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c/- Catalyst Project Consulting Pty Ltd

Mine Subsidence Risk and Preliminary Mine Workings Remediation Assessment for the Proposed Aged Care Development at 40 King St, Adamstown

DGS Report No. CAT-001/1

Date: 12 December 2018

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12 December, 2018

Third Age Villages Pty Ltd

Attention: Tim Mackiewicz
c/-Catalyst Project Consulting
110 King St
NEWCASTLE NSW 2300

Report No. CAT-001/1

Dear Tim,

Subject: Mine Subsidence Risk and Preliminary Mine Workings Remediation Assessment for the Proposed Aged Care Development at 40 King St, Adamstown

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

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

For and on behalf of
Ditton Geotechnical Services Pty Ltd

Steven Ditton
Principal Engineer & Director

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1.0 Introduction

This report has been commissioned by Third Age Villages Pty Ltd to support the application for a Site Compatibility Certificate for a proposed Seniors Housing Development at the Merewether Golf Course, 40 King St, Adamstown. A future development application would then be lodged to build and operate this Seniors Housing proposal. Merewether Golf Club also proposes, at some future time, to redevelop the existing clubhouse at the site to align with this new Seniors Housing development.

The primary purpose of this report is to inform the Site Compatibility Certificate application for the proposed Seniors Housing. However, this Report has also considered the club house portion of the site so that any cumulative impacts can be understood. This report provides an appraisal of the abandoned mine workings conditions and worst-case mine subsidence predictions for the proposed development.

The proposed development will consist of a two-storey club house and five-storey residential tower complex with basement car parking. The site is located above two abandoned bord and pillar mine workings in the 3.5 m to 4 m thick Borehole Seam (circa 1880's to 1920s). The workings are at a depth of 65 m to 75 m with a mine roof level of RL -45 AHD. The workings are likely to be flooded, based on observed conditions in the Borehole Seam workings ~ 2 km to the east of the southern dipping seam.

According to the SA NSW "Merit Based Assessment Policy for Development Applications" in Mine Subsidence Districts, the proposed buildings are classified as B3 Risk Level (i.e. > $5M construction cost and/or > 4-storeys with basement car-parking). For DA Approval to be granted, SA NSW will require the structures to be "Safe, Serviceable and Repairable" under the predicted subsidence parameters assessed for the site. The definition of "Repairable" means mine subsidence impact shall be limited to 'slight' in accordance with AS2870 Damage Classification and readily repairable.

Australian Agricultural Company (AAC) mined the Borehole Seam in the Hamilton Pit from 1850 to 1901 below and to the east of the existing club house. The Newcastle Coal Mining Company (NCC) mined the seam to the west of the AAC workings between 1900 and 1921.

Record Tracings (RT565 and RT566) indicate that the two mines extracted the coal using bord and pillar (first workings) with some pillar extraction (second workings). Second workings invariably resulted in collapse of the mine roof (known as the goaf) with remnant coal pillars or stooks left behind to provide temporary support as the miners retreated away from the collapsed areas. First workings pillars and second workings goaf appear to be below the proposed re-development. At this stage, the new club house is assessed to be located over the AAC mine workings with the proposed apartment buildings located above the NCC workings; see **Figures 1a** and **1b**.

According to SA NSW, an 11 ha area of AAC first workings pillars in the Hamilton Pit are known to have crushed in 1889, subsiding the surface immediately to the east and northeast of the proposed development site. The maximum subsidence at the time of the crush is estimated to be 0.92 m based on a mining height of 3.0 m and extraction ratio of 68%. The subsidence above the second workings areas is estimated to have ranged between 0.92 m and 1.15 m for mining heights between 2.4 m and 3.0 m respectively.

It is possible that some of the NCC first workings below the site are still standing. Based on a mining height of 2.4 m, a maximum subsidence of 0.6 m to 0.42 m could occur if the pillars were to crush under dry and flooded conditions respectively[1]. The consequence of future pillar instability beneath the site is therefore likely to be considered by the Subsidence Advisory NSW as an unacceptable business and public safety risk.

A grouting program in the workings may therefore need to be considered (pending drilling investigations) to reduce worst-case subsidence tilt, curvature and horizontal strain values to within tolerable limits (as defined by structural engineers).

If the first workings have already crushed, the potential for significant subsidence will probably be reduced in these areas, removing the need for grouting. Defining the area of standing and non-standing pillar areas may require a significant investment in investigation drilling however.

The outcomes from this study will therefore need to provide preliminary worst-case subsidence effects for the non-grouted and grouted workings cases, such that the cost-benefit of drilling investigation, drilling and grouting and building designs can be ascertained.

It should be further understood that this assessment is a project feasibility level study only. Drilling investigation and numerical modelling of grout effectiveness on subsidence effects will be required for detailed structural design purposes and to satisfy SA NSW Approval requirements.

2.0 Scope

The scope of work for this feasibility level study will include:

(i) A desktop review of pillar stability of current workings, based on Record Tracings (RT) of the AAC (RT566) and NCC (RT565) mine workings;

(ii) Estimate of worst-case subsidence effects due to crushing of standing pillars under design loading conditions;

(iii) Assessment of the likely location of in-seam grout confinement of key pillars, based on (i) and (ii) in order to control worst-case subsidence to within tolerable limits for the proposed structures.

[1] As the workings are now flooded, any future subsidence estimates may assume buoyancy effects will be active below the water table.

3.0 Methodology

The following methodology has been applied to assess the subsidence beneath the site:

(i) Preparation of a scaled mine plan in real world coordinates (MGA) below the site using the available RTs and cadastre information provided in the NSW Globe (NSW Dept. of Finance, Services & Innovation).

(ii) A desktop review of available nearby geotechnical investigations to the Borehole Seam (~1.8 km due east of the site).

(iii) Development of a geotechnical model of the overburden and mine workings conditions below the site.

(iv) Estimates of likely and worst-case pillar loading on pillars and strength of pillars beneath the site using an industry established empirical models (**ACARP, 1998** and **UNSW, 1998**).

(v) Assessment of the Pillar Factor of Safety (FoS) under design loading conditions and likelihood of a pillar run or local pillar failure to occur beneath the site, based on reference to published failed and unfailed pillar case histories for Australian Bord and Pillar Mines as presented in **UNSW, 1998**.

(vi) Assessment of the maximum predicted 'worst-case' subsidence deformations likely to occur above the locations affected by a pillar run, based on analytical analysis and empirical subsidence models. Estimates of maximum subsidence, tilt, curvature, and horizontal strain profiles over the subject site have been determined using empirical subsidence profile models presented in **DgS, 2018** for the Newcastle bord and pillar mine workings.

(vii) A preliminary assessment of the effect of targeted roadway grouting adjacent to key pillars beneath the site.

(viii) Estimates of grout strengths and volumes required to adequately confine the pillars and control the subsidence effects to within the design limits.

4.0 Site and Mine Workings Conditions

The site is located in mildly undulating to flat terrain with a surface RL of 23 to 25 m AHD and dipping towards the south at 1.5° to 2°.

A two-storey club house with external bitumen sealed carparking to the east currently exists on the site of the proposed club house. The proposed residential apartment will extend to the west from the southern end of the new club house site for approximately 200 m. The foot print of the development (including basement car parking) will be approximately 44 m x 280 m (12,300 m^2).

Flooded bord and pillar AAC (circa 1880 to 1901) and NCC (circa 1900 to 1921) mine workings exist in the Borehole Seam at 65 m to 75 m depth of cover.

Reference to the 1:100,000 Newcastle Coalfield Geological Map indicates that the site is located within the Lambton Subgroup of the Permian Newcastle Coal Measures.

Two investigation boreholes by Douglas Partners (**DPS, 2014**) at another site approximately 1.8 km to the east of the proposed development, indicate the sub-surface profile is likely to include:

- Stiff to very stiff residual sandy clay and clayey sand or extremely weathered sandstone to a depth of 3 m to 5 m, overlying
- 60 m to 70 m of interbedded sandstone and siltstone with medium to high strength (UCS ranges from 20 MPa to 60 MPa) and minor coal (Dudley and Nobbys Seams), overlying
- 0.5 m to 1.5 m thick unit of low strength carbonaceous mudstone and siltstone (shale), overlying
- 3.6 to 4.0 m thick Borehole Seam or 0.5 m to 1.0 m of void, 4.5 m to 5.0 m of collapsed mine roof rubble, overlying
- High strength Waratah Sandstone (UCS of 40 to 60 MPa)

A model of the likely subsurface profile of the overburden lithology is given in **Figure 2**.

Complete drilling fluid losses may occur within 5 m of the first workings roof and 3 to 5 times the mining height or between 10 m and 20 m above second workings goaf. Partial fluid losses into open bedding partings and fractures are expected anywhere from about 20 m below the surface due to previous mine subsidence disturbances.

RT566 shows the AAC mine workings and indicates the eastern portion of the site is located over the bord and pillar workings of the Hamilton Pit. Approximately 50% of the pillars were extracted at this location to form second workings goaf below the site. The northern and southern ends of the new club house site may also be located above unmined pillars of coal that are 15 m to 20 m wide that were left between the two mine workings. Second workings goaf are likely to exist between the first workings areas in both mines (see **Figure 1b**).

A subsidence event to the east of the site due to first workings pillar crush occurred in 1889, which affected a surface area of approximately 11 ha (see **Figure 1a**). The pillars in the crush area were approximately 4 m wide and 52 to 57 m long[2]. The bords were 7 m to 8 m wide and cut-throughs were 4.5 m to 5.0 m wide. The mining method extracted 68% of the coal from the seam. The mining height was likely to be somewhere between around 3 m in the 3.5 m to 4 m thick seam (assuming 0.6 m to 0.9 m of the Morgan and Jerry stone bands were stowed in the mine workings). The slenderness ratio (w/h) of the remnant pillars is estimated to range from 1.33 to 1.6.

It is noted that the time of the crush was just after the Wickham & Bullock Island mine workings crush (1896) which had a similar mining geometry to this area of the AAC mine workings.

RT565 shows the NCC workings and indicates that the western area of the site is located over first workings with second workings below a portion of the proposed club house and apartment building (see **Figure 1b**).

The pillars in the NCC were approximately 6.0 m to 6.5 m wide and 35 m long. The bords were 5.5 to 6.0 m wide with 4 m cut-throughs. The mining method extracted 55% of the coal from the seam. According to **Kingswell, 1890** the mining height was likely to be approximately 2.0 m to 2.4 m in the middle section of the seam, as the mine apparently did not extract the coal below the Jerry Band (the lower 0.6 m to 0.9 m of the 3.6 m to 4 m thick Seam). The slenderness ratio (w/h) for the remnant pillars is estimated to range from 2.1 to 3.0.

A row of barrier pillars running north-south exist below the western half of the site. The pillars are 9.1 m to 10.4 m wide and 25 m to 33 m long. The bords and cut-throughs were 2.5 m, indicating an extraction ratio of 27% and slenderness ratio between 3.8 and 4.5.

A large square barrier pillar with a width of ~ 30 m is located between 13 m and 50 m to the north of the site.

The second workings in both mines were likely to have included the reduction in pillar width or 'robbing' of the pillar ribs with remnant pillars or stooks left to provide temporary support to the roof. The extraction ratio for the second workings probably ranged between 70% and 80%. It is expected that the immediate roof of the second workings areas would have

[2] **Gardiner, 1913** discusses the bord and pillar system used in the early pits. Before the crushes of 1896 and 1898, pillars were specified according to British Guidelines at a minimum width of 4 yards (3.66 m) with bords at 8 yards (7.32m) wide to give a 73% recovery of the resource. After the 1908 Royal Commission into the Newcastle mine subsidence events between 1896 and 1907, bord and pillar geometries in NSW at <60 m and between 60 m and 150 m depth were required to be increased to a minimum pillar width of 8 & 12 yards (7.3 & 11 m) respectively. Maximum bord widths of 6 yards (5.5 m) were also required to give resource recovery for the workings of 50% and 40% respectively. A maximum mining height of 14 ft (4.26 m) was also stipulated; refer **CMRA, 1912**.

collapsed soon after robbing was completed and/or when timber props were removed as mining retreated from a workings area. Stooks of coal would have been left in place to provide temporary support to the roof also. Typical mining section geometries in both mines are shown in **Figures 3a** and **3b**.

It is considered that both mine workings are 'connected' and likely to have been flooded for at least 50 years since mining ceased. Water pressure in the workings is likely to be similar to the water table head, which is expected to be at RL 1 m to 2 m AHD or ~24 m below ground level and 41 m to 51 m above the mine workings roof.

5.0 Structural Design and Risk Assessment Criteria

5.1 Importance Level of Proposed Developments

The assessment of appropriate subsidence risk control measures for new developments in the CBD will depend on the following 'Importance Level' of the structures proposed:

Level B1 - Buildings up to 3 storeys, including roof-top access & no basement.
- <50 m maximum plan dimension.
- <$3M construction cost

Level B2 - Buildings up to 4 storeys, including roof-top access & basement.
- <100 m maximum plan dimension.
- <$5M construction cost

Level B3 - Buildings > 4 storeys, including roof-top access & no basement.
- >100 m maximum plan dimension.
- >$5M construction cost
- Function is essential to community health & education services or storage of hazardous materials.

The proposed development is Level B3 with 3 and 5 storeys (including underground car-parking) and > $5M construction cost.

5.2 Structural Design Criteria

The following tolerable subsidence effect criteria have typically been adopted by SA NSW for Level B3 Importance Level structures in order to assess the potential for significant impact due to a design subsidence event:

- Subsidence < 100 mm
- Tilt < 3 mm/m
- Curvature < 0.2 km^{-1}
- Horizontal Strain < 2 mm/m (over 10 m);
  < 0.5 mm/m (over length of structure of 40 m)

If the above limits are assessed as 'likely' to be exceeded after the design subsidence event, it will be necessary to introduce grout at key locations in the bords beneath the proposed structure locations in order to reduce the subsidence effects to within the magnitudes specified.

5.3 Design Subsidence Event Cases for Bord and Pillar Panels (First Workings)

On-going review of uncertainties associated with pillar geometries and loading scenarios has led to the following pillar panel stability cases to be developed during a recent review of subsidence risk in the Newcastle CBD (refer to **DgS, 2018**) and to allow a robust assessment of subsidence trough development risk:

Base Case (BC) - pillar stability assessments based on measured RT dimensions and known mining heights. This case is the starting point for subsequent risk assessment analysis.

Likely Case (LC) - pillar stability assessments assumed RT dimensions and seam thickness adopted as the likely pillar height in the event of mine workings roof collapse above the seam over time.

It is considered, on the basis of probability, that the pillar panels with an FoS of 1.6 are sufficiently overdesigned such that they would very likely sustain additional abutment load generated by a pillar system failure, thus causing the failure to terminate.

Mine subsidence due to a pillar run event is assumed to extend out to pillars with an FoS of 1.6 under design abutment loading conditions. The corollary to this statement is that pillars with an FoS < 1.6 should not be considered stable in the long-term without further investigation.

The Likely Case may be used to determine if the first workings are still likely to be standing under the design loading scenarios (i.e. FTA and abutment loading adjacent to second workings areas).

Credible Worst Case (CWC) - pillar side dimensions scaled from RT plans of the mine workings reduced by 0.5 m (a nominal amount due to the lack of observed spalling) and effective pillar height increased by 0.5 m above the seam height to allow for roof fall above the seam.

The assumed adjustment in pillar dimensions allows for a conservative amount of rib spall, RT plan distortion, geological discontinuity effects and pillar height increase due to roof falls. Mine subsidence due to a pillar run is assumed to extend out to pillars with an FoS of 2.1 under design loading conditions. The increase to FoS compared to the Likely Case is considered reasonable in the context of the consequences associated with a pillar run occurring beneath an occupied building > 4 storeys high.

The Credible Worst Case represents the ‘Serviceability’ Limit State and is appropriate for assessing the long-term stability of the pillars under the design loading scenarios (i.e. FTA and abutment loading adjacent to second workings areas). Level B3 Importance level structures will therefore be required to remain ‘serviceable’ & ‘repairable’ after a Credible worst-case (CWC) subsidence event occurs.

Determining whether pillars have already crushed or remain standing (with the potential to crush) is also critical for assessing the subsidence risk profile and necessary remediation strategies for a given site (see Likely Case definition also).

Absolute Worst Case (AWC) - The AWC is the case that ignores the pillar FoS and assumes that all pillars beneath the site are still standing and crush to the known limits of the mine workings.

The AWC represents the 'Ultimate' Limit State and is applied to developments when the consequence of an incorrect CWC subsidence assessment or inadequate mine remediation works strategy could result in the exceedance of structural strength and cause personal injury and/or loss of life.

Level B3 Importance level structures will therefore be required to remain 'safe' for an Absolute worst-case (AWC) event.

Where any of these above case requirements above cannot be achieved, it will be necessary to implement a verifiable grouting strategy to satisfy the design criteria.

It should also be noted that if it can be established with a reasonable level of confidence that the mine workings have already failed below the site, the predicted subsidence effect predictions for the proposed buildings may not require grout to protect the buildings against residual goaf settlement. Residual settlements of < 100 mm usually occur within 2 to 5 years after second workings is finished and collapsed roof rubble and remnant coal pillars (stooks) have finished consolidating.

As the second workings areas were completed over 100 years ago and likely to have been flooded for over 50 years, further settlements could only occur if (i) the water table was lowered significantly and/or (ii) there are still pockets of standing pillars or stooks that may deteriorate and crush at some point in the future.

5.4 Site Uncertainty Classification

SA NSW have recently developed a procedure to assess the risk of trough and pot-hole subsidence on surface development. The approval conditions for a development will be based on:

- The assessed level of geotechnical uncertainty (the Uncertainty Factor)
- The assessed stability of coal pillars based on the factor safety (FoS) and slenderness of the pillars (w/h)
- The type of structure (building importance level)

The Uncertainty Factor (UF) is a weighted Index that ranges between 0 and 20 and considers the following sources of geotechnical uncertainty (R1 to R4) associated with the assessment of the long-term stability of the mine workings pillars:

R1 = Geological Environment (weighting of 2)

R2 = Level of Geotechnical Investigation (weighting of 2)

R3 = Type of coal mine plans (weighting of 3)

R4 = Method used to assess stability and impact (weighting of 3).

The sum of the products of each uncertainty source weighting and uncertainty score (1, 2 or 3) less 10 gives the overall Uncertainty Factor as follows:

UF = R1 x U1 + R2 x U2 + R3 x U3 + R4 x U4 - 10.

The UF is then categorised as Low (UF < 5), medium ($5<UF\leq10$) and high (UF>10) and is used to derive the minimum long-term stability factors, pillar geometry assumptions and building design constraints for a site.

The assessed uncertainties for the proposed development and the risk of trough subsidence are summarised in **Table 1**.

Table 1 - Geotechnical Uncertainty Factor Assessment Summary

Uncertainty Source	**Description**	**Assessed Information**	**Uncertainty Score (U)**	**Product Score (R1 x U1)**
R1 (weighting of 2)	Geological Environment	No significant faulting or mine plan adjustments. Seam dip < 10^o.	**1**	**2**
R2 (weighting of 2)	Level of Geotechnical Investigation	No site-specific borehole data (nearest two cored boreholes 1.8km to east of site)	**3**	**6**
R3 (weighting of 3)	Type of coal mine plans	Hand worked mines (welsh bords) showing regular to complex layout of first and second workings areas.	**2 - 3**	**6 - 9**
R4 (weighting of 3)	Method used to assess stability and impact	Feasibility level assessment using established empirical methods to estimate FoS & subsidence effects	**2**	**6**
			Uncertainty Factor (UF)	10 - 13

The Uncertainty Factor is assessed to range between 10 and 13 which indicates Medium to High Uncertainty. The following design constraints will therefore be required for a Level B3 development for non-grouted solutions according to *Table C3* of the SA NSW Guideline:

For a Medium level of Geotechnical Uncertainty

- Pillar FoS > 2.1
- Pillar w/h > 4
- Independent peer review of geotechnical report verifying the pillars are long-term stable
- Structural engineers report that confirms the structure will remain safe after the Absolute Worst Case subsidence event
- Structure has been designed to remain serviceable and repairable after the Credible Worst Case subsidence event
- A number of permanent survey marks are established on the buildings and details of these and base-line levels (pre-mine subsidence) are provided to SA NSW.
- Verification of mine working remediation works and evidence that the structures have been constructed in accordance with all relevant building codes and standards are provided to SA NSW on completion of the development.

For a High level of Geotechnical Uncertainty

- It will be necessary to reduce the level of Geotechnical Uncertainty to Medium or Low before applying for a Development Approval (i.e. assessment is based on site drilling investigation results).

The pillar stability has been assessed in **Section 6** for a B3 Risk level Classification and a Medium Level of Geotechnical Uncertainty.

For assessment of the risk of pothole subsidence is usually only included in a desk top study when the cover depth is < 10 times the seam thickness or overburden conditions are very poor. For a seam thickness of 3.5 m to 4 m, the minimum cover depth required to invoke a pot hole risk assessment would be < 40 m. A pot-hole risk assessment has therefore been precluded from this study.

6.0 Pillar Stability Assessment

6.1 General

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

The empirical pillar strength formulae currently used in the Australian coal industry is based on a non-linear power law, which assumes that for a FoS of 1, the pillar panel will have a Probability of Failure (PoF) of 50%. The database includes ‘failed’ and ‘unfailed’ pillar panels from the South African and Australian Coal industries and is plotted in terms of pillar strength v. pillar load in **Figure 4a**.

The pillars within the panels were all considered to be subject to the weight of the full column of rock above the pillars and half the surrounding bords. This is known in the industry as ‘full tributary area’ (FTA) loading conditions as shown in **Figure 4b**.

In **Figure 4a**, several FoS lines have been drawn through the database of 175 cases, 35% of which represent pillar panel failures. The panel failures occurred between FoS values of 0.74 and 1.66 and there is a mix of failed and unfailed cases between FoS values of 1.0 and 1.3.

It should be noted that one Australian pillar failure case in the data base was purposely subject to additional loading by progressively extracting the coal pillars beside it in order to instigate failure in the subject pillar. The additional loading is termed ‘abutment’ loading and its magnitude depends on the type and width of second workings or extracted coal or adjacent goaf development. The deflection of the overburden due to loss of pillar support in the goaf is likely to result in additional load (abutment loading) to develop on the standing pillars, as shown in **Figure 4c**. The magnitude of the stress acting on the pillars will be dependent on the cover depth, direction of loading and width of the second workings area or goaf.

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

Pillars with w/h ratios < 3 are considered most likely to ‘strain-soften’ and result in rapid failure and pillar runs, whereas w/h ratios > 5 are more likely to fail slowly or squeeze, yield and then ‘strain-harden’. The two types of post-yielding behaviour have been discussed in **ACARP, 2005** and demonstrated in **Figure 4d** for pillar w/h ratios between 1 and 10. Several other studies by **Das, 1986** and **Zipf, 1999** demonstrate the ‘strain-softening behaviour of ‘slender’ pillars with width to height ratios < 4; see **Figure 4e**. Zipf applied the w/h ratio to determine the rate of softening or the residual modulus of the pillars.

The assessment of potential pillar instability based on RT plans of old mine workings also needs to consider the following:

- cover depth and density of the overburden[3].
- RT tracing or scaling errors;
- Whether the workings are flooded or dry and the potential for rib and roof deterioration. *Note: the database of pillar strengths has been derived from a 'dry' workings database, so it is recommended that the pillar loads also assume 'dry' conditions exist for FoS assessment*;
- geological structure (faults, dykes, shear zones) that may reduce overburden stiffness;
- potential for unconfined clay rich strata to 'soften' and consolidate under applied loading (i.e. soft floor failure);
- unreported robbing of pillars (i.e. pillar dimensions scaled from RTs may not be accurate);
- the direction in which a pillar 'run' may approach the site will affect the magnitude of the applied pillar loading (i.e. the design action effect);
- the maximum load that may be applied to the pillars in the event of nearby pillar instability (FTA and abutment loading scenarios; see **Figures 4a** and **4b**).
- It is also noted in **UNSW, 1996** that only 5 (26%) of the 'failed' Australian case studies were 'actual' pillar dimensions, with 14 (74%) being the design values (or scaled from the mine plans). The 'unfailed' pillar data base referred to 8 (50%) actual pillar dimensions with 8 (50%) taken 'off-the-plan'.

- **UNSW, 1996** acknowledges that the failed pillar mine dimensions in the South African and Australian databases are unavoidably subject to some errors due to difficulties with inspecting failed panels (which in a high proportion of cases, failed suddenly with little or no warning several months to years after their formation).

It is considered that a reasonable approach to dealing with the above uncertainties in a subsidence risk assessment would be to apply Limit State Design techniques developed by structural and civil geotechnical engineers when designing foundations for structures.

Over the past 20 years or more site investigation and grouting work in the Newcastle CBD and Merewether areas have reduced the level of uncertainty in regard to the reliance on scaled pillar measurements from the RTs. The following information gained from the mine workings has improved our understanding of their condition generally:

- Video and sonar work in the Borehole Seam have repeatedly demonstrated that the standing pillar and ribs are in good condition with similar bord widths to RT records for both the AAC and NCC mine workings.

[3] The empirical UNSW pillar strength formulae are based on an overburden density of 2.5 t/m^3 and acceleration constant 'g' of 10 m/s^2. The presence of significant depths of soil cover may therefore effectively reduce the pillar load.

- The positive pressure head in the flooded workings probably has limited the rate of pillar deterioration and protected the workings from erosion impacts due to flowing ground water through dry workings.

- Any softening of mudstone/claystone beds that would have occurred after flooding is very likely to have ceased after 50 years[4].

6.2 Pillar Stability Analysis Results

The stability of representative pillars located within each of the mine workings in the vicinity of the site (**Figure 1a,b**) have been assessed. The width and length dimensions of all the pillars were scaled from the RTs.

The pillars in the workings are typically located in *super-critical* width panel of pillars that is wider than the cover depth (W/H > 1). It therefore may be reasonably assumed that the pillars will be loaded by the column of rock and soil that exists above each pillar and adjacent bords and cut throughs (i.e. Full Tributary Area (FTA) loading conditions; see **Figure 4b**.

For the assessment of the risk of a pillar run passing beneath the site, abutment loads from two alternative directions have been considered for all the site pillars. Pillar strengths were based on RT (Likely Case) and RT-0.5m (CWC) pillar dimensions. Some additional loading may also occur from alternate directions due to the irregular pillar geometry or existing goaf areas; however, an adjacent pillar would probably need to fail first before it is subject to additional load[5].

The results of the average pillar size FoS analysis assuming a maximum pillar height of 3.65 m (seam thickness) and 4.15 m (seam thickness + 0.5 m) under FTA and single direction abutment loading from pillar sides and ends are presented in **Tables 2A** and **2B**.

[4]Any future changes to the effective stress acting on these materials due to water level changes may result in further settlement however.

[5] Numerical modelling may be necessary to verify the worst-case loading conditions for the pillars assessed herein.

Table 2A – Pillar Stability Review for FTA Loading Conditions & Max. Pillar Height

Cover Depth H (m)	Pillar Width w (m)	Pillar Length l (m)	Bord Width b (m)	Cut-through Width, r (m)	Pillar Height h (m)	Pillar w/h	e (%)	Pillar Strength S_p(MPa)	FTA Load (MPa)	FTA FoS
AAC First Working Production Pillars (RT566): Likely Case (RT side dimensions; Pillar height = Seam Thickness)										
65	4.0	55.0	7.5	5.0	3.65	1.3	68.3	5.88	5.11	*1.15*
75	4.0	55.0	7.5	5.0	3.65	1.3	68.3	5.88	5.88	*1.00*
AAC First Working Production Pillars (RT566): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)										
65	3.5	54.5	8.0	5.5	4.15	0.8	72.4	4.93	5.88	**0.84**
75	3.5	54.5	8.0	5.5	4.15	0.8	72.4	4.93	6.78	**0.73**
NCC First Working Production Pillars (RT565): Likely Case (RT side dimensions; Pillar height = Seam Thickness)										
65	6.0	35.0	6.0	4.0	3.0	2.0	55.1	8.52	3.62	2.35
75	6.0	35.0	6.0	4.0	3.0	2.0	55.1	8.52	4.18	2.04
NCC First Working Production Pillars (RT565): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)										
65	5.5	34.5	6.5	4.5	3.5	1.2	59.5	7.16	4.01	**1.79**
75	5.5	34.5	6.5	4.5	3.5	1.2	59.5	7.16	4.62	**1.55**
NCC First Working Barrier Pillars (RT565): Likely Case (RT side dimensions; Pillar height = Seam Thickness)										
65	9.1	33.0	2.80	2.0	3.0	3.0	27.9	10.57	2.25	4.69
75	9.1	33.0	2.80	2.0	3.0	3.0	27.9	10.57	2.60	4.06
NCC First Working Barrier Pillars (RT565): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)										
65	8.6	32.5	3.30	2.5	3.5	1.9	32.9	9.00	2.42	2.42
75	8.6	32.5	3.30	2.5	3.5	1.9	32.9	9.00	2.79	2.79

Bold - Pillar FoS < 2.11 (minimum value required for CWC conditions); *Italics* - Pillar FoS < 1.6 (minimum value required for LC conditions).

The results are discussed further in **Section 6.3**.

Due to the second workings areas and previous instability in both the AAC and NCC mine workings, it is likely that side-on or end-on abutment loading conditions exist on the standing first workings pillars adjacent to the goafed areas. The pillar stress and FoS for the typical pillars are summarised in **Table 2B**.

Table 2B – Pillar Stability Review for Single Abutment Loading Conditions & Upper Bound Pillar Height

Cover Depth H (m)	Pillar Width w (m)	Pillar Length l (m)	Pillar Strength S_p (MPa)	Single Direction Abutment Load Cases							
				Load Perpendicular to Bords				Load Parallel to Bords			
				Proportion (R) of Abutment Stress (A) Applied to Pillar*		Total Pillar Stress (MPa)	Pillar FoS	Proportion (R) of Abutment Stress (A) Applied to Pillar*		Total Pillar Stress (MPa)	Pillar FoS
				R_{side}	A_{side} (MPa)			R_{end}	A_{end} (MPa)		
AAC First Working Production Pillars (RT566): Likely Case (RT side dimensions; Pillar height = Seam Thickness)											
65	4.0	55.0	5.88	0.62	3.45	8.55	**0.69**	1.0	1.06	6.16	*0.95*
75	4.0	55.0	5.88	0.59	4.36	10.24	**0.57**	1.0	1.41	7.29	*0.81*
AAC First Working Production Pillars (RT566): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)											
65	3.5	54.5	4.93	0.62	3.98	9.86	**0.50**	1.0	1.22	7.10	**0.69**
75	3.5	54.5	4.93	0.59	5.03	11.82	**0.42**	1.0	1.63	8.41	**0.59**
NCC First Working Production Pillars (RT565): Likely Case (RT side dimensions; Pillar height = Seam Thickness)											
65	6.0	35.0	8.52	0.64	3.76	6.04	**1.41**	1.0	1.16	4.78	*1.78*
75	6.0	35.0	8.52	0.61	5.01	7.24	**1.18**	1.0	1.54	5.72	*1.49*
NCC First Working Production Pillars (RT565): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)											
65	5.5	34.5	7.16	0.64	4.17	6.68	**1.07**	1.0	1.54	5.72	**1.35**
75	5.5	34.5	7.16	0.61	5.55	8.01	**0.89**	1.0	1.28	5.29	**1.13**
NCC First Working Barrier Pillars (RT565): Likely Case (RT side dimensions; Pillar height = Seam Thickness)											
65	9.1	33.0	10.57	2.0	4.17	6.98	**1.51**	-	-	-	-
75	9.1	33.0	10.57	2.0	5.55	8.98	**1.19**	-	-	-	-
NCC First Working Barrier Pillars (RT565): Credible Worst Case (RT + 0.5 m side dimensions; Pillar height = Seam Thickness + 0.5 m)											
65	8.6	32.5	9.00	2.0	2.54	7.50	**1.20**	-	-	-	**-**
75	8.6	32.5	9.00	2.0	3.37	9.55	**0.94**	-	-	-	**-**

Bold - Pillar FoS < 2.1 (minimum value required for CWC conditions); *Italics* - Pillar FoS < 1.6 (minimum value required for LC conditions); * - Abutment load influence distance from goaf edge, $D = 5.13\sqrt{H}$ = 41 m to 44 m for the site.

Based on the stability analysis results the probability of failure under worst-case loading conditions have been assessed in **Section 6.3**.

6.3 Results Summary and Pillar Failure Probability for FTA and Abutment Loading Conditions

A summary of the FoS results for the assumed pillar dimension and likely range of loading cases is provided in **Table 3**.

Table 3 - Summary of Pillar Stability Results

Load Scenario	Mine Workings & Pillar Type (P-Production B - Barrier)	FoS for Dry Workings & RT Pillar Side Dimensions (Likely Case)	FoS for Dry Workings & RT Pillar Side Dimensions - 0.5m (Credible Worst Case)	Comment
FTA Loading	AAC-P	1.15 - 1.00	**0.84 - 0.73**	Pillars crushed in 1898
	NCC-P	2.35 - 2.04	**1.79 - 1.55**	FoS **inadequate** for CWC under FTA
	NCC-B	4.69 - 4.06	3.72 - 3.22	FoS **adequate** for CWC under FTA
Perpendicular to Bords or 'side-on' Abutment (SOA) Loading	AAC-P	*0.69 - 0.57*	**0.50 - 0.42**	Pillars crushed in 1898
	NCC-P	*1.41 - 1.18*	**1.07 - 0.89**	FoS **inadequate** for CWC under SOA
	NCC-B	1.51 - 1.19	**1.20 - 0.94**	FoS **inadequate** for CWC under SOA
Parallel to bords or 'end-on' Abutment (EOA) Loading	AAC-P	0.95 - 0.81	**0.69 - 0.59**	Pillars crushed in 1898
	NCC-P	1.78 - 1.49	**1.35 - 1.13**	FoS **inadequate** for CWC under EOA
	NCC-B	N/A	N/A	N/A

Italics - FoS < 1.6, the minimum required for LC conditions; **Bold -** FoS < 2.11, the minimum required for CWC conditions.

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

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

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

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

Based on **Figure 5**, the probability of a panel failure for bord and pillar panels with a FoS > 1.63 is < 1 in 1,000 and < 1 in 1 million for an FoS > 2.11.

Based on Likely Case pillar geometry assumptions, the assessed poFs for the production pillars below the site indicate that the AAC first workings pillars have probably crushed with an FoS range from 1.15 to 1.0 and NCC first workings pillars could still be standing under FTA loading conditions with an FoS ranging from 2.35 to 2.04.

Under abutment loading conditions (adjacent to second workings areas) the FoS for the AAC decreases to < 1 and the NCC pillars decreases to a range from 1.78 to 1.18. It is therefore assessed that the AAC pillars are most likely to have failed, whilst the NCC pillars are possibly still standing if likely case conditions exist.

For Credible Worst-Case pillar geometry assumptions, the assessed poFs for the production pillars below the site indicate that the NCC first workings pillars are also likely to be still standing under FTA loading conditions (FoS ranges from 1.79 to 1.55) but the AAC pillars will probably have crushed (FoS ranges from 0.84 to 0.73).

AAC pillars are expected to fail under CWC abutment loading conditions with FoS < 1 assessed for both side on and end on abutment loading conditions. The NCC pillars may also still be standing with FoS ranging from 1.35 and 0.89.

There is also a row of larger barrier pillars in the NCC mine workings below the site that may still be standing under Likely Case conditions, with an FoS range from 1.78 to 1.19 under double abutment loading conditions (i.e. the production pillars are assumed to have failed on both sides of the barriers). For CWC conditions the barrier FoS ranges between 1.20 and 0.94 and likely to yield in the long-term.

It is concluded that the following mine subsidence cases should be considered as the Credible Worst-Case scenario at this stage:

Case 1 - Some or all AAC mine workings pillars have already failed and the NCC pillars are currently standing (and crush at some point in the future)

Case 2 - All pillars in both AAC and NCC workings have already failed (residual subsidence of up to 100 mm may occur in the future)

The Absolute Worst Case may be based on Case 1 at this stage due to the likelihood that all ACC pillars beneath the site have probably crushed.

The assessment of future subsidence associated with Cases 1 and 2 are presented in **Section 7**.

7.0 Worst-Case Subsidence Assessment

7.1 General

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

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

The model may be calibrated to measured or predicted subsidence profiles over bord and pillar panels of known width, cover depth, mining height and panel extraction ratio. The shape of the subsidence profile may be manipulated by adjusting the influence angle and inflexion point location; see **Figure 6a**. The model may also be used to predict the effect of stable pillars surrounded by failing ones, which makes it suitable for assessing the subsidence mitigating potential of the proposed grouting strategies.

The maximum subsidence over crushed bord and pillar panels has been estimated based on reference to published subsidence data in the Newcastle CBD and mining examples from the Australian and South African Coal Fields; see **Figure 6b**.

In general, the maximum subsidence over a crushed bord and pillar panel will be controlled by:

- the residual strength of the crushed pillar and strain hardening properties of the collapsed roof and pillar rubble.[6]
- the load transfer capability of the overburden, which decreases the applied pillar load as the pillar crushes and loses stiffness;
- the potential buoyancy affects in flooded mine workings to reduce subsidence.[7]

The SDPS® influence function program was used to estimate the subsidence contours with failing pillar panel by linking it to the pillar FoS contours. An effective in-panel goaf edge was assumed where the pillar FoS was > 1. It was considered that on the basis of probability, this contour could be considered an appropriate boundary between elastic and yielding response to determine the effective goaf edge around a grouted area in the SDPS® model.

[6] The adjacent rubble is ignored unless it has been grouted.

[7] Predictions for total (dry) and effective (buoyant) stress conditions acting on the failing pillars have been provided to give an upper and lower limit for the worst-case subsidence predictions.

7.2 Elastic Compression Response under Design Loading

The initial elastic settlement of the pillars (before crushing) or where pillars remain elastic under the design loading condition, may be estimated using elastic solid mechanics theories as follows:

$s_{max} = s_{pillar} + s_{roof} + s_{floor}$ [8]

where

s_{pillar} = $\sigma_{net}\, h/E_{coal}$ = compression of pillar

s_{roof} = $\sigma_{net}\, I(1-\nu^2)[t_1/E_{roof1} + (w-t_1)/E_{roof2}]$ = compression roof strata units

s_{floor} = $\sigma_{net}\, I(1-\nu^2)[t_2/E_{floor1} + (w-t_2)/E_{floor2}]$ = compression of floor strata units

σ_{net} = pillar stress increase (design pillar stress - pre-mining stress)

E_{coal} = Young's Modulus for coal (default 2000 MPa)

$E_{roof1,2}$ = Average Young's Modulus for the immediate & upper roof strata units within one pillar width of the mine roof

$E_{floor1,2}$ = Average Young's Modulus for the immediate & lower floor strata units with one pillar width of the mine floor.

$t_{1,2}$ = thickness of immediate roof and floor strata units (if weaker than upper & lower strata units otherwise $t_{1,2} = w$)

ν = Poisson's Ratio = 0.25 is the default value for roof and floor strata

I = shape factor for square footing = ~ 1.5 (for a semi-rigid footing and rectangular pillars based on **Das, 1998**)

w = pillar width

h = pillar height

The material properties for elastic analysis are defined in **Table 4** and considered to be representative of the conditions in the Borehole Seam mine workings.

[8] Assumes pillars have same size and stiffness. Numerical modelling approaches improve accuracy when irregular pillar geometries are present.

Table 4 - Rock Mass Strength and Modulus Estimates

Stratigraphic Units	In-situ UCS+ (mean) (MPa)	E_{lab}/UCS^	E_{lab} (GPa)	Geological Strength Index# (GSI)	E_{rm}/ E_{lab}*	Rock Mass Moduli E_{rm} (GPa)
Tighes Hill Sandstone and siltstone	21 - 65 (40)	300	12	65	0.5	6
Shale	1 - 16 (4)	300	1.2	40	0.33	0.4
Borehole Seam	15 - 25 (20)	300	6	40	0.33	2
Waratah Sandstone	25 - 65 (50)	300	15	65	0.5	7.5

+ - UCS values derived from bore core samples in Newcastle CBD & Honeysuckle Precinct by several geotechnical consultants; (brackets) - mean values used for modulus estimates;
^ - Young's Modulus (E) derived from rock mass UCS, E_{lab} = 300 x UCS; # - refer **Hoek and Diederichs, 2005**;
* - $E_{rm}/E_{lab} = 0.02+1/(1+e^{(60-GSI)/11})$.

The worst-case subsidence for elastic pillar-roof/floor strata performance under side-on and end-on abutment loading case scenarios for dry mine workings conditions are summarised in **Table 5**.

Table 5 - Analytical Maximum Subsidence Predictions due to Likely Case Abutment Loading

Mine	Cover Depth H (m)	Pillar Width w (m)	Mining Height h (m)	Effective Pillar Height^ h' (m)	Pillar Stress (MPa)	Pillar Stress Increase# (MPa)	Pillar FoS	Subsidence Predictions Based on Analytical Pillar-Roof & Floor Strata System Compression^ (mm)				
								Pillar	Roof	Floor	Total (mean)	2 × Total (design worst-case)
FTA Loading												
AAC (Hamilton)	70	4.0	3.0	3.65	5.49	3.74	1.07	6	14	6	27	53
NCC	70	6.0	2.4	3.0	3.90	2.15	2.19	3	9	4	16	32
Side-On Loading*												
AAC (Hamilton)	70	4.0	3.0	3.65	9.39	7.64	**0.63**	13	29	12	54	**109**
NCC	70	6.0	2.4	3.0	6.63	4.88	1.28	7	20	9	36	72
End-On loading**												
AAC (Hamilton)	70	4.0	3.0	3.65	6.72	4.97	**0.87**	8	19	8	35	**71**
NCC	70	6.0	2.4	3.0	5.24	3.49	1.63	5	16	7	29	57

- stress increase (total stress - pre-mining stress); ^ - Effective pillar height based on seam thickness above workings floor; * - Side-On Abutment Load (perpendicular to the pillar length) = FTA + RA(l+r)/(wl);
** - End-On Abutment Load (parallel to the pillar length) = FTA + RA(w+b)/(wl); $ - weak shale / mudstone in roof; **Bold -** Pillars expected to yield under applied loading (i.e. elastic subsidence not applicable).

7.3 Maximum Subsidence Prediction Method for Crushed Bord and Pillar Panels

The prediction of maximum subsidence over bord and pillar and partial pillar extraction panels with moderate extraction ratios of 40% to 70% is generally difficult in Australia because survey data is scarce for these cases. This has usually resulted in the need to use high extraction ratio pillar panels and longwall data and adjusting the mining height for the extraction ratios to make subsidence predictions instead.

A previous subsidence study of the Newcastle CBD crush events by **Hawkins and Ramage, 2004** noted that the measured subsidence was significantly less than maximum subsidence values predicted using the longwall and total pillar extraction curve presented in **Holla, 1987** and also after adjusting for the effective mining height (which is equal to the true mining height multiplied by the panel extraction ratio); see **Figure 6c**.

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

The collapsed rubble in both cases will probably be subject to the same stress and have similar stiffness properties (i.e. the strains under load will be the same), however, the rubble thickness differences will result in a proportionally greater seam roof convergence and surface subsidence to develop above a longwall. A schematic diagram, which demonstrates these fundamental differences in subsidence mechanics, is presented in **Figure 6d**.

The figure indicates that the subsidence for a longwall panel is likely to be derived from a rubble thickness that ranged from 4 to 6 times the seam thickness. However, a bord and pillar panel that crushes with extraction ratios of 40% and 55% may only have maximum caving heights of about 7.5 to 8.3 m, which is assessed to be 1.2 to 1.4 times the seam thickness (including the pillars with an original mining heights of 4.2 to 5.5 m).

If a longwall or total extraction database is referred to, the predicted outcomes usually indicate a maximum subsidence of 0.5 to 0.6 times the effective mining height (i.e. actual mining height x pillar extraction ratio (e) above a super-critical[9] panel geometry. The measured subsidence above the 'super-critical' pillar panel crushes in the Newcastle CBD have only ranged between 0.17 and 0.45 times the effective mining height, with the lower value (Creep 3) likely to be a case of incomplete crush or pillar 'punching' failure into the roof; see **Figure 6e**.

It is assessed from **Figure 6e** that the maximum subsidence above dry mine workings below the CBD is likely to range between 0.35 and 0.45 times the effective mining height (h' = true mining height x extraction ratio) or 0.4h' +/- 0.05h'.

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

The predicted v. measured ranges of maximum subsidence (S_{max}) in the old mine workings for dry conditions are shown in **Table 6**.

Table 6 - Predicted v. Measured Subsidence for AAC & W&BI/Ferndale Mine Workings

<table>
<tr><th>Mine Workings</th><th>Cover Depth H (m)</th><th>Mining Height, h (m)</th><th>Extraction Ratio e (%)</th><th>Effective Mining Height h' = he (m)</th><th>Measured Subsidence S_{max} (m)</th><th>Predicted Dry S_{max} 0.4h' +/- 0.05h'</th></tr>
<tr><td rowspan="2">New Winning</td><td>115 - 110</td><td>5.5</td><td>39</td><td>2.15</td><td>0.825 - 0.775</td><td>0.75 - 0.97 (0.86)</td></tr>
<tr><td>77</td><td>2.2 - 2.5</td><td>39</td><td>0.86 - 0.98</td><td>0.30</td><td>0.28 - 0.41 (0.34)</td></tr>
<tr><td>W&BI</td><td>60</td><td>4.8</td><td>55</td><td>2.64</td><td>1.2</td><td>0.92 - 1.19 (1.06)</td></tr>
<tr><td>Ferndale</td><td>40</td><td>2.0</td><td>63</td><td>1.26</td><td>N.M.</td><td>0.44 - 0.57 (0.50)</td></tr>
</table>

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

For the AAC and NCC workings below the golf course, similar subsidence to the Wickham and Bullock Island pillar crush has been adopted as shown in **Table 7**.

Table 7 - Predicted v. Measured Subsidence for AAC (Hamilton Pit) & NCC Mine Workings at the Merewether Golf Course (First and Second Workings)

<table>
<tr><th rowspan="2">Mine Workings</th><th rowspan="2">Cover Depth H (m)</th><th rowspan="2">Mining Height, h (m)</th><th rowspan="2">Extraction Ratio e (%)</th><th rowspan="2">Effective Mining Height h' = he (m)</th><th colspan="2">Predicted S_{max}/he</th><th colspan="2">Predicted Dry S_{max} (m)</th></tr>
<tr><th>Dry</th><th>Fld</th><th>Dry</th><th>Fld</th></tr>
<tr><td rowspan="2">AAC (Hamilton Pit)</td><td rowspan="2">70</td><td rowspan="2">3.0</td><td>80</td><td>2.40</td><td>0.45</td><td>0.33</td><td>1.08</td><td>0.79</td></tr>
<tr><td>68</td><td>2.04</td><td>0.45</td><td>0.33</td><td>0.92</td><td>0.67</td></tr>
<tr><td rowspan="2">NCC</td><td rowspan="2">70</td><td rowspan="2">2.4</td><td>80</td><td>1.92</td><td>0.45</td><td>0.33</td><td>0.86</td><td>0.63</td></tr>
<tr><td>55</td><td>1.32</td><td>0.45</td><td>0.33</td><td>0.59</td><td>0.42</td></tr>
</table>

Fld - Flooded (see **Section 7.4**); *italics* - already occurred during mining.

The pillar failure in the W&BI mine workings in 1896 resulted in surface subsidence of 0.9 m to 1.2 m and cracking damage around the limits of mining at a cover depth of 57 m and extraction ratio of 57%.

Inferred pillar crush measurements by **Coffey, 2009**[10] indicates that the convergence of the roof was consistent with expected subsidence profiles for the mining geometry and is demonstrated in **Figure 6f** and **6g**. The following SDPS model input parameters were used to fit the roof convergence data:

[10] Coffey's drilling investigations enabled the extent of pillar crushing beneath the site to be inferred by comparing measured coal seam and core-loss thicknesses with unmined coal seam thicknesses adjacent to the mine workings.

- Maximum supercritical subsidence/effective mining height ratio, $S_{max}/h' = 0.45$
- Inflexion point distance/cover depth ratio, $d/H = 0.25$
- Tangent of the Influence Angle, $\tan(\beta) = 1.8$

The above parameters were applied to the subsidence modelling presented in **Section 7.5**.

7.4 Overburden Buoyancy Effects on Subsidence

Based on FLAC3D modelling, **Mackenzie & Clark, 2005** adopted a pillar loading life-cycle approach that considered initial dry conditions in the workings followed by the effects of buoyancy after flooding.

Assuming the maximum subsidence is a function of the overburden stress, the maximum subsidence (S_{max}') for buoyant overburden conditions may be estimated as follows for a future pillar crush event:

$$S_{max}' = [(\gamma H - \gamma_w H_w)/\gamma H]S_{max}$$

where γ = dry unit weight of rock (default 0.025 MN/m^3)
γ_w = unit weight of water (default 0.01 MN/m^3)
H_w = head of water above mine workings (default H - depth to sea level)

For a surface level of RL 25 m (AHD), the buoyant mine workings condition subsidence is estimated to be approximately 74% of the dry workings subsidence, based on a water table level of RL 0 m (AHD). This value represents a lower bound for future subsidence predictions. The predicted flooded mine workings values are presented in **Table 7**.

7.5 Predicted Subsidence Effect Contours

Credible Worst-case subsidence contour predictions for the AAC and NCC mine workings have been determined at this stage based on the net subsidence or difference between Case 2 and one of the assumed current condition Cases 1a or 1b as defined below:

- **Case 1a** - All NCC mine workings pillars are still standing with RT pillar side dimensions and mining height equal to seam thickness above the mine workings floor. Only ACC pillars are assumed to have crushed where subsidence known to have occurred (i.e. the surrounding AAC pillars are assumed to be standing).

- **Case 1b** - All NCC mine workings pillars are still standing with RT pillar side dimensions and mining height equal to seam thickness. All ACC pillars are assumed to have crushed.

- **Case 2** - All AAC and NCC pillars have crushed (excluding stable barriers).

It is assumed that Case 1a or 1b occurred soon after mining and when conditions were dry. If Case 2 is yet to develop, then future subsidence development will occur under flooded or buoyant conditions. A recent study by DgS demonstrated that the pillar FoS under flooded conditions is practically the same as the dry condition FoS[11].

The Absolute Worst-Case (AWC) may be assumed to be Case 2 (flooded) - Case 1a (dry) at this stage unless drilling investigation can establish which scenario is more-likely. If the workings have all failed, then both the CWC and AWC may be based on residual subsidence parameters only (see **Section 5.2**).

In SDPS, the mine workings were divided up into homogeneous units of similar pillar geometry, seam thickness, mining height, pillar geometry and cover depth as shown in **Figure 7**.

The subsidence contours for Case 1a,b and 2 were then derived using the input parameters for dry and flooded conditions are presented in **Table 8**.

The tilt and curvature contours were derived from the subsidence contours using the calculus module in Surfer12®. The horizontal strain was estimated from the curvature contours using a B_f factor of 10 and strain coefficient (Bs) of 0.257.[12]

[11] The buoyant pillar FoS (FoS') will be within 10% of the dry FoS or FoS' = $(S_p - u)/(\sigma - u)$.

[12] **Holla, 1987** suggests a strain/curvature factor (B_f) of 10 for the Newcastle Coalfield. SDPS applies a strain coefficient $Bs = B_f.\tan\beta/H$, which indicates that the B_f will increase with cover depth (H) and decrease with the tangent of the influence angle β. Values appropriate to supercritical Newcastle mine workings have been used in this report.

Table 8 - Maximum Subsidence Effect Parameters for AAC & NCC Mine Workings

SDPS Panel #	Workings Type [Mine]	Mining Height h (m)	e (%)	he (m)	S_{max}/he		S_{max}		Influence Angle (tanβ)	Inflexion Point Distance d (m)	Strain Coefficient B_s
					Dry (%)	Fld (%)	Dry (m)	Fld (m)			
Case 1a - Only historical area of AAC pillars have crushed and NCC pillars are still standing Case 1b (in brackets) - All AAC pillars have crushed and NCC pillars are still standing											
1	SW [ACC]	3.0	80	2.45	45 (45)	N/A	1.08 (1.08)	N/A	1.8	0	0.257
2											
3											
4											
5											
6											
7											
8	FW [NCC]	2.4	55	1.32	2.4 (2.4)	N/A	0.032 (0.032)	N/A	1.8	0	0.257
9	SW [NCC]	2.4	80	1.92	45 (45)	N/A	0.86 (0.086)	N/A	1.8	17.5	0.257
10											
11	Crushed FW [AAC]	3.0	68	2.04	45 (45)	N/A	0.92	N/A	1.8	0	0.257
12	FW [NCC]	2.4	55	1.32	2.4 (2.4)	N/A	0.032	N/A	1.8	0	0.257
13	FW [ACC]	3.0	68	2.04	2.6 (45)	N/A	0.053 (0.92)	N/A	1.8	0	0.257
14	Barriers [NCC]	2.4	28	*1.32*	*-45*	*-33*	*N/A*	*N/A*	1.8	0	0.257
15			23	*1.32*	*-45*	*-33*	*N/A*	*N/A*			
Case 2 - AAC & NCC Pillars have Crushed											
1	SW [ACC]	3.0	80	2.45	45	(N/A)	1.08	(N/A)	1.8	0	0.257
2											
3											
4											
5											
6											
7											
8	FW [NCC]	2.4	55	1.32	45	33	0.59	0.42	1.8	0	0.257
9	SW [NCC]	2.4	80	1.92	45	(N/A)	0.86	0.64	1.8	17.5	0.257
10											
11	Crushed FW [AAC]	3.0	68	2.04	45	(N/A)	0.92	0.68	1.8	0	0.257
12	FW [NCC]	2.4	55	1.32	45	33	0.59	0.42	1.8	0	0.257
13	FW [ACC]	3.0	68	2.04	45	33	0.92	0.68	1.8	0	0.257
14	Barriers [NCC]	2.4	28	*1.32*	-45	-33	*N/A*	*N/A*	1.8	0	0.257
15			23	*1.32*	-45	-33	*N/A*	*N/A*			

FW = First workings; SW = Second workings; * - Negative values required in SDPS for intra-panel pillars; ^ - inflexion points do not apply to pillars in SDPS (only goaf edge limits); Fld = Flooded (buoyant overburden below water table @ RL 0 (AHD)); *italics* - standing pillars assume the negative ratios for the panels that they are situated in.

The net subsidence contours after the pillar crush cases in the AAC & NCC mine workings for dry conditions are presented in the following figures:

- Cases 1a & 1b (dry): **Figures 8a** & **8b**
- Cases 2: **Figures 9a** (dry) & **9b** (flooded)

The net contours between Case 2 and Case1a,b represent the future potential CWC subsidence for the site. Both dry and flooded scenarios are presented in the following figures:

- Net subsidence contours for Case 2 - Case 1a: **Figures 10a** (dry) & **10b** (flooded)
- Net subsidence contours for Case 2 - Case 1b: **Figure 11a** (dry) & **11b** (flooded)

The differential subsidence effects associated with the net flooded case scenarios only (i.e. tilt, curvature, horizontal strain and displacement) are presented in the following figures:

- Net subsidence effect contours for Case 2(flooded) - Case 1a (dry): **Figures 10c-f**
- Net subsidence effect contours for Case 2(flooded) - Case 1b (dry): **Figures 11c-f**

The results are summarised in **Table 9**.

Table 9 - Predicted Net Subsidence Effect & Profile Parameters for the Site Structures

Parameter	Worst-Case Pillar Crush Subsidence using SDPS				B3 Level Design Limits
	Proposed Clubhouse (Holla,1987)		Proposed Apartments (Holla,1987)		
	Case 2 (flooded) - 1a (dry)	Case 2 (flooded) - 1b (dry)	Case 2 flooded) - 1a (dry)	Case 2 (flooded) - 1b (dry)	
Maximum Subsidence S_{max} (mm)	0.05 - 0.30	< 0.02	0.05 - 0.40	0.02 - 0.40	< 0.1
Maximum Tilt T_{max} (mm/m)	3 - 11	< 1	1 - 9	1 - 9	< 3
Maximum Curvature* C_{max} (km^{-1})	-0.9 / 0.4	< 0.1	-0.4 / 0.35	-0.35 / 0.35	<0.2
Maximum Horizontal Strain E_{max} (mm/m) ^	-9 / 4	< 1	-4 / 3.5	-3.5 / 3.5	<2
Maximum Horizontal# Displacement HD_{max} (mm)	30 - 110	< 10	10 - 90	10 - 90	<30

* - Hogging curvature is positive; ^ - tensile strain is positive over 10 m & E_{max} = 10 x C_{max}; # - HDmax = 10 x T_{max}.

8.0 Conclusions and Recommendations

8.1 Review Outcomes

Based on the results of the CWC subsidence assessment, it is considered that the proposed structures are unlikely to be able to be designed to meet Safe, Serviceable and Repairable (SSR) criteria for the cases where the first workings in either seam are still standing (Case 1a,b) but may be possible if the workings below the structures have already crushed (Case 2).

Assuming that the proposed structure cannot be designed to remain serviceable for the design pillar crush event at this stage (pending drilling investigations), it will therefore be necessary to introduce grout at key locations below the structures to reduce the subsidence effects to within tolerable magnitudes or SSR criteria.

The proposed drilling investigation and preliminary grouting strategy is discussed in **Sections 8.2** and **8.3** respectively.

8.2 Proposed Drilling Investigations

A drilling investigation is proposed to establish the accuracy of the mine plan and the conditions of the overburden and mine workings. The drilling should attempt to determine whether the bord and pillar workings are likely to have crushed or are still standing.

Based on the age and likely inaccuracies in aligning the two mine workings, it is recommended that the drilling be conducted at several locations to assess the existing conditions. A recommended borehole location plan is presented in **Figure 12**.

The proposed investigation will target the first workings pillars to determine if (i) the overburden has been disturbed by subsidence (usually indicated by partial and complete drilling fluid losses) and (ii) if the pillars have yielded or crushed. A minimum of two contingency holes should be allowed for if the boreholes miss the pillars and encounter void or the bord instead.

It is recommended that one fully cored borehole (HQ wireline) be completed with geophysical and video camera logging below casing to the Borehole Seam floor to establish the rock mass properties (point load testing) and seam thickness. The remaining boreholes may be partially cored from 4 m above and cored to 3 m below the seam (~ 10 m of core) to provide a sump for the geophysical testing through the overburden and mine workings.

In-seam sonar mapping around the boreholes that encounter a bord instead of a pillar would assist with the review of the mine plan orientation. The contingency boreholes may also be required if no bords are encountered by the first 5 boreholes.

The boreholes should be located initially at the coordinates indicated in **Table 10** and the mine plan (and subsequent borehole locations) adjusted if conditions differ to the expected drilling results. The revised borehole locations should then be re-located on site by a registered surveyor after drilling is completed.

It is recommended that water levels be checked at the start of each days drilling to establish the water table level. The video inspection of each borehole will allow the in-situ fracturing and water levels to be assessed also. The video footage should also be digitally recorded for subsequent review by stakeholders (including SA NSW and consultants).

Table 10 - Proposed Borehole Locations Targeting First Workings Pillars

Borehole No.	Type	Easting (MGA, m)	Northing (MGA, m)
BH1	Fully Cored	381515	6354590
BH2	Partially Cored	381462	6354578
BH3	Partially Cored	381389	6354587
BH4	Partially Cored	381327	6354581
BH5	Partially Cored	381547	6354638

* - The boreholes should be located on site by a registered surveyor.

Due to the likelihood that drilling fluid will be partially or fully lost during the investigation, contingencies should be allowed for due to slower drilling rates, loss of drilling casing/bits and additional boreholes if mine workings conditions are more complex than anticipated[13]).

The drilling should attempt to measure the following key parameters and conditions:

- Overburden lithology, defects and point load strength index test results
- water table depth (video camera post-drilling or daily dipping before drilling)
- Seam thickness through first workings pillars
- Evidence of pillar crush (core loss, crush & fracture zones)
- Rubble and void height in bords
- Bord alignment and width (from sonar)
- Overburden lithology, defects and point load strength index test results.
- The suite of geophysical tests that should be undertaken in the boreholes include density, natural gamma, neutron with sonar imaging of the mine workings bords.

Geotechnical logs and core photographs should be prepared by a geotechnical consultant experienced with mine subsidence investigation and grouting work. Completed boreholes should be fully grouted back to the surface unless they encountered void and can be re-used for subsequent remediation purposes.

If some of the workings have crushed and some are still standing, it will be necessary to prepare a grouting strategy to stabilise the standing pillars and minimise the risk of transferring additional loading to the adjacent goaf.

[13] It may be necessary to drill several offset boreholes to confirm the extent of the mine workings conditions below the building footprints.

8.3 Preliminary Grouting Strategy

Should the drilling investigation establish that there are standing first workings pillars with marginal stability, it is likely that a program of strategic grouting works will be required to control potential subsidence effects to within SSR requirements as discussed in **Section 5.2**.

The proposed grouting program will need to provide confinement to key standing pillars below the site to (i) increase the effective stiffness of the collapsed roof rubble likely to exist to 3 m above the floor and (ii) modify the strength of the pillars to support the applied abutment loads in the event of future mine workings stability.

It is considered good practice to place grout for a minimum of 20 m lengths in the bords on opposite long sides of a key pillar. Approximately 9 grout pairs are recommended for the apartments and 3 grout pairs for the club house (a total of 24 grouted sections) ; see **Figure 13**.

The proposed grout design will probably require an established numerical model to verify the modified pillar strengths will satisfy SSR criteria and structural design tolerances. The SDPS-estimated post-grouting subsidence effect contours (subsidence, tilt, curvature, horizontal strain and displacement) are shown in **Figures 14a-e**. It should be noted that the analysis assumes that approximately 100 mm of subsidence may occur in in the second workings areas due to load adjustment if either first workings instability develops or water levels drop significantly.

Based on a bord width of 6 m with 3.0 m of collapsed roof rubble with a porosity of 30% and 1.0 to 1.5 m of overlying void, it is estimated that each 20 m section of grout will require 288 m^3 to give a total grout range from 6,200 m^3 to 8,000 m^3 (for 24 grouted sections with up to 15% losses). The grout sections will probably require a minimum of two production holes (125 mm diameter). Verification sampling and testing will also be necessary.

8.4 Preliminary Grouting Works Specification

Grouting works specification should include the following:

- An approved blend of local power station flyash (Eraring) and normal portland cement (5% - 10% by volume usually required)

- A characteristic 90-day grout strength of 5 MPa UCS.

- It is recommended that grout be placed with a tremie (75 mm diameter) inside the collapsed roof rubble and then placed above the rubble to within 100 mm of the roof.

- Site validation of the grouting works. This should include (i) sampling and testing of supplied grout at a rate specified in the relevant Australian Standard for project batch control, and (ii) core drilling at several representative or critical locations to confirm the in-situ grout strengths have been achieved.

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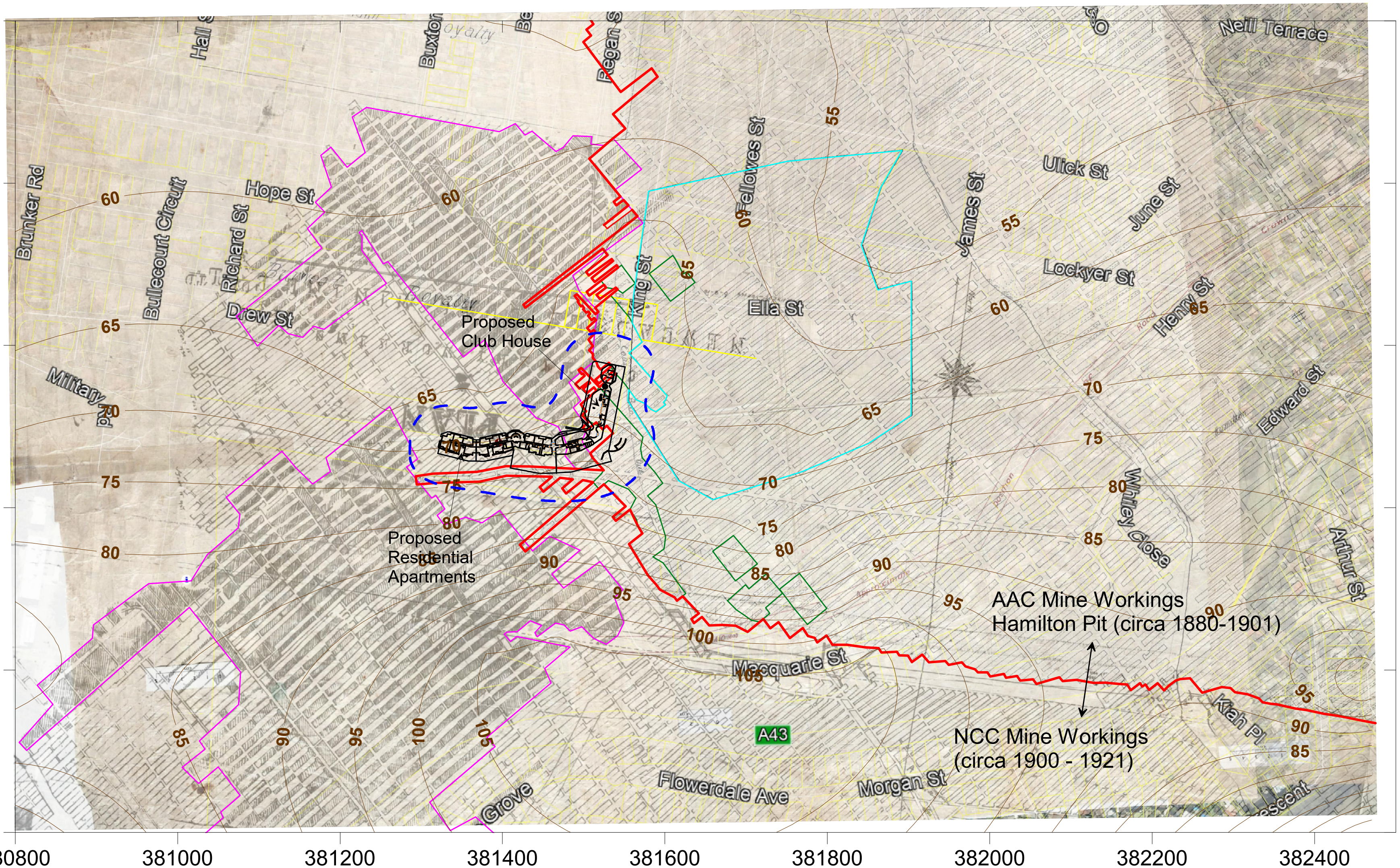


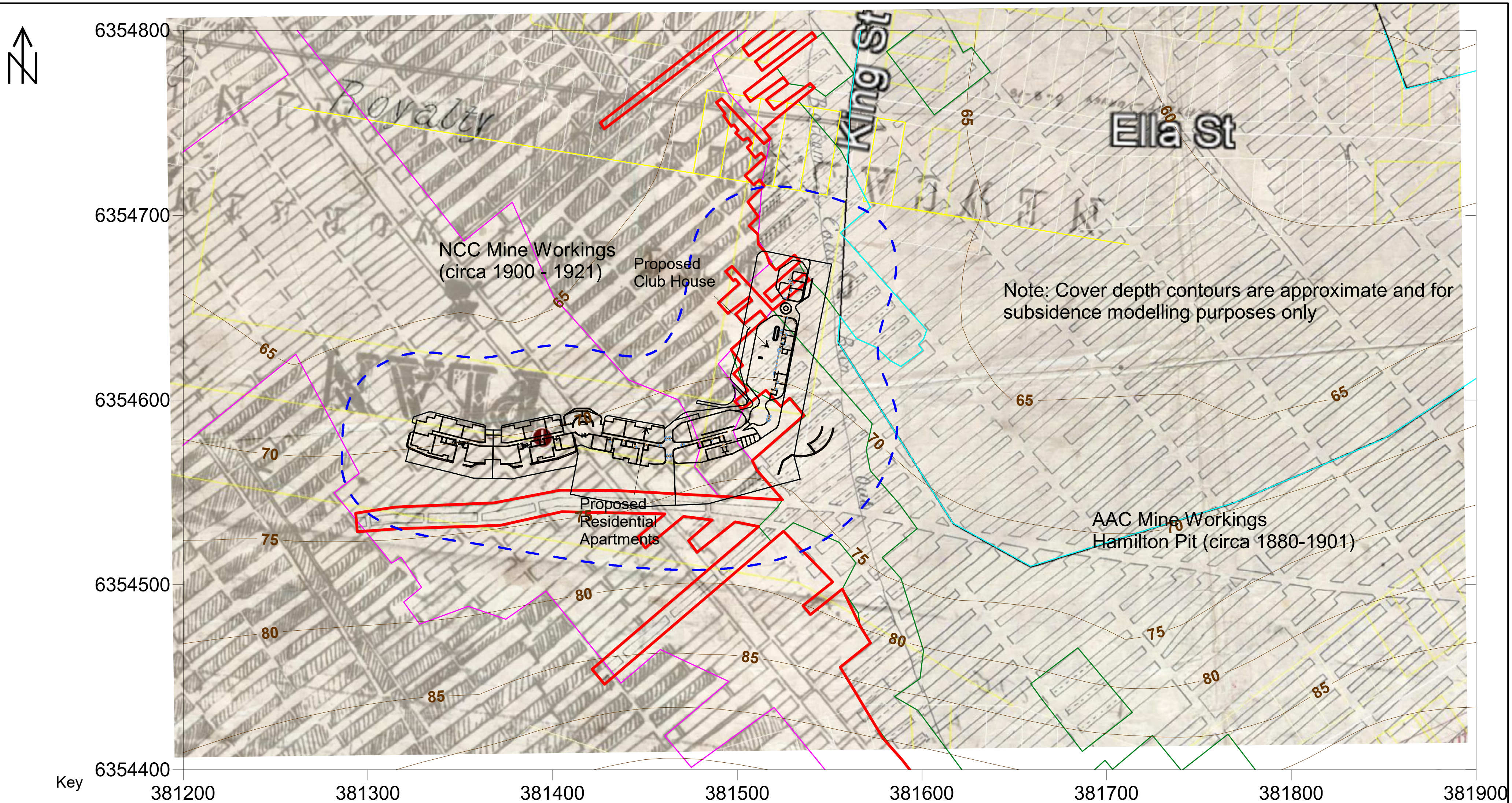
Note:

Cover depth contours are approximate and for subsidence modelling purposes only

Key

- Bord & Pillar (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Cover Depth Contours
- Boundary between AAC & NCC Mines
- Surface Lot Boundaries
- 26.5° Angle of Draw Limits

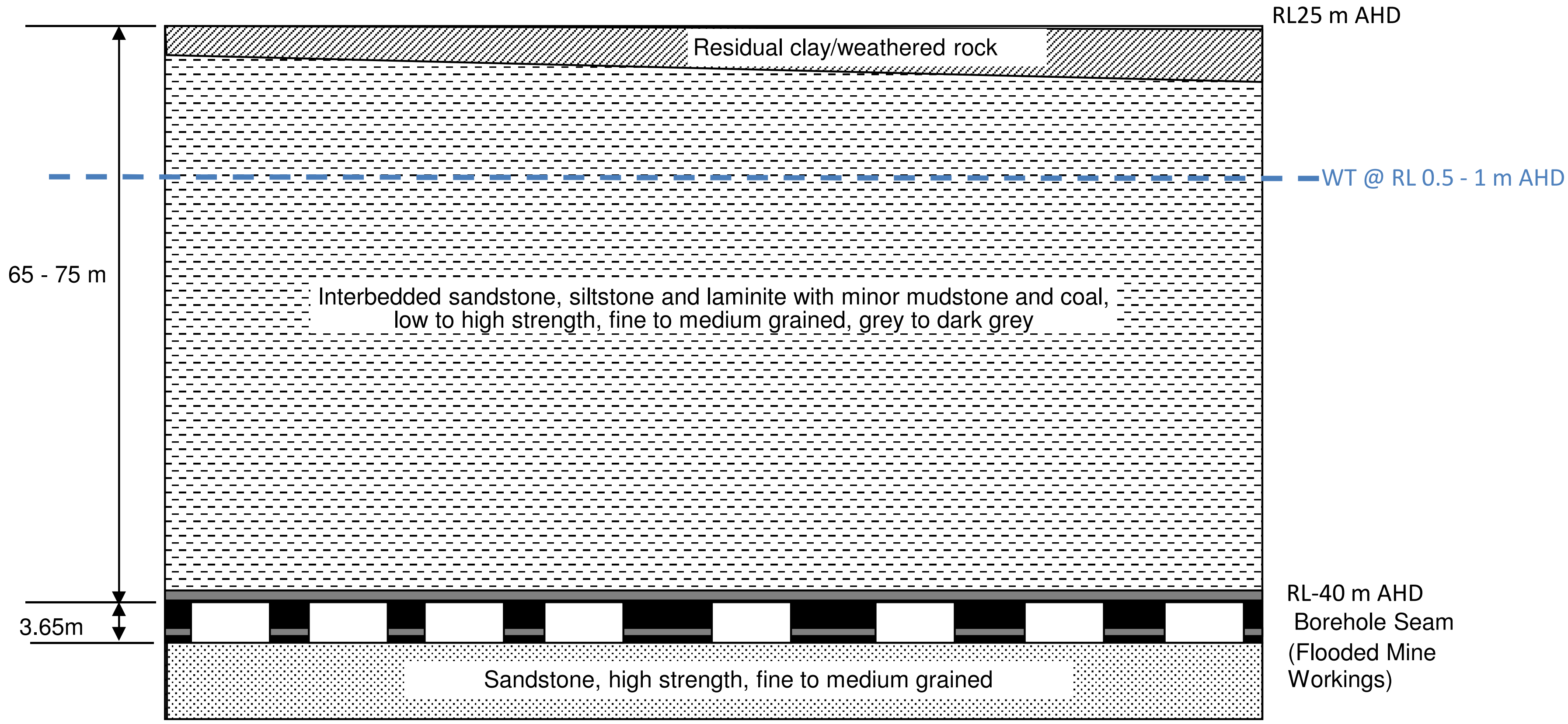
DgS	Engineer: S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn: S.Ditton		
	Date: 15.10.18	Title:	Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development
	Ditton Geotechnical Services Pty Ltd	Scale:	1:7500 (A4) — Figure No: 1a



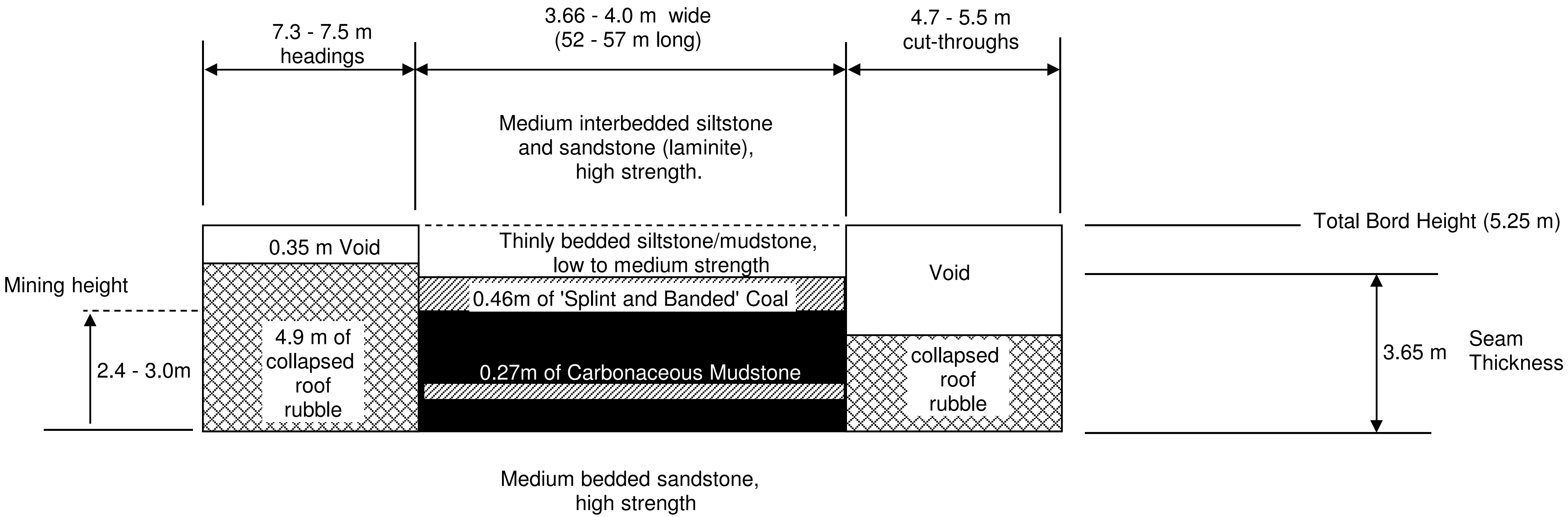
Key

- Bord & Pillar (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Cover Depth Contours
- Boundary between AAC & NCC Mines
- Surface Lot Boundaries
- 26.5° Angle of Draw Limits

Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
Drawn:	S.Ditton		
Date:	15.10.18	Title:	Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development
DgS	Ditton Geotechnical Services Pty Ltd	Scale:	1:3,000 (A4)
		Figure No:	1b

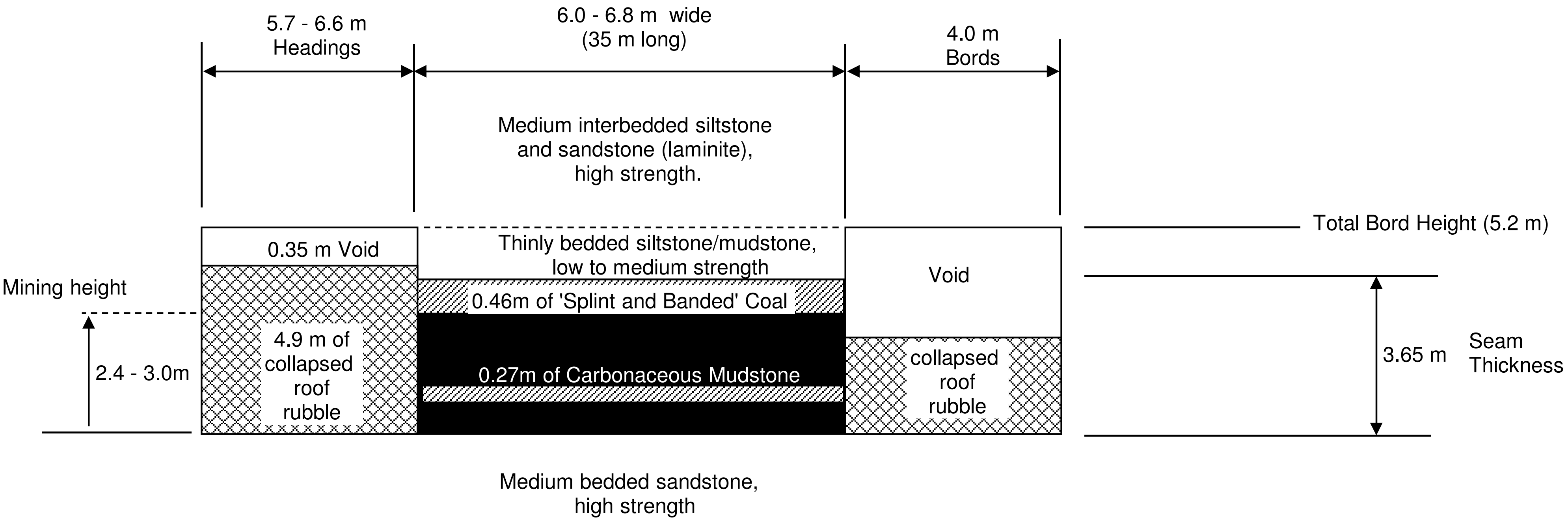


DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1		
	Drawn:	S.Ditton				
	Date:	6.11.18	Title:	Assumed Overburden Conditions Beneath the Site		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	2



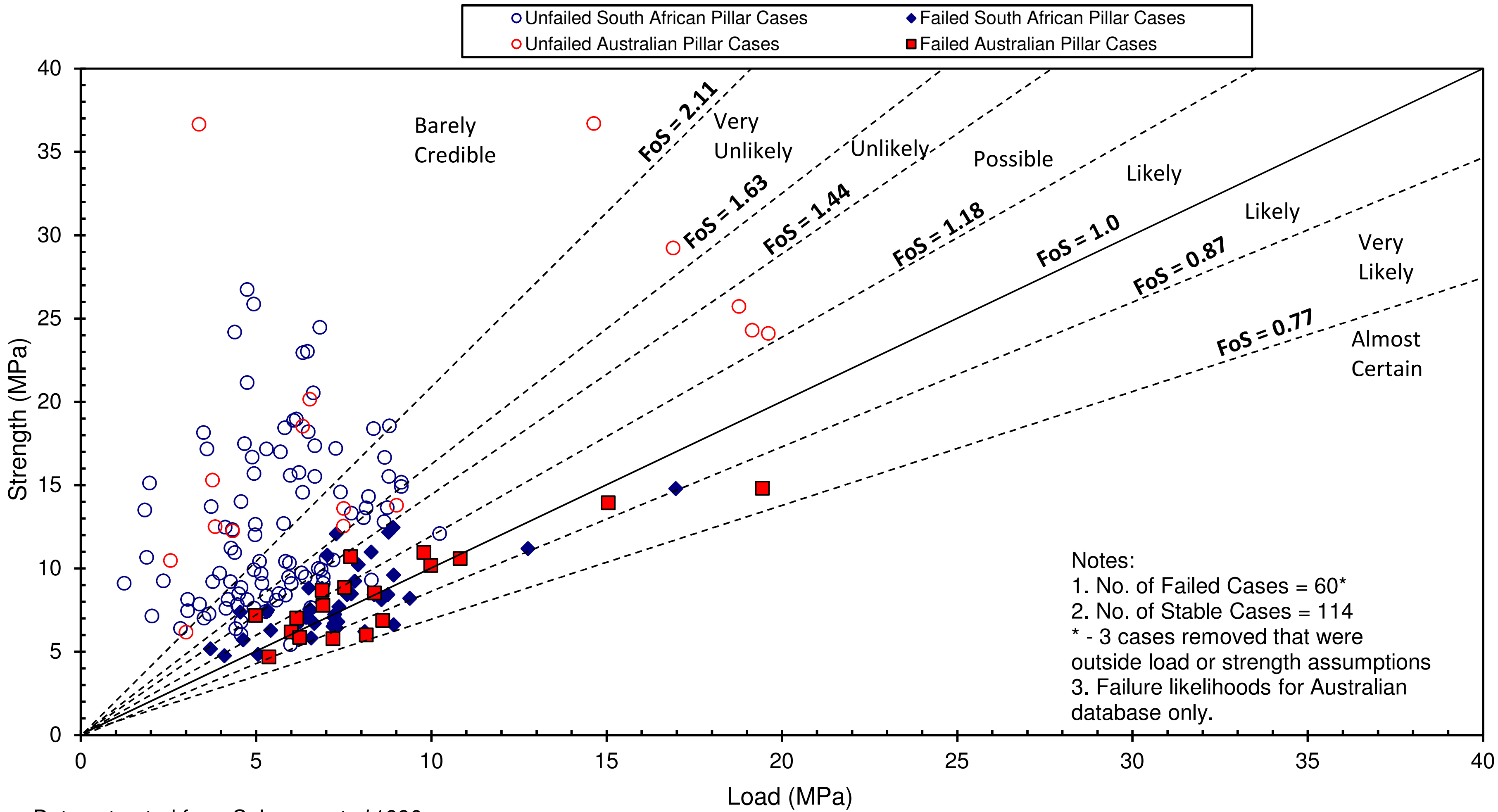
Note:
1. Workings are flooded and under 40 m head of pressure.
2. Coal seam extraction ratio, e = 68%
3. Second Workings extraction ratio, e = 75% to 80%

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1		
	Drawn:	S.Ditton				
	Date:	14.09.13	Title:	Inferred Conditions in AAC Mine Workings in the Borehole Seam (circa 1880-1916) (Hamilton Pit Pillar Crush Location)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	3a



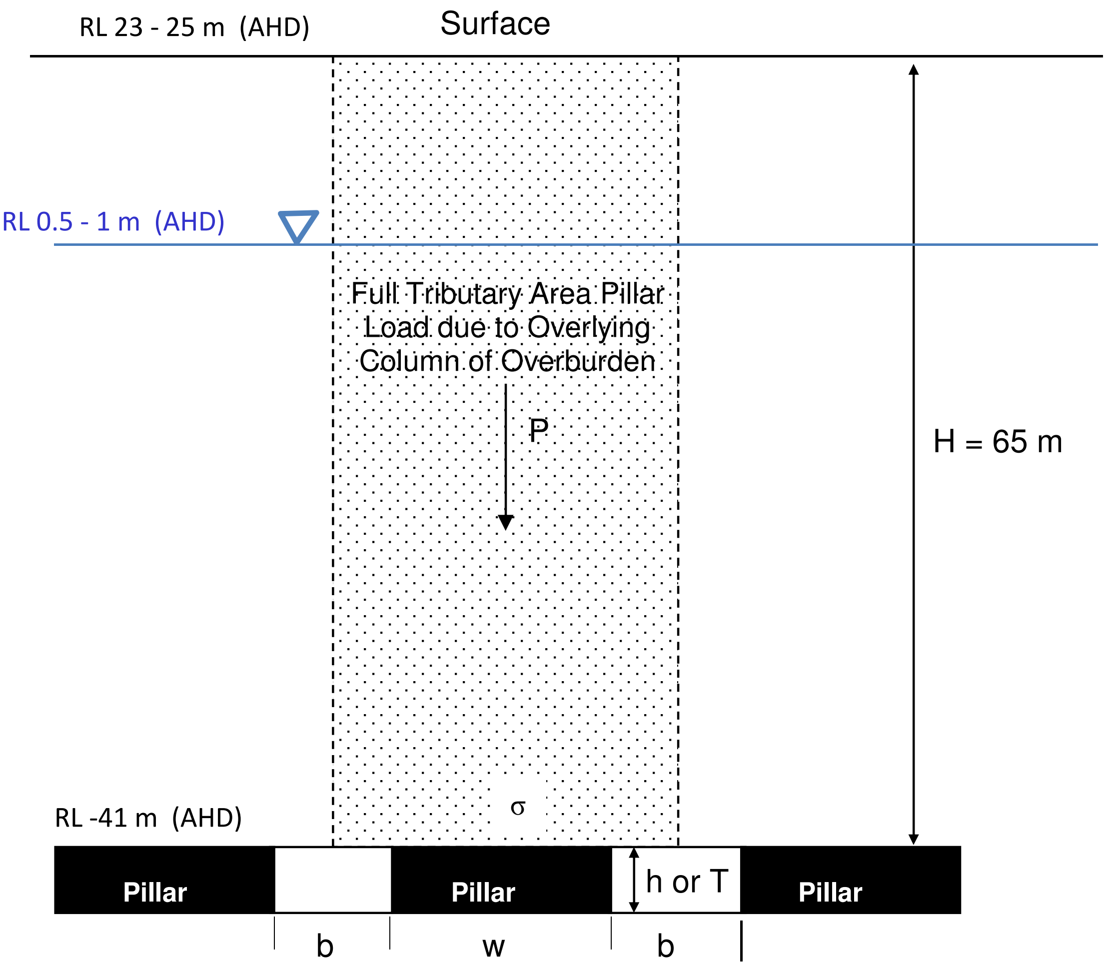
Note:
1. Workings are flooded and under 40 m head of pressure.
2. Coal seam extraction ratio, e = 55%
3. Second workings extraction ratio, e = 70% - 80%

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	14.09.13	Title:	Inferred Conditions in NCC Mine Workings in the Borehole Seam (circa 1910-1921)
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS — Figure No: 3b



Data extracted from Salamon, *et al* 1996.

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	06.11.18	Title:	Database of Failed and Unfailed Bord and Pillar Panels from Australian and South African Coal Mines: Pillar Strength v. FTA Load
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	4a



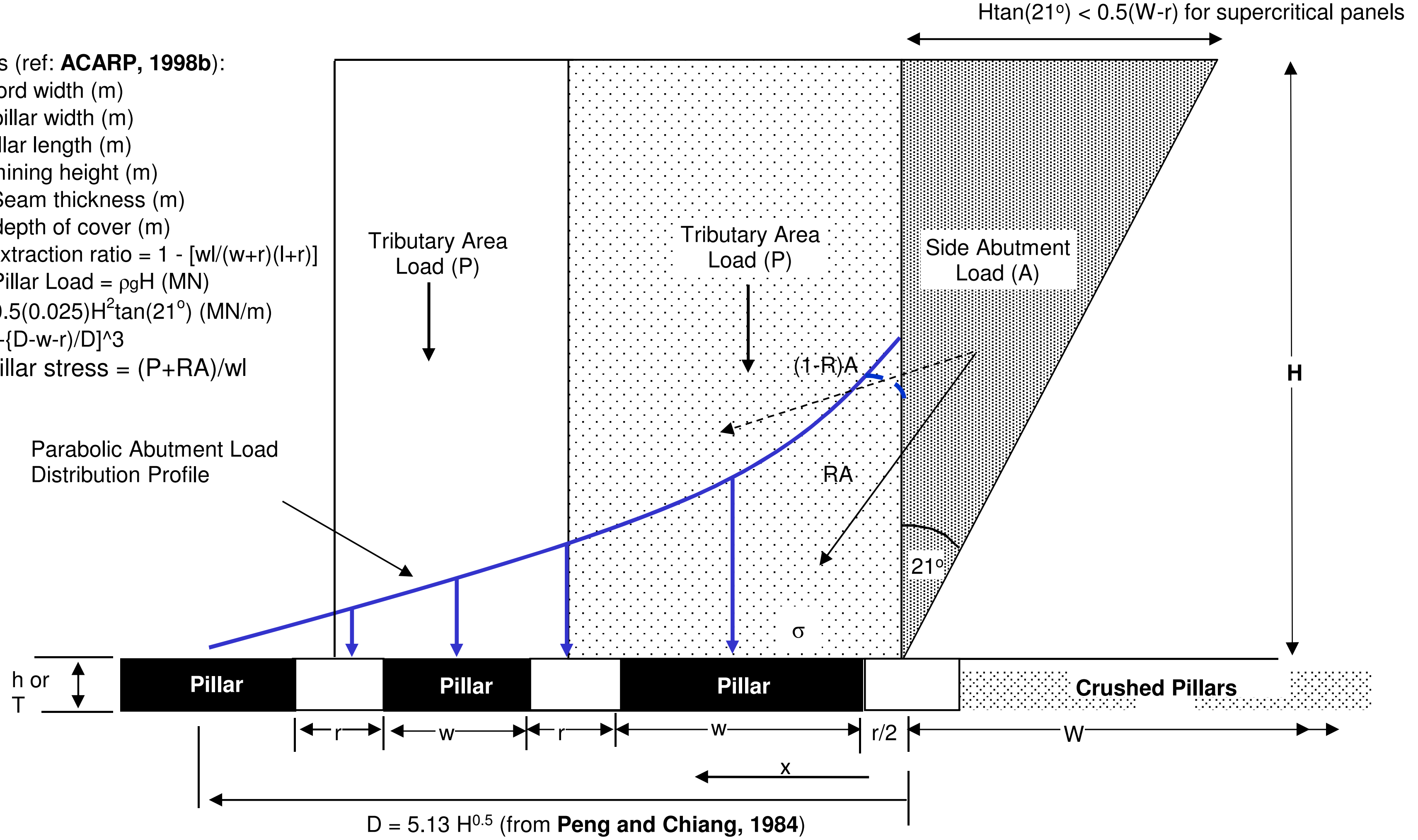
Notes:

w = pillar width (m)
l = pillar length
b = bord width (m)
r = cut-through width (m)
h = mining height (m)
T = Seam thickness (m)
H = depth of cover (m)
ρ = overburden density (t/m3)
g = gravity acceleration = 10 m/s^2
P = Full Tributary Area (FTA) Pillar Load = ρgH(w+b)(l+r) (MN)
σ = FTA pillar stress = P/(wl) (MPa)
e = extraction ratio = 1 - [wl/(w+b)(l+r)]

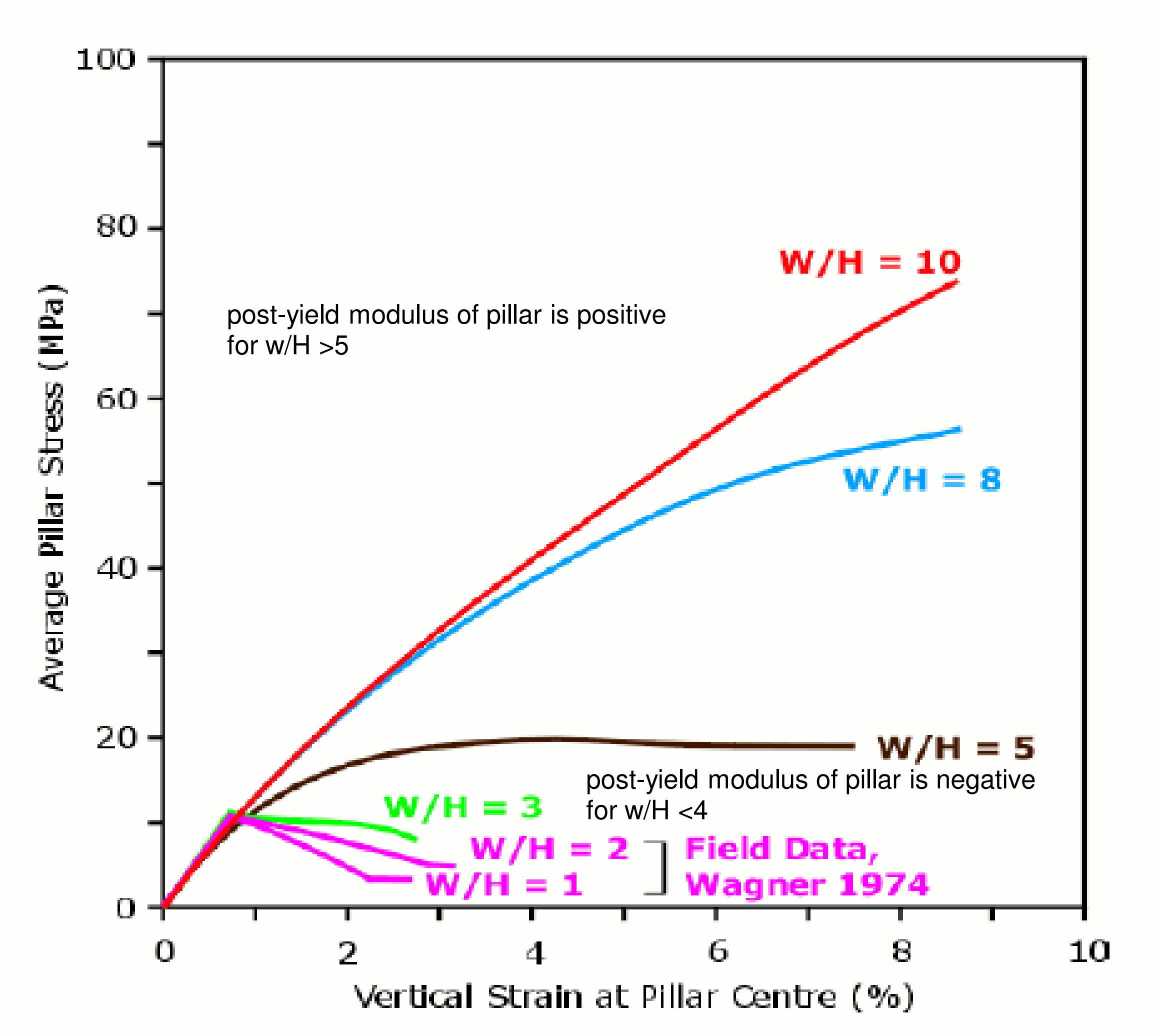
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting		
	Drawn:	S.Ditton		CAT-001/1		
	Date:	06.11.18	Title:	Conceptual Model of Full Tributary Area Loading		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	4b

Notes (ref: **ACARP, 1998b**):

r = bord width (m)
w = pillar width (m)
l = pillar length (m)
h = mining height (m)
T = Seam thickness (m)
H = depth of cover (m)
e = extraction ratio = 1 - [wl/(w+r)(l+r)]
P = Pillar Load = ρgH (MN)
A = 0.5(0.025)H^2tan(21°) (MN/m)
R =1-{D-w-r)/D]^3
σ= pillar stress = (P+RA)/wl



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting
	Drawn:	S.Ditton		CAT-001/1
	Date:	06.11.18	Title:	Conceptual Model of Abutment Load Acting on Site Pillars Due to Pillar Run Scenario
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	4c



Ref: ACARP, 2005

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting		
	Drawn:	S.Ditton		CAT-001/1		
	Date:	06.11.18	Title:	In-situ Pillar Stress v. Strain Behaviour for a Range of Pillar Width/Height Ratios		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	4d

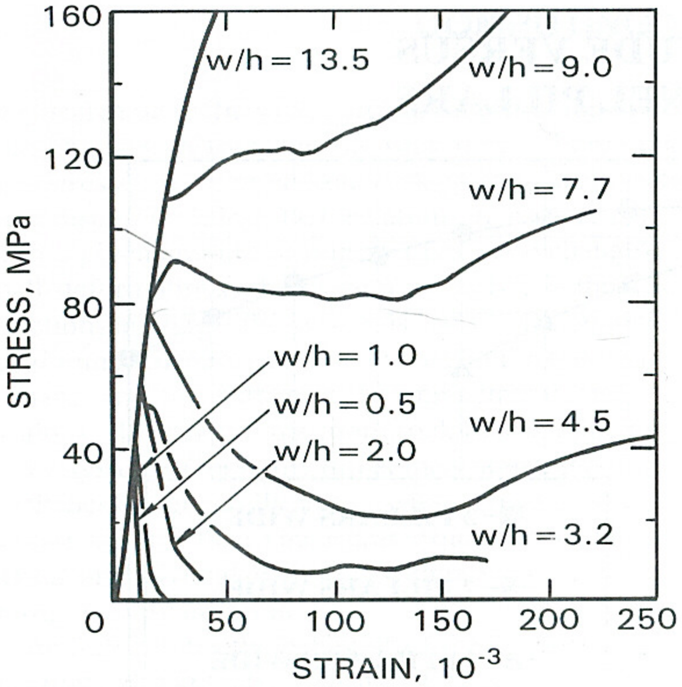


Figure 4.—Complete stress-strain curves for Indian coal specimens showing increasing residual strength and postfailure modulus with increasing w/h (after Das [1986]).

Ref: Das, **1996**

POSTFAILURE MODULUS VERSUS PILLAR WIDTH-TO-HEIGHT RATIO

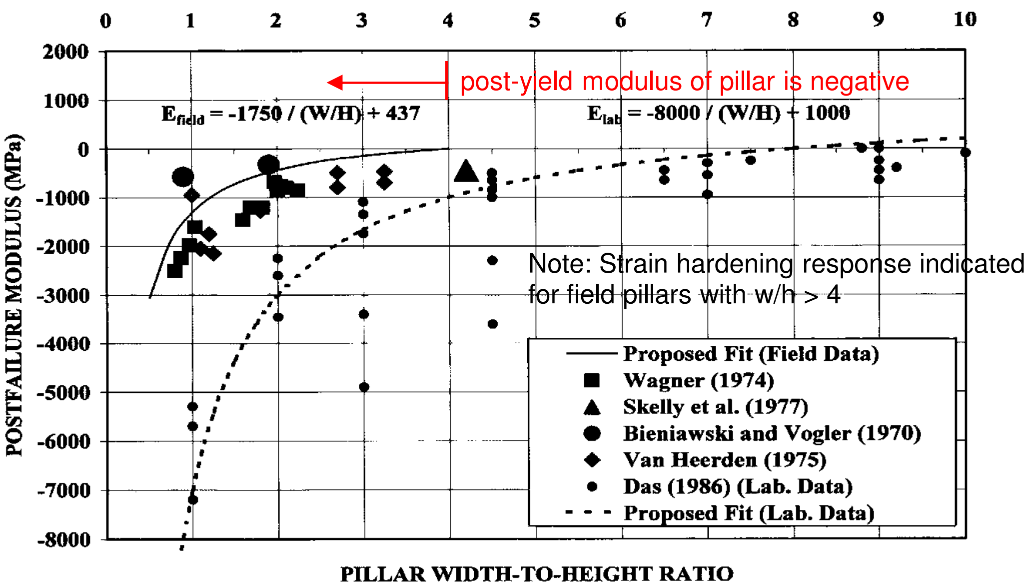
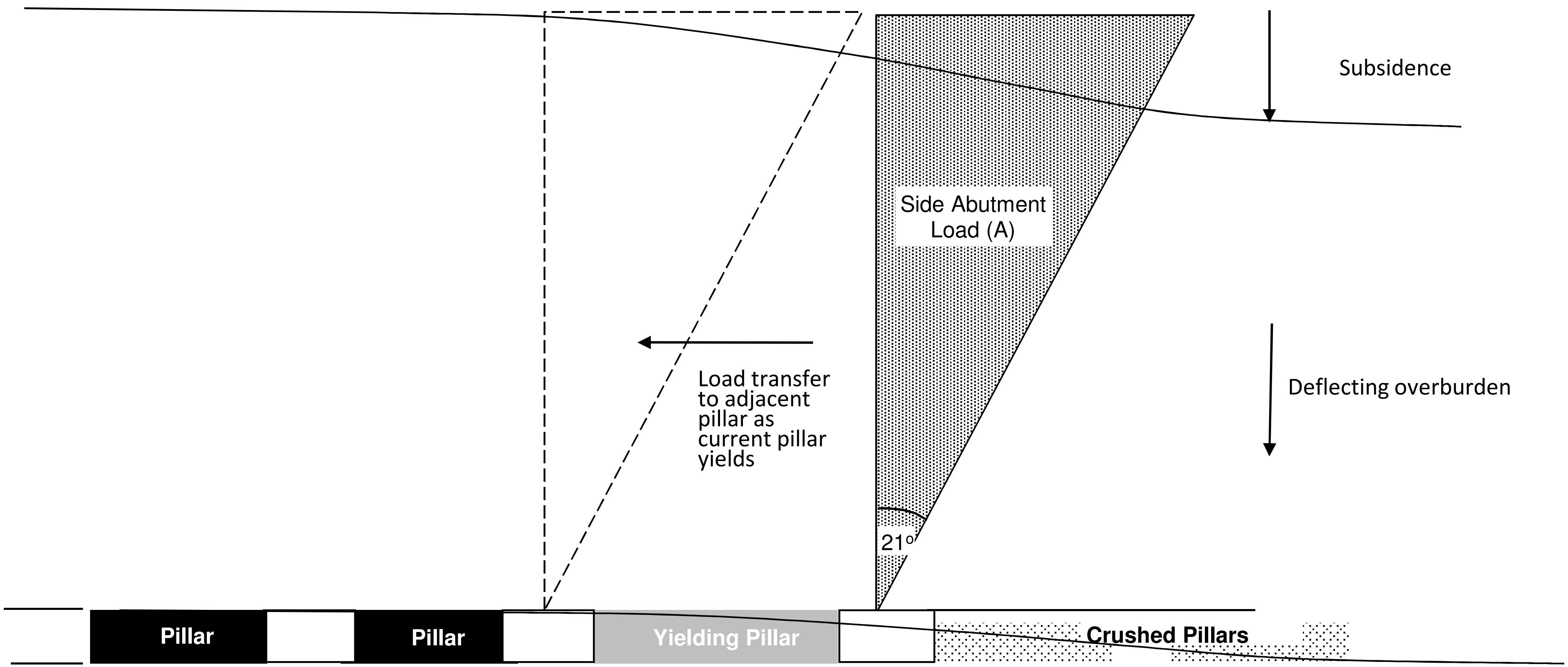


Figure 5.—Summary of postfailure modulus data for full-scale coal pillars and laboratory specimens. Also shown is proposed approximate equation for E_p.

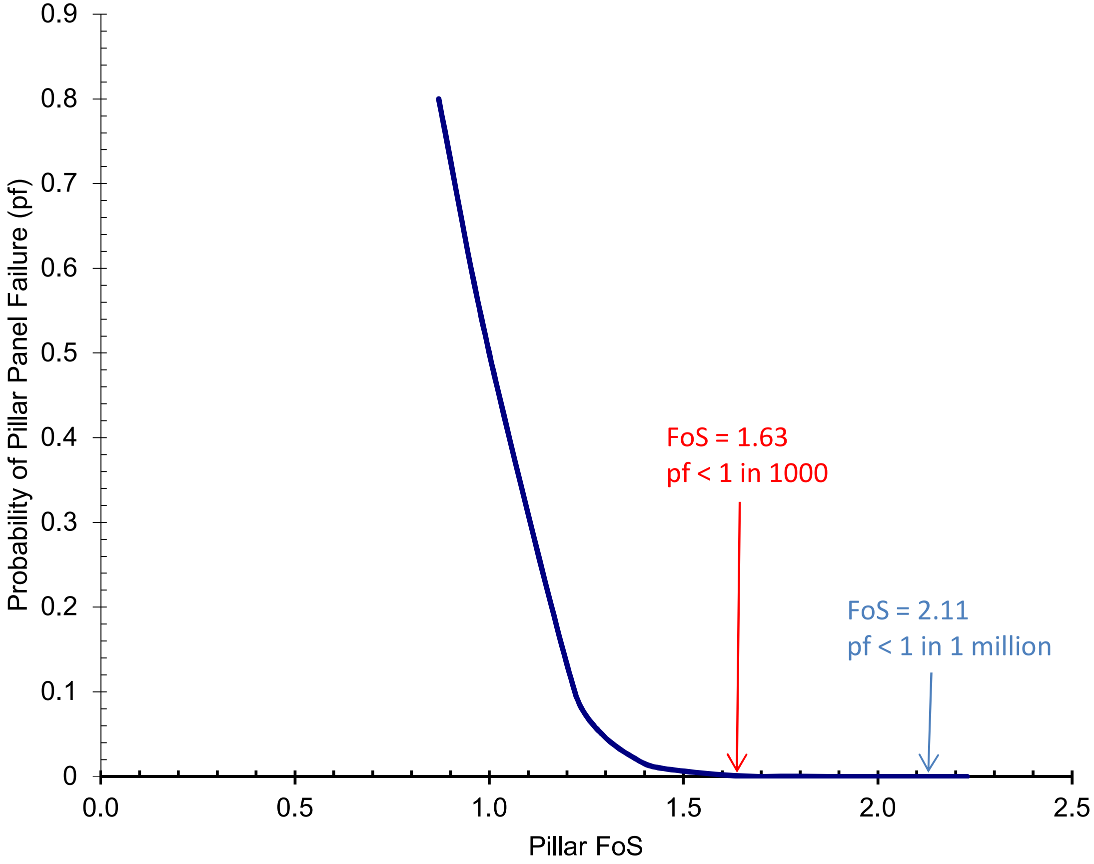
Ref: **Zipf, 1999**

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting	
	Drawn:	S.Ditton		CAT-001/1	
	Date:	06.11.18	Title:	Post-yielded Modulus & Laboratory Stress - Strain Curves for a range of pillar w/h Ratios	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 4e



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting
	Drawn:	S.Ditton		CAT-001/1
	Date:	06.11.18	Title:	Conceptual Model of Abutment Load Transfer to Adjacent Pillars Due to Pillar Run Scenario
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS
			Figure No:	4f

Reference : UNSW, 1998

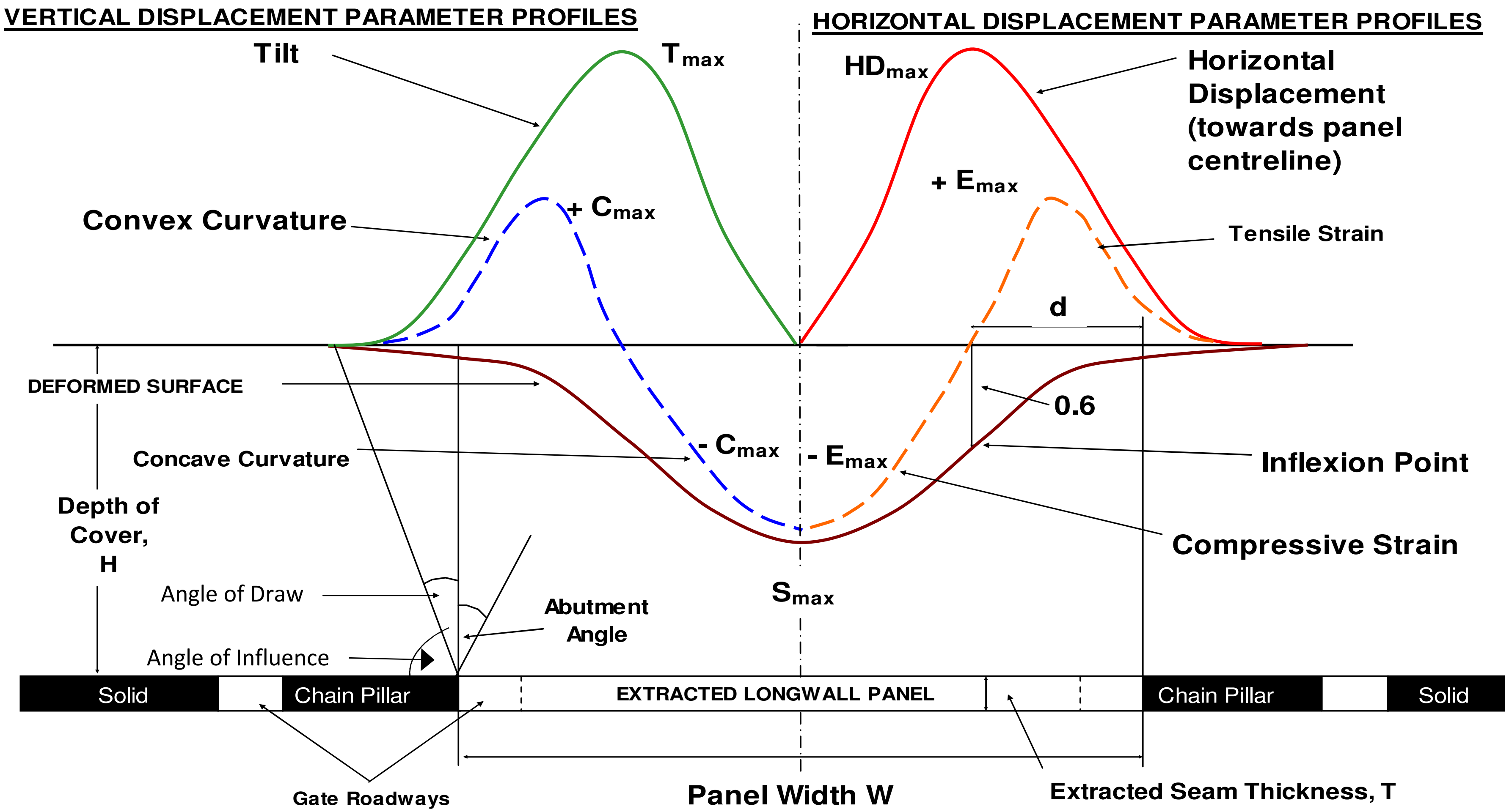


pf	1-pf	lnFoS	FoS
0.8	0.2	-0.13	0.87
0.5	0.5	0.00	1.00
0.1	0.9	0.20	1.22
0.05	0.95	0.26	1.30
0.02	0.98	0.32	1.38
0.01	0.99	0.37	1.44
0.001	0.999	0.49	1.63
0.0001	0.9999	0.58	1.79
0.00001	0.99999	0.67	1.95
0.000001	**0.999999**	**0.75**	**2.11**

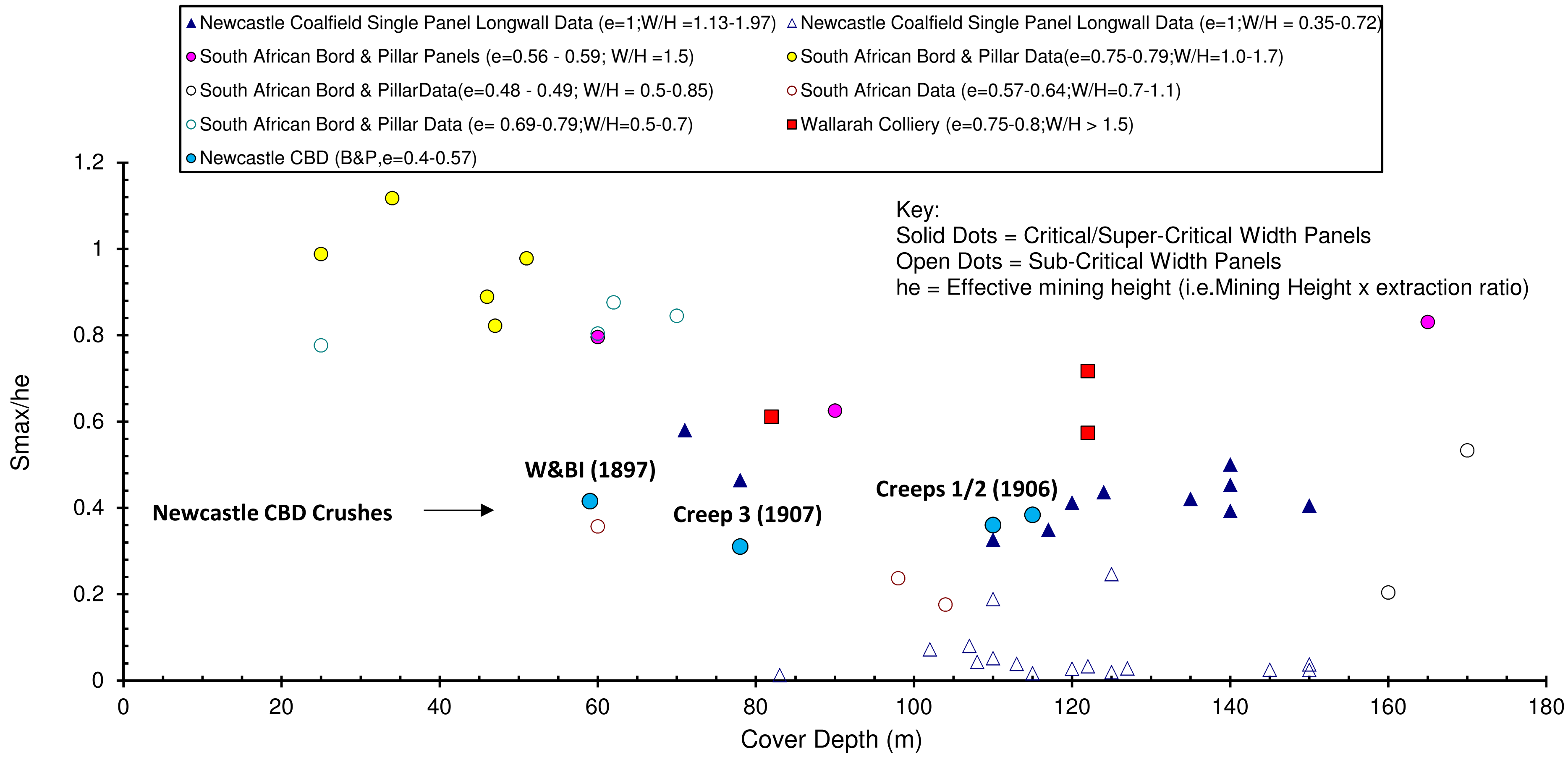
Estimated log-normal pdf parameters:

Parameter	Value
μ	1.000
sigma	0.157

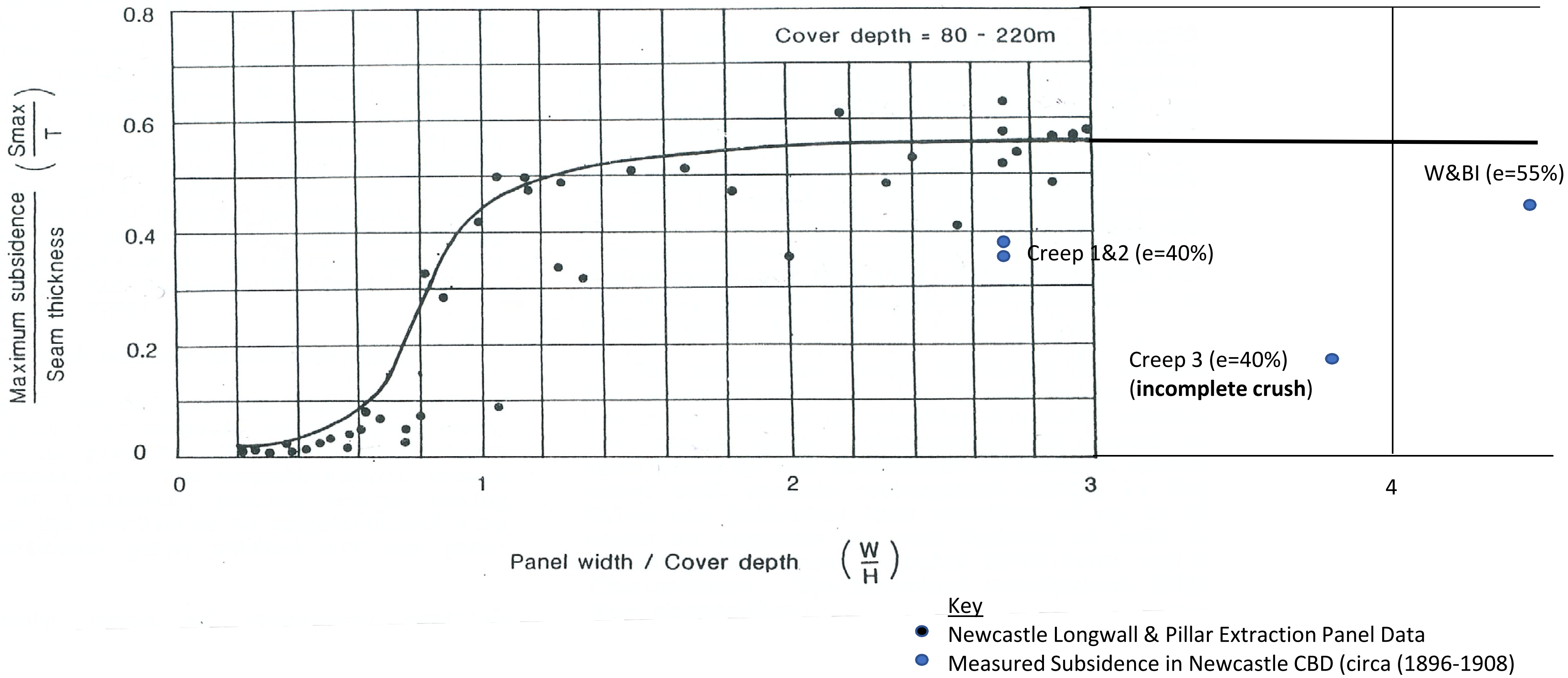
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting	
	Drawn:	S.Ditton		CAT-001/1	
	Date:	06.11.18	Title:	Probability of Australian Bord and Pillar Panel Failure v. FoS under FTA & Abutment Loading Conditions	
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No: 5



DgS	Engineer: S.Ditton	Client: Catalyst Project Consulting CAT-001/1		
	Drawn: S.Ditton			
	Date: 01.08.17	Title: Mine Subsidence Trough Deformation Parameters (adapted from Holla, 1987)		
	Ditton Geotechnical Services Pty Ltd	Scale: NTS	Figure No:	6a



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1			
	Drawn:	S.Ditton					
	Date:	06.11.18	Title:	Database of Smax/he above Failed Bord and Pillar Panels from South Africa & Newcastle Coalfield			
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6b	



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1		
	Drawn:	S.Ditton				
	Date:	06.11.18	Title:	Longwall v. Bord and Pillar Crush Subsidence data in Newcastle Coalfield (ref **Holla, 1987**)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6c

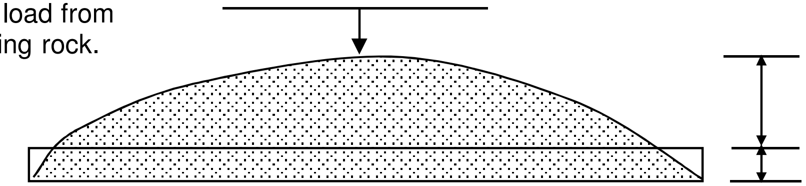
3. Seam/rubble convergence is then transferred to surface and is usually defined as a proportion (a) of the mining height (the overburden stiffness may be ignored for super-critical width panels).

Smax = 0.6T (supercritical)

a = 0.6 (but probably a function of cover depth or goaf stress)

2. Collapsed roof rubble compresses under load from overlying rock.

Cmax = stress x nT/Egoaf



1. Coal seam is extracted and immediate roof falls into void behind face

Longwall Mining Subsidence Mechanics

Key:
T = Mining Height.
Egoaf = Young's Modulus of collapsed roof material.
Cmax = Seam Roof convergence.
n = rubble height/mining height factor (ranges from 4 to 6).
Smax = Maximum surface subsidence.
a = subsidence factor, which relates maximum subsidence to mining thickness.

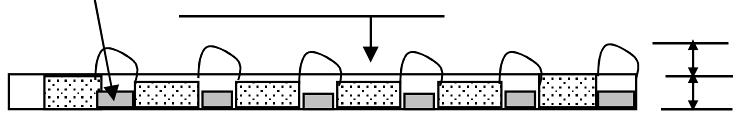
3. Seam/rubble convergence is then transferred to surface and is usually defined as a proportion (b) of the effective mining height (T x extraction ratio) The overburden stiffness may be ignored for super-critical width panels.

Smax = 0.4Te (supercritcal)

a = 0.4 assumed above B& P workings

2. Pillars and immediate mine roof deteriorates after mining and overburden compresses (and sometimes crushes) the remnant coal pillars and collapsed roof rubble along the bords.

Cmax = stress x nT/Er

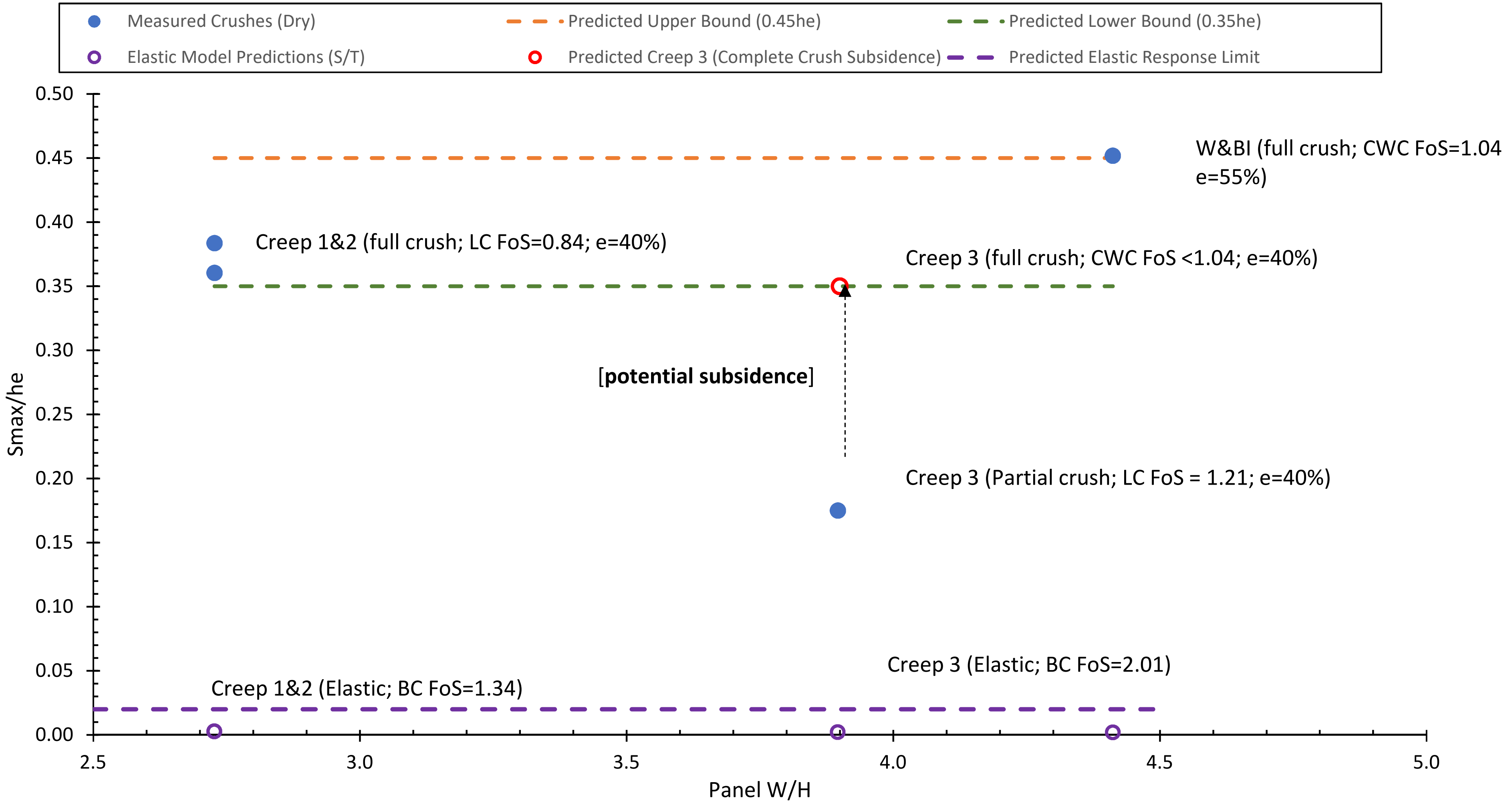


1. Bord and Pillars are formed in the coal seam.

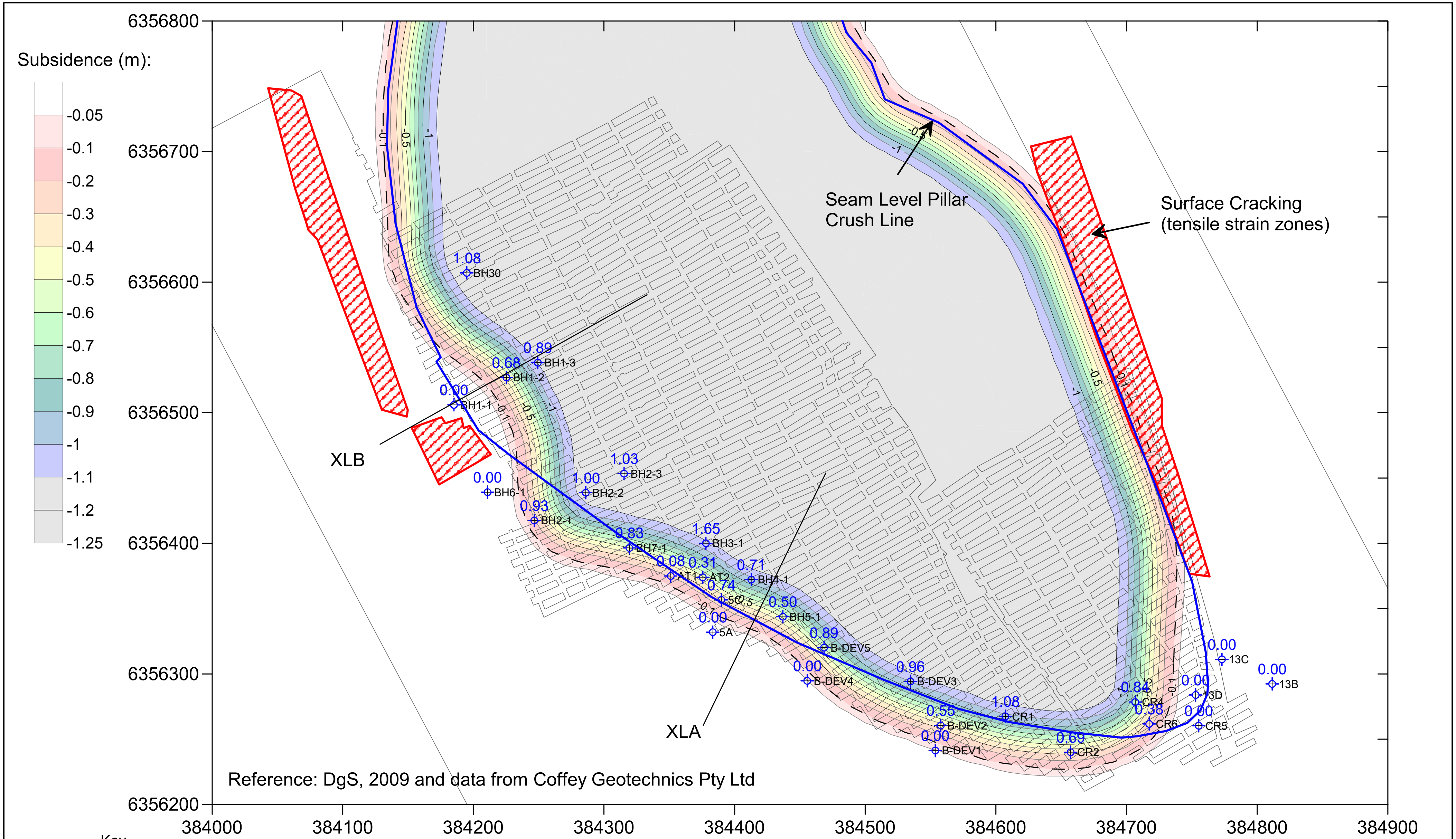
Bord and Pillar Workings Subsidence Mechanics

Key:
T = Mining Height.
Er = Young's Modulus of yielded pillar and collapsed roof material.
Cmax = Seam Roof convergence.
n = rubble height/mining height factor (ranges from 1 to 2)
Smax = Maximum surface subsidence.
a = subsidence factor, which relates maxium subsidence to mining thickness.

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1		
	Drawn:	S.Ditton				
	Date:	06.11.18	Title:	Fundamental Differences between Longwall Subsidence Mechanics and Bord & Pillar Panels (Supercritical Width Panels Only)		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6d



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1		
	Drawn:	S.Ditton				
	Date:	06.11.18	Title:	Maximum Pillar Crush Subsidence Prediction Model for Dry Bord & Pillar Mine Workings in Newcastle CBD		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6e



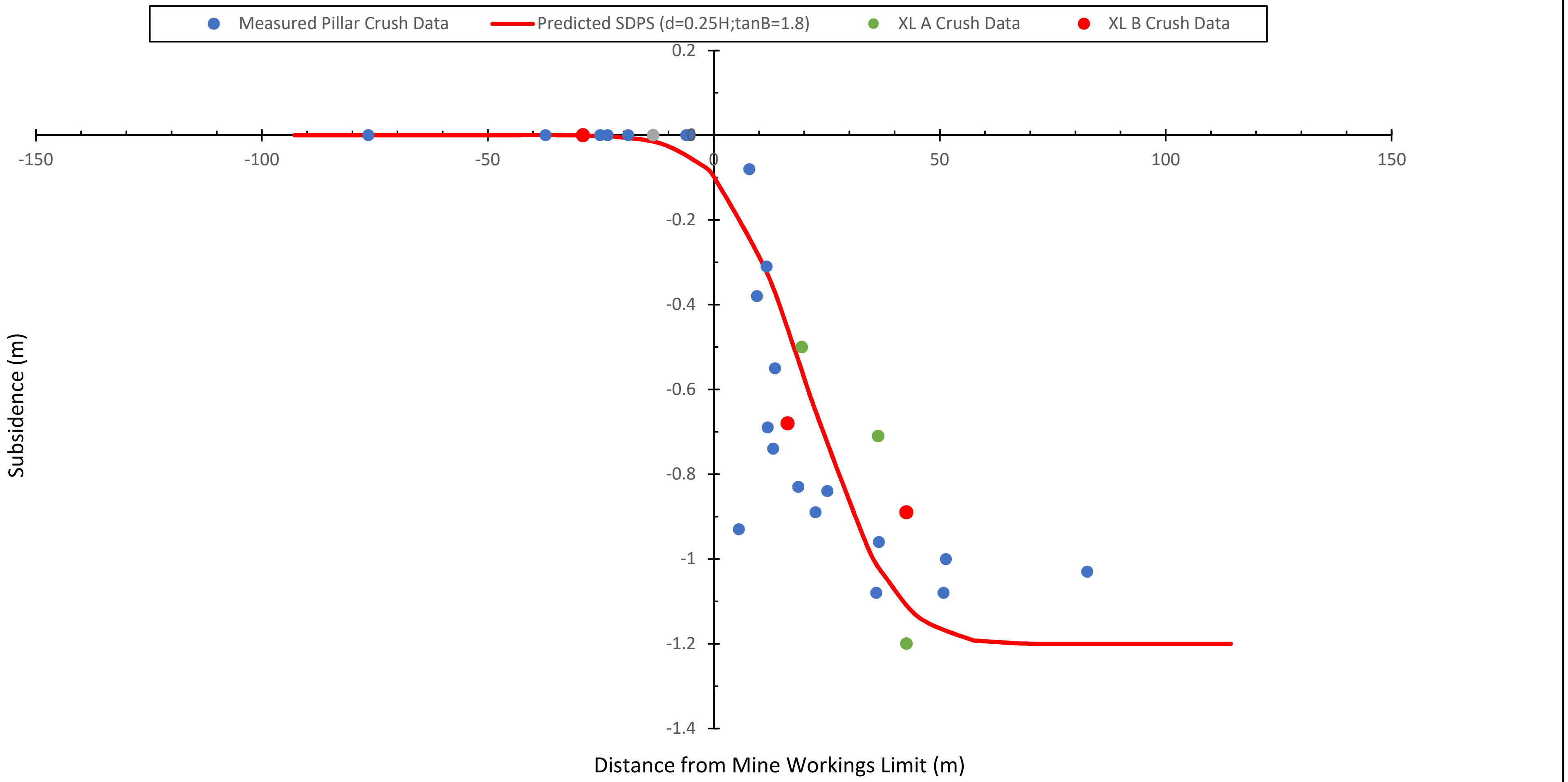
Key

Historical Crush Line (Atkins, 1908)

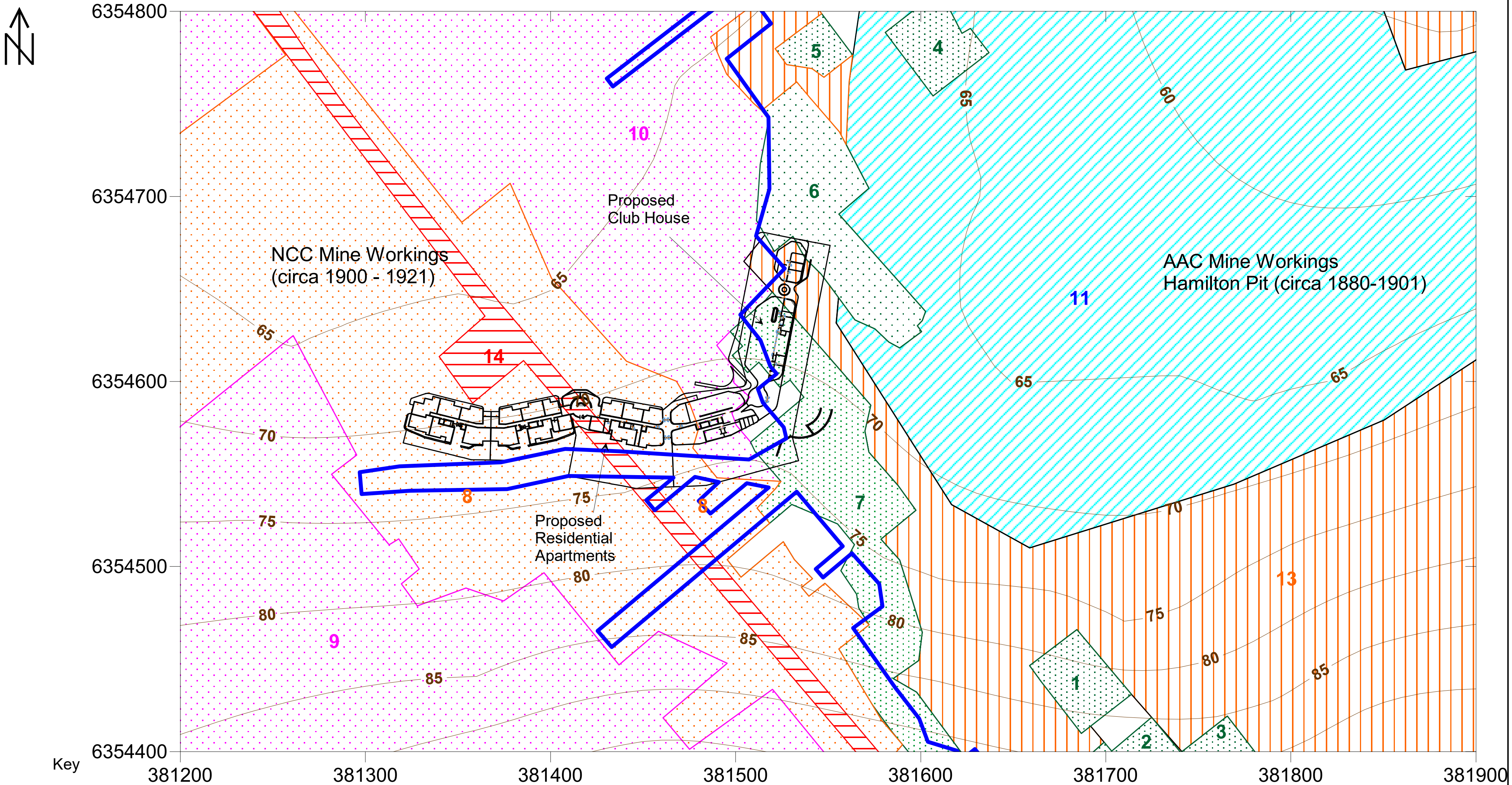
0.60 BH# Seam Crush Thickness (m)

Assessed Crush Line Limit @ 100 mm subsidence

DgS Ditton Geotechnical Services Pty Ltd	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	01.11.18	Title:	Predicted SPDS Subsidence Contours v. Measured Borehole Seam Crush Line in W&BI Coal Company Mine Workings, Honeysuckle
			Scale:	1:4,000
			Figure No:	6f



DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consultants CAT-001/1		
	Drawn:	S.Ditton				
	Date:	01.11.18	Title:	Subsidence Model (SDPS) Calibration to Honeysuckle Crush Data from Coffey Geotechnics, 2009		
	Ditton Geotechnical Services Pty Ltd		Scale:	NTS	Figure No:	6g

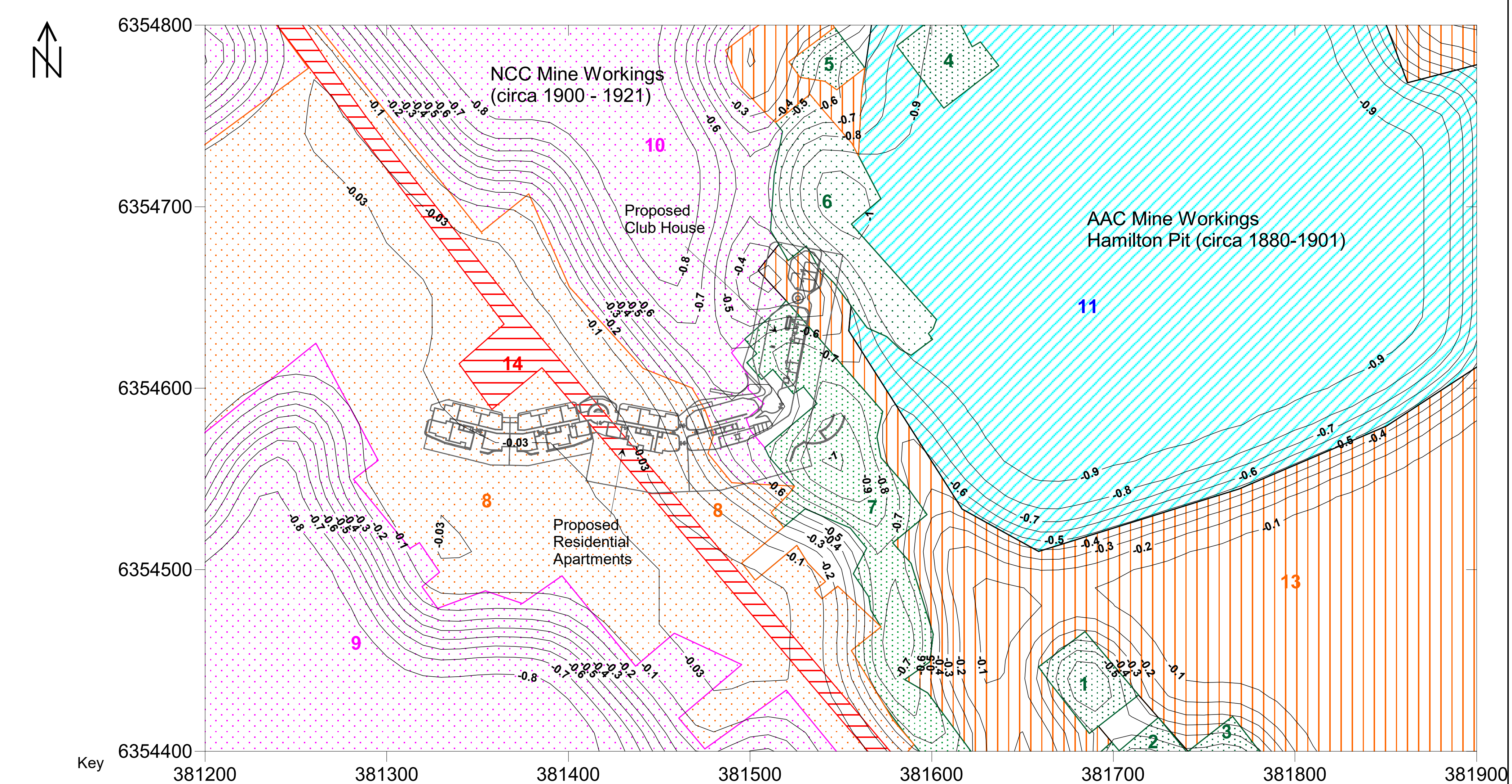


Key

	Bord & Pillar in NCC (First Workings)
	Bord & Pillar in AAC (First Workings)
	Pillar Extraction in NCC Mine (Second Workings)
	Pillar Extraction in AAC Mine (Second Workings)
	Historical Subsidence in AAC Mine (1889)
	Cover Depth Contours
	Boundary between AAC & NCC Mines

Note: Cover depth contours are approximate and for subsidence modelling purposes only

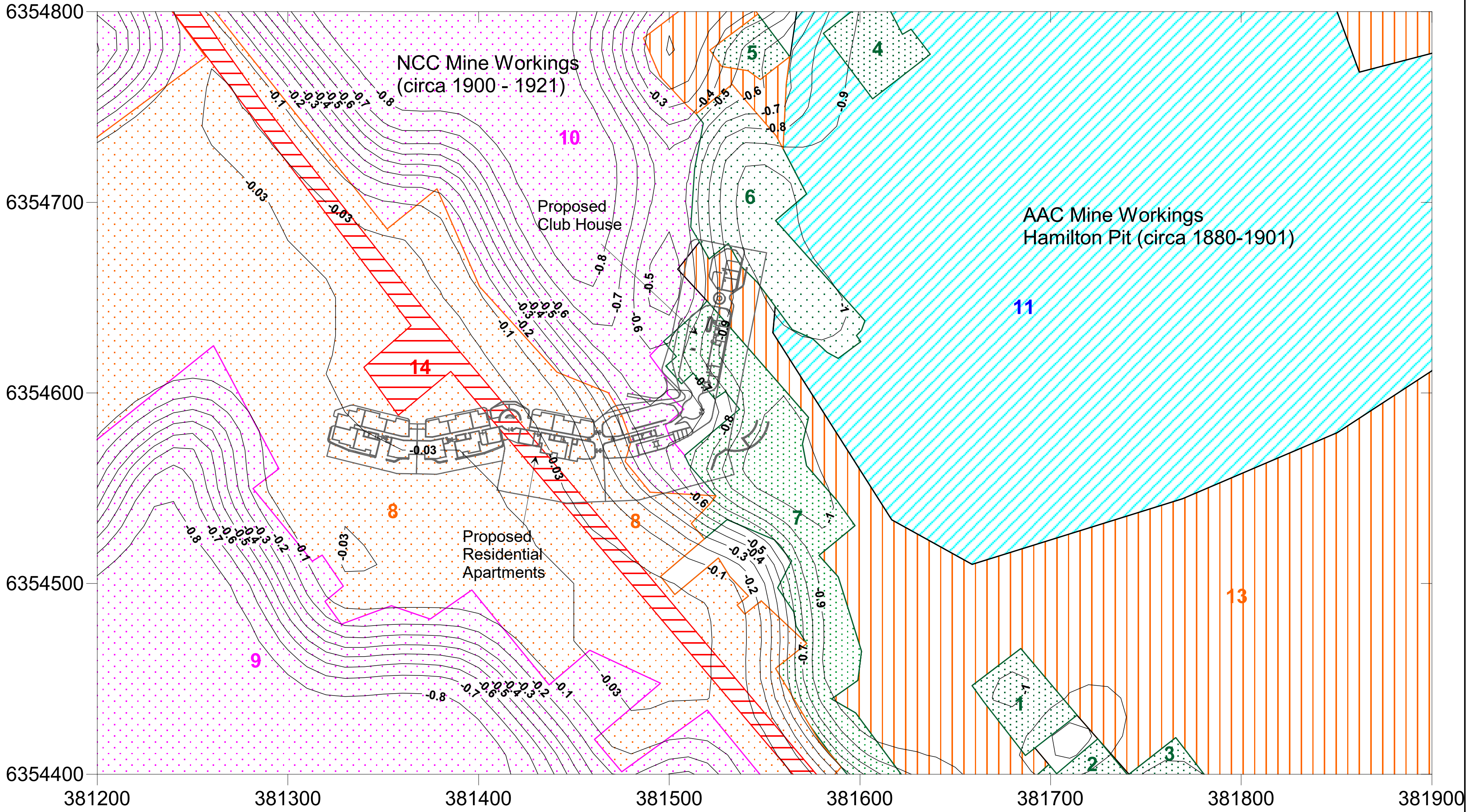
DgS	Engineer: S.Ditton	Client:	Catalyst Project Management CAT-001/1	
	Drawn: S.Ditton			
	Date: 15.10.18	Title:	SDPS Model of Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development	
	Ditton Geotechnical Services Pty Ltd	Scale:	1:3,000 (A4)	Figure No: 7



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

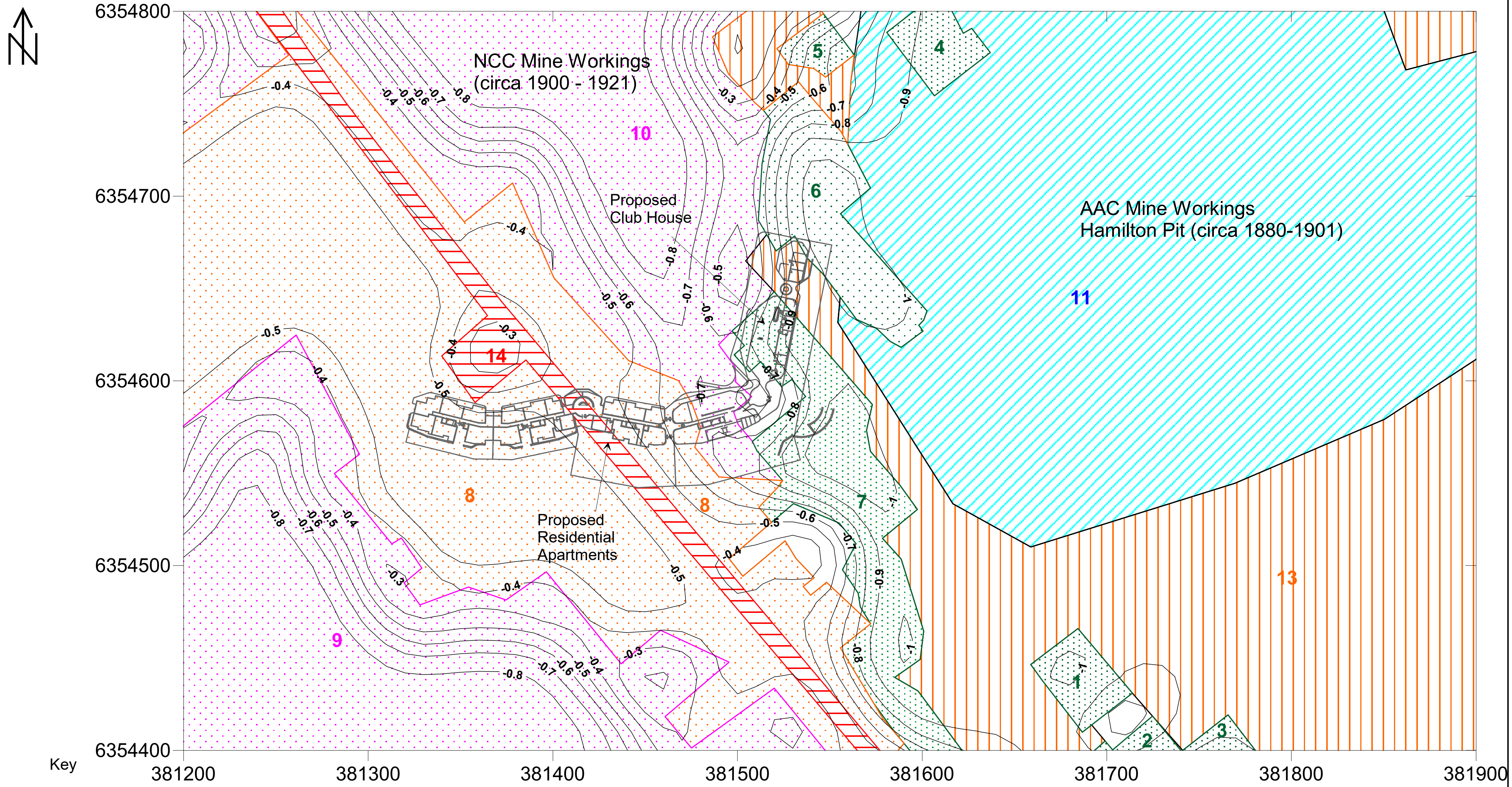
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Case 1a Subsidence Contours over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Dry Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 8a



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

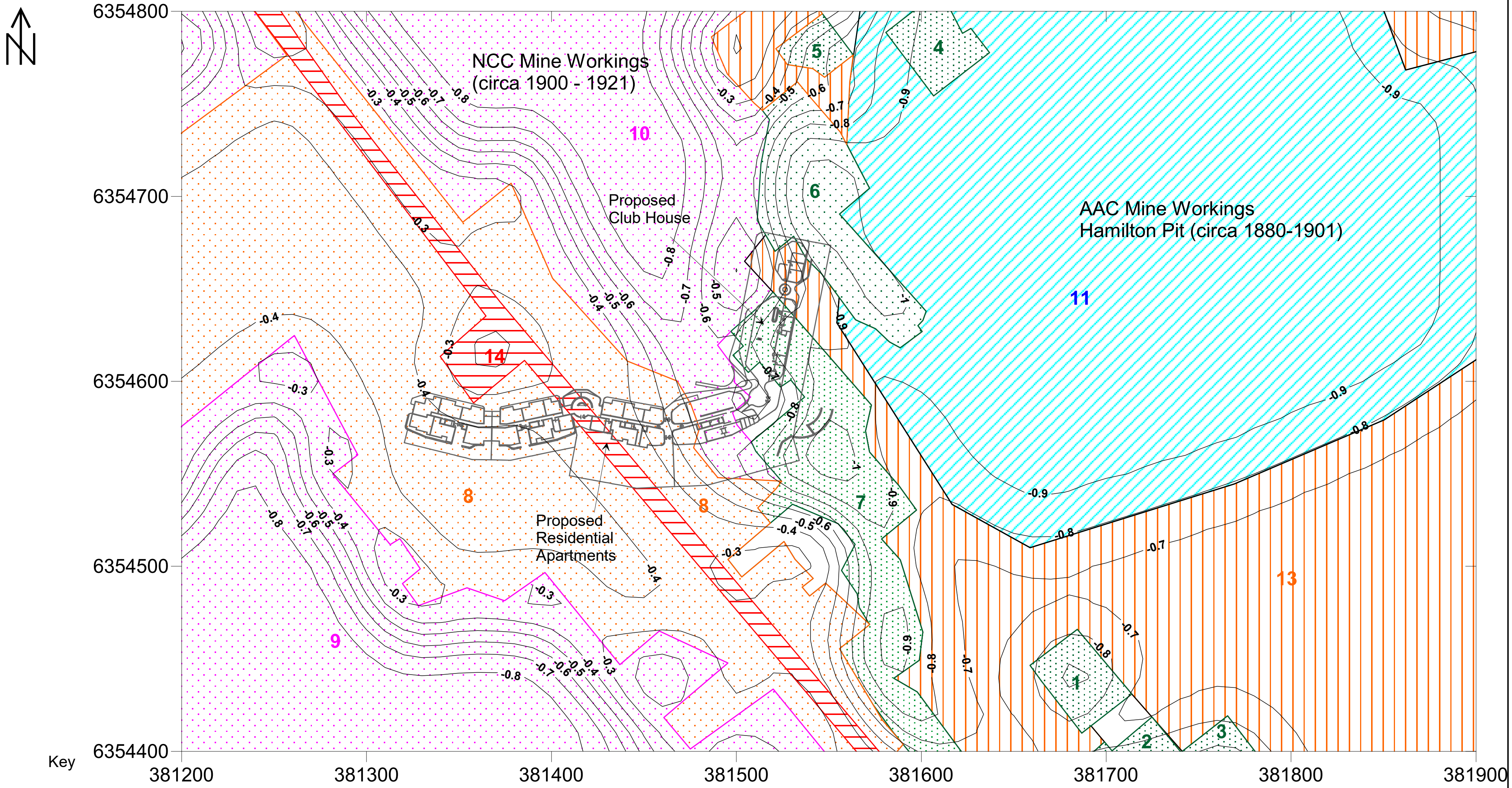
DgS	Engineer: S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn: S.Ditton		
	Date: 4.12.18	Title:	Predicted Case 1b Subsidence Contours over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Dry Conditions)
	Ditton Geotechnical Services Pty Ltd	Scale:	1:3,000 (A4) — Figure No: 8b



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

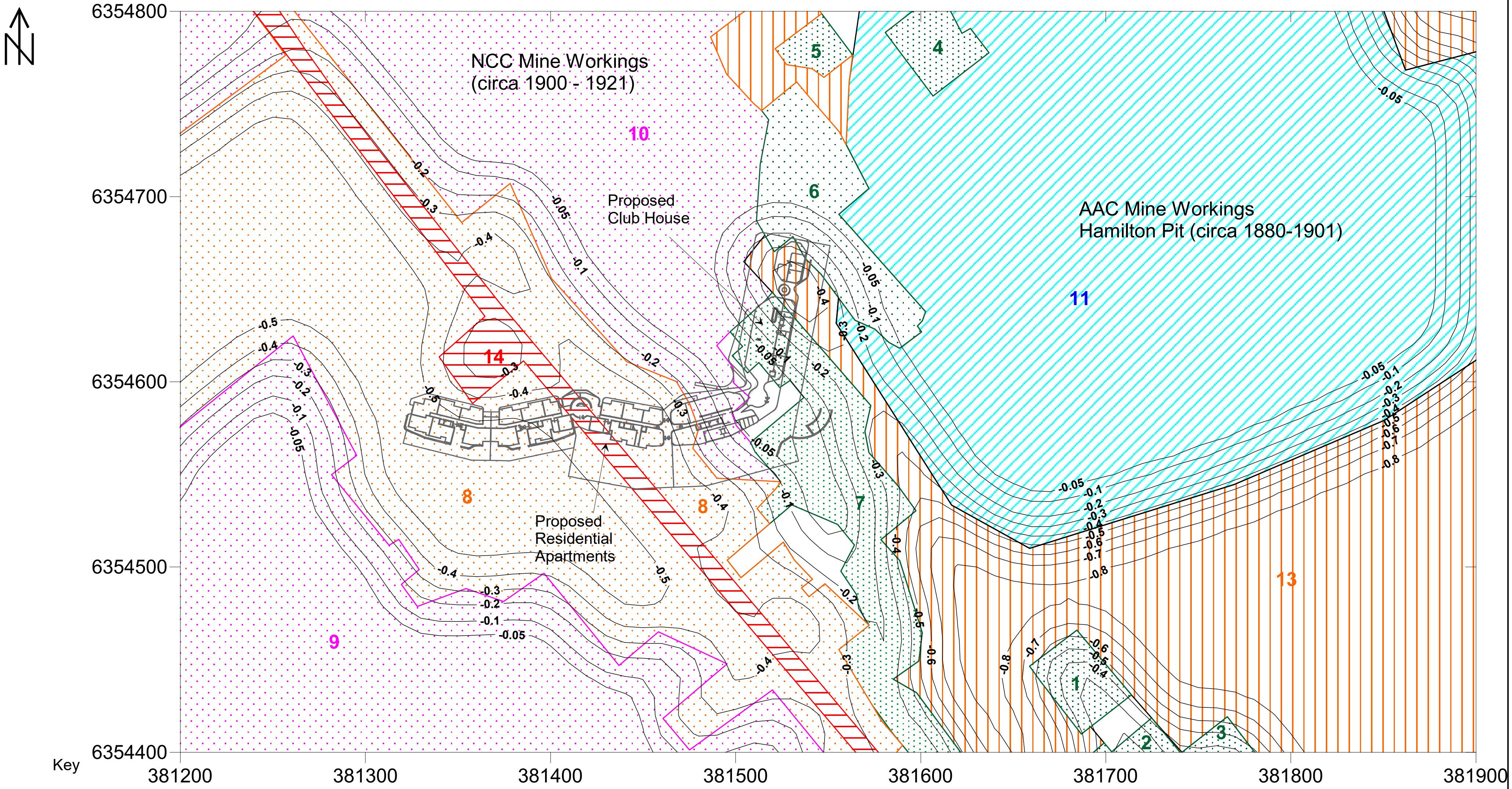
DgS	Engineer: S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn: S.Ditton		
	Date: 4.12.18	Title:	Predicted Case 2 Subsidence Contours over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Dry Conditions)
	Ditton Geotechnical Services Pty Ltd	Scale:	1:3,000 (A4) — Figure No: 9a



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

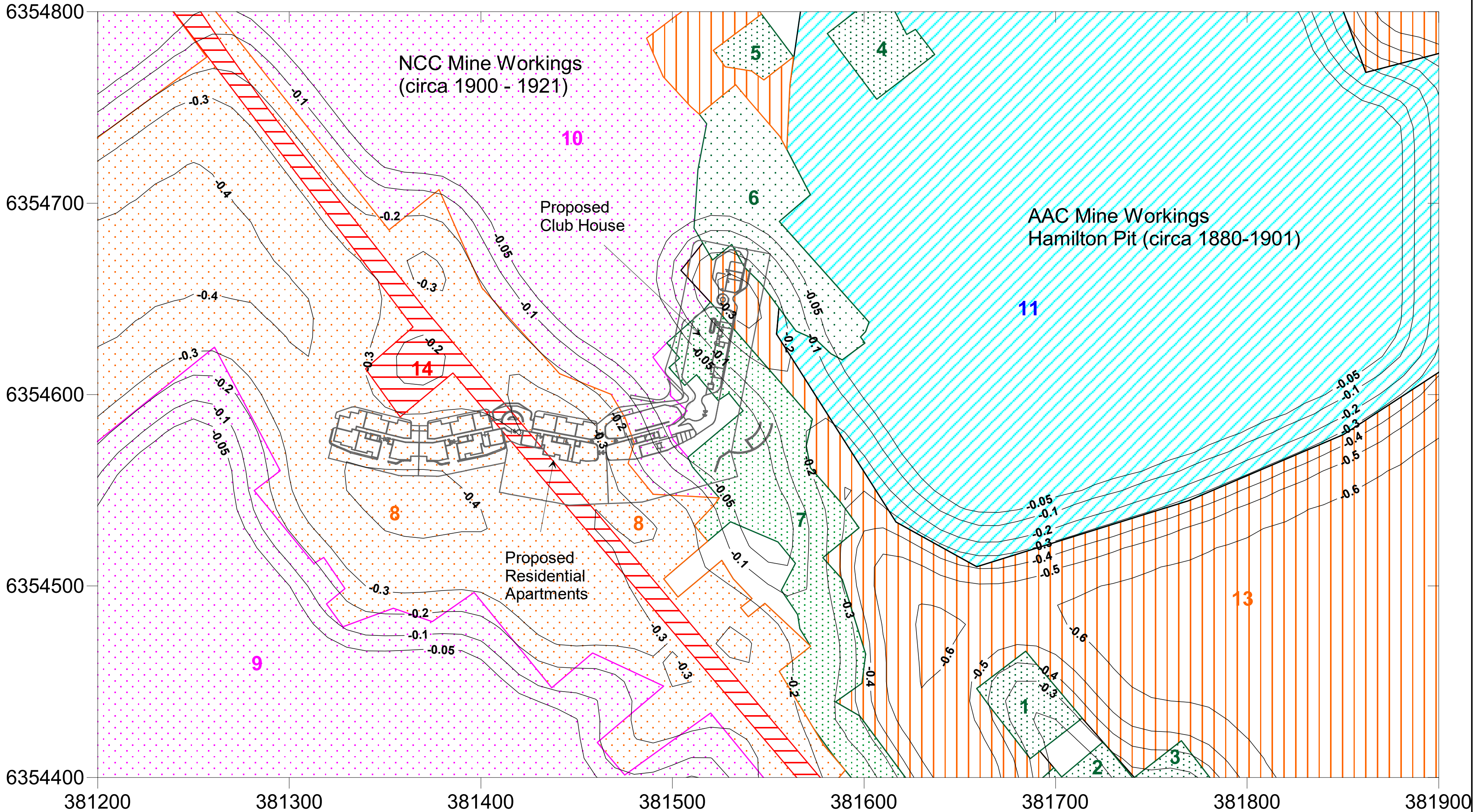
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Case 2 Subsidence Contours over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	9b



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Cover Depth Contours
- Boundary between AAC & NCC Mines

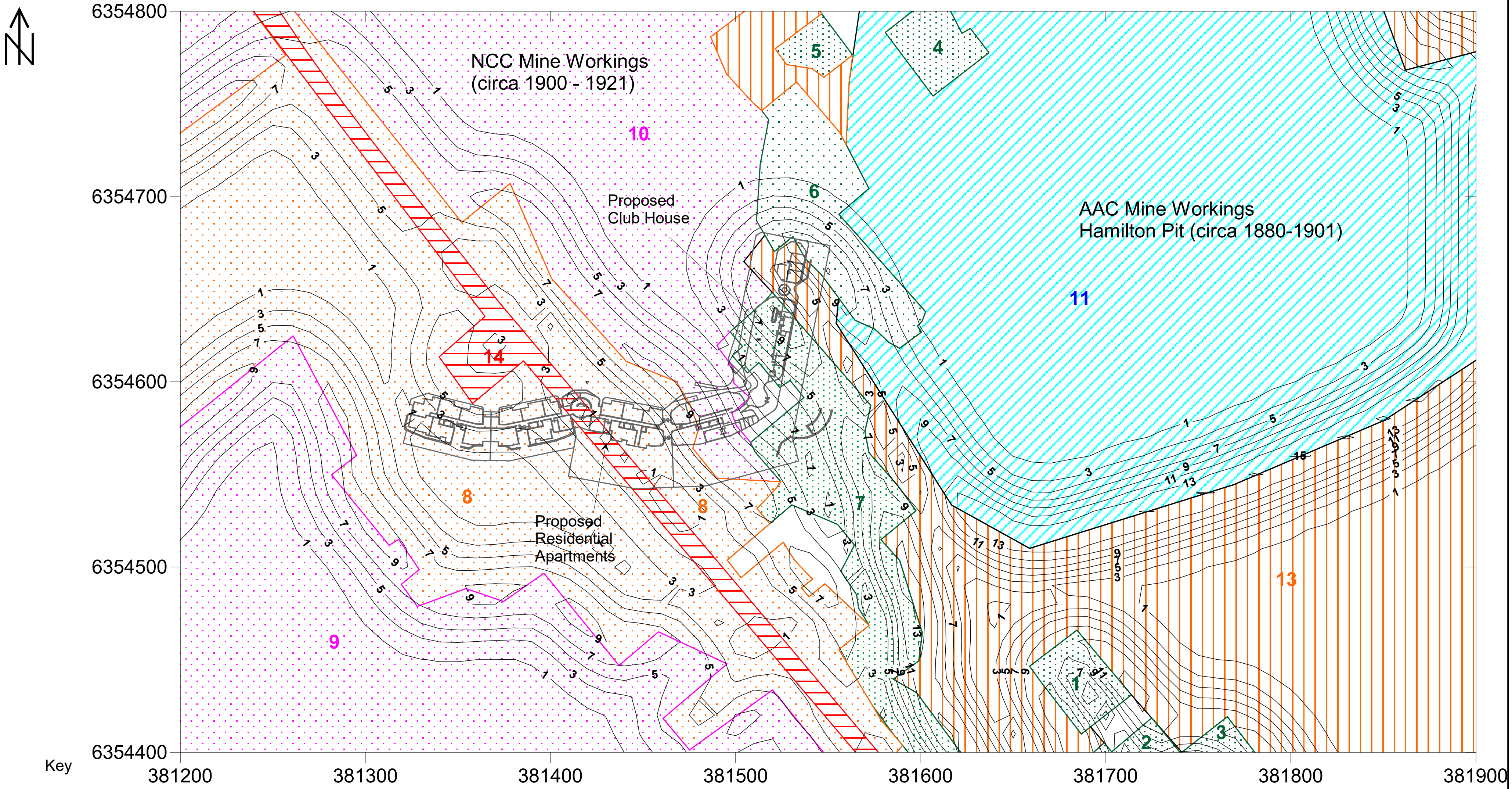
DgS Ditton Geotechnical Services Pty Ltd	Engineer: S.Ditton Drawn: S.Ditton Date: 4.12.18	Client:	Catalyst Project Management CAT-001/1
		Title:	Predicted Net CWC Subsidence Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Dry Conditions)
		Scale:	1:3,000 (A4) — Figure No: 10a



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

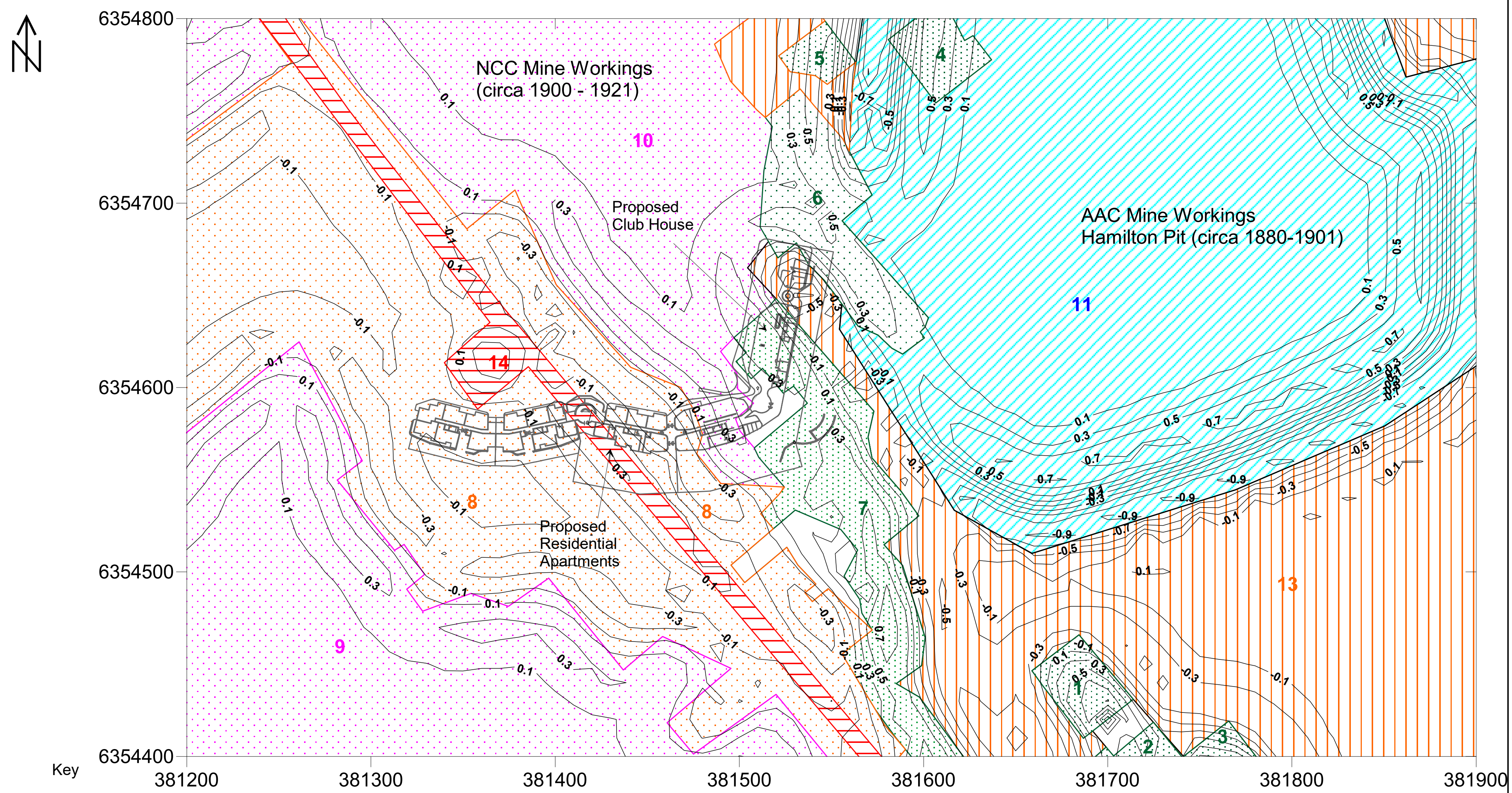
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Subsidence Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 10b



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Tilt Contours (mm/m)
- No Workings

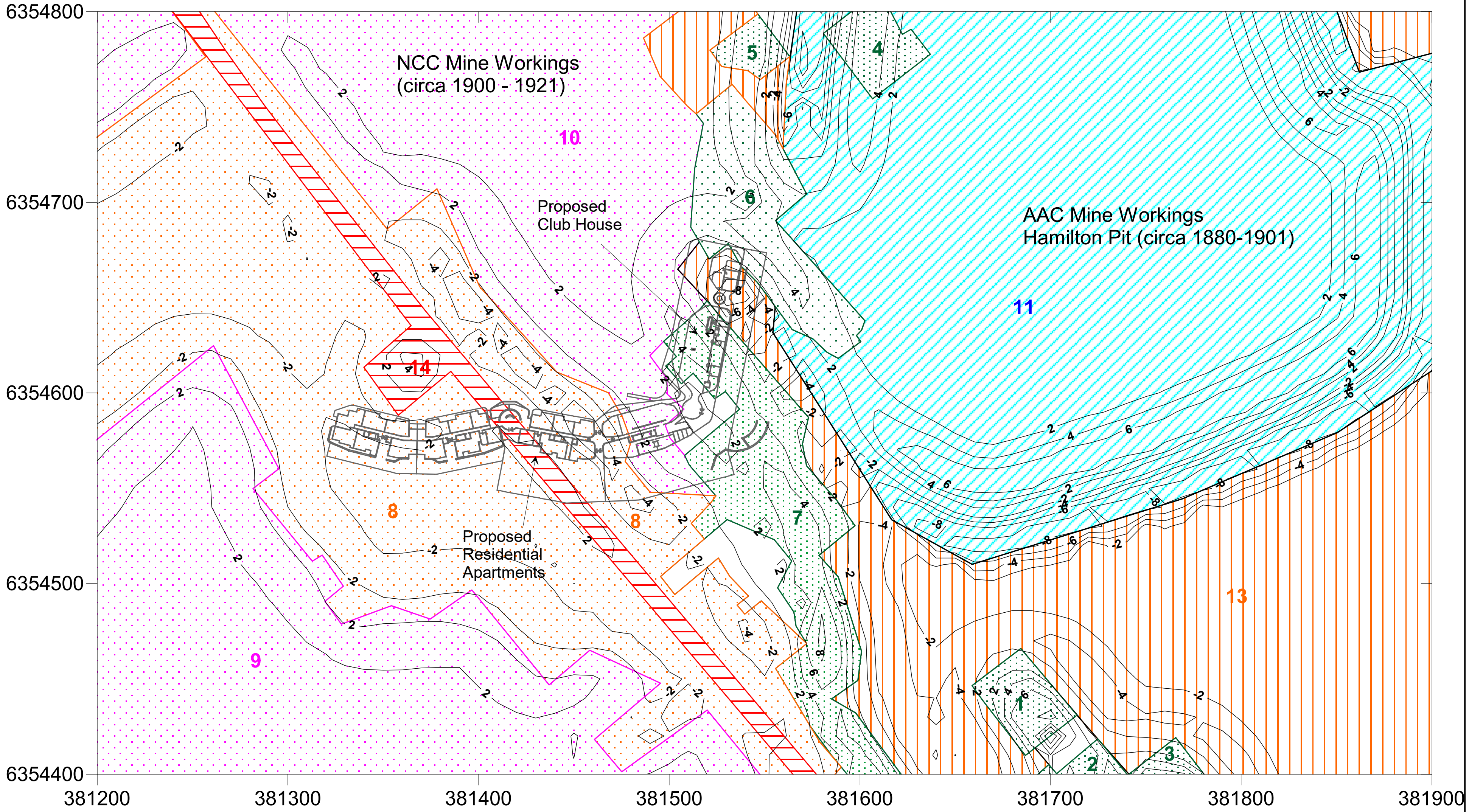
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1		
	Drawn:	S.Ditton				
	Date:	4.12.18	Title:	Predicted Net CWC Tilt Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)	Figure No:	10c



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Curvature Contours (1/km)
- No Workings

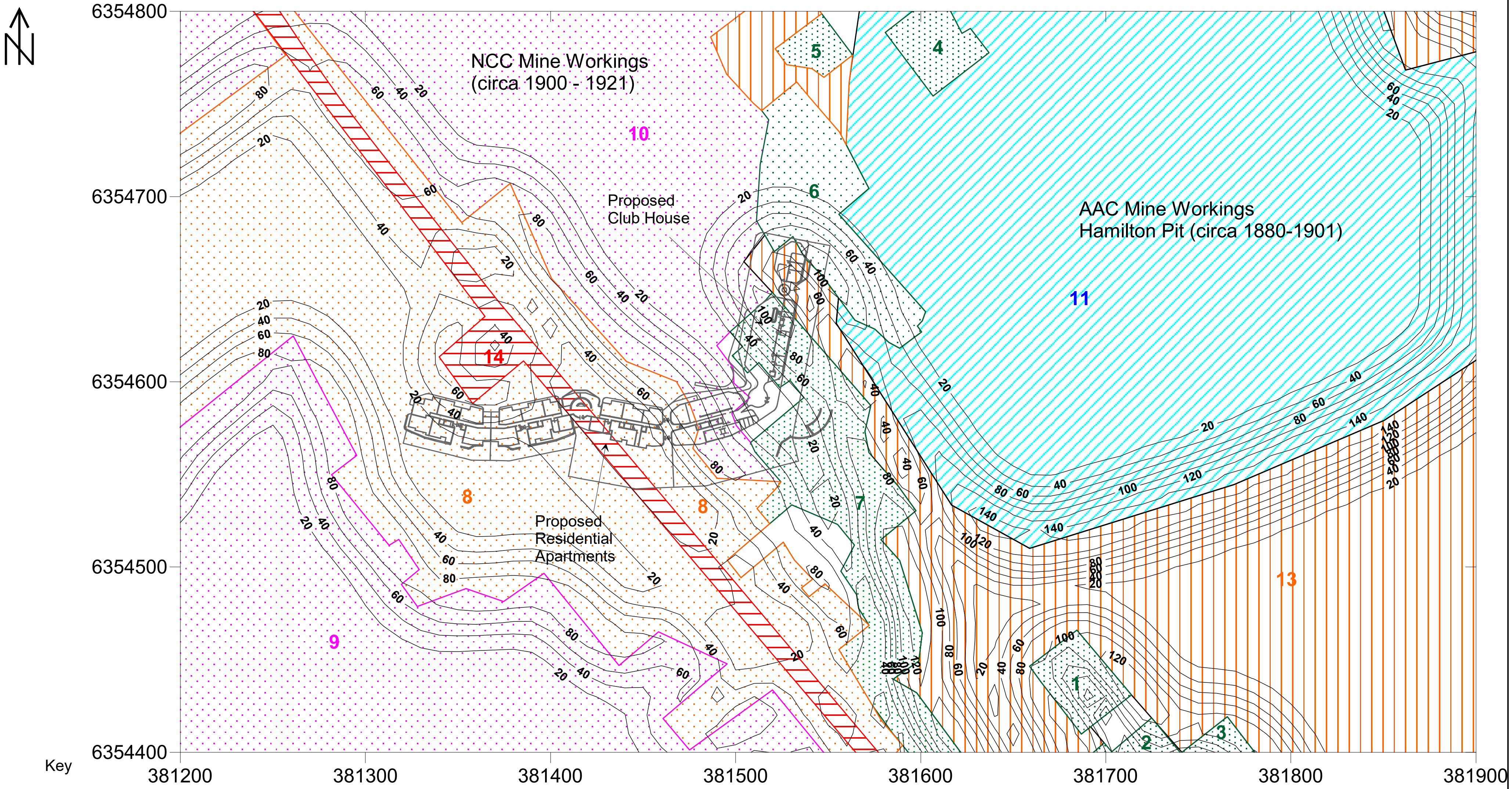
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Curvature Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 10d



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Strain Contours (mm/m)
- No Workings

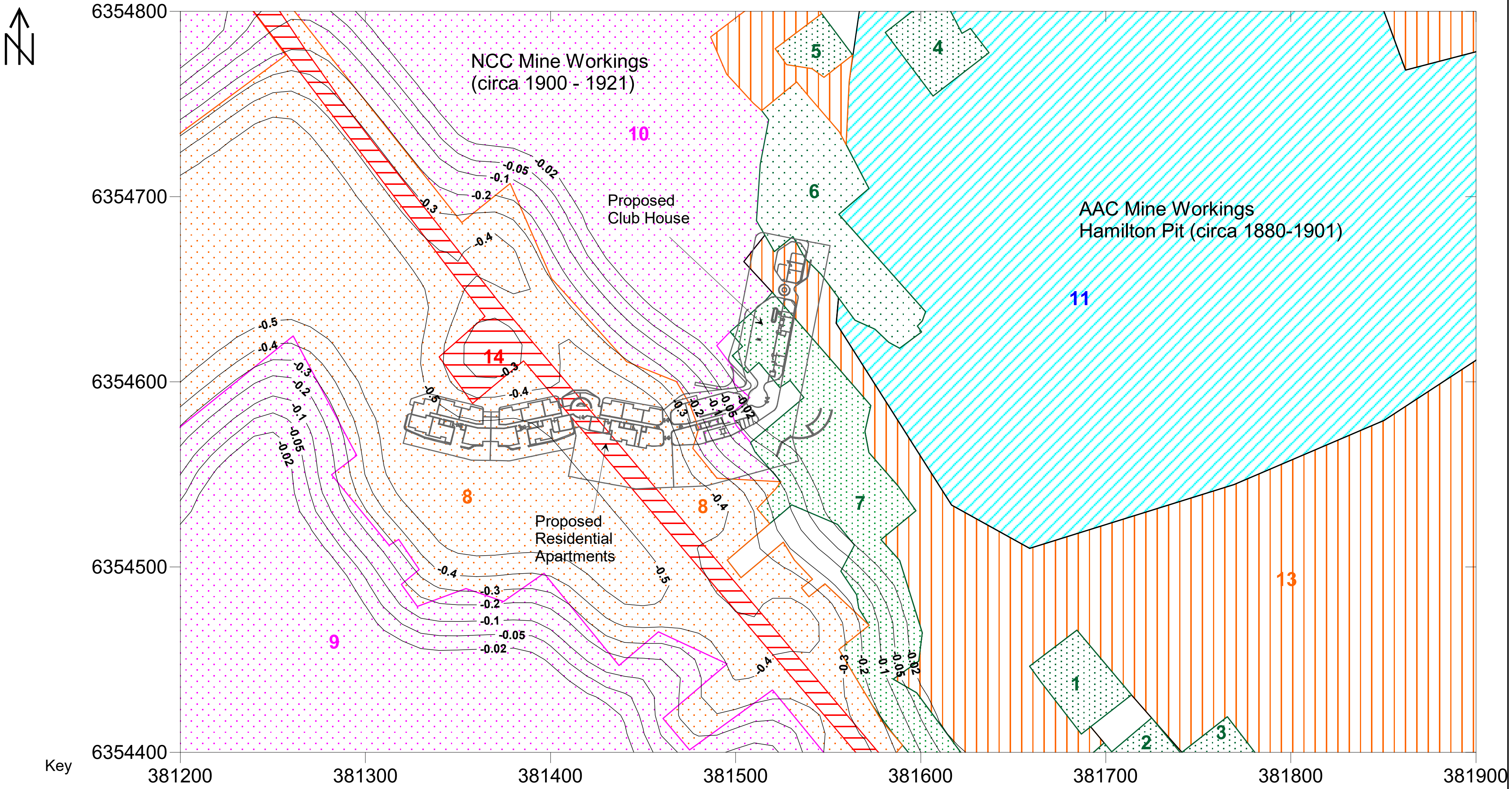
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Horizontal Strain Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 10e



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Horizontal Displacement Contours (mm)
- No Workings

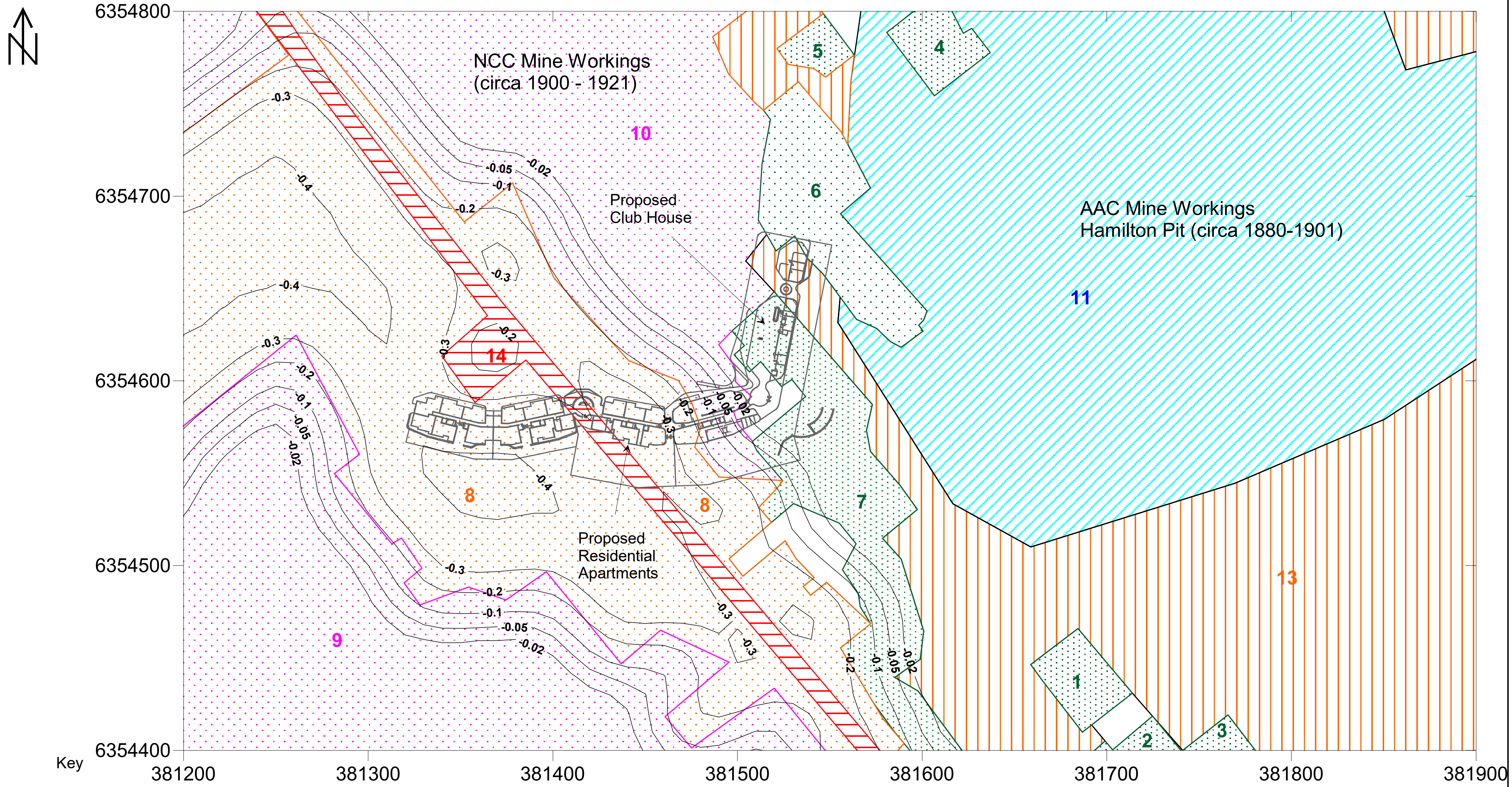
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Horizontal Displacement Contours (Case 2 - 1a) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	10f



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

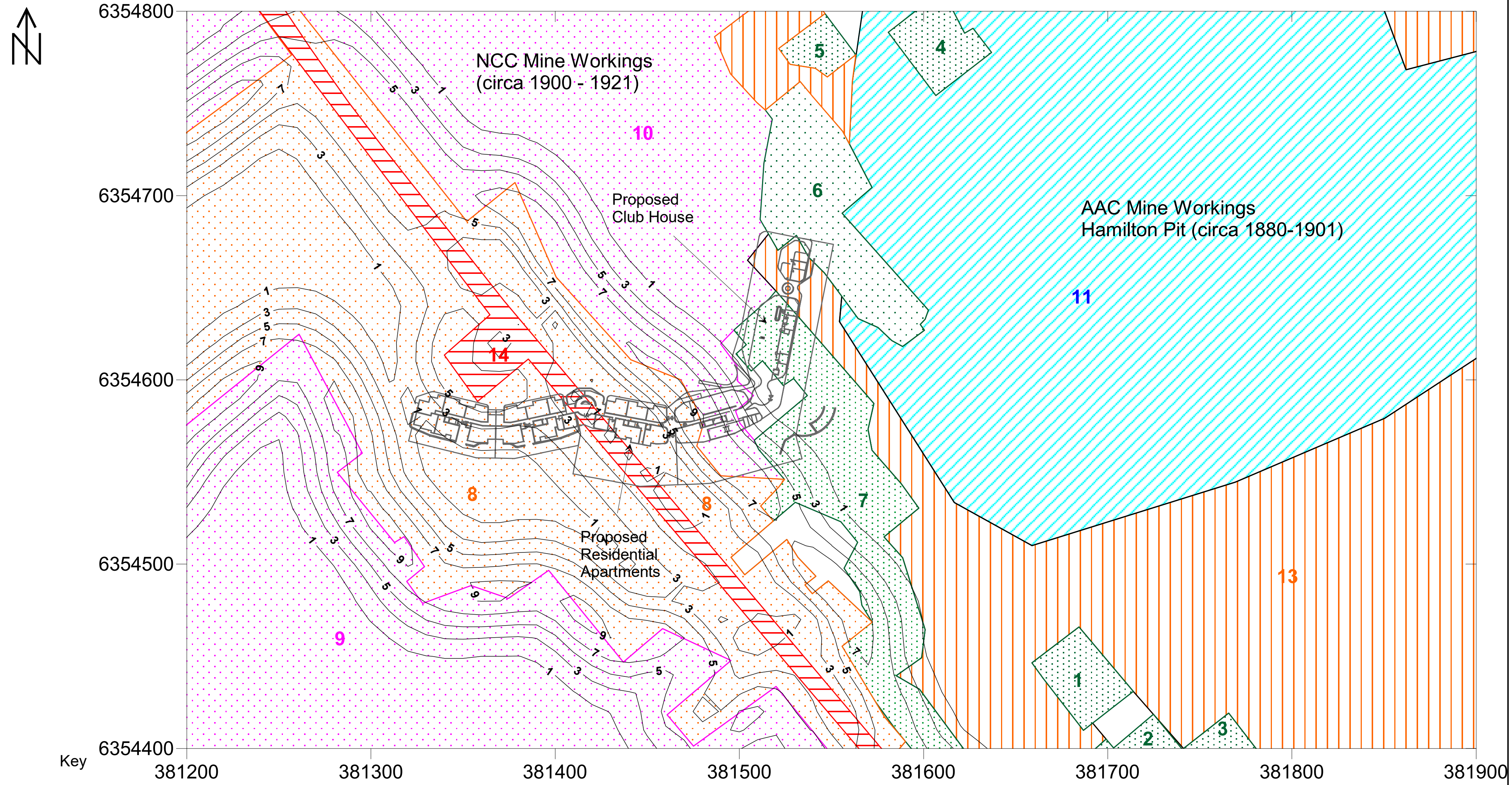
DgS					
Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1		
Drawn:	S.Ditton				
Date:	4.12.18	Title:	Predicted Net CWC Subsidence Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Dry Conditions)		
Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)	Figure No:	11a



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Subsidence Contours (m)
- No Workings

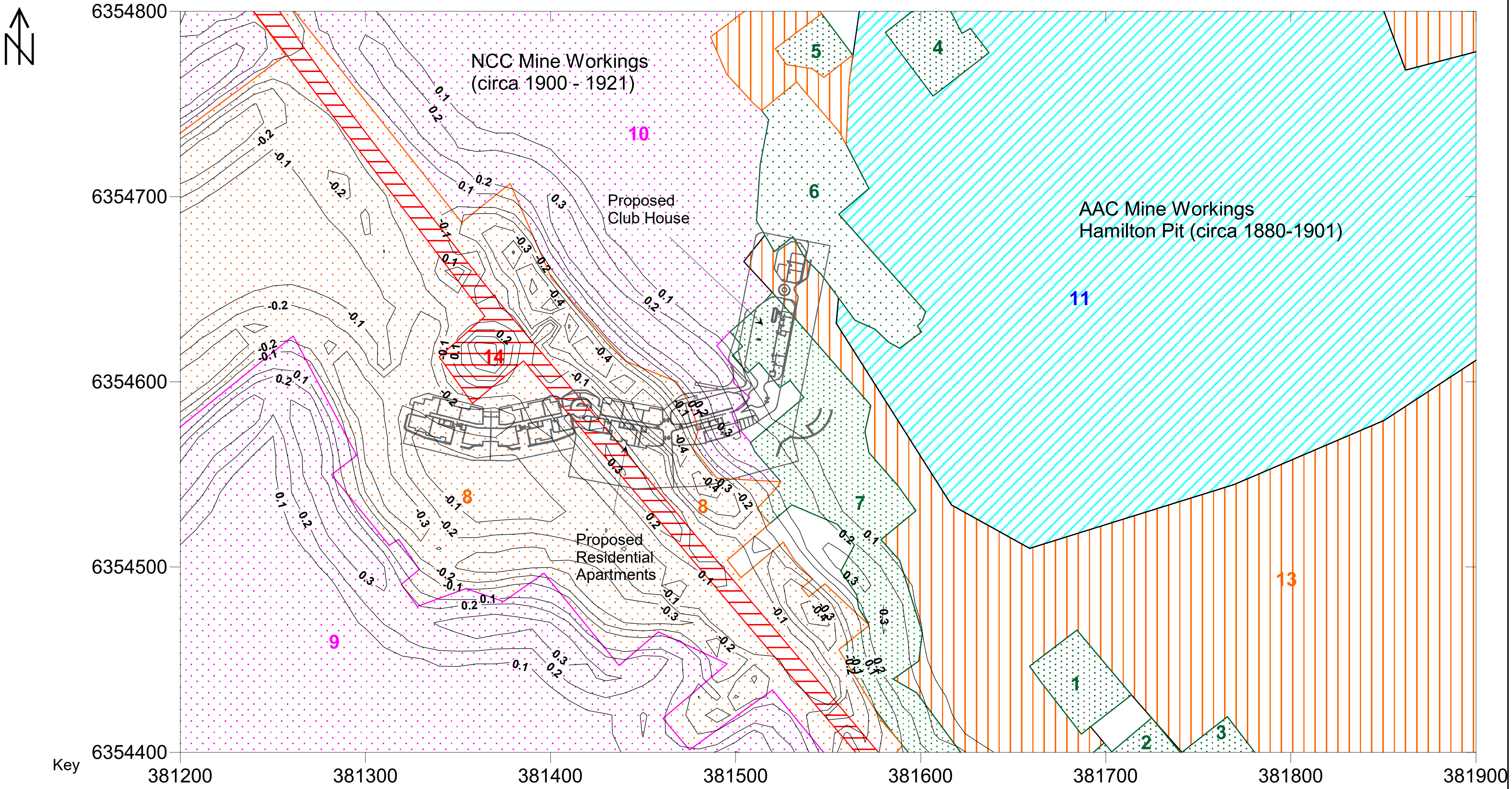
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Subsidence Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	11b



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Tilt Contours (mm/m)
- No Workings

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Tilt Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	11c

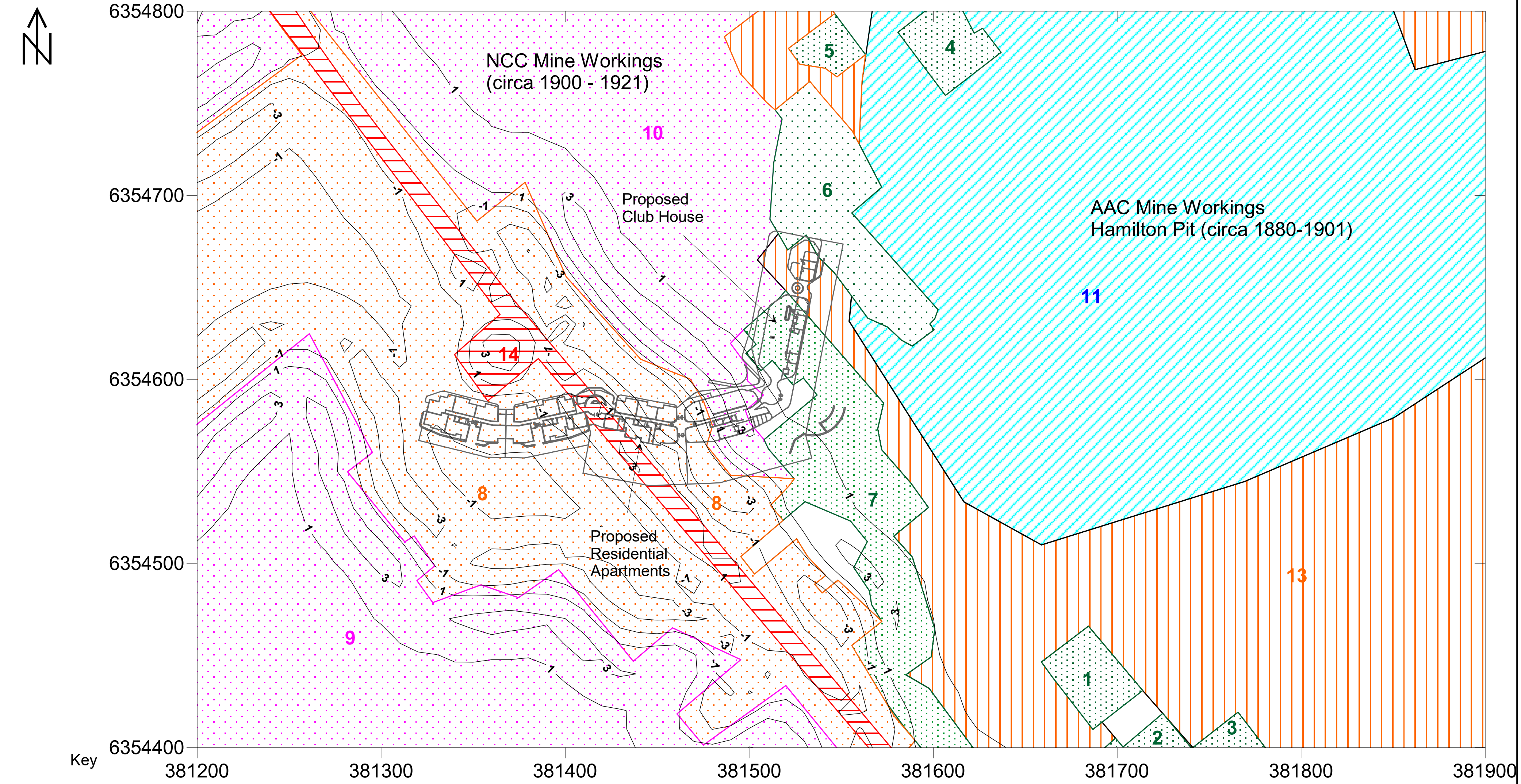


Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Curvature Contours (1/km)
- No Workings

DgS	Engineer:	S.Ditton
	Drawn:	S.Ditton
	Date:	4.12.18
	Ditton Geotechnical Services Pty Ltd	

Client:	Catalyst Project Management CAT-001/1
Title:	Predicted Net CWC Curvature Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
Scale:	1:3,000 (A4)
Figure No:	11d

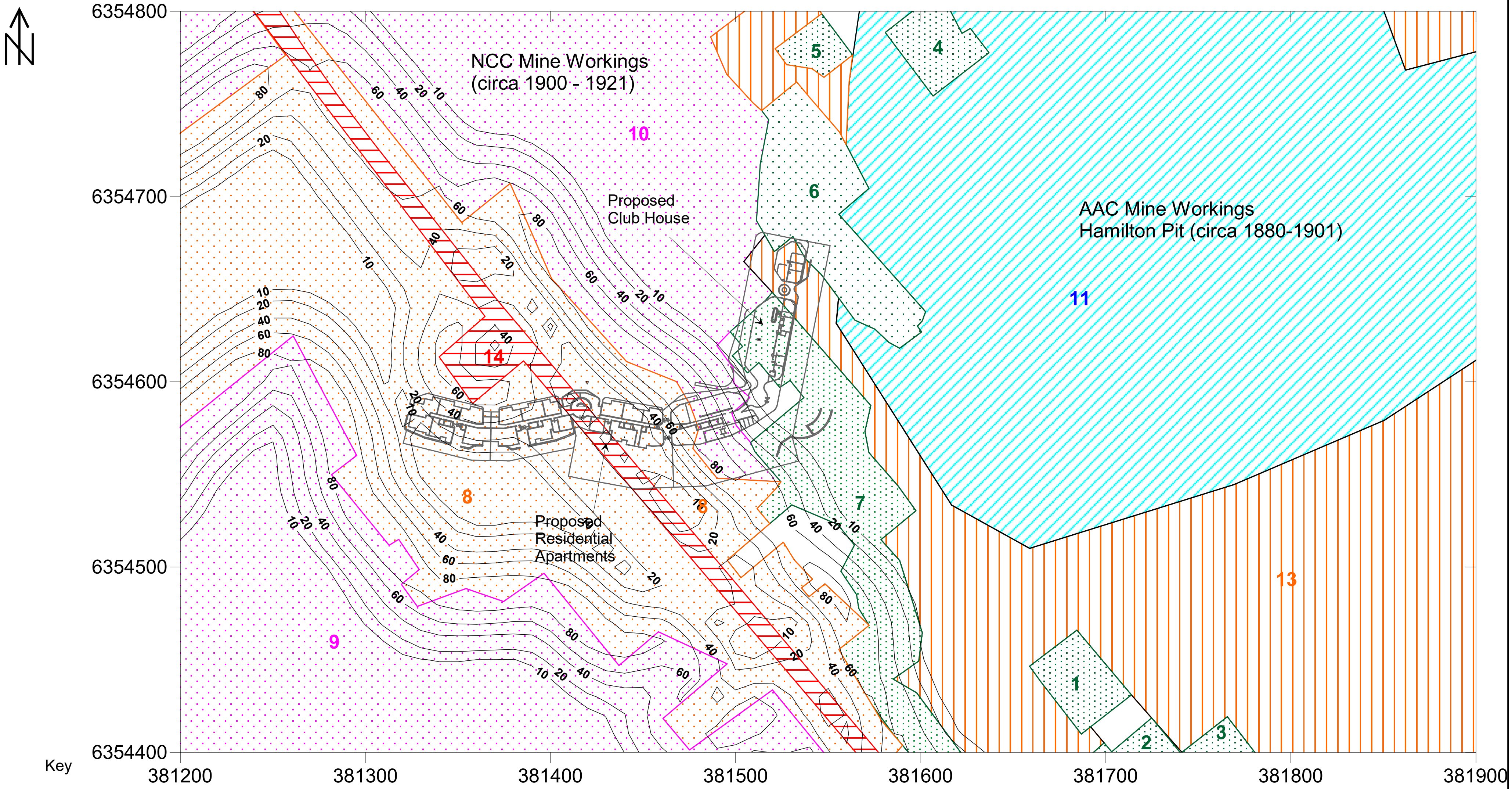


Key

	Bord & Pillar in NCC (First Workings)
	Bord & Pillar in AAC (First Workings)
	Pillar Extraction in NCC Mine (Second Workings)
	Pillar Extraction in AAC Mine (Second Workings)
	Historical Subsidence in AAC Mine (1889)
	Strain Contours (mm/m)
	No Workings

DgS

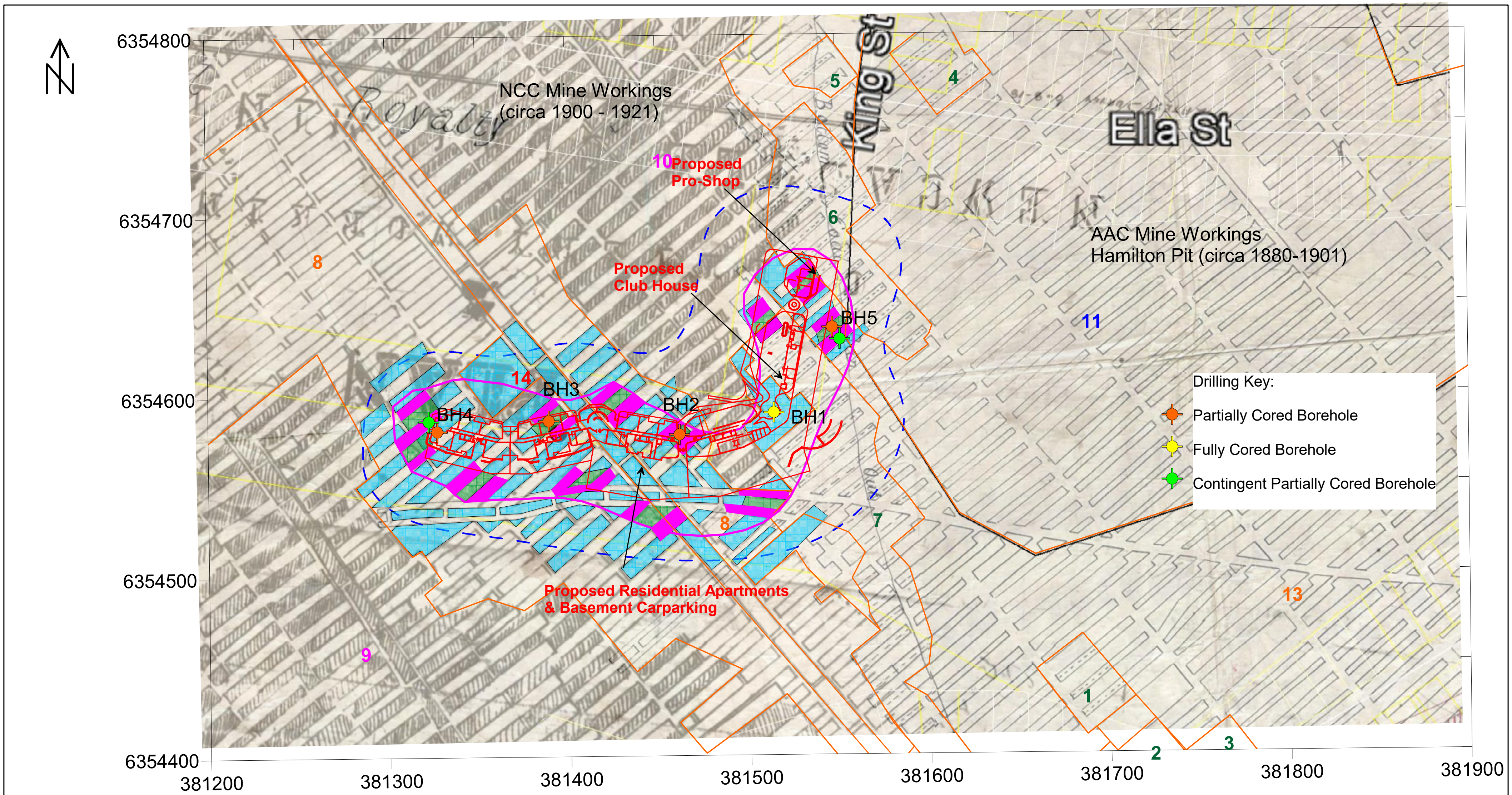
Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
Drawn:	S.Ditton		
Date:	4.12.18	Title:	Predicted Net CWC Horizontal Strain Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam Below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
		Figure No:	11e



Key

- Bord & Pillar in NCC (First Workings)
- Bord & Pillar in AAC (First Workings)
- Pillar Extraction in NCC Mine (Second Workings)
- Pillar Extraction in AAC Mine (Second Workings)
- Historical Subsidence in AAC Mine (1889)
- Horizontal Displacement Contours (mm)
- No Workings

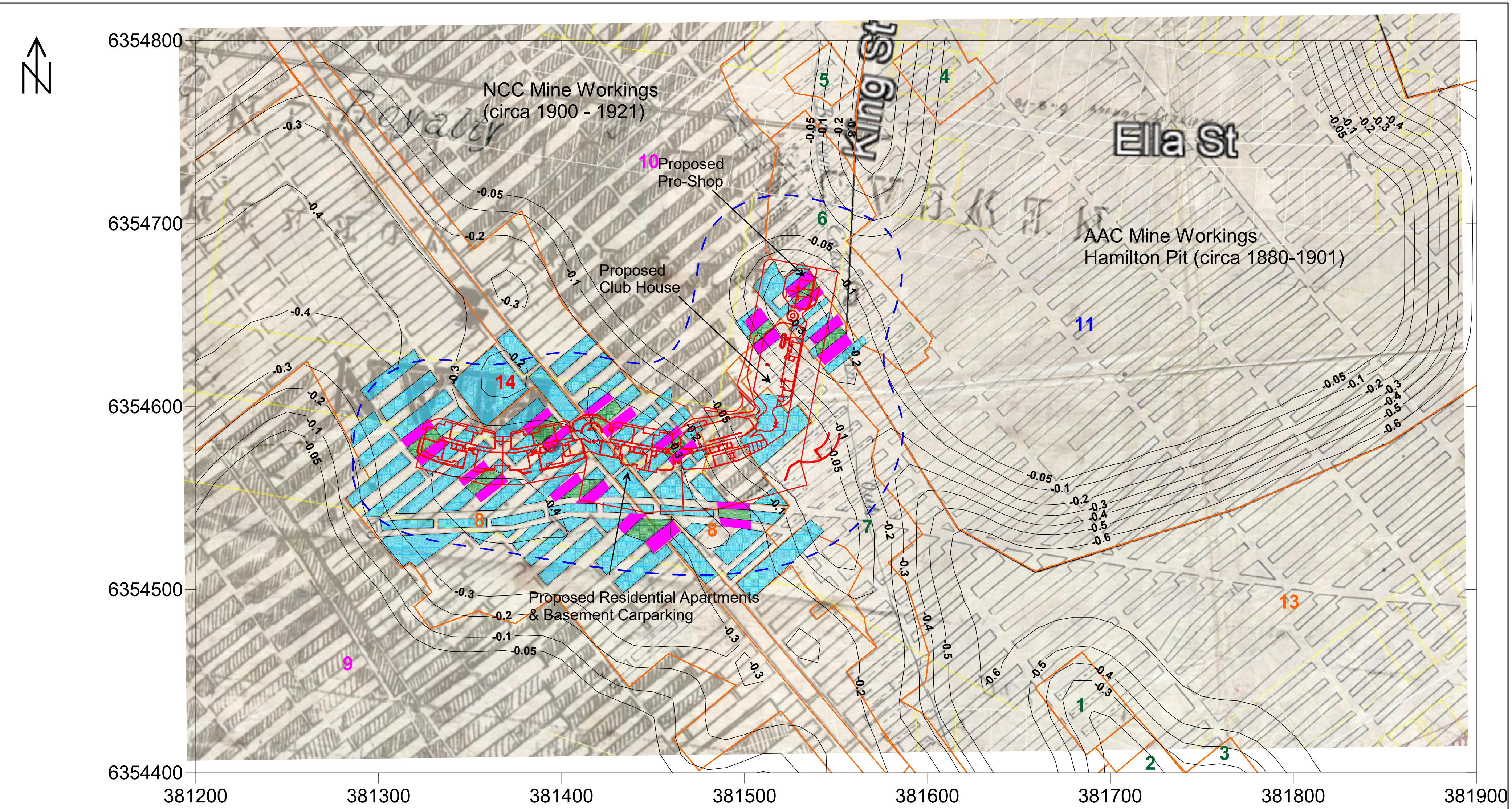
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Management CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Predicted Net CWC Horizontal Displacement Contours (Case 2 - 1b) over Abandoned Mine Workings (AAC & NCC) in Borehole Seam below Proposed Merewether Golf Club Re-Development (Flooded Conditions)
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) Figure No: 11f



Key:

- Inferred Standing Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Proposed Development Footprint
- 11 Mine Workings Zone No. (see text)

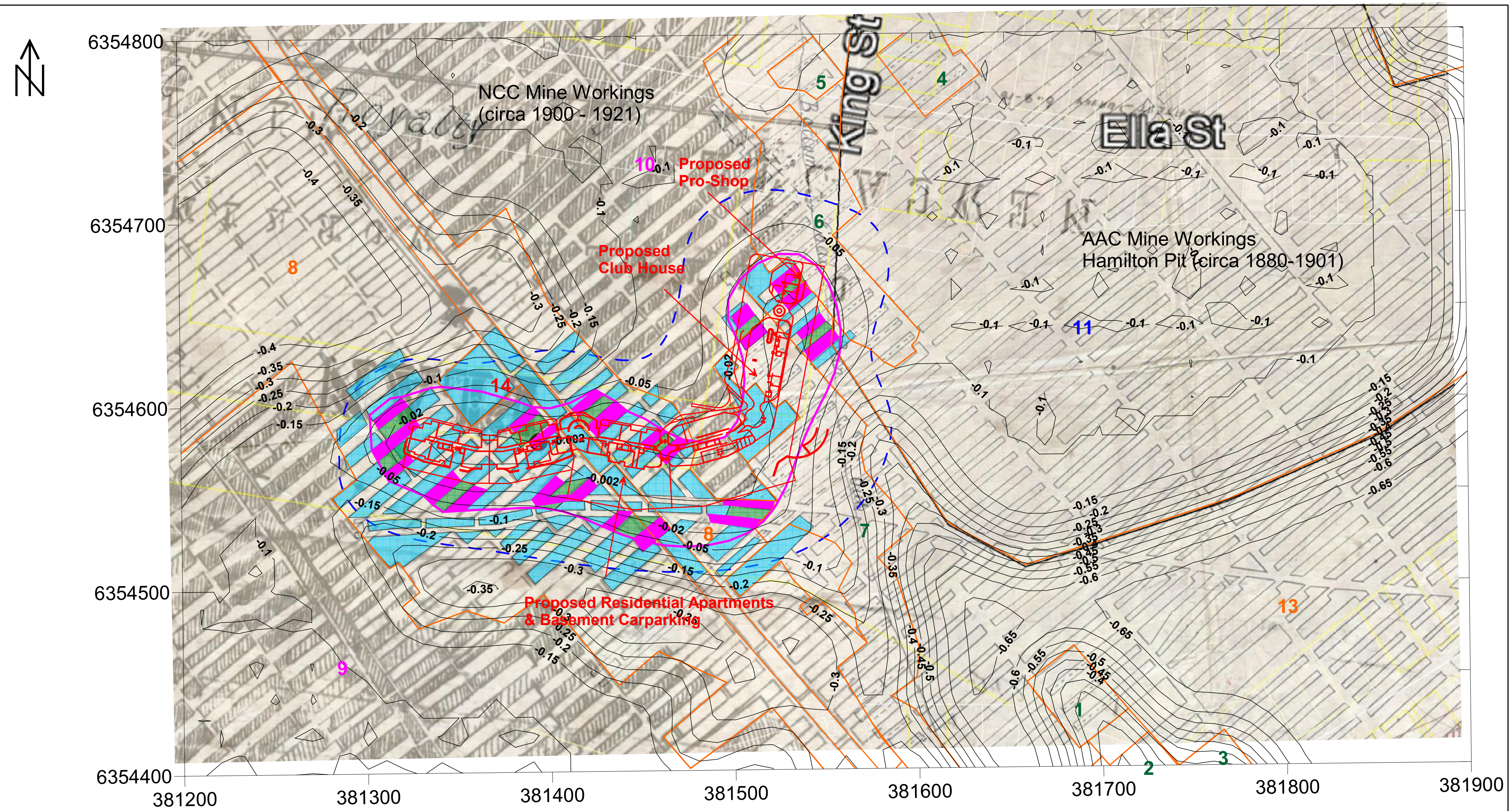
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	8.12.18	Title:	Proposed Drilling Investigation Plan for Mine Workings in Borehole Seam Below Proposed Merewether Golf Club Re-Development
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	12



Key:

- Inferred Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Pre-Grouting Subsidence Contours (m)
- Proposed Development Footprint
- **11** Mine Workings Zone No. (see text)

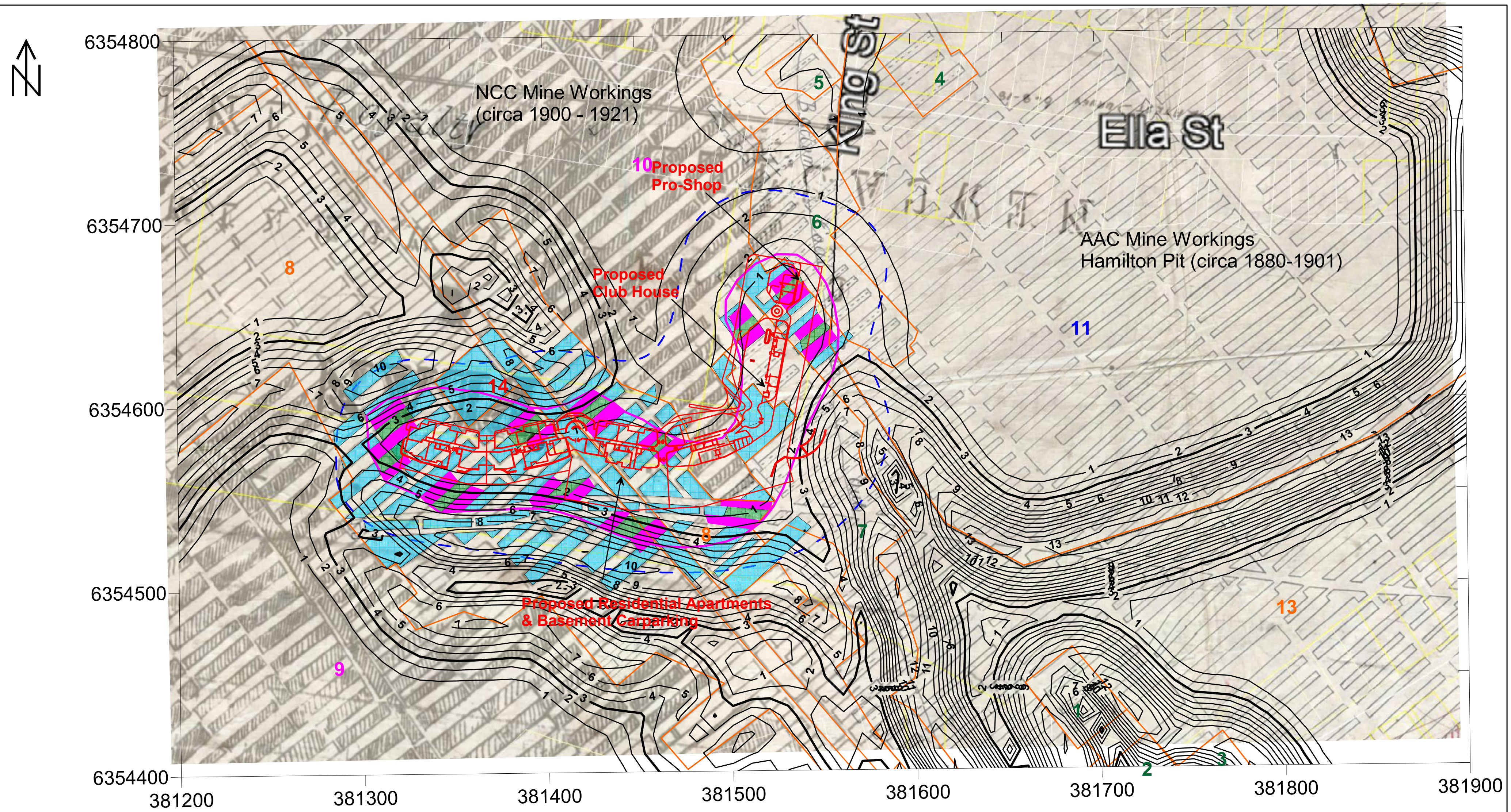
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	4.12.18	Title:	Preliminary Grouting Arrangement for Stabilising the Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still Standing and Crush in Future (i.e. Case 2 (Flooded) - Case 1a (dry))
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 13



Key:

- Inferred Standing Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Subsidence Contours (m)
- Proposed Development Footprint
- 11 Mine Workings Zone No. (see text)

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton	Title:	Post-Grouting Subsidence Contours above Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still Standing and Crush in Future (i.e. Case 2 (Flooded))
	Date:	8.12.18		
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)
			Figure No:	14a



Key:

Inferred Standing Pillar within Angle of Draw from the Proposed Development

Grout Confined Pillar

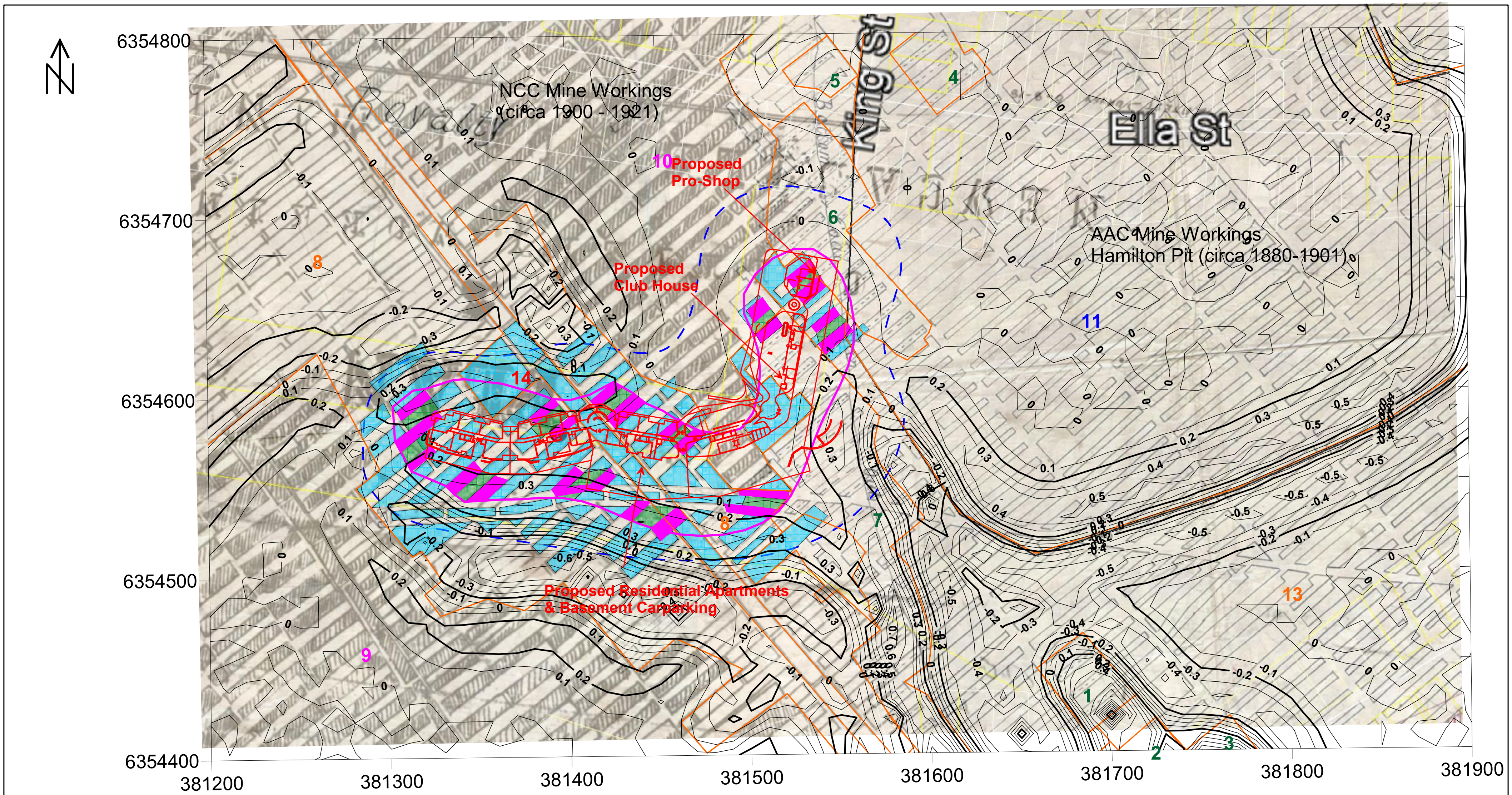
5 MPa Grout

Tilt Contours (mm/m)

Proposed Development Footprint

11 Mine Workings Zone No. (see text)

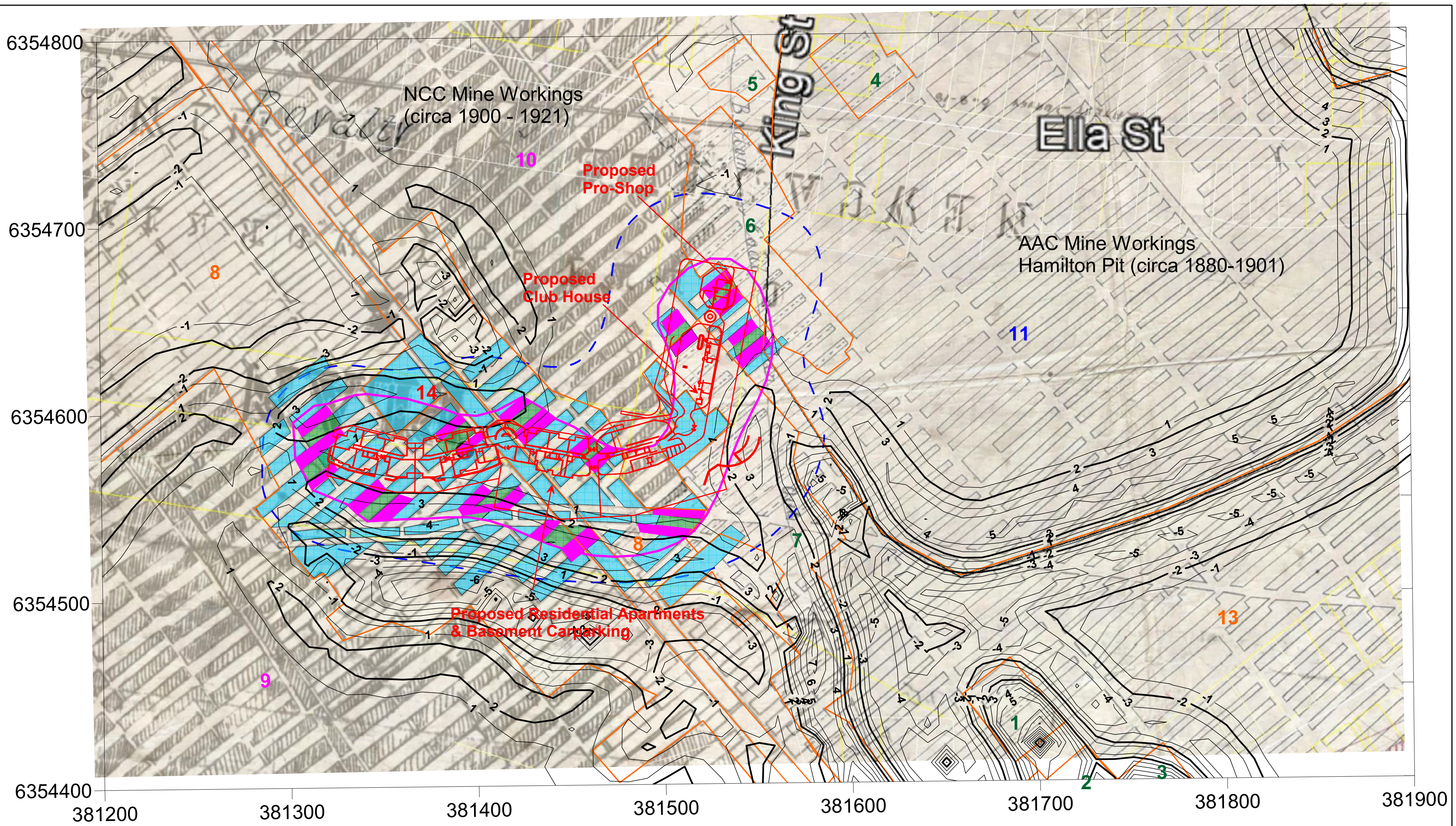
DgS			Client:	Catalyst Project Consulting CAT-001/1	
	Engineer:	S.Ditton			
	Drawn:	S.Ditton			
	Date:	8.12.18	Title:	Post-Grouting Tilt Contours above Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still Standing and Crush in Future (i.e. Case 2 (Flooded))	
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4)	Figure No: 14b



Key:

- Inferred Standing Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Curvature Contours (km-1)
- Proposed Development Footprint
- **11** Mine Workings Zone No. (see text)

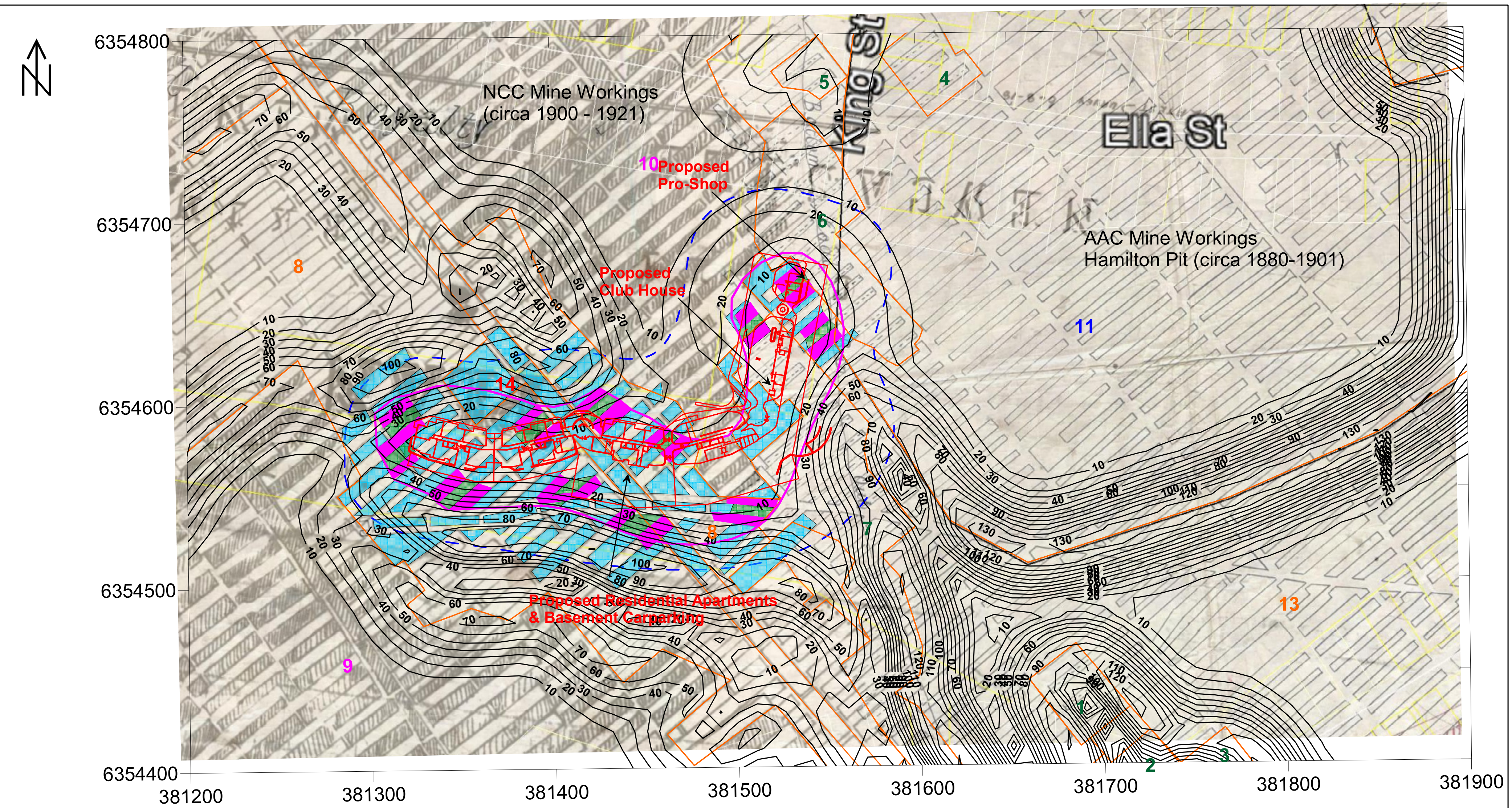
DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	8.12.18	Title:	Post-Grouting Curvature Contours above Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still Standing and Crush in Future (i.e. Case 2 (Flooded))
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 14c



Key:

- Inferred Standing Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Horizontal Strain Contours (mm/m)
- Proposed Development Footprint
- **11** Mine Workings Zone No. (see text)

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	8.12.18	Title:	Post-Grouting Strain Contours above Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still Standing and Crush in Future (i.e. Case 2 (Flooded))
	Ditton Geotechnical Services Pty Ltd		Scale:	1:3,000 (A4) — Figure No: 14d



Key:

- Inferred Standing Pillar within Angle of Draw from the Proposed Development
- Grout Confined Pillar
- 5 MPa Grout
- Horizontal Displacement Contours (mm)
- Proposed Development Footprint
- **11** Mine Workings Zone No. (see text)

DgS	Engineer:	S.Ditton	Client:	Catalyst Project Consulting CAT-001/1
	Drawn:	S.Ditton		
	Date:	8.12.18	Title:	Post-Grouting Horizontal Displacement Contours above Abandoned Mine Workings (AAC & NCC Mines) assuming First Workings Pillars are still standing and crush in future (i.e. Case 2 (Flooded))
	Ditton Geotechnical Services Pty Ltd			
			Scale:	1:3,000 (A4) — Figure No: 14e