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DgS

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Narrabri Coal Operations Pty Ltd

Mine Subsidence Assessment for the Proposed Addition of Longwall (LW) 106 to the Approved LW101 to LW105 Extraction Plan at the Narrabri Mine, Narrabri

DGS Report No. NAR-002/2

Date: 25 May 2015

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25 May, 2015

Mr Steve Farrar
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DGS Report No. NAR-002/2

Dear Steve,

Subject: Mine Subsidence Assessment for the Proposed Addition of Longwall (LW) 106 to the Approved LW101 to LW105 Extraction Plan at the Narrabri Mine, Narrabri.

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

Table of Contents

1.0 Introduction 11

2.0 Mining Geometry 12

2.1 Proposed Mining Geometry 12

2.2 Previous Environment Impact Assessment Mining Geometry 13

3.0 Surface Features 14

3.1 LW101 to LW106 14

3.2 Subsidence Monitoring Lines 15

4.0 Subsidence Prediction Methodology 16

5.0 Sub-Surface Conditions 18

5.1 Overburden 18

5.2 Immediate Mine Workings Conditions 18

6.0 Review of Subsidence Predictions v. Measured Data 20

7.0 Subsidence Effect Predictions for LW101 to LW106 23

7.1 General 23

7.2 Maximum Single Panel Subsidence 23

7.3 Maximum Predicted Subsidence Above Chain Pillars 25

7.3.1 Empirical Model Stress 25

7.3.2 Empirical Model Pillar Strength and FoS 26

7.3.3 Results 26

7.3.4 Bearing Capacity of Roof and Floor Strata 27

7.4 Goaf Edge Subsidence Prediction 28

7.5 Angle of Draw Prediction 28

7.6 Multiple Panel Subsidence Prediction 28

7.7 Modified Mining Layout v. Approved 2012 Extraction Plan Subsidence Effect Predictions 30

7.8 Subsidence Profile Predictions 31

8.0 Prediction of Subsidence Impact Parameter Contours 33

8.1 Calibration of SDPS 3D-Influence Function Model 33

8.2 Predicted Subsidence Effect Contours 34

9.0 Subsidence Impacts 35

9.1 General 35
9.2 Surface Cracking 36
9.2.1 Predicted Effects and Impacts 36
9.2.2 Review of Observed Surface Cracking 37
9.2.3 Impact Management Strategies 37
9.3 Sub-Surface Cracking 38
9.3.1 Sub-Surface Fracturing Zones 38
9.3.2 Sub-Surface Fracture Height and Constrained Zone Thickness Prediction Models 38
9.3.3 Geometry Pi-Term Model 40
9.3.4 Geology Pi-Term Model 41
9.3.5 Panel Width-Based Models 43
9.3.6 T-Based Model 43
9.3.7 Continuous Sub-surface Fracture Height Predictions (A-Zone) 44
9.3.8 Discontinuous Sub-surface Fracture Height Predictions (B-Zone) 45
9.3.9 Rock Mass Permeability Changes 47
9.3.10 Impact Management Strategies 47
9.4 Slope Stability and Erosion 48
9.4.1 Predicted Effects and Impacts 48
9.4.2 Impact Management Strategies 49
9.5 Ponding 49
9.5.1 Predicted Effects and Impacts 49
9.5.2 Impact Management Strategies 50
9.6 Valley Closure and Uplift 51
9.6.1 Predicted Effects and Impacts 51
9.6.2 Impact Management Strategies 52
9.7 Far-Field Horizontal Displacements 52
9.7.1 Predicted Effects and Impacts 52
9.7.2 Impact Management Strategies 53
9.8 Aboriginal Heritage Sites 53
9.8.1 Predicted Effects and Impacts 53
9.8.2 Impact Management Strategies 57
9.9 Unsealed Gravel Access Roads and Tracks 57

9.9.1 Predicted Effects and Impacts 57
9.9.2 Impact Management Strategies 58
9.10 Water Storage Dams and Soil Conservation (Contour) Banks 59
9.10.1 Predicted Effects and Impacts 59
9.10.2 Impact Management Strategies 59
9.11 Property Fences and Livestock and........ 60
9.11.1 Predicted Effects and Impacts 60
9.11.2 Impact Management Strategies 60
9.12 Residential Dwellings and Machinery Sheds........ 61
9.12.1 Predicted Effects and Impacts 61
9.12.2 Impact Management Strategies 61
9.13 Utilities 62
9.13.1 Predicted Effects and Impacts 62
9.13.2 Impact Management Strategies 63
9.14 Narrabri Mine and Other Infrastructure 63
9.14.1 Predicted Effects and Impacts 63
9.14.2 Impact Management Strategies 63
10.0 Comparison of Current Extraction Plan Area Predictions with the Environmental Impact Assessment Report Submission........ 64
11.0 Monitoring Program 66
11.1 Subsidence Development 66
11.2 Surface Monitoring 66
11.3 Sub-surface Monitoring........ 67
12.0 Conclusions 68
13.0 References 72

Figures 1 to 20

Appendix A - Empirical Subsidence Prediction Model Details

GLOSSARY

Angle of Draw	The angle (normally no greater than 26.5^o from the sides or ends of an extracted longwall block) from the vertical of the line drawn between the limits of extraction at seam level to the 20 mm subsidence contour at the surface. The 20 mm subsidence contour is an industry defined limit and represents the practical measurable limit of subsidence.
Chain Pillar	The pillar of coal left between adjacent longwall panels. This forms a barrier that allows the goaf to be sealed off and facilitates tailgate roof stability.
Compressive Strain	A decrease in the distance between two points on the surface. This can cause shear cracking or steps at the surface if > 2mm/m. Compressive strains are usually associated with concave curvatures near the middle of the panels.
Confidence Limits	A term used to define the level of confidence in a predicted subsidence impact parameter and based on a database of previously measured values above geometrically similar mining layouts.
Cover Depth	The depth from the surface to the mine workings.
Critical Longwall Panels	Longwall panels that are almost as deep (H) as they are wide (W) (ie 0.6 <W/H < 1.4) and is the point where natural arching stops and failure of the overburden starts to occur. The presence of massive strata units however, can still provide spanning capability through flatter voussoir arching behaviour. Maximum subsidence will be a function of panel width, mining height and geology.
Curvature	The rate of change of tilt between three points (A, B and C), measured at set distances apart (usually 10 m). The curvature is plotted at the middle point or point B and is usually concave in the middle of the panel and convex near the panel edges. i.e. curvature = (tilt between points A and B - tilt between points B and C)/(average distance between points A to B and B to C) and usually expressed in 1/km. Radius of curvature is the reciprocal of the curvature and is usually measured in km (i.e. radius = 1/curvature). The curvature is a measure of surface ‘bending’ and is generally associated with cracking.
CWC Values	The Credible Worst-Case (CWC) prediction for the predicted impact Parameter and normally based on the Upper 95% or U99% 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.

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

Dynamic Subsidence Effects see **Transient Subsidence Effects.**

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

Extraction Plan Refers to the approval process for managing mine subsidence impacts, in accordance with the Department of Planning and Environment (DP&E) Development Consent document. The mine must prepare an Extraction Plan (EP) to the satisfaction of the Secretary, before the commencement of operations that will potentially lead to subsidence of the land surface.

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

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. The strains due to these movements are usually < 0.5 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.

First Workings The tunnels or roadways driven by a continuous mining machine to provide access to the longwall panels in a mine (i.e. main headings and gate roads). 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 <20mm.

Gate Roads The tunnels or roadways driven down both sides of the longwall block (usually in pairs), to provide airways and access for men, materials, and the coal conveyor to the longwall face. The conveyor side of the block is called the 'maingate' and dust laden air and coal seam gases are exhausted on the opposite side (called the 'tailgate').

Goaf	The extracted area that the immediate roof or overburden collapses into, following the extraction of the coal. The overburden above the ‘goaf’ sags, resulting in a subsidence 'trough' at the surface.
Greenfields Site	Refers to a mining area where no local data of ground response to underground mining exists. Subsidence predictions must therefore be based on experience gained from mining in other areas with similar geological conditions and appropriate engineering models.
Horizontal Displacement	Horizontal displacement of a point after subsidence has occurred above an underground mining area within the angle of draw. It can be predicted by multiplying the tilt by a factor derived for the near surface lithology at a site (e.g. a factor of 10 is normally applied for the NSW Coalfields).
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.
Longitudinal Subsidence Profile	Subsidence measured (or predicted) along a longwall panel or centre line.
Longwall	The method of extracting a wide block of coal (which will be 306.4 m wide in the case of the NCOPL longwalls) using a coal shearer and armoured face conveyor. Hydraulic shields provide roof support across the face and protect the shearer and mine workers. The longwall equipment is installed along the full width of the block in an 8 to 10 m wide installation road at the start of the block before retreating 2 to 3 km back to the end of the block. The shields are progressively advanced across the full width of the face, as shearing continues in a sequence of backwards and forwards motions across the face. Depending on the geological and longwall equipment conditions, the longwall retreats at an average rate of about 80 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 impact parameter value (i.e. of subsidence, tilt and strain) predicted using a line of 'best fit' through a set of measured data points against key independent variables (e.g. panel width, cover depth, extraction height). The mean values are typically two-thirds to half of the credible worst-case values.

Mining Height Refers to the height or thickness of coal extracted along a longwall face.

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.

Shearing The shortening effect of compressive strains due to mine subsidence on surface terrain, which results in localised shearing movements of soils and rock.

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

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

Strain can be estimated by multiplying the curvature by a factor derived for the near surface lithology at a site (e.g. a factor of 10 is normally applied for the Newcastle Coalfield).

Study Area The area which may have features in it that could be impacted by the proposed mine. It is usually defined by a 26.5^{o} to 35^{o} angle of draw to 20 mm of vertical subsidence and up to 3 to 5 times the cover depth to limits of possible far-field horizontal displacement.

Sub-critical Longwall Panels Longwall panels that are deeper than they are wide (W/H < 0.6) and cause lower magnitudes of subsidence than shallower panels due to natural arching of the overburden across the extracted coal seam.

Subsidence The difference between the pre-mining surface level and the

	post-mining surface level at a point, after it settles above an underground mining area.
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 can't be protected by mitigation or amelioration works).
Subsidence Impact	The effect that subsidence has on natural or man-made surface and sub-surface features above a mining area.
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 (if close enough to seam level). The term was defined in an **ACARP, 2003** study into this phenomenon and is common in NSW Coalfields.
Super-Critical Longwall Panels	Longwall panels that are not as deep (H) as they are wide (W) (ie W/H > 1.4) and will cause complete failure of the overburden and maximum subsidence that is proportional to the mining height (i.e 0.58 to 0.6 T).
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.
Tilt	The rate of change of subsidence between two points (A and B), measured at set distances apart (usually 10 m). Tilt is plotted at the mid-point between the points and is a measure of the amount of differential subsidence. i.e. Tilt = (subsidence at point A - subsidence at point B)/(distance between the points) and is usually expressed in mm/m.
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 curvatures near the sides (or ends) of the panels.
Transverse Subsidence Profile	Subsidence measured (or predicted) across a longwall panel or cross line.

Transient Subsidence Effects	Refers to the subsidence tilt and strains associated with the subsidence ‘wave’ at the surface that travels behind the retreating longwall face. The transient tilts and strains are generally less than final subsidence profile values due to the retreat velocity of the longwall face.
Valley Closure	The inward (or outward) movement of valley ridge crests due to subsidence trough deformations or changes to horizontal stress fields associated with longwall mining. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and are usually visually imperceptible.
Valley Uplift	The phenomenon of upward movements along the valley floors due to **Valley Closure** and buckling of sedimentary rock units. Measured movements have ranged between 10 mm and 400 mm in the NSW Coalfields and may cause surface cracking in exposed bedrock on the floor of the valley (or gorge).

1.0 Introduction

This report presents a mine subsidence assessment for the proposed inclusion of Longwall (LW) 106 in the approved 2012 Extraction Plan (EP) for LW101 to LW105 in the Hoskissons Seam at the Narrabri Mine (NM). The mine is currently extracting LW104.

Predictions of credible worst-case subsidence, tilt, curvature, horizontal displacement, and strain have been made that include LW106. This report also provides a review of predicted v. measured subsidence effects and their impacts for LW101 to LW104.

The predictions have been prepared using the same methodology that was used to assess the current extraction plan (refer **DgS, 2012**).

2.0 Mining Geometry

2.1 Proposed Mining Geometry

The modified mine plan and surface features are shown in **Figures 1a-b** with cover depth, contours. The surface level and seam thickness contours are presented in **Figures 2a-b** and **3** respectively.

The following mine workings geometry has been assumed in this assessment:

- The longwall panel centre lines (LW101 to LW106) are located at a depth of approximately 160 m to 250 m below the surface and will be 306.4 m wide (void width).

- The panels will be formed towards the north from east to west orientated main headings.

- The first two longwall panels (LW101 and LW102) had an average face extraction height of 4.2 m in the bottom section of the 4.6 m to 10.5 m thick Hoskissons Seam. The face height will be ramped back to the gate roads at a height of 3.7 m at the Main Gate and Tail Gate ends.

- The face extraction height was increased to 4.3 m for LW103 and will be maintained as such through to LW106.

- One row of chain pillars will be continued to be formed between each longwall panel within the modified plan out to the tailgate for LW106. The pillar widths are nominally 30 m wide between LW101 to LW103, 35 m wide between LW103 and LW105 and 39.5 m between LW105 and LW106. The chain pillars are all nominally 93 m long and 3.5 m high.

- Three-heading gate roads and twin chain pillars with widths ranging from 28 m to 36 m will be formed for LWs 107 to 120, starting at LW106 Maingate.

- The gate roads are all nominally 5.4 m wide.

- The panel width to cover depth ratio (W/H) for the proposed mining layout will range from 1.23 to 1.92, indicating both *critical* and *supercritical* subsidence behaviour (assumed to occur when W/H >0.6 and >1.4 respectively). The chain pillars will have w/h ratios of 8.6 to 11.3 and expected to strain-harden (if overloaded) after mining is completed.

- The main headings pillars to the south of the longwalls are 27 m to 36 m wide and 30 m to 96 m long and designed to remain long-term stable.

2.2 Previous Environment Impact Assessment Mining Geometry

The longwall panels originally assessed for Stage 2 Longwall Project Environmental Assessment (EA) were 305.4 m wide with chain pillar widths ranging from 24.5 to 29.5 m wide. The proposed longwall mining height and roadway development height was 4.2 m and 3.7 m respectively. Roadway widths were nominally 5.5 m wide.

The current longwall panels are < 1% wider than the previously proposed panels for the EA Report. The current chain pillars however, are approximately 20% wider than the EA mining layout. Overall, it is considered that the modified mining geometry has not changed significantly to the previously proposed panels presented in the EA Report.

3.0 Surface Features

3.1 LW101 to LW106

The land above the proposed LW101 - LW106 (i.e. the study area) comprises private land holdings used primarily for livestock grazing with some cereal crop farming. It is understood that NM now owns most of the private land holdings above the proposed longwalls. The land to the west of the proposed longwalls is overlain by native woodlands and the Jacks Creek and Pilliga East State Forests.

Topographic relief above the proposed longwalls ranges from 270 m AHD to 320 m AHD. The surface terrain is generally flat with slopes 2^o - 5^o. Slopes increase to 10^o - 15^o in several of the ephemeral creeks and tributaries (or gullies) of Pine Creek, which drain the mine site towards the north-east. There are no cliffs present in this area.

Sandy alluvial deposits (up to 15 m deep) exist along the creek channels with no rock exposures evident. Silty sand and sandy clay surface soils present on the mine site are mildly to highly erosive / dispersive if exposed to concentrated runoff.

Vegetation across the current EP area consists of some stands of cypress pine and box gum forest with shrubs and grasses across the agricultural land use areas and riparian zones along creeks.

The existing surface features within the zone of expected subsidence due to LW101 to LW106 include the following:

- Semi-cleared, gently undulating terrain (that is owned by the mine).
- Ephemeral watercourses and creeks (Pine Creek and Pine Creek Tributary 1).
- Poor quality sub-surface groundwater aquifers at depths ranging from 5 m to 50 m.
- Ten Aboriginal Heritage sites of 'High' Archaeological Significance, comprising five scattered artefact sites (No. 38, 39.1 to 39.4), one open camp site (No. 43), two Scared Trees (No. 20 and 123) and two open grinding groove site (No. 10b and 122).
- Thirty-six Aboriginal Heritage sites of 'Low' Archaeological Significance, comprising scattered and individual artefacts.
- Two disused orange orchard groves, two buildings and one above ground tank (LW105).
- Fifteen unsealed access roads and property fences.
- Eleven earth embankment dams (all full at present).
- Single-phase suspended power lines and 15 timber power poles (domestic).

- Soil conservation banks (contour banks).

Natural features of note above LW106 include Pine Creek, several ephemeral watercourses and moderate slopes up to 15^{o}. The built features above LW106 include five farm dams, private unsealed access roads and property fence lines. There are no farm structures, power lines or Aboriginal Heritage sites above the panel's extraction limits.

Mine site infrastructure includes temporary gas drainage pipe lines to drainage wells above the panels and gate roads. The pipes are inspected for subsidence damage and de-commissioned as required after mining progresses.

Pit top infrastructure and the Kamilaroi Highway and Northern Branch Railway Line are > 1.9 km to the east of LW101 to 106 and considered to be outside the likely limits of far-field displacement and strain.

The study area with the above feature locations are shown in **Figures 1a/b**, **2a/b**.

3.2 Subsidence Monitoring Lines

The following subsidence monitoring lines have been installed above LW101 to LW104:

- Lines 101 and 102 are full centrelines above LW101 and LW102;
- Line A cross line above LW101 to LW105;
- Line 103 North and South are partial centre lines above the start and finishing ends of LW103;
- Line 104 North is a partial centreline above the starting end of LW104;
- Line B is a longitudinal line along Pine Creek Tributary 1 with transverse lines C, E to G at 300 m spacing;
- Line D is a longitudinal line along Pine Creek;
- Power pole survey markers at base and tops of poles.

The survey line locations are shown in **Figure 1c**.

The subsidence lines consist of pheno markers installed at 10 m spacing and anchored into the soil profile. The pegs are surveyed using a total station utilising static point control before and after mining effects. The surveys indicate systematic errors between surveys ranging from -20 mm to 45 mm and/or soil moisture movement effects.

4.0 Subsidence Prediction Methodology

Single panel subsidence may be estimated using the empirical subsidence curves presented in **ACARP, 2003**. The prediction curves were initially developed from measured subsidence and mining geometry from the Newcastle Coalfield longwall mines with a wide range of geological conditions. Data from other NSW Coalfields has been added by DgS over the past 8 years. Single panel subsidence is mostly due to strata sag above an extracted longwall panel with compression of goaf edges also contributing.

The collapsed ground above the extracted panel of coal collapses into the void to form the 'goaf' which provides some support to the sagging strata and mitigates the magnitude of subsidence to a proportion of the mining height. The subsidence above a single longwall panel depends on the Subsidence Reduction Potential (SRP) of strata units within the overburden (see **Figure 4**), the width of the panel, the cover depth and mining height; see **Figure 5a**.

When several panels are extracted adjacent to each other, further subsidence occurs due to the compression of the row of chain pillars left between the extracted panels. The prediction of the chain pillar subsidence is based on another empirical model developed using measured subsidence data for a given pillar and panel geometry. The subsidence is estimated based on the total pillar stress and mining height; see **Figure 5b**.

Multiple-panel effects are determined by the **ACARP, 2003** model by adding a proportion of the predicted chain pillar subsidence to the predicted single panel 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 and Final S_{max} for the NM longwalls have been predicted by adding 50% and 100% of the predicted subsidence over the chain pillars between the previous and current panels less the goaf edge subsidence above the maingate (because it's already included in the chain pillar subsidence prediction).

A conceptual model of multiple longwall panel subsidence mechanics is given in **Figure 6**.

First and Final Subsidence profiles above the mining area are then estimated after each panel is extracted, based on the maximum panel subsidence, chain pillar subsidence, goaf edge subsidence and the angle of draw distance to 20 mm of subsidence. The profiles are used to calibrate the Surface Deformation Prediction System (SDPS®), which uses a 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.

Further details of the subsidence predictions models used in this study are summarised in *Appendix A* of **DgS, 2012**.

5.0 Sub-Surface Conditions

5.1 Overburden

Typically, the overburden comprises thin to medium bedded siltstone and sandstone laminite with minor claystone between several massive 15 to 49 m thick units of conglomerate and basalt sills and lava flows. The depth of cover ranges from 160 to 250 m with depth of weathering typically varying from about 15 m to 35 m from the surface, although it can be as deep as 80 m below surface where there is also thick alluvial cover along some creek flats.

Previous reviews of available borehole data (see **Figure 7** for borehole locations) suggested there may be potential subsidence reducing units in the overburden (e.g. Digby Conglomerate, intrusive basalt sill in the Napperby Formation and basalt lava flows of the Garrawilla Volcanics.

A summary of the thickness of the massive units and their location in the overburden sequence (in descending order) is presented in **Table 1**.

Table 1 - Summary of Massive Strata Units above LW101 to LW106

Lithological Unit	Massive Unit Thickness, t (m)	Unit Distance Above Proposed LWs, y (m)	Laboratory UCS Strength Range [Mean] (MPa)
Garrawilla Volcanics*	1 - 49	129 - 169	65 - 252 [140]
Intrusive Basalt Sill	7 - 20	50 - 69	91 - 189 [140]
Digby Conglomerate	14 - 25	0.4 - 12	21- 42 [28]

* - The first 15 to 80 m below the surface may be affected by weathering. Unit may have a maximum thickness of only 20 m (**MGS, 2006**)

Based on a review of subsidence data above LW101 to LW104 in **Section 6**, it is concluded that none of the massive units have reduced subsidence to-date. Subsequent predictions of maximum subsidence above the longwalls has therefore assumed the overburden will have Low SRP.

5.2 Immediate Mine Workings Conditions

The Hoskissons Seam ranges in thickness from 4.6 to 10 m in the study area, sub-cropping to the east at 130 m AHD. Based on bore core testing results, the proposed mining section of the seam comprises low to moderate strength coal (UCS of 20 to 40 MPa) with minor carbonaceous siltstone / mudstone bands. The proposed mine roof coal consists of similar strength coal with a higher proportion of low strength carbonaceous siltstone / mudstone (35% to 40% of roof section thickness).

The immediate roof of the proposed development roads will consist of 0.4 to 5 m of coal, with overlying interbedded siltstone and sandstone laminite with minor mudstone (UCS ranges from 33 MPa to 36 MPa) and/or conglomerate of the Digby Formation (UCS ranges from 21 MPa to 42 MPa) in the first 30 m or so above the seam.

The floor of the development roadways will comprise moderate strength carbonaceous siltstone / mudstone and sandstone (UCS ranges from 30 to 45MPa) with low slaking potential.

It is assessed that the immediate roof and floor strata conditions are within the range of the empirical database cases and may be used to estimate the chain pillar subsidence reliably at NM.

The prediction model outcomes have also been validated against measured subsidence data for LW101 to LW104; see **Section 6**.

6.0 Review of Subsidence Predictions v. Measured Data

The measured subsidence effects above LW101 to LW104 are compared to predicted mean and U95%CL values presented in **Tables 2A** and **2B**.

The review of measured First Maximum Subsidence above LW101 to LW102 full centrelines indicates that the 95th percentile S_{max} along centreline for LW101 was 0.6T or 2.52 m, and 0.63T or 2.65 m for LW102 (for a mining height of 4.2m) - see **Figures 8a** and **8b**.

The partial centreline profiles for the start and finishing ends of LW103 and start end of LW104 is shown in **Figures 8c** and **8d** respectively. The U95%CL values of 0.63T are considered to be reasonable estimates for these two panels as first goafing subsidence is usually higher than the rest of the panel once the goafing process has been established.
The increase in panel subsidence after the first panels has been extracted is also due to tailgate chain pillar compression; see **Figure 8e**.

The subsidence prediction model (DgS modified **ACARP, 2003**) used in the approved LW101-LW105 EP estimated a maximum subsidence of 2.44 m or 0.58T. Although the predicted values for LW101 to LW104 have been within 15% of the measured results, the model has now been adjusted to match to reflect the actual 95%CLs for subsequent panels as follows:

- Single Panel S_{max}/T increased from 0.58 to 0.60 for LW101 and 0.63 from LW102 to LW106 (see **Figures 3a,b**).

- Final maximum panel S_{max}/T has been increased to 0.64 for LW101 to LW106.

The chain pillar subsidence model appears to be conservative, with measured values to-date plotting below the mean curve (see **Figures 5b**).

The empirical models used to estimate maximum tilt, curvature and strain are presented with measured NM data in **Figures 9a** to **9d** respectively. Points of note include:

- The maximum tilt database is satisfactorily captured by the empirical model; see **Figure 9a**.

- Convex and concave curvature models now also capture 95% of the database (see **Figures 9b-9c**) with U95%CL Curvature = 2.5 x Mean Curvature.

- The Maximum Horizontal Strain = 10 x Maximum Curvature. Discontinuous movements such as cracking and compression humping may increase the maximum values by 2 to 4 times. The U95%CL Strain value has been assessed to be approximately 25 x mean curvature or 10 x U95%CL Curvature; see **Figure 9d**.

- Supercritical width appears to occur at 1.2H instead of 1.4H, based on measured tilts, curvatures and strains to-date; see **Figures 9a** to **9c**.

The DgS Modified **ACARP, 2003** models have been calibrated / validated against the measured data, with adjustments made to the maximum panel subsidence as described above. The predicted values for the modified mining layout for LW101 to LW106 are presented in **Section 7**.

Table 2A - Summary of Measured v. Predicted EIS Subsidence above LW101 to LW104

LW#	Survey Line	Panel Width W (m)	Cover Depth H (m)	W/H	Chain Pillar Width w_{cp} (m)	Mining Height T (m)	Total Pillar Stress (MPa)	First Maximum Subsidence First S_{max} (m)		Final Chain Pillar Subsidence S_p (m)		Final Maximum Subsidence Final S_{max} (m)	
								Pred.	Meas.	Pred.	Meas.	Pred.	Meas.
101	CL101N	306.4	165	1.86	29.8	4.2	15.3	2.44	2.57	0.42	-	2.44	2.62
	CL101S	306.4	175	1.75	29.8	4.2	16.5	2.44	2.49	0.49	-	2.44	2.55
	XLA	306.4	165	1.86	29.8	4.2	15.0	2.44	2.44	0.44	0.118	2.44	2.516
102	CL101N	306.4	180	1.70	28.8	4.2	18.1	2.44	2.60	0.52	-	2.44	2.64
	CL101S	306.4	185	1.66	28.8	4.2	18.9	2.44	2.64	0.54	-	2.44	2.66
	XLA	306.4	175	1.75	28.8	4.2	17.6	2.44	2.52	0.50	0.183	2.44	2.58
103	CL101N	306.4	195	1.57	34.8	*4.3*	18.1	2.44	2.67	0.44	-	2.44	-
	CL101S	306.4	200	1.53	34.8	*4.3*	18.9	2.44	2.49	0.55	-	2.44	-
	XLA	306.4	195	1.57	34.8	*4.3*	17.6	2.44	2.59	0.53	-	2.44	-
104	CL104N	306.4	180	1.70	39.8	*4.3*	16.0	2.44	2.75	0.57	-	2.44	-

italics - predictions based on mining height of 4.2 m, which was increased to 4.3 m after EIS report.

Table 2B - Summary of Measured and Predicted EIS Subsidence Effects above LW101 to LW104

LW#	Survey Line	Final Goaf Edge Subsidence S_{goe} (m)		Angle of Draw to 20mm Subsidence Contour (o)		Maximum Tilt T_{max} (mm/m)		Maximum Compressive Strain $_{-}E_{max}$ (mm/m) [meas/pred]		Maximum Tensile Strain $_{+}E_{max}$ (mm/m) [meas/pred]	
		Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.
101	CL101N	0.22	0.31	21.2	23.0	47	46.3	14.4 [1.1]	15.9	11.4 [1.0]	11.4
	CL101S	0.23	0.11	21.4	13.7	41	31.1	12.0 [1.3]	**15.6**	9.5 [0.6]	5.9
	XLA	0.22	0.11	21.2	11 - 23.5	47	50.4 - 54.3	14.4 [1.0]	10.9 - 14.3	11.4 [1.3]	13.5-**14.7**
102	CL101N	0.24	0.205	21.7	15.5	40	43.7	11.4 [4.1]	**46.7**	9.0 [2.3]	**20.5**
	CL101S	0.24	0.16	21.7	20.6	38	29.8	10.8 [0.6]	6.4	8.5 [0.9]	7.4
	XLA	0.24	0.17	21.7	14.0	41	**48.5** - **56.3**	12.0 [2.2]	12.3 - **26.7**	9.5[1.6]	10.9-**15.2**
103	CL101N	0.24	0.25	21.9	23.4	43	39	12.8 [2.2]	**27.9**	10.1[1.5]	**14.7**
	CL101S	0.24	0.16	21.9	14.0	34	29.3 - 30.3	9.2 [0.9]	8.5	7.3[1.3]	**9.3**
	XLA	0.24	0.25	21.9	23.2	35	29.3 - 36.6	9.7 [1.0]	5.9 - 9.6	7.6[1.5]	**11.0-11.6**
104	CL104N	0.24	0.18	21.8	17.3	40	41.7	11.4 [3.1]	**35.6**	9.0 [4.7]	**42.6**

Bold - measured value exceeds smooth profile prediction by > 15% (indicating discontinuous behaviour).

7.0 Subsidence Effect Predictions for LW101 to LW106

7.1 General

Total and differential subsidence predictions have been assessed across the study area after:

(i) each longwall block has been extracted, and

(ii) after mining of all of the proposed longwall panels is complete.

The assessment requires the consideration of the following:

- The subsidence reduction potential (SRP) of the overburden and the influence of proposed mining geometry on single panel subsidence development (i.e. whether the panels are likely to 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;

- 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 will be not be affected by the spanning potential of the Garrawilla Volcanics, Basalt Sill or Digby Conglomerate units and the subsidence above the chain pillars between the panels. Subsidence predictions have therefore only considered Low SRP for the worst-case scenario and measured subsidence profiles for LW101 to LW104.

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

7.2 Maximum Single Panel Subsidence

The maximum subsidence above a single longwall panel will depend upon its width (W), cover depth (H), seam thickness (T), and the SRP of the overburden.

Based on reference to the **ACARP, 2003** model, the relevant depth category for LW101 - LW106 is 200 m +/- 50 m cover depth. The depth categories were developed in the **ACARP, 2003** study to cater for the influence of scale on the overburden spanning behaviour above panels of a given geometry.

The maximum subsidence, S_{max} for a single 306.4 m wide longwall panel at 160 to 250 m depth with 'Low' SRP overburden is summarised in **Table 3** based on face extraction heights of 4.2 and 4.3 m.

The values were determined along five representative cross lines (XL1 - 5); see **Figure 1c** for their locations above the proposed mining layout.

Table 3 - Predicted Maximum Single Panel Subsidence for LW101 to LW106

LW	XL	Cover Depth, H (m)	W/H	Mining Height T (m)	SRP	Single S_{max}* (m)	
						Mean	U95%CL
1	3	165	1.86	4.2	Low	2.442	2.52
	4	165	1.86	4.2	Low	2.442	2.52
	5	177	1.73	4.2	Low	2.478	2.52
2	3	180	1.70	4.2	Low	2.478	2.52
	4	175	1.75	4.2	Low	2.478	2.52
	5	188	1.63	4.2	Low	2.478	2.52
3	2	190	1.61	4.3	Low	2.537	2.58
	3	195	1.57	4.3	Low	2.516	2.58
	4	195	1.57	4.3	Low	2.516	2.58
	5	200	1.53	4.3	Low	2.487	2.58
4	1	180	1.70	4.3	Low	2.537	2.58
	2	200	1.53	4.3	Low	2.487	2.58
	3	210	1.46	4.3	Low	2.433	2.58
	4	215	1.43	4.3	Low	2.408	2.58
	5	215	1.43	4.3	Low	2.408	2.58
5	1	200	1.53	4.3	Low	2.487	2.58
	2	215	1.43	4.3	Low	2.408	2.58
	3	225	1.36	4.3	Low	2.349	2.56
	4	235	1.30	4.3	Low	2.319	2.53
	5	235	1.30	4.3	Low	2.319	2.53
6	1	220	1.39	4.3	Low	2.382	2.58
	2	240	1.28	4.3	Low	2.306	2.52
	3	245	1.25	4.3	Low	2.295	2.51
	4	255	1.20	4.3	Low	2.276	2.49
	5	250	1.23	4.3	Low	2.285	2.50

SRP - Subsidence Reduction Potential: L = Low, M = Moderate, H = High.
* - Maximum subsidence limited to 60% of mining height for the mean and U95%CL (refer to **ACARP, 2003**).

The results of the single panel spanning assessment indicate that the maximum panel subsidence for the no spanning volcanic units) will range between 2.44 and 2.58 m (58% to 60% mining height, T).

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

7.3 Maximum Predicted Subsidence Above Chain Pillars

The predicted subsidence values above the chain pillars have been estimated based on an empirical model of the roof-pillar-floor system.

The empirical model has been developed from measured subsidence data over chain pillars (S_p) divided by the face extraction height (T) v. the total pillar stress after longwall panel extraction on both sides, see **Figure 5b**.

The database indicates that when pillar stresses are < 20 MPa, chain pillar subsidence is generally between 5% - 10% T. Between 20 and 40 MPa, the chain pillars start to 'soften' or yield with subsidence increasing to around 15% - 25%T. Above 40 MPa the subsidence does not increase over 30%T, which indicates strain hardening behaviour is occurring and suggests that some of the pillar load will be re-distributed to the adjacent goaf (which also strain hardens) after yielding of the pillar starts to occur.

It is apparent from the measured data **Figure 5b** that the subsidence above the pillars is a function of the strength and stiffness of the coal and surrounding rock mass (i.e. higher subsidence was measured above a pillar with a weak shale roof compared to a pillar with a strong sandstone floor (all other strata and coal properties were similar)).

The database includes longwall mining heights of 2 m to 4.8 m with pillar development heights of 2 to 3.5 m. Pillar widths range from 18 m to 40 m (and one case of 80 m) with corresponding w/h ratios of 7.4 to 25.8. The proposed longwall extraction face and development heights of 4.2 m to 4.3 m and 3.5 m are within the database limits.

7.3.1 Empirical Model Stress

The estimate of the total stress acting on the chain pillars on each side of the panel under double abutment loading conditions is based on the abutment angle concept described in **ACARP, 1998a**. The total stress acting on the chain pillars after mining is completed, was estimated as follows:

σ = pillar load/area = $(T+A_1+A_2)/wl$

where:

T = full tributary area load of column of rock above each pillar;

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

$A_{1,2}$ = total abutment load from each side of pillar in MN/m, and

= $(l+r)\rho g(0.5W'H - W'^2/8\tan\phi)$ (for sub-critical panel widths) or

= $(l+r)(\rho g H^2 \tan\phi)/2$ (for super-critical panel widths);

w = pillar width (solid);

l = pillar length;

r = roadway width;

H = depth of cover;

ϕ = abutment angle (normally taken to be 21º) and

W' = effective panel width (rib to rib distance minus the roadway width).

A panel is deemed sub-critical when $W'/2 < H\tan\phi$.

7.3.2 Empirical Model Pillar Strength and FoS

As presented in **ACARP, 1998b** the FoS of the chain pillars were based on the strength formula for 'squat' pillars with w/h ratios > 5 as follows:

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

where:

h = pillar development height;

Θ = a dimensionless 'aspect ratio' factor or w/h ratio in this case.

The FoS was then calculated by dividing the pillar strength, S, with the pillar stress, σ.

7.3.3 Results

The predicted mean and Upper 95%CL subsidence values above the proposed chain pillars (under double abutment loading conditions and a mining height of 4.2 m) are summarised for representative cross lines XL1to 5 in **Table 4**.

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

LW	XL	Cover Depth, H (m)	Mining Height T (m)	Chain Pillar Width w (m)	Pillar w/h	Chain Pillar Stress (MPa)	Pillar FoS under DA Loading Conditions	Modified Layout Sp First (m) mean	Modified Layout Sp First (m) U95%	Modified Layout Sp Final (m) mean	Modified Layout Sp Final (m) U95%
1	3	165	4.2	29.8	8.5	15.3	1.66	0.18	0.26	0.21	0.30
	4	165	4.2	29.8	8.5	15.0	1.70	0.17	0.26	0.21	0.29
	5	177	4.2	29.8	8.5	16.9	1.51	0.21	0.37	0.25	0.42
2	3	180	4.2	29.8	8.5	17.6	1.45	0.22	0.39	0.27	0.43
	4	175	4.2	29.8	8.5	17.2	1.49	0.21	0.38	0.25	0.42
	5	188	4.2	29.8	8.5	18.7	1.36	0.25	0.41	0.29	0.46
3	2	190	4.3	34.8	9.9	16.9	1.84	0.21	0.29	0.25	0.33
	3	195	4.3	34.8	9.9	18.0	1.73	0.23	0.31	0.27	0.36
	4	195	4.3	34.8	9.9	18.3	1.70	0.24	0.32	0.28	0.37
	5	200	4.3	34.8	9.9	18.7	1.66	0.24	0.33	0.29	0.38
4	1	180	4.3	39.5	11.3	14.7	2.54	0.17	0.25	0.20	0.28
	2	200	4.3	39.5	11.3	17.1	2.19	0.21	0.29	0.25	0.34
	3	210	4.3	34.8	9.9	20.3	1.54	0.28	0.45	0.34	0.51
	4	215	4.3	34.8	9.9	21.4	1.46	0.31	0.48	0.37	0.54
	5	215	4.3	34.8	9.9	21.4	1.46	0.31	0.48	0.37	0.54
5	1	200	4.3	39.5	11.3	17.4	2.15	0.22	0.30	0.26	0.34
	2	215	4.3	39.5	11.3	19.8	1.89	0.27	0.35	0.32	0.41
	3	225	4.3	39.5	11.3	21.0	1.78	0.30	0.38	0.36	0.44
	4	235	4.3	39.5	11.3	22.5	1.66	0.34	0.42	0.41	0.49
	5	235	4.3	39.5	11.3	22.2	1.68	0.33	0.41	0.40	0.48

Notes:
1. DA = Double abutment loading conditions.
2. The chain pillars referred to in the above table are on the Maingate side or leading goaf edge.
3. Pillar height, h = 3.5 m.

The predicted first subsidence over the chain pillars (S_p) between the extracted panels LW101 to LW106 is estimated to range from 0.18 m to 0.48 m for the range of pillar sizes and geometries proposed. The final subsidence over the chain pillars (after mining is completed) is estimated to range from 0.21 m to 0.54 m (an overall increase of 20%).

The vertical stress acting on the pillars are estimated to range from 14.7 to 22.5 MPa with pillar FoS values of 2.54 to 1.36 estimated for a 3.5 m pillar height. The FoS is used in the empirical model to estimate the error band or U95%CL setting as follows:

- for cases with FoS ≥ 1.6, U95%CL error = 0.024T
- for cases with FoS < 1.6, U95%CL error = 0.048T

7.3.4 Bearing Capacity of Roof and Floor Strata

The bearing capacity of the roof/floor strata and chain pillar strength was firstly checked before appropriate rock mass Young's Modulii values were assigned for subsidence prediction under the assessed loading conditions.

Reference to **Pells *et al*, 1998** indicates that the bearing capacity of sedimentary rock under shallow footing type loading conditions is 3 to 5 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 and 165 MPa.

The estimated pillar stresses of 14.7 MPa to 22.5 MPa gives an FoS range of 4.1 to 11.2, which indicates that the roof and floor strata are likely to behave elastically.

7.4 Goaf Edge Subsidence Prediction

Based on the modified **ACARP, 2003** model, the mean and U95%CL goaf edge subsidence predictions of 0.08 to 0.31 m for the proposed longwall panels have been derived from the prediction curves shown in **DgS, 2012** and the maximum final panel subsidence range (see **Section 7.6**).

7.5 Angle of Draw Prediction

Reference to the **ACARP, 2003** longwall panel angle of draw predictions have been derived from the mean goaf edge subsidence predictions. The AoD to the 20 mm subsidence contour is estimated to range from 12.8^o to 24.6^o for the LW101 to LW106 based on the empirical model presented in **DgS, 2012**.

An AoD of 26.5^o is still considered to be an appropriate value for mine planning and impact management purposes near sensitive surface features.

7.6 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 first and final maximum multi-panel subsidence predictions (and associated impact parameters) are summarised in **Table 6** for representative cross lines (XLs 1 to 5) for LW101 to LW104 and the proposed LW105 and LW106.

The review of measured subsidence, tilt and strain above LW101 to LW104 has resulted in the previous assumption that supercritical subsidence effectively occurred at 1.4H to be reduced to 1.2H. The mean and U95%CL values for tilt and strain now represent continuous and discontinuous strata behaviour respectively. This supersedes the previous requirement to multiple the U95% values by 2 times or the mean values by 4 times to estimate the later scenario. If the model has been calibrated correctly, the measured tilts and strains should not be exceeded by more than 1.2 and 1.5 times the U95%CL values respectively, 5% of the time (i.e. occasionally). In regards to the subsidence predictions, the measured subsidence should not exceed the U95%CL values by more than 15%.

Table 6 - Predicted First and Final Maximum Subsidence Effects for LW101 to LW106 (Mean - Upper 95% Confidence Limits)

LW Panel #	Cross Line #	Cover Depth H (m)	Panel Width W (m)	Mining Height T (m)	W/H Ratio	Pillar Width w_{cp} (m)	First S_{max} (m)		Final S_{max} (m)		First Pillar S_p (m)		Final Pillar S_p (m)		Max Tilt* T_{max} (mm/m)		Maximum Strain* $+E_{max}$ & $-E_{max}$ (mm/m)			
																	tensile		compressive	
							mean	U95	mean	U95	mean	U95	mean	U95	mean	U95	mean	U95	mean	U95
101	3	165	306.4	4.2	1.86	29.8	2.44	2.67	2.58	2.69	0.18	0.26	0.21	0.30	47	71	10	26	13	33
	4	165	306.4	4.2	1.86	29.8	2.44	2.67	2.57	2.69	0.17	0.26	0.21	0.29	47	70	10	25	13	32
	5	177	306.4	4.2	1.73	29.8	2.48	2.69	2.65	2.69	0.21	0.37	0.25	0.42	44	66	9	23	12	29
102	3	180	306.4	4.2	1.70	29.8	2.52	2.69	2.65	2.69	0.22	0.39	0.27	0.43	43	65	9	22	11	28
	4	175	306.4	4.2	1.75	29.8	2.52	2.69	2.65	2.69	0.21	0.38	0.25	0.42	45	67	9	23	12	30
	5	188	306.4	4.2	1.63	29.8	2.52	2.69	2.65	2.69	0.25	0.41	0.29	0.46	40	61	8	20	10	26
103	2	190	306.4	4.3	1.61	34.8	2.54	2.75	2.71	2.75	0.21	0.29	0.25	0.33	41	62	8	20	10	26
	3	195	306.4	4.3	1.57	34.8	2.58	2.75	2.71	2.75	0.23	0.31	0.27	0.36	40	59	8	19	10	24
	4	195	306.4	4.3	1.57	34.8	2.58	2.75	2.71	2.75	0.24	0.32	0.28	0.37	40	59	8	19	10	24
	5	200	306.4	4.3	1.53	34.8	2.57	2.75	2.71	2.75	0.24	0.33	0.29	0.38	38	57	7	18	9	23
104	1	180	306.4	4.3	1.70	39.5	2.54	2.75	2.66	2.75	0.17	0.25	0.20	0.28	43	65	9	22	11	28
	2	200	306.4	4.3	1.53	39.5	2.55	2.75	2.71	2.75	0.21	0.29	0.25	0.34	38	57	7	18	9	23
	3	210	306.4	4.3	1.46	34.8	2.51	2.75	2.71	2.75	0.28	0.45	0.34	0.51	36	53	7	17	8	21
	4	215	306.4	4.3	1.43	34.8	2.49	2.75	2.71	2.75	0.31	0.48	0.37	0.54	34	52	6	16	8	20
	5	215	306.4	4.3	1.43	34.8	2.49	2.75	2.71	2.75	0.31	0.48	0.37	0.54	34	52	6	16	8	20
105	1	200	306.4	4.3	1.53	39.5	2.53	2.75	2.71	2.75	0.22	0.30	0.26	0.34	38	57	7	18	9	23
	2	215	306.4	4.3	1.43	39.5	2.48	2.71	2.71	2.75	0.27	0.35	0.32	0.41	34	52	6	16	8	20
	3	225	306.4	4.3	1.36	39.5	2.45	2.68	2.71	2.75	0.30	0.38	0.36	0.44	32	48	6	14	7	18
	4	235	306.4	4.3	1.30	39.5	2.43	2.66	2.71	2.75	0.34	0.42	0.41	0.49	30	45	5	13	7	17
	5	235	306.4	4.3	1.30	39.5	2.43	2.66	2.71	2.75	0.33	0.41	0.40	0.48	30	45	5	13	7	17
106	1	220	306.4	4.3	1.39	28 x 2	2.45	2.73	2.60	2.75	0.18	0.35	0.22	0.39	31	47	6	14	7	18
	2	240	306.4	4.3	1.28	28 x 2	2.40	2.67	2.58	2.75	0.23	0.40	0.28	0.44	27	41	5	12	6	15
	3	245	306.4	4.3	1.25	28 x 2	2.40	2.67	2.59	2.75	0.24	0.41	0.29	0.46	27	40	5	12	6	15
	4	255	306.4	4.3	1.20	28 x 2	2.39	2.67	2.61	2.75	0.27	0.44	0.33	0.49	25	38	4	11	6	14
	5	250	306.4	4.3	1.23	28 x 2	2.40	2.67	2.61	2.75	0.26	0.43	0.31	0.48	26	39	4	11	6	14

* - Predicted tilt and strains include 'smooth' profile (mean values) and 95% of the discontinuous profile (U95%CL values). Subsidence, tilt and strain measurements may exceed the predicted U95%CL values by up to 1.15, 1.2 and 1.5 times respectively 5% of the time (i.e. occasionally).

The predicted mean and credible worst-case (U95%CL) subsidence effect results for LW101 to LW106 are summarised below:

- **First maximum panel subsidence** ranges from 2.39 m to 2.75 m (55% to 64%T).
- **Final maximum panel subsidence** ranges from 2.57 m to 2.75 m (60% to 64%T).
- **Final maximum chain pillar subsidence** ranges from 0.21 m to 0.54 m (5% to 13%T)
- **Final maximum panel tilt** ranges from 25 to 47 mm/m for ‘smooth’ profile behaviour and from 38 to 71 mm/m due to discontinuous movements.
- **Final maximum panel concave curvatures** range from 0.6 to 3.3 km^{-1} (radii of curvature 1.66 km to 0.3 km)
- **Final maximum panel convex curvatures** range from 0.40 to 2.6 km^{-1} (radii of curvature 2.5 km to 0.38 km).
- **Final maximum panel compressive strains** range from 6 to 13 mm/m for ‘smooth’ profile behaviour and from 14 to 33 mm/m due to discontinuous movements.
- **Final maximum panel tensile strains** range from 4 to 10 mm/m for ‘smooth’ profile behaviour and from 11 to 26 mm/m due to discontinuous movements.

Note: The predicted U95%CL values may be exceeded occasionally (<5% of the time) due to local discontinuous strata movements associated with geological structure or topographic interaction.

7.7 Modified Mining Layout v. Approved 2012 Extraction Plan Subsidence Effect Predictions

A comparison between the extended mining layout and the approved 2012 Extraction Plan subsidence effect predictions for the ‘smooth’ profile case are summarised in **Table 7**.

Overall, the extension to the mine plan will not change the level of impact assessed in the 2009 Environmental Assessment or current 2012 extraction plan. However, based on a review of measured subsidence data for LW101 to LW104 and minor model input assumption (i.e. the supercritical panel width reduction) and output definition changes (i.e. discontinuous strata behaviour effects are now included in the U95%CL values provided), the revised subsidence effect predictions represent a marginally higher subsidence than the previous layout predictions (<15%).

The impact of the increased subsidence predictions will be discussed in **Section 9**.

Table 7 - Summary of Comparison between Modified Mining Layout and Approved 2012 EP or 2009 EA Predictions

LW No.	Cross Line	Final S_{max} (m)		Final Pillar S_p (m)		Tilt T_{max} (mm/m)		Horizontal Strain* (mm/m)			
								Tension		Compression	
		2015 Mod	2012 EP	2015 Mod	2012 EP	2015 Mod	2012 EP	2015 Mod	2012 EP	2015 Mod	2012 EP
101	3	2.69	2.44	0.30	0.44	47	47	26	23	33	29
	4	2.69	2.44	0.29	0.44	47	47	25	23	32	29
	5	2.69	2.44	0.42	0.49	44	41	23	19	29	24
102	3	2.69	2.44	0.43	0.52	43	40	22	18	28	23
	4	2.69	2.44	0.42	0.50	45	41	23	19	30	24
	5	2.69	2.44	0.46	0.54	40	38	20	17	26	22
103	2	2.75	2.44	0.33	0.44	41	43	20	20	26	26
	3	2.75	2.44	0.36	0.52	40	35	19	15	24	19
	4	2.75	2.44	0.37	0.53	40	35	19	15	24	19
	5	2.75	2.44	0.38	0.55	38	34	18	15	23	18
104	1	2.75	2.44	0.28	0.47	43	40	22	18	28	23
	2	2.75	2.44	0.34	0.51	38	37	18	16	23	20
	3	2.75	2.44	0.51	0.59	36	33	17	14	21	18
	4	2.75	2.44	0.54	0.63	34	32	16	13	20	17
	5	2.75	2.44	0.54	0.64	34	31	16	13	20	16
105	1	2.75	2.44	0.34	-	38	34	18	15	23	18
	2	2.75	2.44	0.41	-	34	33	16	14	20	18
	3	2.75	2.44	0.44	-	32	30	14	12	18	15
	4	2.75	2.44	0.49	-	30	30	13	12	17	15
	5	2.75	2.44	0.48	-	30	30	13	12	17	15
106	1	2.75	-	-	-	31	-	14	-	18	-
	2	2.75	-	-	-	27	-	12	-	15	-
	3	2.75	-	-	-	27	-	12	-	15	-
	4	2.75	*2.44*	-		25	*30*	11	*10*	14	*16*
	5	2.75	-	-	-	26	-	11	-	14	-

italics - 2009 EA Predictions for 305.4 m wide panels with a 4.2 m mining height.

Angle of draw predictions presented in the approved 2012 EP ranged from 12^o to 22.5^o for the then proposed LW101 to LW105 and predicted goaf edge subsidence range of 0.07 m to 0.25 m.

The revision of the predicted values for LW101 to LW106 are < 24.6^o and < 0.31 m and within the range expected due to the maximum subsidence increase from 2.44 m to 2.75 m discussed.

7.8 Subsidence Profile Predictions

For completeness, the predicted subsidence profiles for LW101 to LW106 panels for XL4 are presented with measured profiles along XL A; see **Figures 10a** to **10c**.

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 U95%CL panel subsidence and mean chain pillar subsidence values to be consistent with previous assessments of worst-case scenarios.

8.0 Prediction of Subsidence Impact Parameter Contours

8.1 Calibration of SDPS 3D-Influence Function Model

Credible worst-case subsidence contours for the extended mining layout have been derived using the **SDPS®** program from the predicted subsidence profiles along XLs 1 to 5. 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 8**

Table 8 - SDPS® Model Calibration Summary

Input Parameters	**Value**
Panel No.s (refer to **Figures 1a** and **1b**)	1-5
Panel Void Width, W (m)	306.5
Cover Depth, H (m)	160 - 250
Mining Height, T (m)	4.2 to 4.3
W/H range	1.20 - 1.86
SRP for Mining Area	Low
Maximum Final Panel Subsidence Range, S_{max}(m)	2.69 - 2.75
S_{max}/T Range for Panels	0.63 - 0.64
Chain Pillar Widths (m)	29.8 - 39.5
Gate road Heading and Cut-through Widths (m)	5.4
Chain Pillar Subsidence (m)	0.21 - 0.54
Modified **ACARP, 2003** Inflection Point Location (d) from Rib-side/Cover Depth (H): d/H	0.30 - 0.31
Modified **ACARP, 2003** Inflection Point Location from Rib-side, d (m)	65 - 90
Calibration Results for Best Fit Solution to the Modified ACARP, 2003 Model Predictions^	**Optimum Value**
Influence Angle (tan(beta))	2.0*
Influence Angle (degrees)	63*
Supercritical Subsidence Factor for Panels and Pillars (S_{max}/T)	61.0 - 70.8*
Mean Distance to Inflexion Point from Rib-Sides (m)	50 - 75*

^ - See SDPS manual extract in Appendix A of **DgS, 2012** for explanation of methodology and terms used.
* - 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).

Representative SDPS v. ACARP model outcomes are presented in **Figures 11a** to **11c** for subsidence, tilt and strain profiles along XL 4.

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

The 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 2 to 4 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.

8.2 Predicted Subsidence Effect Contours

Based on the calibrated SDPS® model, predictions of final subsidence contours for LW101 to LW106 are shown in **Figure 12a**.

Associated subsidence effect contours of principal tilt, horizontal strain and displacement have been subsequently derived using the calculus module provided in **Surfer12®** and the predicted subsidence contours. The outcomes are shown in **Figures 12b** and **12c**.

The pre and post mining surface levels have been generated from the subsidence contours and are shown in **Figure 13a** and **13b** respectively.

Subsidence impacts to the natural and built surface features are discussed in **Section 9**.

9.0 Subsidence Impacts

9.1 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 consultants assessment of the impacts upon and development of management strategies for the existing natural features, developments and heritage sites of the NM.

Due to the uncertainties associated with mine subsidence prediction for a given mining geometry and geology etc, 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 9**, and are based on probabilistic terms used in **AGS, 2010** and **Vick, 2002**.

Table 9 - 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**.

It should be also be understood that the terms ‘mean’ and ‘credible worst-case’ used in this report generally infer that the predictions will be exceeded by 50% and 5% of panels mined with similar geometry and geology etc. Using lower probability of exceedence values (i.e. <5% probability of exceedence) may result in false-positives or potentially uneconomic mining layouts.

9.2 Surface Cracking

9.2.1 Predicted Effects and Impacts

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 and the point of inflexion, which is where convex curvatures and tensile strains will develop. The point of inflexion is assessed to be located 65 to 90 m from the panel ribs for the range of mining geometries proposed. Tensile fractures can also develop above chain pillars that are located between extracted panels.

The compressive shear fractures or shoving zones will generally develop in the area above the longwall panel and inside the inflexion points.

Based on the predicted range of maximum transverse tensile strains (i.e. 4 to 26 mm/m) for cover depths of 160 m to 250 m, maximum surface cracking widths of between 40 mm to 260 mm may occur above the panels and within the limits of extraction.

It should be understood that 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, that the crack widths are increased (once they occur) in direct proportion to the measured tilts due to rigid body rotation of the subsided slope. Whilst this effect is unlikely to occur above LW101 - LW106 generally, the crack widths may exceed the predicted range near steep creek banks along Pine Creek and its tributaries.

Based on reference to **ACARP, 2003**, the cracks will probably have developed by the time the longwall face has retreated past a given location for a distance equal to 1 to 2 times the cover depth. Cracks will usually develop within several days after a mine 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 several weeks later.

The cracks in the tensile strain zones will probably be tapered and extend to depths ranging from 5 to 15 m, and possibly deeper in near surface rock exposures. Cracks within compressive strain zones are generally low-angle shear cracks caused by failure and shoving of near surface strata. Some tensile type cracks can also be present due to buckling and uplift of near surface rock, if it exists (see **Section 9.5**).

The cracks usually develop in groups of two or three over a tensile zone of 20 m in width. Once the cracks develop, the strain is usually relieved in the adjacent ground, however, the topography and near surface geology also can influence the extent of cracking.

Surface crack widths (in mm) have been estimated by multiplying the predicted strains by 10 (and assuming a 10 m distance between survey pegs). The above crack width estimation method assumes all of the strain will concentrate at a single crack between the survey pegs. This can occur where near surface bedrock exists, but is more likely to develop as two or three smaller width cracks in deep alluvial soil profiles. Therefore, the crack widths are expected to be wider on ridges than along sandy-bottomed creek beds (generally).

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 angle, vertical jointing and the subsidence at the toe of the slope.

9.2.2 Review of Observed Surface Cracking

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 measured cracks have therefore been within the predicted crack width ranges of between 40 mm and 220 mm in the approved EP Report for LW101 to LW105. The revised cracking width range of 40 mm to 260 mm for LW101 to LW106 is therefore likely to be conservative. It is noted that the largest cracks are predicted over LW101 to LW104, with cracking over LW106 expected to range between 40 mm to 110 mm.

9.2.3 Impact Management Strategies

The practical options available for controlling 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 widths in Autocad.

- Repair large surface cracks if they occur, but usually after subsidence development for a given longwall. *Note: Temporary fencing may be necessary before effective repairs can be completed.*

- Decrease mining height and/or panel width to limit subsidence and hence tensile strains; *Note: This option will require local subsidence and sub-surface monitoring data to make effective and reliable changes to the mining layout.*

- Leave a barrier pillar beneath a sensitive area or limit mining to first workings.

Surface crack repair works (such as ripping or ploughing and re-seeding or pouring gravel or grout into large, deep cracks) may need to be implemented around the affected areas of the lease, and in particular, any public (or private) access roads or ephemeral watercourses that do not infill naturally with sediment due to natural geomorphic processes.

9.3 Sub-Surface Cracking

9.3.1 Sub-Surface Fracturing Zones

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. 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 subsurface fracturing; see **Figures 14a** and **14b**. The zones are based on the **Forster, 1995** and **ACARP, 2007** models and are defined (in descending order) as follows:

- Surface Zone (D-Zone) - Unconstrained
- Elastic Zone (C-Zone) - Constrained
- Discontinuous Fracture Zone (B-Zone) - Constrained
- Continuous Fracture Zone (A-Zone) - Unconstrained
- Caved Zone (included in the A-Zone) - Unconstrained

Further details of the sub-surface fracture mechanics, including the strain and permeability increases in the A, B and C-Zones is presented in **Appendix A**.

9.3.2 Sub-Surface Fracture Height and Constrained Zone Thickness Prediction Models

The prediction of connective subsurface 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)
- Mining 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 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 by DgS for the NM site using recently developed Pi-Term empirical models (**Ditton & Merrick, 2014**). The models have been validated to measured NSW case studies with a broad range of mining geometries and geological conditions. Details of the *Geometry* and *Geology* Pi-Term Model's development are presented further below and in **Attachment A**.

The Pi-term models are based on a conceptual model of the subsurface fracturing that develops above a longwall panel with varying mining geometry and geology; see **Figure 14c**. A database of measured (interpreted) heights of A 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 included).

The conceptual model demonstrates that longwall panel geometries and overburden geology determine the height of 'continuous' and 'discontinuous' fracturing. Continuous fractures above the mine workings tend to form up into the overburden at an angle of 12^o to 19^o from the rib sides, based on physical and numerical modelling observations and subsidence data; see **Figure 14d**. The extent of vertical fractures above the mine workings (i.e. the A-Zone) will 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'.

A review of measured heights of A-Zone fracturing and borehole data above longwall panels in NSW and Queensland Coalfields in **Ditton and Merrick, 2014** demonstrates the overburden develops an effective strata unit thicknesses (t') that limits the A-Zone at a given height above a longwall; see **Figure 14e**. 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 data base bias when applying the model in different coalfields. The t' may also be calibrated to local mine site data.

Continuous sub-surface fracture height predictions (A) for LW101 to LW106 have 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 and Merrick, 2014)**

- Geology Pi-Term Model ($A = 1.52W'^{0.4} H'^{0.535} T^{0.464} t'^{-0.4}$) (**Ditton and Merrick, 2014**)

- Panel Width-based model (A=1.0W - 1.5W) **(SCT, 2008)**

- Mining Height-based model (A= 21 - 33T) **(Forster, 1995)**

Details of the development of each model and their limitations are provided in **Appendix A**

9.3.3 Geometry Pi-Term Model

The model was developed in 2013-14 in response to several Planning Assessment Commission concerns in regards to large apparent differences between established prediction methods that use only one parameter in a particular coalfield (eg the mining height v. panel void width models).

The Geometry Pi-term model considers the influence of the panel width, cover depth and mining 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.

A-Zone Prediction Model:

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:

Mean A/W’ = 2.215 (H/W’)$^{0.271}$(T/W’)$^{0.372}$ R^2 = 0.61 (rmse=21%)

U95%CL A/W’ = Mean A/W’ + a

where

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

H = cover depth = maximum potential goaf load height

W’ = effective panel width = minimum of W and 1.4H.

T = mining height.

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

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

B-Zone Prediction Model:

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

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

U95% B/W’ = Mean B/W’ + b

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

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

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

9.3.4 Geology Pi-Term Model

Further to the Geometry Model, the Pi-term Geology model also considers the influence of the panel width, cover depth and mining height with the inclusion 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; see **Figure 14e**.

A-Zone Prediction Model:

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:

$\underline{\text{Mean } A/W' = 1.52\,(H/W')^{0.535}(T/W')^{0.464}(t'/W')^{-0.4}}$ $R^2 = 0.8$ (rmse=15%)
$\underline{\text{U95\%CL } A/W' = \text{Mean } A/W' + a}$

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 = maximum potential goaf load height.

W’ = effective panel width = minimum of W and 1.4H.

T = mining height.

t’ = effective strata unit thickness in the overburden above the A-Zone and ranges between 16 m and 54 m across the Newcastle Coalfield with a median value of 20 m. (see *Section A11.4.4* in **Appendix A** for further details).

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

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

B-Zone Prediction Model:

It is considered that the Geology Pi-Term model is superior to the Geometry Pi-Term Model as the t’ factor may be back-analyzed to local height of A-Zone fracture height measurements once mining commences.

The two models are likely to provide conservative predictions if massive strata are present in the overburden with the capability to span the goaf and ‘truncate’ the A-Zone heights.

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

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

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

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:

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

9.3.5 Panel Width-Based Models

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

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

A = 1.0W to 1.5W

The width-based models do not consider the effect of cover depth or mining height and also assume the A-Zone will continue to increase above *supercritical* panel geometries. This usually means that surface to seam connectivity will 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 presented in **Appendix A** indicate that only 2 or 3 cases out of 14 (15% - 20%) or 1 in 5 supercritical longwalls have resulted in surface to seam connectivity; see **Figure 14d**.

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

9.3.6 T-Based Model

The height of the A-Zone fracturing has been successfully predicted from relationships established with extensometer and piezometeric 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 located at horizons just above the extracted coal seams where the continuous fracturing extended to. The model has been validated against Wyee LWs 17 to 23 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 present however.

9.3.7 Continuous Sub-surface Fracture Height Predictions (A-Zone)

The predicted values for continuous (A-Zone) sub-surface fracture heights above NM LW101 to LW106 are summarised in **Table 10**. Predicted A-Zone horizons of 21T to 33T from **Forster, 1995** for 'critical' to 'supercritical' panel width geometries are also provided for comparison with the proposed panels.

An effective strata unit thickness t' = 20 m has been back-analysed for the Pi-Term Geology Model from measured height of fracturing data (**Figure 15a**) and the maximum strain/curvature regression analysis (**Figure 9d**) for the completed NM LW101 to LW103. *Note: the effective bending beam thickness at the surface is approximately twice the horizontal strain/curvature ratio.*

The *continuous* sub-surface fracture heights (A-Horizon) have been plotted against depth of rock cover in **Figure 15b** for LW101 to LW106.

The Pi-Term Geology model predicts the highest A-Zone out of the three models assessed, with U95%CL values ranging from 140 m to 208 m for 4.2 to 4.3 m mining height and cover depths from 160 m to 255 m respectively. In terms of key mining parameters such as cover depth (H), effective panel void width (W') and mining height (T), the results range from 0.81H to 0.88H; 0.47-0.68W and 33T to 48T.

The next highest A-Zone predictions are indicated by the Geometry-only Pi-Term model, which predicts it will range from 0.66H to 0.78H; 0.41W to 0.55W and from 31T to 39T.

The **Forster, 1995** model gives the lowest A-Zone range equivalent with 0.56H to 0.87H and 0.45W to 0.46W based on 33T.

The results indicate that the Geology Pi-Term Model is therefore the most conservative of the three models assessed. Based on this model then, it is considered 'very unlikely' the A-Zone will encroach within the surface cracking zone (i.e. within 10 m below the surface) for the range of cover depths above LW101 to LW106.

Table 10 - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed LW101 to LW106

Longwall Panels	Cover Depth, H (m)	Mining Height, T (m)	Effective Panel Width W' (m)	Predicted Continuous (A Horizon) Fracture Heights (m)				
				Pi-Term Geology Model		**Forster, 1995**	Pi-Term Geometry Model	
				mean	U95%CL	21-33T	mean	U95%CL
101	165	4.2	231.0	121	144	88 - 139	105	128
	160	4.2	224.0	117	140	88 - 139	103	126
	175	4.2	245.0	128	152	88 - 139	109	134
102	175	4.2	245.0	128	152	88 - 139	109	134
	180	4.2	252.0	131	156	88 - 139	111	136
	185	4.2	259.0	135	160	88 - 139	113	139
103	190	4.3	266.0	139	166	90 - 142	116	143
	195	4.3	273.0	143	170	90 - 142	118	145
	195	4.3	273.0	143	170	90 - 142	118	145
	200	4.3	280.0	146	174	90 - 142	120	148
104	180	4.3	252.0	133	158	90 - 142	112	137
	200	4.3	280.0	146	174	90 - 142	120	148
	210	4.3	294.0	153	183	90 - 142	123	153
	215	4.3	301.0	157	187	90 - 142	125	155
	215	4.3	301.0	157	187	90 - 142	125	155
105	200	4.3	280.0	146	174	90 - 142	120	148
	215	4.3	301.0	157	187	90 - 142	125	155
	225	4.3	306.4	162	193	90 - 142	128	159
	235	4.3	306.4	165	198	90 - 142	129	162
	235	4.3	306.4	165	198	90 - 142	129	162
106	220	4.3	306.4	160	190	90 - 142	127	158
	240	4.3	306.4	167	201	90 - 142	130	164
	245	4.3	306.4	169	203	90 - 142	131	165
	255	4.3	306.4	173	208	90 - 142	132	168
	250	4.3	306.4	171	205	90 - 142	131	167

Notes:
* - Predictions determined along XLs 1 to 5 (see **Figure 1** for cross line location)
W' = minimum (W, 1.4H).
Bold - Direct hydraulic connection to the surface is considered possible if A-Horizon prediction within 10 m of the surface.

9.3.8 Discontinuous Sub-surface Fracture Height Predictions (B-Zone)

The predicted values for constrained discontinuous (B-Zone) sub-surface fracture heights above NM LW101 to LW106 are summarised in **Table 11** for the two Pi-Term models presented earlier.

The *discontinuous* sub-surface fracture heights (A-Horizon) have been plotted against depth of rock cover in **Figure 15c** for LW101 to LW106.

Table 11 - Summary of Predicted Sub-Surface Fracturing Heights above the Proposed LW101 to LW106

Longwall Panels	Cover Depth, H (m)	Mining Height, T (m)	Effective Panel Width W' (m)	Predicted Discontinuous (B Horizon) Fracture Heights (m)				Depth to B-Zone from Surface, dB (m)	
				Pi-Term Geology Model		Pi-Term Geometry Model			
				mean	U95%CL	mean	U95%CL	mean	U95%CL
101	165	4.2	231.0	*183*	*206*	169	192	-18	-41
	160	4.2	224.0	*178*	*201*	165	187	-18	-41
	175	4.2	245.0	*192*	*217*	178	202	-17	-42
102	175	4.2	245.0	*192*	*217*	178	202	-17	-42
	180	4.2	252.0	*197*	*222*	182	207	-17	-42
	185	4.2	259.0	*201*	*227*	186	212	-16	-42
103	190	4.3	266.0	*207*	*234*	191	218	-17	-44
	195	4.3	273.0	*212*	*239*	195	222	-17	-44
	195	4.3	273.0	*212*	*239*	195	222	-17	-44
	200	4.3	280.0	*216*	*244*	199	227	-16	-44
104	180	4.3	252.0	*198*	*223*	183	208	-18	-43
	200	4.3	280.0	*216*	*244*	199	227	-16	-44
	210	4.3	294.0	*225*	*255*	207	237	-15	-45
	215	4.3	301.0	*230*	*260*	211	242	-15	-45
	215	4.3	301.0	*230*	*260*	211	242	-15	-45
105	200	4.3	280.0	*216*	*244*	199	227	-16	-44
	215	4.3	301.0	*230*	*260*	211	242	-15	-45
	225	4.3	306.4	*234*	*265*	216	248	-9	-40
	235	4.3	306.4	237	269	219	252	-2	-34
	235	4.3	306.4	237	269	219	252	-2	-34
106	220	4.3	306.4	233	264	215	246	-13	-44
	240	4.3	306.4	238	271	220	254	2	-31
	245	4.3	306.4	239	272	221	256	6	-27
	255	4.3	306.4	241	275	224	260	14	-20
	250	4.3	306.4	240	274	223	258	10	-24

Notes:
* - Predictions determined along XLs 1 to 5 (see **Figure 1** for cross line location); W' = minimum (W, 1.4H).
Italics - Discontinuous fracturing likely to interact with surface cracks as B-Horizon within 10 m of surface, resulting in surface flow re-routing.

The Geology Pi-Term Model predicts discontinuous sub-surface fracturing is likely to interact with surface cracks (D-Zones) where cover depths are < 255 m. Creek flows could be re-routed to below-surface pathways and re-surfacing down-stream of the mining extraction limits in these areas.

Discontinuous fracturing would be expected to occur above these limits and increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings.

The observation of tree stress above the extracted longwalls to-date has been found to be due to root shear (and not loss of soil moisture). This indicates B-Zone interaction has occurred with tree root systems.

9.3.9 Rock Mass Permeability Changes

Rock mass permeability is unlikely to be affected outside a distance of 20 m from the panel extraction limits.

In regards to changes to rock mass permeability, **Forster, 1995** indicates that horizontal permeabilities in the Fractured Zone or A-Zone above longwall mines (see **Figure 14b**) could increase by 2 to 4 orders of magnitude (e.g. pre-mining $k_h = 10^{-9}$ to 10^{-10} m/s; post-mining $k_h = 10^{-7}$ to 10^{-6} m/s).

Vertical permeability in the A-Zone would be expected to be high between the transition boundary with the B-Zone where de-saturation is expected to occur. Re-saturation of the strata within the A-Zone and a decrease in permeability is usually assumed to occur with depth (towards the mine works) by experienced ground water modellers.

In the B-Zone, only a slight increase in the vertical permeability would be expected, with horizontal permeability currently believed to increase between 10 and 100 times due to an increase in available void space and groundwater storage from discontinuous fracturing or bedding dilation.

9.3.10 Impact Management Strategies

Water impact studies should consider the above uncertainties in regards to surface and groundwater impacts. The practical options available for controlling sub-surface fracturing are limited to (in order of increasing impact to mining):

- Repair surface cracks when they occur.

- Decrease mining height longwall panel width to limit continuous fracture heights.

  Note: This option will require local subsidence and sub-surface monitoring data to make effective and reliable changes to the mining layout.

- Leave a barrier pillar beneath sensitive area or limit mining to first workings.

Further discussion on suggested monitoring programs may be found in **Section 12**.

9.4 Slope Stability and Erosion

9.4.1 Predicted Effects and Impacts

The surface topography overlying the first six longwall blocks is 'gently' to moderately undulated, with slope angles < 15^{o} generally.

The likelihood of *en-masse* sliding (i.e. a landslip) of the surface terrain over basal siltstone beds tilted by subsidence has been assessed as barely credible, based on the landslide risk assessment terminology presented in **AGS, 2010**.

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

The rate of soil erosion is expected to increase significantly in areas with exposed dispersive/reactive soils and slopes < 10° are expected to have low erosion rate increases, except for the creek channels, which would be expected to re-adjust to any changes in gradient; see **Figure 16** for predicted gradient changes over the site generally of +/- 2^{o} and **Figures 17a,b** and **18a,b** for predicted level and gradient changes along Pine Creek and Pine Creek Tributary No.1 respectively. The results are summarised in **Table 12A**.

Table 12A - Predicted Subsidence Effects along Pine Creek and Pine Creek Tributary 1

Creek	**Creek Bed Gradient Change due to LW101 to LW106 (o)**					
	LW101	**LW102**	**LW103**	**LW104**	**LW105**	**LW106**
Pine Creek	-	-	-	+1.5 -1.5	+1.4 -1.3	+1.5 -1.4
Pine Creek Tributary 1	+1.8 -1.5	+1.0 -1.8	+1.4 -1.3	- -0.3	-	-

The re-calibration of the subsidence prediction model results in a net change to the predicted gradients of +/- 0.3^{o} along Pine Creek. Measured subsidence along Pine Creek Tributary 1 (Line B) reasonably matches the predicted subsidence and gradient changes as shown in **Table 12B**.

Table 12B - Predicted v. Measured Pine Creek Tributary 1 (B-Line) Subsidence Effects

LW	**Maximum Panel Subsidence (m)**		**Chain Pillar Subsidence (m)**		**Creek Bed Gradient Change (o)**	
	Predicted	*Measured*	*Predicted*	*Measured*	*Predicted*	*Measured*
101	2.55	2.459	0.11	0.09	-1.5 to +1.6	**-3.1** to +1.5
102	2.68	2.585	0.10	**0.235**	-1.5 to +0.8	-1.2 to **+1.0**

Bold - measured value exceeds predicted value .

Head-cuts would be expected to develop above chain pillars between the panels and on the side where gradients increase. Sediment would be expected to accumulate where gradients decrease. Therefore the proposed changes to the mining model and extended layout are likely to be minor along the subsided creeks.

9.4.2 Impact Management Strategies

To minimise the likelihood of slope instability from increased erosion due to cracking or changes to drainage patterns after extraction, the management strategy should include:

- surface slope displacement monitoring along subsidence cross lines (combined with general subsidence monitoring plans);
- infilling of surface cracking.
- 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; and
- 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.

9.5 Ponding

9.5.1 Predicted Effects and Impacts

Surface slopes in the elevated areas between the creeks range between 0.5° and 4° typically (1% to 7%), 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 2.75 m could therefore result in closed form depressions forming in the central areas of the panels and disrupt natural drainage pathways to the water courses.

Analysis of the pre and post mining surface levels shown in **Figures 13a,b** suggests that ponding is likely to develop near existing watercourses. Maximum potential ponding depths of between 0.1 and 1.3 m are estimated after LW101 to LW106 are completed. Reference to post-panel reports indicate that ponding location and it's extent have been consistent with the predicted ranges.

The potential maximum ponding depths, affected area and volume above the proposed panels after mining have been updated with the re-calibrated prediction are summarised in **Table 13**.

Table 13 - Potential Worst-Case Ponding Assessment for LW101 to LW105

Location	Longwall	Max Pond RL (AHD)	Max. Depth h (m)	Pond Area Dimensions B x L (m)	Ponded Area Increase After Mining# (m^2)	Ponded Volume Increase After Mining# (ML)
Pine Creek	103	276.9	0.7	63 x 95	5,463	1.92
	104	266.2	2.0	125 x 223	25,862	25.8
	105	268.7	2.1	14 x 226	25,214	26.47
	106	**271.1**	**1.40**	**63 x 145**	**8,996**	**6.30**
Pine Creek Tributary 1	101	271.8	1.3	185 x 321	51,567	33.52
	102	274.3	1.3	80 x 530	36,695	23.85
	103	281.2	0.3	75 x 138	8,388	1.258
	103	*278.8*	*1.9*	*75 x 183*	*12,789*	*1.918*
	104	*283.3*	*0.3*	*27 x 120*	*4,461*	*0.67*
	104	*285.5*	*0.25*	*53 x 81*	*4,926*	*0.616*

Bold - LW106 results; Pond Area = π BL/4 (ellipse); Pond Volume = Pond Area x h/2 (paraboloid)
- Pre-mining pond areas and volumes assumed to be nil; *italics* - ponding on different branch of Tributary 1.

LW106 is expected to cause ponding up to 1.4 m deep over an area of ~0.9ha. The total area that may be affected by ponding has been increased by 5% to 18.4 ha with a combined volume of 122 ML. The maximum pond depths for LW101 to LW106 range from 0.25 m to 2.1 m.

The previous ponded area and volume estimates were 9 ha and 47 ML in the 2013 EP, with maximum pond depths ranging from 0.05 m to 1.3 m.

The increase in maximum subsidence from 2.44 m to 2.75 m appears to have had a significant effect on the predicted values. The consequences of these increases will need to be addressed by specialist environmental consultants.

It should also be noted that the actual ponding depths, areas and volumes will still depend upon several other factors, such as rain duration, surface cracking and effective percolation rates of the surface soils along the creeks.

9.5.2 Impact Management Strategies

Despite the increases in predicted ponding depths, areas and volumes, 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.

Based on the post-mining surface level predictions, it is assessed that channel earthworks may be required to re-establish drainage path ways to the east of LW104 and LW105 along Pine Creek and LW101 and LW102 along No. 1 Tributary to the south.

9.6 Valley Closure and Uplift

9.6.1 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 lines and the ground beyond them.

It should also be understood that valley closure and uplift movements are strongly dependent on the level of 'locked-in' horizontal stress immediately below the floor of the gullies and more importantly the bedding thickness of the floor strata (i.e. thin to medium bedded sandstone is more likely to buckle than thicker beds). The influence of the aspect ratio (i.e. valley width/depth) is also recognised as an important factor, with deep, narrow valleys having greater 'upsidence' than broad, rounded ones, due to higher stress concentrations.

Measured closure movements along valley crests have ranged between 10 mm and 400 mm in the Southern NSW Coalfields, with measured upsidence movements (associated with the closure) also ranging between 10 mm and 400 mm. The impact of the movements range from imperceptible to moderate surface cracking in exposed bedrock on the floor of the valley (or gorge).

As the valleys across NM's mining lease 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 LW101 to LW105 is likely to be negligible.

If 'upsidence' does occur, it may cause some minor, localised deviation of surface flows along ephemeral creek beds into sub-surface routes above the longwall panels. Failure and cracking of the near surface rocks due to tensile bending or compressive/shear strains will also contribute to the re-routing of surface flows. Re-routed surface flows would be expected to re-surface downstream of the damaged area.

Survey measurements across Pine Creek Tributary 1 (Lines C and E-G) 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 LW104. The measured movements are within the predicted range previously presented in the approved 2012 EP.

9.6.2 Impact Management Strategies

The impact of upsidence and valley bending effects along Pine Creek Tributary 1 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. Combine surveys 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 slope 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 along Pine Creek Tributary No. 1. It is understood that the mine is proposing to reduce the amount of ground surveys with the introduction of LIDAR for future longwalls.

Provided that there are visual inspections of the subsidence effected creeks, and several representative centrelines and crosslines to provide ground truthing and angle of draw data for the LIDAR surveys, it is not considered necessary to install survey lines along or across Pine Creek for LW106.

9.7 Far-Field Horizontal Displacements

9.7.1 Predicted Effects and Impacts

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

For example, at Cataract Dam in the Southern NSW Coalfield, **Reid, 1998**, reported horizontal movements of up to 25 mm when underground coal mining was about 1.5 km away. Seedsman reported movements in the Newcastle Coalfield of around 20 mm at distances of approximately 220 m, for a cover depth ranging from 70 to 100 m and a panel width of 193 m, however, the results may have been due to GPS baseline accuracy limitations.

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) the maximum subsidence over the extracted area, (iv) topographic relief and (v) the horizontal stress field characteristics.

An empirical model for predicting Far-field displacement (FFDs) in the Newcastle Coalfield is presented in **Figure 19a**. The model indicates that measurable FFD movements (i.e. 20 mm) generally occur in relatively flat terrain for distances up to 3 to 4 times the cover depth.

The direction of the movement is generally towards the extracted area, but can vary due to the degree of regional horizontal stress adjustment around extracted area and the surface topography.

Far-field displacements (FFDs) generally only have the potential to damage long, linear features such as pipelines, bridges, dam walls and railway lines.

Overall, the far-field movements outside a distance equal to one cover depth from the longwall extraction limits are unlikely to generate significant strains or movement to cause cracking or damage to the surface (see **Figure 19b**).

9.7.2 Impact Management Strategies

Any surface features such as bridges or culverts within 5 times the cover depth (e.g. 800 m from the proposed longwalls on the eastern side of Stage 2) should be monitored for FFD movements during mining. It is understood that the northern railway line and Narrabri-Gunnedah Highway with their associated infrastructure are the only public utilities that exist to the east of the proposed EP extension area and are outside the 5 x cover depth range.

It is therefore still considered unnecessary to develop a FFD Impact Management Plan unless the mine is required to confirm that the movements are negligible at selected points along the boundary of the NM mining lease and/or railway line bridges.

9.8 Aboriginal Heritage Sites

9.8.1 Predicted Effects and Impacts

There are forty-six known Aboriginal Archaeological Sites above LW101 to LW106.

Nine sites are to be subsided by LW105 and two above LW106. For impact review purposes, it has been necessary to update the subsidence predictions for the sites previous presented in the approved 2012 EP.

The revised predictions of final subsidence, tilt, horizontal strain and surface gradient change for each listed archaeological site after the extraction of LW101 – LW106 are presented in **Table 14**. The locations of the sites are shown in **Figures 1b** and **2b**.

Table 14 - Predicted Worst-case Subsidence Effects at Aboriginal Heritage Sites

Site No	Type	Easting (MGA) (m)	Northing (MGA) (m)	LW #	Archaeological Significance	Subsidence (m)	Tilt (mm/m)	Gradient Change (%)	Horizontal Strain (mm/m)*	
									Final	Transient
3	AS	774680	6623380	106	Low	-0.27	17	0.6	11	6
5	AS	775150	6622600	105	Low	2.64	14	-0.9	-12	6
6	AS	775250	6623000	105	Low	0.82	38	-1.0	11	5
7	AS	775170	6623200	105	Low	2.74	5	0.2	-8	4
8	IA	775100	6623230	105	Low	2.30	29	0.9	-14	7
9	IA	775000	6623380	105	Low	0.10	6	0.4	9	5
10a	AS	775270	6623190	105	Low	0.68	36	2.1	13	7
10b	**GG**	**775260**	**6623160**	**105**	**High**	**0.90**	**40**	**2.1**	**10**	**5**
11	AS	775030	6623313	105	Low	0.43	25	-0.5	14	7
12	AS	775640	6621690	103	Low	0.63	33	1.4	14	7
13	AS	775700	6621640	103	Low	2.30	29	2.0	-15	8
14	IA	775780	6621690	103	Low	2.72	5	-0.3	-8	4
15	AS	775820	6621630	103	Low	2.22	33	1.5	-16	8
16	AS	776130	6621700	102	Low	2.65	6	-0.2	-7	4
17	IA	776180	6621690	102	Low	1.89	44	2.2	-15	8
18	AS	776200	6621700	102	Low	1.25	51	2.0	3	1
19	AS	776250	6621700	102	Low	0.12	11	0.1	16	8
20	**ST**	**776400**	**6621660**	**101**	**High**	**2.54**	**3**	**0.1**	**-5**	**2**
21	IA	776600	6621740	101	Low	0.04	6	-0.2	9	4
22	AS	776050	6621620	102	Low	2.57	12	0.4	-12	6
23	AS	776100	6621620	102	Low	2.69	1	0.0	-2	1
24	AS	776130	6621450	102	Low	2.57	12	-0.8	-13	6
25	IA	775980	6621270	102	Low	1.41	46	3.0	-1	1
26	IA	776020	6621260	102	Low	2.40	23	1.1	-16	8
27	AS	776010	6621200	102	Low	2.24	30	2.0	-16	8
28	IA	775900	6621080	103	Low	0.10	2	0.1	12	6
29	IA	775780	6620780	103	Low	1.89	35	1.5	-9	4
30	AS	775690	6620800	103	Low	2.58	13	0.0	-9	4
31	AS	775730	6620740	103	Low	1.64	41	2.5	-6	3
32	AS	776250	6621480	101	Low	0.09	2	0.0	14	7
33	AS	776250	6621510	101	Low	0.08	4	0.1	14	7
34	AS	776270	6621560	101	Low	0.11	9	-0.2	15	8
35	AS	775710	6622970	104	Low	0.00	0	0.0	0	0
36	IA	775760	6623060	104	Low	0.00	0	0.0	0	0
37	IA	775640	6623290	104	Low	0.25	22	1.4	18	9
38	**AS**	**775580**	**6623390**	**104**	**High**	**2.13**	**39**	**2.1**	**-18**	**9**
39.1	**AS**	**775660**	**6623460**	**104**	**High**	**0.12**	**13**	**-0.8**	**14**	**7**
39.2	**AS**	**775680**	**6623480**	**104**	**High**	**0.03**	**4**	**-0.3**	**5**	**3**
39.3	**AS**	**775680**	**6623520**	**104**	**High**	**0.03**	**4**	**0.0**	**6**	**3**
39.4	**AS**	**775650**	**6623530**	**104**	**High**	**0.27**	**23**	**0.7**	**19**	**9**
40	AS	775720	6623530	104	Low	0.00	0	0.0	0	0
41	AS	775630	6623220	104	Low	0.37	28	-0.5	19	10
42	AS	775640	6623140	104	Low	0.19	17	-1.1	14	7
43	**OCS**	**775080**	**6620610**	**105**	**High**	**0.00**	**0**	**0.0**	**0**	**0**
122	**GG**	**776000**	**6622361**	**102**	**High**	**-0.32**	**22**	**1.4**	**15**	**8**
123	**ST**	**774755**	**6623246**	**106**	**High**	**-2.05**	**31**	**0.2**	**-9**	**5**

^ AS - Artefact Scatter; IA- Individual Artefact; GG - Grinding Groove; Open Camp Site;* - The sites may also be subject to transient phases of tensile and compressive strains of lower or higher magnitude than the final strains.

The Project Approval conditions require the sites of ‘High’ Archaeological significance to be protected from mine subsidence related impact (including proposed remediation measures). The sites of ‘High’ archaelogical significance include:

- five scattered artefact sites (No. 38 and 39.1 to 39.4) above LW104;
- two grinding groove sites (No. 10b and 122) which comprises grooves in separate sandstone floaters above LW102 and 105 respectively;
- an open camp site (No. 43) is located to the south and outside of extraction limits for LW105;
- two Scared Trees (No. 20 and 123) above LW101 and 106.

The likelihood of cracking and/or erosion damage occurring at the sites was assessed in the approved 2012 EP based on the following impact parameter criteria (see **Table 15**). The criteria consider the theoretical cracking limits of rock of 0.3 to 0.5 mm/m and the ‘system’ slackness or strain ‘absorbing’ properties of a jointed and weathered rock mass during subsidence deformation.

The lack of measured observed impact (i.e. surface cracking) due to measured strains of up to 1.5 mm/m at other mine sites in the Newcastle Coalfield is an example of the difference between theoretical and in-situ rock mass cracking behaviour. At this stage, the specific geotechnical characteristics of each site have been included for the Heritage Management Plan development.

Table 15 – Impact Potential Criteria for Aboriginal Heritage Sites

Indicative Probabilities of Cracking Occurrence	Predicted 'smooth profile' Horizontal Strain (mm/m)	
	Tensile	**Compressive**
Very Unlikely (<5%)	<0.5	<2
Unlikely (5 - 10%)	0.5 - 1.5	2 - 3
Possible (10 - 25%)	1.5 - 2.5	3 - 5
Likely (>25%)	>2.5	>5
Indicative Probabilities of Erosion Occurrence	**Predicted Surface Gradient or Tilt Change**	
Very Unlikely (<5%)	<0.3% (<3 mm/m)	
Unlikely (5 - 10%)	0.3-1% (3 - 10 mm/m)	
Possible (10 - 25%)	1-3% (10 - 30 mm/m)	
Likely (>25%)	>3% (>30 mm/m)	

The ‘Cracking Potential’ is considered the primary damage potential indicator and includes the potential for artefact loss into the cracks. The ‘Erosion Potential’ is a secondary indicator of damage (i.e. the presence of erosion and sedimentation increases at a site may result in unacceptable long-term degradation of a site). The results of the impact assessment are presented in **Table 16**.

Table 16 - Predicted Subsidence Impacts at Aboriginal Heritage Sites

Site No	Type ^	Archaeological Significance	Predicted Strain*		Predicted Gradient Change (%)	Site Cracking & Loss Potential		Site Erosion Potential
			Transient	Final		Transient	Final	
3	AS	Low	5	11	0.6	Likely	Likely	Unlikely
5	AS	Low	6	-12	-0.9	Likely	Likely	V.Unlikely
6	AS	Low	5	11	-1.0	Likely	Likely	V.Unlikely
7	AS	Low	4	-8	0.2	Likely	Likely	V.Unlikely
8	IA	Low	7	-14	0.9	Likely	Likely	Unlikely
9	IA	Low	5	9	0.4	Likely	Likely	Unlikely
10a	AS	Low	7	13	2.1	Likely	Likely	Possible
10b	**GG**	**High**	**5**	**10**	**2.1**	**Unlikely#**	**Unlikely#**	**Possible**
11	AS	Low	7	14	-0.5	Likely	Likely	V.Unlikely
12	AS	Low	7	14	1.4	Likely	Likely	Possible
13	AS	Low	8	-15	2.0	Likely	Likely	V.Unlikely
14	IA	Low	4	-8	-0.3	Likely	Likely	Possible
15	AS	Low	8	-16	1.5	Likely	Likely	V.Unlikely
16	AS	Low	4	-7	-0.2	Likely	Likely	Possible
17	IA	Low	8	-15	2.2	Likely	Likely	Possible
18	AS	Low	1	3	2.0	Unlikely	Likely	V.Unlikely
19	AS	Low	8	16	0.1	Likely	Likely	V.Unlikely
20	**ST**	**High**	**2**	**-5**	**0.1**	**Possible**	**Possible**	**V.Unlikely**
21	IA	Low	4	9	-0.2	Likely	Likely	Unlikely
22	AS	Low	6	-12	0.4	Likely	Likely	V.Unlikely
23	AS	Low	1	-2	0.0	Unlikely	Unlikely	V.Unlikely
24	AS	Low	6	-13	-0.8	Likely	Likely	Likely
25	IA	Low	1	-1	3.0	Unlikely	V.Unlikely	Possible
26	IA	Low	8	-16	1.1	Likely	Likely	Possible
27	AS	Low	8	-16	2.0	Likely	Likely	V.Unlikely
28	IA	Low	6	12	0.1	Likely	Likely	Possible
29	IA	Low	4	-9	1.5	Likely	Likely	V.Unlikely
30	AS	Low	4	-9	0.0	Likely	Likely	Possible
31	AS	Low	3	-6	2.5	Likely	Likely	V.Unlikely
32	AS	Low	7	14	0.0	Likely	Likely	V.Unlikely
33	AS	Low	7	14	0.1	Likely	Likely	V.Unlikely
34	AS	Low	8	15	-0.2	Likely	Likely	V.Unlikely
35	AS	Low	0	0	0.0	V.Unlikely	V.Unlikely	V.Unlikely
36	IA	Low	0	0	0.0	V.Unlikely	V.Unlikely	Possible
37	IA	Low	9	18	1.4	Likely	Likely	Possible
38	**AS**	**High**	**9**	**-18**	**2.1**	**Likely**	**Likely**	V.Unlikely
39.1	**AS**	**High**	**7**	**14**	**-0.8**	**Likely**	**Likely**	V.Unlikely
39.2	**AS**	**High**	**3**	**5**	**-0.3**	**Likely**	**Likely**	V.Unlikely
39.3	**AS**	**High**	**3**	**6**	**0.0**	**Likely**	**Likely**	Unlikely
39.4	**AS**	**High**	**9**	**19**	**0.7**	**Likely**	**Likely**	V.Unlikely
40	AS	Low	0	0	0.0	V.Unlikely	V.Unlikely	V.Unlikely
41	AS	Low	10	19	-0.5	Likely	Likely	V.Unlikely
42	AS	Low	7	14	-1.1	Likely	Likely	V.Unlikely
43	OCS	High	0	0	0.0	V.Unlikely	V.Unlikely	V.Unlikely
122	**GG**	**High**	**15**	**8**	**1.4**	**Unlikely#**	**Unlikely#**	**Possible**
123	**ST**	**High**	**-9**	**5**	**0.2**	**Possible**	**Possible**	**V.Unlikely**

^ - AS - Artefact Scatter; IA- Individual Artefact; GG - Grinding Groove; Open Camp Site.
* - Tensile strain is positive; # - Grinding grooves are considered to be located on sandstone ‘floaters’ in alluvial soils; **Bold** - Cracking likely to occur at site of ‘high’ Archaeological Significance.

Based on the results in **Table 16**, it was assessed that the potential for cracking is ‘likely’ at the ‘high’ archaeologically significant Scattered Artefact site No.s 38 to 39 after extraction of LW104. It is considered unlikely that the cracking will result in direct damage to the artefacts themselves; however, they could be lost into cracks if they occur.

The possibility of erosion damage due to gradient increases is assessed for eleven artefact sites of ‘Low’ significance and the two grinding groove sites of ‘High’ significance.

It is understood that there has been no impacts to the sites as a result of subsidence effects above LW101 to LW104, however, the Registered Aboriginal Parties (RAPs) have raised the temporary salvage artefacts as a management measure. This is yet to be approved in a revision to the sites Aboriginal Cultural Heritage Management Plan (ACHMP).

Cracking of the Grinding Groove Sites (No. 10b) due to LW105 is considered ‘unlikely’ because they are on sandstone ‘floaters’ in soil and not attached to bedrock. It is noted that similar ‘floating’ grinding grooves above LW102 and 103 (Site No. 122) were not impacted by cracking.

It is considered ‘unlikely’ that the Scarred Trees will be damaged by surface cracking and tilting.

9.8.2 Impact Management Strategies

Impact management strategies for Aboriginal sites are presented in the Heritage Management Plan for LW101 – LW106 and have been developed in consultation with Aboriginal stakeholders. It is understood that the sites of ‘high’ Archaeological Significance will be fenced off and remediated as necessary after mining of LW104 and LW105.

At this stage the assumption is that the grinding grooves are effectively detached from underlying bedrock and fully surrounded by un-consolidation soils (alluvium) as demonstrated for the grinding grooves identified above LW102/LW103, where subsidence cracking occurred in the immediate vicinity but the grinding grooves were unaffected.

9.9 Unsealed Gravel Access Roads and Tracks

9.9.1 Predicted Effects and Impacts

Based on **Figures 12a** to **12c**, the maximum final subsidence effects predicted for the gravel access roads above LW101 to LW106 are summarised in **Table 17**.

Table 17 – Maximum Final Subsidence Effect Predictions for Access Roads above LW101 to LW105

LW	Cover Depth (m)	Subsidence S_{max}(m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
101	160 - 170	2.58 - 2.69	47 - 71	10 - 26	13 - 33
102	170 - 180	2.65 - 2.69	43 - 67	9 - 23	11 - 30
103	170 - 200	2.71 - 2.75	40 - 59	8 - 19	10 - 24
104	210 - 215	2.71 - 2.75	34 - 52	6 - 22	8 - 28
105	200 - 240	2.71 - 2.75	30 - 57	5 - 18	7 - 23
106	210 - 270	2.58 - 2.75	25 - 41	4 - 12	6 - 15

The unsealed gravel access roads and tracks above the proposed longwall panels are likely to be damaged by cracking and 'shoving' at tensile and compressive strain zones; see **Figure 12c**.

Maximum tensile crack widths across or along roads are estimated to range between 40 mm and 260 mm. Surface 'steps' or humps due to compressive shear failures are estimated to range between 60 mm and 330 mm. Some sections of road may also require re-grading or drainage remediation works after subsidence development.

9.9.2 Impact Management Strategies

Appropriate impact management strategies relevant to EP development would include the following:

- Regular inspection (i.e. daily) 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 and/or site personnel working or passing through these areas should be informed of when and where the above subsidence effects may occur and temporary warning signs should be erected near the limits of actively subsiding areas.

Subsidence impacts may be assumed to start to occur within a 26.5^o angle of draw or 0.5 x 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 90% complete when the longwall face has retreated a distance past the road of 1.5 x cover depth or a 56^o angle of draw; see also **Section 11**).

9.10 Water Storage Dams and Soil Conservation (Contour) Banks

9.10.1 Predicted Effects and Impacts

A total of 17 farm dams are shown to exist above LW102 to LW106 in **Figure 1**.

Non-engineered farm dams and water storages will 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, foundation type and acceptable levels of repair costs to re-establish the dam's function and pre-mining storage capacity (if necessary).

The predicted worst-case subsidence deformations (subsidence, tilt and horizontal strain) at the dams within the limits of longwall extraction are shown in **Figures 12a** to **12c**. A summary of likely subsidence effects at the dams above each longwall are summarised in **Table 18**.

Table 18 – Maximum Final Subsidence Effect Predictions for Dams* above LW101 to LW106

LW	No. Existing Dams	Cover Depth (m)	Subsidence S_{max}(m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
101	nil	160 - 190	2.58 - 2.69	44 - 71	9 - 26	12 - 33
102	4	170 - 180	2.65 - 2.69	40 - 61	8 - 23	10 - 30
103	2	170 - 200	2.71 - 2.75	38 - 59	7 - 19	9 - 24
104	2	205 - 210	2.71 - 2.75	34 - 53	6 - 17	8 - 20
105	4	205 - 235	2.71 - 2.75	30 - 57	5 - 18	7 - 23
106	5	210 - 240	2.58 - 2.75	25 - 41	4 - 14	6 - 15

* - Not all dams will be subject to maximum values shown. Refer to Figures 12a to 12c for specific location predictions.

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 area. 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 40 mm and 260 mm. Surface 'steps' or humps due to compressive shear failures are estimated to range between 60 mm and 330 mm. Damage to windmills and fences near the dams and soil conservation (contour) banks may also occur and require repairing.

9.10.2 Impact Management Strategies

It should be noted that dams similar to those across ML1609 have been undermined by longwalls elsewhere in Australia and any damage and water supply impacts have been effectively managed. The dams were repaired and reinstated in a timely manner and an alternative supply of water was provided by the mine during the interim period.

Subsidence impacts may be assumed to start to occur within a 26.5^{o} angle of draw or 0.5 x 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 road of 1.5 x cover depth.

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; see also **Section 10**.

9.11 Property Fences and Livestock and

9.11.1 Predicted Effects and Impacts

The fence lines, orchards and grazing areas above longwalls 101 to 106 will be subject to the maximum predicted subsidence effects and cracking presented in **Table 19**.

Table 19 - Maximum Final Subsidence Effect Predictions for Fences above LW101 to LW106

LW	No. of Existing Fences (orchards)	Cover Depth (m)	Subsidence S_{max}(m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
101	7	160 - 170	2.58 - 2.69	47 - 71	10 - 26	13 - 33
102	8	170 - 180	2.65 - 2.69	43 - 67	9 - 23	11 - 30
103	5	170 - 200	2.71 - 2.75	40 - 59	8 - 19	10 - 24
104	9	210 - 215	2.71 - 2.75	34 - 52	6 - 22	8 - 28
105	9 (2)	200 - 240	2.71 - 2.75	30 - 57	5 - 18	7 - 23
106	9	210 - 270	2.58 - 2.75	25 - 41	4 - 12	6 - 15

The following impact to fences is likely to result from the predicted subsidence:

- 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.

The impacts are also likely to affect the management of livestock (see **Section 9.11.2**).

9.11.2 Impact Management Strategies

The impact of subsidence on the grazing of livestock would primarily require either the installation of temporary fencing or re-location of the livestock during repair of surface cracking and damaged fences. The location and suggested methods of repair to surface cracking is discussed further in **Section 9.2**.

9.12 Residential Dwellings and Machinery Sheds

9.12.1 Predicted Effects and Impacts

The existing buildings within the limits of LW101 to LW106 include an existing residential dwelling, a machinery shed and one water storage tank (see **Figure 1a** for their location). The structures may be subject to between 50% and 100% of the subsidence effects presented in **Table 20**. All other existing buildings are located outside a 26.5^{o} angle of draw to the longwall panels and are unlikely to be impacted by subsidence effects.

Table 20- Maximum Final Subsidence Effect Predictions for Buildings above LW101 to LW105

LW	No. of Existing Buildings (tanks)	Cover Depth (m)	Subsidence S_{max}(m)	Tilt T_{max} (mm/m)	Tensile Strain (mm/m)	Compressive Strain (mm/m)
101	Nil	160 - 170	2.58 - 2.69	47 - 71	10 - 26	13 - 33
102	Nil	170 - 180	2.65 - 2.69	43 - 67	9 - 23	11 - 30
103	Nil	170 - 200	2.71 - 2.75	40 - 59	8 - 19	10 - 24
104	Nil	210 - 215	2.71 - 2.75	34 - 52	6 - 22	8 - 28
105	2 (1)	200 - 240	2.71 - 2.75	30 - 57	5 - 18	7 - 23
106	Nil	210 - 270	2.58 - 2.75	25 - 41	4 - 12	6 - 15

The buildings above LW105 are located near the centre of the panel and will be temporarily affected by tilts and strains in the same order of magnitude as **Table 18** indicates from the ‘travelling’ subsidence wave, which follows behind the retreating longwall face. It is likely that the travelling tilts and strains will also be at their maximum values at the centre of the panel.

Based on **Holla & Barclay, 2000**, significant damage to the existing buildings and tank is likely where tilts > 7 mm/m and tensile and/or compressive strains > 2 mm/m. The severity of the damage will also be dependent on the type and geometry of each structure.

Therefore, it will probably be the travelling waves tilts and tensile strains that cause most of the damage to the buildings, with residual tilt values that may or may not be lower than the travelling wave, depending on whether there are secondary ‘humps’ and troughs develop over the goaf as it consolidates. The maximum compressive strains will be located in the central third area of the panel and may be greater than the travelling wave values.

9.12.2 Impact Management Strategies

Based on the above, it may be assumed that all of the structures above LW105 will require repairs after undermining occurs and that they should be vacated before subsidence develops.

Mine subsidence (and possibly surface vibrations) will start to develop soon after LW105 retreats beneath the buildings. Mine subsidence movements would be expected to continue until the longwall face is 1 to 2 times the cover depth past the property. Subsidence movements would also be expected to ‘start again’ soon after the passing of subsequent longwall panels, albeit at decreasing rates and magnitudes. It is considered likely that primary subsidence movements will affect undermined properties for periods of 3 to 6 weeks after undermining, with residual subsidence occurring for periods of another 1 to 2 years after primary subsidence is complete (see **Section 11** and **Glossary** for definition of primary and residual subsidence).

An inspection of mine subsidence damaged properties should be made by qualified building consultants and any repair works to internal/externals cracking or re-levelling of damaged structures be implemented before allowing residents to move back into the dwellings.

9.13 Utilities

9.13.1 Predicted Effects and Impacts

It is understood that the existing properties within the mining lease are connected to the Essential Energy domestic power supply (suspended 11kV). There are fifteen timber power poles (P1 to 15) within the angle of draw above LW101 – LW105. The line provides power to the residence and machinery shed adjacent to the orchard above LW105. The poles are approximately 15 m high and 85 m apart on average (distances vary from 31 m to 132 m) as shown in **Figure 1**.

Worst-case predictions of final subsidence, tilt, strain and final tilt direction at each pole have been updated in **Table 21**.

Table 21 - Worst-Case Final Subsidence Predictions for the Power Poles in the EP Area

Pole No.	E	N	Maximum Subsidence S_{max} (m)	Final Tilt[+] T_{max} (mm/m)	Final Tilt Direction (grid) (o)	Final Ground Strain[&] (mm/m)	Final HD* Base (mm)	HD^ Top (mm)	Maximum Conductor Clearance Loss[#] (m)	
									First	**Final**
1	776938	6620616	0.00	0	-	0	0	0	0.00	0.00
2	776621	6620675	0.00	0	292	0	0	0	-0.77	-0.77
3	776342	6620726	2.19	22	039	-10	346	670	-1.11	-1.96
4	776103	6620771	2.28	24	289	-12	381	739	-0.07	0.13
5	775879	6620812	0.11	2	272	12	27	52	-0.11	0.16
6	775620	6620860	1.19	41	093	4	659	1276	-0.91	-1.20
7	775365	6620907	2.72	7	091	-11	114	221	-1.25	-1.78
8	775110	6620954	1.72	39	273	-4	622	1206	0.00	0.00
9	775087	6621106	2.40	25	272	-12	398	772	0.01	0.00
10	775064	6621255	2.71	6	276	-13	92	179	na	na
11	775084	6620724	0.15	10	349	7	159	309	-0.01	-0.01
12	775058	6620496	0.00	0	-	0	0	0	0.00	0.00
13	775032	6620270	0.00	0	-	0	0	0	0.00	0.00
14	775011	6620083	0.00	0	-	0	0	0	0.00	0.00
15	774811	6619832	0.00	0	-	0	0	0	0.00	0.00

+ - Transient tilts due to travelling subsidence wave may be assumed to equal the final tilt magnitudes at a given location. Further analysis may be required if marginal conditions indicated; & - Tension is positive. Transient strains may be assumed to equal to Final values; * - HD Base = Absolute horizontal displacement of pole at ground level; ^ - HD top = Absolute horizontal displacement of pole at conductor level (assumed to be 15 m above the ground); # - clearance loss at goaf edge between next pole and current pole; **Bold** - Maximum clearance loss for the power line.

The power poles will be subject to transient movements towards the retreating longwall face, and will generally start moving towards the north and then 'swing' around (up to 90 degrees in bearing) to their final positions after subsidence is fully developed. The poles will also be subject to tensile and compressive strains associated with the subsidence 'wave' as it passes underneath the poles. The transient tilts and strains are expected to range from 50% to 100% of the final values, and will be dependent on longwall face retreat rates.

Some of the poles have been undermined by LW101 to LW103, with some prediction exceedances apparent. Conductor clearances are estimated to be decreased by between 0.00 m and 1.87 m along the easement. The conductors are supported by relatively inflexible ceramic insulators that will probably not be able to tolerate the predicted pole movements. Sheaves and rollers have subsequently been installed to allow poles to move in accordance with the EEMP.

9.13.2 Impact Management Strategies

In addition to the Essential Energy Management Plan (EEMP) developed for the power line that traverses LW101 to LW105, impact management strategies could also include:

(i) Replacement of any damaged poles and/or mitigation works to conductors as mine subsidence develops. Flexible/roller-type conductor sheathing on the poles to control the conductor tension during/after mining impacts have already been implemented.

(ii) Damage from subsidence (i.e. cracking and tilting) can manifest quickly after mining (i.e. within hours). The appropriate management plan will therefore need to consider the time required to respond to an impact exceedence if it occurs.

9.14 Narrabri Mine and Other Infrastructure

9.14.1 Predicted Effects and Impacts

No damage or impacts are expected to the proposed mine site infrastructure, given it is located > 800 m east of the subsidence and strain zone (i.e. 0.5 times the cover depth of 160 m) and the far-field displacement zone (i.e. 5 times the cover depth of 160 m).

The North Western Branch Railway Line and Kamilaroi Highway are both located > 1.9km to the east of the approved 2012 EP area and it is therefore extremely unlikely that they will be affected by horizontal or vertical movements due to mine subsidence.

9.14.2 Impact Management Strategies

As measurable subsidence and horizontal displacement due to mining is very unlikely to occur, no survey monitoring of the above features is considered necessary except for visual inspections after each panel is completed.

10.0 Comparison of Current Extraction Plan Area Predictions with the Environmental Impact Assessment Report Submission

Due to adjustments to the subsidence prediction model in response to measured values at NM, a comparison of the subsidence effect predictions and impacts in the Environmental Assessment Report (refer to **DgS, 2009**) has been made with the current subsidence assessment outcomes provided in this study.

A summary of the proposed mining geometry and subsidence effects for LW101 to LW106 for XL 4 from both reports are presented in **Table 22**.

Table 22 - Comparison of Proposed LW101 - LW106 Mining Geometries and Predicted Subsidence Effects Presented in the EA and the Current Study Outcomes

Parameter	EA Report (refer DgS, 2009)						Current (this study)					
	1	2	3	4	5	6	101	102	103	104	105	106
Panel Width, W (m)	305	305	305	305	305	305	306.5	306.5	306.5	306.5	306.5	306.5
Cover Depth, H (m)	165	175	195	210	230	230	165	175	195	215	235	255
Mining Height (T)	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3
Chain Pillar Width (w)	24.6	24.6	24.6	29.6	29.6	29.6	29.8	29.8	34.8	34.8	39.5	2 x 28
W/H	1.85	1.75	1.57	1.45	1.33	1.33	1.86	1.75	1.57	1.43	1.30	1.20
Final Maximum Subsidence (m)	2.44	2.44	2.44	2.44	2.44	2.44	2.69	2.69	2.75	2.75	2.75	2.75
Maximum Tilt (mm/m)*	45	41	35	32	30	30	47	45	40	34	30	25
Maximum Tensile Strain (mm/m)*	11	9	8	6	6	6	12.5	11.5	9.5	8	6.5	5.5
Maximum Compressive Strain (mm/m)*	14	12	10	8	8	8	16	15	12	20	17	14
Final Chain Pillar Subsidence (m)	0.46	0.53	0.63	0.63	0.75	0.75	0.29	0.42	0.37	0.54	0.49	0.49

* - Predicted tilts and strains for ‘smooth’ subsidence profiles. Cracking or discontinuous displacements may cause the smooth profile values to double.

The results indicate increases between the EA and approved EP submissions of approximately 15%.

Based on the predicted impacts in **Table 23**, the increases in subsidence effect are unlikely to result in significantly higher impacts or environmental consequences between the two reports. It is noted that the height of continuous fracturing predicted using the 2014 Geology Pi-Term Model are 26 to 83 m higher than the EA Report indicated. The overall impact should therefore be re-assessed by the groundwater modelling consultant.

Table 23 - Comparison of Proposed LW101 - LW106 Mining Geometries and Predicted Subsidence Impacts Presented in the EA and the Current Study Outcomes

Parameter	EIS Report (refer DgS, 2009)						Current (this study)					
	1	**2**	**3**	**4**	**5**	**6**	**101**	**102**	**103**	**104**	**105**	**106**
Panel Width, W (m)	305	305	305	305	305	305	306.5	306.5	306.5	306.5	306.5	306.5
Cover Depth, H (m)	165	175	195	210	230	230	165	175	195	215	235	255
Mining Height (T)	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.3	4.3	4.3
Chain Pillar Width (w)	24.6	24.6	24.6	29.6	29.6	29.6	29.8	29.8	34.8	34.8	39.5	2 x 28
W/H	1.85	1.75	1.57	1.45	1.33	1.33	1.86	1.75	1.57	1.43	1.30	1.20
Surface Crack Widths (mm)	110	90	80	60	60	60	125	115	95	80	65	55
Height of Continuous Subsurface Fracturing above Workings, A (m)	114	116	120	120	125	125	140 (26)	152 (26)	170 (50)	187 (67)	198 (73)	208 (83)
Surface Gradient Change along Pine Creek (o)	0	0	0	+1.4 -1.5	+1.3 -1.2	+1.3 -1.2	0	0	0	+1.5 -1.5	+1.4 -1.3	+1.5 -1.4
Potential Ponding Depth & Area along Pine Creek (m) [ha]	0 [0.0]	0 [0.0]	0 [0.0]	1.0 [1.5]	1.2 [1.0]	1.2 [1.0]	0 [0.0]	0 [0.0]	0.7 [0.55]	2.0 [2.5]	2.1 [2.5]	1.4 [0.9]
Surface Gradient Change along Pine Creek - Tributary 1 (o)	+1.4 -1.0	+1.5 -0.8	+1.0 -1.1	0	0	0	+1.4 -1.5	+1.5 -0.8	+1.0 -1.1	0	0	0
Potential Ponding Depth & Area along Pine Creek-Trib 1 (m) [ha]	1.2 [4.3]	1.0 [1.1]	0.15 [0.2]	0 [0.0]	0 [0.0]	0 [0.0]	1.2 [4.1]	1.0 [0.8]	0.15 [0.2]	0 [0.0]	0 [0.0]	0 [0.0]

* - crack widths based on smooth profile strains but could double due to strain concentration effects.
(brackets) - A-Zone height difference between EIS and current study.

11.0 Monitoring Program

11.1 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 the 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 will be on-going 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 to 100 m ahead of the retreating longwall face; accelerate up to rates from 50 to 300 mm/day when the face is 0.2 to 1 times the cover depth past the point; and decrease to < 0.020 m/week when the face is > 1.5 times the cover depth past the point (see **Figure 20**). Further subsidence is likely to develop due to compression of chain pillars when adjacent panels are subsequently mined.

11.2 Surface Monitoring

Surface monitoring to-date has been conducted in relatively cleared grazing areas above the eastern portion of NM. Future mining will be extended below natural bushland areas that would require extensive clearing to install survey monitoring lines.

It is therefore considered appropriate to reduce the number of ground based survey lines and rely more upon remote LIDAR monitoring techniques and existing access roads (instead of clearing new lines). It is not considered necessary to extend the creek lines or cross lines any further if ground-truthed LIDAR information can be used instead to derive subsided profiles.

Subsidence effects (including angle of draw data) could still be obtained along selected access roads to avoid clearing any more vegetation to the west of LW106.

It is still considered necessary to measure cross line and panel starting end centreline angles of draw to the 20 mm subsidence contour due to the level accuracy limitations of the LIDAR results (which only has +/- 0.15 m level accuracy).

The following subsidence and strain-monitoring program is therefore suggested to provide adequate information to monitor and implement appropriate subsidence impact management plans data for planning review purposes.

(i) Extend the transverse subsidence line (Line A) across LW106 to the existing woodland before undermining occurs. Continue survey line along access road to West of LW106 Tailgate to provide survey data overlap and assess differences between the two lines.

(ii) A longitudinal line extending in-bye and out-bye from the panel starting and finishing points for LW105 respectively for a minimum distance equal to the cover depth.

The survey pegs should be spaced at a minimum of 10 m and a maximum of 15 m apart. A minimum of two baseline surveys of subsidence and strain is recommended before mine subsidence effects occur. Survey frequency will be dependent upon mine management requirements for subsidence development data in order to implement subsidence and mine operation management plans.

The suggested monitoring program also assumes that visual inspections and mapping of surface impacts will be conducted before, during, and after mining.

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 EDM and traverse techniques from a terrestrial base line is normally expected to be +/- 2mm 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).

11.3 Sub-surface Monitoring

Monitoring of sub-surface fracture heights above longwall panels usually requires the direct measurement of vertical strata dilation between the surface - 10 m and the seam level + 50 m with deep borehole extensometers above the centre of a longwall panel. The instrument should also be installed at a distance greater than the panel width from the ends to avoid end effects.

Deep boreholes with multi-level vibrating wire piezometers may be installed to monitor groundwater impacts adjacent to the extensometers but upstream of the extraction limits or above the chain pillars between the panels.

The height of fracturing zones above NM has been estimated from deep extensometer anchors in the Digby Conglomerate and surface standpipe piezometers. Inspections and monitoring of underground workings stability, groundwater makes and goaf air entry should also be recorded and included with subsidence monitoring data.

12.0 Conclusions

The multiple longwall panel subsidence predictions presented in this study have been primarily based on several empirical and calibrated analytical models of overburden and chain pillar behaviour.

The modified EP area will have six longwall blocks (LW101 to LW106) that will be 306.5 m wide with cover depths varying from 160 m to 180 along the eastern side and from 200 m to 240 m along the western side. The mining height for the panels will be 4.3 m from LW103 with 3.7 m high gate roads. The nominal roadway widths will be 5.4 m.

The subsidence prediction model used in the approved LW101 – LW105 EP estimated a maximum subsidence of 2.44 m or 0.58T. Although the predicted values for LW101 to LW104 have been within 15% of the measured results, the model has now been adjusted to match to reflect the actual 95%CLs for subsequent panels as follows:

- Single maximum panel S_{max}/T has been increased from 0.58 to 0.60 for LW101 and to 0.63 from LW102 to LW106;

- Final maximum panel S_{max}/T has been increased to 0.64 from LW102 to LW106.

- Supercritical width appears to occur at 1.2H instead of 1.4H, based on measured tilts and strains to-date.

As mentioned previously, it is considered that the development of subsidence impacts will be not be affected by the spanning potential of the Garrawilla Volcanics, Basalt Sill or Digby Conglomerate units. Subsidence predictions have therefore only considered ‘Low’ SRP for the worst-case scenario.

Revised subsidence profiles and contours have subsequently been derived for LW101 to LW106.

The key outcomes of the results of the study are presented below for the six panels:

(i) First and Final maximum panel subsidence is likely to range between 2.69 m and 2.75 m (64% of the mining height).

(ii) Maximum chain pillar subsidence is estimated to range between 0.29 m and 0.54 m above pillar widths ranging from 30 m to 39.5 m. The vertical stress acting on the pillars are estimated to range from 14.7 to 22.5 MPa with pillar FoS values of 2.54 to 1.36 estimated for a 3.5 m pillar height under double abutment loading conditions.

(iii) Yielding of the chain pillars is not expected for the proposed mining layout (i.e. the predicted FoS values are > 1). However, strain-hardening of the pillars due to core confinement and goaf materials within the panels themselves will limit and result in eventual cessation of subsidence if overloading conditions were to occur.

(v) Maximum panel tilts are estimated to range from 25 to 47 mm/m for ‘smooth’ profile subsidence, with occasional tilts from 38 mm/m to 71 mm/m due to discontinuous strata behaviour (i.e. localised block rotations).

(vi) The maximum tensile and compressive strains are expected to range from 4 mm/m to 14 mm/m for ‘smooth’ profile subsidence, with occasional strains ranging from 11 mm/m to 33 mm/m due to discontinuous strata behaviour (i.e. cracking).

The results of this study indicate that the surface deformations due to mining within ML1609 are likely to cause the following impacts:

- Surface cracking and shearing within tensile and compressive strain zones and ranging in width from 40 mm to 130 mm at cover depths ranging from 255 m to 160 m respectively. Strain concentrations in near surface rock could double the above crack widths to 110 mm and 330 mm.

  It should be understood that the above crack widths are U95%CL values, which means that 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, that the crack widths are increased (once they occur) in direct proportion to the measured tilts due to rigid body rotation of the subsided slope. Whilst this effect is unlikely to occur above LW101 – LW106, the predicted crack widths may be exceeded near the steeper creek banks along Pine Creek and its tributaries or on moderate slopes.

- Surface gradients are likely to increase or decrease by up to 3% (+/- 1.5^o) along creeks, with occasional increases of up to 3^o.

- Potential ponding depths of 0.15 to 2.1 m may develop above several of the longwalls and creeks in the flatter areas of the site, based on post-mining contour predictions.

- Direct hydraulic connection to the surface, due to sub-surface fracturing above the panels, is considered unlikely to occur where cover depths are > 160 m.

- According to the **Ditton and Merrick, 2014** Pi-Term models, sub-surface aquifers within 140 m to 208 m above the proposed panels (i.e. 81% to 88% of the cover depth; 0.47 to 0.68 times the panel width or 33 to 48 times the mining height) may be affected by direct hydraulic connection to the workings, with significant long-term increases to vertical permeability.

- Discontinuous fracturing would be expected to occur above these limits and increase rock mass storage capacity and horizontal permeability without direct hydraulic connection to the workings. Rock mass permeability is unlikely to increase significantly outside the limits of extraction.

- In-direct or discontinuous sub-surface fracturing could interact with surface cracks where cover depths are < 255 m. Creek flows could be re-routed to below-surface pathways and re-surfacing down-stream of the mining extraction limits in these areas due to this interaction. This phenomenon behaviour usually only occurs where shallow surface rock is present and unlikely to occur where deep soil profiles exist.

- General and localised slope instability along low-level hills is considered very unlikely due to the predicted cracking and tilting caused by LW101 – LW106.

- The development of valley closure and associated uplift in valley floors and along creek beds are considered unlikely to exceed 150 mm, based on measured results along Pine Creek Tributary No. 1.

- Stock watering dams are likely to be damaged by mine induced cracking and/or shearing, resulting in dam wall breach or storage losses through the floor of the dam storage areas. Repairs to the dams and temporary supplies of water may be required by the stakeholders. Windmills and fences around the dams could also be damaged and require repairs after mining.

- Thirty-six scattered Aboriginal artefact sites, two grinding groove sites and two (one modified) scared trees exist within the mine subsidence area for LW101 and LW106.

  It is assessed that the potential for cracking is ‘Likely’ at the ‘High’ archaeologically significant Scattered Artefact site No.s 38 to 39 after extraction of LW104. It unlikely that the cracking will result in direct damage to the artefacts themselves, however, they could be lost into cracks.

  Cracking of the Grinding Groove Sites (No. 10b and 122) are considered ‘unlikely’ as inspections to-date have indicated that the grinding grooves present in the EP area are located on sandstone floaters. Therefore no additional investigations are required.

  Impact to the Scarred Trees (20 and 123) is also ‘unlikely’.

  The potential for erosion damage due to gradient changes is ‘unlikely’ to ‘possible’ at the above sites, however the presence of cracks may increase the potential for artefact loss into the cracks.

- The various unsealed roads and tracks around the site are likely to be subject to cracking and and/or heaving during mine subsidence development. The roads are likely to require maintenance and repair works after undermining occurs. Mine subsidence warning signs and possibly closure of the roads should be considered where public safety risks are identified.

  Residential dwellings and farm machinery are also likely to be significantly damaged and affected by ground vibrations during mining. It is recommended that the premises are vacated and all equipment/property of value removed before mining impacts. It is considered likely that subsidence movements will affect undermined properties for periods of at least 2 years after mining. Some of the structures will probably not be repairable after mining is completed.

- The fifteen powerline and poles to the various residences and orchards within the mining lease will be subsided by above LW101 to LW105 by between 0.0 m and 2.72 m. The differential subsidence between subsided and non-subsided poles with chain pillars in between them may have conductor clearances decreased by up to 1.96 m or increased by up to 0.16 m.

- The poles will be affected by transient and final tilts towards the centre of the goaf of up to 41 mm/m. The ground strains at the poles are likely to range from +/- 12 mm/m. The predicted tilts and strains have the potential to damage the poles and ceramic conductor isolators. Sheaves and rollers have subsequently been installed to allow poles to move in accordance with the EEMP.

The above items will require further discussion with the stakeholders to enable acceptable Subsidence Management Plans (EP) to be developed. A suggested program for monitoring subsidence, tilt and strain at the relevant locations has been provided for the purpose of implementing and reviewing the EP. The use of remote Aerial Laser Scanning is considered an appropriate subsidence monitoring technique *in lieu* of some of the traditional ground based subsidence survey lines.

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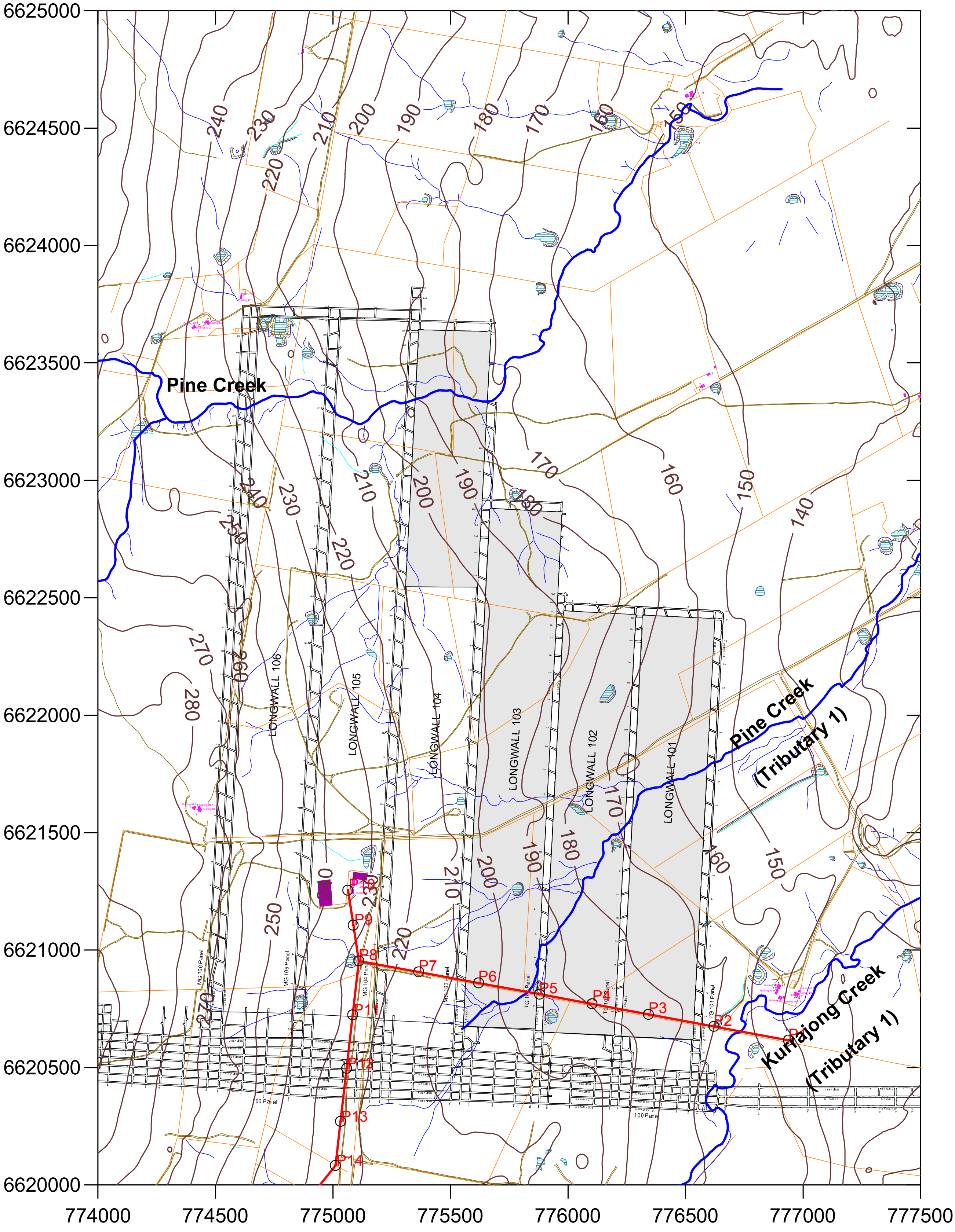
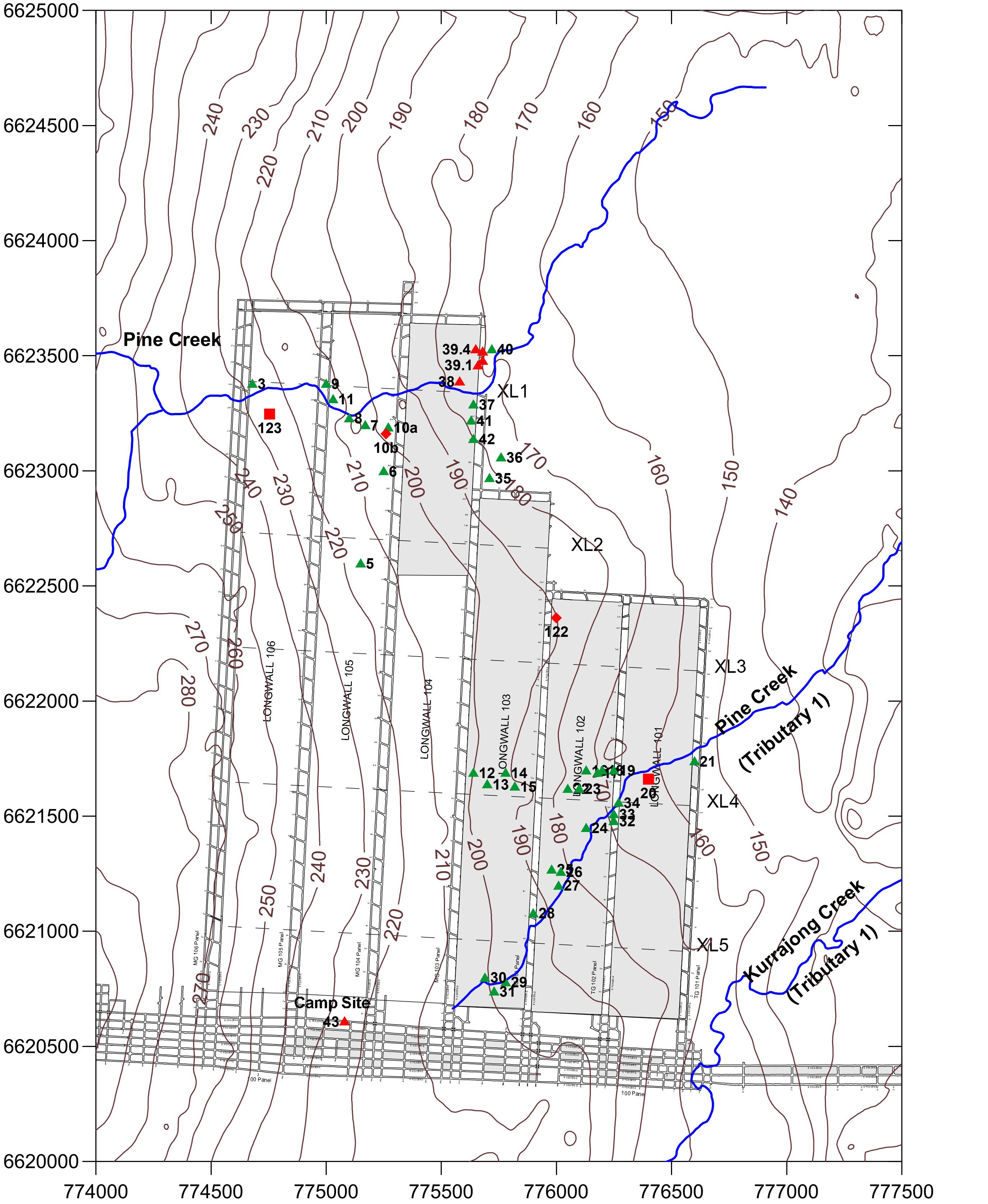


Key:

Cover Depth Contours (m)	Main Creeks	Fences	Unsealed Roads/ Tracks
P5 Powerlines & Poles	Extracted LW	Farm Dams	T Buildings/Tanks
Orchard			

DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton	Client:	Narrabri Coal Operations Pty Ltd - Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn: S.Ditton	Title:	Cover Depth Contours Above the Approved Longwalls 101-105 & Proposed LW106 in the Hoskisson Seam
	Date: 01.05.15	Scale:	1:25,000 — Figure No: 1a



Key:

Cover Depth Contours (m)			Artefact Scatters (High)		Grinding Grooves (High)	XL1	Subsidence Prediction Lines
Creeks		Extracted LW	Artefact Scatters (Low)		Scarred Tree (High)		

DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn: S.Ditton	Title:	Cover Depth Contours Above the Approved Longwalls 101-105 & the Proposed LW106 in the Hoskisson Seam with Aboriginal Heritage Sites
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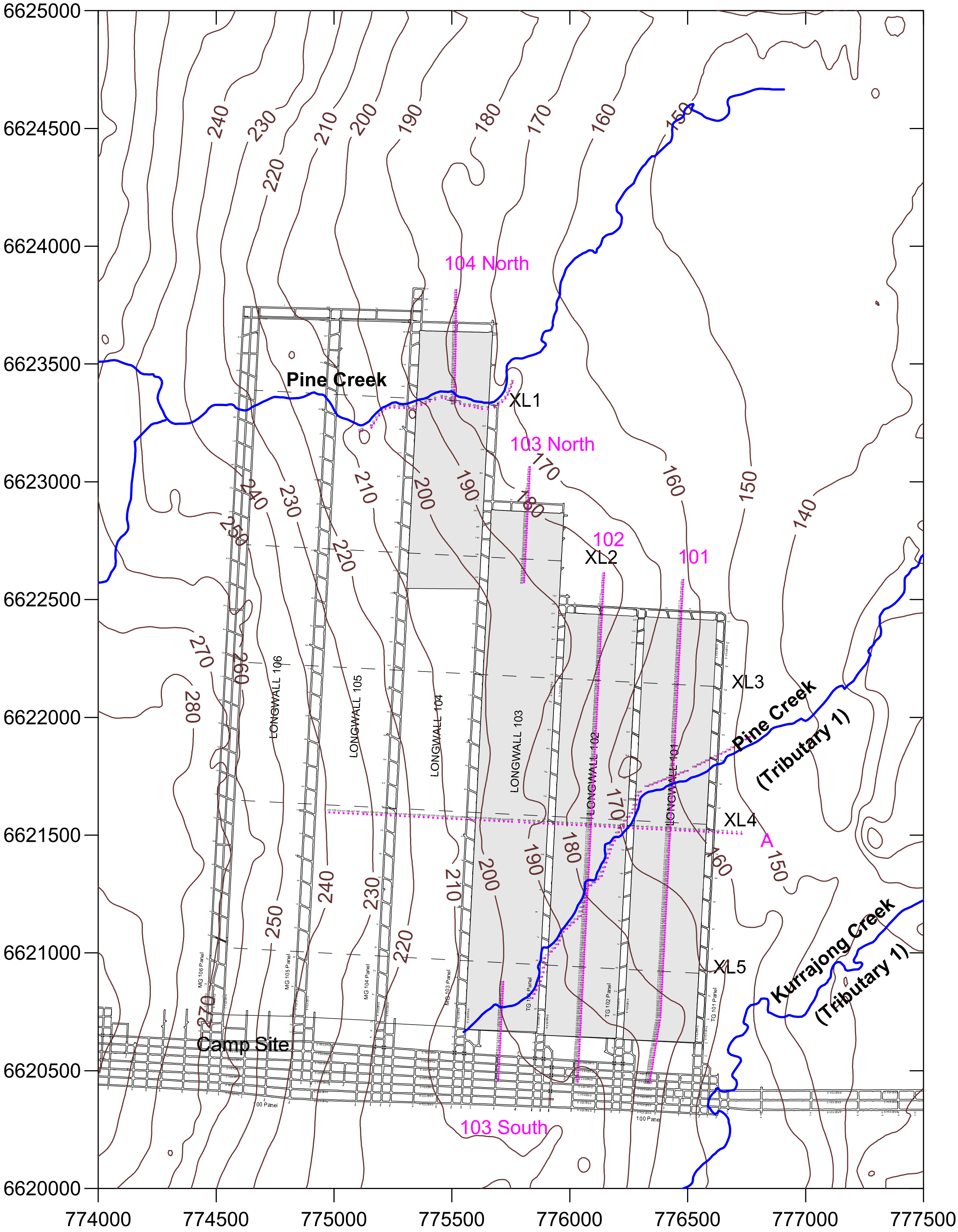

Key:

Cover Depth Contours (m)

Subsidence Survey Lines

Creeks

Extracted LW

XL1 Subsidence Prediction Lines

DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Operations Pty Ltd - Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn:	S.Ditton		
	Date:	01.05.15	Title:	Cover Depth Contours Above the Approved Longwalls 101-105 & the Proposed LW106 in the Hoskisson Seam with Subsidence Survey Lines
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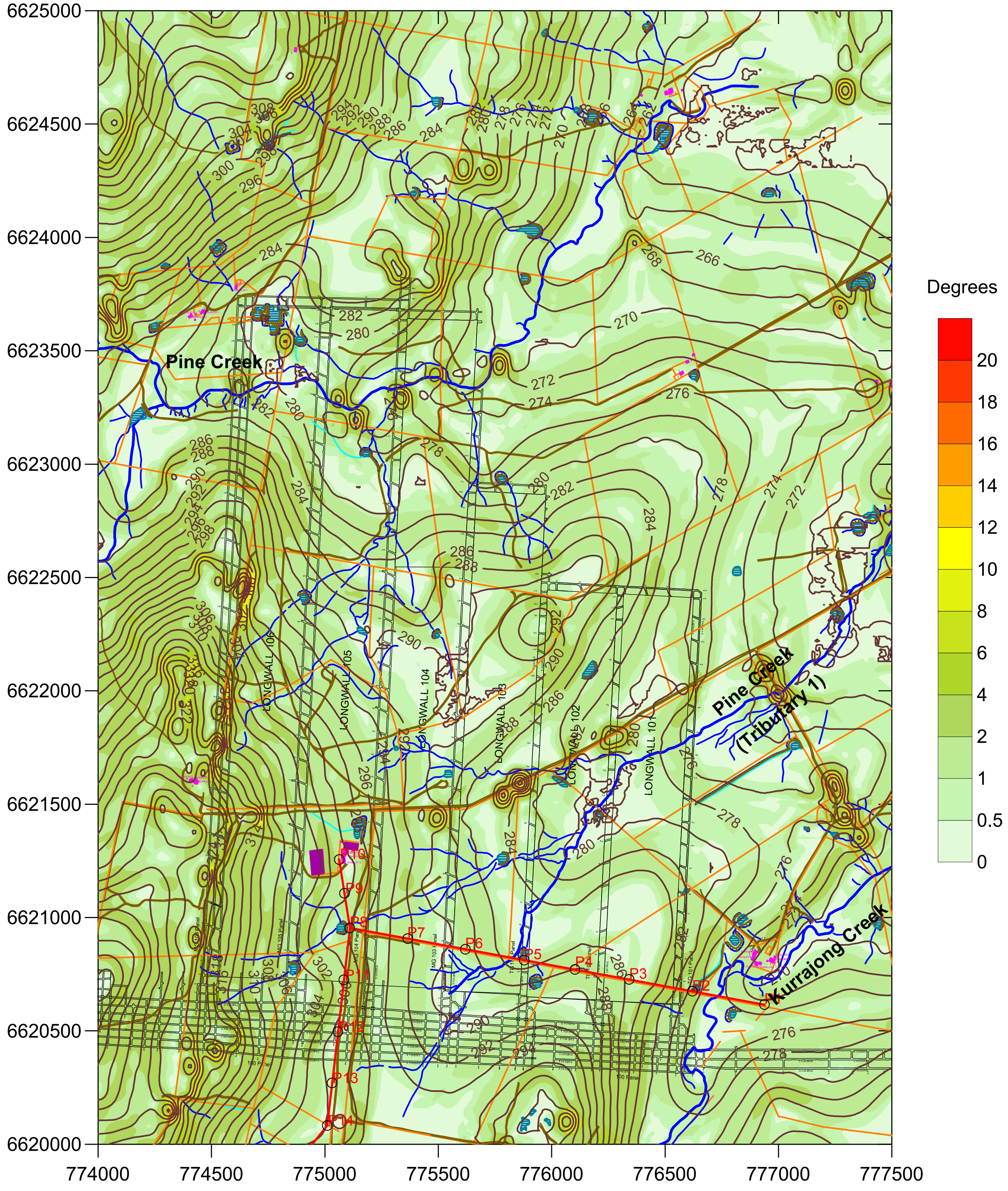

Key:

Pre-mining Levels
Main Creeks
Fences
Unsealed Roads/ Tracks
P5
Powerlines & Poles
Farm Dams
T
Buildings/Tanks
Orchard

DgS	Engineer: S.Ditton	Client:	Narrabri Coal Operations - Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn: S.Ditton		
	Date: 01.05.15	Title:	Pre-mining Surface Slopes and Surface Features Above the Approved LWs 101 - 105 & Proposed LW106
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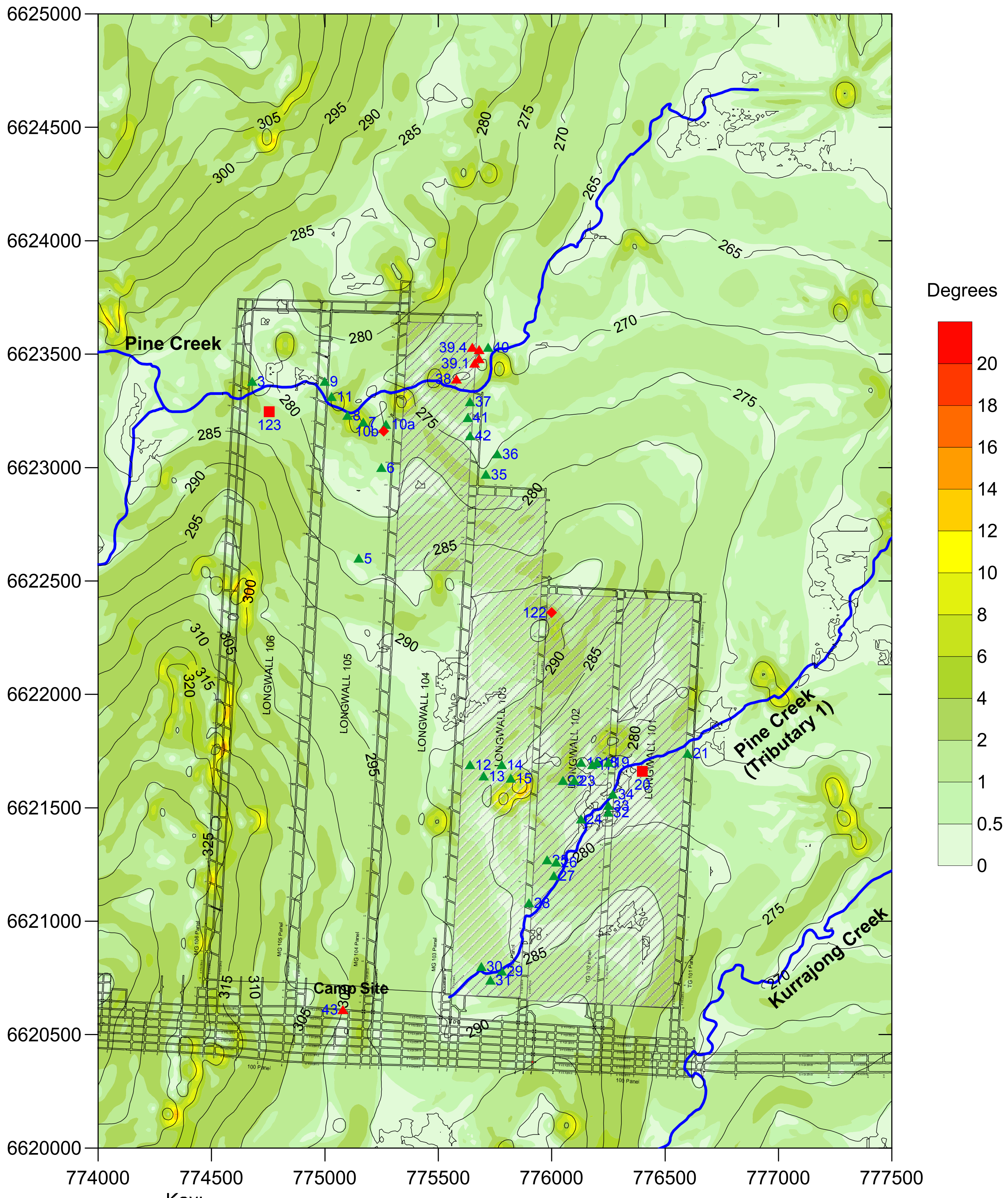

Key:

Level Contours (AHD, m)		Artefact Scatters (High)	Grinding Grooves (High)
Creeks	Extracted LW	Artefact Scatters (Low)	Scarred Tree (High)

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	Drawn: S.Ditton	Title:	Pre-mining Surface Slopes and Surface Features Above the Approved LWs 101 - 105 & Proposed LW106 with Aboriginal Heritage Sites
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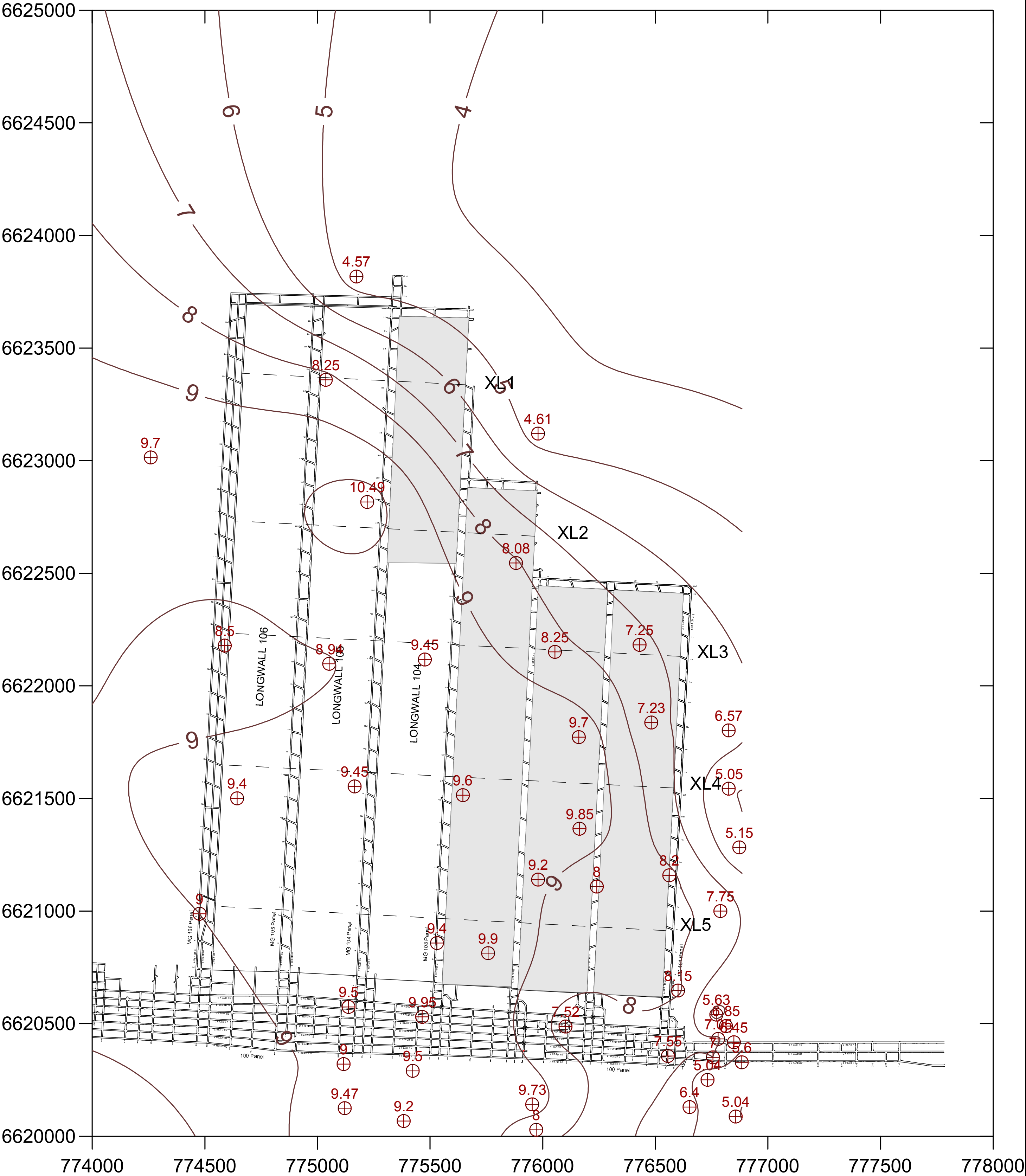

Key:

Cover Depth Contours (m)

Boreholes

Extracted LW

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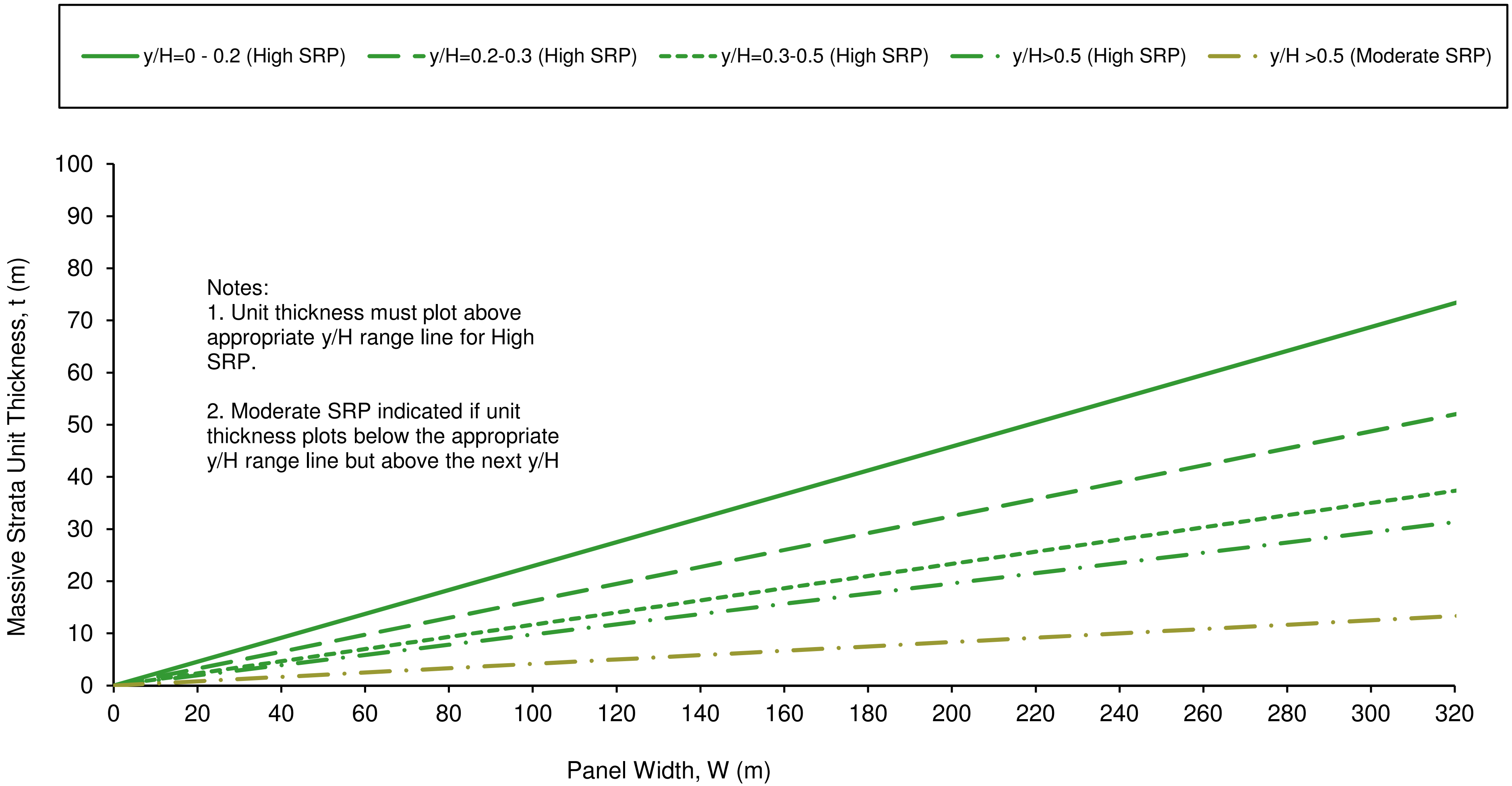

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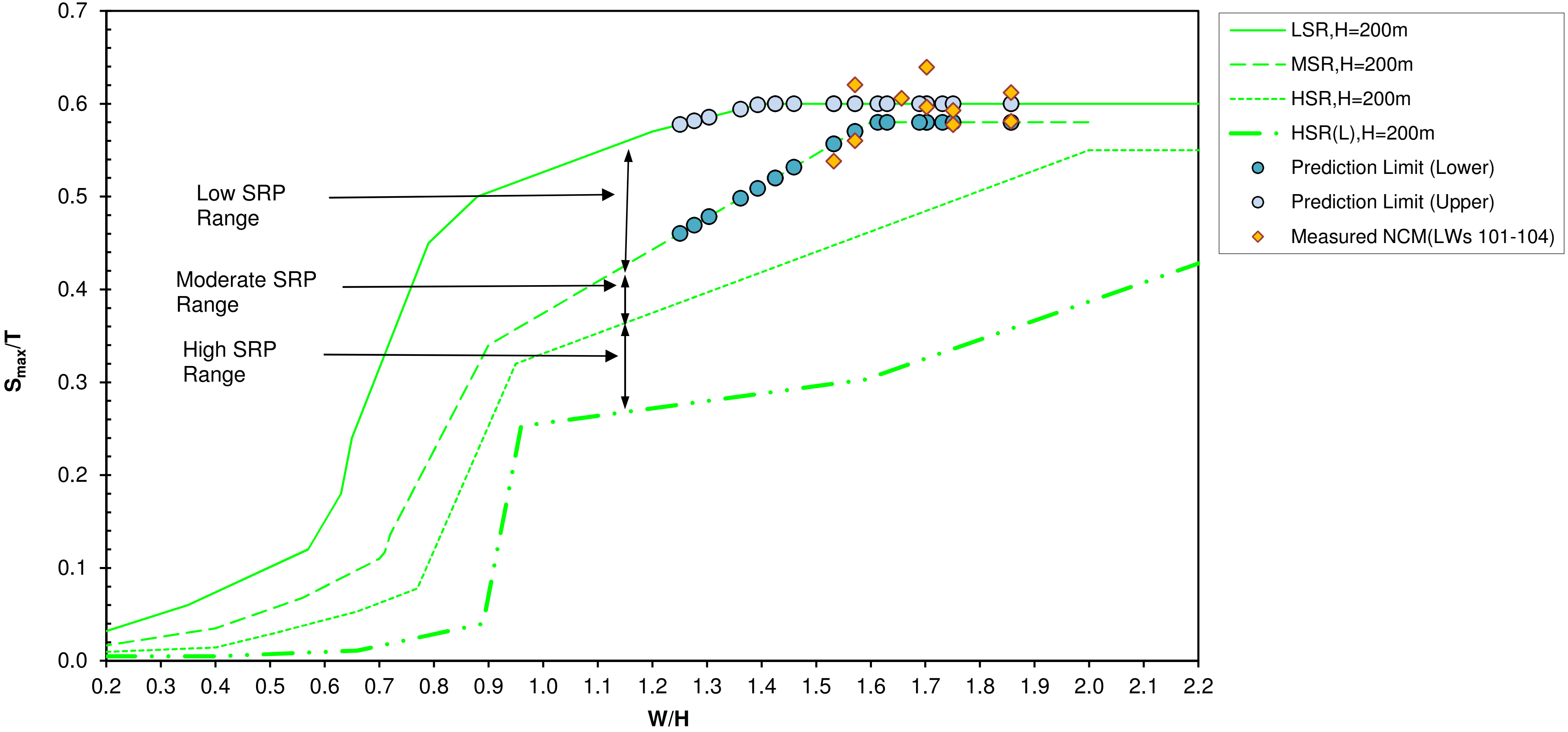

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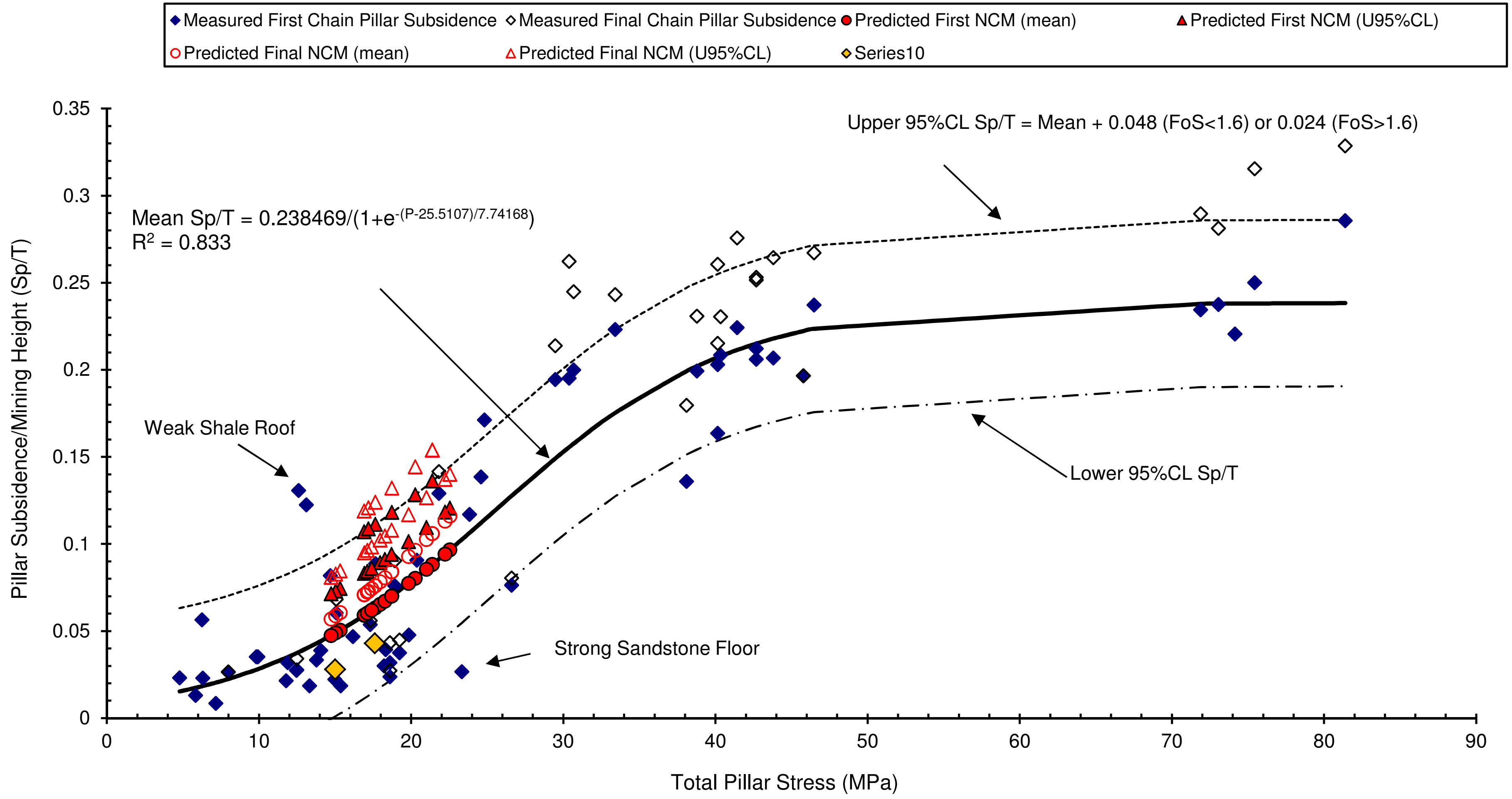

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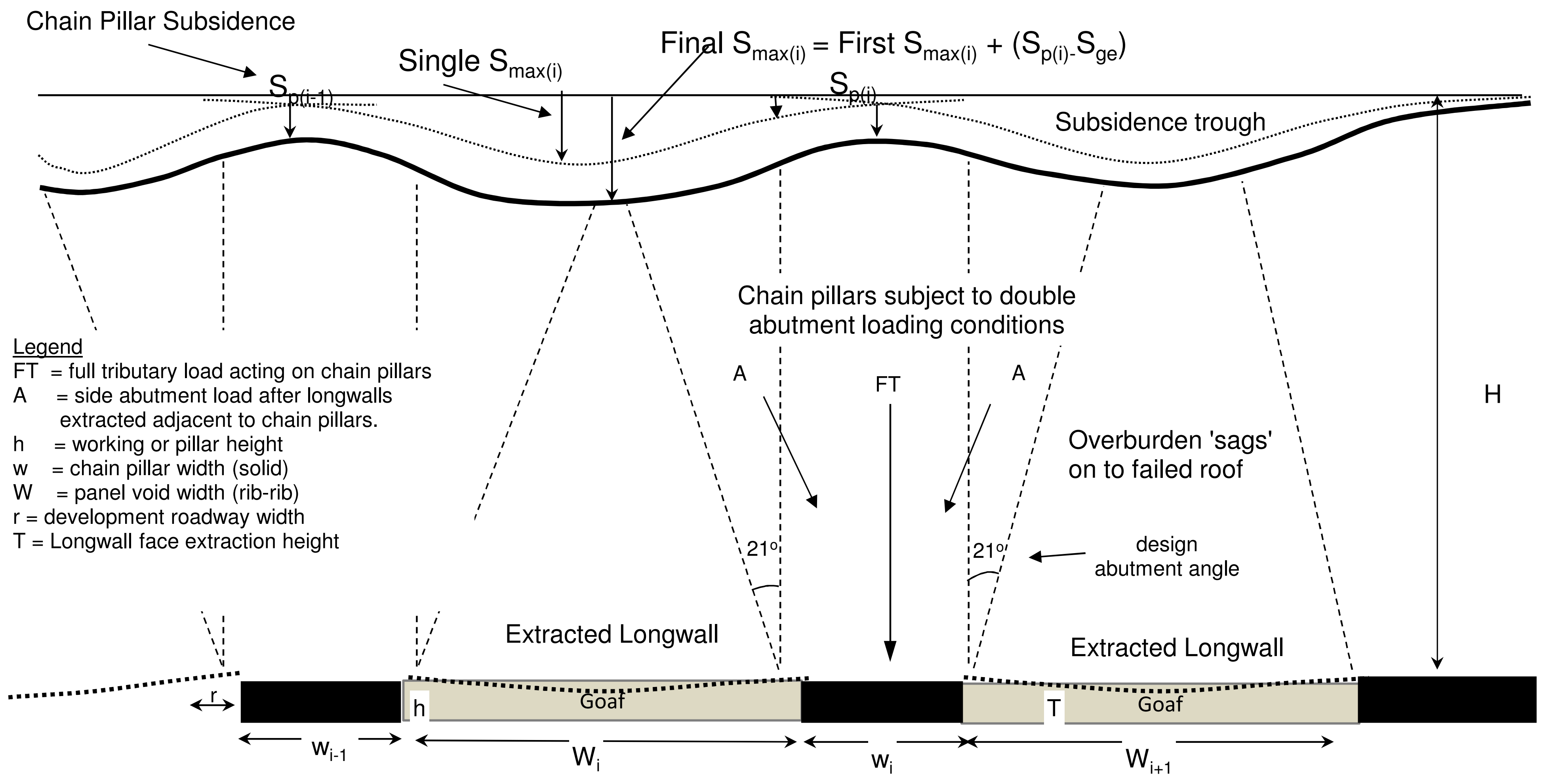

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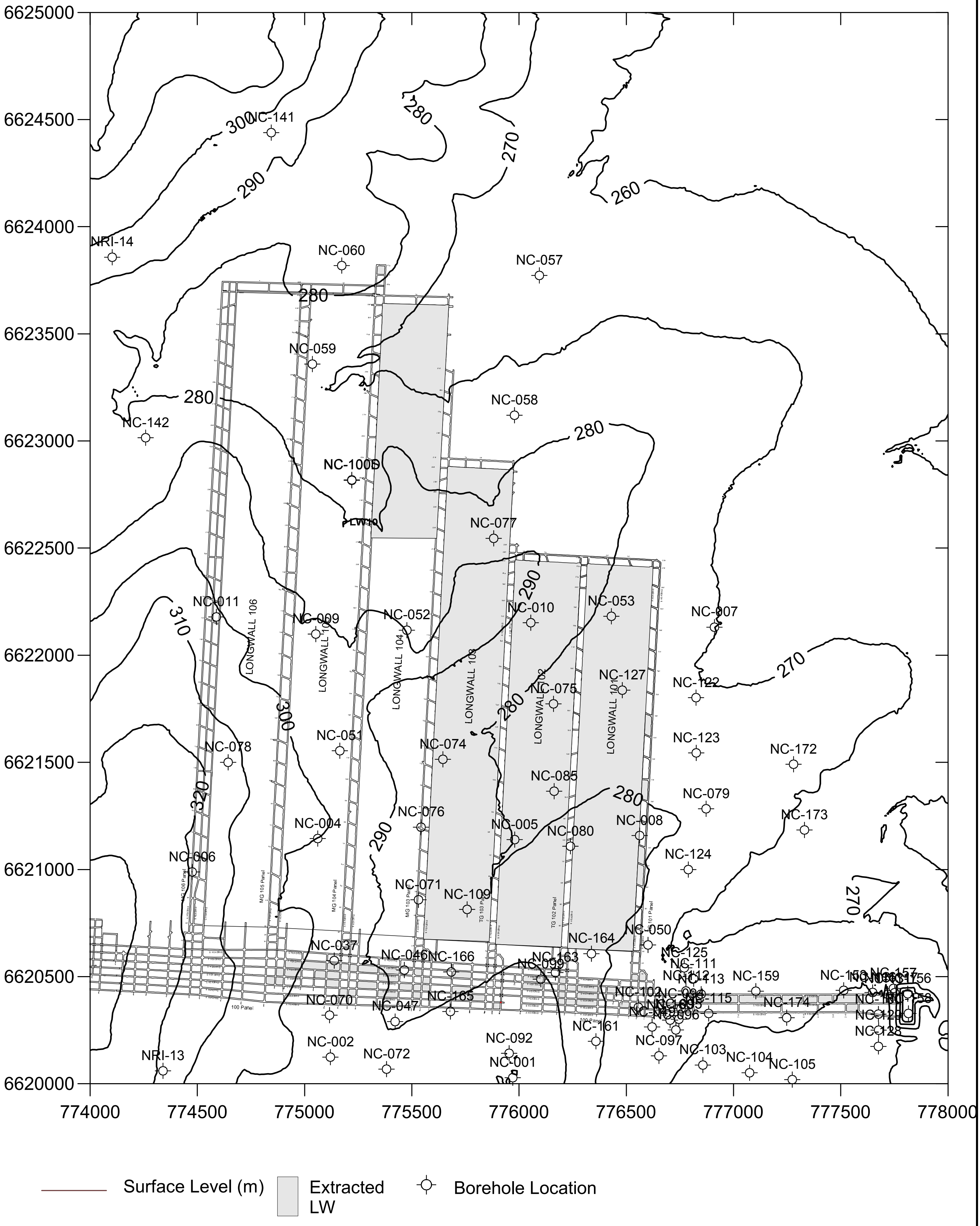

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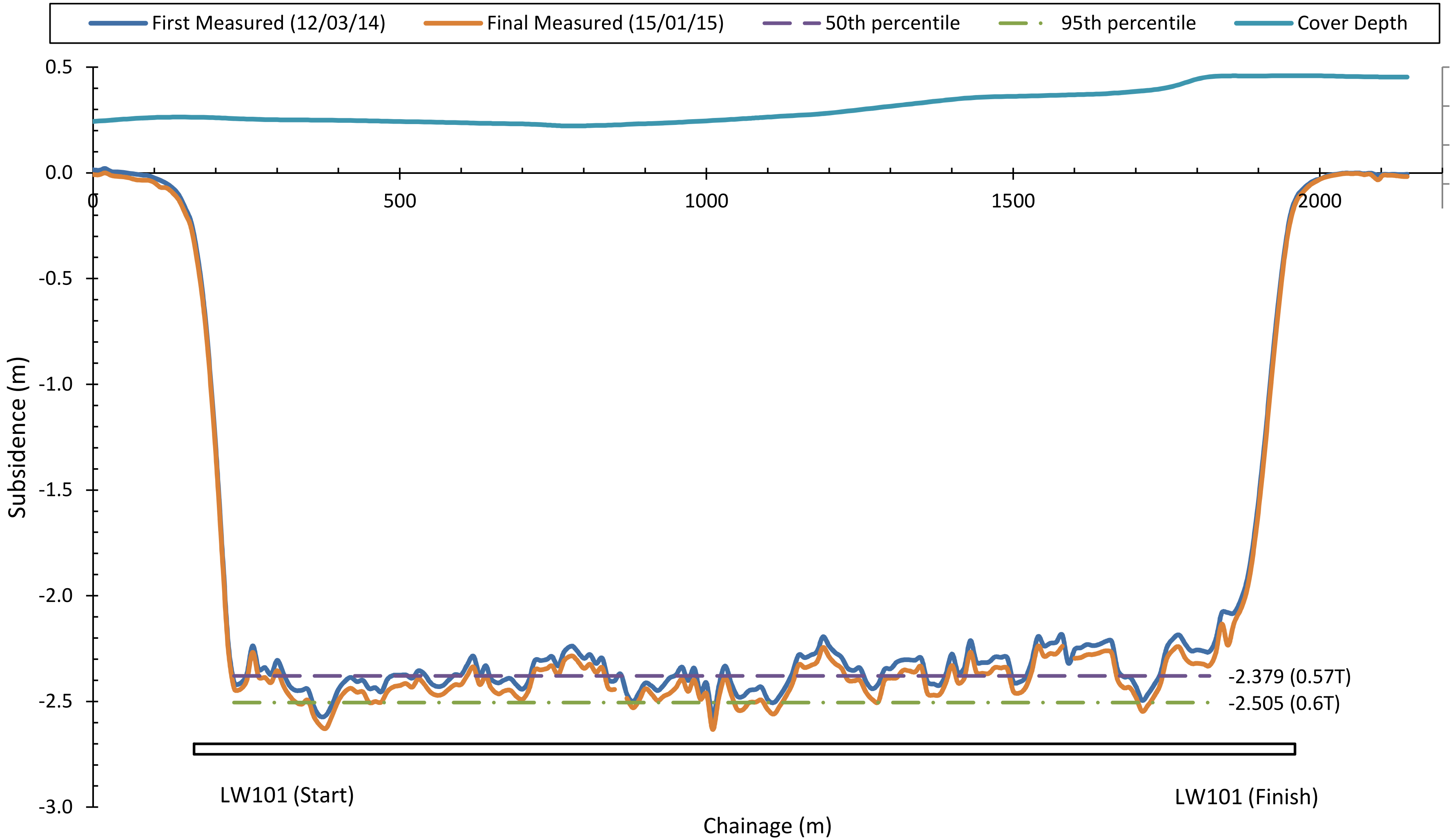

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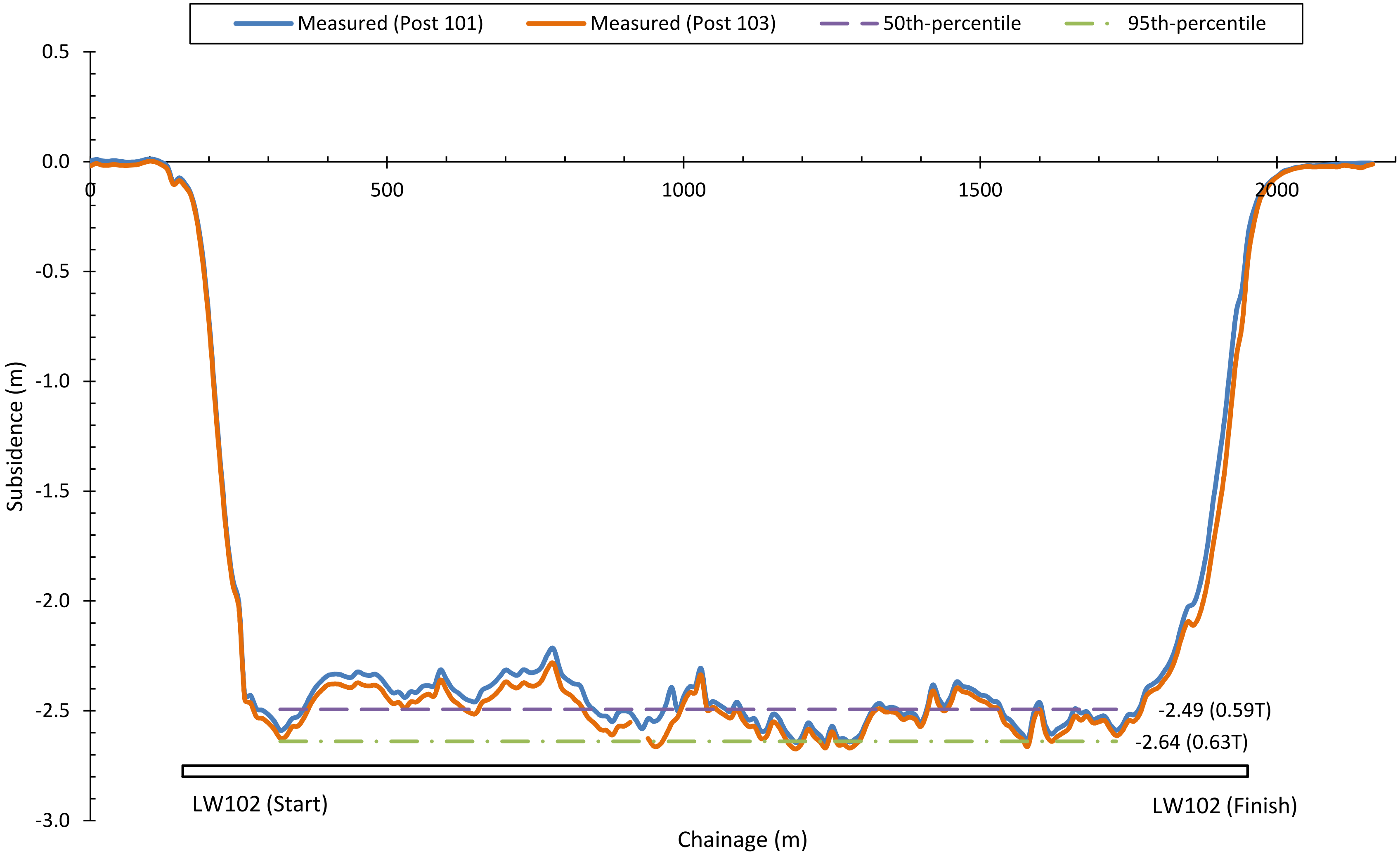

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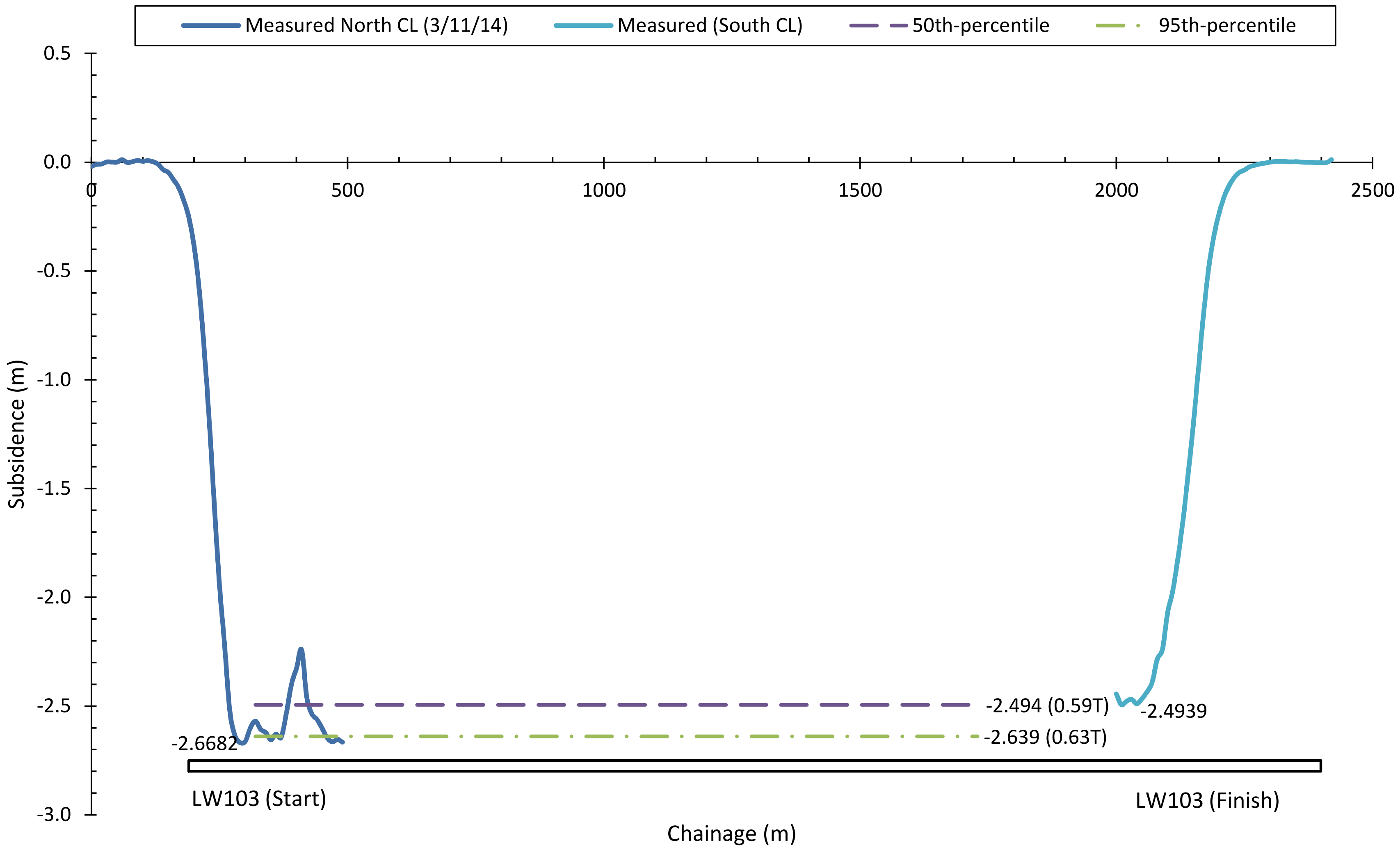

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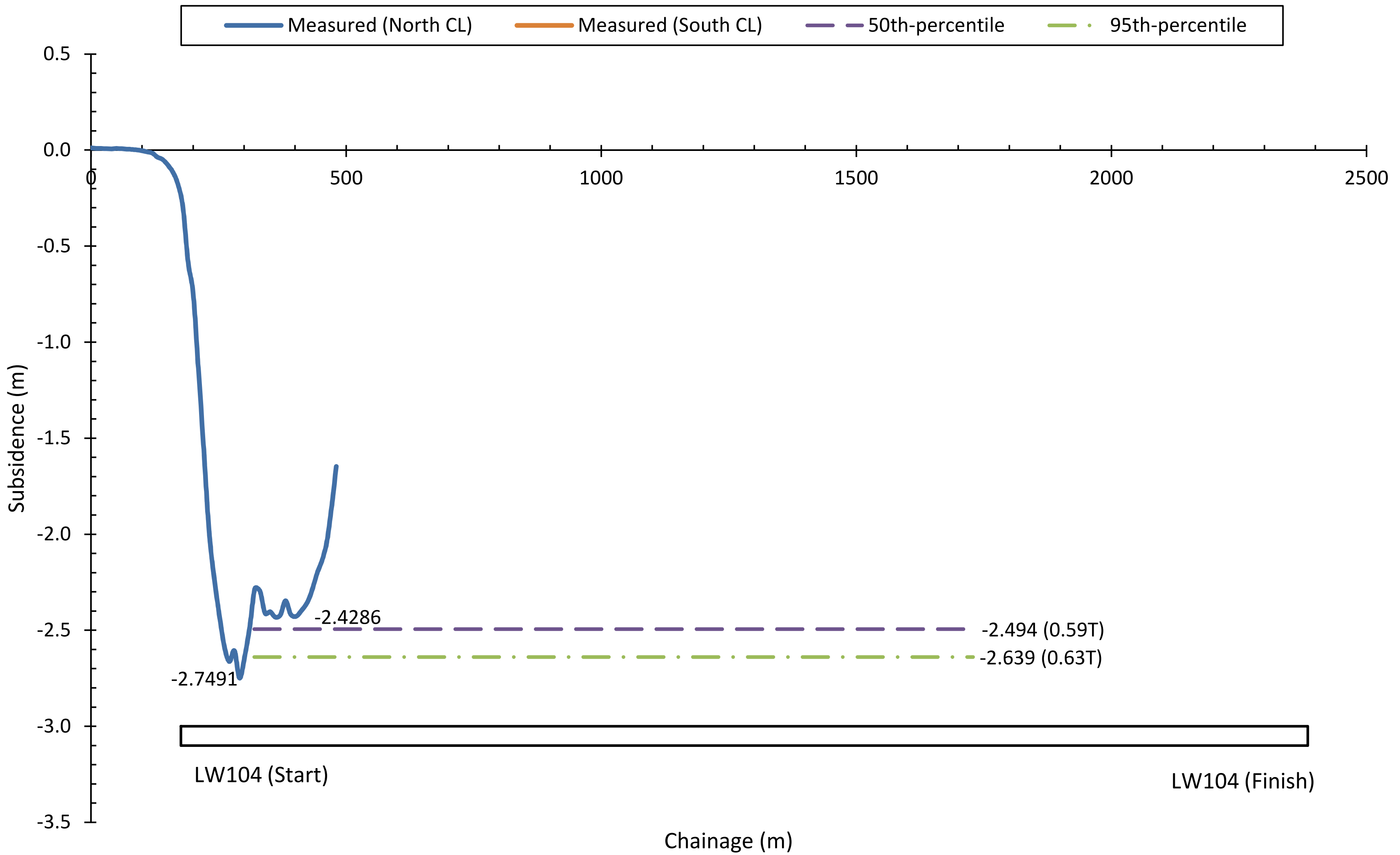

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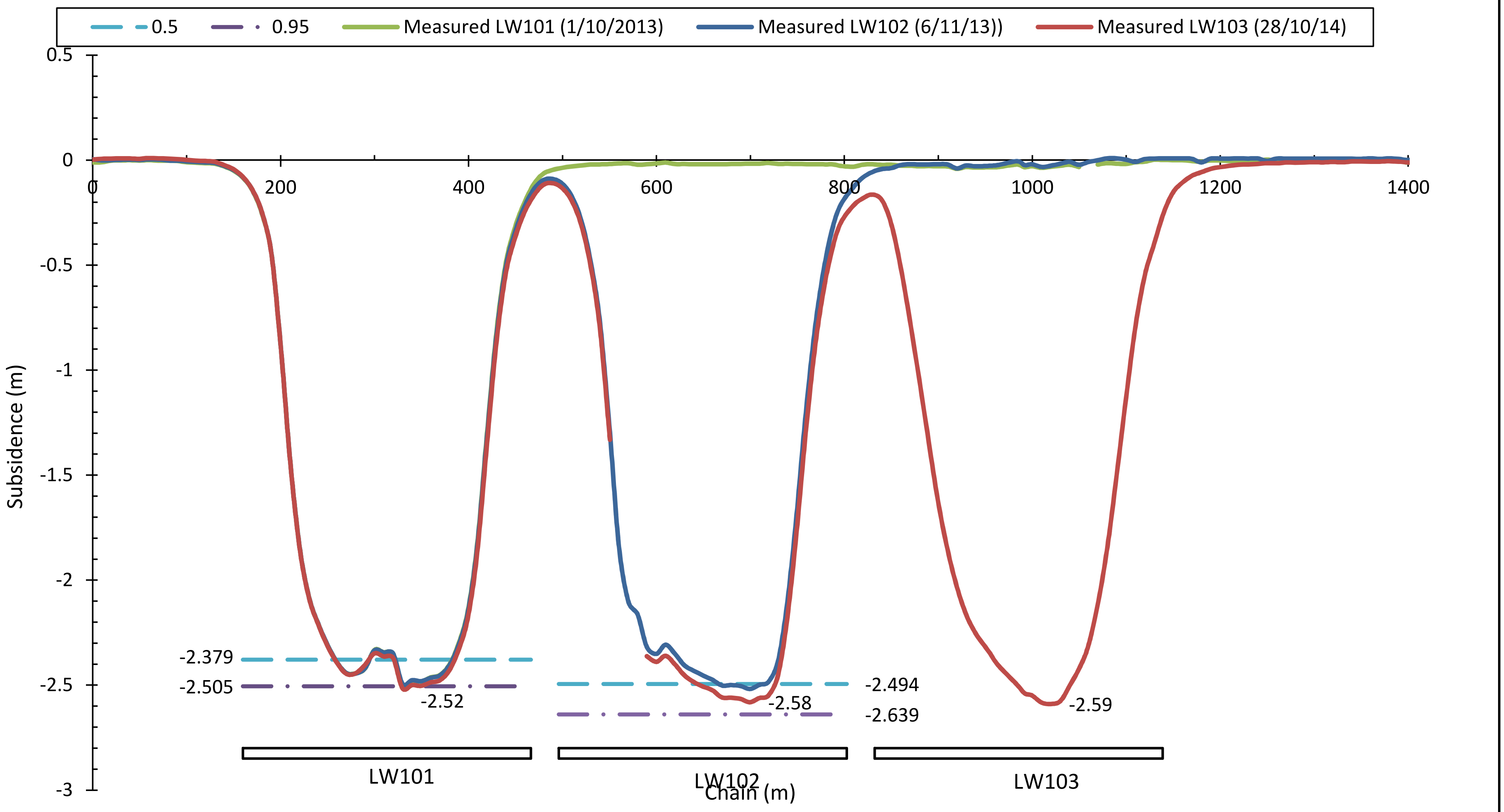

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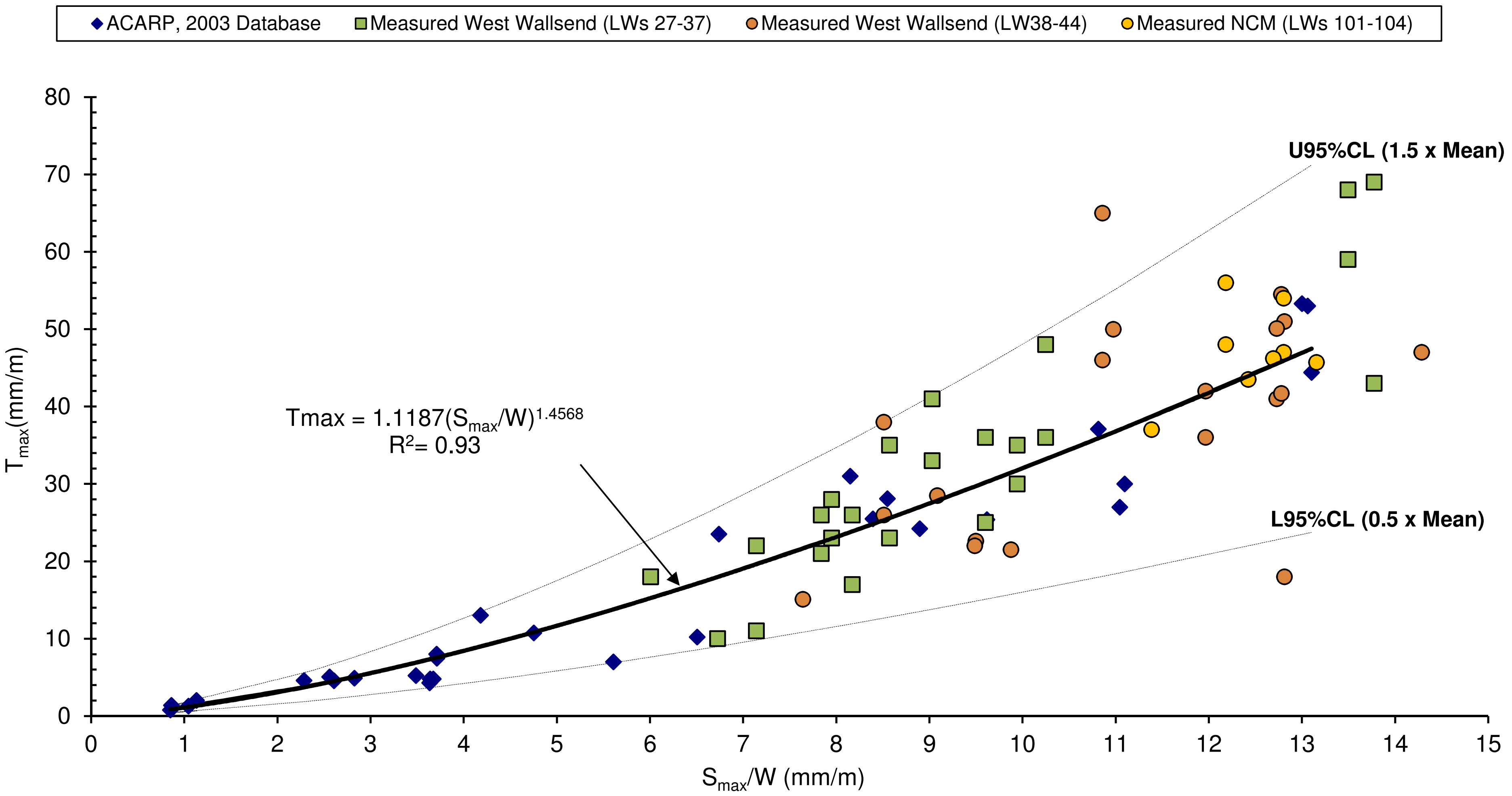

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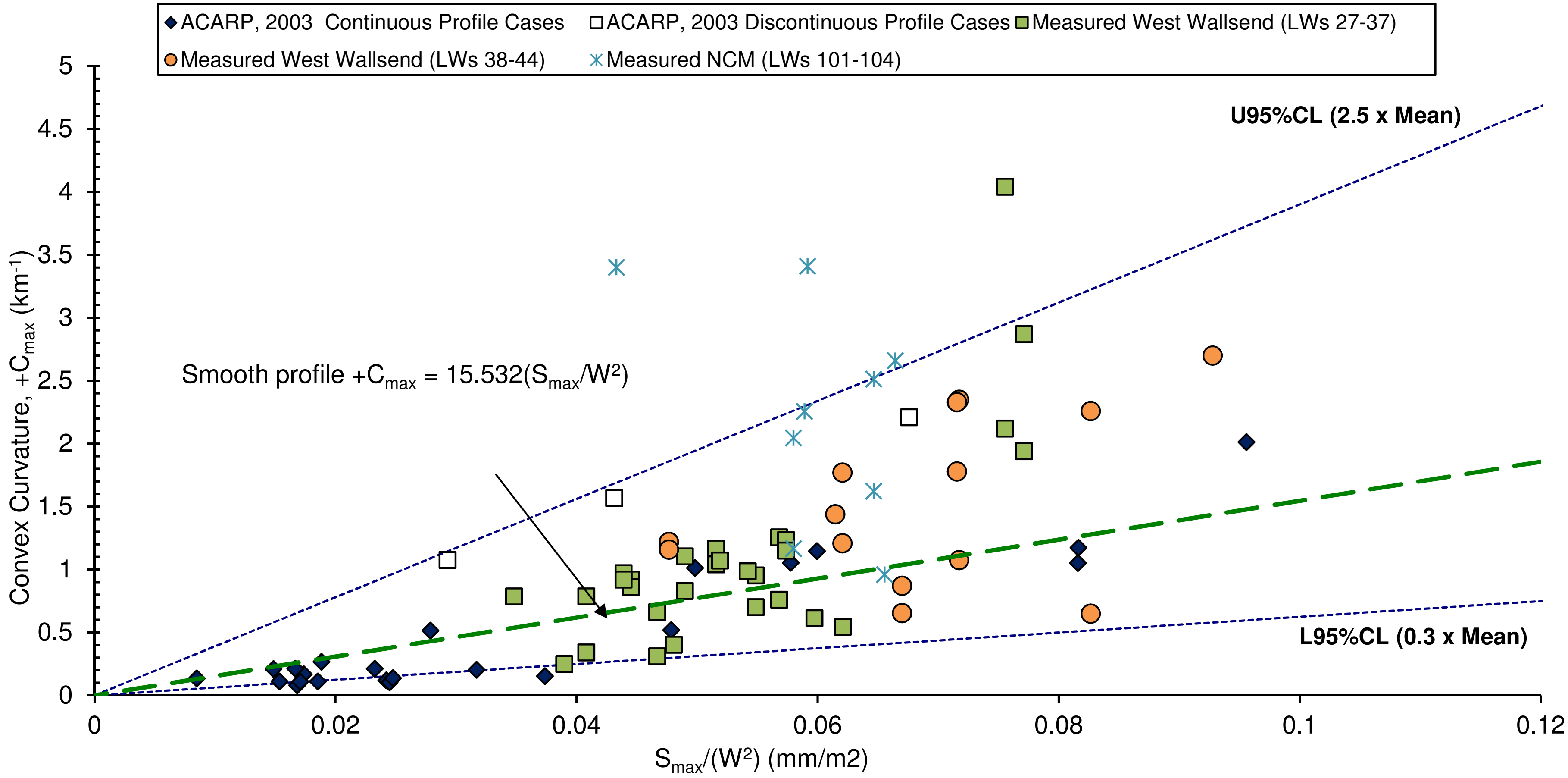
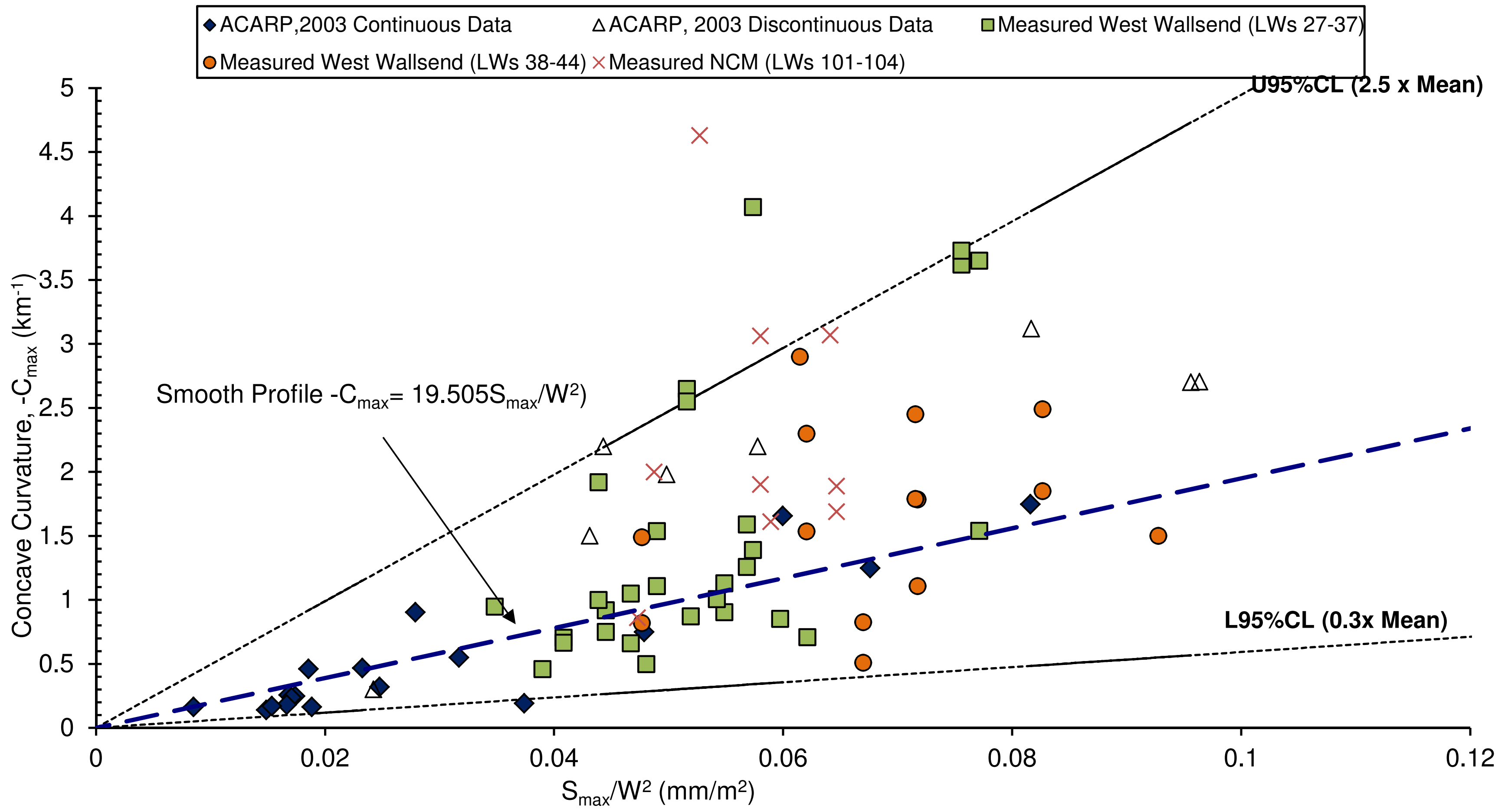
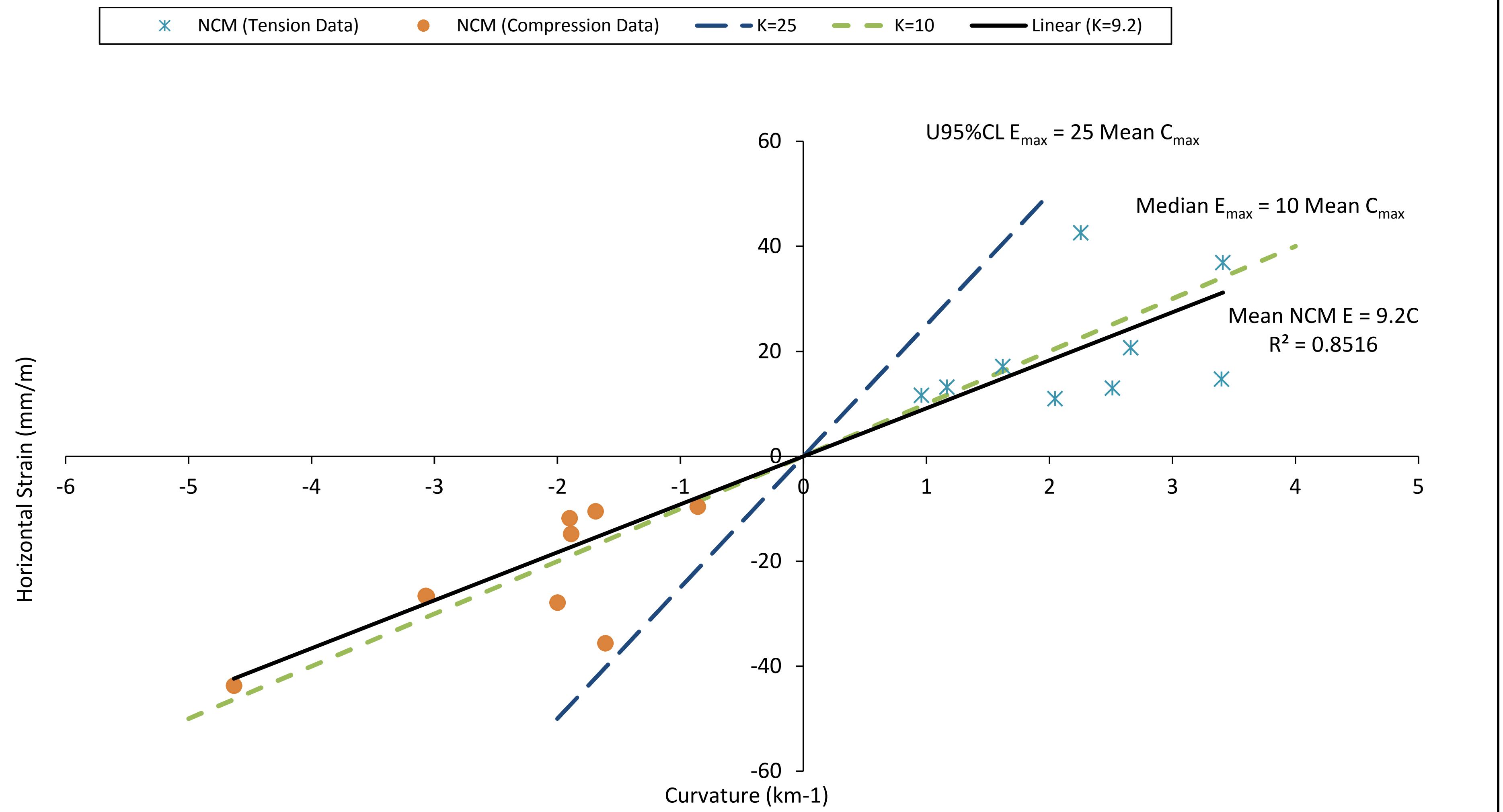


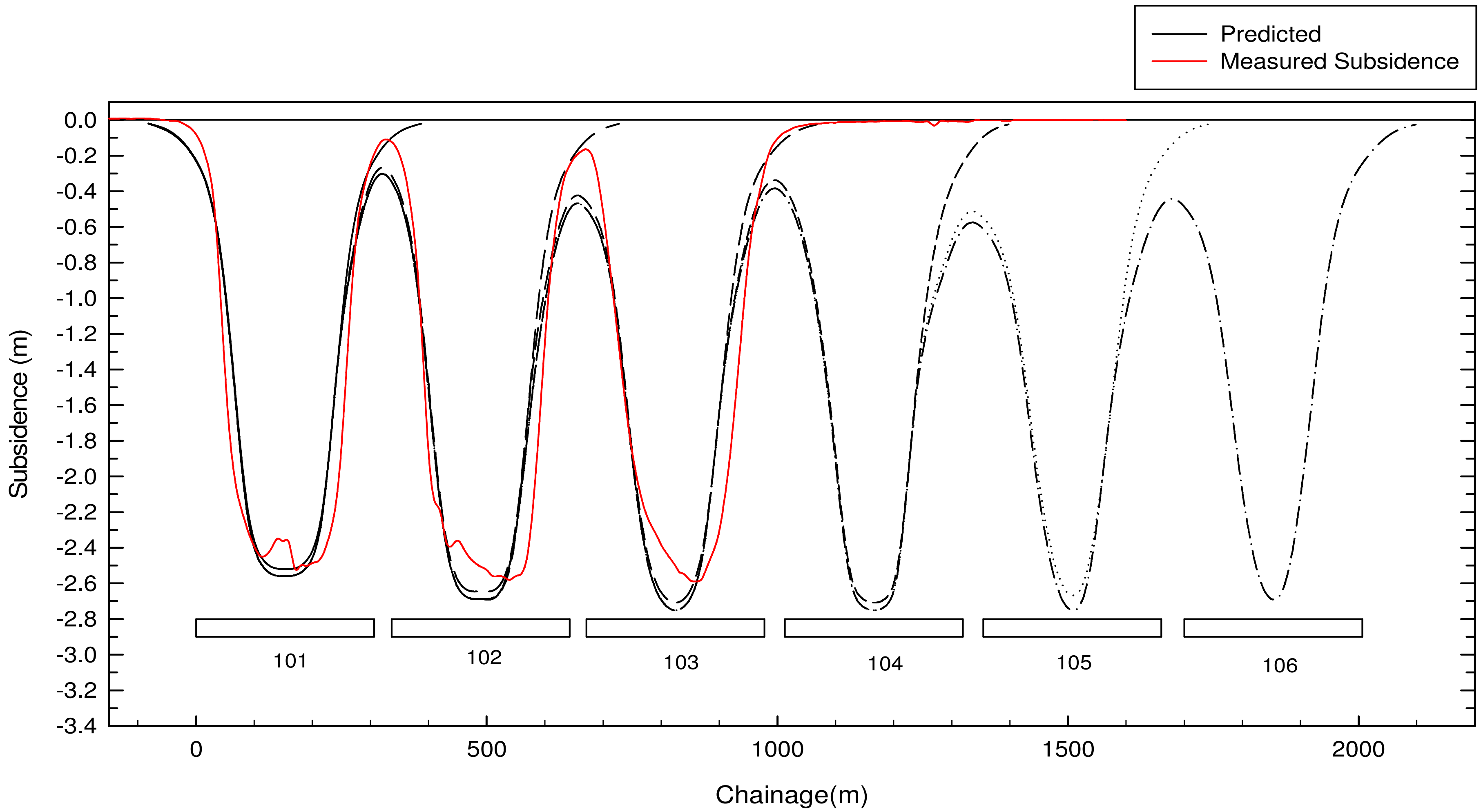
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2	
	Drawn:	S.Ditton			
	Date:	02.06.14	Title:	ACARP,2003 Regression Model of Maximum Convex Curvature with Measured Values for the NCM Longwalls 101 - 104	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 9b



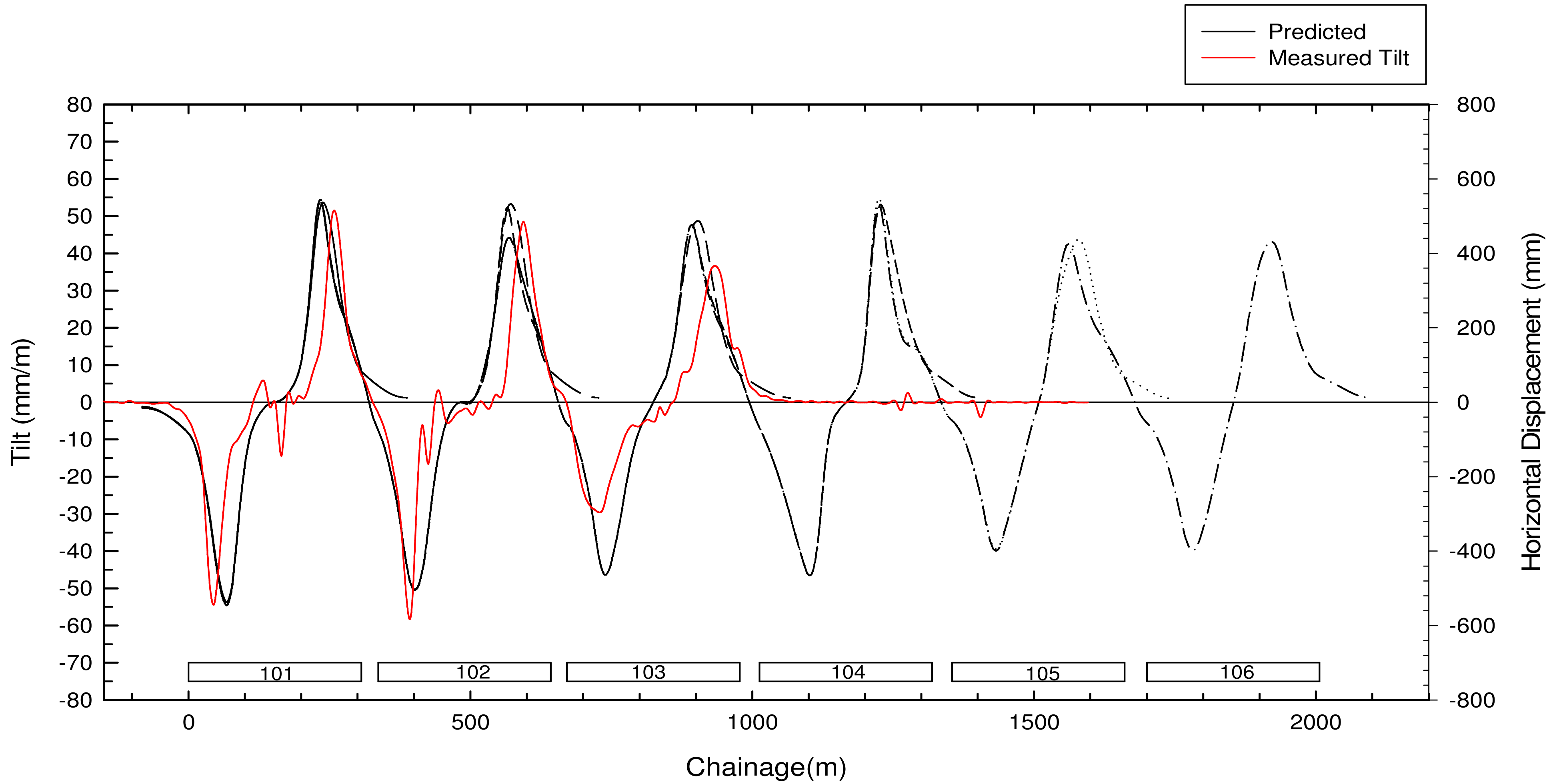
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2		
	Drawn:	S.Ditton				
	Date:	02.06.14	Title:	ACARP,2003 Regression Model of Maximum Concave Curvature with Measured Values for the NCM Longwalls 101 - 104		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	9c



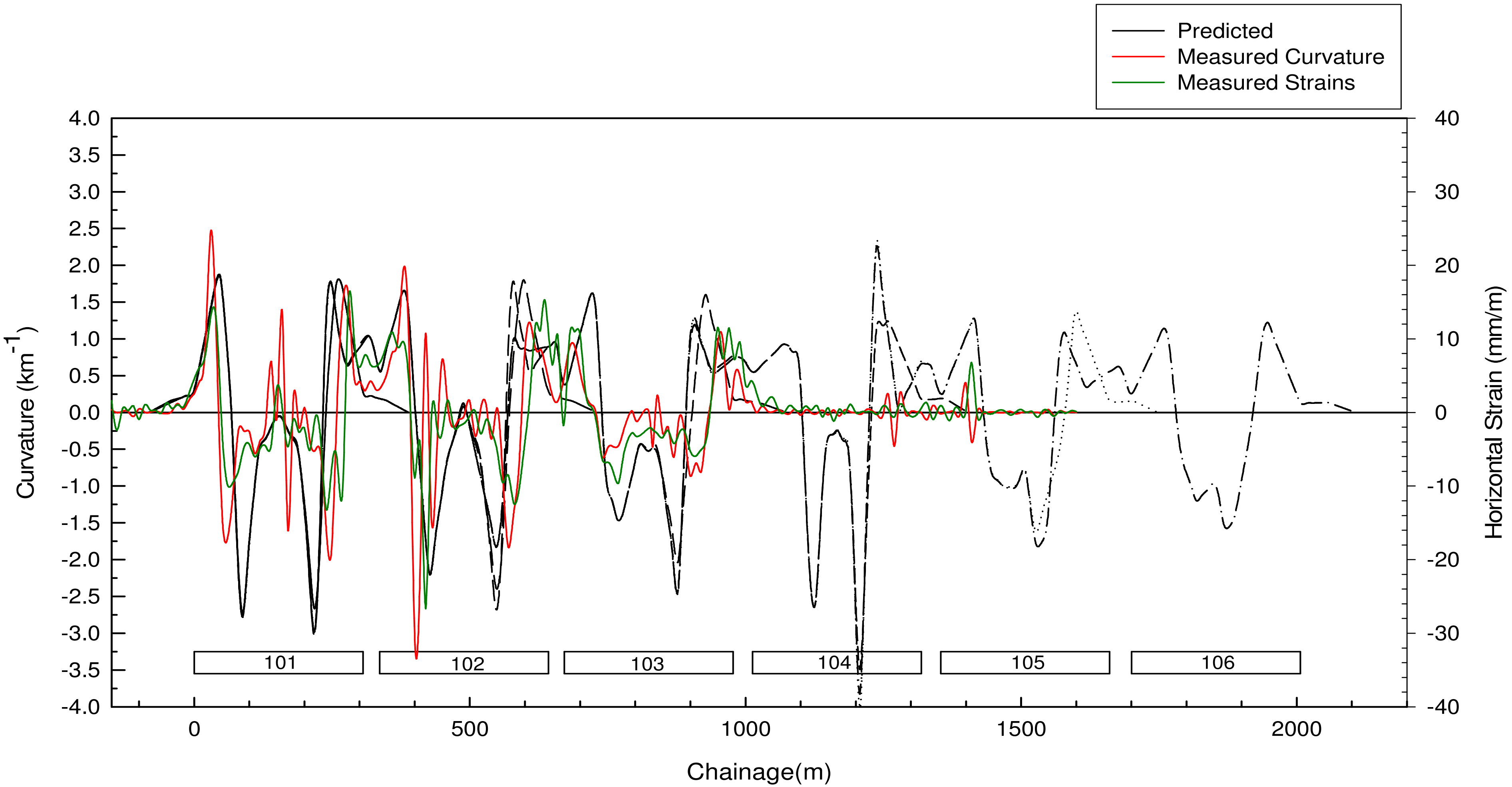
DgS	Engineer: S.Ditton		Client:	Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn: S.Ditton			
	Date: 01.05.15		Title:	Linear Regression of Maximum Strain v. Curvature for ACARP, 2203 and Values for the NCM Longwalls 101 - 104
	Ditton Geotechnical Services Pty Ltd			
			Scale:	NTS
			Figure No:	9d



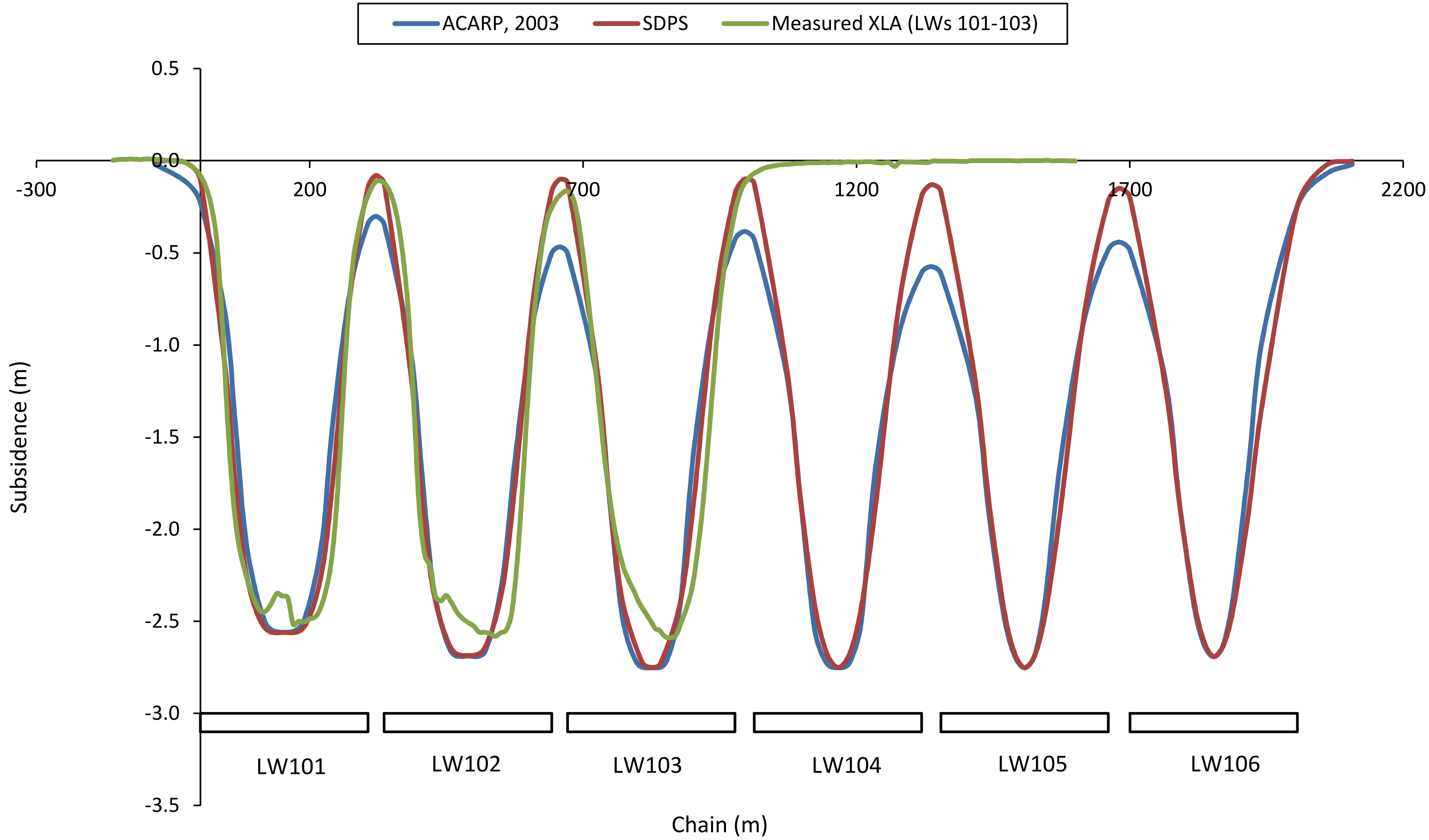
DgS Ditton Geotechnical Services Pty Ltd	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2		
	Drawn:	S.Ditton				
	Date:	01.05.15	Title:	Predicted Subsidence Profiles along XL4 above LWs 101 to 106		
			Scale:	NTS	Figure No:	10a



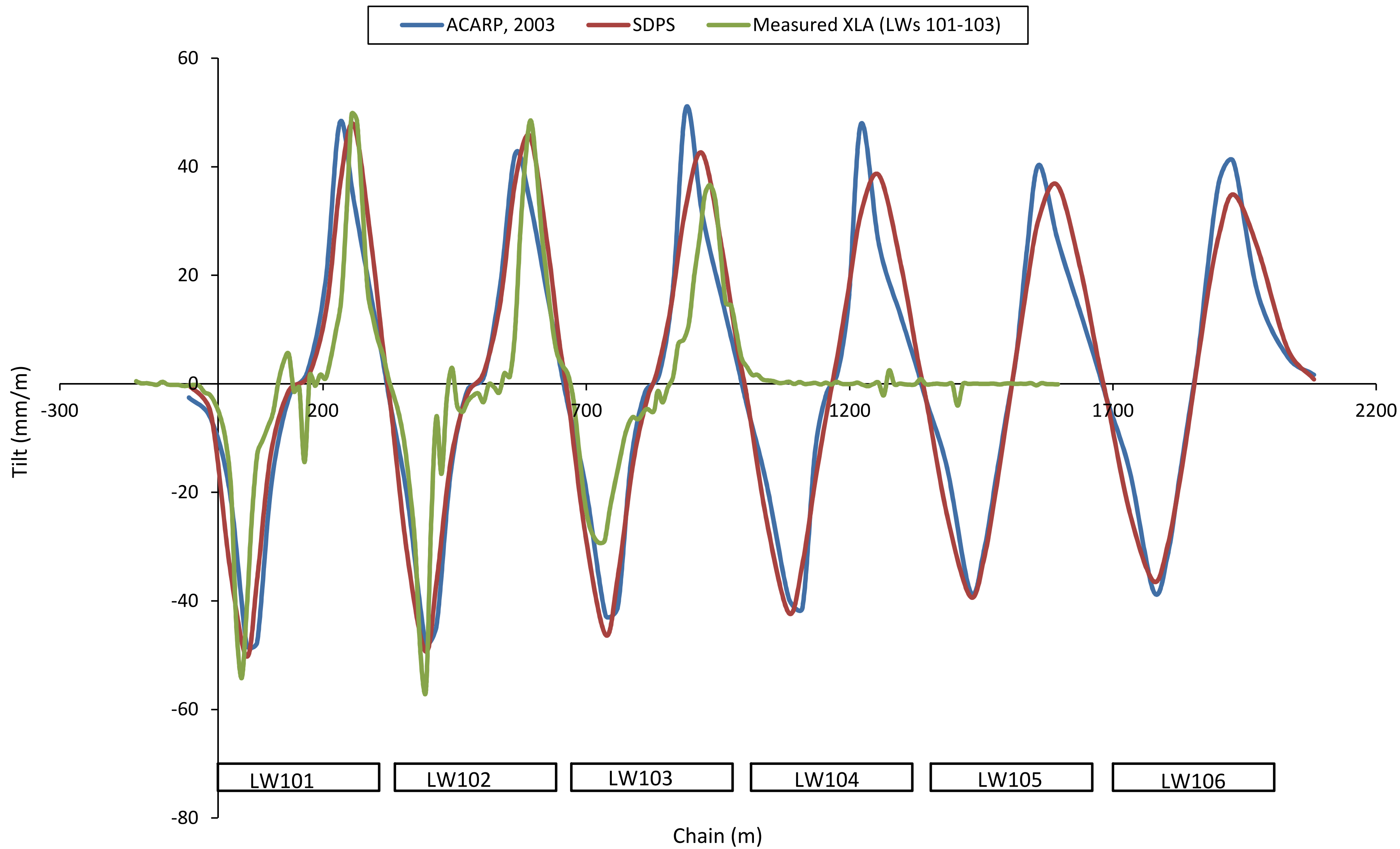
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2)		
	Drawn:	S.Ditton		NAR-002/2		
	Date:	01.05.15	Title:	Predicted Tilt & Horizontal Displacements Profiles along XL4 above LWs 101 to 106		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	10b



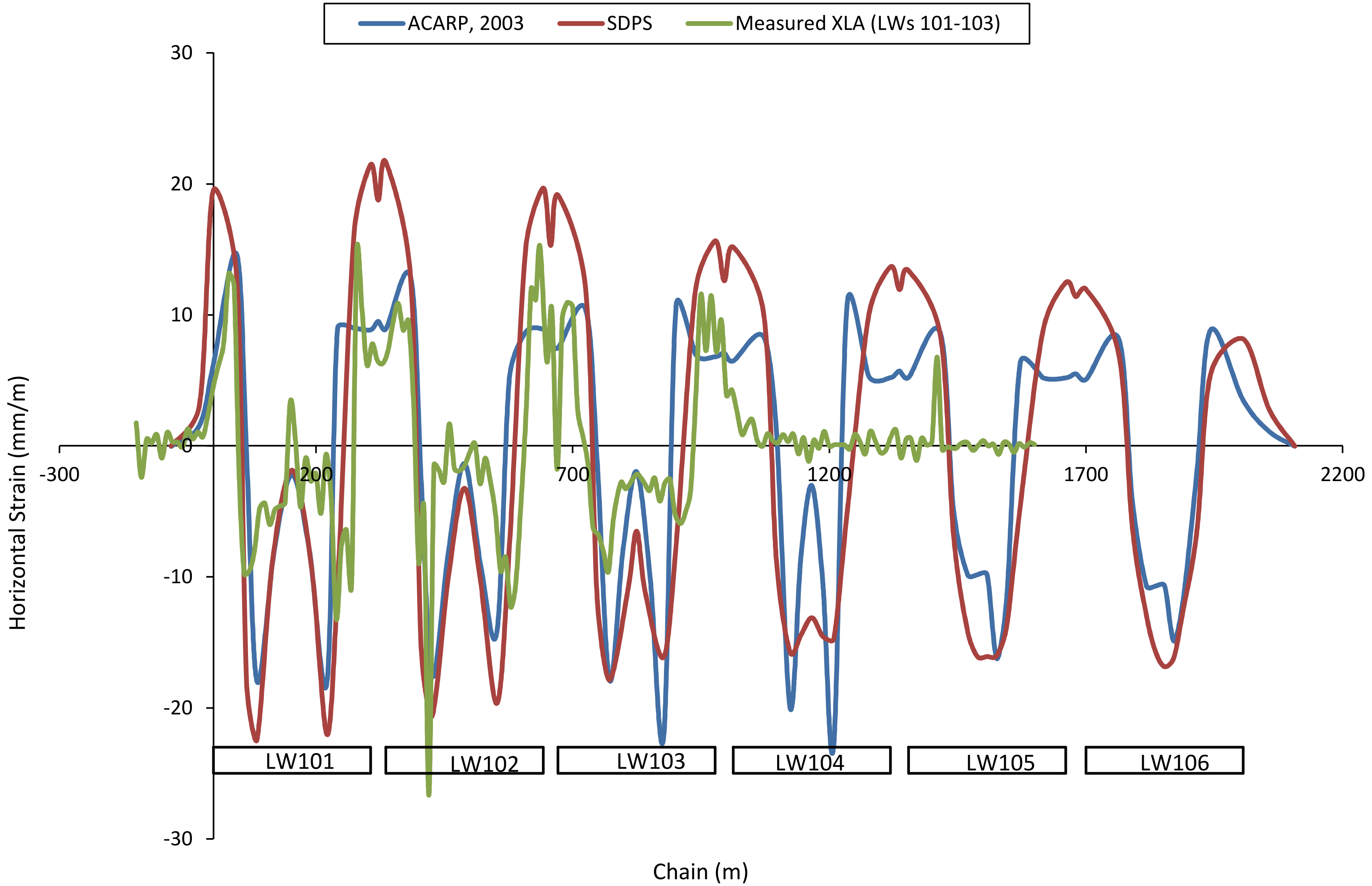
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2	
	Drawn:	S.Ditton			
	Date:	02.06.14	Title:	Predicted Curvature & Horizontal Strain Profiles along XL4 above LWs 101 to 106	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 10c



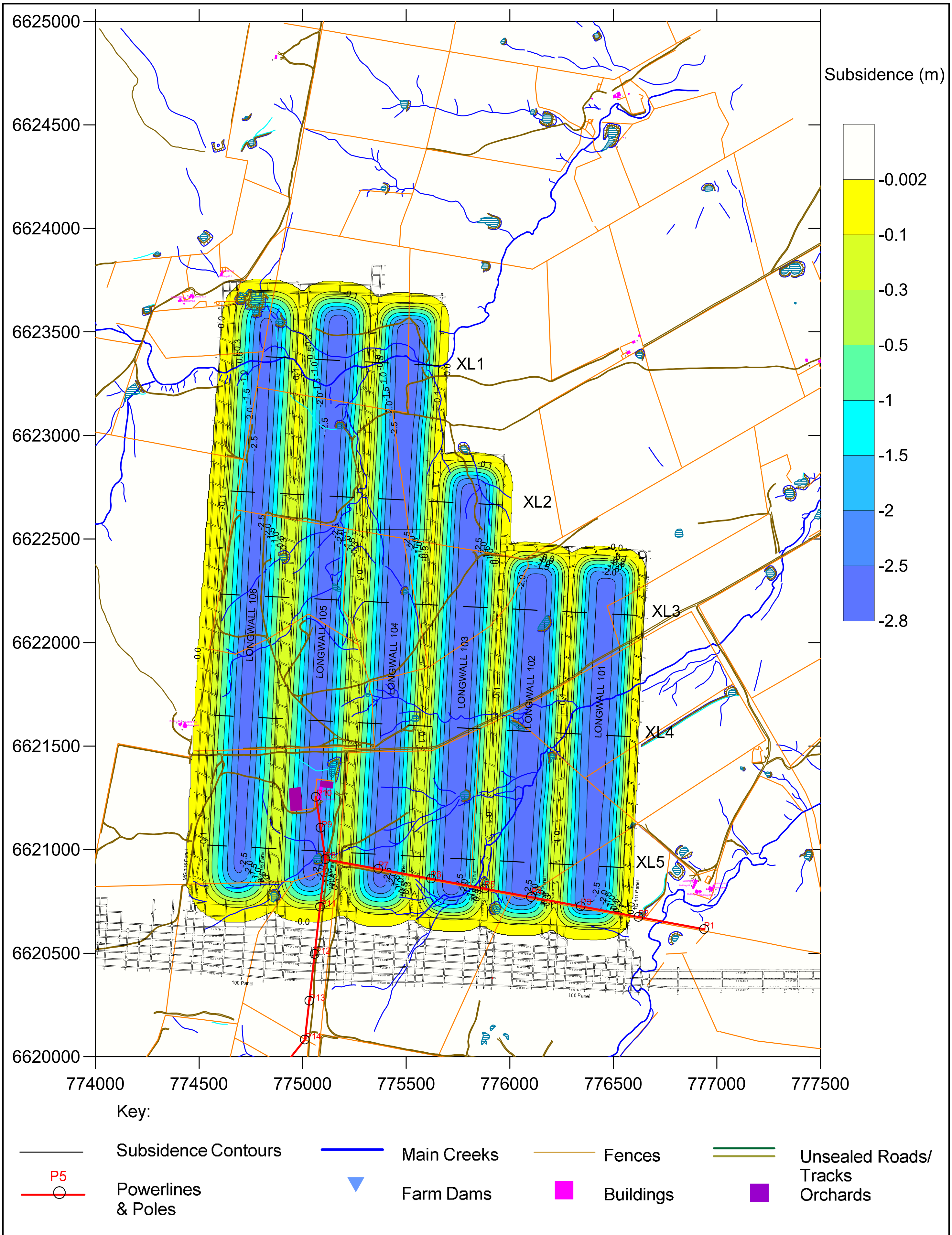
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2)		
	Drawn:	S.Ditton		NAR-002/2		
	Date:	01.05.15	Title:	Calibrated SDPS v. ACARP, 2003 Subsidence Profile Predictions along XL 4 for LWs 101 to 106		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11a



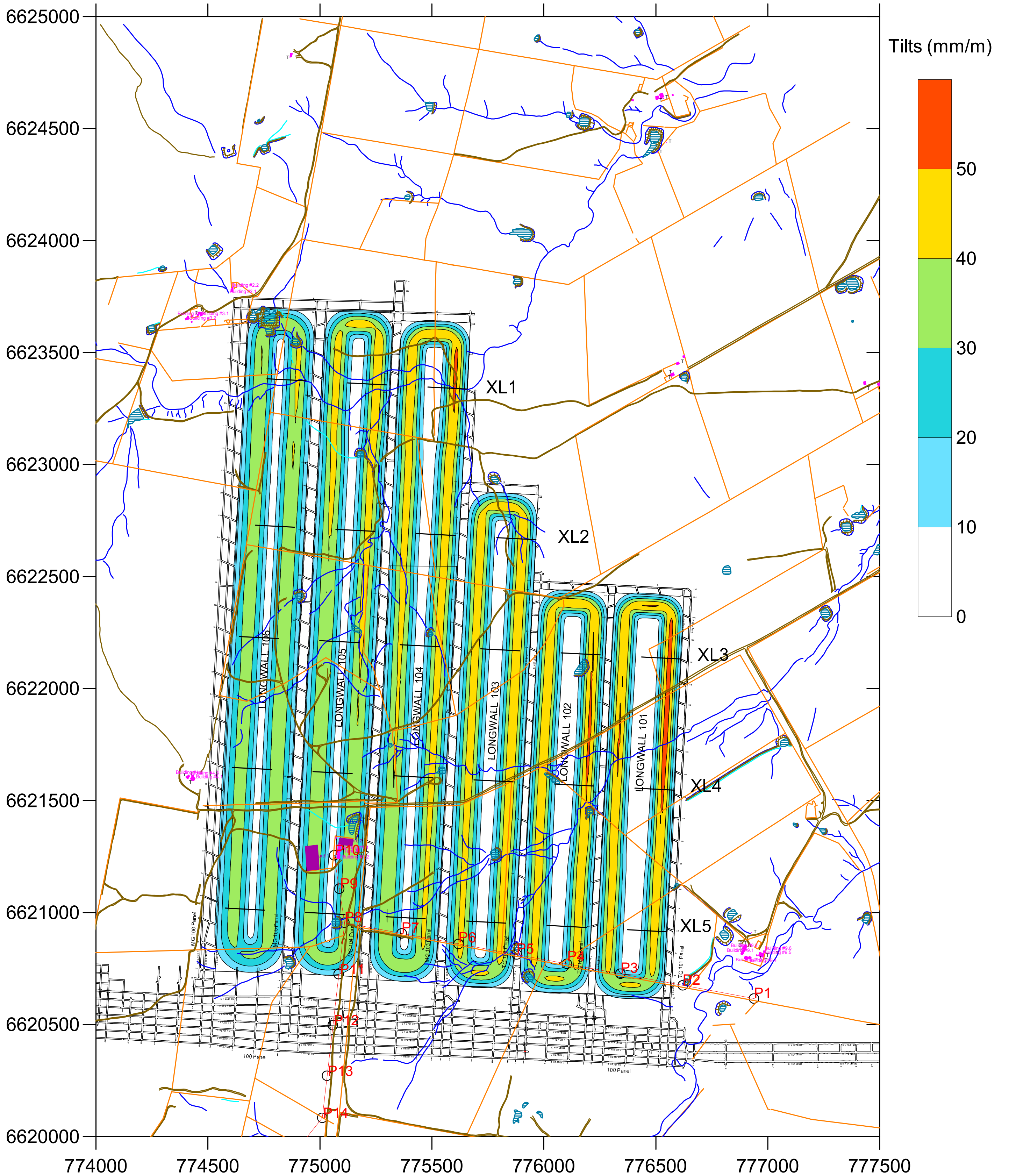
DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2		
	Drawn:	S.Ditton				
	Date:	01.05.15	Title:	Calibrated SDPS v. ACARP, 2003 Tilt Profile Predictions along XL 4 for LWs 101 to 106		
	Ditton Geotechnical Services Pty Ltd					
			Scale:	NTS	Figure No:	11b



DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2		
	Drawn:	S.Ditton				
	Date:	01.05.15	Title:	Calibrated SDPS v. ACARP, 2003 Horizontal Strain Profile Predictions along XL 4 for LWs 101 to 106		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	11c



DgS	Engineer:	S.Ditton	Client:	Narrabri Coal Operations Pty Ltd - Narrabri Coal Mine (Stage 2) NAR-002/2
	Drawn:	S.Ditton		
	Date:	01.05.15	Title:	Predicted Worst-Case Mine Subsidence Contours above LWs 101-106
Ditton Geotechnical Services Pty Ltd			Scale:	1:25,000 — Figure No: 12a



Key:

Tilt Contours

P5 Powerlines & Poles

Main Creeks

Farm Dams

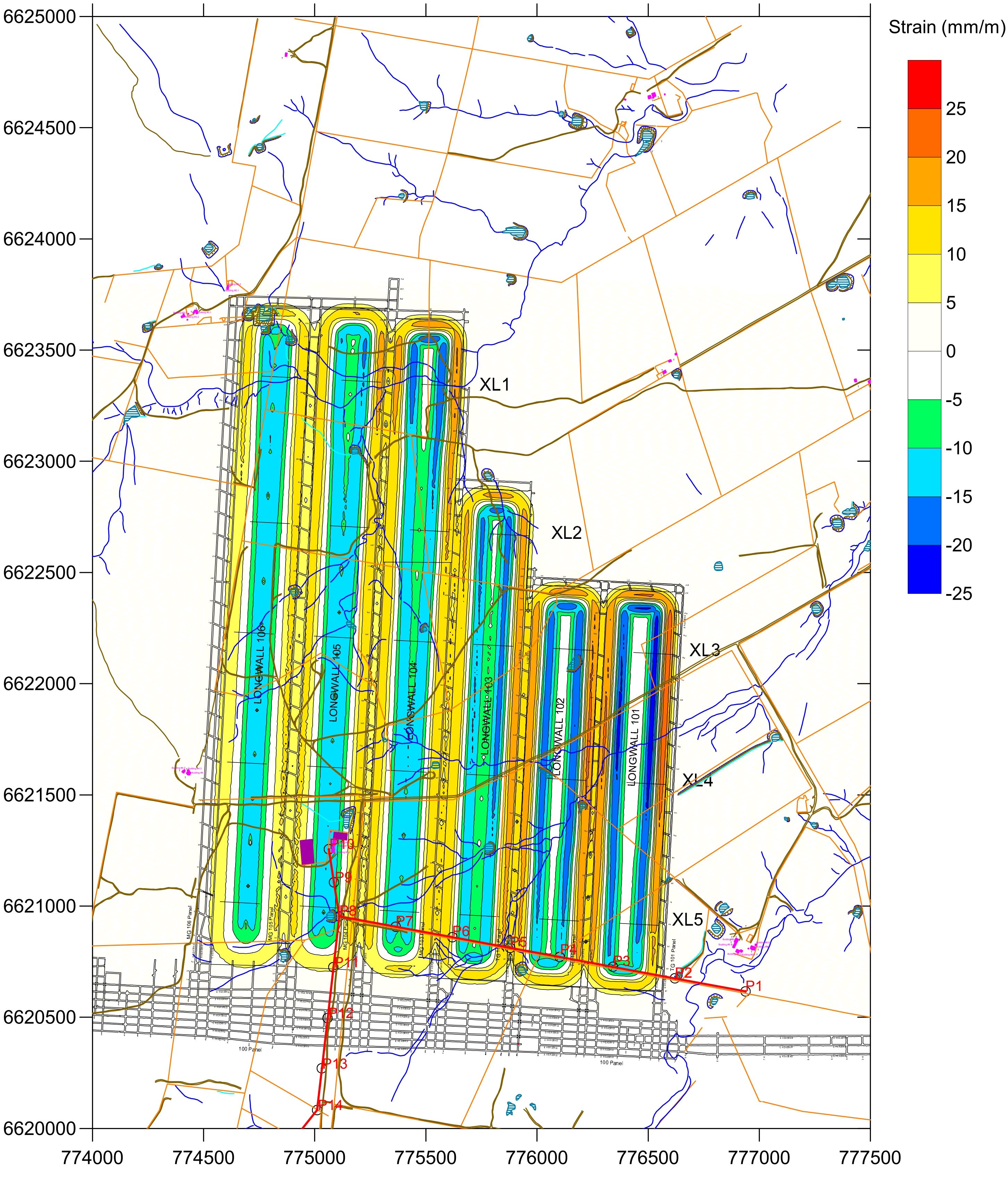
Fences

Buildings

Unsealed Roads/ Tracks

Orchards

Engineer:	S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2
Drawn:	S.Ditton		
Date:	01.05.15	Title:	Predicted Worst-Case Principle Tilt Contours above LWs 101 - 106
DgS Ditton Geotechnical Services Pty Ltd		Scale:	1:25,000
		Figure No:	12b



Key:

Strain Contours	Main Creeks	Fences
Unsealed Roads/ Tracks	P5 Powerlines & Poles	Farm Dams
Buildings	Orchards	

DgS	Engineer: S.Ditton	Client:	Narrabri Coal Mine (Stage 2) NAR-002/2
Ditton Geotechnical Services Pty Ltd	Drawn: S.Ditton	Title:	Predicted Worst-Case Horizontal Strain Contours above LWs 101 - 106
	Date: 01.05.15	Scale:	1:25,000
		Figure No:	12c