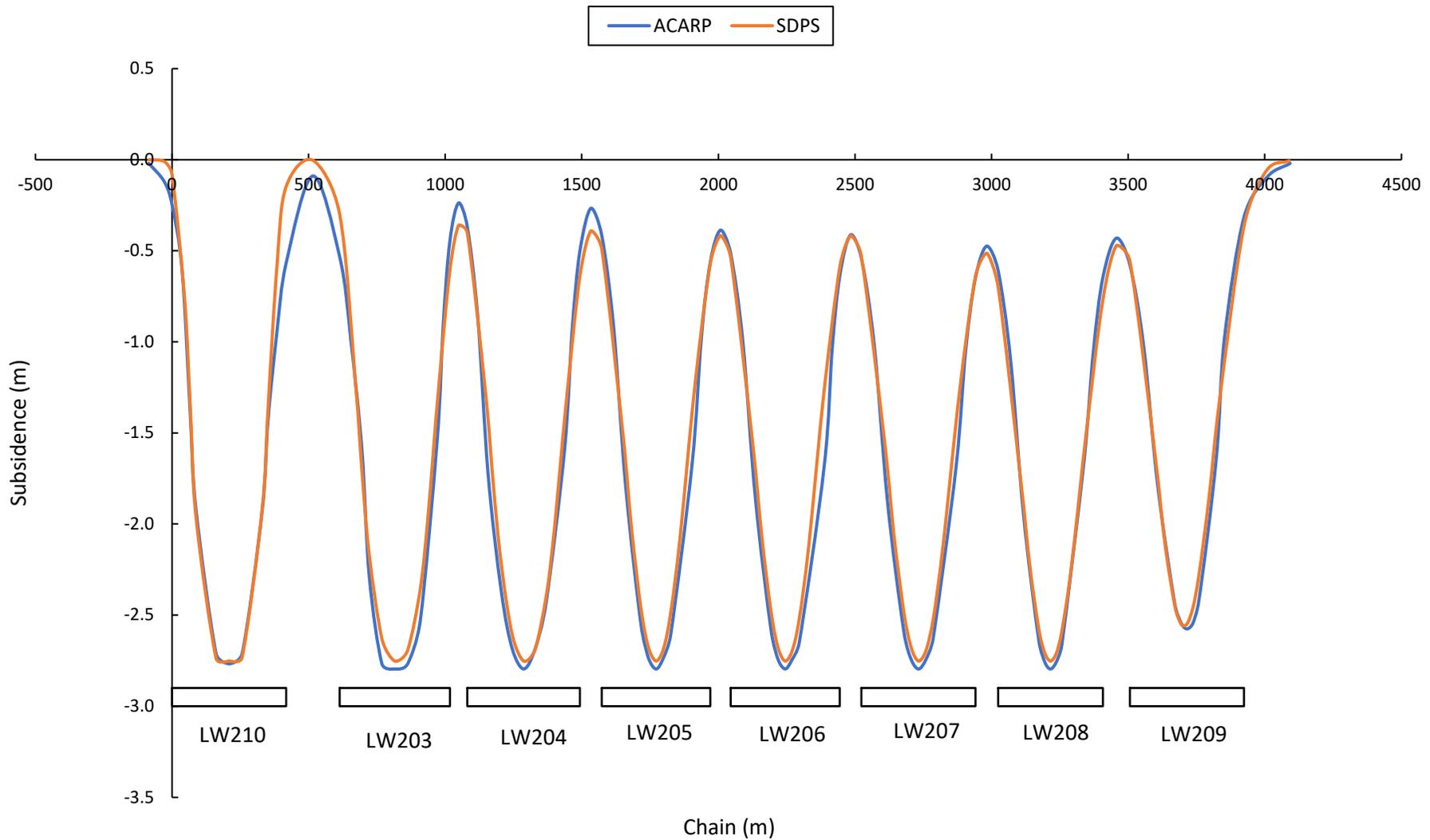
Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	20.11.18	Title:	Predicted ACARP v SDPS (U95%CL) Subsidence Profiles along XL6 above the Approved LW201 to 202 and the Proposed LW203 to 209 in ML1609	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 12a



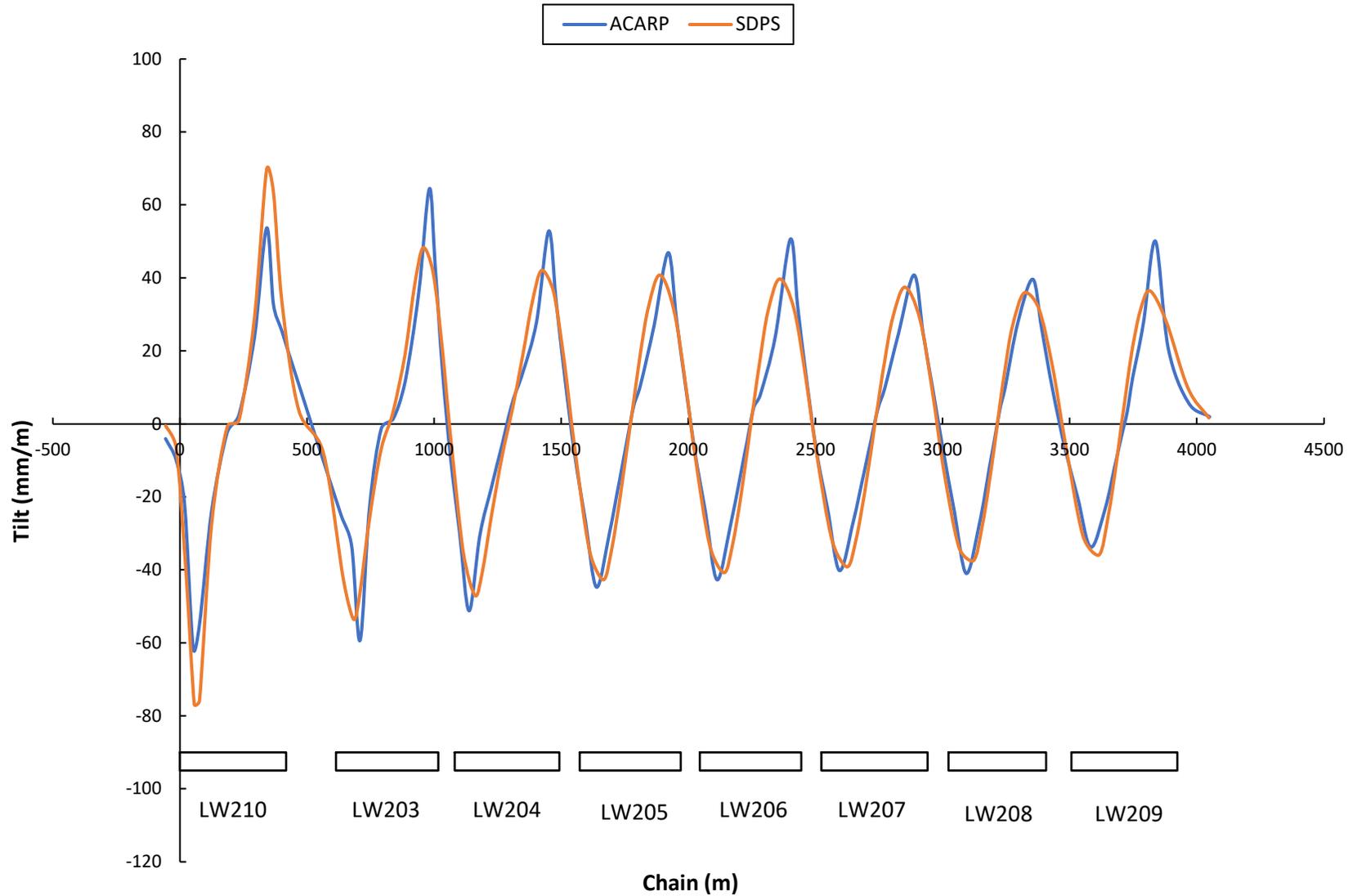
	Engineer: S.Ditton	Client: Narrabri Mine NAR-005/2
	Drawn: S.Ditton	
	Date: 15.11.19	Title: Predicted ACARP v SDPS (U95%CL) Tilt Profiles along XL6 above the Approved LW201 to 202 and the Proposed LW203 to 209 in ML1609
	Ditton Geotechnical Services Pty Ltd	
Scale: NTS	Figure No: 12b	



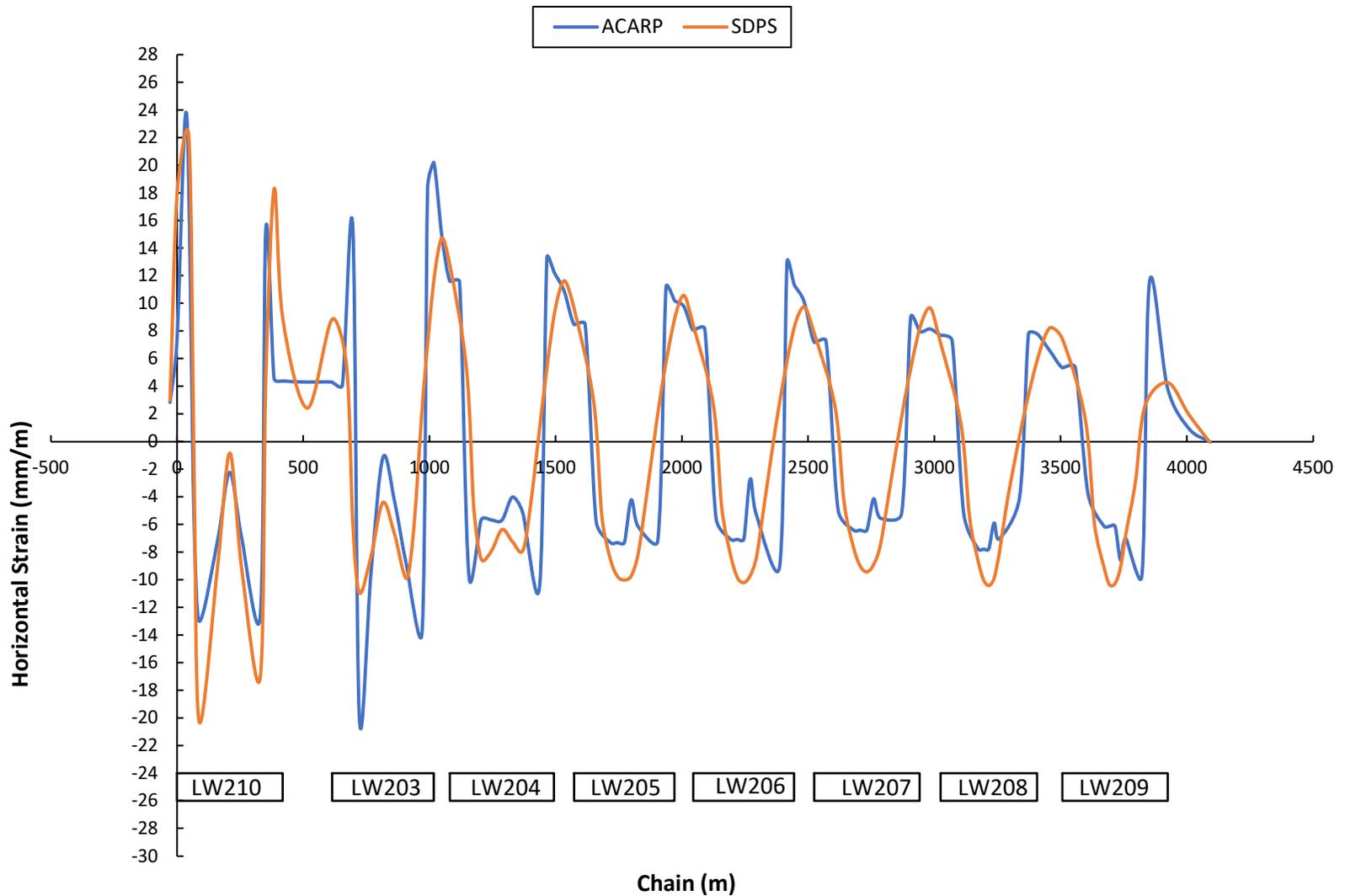
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted ACARP v SDPS (U95%CL) Horizontal Strain Profiles along XL6 above the Approved	
	Ditton Geotechnical Services Pty Ltd		LW201 to 202 and the Proposed LW203 to 209 in ML1609		
	Scale:	NTS			Figure No: 12c



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted ACARP v SDPS (U95%CL) Subsidence Profiles along XL10 above the Proposed	
	Ditton Geotechnical Services Pty Ltd		LW203 to 210 in MLA Areas 1 & 2		
	Scale:	NTS			Figure No: 12d

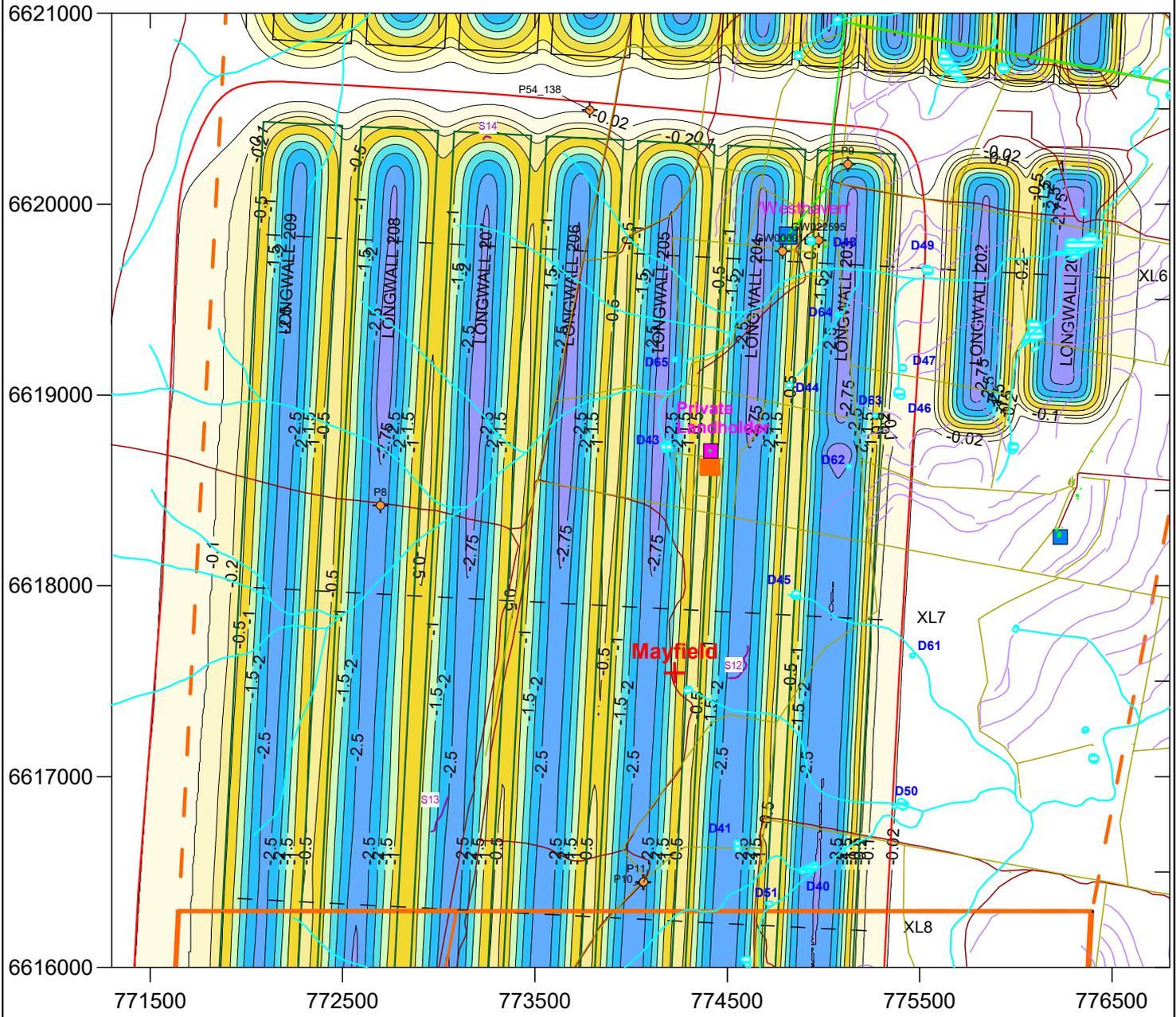
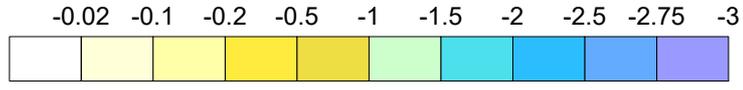


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted ACARP v. SDPS (U95%CL) Tilt Profiles along XL10 above the Proposed	
	Ditton Geotechnical Services Pty Ltd		LW203 to 210 in MLA Areas 1 & 2		
	Scale:	NTS			Figure No: 12e



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.11.19	Title:	Predicted ACARP v. SDPS U95%CL Horizontal Strain Profiles along XL10 above Proposed	
	Ditton Geotechnical Services Pty Ltd		LW203 to 210 in MLA Areas 1 & 2		
		Scale:	NTS		Figure No: 12f

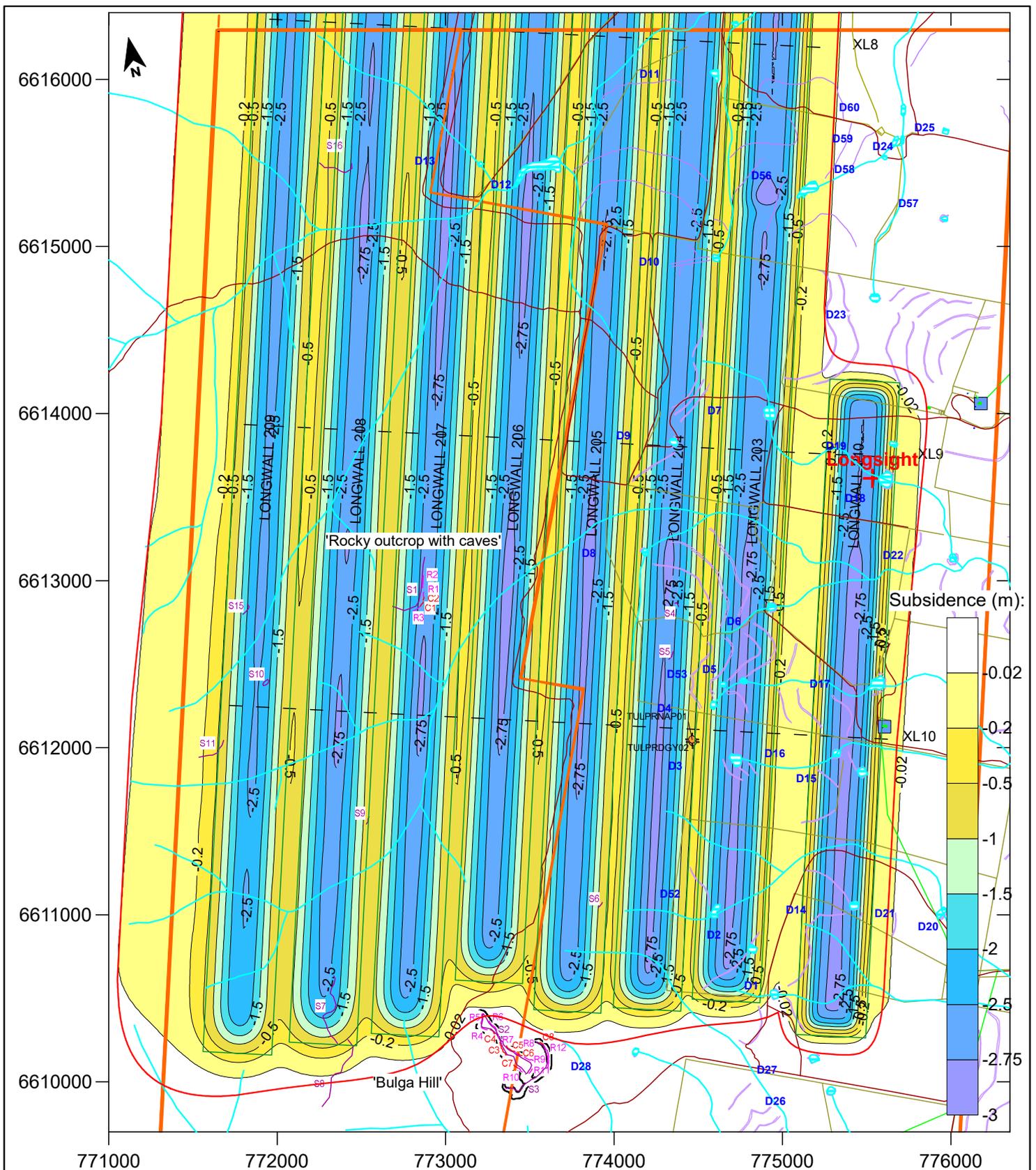
Subsidence (m):



Key:

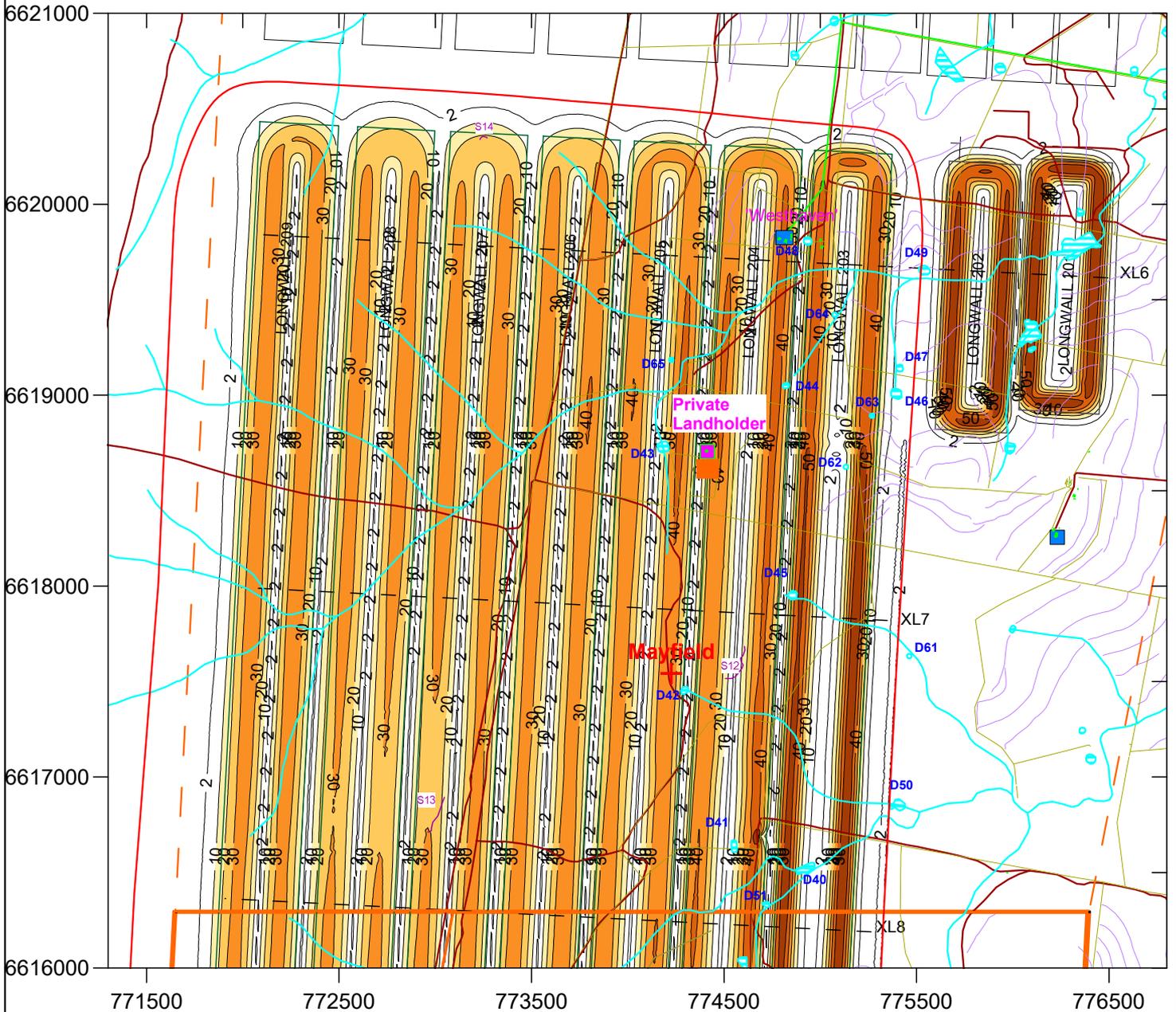
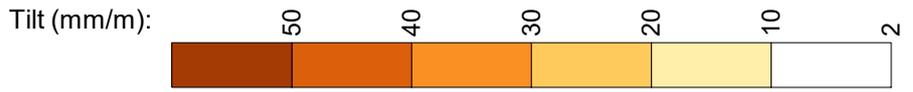
- Prediction Lines
- Roads (unsealed)
- Dwellings (Private / NCO-Owned)
- Dwellings & Sheds/Tanks/Orchards
- Proposed LW203 to 209
- Powerlines (Domestic)
- - - Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Angle of Draw to 20 mm subsidence
- ⬢ Groundwater Bores
- Contour banks
- C1/ R1/S1/ Minor Cliffs, Rock Faces & Steep Slope Crests
- Ephemeral Creeks & Watercourses
- ▴ Farm Dams
- ⊕ Aboriginal Heritage Sites (Grinding Grooves)
- Lot Boundaries/Fences

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton		Title:	Predicted Subsidence Contours (U95%CL) above the Approved LW201-202 and the Proposed LW203 to 209 in ML1609	
	Date:	15.10.19	Scale:		1:40,000	Figure No:
	Ditton Geotechnical Services Pty Ltd					



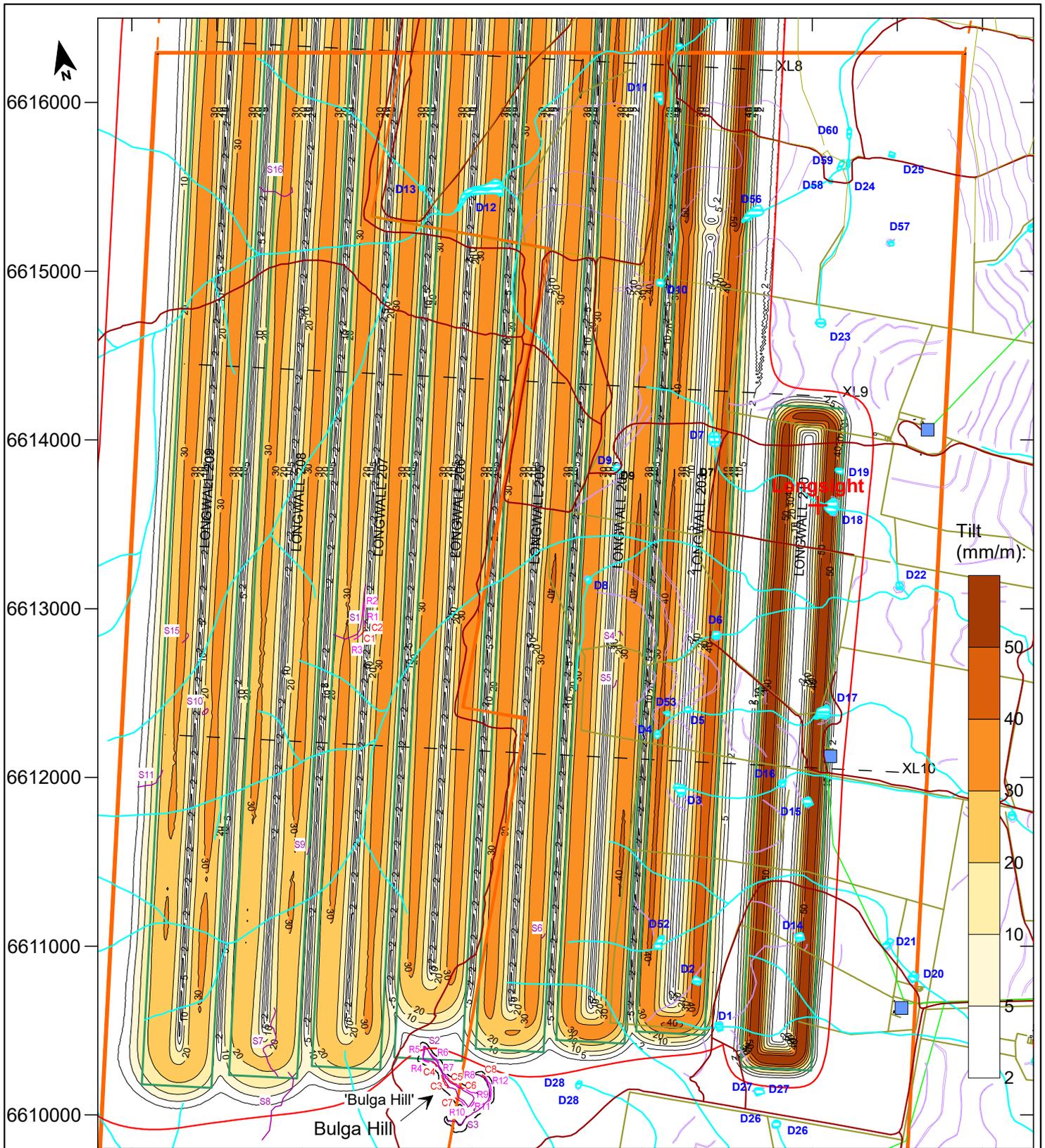
- Subsidence Prediction Lines
- Roads (unsealed)
- Dwellings (Private/NCO-Owned)
- Powerlines (Domestic)
- ▭ Proposed Longwall Panels
- MLA Areas 1 & 2 Boundaries
- Angle of Draw to 20mm subsidence
- +
- Contour banks
- Lot Boundaries/Fences
- C1/R1/S1 Minor Cliffs, Rock Faces & Steep Slope Crests
- Ephemeral Creeks & Watercourses
- Farm Dams
- Groundwater bores

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Predicted Subsidence Contours (U95%CL) above the Proposed LW203 to 210 in MLA Areas 1 & 2		
	Date:	21.11.18	Scale:	1:40,000	Figure No:	13b
	Ditton Geotechnical Services Pty Ltd					



Key:	Powerlines (Domestic)	Minor Cliffs, Rock Faces & Steep Slope Crests
Prediction Lines	Mining Lease 1609 Boundary	Ephemeral Creeks & Watercourses
Roads (unsealed)	Mining Lease Application Areas 1 & 2 Boundaries	Farm Dams
Dwellings (Private / NCO-Owned)	Angle of Draw to 20 mm subsidence	Aboriginal Heritage Sites (Grinding Grooves)
Dwellings & Sheds/Tanks/Orchards	Groundwater Bores	Lot Boundaries/Fences
Proposed LW203 to 209	Contour banks	

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2			
	Drawn:	S.Ditton		Title:	Predicted Tilt Contours (U95%CL) above the Approved LW201 to 202 and the Proposed LW203 to 209 in ML1609		
	Date:	15.11.19	Scale:		1:60,000	Figure No:	13c
	Ditton Geotechnical Services Pty Ltd						

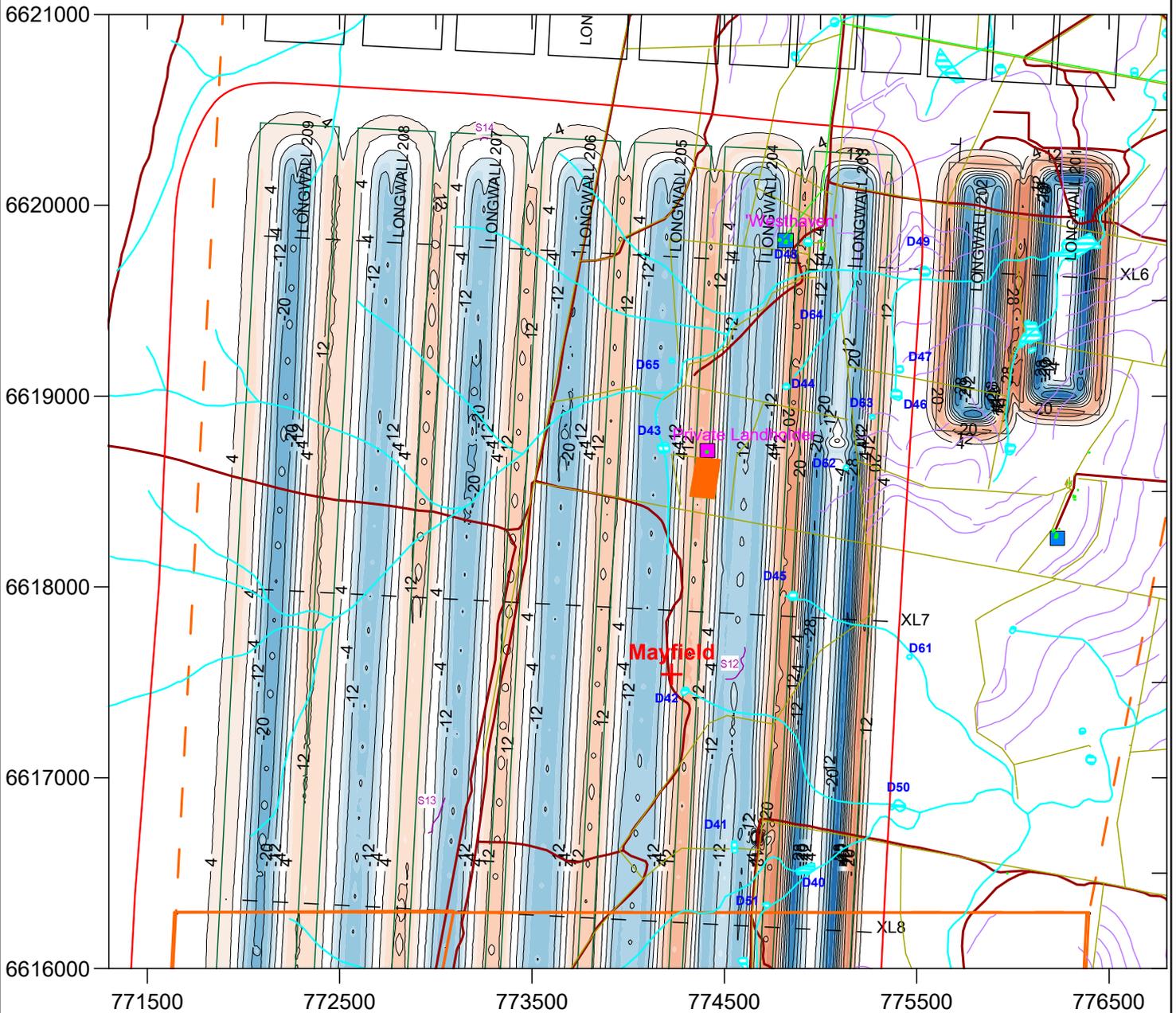
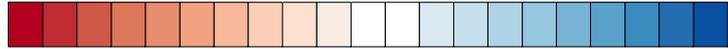


- | | | | | | |
|--|-------------------------------|--|----------------------------|---|---|
| --- | Subsidence Prediction Lines | | Proposed Longwall Panels | C1/R1/S1 | Minor Cliffs, Rock Faces & Steep Slope Crests |
| — — — | Roads (unsealed) | | MLA Areas 1 & 2 Boundaries | — — — | Angle of Draw to 20mm subsidence |
| | Dwellings (Private/NCO-Owned) | + | Grinding Grooves | — — — | Ephemeral Creeks & Watercourses |
| | Powerlines (Domestic) | | Contour banks | ▽ | Farm Dams |
| | | | Lot Boundaries/Fences | ● | Groundwater bores |

DgS	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Predicted Tilt Contours (U95%CL) above the Proposed LW203 to 210 in MLA Areas 1 & 2		
	Date:	15.01.19	Scale:	1:60,000	Figure No:	13d
	Ditton Geotechnical Services Pty Ltd					



Strain (mm/m): 40 36 32 28 24 20 16 12 8 4 0 -4 -8 -12 -16 -20 -24 -28 -32 -36 -40



Key:

- Prediction Lines
- Roads (unsealed)
- Dwellings (Private / NCO-Owned)
- Dwellings & Sheds/Tanks/Orchards
- Proposed LW203 to 209
- Powerlines (Domestic)
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Angle of Draw to 20 mm subsidence
- Groundwater Bores
- Contour banks
- Ephemeral Creeks & Watercourses
- Farm Dams
- Aboriginal Heritage Sites (Grinding Grooves)
- Lot Boundaries/Fences
- Minor Cliffs, Rock Faces & Steep Slope Crests

DgS

Engineer:	S.Ditton
Drawn:	S.Ditton
Date:	15.11.19

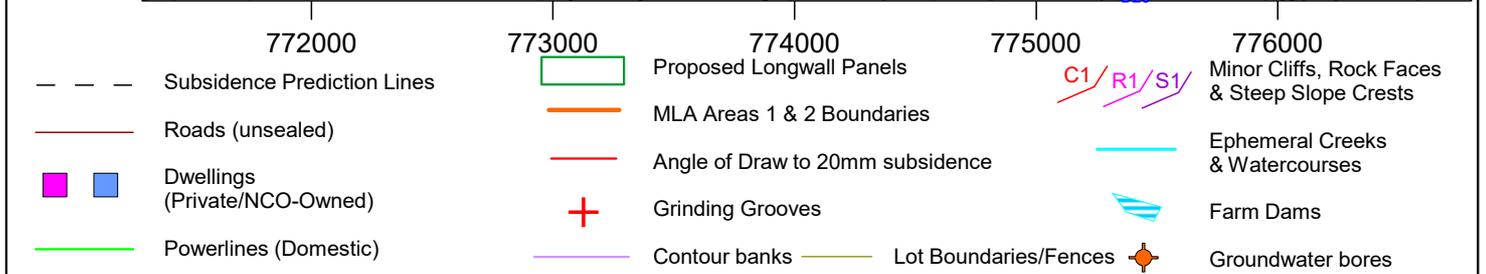
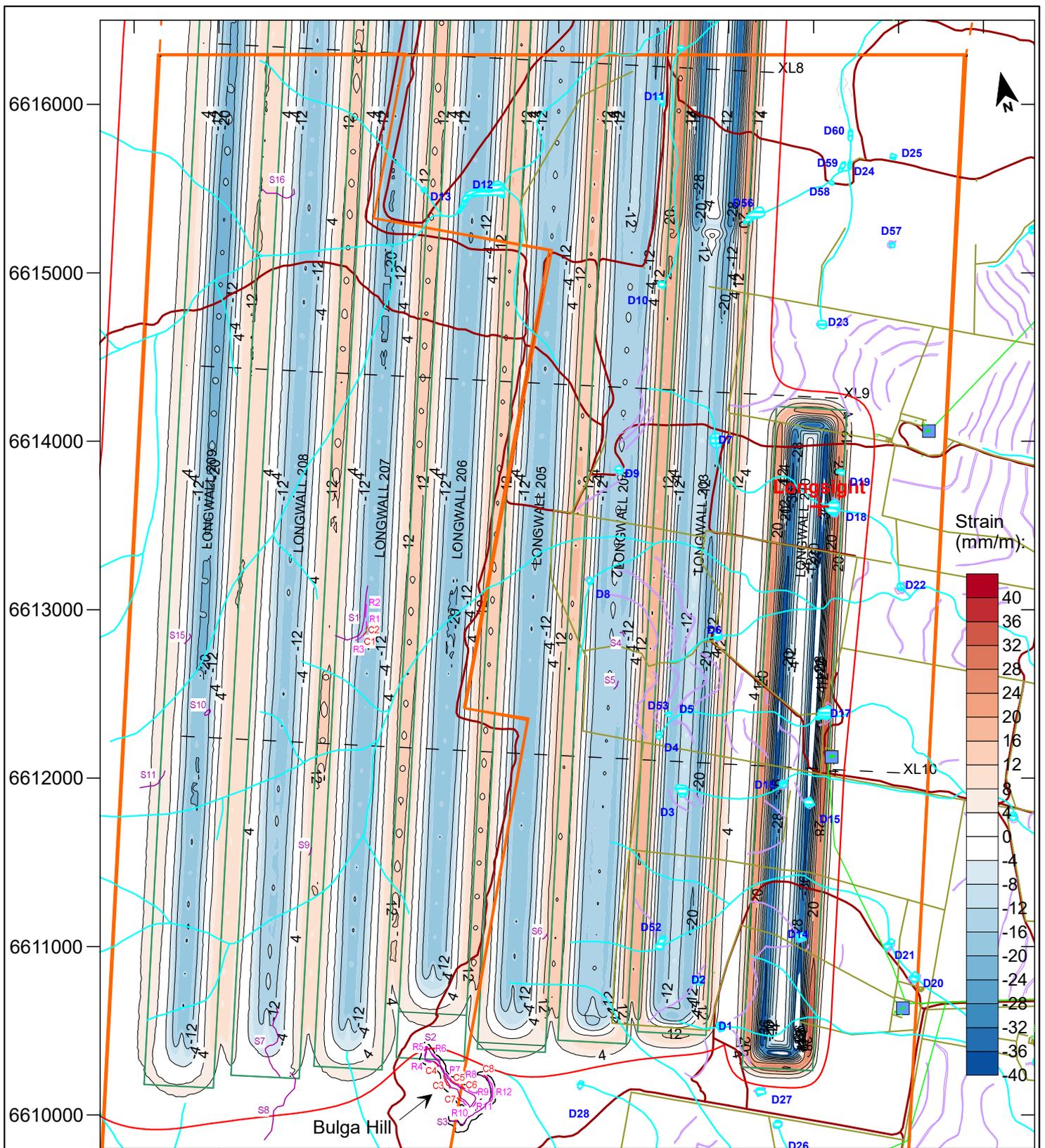
Ditton Geotechnical Services Pty Ltd

Client:	Narrabri Mine NAR-005/2
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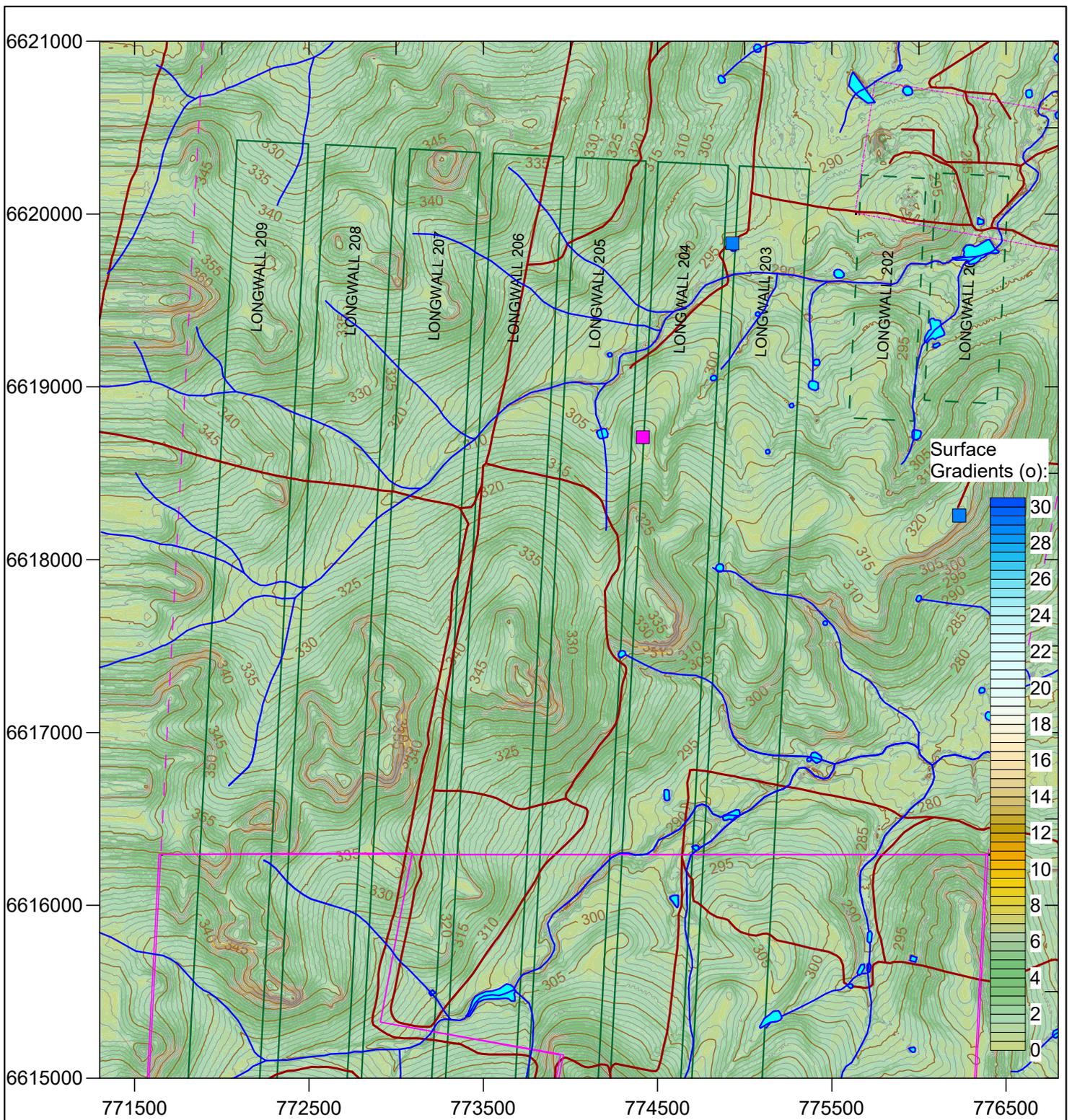
Title:	Predicted Horizontal Strain Contours (U95%CL) above the Approved LW201 to 202 and Proposed LW203 to 209 in ML1609
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Scale:	1:40,000
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Figure No:	13e
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	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Predicted Horizontal Strain Contours (U95%CL) above the Proposed LW203 to 210 in MLA Areas 1 & 2		
	Date:	15.11.19	Scale:	1:40,000	Figure No:	13f
	Ditton Geotechnical Services Pty Ltd					



Key:

- Surface Level contours (m)
- Proposed LW203-209
- Ephemeral Watercourses & Creeks
- Dwellings (Private/NCO-Owned)
- - - Mining Lease 1609 Boundary
- ▲ Farm Dams
- - - Approved LW201 - 202
- Mining Lease Application Areas 1 & 2 Boundaries
- Roads (unsealed)

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19

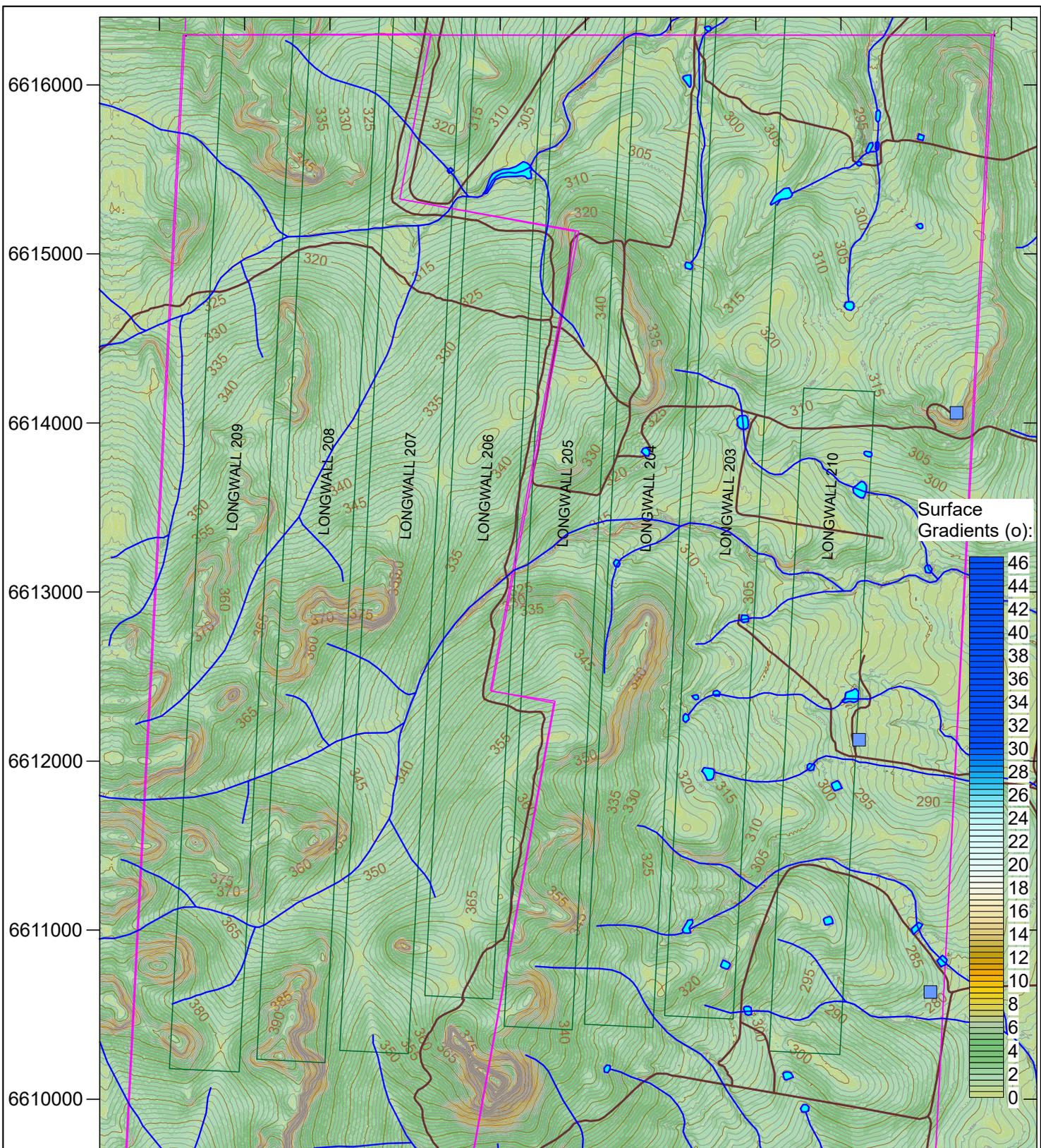
Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

Title: Surface Level Contours (Pre-Mining) above the Approved LW201 to 202 and Proposed LW203 to 209 in ML1609

Scale: 1:40,000

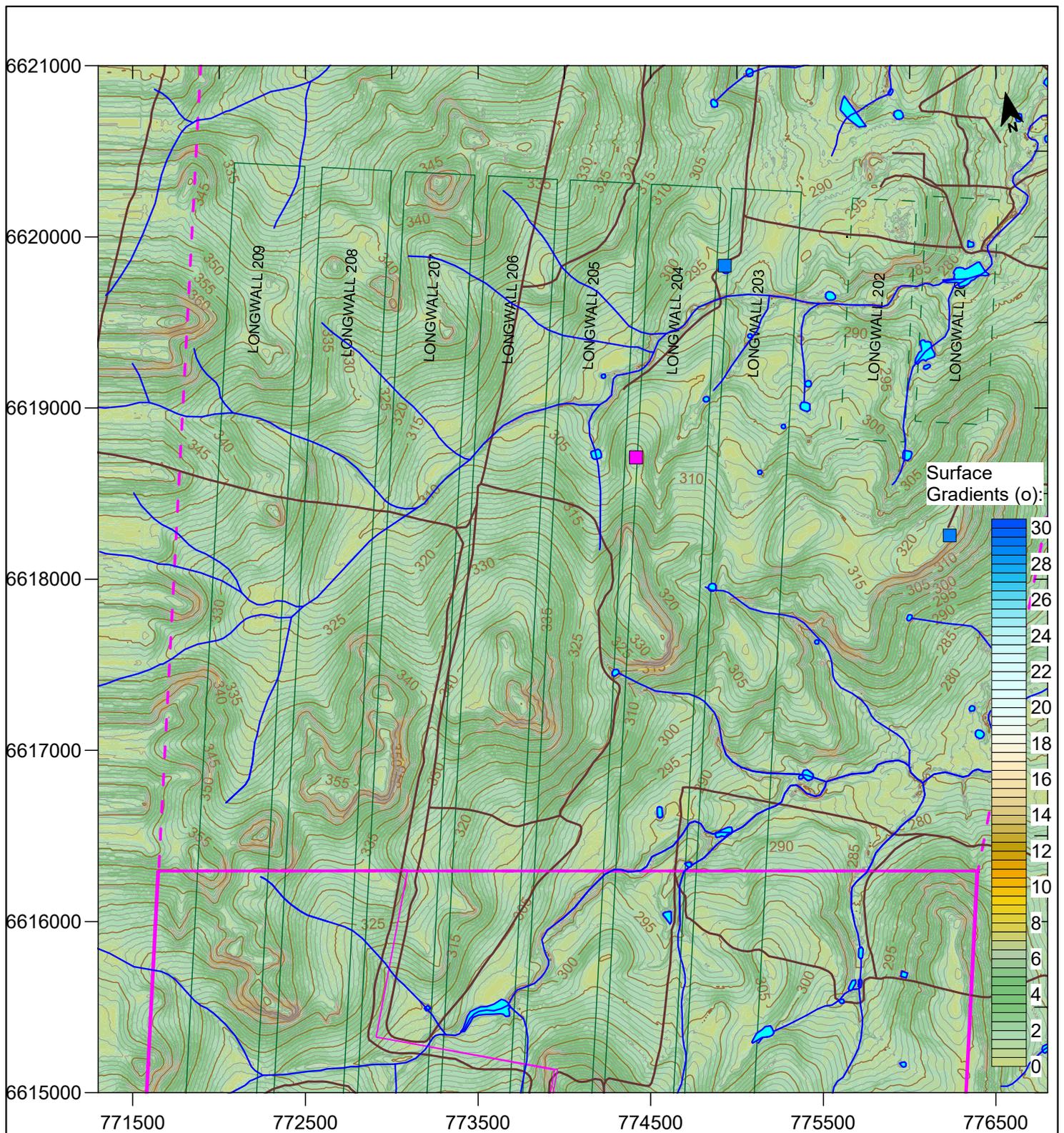
Figure No: 14a



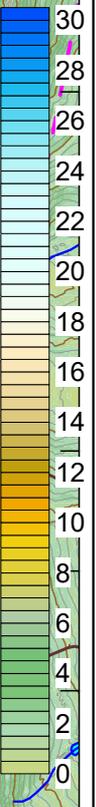
Key: 771500 772500 773500 774500 775500 776500

- Surface Level contours (m)
- Proposed LW203 - 210
- Mining Lease 1609 Boundary
- Mining Lease Application Areas 1 & 2 Boundaries
- Dwellings (Private/NCO-Owned)
- Farm Dams
- Roads (unsealed)
- Ephemeral Watercourses & Creeks

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton	Title:	Surface Level Contours (Pre-Mining) above the Proposed LW203 to 210 in MLA Areas 1 & 2	
	Date:	15.11.19	Scale:		
	Ditton Geotechnical Services Pty Ltd			Figure No:	14b



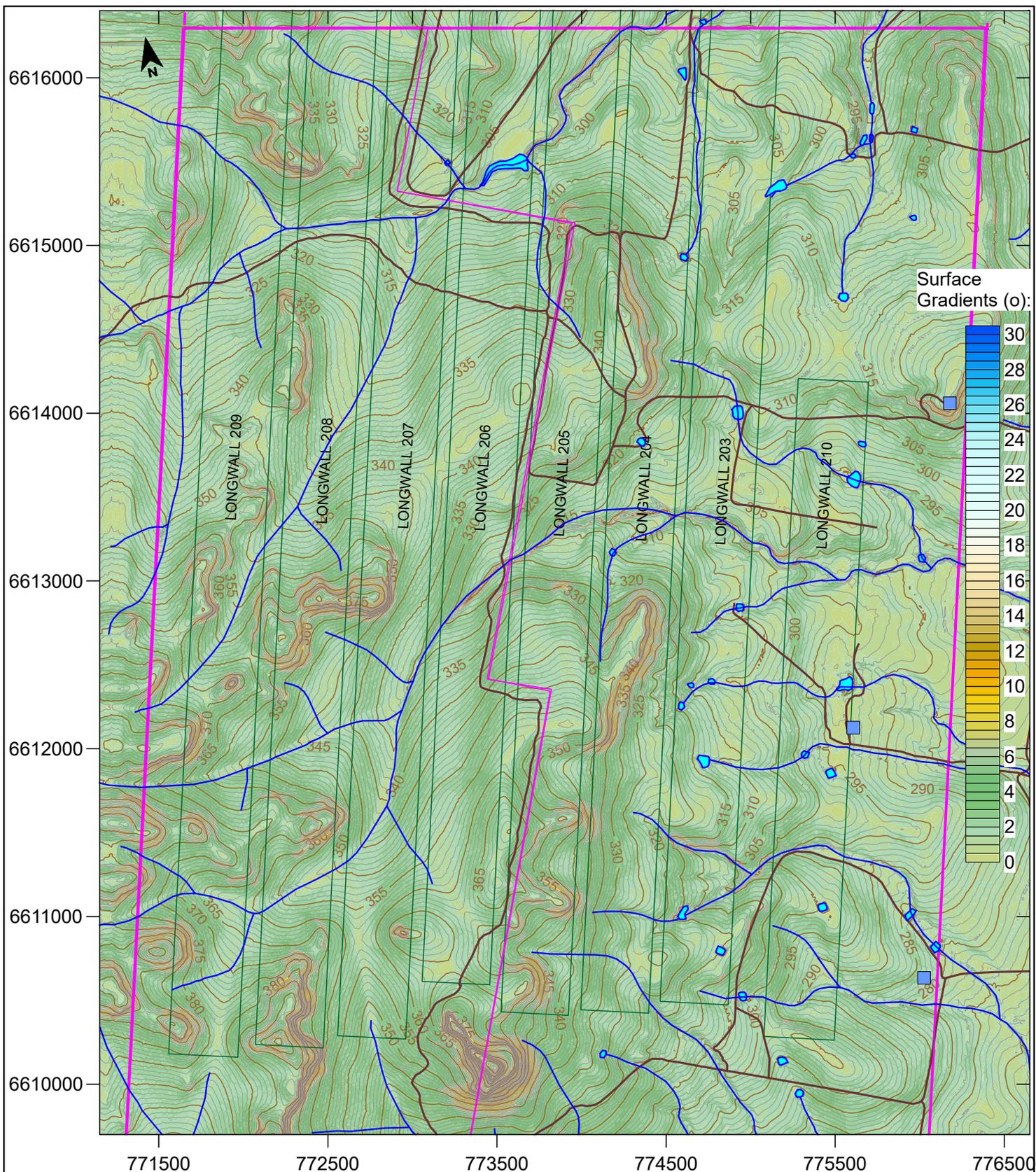
Surface Gradients (o):



Key:

- Surface Level contours (m)
- Proposed LW203-209
- Ephemeral Watercourses & Creeks
- Dwellings (Private/NCO-Owned)
- - - Mining Lease 1609 Boundary
- ▭ Farm Dams
- - - Approved LW201 - 202
- Mining Lease Application Areas 1 & 2 Boundaries
- Roads (unsealed)

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Predicted Post-Mining Surface Level Contours above the Approved LW201 - 202 and the Proposed LW203 to 209 in ML1609		
	Date:	15.11.19	Scale:	1:40,000	Figure No:	14c
	Ditton Geotechnical Services Pty Ltd					



Key:

- Surface Level contours (m)
- Mining Lease 1609 Boundary
- Dwellings (Private/NCO-Owned)
- Proposed LW203 - 210
- Mining Lease Application Areas 1 & 2 Boundaries
- Ephemeral Watercourses & Creeks
- Farm Dams
- Roads (unsealed)

DgS

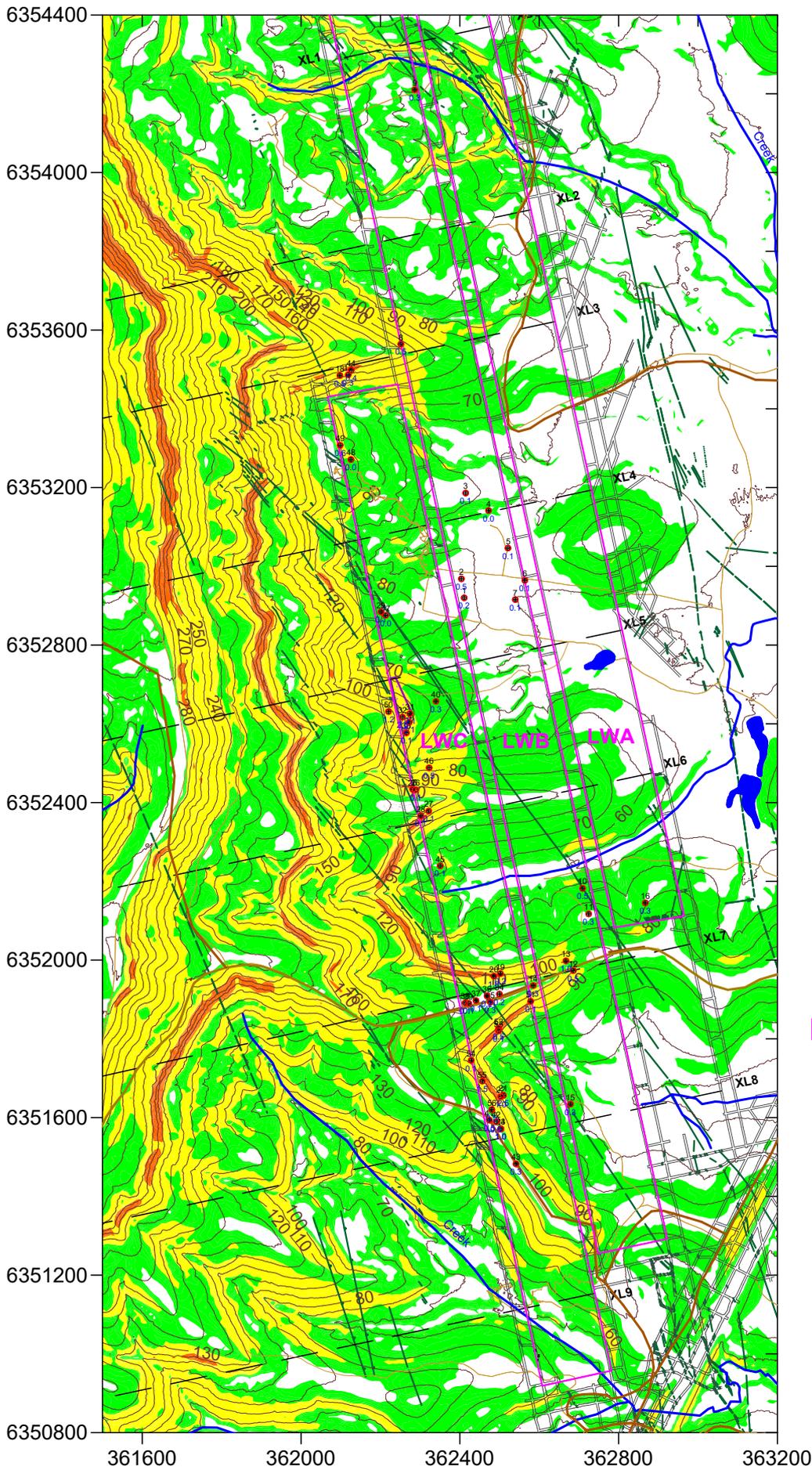
Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19
 Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

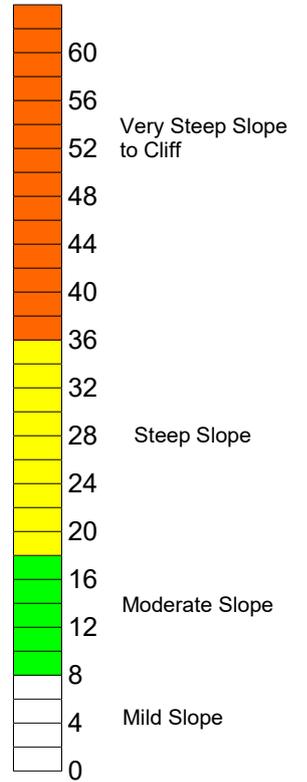
Title: Predicted Post-Mining Surface Level Contours above the Proposed LW203 to 210 in MLA Areas 1 & 2

Scale: 1:40,000

Figure No: 14d



Gradients (o):



Key:

- Creeks (Ephemeral)
- Farm Dams
- Gravel Access Roads
- Subsidence Prediction Lines
- Mine Workings
- Extracted Longwall Limits
- Fault/Shear Zone
- Dyke
- Surface Level Contours (AHD)
- LWA-C Cracking Impacts (No. & width (m))
- Step-down feature

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.12.19

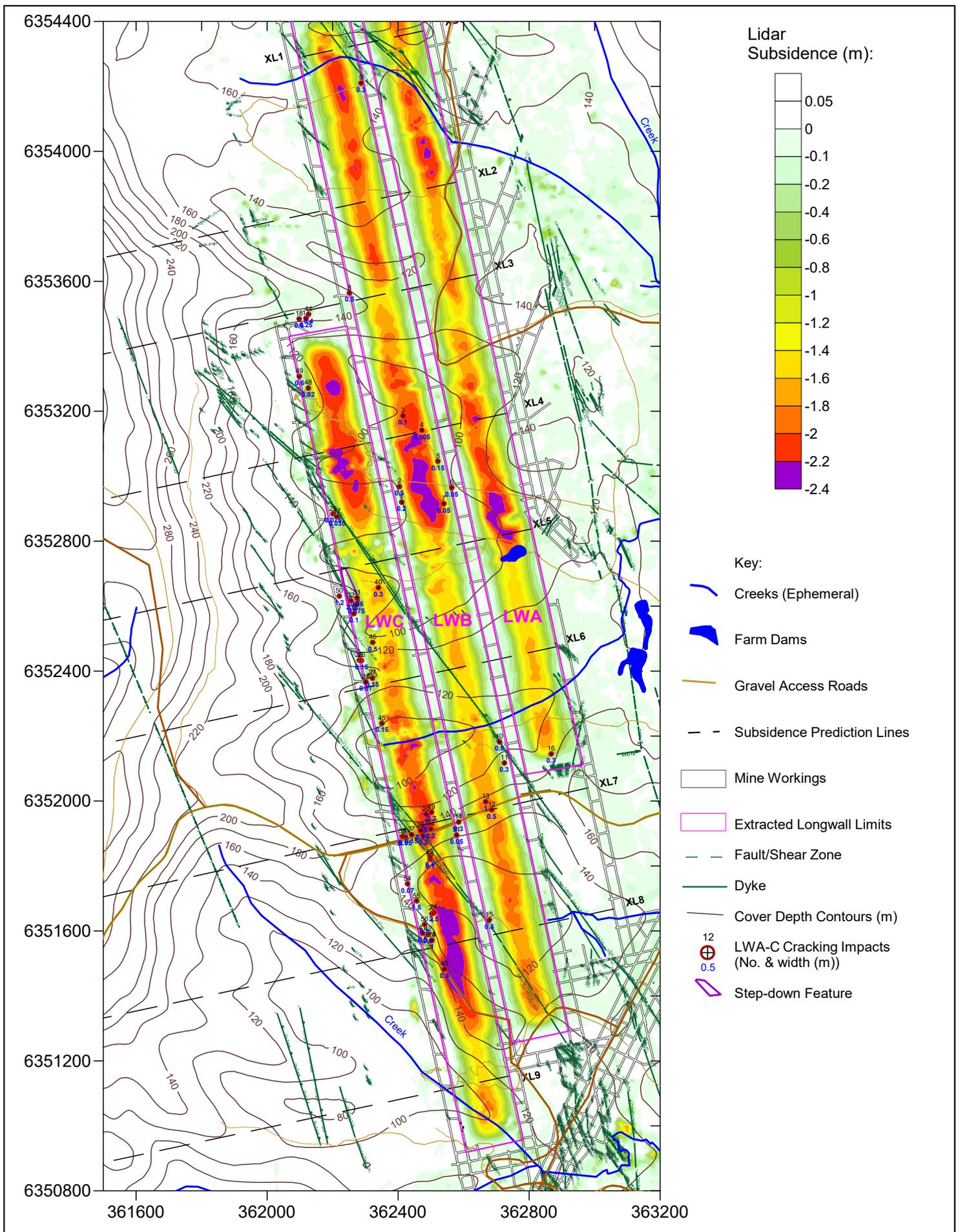
Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

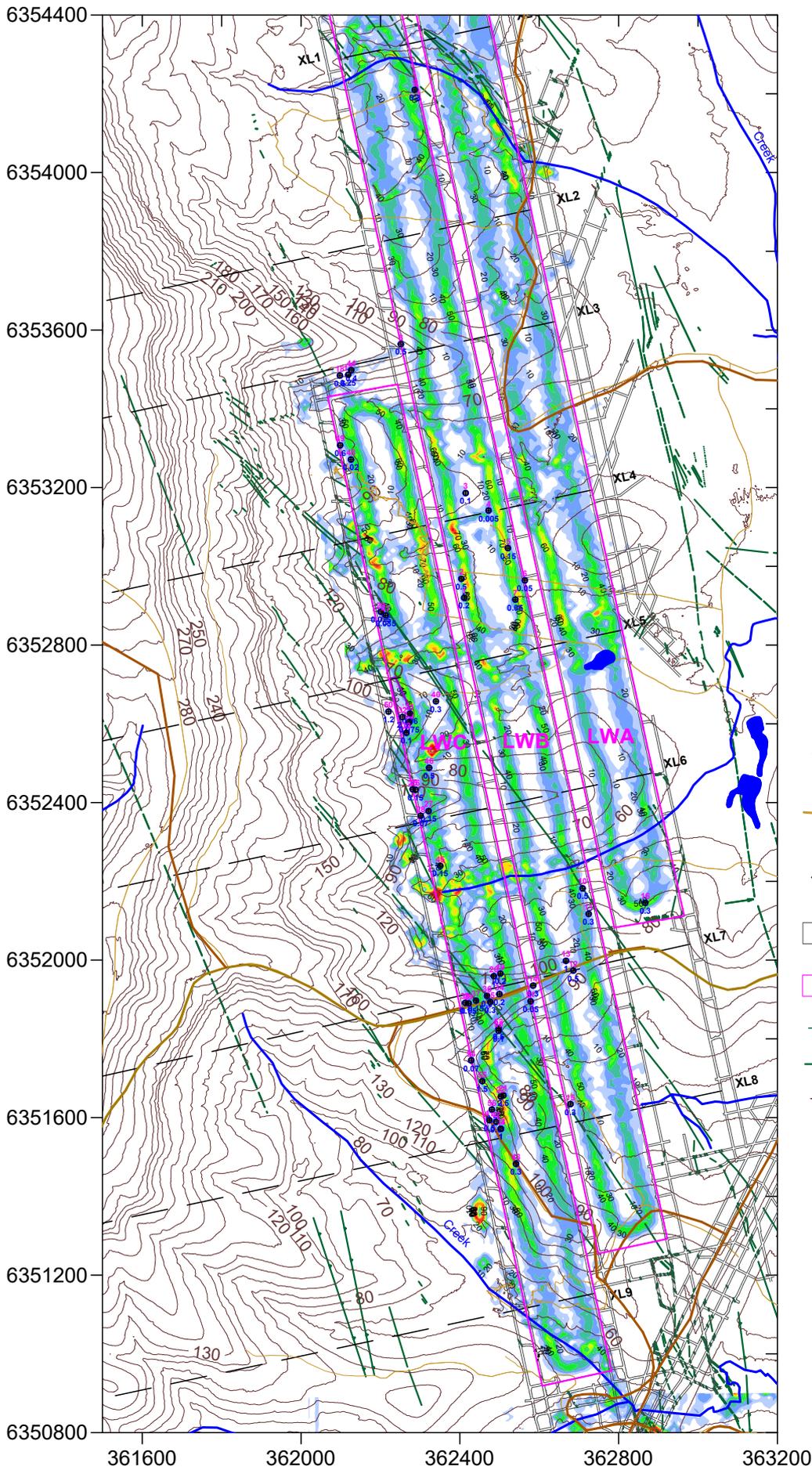
Title: Measured Cracking above Longwalls A, B & C with Steep Slopes in the Newcastle Coalfield: Surface levels and gradients

Scale: 1:15,000

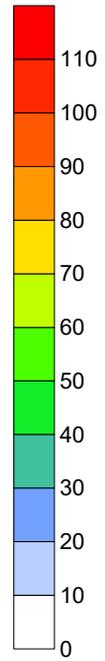
Figure No: 14e



	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	15.12.19	Title:	Measured Cracking above Longwalls A, B & C with Steep Slopes in the Newcastle Coalfield: Measured Subsidence Contours
	Ditton Geotechnical Services Pty Ltd		Scale:	1:15,000
				Figure No: 14f



Lidar
Tilt (mm/m):



Key:

- Creeks (Ephemeral)
- Farm Dams
- Gravel Access Roads
- Subsidence Prediction Lines
- Mine Workings
- Extracted Longwall Limits
- Fault/Shear Zone
- Dyke
- Surface Level Contours (AHD)
- LWA-C Cracking Impacts (No. & width (m))
12
0.5
- Step-down Feature

DgS

Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.12.19

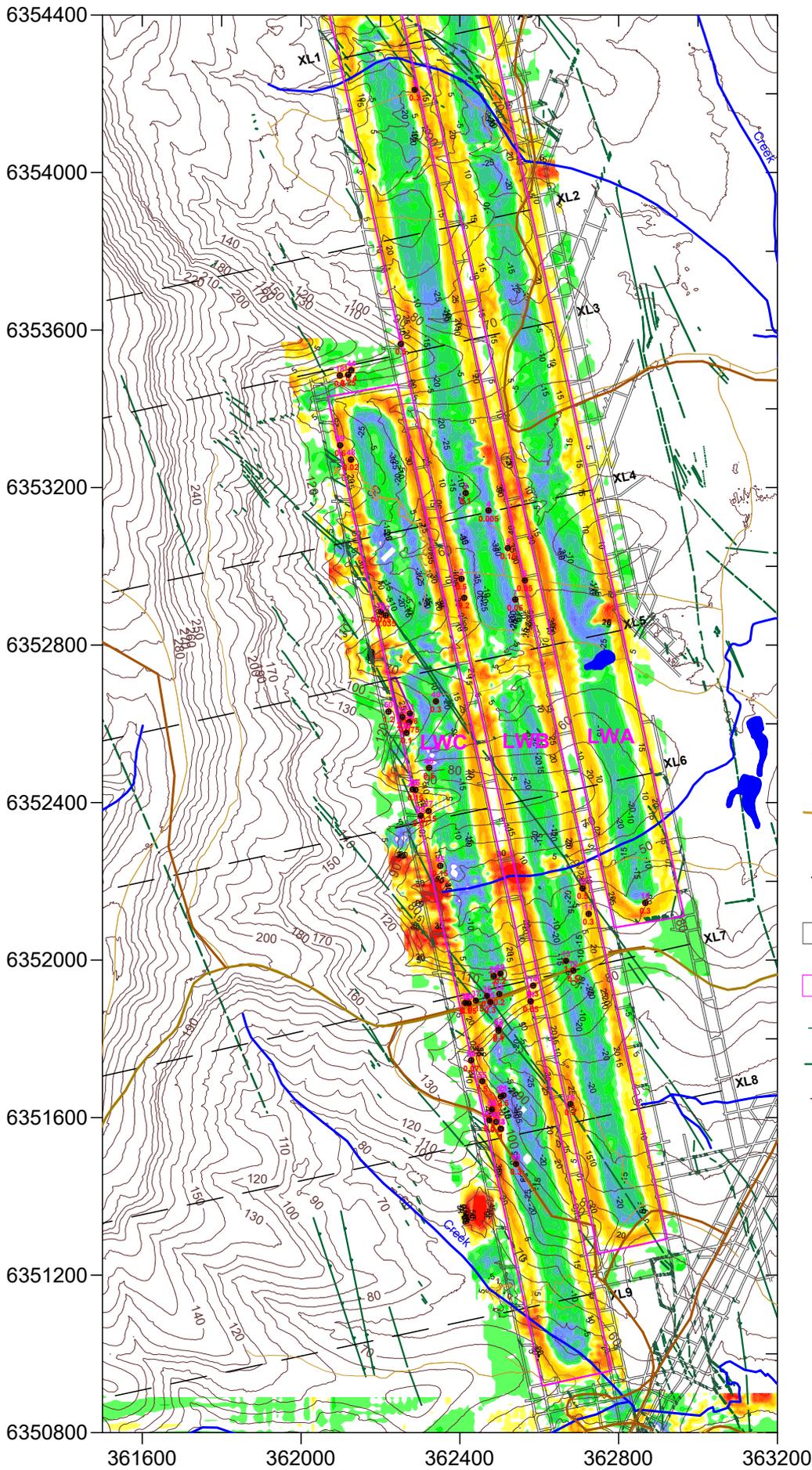
Ditton Geotechnical
 Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2

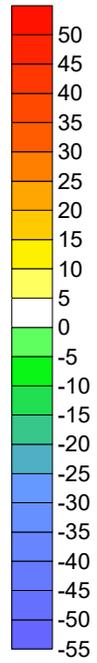
Title: Measured Cracking above Longwalls A, B & C with Steep Slopes in the Newcastle Coalfield: Measured Tilt Contours

Scale: 1:15,000

Figure No: 14g



Lidar Strain (mm/m):



Key:

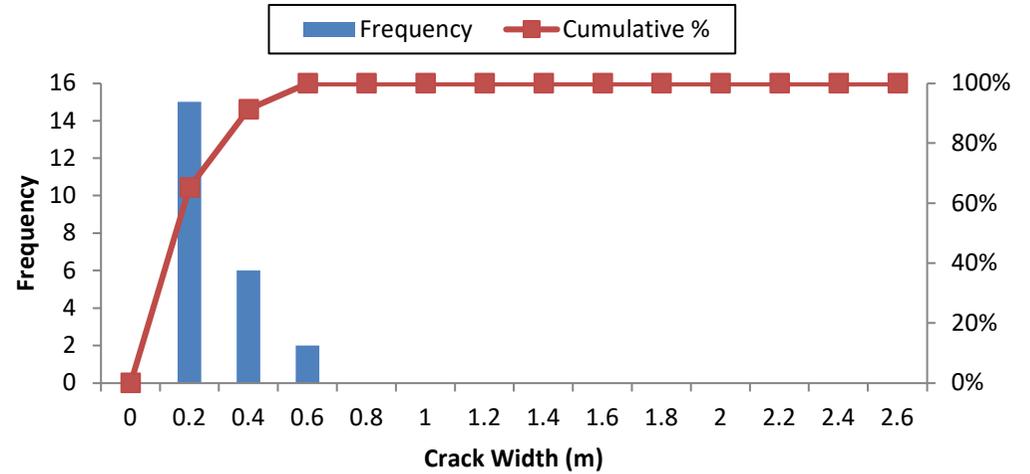
- Creeks (Ephemeral)
- Farm Dams
- Gravel Access Roads
- Subsidence Prediction Lines
- Mine Workings
- Extracted Longwall Limits
- Fault/Shear Zone
- Dyke
- Surface Level Contours (AHD)
- LWA-C Cracking Impacts (No. & width (m))
- Step-down Feature

	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	15.12.19	Title:	Measured Cracking above Longwalls A, B & C with Steep Slopes in the Newcastle Coalfield: Measured Strain Contours
	Ditton Geotechnical Services Pty Ltd		Scale:	1:15,000
				Figure No: 14h

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

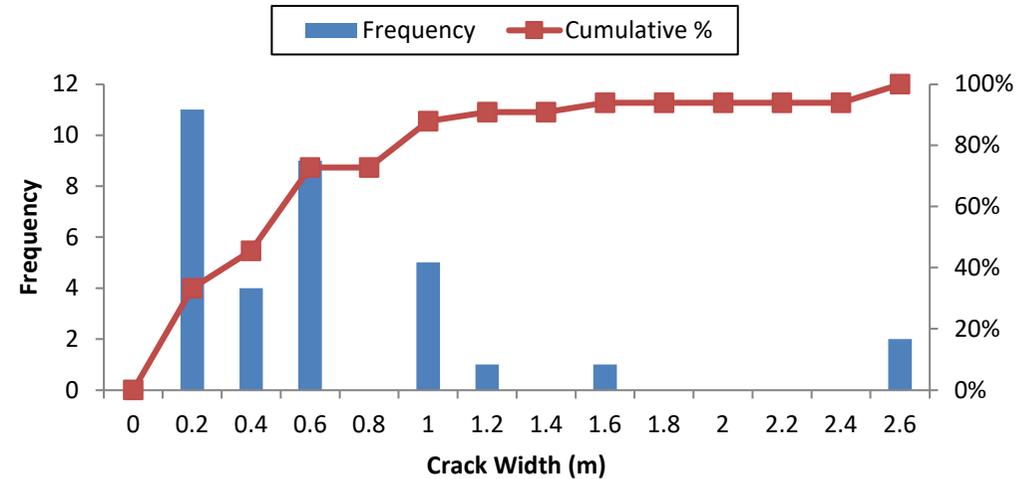
Max	0.50	m
Min	0.01	m
Median	0.15	m
Mean	0.19	m
U95%	0.5	m
n	23	



Supercritical Longwalls (W/H > 1.2 + Steep Slopes)

(Slopes > 18°)

Max	2.50	m
Min	0.05	m
Median	0.50	m
Mean	0.60	m
U95%	1.9	m
n	33	

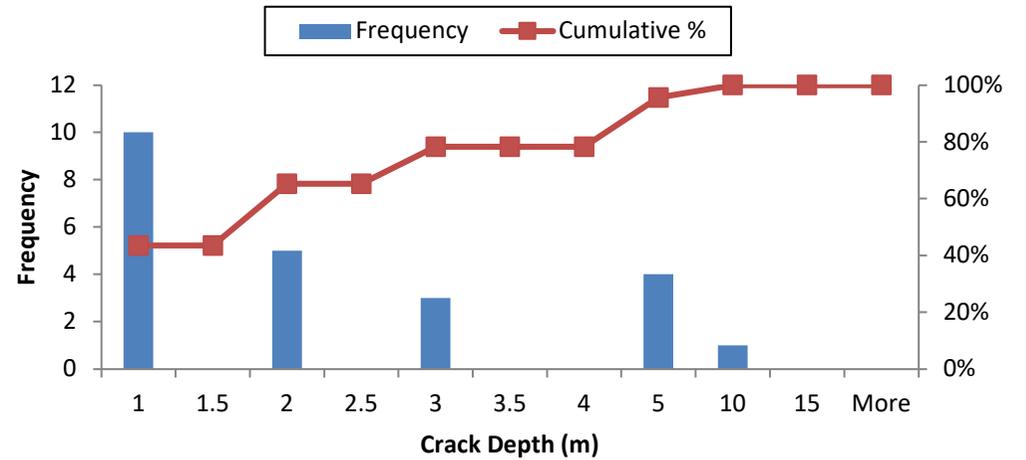


	Engineer:	S.Ditton	Client:	Narrabri Mine	Scale:	NTS	Figure No:	14i
	Drawn:	S.Ditton		NAR-005/2				
	Date:	15.01.20	Title:	Surface Crack Width Data for Longwalls below Steep Slopes in the Newcastle Coalfield				
	Ditton Geotechnical Services Pty Ltd							

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

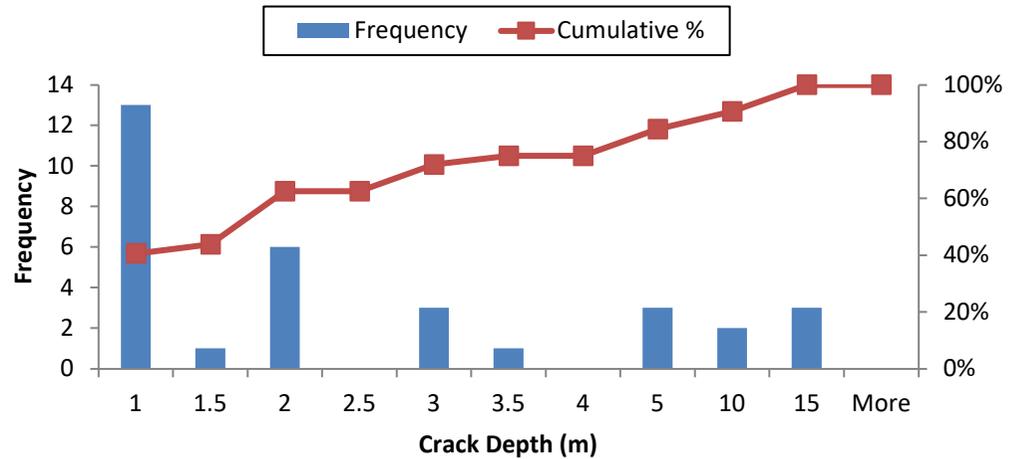
Max	10	m
Min	0.05	m
Median	2.0	m
Mean	2.4	m
U95%	5.0	m
n	23	



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	

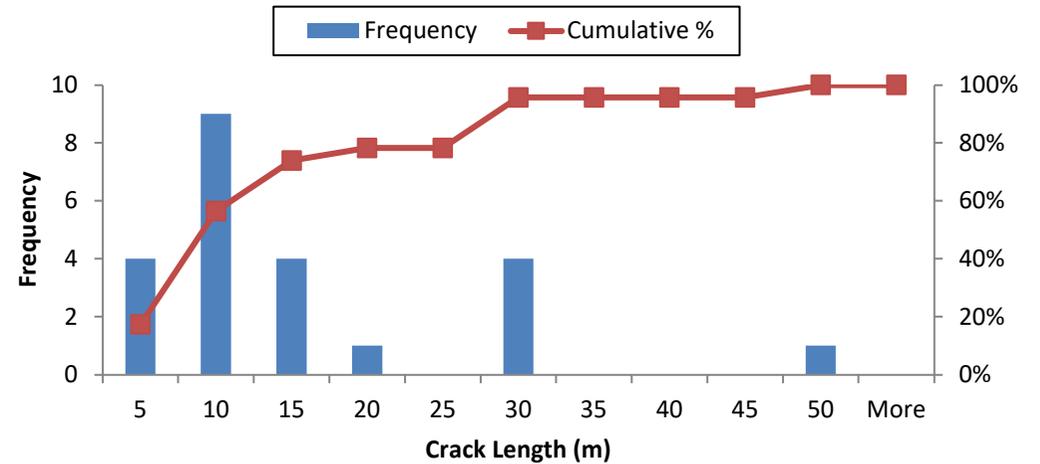


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.01.20	Title:	Surface Crack Depth Data for Longwalls below Steep Slopes in the Newcastle Coalfield	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

Supercritical Longwalls (W/H > 1.2 + 'Flat' Terrain)

(Slopes < 18°)

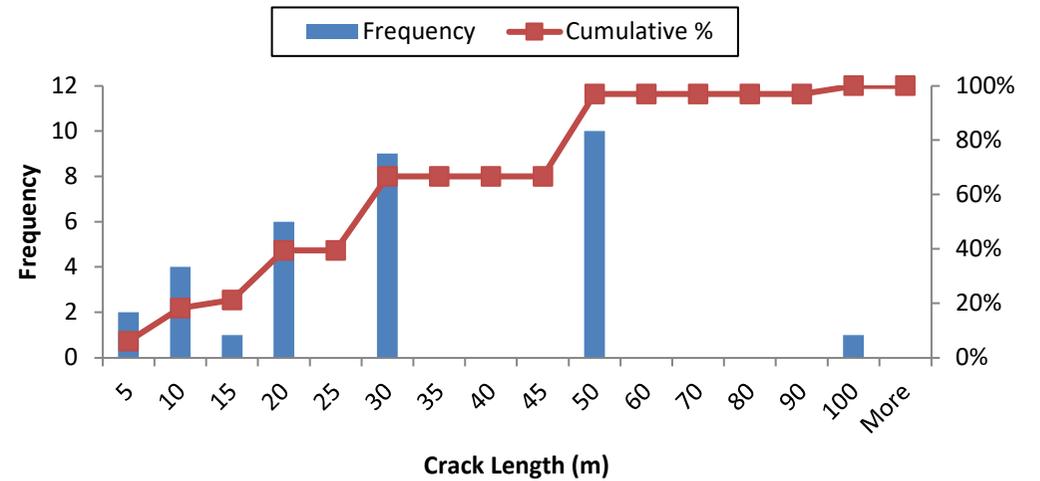
Max	50	m
Min	3	m
Median	10	m
Mean	15	m
U95%	30	m
n	23	



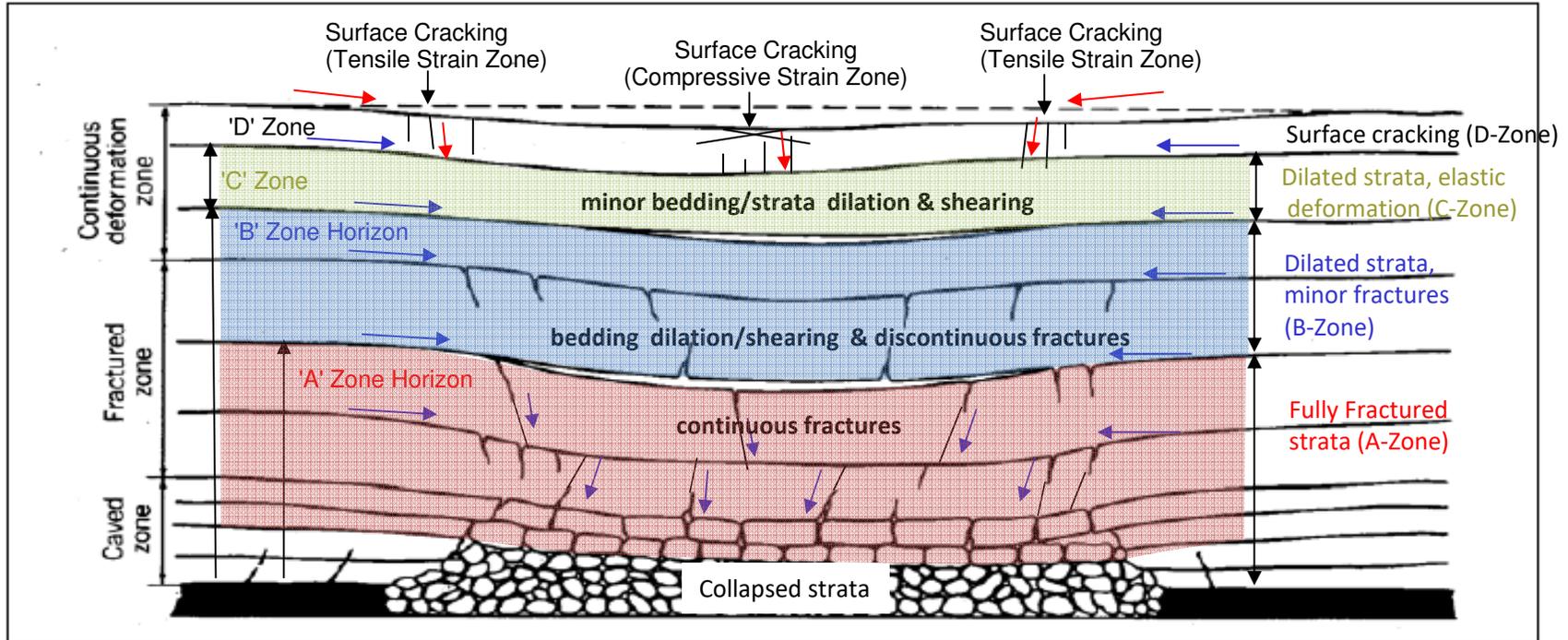
Supercritical Longwalls (W/H > 1.2 + Steep Slopes)

(Slopes > 18°)

Max	100	m
Min	3	m
Median	30	m
Mean	32	m
U95%	50	m
n	33	



	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	15.01.20	Title:	Surface Crack Length Data for Longwalls below Steep Slopes in the Newcastle Coalfield
	Ditton Geotechnical Services Pty Ltd			Scale:
			Figure No:	14k



Zones in the Overburden According to Peng and Chiang (1984)

Key

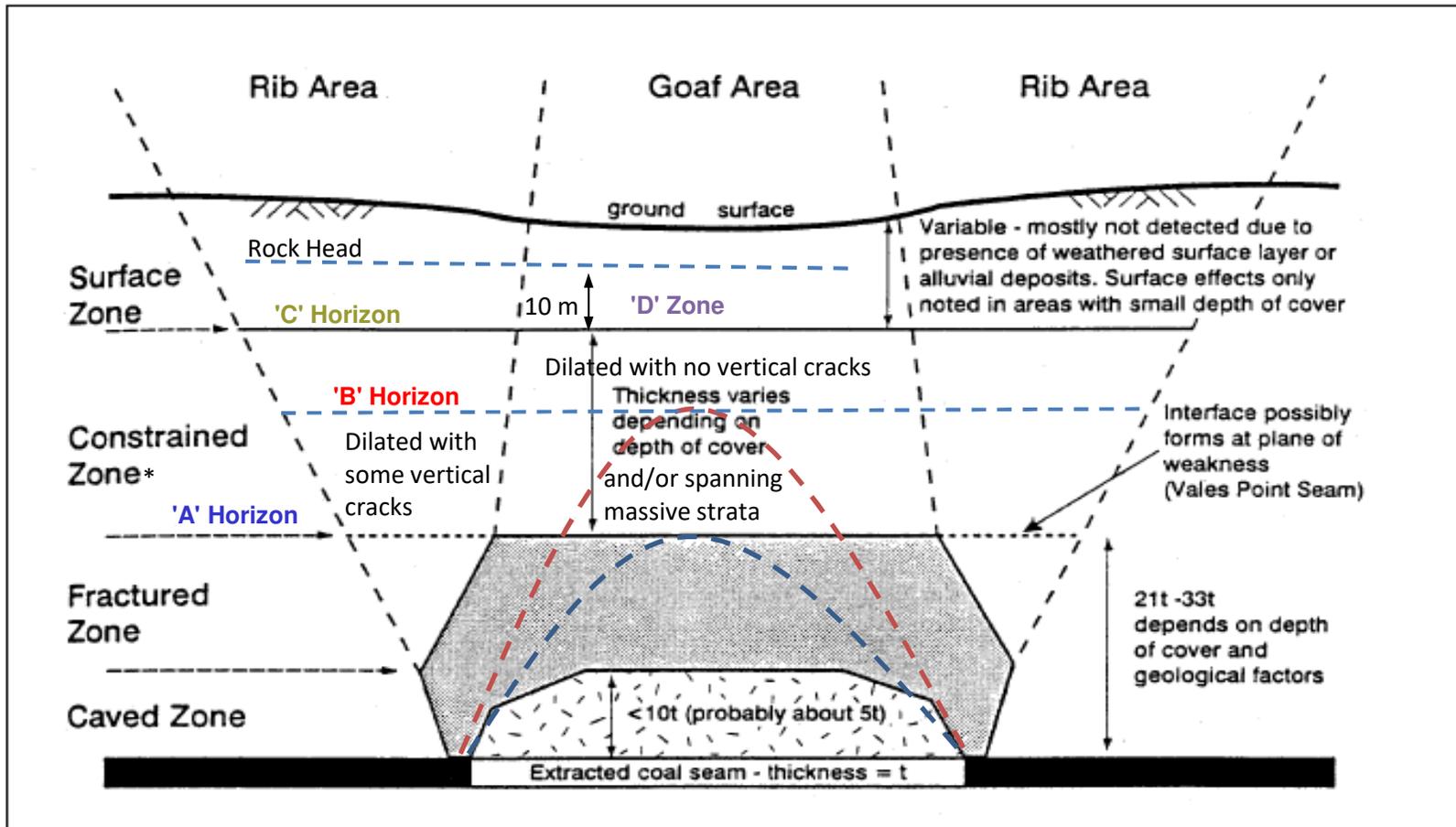
'A' Horizon - Zone of Continuous Crack Connection to Workings (**Whittaker and Reddish, 1989**)

'B' Horizon - Zone Of Discontinuous Crack Connection to Workings (**Whittaker and Reddish, 1989**)

→ Surface water flow path

→ Sub-surface water flow path

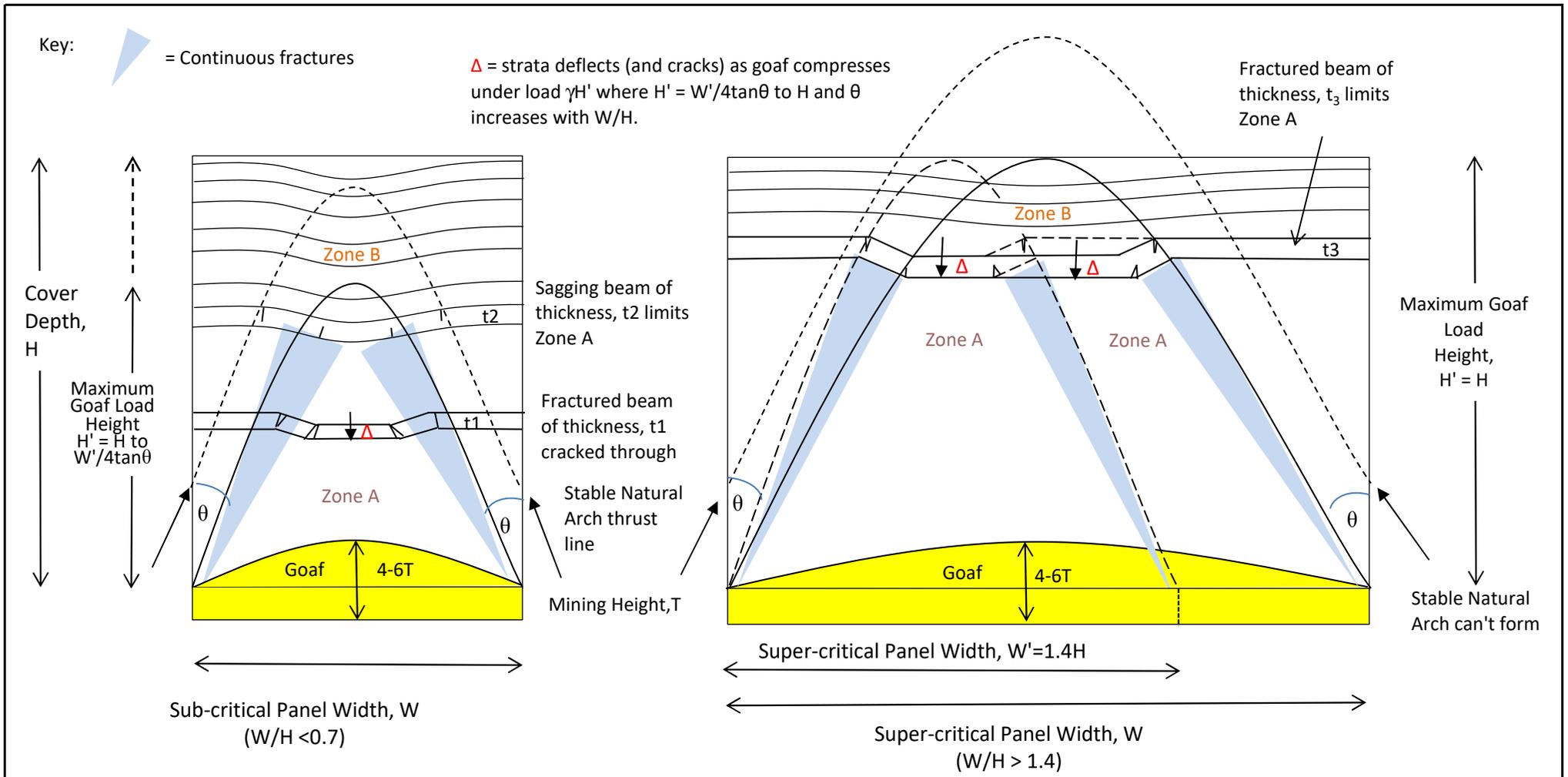
	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	15.08.19	Title:	Schematic Model of Overburden Fracture Zones Above Longwall Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
				Figure No: 15a



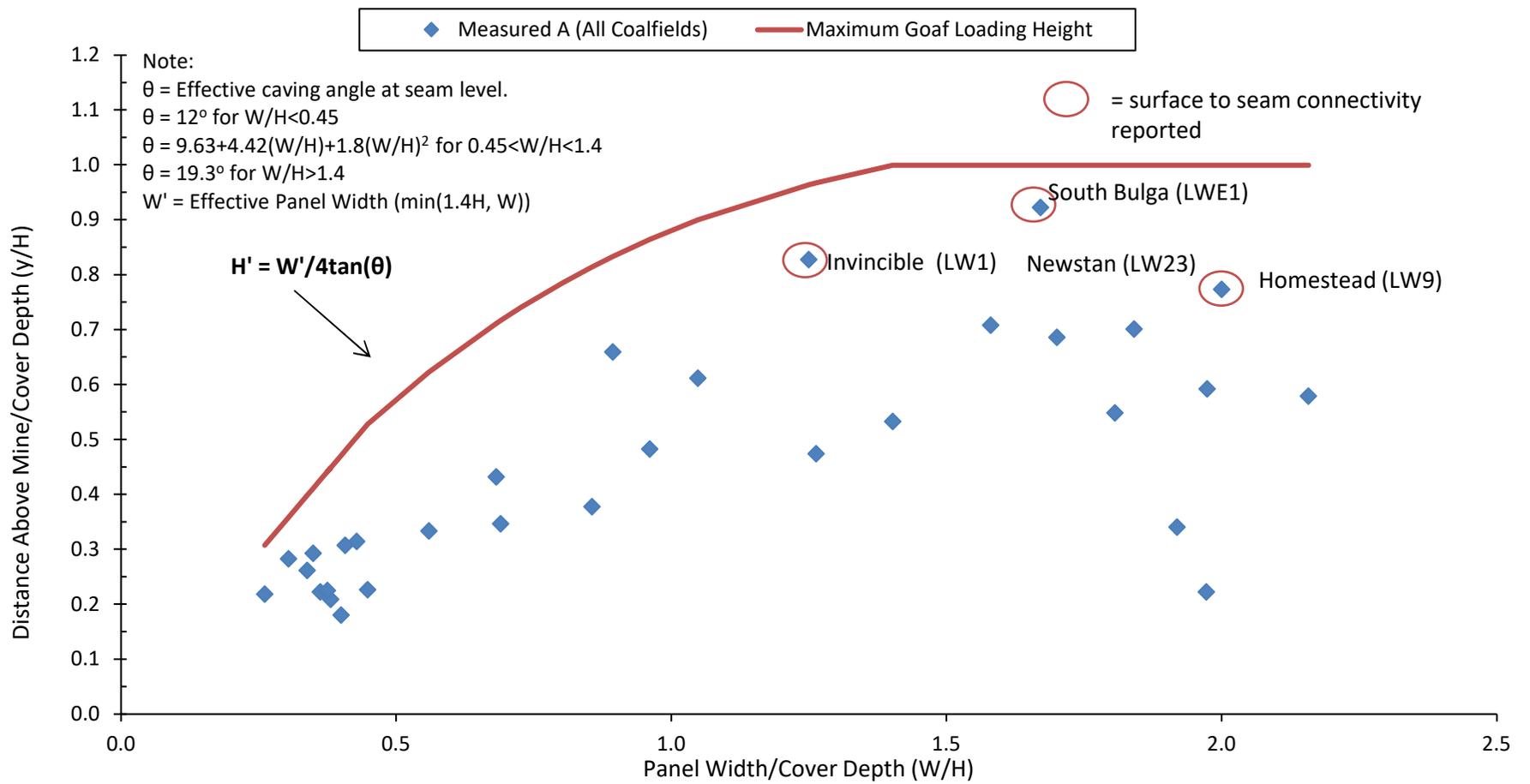
Zones in the Overburden according to Forster (1995)

* - Constrained Zone generally means B-Zone, but may include C-Zone, depending on W/H ratio and geology

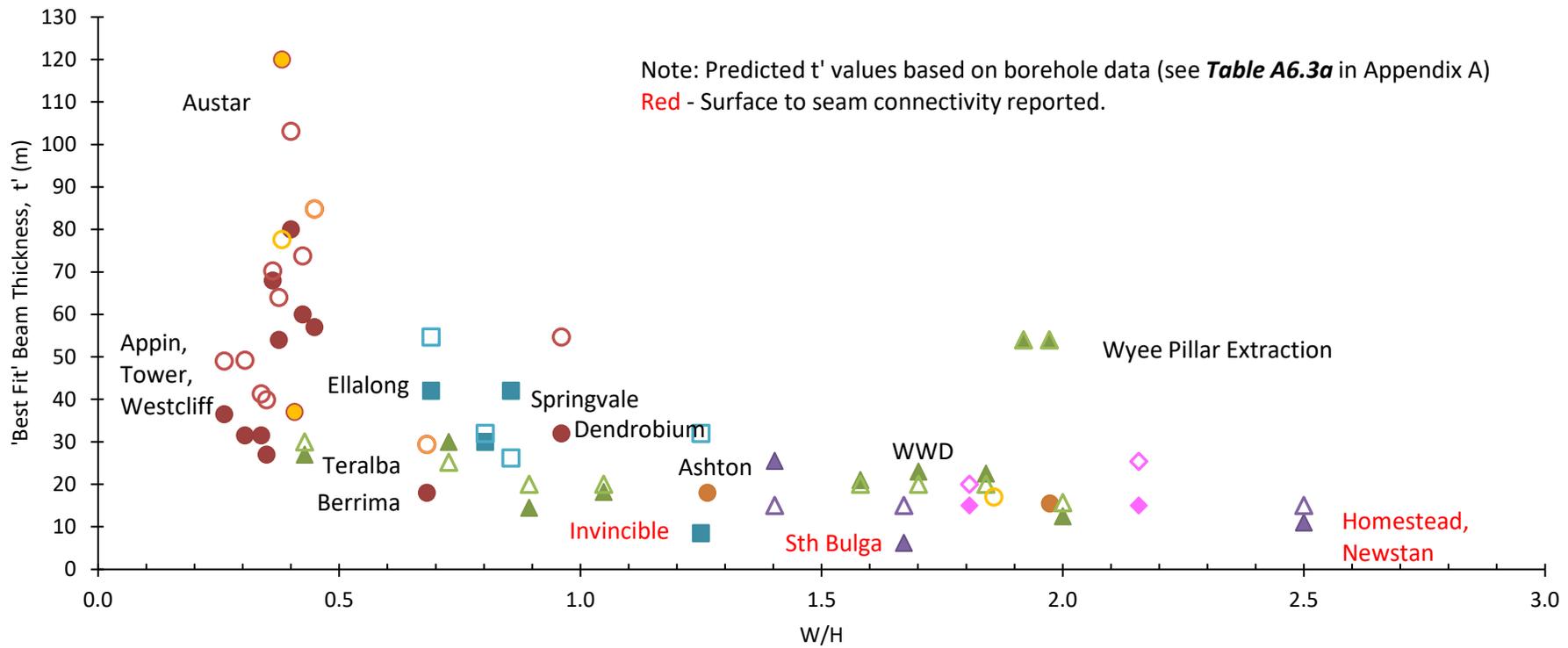
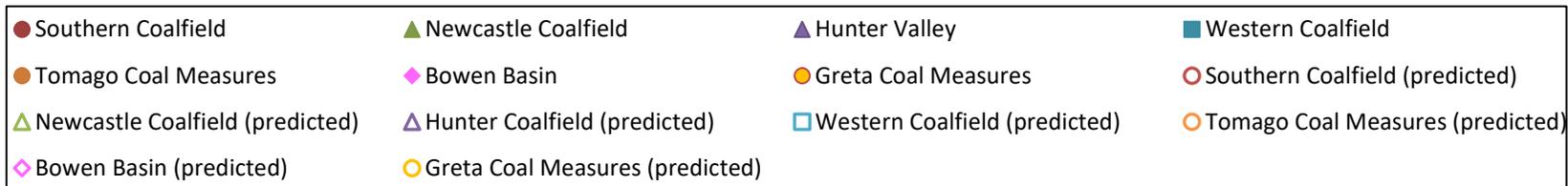
	Engineer:	S.Ditton	Client:	Narrabri Mine	Figure No: 15b
	Drawn:	S.Ditton		NAR-005/2	
	Date:	20.10.19	Title:	Schematic Model of Overburden Fracture Zones in Forster, 1995 Model (based on Piezometric Data Above High Extraction Panels in the Newcastle Coalfield)	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	



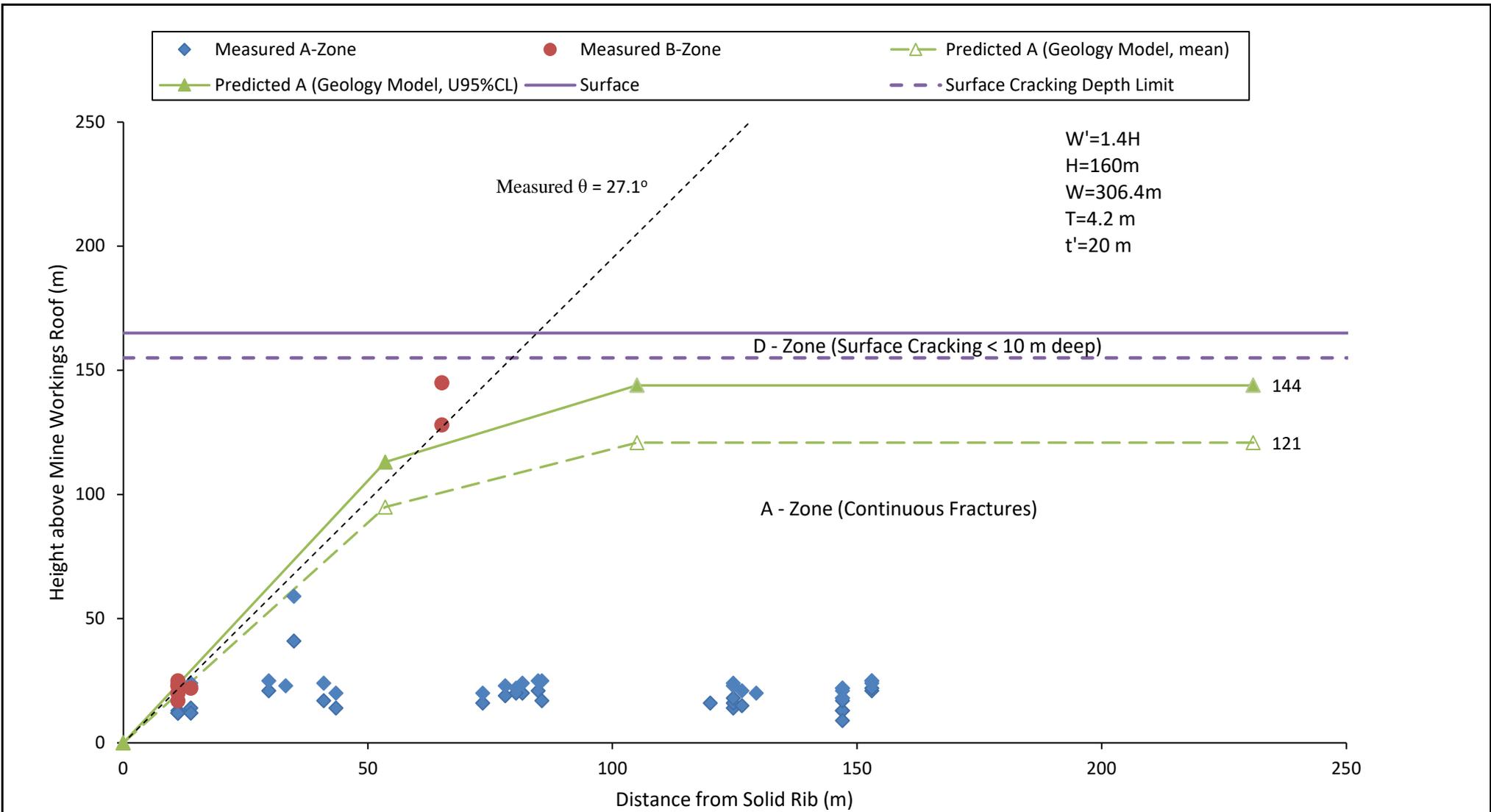
	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	15.08.19	Title:	Conceptual Model for Development of Height of Continuous Fracturing Zone for a range of Longwall Panel Geometries
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
				Figure No: 15c



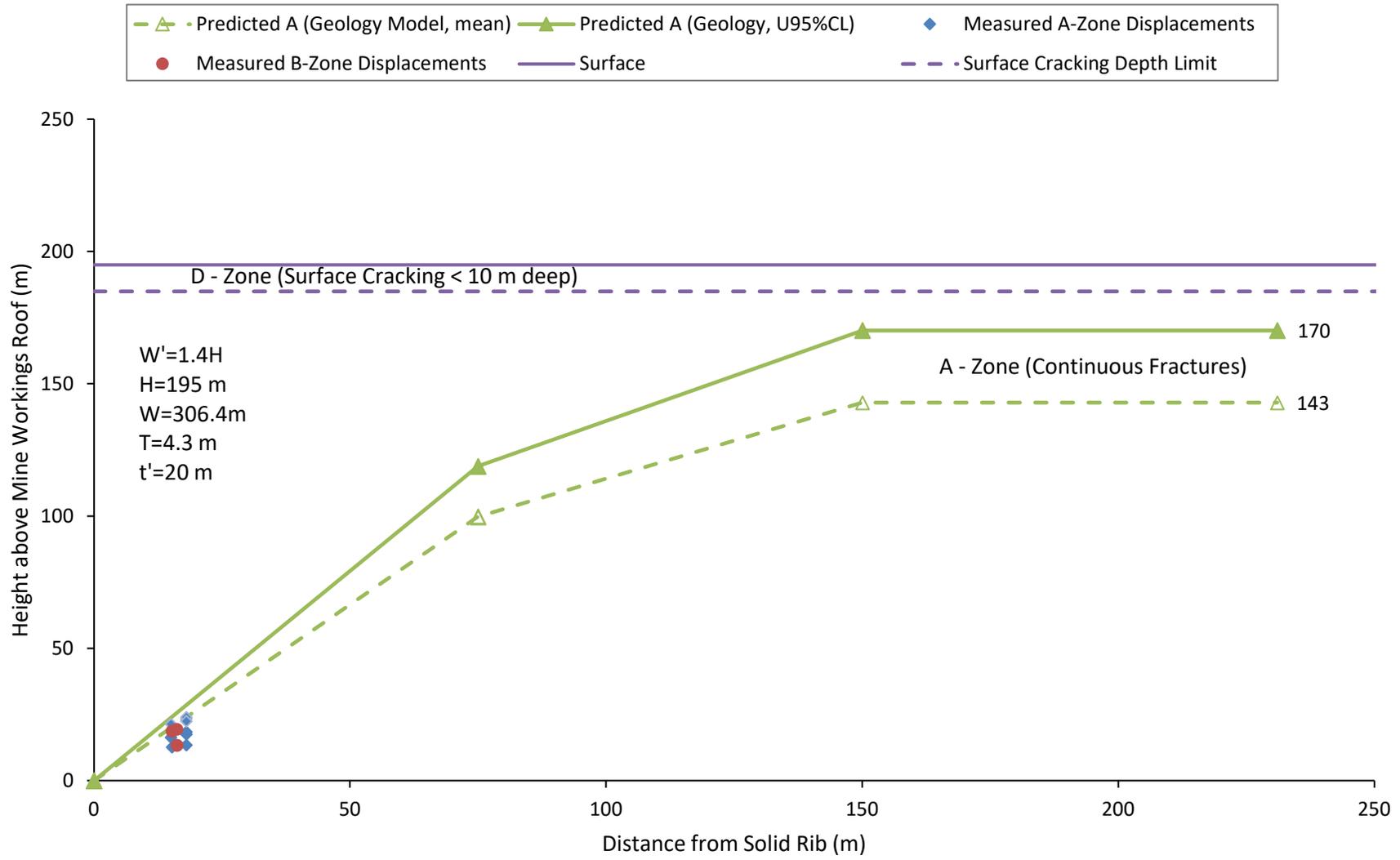
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.08.19	Title:	Measured Heights of Continuous Fracturing in NSW and QLD Coalfields with Reported Surface to Seam Connectivity Cases, caving angles and theoretical Goaf Loading Height	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
				Figure No:	15d



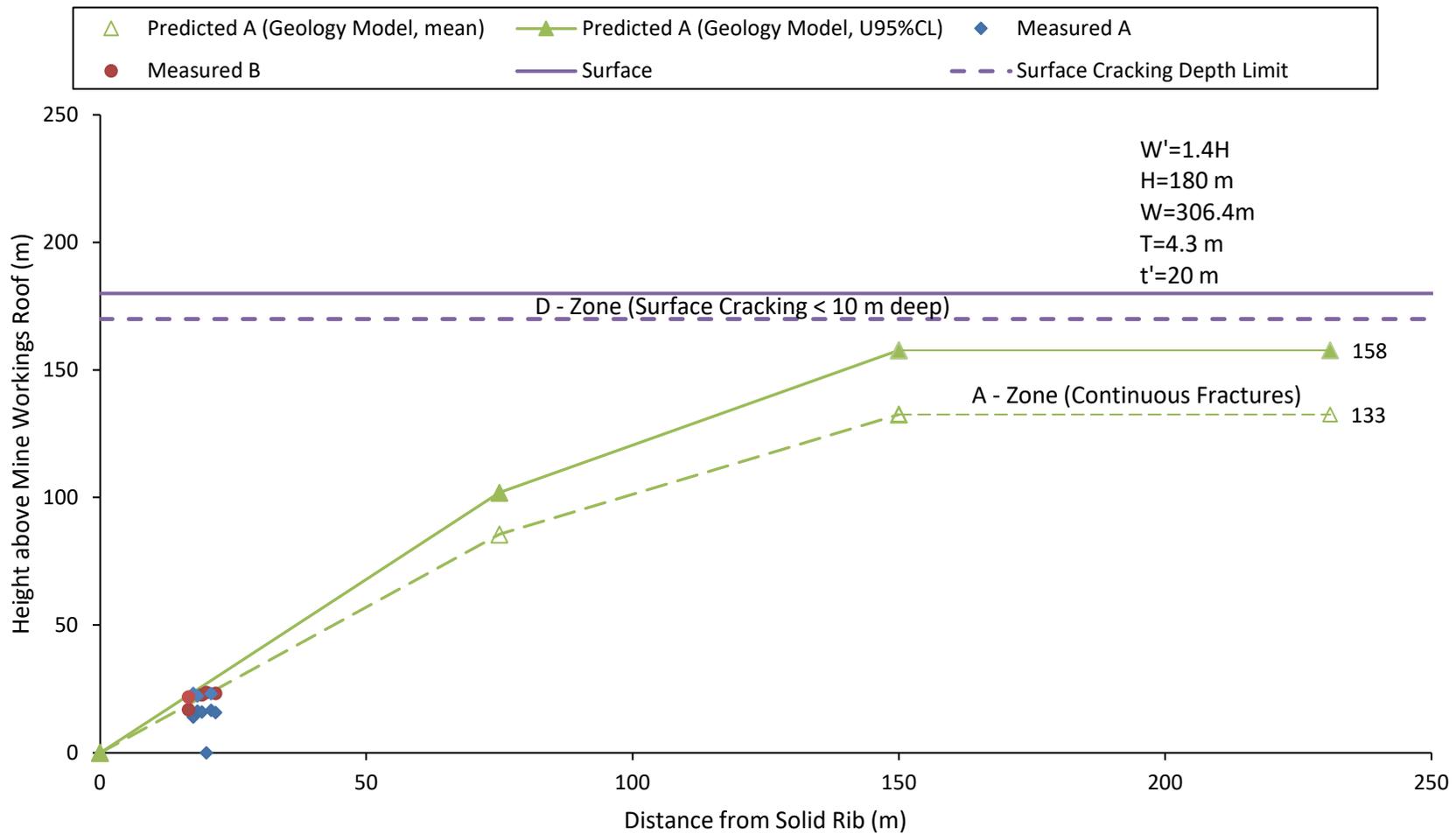
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	10.09.19	Title:	Results of Back-analysis of Effective Strata Units required to Match the Observed A-Zone Heights above Longwall Panel Goafs using the Geology Pi-Term Model	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



Engineer:	S.Ditton	Client:	Narrabri Mine
Drawn:	S.Ditton		NAR-005/2
Date:	15.08.17	Title:	Measured v. Predicted Subsurface Fracturing Above LW101 to 102 from Borehole
Ditton Geotechnical Services Pty Ltd			Extensometers
Scale:	NTS		Figure No: 16a

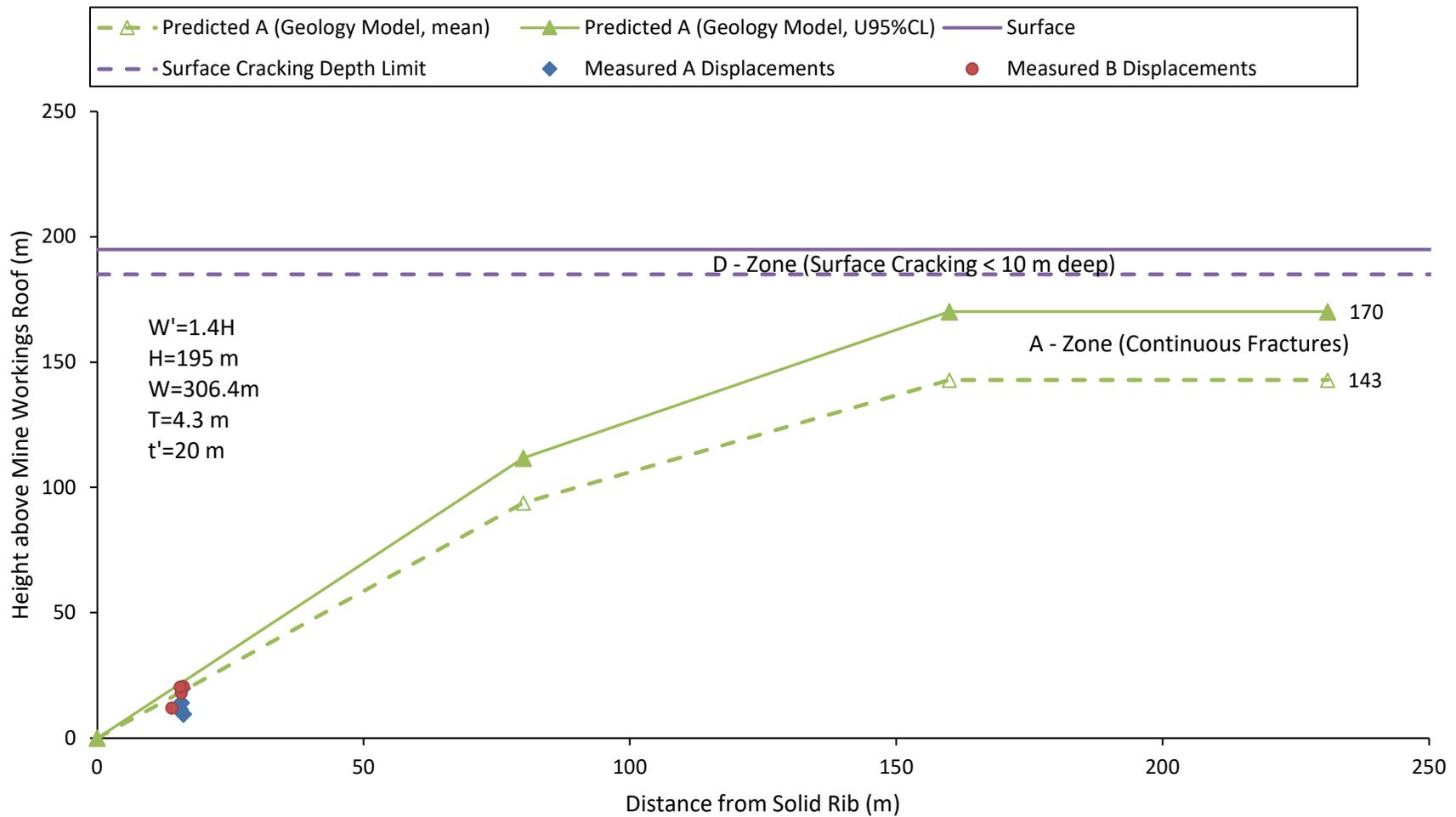


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.08.17	Title:	Measured Subsurface Fracturing Above LW103 from Borehole Extensometers	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

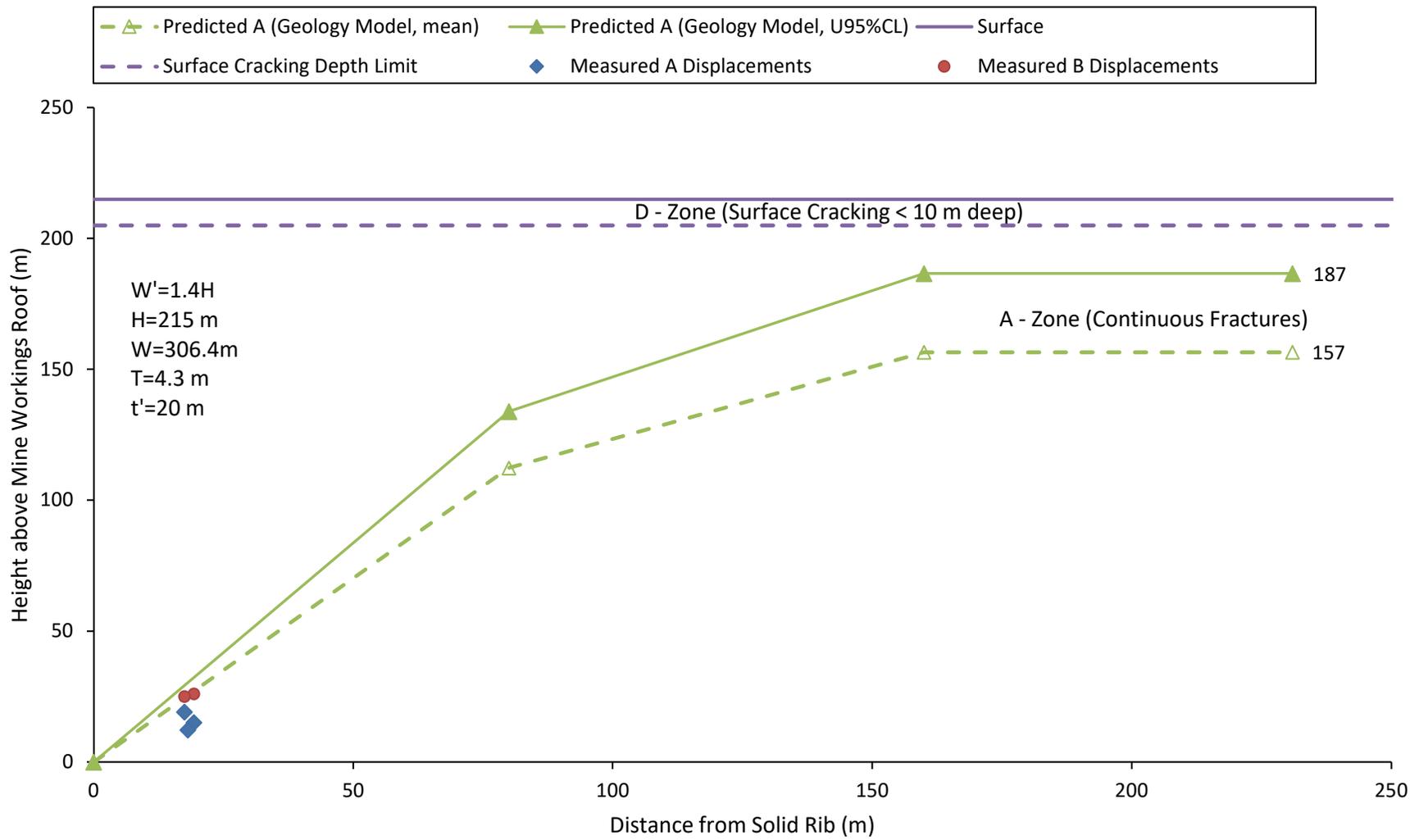


Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.08.17
 Ditton Geotechnical Services Pty Ltd

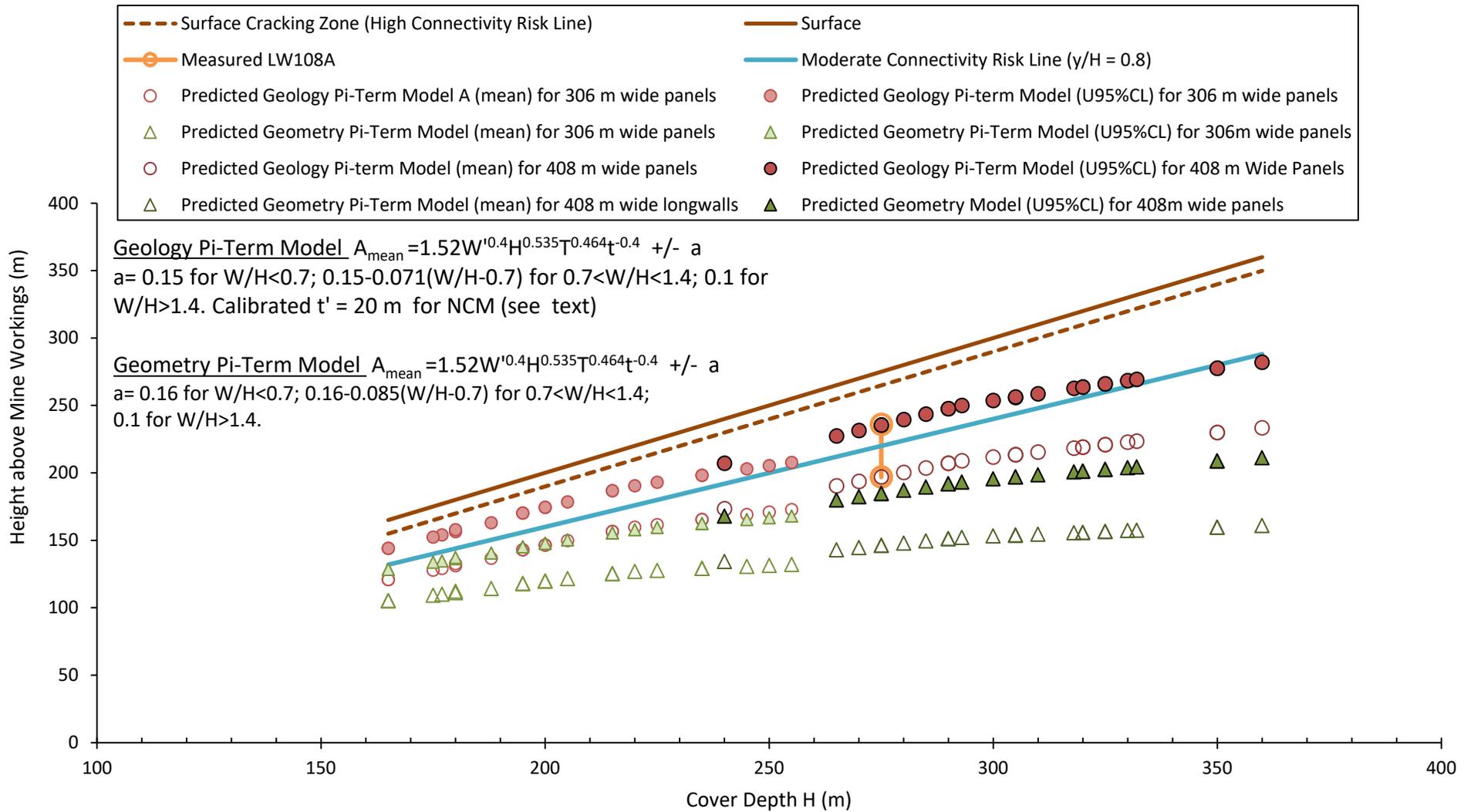
Client: Narrabri Mine
 NAR-005/2
 Title: Measured Subsurface Fracturing Above LW104 from Borehole Extensometers
 Scale: NTS
 Figure No: 16c



Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	15.08.17	Title:	Measured Subsurface Fracturing Above LW105 from Borehole Extensometers	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 16d

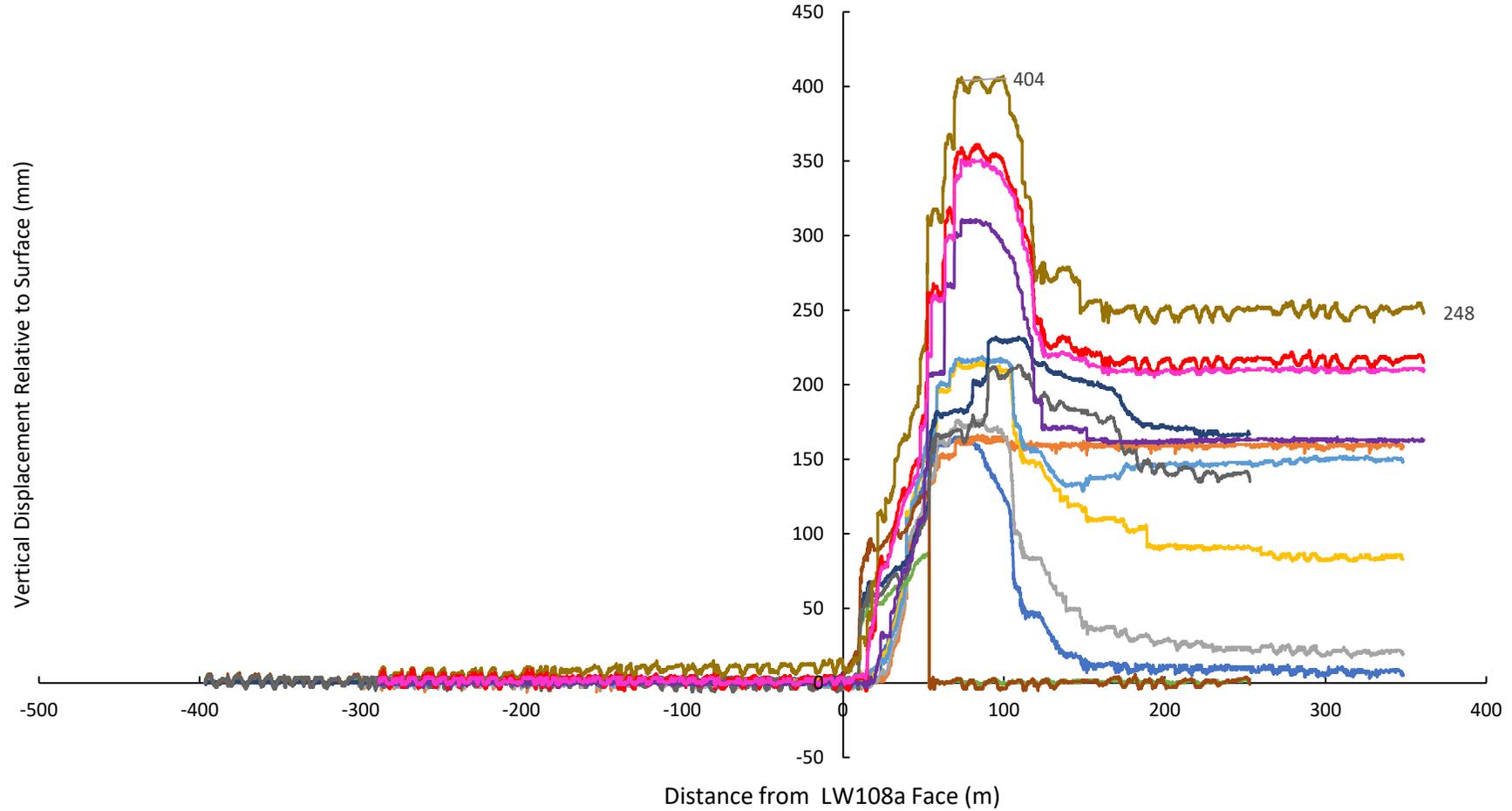
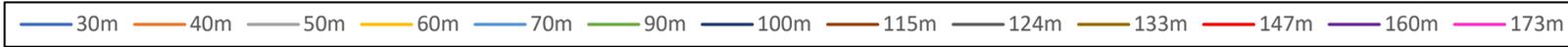


Engineer:	S.Ditton	Client:	Narrabri Mine	
Drawn:	S.Ditton		NAR-005/2	
Date:	15.08.17	Title:	Measured Subsurface Fracturing Above LW106 from Borehole Extensometers	
Ditton Geotechnical Services Pty Ltd		Scale:	NTS	
			Figure No:	16e

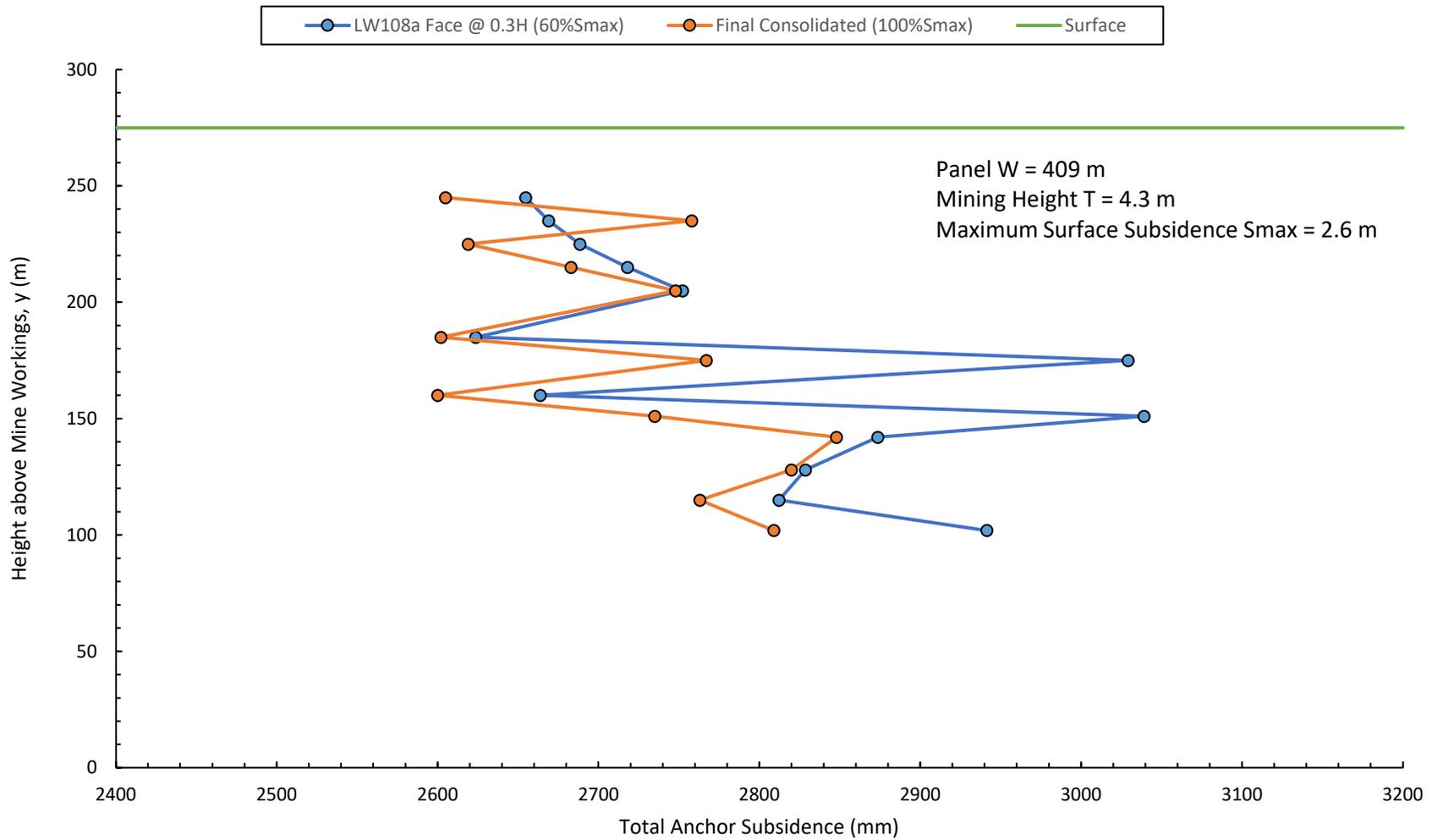


	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	20.11.18	Title:	Predicted Heights of Connective Cracking Above LW101 to 111 based on Pi-Term Models (refer Ditton & Merrick, 2014)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	16f

Anchor Depth (m):

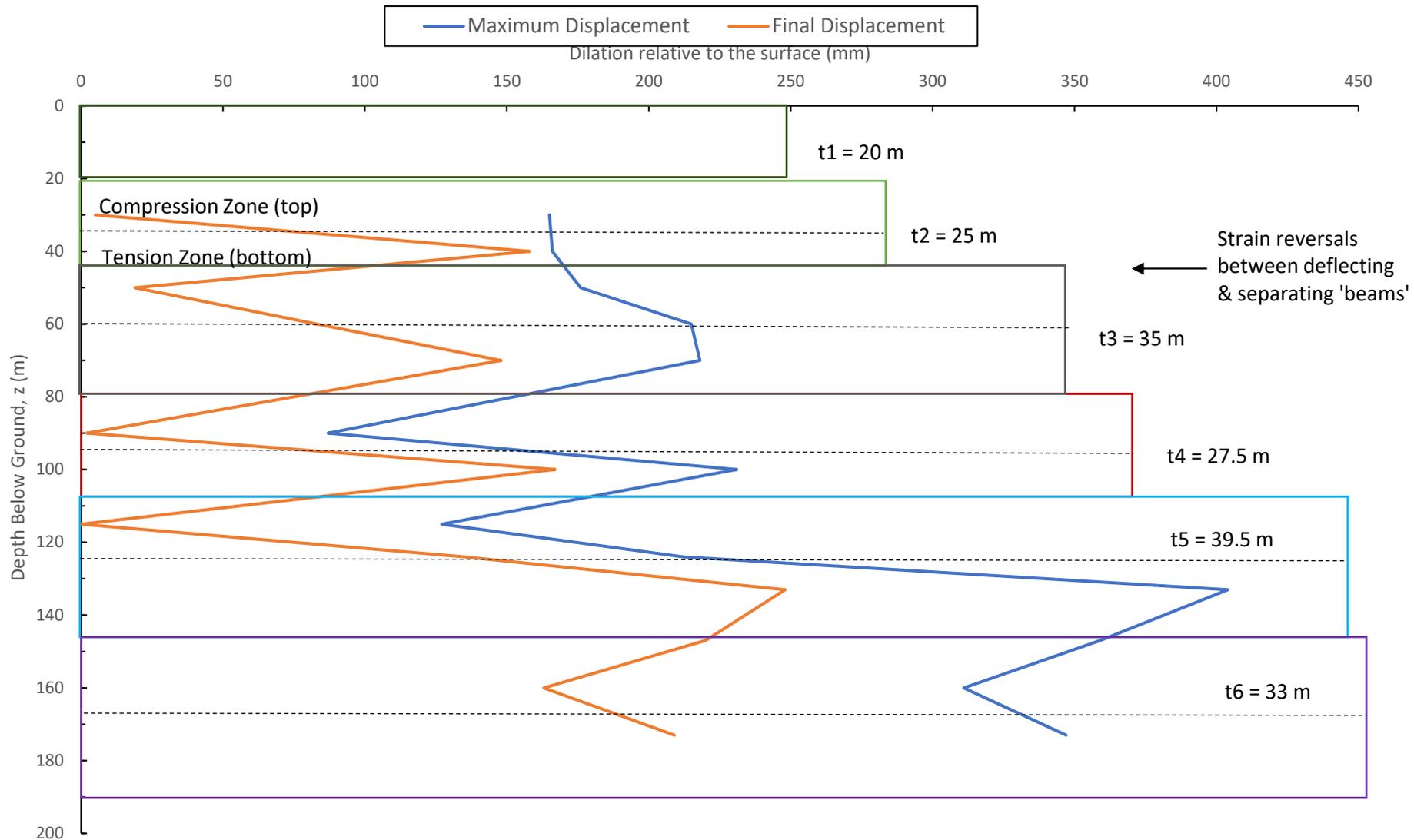


	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-005/2		
	Date:	15.10.19	Title:	Measured Relative Subsurface Displacements Above LW108a from Borehole Extensometers		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		
					Figure No:	16g

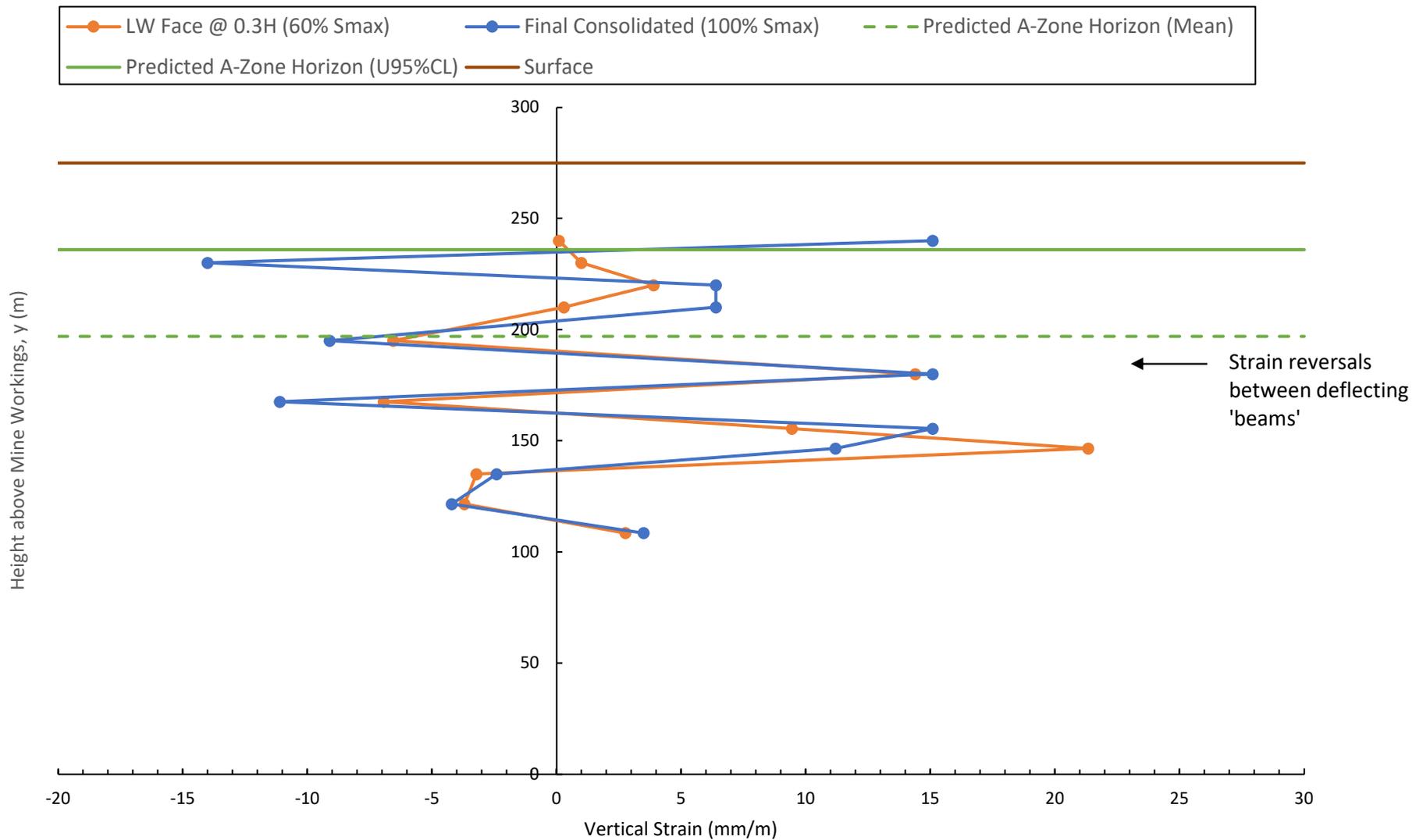


Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.10.19
 Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2
 Title: Measured Total Subsurface Displacements Above LW108a from Borehole Extensometers
 Scale: NTS
 Figure No: 16h

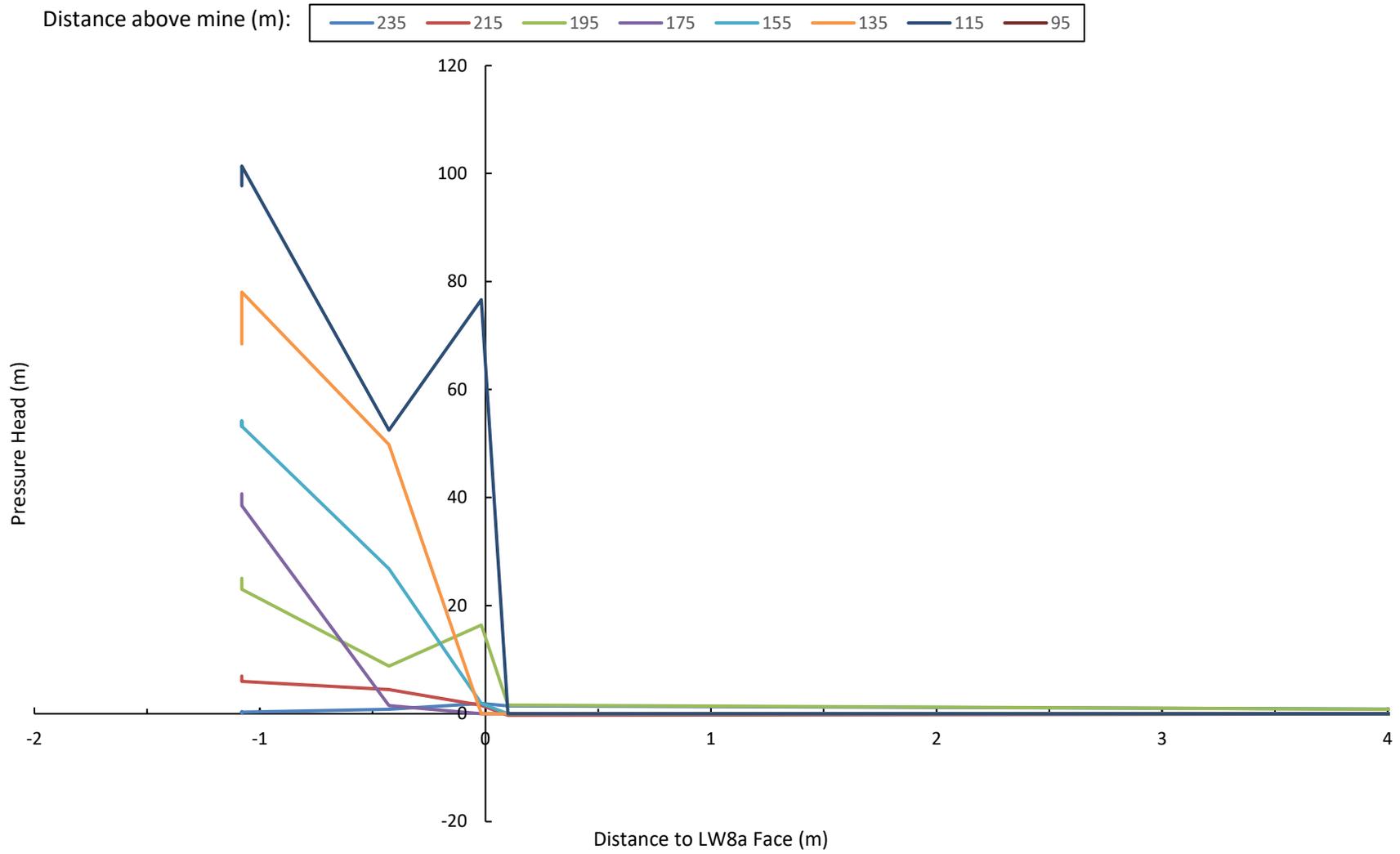


	Engineer:	S.Ditton	Client:	Narrabri Mine		
	Drawn:	S.Ditton		NAR-005/2		
	Date:	15.10.19	Title:	Measured Vertical Dilation Above LW108a in Borehole Extensometers with inferred deflecting beam thicknesses		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS		
					Figure No:	16i

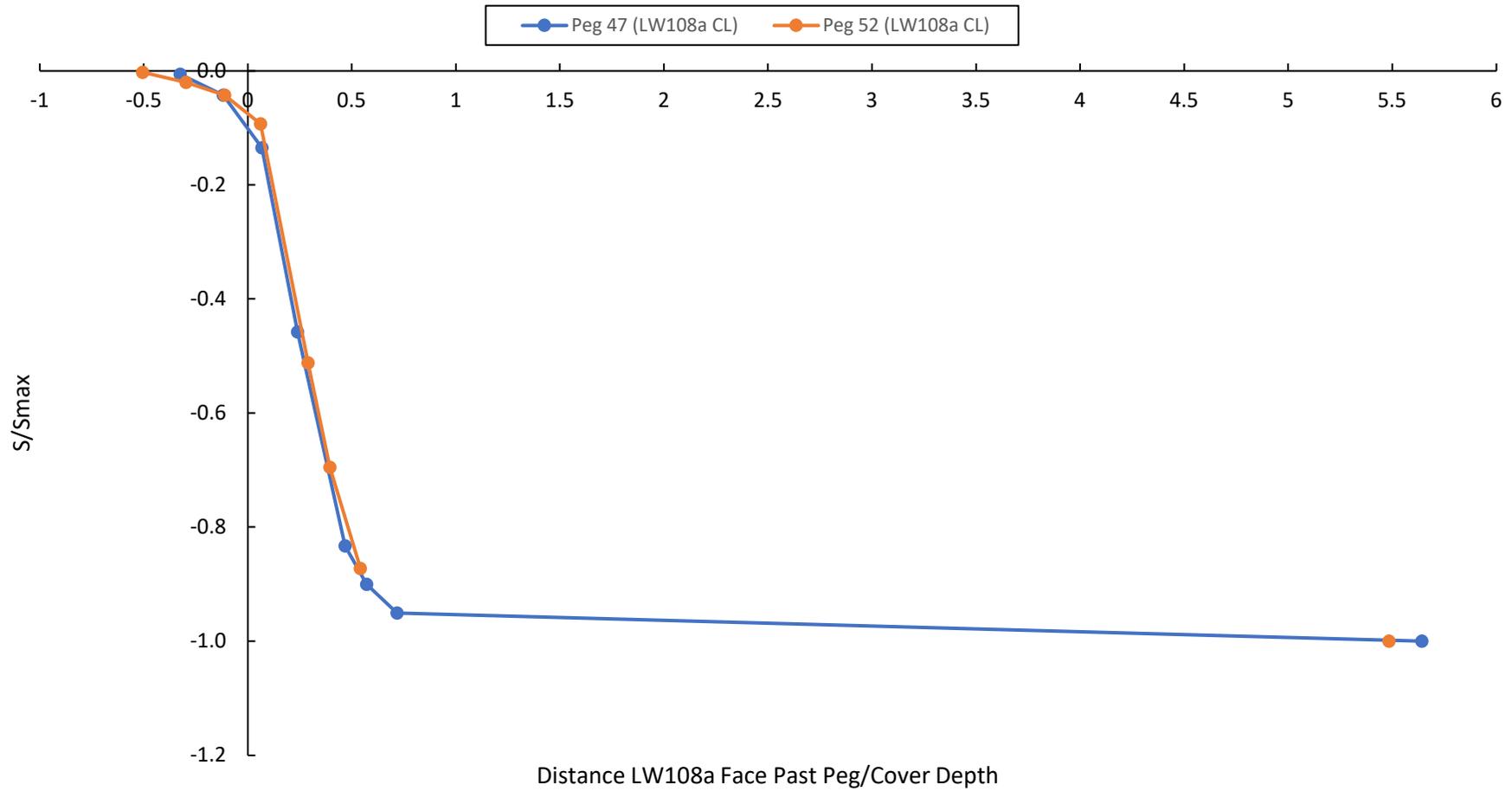


Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.10.19
 Ditton Geotechnical Services Pty Ltd

Client: Narrabri Mine
 NAR-005/2
 Title: Measured Subsurface Vertical Strain Above LW108a from Borehole Extensometers
 Scale: NTS
 Figure No: 16j

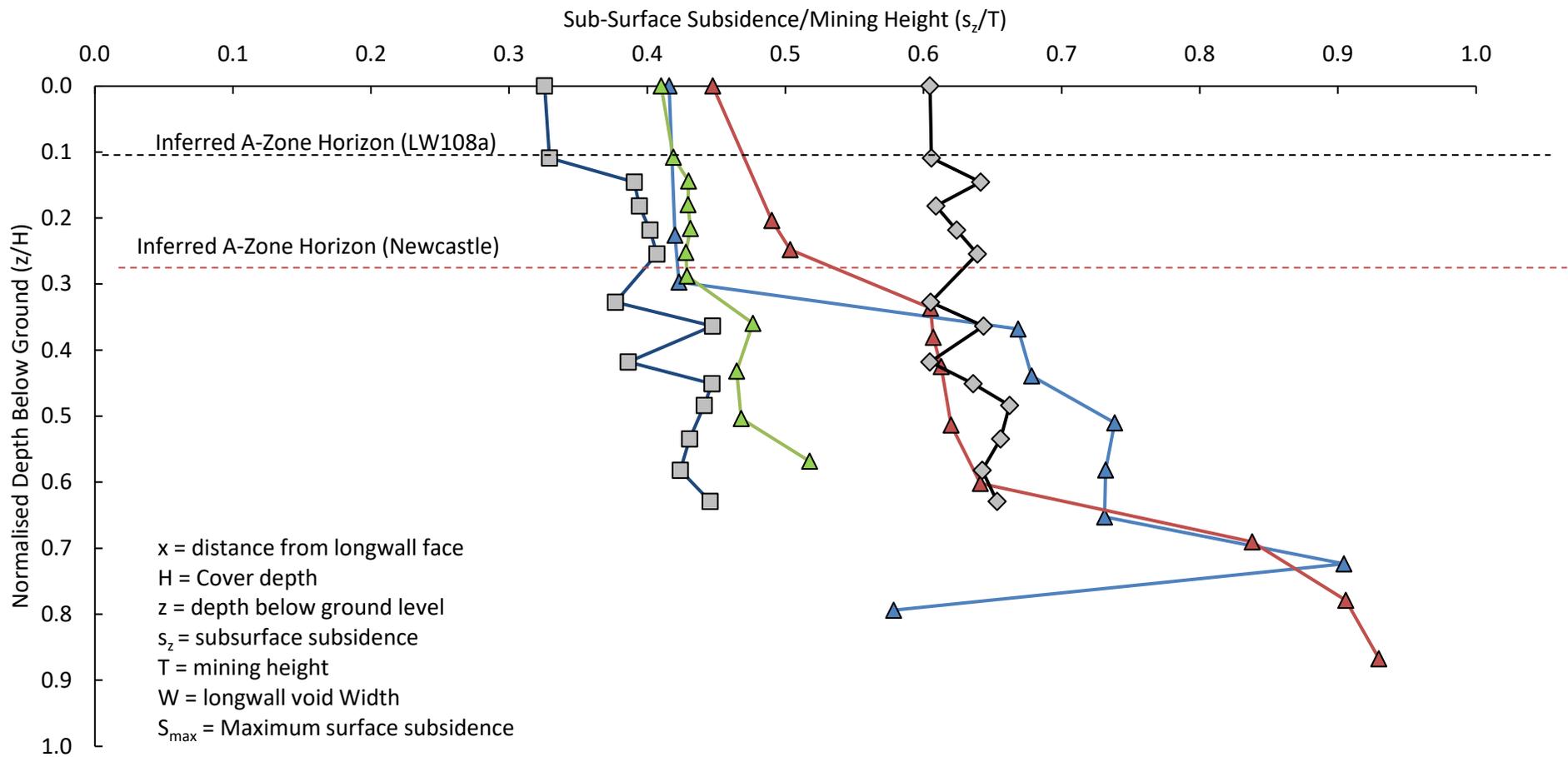
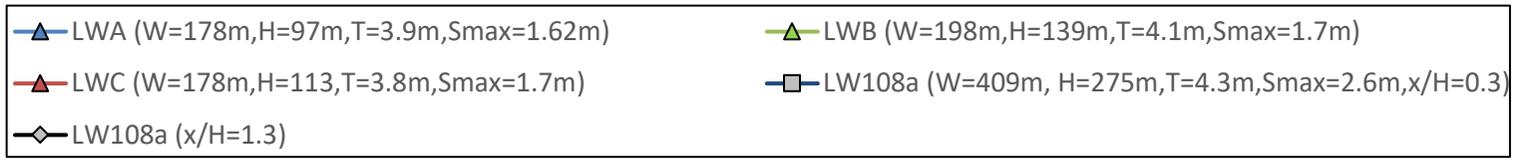


	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.08.17	Title:	Measured Pressure heads in Borehole P57 relative to LW108a Face	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:

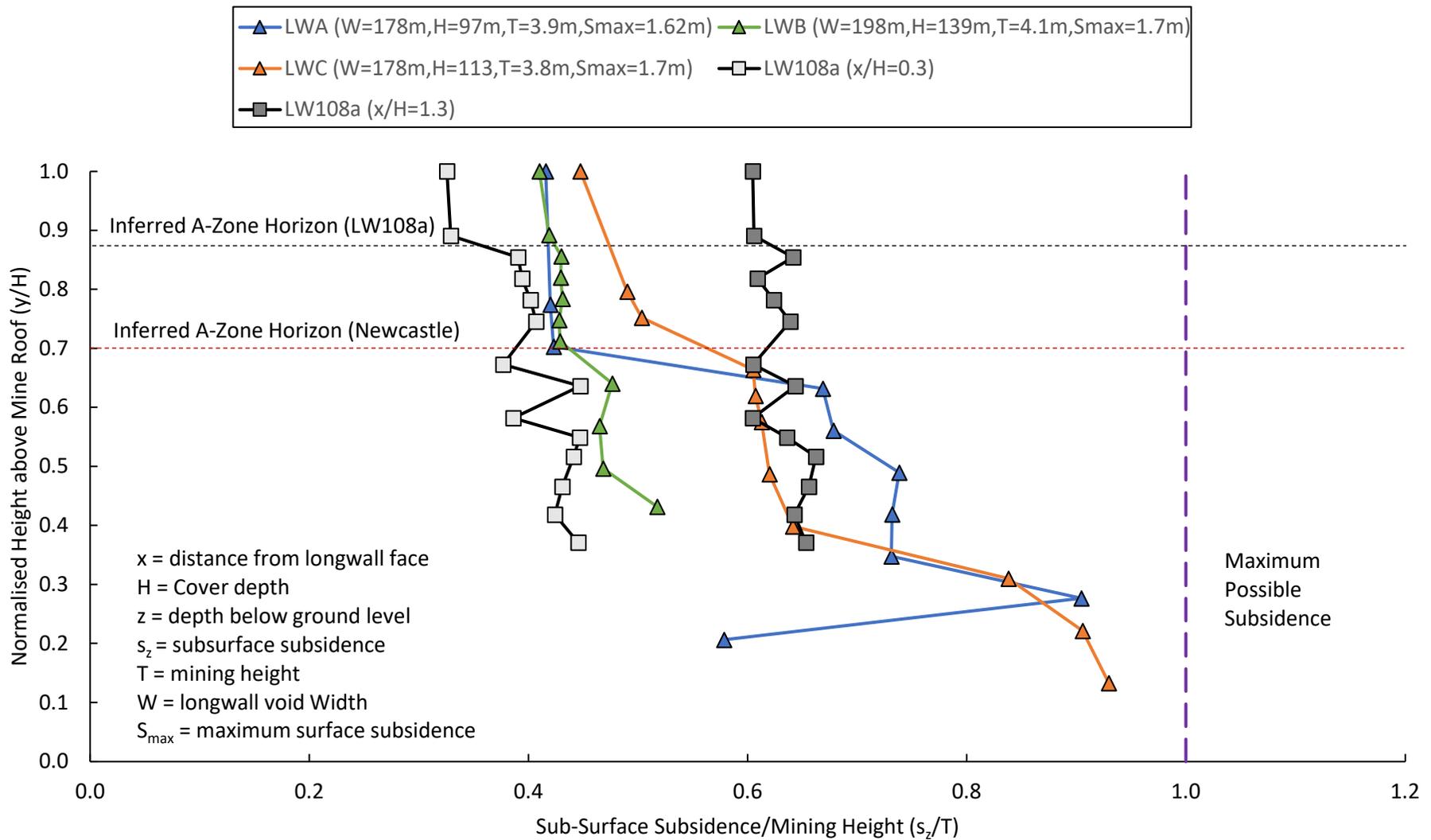


Engineer: S.Ditton
 Drawn: S.Ditton
 Date: 15.11.19
 Ditton Geotechnical
 Services Pty Ltd

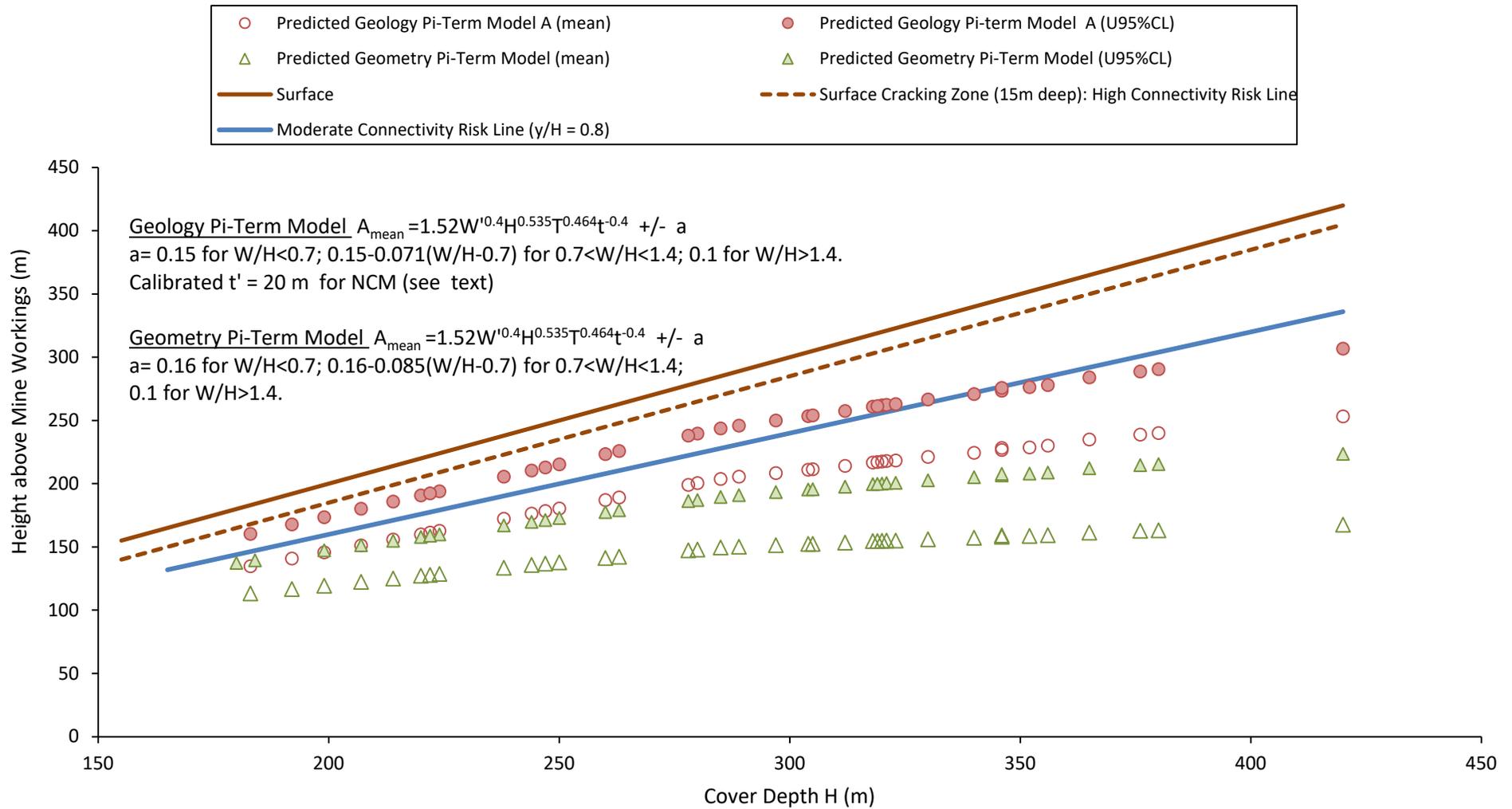
Client:	Narrabri Mine NAR-005/2		
Title:	Measured Subsidence Development along LW108a Centreline		
Scale:	NTS		Figure No: 16l



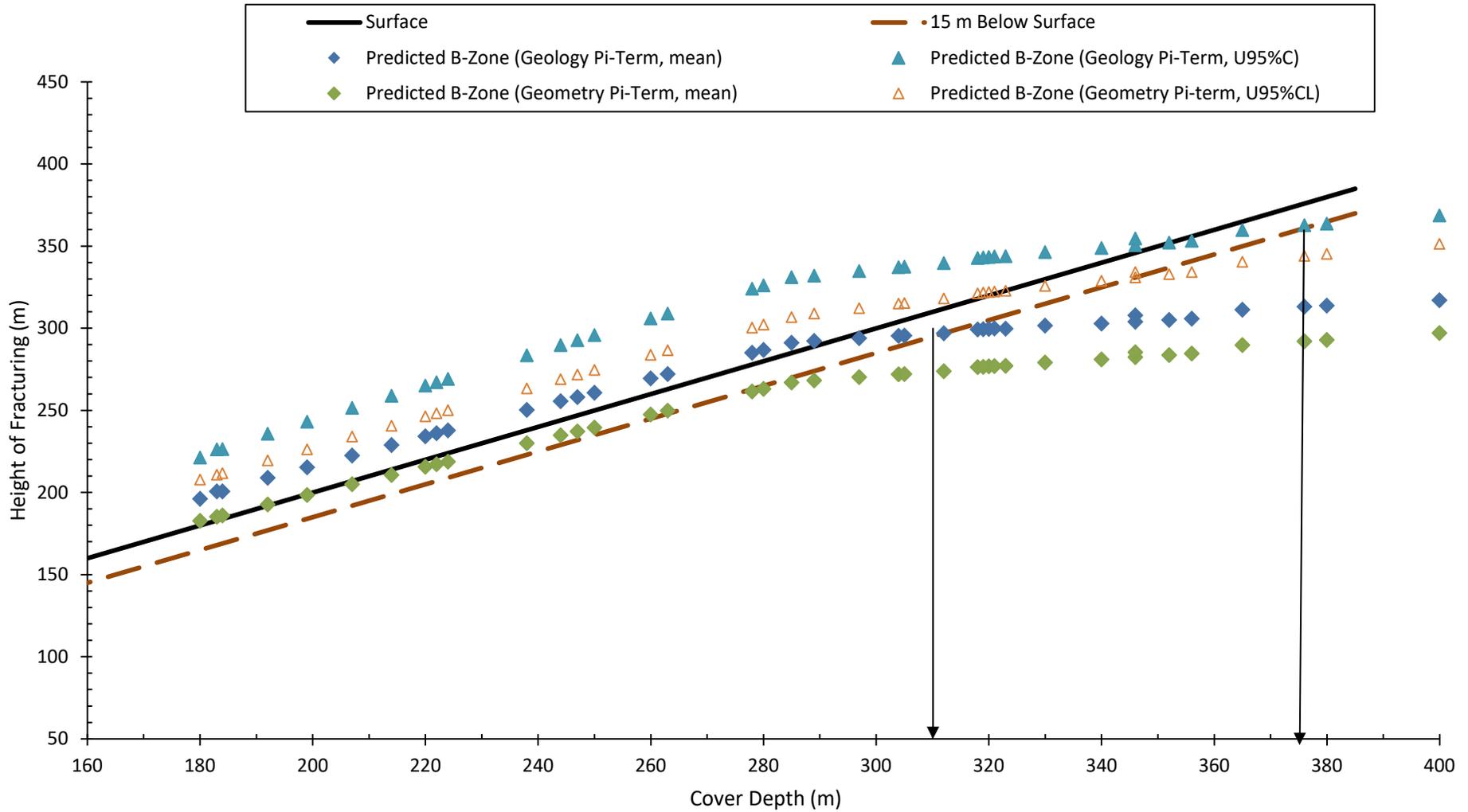
	Engineer: S.Ditton	Client: Narrabri Mine
	Drawn: S.Ditton	NAR-005/2
	Date: 02.06.15	Title: Measured Subsurface Strata Subsidence/Mining Height v. Depth/Cover Depth
	Ditton Geotechnical Services Pty Ltd	in the Newcastle Coalfield & Narrabri Mine
	Scale: NTS	Figure No: 16m



Engineer:	S.Ditton	Client:	Narrabri Mine
Drawn:	S.Ditton		NAR-005/2
Date:	02.06.15	Title:	Measured Subsurface Strata Subsidence/Mining Height v. Height above Mine/Cover Depth
Ditton Geotechnical Services Pty Ltd		in the Newcastle Coalfield & Narrabri Mine	
Scale:	NTS		Figure No: 16n



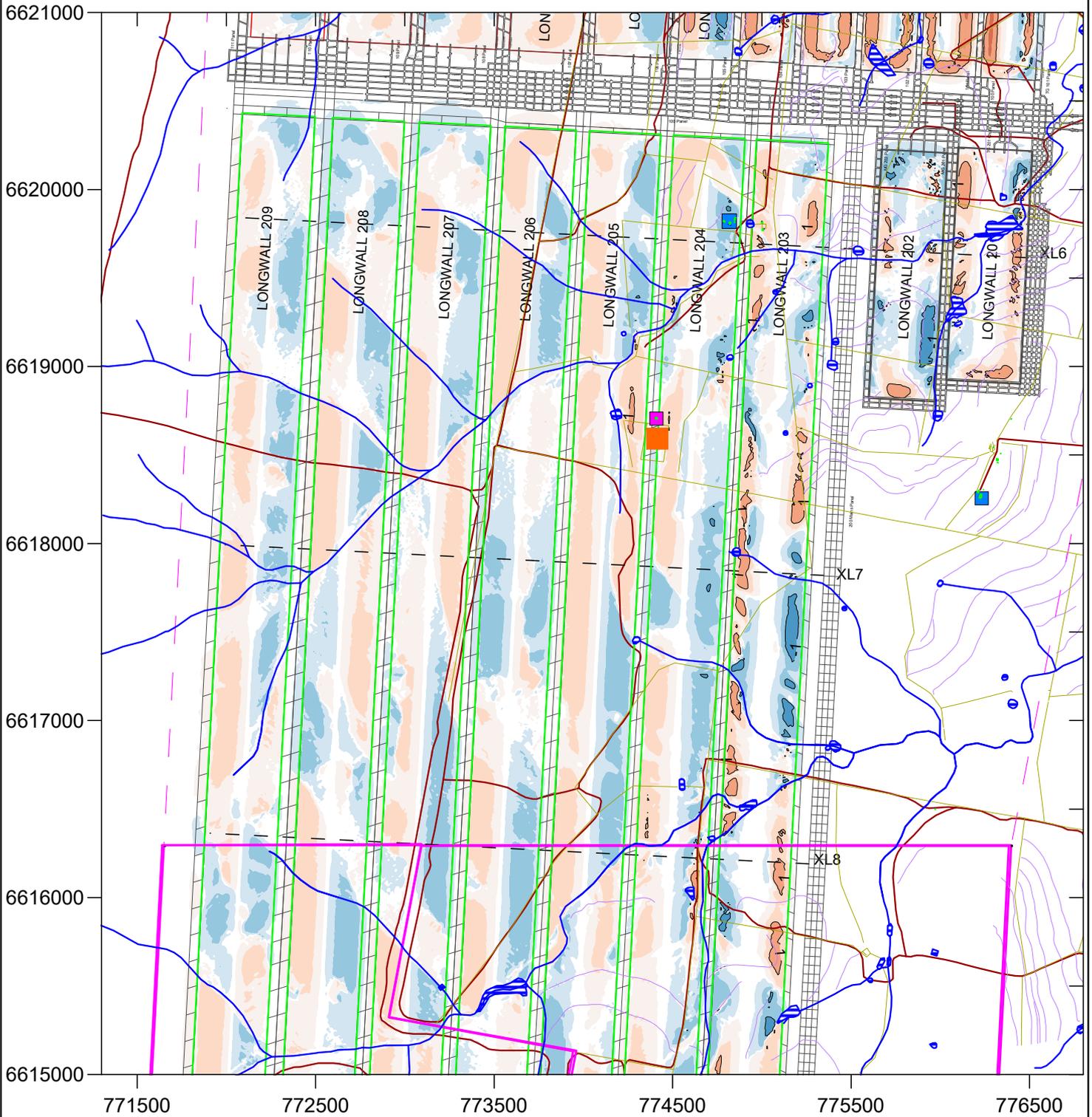
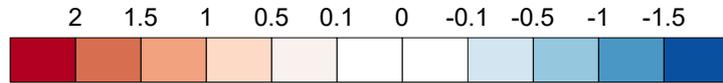
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	25.09.19	Title:	Predicted Heights of Connective Cracking Above LW203 to 210 based on Pi-Term Models (refer Ditton & Merrick, 2014)	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



Reference: Ditton & Merrick, 2014 Sub-surface Fracture Model Outcomes

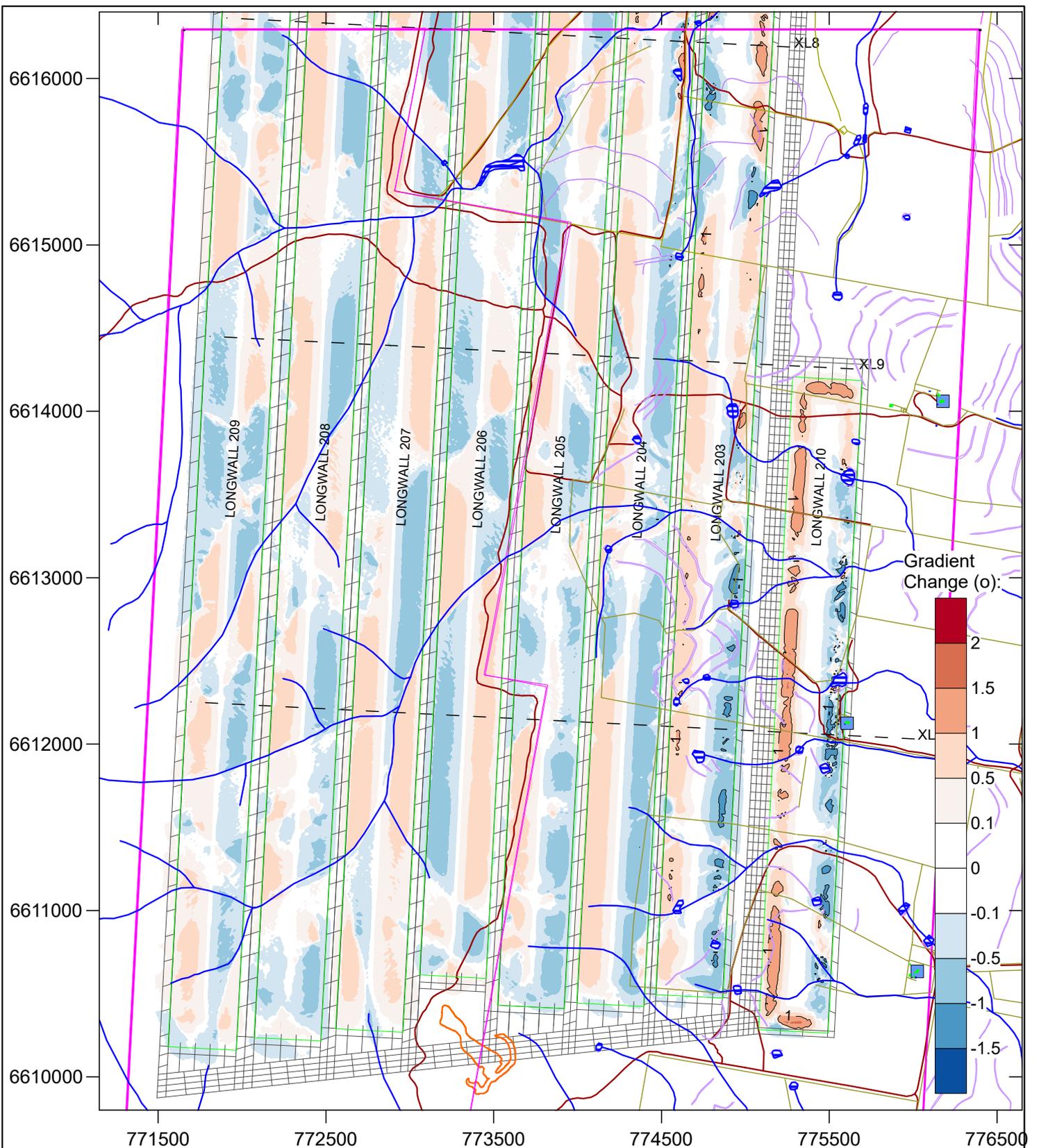
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	15.07.20	Title:	Discontinuous (B-Zone) Sub-Surface Fracture Heights in Constrained Zone	
	Ditton Geotechnical Services Pty Ltd		above the Proposed 203 to 210		
	Scale:	NTS			Figure No: 17b

Gradient Change (o):



- Roads (unsealed)
- Proposed LW203-210
- Ephemeral Creeks & Watercourses
- Dwellings & Sheds/Tanks/Orchards
- Approved LW201 - 202
- Farm Dams
- Dwellings (Private / NCOPL Owned)
- Mining Lease 1609 Boundary
- Contour Banks
- Subsidence Prediction Lines
- Mining Lease Application Areas 1 & 2 Boundaries
- Lot Boundaries/Fences

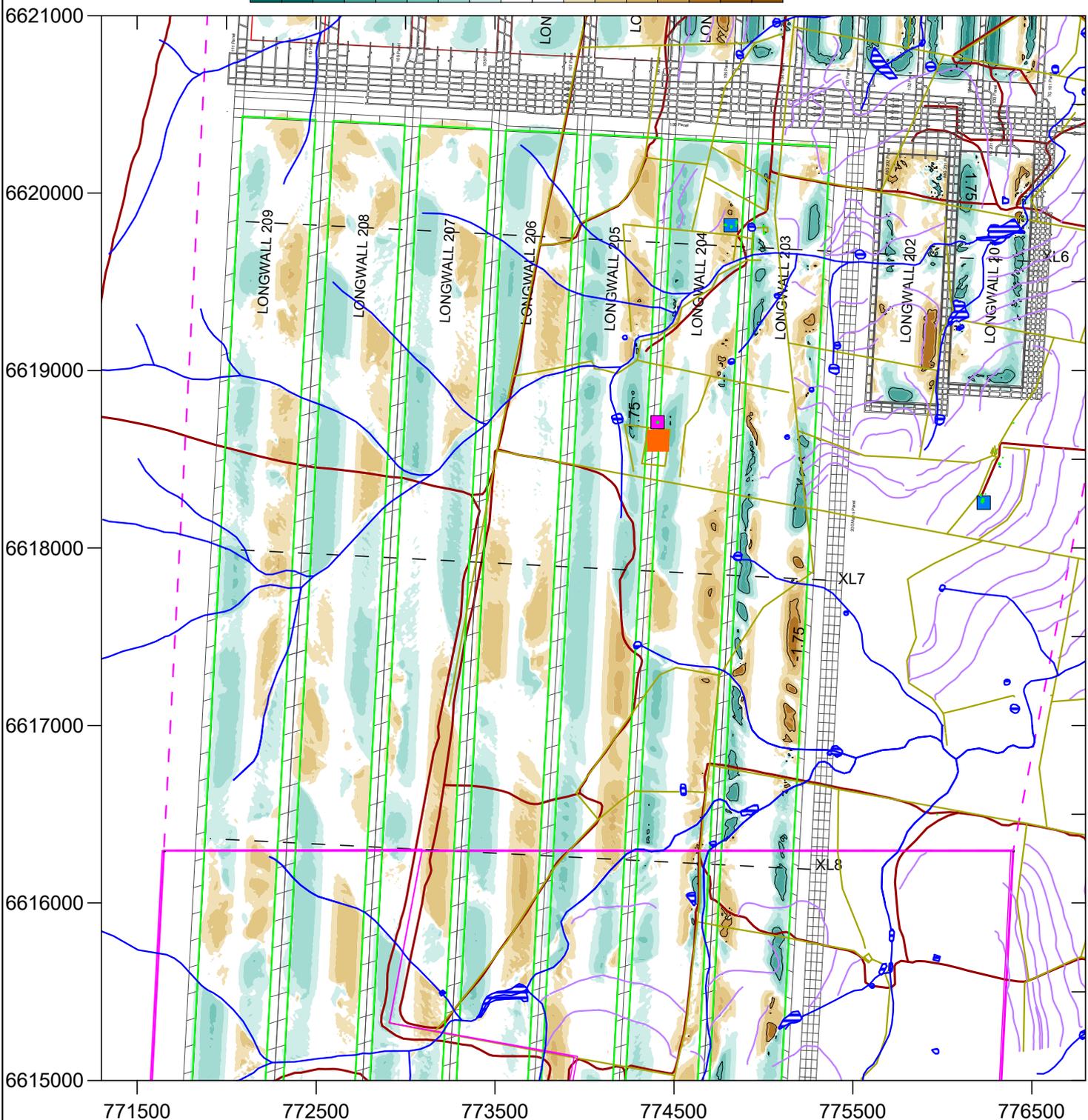
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton		Title:	Predicted Surface Gradient Changes (degrees) due to U95%CL Subsidence Contours above the Approved LW201 & 202 and Proposed LW203 to 209 in ML1609	
	Date:	15.11.19	Scale:		1:60,000	Figure No:
	Ditton Geotechnical Services Pty Ltd					



- Roads (unsealed)
- ● Dwellings & Sheds/Tanks/Orchards
- Dwellings (Private / NCOPL Owned)
- - - Subsidence Prediction Lines
- Proposed LW203-210
- Approved LW201 - 202
- Mining Lease Application Areas 1 & 2 Boundaries
- ⤴ Bulga Hill
- Ephemeral Creeks & Watercourses
- ▤ Farm Dams
- Contour Banks
- Lot Boundaries/Fences

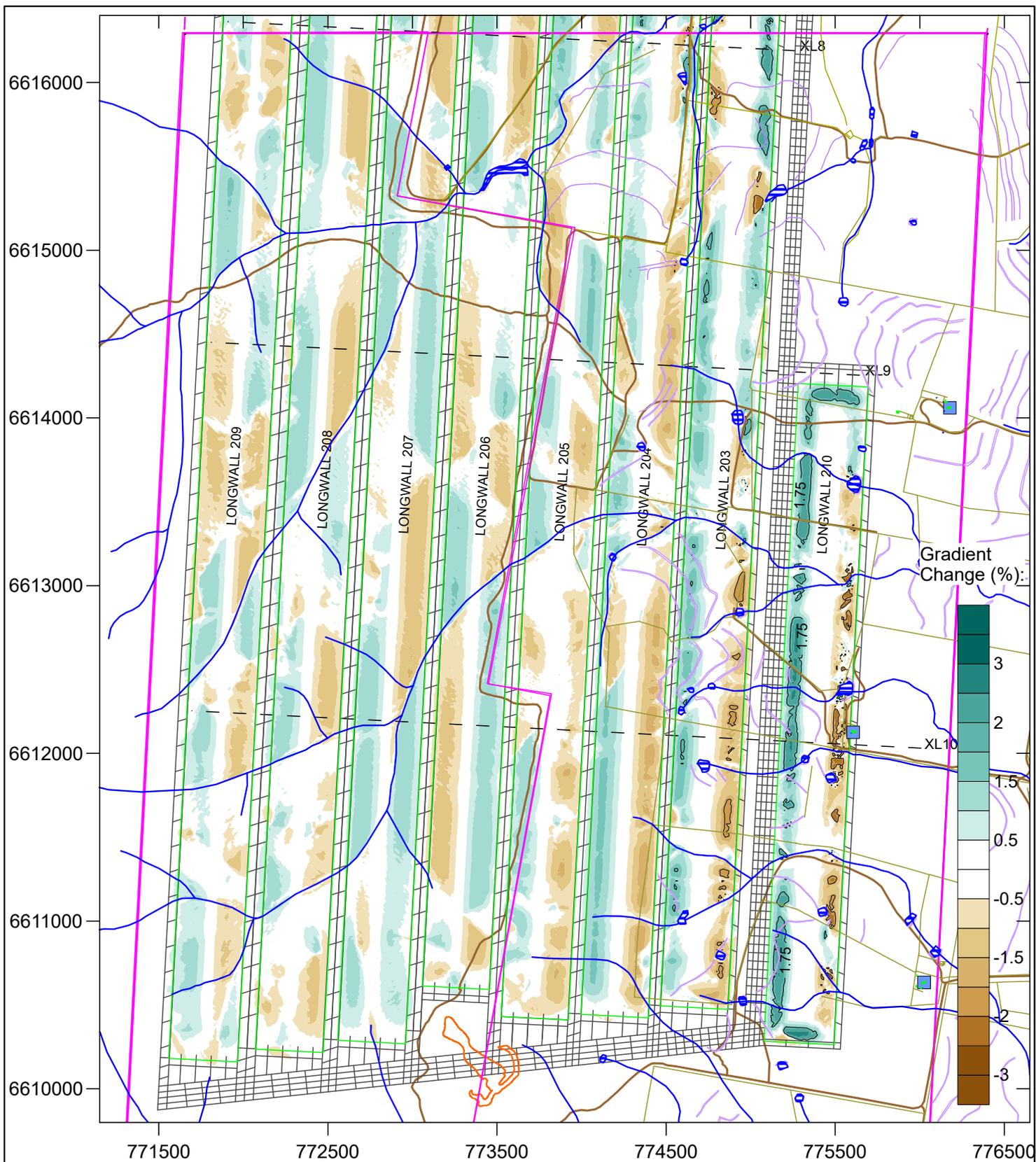
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2			
	Drawn:	S.Ditton		Title:	Predicted Surface Gradient Changes (degrees) due to U95%CL Subsidence Contours above the Proposed LW203 to 210 in MLA Areas 1 & 2		
	Date:	15.11.19	Scale:		1:60,000	Figure No:	18b
	Ditton Geotechnical Services Pty Ltd						

Gradient Change (%):



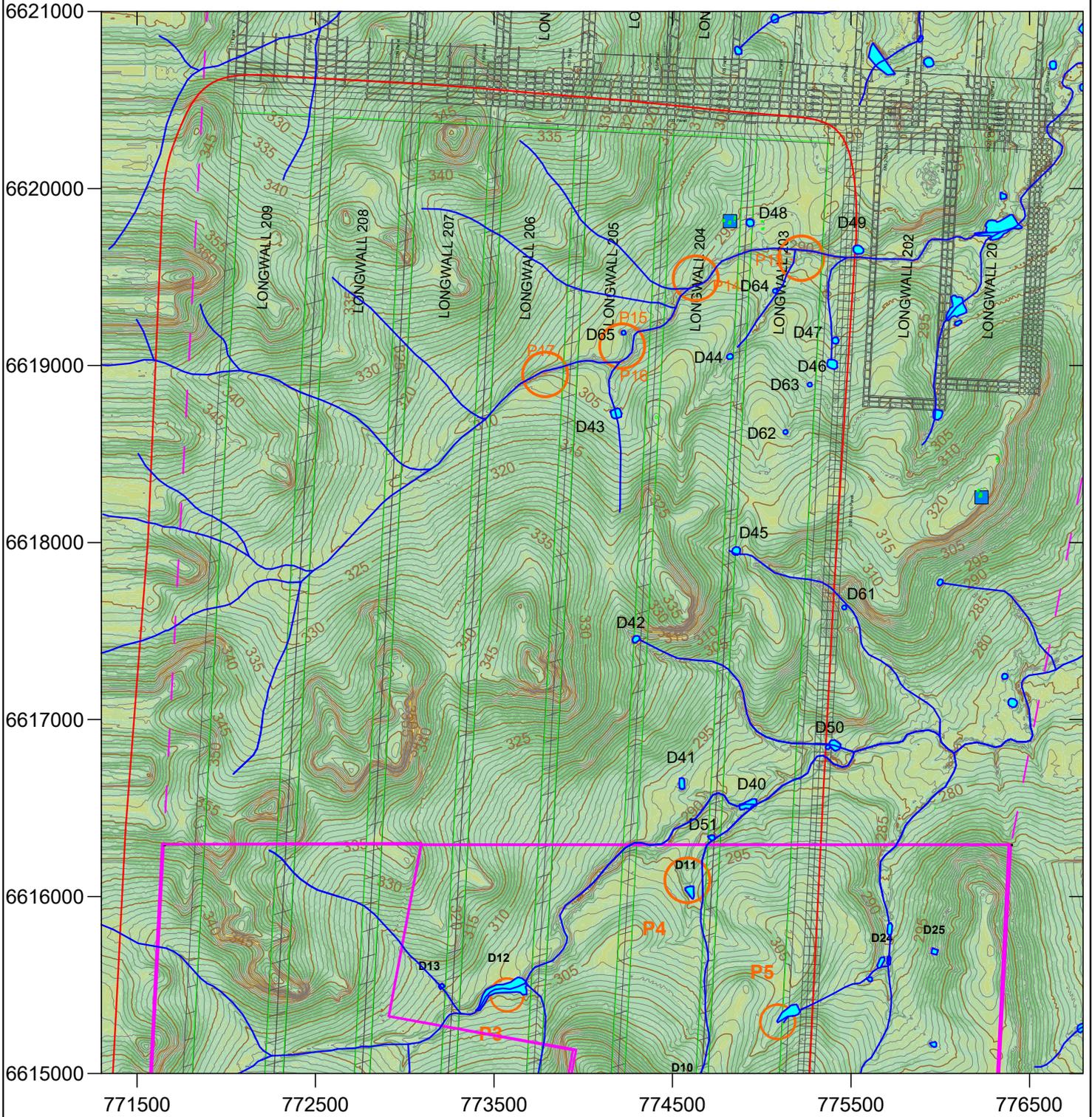
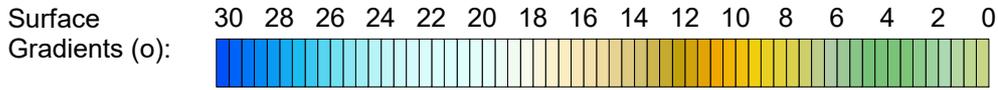
- Roads (unsealed)
- Proposed LW203-210
- Ephemeral Creeks & Watercourses
- Dwellings & Sheds/Tanks/Orchards
- Approved LW201 - 202
- Farm Dams
- Dwellings (Private / NCOPL Owned)
- Mining Lease 1609 Boundary
- Contour Banks
- Subsidence Prediction Lines
- Mining Lease Application Areas 1 & 2 Boundaries
- Lot Boundaries/Fences

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton		Title:	Predicted Surface Gradient Changes (percent) due to U95%CL Subsidence Contours above the Approved LW201 - 202 and the Proposed LW203 to 209 in ML1609	
	Date:	15.11.19	Scale:		1:60,000	Figure No:
	Ditton Geotechnical Services Pty Ltd					



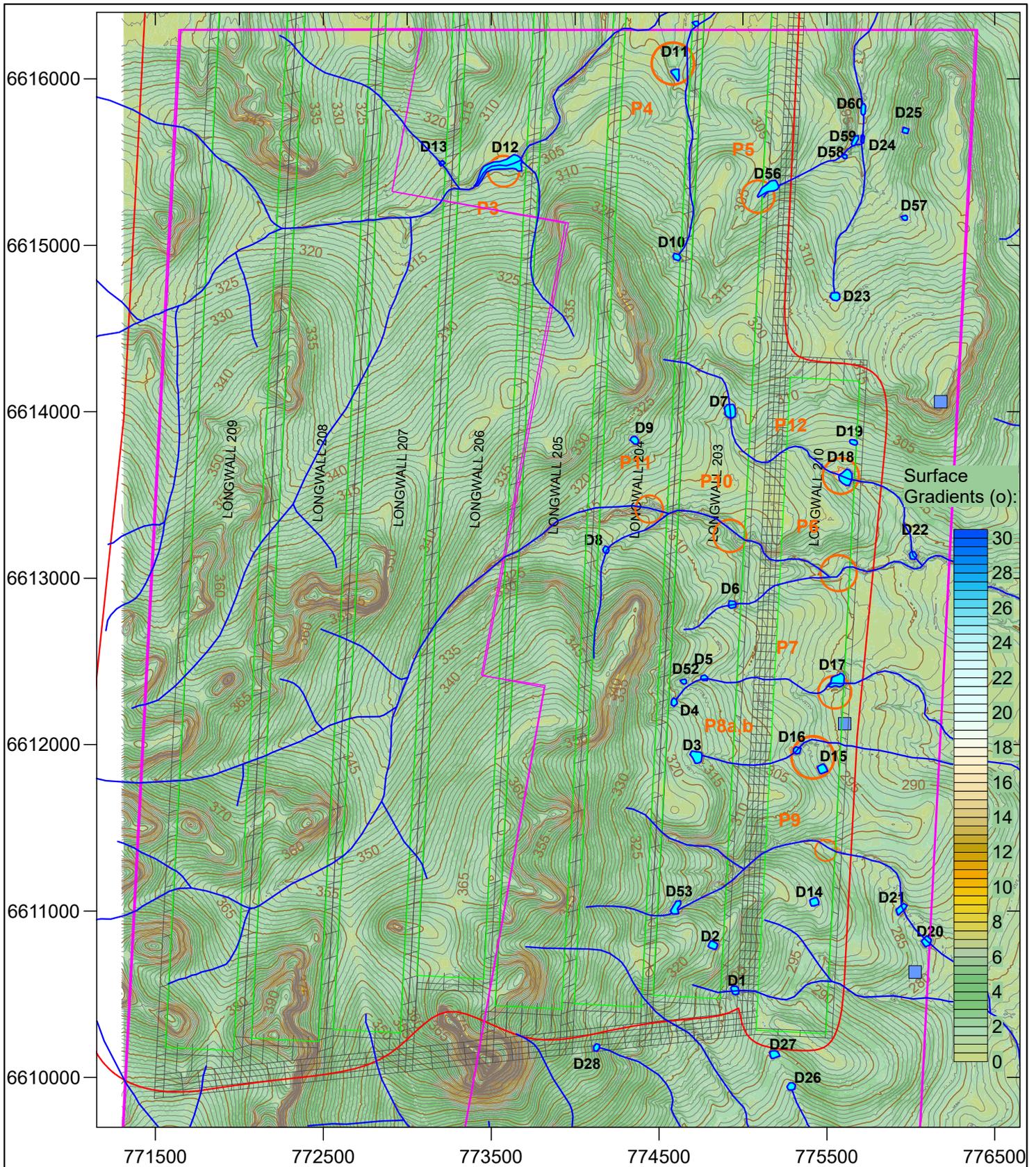
- Roads (unsealed)
- Dwellings & Sheds/Tanks/Orchards
- Dwellings (Private / NCOPL Owned)
- - - Subsidence Prediction Lines
- Proposed LW203-210
- Approved LW201 - 202
- Mining Lease Application Areas 1 & 2 Boundaries
- Bulga Hill
- Ephemeral Creeks & Watercourses
- ▽ Farm Dams
- Contour Banks
- Lot Boundaries/Fences

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2
	Drawn:	S.Ditton	Title:	Predicted Surface Gradient Changes (percent) due to U95%CL Subsidence Contours above the Proposed LW203 to 210 in MLA Areas 1 & 2
	Date:	15.11.19	Scale:	1:60,000
	Ditton Geotechnical Services Pty Ltd		Figure No:	18d



- Surface Level contours (m)
- Mining Lease 1609 Boundary
- Angle of Draw to 20mm subsidence
- Proposed LW203 to 209
- Mining Lease Application Areas 1 & 2 Boundaries
- Creeks/Ephemeral Watercourses
- Dwellings (Private/NCO-Owned)
- Farm Dams (D40-D51, D61-D65)
- Likely Ponding Change Locations (Pre-Mining)

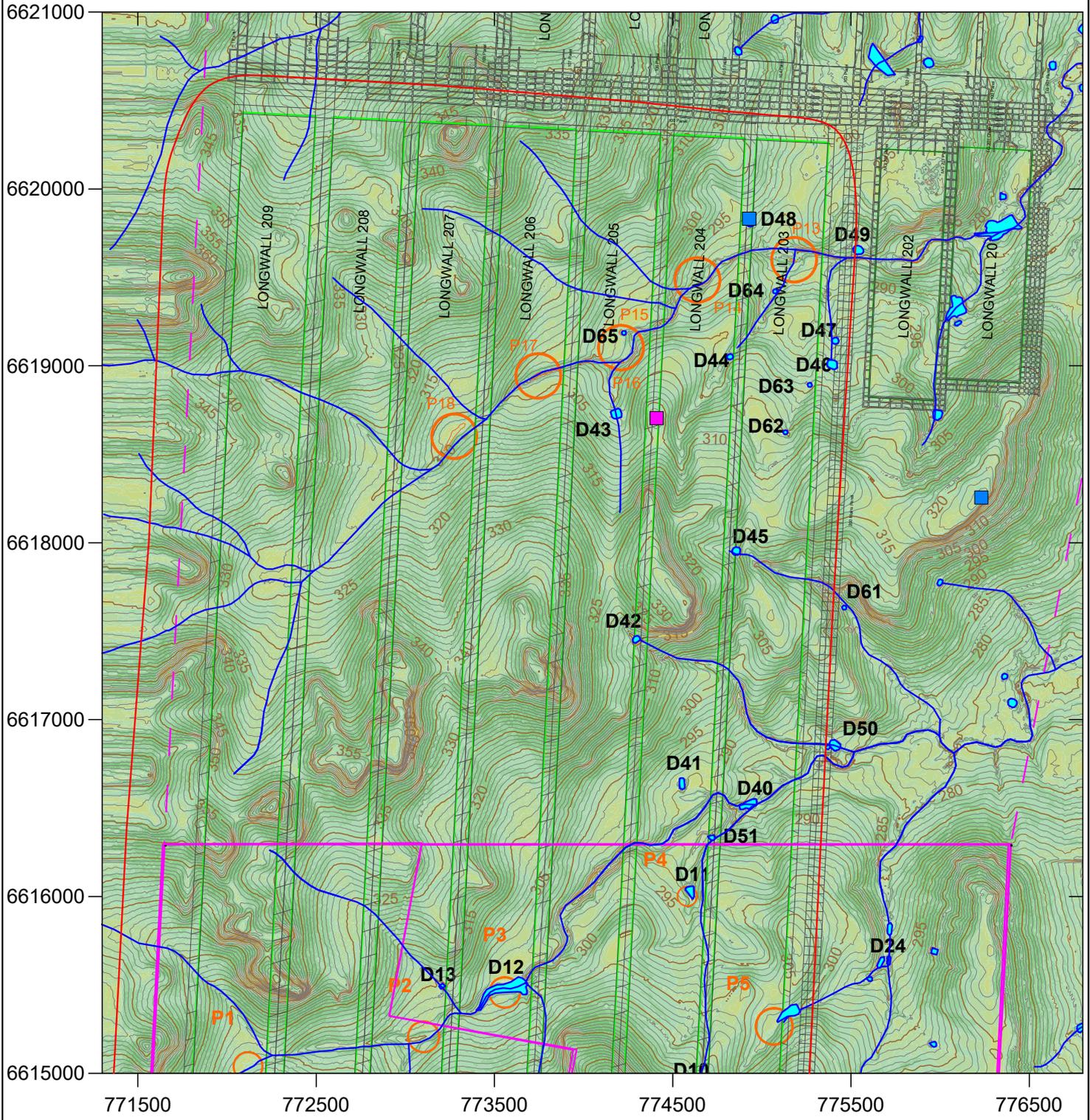
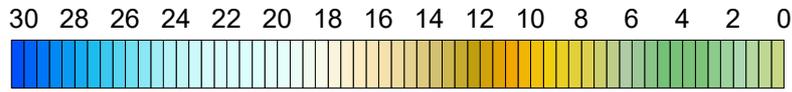
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2		
	Drawn:	S.Ditton	Title:	Predicted Pre-Mining Surface Level Contours and Likely Ponding Locations above the Proposed LW203 to 209 in ML1609		
	Date:	15.11.19	Scale:	1:60,000	Figure No:	19a
	Ditton Geotechnical Services Pty Ltd					



- Surface Level contours (m) - - - Mining Lease 1609 Boundary — Angle of Draw to 20 mm subsidence
- ▭ Proposed mine workings - - - Mining Lease Application Areas 1 & 2 Boundaries — Creeks/Ephemeral Watercourses
- ▭ Existing Dwellings (Private/NCO-Owned) ▽ Farm Dams (D1-D39, D52-60) ○ P10 Likely Ponding Locations (Pre - Mining)

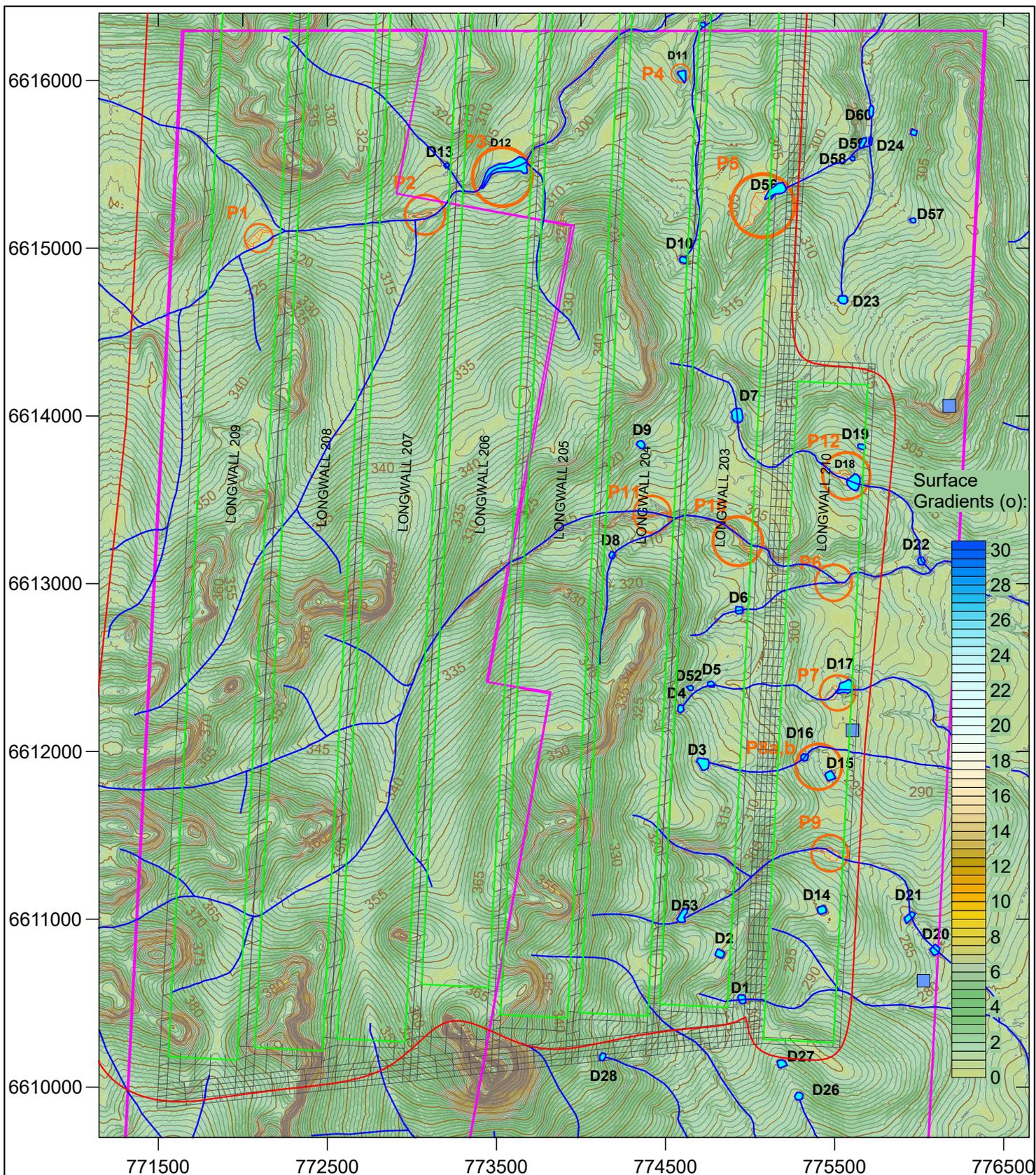
	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2	
	Drawn:	S.Ditton			
	Date:	15.11.19	Title:	Predicted Pre-Mining Surface Level Contours and Likely Ponding Locations above the Proposed LW203 to 210 in MLA Areas 1 & 2	
	Ditton Geotechnical Services Pty Ltd				
Scale:			1:60,000	Figure No: 19b	

Surface Gradients (o):



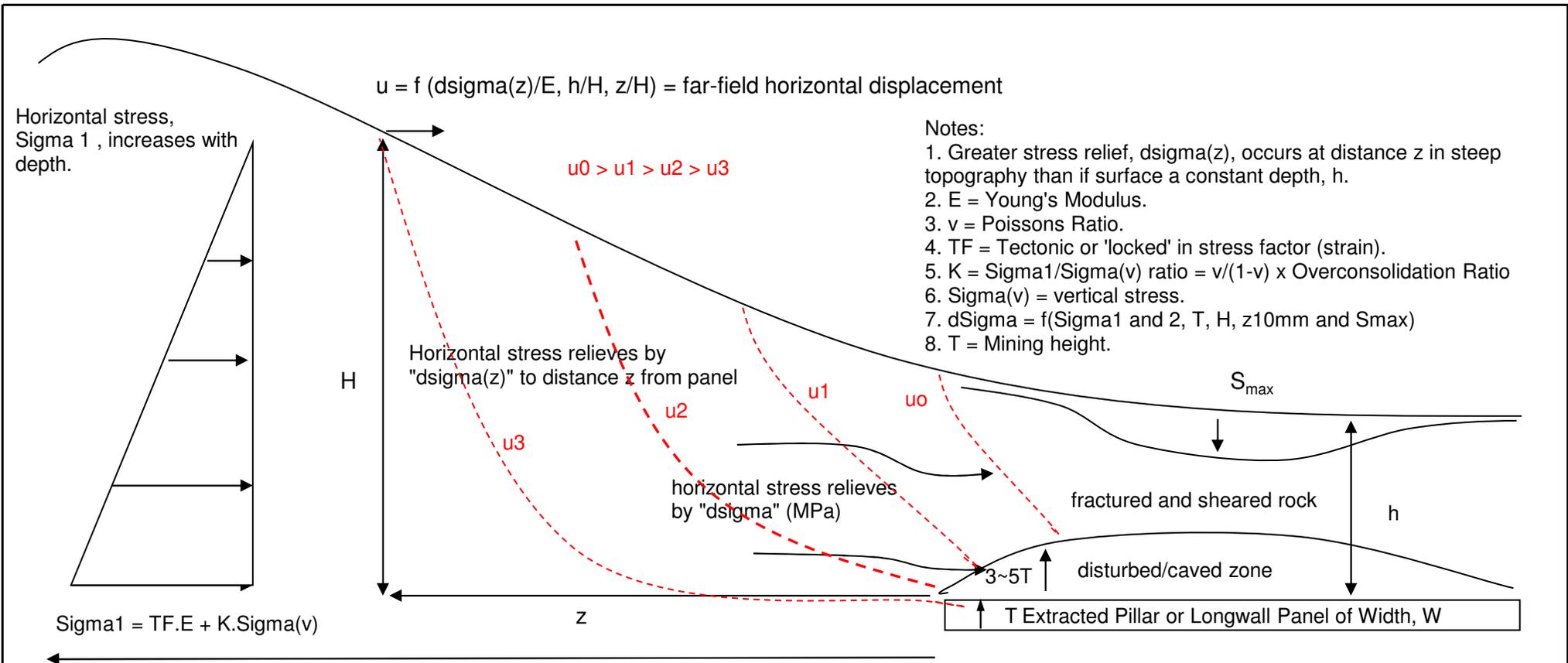
- Surface Level contours (m)
- Mining Lease 1609 Boundary
- Angle of Draw to 20mm subsidence
- Proposed mine workings
- Mining Lease Application Areas 1 & 2 Boundaries
- Creeks/Ephemeral Watercourses
- Dwellings (Private/NCO-Owned)
- Farm Dams (D40-D51, D61-D65)
- P10 Likely Ponding Change Locations (Post - Mining)

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/2
	Drawn:	S.Ditton	Title:	Predicted Post-Mining Surface Level Contours and Likely Ponding Locations above the Proposed LW203 to 209 in ML1609
	Date:	15.11.19	Scale:	1:60,000
	Ditton Geotechnical Services Pty Ltd		Figure No:	19c



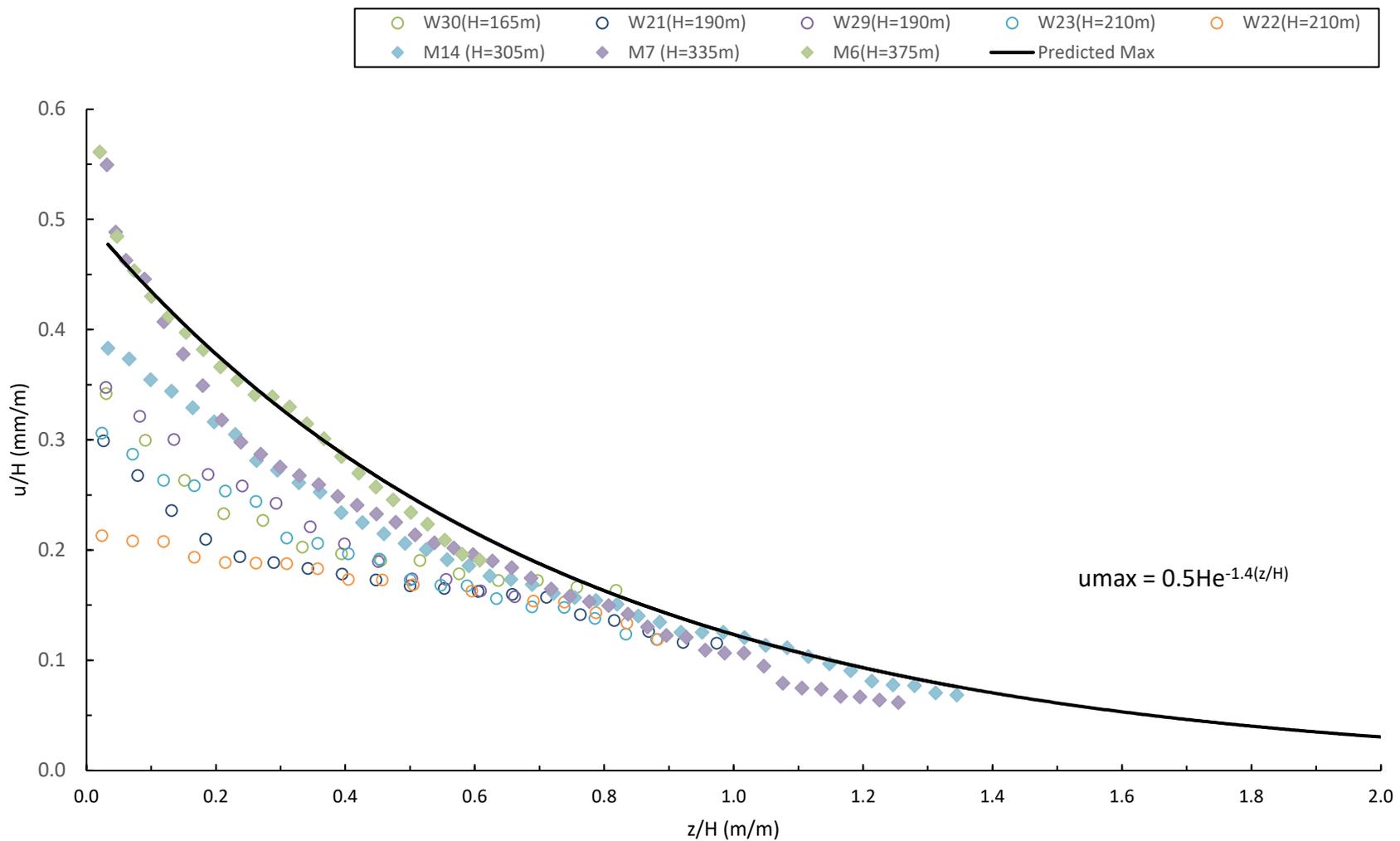
- Surface Level contours (m) - - - Mining Lease 1609 Boundary — Angle of Draw to 20 mm subsidence
- ▭ Proposed mine workings — Mining Lease Application Areas 1 & 2 Boundaries — Creeks/Ephemeral Watercourses
- Dwellings (Private/NCO-Owned) ▽ Farm Dams (D1-D39, D52-D60) ○ P10 Likely Ponding Locations (Pre - Mining)

	Engineer:	S.Ditton	Client:	Narrabri Mine NAR-005/1
	Drawn:	S.Ditton	Title:	Predicted Post-Mining Surface Level Contours and Likely Ponding Locations above the Proposed LW203 to 210 in MLA Areas 1 & 2
	Date:	20.11.18	Scale:	1:60,000
	Ditton Geotechnical Services Pty Ltd		Figure No:	19d

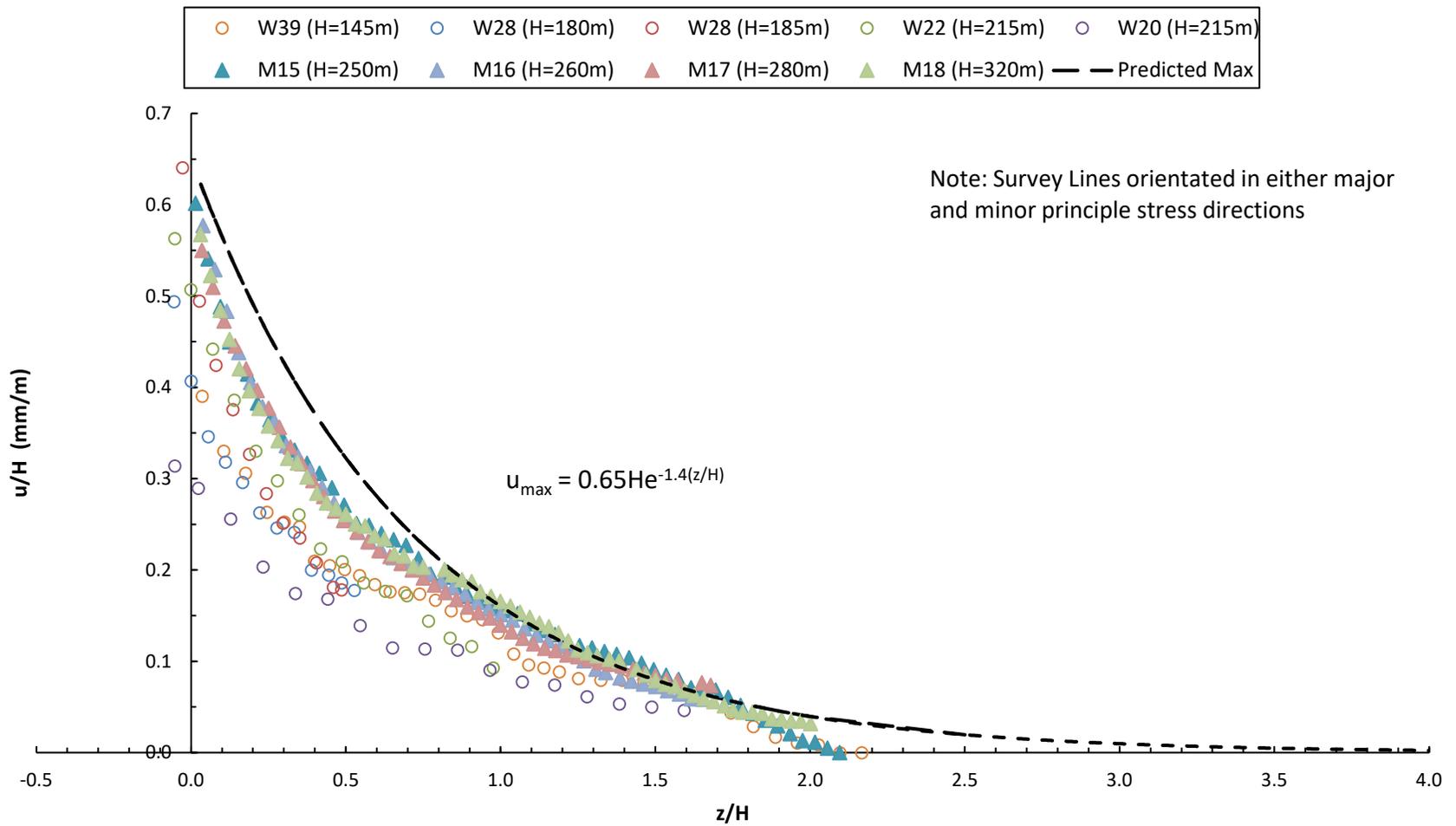


z_{10mm} is ~ 2 to $4 H$ with and without topographical effects and represents practical, measurable FFD limit of 10mm.

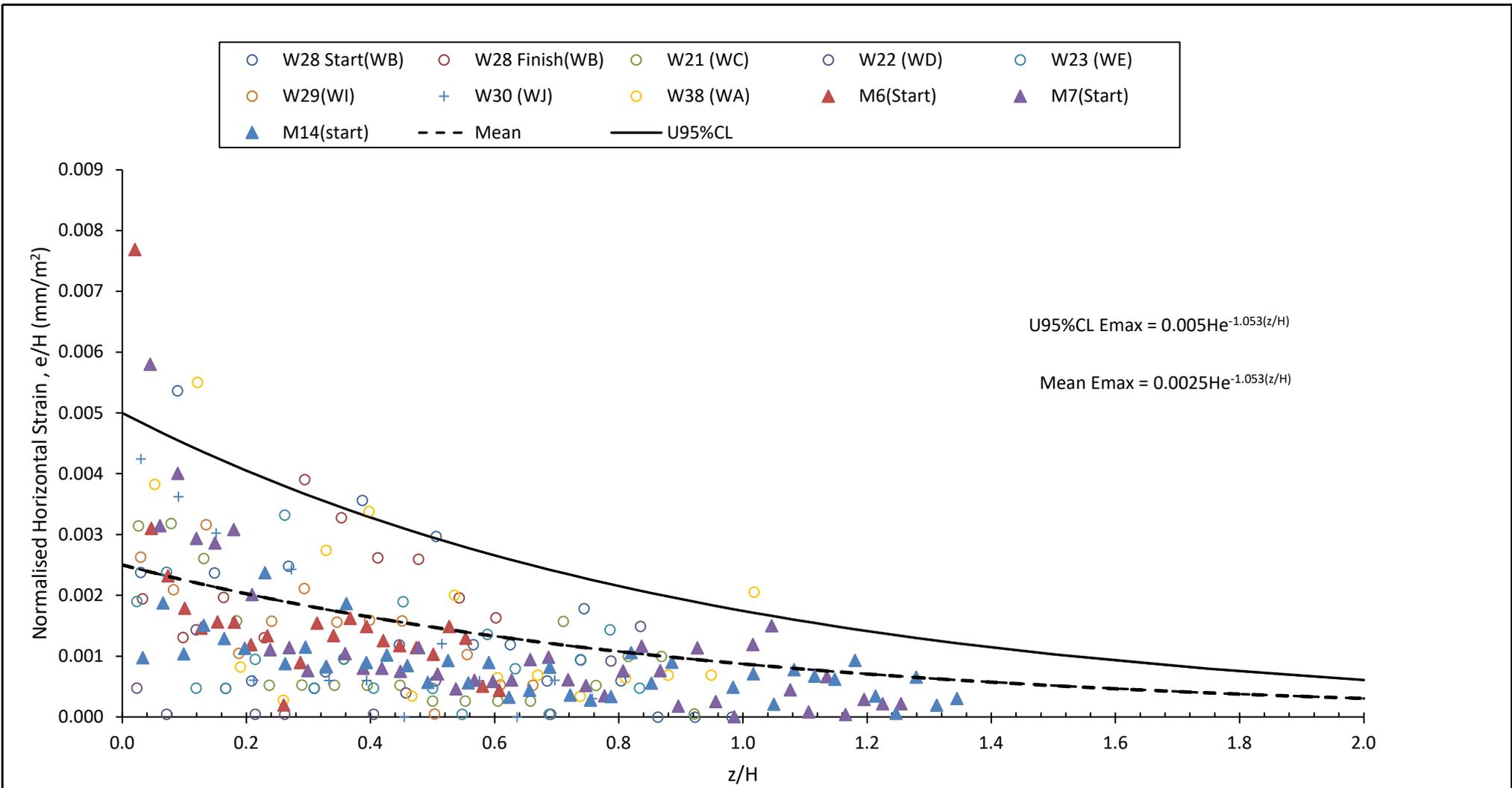
	Engineer:	S.Ditton	Client:	Narrabri Mine
	Drawn:	S.Ditton		NAR-005/2
	Date:	22.11.19	Title:	Conceptual Model of Far-Field Displacement Outside Angle of Draw Limits from Pillar Extraction or Longwall Panels
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
				Figure No: 20a



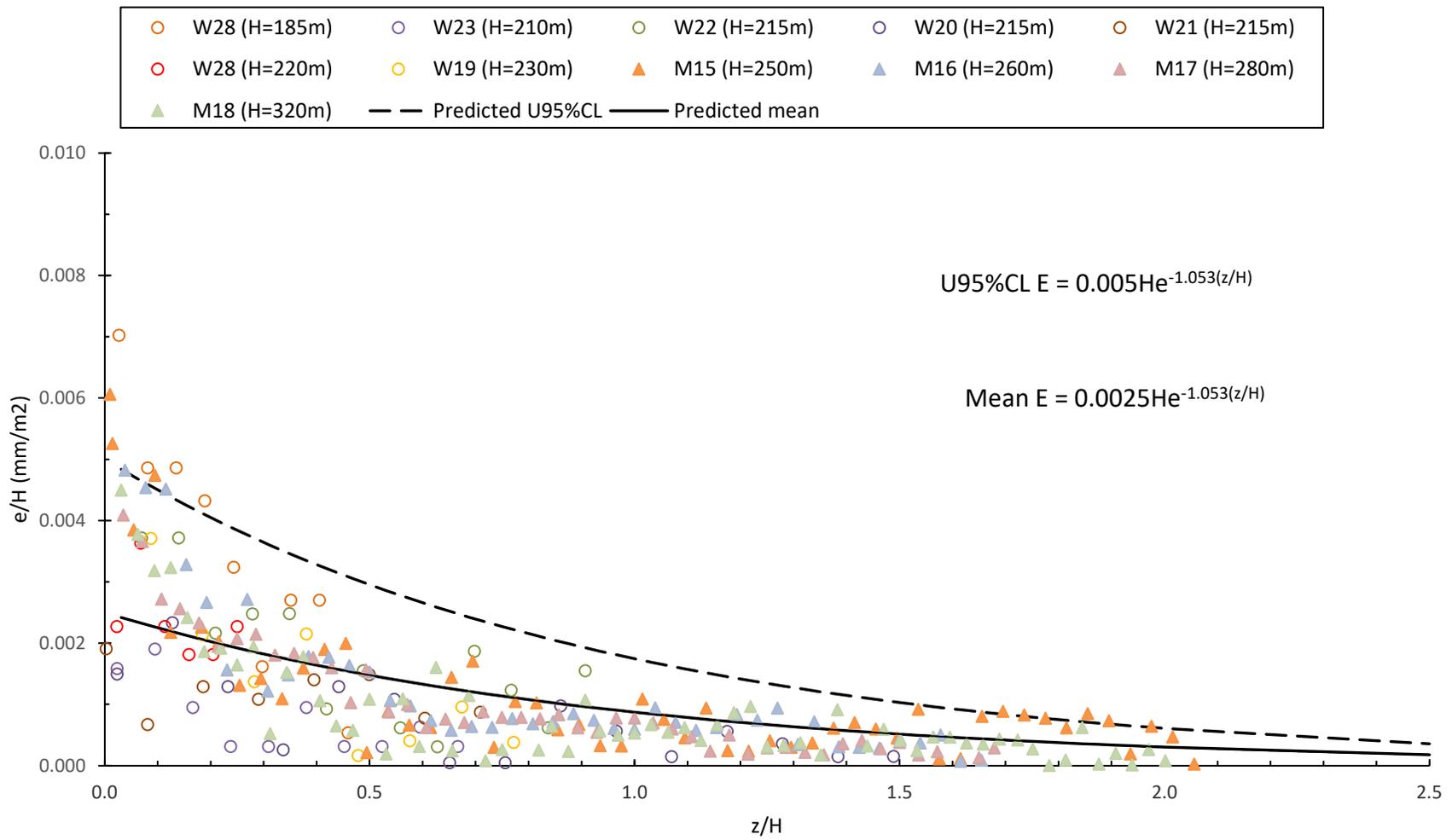
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	04.11.19	Title:	Empirical Model and Data for Horizontal Displacement Estimates around Longwalls in Southern Newcastle Coal Field: Centreline Data normalised to Cover Depth	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



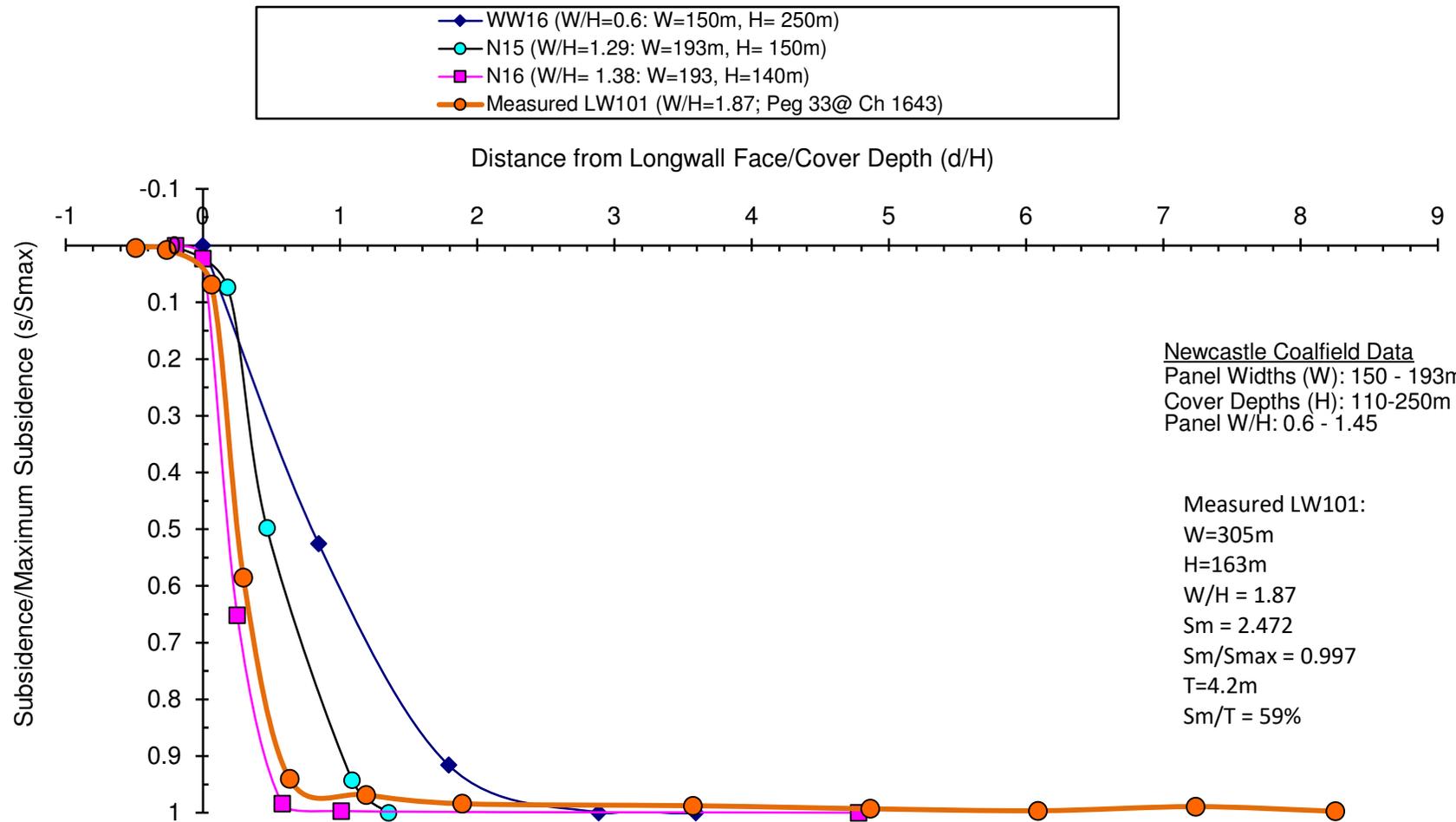
	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	04.11.19	Title:	Empirical Model and Data for Horizontal Displacement Estimates around Longwalls in Southern Newcastle Coal Field: Crossline Data normalised to Cover Depth	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	04.11.19	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:



	Engineer:	S.Ditton	Client:	Narrabri Mine	
	Drawn:	S.Ditton		NAR-005/2	
	Date:	04.11.19	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:



	Engineer: S.Ditton	Client: Narrabri Coal Operations Pty Ltd	NAR-005/2
	Drawn: S.Ditton		
	Date: 22.11.19	Title: Empirical Single Longwall Centreline Subsidence Development Prediction Model	
	Ditton Geotechnical Services Pty Ltd	(based on Newcastle Coalfield Measurements and LW101 Data)	
	Scale: NTS	Figure No:	21