Wallarah 2
COAL PROJECT

Wallarah 2 Coal Project

Environmental Impact Statement

April 2013

Appendix H

Subsidence Predictions and Impact Assessments

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REPORT: SUBSIDENCE PREDICTIONS AND IMPACT ASSESSMENTS

msec
mine subsidence
ENGINEERING CONSULTANTS

Wallarah 2
COAL PROJECT

WYONG AREAS COAL JOINT VENTURE:

Wallarah 2 Coal Project

Assessment of Mine Subsidence Impacts on the Natural Features and Surface Infrastructure for the Wallarah 2 Coal Project

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Report produced to:- Support the Environmental Impact Statement Application being submitted by the Wyong Areas Coal Joint Venture (WACJV) to the Department of Planning and Infrastructure.

Background reports available at *www.minesubsidence.com*:-

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

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Information relating to infrastructure has been provided by the infrastructure owners, including Telstra, TransGrid and the Wyong Shire Council. The Mine Subsidence Board has also provided valuable assistance with the provision of information relating to impacts on surface features and approved design parameters.

EXECUTIVE SUMMARY

Wyong Areas Coal Joint Venture (WACJV) seeks a Development Consent under Division 4.1 in Part 4 of the *Environmental Planning and Assessment Act* 1979 (EP&A Act) from the Department of Planning and Infrastructure (DP&I) for the development of the proposed Wallarah 2 Coal Project (*the Project*), including the development of an underground mine to extract coal using longwall mining techniques. *The Project* is located 4.7 kilometres (km) north-west of central Wyong and approximately 45 km south-west of Newcastle.

A detailed description of *the Project* is provided in the Wallarah 2 Coal Project Environmental Impact Statement (*Wallarah2 EIS*) prepared by Hansen Bailey Environmental Consultants (Hansen Bailey). This Mine Subsidence Impact Assessment Report has been prepared in accordance with the Director-General's Environmental Assessment Requirements (DGRs) for *the Project* issued on the 12th January 2012 in accordance with the requirements in Part 2 in Schedule 2 to the *Environmental Planning & Assessment Regulation* 2000 (EP&A Regs).

The extents of the proposed mine plan (*Extraction Area*) and the extents of the areas that are predicted to experience mine subsidence ground movements (*Study Area*) are shown in Drawing No. MSEC515-01, which together with all other drawings is included in Appendix F of this report. *The Project* involves the proposed extraction forty-six (46) longwalls to the north-east of Wyong within the coalesced Wallarah and Great Northern Seams of the Newcastle Coal Measures. The majority of the mineable coal resource lies beneath the Wyong State Forest and surrounding ranges, including the Jilliby State Conservation Area (SCA), whilst a proportion, to be extracted first, lies beneath the Dooralong Valley, the Hue Hue area, and to a much lesser extent lies beneath the Yarramalong Valley. Information regarding the key features of *the Project* is included in the *Wallarah2 EIS*.

Mine Subsidence Engineering Consultants (MSEC) has been involved in the subsidence prediction research and impact assessment studies at various stages throughout the development of the mine plan for *the Project*, since January 1999, and, on completion of the subsidence prediction phase of *the Project*, MSEC was commissioned by the WACJV, in September 2009, to:-

- identify the natural features and built items of surface infrastructure within the *Study Area* that could be affected by mine subsidence ground movements,
- calibrate the Incremental Profile Method, based on the numerical modelling advice from Strata Control Technology Pty Ltd (SCT), and undertake robust sensitivity analyses of these predictions,
- provide subsidence predictions for each natural feature and item of surface infrastructure using the calibrated Incremental Profile Method,
- assess impacts, with other specialist consultants, for each of the identified natural features and items of surface infrastructure within the *Study Area*,
- provide a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset the subsidence impacts of *the Project*, and to
- prepare a detailed report on the mine subsidence impact assessments at *the Project*.

This *Subsidence Impact Report* (MSEC515, 2013) has been prepared as a result of this mine subsidence impact assessment study and it is to be included as an appendix in the *Wallarah2 EIS*.

A separate *Subsidence Prediction Report* (WACJV, 2012), which is also appended to the *Wallarah2 EIS*, has been prepared by the WACJV to detail the combined mine subsidence research, modelling and prediction work that was undertaken by the WACJV, SCT and MSEC. The *Subsidence Prediction Report* details the reasons why a hybrid subsidence prediction model was developed for *the Project* and it discusses the mine planning options and mitigation measures that were considered so that the predicted mine subsidence ground movements complied with required ground tilt levels and the requirements to reduce impacts. Work on this *Subsidence Impact Report* commenced after the mine subsidence research and prediction modelling study was completed. To fully appreciate the detailed impact assessments in this *Subsidence Impact Report*, it would be best to read and review the *Subsidence Prediction Report* first.

After the *Subsidence Prediction Report* (WACJV) and the *Subsidence Impact Report* (MSEC) were completed, Hansen Bailey, on behalf of, the WACJV, engaged Prof. Bruce Hebblewhite, Head of School of Mining, University of NSW, to provide an independent peer review of the mine subsidence predictions and impact assessments that were carried out for *the Project*. Bruce Hebblewhite's report, which is attached to this report as Appendix G, concludes; "*I am of the opinion that "best-practice" subsidence prediction techniques have been adopted using innovative hybrid empirical and numerical techniques. These techniques have been rigorously evaluated, and validated as far as possible against available databases. However it will be absolutely essential that some Wallarah site-based validation is carried out once data is collected from subsidence associated with the initial longwall panels to provide an even better level of confidence in the prediction techniques and findings*".

The depths of cover above the proposed longwalls range from 345 metres, over longwalls in the north-eastern area of *the Project*, to 690 metres, below some steep-sided hills separating the Yarramalong and Dooralong Valleys. Geological information is provided in the Wallarah2 Coal Project Geology Report (WACJV 2013) (*Geology Report*). The available seam thickness of the coalesced coal seams within the *Extraction Area* ranges from 4.2 metres to 6.8 metres. As discussed in the *Subsidence Prediction Report,* the Warnervale Conglomerate and the Awaba Tuff both lie under the coal seam and both units are banded with laminates that have extremely variable properties, ranging from very soft and weak to hard and competent.

The proposed panel widths, pillar widths and the proposed seam working section to be extracted vary across *the Project*. Wider longwall panels and a thicker working section could have been extracted, however, to limit ground movements in the *Hue Hue Mine Subsidence District,* which is in the north-east of the *Study Area*, it is proposed to both narrow the longwalls to panel void widths between 125 metres and 175 metres and to limit the extracted seam thickness to 3.5 metres. Also, to limit the ground movements in the Dooralong Valley (Jilliby Jilliby Creek) and in the Yarramalong Valley (Wyong River, which itself is not proposed to be directly mined beneath), it is proposed to both narrow the longwalls to the panel void widths between 175 metres to 205 metres and to limit the extracted seam thickness in these longwalls to 4.0 metres. Elsewhere the proposed extracted seam thickness is 4.5 metres and the longwall panel void widths increase from 205 metres up to 255 metres. The chain pillar widths range from 45 metres to 75 metres across the *Extraction Area*.

The *initial* subsidence predictions for *the Project* were prepared by MSEC in 1999 using a standard version of the MSEC IPM model without any calibration. The IPM model is an empirical subsidence prediction method that has the capacity to provide detailed predictions of subsidence, tilt, curvature and strain at any location over a series of mined panels with varying panel and pillar widths, depths of cover and extracted seam thicknesses with good accuracy, if, the IPM model has been calibrated for the local geological site conditions. However, because of the potential soft floor conditions and the absence of subsidence monitoring data at sites with similar overburden geology, thick coal seams and soft floor conditions, the WACJV Project design team decided, in 2003, to engage the assistance of Strata Control Technology (SCT) to use their state of the art numerical modelling techniques to assist in the ongoing design and modelling of the mine layout.

The SCT numerical model was adjusted and calibrated to simulate both the caving of the overburden over the longwall panels and the possible behaviour of the relatively tall chain pillars that, in places, were founded on a soft floor of the Awaba Tuff, using the available monitored data from various sites that had, in part, similar geological conditions. The claystone associated with the Awaba Tuff section was modelled as bedded, tuffaceous sandstone with weak clay rich bedding planes, as noted in the large diameter coring program. These soft and weak sections of the Awaba Tuff were considered responsible for various unexpected subsidence instabilities that affected lake foreshores in the southern Newcastle area in the mid-1980s and early-1990s. As detailed in the *Subsidence Prediction Report,* a design approach was adopted by WACJV to accommodate the potential soft floor conditions from the Awaba Tuff whereby the chain pillars were designed to yield when isolated in the goaf so as to minimise the risk and impacts of any long term pillar failure. With this approach the pillars are designed to fail and then become confined by goaf material so that any subsequent strength losses due to long-term claystone behaviour would occur as a variation in the residual pillar strength rather than large-scale intact pillar strength losses. The resultant change in subsidence would be largely controlled by the goaf and would be expected to be significantly less than impacts from long-term failure of intact pillars.

Having adjusted the numerical model to suite the specific geological conditions at *the Project*, SCT then modelled three prediction cases over the *Extraction Area*, one in the Hue Hue Area; one in the valley floor areas and recently a further modelling case was undertaken by SCT for a forest case using the wider panel widths and deep cover in the hilly regions. Each site has differing depths of cover, extracted seam thickness, geology and mined longwall panel and pillar widths.

The MSEC IPM model was then calibrated against the results of the SCT numerical model for these three sites for both the magnitude of subsidence and the shapes of the incremental subsidence profiles expected at *the Project*. The calibrated IPM model was then used to predict the conventional subsidence, tilt and strain contours across *the Project* for all the proposed longwalls, based on the variations in the proposed extracted seam thickness, depths of cover and mining geometry. After applying this hybrid subsidence prediction approach, the magnitudes of the predicted mine subsidence movements increased significantly compared to subsidence predictions that were predicted using the standard Newcastle Coalfield mine subsidence empirical formulae that do not account for the softening effects of the Awaba Tuff, high depths of cover, lack of massive strata and the thick extracted seam thickness.

The range of predicted subsidence ground movements varies across the *Study Area* with maximum predicted total conventional subsidence of 2,600 mm occurring in the western forested hill zones where seam extraction height and panel widths are greater than those proposed in the floodplain or the Hue Hue areas. Similarly, the maximum predicted total conventional tilt of 15 mm/m, the maximum predicted total conventional hogging curvature of 0.28 km^{-1} and the maximum predicted total conventional sagging curvature of 0.37 km^{-1} occur in parts of the western forested areas.

The WACJV team has recognised that the conservative (cautious) modelling undertaken for *the Project* will have to be continually reviewed, adjusted, updated and revised as the model is validated with observation data that will be collected whilst the initial longwalls are extracted as well as throughout all *the Project* operations. There will always be a level of uncertainty associated with any predictive modelling and the adaptive management approach has been recognised as an effective tool that can be used to refine, mitigate and manage the long term impacts of mining to ensure the required subsidence parameters and acceptable impact consequences are met across the entire *Extraction Area*.

Numerous variations on the mine plan for *the Project* were considered by the WACJV team throughout the planning process and further variations can be applied if monitoring indicates it is required. For example, narrow longwall panel widths and lower extraction heights have been proposed in the *Hue Hue Mine Subsidence District* in order to comply with the Mine Subsidence Board requirement that final tilts at houses in the *Hue Hue Mine Subsidence District* did not exceed 4 mm/m. The mine plan was also amended under the valley areas to reduce possible impacts on surface water flows and alluvial contributions to water flow and to reduce flooding impacts. Further narrowing may be required, when survey data over the initial longwalls is available, to minimise potential ponding along the Jilliby Jilliby Creek. The monitoring and validation process is expected to provide further confidence and refinement in the subsidence predictions and to ensure the required subsidence effects, impacts and consequences are met across the entire *Extraction Area*.

In January 2012, *the Project* was given the requirements of the Director General of the Department of Planning & Infrastructure (DP&I) for the EIS for *the Project*. The Department advised that the EIS needs to comply with the Director-General's requirements (DGRs), and provide an accurate and technically robust assessment of the potential subsidence impacts of *the Project*.

The hybrid prediction methodology is believed to be leading practice for conventional subsidence for the geological conditions at *the Project*. Various reviews have noted that there is a high degree of conservatism built into the prediction of conventional subsidence effects and have recognised that the resulting predictions likely to be more accurate than those produced by alternative techniques alone.

Chapter 1 of this report provides a general introduction to the study and also includes a discussion on the proposed mining layouts and geological details of the proposed *Extraction Area*.

Chapter 2 provides an overview of key natural features and built infrastructure within the *Study Area*. The predicted mine subsidence ground movements will potentially affect a range of natural features and built infrastructure that has been identified within the *Study Area*.

Chapter 3 provides a brief overview of longwall mining and an overview of the development of the specific methods used to predict the mine subsidence parameters for *the Project* to suit the specific geology and seam thicknesses to be extracted by the proposed longwalls.

Chapter 4 provides an overall summary of the maximum predicted subsidence parameters resulting from the extraction of the proposed longwalls.

Chapter 5 provides specific subsidence predictions and impact assessments for all identified natural features and built infrastructure within the *Study Area*.

The impact assessments provided in this report indicate that the levels of impact on the natural features and items of surface infrastructure can be managed by the preparation and implementation of the appropriate management strategies. It is recommended that the management of subsidence over *the Project* be controlled by the preparation and implementation of specific extraction or management plans that should be developed with and approved by the owners of infrastructure and the relevant government agencies. It should be noted, however, that more detailed impact assessments of some natural features and items of surface infrastructure have also been undertaken by other consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

Mitigation measures and alternative mine layouts were considered by the WACJV throughout the development of the mine plan to mitigate or avoid the risk of serious consequences should impacts occur to some sensitive surface natural and built features. Further changes to the mine plan will be considered by the WACJV, the owners of surface properties and improvements and the relevant government bodies as part of the adaptive management approach that will be based on the results of the subsidence monitoring programme. The subsidence monitoring programme will generally include the recording of the condition and the value of surface natural and built features and the detailed monitoring of ground movements near these features. Further details of the management strategy are included in the Subsidence Prediction Report (WACJV, 2012).

The findings in this report should be read in conjunction with the *Wallarah2 EIS* and all other technical appendices to the *Wallarah2 EIS*.

The overall findings of the mine subsidence impact assessments, that have been undertaken by MSEC based on the conservative subsidence predictions that have resulted from the hybrid subsidence prediction approach, are that the levels of likely impact at all identified natural features and built infrastructure items within the *Study Area* are manageable, and these impacts can be controlled and managed by the preparation and implementation of the extraction or management plans.

CONTENTS

LIST OF TABLES, FIGURES AND DRAWINGS

Tables

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Figures are prefixed by the number of the chapter or the letter of the appendix in which they are presented.

Drawings

Drawings referred to in this report are included in Appendix F at the end of this report.

1.0 INTRODUCTION

1.1. Introduction on *the Project*

Wyong Areas Coal Joint Venture (WACJV), seeks a Development Consent from the Department of Planning and Infrastructure (DP&I) under Division 4.1 in Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) for the development of the Wallarah 2 Coal Project (*the Project*), including the development of an underground mine to extract coal using longwall mining techniques.

The Project was initiated following a 1995 tender to the then Department of Mineral Resources for a new coal development north-west of Wyong. Exploration Licence 4911 was granted to the WACJV with conditions that subsidence would not be permitted east of the F3 Freeway nor under the Warnervale Airport. These conditions, including an expectation that coal mined from the WACJV areas would not be transported on public roads, appeared to be a tightening of those arising out of the Clough–Smith Report (1988).

A detailed description of *the Project* is provided in the Wallarah 2 Coal Project Environmental Impact Statement (*Wallarah2 EIS*) prepared by Hansen Bailey Environmental Consultants (Hansen Bailey). The extents of the proposed mine plan (*Extraction Area*) and the extents of the predicted mine subsidence (*Study Area*) are shown in Drawing No. MSEC515-01, which together with all other drawings is included in Appendix F of this report. Information regarding the key features of *the Project* is included in the *Wallarah2 EIS.*

Forty-six (46) longwalls are planned to be extracted within the entire *Extraction Area*, which is located to the north-west of Wyong and to the west of the F3 Freeway. Geological information is provided in the Wallarah2 Coal Project Geology Report (WACJV 2013) (*Geology Report*). Over half of the mineable coal resource lies beneath the Wyong State Forest and surrounding ranges, whilst the remainder lies beneath the Dooralong Valley, the Hue Hue area, and to a much lesser extent, the Yarramalong Valley.

All of the *Study Area* is covered by declared Mine Subsidence Districts. The *Hue Hue Mine Subsidence District* was proclaimed in 1985 and the Wyong Mine Subsidence District was proclaimed in 1997. Parts of the initial seven longwalls of *the Project* are located under the *Hue Hue Mine Subsidence District*, which requires that mining induced ground movements be limited to maximum ground strains of 3 mm/m, and maximum ground tilts of 4 mm/m. The Wyong Mine Subsidence District, which extends over rest of the *Extraction Area* was proclaimed in recognition of the significant resource underlying the Wyong State Forest, the Dooralong Valley and the Yarramalong Valley and requires that structures are designed to withstand tilt and strain predictions that are generally set to be consistent with the extraction of longwall blocks up to 255 metres wide and working heights of up to 4.5 metres.

The longwalls are planned to be extracted with relatively narrow panel void widths varying from 125 metres to 255 metres and with chain pillar widths ranging from 45 metres to 75 metres. The depths of cover above the *Extraction Area* range from 345 metres, over the longwalls in the north-eastern area of *the Project*, to 690 metres, below some steep-sided hills separating the Yarramalong and Dooralong Valleys over the longwalls in the south-western area of *the Project*.

As detailed in the *Geology Report*, the available seam thicknesses for the coalesced Wallarah and Great Northern Seams within the proposed longwall panels range from 4.2 metres to 6.8 metres. Under this coal seam lies the Warnervale Conglomerate and the Awaba Tuff and both units are banded with laminates that have extremely variable properties, ranging from very soft and weak to hard and competent.

Although these two named units indicate completely different rock types, the WACJV geologists advise that within each of these two named strata units, there are varying laminates of shale, sandstone and tuff. That is, the Awaba Tuff is not comprised entirely of tuffaceous layers, as there are sandstone and conglomerate layers within the Awaba Tuff and, whilst the Warnervale Conglomerate includes a high proportion of conglomerate, there are tuffaceous layers within this Warnervale Conglomerate. These soft and weak sections of the Awaba Tuff were considered responsible for various unexpected subsidence instabilities that affected lake foreshores in the southern Newcastle area in the mid-1980s and early-1990s. The difficulty for *the Project* is that even small layers of tuff and, in particular montmorillonite clays, beneath the chain pillars can reduce the load bearing capacity of the roof-pillar-floor system and the WACJV team has allowed for the possible effects of these tuffaceous layers in its mine design.

1.2. Background on Mine Subsidence Prediction Studies

The *initial* mine subsidence predictions for *the Project* were requested by the WACJV team in 1999 and preliminary subsidence, tilt and strain predictions were prepared by Waddington Kay & Associates, now Mine Subsidence Engineering Consultants, (MSEC), using a standard version of the Incremental Profile Method (IPM) without calibrations to suite the local site geological conditions.

The IPM model is an empirical subsidence prediction method that was developed by MSEC in 1994 based on the regularity of the shapes of observed incremental subsidence profiles that were derived by subtracting the observed subsidence at pegs before the extraction of a longwall panel from the observed subsidence after that panel had been mined. The incremental subsidence profiles that were observed across a longwall panel show the change in subsidence profiles that were caused by the mining of one longwall panel and provide useful information on the sag subsidence over the centre of a panel and the settlement over the chain pillars.

The IPM model has been continually refined to suit a wide variety of mine layouts with differing geological conditions and it has the capacity to provide detailed site specific "empirical" predictions of subsidence, tilt, curvature and strain over a series of mined panels with differing panel and pillar widths, depths of cover and extracted seam thicknesses with good accuracy where the geology and mining conditions are within the range of available empirical data that was used to develop the method and if the IPM model has been calibrated for the local geological site conditions.

MSEC provided the *initial* subsidence predictions in 1999 using a standard version (i.e. uncalibrated) of the IPM model. Some of these predictions were based on the Newcastle Coalfield mine subsidence empirical prediction curves, whilst, the other *initial* predictions were provided based on the Southern Coalfield mine subsidence empirical prediction curves, because, it was recognised that no mine subsidence survey data was available in the Newcastle Coalfield at the depths of cover present over the *Extraction Area* (up to 690 metres) with similar seam thicknesses being extracted (up to 4.5 metres) and with similar soft seam floor conditions (Awaba Tuff).

Subsidence monitoring data is available at some locations where the depth of cover was 600 metres. Subsidence monitoring data is available at other locations where the seam thickness extracted was greater than 4.5 metres and monitoring data is available at various locations where soft floor conditions occurred. But there is no one site where subsidence monitoring data was available where all these geological conditions applied.

Because of the potential soft floor conditions at *the Project* and the absence of subsidence monitoring data at sites with similar overburden geology, thick coal seams and soft floor conditions, the WACJV Project design team decided, in February 2003, to engage the assistance of Strata Control Technology (SCT) to use their state of the art numerical modelling techniques to assist in the ongoing design and modelling of the mine layout.

WACJV and SCT reviewed the geological conditions across the *Extraction Area* and the *initial* empirical subsidence predictions and concluded that the observed subsidence profiles over the *Study Area* are most likely to be greater in magnitude than typical Newcastle and the Southern Coalfield subsidence profiles and would be similar in profile shape to the Southern Coalfield subsidence profiles, because;

- deeper depths of cover occur over the *Extraction Area* compared to other Newcastle Coalfield mines,
- there is an absence of massive strata units compared to other Newcastle Coalfield mines,
- a thicker coal seam is to be extracted compared to the Southern Coalfields, and
- a relatively weak roof-pillar-floor system exists compared to pillars in the Southern Coalfield because of the taller pillars, deep cover and the soft floor conditions associated with the underlying Awaba Tuff.

The SCT numerical model was then adjusted and calibrated to simulate both the caving of the overburden over the longwall panels and the possible behaviour of the relatively tall chain pillars that, in places, were founded on a soft floor of the Awaba Tuff, using the available monitored data from various sites that had, in part, similar geological conditions. These soft and weak sections of the Awaba Tuff were considered responsible for various unexpected subsidence instabilities that affected lake foreshores in the southern Newcastle area in the mid-1980s and early-1990s. The claystone associated with the Awaba Tuff section was modelled as bedded, tuffaceous sandstone with weak clay rich bedding planes, as noted in the large diameter coring program.

Having adjusted the numerical model to suite the specific geological conditions, this calibrated SCT numerical model was then applied to three prediction cases, or prediction sites, over the *Extraction Area* which have differing depths of cover, extracted seam thickness, geology and mined longwall panel and pillar widths; one in the Hue Hue Area; one in the valley floor areas and, recently, a further modelling case was undertaken by SCT for a forest case using the wider panel widths and higher deep cover in the hilly regions. At each of these three prediction sites the SCT numerical model provided a predicted subsidence profile across a series of longwalls.

A separate detailed *Subsidence Prediction Report* (WACJV, 2012), which is appended to the *Wallarah2 EIS*, has been prepared by the WACJV to detail and combine the mine subsidence research, modelling and prediction work that was undertaken by the WACJV, SCT and MSEC. This *Subsidence Prediction Report* (WACJV, 2012), details the reasons why the hybrid subsidence prediction model was developed for the *Project* and it discusses several of the mine planning options and mitigation measures that were considered so that the predicted mine subsidence ground movements complied with required ground tilt levels and the requirements to reduce impacts.

As detailed in the *Subsidence Prediction Report,* a design approach was adopted by WACJV to accommodate the potential soft floor conditions from the Awaba Tuff whereby the chain pillars were designed to yield when isolated in the goaf so as to minimise the risk and impacts of any long term pillar failure. With this approach pillars are designed to fail and then become confined by goaf material so that any subsequent strength losses due to long-term claystone behaviour would occur as a variation in the residual pillar strength rather than large-scale intact pillar strength losses. The resultant change in subsidence would be largely controlled by the goaf and would be expected to be significantly less than impacts from long-term failure of intact pillars.

The MSEC IPM model was then calibrated against the results of the SCT numerical model for both the magnitude of subsidence and the shapes of the incremental subsidence profiles at each of these three prediction sites. The calibrated IPM model was then used to predict the subsidence, tilt and strain contours across *the Project* for all the proposed longwalls, based on the variations in the proposed extracted thicknesses, depths of cover and mining geometry.

After the hybrid approach of predicting subsidence was developed and applied across *the Project* using the MSEC IPM model, the magnitudes of the predicted mine subsidence movements were noticed to have increased significantly from the *initial* subsidence predictions. This cautious or conservatively based hybrid study approach now provides predicted subsidence profiles and subsidence parameters at each natural feature and item of infrastructure that are approximately one-and-a-half to two times higher than the magnitude of values that would be predicted using the standard Newcastle Coalfield mine subsidence empirical formulae that do not account for the weakening effects of the underlying Awaba Tuff, the deep depths of cover, the lack of massive strata and the relatively thick extracted seam thickness. In effect the hybrid approach of predicting subsidence provides a “worst case” scenario and the observed subsidence levels will most likely be less than these cautious or conservatively based predictions.

The outcomes of this hybrid mine subsidence prediction model were then used by the WACJV team to modify and select the appropriate longwall panel widths, interpanel pillar widths and the seam mining heights so that predicted subsidence parameters will be limited to the required pre-determined levels under sensitive surface features. For example, the proposed panel void widths beneath the north-eastern portion of the *Hue Hue Mine Subsidence District* range from 125 metres to 175 metres and the proposed panel widths beneath the 1 in 100 year flooding zones range from 155 metres to 205 metres, depending on depth of cover. Elsewhere, the proposed longwall panel void widths are 205, 225 or 255 metres to ensure the impacts and consequences of the predicted levels of mine subsidence ground movements on all the natural and built features over these areas were assessed to be manageable and acceptable.

The range of the predicted final subsidence ground movements varies across the *Study Area* for a number of reasons including the degree of surface constraint and sensitivity that influenced the final mine design. Details of how the WACJV selected the appropriate longwall panel and pillar dimensions and seam thicknesses to be extracted are discussed in the *Subsidence Prediction Report* (WACJV, 2012),

The maximum predicted total conventional subsidence of 2,600 mm occurs in the western forested hill zones where the seam extraction height and panel widths are greater than those proposed in the floodplain and Hue Hue areas. Similarly, the maximum predicted total conventional tilt of 15 mm/m, the maximum predicted total conventional hogging curvature of 0.28 km^{-1} and the maximum predicted total conventional sagging curvature of 0.37 km^{-1} are also predicted to occur in parts of the western forested areas.

After the *Subsidence Prediction Report* (WACJV) and the *Subsidence Impact Report* (MSEC) were completed, Hansen Bailey, on behalf of, the WACJV, engaged Prof. Bruce Hebblewhite, Head of School of Mining, University of NSW, to provide an independent peer review of the mine subsidence predictions and impact assessments that were carried out for *the Project*. Bruce Hebblewhite’s report, which is attached to this report as Appendix G, concludes; “*I am of the opinion that “best-practice” subsidence prediction techniques have been adopted using innovative hybrid empirical and numerical techniques. These techniques have been rigorously evaluated, and validated as far as possible against available databases. However it will be absolutely essential that some Wallarah site-based validation is carried out once data is collected from subsidence associated with the initial longwall panels to provide an even better level of confidence in the prediction techniques and findings*”.

It is also important to note that the conservative modelling undertaken for *the Project* can be continually updated and revised as the model is validated with observation data that is to be collected throughout the operations. It has been noted that there is always a level of uncertainty associated with any predictive modelling and that the adaptive management approach is an effective tool that can be used to refine, mitigate and manage the long term impacts of mining. Reviews of the hybrid subsidence modelling approach have concluded that it is leading practice, more accurate than alternative techniques and is appropriate for *the Project.* These reviews recognised the need for the hybrid approach and they identified that the predicted cautious or conservative levels of subsidence will probably be higher than the subsidence values that will be observed.

Because of this conservative approach, the WACJV has committed itself to working, with the government and surface land and structure owners through appropriate subsidence management plans, with an adaptive and continuous improvement approach to the ongoing longwall panel design, whereby the mining dimensions and the resulting subsidence parameter limits of the future mine workings will be continuously reviewed and modified as necessary, as experience is gained, to ensure the required subsidence parameters and acceptable impact consequences are observed at both the houses in the *Hue Hue Mine Subsidence District* and within the Dooralong and Yarramalong Valley floodplains. For example, numerous variations on the mine plan for *the Project* have already been considered by the WACJV team throughout *the Project* planning process and, subject to obtaining the necessary approvals, further variations of the mine plan can be applied if the monitoring indicates it is required as is discussed in the separate *Subsidence Prediction Report* (WACJV, 2012).

1.3. Mine Subsidence Impact Assessment Study

Essentially, as detailed in the Sections above, the SCT numerical model provided specific mine subsidence predictions at three selected sites within the *Study Area* and then, after the MSEC IPM model was calibrated against these modelling results, the IPM model was applied across the entire *Study Area*.

Details of how the site specific subsidence predictions were determined is discussed in the *Subsidence Prediction Report* (WACJV, 2012), however basically, it was achieved based on the variations in longwall panel and pillar widths, the extracted seam thicknesses and the depths of cover across the *Study Area*. After the mine subsidence prediction phase of *the Project* was completed, then, the mine subsidence impact assessment phase of *the Project* commenced.

Mine Subsidence Engineering Consultants (MSEC) was involved in the subsidence prediction studies at various stages throughout the development of *the Project* and, after the prediction phase was completed, then, MSEC was commissioned by the WACJV to undertake the subsidence impact assessment aspects of *the Project*, i.e. to:-

- identify the natural features and built items of surface infrastructure within the *Study Area* that could be affected by mine subsidence ground movements,
- calibrate the Incremental Profile Method, based on the extensive geological information that is detailed in the *Geology Report* and based on the numerical modelling advice from Strata Control Technology (SCT) and, then, undertake robust sensitivity analyses of these predictions,
- provide subsidence predictions for each natural feature and item of surface infrastructure using the calibrated Incremental Profile Method,
- assess impacts, with other specialist consultants, for each of the identified natural features and items of surface infrastructure,
- provide a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset the subsidence impacts of *the Project*, and to
- prepare a detailed report on the mine subsidence impact assessments at *the Project*.

This *Subsidence Impact Report* (MSEC515, 2013) has been prepared as a result of this mine subsidence impact assessment study and this report is to be included as an appendix in the *Wallarah2 EIS*.

As discussed above, the *Subsidence Prediction Report* (WACJV, 2012) detailed the background and explained why the hybrid mine subsidence prediction model was developed for *the Project*. To fully appreciate the detailed subsidence impact assessments that are included in this *Subsidence Impact Report*, it would be best to first read and review the *Subsidence Prediction Report*.

1.3.1. Requirements for Mine Subsidence Reports for *the Project*

After reviewing the Wallarah 2 Coal Project Area's Coal Joint Venture Background Document, dated October 2011, the Department of Trade and Investment, Regional Infrastructure and Services, Division of Resources & Energy (DRE) provided, in November 2011, the following comments to the Director General of the Department of Planning and Infrastructure (DoPI) on the mine subsidence predictions for his considerations in setting the Director General requirements (DGRs) for the *Wallarah2 EIS*;

- The proposed mine layout should be designed and management systems developed, taking into consideration identified subsidence, existing surface structures and stakeholder and community issues.
- The EIS should provide an assessment of subsidence levels associated with underground mining, using best available predictive formulae.

- The EIS should identify if the predicted subsidence will result in fracture connectivity to the surface, and the environmental consequence to the ground surface, groundwater aquifers and groundwater dependant ecosystems of the predicted subsidence. Baseline assessment of the surface features above the proposed mining areas must be sufficient to identify environmental features at risk, and appropriate setback or protection zones if necessary for sensitive features.
- The following significant issues relating to subsidence impacts/management for the Wallarah No 2 proposal have been identified by DRE:
  - The proposed Wallarah No.2 project site differs from many other longwall extraction sites in that adequate subsidence management may be achieved by implementing appropriate mine layout designs. In other words, mine design is to a large extent driven by subsidence issues.
  - High voltage angle towers - based on current technology, it is not considered possible to undermine high voltage angle towers. The proponent should consider either re-designing the mine layout or re-routing of the power lines in question.
    Based on DRE's experience with other mining proposals with similar issues either of the aforementioned options will require significant planning and consultation.
    DRE understands that the high voltage angle towers in question will be undermined in approximately 20 years and that management options may be reviewed at a future stage. Any later decision must be made well in advance of mining to allow the implementation of the chosen management option.
  - A significant number of properties/structures located in flood prone areas are proposed to be undermined. Properties / structures already affected by flooding may be subject to greater flood impacts and properties/structures not previously affected by flooding may be impacted by flooding as a result of the proposed mining. In addressing this issue, the proponent will have significant challenges with respect to community issues, identification of all affected features, selection of appropriate mine design and development of effective management strategies.
  - There are identified watercourses, catchment areas and aquifers that may be affected by subsidence which provide or may provide water to the population centre of Wyong. A detailed and rigorous assessment of the potential impacts to water resources as a result of subsidence will be necessary.
  - There is a need for the proponent to have a clearly defined mine design and planning strategy with respect to subsidence issues, taking into consideration the following:
    - the need for accurate subsidence predictions in an area where the site conditions may present difficulties and uncertainties;
    - a detailed knowledge of the distribution of major surface constraints and sensitive features in *the Project* area;
    - appropriate scheduling and mine layout to ensure adequate subsidence management. Conservatism in mine design is required should important/sensitive surface features be undermined in the early stages of *the Project* without the benefit of site-specific data to enable an adequate understanding of subsidence development within the Wallarah No 2 site;
    - clearly defined subsidence design criteria, to reflect the nature of the potentially affected features, e.g. vertical displacement must be the primary controlling parameter for longwalls under flood prone land, and strain/tilts for dwellings etc.

The Director General of the Department of Planning and Infrastructure (DoPI) required, in January 2012, that *the Project EIS* must include a detailed quantitative and qualitative assessment of the potential conventional and non-conventional subsidence impacts of the development that includes:

- the identification of the natural and built features (both surface and subsurface) within the area that could be affected by subsidence, and an assessment of the respective values of these features using any relevant statutory or policy documents;
- accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions;
- a detailed assessment of the potential environmental consequences of these effects and impacts on both the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental values; and
- a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset subsidence impacts and environmental consequences (including adaptive management and proposed performance measures);

This *Subsidence Impact Report* (MSEC, 2013), the *Subsidence Prediction Report* (WACJV, 2012), the *Wallarah 2 Coal Project Flood Impact Assessment* (GHA, 2013) and the *Wallarah 2 Coal Project Groundwater Management Studies* (Mackie, 2013) have all been prepared for the WACJV to address the subsidence related DRE and DGR requirements and in accordance with the requirements in Part 2 in Schedule 2 to the *Environmental Planning & Assessment Regulation 2000* (EP&A Regs).

The following tables identify where the DoPI Director General's requirements (DGRs) and the DRE requirements have been addressed in these reports.

Table 1.1 Advice on the DRE's Requirements for the *Wallarah2 EIS*

DRE's Requirements for *Wallarah2 EIS*	Report where requirements are addressed	Section Number in this Impact Report where these requirements are addressed or referenced
DRE's Requirements;		
The proposed mine layout should be designed and management systems developed, taking into consideration identified subsidence, existing surface structures and stakeholder and community issues	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2
The EIS should provide an assessment of subsidence levels associated with underground mining, using best available predictive formulae	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2
The EIS should identify if the predicted subsidence will result in fracture connectivity to the surface, and the environmental consequence to the ground surface, groundwater aquifers and groundwater dependant ecosystems of the predicted subsidence	*Groundwater Management Studies* (Mackie, 2013)	Sections 5.3 and 5.4
Baseline assessment of the surface features above the proposed mining areas must be sufficient to identify environmental features at risk, and appropriate setback or protection zones if necessary for sensitive features	*Groundwater Management Studies Report* (Mackie, 2013), *Flood Impact Assessment Report* (GHA, 2013)	Sections 5.3 and 5.4
The proposed Wallarah No.2 project site differs from many other longwall extraction sites in that adequate subsidence management may be achieved by implementing appropriate mine layout designs.	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2
High voltage angle towers	*Subsidence Impact Report* (MSEC, 2013),	Sections 2.5.8, 5.14
Flooding issues	*Flood Impact Assessment Report* (GHA, 2013)	Sections 5.3 and 5.4
A detailed and rigorous assessment of the potential impacts to water resources, catchment areas and aquifers	*Groundwater Management Studies Report* (Mackie, 2013), *Flood Impact Assessment Report* (GHA, 2013)	Sections 5.3 and 5.4
The need for accurate subsidence predictions in an area where the site conditions may present difficulties and uncertainties	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2
A detailed knowledge of the distribution of major surface constraints and sensitive features in *the Project* area	*Subsidence Impact Report* (MSEC, 2013),	Chapter 2 and 5
Appropriate scheduling and mine layout to ensure adequate subsidence management.	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2
Clearly defined subsidence design criteria, to reflect the nature of the potentially affected features, e.g. vertical displacement must be the primary controlling parameter for longwalls under flood prone land, and strain/tilts for dwellings etc.	*Subsidence Prediction Report* (WACJV, 2012),	Section 1.2

Table 1.2 Advice on DoPI Director General's Requirements for *Wallarah2 EIS*

DoPI Director General's Requirement and DRE's Requirements for *Wallarah2 EIS*	Report where requirements are addressed	Section Number in this Impact Report where these requirements are addressed or referenced
DoPI Director General's Requirements;		
The Project EIS must include a detailed quantitative and qualitative assessment of the potential conventional and non-conventional subsidence impacts of the development	*Subsidence Prediction Report* (WACJV, 2012), *Subsidence Impact Report* (MSEC, 2013),	Section 1.2 and Chapter 5
The Project EIS must include the identification of the natural and built features (both surface and subsurface) within the area that could be affected by subsidence	*Subsidence Impact Report* (MSEC, 2013),	Chapter 2
The Project EIS must include an assessment of the respective values of these features	*Subsidence Impact Report* (MSEC, 2013),	Chapter 5
The Project EIS must include accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions	*Subsidence Impact Report* (MSEC, 2013),	Chapter 5
The Project EIS must include a detailed assessment of the potential environmental consequences of these effects and impacts on both the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental values;	*Subsidence Impact Report* (MSEC, 2013),	Chapter 5
The Project EIS must include a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset subsidence impacts and environmental consequences (including adaptive management and proposed performance measures	*Subsidence Impact Report* (MSEC, 2013),	Chapter 5

1.3.2. Outline of this Subsidence Impact Report

The remainder of Chapter 1 of this report discusses the mine geometry of the proposed longwalls, an overview of the geology, information on the seam and the surface areas over the *Extraction Area* at *the Project*. Various natural features and items of surface development and infrastructure have been identified in the vicinity of the proposed longwalls, and these are described in Chapter 2 of this report.

The locations of the proposed longwalls and the *Study Area*, which is defined in Section 2.2, have been overlaid on an orthophoto and topographic map of the area and these are shown in Fig. 1.1 and Fig. 2.1, respectively. The major natural features and items of surface infrastructure within the *Study Area* are also illustrated in these figures.

Chapter 3 of this report includes a brief overview of longwall mining, the development of mine subsidence and a brief discussion on the specific method that has been used to predict the mine subsidence movements resulting from the extraction of the proposed longwalls. A separate detailed *Subsidence Prediction Report* (WACJV, 2012), has been prepared by the WACJV which combines the subsidence prediction research and detailed prediction work undertaken by the WACJV, SCT and MSEC.

Chapter 4 provides a general overview of the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls.

Chapter 5 provides the site-specific predicted subsidence parameters for each natural feature and item of surface infrastructure described in Chapter 2. The impact assessments and recommendations for each of these features have been made based on the predicted subsidence parameters.

Fig. 1.1 Aerial Photograph showing the Proposed W2CP Longwalls and the extent of the *Study Area*

1.4. Mining Geometry

The proposed longwall mining layout was developed by the WACJV, based on the available information from the exploration drilling programmes, current mining technologies, the hybrid mine subsidence prediction approach and the locations of significant features within the *Study Area*. Numerous variations on the mine plan for *the Project* were considered throughout the planning process, as discussed in Chapter 1, to ensure that impacts were kept to an acceptable level. The final layout of the proposed longwalls is shown in Drawing No. MSEC515-01.

A summary of the dimensions of the proposed longwalls is provided in Table 1.3. The proposed longwall lengths vary between 1.4 kilometres and 3.4 kilometres, the proposed panel void widths vary between 125 metres and 255 metres and the proposed chain pillar widths vary between 45 metres and 75 metres.

Table 1.3 Dimensions of the Proposed Longwalls in the *Extraction Area*

Series	Longwall	Overall Void Length Including Installation Heading (m)	Overall Void Width Including First Workings (m)	Overall Tailgate Chain Pillar Width (m)
LW1N to LW26N	LW1N	1815	125	-
	LW2N to LW5N	2040 to 2810	155	65
	LW6N to LW11N	2960 to 3435	175	65
	LW12N	3260	175	75
	LW13N to LW14N	2950 to 3105	175	65
	LW15N	2805	175	55
	LW16N	2620	175 and 225	55
	LW17N	2455	205	50
	LW18N	2365	225	50
	LW19N	2370	225	75
	LW20N to LW21N	2315 to 2370	255	50
	LW22N	2370	205	65
	LW23N	2370	205	75
	LW24N	2370	205	65
	LW25N	2415	225	65
	LW26N	2415	225	50
LW1S to LW10S	LW1S	1415	205	-
	LW2S to LW4S	2590 to 2675	175	65
	LW5S	2440	205	45
	LW6S	2255	205	45
	LW7S to LW10S	1685 to 1875	255	50
LW1SW to LW10SW	LW1SW	2465	205	-
	LW2SW to LW6SW	1945 to 2360	205	50
	LW7SW	1830	205	75
	LW8SW to LW10SW	1515 to 1725	205	50

Numerous variations on the mine plan for *the Project* have already been considered by the WACJV team throughout *the Project* planning process and further variations can be applied if the monitoring indicates it is required. In this regard, the WACJV has committed itself to an adaptive and continuous improvement approach to the longwall panel design, whereby the mining dimensions and limits of future mine workings will be continuously reviewed and modified as necessary, as experience is gained, to ensure the required subsidence parameters and impact consequences are observed at both the houses in the *Hue Hue Mine Subsidence District* and within the Dooralong and Yarramalong Valley floodplains.

There will always be a level of uncertainty associated with any predictive modelling and the adaptive management approach has been recognised as an effective tool that can be used to refine, mitigate and manage the long term impacts of mining to ensure the required subsidence parameters and impact consequences are met across the entire *Extraction Area*.

Accordingly, the cautious conservative modelling undertaken for *the Project* will be continually reviewed, updated and revised as the model is validated with observation data as it is collected throughout the operations. This validation will provide further confidence and refinement in the subsidence predictions and enable coal recovery to be maximised whilst ensuring the required subsidence parameters and impact consequences are met across the entire *Extraction Area*.

Any such modifications to the longwall layouts would be constrained within the *Extraction Area* as shown in Drawing No. MSEC515-01. Discussions on the effects of changes in the longwall layouts on the predicted subsidence parameters are provided in the impact assessments for each feature provided in Chapter 5.

1.5. Geological Details

As detailed in the *Geology Report*, the WACJV undertook detailed and extensive exploration investigations throughout the Exploration Lease and advised that the various available seams were subject to significant splitting and coalescence through the development of conglomerate filled fluvial channels. The economic coal resources were found to be contained in the Wallarah and Great Northern Seams, which are within the upper part of the Permian Newcastle Coal Measures.

The *Extraction Area* lies within the north-eastern margin of the Sydney Basin and in the southern part of the Newcastle Coalfield. A diagrammatic and exaggerated east-west geological cross section of the southern part of the Newcastle Coalfield showing the available Permian Newcastle Coal Measures and part of the overlying Triassic Narrabeen Group strata layers is presented in Fig. 1.2.

This cross section indicates that these strata within the Newcastle Coal Measures outcrop to the east of the region and dip gently to the west beneath the *Extraction Area*, however, these measures actually outcrop to the far north and north-east and dip to the south-west of the *Extraction Area* at grades of 1 in 30 to 1 in 50. This cross section also shows the proposed mining area within a western thick zone of this sketch. Below the coalesced Wallarah and Great Northern Coal Seams in this area lies the Awaba Tuff and the Warnervale Conglomerate. Above these coal seams lies the Dooralong Shale, Munmorah Conglomerate and other Narrabeen Group formations. Within each of these stratigraphic conglomerate units there are a number of rock types that include numerous mudstones, sandstones and conglomerates and there are no individual massive strata units thicker than 5 metres.

The Wallarah and Great Northern Coal Seams are in the upper part of the Newcastle Coal Measures and were formed during the late Permian Period. As shown in Fig. 1.2 they are overlain by the Triassic Narrabeen Group, which outcrops across the *Extraction Area*. The lowermost strata of the Narrabeen Group comprises the Dooralong Shale, which consists of between 50 metres and 70 metres of interbedded shales and laminites, and this sequence coarsens upwards to contain beds of pebbly sandstone. The overlying Munmorah Conglomerate is generally 70 metres to 80 metres thick and consists of interbedded coarse and pebbly sandstones and green-grey shales. Neither of these sequences outcrops in the proposed target mining area.

Outcropping in the north-east of the area is the Tuggerah Formation, a 200 metres thick sequence of sandstones with minor siltstones and rare conglomerates. Above this, the Patonga Claystone, which consists of 80 metres to 110 metres of interbedded grey-green and red-brown claystones and minor fine-grained sandstones, commonly outcrops in the lower, more undulating areas through (and immediately beneath) the Yarramalong and Dooralong Valleys. The uppermost strata of the Narrabeen Group in the area belong to the Terrigal Formation and consist of sandstones and minor siltstones. This sequence occurs through the more elevated zones of the south-western half of *the Project* Boundary, which is typically covered by State Forests. A generalised stratigraphic column over the *Extraction Area* from the Terrigal Formation on the surface down to the Permian Newcastle Coal Measures is shown in Fig. 1.3.

The geological structures, which have been identified at seam level based on an extensive drilling program, are shown in Drawing No. MSEC515-06. As shown in this drawing there are no major geological structures identified at seam level within the *Extraction Area*. Outside the *Extraction Area* there are a series of dykes, sills, and other igneous structures and a number of faults. However these are not expected to affect the proposed recovery of the coal resource.

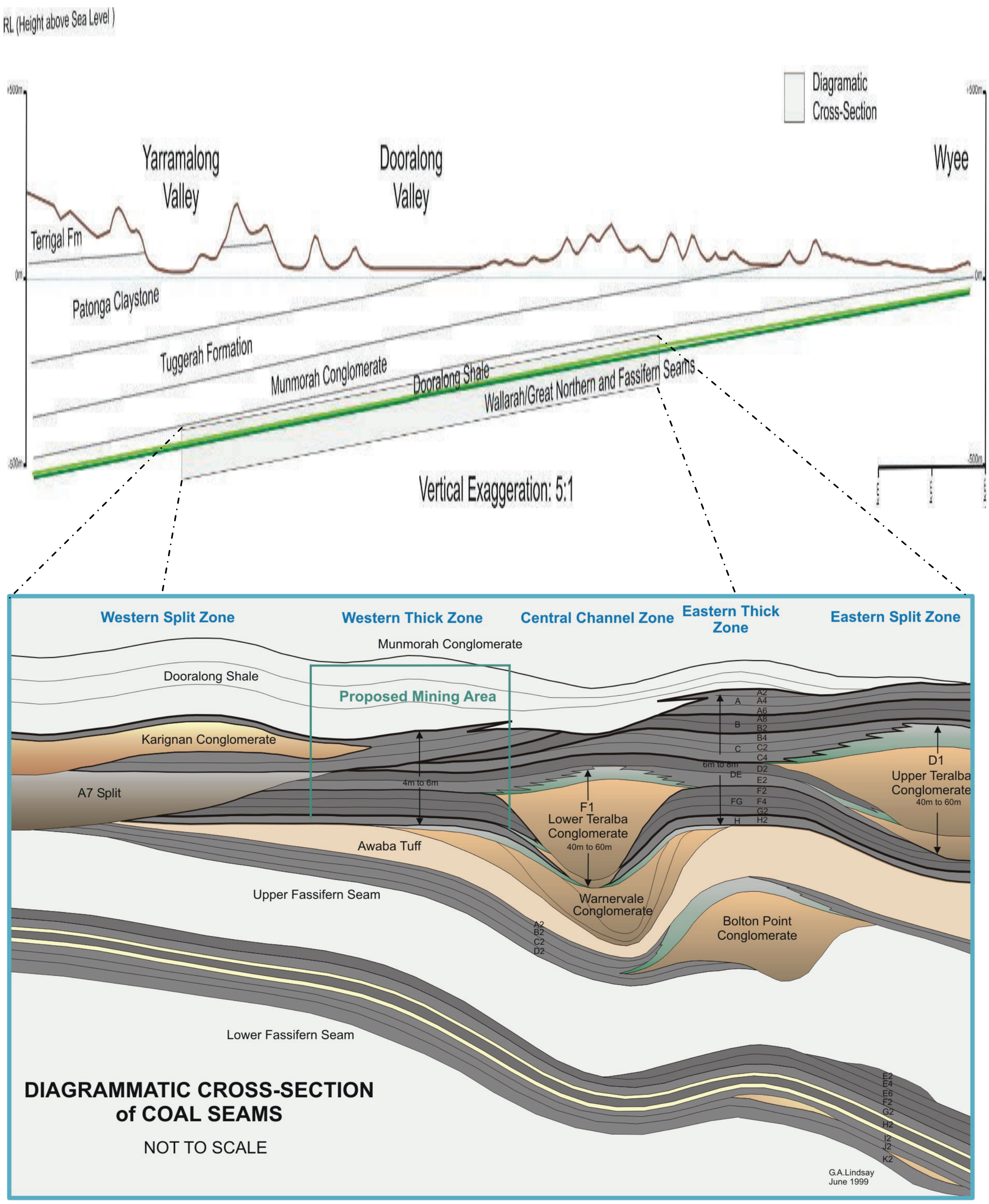

Fig. 1.2 Diagrammatic East–West Stratigraphic Cross Section across the *Study Area* and Surrounding Regions with Focus on the Upper Permian Newcastle Coal Measures

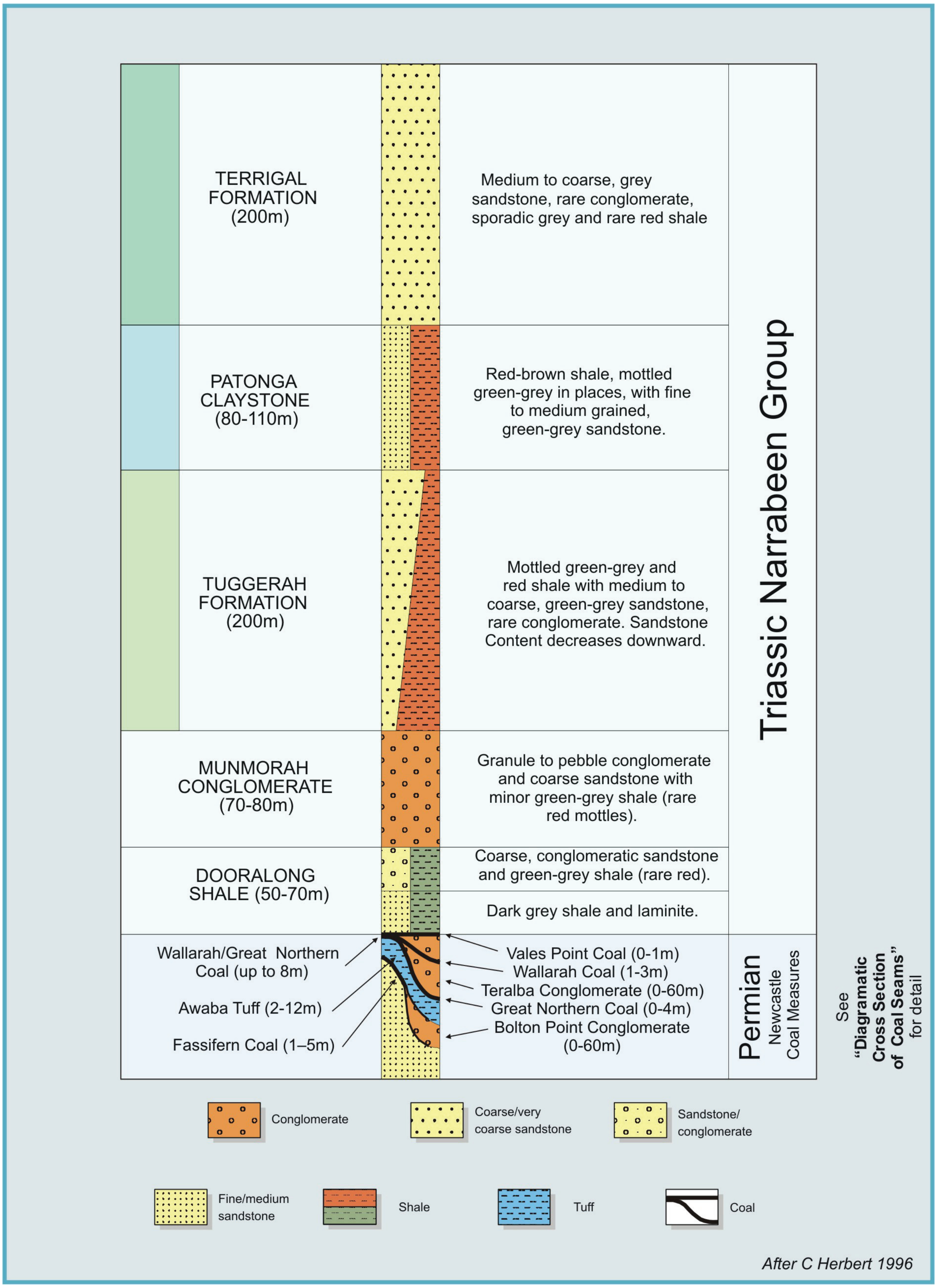

Fig. 1.3 Generalised Stratigraphic Column

The surface geology within the *Study Area* and surrounding areas can be seen in Fig. 1.4, which shows the proposed longwalls overlaid on a plan prepared by the WACJV.

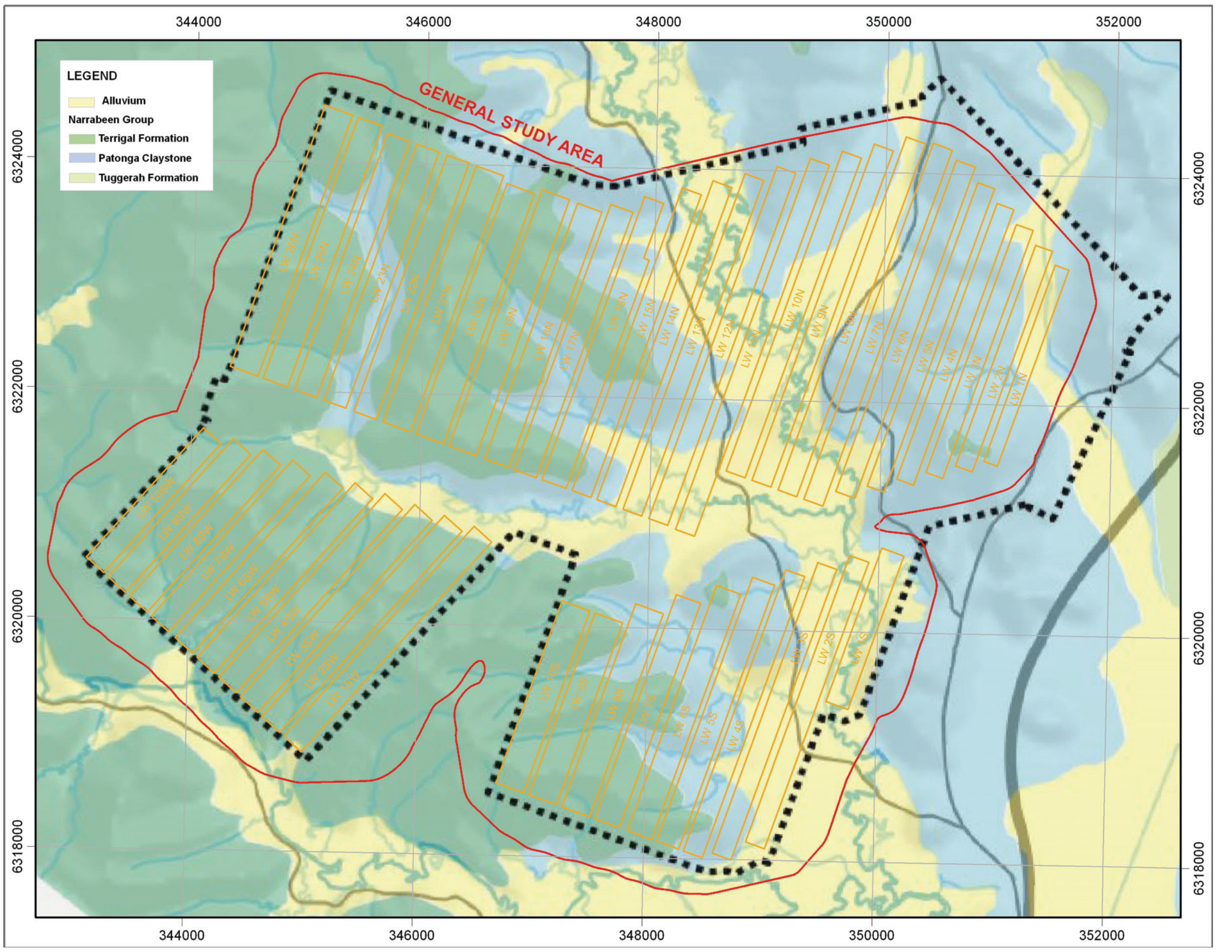

Fig. 1.4 Surface Geology within the *Study Area* and Surrounding Areas

It can be seen from the above figure that the surface geology within the *Study Area* is comprised predominantly of areas derived from the Terrigal Formation and the Patonga Claystone from Narrabeen Group and Quaternary deposits.

1.6. Surface and Seam Information

The surface level contours across the *Study Area* are shown in Drawing No. MSEC515-02. The surface levels within the *Study Area* range from RL 5 metres (AHD), along the Jilliby Jilliby Creek over the southern end of Longwall 1S, to RL 235 metres (AHD), within the Jilliby State Conservation Area over the northern end of Longwall 22N.

As detailed in the *Geology Report* and as shown in Fig. 1.2, the Wallarah and Great Northern Seams coalesce to form a single seam within the proposed *Extraction Area*. These seams are subject to splitting by conglomerate filled fluvial channels beyond the proposed *Extraction Area*. The available seam thickness of the combined Wallarah and Great Northern Seams, within the *Extraction Area*, ranges between 4.2 metres and 6.8 metres, as shown in Drawing No. MSEC515-04. Beyond the *Extraction Area* and within the *Study Area*, the available seam thickness ranges from 2.5 metres to 6.8 metres.

Accordingly, a working section of 4.2 metres could have been extracted over the entire *Extraction Area*. However, as shown in Fig. 1.5 and Drawing No. MSEC515-04, the proposed seam thicknesses to be extracted have been limited to 3.5 metres and 4.0 metres in various areas to limit ground movements in the east and north-east of the *Extraction Area*, including the *Hue Hue Mine Subsidence District* and in the Dooralong Valley (Jilliby Jilliby Creek).

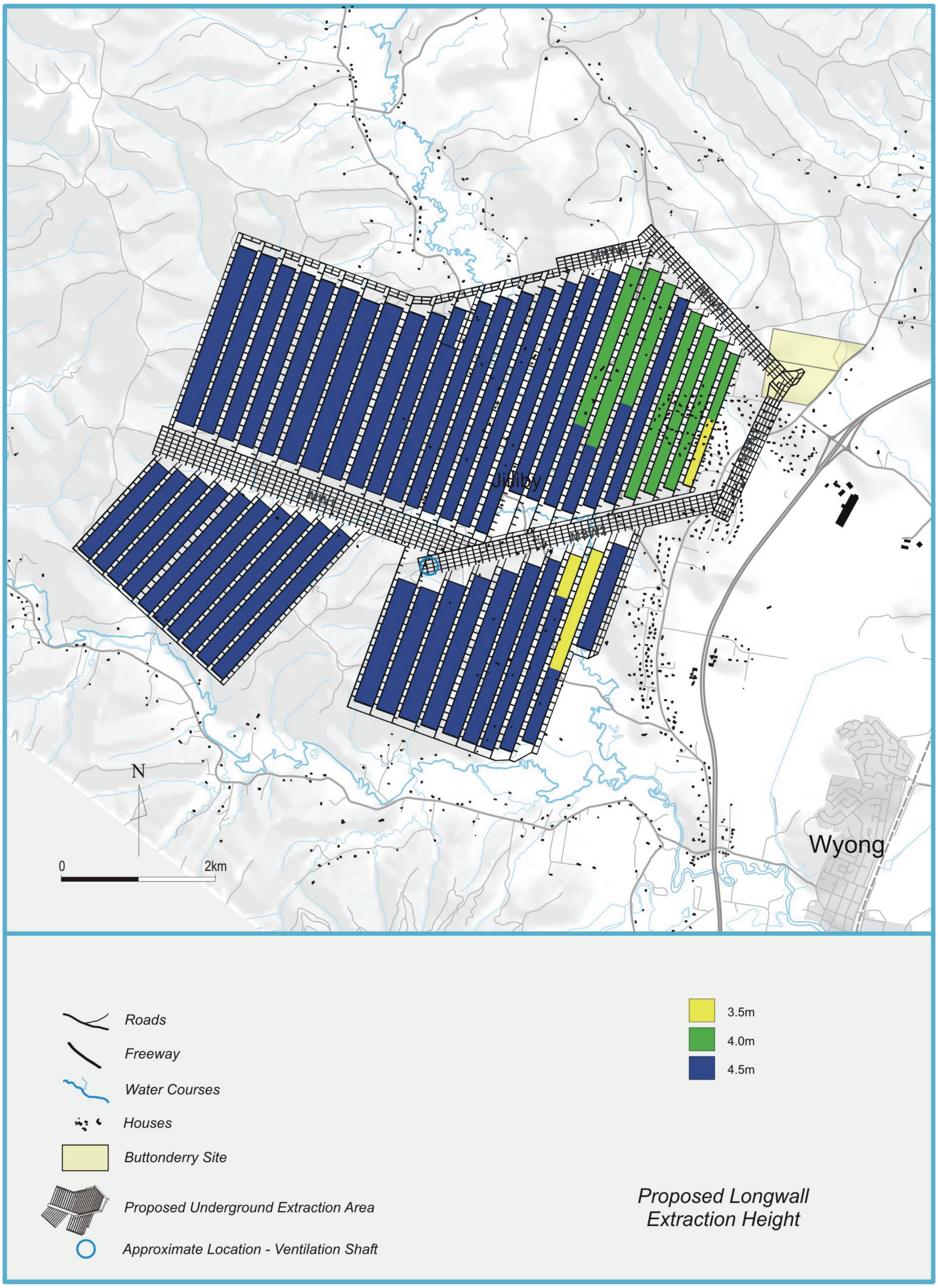

Fig. 1.5 Proposed Longwall Extracted Heights

A summary of the minimum, maximum and average proposed longwall extraction heights is provided in Table 1.4. The average seam thickness provides an indication of the extents of the minimum and maximum proposed longwall extraction heights within each longwall. The actual proposed extraction heights at each location has been used in the MSEC IPM method calculations rather than assuming the minimum, maximum or average proposed longwall extraction heights that are shown in the table below.

Table 1.4 Proposed Longwall Extraction Heights

Longwalls	Proposed Extraction Heights (m)		
	Minimum	Maximum	Average
LW1N to LW4N	3.5	4.0	3.95
LW5N to LW8N	4.0	4.5	4.3
LW9N to LW15N	4.5	4.5	4.5
LW16N to LW20N	4.5	4.5	4.5
LW21N to LW26N	4.5	4.5	4.5
LW1S to LW3S	3.5	4.5	4.15
LW4S to LW10S	4.5	4.5	4.5
LW1SW to LW5SW	4.5	4.5	4.5
LW6SW to LW10SW	4.5	4.5	4.5

The seam floor contours, seam thickness contours and the depth of cover contours, for the combined Wallarah-Great Northern Seam, are shown in Drawings Nos. MSEC515-03, MSEC515-04 and MSEC515-05, respectively.

The seam floor levels of the Wallarah Seam, within the *Extraction Area*, vary from 322 metres below AHD, at the northern end of Longwall 7N, to 504 metres below AHD, at the southern end of Longwall 7SW.

A summary of the minimum, maximum and average depths of cover directly above the proposed longwalls in each mining domain is provided in Table 1.5. The actual proposed depths of cover at each location have been used in the MSEC IPM method calculations rather than assuming the minimum, maximum and average proposed depths of cover that are shown in the table below.

Table 1.5 Depths of Cover to the Wallarah – Great Northern Seam

Longwalls	Depth of Cover (m)		
	Minimum	Maximum	Average
LW1N to LW5N	345	485	385
LW6N to LW10N	345	465	385
LW11N to LW15N	380	555	415
LW16N to LW20N	380	630	485
LW21N to LW26N	410	620	505
LW1S to LW5S	395	545	430
LW6S to LW10S	430	660	515
LW1SW to LW5SW	470	685	575
LW6SW to LW10SW	480	690	570

2.0 IDENTIFICATION OF SURFACE FEATURES

2.1. Definition of the *Extraction Area*

The *Extraction Area* is defined as the area bounded by the maximum extents of the proposed longwalls, (i.e. second workings only and excluding the development headings), as shown in Drawings Nos. MSEC515-01 to MSEC515-20. The total area of the proposed longwalls, i.e. the sum of the void widths times the void lengths of each of the forty-six longwalls, is 21.8 square kilometres.

2.2. Definition of the *General Study Area* and the *Study Area*

A line has been shown in Figs. 1.1, 1.3 and 2.1 and Drawings Nos. MSEC515-01 to MSEC515-20 that defines the *General Study Area* for *the Project*, which is based upon either the 26½ degree angle of draw line or the predicted total 20 mm subsidence contour, whichever extends further from the proposed *Extraction Area.* The *General Study Area* provides an indication of the extents of the land area that will be affected by vertical subsidence ground movements.

Given that the depth of cover varies above the *Extraction Area* between 345 metres and 690 metres, the 26½ degree angle of draw line was determined by drawing a line that is a horizontal distance varying between 172.5 metres and 345 metres around the limits of the *Extraction Area*.

The predicted limit of vertical subsidence, taken as the predicted total 20 mm subsidence contour, has been determined using the calibrated IPM model, which is dependent on many factors as described in further detail in Section 3.10. In some locations, the predicted total 20 mm subsidence contour extended further from the edge of the mined panel than the 26½ degree angle of draw line and, in other locations, the 26½ degree angle of draw line extended further than the predicted total 20 mm subsidence contour.

The *Study Area* for *the Project* is a term used in this report to describe all the areas above and near the *Extraction Area* that have been reviewed to determine the effects of mine subsidence for *the Project*. The *Study Area* includes the above *General Study Area* plus any surface feature or structure in the surrounding areas that have also been included in the impact assessments that may be sensitive to far-field horizontal movements or valley related upsidence and closure movements. The extent of the *Study Area* can therefore be seen to include any natural feature or structure that may be impacted by mining-induced vertical or horizontal ground movements and the *Study Area* combines areas bounded by the following three limits:-

- The 26½ degree angle of draw line,
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour, and
- Any natural feature or structure that may be sensitive to far-field horizontal movements or valley related upsidence and closure movements.

A review was undertaken of all the natural surface features and infrastructure items which are located within several kilometres of the *Extraction Area* and any feature or item which may be sensitive to such remote mining induced horizontal movements was included in the *Study Area*. The potential impacts of far-field horizontal movements and valley related upsidence and closure movements at these features and items have been included in the assessments provided later in this report. The remote surface features and infrastructure items that were included are:-

- Streams, that were located outside the *General Study Area* where the predicted valley related movements are greater than 20 mm total upsidence and 20 mm total closure, (up to 1 km from the *Extraction Area*),
- Bridges along the Sydney-Newcastle Freeway, (up to 1.4 kms from the *Extraction Area*),
- Mardi-Mangrove Transfer Main Pipeline, (up to 2.5 kms from the *Extraction Area),*
- Groundwater bores, (Up to 5 kms from the Extraction Area), and
- Survey control marks, (Up to 3 kms from the *Extraction Area).*

The *Study Area,* as defined in this report, therefore includes all those areas where mine subsidence impacts assessments have been undertaken for *the Project*.

2.3. General Description of the Natural Features and Items of Surface Infrastructure

The proposed longwalls and the *General Study Area* have been overlaid on an extract of these CMA maps, and are shown in Fig. 2.1. The major natural features and items of surface infrastructure within the *Study Area* and over the *Extraction Area* can be seen in the 1:25,000 topographic maps of the area, published by the Central Mapping Authority (CMA), numbered 9131-1-N and 9131-1-S.

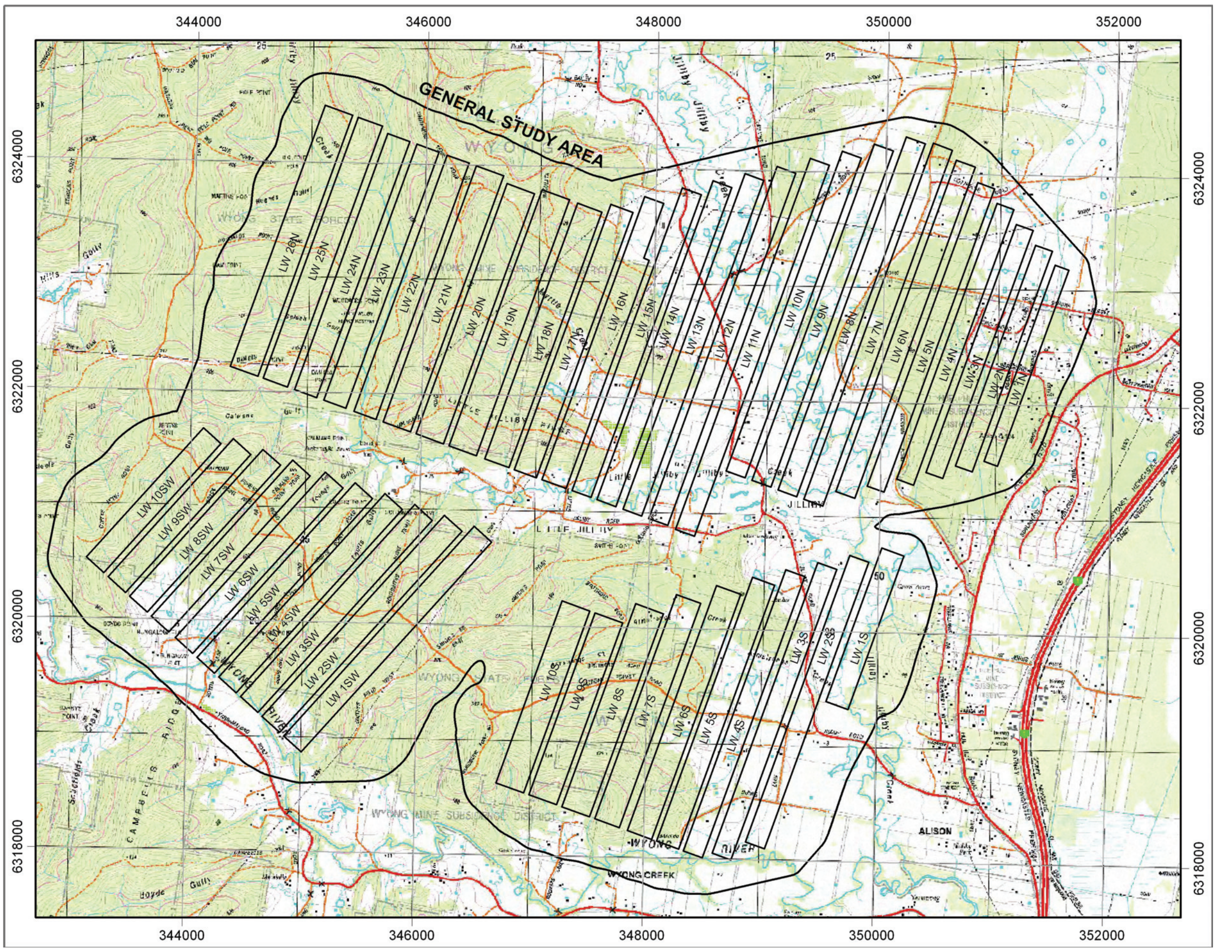

Fig. 2.1 The Proposed Longwalls and the *General Study Area* Overlaid on CMA Maps Nos. 9131-1-N and 9131-1-S

Table 2.1 provides a checklist of the natural features and items of surface infrastructure that could possibly be impacted by mine subsidence movements.

Where no natural features or items of infrastructure of a specified type have been found over the *Study Area,* then a cross is marked in Table 2.1.

Where a natural feature and item of surface infrastructure has been identified within the *Study Area*, then Table 2.1 has been marked with a tick and a reference to the section number of this report where a description has been provided on that natural feature or item of surface infrastructure.

Table 2.1 Identification of Natural Features and Surface Infrastructure within the *Study Area*

Item	Within *Study Area*	Report Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	✓	2.4.1
Rivers or Creeks	✓	2.4.2
Aquifers or Known Groundwater Resources	✓	2.4.3
Springs	✓	2.4.4
Sea or Lakes	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Natural Rock Formations	✓	2.4.8
Steep Slopes	✓	2.4.9
Escarpments	×	
Land Prone to Flooding or Inundation	✓	2.4.11
Swamps, Wetlands or Water Related Ecosystems	✓	2.4.12
Threatened, Protected Species or Critical Habitats	✓	2.4.13
National Parks or Wilderness Areas	×	
State Recreational or Conservation Areas	✓	2.4.15
State Forests	✓	2.4.16
Natural Vegetation	✓	2.4.17
Areas of Significant Geological Interest	×	
Any Other Natural Feature Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	2.5.2
Bridges	✓	2.5.3
Tunnels	×	
Culverts	✓	2.5.5
Water, Gas or Sewerage Pipelines	✓	2.5.6
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	2.5.8
Telecommunication Lines or Associated Plants	✓	2.5.9
Water Tanks, Water or Sewage Treatment Works	✓	2.5.10
Dams, Reservoirs or Associated Works	✓	2.5.11
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	✓	2.6.3
Shopping Centres	×	
Community Centres	✓	2.6.5
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Racecourses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within *Study Area*	Section Number Reference
FARM LAND AND FACILITIES		
Agricultural Utilisation, Agricultural Improvements or Agricultural Suitability of Farm Land	✓	2.7.1
Farm Buildings or Sheds	✓	2.7.2
Gas or Fuel Storages	✓	2.7.4
Poultry Sheds	×	
Glass Houses or Green Houses	×	
Hydroponic Systems	×	
Irrigation Systems	✓	2.7.8
Fences	✓	2.7.9
Farm Dams	✓	2.7.10
Wells or Bores	✓	2.7.11
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	✓	2.8.3
Gas or Fuel Storages or Associated Plants	×	
Waste Storages and Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids and Rehabilitated Areas	✓	2.8.7
Mine Infrastructure Including Tailings Dams or Emplacement Areas	×	
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	2.9 & 2.10
PERMANENT SURVEY CONTROL MARKS	✓	2.12
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	2.13.1
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	✓	2.13.5
Any Other Residential Features	✓	2.13.6
ANY OTHER ITEM OF SIGNIFICANCE	×	

2.4. Natural Features

2.4.1. Catchment Areas or Declared Special Areas

The Wyong Water Supply Catchment District was declared in Gazette 153 in 1950 under the Local Government Act of 1919 in connection with the Wyong Water Supply under the control of the Council of the Shire of Wyong.

The Gosford and Wyong Councils advise that the combined water catchment areas of the Wyong and Gosford drinking water system are about 727 square kilometres (sq km) and of this total catchment area, the Wyong River Weir has a water catchment area of 355 sq km.

2.4.2. Streams

The locations of the streams within the *Study Area* are shown in Drawing No. MSEC515-08. A summary of the major streams within the *Study Area* is provided in Table 2.2.

Table 2.2 Streams within the *Study Area*

Stream	Description	Longwalls located over Stream	Average Natural Gradient of Stream over Longwalls
Wyong River	Flows into Tuggerah Lake at Rocky Point	Located to the south and outside the *Extraction Area*	(10 metres over 14 kms, 0.7 mm/m)
Jilliby Jilliby Creek	Drains into the Wyong River	LW11N to LW13N & LW22N to LW26N	13 metres over 10 kms, 1.3 mm/m
Little Jilliby Jilliby Creek	Drains into Jilliby Jilliby Creek	LW6N to LW15N, LW1S and LW2S	5.2 mm/m
Myrtle Creek	Drains into Little Jilliby Jilliby Creek	LW11N to LW21N	12 mm/m
Armstrong Creek	Drains into Jilliby Jilliby Creek	LW2S to LW10S	16 mm/m
Youngs Gully	Drains into Little Jilliby Jilliby Creek	LW5SW and LW6SW	160 mm/m
Calmans Gully	Drains into Little Jilliby Jilliby Creek	LW9SW and LW10SW	50 mm/m
Splash Gully	Drains into Little Jilliby Jilliby Creek	LW23N and LW26N	35 mm/m
Hughes Gully	Drains into Little Jilliby Jilliby Creek	LW26N	75 mm/m
Hue Hue Creek	Drains to Porters Creek	LW1N to LW5N	45 mm/m

There are also a number of smaller tributaries within the *Study Area*, the locations of which are shown in Drawing No. MSEC515-08. These tributaries are located directly above and across the extents of the proposed longwalls.

The largest stream within the *Study Area* is the Wyong River, which is a 6^{th} order perennial stream which has formed within a wide alluvial filled valley. The Wyong River is not undermined by the proposed longwalls and sections of the river are located within the Study Area near Longwalls LW2S to LW6S and LW1SW to LW6SW as shown in Drawing No. MSEC515-08. As shown in Fig. E.05, over the section of the Wyong River where it flows near LW10SW to near LW1S the river falls approximately 10 metres in 14 kilometres or a natural gradient of 0.7 mm/m.

Jilliby Jilliby Creek and Little Jilliby Jilliby Creek are 5th order and 4th order streams, respectively, which have also formed within wide alluvial filled valleys. As shown in Fig. E.06, the Jilliby Jilliby Creek falls approximately 13 metres in 10 kilometres, or a natural gradient of 1.3 mm/m. As shown in Fig. E.07, the Little Jilliby Jilliby Creek falls approximately 52 metres in 10 kilometres, or a natural gradient of 5.2 mm/m. Detailed descriptions of these and the other larger streams are provided in the other specialist consultant reports and in the *Wallarah 2 EIS*. As shown in Table 2.2, apart from the Wyong River and Jilliby Jilliby Creek, the average natural gradients of the other streams are generally steep as is also shown in the following plot, Fig. 2.2.

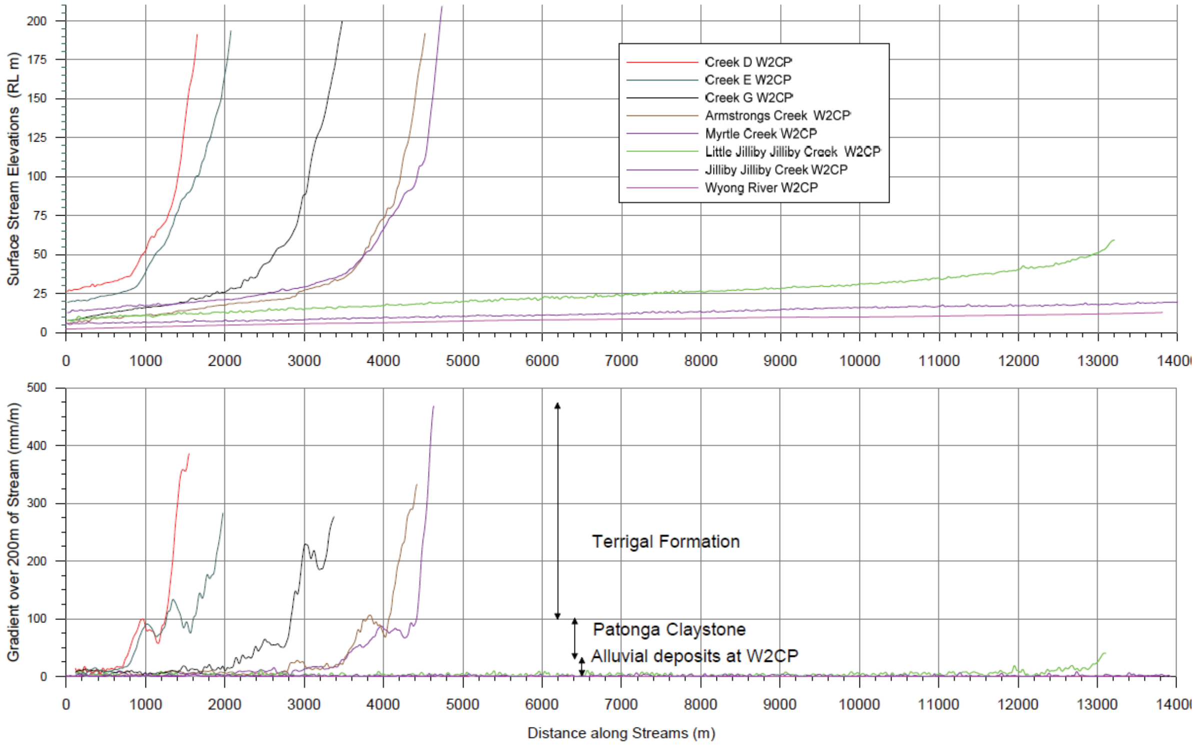

Fig. 2.2 Comparison of Steam Natural Profiles and Stream Gradients, measured over 200 metres lengths, within the *Study Area*

The smaller streams within the *Study Area* are ephemeral and are generally 1st and 2nd order streams, however, some of the lower reaches of these streams are 3rd order. These smaller streams have formed in the hills above and around the *Study Area* and are founded in the Terrigal Formation (upper reaches) and in the Patonga Formation (lower reaches). The beds of the smaller streams comprise alluvials and boulders, with the bedrock outcropping as benches in some locations. There were no significant standing pools identified along these smaller streams, as the natural gradients are too steep and since the Patonga Claystone is too weak for rockbars to form.

Detailed descriptions of the hydrology of *the Project* boundary are provided in the other specialist consultant reports and in the *Wallarah2 EIS*.

2.4.3. Aquifers and Known Groundwater Resources

Details on the aquifers and groundwater resources within the *Study Area* are provided in the report by Mackie (2013). Three principal groundwater systems have been identified within the region:-

- the unconsolidated surface alluvial aquifers within the Yarramalong and Dooralong Valleys and within the valley of Hue Hue Creek,
- the shallow weathered rock zone, and
- the more regional Narrabeen Group of sedimentary rocks overlying the Wallarah-Great Northern (WGN) seam.

Narrabeen Group is regarded as an aquifer only in the shallow weathered zone or in areas where secondary permeability has been induced through jointing and stress relief at shallower depths, more generally within the Terrigal Formation. For the greater part, however, strata within this group of rocks are considered to be aquitards (very poor groundwater transmission characteristics) or aquicludes (impermeable).

The groundwater resources within the *Study Area* are utilised, in some part, for water supply using bores and wells. The locations of these groundwater bores are shown in Drawing No. MSEC342-17 and details of these bores are provided in Section 2.7.11.

Mackie (2013) discusses the potential environmental impacts and consequences on the aquifers and groundwater resources.

2.4.4. Springs

There are no specific springs identified within the *Study Area*, however, minor natural springs or seeps may occur at the interfaces of certain strata, particularly in the southern facing (down-dip) slopes of the valleys, as described in the Wallarah 2 Hydromorphology Study Report (IEC 2012).

2.4.5. Seas or Lakes

There are no seas or lakes within the *Study Area*.

2.4.6. Shorelines

There are no shorelines within the *Study Area*, other than the shorelines associated with the streams, which were described in Section 2.4.2.

2.4.7. Natural Dams

There are no natural dams within the *Study Area*. There are, however, a number of farm dams within the *Study Area*, which are described in Section 2.7.10.

2.4.8. Cliffs and other Natural Rock Formations (not Construction or Excavation Sites)

For the purposes of this report, a cliff has been defined as a natural rock formation with a continuous rockface having a minimum height of 10 metres, a minimum length of 20 metres and a minimum slope of 2V to 1H, i.e. having a minimum angle to the horizontal of 63°. The locations of any possible cliff sites within the *Study Area* were determined after studying the 0.5 metre surface level contours which were generated from an airborne laser scan of the area. This determination revealed that there are no cliffs, according to this definition, within the *Study Area*.

There were, however, some isolated rock formations identified within the *Study Area*, which had slopes greater than a slope of 2V to 1H, heights less than 10 metres and lengths less than 10 metres, which were located up the sides of the Dooralong, Yarramalong and Little Jilliby Jilliby Creek Valleys. These isolated rock formations were also identified across the *Study Area* from the 0.5 metre surface level contours.

A quarry face has been identified within the *Study Area*, which is discussed in Section 2.8.3. This quarry is presently not in use although, it is possible that it may become active during the life of *the Project* and as such is considered in this assessment.

2.4.9. Steep Slopes

A number of areas containing steep slopes have been identified within the *Study Area*. The reason for identifying steep slopes is to highlight areas where the existing ground slopes may be marginally stable. For the purposes of this report, a steep slope has been defined as an area of land having a natural gradient that is less than a cliff but greater than 1V to 3H, i.e. a grade of 33 %, or an angle to the horizontal of 18°.

The minimum grade of 1 to 3 represents a slope that would generally be considered stable for natural ground consisting of rocky soils or loose rock fragments. Clearly the stability of natural slopes varies depending on their soil or rock types, and in many cases, natural slopes can be stable at much higher gradients than 1 to 3, for example talus slopes.

The areas of steep slopes with grades that are greater than 1V:3H have been identified from the 0.5 metre surface level contours which were generated from an airborne laser scan of the area, and the locations have been shown in Drawing No. MSEC515-09. This drawing shows the steep slope areas with grades between 1V:3H and 1V:2H in green, the steep slope areas with grades that are between 1V:2H and 1V:1.5H in blue, the steep slope areas with grades that are between 1V:1.5H and 1V:1H in red and the steep slope areas with grades that are greater than 1V:1H and less than 2V:1H are shown in yellow.

It can be seen from this drawing, that the steep slopes over the *Study Area* have natural grades typically between 1V:3H and 1V:1.5H, with more localised areas having natural grades between 1V:1.5H and 2V:1H on the sides of the Dooralong, Yarramalong and Little Jilliby Jilliby Creek Valleys which are located directly above the proposed longwalls.

Photographs of the Dooralong and Yarramalong Valleys are provided in Fig. 2.3 and Fig. 2.4, respectively.

Fig. 2.3 Photographs of the Dooralong Valley

Fig. 2.4 Photograph of the Yarramalong Valley

The distribution of the natural surface slopes within the *Study Area* is provided in Fig. 2.5.

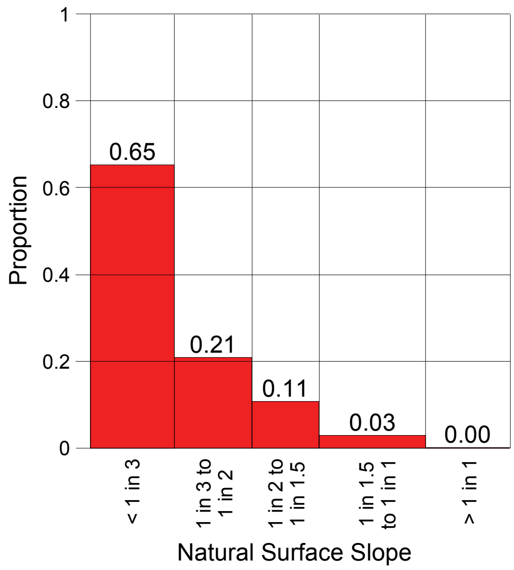

Fig. 2.5 Distribution of Natural Surface Slopes within the *Study Area*

The steep slopes within the *Study Area* are generally stabilised by the natural vegetation. The surface geology within the *Study Area* is discussed in Section 1.5.

2.4.10. Escarpments

There are no escarpments within the *Study Area*.

2.4.11. Land Prone to Flooding or Inundation

The land within the *Study Area* drains freely into the major streams within the *Study Area*.

The wide alluvial flats within the Dooralong Valley floodplain (containing the Jilliby Jilliby Creek, Little Jilliby Jilliby Creek and minor tributaries), the Yarramalong Valley floodplain (containing the Wyong River and tributaries) and the Hue Hue Creek floodplain are susceptible to inundation during major flood events (i.e. 1 in 100 year flood events).

The Yarramalong Valley floodplain is relatively narrow and the majority of it is classified as high hazard based on flood depths. The Dooralong Valley floodplain is wider and high hazard zones are mainly restricted to low lying areas adjacent to Jilliby Jilliby Creek and large farm dams. In the Hue Hue Creek floodplain flood depths are significantly less, as described in the report by GHA (2013)

2.4.12. Wetlands, Swamps and Water Related Ecosystems

There are no swamps or wetlands that have been identified within the *Study Area*. There are, however, water-related and groundwater dependant ecosystems within the *Study Area*, in particular, along the streams where there is a permanent source of water. These have been investigated and are described in the report by OzArk (2012a).

2.4.13. Threatened, Protected Species or Critical Habitats

There are no lands within the *Study Area* that have been declared as critical habitat under the *Threatened Species Conservation Act 1995*. Further, *the Project* has been referred to the Commonwealth Department of Sustainability, Environment, Water, Population and the Community (SEWPaC) in relation to the potential impacts on Matters of National Environmental Significance, namely Threatened species, populations and their communities. These are described in the report by OzArk (2012a).

2.4.14. National Parks or Wilderness Areas

There are no National Parks or any land identified as wilderness under the *Wilderness Act 1987* within the *Study Area*.

2.4.15. State Recreation Areas and Conservation Areas

The north-western portion of the *Study Area* is located within the Jilliby State Conservation Area. This area was initially part of Wyong State Forest and was created as a Conservation Area in July 2003. It covers an area of 12,159 hectares. Approximately 10 % of the Jilliby State Conservation Area is located within the *Study Area*.

2.4.16. State Forests

A portion of the north-western part of the *Study Area* is located within Wyong State Forest. Approximately 640 hectares of native vegetation within the proposed subsidence area occurs occur within the Wyong State Forest (OzArk, 2012a).

2.4.17. Natural Vegetation

The slopes of the Dooralong, Yarramalong and Little Jilliby Jilliby Creek Valleys have natural vegetation, which can be seen in Fig. 1.1. The land along the wide alluvial flats of the major streams has generally been cleared.

The descriptions of the natural vegetation within the *Study Area* are provided in the report by OzArk (2012a).

2.4.18. Areas of Significant Geological Interest

There are no areas of significant geological interest within the *Study Area*.

2.4.19. Any other Natural Feature Considered Significant

There are no other significant natural features within the *Study Area*.

2.5. Public Utilities

2.5.1. Railways

There are no railways within the *Study Area*. The closest railway is the Main Northern Railway, which is located at a distance of over 4 kilometres east of the proposed longwalls. This railway is not expected to experience any significant subsidence movements resulting from the extraction of the proposed longwalls.

2.5.2. Roads

The locations of the major roads within the *Study Area* are shown in Drawing No. MSEC515-12. A summary of these roads is provided in Table 2.3.

Table 2.3 Major Local Roads within the *Study Area*

Road	Location Relative to Longwalls
Brothers Road (fire trail)	Located directly above LW6S to LW10S
Cottesloe Road	Located directly above LW4N to LW7N
Dicksons Road	Located directly above LW5N to LW8N
Durren Road	Located directly above LW10N to LW13N
Jilliby Road	Located directly above LW11N to LW15N and LW2S to LW4S
Little Jilliby Road	Not directly mined beneath
Maculata Road	Located directly above LW15N and LW16N
Brothers Road (fire trail)	Located directly above LW6S to LW10S

The local roads are managed by the Wyong Shire Council and generally have bitumen seals or asphaltic pavements. Some of the minor local roads, fire trails and privately owned roads within the *Study Area* are unsealed. Photographs of some of the major local roads are provided in Fig. 2.6 to Fig. 2.8.

Fig. 2.6 Photograph of Jilliby Road

Fig. 2.7 Photograph of Parkridge Drive

Fig. 2.8 Photograph of Brothers Road (fire trail within Jilliby State Conservation Area)

The Sydney-Newcastle Freeway is situated is outside the *General Study Area*, as shown in Drawing No. MSEC515-12. The freeway is located at a distance of 1.1 kilometres south-east of Longwall 1N, at its closest point from the *Extraction Area*.

The freeway could experience very small far-field horizontal movements, resulting from the extraction of the proposed longwalls, however, it is unlikely that the freeway pavement itself would experience any adverse impacts as the result of the proposed mining. It is possible that the freeway bridges could be sensitive to the far-field horizontal movements, which are discussed in Section 2.5.3.

2.5.3. Bridges

There are a number of local road bridges that have been identified within the *Study Area*. The locations of these bridges are shown in Drawing No. MSEC515-12 and details are provided in Table 2.4. It is noted, that some of the bridges are in the process or are proposed to be upgraded.

Table 2.4 Local Road Bridges within the *Study Area*

Bridge Label	Crossing	Description
Bridge WR-B1	Boyds Lane over the Wyong River	Steel girder with timber deck
Bridge WR-B2	Private Road over the Wyong River	Steel girder with timber deck
Bridge LJ-B1	Jilliby Road over Little Jilliby Jilliby Creek	Concrete bridge
Bridge LJ-B2	Little Jilliby Road over Little Jilliby Jilliby Creek	Timber bridge (Heritage Site M)
Bridges LJ-B3 and LJ-B4	Little Jilliby Road over Little Jilliby Jilliby Creek	Timber bridge
Bridges JJ-B1 and JJ-B2	Durren Road over Jilliby Jilliby Creek	Concrete box culvert

Photographs of the local road bridges are provided in Fig. 2.9 to Fig. 2.11.

The freeway bridges in the vicinity of the proposed longwalls have been included as part of the assessments provided in this report.

Fig. 2.9 Photographs of Bridge WR-B1 – Boyds Lane over the Wyong River

Fig. 2.10 Photograph of Bridge LJ-B1 – Jilliby Road Bridge over Little Jilliby Jilliby Creek

Fig. 2.11 Photographs of Bridge LJ-B2 (Heritage Site M)
Little Jilliby Road Bridge over Little Jilliby Jilliby Creek

As mentioned above, the Sydney-Newcastle Freeway is located more than 1 kilometre outside the *General Study Area*. The bridges along the freeway could, however, be sensitive to the far-field horizontal movements resulting from the extraction of the proposed longwalls and, hence, these bridges have been included in the *Study Area*.

The closest freeway bridge is that over a small drainage line, which is located approximately 1.1 kilometres south-east of Longwall 1N. Other nearby bridges include the St. Johns Road underpass, which is located approximately 1.3 kilometres east of Longwall 1S, and the Sparks Road overbridge, which is located approximately 1.4 kilometres east of Longwall 1N. Photographs of the Sparks Road Bridge are provided in Fig. 2.12.

Fig. 2.12 Photographs of Sparks Road Bridge over the Sydney-Newcastle Freeway

2.5.4. Tunnels

There are no tunnels within the *Study Area*.

The closest tunnel to the *Study Area* is Boomerang Creek Tunnel, which transfers water from Mangrove Creek Dam to Bunning Creek, and then into the Wyong River. The Boomerang Creek Tunnel is located at a distance of approximately 5.8 km from the *Study Area* at its closest point and, therefore, is not expected to experience any adverse impacts as the result of *the Project*.

2.5.5. Drainage Culverts

Drainage culverts have been constructed where some of the local roads cross the drainage lines. The culverts vary from small circular culverts to large box culverts across the larger stream crossings.

The locations of the main culverts within the *Study Area* were identified from the aerial photograph of the area and from various site inspections. Further details on the culverts that are located within the *Study Area* were included from the report GHA (2013). The locations of all known culverts are shown in Drawing No. MSEC515-12.

2.5.6. Water, Gas or Sewerage Pipelines

The locations of the water and gas pipelines within and in the vicinity of the *Study Area* are shown in Drawing No. MSEC515-13. The descriptions of these pipelines are provided below:-

Water Pipelines

A short section of water pipeline is located within the eastern extent of the *Study Area*, which carries water from the Jilliby Hue Hue Pipeline to Treelands Drive Reservoir.

A section of the Jilliby Hue Hue Water Pipeline follows Hue Hue Road and is located just outside and to the east of the *General Study Area*. This pipeline could experience small far-field horizontal movements, resulting from *the Project*; however, it is unlikely that it would experience any adverse impacts as the result of *the Project*.

The Hunter Water Corporation Pipeline follows the Sydney-Newcastle Freeway and Sparks Road and is located at a minimum distance of 1.7 kilometres east of Longwall 1N, at its closest point to the *Extraction Area*. This pipeline could experience small far-field horizontal movements, resulting from the extraction of the proposed longwalls, however, it is unlikely that it would experience any adverse impacts.

The Gosford City and Wyong Shire Councils recently constructed the Mardi-Mangrove Link pipelines as a key element of their long term water supply strategy for the Central Coast. The Mardi-Mangrove Link system was an initiative of with Australian Government from the Water Smart Australia Program. The Mardi-Mangrove Link system was completed in 2011. Two pipelines were involved one to link the Wyong River to Mardi Dam and the other to link the Mardi Dam to Mangrove Creek Dam.

The new Mardi-Mangrove Transfer Main pipeline was designed with a minimum diameter of 1000 mm and is approximately 19 kilometres long linking the Mardi Dam with the end of the existing Boomerang Creek Tunnel (which leads to Mangrove Creek Dam). This rising main pipeline allows water to flow in either direction according to operational needs.

The alignment of this Mardi-Mangrove Transfer Main pipeline is shown in Drawing MSEC515-13 and a part of the pipeline is located on the *Study Area* boundary, and the distance from the nearest edge of the *Extraction Area* to the pipeline is about 370 metres.

The majority of the pipeline is in private property and constructed using open trenching. However, there are sections of the route where the pipeline was constructed in the road reserve of the Yarramalong Road where there are a number of river crossings.

The other pipeline is a new rising main water pipeline has been constructed from the Wyong River Pumping Station to Mardi Dam. This pipeline is located outside the *General Study Area*, some 2.5 km to the south-east and, therefore, is not expected to experience any adverse impacts as the result of *the Project*.

Oil and Gas Pipeline

There are no oil or gas pipelines located within the *Study Area*.

The Sydney to Newcastle Oil and Gas Pipeline is located on the eastern side of the Sydney-Newcastle Freeway and parallels the freeway in this area. The pipeline is located at a distance of 1.1 kilometres south-east of Longwall 1N, at its closest point from the proposed longwalls. The pipeline could experience small far-field horizontal movements, resulting from the extraction of the proposed longwalls, however, it is unlikely that it would experience any adverse impacts as the result of *the Project*.

Sewerage Pipelines

There are no public sewerage pipelines in the *Study Area*.

2.5.7. Liquid Fuel Pipelines

There are no liquid fuel pipelines within the *Study Area*.

2.5.8. Electrical Services

There are two 330 kV transmission lines (Lines 21 and 22) which cross the *Study Area*, the locations of which are shown in Drawing No. MSEC515-14.

There are a total of 29 transmission towers within the *Study Area*, which are labelled in Drawing No. MSEC515-14, and the details of these towers are provided in Table 2.5.

Table 2.5 330 kV Transmission Towers within the *Study Area*

Line	Tower ID	Type	Approximate Change in Angle (deg)	Approximate Surface Level (m AHD)	Approximate Span between Towers (m)
Line 21	21-53-T	Tension	5	132	-
	21-52-S	Suspension	-	167	267
	21-51-S	Suspension	-	194	413
	21-50-T	Tension	< 5	235	555
	21-49-T	Tension	< 5	143	387
	21-48-T	Tension	< 5	154	447
	21-47-T	Tension	5	180	1235
	21-46-T	Tension	5	215	1111
	21-45-T	Tension	10	43	903
	21-44-T	Tension	50	42	377
	21-43-S	Suspension	-	41	404
	21-42-S	Suspension	-	50	282
	21-41-S	Suspension	-	38	437
	21-40-S	Suspension	-	38	434
	21-39-S	Suspension	-	49	380
	21-38-T	Tension	20	68	331
	21-37-S	Suspension	-	54	430
	21-36-S	Suspension	-	41	496
Line 22	22-56-S	Suspension	-	233	-
	22-55-S	Suspension	-	216	327
	22-54-S	Suspension	-	219	284
	22-53-T	Tension	5	196	264
	22-52-T	Tension	40	231	1002
	22-51-T	Tension	< 5	216	668
	22-50-T	Tension	5	172	812
	22-49-T	Tension	10	93	474
	22-48-S	Suspension	-	54	557
	22-47-S	Suspension	-	56	260
	22-46-S	Suspension	-	43	457

Photographs of some of the towers along these transmission lines are presented in Fig. 2.13 and Fig. 2.14.

Fig. 2.13 Photographs of Transmission Towers within the *Study Area*

Fig. 2.14 Photographs of Transmission Towers within the *Study Area*

The towers are 330 kV single circuit latticed steel towers that are approximately 30 metres high. A third transmission line (Line 25) is located just outside the *Study Area* and is at a distance of 470 metres north of the commencing end of Longwall 1N, at its closest point to the proposed longwalls.

A 132 kV transmission line is located outside the *Study Area* at a distance of 950 metres east of Longwall 1N, at its closest point to the proposed longwalls.

There are also aerial powerlines within the *Study Area*, the locations of which are shown in Drawing No. MSEC515-14.

A local substation is located near the intersection of Jilliby and Little Jilliby Roads as shown in Drawing No. MSEC515-14. The substation is located between the northern and south-eastern series of longwalls and is 250 metres north of Longwall 5S, at its closest point to the proposed longwalls.

2.5.9. Telecommunication Services

The locations of the telecommunications infrastructure within and adjacent to the *Study Area* are shown in Drawing No. MSEC515-15. The telecommunications infrastructure includes direct buried optical fibre cables, direct buried and aerial copper cables and a Cellular Mobile Telephone Services (CMTS) site.

A Telstra optical fibre cable is located directly above the proposed longwalls and follows a similar alignment as Jilliby Road within the *Study Area*. The total length of cable located directly above the proposed longwalls is approximately 4.2 kilometres.

There is a Telstra optical fibre cable located immediately south of the *Study Area* which follows the alignment of Yarramalong Road. This cable is located at a minimum distance of 400 metres from the proposed longwalls.

There are Telstra and NextGen optical fibre cables located immediately east of the *Study Area* which follow the alignment of Hue Hue Road. There is also an Optus optical fibre cable further east which follows the alignment of the Sydney-Newcastle Freeway.

The Telstra CMTS site is located above the commencing end of Longwall 1N, which includes a GSM tower (Global System for Mobile) and a shed enclosure. An optical fibre cable connects this site with the main optical fibre cable along Hue Hue Road. A photograph of the CMTS site is provided in Fig. 2.15.

Fig. 2.15 Photograph of the CMTS Site

2.5.10. Water Tanks, Water and Sewerage Treatment Works

The rural properties within the *Study Area* have water storage tanks and on-site water systems. The locations of the above ground tanks within the *Study Area* are shown in Drawing No. MSEC515-19.

The Treelands Drive Reservoir tanks are located just inside the eastern extent of the *General Study Area* and are 300 metres east of the proposed Longwall 1S, at their closest point to the proposed longwalls. The locations of these tanks are shown in Drawing No. MSEC515-13.

2.5.11. Dams, Reservoirs and Associated Works

Apart from the abovementioned water tanks and the farm dams (refer to Section 2.7.10), there are no other public dams, reservoirs or associated works within the *Study Area*.

2.5.12. Air Strips

There are no air strips within the *Study Area*.

2.5.13. Any Other Public Utilities

There are no other public utilities within the *Study Area*.

2.6. Public Amenities

2.6.1. Hospitals

There are no hospitals within the *Study Area*.

2.6.2. Places of Worship

There are no places of worship within the *Study Area*.

2.6.3. Schools

The Jilliby Public School is located between the northern and south-eastern series of longwalls and is at a distance of 250 metres north of Longwall 5S, at its closest point to the proposed longwalls. The location of this school is shown in Drawing No. MSEC515-20.

2.6.4. Shopping Centres

There are no shopping centres within the *Study Area*.

2.6.5. Community Centres

A scout camp is located on the northern end of Brothers Road. This property is used for camping and has a covered all weather shelter on a concrete slab, a small area that can be locked in the shelter and outdoor toilets for the campers. The location of this site is shown in Drawing No. MSEC515-20.

2.6.6. Office Buildings

There are no office buildings within the *Study Area*.

2.6.7. Swimming Pools

There are no public swimming pools within the *Study Area*. There are, however, a number of privately owned swimming pools within the *Study Area*, which are described in Section 2.13.5.

2.6.8. Bowling Greens

There are no bowling greens within the *Study Area*.

2.6.9. Ovals or Cricket Grounds

There are no ovals or cricket grounds within the *Study Area*.

2.6.10. Racecourses

There are no racecourses within the *Study Area*.

2.6.11. Golf Courses

There are no golf courses within the *Study Area*.

2.6.12. Tennis Courts

There are no public tennis courts within the *Study Area*. There are, however, a number of privately owned tennis courts within the *Study Area*, which are described in Section 2.13.5.

2.6.13. Any Other Public Amenities

There are no other public amenities within the *Study Area*.

2.7. Farm Land or Facilities

2.7.1. Agricultural Utilisation and Agriculture Improvements

The land on the wide alluvial flats within the *Study Area* is predominantly cleared pasture, which is mainly used for agricultural and residential purposes.

The dominant agricultural activity in the valleys is intensive grazing, although turf farming is also common in the more fertile areas near the Wyong River and Jilliby Jilliby Creek. Over the last 20 years large holdings have been fragmented and converted to hobby farms, rural weekend retreats, market gardens, nurseries, horse studs and turf farms. As a result the character is rural rather than agricultural.

The features on the rural properties are described in the following sections.

2.7.2. Farm Buildings and Sheds

There are 755 rural building structures that have been identified within the *Study Area*, which includes sheds, garages, gazebos, pergolas, greenhouses, playhouses, shade structures and other non-residential building structures.

The locations of the rural building structures are shown in Drawing No. MSEC515-19 and details are provided in Table D.02, in Appendix D. The locations and sizes of the rural building structures were determined from the 2007 and 2011 aerial photographs of the area. It is likely that additional rural building structures will be constructed prior to the commencement of mining.

2.7.3. Farm Tanks

There are privately owned water tanks on the rural properties within the *Study Area*, which are described in Section 2.5.13.

2.7.4. Farm Gas and Fuel Storages

There are privately owned gas and fuel storages on the rural properties within the *Study Area*.

2.7.5. Poultry Sheds

There are no large poultry sheds within the *Study Area*.

2.7.6. Farm Glass Houses

There are no large glasshouses within the *Study Area*. There are, however, some small greenhouses on the rural properties within the *Study Area*.

2.7.7. Hydroponic Systems

There are no known large hydroponic systems within the *Study Area*.

2.7.8. Farm Irrigation Systems

Some rural properties and turf businesses within the *Study Area* have irrigation systems consisting of pipes and sprinkler systems.

2.7.9. Farm Fences

There are a number of farm fences within the *Study Area*. The majority of fences mark property boundaries and have been constructed using timber or steel posts, with fencing wire or timber railings. There are other fences within the properties within the *Study Area*, around in-ground pools and enclosures that contain livestock and pets.

2.7.10. Farm Dams

There are 420 farm dams that have been identified within the *Study Area*. The locations of the farm dams are shown in Drawing No. MSEC515-19 and details are provided in Table D.03, in Appendix D. The locations and sizes of the farm dams were determined from the 2007 and 2011 aerial photographs of the area. It is likely that additional farm dams will be constructed prior to the commencement of mining.

The dams are typically of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. The distributions of the longest lengths and surface areas of the farm dams within the *Study Area* are shown in Fig. 2.16.

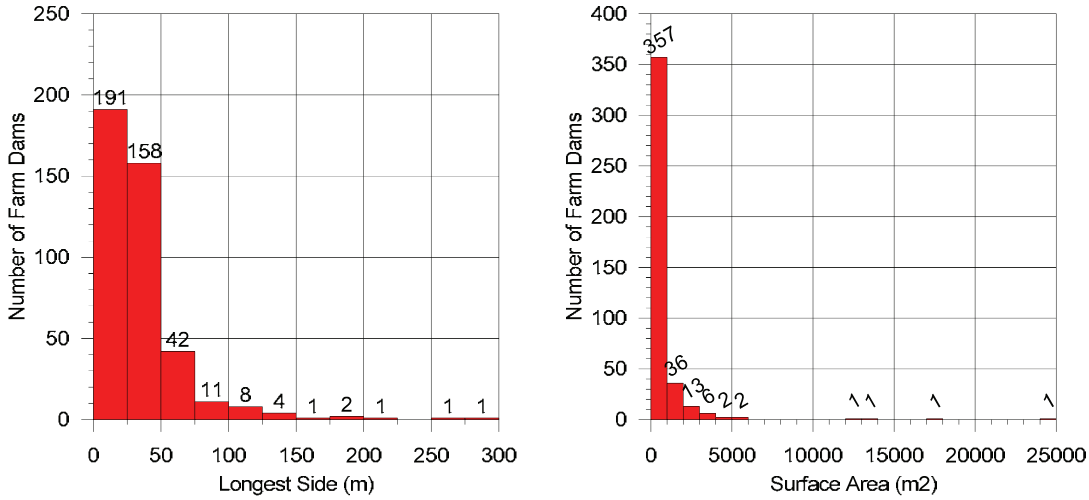

Fig. 2.16 Distributions of Longest Lengths and Surface Areas of the Farm Dams

2.7.11. Wells and Bores

There are 13 registered groundwater bores within the *General Study Area*. The locations of these bores are shown in Drawing No. MSEC515-17 and details are provided in Table 2.6.

Table 2.6 Registered Groundwater Bores within the *General Study Area*

Bore ID	Approximate MGA Easting (m)	Approximate MGA Northing (m)	Intended Purpose(s)
GW028035	348850	6318475	Farming
GW033297	349025	6321300	Domestic
GW051560	348275	6323125	Stock
GW056521	345800	6321400	Domestic stock
GW058390	345675	6321250	Domestic
GW058391	345825	6321425	Domestic
GW058392	345900	6321650	Domestic
GW059092	349175	6320825	Irrigation
GW078221	349125	6319450	Commercial
GW078609	348975	6323850	Domestic stock
GW080608	349625	6321475	Domestic stock
GW200211	342975	6320550	Domestic stock
GW200505	351025	6322200	Domestic stock

The locations and details of the registered groundwater bores were obtained from the Department of Natural Resources using the *Natural Resource Atlas* website (NRAtlas, 2011).

Further descriptions of the registered groundwater bores are provided in the report by Mackie (2013).

2.7.12. Any Other Farm Features

There are no other significant farm features within the *Study Area*.

2.8. Industrial, Commercial or Business Establishments

2.8.1. Factories

There are no factories within the *Study Area*.

2.8.2. Workshops

There are no workshops within the *Study Area*.

2.8.3. Business or Commercial Establishments or Improvements

One quarry site has been identified within the *Study Area*, above Longwalls 14N and 15N, the location of which is shown in Drawing No. MSEC515-20. This quarry currently appears to be disused, however, it is possible that this quarry could be used at some time in the future. A photograph of the quarry site is provided in Fig. 2.17.

Fig. 2.17 View of the Disused Quarry from Jilliby Road

A number of other commercial establishments have been identified within the *Study Area*, including:-

- Linton Park and Parkview Horse Studs,
- Moonpar Nursery,
- Highland Park Aviary, and
- Dooralong Valley Turf Farm.

The locations of these commercial establishments are shown in Drawing No. MSEC515-20.

2.8.4. Commercial Gas or Fuel Storages and Associated Plant

There are no commercial gas or fuel storages or associated plant within the *Study Area*.

2.8.5. Commercial Waste Storages and Associated Plant

There are no waste storages or associated plant within the *Study Area*. The closest commercial waste storage is the Wyong Council's *Buttonderry Waste Management Facility*, which is located approximately 1.1 kilometres north-east of Longwall 1N, at its closest point to the proposed longwalls.

2.8.6. Commercial Buildings, Equipment or Operations that are Sensitive to Surface Movements

There are no known commercial buildings, equipment or operations that are sensitive to surface movements (i.e. equipment that requires tight operational tolerances) within the *Study Area*.

2.8.7. Surface Mining (Open Cut) Voids and Rehabilitated Areas

One disused quarry site has been identified within the *Study Area*, which is discussed in Section 2.8.3. There are no other quarries, open cut mines or rehabilitation areas within the *Study Area*.

2.8.8. Mine Infrastructure Including Tailings Dams and Emplacement Areas

There is no mine infrastructure within the *Study Area*.

2.8.9. Any Other Industrial, Commercial or Business Features

There are no other identified industrial, commercial or business features within the *Study Area*.

2.9. Items of Archaeological Significance

There are no lands within the *Study Area* declared as an Aboriginal Place under the *National Parks and Wildlife Act 1974*.

The locations of the archaeological sites within the *Study Area* were identified by OzArk (2012b) using the Department of Environment and Climate Change Aboriginal Heritage Information Management System and site investigations. A total of 27 archaeological sites were identified, the locations of which are shown in Drawing No. MSEC515-16 and details are provided in Table 2.7.

Table 2.7 Archaeological Sites within the *Study Area*

Site ID	Site Type
45-3-3040	Axe-grinding Groove
45-3-3041	Axe-grinding Groove
45-3-3041 a	Axe-grinding Groove
45-3-3041 b	Axe-grinding Groove
45-3-3041 c	Axe-grinding Groove
45-3-3042	Axe-grinding Groove
45-3-3042 a	Axe-grinding Groove
45-3-3042 b	Axe-grinding Groove
WC-OS1	Open Camp Site
WC-OS2 a	Open Camp Site
WC-OS2 b	Open Camp Site
WC-OS2 c	Open Camp Site
WC-OS2 d	Open Camp Site
WC-OS2 e	Open Camp Site
WC-OS2 f	Open Camp Site
WC-OS2 g	Open Camp Site
WC-OS2 h	Open Camp Site
WC-OS2 i	Open Camp Site
WC-OS2 j	Open Camp Site
WC-OS2 k	Open Camp Site
WC-OS2 l	Open Camp Site
WC-ST1	Aboriginal Modified Tree
WSF-AG2	Axe-grinding groove site
WSF-AG3	Axe-grinding groove site
WSF-AG4	Axe-grinding groove site
WSF-AG1	Axe-grinding groove site
WC-IF1	Isolated Find

It is noted, that Sites WSF-AG1 and WSF-AG2 are located north of the *General Study Area*, however, as these sites are located along a creek line and could experience valley related movements they have, therefore, been included as part of the *Study Area*.

Further details are provided in OzArk (2012b).

2.10. Items of Historical or European Heritage Significance

There are no items of European heritage significance listed in the Australian Heritage Database that are located within the *Study Area*.

There are three heritage items listed in the Wyong Shire LEP 1991 (which includes all listings on the NSW Heritage Office inventory) that are located within the *General Study Area*. The locations of these items are shown in Drawing No. MSEC515-16 and details are provided Table 2.8.

Table 2.8 Heritage Sites within the *Study Area*

Site ID	Site Description	Level of Significance
Site 1	Brick and iron silo located south of Davenport Lane above Longwall 2S	Regional Significance
Site 3	The dwelling “Bangalow” which is located on the south-western corner of Longwall 5SW	Regional Significance
Site 11	Jilliby Public School, which is located between the northern and south-eastern series of longwalls	Local Significance

Further details on the Heritage Sites are provided in the report by OzArk (2012b).

OzArk (2012b) discussed some sites that were previously identified by ERM (2012) as additional items of Potential Heritage Significance within the *Study Area*. These items are shown in Drawing No. MSEC515-16 and details are provided in Table 2.9.

Table 2.9 Potential Heritage Sites within the *Study Area*

Site ID(s)	Site Description
Sites G, I, J, K, L, R and S	Dwellings
Site M	Little Jilliby Road Bridge
Site N	Bunya Pine
Site O	Keegan’s Silo
Site P	Picket fence on Durren Road
Site Q	Silos

Further details are provided in OzArk (2012b).

2.10.1. Items on the Register of the National Estate

There are no items on the *Register of National Estate* within the *Study Area*.

2.11. Items of Architectural Significance

There are no items of architectural significance within the *Study Area*.

2.12. Permanent Survey Control Marks

There are a number of survey control marks in the vicinity of the proposed longwalls, the locations of which are shown in Drawing No. MSEC515-18. There are 16 survey control marks have been identified within the *General Study Area*. The locations and details of the survey control marks were obtained from the *Land and Property Management Authority* using the *SCIMS Online* website (SCIMS, 2009).

2.13. Residential Establishments

2.13.1. Houses

There are 245 houses that have been identified within the *Study Area*. The locations of the houses are shown in Drawing No. MSEC515-19 and details are provided in Table D.01 in Appendix D. The locations and sizes of the houses were determined from the 2007 and 2011 aerial photographs of the area. The types of construction of the houses were determined from kerb side inspections. It is likely that additional houses will be constructed prior to the commencement of mining.

The distribution of the maximum plan dimensions of the houses within the *Study Area* is provided in Fig. 2.18. The distributions of the wall and footing constructions of the houses within the *Study Area* are provided in Fig. 2.19. The distribution of the natural surface slope at the houses within the *Study Area* is provided in Fig. 2.20.

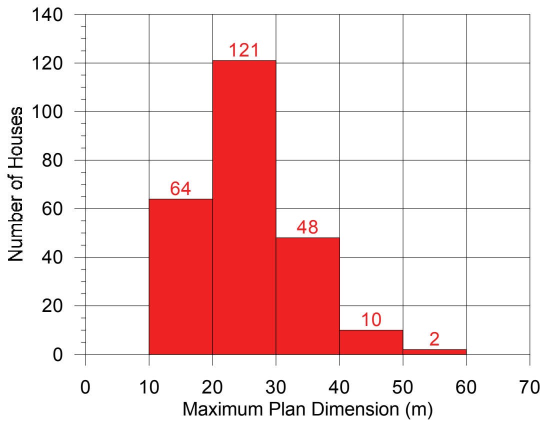

Fig. 2.18 Distribution of the Maximum Plan Dimension of Houses within the *Study Area*

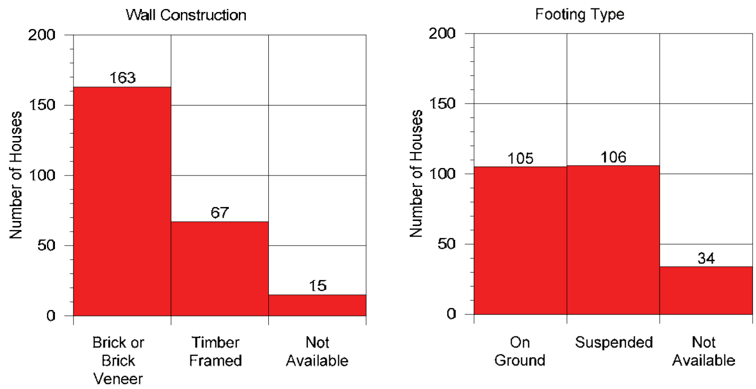

Fig. 2.19 Distributions of Wall and Footing Construction for Houses within the Study Area

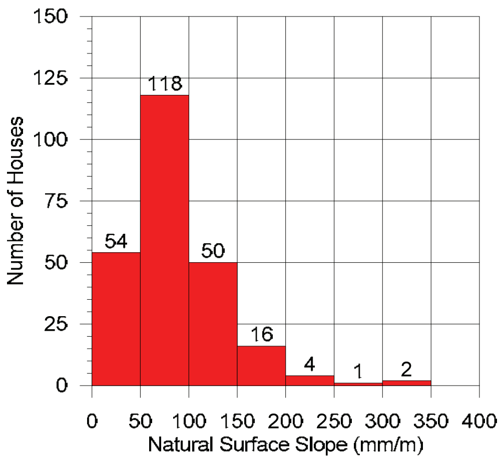

Fig. 2.20 Distribution of the Natural Surface Slope at the Houses within the Study Area

The houses within the *Study Area* are located within the *Hue Hue* and the *Wyong* Mine Subsidence Districts, which are shown in Drawing No. MSEC515-10. There are a total of 88 houses identified within the Hue Hue Mine Subsidence District, which was proclaimed on the 31st December 1985 and notified on the 31st January 1986. There are a total of 157 houses identified within the Wyong Mine Subsidence District, which was proclaimed on the 9th April 1997 and notified on the 18th April 1997.

2.13.2. Flats or Units

There are no flats or units within the *Study Area*.

2.13.3. Caravan Parks

There are no caravan parks within the *Study Area*.

2.13.4. Retirement or Aged Care Villages

There are no retirement or aged care villages within the *Study Area*.

2.13.5. Any Other Associated Structures

Descriptions of rural building structures and tanks are provided in Sections 2.7.2 and 2.7.3.

There are 496 water tanks that have been identified within the *Study Area*, the locations of which are shown in Drawing No. MSEC515-19. The locations and sizes of the tanks were determined from the 2007 and 2011 aerial photographs of the area. It is likely that additional tanks will be constructed prior to the commencement of mining.

There are privately owned gas and fuel storages on the rural properties within the *Study Area*.

There are 107 privately owned swimming pools which have been identified within the *Study Area*, of which 101 are in-ground pools and 6 are above ground pools. There are also 11 privately owned tennis courts which have been identified within the *Study Area*. The locations of these features are shown in Drawing No. MSEC515-19, which were determined from the 2007 and 2011 aerial photographs of the area. It is likely that additional swimming pools and tennis courts will be constructed prior to the commencement of mining.

The houses within the *Study Area* have on-site waste systems. Many of the houses within the *Study Area* also have concrete driveway pavements or footpaths.

2.13.6. Any Other Residential Feature

There are no other residential features identified within the *Study Area*.

2.14. Any Other Item

There are no other significant items within the *Study Area*.

2.15. Any Known Future Developments

It is likely that there will be future development of houses and possible future development of residential subdivisions within the *Study Area*.

3.0 OVERVIEW OF LONGWALL MINING, THE DEVELOPMENT OF SUBSIDENCE, AND THE METHODS USED TO PREDICT THE MINE SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS

3.1. Introduction

A separate detailed *Subsidence Prediction Report* (WACJV, 2012) has been prepared by the WACJV that presents the combined mine subsidence prediction research work that was undertaken by the WACJV, SCT and MSEC. This *Subsidence Prediction Report* (WACJV, 2012) is included as an appendix in the *Wallarah2 EIS*.

This *Subsidence Impact Report* (MSEC515), which is included as an appendix in the *Wallarah2 EIS*, has been prepared by MSEC to:-

- identify the natural features and items of surface infrastructure within the *Study Area*,
- calibrate the Incremental Profile Method, based on the numerical modelling advice from SCT, and undertake robust sensitivity analyses of these predictions,
- provide subsidence predictions for each natural feature and item of surface infrastructure using the calibrated Incremental Profile Method,
- provide impact assessments, in conjunction with other specialist consultants, for each of the identified natural features and items of surface infrastructure, and to
- provide a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset the subsidence impacts of *the Project*.

This chapter provides a brief overview of longwall mining, the development of mine subsidence and describes the specific subsidence prediction methods that have been used to predict the mine subsidence movements at *the Project*.

This *Subsidence Impact Report* has adopted some new terms and definitions that were first published in another Independent Inquiry report entitled "*Strategic Review of Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield",* (Southern Coalfields Inquiry Report), which was published in July 2008. The new terms and definitions draw a distinction between subsidence effects, subsidence impacts, environmental consequences, consequences, secondary consequences, conventional effects and non-conventional effects. These new terms and definitions were also published in an Independent Strategic Inquiry report into proposed coal mining activities in the Wyong Local Government Area, that was titled "*Strategic Review of Impacts of Potential Underground Coal Mining in the Wyong Local Government Area",* (Wyong Inquiry Report) as released in December 2008 (Independent Expert Panel, 2008) and in later reviews which further expanded on new mine subsidence terms and definitions. These new terms are detailed and referenced below;

- *"**Subsidence effects**: the deformation of the ground mass surrounding a mine due to the mining activity. The term is a broad one, and includes all mining-induced ground movements, including both vertical and horizontal displacement, tilt, strain and curvature."* [Glossary Section of the Southern Coalfields Inquiry Report].

  *"The term '**subsidence effects'** is used to describe subsidence itself – i.e. deformation of the ground mass caused by mining, including all mining-induced ground movements such as vertical and horizontal displacements and curvature as measured by tilts and strains."* [Section 2.8 of the Wyong Inquiry Report].

- *"**Subsidence impacts:** the physical changes to the ground and its surface caused by **subsidence effects.** These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs."* [Glossary Section of the Southern Coalfields Inquiry Report].

  *"The term **'subsidence impacts'** is used to describe the physical changes to the ground and its surface that may be caused by these subsidence effects. These impacts are principally surface depressions, tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence."* [Section 2.8 of the Wyong Inquiry Report].

- "***Environmental consequences:*** *the environmental consequences of* ***subsidence impacts,*** *including loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls, rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc*." [Glossary Section of the Southern Coalfields Inquiry Report].

  "The ***environmental consequences*** *of these impacts may include ponding, loss of groundwater, loss of surface flows to the subsurface, adverse water quality impacts, impacts on aquatic ecology, cliff falls, rock falls etc."* [Section 2.8 of the Wyong Inquiry Report]

  "The Southern Coalfield Inquiry defined the terms ***subsidence impact****,* ***subsidence effect*** *and* ***environmental consequence*** *in respect of subsidence and natural features. The Panel has extended the use of these terms to also include man-made structures and surface modifications. The term* ***effect*** *describes subsidence itself. Any physical change to the fabric or structure of the ground, its surface, or man-made features is described as an* ***impact****. The term* ***consequence*** *is used to describe any change in the amenity or function of a feature that arises from an* ***impact****. In turn, some* ***consequences*** *may give rise to secondary* ***consequences****."* [Section 3.2.1 The Metropolitan Coal Project PAC Inquiry Report, 2009].

- ***"Consequences*** *related to natural features are referred to as* ***environmental consequences****. By way of example, tensile strain due to the ground surface being 'stretched' as a result of undermining is an* ***effect****, a crack resulting from the tensile strain is an* ***impact****, loss of water down the crack is a* ***consequence****, and the drying of a water dependent ecosystem as a result of this loss of water is a* ***secondary consequence****. The latter two are included under* ***environmental consequences*** *in some contexts."* [Section 3.2.1 The Metropolitan Coal Project PAC Inquiry Report, 2009].

- "***Conventional*** *or general model of surface subsidence is based on the presence of straightforward and uniform site conditions, including:*

  - the surface topography is relatively flat and the seam is level,
  - the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities,
  - the mine workings are laid out on a regular pattern." [Section 4.1.2 of the Southern Coalfields Inquiry Report].

  "***Conventional*** *surface subsidence effects and their impacts are well understood and are readily and reasonably predictable by a variety of established method."* [Section 6 of the Southern Coalfields Inquiry Report].

  "The various subsidence parameters associated with this ***conventional****, or general, model of subsidence behaviour are sometimes referred to as the systematic components of subsidence, whist those associated with site-specific behaviours are referred to as non-systematic. This distinction in subsidence behaviour can be misleading since most site specific features also respond to undermining in a systematic manner. This Inquiry has maintained the convention of treating subsidence outcomes based on the* ***conventional*** *model of subsidence behaviour as being the standard or norm, and then adapting these to take account of variations created by the effects of the presence of specific natural features*". [Section 4.1.2 of the Southern Coalfields Inquiry Report].

  "Conventional *behaviour refers to the manner in which the surface responds to subsidence effects when the topography is flat, the coal seam is level and the geology is uniform and free of structural disturbances."* [Section 2.8 of the Wyong Inquiry Report].

  "In ***conventional*** *subsidence circumstances, a number of empirical, analytical and numerical subsidence prediction techniques are capable of producing reasonably accurate predictions of vertical displacement, typically within ±150 mm. The more noteworthy of these are the incremental subsidence prediction technique, the influence function technique and a number of numerical modelling codes. However, the accuracy of any subsidence prediction technique should never be taken for granted. All depend to some extent on input parameters being representative of the specific site conditions." "Particular care has to be taken when predicting subsidence for a greenfields site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated."* [Section 2.8.6.1 of the Wyong Inquiry Report].

- *"Where conventional conditions are not met, surface subsidence effects may vary from those that would be predicted using the conventional model. Such subsidence effects are generally known as '**non-conventional'**,"* [Section 4.1.3 of the Southern Coalfields Inquiry Report]

  "*Prediction of some of the subsidence effects on specific features, such as valley closure, uplift and upsidence and far-field horizontal displacements, is being carried out by a number of specialist consultants and research institutions in New South Wales, although the science of such prediction, and hence its reliability, is at a far earlier stage than the prediction of **conventional** subsidence effects."* [Section 4.3.2 of the Southern Coalfields Inquiry Report]

  *"A number of the site conditions which are associated with **non-conventional** subsidence effects are present in the Southern Coalfield, in particular, valleys and gorges, locally-steep topography and geological features including faults and dykes"* [Section 6 of the Southern Coalfields Inquiry Report].

  "*The understanding of **non-conventional** surface subsidence effects (especially far-field horizontal movements, valley closure, upsidence and other topographical effects) is not as advanced. Both valley closure and upsidence are difficult to predict. Upsidence is a highly variable factor, particularly at the local scale, and is less predictable than valley closure. However, there is a rapidly developing database of **non-conventional** surface subsidence impacts in the Southern Coalfield which is being used to develop improved prediction. It is the Panel's view that these techniques are less advanced, and less reliable than those used for **conventional** subsidence."* [Section 6 of the Southern Coalfields Inquiry Report]

  *"Since unpredicted impacts of subsidence on rivers and significant streams in the Southern Coalfield first came to public attention, the coal mining industry has made significant advances in its understanding of and ability to predict **non-conventional** subsidence effects. The level of understanding which has resulted from this work leads this field internationally."* [Section 6 of the Southern Coalfields Inquiry Report].

  *"Coal mining companies should place more emphasis on identifying local major geological disturbances or discontinuities (especially faults and dykes) which may lead to **non-conventional** subsidence effects, and on accurately predicting the resultant so-called 'anomalous' subsidence impacts."* [Section 6 of the Southern Coalfields Inquiry Report]

  *"**Non-Conventional Surface Subsidence Effects;** The more common site specific variations to the conventional model of surface subsidence encountered in New South Wales that can affect surface subsidence relate to;*

  - *steep topography;*
  - *valleys and gorges;*
  - *far-field horizontal movements;*
  - *massive overburden strata; and*
  - *pillar foundation settlement or failure."* [Section 2.8.3 of the Wyong Inquiry Report].

This report follows the new terminology suggested in these Inquiry reports. The predicted values of subsidence, tilt, curvature, strain, as discussed in Chapters 3 to 5, are the **subsidence effects** that are referred to in these Inquiry reports. The predicted values of closure and upsidence, as discussed in Chapters 3 to 5, are **subsidence impacts** as referred to in these Inquiry reports.

Chapter 5 of this report assesses the **subsidence impacts, consequences, secondary consequences** and **environmental consequences** that are caused by the **subsidence effects**. Other consultants' reports also provide further discussions on the **subsidence impacts, consequences, secondary consequences** and **environmental consequences.**

3.2. Overview of Longwall Mining

WACJV proposes to extract coal within the *Extraction Area* using conventional longwall mining techniques. A generic cross-section through the immediate roof strata and along the length of a typical longwall, at the coal face, is shown in Fig. 3.1, which has been sketched by both MSEC and Hansen and Bailey.

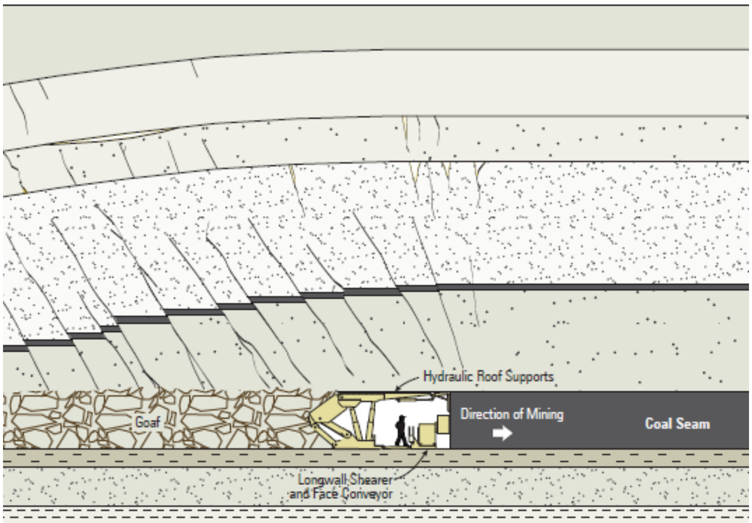

Fig. 3.1 Cross-section along the Length of a Typical Longwall at the Coal Face

The coal is removed by a shearer, which cuts the coal from the coal face on each pass as it traverses the width of the longwall. The roof at the coal face is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata, and provide a secure working space at the coal face. The coal is then transported by an armoured face conveyor belt which is located behind and beneath the shearer. As the coal is removed from each section of the coal face, the hydraulic supports are stepped forward, and the coal face progresses (retreats) along the length of the longwall.

The strata directly behind the hydraulic supports, immediately above the coal seam, collapses into the void that is left as the coal face retreats. The collapsed zone comprises loose blocks and generally contains large voids. Immediately above the collapsed zone, the strata remains relatively intact and bends into the void, resulting in new vertical factures, opening up of existing vertical fractures and bed separation. The amount of strata sagging, fracturing and bed separation reduces towards the surface.

At the surface, the ground subsides vertically as well as moving horizontally towards the centre of the mined goaf area. Some mining induced fractures can be observed on the surface.

The maximum subsidence at the surface varies, depending on a number of factors including longwall geometry, depth of cover, extracted seam thickness and overburden geology. Based on many years of subsidence monitoring over mined areas in the Sydney Basin, the maximum achievable subsidence in the NSW Coalfields is 65 % of the extracted seam thickness, for single-seam mining conditions.

Further details on longwall mining, the development of subsidence and the methods used to predict mine subsidence movements are provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

3.3. Overview of Conventional Subsidence Movements

The normal or conventional or systematic mine subsidence ground movements resulting from the extraction of longwalls are typically described by the following parameters:-

- **Subsidence** usually refers to vertical movement of a point, but 'subsidence of the ground' actually includes both a vertical and horizontal movement components. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm).* The **horizontal** component of subsidence can be measured as relative movement (mm) between adjacent pegs (2D surveys) or the absolute movements (mm) from fixed datum points (3D surveys).
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1,000.

- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km^{-1})*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.

- **Strain** is the relative differential horizontal displacement of the ground. Normal strain is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them, i.e. strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases.

  Slope strains have occasionally been determined, but, they should not be confused with the horizontal strains that are usually discussed when comparing mine subsidence issues. In most subsidence literature strain is expressed in units of *mm/m*. So that these mining induced strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining induced **normal strains** are measured **along** monitoring lines, ground **shearing** can also occur both vertically and horizontally **across** the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured **along** subsidence monitoring lines, however, differential ground movements can also be measured **across** monitoring lines using 3D survey monitoring techniques.

  Transient horizontal ground movement patterns vary across and along longwalls as the travelling face approaches and passes beneath a point and predicting these movement patterns is extremely complex. Accordingly to the rigorous definitions, it is not possible to measure **horizontal shear strains** using 3D survey data from a straight line of survey points.

- **Horizontal shear deformations** across monitoring lines can be measured and these are described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is difficult to compare observed horizontal shear deformations for monitoring lines that were not installed in straight lines parallel or perpendicular to mined panels, as the initial orientations of the monitoring lines affect the magnitudes and directions of observed horizontal ground measurements. It is easier to compare measured ground deformations after they have been translated into movements parallel or movements perpendicular to the mined panel.

  High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations), and vice versa.

A cross-section through a typical single longwall panel showing typical profiles of conventional subsidence, tilt, curvature and strain is provided in Fig. 3.2.

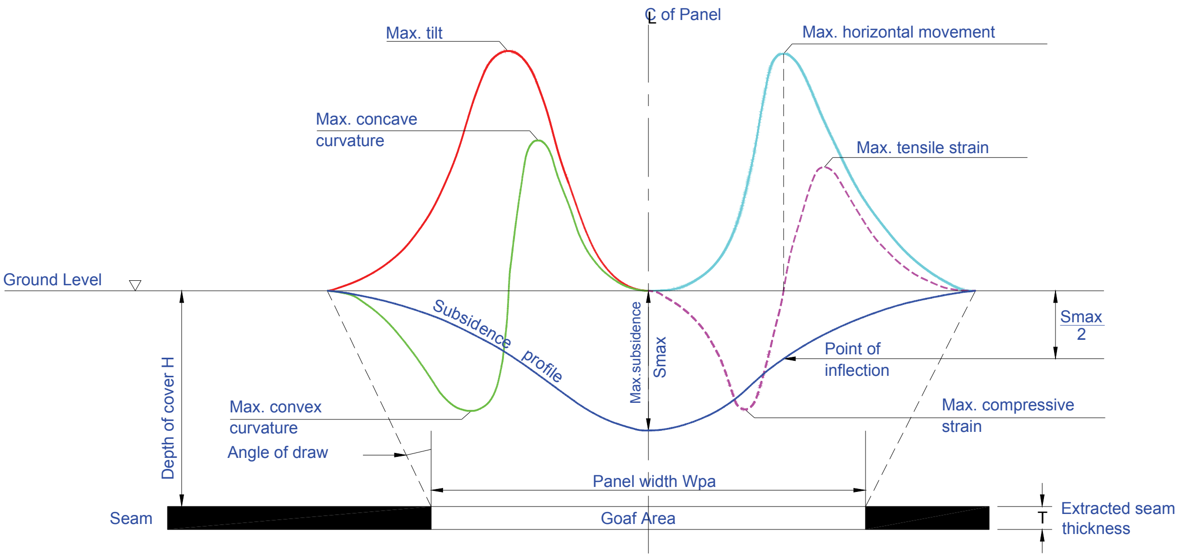

Fig. 3.2 Typical Profiles of Conventional Subsidence Parameters for a Single Longwall Panel

Where both vertical and horizontal movements of pegs are measured, usually, the vertical subsidence movement is greater than the horizontal movement for those pegs that are located over the extracted longwall panel. Where the vertical subsidence is very small, and particularly at those pegs that are located well beyond the panel edges and over solid unmined coal areas, the measured horizontal movement at the pegs can be much greater than the vertical movement.

3.4. Vertical Subsidence Movements

The magnitude of the maximum vertical subsidence at the surface will vary depending on a number of factors including the longwall panel and pillar widths, the chain pillar stability, the presence of nearby previously extracted mined panels, the depth of cover, the extracted seam thickness, the geology of the strata layers between the surface and coal seam and on the geology of the strata layers in the floor below the seam.

The maximum subsidence normally observed in the Newcastle Coalfield, i.e. where there are often relatively strong and massive conglomerate and sandstone strata units present, is typically between 55 % and 60 % of the extracted seam thickness, for single seam extractions, which is lower than the 65% of the extracted seam thickness observed in the Southern Coalfield. These maximum subsidence percentages would be observed where ever the widths of the panels are supercritical, i.e. greater than 1.4 times the depths of cover. Lower levels of subsidence would be observed where the panels are sub-critical and unmined coal left in chain pillars reduces the levels of the observed subsidence.

For information on the combined mine subsidence prediction research work that was undertaken by the WACJV, SCT and MSEC for *the Project,* refer to the separate detailed *Subsidence Prediction Report* (WACJV, 2012).

After the combined mine subsidence prediction research work was completed MSEC then applied the results of the new subsidence model at all natural features, structures and infrastructure sites that are located over the *Study Area.*

3.5. Horizontal Subsidence Movements

The predictions of mining induced horizontal movements are not as accurate as the predictions of vertical movements. Studies have shown that the magnitudes of the absolute horizontal displacements can be estimated in the Newcastle Coalfield, from the predicted tilt profiles, by applying a tilt-to-horizontal displacement factor of 15, and it is generally assumed that these movements are generally directed towards the centre of the mined longwall panel, as shown in Fig. 3.3.

Considering the relationship between mining induced bending curvature of a surface strata layer and horizontal strain on the surface, it can be deduced that a tilt-to-horizontal displacement factor of 15, equates to the bending in a surface strata beam of 30 metres depth bending about its centre line. This general rule is considered approximate only since the observed mining-induced horizontal movements showed considerable scatter in magnitude from these estimates and, the observed movements are not always directed towards the centre of the mined panel. It was recognised that applying this factor was more accurate for predicting the maximum value of horizontal movements over a panel than in predicting the lower values of mining-induced horizontal movements and it was accepted that many other variables had also been found to influence mining induced horizontal movements.

The understanding of mining induced horizontal ground movements is improving with developments in the monitoring techniques to measure the magnitude, direction, and lateral extent of mining induced horizontal ground movements. The early subsidence monitoring involved the two dimensional measurement of vertical displacement and differential horizontal movements in one direction. Improvements in three dimensional monitoring, stress change monitoring, high resolution surveying techniques, GPS technology and satellite based differential interferometry using synthetic aperture radar (DinSAR) are providing a much better basis for understanding the extent and the mechanics of the mining induced horizontal ground movements.

With the development of accurate three dimensional surveying techniques, horizontal mining induced movements are now routinely observed to extend well beyond measureable vertical subsidence movements and the distances defined by the 26.5 degree angle of draw. It has now been found that the magnitude of mining-induced horizontal movements and the direction of these horizontal movements are controlled by a complex interaction of multiple factors, including the magnitude of the vertical subsidence, the presence of previously extracted panels, the depth of cover, the location of the survey peg relative to the extracted voids, the surface topography, the strata thicknesses and geology and the magnitude and direction of the in-situ horizontal stresses.

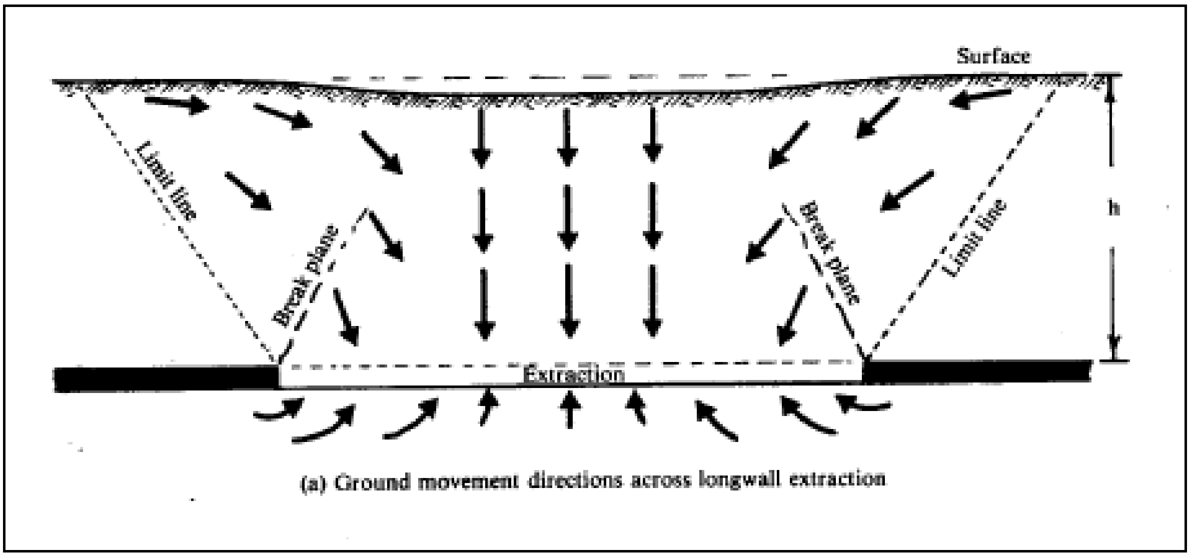

Fig. 3.3 Normal Mining Induced Movements above an Extracted Area (after Whittaker, Reddish and Fitzpatrick, 1985)

Before the year 2000, it was not common to have survey control for mine subsidence monitoring only extending about one depth of cover or a few hundred metres from the edges of the approaching longwall goaf because of the challenges associated with maintaining survey accuracy over large distances. Now an array of bench marks is established around the area being subsided with far more accurate equipment and surveying techniques. Anderson et al (2007) describe the current use of concentric networks of survey control remote from mining and located on all sides of the mining areas. While it took some years before GPS technology became readily available and was able to be routinely used for subsidence monitoring at a high enough resolution, the effect has been profound. After survey control was established all around a mining area it became apparent that there was a need for reconciliation of small horizontal movements at either end of these early subsidence lines.

In flat terrain the vertical subsidence movements that are observed directly over extracted longwall panels are generally greater than the horizontal ground movements. The magnitude of the observed horizontal movements over the extracted panels represent about 30% of the vertical movements and the pegs are observed to move in changing directions with time as a longwall face first approaches, passes underneath and then moves beyond a point.

Mining induced horizontal movements have been recorded in all directions but typically they occur in the direction toward the active mining and, in non-convention conditions of steep terrain, additional down slope movements are common. Outside the longwall panel boundaries though the mining induced horizontal ground movements are often found to be greater than the vertical ground movements. Near the edge of the panel, the mining induced horizontal ground movements are typically observed to be about twice the magnitude of the observed vertical movements at that survey peg. In areas further away and beyond the boundaries of the *General Study Area*, and horizontal ground movements tend to be many times the magnitude of the observed vertical subsidence movements. Small uniform horizontal movements have been measured kilometres from the edges of some panels in certain conditions. These small mining induced horizontal ground movements are called far-field movements and these regional, remote or far-field movements tend to be small, uniform and have low associated tilts and strains.

The three main mechanisms have been recognised to contribute to the observed magnitude and direction of the mining induced horizontal ground movements and the measured movements are a combination of all three of these mechanisms in greater or lesser proportions depending on the site conditions:

- Conventional horizontal movement that occurs generally toward the subsidence trough associated with the bending curvature of the overburden strata beams directly over an extracted longwall panel, typically, estimated with tilt-horizontal movement factors of 10 to 15 depending on geological conditions,
- Stress relief of the overburden strata toward the extracted panel, which are very dependent on the levels of in-situ horizontal stress that are locked in the various overburden layers, the goaf height goaf relative to the depth of cover and extent of interlocking or friction resistance between these layers, and
- Horizontal movements toward topographic low points in a downslope direction, (i.e. steep slope and valley closure movements, which include vertical and horizontal components), caused by in-situ stress relief and re-distribution, by strata dilation along vertical joints/fractures and by block rotation mechanism within the overburden.

Although the prediction of vertical subsidence can be undertaken with reasonable accuracy the prediction of mining-induced horizontal ground movements is far less accurate when based on tilt-horizontal movement factors only. Previous studies have shown that this horizontal ground displacement prediction method is only approximate and, whilst it tends to be conservative where the tilts are high, it tends to underestimate the horizontal movements where the tilts are low. When comparing the predicted and observed horizontal movements over many longwalls, it becomes apparent that these approximate horizontal movement predictions are most accurate in conventional conditions, i.e. above simple mine layouts with consistent geological conditions and uniform extracted coal seam thicknesses under flat surface terrains.

Increased magnitudes of horizontal movements are generally observed when non-conventional conditions occur, i.e. where steep slopes or surface incisions exist, as these natural topographic features influence both the magnitude and the direction of horizontal ground movement patterns. Similarly, increased levels of observed horizontal movements are often measured around sudden changes in geology, or where blocks of coal are left between longwalls or near other previously extracted series of longwalls.

The observed far-field horizontal movements beyond the normal vertical subsidence limits of the extracted panels also tend to be higher than the predicted horizontal movements using the above approximate horizontal ground displacement prediction method because these far-field horizontal movements are generated by the stress relief mechanism rather than the bending curvature of the overburden strata beams.

With ongoing monitoring, analysis and research of subsidence induced ground movements, an improved understanding of the influence of the various mechanisms that affect the observed mining induced horizontal displacements is continually being developed and more accurate horizontal movements may be predicted in the future by combining the predicted horizontal displacements from the varying components from each of these mechanisms.

As described previously, normal strains are the differential horizontal movements of the ground. Conventional ground strains can, therefore, be estimated by multiplying the ground curvature by the same factor used to determine absolute horizontal movement from tilt. That is, for the proposed longwalls, the maximum conventional ground strains can be estimated by applying a factor of 15 to the maximum conventional curvatures. However, like the prediction of horizontal movement, it should be noted that these horizontal strain predictions are not as accurate as the vertical predictions of subsidence and tilt.

To allow for the variability in the predicted horizontal movements and strains, a statistical approach has been used to provide the distributions of strain, rather than providing a single predicted conventional strain. As discussed in Section 4.3, the range of potential strains resulting from the extraction of the proposed longwalls are provided with the probabilities of exceedance of the various strain ranges, based on monitoring data from previously extracted longwalls in the Newcastle Coalfield.

It is generally accepted that vertical subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In many locations, ground movements of more than 20 mm have been observed due to moisture and climatic conditions. In the Newcastle Coalfield, if local data is not available, the cut-off-point or the limit of vertical subsidence is taken as a point on the surface defined by an angle of draw of 26½ degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the longwall goaf edges. Where local data exists and it can be shown that the angle is generally less than 26½ degrees, then, the lower angle of draw can be used.

3.6. Far-field Movements

As discussed above, far-field movements are the measured horizontal movements at survey pegs located beyond the longwall panel edges and over solid unmined coal areas that were generated by the release of in-situ horizontal stress.

Far-field horizontal movements tend to be small bodily movements towards the extracted goaf area. The measured far-field movements at survey pegs that are located beyond the longwall panel edges and over solid unmined coal areas are often much greater than the observed vertical movements at those pegs. An empirical database of observed horizontal movements has been developed which confirms this.

For example, at the location beyond the panel edges, where the predicted conventional vertical subsidence value is 20 mm, i.e. at a distance of about half of the depth of cover from the panel edges, horizontal movements of up to around 100 mm have been observed, with an average observed horizontal movement of approximately 40 mm.

These far-field horizontal movements are higher than the vertical movements beyond the longwall panel edges and over solid unmined coal since these movements are derived from two components. First there is the mining induced horizontal movement component caused by the mining induced bending curvature of the strata beds into the goaf areas plus, there is an additional component caused by a relief of the in situ horizontal compressive stresses in the strata around the longwalls. Further away from the longwalls and remote from the *General Study Area,* the observed far-field horizontal movements are believed to be predominantly a result of the in situ stress relief mechanism. Before mining these in situ stresses, which are generally compressive in all directions, are in equilibrium or balance. When mining occurs, the equilibrium is disturbed and the stresses achieve a new balance by shearing through the weaker strata units allowing the strata to move or expand towards the goaf areas, where the confining stresses have been relieved.

When large horizontal displacements are measured outside the *Extraction Area*, they are more likely to be a result of far-field movements than a result of the mining induced curvature mechanism. Far-field horizontal movements have been observed at considerable distances from extracted longwalls. Such stress relief movements are becoming more predictable and also occur whenever significant excavations occur at the surface or underground. The methods used to predict far-field horizontal movements have continued to develop in recent years using the current and available 3D monitoring data and the confidence levels in these predictions continue to improve.

Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. As such, these movements generally do not result in impacts on natural features or built environments, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In some cases increased higher levels of far-field horizontal movements are observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased observed horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls.

Far-field horizontal movements and the method used to predict such movements are described further in Sections 3.6 and 4.5.

The predicted 20 mm conventional vertical subsidence contour is shown in Drawing No. MSEC515-21. It can be seen on this drawing, that an area between the northern and south-eastern series of longwalls is predicted to experience less than 20 mm of vertical subsidence. It is possible that this area could experience slightly greater subsidence due to far-field vertical movements as the result of stress redistribution from the proposed mining on both sides of this area. It would not be expected, however, that this area would experience any significant tilts, curvatures or strains.

3.7. Overview of Non-Conventional Subsidence Movements and Irregular Subsidence Profiles

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata collapsing into a void. Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat. Unfortunately conventional conditions rarely occur in real mining cases.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near surface strata layers. Where the depth of cover is high, say greater than 400 metres, the observed subsidence profiles along monitored survey lines are generally smooth. Where the depth of cover is shallow, say less than 100 metres, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are accompanied with much higher tilts, curvatures and strains at very shallow depths of cover, where the collapsed zone above the extracted longwalls extends up to or near to the surface.

However, irregular subsidence movements are occasionally observed at the higher depths of cover along an otherwise smooth subsidence profile. The cause of these irregular subsidence movements can be associated with:-

- sudden or abrupt changes in geological conditions,
- steep topography, and
- valley related mechanisms.

These non-conventional movements due to geological conditions and valley related movements are discussed in the following sections.

3.7.1. Irregular Subsidence Movements caused by Changes in Geological Conditions

It is believed that most of the observed irregular subsidence ground movements are a result of the reaction of near surface strata to increased horizontal compressive stresses. Some of the geological conditions that are believed to influence these irregular subsidence movements are the blocky nature of near surface sedimentary strata layers and the possible presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts, curvatures and strains. Buckling of the bedrock can also occur.

Even though it may be possible to attribute a reason behind most observed conventional and non-conventional ground movements, there remain some observed irregular ground movements that still cannot be explained with the available geological and mining-induced behavioural understanding. The term "anomaly" is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained with by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.3 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural features and items of surface infrastructure, which are provided in Chapter 5, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

3.7.2. Valley Related Movements

Mining induced valley related movements, called upsidence and closure, are commonly observed in monitored mine subsidence data across river and creek alignments within the Southern Coalfield. Occasionally mining induced valley related movements have also been observed in mine subsidence data monitored in the Western, Newcastle and Hunter Coalfields.

These mining induced valley related movements are similar to the naturally occurring valley bulging movements that are often observed in areas where there are high in situ horizontal stresses. These natural valley formation movements, coupled with erosion events, result in the ongoing development of valleys as is illustrated in Fig. 3.4.

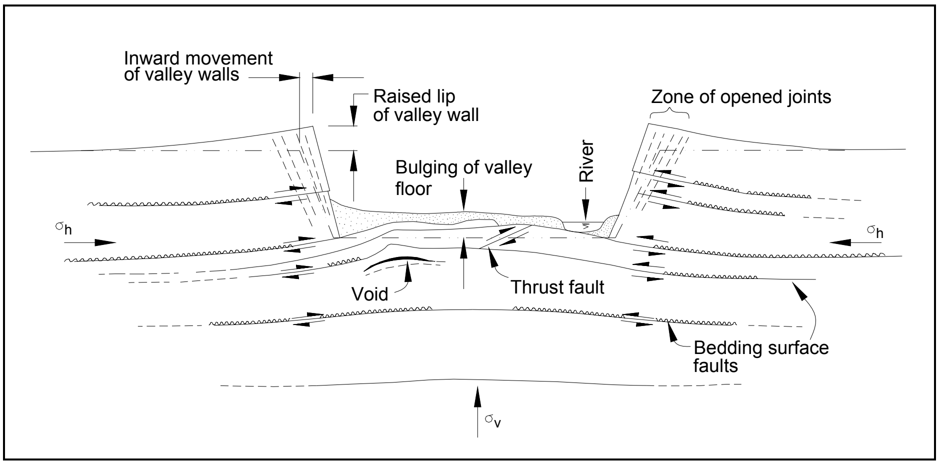

Fig. 3.4 Natural Valley Formation in Flat Lying Sedimentary Rocks (Patton and Hendren 1972)

These natural valley formation movements can be accelerated by coal mining and mine subsidence. Mining induced valley movements have similar effects and consequences as the natural valley bulging movements. The mechanisms that are involved in both the natural and mining induced valley related movements are very complex and are thought to be influenced by a number of factors, including dilation and down slope movements. However the principal factor appears to be associated with a redistribution of horizontal in situ stresses.

Coal was formed when ancient ferns, plants and trees died, and sank to the bottom of vast swamps, initially forming peat. Accumulations of thousands of metres of sand and clay materials and sediments over the peat over millions of years squeezed the water out and produced sufficient heat and pressure to transform the peat layers into coal seams and the soft sediments into sandstones and shales. The coal seams were therefore buried and formed at significantly greater depths than where they are found today and, at these depths, high vertical and horizontal stresses existed. As erosion has taken place over geologic time, the vertical (loading) stresses have been relieved but a component of the high horizontal stresses remain locked in the seams and surrounding strata. It is not uncommon in coalfield strata for the in-situ horizontal stresses to be up to three times greater than the vertical stress.

Steep, incised topography interrupts the transmission of horizontal stress, causing it to be redirected from the hills and into the floor of the valleys or gorges as discussed above and as is shown in Fig. 3.4. This can lead to overstressing of valley floors, with the near-surface rock strata uplifting under the effects of bending and buckling. The valley is deepened which, in turn, causes an increase in the horizontal stress redirected into the floor of the valley. This very slow, self-perpetuating natural valley formation process is also referred to as valley bulging. Field investigations have revealed that this process can result in the creation of voids beneath water courses, often in the form of open bedding planes which may act as underground flow paths for groundwater and stream water (Patton and Hendren, 1972, Fell et al, 1992, Everett et al, 1998, Waddington and Kay, 2002).

Mining causes further disruptions around valleys because it creates large voids at the coal seam and above the coal seam through which the horizontal stress can be released causing the surrounding rock mass to move horizontally towards the caved and fractured zones. The regional horizontal stress is redirected around the void and the valley floor as shown conceptually in Fig. 3.5, thereby increasing the stresses acting across the valley floor and resulting in the mining induced valley related movements.

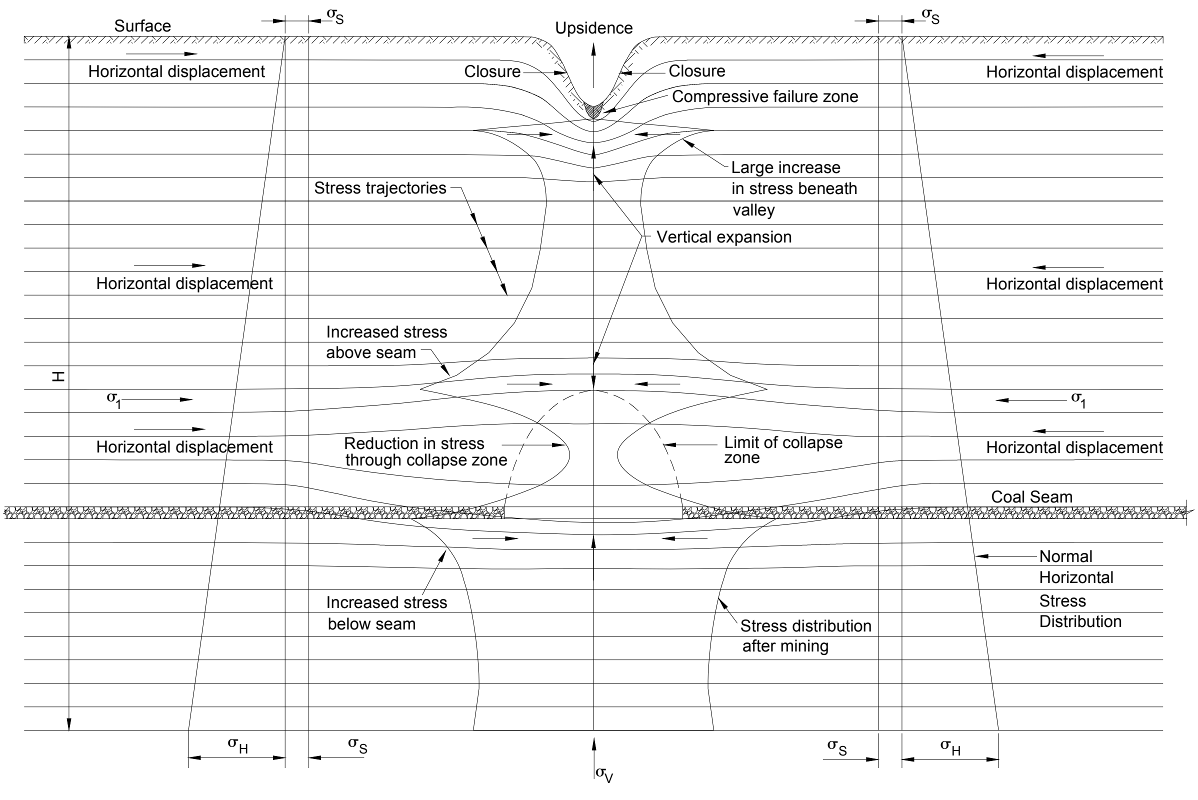

Fig. 3.5 Redistribution of In-situ Horizontal Stresses due to Mining beneath a Valley

Studies have shown that the observed upsidence and closure movements increase with increased mining induced vertical subsidence, when the mined panel is directly underneath the valley, where the valleys are steep and incised and with increased valley depths.

The main watercourses within the *Study Area* are positioned within wide, alluvial-filled floodplains. This wide valley morphology, allied with bedrock being up to 40 metres deep below the alluvial sedimentary fill with very low in situ horizontal stresses, is distinctly different to most valleys in the Southern Coalfield which feature sandstone rock based streams within deeply incised, narrow, steep-sided valleys. As a result, far less mining induced valley related movements are anticipated within the *Study Area* than have been observed in the Southern Coalfield.

Nevertheless, the valley landscapes within the *Study Area* may be subjected to some mining induced valley related movements and these issues are discussed below.

Mining induced valley related movements are normally described by the following parameters:-

- **Upsidence** is the reduced subsidence within a valley which results from the dilation or buckling of near surface strata at or near the base of the valley, i.e. the ground has subsided less in the base of the valley than it has subsided in the sides of the valley.
  In some rare cases the amount of **upsidence** observed in the base of the valley is greater than the subsidence observed in the sides of the valley, i.e. the ground in the base of the valley was lifted up higher after mining than its level before mining. In these rare cases this upsidence is called **uplift**.
  The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.
- **Closure** is the reduction in the horizontal distance between the valley sides.
  The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downslope movement and other possible strata mechanisms.
- **Compressive Strains** occur within the bases of valleys as a result of valley closure and the buckling or shearing of the near surface strata. **Tensile Strains** also occur at the tops of the valleys as the result of valley closure movements.
  The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

3.8. Definitions of Incremental, Cumulative, Total and Travelling Subsidence Parameters

For the purposes of this report, the definitions of incremental, cumulative, total and travelling subsidence parameters are as follows:-

- **Incremental** subsidence parameters are the additional movements which occur due to the extraction of a single longwall. Incremental subsidence profiles are determined by subtracting the subsidence profiles before from the subsidence profiles after the extraction of each longwall.
- **Total** subsidence parameters are the accumulated movements which occur due to the extraction of a number of longwalls within a series of longwalls.
- **Travelling** subsidence parameters are the transient movements which occur as the longwall extraction faces mine directly beneath a point. The maximum travelling tilts, curvatures and strains are typically aligned along the longitudinal axes of the longwalls, with the maximum values typically occurring at the locations of maximum incremental subsidence for each longwall.

3.9. Calibration of Subsidence, Tilt and Curvature Predictions for *the Project*

All detailed discussion on the research, development and calibration of the new state of the art hybrid approach to subsidence prediction was developed for *the Project* is presented in the separate detailed *Subsidence Prediction Report* (WACJV, 2012).

As discussed in this *Subsidence Prediction Report* (WACJV, 2012), SCT ran a state of the art numerical model to provide results for three locations over *the Project* area. One was called the Hue Hue Case. The second was called the Valley Case and the third case was called the Forest or Hilly Case. MSEC then calibrated the MSEC IPM empirical model based on these modelling results, which are more conservative than normal empirical model results because of the expected behaviour of the relatively tall chain pillars that, in places, are founded on the soft floor of the Awaba Tuff. After calibrating the IPM model MSEC then determined site specific subsidence, tilt and curvature predictions at each natural feature, structure and item of infrastructure that was identified within the *Study Area* based on changes in panel widths, pillar widths, seam extraction heights, seam levels, surface levels and depths of cover.

To make predictions of the site specific subsidence, tilts and curvatures, the IPM model used the surface level contours, seam floor contours and seam thickness contours, which are shown in Drawings Nos. MSEC515-02, MSEC515-03 and MSEC515-04, respectively. The geological structures identified at seam level are shown in Drawing No. MSEC515-06. The surface and seam information shown in these drawings was provided by the WACJV.

The IPM model provides mine subsidence parameter predictions at points on a regular grid orientated north-south and east-west across the *Study Area*. A grid spacing of 10 metres in each direction was generally adopted, which provides sufficient resolution for the generation of subsidence, tilt and curvature contours.

The maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls are provided in Chapter 4. Discussions on the predicted strains for the proposed longwalls are described in Section 4.3.

The predicted subsidence parameters for the natural features and items of surface infrastructure within the *Study Area* are provided in Chapters 5. The impact assessments for these features have been based on these predicted subsidence parameters.

3.10. The Incremental Profile Method

The IPM has been successfully used to make subsidence predictions for many previously extracted longwalls in the NSW and Queensland Coalfields. The IPM was developed by MSEC, which was formally known as Waddington Kay and Associates. The method is an empirical model based on a large database of observed monitoring data from previous mining within the NSW Coalfields. The method initially evolved following detailed analyses of subsidence monitoring data from the Southern Coalfields of NSW, which showed that, whilst the final subsidence profiles measured over a series of longwalls were irregular, the observed incremental subsidence profiles due to the extraction of individual longwalls were consistent in both magnitude and shape and varied according to local geology, depth of cover, panel width, seam thickness, the extent of adjacent previous mining, the pillar width, stability of the chain pillar and a time-related subsidence component.

Since it was developed in 1994, extensive monitoring data has been gathered by MSEC from the Southern, Newcastle and Hunter Coalfields of New South Wales and from the Bowen Basin in Queensland, including: Angus Place, Appin, Awaba, Austar, Baal Bone, Bellambi, Beltana, Blakefield South, Bulga, Bulli, Burwood, Carborough Downs, Chain Valley, Central, Clarence, Coalcliff, Cook, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Donaldson, Eastern Main, Ellalong, Elouera, Fernbrook, Glennies Creek, Grasstree, Gretley, Invincible, John Darling, Kemira, Kestrel, Lambton, Liddell, Mandalong, Metropolitan, Moranbah North, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, NRE Wongawilli, Oaky Creek, Ravensworth, South Bulga, South Bulli, Southern, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

The database consists of the observed incremental subsidence profiles, which are the additional subsidence profiles resulting from the extraction of each longwall within a series of longwalls. It can be seen from the normalised incremental subsidence profiles within the database, that the observed shapes and magnitudes are reasonably consistent where the mining geometry and local geology are similar. The maximum width of extracted longwalls in the empirical database is 410 metres, and the maximum width of extracted panels in the database is more than 800 metres for continuous miner operations.

It has been found that the incremental subsidence profiles resulting from the extraction of individual longwalls are consistent in shape and magnitude where the mining geometries and overburden geologies were similar, however, slight changes in magnitude and profile shapes occur between differing coalfields. Based on this extensive empirical data, MSEC has developed standard subsidence prediction curves for differing coalfields for the local geology and specific local conditions, based on the available monitoring data from each area.

The extraction heights in the database varying from less than 2 metres and up to 5 metres, of which 7 % are for cases having seam extraction heights of less than 2 metres, 74 % are for cases having seam extraction heights between 2 and 3 metres, 15 % are for cases having seam extraction heights between 3 metres and 4 metres, and 4 % are for cases having seam extraction heights between 4 metres and 5 metres. The empirical database also includes longwalls mined using Longwall Top Coal Caving (LTCC) mining techniques, where the effective extracted seam thickness was greater than 5 metres.

Subsidence predictions made using the IPM use the database of observed incremental subsidence profiles, the longwall geometries, local surface and seam information and geology. The method has a tendency to over-predict the conventional subsidence parameters (i.e. is slightly conservative) where the mining geometry and geology are within the range of the empirical database.

The IPM has been calibrated to the site specific mining geometry and overburden geology, using the results of the SCT numerical model, as described in the *Subsidence Prediction Report* (WACJV, 2012), which is included in as an appendix of the Environmental Assessment Statement.

Further details on the standard IPM are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

3.11. Reliability of the Predicted Subsidence, Tilt and Strain Parameters

Empirical methods of subsidence prediction are generally accepted as providing predictions of maximum subsidence to an accuracy of ±10 % to ±15 % where mining and geological conditions are similar. In this case, the empirical IPM has been calibrated to the site specific mining geometry and overburden geology, using the results of the SCT numerical model. A thorough calibration of the IPM model to *the Project* conditions will only be achieved after site subsidence monitoring data is obtained and analysed after the proposed extraction of the early longwalls.

The conservatively based hybrid subsidence prediction approach now provides subsidence parameters that are approximately one-and-a-half to two times the values predicted if conventional empirical formulae are used to predict subsidence in the Newcastle Coalfield without modifications to account for weakening effect of the underlying Awaba Tuff and the relatively thick extracted seam thickness.

The ground conditions modelled by SCT were selected from an extensive borehole drilling and geomechanical testing programme to represent a cautious or conservative assessment in order to ensure a worst-case scenario. This modelling included the full coal seam thickness, the weak seam floor and other geological factors to ensure the model simulated pillar floor collapses. Under these conditions, it is believed that the resulting conservatively based hybrid subsidence predictions are likely to be greater than the observed subsidence values and, in this case, are likely to be greater than the typical upper level of the accuracy of empirical predictions of +10 % to +15 %.

All impact and consequence assessments have therefore been undertaken based on these conservative worst-case scenario assessments. Accordingly, it will be necessary to monitor the ground movements over the initial longwall panels at *the Project*, so that the management strategies can be reviewed and modified, if and as needed, based on the actual ground movements that are observed over the previously extracted longwalls.

Even though a conservative approach has been adopted for the mine subsidence prediction and impact assessment methodology, the WACJV has committed itself to an adaptive and continuous improvement approach to the longwall panel design whereby the mining dimensions and limits of future mine workings will be continuously reviewed and modified as necessary as experience is gained to ensure the required subsidence parameters are observed at houses in the Hue Hue Mine Subsidence District and within the Dooralong and Yarramalong Valley floodplains. In particular, it will be necessary to undertake detailed monitoring of the ground movements over the initial longwall panels at *the Project*. Whilst the current conservative approach is appropriate for the current mine planning study, the proposed monitoring and analysis of the actual subsidence measured during the initial mining will enable further verification of the model and enhance its future predictive capability and will allow appropriate Extraction Plans to be developed.

The comparison between the observed and predicted tilts and curvatures, for previous longwall mining in the NSW Coalfields, indicate that the IPM generally provides reasonable, if not, conservative predictions. It is expected, in this case, that the calibrated hybrid subsidence prediction model will provide conservative conventional subsidence predictions for the proposed longwalls. As discussed in Section 3.12, it is likely, however, that the predicted conventional tilts and curvatures may be exceeded at the watercourses, as a result of valley related movements. For these cases, a separate method of predicting valley closure, upsidence and strain is provided in this report and the reliability of the predictions is provided in Section 3.12.

Observations of strain show that there is an overall trend of increasing tensile strain with increasing hogging curvature and an increasing compressive strain with increasing sagging curvature. As discussed in Section 3.5 and in more detail in Section 4.3, applying a linear relationship between curvature and strain provides a reasonable estimate for the conventional tensile and compressive strains. However, there is still a considerable variability in the strain observations, principally because, as discussed in Section 3.5, horizontal displacements principally result from strata curvature, but, some horizontal movements can result from a stress relief mechanism and a surface slope mechanism. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strains for low curvatures.

The predictions of strain provided in this report have therefore adopted a statistical approach to account for this variability, rather than providing a single predicted conventional strain. The variations in strain occur for the following reasons:-

- Several differing mechanisms generate the mining induced horizontal movements, as discussed in Section 3.5, and the measured horizontal movements, and differential horizontal movements are a combination of all three of these mechanisms in greater or lesser proportions depending on the site conditions,
- Points on the surface are seen to move in varying directions as the longwall face approaches and passes and variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If localised cross bedding exists, this shearing can occur at relatively low values of stress. This can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zone, existing joints can be opened up and new fractures can be formed at random, leading to localised concentrations of tensile strain.
- Where a thick surface layer of soil, clay or rock exists, the underlying movements in the bedrock are often transferred to the surface at reduced levels and the measured strains are, therefore, more evenly distributed and hence more systematic in nature than they would be if they were measured at rockhead.
- Strain measurements can sometimes give a false impression of the state of stress in the ground. For example:-
  - buckling of the near-surface strata can result in localised cracking and apparent tensile strain in areas where overall, the ground is in fact being compressed, because the actual values of the measured strains are dependent on the locations of the survey pegs.
  - where joints open up or cracks develop in the tensile phase and fail to close in the compressive phase, as they sometimes do if they are subsequently filled, the ground can appear to be in tension when it is actually in compression.
- Sometimes, survey errors can also affect the measured strain values and these can result from movement in the benchmarks, inaccurate instrument readings, or disturbed survey pegs.
- In sandstone dominated environments, much of the earlier ground movements can be concentrated at the existing natural joints, which have been found to be at an average spacing of 7 to 15 metres.

It is also recognised that the ground movements above a longwall panel can be affected by the gradient of the coal seam, the direction of mining and the presence of valleys all of which can cause a lateral shift in the subsidence profile. While an adjustment for seam dip has been included in the predictions and assessments for the influence of valleys has been included, the assessments at isolated features have, been based upon the highest predicted values of subsidence, tilt and curvature within a radius of 20 metres of each feature, rather than the predicted values at the specific points.

3.12. Reliability of Predictions of Upsidence and Closure Movements

The predicted valley related movements resulting from the extraction of the proposed longwalls were made using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002). Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

The development of the predictive methods for upsidence and closure are the result of recent and ongoing research and the methods do not, at this stage, have the same confidence level as conventional subsidence prediction techniques. As further case histories are studied, the method will be improved, but it can be used in the meantime, so long as suitable factors of safety are applied. This is particularly important where the predicted levels of movement are small, and the potential errors, expressed as percentages, can be higher.

Whilst the major factors that determine the levels of movement have been identified, there are some factors that are difficult to isolate. One factor that is thought to influence upsidence and closure movements is the level and direction of horizontal in situ stress that exists within the strata. In situ stresses are difficult to obtain and not regularly measured and the limited availability of data makes it impossible to be definitive about the influence of the in situ stress on the upsidence and closure values. The methods are, however, based predominantly upon the measured data from Tower Colliery in the Southern Coalfield, where the in situ stresses are high. The methods should, therefore, tend to over-predict the movements in areas of lower stress.

Variations in local geology can affect the way in which the near surface rocks are displaced as subsidence occurs. In the compression zone, the surface strata can buckle upwards or can fail by shearing and sliding over their neighbours. If localised cross bedding exists, this shearing can occur at relatively low values of stress. This can result in fluctuations in the local strains, which can range from tensile to compressive. In the tensile zone, existing joints can be opened up and new fractures can be formed at random, leading to localised concentrations of tensile strain.

A factor that is thought to influence the movements is the characteristics of near surface geology, particularly in stream beds. Upsidence in particular is considered to be sensitive to the way in which the bedrock responds, since thin strata layers may respond differently to thicker ones. The location of the point of maximum upsidence is also considered to be strongly influenced by the characteristics of near surface geology.

Another factor that is thought to influence upsidence and closure movements is the presence of geomorphological features. Recent monitoring along a deeper and more incised valley has shown variable measurements around bends. There tended to be less movement at the apex of the bend than in the straight sections.

Where a thick surface layer of soil, clay or rock exists, the underlying movements in the bedrock are often transferred to the surface at reduced levels and the measured strains are, therefore, more evenly distributed and hence more conventional in nature than they would be if they were measured at rockhead.

Some upsidence and closure ground movements have been monitored in the Newcastle and Western Coalfields, however, these movements are not often observed outside the Southern Coalfield at locations where the depths of cover are shallower and where the levels of monitored conventional strains exceed the levels of the upsidence and closure ground movements.

No significant upsidence and closure ground movements have been observed where there are thick alluvial beds over the bedrock. Accordingly, as discussed above, it will therefore be necessary to undertake detailed monitoring of the ground movements over the initial longwall panels at *the Project*. Whilst the current conservative approach is appropriate for the current mine planning study, the proposed monitoring and analysis of the actual subsidence measured during the initial mining will enable further verification of the model and enhance its future predictive capability and will allow appropriate Extraction Plans to be developed.

4.0 MAXIMUM PREDICTED CONVENTIONAL SUBSIDENCE PARAMETERS FOR THE PROPOSED LONGWALLS IN *THE PROJECT* MINING AREA

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed longwalls. The predicted subsidence parameters and the impact assessments for the natural features and items of surface infrastructure within the *Study Area* are provided in Chapter 5.

4.2. Maximum Predicted Conventional Subsidence, Tilt and Curvatures

The predicted conventional subsidence parameters for the proposed longwalls were determined using the Incremental Profile Method, which was calibrated using an advanced numerical model that was developed by SCT to simulate caving and to incorporate the appropriate geology. The background on the method of calibration of the prediction model and discussions on the reliability of the predictions is provided in Chapter 3 and further details of the subsidence prediction methodology are described in a separate detailed *Subsidence Prediction Report* (WACJV, 2012).

The predicted total conventional subsidence contours, resulting from the extraction of all the proposed longwalls, are shown in Drawing No. MSEC515-21. A summary of the maximum predicted values of total conventional subsidence, tilt and curvatures, resulting from the extraction of the proposed longwalls, is provided in Table 4.1.

Table 4.1 Maximum Predicted Total Conventional Subsidence, Tilt and Curvatures Resulting from the Extraction of the Proposed Longwalls

Longwalls	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Final Conventional Tilt (mm)	Maximum Predicted Total Conventional Hogging Curvature (km^{-1})	Maximum Predicted Total Conventional Sagging Curvature (km^{-1})
LW1N to LW4N	1000	5	0.20	0.20
LW5N to LW15N	2000	10	0.28	0.30
LW16N to LW26N	2500	15	0.28	0.37
LW1S to LW4S	2100	9	0.15	0.20
LW5S to LW10S	2600	13	0.25	0.30
LW1SW to LW10SW	2550	12	0.11	0.19
Study Area	**2600**	**15**	**0.28**	**0.37**

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapter 5.

The maximum predicted conventional tilt within the *Study Area* is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65. The maximum predicted conventional curvatures within the *Study Area* are 0.28 km^{-1} hogging and 0.37 km^{-1} sagging, which represent minimum radii of curvature of approximately 4 kilometres and 3 kilometres, respectively.

The predicted conventional subsidence parameters vary across the *Study Area* as the result of, amongst other factors, variations in the depths of cover, longwall void widths, chain pillar widths and extraction heights. To illustrate this variation, the predicted profiles of conventional subsidence, tilt and curvature have been determined along four prediction lines, the locations of which are shown in Drawing No. MSEC515-21. The predicted profiles of conventional subsidence, tilt and curvature along Prediction Lines 1, 2, 3 and 4, resulting from the extraction of the proposed longwalls, are shown in Figs. E.01, E.02, E.03 and E.04, respectively, in Appendix E.

4.3. Predicted Strains

As discussed in Sections 3.5 and 3.11, the prediction of strain is more difficult than the prediction of subsidence, tilt and curvature. The reasons for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the relief and redistribution of in-situ horizontal stress, the locations of pre-existing natural joints at bedrock, the depth of bedrock and the three dimensional and time based responses of jiggered jointing sets as mining approaches and passes a surface point. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. Anomalous strains leading to very localised fracturing in the ground surface can also occur, within an otherwise uniform subsidence distribution. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

In previous MSEC subsidence reports, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

As discussed in Section 3.5 adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones.

In the Newcastle and Hunter Coalfields, it has been found that a factor of 10 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains. In the Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains.

The hybrid mine subsidence prediction approach, combining the SCT numerical modelling with the MSEC empirical modelling, indicates that the shapes of the predicted subsidence profiles are closer to those observed in the Southern Coalfield than those observed in the Newcastle of Hunter Coalfields. For this reason, it has been considered that a factor of 15 would be more appropriate for the relationship between the maximum conventional curvature and the maximum conventional strain for the proposed longwalls.

The maximum predicted conventional strains resulting from the extraction of the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- LW1N to LW5N - 3 mm/m tensile and 4 mm/m compressive,
- LW6N to LW26N - 4 mm/m tensile and 5.5 mm/m compressive,
- LW1S to LW10S - 4 mm/m tensile and 4.5 mm/m compressive, and
- LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

At a point, however, there can be considerable variation from the linear relationship, resulting from the many factors discussed above and resulting in apparent anomalous movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, instead of just providing a single predicted conventional strain.

The range of potential strains resulting from the extraction of the proposed longwalls has been determined using monitoring data from previously extracted longwalls in the NSW Coalfields. The monitoring data was taken from the Newcastle and Hunter Coalfields, where the longwalls have similar width-to-depth (W/H) ratios and extraction heights as for the proposed longwalls. A summary of the monitoring data used in the strain analysis is provided in Table 4.2.

Table 4.2 Monitoring Data used in the Strain Analysis

Colliery	Number of Monitoring Lines	Longwall W/H Ratio	Extraction Height (m)
Austar LWA1 and LWA2	6	0.3 ~ 0.6	≈ 5.5 m (LTCC[1])
Ellalong LWs SL1 to SL4 and LWs 1 to 13A	8	0.4 ~ 0.7	3.0 ~ 3.5
West Wallsend LW11 to LW18	1	0.5 ~ 0.8	2.5 ~ 4.8
Newstan LW8 to LW14	2	0.7 ~ 0.8	3.5 ~ 4.5
Teralba LW8 and LW9	4	0.5 ~ 0.8	2.5 ~ 4.8

[1] LTCC is Longwall Top Coal Caving

The width-to-depth ratios for the proposed longwalls vary between 0.3 and 0.5 and the proposed extraction heights vary between 3.5 metres and 4.5 metres. It can be seen from the above table, that the monitoring data used in the strain analysis include previously extracted longwalls with similar width-to-depth ratios and extraction heights as those for the proposed longwalls.

The range of strains measured during the extraction of the longwalls listed in Table 4.2 should, therefore, provide a reasonable indication of the range of potential strains for the proposed longwalls. The data used in the analysis included those resulting from both conventional and non-conventional anomalous movements, but did not include those resulting from valley related movements, which are addressed separately in this report. The strains resulting from damaged or disturbed survey marks have also been excluded.

4.3.1. Analysis of Strains Measured in Survey Bays

For features that are in discrete locations, such as building structures, farm dams and archaeological sites, it is appropriate to assess the frequency of the observed maximum strains for individual survey bays. The analyses of strain measured in survey bays above and outside the extents of longwall mining are provided in the following sections.

Survey Bays Located Above Goaf

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of previous longwalls, shown in the Table 4.2, for survey bays that were located directly above goaf or the chain pillars that are located between the extracted longwalls.

The strain distributions were analysed with the assistance of the centre of Excellence for Mathematics and Statistics of Complex Systems (MASCOS). A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided the best fit to the raw strain data.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above goaf is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

Confidence levels have been determined from the empirical strain data using the fitted GPD. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

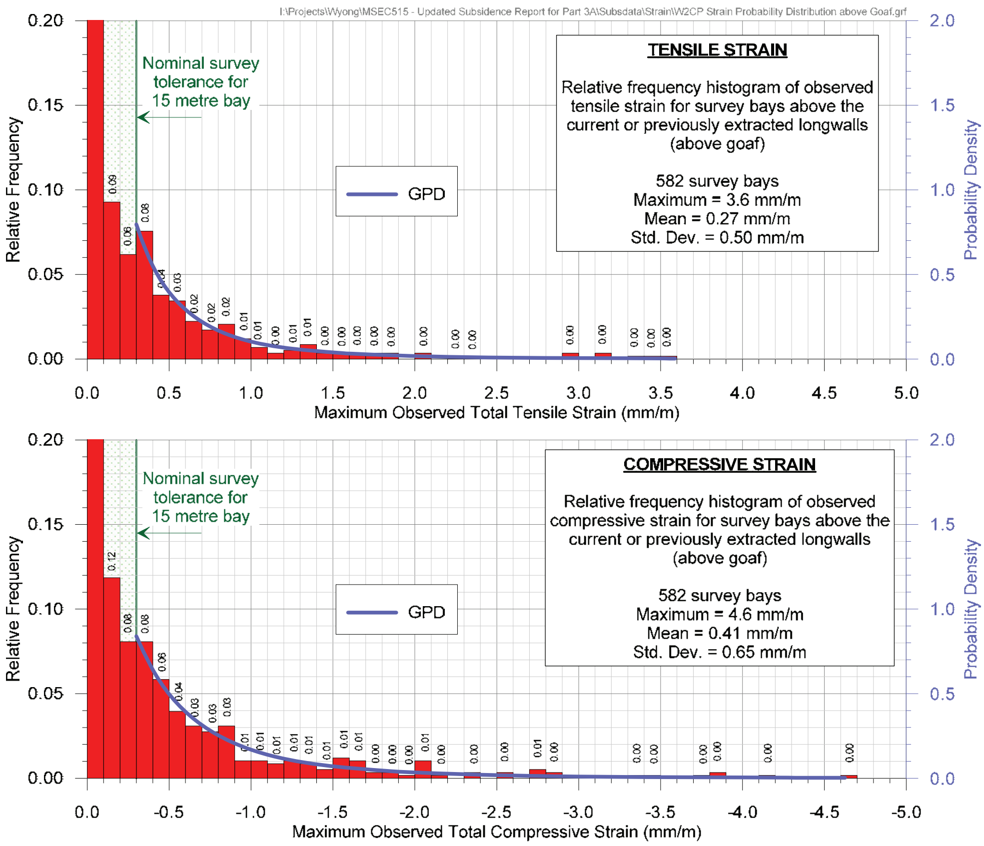

Fig. 4.1 Distributions of the Measured Maximum Tensile and Compressive Strains at Any Time during the Extraction of Previous Longwalls for Survey Bays Located Above Goaf

A summary of the probabilities of exceedance for tensile and compressive strains for survey bays located above goaf, based on the fitted GPDs, is provided in Table 4.3.

Table 4.3 Probabilities of Exceedance for Strain for Survey Bays Located above Goaf

Strain (mm/m)		Probability of Exceedance
Compression	-5.0	1 in 300
	-4.0	1 in 150
	-3.0	1 in 80
	-2.0	1 in 30
	-1.5	1 in 20
	-1.0	1 in 10
	-0.5	1 in 4
	-0.3	1 in 2
Tension	+0.3	1 in 4
	+0.5	1 in 6
	+1.0	1 in 15
	+1.5	1 in 35
	+2.0	1 in 60
	+3.0	1 in 150
	+4.0	1 in 300
	+5.0	1 in 500

The 95 % confidence levels for the maximum strains that the individual survey bays located above goaf experienced at any time during mining were 1.1 mm/m tensile and 1.6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays above goaf experienced at any time during mining were 2.5 mm/m tensile and 3.3 mm/m compressive.

Survey Bays Located Above Solid Coal

The survey database has also been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls, shown in Table 4.2, for survey bays that were located directly above solid coal and within 200 metres of the nearest longwall goaf edge. Solid coal is defined as the coal that has not been extracted by headings, panels or longwalls.

The histogram of the maximum observed tensile and compressive strains measured in survey bays above solid coal is provided in Fig. 4.2. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

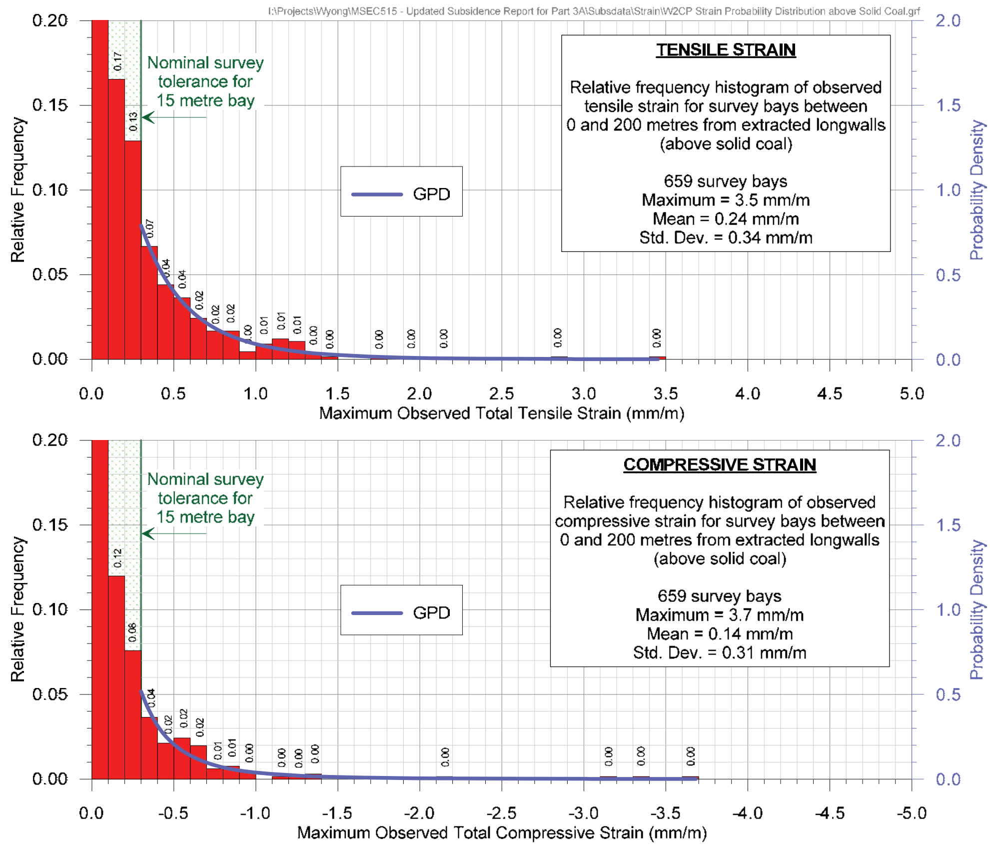

Fig. 4.2 Distributions of the Measured Maximum Tensile and Compressive Strains at Any Time during the Extraction of Previous Longwalls for Survey Bays Located Above Solid Coal

Confidence levels have been determined from the empirical strain data using the fitted GPD. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

A summary of the probabilities of exceedance for tensile and compressive strains for survey bays located above solid coal, based on the fitted GPDs, is provided in Table 4.4.

The 95 % confidence levels for the maximum strains that the individual survey bays located above solid coal experienced at any time during mining were 0.9 mm/m tensile and 0.6 mm/m compressive. The 99 % confidence levels for the maximum strains that the individual survey bays located above solid coal experienced at any time during mining were 1.6 mm/m tensile and 1.3 mm/m compressive.

Table 4.4 Probabilities of Exceedance for Strain for Survey Bays Located above Solid Coal

Strain (mm/m)		Probability of Exceedance
Compression	-3.0	1 in 800
	-2.5	1 in 500
	-2.0	1 in 250
	-1.5	1 in 125
	-1.0	1 in 50
	-0.5	1 in 15
	-0.3	1 in 8
Tension	+0.3	1 in 4
	+0.5	1 in 7
	+1.0	1 in 25
	+1.5	1 in 80
	+2.0	1 in 200
	+2.5	1 in 500
	+3.0	1 in 1,000

4.3.2. Analysis of Strains Measured along Whole Monitoring Lines

For linear features such as roads, cables and pipelines, it is more appropriate to assess the frequency of observed maximum strains along whole monitoring lines, rather than for individual survey bays. That is, an analysis of the maximum strains anywhere along the monitoring lines, regardless of where the strain actually occurs.

The frequency distribution of maximum observed tensile and compressive strains measured anywhere along the monitoring lines, at any time during or after the extraction of the previous longwalls, is provided in Fig. 4.3.

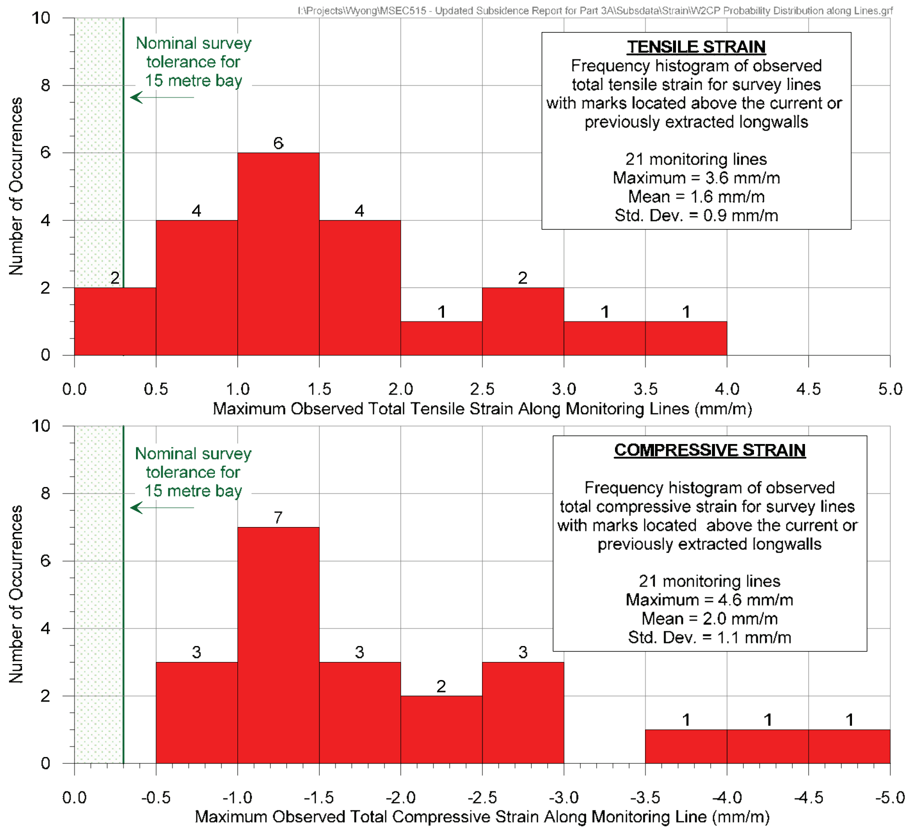

Fig. 4.3 Distributions of Measured Maximum Tensile and Compressive Strains along the Monitoring Lines at Any Time during the Extraction of Previous Longwalls

It can be seen from the above figure, that 16 of the 21 monitoring lines (i.e. 76 %) have recorded maximum total tensile strains of 2.0 mm/m or less, and that 13 of the 21 monitoring lines (i.e. 62 %) have recorded maximum total compressive strains of 2.0 mm/m or less. The maximum observed tensile strain was 3.6 mm/m and the maximum observed compressive strain was 4.6 mm/m.

4.3.3. Analysis of Shear Strains

As described in Section 3.3, ground strain comprises two components, being normal strain and shear strain, which can be interrelated using Mohr's Circle. The magnitudes of the normal strain and shear strain components are, therefore, dependant on the orientation in which they are measured. The maximum normal strains, referred to as the principal strains, are those in the direction where the corresponding shear strain is zero.

Normal strains along monitoring lines can be measured using 2D and 3D techniques, by taking the change in horizontal distance between two points on the ground and dividing by the original horizontal distance between them. This provides the magnitude of normal strain along the orientation of the monitoring line and, therefore, this strain may not necessarily be the maximum (i.e. principal) normal strain.

Shear deformations are more difficult to measure, as they are the relative horizontal movements perpendicular to the direction of measurement. However, 3D monitoring techniques now provide data on the direction and the absolute displacement of survey pegs and, therefore, the shear deformations perpendicular to the monitoring line can be determined. Although, in accordance with rigorous definitions and the principles of continuum mechanics, (e.g. Jaeger, 1969), it is not possible to determine horizontal shear strains in any direction relative to the monitoring line using 3D monitoring data from a straight line of survey marks.

As described in Section 3.3, shear deformations perpendicular to monitoring lines can be quantified using a number of different parameters, including shear index, horizontal tilt, horizontal curvature and mid-ordinate deviation, each of which have their advantages and disadvantages. In this report, horizontal mid-ordinate deviation has been used as the measure for shear deformation, which is defined as the differential horizontal movement of each survey mark, perpendicular to a line drawn between two adjacent survey marks, as indicated in Fig. 4.6.

There is less 3D subsidence monitoring data than 2D subsidence monitoring data from the NSW Coalfields. For this study, therefore, an analysis of horizontal mid-ordinate deviation was undertaken for the available 3D monitoring lines in the NSW Coalfields, where the typical bay lengths were 20 metres and the depths of cover were greater than 350 metres, such as the case within the *Study Area*. As the typical bay length was 20 metres, the calculated horizontal mid-ordinate deviations were over a chord length of 40 metres.

The frequency distribution of the maximum horizontal mid-ordinate deviation measured at survey marks above goaf, for previously extracted longwalls where the depths of cover were greater than 350 metres, is provided in Fig. 4.4. A plot showing mid-ordinate deviation is presented in Fig. 4.6. The probability distribution function, based on the fitted GPD, has also been shown in this figure.

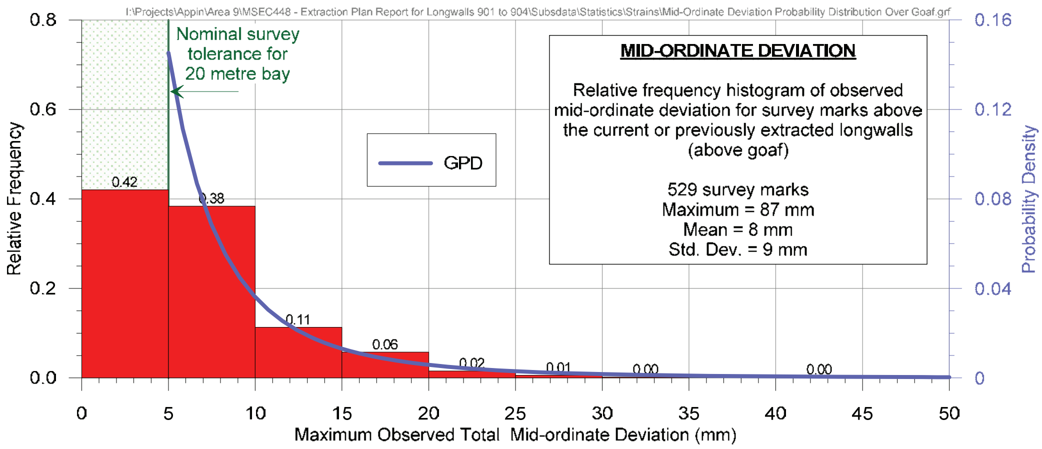

Fig. 4.4 Distribution of Measured Maximum Horizontal Mid-ordinate Deviation at Any Time during the Extraction of Previous Longwalls for Marks Located Above Goaf

Confidence levels have been determined from the empirical strain data using the fitted GPD. In the cases where survey marks were measured multiple times during a longwall extraction, the maximum horizontal mid-ordinate deviation was used in the analysis (i.e. single measurement per survey mark).

A summary of the probabilities of exceedance for horizontal mid-ordinate deviation for survey marks located above goaf, based on the fitted GPD, is provided in Table 4.5.

Table 4.5 Probabilities of Exceedance for Horizontal Mid-Ordinate Deviation for Survey Marks above Goaf

Horizontal Mid-Ordinate Deviation (mm)		Probability of Exceedance
Horizontal Mid-Ordinate Deviation over 40 metre Chord Length	10	1 in 5
	20	1 in 20
	40	1 in 100
	60	1 in 250
	80	1 in 500
	100	1 in 1,000

The 95 % confidence level for the maximum horizontal mid-ordinate deviation that the individual survey marks located above goaf experienced at any time during mining was 21 mm. The 99 % confidence level for the maximum horizontal mid-ordinate deviation that the individual survey marks located above goaf experienced at any time during mining was 42 mm.

4.4. Predicted Horizontal Movements

The predicted conventional horizontal movements in flat terrain are calculated by applying a factor to the predicted conventional tilt values. In the Newcastle Coalfield a factor of 10 is generally adopted, being the same factor as that used to determine the maximum conventional strain from the maximum conventional curvature, and this has been found to give a reasonable correlation with measured data in flat terrain.

The calibration of the subsidence prediction model indicates that the shapes of the subsidence profiles for the proposed longwalls are expected to be closer to those observed in the Southern Coalfield, than those observed the Newcastle Coalfield, as described in the report entitled *Subsidence Prediction Report* (WACJV, 2012), which is included in as an appendix of the Environmental Assessment Statement.

Monitoring data from the Southern Coalfield indicates that a factor of 15 provides a better correlation for prediction of conventional horizontal movements in flat terrain. This factor will in fact vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted conventional tilt within the *Study Area*, resulting from the extraction of the proposed longwalls, is 15 mm/m. The maximum predicted conventional horizontal movement in flat terrain is, therefore, in the order of 225 mm, i.e. 15 mm/m multiplied by a factor of 15. The predicted conventional tilt and, hence, the predicted conventional horizontal movements vary across the *Study Area*, as illustrated by the predicted subsidence movements along Prediction Lines 1, 2, 3 and 4, which are shown in Figs. E.01, E.02, E.03 and E.04, respectively, in Appendix E.

Larger horizontal movements are expected to occur as the result of downslope movements in steeply sided terrain and closure movements within the valleys. The predicted horizontal movements resulting from downslope and valley related movements are discussed in the impact assessments provided in Chapter 5.

Horizontal movements do not directly impact on natural features or items of surface infrastructure, rather impacts occur as the result of differential horizontal movements. Strain is the rate of change of horizontal movement. The impacts of strain on the natural features and items of surface infrastructure are addressed in impact assessments for each feature, which have been provided in Chapter 5.

4.5. Predicted Far-Field Horizontal Movements

In addition to the conventional mining induced movements that have been predicted above and adjacent to the longwalls due to bending and curvature mechanisms and the predicted valley related movements along the rivers, creeks and drainage lines, it is also likely that far-field horizontal movements will be experienced during the extraction of the longwalls for *the Project*.

The measured far-field horizontal movements around extracted panels are the result of not one, but, various mechanisms. At locations that are well beyond the edges of the extracted areas, it is believed that the main mechanism causing these far-field horizontal movements is a relief or redistribution of the horizontal in situ stress in the strata around the collapsed zones above the extracted voids. Such movements are, to some extent, predictable and occur whenever significant excavations occur at the surface or underground.

Far-field horizontal movements used to be regarded as unusual or irregular movements, however, as monitoring methods improve, the observed far-field horizontal movements are now seen to be consistent and predictable. The methods used to predict far-field horizontal movements have developed in recent years using newly available 3D horizontal displacement monitored data and confidence levels in these far-field horizontal displacement predictions continue to improve.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data primarily from the Southern Coalfield. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The observed incremental far-field horizontal movements, resulting from the previous extraction of longwalls in the NSW Coalfields, are illustrated in Fig. 4.5. The confidence levels, based on fitted GPDs, have also been shown in this figure to illustrate the spread of the data, i.e. for example the red line indicates the incremental horizontal far-field movement for given distances from the longwall edges for which only 1 percent of the monitored data fits above. These confidence lines are based on all the available data and further refinements to these confidence levels can be filtered out as required for specific cases such as no valley affected cases or over solid coal cases only.

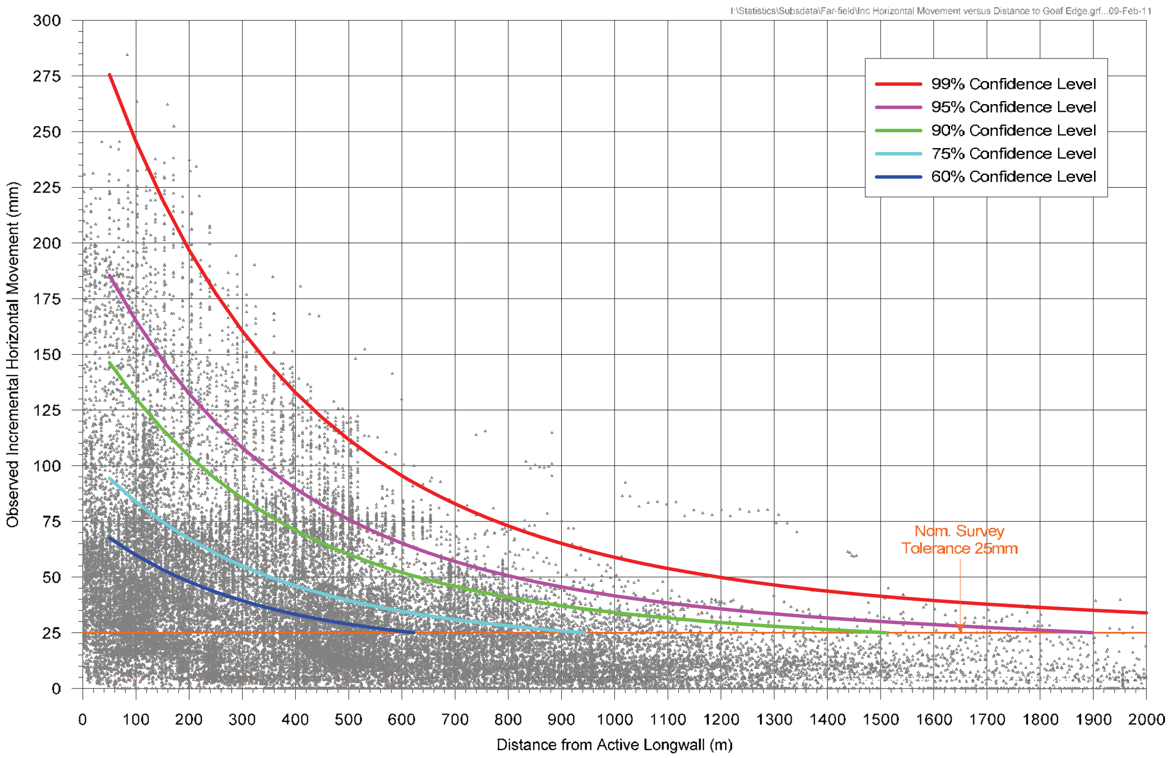

Fig. 4.5 Observed Incremental Far-Field Horizontal Movements from the NSW Coalfields

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements decrease. This is possibly due to the fact that once the in situ stresses within the strata has been redistributed around the collapsed zones above the first few extracted longwalls, the potential for further movement is reduced. The total far-field horizontal movement is not, therefore, the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field horizontal movements resulting from the extraction of the proposed longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain, which are generally less than the order of survey tolerance. These levels of movement are generally not significant, except where they occur at large structures which are sensitive to small differential movements.

An additional method of assessment of expected far-field horizontal movements has been undertaken to better reflect the potential movements at the freeway bridges and to assess horizontal bending by calculating the horizontal mid-ordinate deviation between three survey pegs. The mid-ordinate deviation is the change in perpendicular horizontal distance from a point to a chord formed by joining points on either side. The horizontal mid-ordinate deviation was calculated for sets of survey results representing the increment of extraction of one longwall.

A schematic sketch showing the horizontal mid-ordinate deviation of a peg compared to its adjacent survey pegs between two survey epochs is provided in Fig. 4.6. This calculation was considered to be a better representation of the potential transverse movements across the freeway bridges.

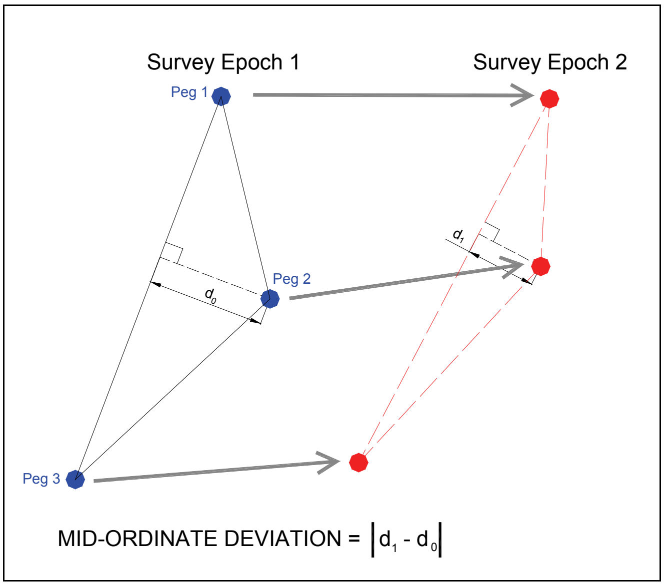

Fig. 4.6 Schematic Representation of Mid-Ordinate Deviation

A plot of the observed horizontal mid-ordinate deviations from the current empirical database is provided in Fig. 4.7. The horizontal mid-ordinate deviation was calculated for marks with spacings of 20 metres ±10metres, or an approximate spacing of 40 metres over the three marks, since these distances represent the typical range of spacing between the bridge piers and abutments.

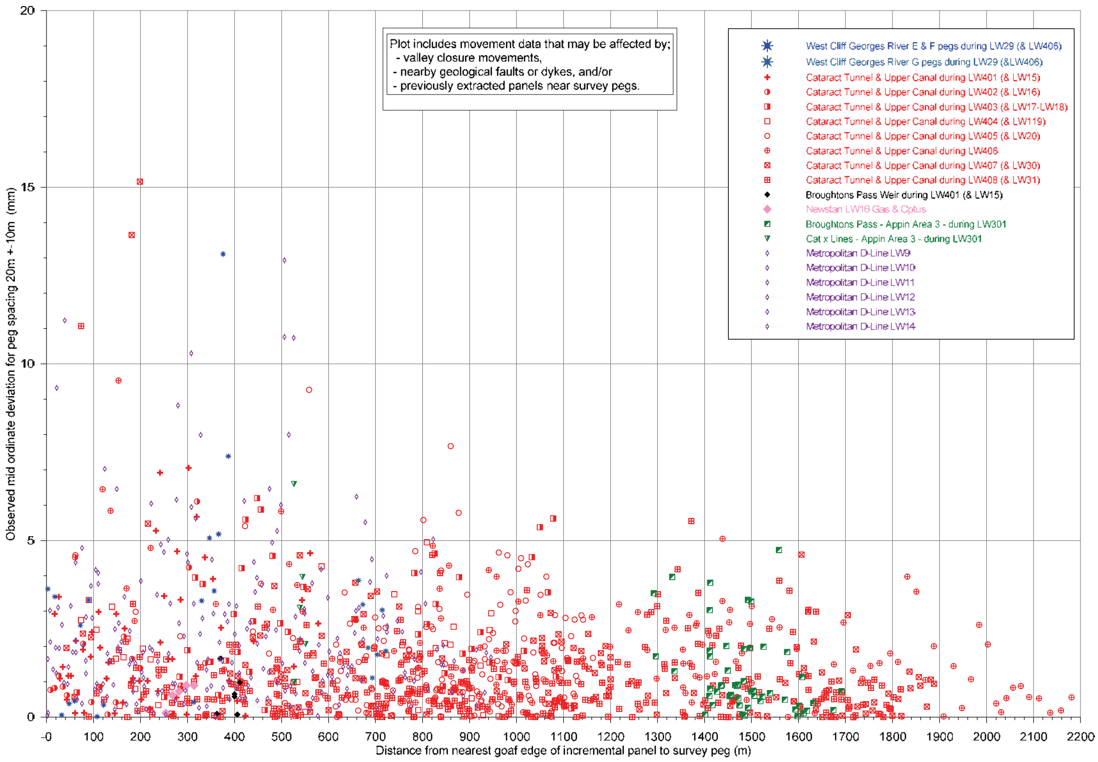

Fig. 4.7 Incremental Observed Mid-Ordinate Deviation due to the Extraction of Each Longwall (20m peg spacing ±10m) Only Pegs with Solid Coal Between Peg and Longwall

The potential impacts of far-field horizontal movements at the bridges along the Sydney-Newcastle Freeway are discussed in Section 5.12.

The impacts of far-field horizontal movements on the natural features and the remaining items of surface infrastructure within the vicinity of the *Study Area* are not expected to be significant and do not warrant any further discussion in this report.

4.6. General Discussion on Mining Induced Cracking, Humping and Stepping

As discussed in Chapter 3, longwall mining results in mine subsidence and some surface fractures, cracking, heaving, buckling, humping and stepping of the ground surface have been observed. These types of mining induced deformations are more often observed over shallow mines but are also occasionally observed over deeper coal mines.

Fractures and joints in bedrock occur naturally during the both the formation of the strata and from subsequent erosion and weathering processes. Within the proposed *Extraction Area*, the depths of cover are greater than 350 metres, there are few exposed rock platforms and alluvial deposits cover most of the valleys floors.

Mining induced fracture widths tend to decrease as the depth of cover increases. Mining induced surface cracks at *the Project* will be limited to the opening of existing natural joints or an occasional tension crack located on steeply sloping terrain or a rare crack within exposed bedrock in valley floors. Few mining induced surface cracks are expected to occur where deep soil or alluvial cover covers the bedrock.

The numerical modelling that was undertaken by SCT indicated that the caving related fracturing extends to approximately 200 metres above the seam, beyond which the disturbance to the strata will be limited to bedding plane shear and localised, non-continuous fracturing. The modelling showed that there would be some increased permeability in the near surface strata as a result of subsidence-related surface tension cracking. The modelling also showed no evidence of connectivity with the deeper, mining induced fracture systems and this is not unexpected since the two fracture systems will be vertically separated by 200 metres to 300 metres of strata.

Mining induced surface tensile fracturing in exposed bedrock is likely to occur coincident with the maximum tensile strains, but open fractures could also occur due to buckling of surface beds that are subject to compressive strains. Surface tensile cracking can also occur at the top of steep slopes, generally as a result of down slope soil movements. The potential surface impacts for the steep slopes in the *Study Area* are further discussed in Section 5.6.

Elevated compressive strains could occur in the base of creeks due to valley closure movements. Fracturing of the exposed bedrock in valleys and along the creeks could occur, which is discussed in Chapter 3 and in the impact assessments for the streams in Chapter 5.

The incidence of mining induced surface cracks is additionally dependent on the thickness and inherent plasticity of the soils that overlie the bedrock. Surface soils above the proposed longwalls are generally weathered to a reasonable depth. The widths and frequencies of the cracks are also dependent upon the pre-existing jointing patterns in the bedrock. Large joint spacing can lead to concentrations of strain and possibly the development of fissures at the rockhead, which are not necessarily coincident with the joints.

Localised ground buckling and shearing can occur wherever faults, dykes and abrupt changes in geology occur near the ground surface. No major faults, dykes or abrupt changes in surface geology have been identified above the proposed longwalls. The frequency of occurrence of these types of movements is generally uncommon but is still possible that they could be encountered at some time during the mining period.

A general guide as to the frequency, width and extent of such mining induced fractures on the steeply sloping areas can be obtained from the monitoring over longwall areas in the Southern Coalfield, where it is rare to observe any surface cracking except at locations of non-conventional movements, geological features, on the tops of steep slopes, or within bedrocks of valley floors.

Surface cracks are more readily observed in built infrastructure such as road pavements. In the majority of these cases, no visible ground deformations can be seen in the natural ground adjacent to the cracks in the road pavements. In rare instances more noticeable ground deformations, such as humping or stepping of the ground can be observed at thrust faults.

Examples of these rarely observed ground deformations from the Southern Coalfield, where the depths of cover exceed 450 metres, are provided in the photographs in Fig. 4.8 to Fig. 4.13 below. No such thrust faults have been identified within the *Extraction Area*. Further information on non-conventional subsidence movements are discussed in more detail in Section 3.7

The main impacts that may result from these potential surface fractures are associated with the disruption of surface aquifers and/or surface water regimes and further discussion on the potential impacts of surface cracking on groundwater water are provided in the report by Mackie (2013).

Fig. 4.8 Example of Surface Compression Humping along Outcropping of a Low Angle Thrust Fault in the Southern Coalfield

Fig. 4.9 Example of Surface Compression Humping along Outcropping of a Low Angle Thrust Fault in the Southern Coalfield

Fig. 4.10 Example of Surface Compression Buckling Observed in a Pavement

Fig. 4.11 Example of Surface Tension Cracking along the Top of a Steep Slope

Fig. 4.12 Example of Surface Tension Cracking along the Top of a Steep Slope

Fig. 4.13 Example of Sandstone Fracturing and Bedding Plane Slippage in Bedrock in the Base of a Stream in the Southern Coalfield

5.0 PREDICTED SUBSIDENCE PARAMETERS AND IMPACT ASSESSMENTS FOR THE NATURAL FEATURES AND ITEMS OF SURFACE INFRASTRUCTURE WITHIN THE STUDY AREA

5.1. Introduction

The following sections provide the predicted subsidence parameters and the impact assessments for the natural features and items of surface infrastructure within the *Study Area*. All significant natural features and items of surface infrastructure located outside the *Study Area*, which may be subjected to far-field movements or valley related movements and may be sensitive to these movements, have also been included as part of these assessments.

The references to the section number of this report, where the assessed impacts and consequences of mine subsidence, are provided in Table 5.1, for each of the major natural features and items of surface infrastructure that are located within the *Study Area*. The features in the following sections are presented in the same order as they were presented in Chapter 2.

The depths of cover in the *Study Area* are similar to or greater than those in the Southern Coalfield. The experiences of impacts and consequences resulting from previous longwall mining in the Southern Coalfield, therefore, have been described in the impact assessments provided in this report. The hybrid subsidence modelling approach has provided maximum predicted subsidence parameters for the proposed longwalls that are greater than those typically experienced in the Southern Coalfield. Accordingly, the experiences of mine subsidence impacts and consequences resulting from previously extracted longwalls in the Hunter and Newcastle Coalfields, where the depths of cover are similar to those in the *Study Area*, have also been described in the impact assessments provided in this report.

5.2. Catchment Areas or Declared Special Areas

The potential impact of proposed underground mining on the surface water supply system was identified as a key area for detailed assessment and a rigorous analysis of potential effects was considered important. Water quality was also considered very important because it can determine the usefulness of the supply for municipal and other purposes.

The proposed mine layout will underlie parts of the water catchment that feed the Gosford City and Wyong Shire Councils Water Supply Scheme. Detailed assessments of the potential impacts and consequences of mine subsidence on the catchment areas, the near-surface unconfined alluvial aquifers and the aquifers found in the deeper hard rock are included in the report by Mackie (2013).

The report for the Wyong Local Government Area Strategic Inquiry, by an Independent Expert Panel (2008), advised that the proposed longwalls will not have a significant impact or consequence on the region's catchment area or the existing or planned water supply infrastructure. The Panel also advised that the concerns raised by other interest groups, that the infrastructure would be damaged by the proposed longwalls, were also considered to be highly unlikely.

In recognition of the importance of protecting the water supply catchment, the WACJV has made public commitments regarding the safeguarding of the surface water supply catchment from mining impacts (refer to the *Wallarah2 EIS*).

To further ensure that *the Project* will not adversely affect the functions of the water supply catchment, *the Project* includes a catchment environmental enhancement program designed to improve the quality of the water supply catchment (refer to the *Wallarah2 EIS*).

5.3. Streams

The major streams within the *Study Area* include the Wyong River, Jilliby Jilliby Creek and Little Jilliby Jilliby Creek. There are also other streams within the *Study Area*, including Armstrong Creek, Myrtle Creek, Hue Hue Creek, Calmans Gully, Hughes Gully, Splash Gully, Youngs Gully and a number of unnamed tributaries.

The descriptions of the streams within the *Study Area* are provided in Section 2.4.2 and the locations are shown in Drawing No. MSEC515-08. The predictions and impact assessments for the major streams are provided in the following sections.

Table 5.1 References for Impact Assessments for Natural Features and Surface Infrastructure

Item	Within *Study Area*	Section Number Reference
NATURAL FEATURES		
Catchment Areas or Declared Special Areas	✓	5.2
Rivers or Creeks	✓	5.3
Aquifers or Known Groundwater Resources	✓	5.4
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	✓	5.5
Steep Slopes	✓	5.6
Escarpments	×	
Land Prone to Flooding or Inundation	✓	5.3
Swamps, Wetlands or Water Related Ecosystems	✓	5.7
Threatened or Protected Species	✓	5.8
National Parks or Wilderness Areas	×	
State Recreational or Conservation Areas	✓	5.2
State Forests	✓	5.2
Natural Vegetation	✓	5.2
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	×	
Roads (All Types)	✓	5.9 & 5.12
Bridges	✓	5.10 & 5.12
Tunnels	×	
Culverts	✓	5.11
Water, Gas or Sewerage Infrastructure	✓	5.13
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	✓	5.14, 5.15, 5.16 & 5.17
Telecommunication Lines or Associated Plants	✓	5.18, 5.19 & 5.20
Water Tanks, Water or Sewage Treatment Works	✓	5.13
Dams, Reservoirs or Associated Works	×	
Air Strips	×	
Any Other Public Utilities	×	
PUBLIC AMENITIES		
Hospitals	×	
Places of Worship	×	
Schools	✓	5.21.1
Shopping Centres	×	
Community Centres	✓	5.21.2
Office Buildings	×	
Swimming Pools	×	
Bowling Greens	×	
Ovals or Cricket Grounds	×	
Race Courses	×	
Golf Courses	×	
Tennis Courts	×	
Any Other Public Amenities	×	

Item	Within *Study Area*	Section Number Reference
FARM LAND AND FACILITIES		
Agricultural Utilisation or Agricultural Suitability of Farm Land	✓	5.22
Farm Buildings or Sheds	✓	5.24
Gas or Fuel Storages	×	
Poultry Sheds	×	
Glass Houses	×	
Hydroponic Systems	×	
Irrigation Systems	×	
Farm Fences	✓	5.25
Farm Dams	✓	5.26
Wells or Bores	✓	5.27
Any Other Farm Features	×	
INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS		
Factories	×	
Workshops	×	
Business or Commercial Establishments or Improvements	✓	5.23
Gas or Fuel Storages or Associated Plants	×	
Waste Storages or Associated Plants	×	
Buildings, Equipment or Operations that are Sensitive to Surface Movements	×	
Surface Mining (Open Cut) Voids or Rehabilitated Areas	✓	5.23.1
Mine Infrastructure Including Tailings Dams or Emplacement Areas	×	
Any Other Industrial, Commercial or Business Features	×	
AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE	✓	5.28 & 5.29
PERMANENT SURVEY CONTROL MARKS	✓	5.30
RESIDENTIAL ESTABLISHMENTS		
Houses	✓	5.31
Flats or Units	×	
Caravan Parks	×	
Retirement or Aged Care Villages	×	
Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts	✓	5.32, 5.33, 5.34, 5.35, 5.36, 5.37 & 5.38
Any Other Residential Features	×	
ANY OTHER ITEM OF SIGNIFICANCE	×	

5.3.1. Predictions for the Streams

The streams that were identified in Chapter 2 are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4. These streams could also be subjected to valley related movements, which are commonly observed along streams in the Southern Coalfield, but less commonly observed in the Newcastle Coalfield, where the depths of cover are generally much shallower.

It is considered that valley related movements are less commonly observed in the Newcastle Coalfield because the conventional subsidence movements are typically much larger than those observed in the Southern Coalfield. These larger conventional subsidence movements tend to mask any smaller valley related movements which may occur. The predicted valley related movements resulting from the extraction of the proposed longwalls were determined using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002).

The ACARP upsidence and closure prediction method is based on measured data from the Southern Coalfield, predominately from large and steeply incised valleys including the Cataract, Nepean, Bargo and Georges Rivers. The empirical prediction curves were conservatively drawn over the majority (i.e. more than 95 %) of the available upsidence and closure monitoring data from the Southern Coalfield. The higher measured movements from the database are believed to be associated with brittle, thin and cross-bedded bedrock layers and additional research is currently being undertaken for a current ACARP funded research project. Although there is very little upsidence and closure ground movement monitoring data available for wide alluvial filled valleys, such as those within the *Study Area*, the data that is available indicates that the ACARP method should provide a conservative indication of the overall level of valley related movements at bedrock level for the streams within the *Study Area*.

The predicted profiles of subsidence, upsidence and closure along the Wyong River, Jilliby Jilliby Creek and Little Jilliby Jilliby Creek, resulting from the extraction of the proposed longwalls, are illustrated in Figs. E.05, E.06 and E.07, respectively, in Appendix E. The predicted profiles of subsidence, upsidence and closure along the other streams within the *Study Area* are also shown in Figs. E.08 to E.28.

A summary of the maximum predicted conventional subsidence, tilt and curvatures along the alignments of the streams within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.2. A summary of the maximum predicted valley related upsidence and closure movements along these streams is provided in and Table 5.3.

Table 5.2 Maximum Predicted Conventional Subsidence, Tilt and Curvatures along the Major Streams Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Wyong River	175	1	0.01	0.01
Jilliby Jilliby Creek	1500	10	0.15	0.20
Little Jilliby Jilliby Creek	2000	12	0.20	0.25
Armstrong Creek	2600	13	0.25	0.30
Myrtle Creek	2500	15	0.28	0.37
Remaining Streams	2600	15	0.28	0.37

Table 5.3 Maximum Predicted Valley Related Upsidence and Closure Movements along the Major Streams Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Wyong River	150	100
Jilliby Jilliby Creek	150	75
Little Jilliby Jilliby Creek	650	775
Armstrong Creek	650	775
Myrtle Creek	800	1000
Remaining Streams	800	1000

The streams will also experience ground strains resulting from conventional subsidence and valley related movements. The discussions on ground strain are provided in the impact assessment for the streams.

5.3.2. Impact Assessments for the Streams

The WACJV recognised that mine subsidence has the potential to increase the impacts of flooding and consequently a number of mine layouts were modelled to determine the sensitivity of flood impacts to vertical subsidence. The output from the hybrid subsidence modelling was a direct input into the flood modelling which assessed the impacts of mine subsidence on the 1 in 100 year flood extent line, relative flood levels and various inundation issues in the Yarramalong Valley, Dooralong Valley and Hue Hue Creek areas. The detailed results of these studies are contained within the flood study report (GHA, 2013).

The predicted mine subsidence movements are based on a worst case assessment of the geological conditions within the *Study Area* and, hence, it is believed that conservative levels of predicted ground movements have been provided for this flood study. It should be noted that the sequencing of the longwall extractions will allow the mining layout to be adjusted near the streams, depending on the subsidence observations during the mining of the earlier longwalls. After detailed subsidence monitoring data has been gathered and analysed during the mining process, further reviews will be undertaken of the subsidence predictions and of the assessed flood impacts.

The impact assessments for the streams within the *Study Area* are provided in the following sections. The findings in this report should be read in conjunction with the detailed findings from the following reports that are also appended to the *Wallarah2 EIS*:-

- The flood model studies which are provided in the report by GHA, (2013), and
- The groundwater studies which are provided in the report by Mackie, (2013).

The streams could experience a number of potential impacts as a result of mining the proposed longwalls, which include:-

- Increased levels of ponding, flooding or scouring,
- Changes to stream alignment,
- Fracturing of the bedrock in the floors of the valleys,
- Surface water flow diversions into the shallow sub-strata,
- Loss of surface water through hydraulic connection to the mine,
- Changes to water quality,
- Release of strata gas, and
- Impacts on terrestrial and aquatic flora and fauna.

Mining has occurred under many streams and other bodies of surface water, including streams located in the Southern Coalfield, where the depths of cover are greater than 350 metres, such as the case within the *Study Area*. It should be noted that the geomorphology of the streams over the *Extraction Area* is significantly different to those in the Southern Coalfield. Many of the mine subsidence impacts on the streams in the Southern Coalfield were very noticeable because the surface water levels in these streams were controlled by a series of exposed rockbars and the groundwater levels around these perched pools were generally below the water levels in these pools.

It is relevant to note then that the streams in the wide alluvial filled valleys within the *Extraction Area* have water levels that, in times of drought, can be above the surrounding groundwater levels (gaining stream). In wet period times, the water levels in these streams can be below the surrounding groundwater levels (losing stream). In times of flood, floodwaters recharge the groundwater throughout the flooded areas.

It is also important to realise that the water levels in both the alluvial streams and the steeper streams within the surrounding hills and forest areas are not controlled by series of exposed rockbars. This important distinction means that mine subsidence movements, resulting from the extraction of the proposed longwalls, is expected to have less impact over the *Extraction Area* than have been experienced in the Southern Coalfield. Nevertheless, a general discussion is presented below of all the possible impacts on the streams in order to provide a clearer understanding of the likely impacts and consequences over *the Project*.

Increased levels of ponding, flooding, scouring and changes to stream alignments can occur and the assessments of these potential impacts and the consequences for the streams within the *Study Area* are contained within the flood study report (GHA, 2013). The flood study will act as a key element in the preparation of the future Extraction Plans.

Surface cracking and surface water flow diversions are the most visible and well known impacts associated with the mining beneath the valleys and streams in the Southern Coalfield. However, these surface water flow diversion impacts are unlikely to occur within the *Study Area* because the major watercourses within the *Study Area* have deep alluvial deposits covering the bedrock and there are few rockbars or exposed bedrock areas within the smaller tributaries to these major streams.

Changes to water quality and, to a lesser extent, impacts on flora and fauna are largely dependent on the severity of these physical impacts and are detailed in the *Wallarah2 EIS*. The impacts and consequences of mine subsidence ground movements on terrestrial and aquatic flora and fauna are discussed in detail in the report by OzArk (2012a).

The extent, severity and manner of impacts vary between different streams and coal mines because every situation is different. Each stream is unique in terms of its characteristics, which include flow conditions, water quality, gradients, valley depths and degree of incision, sediment and nutrient load, ecosystems, bedrock mineralogy and geomorphology. The nature and extent of mining beneath or near these streams also varies considerably in terms of the proximity of the extraction to the stream, the size of the extraction and the depth of cover.

The complexity of factors requires impact assessments for mining applications near streams to be undertaken on a case by case basis. There are, however, a number of common themes that can be found in each case and these are discussed below.

5.3.2.1. The Potential for Increased Levels of Ponding, Flooding and Scouring

Longwall mining can result in increased levels of flooding or scouring of the stream banks in the locations where the mining induced tilts considerably increase the natural stream gradients. Longwall mining can also result in increased levels of ponding in the locations where the mining induced tilts considerably decrease the natural stream gradients. The potential for these impacts are dependent on the magnitudes and locations of the mining induced tilts, the natural stream bed gradients, as well as the depth, velocity and rate of surface water flows.

The maximum predicted conventional tilt along the Wyong River, based on the predicted maximum subsidence along the river of 175 mm, is 1 mm/m (i.e. 0.1 %), which represents a change in grade of 1 in 1,000. This figure does not include the maximum predicted upsidence along the Wyong River, of 130 mm, which as shown in Fig. E.05 occurs at approximately the same location as the maximum predicted subsidence (i.e. reduces the maximum subsidence). Since the predicted maximum subsidence and the predicted maximum change in grade along the Wyong River are very small, they are unlikely to result in any noticeable changes in the levels of ponding, flooding and scouring.

The maximum predicted conventional tilt along Jilliby Jilliby Creek, resulting from the extraction of the proposed longwalls, is 10 mm/m (i.e. 1 %), which represent changes in grade of 1 in 100. As the natural gradient down Jilliby Jilliby Creek is approximately 1.3 mm/m, see Table 2.2, reversals of grade and ponding are likely occur, particularly over the commencing end of LW6N. The relationship between Jilliby Jilliby Creek and the proposed longwalls is shown in Drawing No. MSEC515-01.

Fig. 5.1 provides greater detail than Fig. E.05 on the predicted levels of mine subsidence and the subsided surface levels along Jilliby Jilliby Creek on a longwall by longwall basis. Fig. 5.1 indicates that ponding along Jilliby Jilliby Creek may occur over LW1S and LW6N based on the current mine layout. This reversal of grade can be avoided by locally narrowing the widths of some of these longwalls. If this adjustment is required, it would be best arranged when the subsidence monitoring information from longwalls 1W1N to LW3N is available.

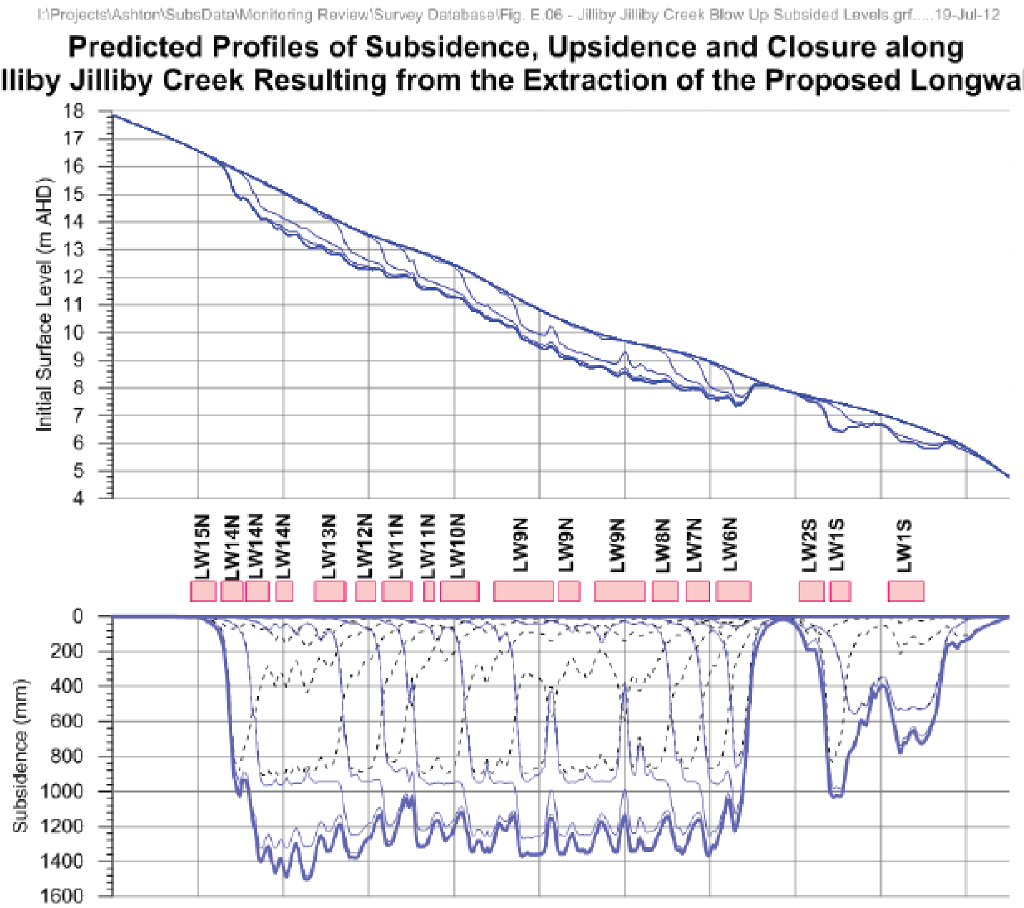

Fig. 5.1 Predicted Subsided Surface Levels of the bed of the Jilliby Jilliby Creek

The maximum predicted conventional tilt along Little Jilliby Jilliby Creek, resulting from the maximum predicted subsidence along the creek of 2,000 mm, is 12 mm/m (i.e. 1.2 %), which represents a change in grade of 1 in 85. As the average natural gradient of Little Jilliby Jilliby Creek is 5.2 mm/m, see Table 2.2, minor reversals of grade and ponding may occur along the creek over the commencing end of LW23N. However, as the predicted tilts and the natural gradients are almost equal at this location, this potential ponding would only be very minor and it is unlikely that it would be noticeable.

The maximum predicted conventional tilt for the remaining streams within the *Study Area*, resulting from the extraction of the proposed longwalls, is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65. These changes of grade are likely to be far less than the natural gradients down these streams, see Table 2.2, and hence no ponding or reversals of grade are expected. The predicted profiles of subsidence, upsidence and closure along the other streams within the *Study Area* are also shown in Figs. E.08 to E.28.

Analyses have been undertaken to assess whether the predicted levels may cause stream bed reversals of gradient along the flat low lying sections of the Wyong River and Jilliby Jilliby Creek. The results of these analyses were presented in the predicted profiles of subsidence, upsidence and closure along the Wyong River, Jilliby Jilliby Creek and Little Jilliby Jilliby Creek, that are illustrated in Figs. E.05, E.06 and E.07, respectively, in Appendix E. More detailed analyses of these possible effects, impacts and consequences are presented in the other expert consultant reports from GHA (2013) and Mackie (2013).

A detailed flood model of the streams has been developed by GHA (2013), which was based on the results of the hybrid subsidence prediction models. The potential for increased levels of ponding and flooding along the streams have been assessed in the flood model and are discussed in that report.

Flood prone land is defined as land which may become inundated during a 1 in 100 year flood event. The majority of flood prone houses are located outside the proposed mine plan. Baseline flood studies undertaken by GHA have demonstrated that the Yarramalong and Dooralong Valleys are currently flood prone. The floodplains are subject to regular inundation. Some bridges and culverts are cut off during relatively small floods.

Large sections of the main roads into both valleys are flood affected and many of the access roads pass through the floodplain. The Hue Hue Creek floodplain is different as flood depths are significantly less and the majority of flood prone land is located in rural or public open space areas of the catchment rather than in rural residential areas.

Within the *Study Area*, there are many dwellings in the Yarramalong and Dooralong Valleys and in the Hue Hue Creek floodplain. Subsidence can result in a change in floodplain storage and a change in hydraulic gradients within the floodplain. This will alter flooding behaviour depending on the timing of longwall extraction and their influence on subsided topography. It is also relevant to note that the nature of the land surface and the characteristics soils and alluvium mean that any reduction in runoff due to subsidence is unlikely to be measurable. Such effects can have both adverse and beneficial impacts on flooding within the subsided area and in areas upstream and downstream, depending on the provisions made for flood management.

The report by GHA (2013) also discusses the envisaged mining induced changes in the level of flood waters, the changes in the depths of flood waters, the changes in the extent and frequencies of flooded areas and proposes mitigation and preventative works that can be undertaken.

The findings and recommendations of the report by the Independent Expert Panel (2008) for the Strategic Inquiry into coal mining potential in the Wyong LGA, in respect to the effects of mine subsidence on the flooding of these valleys, have been reviewed by WACJV and its consultants. These findings and conclusions have been found to be consistent with the conclusions and proposed commitments set out in the flood impact assessment study by GHA (2013).

It is considered that potential impacts resulting from increased ponding or flooding can be managed by increasing embankment heights for any affected roads, tracks or driveways and by regrading small sections of stream, if required. Furthermore the widths of the particular longwalls can be narrowed to locally reduce the predicted levels of subsidence, if this option is required.

It is recommended that WACJV develop management plans, in consultation with Wyong Shire Council and private landowners, to manage the potential impacts of increased ponding or flooding.

Although the major streams within the *Study Area* have relatively shallow natural gradients, it is unlikely that there would be any significant increases in the levels of scouring of the stream banks, as the maximum predicted changes in grade along the streams are very small, being in the order of 1 %. Some very localised areas of increased scouring could occur, in the locations of maximum increasing tilt, however, the levels of impact would be expected to be small when compared to natural scouring which occurs during natural flooding events.

The impacts and consequences of mine subsidence ground movements on flooding within the *Study Area* are discussed in detail in the report by GHA (2013).

5.3.2.2. The Potential for Changes in Stream Alignment

Longwall mining can result in changes in stream alignment due to mining induced cross-bed tilts. The potential for mining-induced changes in the stream alignment depends upon the magnitudes and locations of the mining induced cross-bed tilts, the natural stream cross-bed gradients, as well as the depth, velocity and rate of surface water flows. Changes in stream alignment can potentially impact upon riparian vegetation, or result in increased scouring of the stream banks.

The WACJV was aware of this potential and iteratively amended the mine plan on several occasions so as to minimise the potential changes in stream alignment, as discussed in the *Subsidence Prediction Report* (WACJV (2012).

The maximum predicted conventional tilt across the alignment of the Wyong River, resulting from the extraction of the proposed longwalls, is less than 1 mm/m (i.e. < 0.1 %), which represents a change in cross-grade of less than 1 in 1,000. The predicted maximum change in cross-grade for the Wyong River is very small and is unlikely, therefore, to result in any noticeable changes in stream alignment.

The maximum predicted conventional tilts across the alignments of Jilliby Jilliby Creek and Little Jilliby Jilliby Creek, resulting from the extraction of the proposed longwalls, are 10 mm/m (i.e. 1 %) and 12 mm/m (i.e. 1.2 %), respectively, which represent changes in cross-grade of 1 in 100 and 1 in 85, respectively. The maximum predicted conventional cross-tilt for the remaining streams within the *Study Area*, resulting from the extraction of the proposed longwalls, is 15 mm/m (i.e. 1.5 %), which represents a change in cross-grade of 1 in 65. These predicted changes in the cross-bed gradients are small and are expected to be an order of magnitude less than the natural stream cross-bed gradients. The potential impacts associated with changes in the stream alignment, resulting from the extraction of the proposed longwalls are, therefore, expected to be small.

The potential impacts of the changes in stream alignment are expected to be minor when compared to the changes in the surface water flow depths and widths that occur during natural flooding events. In the locations where the stream beds comprise sediments and deposited debris, rainfall events can result in changes in the stream alignment. In a big storm event, even rocks and vegetation can be carried away downstream. The increased flow velocities in such events are likely to be an order of magnitude greater than those resulting from mining induced changes to bed gradients.

The impacts and consequences of mine subsidence ground movements on the changes in stream alignment within the *Study Area* are discussed in detail in the report by GHA (2013).

5.3.2.3. The Potential for Fracturing of Bedrock in the Floors of Valleys

Fractures and joints in bedrock occur naturally during the formation of the strata and from erosion and weathering processes, which include natural valley bulging movements.

When longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or reactivation of existing joints. A number of factors are thought to contribute to the likelihood of mining-induced fracturing and these are listed below:-

- Mining-related factors, which affect the level of mining-induced ground movements in the valley. These include, amongst other factors, the depth of cover and proximity of the mining to the stream, panel width and extracted thickness, and geology of the overburden.
- Topographic factors associated with the stream valley, which include valley depth, valley width and the shape and steepness of the valley sides.
- Local, near-surface geological factors, which include alluvial deposit thickness, bedrock lithology such as rock strength, thickness of beds within the strata, orientation and dip of strata, degree of cross-bedding and existing jointing.
- Horizontal in situ stresses in the bedrock.
- Presence of deep alluvial deposits covering the bedrock.

Monitoring of stream beds affected by longwall mining indicates that mining-induced fractures in bedrock are greatest in size and number directly above the extracted longwalls. Fewer fractures have developed above narrow longwalls than above wider longwalls. Where mining occurred close to but not directly beneath streams, a smaller number of mining-induced fractures were observed in the bedrock. These fractures may only be visible when the bedrock is exposed. The level of pre-existing stress in the valley bedrock varies depending on its position in the natural erosive cycle and the level of regional stress that has been imposed on it. The bedrock strength varies along the streams depending on the type of rock, its layer thickness and extent of natural joints and fractures.

In the cases of the major streams within the *Study Area*, exploration drilling indicates the presence of alluvial deposits up to 40 metres deep and, therefore; it is unlikely that any fracturing of the bedrock would be visible at the surface. The bedrock beneath these saturated stream beds may fracture, buckle, or uplift due to the valley closure and upsidence movements, creating a small zone of increased permeability in the upper few metres of rockhead. While these effects can cause noticeable impacts in rockbar controlled streams, this condition does not occur for the major watercourses within the *Study Area*, which are within these broad 30 metres deep alluvial filled valleys.

Fracturing, shearing and buckling may occur at the rock head in these valleys. However since this will occur beneath the saturated alluvial deposits, the fracture zone will fill as it develops with little or no effect to the surface water level. Similarly, since this increased permeability zone will develop quite gradually, and its volume will be small compared to the volume of the overlying saturated alluvium, the impact on the alluvial and the overall surface stream flow is expected to be small.

It is possible, that compressive buckling in the bedrock could occur directly above and within say 250 metres of the proposed longwalls. In the smaller streams located up the sides of the valleys, where the bedrock is exposed, some fracturing may be visible at the surface.

It has been observed in the past, that the depth of buckling and dilation of the uppermost bedrock, resulting from valley related movements, is generally less than 10 metres to 15 metres. However this has only been noticed where there are extensive exposed rock platforms in the beds of valleys, where the strata are relatively thin and brittle, and these conditions have not been identified over *the Project*.

If surface cracking were to occur within the stream alignments, it would be expected that, in times of heavy rainfall, any dilated bedrock beneath the stream beds would become water charged, and the surface water would flow over any surface cracks. Surface water that is diverted into the dilated bedrock beneath the streams, during times of rainfall, is unlikely to significantly affect the overall quality or quantity of the surface water flow, as the cross-sectional area of dilated bedrock is very small when compared to the cross-sectional area of the stream channels.

Any surface cracking would tend to be naturally filled with alluvial materials during subsequent flow events, especially during times of heavy rainfall. If any surface cracks were found not to fill naturally, some remediation measures may be required at the completion of mining. Where necessary, any significant surface cracks in the stream beds could be remediated by infilling with alluvial or other suitable materials, or by locally regrading and recompacting the surface.

The impacts and consequences of mine subsidence ground movements on groundwater resources are discussed in detail in the report by Mackie (2013).

5.3.2.4. The Potential for Surface Water Flow Diversions

The mining geometry, overburden geology, stream bed geology and stream flow conditions in the *Study Area* are different to the conditions in the Southern Coalfield. The potential mine subsidence related impacts on the streams over *the Project* will, therefore, be different to those experienced in the Southern Coalfield. Nevertheless, community concerns have been raised that there may be potential surface water flows impacts at *the Project* similar to those reported in the Southern Coalfield. Accordingly a brief review is required to explain the observed ground movements and the reported impacts on streams in the Southern Coalfield, so that comparisons can be made with the predicted and assessed impacts and the consequences expected over *the Project*.

The mine subsidence related impacts on surface water flows in the Southern Coalfield are primarily concerned with the diversion of surface water in the following ways:-

- Infiltration into the groundwater system, particularly where the groundwater table is lower than the surface water level of the stream, or where a flow path is established to a lower groundwater aquifer,
- Direct connectivity between the surface and the mine, and
- Diversion of surface water flows into subterranean flows and rockbar leakages, where surface water has been observed to flow via fractures and joints in the bedrock and via near-surface dilated strata and bedding plan separations within the bedrock. This water is generally observed to resurface downstream of the affected area. These diversions of surface water can also occur naturally, but mine subsidence ground movements have been observed to increase the quantity of water that can flow beneath the surface through these leakage paths.

Infiltration of surface water into deeper groundwater cannot result unless a conduit already exists or is established for flow through to a deeper permeable horizon. The potential for this type of impact within the *Study Area* is discussed in the report by Mackie (2013).

Where the depth of cover is shallow, connectivity between the surface and underground mine workings can result in a direct path from the surface to the mine. This has not been observed in the areas where the depths of cover are greater than 350 metres, such as the case within the *Study Area*. Following careful mine planning and rigorous assessments and approvals by the Dams Safety Committee, the Sydney Catchment Authority and the Department of Trade and Investment, Regional Infrastructure and Services, Division of Resources & Energy (DRE) mining has successfully occurred beneath various stored waters at such depths in the Newcastle and Southern Coalfields.

Intensive monitoring of mining beneath or near various water storage areas indicated that negligible impacts have occurred with appropriately designed mine layouts (Reid, 1991). Similar observations have been made with respect to mining beneath the Nepean River between the Douglas Park and Menangle Weirs. Monitoring in the river confirmed that the river bed and banks subsided similar to the predicted ground movements, while the water level remained unchanged. It is likely that the bedrock in this river experienced fracturing and uplift, as observed in other streams. However, the consequences of these small increased zones of increased permeability were not noticeable on the surface, as the fracturing and uplift was submerged below the permanent water level and often below impounded sediments.

A discussion on the likely height of the fractured zone above the longwalls, which was based on the numerical modelling by SCT, is included in the Subsidence Prediction Report WACJV (2012). The impacts and consequences of mine subsidence ground movements on groundwater resources are discussed in detail in the report by Mackie (2013).

Mining-induced surface flow diversion into subterranean flows occur where there is an upwards thrust of bedrock (measured as upsidence), resulting in fracturing of bedrock and redirection of surface water through the dilated strata beneath it, and this is illustrated in Fig. 5.1.

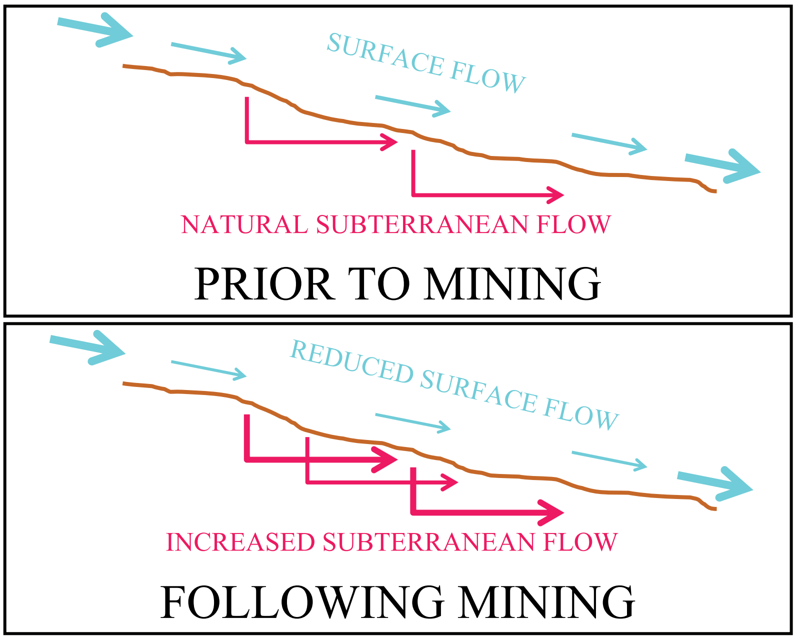

Fig. 5.2 Diagrammatic Representation of Subterranean Flows for Certain Rock-Lined Streams in the Southern Coalfield

While fractures in bedrock can provide a conduit through which water can travel beneath the surface, it does not necessarily follow that every fracture will result in surface flow diversion. Some minor fractures may not provide a continuous flow path to allow water to flow under the bedrock, and these types of fracture do not significantly impact surface water flows.

The most dramatic outcome of surface water flow diversion occurs when the stream bed becomes completely dry. The potential for noticeable or complete surface water flow diversions is not only dependent on the amount of fracturing and bed dilation, but also the magnitude of flow in the stream. Where the surface water flow is greater than the rate of leakage into subterranean flow or through a controlling feature, such as a rockbar, then surface water will still flow, at a reduced rate, through the impacted section of stream. The stream will only become completely dry where the upstream flow is less than the rate of leakage into subterranean flow or rockbar leakage.

The main concern of mine subsidence impacts on streams in the Southern Coalfield therefore relates to mining induced surface flow diversion into subterranean flows within deeply incised valleys, where the surface water flows are small and occur between pools that are controlled by a series of rockbars. These rockbars in the Southern Coalfield are formed within the Hawkesbury Sandstones which commonly comprise thin bands of strong and brittle sandstone, occasional natural vertical joints and occasional cross bedding. There are many cases where the natural erosion and weathering processes have led to natural surface water diversions through and beneath these rockbars.

However this process is not expected to be significant over *the Project* because of the following:-

- The major streams are wide valleys with deep alluvial deposits and, therefore, any fracturing of the bedrock is unlikely to be visible at the surface and any dilation of the bedrock is likely to become water charged and not result in increased subterranean flows,
- There are few exposed rock platforms over the steep slopes and along the smaller streams that are located up the sides of the valleys,
- There are no large exposed rockbars along the streams, and
- There are no thin, brittle or cross bedded strata layers exposed in the stream beds.

Accordingly water flow diversions are not anticipated over *the Project*.

5.3.2.5. Loss of Surface Water through Hydraulic Connection to the Mine

The extent, severity and manner of impacts of mining on surface water resources can vary significantly between different longwall panels because every situation is different. Each stream is unique in terms of its characteristics, which include flow conditions, water quality, gradients, valley depths and degree of incision, sediment and nutrient load, ecosystems, bedrock mineralogy and geomorphology. The nature and extent of mining beneath or near these streams also varies considerably in terms of the proximity of the extraction to the stream, the size of the extraction, the geology of the overburden and the depth of cover. The specific geology of each case should be closely considered as the presence or absence of strong channels and the presence or absence of impermeable layers which would completely change the standard generalisations as to hydraulic connectivity that are based on solely on mined panel width or seam thickness. The complexity of the factors that are involved requires assessments for mining applications near streams to be undertaken on a case by case basis.

The impact assessments and discussions on the potential impacts on mine subsidence on the groundwater resources and a description of potential impacts on hydraulic connectivity are provided in the report by Mackie (2013).

Based on the high depths of cover over the proposed longwalls, the nature and thinness of the many shale, claystone and tuffaceous layers that exist throughout the overburden, the absence of massive sandstone units and subject to the absence of major unforseen geological features, connectivity between the alluvial valleys and their streams and underground mine workings at *the Project*, with consequent loss of surface water, is considered to be extremely unlikely.

5.3.2.6. The Potential Consequences to Water Quality

Impacts on water quality are highly influenced by the amount of surface water flow within the affected stream. Where there are low surface water flows, water quality can be noticeably degraded, for example increased iron oxide precipitation and reduced dissolved oxygen. Where there are high surface water flows, the impacts on water quality are less noticeable.

A description of potential impacts on water quality is presented in the report by Mackie (2013).

5.3.2.7. The Potential for Gas Emissions

It is known that mining results in fracturing of the strata above and adjacent to the *Extraction Area* and this may result in the liberation of methane and other gases. Gas emissions have been observed at other mines in streams and in groundwater bores. Emissions are most noticeable in the form of bubbles in water and, in some cases, emissions are concentrated enough to support a flame if lit.

Substantial studies have been undertaken into the properties of gas within rock strata. Gas is found in most rocks, and can exist in three different states – free gas, dissolved gas in water and adsorbed gas (Moelle et al, 1995). Analyses of gas compositions indicate that the near surface strata are the direct and major source of the gas rather than the extracted resource, particularly where mining occurs at significant depths. As rocks in the near surface strata experience compression in response to mining movements, free or adsorbed gas can be released, typically releasing at existing or new fractures and joints.

Gas emissions typically occur in isolated locations and the majority of gas emissions occur in areas that are directly mined beneath. These emissions are also typically the most vigorous. However, gas emissions do also occur in areas that have not been directly mined beneath.

Gas released into water quickly rises to the water surface where it is released to the atmosphere ensuring that is has very limited time to dissolve into the water body. The gas released is predominately methane, which is not particularly soluble in water. It is unlikely, therefore, to have an adverse impact on water quality within the stream.

It is possible, if substantial gas emissions occur at the surface, that these could cause localised vegetation dieback. Such vegetation dieback is rare and has only been recorded in one location in the Southern Coalfield. These impacts were limited to small areas of vegetation and local to the points of emission. The gas emissions have declined and the affected areas have successfully recovered. Vegetation dieback has not been observed in areas that have not been directly mined beneath.

5.3.3. Impact Assessments for the Streams Based on Increased Predictions

As discussed in Section 3.11, a hybrid approach was developed for predicting subsidence at *the Project* and significantly increased levels of mine subsidence have been predicted across the *Study Area* when compared to normal subsidence predictions at similar depths of cover within the NSW Coalfields.

It is therefore believed that the predicted subsidence ground movements are realistic, if not conservative, such that the observed movements are likely to be lower than these predicted values. Whilst the current conservative approach is considered appropriate for the current mine planning study, the proposed monitoring and analysis of the actual subsidence measured during the initial mining will enable further verification of the model and adjustments to the subsidence management strategies.

5.3.4. Recommendations for the Streams

The WACJV has committed to an adaptive and continuous improvement approach to the longwall panel design whereby the mining dimensions and limits of future mine workings will be continuously reviewed and modified as necessary as experience is gained to ensure the required subsidence parameters are observed within the various streams and floodplains.

The effects of mine subsidence movements on flooding and surface drainage were identified as an important environmental issue to be assessed. GHA (2013) was commissioned by the WACJV to investigate and assess the potential impacts of the mine subsidence movements on flooding within the Dooralong and Yarramalong Valleys and within the Hue Hue Creek catchment. The flood model became an integral component in the finalisation of the mine plan and has been developed in conjunction with subsidence and groundwater assessments. The process has been iterative with several modifications being made to the mine plan in order to achieve the best outcome for flood affected properties within the *Study Area* and to minimise the extent and severity of potential flood impacts.

The changes made to the mine plan have included variations to the longwall panel layout, the locations of the main roadways within Little Jilliby Jilliby Creek valley and the protection of its confluence with Jilliby Jilliby Creek, the reduction in longwall extraction height and panel width within the valley area and the restriction of mining activity near the Wyong River and the Yarramalong Valley.

Management plans should be developed to manage the potential impacts on streams during the mining of the proposed longwalls. These plans should cover five to ten longwalls and have been approved in the past up to a maximum of seven years. The management plans should include monitoring and triggered response plans to mitigate impacts as they are observed. They should also include monitoring of pre-mining conditions and data collection during mining. Monitoring should continue for a period following mining and to determine the success of any rehabilitation requirements.

5.4. Aquifers and Groundwater Resources

A detailed groundwater and aquifer model has been developed by Mackie (2013), which was based on the results of the hybrid subsidence prediction models. The potential impacts on the groundwater resulting from the proposed longwalls are discussed in that report.

As discussed in Section 5.3.2.5, based on the deep depths of cover over the proposed longwalls, the nature and thinness of the many shale, claystone and tuffaceous layers that exist throughout the overburden, the absence of massive sandstone units and subject to the absence of major unforseen geological features, connectivity between the alluvial valleys and their streams and underground mine workings at *the Project*, with consequent loss of surface water, is considered to be extremely unlikely.

The impact assessments and discussions on the potential impacts on mine subsidence on the groundwater resources are provided in the report by Mackie (2013).

Any conditions of approval for *the Project* should require management plans with requirements specific to geological discontinuities (structures) that are underpinned by an extensive groundwater and surface water monitoring system, continuous water balance assessments (water in – water out of the mine), and a requirement to review subsidence and groundwater related predictions whenever geological structures above nominated thresholds (displacement, width etc.) are encountered and to seek approval to continue to mine in those areas.

5.5. Rock Outcrops and Isolated Cliffs

As defined in Section 2.4.8, no cliffs were identified within the *Study area*; however, as also discussed in Section 2.4.8, some small isolated rock formations were identified within the *Study Area*, located primarily along the sides of the Dooralong, Yarramalong and Little Jilliby Jilliby Creek Valleys. The predictions and impact assessments for these rock formations are provided in the following sections.

5.5.1. Predictions for the Isolated Rock Formations

These isolated rock formations are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. These features occur along the sides of the valleys, where the depths of cover are greater and, therefore, at these locations, the maximum predicted parameters in these locations are less than the maxima provided in Chapter 4.

A summary is provided in Table 5.4 of the maximum predicted conventional subsidence, tilt and curvatures for the rock formations within the *Study Area*, resulting from the extraction of the proposed longwalls. The ranges of the depths of cover are also shown in this table for comparison. The parameters provided in this table are the maximum predicted values at any time during or after the extraction of the proposed longwalls.

Table 5.4 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Rock Formations within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Location	Depth of Cover (m)	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Rock Formations above LW1N to LW8N	400 ~ 490	1250	8.5	0.15	0.20
Rock Formations above LW12N to LW26N	400 ~ 610	2525	15	0.20	0.30
Rock Formations above LW1S to LW10S	470 ~ 660	2575	14	0.20	0.25
Rock Formations above LW1SW to LW10SW	500 ~ 690	2525	12	0.10	0.20

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual rock formations would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement at the rock formations across the *Study Area* would not be expected to change significantly.

The maximum predicted conventional strains for the rock formations, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- Rock formations above LW1N to LW8N - 2.5 mm/m tensile and 3 mm/m compressive,
- Rock Formations above LW12N to LW26N - 3 mm/m tensile and 4.5 mm/m compressive,
- Rock Formations above LW1S to LW10S - 3 mm/m tensile and 4 mm/m compressive, and
- Rock Formations above LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

The rock formations are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Irregular subsidence movements can also occur at the rock formations. The analysis of strains provided in Chapter 4 includes those resulting from conventional and non-conventional anomalous movements.

5.5.2. Impact Assessments for the Isolated Rock Formations

Mining has occurred beneath many rock formations in the Western and Southern Coalfields of NSW and minor rock falls, surface cracking and major cliff falls have been observed. Detailed monitoring has been undertaken of survey pegs and reflectors that were placed on rock formations, cliffs and escarpments as coal as longwalls approached, passed under and beyond rock formations, cliffs and escarpments. A large quantity of field monitoring data was collected into a mining induced cliff movement and rock fall database as part of a NERDDC funded research project that was titled "*Effects of Subsidence on Steep Topography and Cliff Lines*" (Kay, 1991).

Observations concerning the magnitude and direction of the monitored ground movements at all the reflectors around particular cliff lines assisted in understanding why certain cliffs fell. In particular, monitoring showed that the horizontal movements, at cliffs at the time of the rock falls, were higher than expected and that reflectors attached to the cliff face and steep slope areas moved "en masse" in a down slope direction and towards the valley. Monitored data is available from these studies on the magnitude of the ground movements in the vicinity of the cliffs that did not fall, as well as the ground movements and differential ground movements in the vicinity of cliffs, at the time of the falls, for those cliffs that did fall.

It was historically believed before this study that, mining induced rock falls would be more likely to happen at cliff faces that were undercut and eroded, rather than the other cliff faces that were not in such an advanced stage of weathering. However, it was found that only one third of the cliffs that experienced rock falls were heavily eroded, undercut, or sloping forward, whilst two thirds of the cliffs that fell appeared, before mining, to be relatively stable and were sloping backwards. Quite often, after mining had ceased, it was realised that most of the undercut or overhung sections of the cliffs had remained standing, whilst rock falls were observed off other sections of the cliff line. Similarly it was not always the highest cliffs that fell. So it was concluded that it was extremely difficult to assess before mining occurred exactly which part of a cliff line would experience rock falls. It became clear that it was better to discuss possible mining impacts on cliffs in terms of “what percentage of a cliff line had experienced rock falls”.

The monitored rock fall data at mining induced rock falls suggested that higher cliffs are more susceptible to failure than lower cliffs, although a wide scatter in the plotted data indicates that other important factors must also influence the likelihood of rock falls. An important observation for the impact assessment at *the Project* was that no rock falls were noticed to occur off small isolated rock formations where the cliff line length was less than 30 metres, i.e. no falls were observed off narrow pagoda type rock features. Eighty per cent of the observed falls at Baal Bone Colliery occurred off rock formations that were relatively continuous and had cliff line lengths that were greater than 60 metres.

Tilt can increase the overturning moments in steep or overhanging rock formations which, if of sufficient magnitude, could result in toppling type cliff failures. However, the predicted maximum tilts for the rock formations at *the Project* are small in comparison to the natural slopes of the rock faces and are unlikely, therefore, to result in topping type failures in these cases.

If the ground curvatures or strains are of sufficient magnitude, sections of rock within the rock face could fracture along existing bedding planes or joints and become unstable, resulting in cracking, sliding or toppling type failures along the cliffs.

The maximum predicted ground curvatures for the identified rock formations that are located above Longwalls 1N to 8N and above Longwalls 1SW to 10SW are 0.15 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 7 kilometres and 5 kilometres, respectively. These maximum predicted ground curvatures and strains for these rock formations are similar to those typically experienced in the Southern Coalfield where relatively low levels of mine subsidence induced impacts on rock formations have been observed compared to the Western Coalfields where the depths of cover are much shallower.

Monitoring in the Southern Coalfields has included large cliffs and isolated rock formations along the Cataract, Nepean, Bargo and Georges Rivers of the Southern Coalfields. The potential impacts on the isolated rock formations that are located above Longwalls 1N to 8N and above Longwalls 1SW to 10SW are therefore expected to be similar or lower to those previously observed in the Southern Coalfield and, hence, a closer review of the observed mining induced impacts to cliffs in the Southern Coalfield was undertaken.

There were a total of 10 cliff instabilities recorded along the Cataract and Nepean Rivers, as a result of the extraction of Tower Longwalls 1 to 17, all of which occurred where the longwalls mined directly beneath the cliff faces that were approximately 60 metres high. The total length of cliff lines where instabilities occurred was 200 metres and the total length of cliff lines that were undermined within 0.7 times the depth of cover from the extracted longwalls was 5,575 metres, resulting in impacts to approximately 4 % of the total length of cliff lines.

Tahmoor Longwalls 14 to 19 mined directly beneath the Bargo River and cliffs that were up to 25 metres high. The total length of the cliffs that were directly mined beneath or located within the 35 degree angle of draw from these longwalls was approximately 2.5 kilometres. The overall heights of the cliffs varied between 10 metres and 25 metres and no cliff falls or instabilities were observed during or after the mining period.

There were also no cliff instabilities observed along the Cataract River, where there were cliffs up to 60 metres high, as a result of the nearby extraction of Appin Longwalls 301 and 302, which did not pass under the cliff lines. There were, however, five minor rock falls or disturbances which occurred during the mining period, of which, three were considered likely to have occurred due to a significant rainfall event and natural instability of the cliff/overhang. The total lengths of cliffs disturbed as a result of the extraction of Appin Longwall 301 and Longwall 302 was, therefore, estimated to be less than 1 % of the total plan length of cliff line within the area.

There were no cliff instabilities observed along the cliffs and isolated rock formations of the Nepean River, where there were cliffs up to 40 metres high, as a result of the extraction of Tower Longwalls 18 to 20 and Appin Longwalls 701 and 702. Longwall extraction did not occur directly under the cliff lines.

Based on the case study history of mining at Appin, Tower and Tahmoor Collieries, where the depths of cover is approximately 500 metres;

- there is a moderate probability that up to 4% of a cliff line will experience rock falls and cliff instabilities, somewhere along those cliff lines that are directly mined beneath, but, there is a very low probability of rock falls and cliff instabilities occurring at cliffs that are located beyond the extracted area, i.e. over solid unmined coal.
- there is a much lower probability that rock falls and cliff instabilities will occur at isolated rock formations which are directly mined beneath, but, there is an extremely low probability of rock falls and cliff instabilities occurring at isolated rock formations that are located beyond the extracted area, i.e. over solid unmined coal.

At Dendrobium Mine, where the depth of cover at the cliff lines ranged from 200 metres to 300 metres, longwall mining occurred directly under cliff lines that were up to 30 metres high. The main impacts on the cliff lines and rock formations at Dendrobium occurred at the large and continuous cliff lines, which affected approximately 7 % to 10 % of the total length of the cliff lines that were directly mined beneath. The incidence of impacts on the smaller rock outcrops was very low and occurred in isolated locations.

At *the Project*, the depths of cover at the small isolated rock formation are greater than the depths of cover at Dendrobium and are similar to the depths of cover at Appin, Tower and Tahmoor Collieries. No cliffs have been identified within the *Study Area.* The small isolated rock formations are located over the proposed longwalls and, hence, are expected to experience the full range of predicted subsidence movements. These features occur along the sides of the valleys, where the depths of cover are greater and, therefore, at these locations, the maximum predicted parameters in these locations are less than the maxima provided in Chapter 4.

Any impacts on the small isolated rock formations at *the Project* are expected to be less than the small isolated rock formations experienced at Appin, Tower and Tahmoor Collieries, say less than 3% of the total length of small isolated rock formations that are directly mined beneath. It is extremely difficult to accurately predict which small isolated rock formations will experience impacts. As a general rule, however, the small isolated rock formations at greater risk of impact are those with larger overhangs located along concave sections of the creeks.

While the risk of cliff instability is extremely low, some risk remains and attention must therefore be paid with appropriate management plans to limit all risks when it is proposed to mine near the small isolated rock formations. The incidence of impacts on the small isolated rock formations within the *Study Area* is expected to be very low and occur in isolated locations. It will be necessary to manage the potential risks of rockfalls to people and infrastructure downslope of the rock formations, which include the roads and fire trails, the CMTS site, and houses.

5.5.3. Impact Assessments for the Rock Formations Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the potential impacts on the rock formations would not be expected to increase significantly, as the predicted tilts would still be much less than the natural slopes of the rock faces within the *Study Area*.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the incidence of rock falls would increase directly above the proposed longwalls. The incidence of impacts on the rock formations (i.e. not including the large cliff lines) was small at Dendrobium Mine, where the predicted curvatures and ground strains were more than 2 times those predicted within the *Study Area*. Based on this previous experience, it would still be expected that the incidence of impacts on the rock outcrops in the *Study Area* would still be small if the actual movements exceeded those predicted.

5.5.4. Recommendations for the Rock Formations

It is recommended that management strategies are developed to minimise the risk of rock falls, which may include:-

- Identification of all features and items of infrastructure that are located downslope of the rock formations which are directly mined beneath,
- The provision of signage warning of the potential for rock falls, and
- Periodic visual inspections of the rock formations deemed to be at greatest risk during the active subsidence period.

5.6. Steep Slopes

The locations of the steep slopes within the *Study Area* are shown in Drawing No. MSEC515-09. The predictions and impact assessments for the steep slopes are provided in the following sections.

5.6.1. Predictions for the Steep Slopes

The steep slopes are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. The steep slopes occur along the sides of the valleys, where the depths of cover are higher and, therefore, the maximum predicted parameters in these locations are less than the maxima provided in Chapter 4.

A summary of the maximum predicted conventional subsidence, tilt and curvatures for the steep slopes within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.5. The ranges of the depths of cover are also shown in this table for comparison.

Table 5.5 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Steep Slopes within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Location	Depth of Cover (m)	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Steep Slopes above LW1N to LW8N	400 ~ 490	1250	8.5	0.15	0.20
Steep Slopes above LW12N to LW26N	400 ~ 610	2525	15	0.20	0.30
Steep Slopes above LW1S to LW10S	470 ~ 660	2575	14	0.20	0.25
Steep Slopes above LW1SW to LW10SW	500 ~ 690	2525	12	0.10	0.20

The parameters provided in the above table are the maximum predicted values at any time during or after the extraction of the proposed longwalls. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in the above table.

The maximum predicted conventional strains for the steep slopes, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- Steep Slopes above LW1N to LW8N - 2.5 mm/m tensile and 3 mm/m compressive,
- Steep Slopes above LW12N to LW26N - 3 mm/m tensile and 4.5 mm/m compressive,
- Steep Slopes above LW1S to LW10S - 3 mm/m tensile and 4 mm/m compressive, and
- Steep Slopes above LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

The steep slopes are planar features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements and downslope movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.6.2. Impact Assessments for the Steep Slopes

The maximum predicted tilt for the steep slopes, resulting from the extraction of the proposed longwalls, is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65. The predicted changes in grade are small when compared to the natural grades of the steep slopes, which are greater than 1 in 3 and, therefore, unlikely to result in any significant impact on the stability of the steep slopes.

The steep slopes are more likely to be impacted by ground curvatures and strains. The potential impacts would generally result from the downslope movement of the ground, causing tension cracks to appear at the tops and the sides of the slopes and compression ridges to form at the bottoms of the slopes.

The maximum predicted ground curvatures for the steep slopes above Longwalls 1N to 8N and above Longwalls 1SW to 10SW are 0.15 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 7 kilometres and 5 kilometres, respectively. The maximum predicted ground curvatures at these steep slopes are similar to those typically experienced in the Southern Coalfield. The potential impacts on the steep slopes above Longwalls 1N to 8N and above Longwalls 1SW to 10SW, therefore, are expected to be similar to those previously observed in the Southern Coalfield.

There is extensive experience of mining beneath steep slopes in the Southern Coalfield. These include steep slopes along the Cataract, Nepean, Bargo and Georges Rivers. No large-scale slope failures have been observed along these slopes, even where longwalls have been mined directly beneath them. Although no large-scale slope failures have been observed in the Southern Coalfield, tension cracking has been observed at the tops of steep slopes as the result of downslope movements.

Cracking from downslope movements at depths of cover greater than 350 metres, such as the case in the *Study Area*, is generally isolated and small, typically having maximum crack widths in the order of 50 mm. Larger cracking has been observed at the tops of very steep slopes and adjacent to large rock formations, where maximum crack widths in the order of 100 to 150 mm have been observed.

The maximum predicted ground curvatures for the steep slopes above Longwalls 12N to 26N and above Longwalls 1S to 10S are 0.20 km^{-1} hogging and 0.30 km^{-1} sagging, which represent minimum radii of curvature of 5 kilometres and 3 kilometres, respectively. The maximum predicted ground curvatures and strains for these steep slopes are less than those predicted to have occurred at Dendrobium Mine, where longwalls have been extracted directly beneath a number of ridgelines.

The widths of the cracks observed near the tops of the ridgelines at Dendrobium Mine, resulting from downslope movement, varied up to 400 mm wide. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the steep slopes. The surface cracks above the proposed longwalls are expected to be narrower and less extensive than those observed at Dendrobium Mine, as the depth of cover is greater than the predicted movements are smaller within the *Study Area*.

If tension cracks were to develop, as the result of the extraction of the proposed longwalls, it is possible that soil erosion could occur if these cracks were left untreated. It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

While in most cases, impacts on steep slopes are likely to consist of surface cracking, there remains a low probability of large-scale downslope movements. Experience indicates that the probability of mining induced large-scale slippages is extremely low due to the significant depth of cover within the *Study Area*.

While the risk is extremely low, some risk remains and attention must therefore be paid to any features or items of infrastructure that are located in the vicinity of steep slopes which are directly mined beneath, which include the:-

- Houses,
- Roads and fire trails,
- Transmission Towers 21-46-T to 21-53-T and 22-49T to 22-56-S,
- CMTS site and optical fibre cable, and
- Survey control marks.

5.6.3. Impact Assessments for the Steep Slopes Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the potential impacts on the steep slopes would not be expected to increase significantly, as the predicted tilts would still be much less than the natural ground slopes within the *Study Area*.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the extent of surface cracking would increase at the steep slopes located directly above the longwalls. In this case, the curvatures and strains at the steep slopes would still be less than those predicted to have occurred as the result of the extraction of the longwalls at Dendrobium Mine, which mined directly beneath a number of ridgelines. Whilst large tensile cracks were observed near the tops of the steep slopes, there were no reports of slope instabilities.

Any significant surface cracking could be remediated by infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the slopes in the longer term.

5.6.4. Recommendations for the Steep Slopes

It is recommended that the steep slopes are periodically visually monitored during the mining period and until any necessary remediation measures are completed. It is also recommended that management strategies be developed to ensure that these measures are implemented. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the environment resulting from the extraction of the proposed longwalls.

It is recommended that management strategies are for the steep slopes, which may include:-

- Identification of all features that are located in the vicinity of steep slopes which are directly mined beneath,
- Site investigation and landslide risk assessment by a qualified geotechnical engineer for the critical features in the vicinity of the steep slopes which are directly mined beneath,
- Site investigation and structural assessment of structures where recommended by the geotechnical engineer. This may include recommendations to mitigate against potential impacts,
- Monitoring, including ground survey and visual inspections of critical features, and
- Remediation, where required, of any significant surface cracking or slippage.

5.7. Water Related Ecosystems

There are water-related and groundwater dependant ecosystems within the *Study Area*, particularly along the alignments of the streams and tributaries.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the groundwater dependant ecosystems within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.6.

Table 5.6 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Groundwater Dependant Ecosystems Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Blackbutt	< 20	< 0.2	< 0.01	< 0.01
Coachwood	2550	15	0.25	0.30
Paperbark	< 20	< 0.2	< 0.01	< 0.01
Phragmites australis and Typha orientalis	1350	10	0.15	0.20
Swamp Mahogany	1300	6	0.10	0.05
Woollybutt	1500	12	0.30	0.30

The tilts provided in the above table are the maximum predicted values at the completion of any or all proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls. The maximum predicted conventional strains, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4.5 mm/m tensile and compressive.

The groundwater dependant ecosystems are planar features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The potential impacts on the water-related and groundwater dependant ecosystems include surface cracking, changes in surface water drainage and changes in ground water regime.

The surface cracking is expected to be less than that typically observed in the Southern Coalfield, due to the high depth of alluvial deposits above bedrock. Any surface cracking is expected to be very minor and isolated and represent a very small percentage of the mining area.

The potential impacts on the streams, resulting from the extraction of the proposed longwalls, are discussed in Section 5.3 and in the report by GHA (2013). Discussions on the groundwater model and potential impacts on the groundwater regime are provided in the report by Mackie (2013). The potential impacts on the water-related ecosystems within the *Study Area* are discussed in the report by OzArk (2012a).

5.8. Threatened, Protected Species or Critical Habitats

The greatest potential for impacts on fauna and their habitats will occur where the disturbance of the soils and near surface strata are the greatest. This is more likely to occur where the levels of curvature and ground strain are the highest. The most important changes in the surface relating to subsidence will be changes in the surface water conditions. The potential impacts on fauna and their habitats, resulting from the extraction of the proposed longwalls, are discussed in the report by OzArk (2012a)

5.9. The Local Roads

The locations of the local roads within the *Study Area* are shown in Drawing No. MSEC515-12. The predictions and impact assessments for roads are provided in the following sections.

5.9.1. Predictions for the Local Roads

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the main (i.e. sealed) local roads within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.7. The predicted profiles of subsidence, tilt and curvature along Jilliby Road, resulting from the extraction of the proposed longwalls, are also illustrated in Fig. E.29, in Appendix E.

Table 5.7 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Main Local Roads Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Dickson Road	1350	9.0	0.12	0.17
Durren Road	1400	6.5	0.08	0.10
Jilliby Road	1750	7.5	0.09	0.09
Little Jilliby Road	175	1.0	0.01	0.01
Parkridge Drive Crestwood Road Sandra Street	1050	7.0	0.11	0.15

The tilts provided in the above table are the maximum predicted values at the completion of any or all proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls.

The unsealed roads are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would still be expected to be similar to those provided in Chapter 4.

The maximum predicted conventional strains for the local roads, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- Dickson Road - 2 mm/m tensile and 2.5 mm/m compressive,
- Durren Road - 1 mm/m tensile and 1.5 mm/m compressive,
- Jilliby Road - 1.5 mm/m tensile and compressive,
- Little Jilliby Road - less than 0.5 mm/m tensile and compressive, and
- Parkridge Drive, Crestwood Road and Sandra Street - 1.5 mm/m tensile and 2.5 mm/m compressive.

The roads are linear features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements and downslope movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The roads cross a number of streams within and immediately adjacent to the *Study Area*, the locations of which are shown in Drawing No MSEC515-12. The predictions and impact assessments for the bridges and culverts at the stream crossings are provided in Sections 5.10 and 5.11, respectively.

5.9.2. Impact Assessments for the Local Roads

The effects of vertical subsidence on the potential for increased flooding of the local roads was assessed as part of the flood model, which is described in the report by GHA (2013).

The maximum predicted tilt for the main local roads, resulting from the extraction of the proposed longwalls, is 9 mm/m (i.e. 0.9 %), which represents a change in grade of 1 in 110. The maximum predicted tilt for the unsealed local roads anywhere within the *Study Area*, resulting from the extraction of the proposed longwalls, is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65.

The predicted changes in grade are small, in the order of 1 % to 2 % and are unlikely, therefore, to result in any significant impacts on the surface water drainage or serviceability of these roads. If any additional ponding or adverse changes in surface water drainage were to occur as the result of mining, the roads could be remediated using normal road maintenance techniques.

The maximum predicted ground curvatures for the main local roads are 0.12 km^{-1} hogging and 0.17 km^{-1} sagging, which represent minimum radii of curvature of 8 kilometres and 6 kilometres, respectively. The maximum predicted ground curvatures at these roads are similar to those typically experienced in the Southern Coalfield. The potential impacts on the main local roads in the *Study Area*, therefore, are expected to be similar to those previously observed in the Southern Coalfield.

The most extensive experience has come from the extraction of Tahmoor Longwalls 22 to 24A, where these longwalls have mined directly beneath approximately 10 kilometres of local roads. A total of 12 impact sites have been observed, which equates to an average of one impact for every 860 metres of pavement. The impacts were minor and did not present a public safety risk.

Of these impact sites, one was substantially greater than the other observed impact sites, and this is shown in Fig. 5.3. Two additional sites with substantially greater impacts were recently observed during the mining of Tahmoor Longwall 25. One of the sites was located at a roundabout and a photograph is shown in Fig. 5.3. Photographs of other cracking and the buckling of a kerb and gutter are shown in Fig. 5.4.

More frequent impacts have been observed to concrete kerbs and gutters. The impacts are most commonly focussed around driveway laybacks and involve cracking, spalling or buckling. A typical buckling impact of a kerb is shown in Fig. 5.4.

A total of five drainage pits have been impacted during the mining of Tahmoor Longwalls 24A and 25. Investigations are currently underway to determine whether impacts have occurred to stormwater pipes in these areas.

Fig. 5.3 Cracking and Bump at Roundabout in the Southern Coalfields

Fig. 5.4 Cracking and Buckling of Kerb in the Southern Coalfields

It would be expected that any impacts on the main local roads within the *Study Area* could be remediated using normal road maintenance techniques. With the necessary remediation measures implemented, it would be expected that the main local roads could be maintained in safe and serviceable conditions throughout the mining period.

The maximum predicted ground curvatures for the unsealed roads, resulting from the extraction of the proposed longwalls, are 0.28 km^{-1} hogging and 0.37 km^{-1} sagging, which represent minimum radii of curvature of 4 kilometres and 3 kilometres, respectively. The potential impacts on the unsealed roads within the *Study Area* include cracking and heaving of the unseal road surfaces. It would be expected that any impacts on the unsealed roads could be remediated by infilling the cracks, or by regrading and recompacting the surface.

5.9.3. Impact Assessments for the Local Roads Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum changes in grade at the local roads within the *Study Area* would be in the order of 1 % to 3 %. It would still be expected that any additional ponding or adverse changes in surface water drainage could still be remediated using normal road maintenance techniques.

If the maximum predicted curvatures or ground strains were increased by factors of up to 2 times, the likelihood and extent of cracking and heaving of the local road surfaces would increase directly above the longwalls. It would still be expected that any impacts could be managed and repaired using normal road maintenance techniques.

5.9.4. Recommendations for the Local Roads

It is recommended that management strategies are developed, in consultation with the Wyong Shire Council, such that the roads can be maintained in a safe and serviceable condition throughout the mining period.

5.10. Local Road Bridges

The locations of the local road bridges which have been identified within the *Study Area* are shown in Drawing No. MSEC515-12. The following sections provide the predictions and impact assessments for these bridges.

5.10.1. Predictions for the Local Road Bridges

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the local road bridges within the *Study Area*, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.8.

Table 5.8 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Local Bridges Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
JJ-B1 and JJ-B2	1350	2.0	0.05	0.04
LJ-B1	75	0.5	< 0.01	< 0.01
LJ-B2	75	0.8	< 0.01	< 0.01
LJ-B3	75	0.2	< 0.01	< 0.01
LJ-B4	100	0.8	< 0.01	< 0.01
WR-B1	150	1.2	< 0.01	< 0.01
WR-B2	75	0.7	< 0.01	< 0.01

The values provided in the above table are the maximum predicted parameters within 20 metres of the centre of each bridge, at any time during or after the extraction of the proposed longwalls.

The local bridges cross streams and, therefore, could also experience valley related movements. A summary of the maximum predicted upsidence and closure movements for the local bridges, resulting from the extraction of the proposed longwalls, is provided in Table 5.9.

Table 5.9 Maximum Predicted Upsidence and Closure Movements for the Local Bridges Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
JJ-B1 and JJ-B2	25	25
LJ-B1	25	< 20
LJ-B2	50	50
LJ-B3	75	75
LJ-B4	75	100
WR-B1	100	75
WR-B2	25	50

The maximum predicted conventional strains for the local road bridges, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- JJ-B1 and JJ-B2 - 1 mm/m tensile and 0.5 mm/m compressive, and
- LJ-B1 to LJ-B4, WR-B1 and WR-B2 - less than 0.5 mm/m tensile and compressive.

The local road bridges are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

5.10.2. Impact Assessments for the Local Road Bridges

The effects of vertical subsidence on the potential for increased flooding at the local road bridges was assessed as part of the flood model, which is described in the report by GHA (2013).

The predicted maximum tilts for the local road bridges, resulting from the extraction of the proposed longwalls, vary between 0.2 mm/m (i.e. < 0.1 %) and 2 mm/m (i.e. 0.2 %), which represent changes in grades varying from less than 1 in 5,000 to 1 in 500, respectively. The predicted changes in grade are small, less than 1 % and are unlikely, therefore, to result in any significant impacts on the surface water drainage or serviceability of these road bridges.

The maximum predicted ground curvatures for Bridges JJ-B1 and JJ-B2 are 0.05 km^{-1} hogging and 0.04 km^{-1} sagging, which represent minimum radii of curvature of 20 kilometres and 25 kilometres, respectively. The maximum predicted ground curvatures for the remaining bridges are less than 0.01 km^{-1}, which represents a minimum radius of curvature of greater than 100 kilometres. The maximum predicted ground curvatures at the bridges are small and, therefore, are unlikely to result in adverse impacts on these bridges.

The maximum predicted upsidence for the local road bridges vary between 25 mm and 100 mm and the maximum predicted closures for the local bridges also vary between 25 mm and 100 mm. The greatest upsidence and compressive strain due to closure movements are expected to occur near the bases of the streams. The greatest closure movements could occur at the bridge abutments.

Bridges JJ-B1 and JJ-B2 are concrete box culvert bridges and Bridge LJ-B1 is a single span concrete bridge. As these bridges span the streams, the predicted upsidence and compressive strain due to valley closure are unlikely to be transferred into the bridge structures. The predicted closures could be transferred into the bridge structures if the movement joints do not have sufficient capacity to accommodate these movements. It is recommended that structural inspections of these bridges are undertaken, to assess the movement tolerances of these bridges and, if necessary, to develop the necessary preventive measures.

The remaining bridges are single or double span timber bridges or steel girder with timber deck bridges. Timber and steel bridges are flexible structures which would be expected to accommodate the magnitudes of the predicted valley related movements. Some minor impacts could occur at these bridges, if the full predicted valley related movements were transferred into the structures, but it would be expected that preventive measures could be undertaken to accommodate these movements. It is recommended that structural inspections of these bridges are undertaken, to assess the movement tolerances of these bridges and, if necessary, to develop the necessary preventive measures.

5.10.3. Impact Assessments for the Local Road Bridges Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum changes in grade at the local road bridges would still be less than 1 % and unlikely, therefore, to result in any significant impacts on the surface water drainage or serviceability of these road bridges.

If the actual curvatures exceeded those predicted by a factor of 2 times, the maximum predicted curvatures would be 0.10 km^{-1} hogging and 0.08 km^{-1} sagging, which represent minimum radii of curvature of 10 kilometres and 13 kilometres, respectively. In this case, the maximum ground curvatures would still be small and would be likely to be accommodated by the bridge movement joints.

If the actual valley related movements exceeded those predicted by a factor of 2 times, the potential for impacts would increase if the concrete bridge movement joints did not have sufficient capacity to accommodate the closure movements, or the full valley related movements were transferred into the timber or steel bridge structures. The management strategies for the local bridges should consider the potential for the actual movements exceeded those predicted.

5.10.4. Recommendations for the Local Road Bridges

It is recommended that management strategies are developed, in consultation with the Wyong Shire Council, such that the local road bridges are maintained in safe and serviceable conditions throughout the mining period. The strategies may include:-

- Structural inspection of the bridges to determine the existing movement allowance of the bridges,
- Adjustment of the movement joints, if necessary, to accommodate the predicted closure movements, and
- Visual inspections of the bridges during the active subsidence period.

5.11. Drainage Culverts

The locations of the identified drainage culverts along the local roads within the *Study Area* are shown in Drawing No. MSEC515-12. It is possible that there are other small culverts within the *Study Area*, i.e. in addition to those shown in this drawing, on drainage lines that were not visible on the available aerial photographs or on private land and have not been seen. However, it is unlikely that these smaller culverts will be impacted by mine subsidence movements. The following sections provide the predictions and impact assessments for the drainage culverts.

5.11.1. Predictions for the Drainage Culverts

The drainage culverts are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The culverts are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

5.11.2. Impact Assessments for the Drainage Culverts

The maximum predicted tilt within the *Study Area* is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65. It is expected that the culverts will generally experience tilts less than this maximum, as the result of the variations in the predicted tilts across the *Study Area* and the orientations of the culverts relative to the subsidence troughs.

The predicted changes in grade are small, in the order of 1 % and, therefore, are unlikely to result in any significant impacts on the serviceability of the culverts. If the flow of water through any culverts were to be adversely affected, as the result of the extraction of the proposed longwalls, this could be remediated by relevelling the affected culverts.

The maximum predicted ground curvatures within the *Study Area*, resulting from the extraction of the proposed longwalls, are 0.28 km^{-1} hogging and 0.37 km^{-1} sagging, which represent minimum radii of curvature of 4 kilometres and 3 kilometres, respectively. It is expected that the culverts will generally experience curvatures less than these maxima, as the result of variations in the predicted curvatures across the *Study Area* and the orientations of the culverts relative to the subsidence trough.

The drainage culverts are located along drainage lines and could, therefore, experience valley related upsidence and closure movements. The drainage culverts are orientated along the alignments of the drainage lines and, therefore, the upsidence and closure movements are orientated perpendicular the main axes of the culverts and unlikely to result in any significant impacts.

Drainage culverts have been mined beneath by previously extracted longwalls throughout the NSW Coalfields. The incidence of impacts is low and is generally limited to cracking in the concrete headwalls which can be readily remediated. In some cases, cracking in the culvert pipes occurred which required the culverts to be replaced. Visual inspections and more detailed analysis should be undertaken to review the potential impacts on the larger box culverts within the *Study Area*. In some cases, it may be necessary to provide some preventive measures to the larger concrete box culverts within the *Study Area*.

With the preventive or remediation measures implemented, it is expected that the drainage culverts within the *Study Area* can be maintained in serviceable conditions throughout the mining period.

5.11.3. Impact Assessments for the Drainage Culverts Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum change in grade at the culverts would be 3 %. If the flow of water through any drainage culverts were to be adversely affected, this could be remediated by relevelling the affected culverts.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the likelihood of impacts would increase for the drainage culverts directly above the longwalls. Based on previous experience of mining beneath drainage culverts in the NSW Coalfields, it would still be expected that the incidence of impacts on the drainage culverts would still be relative low. Any drainage culvert impacted by mining could be repaired or, if required, replaced.

5.11.4. Recommendations for the Drainage Culverts

The potential impacts on the drainage culverts within the *Study Area* can be managed by visual monitoring and the implementation of any necessary preventive or remediation measures. The ground movements will occur gradually as mining progresses, which will provide adequate time to remediate the culverts at the appropriate time, should these works be required. With these remediation measures in place, it is unlikely that there would be any significant impacts on the serviceability of the culverts.

5.12. The Sydney-Newcastle Freeway

The Sydney-Newcastle Freeway is located at a distance of 1.1 kilometres south-east of Longwall 1N, at its closest point from the proposed longwalls. At this distance, it is unlikely that the freeway pavement would experience any significant conventional subsidence movements resulting from the extraction of the proposed longwalls.

The freeway could be subjected to small far-field horizontal movements as a result of the extraction of the proposed longwalls. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.6 and 4.5.

Far-field horizontal movements have, in the past, been observed at similar distances as the freeway is from the proposed longwalls, however, these movements tend to be bodily movements associated with very low levels of strain. It is unlikely, therefore, that the freeway pavement itself would be impacted by far-field horizontal movements resulting from the extraction of the proposed longwalls.

The freeway bridges, however, could be sensitive to far-field horizontal movements, if the differential movements at the bridge movement joints were greater than the tolerances provided for thermal movements. Horizontal mid-ordinate deviation is a measure for differential movement along monitoring lines, which is defined as the differential horizontal movement of each survey mark, perpendicular to the monitoring line, relative to the two adjacent survey marks, as illustrated in Fig. 4.6.

The horizontal mid-ordinate deviations measured along survey lines in the Southern Coalfield, for survey marks spaced nominally 20 metres apart, is provided in Fig. 4.7. It can be seen from this figure, at distances greater than 1 kilometre from extracted longwalls, such as the freeway bridges near the proposed longwalls, that horizontal mid-ordinate deviations of up to 5 mm have been observed. It should be noted, that survey tolerance is likely to represent a large proportion of these measurements.

It is recommended that the predicted mine subsidence movements, resulting from the extraction of the proposed longwalls, are provided to the Roads and Maritime Services (RMS), so that a structural assessment of the bridges can be undertaken based on the predicted far-field horizontal movements. It may be necessary to undertake some preventive measures, if the bridge movement joints and bearings were not able to tolerate the predicted differential movements.

It is also recommended that management strategies are developed, in consultation with the RMS, which could include the:-

- Implementation of preventive measures, if required, to provide the necessary capacity at the bridge movement joints and bearings,
- Installation of a monitoring system, which could include, amongst other things, the monitoring of ground movements, structure movements, bridge joint displacements and visual inspections,
- Implementation of a response plan, where actions are triggered by monitoring results, and
- Implementation of a reporting and communication plan.

5.13. Water Infrastructure

The locations of the water infrastructure within the *Study Area* are shown in Drawing No. MSEC515-13. The predictions and impact assessments for the water infrastructure are provided in the following sections.

5.13.1. Treelands Drive Reservoir

The Treelands Drive Reservoir is located just inside the eastern extent of the *General Study Area* and is at a distance of 300 metres east of the Longwall 1S, at its closest point to the proposed longwalls. The locations of the reservoir tanks are shown in Drawing No. MSEC515-13.

At this distance, the reservoir is predicted to experience less than 50 mm of subsidence. While it is possible that the reservoir could experience subsidence slightly greater than 50 mm, it would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the Treelands Drive Reservoir would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

5.13.2. The Mardi to Mangrove Creek Dam Pipeline

The Mardi to Mangrove Creek Dam pipeline touches the *General Study Area*, south-west of Longwalls 1SW and 2SW, but otherwise is located outside the *General Study Area*. The location of the pipeline route is shown in Drawing No. MSEC515-13.

At this distance, the pipeline is predicted to experience less than 20 mm of vertical subsidence. While it is possible that the pipeline could experience subsidence slightly greater than 20 mm, the pipeline would not be expected to experience any significant conventional tilts, curvatures or strains.

It is unlikely, therefore, that the pipeline would experience any significant impacts, resulting from the conventional subsidence movements, even if the predictions were increased by a factor of 2 times.

The pipeline is located within the valley of the Wyong River and, therefore, could experience valley related upsidence and closure movements. The predicted profiles of subsidence, upsidence, horizontal movement along and horizontal movement across the pipeline route, resulting from the extraction of the proposed longwalls, are provided in Fig. 5.5.

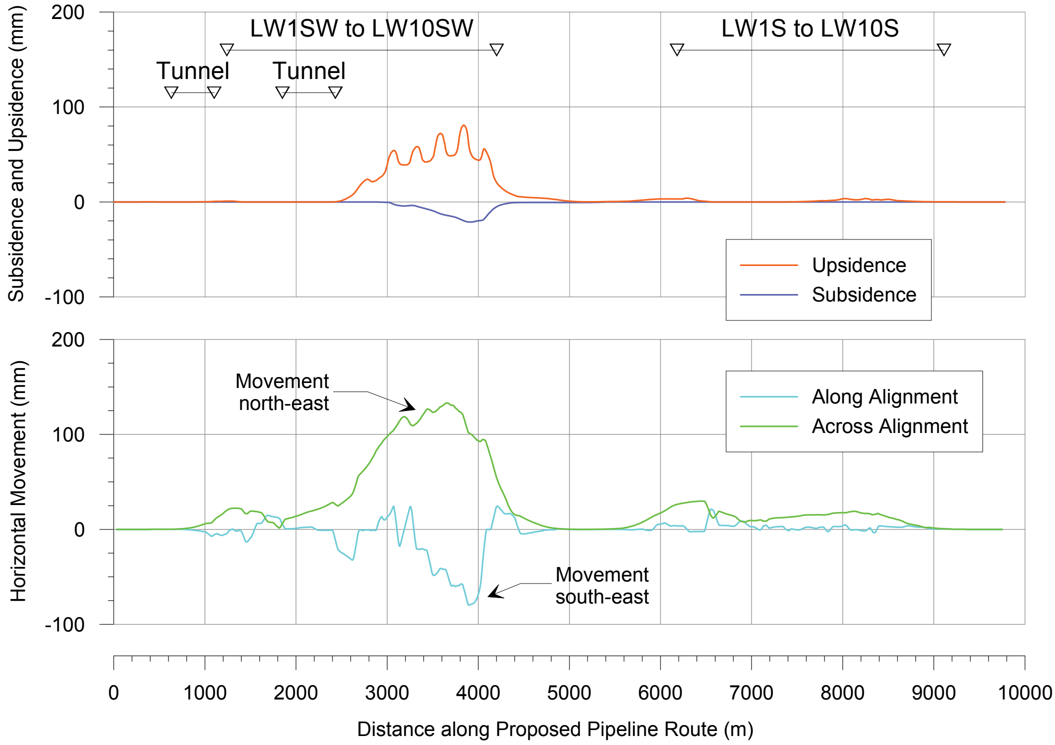

Fig. 5.5 Predicted Profiles of Subsidence, Upsidence, Horizontal Movement Along and Horizontal Movement Across the Alignment of the Pipeline Route

These predicted movements along the alignment of the pipeline were provided to the designers of the pipeline for consideration into the final design of this pipeline. It is understood that the pipeline was designed to accommodate the predicted movements resulting from the extraction of the proposed longwalls. It is unlikely, therefore, that the pipeline would experience any adverse impacts from the proposed mining, provided that it is constructed in accordance with the design which accommodates these predicted movements.

5.13.3. Other Water Pipelines

There are a number of other water pipelines located immediately to the east of the *Study Area*, the locations of which are shown in Drawing No. MSEC515-13.

These pipelines are located outside the *General Study Area* and, at these distances, the pipelines are predicted to experience less than 20 mm of subsidence. While it is possible that the pipelines could experience subsidence slightly greater than 20 mm, the pipelines would not be expected to experience any significant conventional tilts, curvatures or strains.

It is unlikely, therefore, that the water pipelines would experience any significant impacts, resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

The pipelines located immediately to the east of the *Study Area* do not cross any significant valleys and, therefore, are unlikely to experience any significant valley related movements. It is unlikely, therefore, that these pipelines would experience any adverse impacts resulting from the extraction of the proposed longwalls.

5.14. 330 kV Transmission Lines

The locations of the 330 kV transmission lines within the *Study Area* are shown in Drawing No. MSEC515-14. The predictions and impact assessments for these transmission lines are provided in the following sections.

5.14.1. Predictions for the 330 kV Transmission Lines

The predicted profiles of conventional subsidence, tilt along and tilt across the alignments of the Transmission Lines 21 and 22, resulting from the extraction of the proposed longwalls, are shown in Figs. E.30 and E.31, respectively, in Appendix E.

A summary of the maximum predicted values of conventional subsidence, tilts along the alignments, tilts across the alignments and curvatures for the transmission lines, resulting from the extraction of the proposed longwalls, is provided in Table 5.10. The values provided in this table are the maximum predicted parameters anywhere along the transmission lines, at any time during or after the extraction of the proposed longwalls.

Table 5.10 Maximum Predicted Conventional Subsidence, Tilt Along, Tilt Across and Curvatures for the 330 kV Transmission Lines Resulting from the Extraction of the Proposed Longwalls

Line	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt Along Alignment (mm/m)	Maximum Predicted Conventional Tilt Across Alignment (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Line 21	2100	11	13	0.30	0.30
Line 22	2500	12	13	0.15	0.30

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters at the transmission lines would be expected to be similar to those provided in the above table.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the transmission towers within the *Study Area*, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.11. The 330 kV transmission lines are single circuit steel towers and the top earth wires are connected to the towers at a height of approximately 28 metres above ground level.

A summary of the maximum predicted horizontal movements at the tops of the towers, resulting from the extractions of the proposed longwalls, is also provided in Table 5.11.

Table 5.11 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Transmission Towers within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Line	Tower ID	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})	Maximum Predicted Conventional Horizontal Movement at Top of Tower (mm)
Line 21	21-36-S	20	< 0.5	< 0.01	< 0.01	< 20
	21-37-S	925	4.5	0.12	0.03	200
	21-38-T	1175	8.5	0.14	0.19	375
	21-39-S	1150	4.0	0.09	0.04	175
	21-40-S	1400	8.5	0.06	0.27	375
	21-41-S	1400	4.5	0.06	0.04	200
	21-42-S	1125	3.5	0.06	0.03	150
	21-43-S	1275	4.0	0.05	0.03	175
	21-44-T	1225	10	0.15	0.03	425
	21-45-T	1425	9.5	0.05	0.22	400
	21-46-T	2050	5.0	0.03	0.16	200
	21-47-T	1850	5.5	0.04	0.05	225
	21-48-T	400	3.0	0.03	0.01	125
	21-49-T	350	2.0	0.02	< 0.01	100
	21-50-T	250	1.5	0.01	< 0.01	50
	21-51-S	175	1.0	0.01	< 0.01	50
	21-52-S	100	0.5	0.01	< 0.01	25
	21-53-T	35	0.5	< 0.01	< 0.01	20

Line	Tower ID	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})	Maximum Predicted Conventional Horizontal Movement at Top of Tower (mm)
Line 22	22-46-S	< 20	< 0.5	< 0.01	< 0.01	< 20
	22-47-S	150	1.5	0.01	0.01	75
	22-48-S	425	5.0	0.08	0.03	225
	22-49-T	2175	5.5	0.06	0.05	250
	22-50-T	1875	4.0	0.05	0.03	175
	22-51-T	2425	5.0	0.04	0.08	200
	22-52-T	2125	9.5	0.03	0.19	400
	22-53-T	575	6.0	0.06	< 0.01	250
	22-54-S	300	2.5	0.03	< 0.01	100
	22-55-S	100	1.0	0.01	0.01	50
	22-56-S	< 20	< 0.5	< 0.01	< 0.01	< 20

The values provided in the above table are the maximum predicted parameters within 20 metres of the centre of each tower, at any time during or after the extraction of the proposed longwalls.

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual towers would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement at the towers across the *Study Area* would not be expected to change significantly.

The maximum predicted conventional strains for the transmission towers, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- Line 21 - 2.5 mm/m tensile and 4 mm/m compressive, and
- Line 22 - 1 mm/m tensile and 3 mm/m compressive.

The transmission towers are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, downslope movements or anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The 330 kV Transmission Line No. 25 is predicted to experience less than 20 mm of subsidence. While it is possible that this transmission line could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant tilts, curvatures or strains. It is also likely that Transmission Line 25 would experience far-field horizontal movements, resulting from the extraction of the proposed longwalls, which are discussed in Sections 3.6 and 4.5.

5.14.2. Impact Assessments for the 330 kV Transmission Lines

The transmission towers can be impacted by the mining induced horizontal loads due to the changes in bay lengths, i.e. the distances between the towers at the level of the cables, which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the towers due to tilting of the towers. The stabilities of the towers can also be affected by the curvatures and strains at the bases of the towers.

The maximum predicted tilt at the transmission towers is 10 mm/m (i.e. 1 %), which represents a change in verticality of 1 in 100. The predicted horizontal ground movement associated with the maximum predicted tilt is around 150 mm. The maximum predicted horizontal movement at the tops of the towers, based on a height of approximately 28 metres, therefore, is around 425 mm.

Where the horizontally movements at adjacent towers are of similar magnitude and in similar directions, there will only be small changes in the catenary profiles of the aerial cables. Where there are large differential horizontal movements at the levels of the cables, the changes in the catenary profiles of the aerial cables result in differential horizontal loads on the towers. The maximum predicted change in baylength between adjacent towers is 485 mm, which occurs over a span of 339 metres and, therefore, equates to an overall strain of approximately 1.4 mm/m.

The maximum predicted hogging and sagging curvatures at transmission lines, resulting from the extraction of the proposed longwalls, are both 0.30 km^{-1}, which equates to minimum radius of curvature of 3 kilometres. The maximum predicted curvatures and ground strains could result in increased stresses within the tower structural members.

Predictions of subsidence, tilt and strain at each tower and the predicted changes in bay lengths between the towers were issued to and discussed with TransGrid in 2006, 2007, 2008 and 2009. As the proposed mine layout and the predicted levels of the mine subsidence movements at the transmission lines and towers have not changed significantly since January 2007.

TransGrid has already reviewed the potential impacts of mining on the transmission lines and towers and these potential impacts have been discussed in the various meetings between WACJV and TransGrid. The main potential impacts that have been identified include:-

1. Increased conductor tensions which could overload the towers,
2. Ground strains and curvature which could deform the tower bases, and
3. Reduced cable heights which do not maintain the statutory minimum clearances.

Subsequent to one of these meetings, TransGrid advised the WACJV on 29th August 2008 by letter:-

> "*In relation to the impact of the proposed mining of TransGrid assets the following is advised;*
>
> 1. *The magnitude of the possible strains that will be imposed on the towers is such that they would require the installation of some protective measures. These measures may include the installation of cruciform footings on suspension structures. Protective measures for tension structures are less well developed and may not be available for those structures with large deviation angles.*
> 2. *The predicted tilts and translations can cause major tension changes to the conductors and earth wires that may adversely affect the safety and security of the transmission lines. The installation of sheaves on the conductors and/or earth wires would assist in alleviating the impact on suspension structures. However, this is generally not feasible for tension structures.*
> 3. *The levels of subsidence may result in the clearance between the conductors and ground under maximum operating conditions being reduced to less than the required levels. If this occurs, protective measures would be required to protect the safety of the general public and the security of the lines.*
>
> *While the above concerns can generally be addressed through protective measures for the suspension structures, the protection of tension structures is more problematic and measures for such towers are more limited. This is particularly, the case for structures 22-52-T and 21-44-T which both have large deviation angles. Protection of tension towers may require sterilisation of coal or variation of the mine layout to limit the strains and tilts to an acceptable level.*"

The assessments of the transmission lines that have been undertaken by TransGrid, to date, indicate that it is likely that the stability of the suspension towers (Potential Impacts 1 and 2) and the reduction of cable clearances (Potential Impact 3) could be managed by the implementation of suitable management strategies. These management strategies could include:-

- Installation of cable sheaves on the suspension towers where the mining induced horizontal movements could adversely affect the structural integrity of these towers,
- Fencing off the easement where the cable clearances are less than the minimum requirements until adjustments have been made to reinstate the clearances,
- Groundwork within the easement to increased the existing cable clearances, and
- Installation of cruciform bases for the suspension towers where the ground movements could adversely affect the structural integrity or the stability of these towers.

The required preventive measures will be developed as part of the ongoing discussions between WACJV and TransGrid. The preventive measures will be designed to ensure the safe operations of the transmission lines at all the towers within the *Study Area*.

As described in Table 2.1 and Table 5.11, there are 29 transmission towers located within the *Study Area*, of which 14 are tension towers and 15 are suspension towers. The assessments of the transmission lines undertaken by TransGrid also indicate that it is more difficult to provide preventive measures for the tension towers, especially Towers 22-52-T and 21-44-T.

Some of the tension towers were built because of the wide spans across the larger valleys and many of these only have very small changes in angle of the transmission line. The two tension towers with the greatest angled changes of the transmission line directions are labelled Tower 21-44-T and Tower 22-52-T. Tower 21-44-T is located at Dooralong in the floor of the valley, whilst Tower 22-52-T is located on top of a steep hill within the Jilliby Conservation Area.

Preventive measures such as cable sheaves and cruciform bases may not be able to be used at some of the tension towers, due to the permanent lateral load resulting from the change in direction of the cables. Detailed structural assessments of the towers will need to be undertaken to determine which, if any, tension towers are suitable for these types of preventive measures.

Where tension towers are found to be unable to tolerate the predicted mine subsidence movements and are not suitable for traditional preventive measures, as described above, other strategies would need to be considered, including the:-

- Strengthening of the tension towers,
- Installation of additional temporary towers or poles, although it is accepted that this may be difficult to achieve within the existing easement,
- Realignment or re-routing of the transmission lines, but this may be difficult based on the surrounding land use,
- Direct burying the transmission line cables, providing approvals can be obtained from the land owners and that the engineering and safety constraints can be overcome, or
- Providing coal barriers beneath the tension towers.

Based on preliminary assessments of the towers using the predicted curvatures and strains, it is believed that mitigation works can be undertaken to allow the safe operations at all the towers within the *Study Area*, except the two high angle tension towers, being Tower 21-44-T and Tower 22-52-T. As indicated by the above quoted TransGrid letter, dated 29th August 2008, cruciform footings will be required under many towers and coal sterilisation may be required under the two high angled tension towers labelled Tower 21-44-T and Tower 22-52-T.

An assessment has been undertaken to determine the quantity of coal that would be required to be sterilised to protect these two towers. A modification to the current mine plan, by stopping the longwalls short of these towers and then re-commencing extraction beyond the towers, is illustrated in Fig. 5.6.

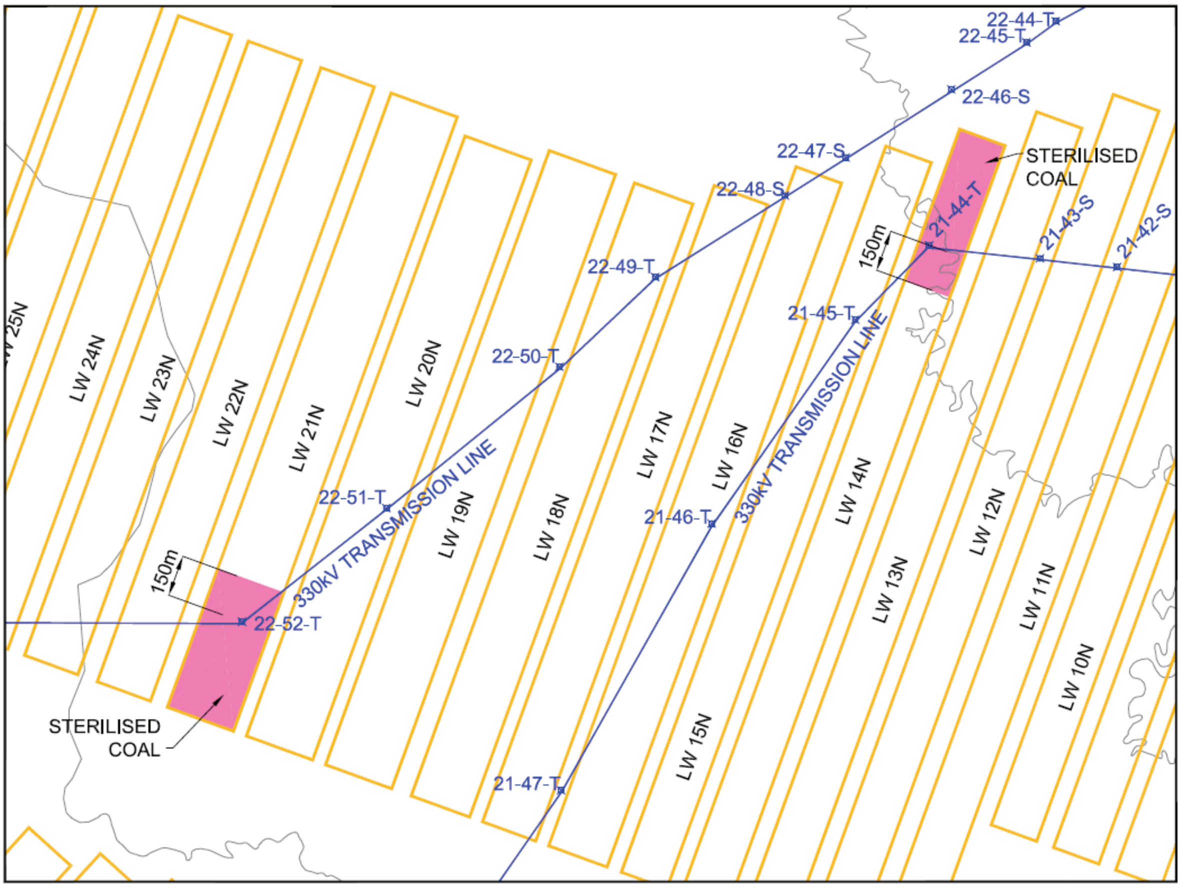

Fig. 5.6 Plan showing potential coal sterilisation if no preventative works are undertaken at the two high angled tension towers labelled Tower 21-44-T and Tower 22-52-T

Since the two high angled tension towers labelled Tower 21-44-T and Tower 22-52-T are not planned to be undermined within the first twenty years of the life of *the Project*, it is recommended that a subsidence management committee be established, with officers from the WACJV, TransGrid and the Mine Subsidence Board, with the view to avoid sterilising coal in the cases where cruciform solutions would not work. As subsidence-resistant tension towers have been constructed in many countries overseas, it is expected that replacement towers could be installed to support these transmission lines.

The research programme would need to consider new solutions to overcome this subsidence problem and the study would include further literature reviews, detailed analysis and possibly building some trial towers over active longwalls to help analyse, observe and monitor the performance of various alternative towers that may allow the safe operation of the transmission lines and may avoid coal sterilisation. This research would only proceed with this option if TransGrid, MSB and the WACJV all agreed to work on this potential research project.

It will be necessary to monitor the ground movements, so that the management strategies can be assessed based on actual ground movements.

5.14.3. Impact Assessments for the 330 kV Transmission Lines Based on Increased Predictions

It is recommended that appropriate factors of safety are applied in the detailed structural analysis of the transmission lines undertaken by TransGrid. These factors of safety should be applied in the design of any necessary preventive measures required for the towers.

5.14.4. Recommendations for the 330 kV Transmission Lines

It is recommended that the discussions between WACJV and TransGrid should continue so that preventive measures can be developed by investigating each of the possible options that provide for the continued safe operation of the transmission lines and avoid the sterilisation of such large quantities of coal resources. It is also recommended that a subsidence management committee be established, with officers from the WACJV, TransGrid and the Mine Subsidence Board, so that the appropriate management strategies can be developed.

It is recommended that the ground movements are monitored so that the subsidence predictions can be reviewed and, if necessary, revised based on the latest available monitoring data. The first tension tower is located above Longwall 5N and monitoring data will be available from the first four longwalls prior to this tower being directly mined beneath. At least twenty years of monitoring data will be available before longwall extraction approaches the first high angled tension tower, above Longwall 14N, and at that time appropriate management strategies can be developed by the envisaged subsidence management committee.

5.15. 132 kV Transmission Line

The 132 kV transmission line is predicted to experience less than 20 mm of subsidence. While it is possible that this transmission line could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant tilts, curvatures or strains.

The 132 kV transmission line could be subjected to small far-field horizontal movements as the result of the extraction of the proposed longwalls. Far-field horizontal movements have, in the past, been observed at similar distances as the transmission line is from the proposed longwalls, however, these movements tend to be bodily movements associated with very low levels of strain.

It is unlikely, therefore, that the 132 kV transmission line would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

5.16. Powerlines

The locations of the powerlines within the *Study Area* are shown in Drawing No. MSEC515-14. The predictions and impact assessments for powerlines are provided in the following sections.

5.16.1. Predictions for the Powerlines

The powerlines are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The predicted subsidence parameters vary across the *Study Area* as the result of, amongst other factors, variations in the depths of cover, longwall void widths and extraction heights. The variations in the predicted conventional subsidence parameters are illustrated along Prediction Lines 1, 2, 3 and 4 which are provided in Figs. E.01, E.02, E.03 and E.04, respectively, in Appendix E.

The powerlines are linear features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The aerial powerlines are not affected by ground strains, as they are supported by the poles above ground level. The aerial cables can, however, be affected by the changes in bay lengths, i.e. the distances between the poles at the levels of the cables, which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the poles due to tilting of the poles. The stabilities of the poles can also be affected by mining induced tilts and by changes in the catenary profiles of the cables.

The maximum predicted conventional tilt within the *Study Area* is 15 mm/m (i.e. 1.5 %), which represents a change in verticality of 1 in 65. The predicted horizontal ground movement associated with the maximum predicted conventional tilt is in the order of 200 mm. The maximum predicted horizontal movement at the tops of the poles, based on a height of 12 metres is, therefore, approximately 400 mm.

A number of powerlines have been mined directly beneath by longwalls previously extracted in the NSW Coalfields, some of which have been summarised in Table 5.12.

Table 5.12 Previous Experience of Mining Beneath Powerlines in the NSW Coalfields

Colliery and LWs	Length of Powerlines Directly Mined Beneath (km)	Observed Maximum Movements at Powerlines	Observed Impacts
Beltana Why LW1 to LW14	Longwalls have mined beneath 2 km of 66 kV powerlines	1700 mm Subsidence 50 mm/m Tilt (Measured Charlton Rd)	No significant impacts after installation of preventive measures including roller sheaves and intermediate poles
Dendrobium LW3 to LW5	Longwalls have mined beneath 1.2 km of a 33 kV powerline	1100 mm Subsidence 40 mm/m Tilt (Measured D2000-Line)	No significant impacts
South Bulga Why LW1 to LW6	Longwalls have mined beneath 4 km of 11 kV and 4 km of 66 kV powerlines	1800 mm Subsidence 40 mm/m Tilt (Measured Broke Rd)	No significant impacts after installation of preventive measures including roller sheaves and intermediate poles
Tahmoor LW22 to LW25	Longwalls have mined beneath approx. 22 km of powerlines and approx. 600 power poles	1200 mm Subsidence 6 mm/m Tilt (Extensive street monitoring)	Some minor adjustments to cable catenaries, pole tilts and consumer cables required.

It can be seen from the above table, that there have been only minor impacts on powerlines which have been directly mined beneath by previously extracted longwalls in the NSW Coalfields. In some cases preventive measures were required, including the installation of roller sheaves and additional poles, and in other cases remedial measures were required, including adjustments to the cable catenaries, pole tilts and consumer cables which connect between the powerlines and the houses. The incidence of these impacts were, however, relatively infrequent and were readily repaired.

Based on this experience, it is likely that the extraction of the proposed longwalls would only result in relatively minor impacts on the powerlines within the *Study Area*. It is possible that some remedial measures would be required, including some adjustments of the cable catenaries, pole tilts and the consumer cables, as has been undertaken in the past, and that any impacts are expected to be relatively infrequent and readily repaired.

5.16.2. Impact Assessments for the Powerlines Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt within the *Study Area* would be 30 mm/m (i.e. 3 %), which represents a change in verticality of 1 in 35. As shown in Table 5.12, longwalls have been successfully mined beneath powerlines in the NSW Coalfields, where the tilts were greater than 30 mm/m, after the implementation of the necessary preventive measures, such as the installation of roller sheaves and additional poles.

In this case, it would be expected that some remedial measures would be required, including the adjustments of the cable catenaries, pole tilts and the consumer cables, as has been undertaken in the past, but any impacts would still be expected to be relatively infrequent and readily repaired.

5.16.3. Recommendations for the Powerlines

It is recommended that the powerlines are visually inspected by a suitably qualified person prior to the proposed longwalls mining beneath them, to determine the existing conditions, and whether any preventive measures are required. It is also recommended that the powerlines are visually monitored as the proposed longwalls mine beneath them.

It is recommended that management strategies are developed, in consultation with Ausgrid, such that the powerlines can be maintained in safe and serviceable conditions throughout the mining period.

5.17. Local Substations

The local substation is located between the northern and south-eastern series of longwalls and is at a distance of 250 metres north of Longwall 5S, at its closest point to the proposed longwalls.

At this distance, the substation is predicted to experience less than 20 mm of subsidence. While it is possible that the substation could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the substation would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

5.18. Copper Telecommunications Cables

The locations of the copper telecommunications cables within the *Study Area* are shown in Drawing No. MSEC515-15. The predictions and impact assessments for these cables are provided in the following sections.

5.18.1. Predictions for the Copper Telecommunications Cables

The copper telecommunications cables are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The predicted subsidence parameters vary across the *Study Area* as the result of, amongst other factors, variations in the depths of cover, longwall void widths and extraction heights. The variations in the predicted conventional subsidence parameters are illustrated along Prediction Lines 1, 2, 3 and 4 which are provided in Figs. E.01, E.02, E.03 and E.04, respectively, in Appendix E.

The cables are linear features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

5.18.2. Impact Assessments for the Copper Telecommunications Cables

The direct buried copper telecommunications cables are unlikely to be impacted by tilt. The cables are also unlikely to be impacted by curvature, as the cables are flexible and would be expected to tolerate the minimum predicted radius of curvature within the *Study Area* of 3 kilometres.

The direct buried copper cables could, however, be affected by the ground strains resulting from the extraction of the proposed longwalls. The cables are more likely to be impacted by tensile strains rather than compressive strains.

It is possible, that the direct buried cables could experience higher tensile strains where they are anchored to the ground by associated infrastructure, or by tree roots. The cables could also experience higher compressive strains at the creek crossings as the result of valley related movements.

The aerial copper telecommunications cables are not affected by ground strains, as they are supported by the poles above ground level. The aerial cables can, however, be affected by the changes in bay lengths, i.e. the distances between the poles at the levels of the cables, which result from mining induced differential subsidence, horizontal ground movements and lateral movements at the tops of the poles due to tilting of the poles. The stabilities of the poles can also be affected by mining induced tilts and by changes in the catenary profiles of the cables.

The maximum predicted conventional tilt within the *Study Area* is 15 mm/m (i.e. 1.5 %), which represents a change in verticality of 1 in 65. The predicted horizontal ground movement associated with the maximum predicted conventional tilt is in the order of 200 mm. The maximum predicted horizontal movement at the tops of the poles, based on a height of 12 metres is, therefore, approximately 400 mm.

A number of direct buried and aerial copper telecommunications cables have been mined directly beneath by previously extracted longwalls in the NSW Coalfields, some of which have been summarised in Table 5.13.

Table 5.13 Previous NSW Experience of Mining Beneath Copper Telecommunications Cables

Colliery and LWs	Copper Cables	Observed Maximum Movements at the Copper Cables	Observed Impacts
Appin LW401 to LW408	Longwalls have mined beneath 4 km of underground cables and 0.8 km of aerial cables	700 mm Subsidence 5 mm/m Tilt 1 mm/m Tensile Strain 2 mm/m Comp. Strain (Measured A6000-Line)	No significant impacts
Beltana Why LW1 to LW14 and South Bulga LW1 to LW6 and LWE1	Longwalls have mined beneath 2 km of aerial and underground cables	1700 mm Subsidence 50 mm/m Tilt 26 mm/m Tension Strain 24 mm/m Comp. Strain (Measured Charlton Rd)	No significant impacts
Tahmoor LW22 to LW25	Longwalls have mined beneath 19 km of underground cables and 2.5 km of aerial cables	1200 mm Subsidence 6 mm/m Tilt 1.5 mm Tensile Strain 2.0 mm (typ.) and up to 5.0 mm/m Comp. Strain (Extensive street monitoring)	No significant impacts to underground cables. Some pole tilts and cable catenaries adjusted. Some consumer cables were re-tensioned as a precautionary measure
West Cliff LW5A3, LW5A4 and LW29 to LW34	Longwalls have mined beneath 13 km of underground cables	1100 mm Subsidence 1.5 mm/m Tensile Strain 5.5 mm/m Comp. Strain (Measured B-Line)	No significant impacts

It can be seen from the above table, that there were no reported impacts on the direct buried copper telecommunications cables in the above examples. It is also understood, that there have been no significant impacts on direct buried copper telecommunications cables elsewhere in the NSW Coalfields, where the depths of cover were greater than 350 metres, such as the case for the proposed longwalls.

It can also be seen from the above table, that there have been only minor impacts on the aerial copper telecommunications cables in the above examples. Some remedial measures were required, which included adjustments to cable catenaries, pole tilts and consumer cables which connect between the poles and houses. The incidence of these impacts was very low.

Based on this experience, it is unlikely that the extraction of the proposed longwalls would result in any significant impacts on the direct buried or aerial copper telecommunications cables within the *Study Area*. Any impacts on these cables would be expected to be relatively infrequent and readily repaired.

5.18.3. Impact Assessments for the Copper Telecommunications Cables Based on Increased Predictions

If the actual strains exceeded those predicted by a factor of 2 times, the magnitudes of strains would be less than the range of strains experienced at collieries with much shallower depths of cover, such as Beltana and South Bulga. As, as shown Table 5.13, longwalls have been successfully mined beneath direct buried copper telecommunications cables where the measured strains were greater than 20 mm/m.

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt within the *Study Area* would be 30 mm/m (i.e. 3 %), which represents a change in verticality of 1 in 35. In this case, the magnitudes of the tilts would be less than those experienced at collieries with much shallower depths of cover, such as Beltana and South Bulga. Also, as shown Table 5.13, longwalls have been successfully mined beneath aerial copper telecommunications cables in the NSW Coalfields where measured tilts have been up to 50 mm/m.

5.18.4. Recommendations for the Copper Telecommunications Cables

It is recommended that management strategies are developed, in consultation with Telstra, such that the copper telecommunications cables can be maintained in serviceable conditions throughout the mining period.

5.19. Optical Fibre Cables

The locations of the optical fibre cables within the *Study Area* are shown in Drawing No. MSEC515-15. The predictions and impact assessments for the cables are provided in the following sections.

5.19.1. Predictions for the Optical Fibre Cables

A Telstra optical fibre cable crosses directly above Longwalls 11N to 15N and Longwalls 1S to 5S. The predicted profiles of conventional subsidence, tilt and curvature along this cable, resulting from the extraction of the proposed longwalls, is provided in Fig. E.32 in Appendix E. A summary of the maximum predicted values of conventional subsidence movements for this cable is provided in Table 5.14.

Table 5.14 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Telstra Optical Fibre Cable Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Telstra Optical Fibre Cable	2150	10	0.13	0.19

The maximum predicted conventional strains for this optical fibre cable, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 2 mm/m tensile and 3 mm/m compressive.

The optical fibre cable is a linear feature and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

A second Telstra optical fibre cable services the CMTS site, which is located above the commencing (south-western) end of Longwall 1N. The maximum predicted conventional subsidence parameters for this cable are the same as those for CMTS site, which are summarised in Section 5.20.

A third Telstra optical fibre cable is located south of the *Study Area* at a minimum distance of 400 metres from the proposed longwalls. Other optical fibre cables are also located along Hue Hue Road and the Sydney-Newcastle Freeway, which are located at minimum distances of 285 metres and 1.1 kilometres, respectively, from the proposed longwalls. It is not expected that these cables will be subjected to any significant conventional subsidence movements resulting from the extraction of the proposed longwalls.

The optical fibre cables cross a number of streams within and immediately adjacent to the *Study Area*, the locations of which are shown in Drawing No MSEC515-15. A summary of the maximum predicted valley related upsidence and closure movements at the major stream crossings, resulting from the extraction of the proposed longwalls, is provided in Table 5.15.

Table 5.15 Maximum Predicted Valley Related Upsidence and Closure Movements at the Major Stream Crossings Resulting from the Extraction of the Proposed Longwalls

Location	Description	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Crossing 1	Tributary 1 to Jilliby Jilliby Creek	< 20	< 20
Crossing 2	Tributary 2 to Jilliby Jilliby Creek	100	70
Crossing 3	Little Jilliby Jilliby Creek	30	25
Crossing 4	Tributary 3 to Jilliby Jilliby Creek	200	175
Crossing 5	Jilliby Jilliby Creek	40	25
Crossing 6	Jilliby Jilliby Creek	< 20	< 20
Crossing 7	Jilliby Jilliby Creek	< 20	< 20
Crossing 8	Hue Hue Creek	< 20	< 20

5.19.2. Impact Assessments for the Optical Fibre Cables

The optical fibre cables are direct buried and, therefore, could potentially be impacted by ground strains. The greatest potential for impacts will occur as the result of localised ground strains due to non-conventional movements or valley related movements.

The tensile strains in the optical fibre cables could be higher than predicted, where the cables connect to the support structures, which may act as anchor points, preventing any differential movements that may have been allowed to occur in the ground. Tree roots have also been known to anchor cables to the ground. The extent to which the anchor points affect the ability of the cables to tolerate the mine subsidence movements depends on the cable size, type, age, installation method and ground conditions.

In addition to this, optical fibre cables contain additional fibre lengths over the sheath lengths, where the individual fibres are loosely contained within tubes. Compression of the sheaths can transfer to the loose tubes and fibres and result in “micro-bending” of the fibres constrained within the tubes, leading to higher attenuation of the transmitted signal. If the maximum predicted compressive strains were to be fully transferred into the optical fibre cables, the strains could be of sufficient magnitude to result in the reduction in capacities of the cables or transmission loss.

The strains transferred into the optical fibre cables can be monitored using Optical Time Domain Reflectometry (OTDR), which can be used to notify the infrastructure owners of strain concentrations due to anomalous or valley related movements. If the measured strains in the cable were seen to approach the allowable tolerances, then preventive measures could be implemented, which could include locally exposing and stress relieving the affected section of the cable.

A number of optical fibre cables have been mined directly beneath by previously extracted longwalls in the Coalfields of New South Wales. A summary of some of the optical fibre cables which have been directly mined beneath is provided in Table 5.16.

It can be seen from this table, that optical fibre cables have been successfully directly mined beneath by previously extracted longwalls in the NSW Coalfields, with the implementation of suitable management strategies. It is recommended that the predicted movements are reviewed by Telstra, to assess the potential impacts and to develop the appropriate management strategies.

Table 5.16 Previous Experience of Mining Beneath Optical Fibre Cables

Colliery and LWs	Length of Optical Fibre Cables Directly Mined Beneath (km)	Observed Maximum Movements at Optical Fibre Cables	Pre-Mining Mitigation, Monitoring and Observed Impacts
Appin LW301 and LW302	0.8	650 mm Subsidence 0.7 mm/m Tensile Strain 2.8 mm/m Comp. Strain (Measured M-Line)	600 metre aerial cable on standby. Ground survey, visual, OTDR. No reported impacts.
Beltana Why LW1 to LW14 and South Bulga LW1 to LW6 and LWE1	7.4	1700 mm Subsidence 26 mm/m Tensile Strain 24 mm/m Comp. Strain (Measured Charlton Rd)	Installed in conduit at Beltana and partial cut over at South Bulga. Ground survey, visual, OTDR. None at Beltana and loss of 2dB at South Bulga
Tahmoor LW22 to LW25	1.2	1200 mm Subsidence 1.5 mm Tensile Strain 2.0 mm (typ.) and up to 5.0 mm/m Comp. Strain (Extensive street monitoring)	Ground survey, visual, OTDR, SBS. No reported impacts.
Tower LW1 to LW10	1.7	400 mm Subsidence 3 mm/m Tilt 0.5 mm/m Tensile Strain 1.0 mm/m Comp. Strain	No reported impacts
West Cliff LW5A3, LW5A4 and LW29 to LW34	2.3	1100 mm Subsidence 1.5 mm/m Tensile Strain 5.5 mm/m Comp. Strain (B-Line)	Survey, visual, OTDR, SBS. No reported impacts.
West Wallsend LW27	0.2	350 mm Subsidence 1.3 mm/m Tensile Strain 1.7 mm/m Comp. Strain	Cut over clear of Longwall 27. Ground survey, visual, OTDR. No reported impacts.

5.19.3. Impact Assessments for the Optical Fibre Cables Based on Increased Predictions

If the actual tilts and curvatures exceeded those predicted by a factor of 2 times, it would still be unlikely that the optical fibre cable would be adversely affected. The optical fibre cable is not directly affected by tilt and is capable of tolerating curvatures much greater than those predicted within the *Study Area*.

If the actual strains exceeded those predicted by a factor of 2 times, the maximum strains for the optical fibre cables within the *Study Area* would be less than the range of strains experienced at collieries with much shallower depths of cover, such as Beltana and South Bulga. As shown in Table 5.16, longwalls have been successfully mined beneath optical fibre cables where the measured strains greater than 20 mm/m, with the implementation of suitable management strategies.

5.19.4. Recommendations for the Optical Fibre Cables

It is recommended that the optical fibre cables are monitored during the extraction of the proposed longwalls using optical fibre sensing techniques, such as OTDR monitoring. Mitigation measures can be undertaken, such as excavating and exposing the cables, if strain concentrations are detected during the mining period. With the required mitigation measures in place, it is expected that the optical fibre cables can be maintained in serviceable conditions throughout the mining period.

It is recommended that management strategies are developed, in consultation with the infrastructure owners, such that the cables can be maintained in serviceable conditions throughout the mining period.

5.20. Cellular Mobile Telephone Service Sites

There is one Cellular Mobile Telephone Services (CMTS) site identified within the *Study Area*, the location of which is shown in Drawing No. MSEC515-15. The predictions and impact assessments for this site are provided in the following sections.

5.20.1. Predictions for the CMTS Site

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the CMTS site, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.17.

Table 5.17 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the CMTS Site Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
CMTS Site	250	2.5	0.02	< 0.01

The values provided in the above table are the maximum predicted parameters within 20 metres of the centre of the site, at any time during or after the extraction of the proposed longwalls.

The maximum predicted conventional strains for the CMTS Site, based on applying a factor of 15 to the maximum predicted conventional curvatures, are less than 0.5 mm/m tensile and compressive.

The CMTS site is at a discrete location above goaf and, therefore, the most relevant distribution of strain is the maximum strains measured in individual survey bays above goaf from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.20.2. Impact Assessments for the CMTS Site

The maximum predicted tilt for the CMTS site, resulting from the extraction of the proposed longwalls, is 2.5 mm/m (i.e. 0.3 %), which represents a change in grade of 1 in 400. The maximum predicted tilt is small, less than 1 % and unlikely, therefore, to affect the structural integrity or serviceability of the shed structures containing the telecommunications equipment.

It is possible, however, that predicted tilt could affect the performance of the tower mounted panels or microwave dishes, as these antennae can be sensitive to angular deviations. The maximum predicted tilt represents an angular deviation of approximately 0.1° and, therefore, it is expected that this could be managed by making any necessary adjustments to the lines of sight during the active subsidence period.

The maximum predicted ground curvatures for the CMTS site are 0.02 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvature of 50 kilometres and less than 100 kilometres, respectively. The shed structures containing the telecommunications equipment are small and of light-weight construction and, therefore, would not be expected to be impacted by the predicted curvatures and ground strains.

It is recommended that the predicted movements for the CMTS site are provided to Telstra so that detailed structural analyses of the tower and associated infrastructure can be undertaken. Suitable preventive measures should be established, in consultation with Telstra, so that the towers and associated infrastructure can be maintained in safe and serviceable conditions throughout the mining period.

5.20.3. Impact Assessments for the CMTS Site Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilt for the CMTS would still be less than 1 % and unlikely, therefore, to affect the structural integrity or serviceability of the shed structures containing the telecommunications equipment. It would still be expected that the serviceability of the antennae could be managed by making any necessary adjustments to the lines of sight during the active subsidence period.

If the actual curvatures exceeded those predicted by a factor of 2 times, the minimum radius of curvature would be 25 kilometres and unlikely, therefore, to result in any impacts on the small and light-weight sheds containing the telecommunications equipment.

It is recommended that that detailed structural analyses of the towers and associated infrastructure include the appropriate factors of safety. In this way, the towers and associated infrastructure can be maintained in safe and serviceable conditions throughout the mining period.

5.20.4. Recommendations for the CMTS Site

It is recommended that the predicted movements for the CMTS site are provided to Telstra so that detailed structural analyses of the tower and associated infrastructure can be undertaken. Suitable preventive measures should be established, in consultation with Telstra, so that the towers and associated infrastructure can be maintained in safe and serviceable conditions throughout the mining period.

It is also recommended that strategies to developed to manage the potential risks of rockfalls from the rock face that is adjacent to the site. It is recommended that periodic visual inspections of the rock face are undertaken during the active subsidence period.

5.21. Public Amenities

The locations of the public amenities within the *Study Area* are shown in Drawing No. MSEC515-20. The predictions and impact assessments for these features are provided in the following sections.

5.21.1. Jilliby Public School

The Jilliby Public School is located between the northern and south-eastern series of longwalls and is at a distance of 250 metres north-west of Longwall 4S, at its closest point to the proposed longwalls.

At this distance, the school is predicted to experience less than 20 mm of subsidence. While it is possible that the school could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the school would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

5.21.2. Scout Camp

The scout camp is located between the northern and south-eastern series of longwalls and is at a distance of 325 metres north-west of Longwall 7S, at its closest point to the proposed longwalls.

At this distance, the scout camp is predicted to experience less than 20 mm of subsidence. While it is possible that the camp could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the scout camp would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by a factor of 2 times.

5.22. Agriculture and Farm Lands

As farming could be affected by changes in the surface water and groundwater regimes, resulting from the extraction of the proposed longwalls, detailed studies on the potential impacts and consequences of subsidence have been undertaken and the results are presented in the reports by GHA (2013) and Mackie (2013), respectively.

It is recommended that the WACJV develop management strategies, in consultation with the owners, to manage the potential for impacts to these agricultural businesses.

5.23. Commercial Sites

The locations of the commercial sites within the *Study Area* are shown in Drawing No. MSEC515-20. The predictions and impact assessments for these sites are provided in the following sections.

5.23.1. Disused Quarry Site

The disused quarry site is located above the proposed Longwalls 14N and 15N. It is possible that the quarry could become operational by the time longwall mining occurs beneath this site.

The mine subsidence movements resulting from the extraction of the proposed longwalls could dislodge marginally stable rocks or loose boulders on the quarry faces. The potential for rock falls poses a safety risk for people beneath the quarry faces.

It is recommended that access should be restricted from beneath the quarry faces as the proposed longwalls are mined beneath the site. At that time, if the quarry site is operational, it is recommended that management strategies are developed, in consultation with the owners, so that the potential for rock falls can be managed throughout the mining period. If the quarry site is operational, then it is also recommended that the quarry faces should be visually monitored by a geotechnical engineer on a regular basis during the active subsidence period.

5.23.2. Horse Studs

The Linton Park and the Parkview horse studs are generally located between the northern and south-eastern series of longwalls. The northern boundary of Linton Park is located above the southern ends of Longwalls 7N to 9N and the southern boundary of Parkview is located above the northern ends of Longwalls 3S and 4S.

The main potential impact at these sites is considered to be surface cracking. The depth of cover in the locations of these horse studs is 400 metres and, therefore, only minor and isolated surface cracking would be expected directly above the proposed longwalls. Surface cracking can be identified by visual inspections and can be easily repaired so as to manage any hazards to horses. Further discussions on the potential for surface cracking are provided in Section 4.6. The potential impacts on the building structures, farm dams and associated infrastructure on these sites are provided in Sections 5.24 to 5.26.

5.23.3. Nursery

The Moonpar Nursery is located above Longwall 3S. The nursery could experience the full range of predicted subsidence movements from this longwall. A summary of the maximum predicted conventional subsidence movements above Longwalls 1S to 10S is provided in Chapter 4.

It is possible, that the in-ground plants could be affected by changes in the groundwater regime resulting from the extraction of the proposed longwalls. Discussions on the groundwater model and potential impacts on the groundwater regime are provided in the report by Mackie (2013). The potential impacts on the building structures and associated infrastructure on this site are provided in Sections 5.24 to 5.26.

5.23.4. Aviary

The Highland Park Aviary is located above Longwalls 6N and 7N. The aviary could experience the full range of predicted subsidence movements from these longwalls. A summary of the maximum predicted conventional subsidence movements above Longwalls 6N to 26N is provided in Chapter 4. The potential impacts on the building structures and associated infrastructure on this site are provided in Sections 5.24 to 5.26.

5.23.5. Turf Farm

The Dooralong Valley Turf farm is located above Longwall 12N. The farm could experience the full range of predicted subsidence movements from this longwall. A summary of the maximum predicted conventional subsidence movements above Longwalls 6N to 26N is provided in Chapter 4.

Planted turf activities require soil moisture management involving substantial irrigated water application and are influenced by natural rainfall and groundwater conditions. Discussions on the groundwater model and potential impacts on the groundwater regime are provided in the report by Mackie (2013). The potential impacts on the building structures and associated infrastructure on this site are provided in Sections 5.24 to 5.26.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the turf farm and horse studs within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.18.

Table 5.18 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Turf Farm and Horse Studs Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Turf Farm	1750	11	0.25	0.25
Horse Stud	1600	11	0.15	0.25

The tilts provided in the above table are the maximum predicted values at the completion of any or all proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls.

The maximum predicted conventional strains, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4 mm/m tensile and compressive for the Turf Farm, and 2.5 mm/m tensile and 4 mm/m compressive for the Horse Studs.

The Turf Farms and Horse Studs are planar features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The potential impacts on the Turf Farm and Horse Studs include surface cracking, changes in surface water drainage (refer to Section 5.3) and ground water utilisation (refer to Sections 5.4 and 5.27), and impacts to associated building structures and farm dams (refer to Sections 5.24 to 5.26).

In the locations of the Turf Farms and Horse Studs, the surface cracking is expected to be less than that typically observed in the Southern Coalfield, due to the high depth of alluvial deposits above bedrock. Any surface cracking is expected to be very minor and isolated and represent a very small percentage of the mining area. Discussions on the groundwater model and potential impacts on the groundwater regime are provided in the report by Mackie (2013).

5.24. Rural Building Structures

The locations of the rural building structures within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for these structures are provided in the following sections.

5.24.1. Predictions for the Rural Building Structures

Predictions for the rural building structures of conventional subsidence, tilt and curvature have been made at the centroid and at the vertices of each structure, as well as eight equally spaced points placed radially around the centroid and vertices at a distance of 20 metres. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each rural building structure within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table D.02 in Appendix D.

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual rural building structures would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the rural building structures across the *Study Area* would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the rural building structures within the *Study Area*, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 5.7 and Fig. 5.8.

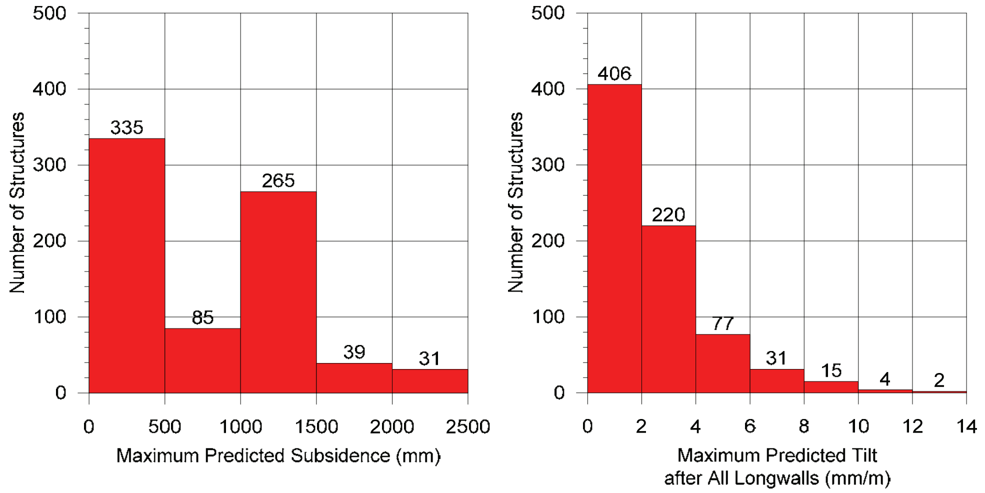

Fig. 5.7 Maximum Predicted Conventional Subsidence and Tilt for the Rural Building Structures within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

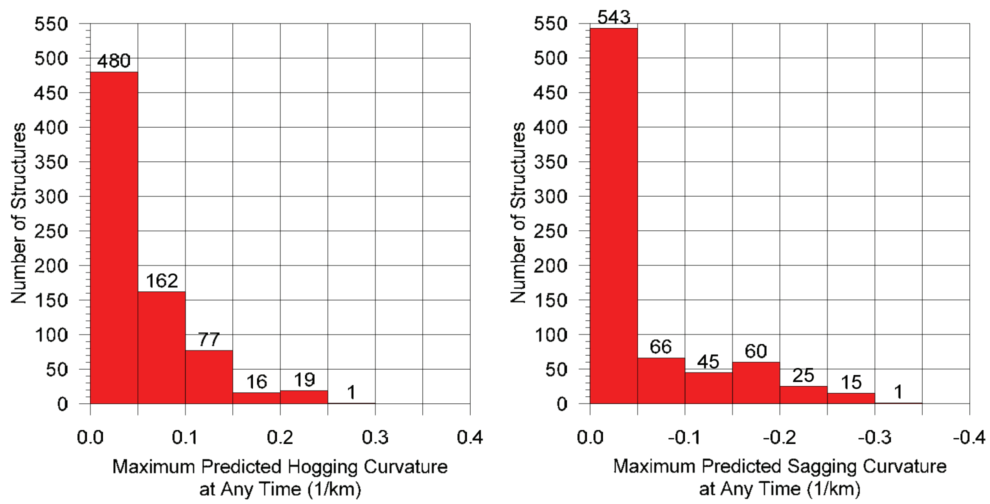

Fig. 5.8 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Rural Structures Resulting from the Extraction of the Proposed Longwalls

The rural building structures are located across the *Study Area* and, therefore, could experience the full range of predicted strains. The maximum predicted conventional strains resulting from the extraction of the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- LW1N to LW5N - 3 mm/m tensile and 4 mm/m compressive,
- LW6N to LW26N - 4 mm/m tensile and 5.5 mm/m compressive,
- LW1S to LW10S - 4 mm/m tensile and 4.5 mm/m compressive, and
- LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

The rural building structures are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.24.2. Impact Assessments for the Rural Building Structures

The predicted maximum final tilts are less than 7 mm/m at 722 structures (i.e. 95 %), between 7 mm/m and 10 mm/m at 27 structures (i.e. 4 %) and greater than 10 mm/m at six structures (i.e. 1 %) at the completion of mining. The maximum predicted conventional tilt for the rural building structures within the *Study Area*, at the completion of mining, is 13 mm/m (i.e. 1.3 %), which represents a change in grade of 1 in 75.

The majority of the rural building structures within the *Study Area* are of lightweight construction. It has been found from past longwall mining experience, that tilts of the magnitudes predicted within the *Study Area* generally do not result in any significant impacts on rural building structures. Some minor serviceability impacts could occur at the higher levels of predicted tilt, including door swings and issues with roof and pavement drainage, all of which can be remediated using normal building maintenance techniques.

The predicted maximum hogging and sagging curvatures are less than 0.15 km^{-1} at 635 rural structures within the *Study Area* (i.e. 84 %), which represent minimum radii of curvature greater than 7 kilometres. The range of predicted curvatures at these rural building structures, therefore, is similar to that typically experienced in the Southern Coalfield.

For these 635 rural building structures, the observed levels of impact on rural building structures in the Southern Coalfield should provide a reasonable guide to the potential levels of impact. A number of rural building structures have been mined directly beneath by previously extracted longwalls in the Southern Coalfield, some of which have been summarised in Table 5.19.

Table 5.19 Previous Experience of Mining Beneath Rural Building Structures

Colliery and LWs	Rural Building Structures	Maximum Predicted Movements at the Structures	Observed Impacts
Appin LW301 and LW302	4	650 mm Subsidence 4.5 mm/m Tilt 1 mm/m Tensile Strain 3 mm/m Comp. Strain	No reported impacts
Appin LW401 to LW409	100	1200 mm Subsidence 5 mm/m Tilt 1 mm/m Tensile Strain 2 mm/m Comp. Strain	No reported impacts
Appin LW701 to LW704	55	1100 mm Subsidence 7.5 mm/m Tilt 1.5 mm/m Tensile Strain 4 mm/m Comp. Strain	No reported impacts
Tahmoor LW22 to LW25	716	1200 mm Subsidence 6 mm/m Tilt 1.5 mm/m Tensile Strain 2 mm (typ.) and up to 5 mm/m Comp. Strain	Impacts reported at three rural building structures
West Cliff LW29 to LW34	196	1100 mm Subsidence 10 mm/m Tilt 1 mm/m Tensile Strain 5.5 mm/m Comp. Strain	Impacts to four large chicken sheds due to non-conventional movements.

There is extensive experience of mining directly beneath rural building structures in the Southern Coalfield which indicates that the incidence of impacts on these structures is very low. This is not surprising as rural building structures are generally small in size and of light-weight construction, which makes them less susceptible to impact than houses which are typically more rigid. In all cases, the rural building structures remained in safe and serviceable conditions.

The remaining 120 of the 755 rural building structures within the *Study Area* (i.e. 16 %) are predicted to experience hogging curvatures up to 0.25 km^{-1} and sagging curvatures up to 0.30 km^{-1}, which represent minimum radii of curvature of 4 kilometres and 3 kilometres, respectively. The maximum predicted curvatures at these rural building structures are greater than those typically experienced in the Southern Coalfield.

For these 120 rural building structures, the predicted movements are less than those which have occurred at shallower mines in the Newcastle and Hunter Coalfields, such as at the Beltana No. 1 Underground Mine and South Bulga, where the maximum observed tilts were greater than 50 mm/m and the maximum observed strains were greater than 20 mm/m. It is understood, that all domestic rural building structures have remained safe where they have been directly mined beneath in the NSW Coalfields at depths of cover greater than 200 metres. Also, it is understood that impacts on these rural building structures have generally been repairable using normal building construction techniques.

It is expected, therefore, that all the rural building structures within the *Study Area* would remain safe and repairable during the mining period, provided that they are in sound existing condition. The risk of impact is clearly greater if the structures are in poor condition, though the chances of there being a public safety risk remains very low. A number of rural building structures which were in poor existing conditions have been directly mined beneath and these structures have not experienced adverse impacts during mining.

Any impacts on the rural building structures that occur as the result of the extraction of the proposed longwalls are expected to be remediated using well established building techniques. With these remediation measures available, it is unlikely that there would be any significant long term impacts on rural building structures resulting from the extraction of the proposed longwalls.

5.24.3. Impact Assessments for the Rural Building Structures Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the incidence of serviceability impacts, such as door swings and issues with gutter and pavement drainage, would increase for the structures located directly above the longwalls. It would still be unlikely that stabilities of these rural building structures would be affected by tilts of these magnitudes.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the incidence of impacts on the rural building structures would increase for the structures located directly above the longwalls. Since rural building structures are generally small in size and of light-weight construction, they would still be expected to remain safe and repairable using normal building maintenance techniques. With the implementation of any necessary remediation measures, it is unlikely that there would be any significant long term impacts on the rural building structures.

5.24.4. Recommendations for the Rural Building Structures

The assessed impacts on the rural building structures within the *Study Area*, resulting from the extraction of the proposed longwalls, could be managed with the implementation of suitable management strategies.

It is recommended that the rural building structures located above the proposed longwalls should be inspected, prior to being mined beneath, to assess the existing conditions and whether any preventive measures may be required. It is also recommended that the rural building structures are visually monitored during the extraction of the proposed longwalls. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the rural building structures.

5.25. Farm Fences

The fences are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4.

The fences are linear features and, therefore, the most relevant distribution of strain is the maximum strains measured along whole monitoring lines from previous longwall mining. The analysis of strains measured along monitoring lines during the mining of previous longwalls in the Newcastle Coalfield is provided in Section 4.3.2.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The fences within the *Study Area* are constructed in a variety of ways, generally using either timber or metal materials.

Wire fences can be affected by tilting of the fence posts and by changes of tension in the fence wires due to strain as mining occurs. These types of fences are generally flexible in construction and can usually tolerate tilts of up to 10 mm/m and strains of up to 5 mm/m without significant impacts. It is likely, therefore, that some of the wire fences within the *Study Area* would be impacted as the result of the extraction of the proposed longwalls. Any impacts on the wire fences are likely to be of a minor nature and relatively easy to remediate by re-tensioning the fencing wire, straightening the fence posts, and if necessary, replacing some sections of fencing.

Colorbond and timber paling fences are more rigid than wire fences and, therefore, are more susceptible to impacts resulting from mine subsidence movements. It is possible that these types of fences could be impacted as the result of the extraction of the proposed longwalls. Any impacts on Colorbond or timber paling fences can be remediated or, where necessary, affected sections of the fences replaced.

5.26. Farm Dams

The locations of the farm dams identified within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for these features are provided in the following sections.

5.26.1. Predictions for the Farm Dams

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and around the perimeters of each farm dam. A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each dam within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table D.03 in Appendix D.

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual farm dams would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the farm dams across the *Study Area* would not be expected to change significantly.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the farm dams within the *Study Area*, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 5.9, Fig. 5.10 and Fig. 5.11.

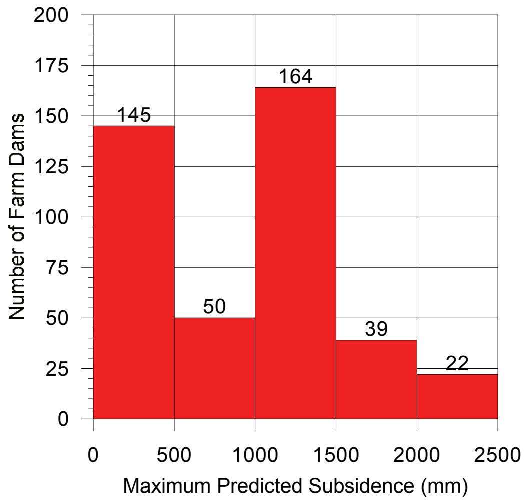

Fig. 5.9 Maximum Predicted Conventional Subsidence for the Farm Dams within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

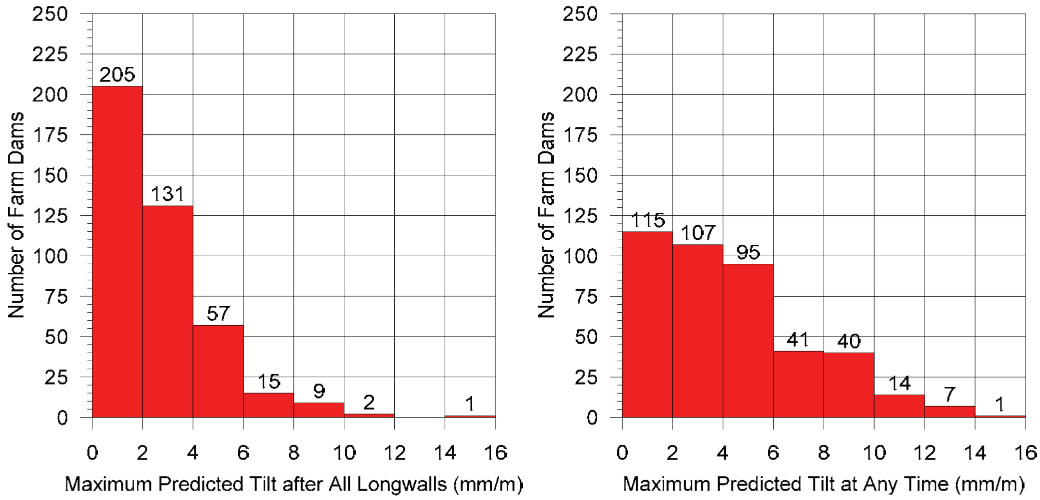

Fig. 5.10 Maximum Predicted Conventional Final and Transient Tilts for the Farm Dams within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

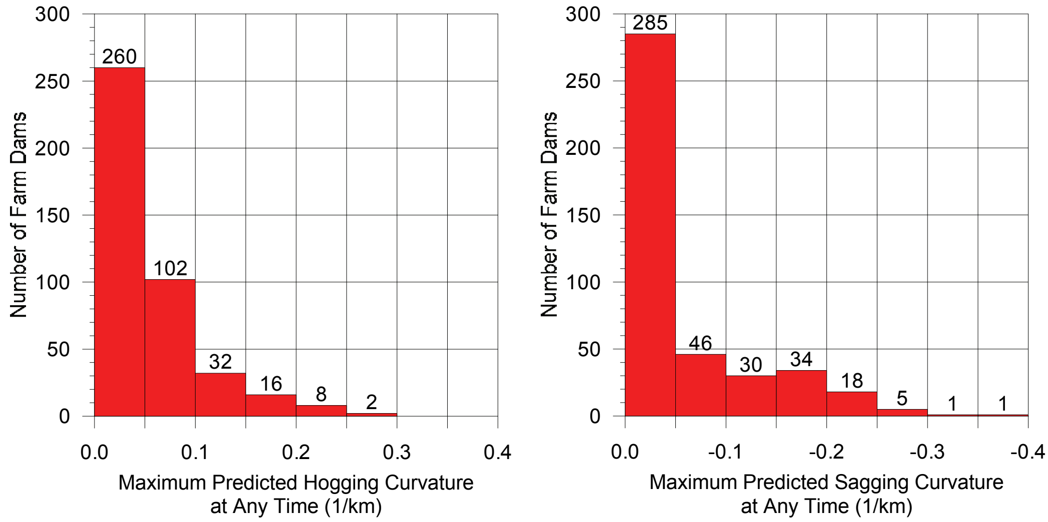

Fig. 5.11 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Farm Dams Resulting from the Extraction of the Proposed Longwalls

The dams have typically been constructed within the drainage lines and, therefore, may be subjected to valley related movements resulting from the extraction of the proposed longwalls. The equivalent valley heights at the dams are very small and it is expected that the predicted valley related upsidence and closure movements at the dam walls would be much less than the predicted conventional subsidence movements and, therefore, are not significant.

The farm dams are located across the *Study Area* and, therefore, could experience the full range of predicted strains. The maximum predicted conventional strains resulting from the extraction of the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- LW1N to LW5N - 3 mm/m tensile and 4 mm/m compressive,
- LW6N to LW26N - 4 mm/m tensile and 5.5 mm/m compressive,
- LW1S to LW10S - 4 mm/m tensile and 4.5 mm/m compressive, and
- LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

The farm dams are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

5.26.2. Impact Assessments for the Farm Dams

The maximum predicted final tilt for the farm dams within the *Study Area*, at the completion of mining, is 14 mm/m (i.e. 1.4 %), which represents a change in grade of 1 in 70. The maximum predicted tilt for the farm dams within the *Study Area*, at any time during the extraction of the proposed longwalls, is 15 mm/m (i.e. 1.5 %), which represents a change in grade of 1 in 65.

Mining induced tilts can affect the water levels around the perimeters of farm dams, with the freeboard increasing on one side, and decreasing on the other. Tilt can potentially reduce the storage capacity of farm dams, by causing them to overflow, or can affect the stability of the dam walls.

The predicted changes in freeboard at the farm dams within the *Study Area* were determined by taking the difference between the maximum predicted subsidence and the minimum predicted subsidence anywhere around the perimeter of each farm dam. The predicted maximum changes in freeboard at the farm dams within the *Study Area*, after the completion of the proposed longwalls, are provided in Table D.03 in Appendix D and is illustrated in Fig. 5.12.

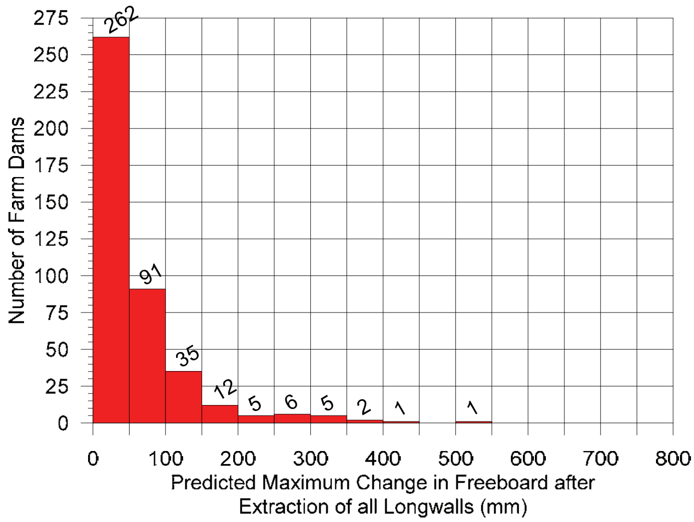

Fig. 5.12 Predicted Changes in Freeboards for the Farm Dams within the *Study Area*

The maximum predicted change in freeboard is 500 mm, which occurs at a dam near the finishing (north-eastern) end of Longwall 2N. The predicted changes in freeboard at the remaining farm dams within the *Study Area* are 400 mm or less. The predicted changes in freeboard could, in some locations, reduce the storage capacities and it may be necessary to remediate these dams, if required, to restore the storage capacities. The predicted changes in freeboard are unlikely to have any adverse impacts on the stabilities of the dam walls.

The predicted maximum hogging and sagging curvatures are less than 0.15 km^{-1} at 341 farm dams within the *Study Area* (i.e. 81 %), which represent minimum radii of curvature greater than 7 kilometres. The range of predicted curvatures at these farm dams, therefore, is similar to that typically experienced in the Southern Coalfield.

For these 341 farm dams, the observed levels of impact on farm dams in the Southern Coalfield should provide a reasonable guide to the potential levels of impact. A number of farm dams have been mined directly beneath by previously extracted longwalls in the Southern Coalfield, some of which have been summarised in Table 5.20.

Table 5.20 Previous Experience of Mining Beneath Farm Dams in the Southern Coalfield

Colliery and LWs	Number of Farm Dams Directly Mined Beneath	Predicted Maximum Movements at the Dams	Observed Impacts
Appin LW301 and LW302	3	650 mm Subsidence 4.5 mm/m Tilt 1 mm/m Tensile Strain 3 mm/m Comp. Strain	No reported impacts
Appin LW401 to LW409	52	1200 mm Subsidence 5 mm/m Tilt 1 mm/m Tensile Strain 2 mm/m Comp. Strain	No reported impacts
Appin LW701 to LW704	30	1100 mm Subsidence 7.5 mm/m Tilt 1.5 mm/m Tensile Strain 4 mm/m Comp. Strain	One farm dam reported to drain
Tahmoor LW22 to LW25	36	1200 mm Subsidence 6 mm/m Tilt 1.5 mm/m Tensile Strain 2 mm (typ.) and up to 5 mm/m Comp. Strain	No reported impacts
West Cliff LW29 to LW34	49	1100 mm Subsidence 10 mm/m Tilt 1 mm/m Tensile Strain 5.5 mm/m Comp. Strain	No reported impacts

It can be seen from the above table, that the incidence of impacts on farm dams in the Southern Coalfield is extremely low. The farm dam reported to drain in Appin Area 7 was of poor, shallow construction and seepage was observed at the base of the dam wall prior to mining. While no impacts were observed on the dam wall itself, the dam was observed to drain following mining.

The remaining 79 of the 420 farm dams within the *Study Area* (i.e. 19 %) are predicted to experience hogging curvatures up to 0.25 km^{-1} and sagging curvatures up to 0.35 km^{-1}, which represent minimum radii of curvature of 4 kilometres and 3 kilometres, respectively. The maximum predicted curvatures at these farm dams are greater than those typically experienced in the Southern Coalfield.

For these 79 farm dams, the predicted movements are less than those which have occurred at shallower mines in the Newcastle and Hunter Coalfields, such as at the Beltana No. 1 Underground Mine and South Bulga, where the maximum observed tilts were greater than 50 mm/m and the maximum observed strains were greater than 20 mm/m. It is understood that all farm have remained serviceable where they have been directly mined beneath in the NSW Coalfields at depths of cover greater than 300 metres. Also, it is understood that impacts on these farm dams have been repairable by infilling the major surface cracking.

It is expected, therefore, that the incidence of impacts on the farm dams within the *Study Area*, resulting from the extraction of the proposed longwalls, will be low. If cracking or leakage of water were to occur in the farm dam walls, it is expected that this could be easily identified and repaired as required. It is not expected that any significant loss of water will occur from the farm dams, and any loss that did occur would flow into the tributary in which the dam was formed.

5.26.3. Impact Assessments for the Farm Dams Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum change in freeboard would be around 1,000 mm, with the changes in freeboard at the remaining dams being 800 mm or less. In this case, the changes in freeboard would still be unlikely to have any adverse impacts on the stabilities of the dam walls. The changes in freeboard could, in some locations, reduce the storage capacities and it may be necessary to remediate these dams, if required, to restore the storage capacities.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the incidence of cracking in the farm dams would increase for the farm dams located directly above the longwalls. Any surface cracking would still be expected to be of a minor nature and could be readily repaired. With any necessary remediation measures implemented, it is unlikely that any significant impact on the farm dams would occur resulting from the extraction of the proposed longwalls.

5.26.4. Recommendations for the Farm Dams

The assessed impacts on the farm dams, resulting from the extraction of the proposed longwalls, can be managed with the implementation of suitable management strategies. It is recommended that all water retaining structures be visually monitored during the extraction of the proposed longwalls, to ensure that they remain in safe and serviceable conditions. With these management strategies in place, it is unlikely that there would be any significant long term impacts on the farm dams.

5.27. Wells and Bores

There are a total of 13 registered groundwater bores within the *General Study Area*, the locations of which are shown in Drawing No. MSEC515-17.

The bores are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4.

The bores are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

It is likely that the groundwater bores will experience some impacts as the result of mining of the longwalls, particularly those directly above the proposed longwalls. Impacts may include temporary lowering of the piezometric surface, blockage of the bore due to differential horizontal displacements at different horizons within the strata and changes to groundwater quality. Such impacts on the groundwater bores can be readily managed, where necessary, by reinstating the affected bores.

Further discussions on the potential impacts on the groundwater regime, resulting from the extraction of the proposed longwalls, are provided in the report by Mackie (2013).

5.28. Archaeological Sites

An indigenous heritage assessment has being undertaken by OzArk Environmental and Heritage Management. The following sections provide discussions on the potential impacts on the archaeological sites within the *Study Area*, which should be read in conjunction with the report by OzArk (2012b).

5.28.1. Predictions for the Archaeological Sites

The locations of the archaeological sites identified within and immediately adjacent to the *Study Area* are shown in Drawing No. MSEC515-16. A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for these archaeological sites, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.21.

Table 5.21 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Identified Archaeological Sites Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
45-3-3040	2350	5.0	0.04	0.17
45-3-3041	2250	5.5	0.05	0.04
45-3-3041 a	2400	13.0	0.11	0.16
45-3-3041 b	2250	5.5	0.05	0.04
45-3-3041 c	2300	12.5	0.17	0.08
45-3-3042	2500	6.0	0.06	0.21
45-3-3042 a	2450	11.5	0.06	0.25
45-3-3042 b	2500	6.0	0.06	0.21
WSF-AG3	25	0.3	< 0.01	< 0.01
WSF-AG4	25	< 0.2	< 0.01	< 0.01
Remaining Sites	< 20	< 0.2	< 0.01	< 0.01

The values provided in the above table are the maximum predicted parameters within 20 metres of the centre of each archaeological site, at any time during or after the extraction of the proposed longwalls. The predictions are based on the co-ordinates of the sites which were provided by OzArk (2012b).

The maximum predicted conventional strains for the archaeological sites, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- 45-3-3040 - 0.5 mm/m tensile and 2.5 mm/m compressive,
- 45-3-3041 - 1.0 mm/m tensile and 0.5 mm/m compressive,
- 45-3-3041a - 1.5 mm/m tensile and 2.5 mm/m compressive,
- 45-3-3041b - 1.0 mm/m tensile and 0.5 mm/m compressive,
- 45-3-3041c - 2.5 mm/m tensile and 1.0 mm/m compressive,
- 45-3-3042 - 1.0 mm/m tensile and 3.0 mm/m compressive,
- 45-3-3042a - 1.0 mm/m tensile and 3.5 mm/m compressive,
- 45-3-3042b - 1.0 mm/m tensile and 3.0 mm/m compressive, and
- Remaining sites - less than 0.5 mm/m tensile and compressive.

The archaeological sites are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, valley related upsidence and closure movements and anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements. The strains resulting from valley related movements are discussed separately in the following sections.

There are likely to be other archaeological sites within the *Study Area* in addition to those which have been identified. It is possible that these archaeological sites could be located across the *Study Area* and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4.

5.28.2. Impact Assessments for the Open Sites

Open Sites can potentially be affected by cracking in the surface soils as the result of mine subsidence movements. It is unlikely, however, that the scattered artefacts or isolated finds themselves would be impacted by surface cracking, as the likelihood of surface cracking being coincident with the precise location of the artefacts is considered low.

Surface cracking in soils as the result of conventional subsidence movements is generally of a minor nature at depths of cover greater than 350 metres, such as the case above the proposed longwalls. Larger cracking or soil heaving has been observed as the result of downslope movements along steep slopes, or in locations of non-conventional movements resulting from near surface geological structures. Further discussions on the surface cracking and are provided in Section 4.6.

Whilst it is unlikely that the scattered artefacts or isolated finds themselves would be impacted by mine subsidence, it is possible that if remediation of surface was required after mining, that these works could potentially impact on the archaeological sites.

It will be necessary to develop the appropriate surface remediation strategies, in the locations of the Open Sites, such that these sites are not adversely affected by any necessary remediation measures.

Further discussions are provided in the report by OzArk (2012b).

5.28.3. Impact Assessments for Grinding Groove Sites

Grinding Groove Sites can potentially be impacted by fracturing of the bedrock. The main mechanisms which could potentially result in impacts on grinding groove sites are the curvatures, strains and valley related upsidence and closure movements.

The maximum predicted curvatures, strains and valley closure movements are of sufficient magnitude to result in fracturing in the bedrock. Experience in the NSW Coalfields indicates that fracturing of bedrock at depths of cover greater than 350 metres, such as the case within the *Study Area*, generally occurs in isolated locations and the likelihood that fracturing would be coincident with the grinding groove sites would be considered relatively low.

Preventive measures could be implemented at the grinding groove sites, where required, including slotting of the bedrock around the sites to isolate them from the ground movements. It is possible, however, that the preventive measures could result in greater impacts on the sites than those which would have occurred as the result of mine subsidence movements.

Further discussions are provided in the report by OzArk (2012b).

5.28.4. Impact Assessments for Scarred Trees

Scarred Trees can potentially be impacted by large ground deformations, however, this type of impact has only been observed at very shallow depths of cover. Based on the experience of previous longwall mining in the NSW Coalfields, it has been observed that trees are not impacted by mine subsidence movements at depths of cover greater than 350 metres, such as the case within the *Study Area*. It is unlikely, therefore, that the scarred trees would be impacted as the result of the extraction of the proposed longwalls.

Further discussions are provided in the report by OzArk (2012b).

5.29. Heritage Sites

The locations of the Heritage Sites and the Potential Heritage Sites within the *Study Area* are shown in Drawing No. MSEC515-16. The predictions and impact assessments for these sites are provided in the following sections.

5.29.1. Predictions for the Heritage Sites

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the Heritage Sites, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.22. A summary of the maximum predicted values of conventional subsidence, tilts and curvatures for the Potential Heritage Sites within the *Study Area*, at any time during or after the extraction of the proposed longwalls, is provided in Table 5.23.

Table 5.22 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Heritage Sites Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Site 1	850	7.5	0.09	0.04
Site 3	650	7.5	0.08	< 0.01
Site 11	< 20	< 0.2	< 0.01	< 0.01

Table 5.23 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Potential Heritage Sites Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Site G	25	0.4	< 0.01	< 0.01
Site I	25	0.2	< 0.01	< 0.01
Site J	50	0.4	< 0.01	< 0.01
Site K	150	1.5	0.02	< 0.01
Site L	< 20	< 0.2	< 0.01	< 0.01
Site M	75	0.8	< 0.01	< 0.01
Site N	50	0.3	< 0.01	< 0.01
Site O	1250	8.5	0.13	0.15
Site P	1350	8.0	0.06	0.25
Site Q	25	0.4	< 0.01	< 0.01
Site R	1200	4.0	0.05	0.04
Site S	850	11	0.17	0.02

The values provided in the above tables are the maximum predicted parameters within 20 metres of the centre of each site, at any time during or after the extraction of the proposed longwalls.

The maximum predicted conventional strains for the Heritage and Potential Heritage Sites, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- Site 1 - 1.5 mm/m tensile and 0.5 mm/m compressive,
- Site 3 - 1 mm/m tensile and less than 0.5 mm/m compressive,
- Site 11 - less than 0.5 mm/m tensile and compressive,
- Site G to Site N - less than 0.5 mm/m tensile and compressive,
- Site O - 2 mm/m tensile and 2.5 mm/m compressive,
- Site P - 1 mm/m tensile and 4 mm/m compressive,
- Site Q - less than 0.5 mm/m tensile and compressive,
- Site R - 1 mm/m tensile and 0.5 mm/m compressive, and
- Site S - 2.5 mm/m tensile and less than 0.5 mm/m compressive.

The Heritage Sites and the Potential Heritage Sites are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.29.2. Impact Assessments for Heritage Site 1 – Brick and Iron Silo

The maximum predicted tilt for the brick and iron silo, at the completion of the proposed longwalls, is 7.5 mm/m (i.e. 0.8 %), which represents a change in grade of 1 in 135. The structure comprises full masonry walls and, therefore, it is unlikely that a tilt of this magnitude would adversely affect the stability of this structure.

The maximum predicted curvatures for the brick and iron silo, resulting from the extraction of the proposed longwalls, are 0.09 km^{-1} hogging and 0.04 km^{-1} sagging, which represent minimum radii of curvature of 11 kilometres and 25 kilometres, respectively.

The Australian Standard AS 2870 (1996) provides guidance on the allowable deflection ratios for various types of structures. The allowable deflection ratio for full masonry structures with non-load bearing walls is 1:1,500, which represents an allowable radius of curvature of approximately 3 kilometres based on the structure length of 15 metres.

It is possible, therefore, that the extraction of the proposed longwalls could result in cracking in the masonry walls. Any cracking would be expected to occur in the corners around the openings, possibly limited to the mortar, due to the robust construction of the structure. It would be expected that any cracking could be repaired using normal building maintenance techniques, however, any remediation works on the structure may need to be reviewed by a heritage consultant.

It is recommended that a study is undertaken to assess the potential impacts on the structure. The study may require input from a structural engineer, a subsidence engineer and a heritage consultant. Management strategies should be developed such that the heritage significance of the structure is not adversely affected by mining and to establish the appropriate remediation measures.

5.29.3. Impact Assessments for Heritage Site 3 – Dwelling "Bangalow"

The maximum predicted tilt for the dwelling "Bangalow", at the completion of the proposed longwalls, is 7.5 mm/m (i.e. 0.8 %), which represents a change in grade of 1 in 135. As described in Section 5.31.2, tilts of around 7 mm/m can result in some minor serviceability impacts on houses, including door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques.

In this case, the predicted tilt is slightly greater than 7 mm/m and it is possible, therefore, that some more substantial remediation measures may be required, including the relevelling of some wet areas. Any remediation works on the structure may need to be reviewed by a heritage consultant.

The maximum predicted curvatures for the dwelling "Bangalow", resulting from the extraction of the proposed longwalls, are 0.08 km^{-1} hogging and less than 0.01 km^{-1} sagging, which represent minimum radii of curvature of 13 kilometres and greater than 100 kilometres, respectively. The impact assessment for the structure has been made in accordance with the method described in Section 5.31.2 and Appendix C and the results are summarised in Table 5.24.

Table 5.24 Assessed Impact for Heritage Site 3

Location	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
Site 3	84 %	12 %	4 %	< 0.5 %

The repair categories R0 to R5 are described in Table C.4 in Appendix C.

The impact assessment indicates that there is a probability of approximately 95 % that none or only minor impacts (i.e. R0, R1, R2) will occur as the result of the extraction of the proposed longwalls. There is a small probability, approximately 5 %, that more substantial impacts could occur (i.e. R3 or greater) as the result of the extraction of the proposed longwalls.

It is recommended that a study is undertaken to assess the potential impacts on the dwelling "Bangalow". The study may require input from a structural engineer, a subsidence engineer and a heritage consultant. Management strategies should be developed such that the heritage significance of the structure is not adversely affected by mining and to establish the appropriate remediation measures.

5.29.4. Impact Assessments for Heritage Site 11 – Jilliby Public School

The Jilliby Public School is located between the northern and south-eastern series of longwalls and is at a distance of 250 metres north-west of Longwall 4S, at its closest point to the proposed longwalls. The impact assessments for this school are provided in Section 5.21.1.

5.29.5. Impact Assessments for the Potential Heritage Sites G, I, J, K, L, R and S – Dwellings

The Potential Heritage Sites G, I, J, K, L, R and S comprise dwellings which are located across the *Study Area*. The maximum predicted tilts for these sites, at the completion of the proposed longwalls, vary from less than 0.2 mm/m (i.e. < 0.1 %) to 11 mm/m (i.e. 1.1 %), which represent changes in grade varying from less than 1 in 5,000 to 1 in 90.

As described in Section 5.31.2, that tilts of less than 7 mm/m generally do not result in any significant impacts on houses. Some minor serviceability impacts can occur at these levels of tilt, including door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques. Tilts greater than 7 mm/m can result in greater serviceability impacts which may require more substantial remediation measures, including the relevelling of wet areas or, in some cases, the relevelling of the building structure.

The maximum predicted curvatures for the Potential Heritage Sites G, I, J, K, L, R and S, resulting from the extraction of the proposed longwalls, vary from less than 0.01 km^{-1} to 0.17 km^{-1} hogging curvature and vary from less than 0.01 km^{-1} to 0.04 km^{-1} sagging curvature. The impact assessments for these structures have been made in accordance with the method described in Section 5.31.2 and Appendix C and the results are summarised in Table 5.25.

Table 5.25 Assessed Impacts for the Potential Heritage Sites G, I, J, K, L, R and S

Location	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
Site G	94 %	5 %	1 %	< 0.1 %
Site I	94 %	5 %	1 %	< 0.1 %
Site J	94 %	5 %	1 %	< 0.1 %
Site K	90 %	9 %	1 %	< 0.1 %
Site L	93 %	6 %	1 %	< 0.1 %
Site R	73 %	19 %	8 %	< 0.5 %
Site S	81 %	14 %	5 %	< 0.5 %

The repair categories R0 to R5 are described in Table C.4 in Appendix C.

The impact assessments indicate that each dwelling has a probability between approximately 92 % and 99 % that none or only minor impacts (i.e. R0, R1, R2) will occur as the result of the extraction of the proposed longwalls. There is a small probability for each of these dwellings, between 1 % and 8 %, that more substantial impacts could occur (i.e. R3 or greater) as the result of the extraction of the proposed longwalls.

It is recommended that a study is undertaken to assess the potential impacts on the Potential Heritage Sites G, I, J, K, L, R and S. The study may require input from a structural engineer, a subsidence engineer and a heritage consultant. Management strategies should be developed such that these structures are not adversely affected by mining and to establish the appropriate remediation measures.

5.29.6. Impact Assessments for the Potential Heritage Site M – Little Jilliby Bridge

The timber bridge over Little Jilliby Jilliby Creek is located approximately 200 metres south of the proposed Longwall 16N, at its closest point to the proposed longwalls. The impact assessments for this bridge are provided in Section 5.10, where it is referred to as Bridge LJ-B2.

It is recommended that a study is undertaken to assess the potential impacts on the bridge structure. The study may require input from a structural engineer, a subsidence engineer and a heritage consultant. Management strategies should be developed such that the bridge is not adversely affected by mining.

5.29.7. Impact Assessments for the Potential Heritage Site N – Bunya Pine

The Bunya Pine is located between the northern and south-western series of longwalls and is at a distance of approximately 300 metres north-east of the proposed Longwall 1SW, at its closest point to the proposed longwalls.

At this distance, the Bunya Pine is predicted to experience around 50 mm of subsidence. While it is possible that the pine could experience subsidence slightly greater than 50 mm, it would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the Bunya Pine would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by factors up to 2 times.

5.29.8. Impact Assessments for the Potential Heritage Site O – Keegan's Silo

The Keegan's Silo is located above Longwall 12N. The maximum predicted tilt for this site, at the completion of the proposed longwalls, is 8.5 mm/m (i.e. 0.9 %), which represents a change in grade of 1 in 115. The structure is of light-weight construction with metal cladding and, therefore, it is unlikely that a tilt of this magnitude would adversely affect the stability of this structure.

The maximum predicted curvatures for the Keegan's Silo, resulting from the extraction of the proposed longwalls, are 0.13 km^{-1} hogging and 0.15 km^{-1} sagging, which represent minimum radii of curvature of 8 kilometres and 9 kilometres, respectively. The structure is of light-weight construction and, therefore, would be expected to tolerance curvatures of these magnitudes without any adverse impacts.

It is recommended that a study is undertaken to assess the potential impacts on the structure. The study may require input from a structural engineer, a subsidence engineer and a heritage consultant. Management strategies should be developed such that the structure is not adversely affected by mining.

5.29.9. Impact Assessments for the Potential Heritage Site P – Picket Fence

The picket fence is located above Longwall 10N. Timber fences are generally flexible in construction and it is likely, therefore, that this fence would experience any adverse impacts resulting from the extraction of the proposed longwalls.

Adverse impacts could occur, however, if significant irregular movements were to occur in this location. These types of movements develop slowly, which would allow the implementation of the necessary preventive measures if required.

5.29.10. Impact Assessments for the Potential Heritage Site Q – Silos

The Silos are located approximately 300 metres east of the proposed Longwall 1S, at its closest point to the proposed longwalls.

At this distance, the Silos are predicted to experience around 25 mm of subsidence. While it is possible that the Silos could experience subsidence slightly greater than 25 mm, they would not be expected to experience any significant tilts, curvatures or strains.

It is unlikely, therefore, that the Silos would experience any significant impacts resulting from the extraction of the proposed longwalls, even if the predictions were increased by factors up to 2 times.

5.30. Survey Control Marks

The locations of the state survey control marks within and immediately adjacent to the *Study Area* are shown in Drawing No. MSEC515-18.

The state survey control marks are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4. If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the maximum predicted subsidence parameters would be expected to be similar to those provided in Chapter 4.

The state survey control marks located outside and in the vicinity of the *Study Area* are also expected to experience small amounts of subsidence and small far-field horizontal movements. It is possible that other survey control marks outside the immediate area could also be affected by far-field horizontal movements, up to 3 kilometres outside the *Study Area*. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.6 and 4.5.

It will be necessary on the completion of the longwalls, when the ground has stabilised, to re-establish any survey control marks that are required for future use. Consultation between the WACJV and Land and Property Information (LPI), a division of the Department of Finance & Services will be required to ensure that these state survey control marks are reinstated at the appropriate time, as required.

5.31. Houses

The locations of the houses within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for these structures are provided in the following sections.

5.31.1. Predictions for the Houses

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at the vertices of each house, as well as eight equally spaced points placed radially around the centroid and vertices at a distance of 20 metres. In the case of a rectangular shaped structure, predictions have been made at a minimum of 45 points within and around the structure.

A summary of the maximum predicted values of conventional subsidence, tilt and curvature for each house within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table D.01 in Appendix D.

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual houses would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the houses across the *Study Area* would not be expected to change significantly.

The distribution of the predicted conventional subsidence parameters for the houses within the *Study Area* are illustrated in Fig. 5.13, Fig. 5.14 and Fig. 5.15 below.

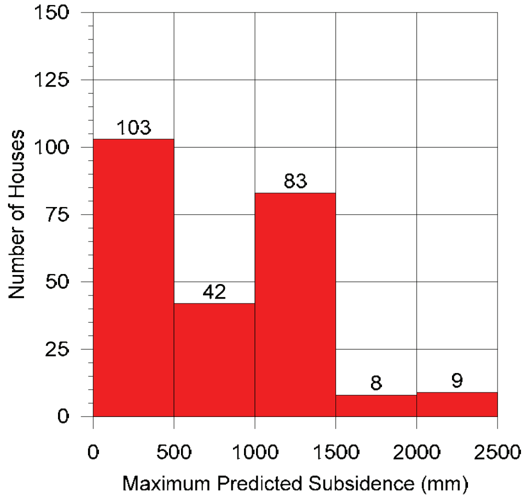

Fig. 5.13 Maximum Predicted Conventional Subsidence for the Houses within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

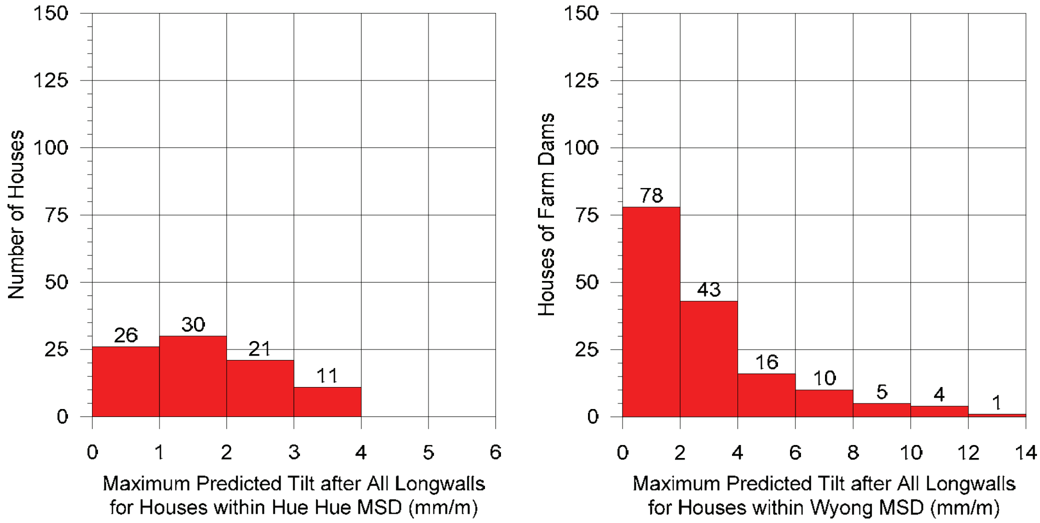

Fig. 5.14 Maximum Predicted Conventional Final Tilts for the Houses within the Hue Hue MSD (Left) and the Wyong MSD (Right) Resulting from the Extraction of the Proposed Longwalls

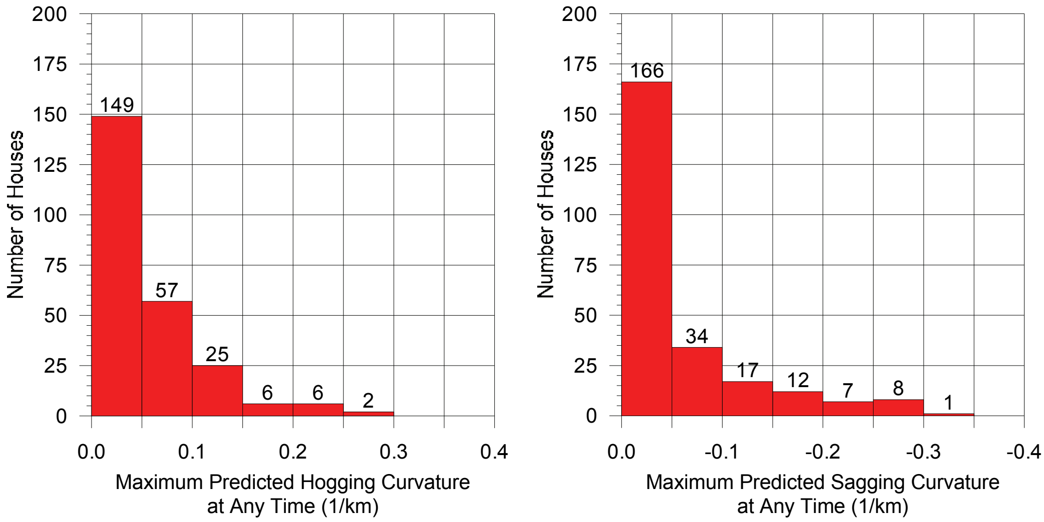

Fig. 5.15 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Houses Resulting from the Extraction of the Proposed Longwalls

The houses are located across the *Study Area* and, therefore, could experience the full range of predicted strains. The maximum predicted conventional strains resulting from the extraction of the proposed longwalls, based on applying a factor of 15 to the maximum predicted conventional curvatures, are as follows:-

- LW1N to LW5N - 3 mm/m tensile and 4 mm/m compressive,
- LW6N to LW26N - 4 mm/m tensile and 5.5 mm/m compressive,
- LW1S to LW10S - 4 mm/m tensile and 4.5 mm/m compressive, and
- LW1SW to LW10SW - 1.5 mm/m tensile and 3 mm/m compressive.

The houses are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.31.2. Impact Assessments for the Houses

The following sections provide the impact assessments for the houses within the *Study Area*.

Potential Impacts Resulting from Vertical Subsidence

Vertical subsidence does not directly affect the stability or serviceability of houses. The potential for impacts on houses are affected by differential subsidence, which includes tilt, curvature and ground strain, and the impact assessments based on these parameters are described in the following sections.

Vertical subsidence in this case, however, can affect the heights of the houses above the flood level. The potential impacts on the houses resulting from the changes in flood level from the proposed mining has been assessed as part of the flood model, which is described in the report by GHA (2013).

Potential Impacts Resulting from Tilt

It has been found from past longwall mining experience that tilts of less than 7 mm/m generally do not result in any significant impacts on houses. Some minor serviceability impacts can occur at these levels of tilt, including door swings and issues with roof gutter and wet area drainage, all of which can be remediated using normal building maintenance techniques. Tilts greater than 7 mm/m can result in greater serviceability impacts which may require more substantial remediation measures, including the relevelling of wet areas or, in some cases, the relevelling of the building structure.

There are 88 houses identified within the Hue Hue Mine Subsidence District. It can be seen from Fig. 5.14, that the predicted maximum final tilts for all these houses are less than 4 mm/m at the completion of mining. It is expected, therefore, that only minor serviceability impacts would occur at these houses, as the result of tilt, which could be remediated using normal building techniques.

There are 157 houses identified within the Wyong Mine Subsidence District. The predicted maximum tilts are less than 7 mm/m at 144 of these houses (i.e. 92 %) at the completion of mining. It is expected that only minor serviceability impacts would occur at these houses, as the result of tilt, which could be remediated using normal building techniques.

The predicted maximum tilts are between 7 mm/m and 10 mm/m at eight houses (i.e. 5 %) and are greater than 10 mm/m at five houses (i.e. 3 %) within the Wyong Mine Subsidence District at the completion of mining. The potential for serviceability impacts is greater for these houses than for the other houses within the *Study Area*. In some cases, more substantial remediation measures may be required, such as relevelling of the building structure.

It is expected that, in all cases, the houses within the *Study Area* will remain in safe conditions as the result of the mining induced tilts.

Potential Impacts Resulting from Curvature and Strain

The methods for predicting and assessing impacts on building structures have developed over time as knowledge and experience has grown. MSEC has provided predictions and impact assessments for the houses within the *Study Area* using the latest methods available at the time.

Background to the Method of Impact Assessment for Houses

Building structures have been directly mined beneath at a number of collieries throughout the NSW Coalfields. The experience gained has provided substantial information that has been used to continually development of the methods of impact assessment for houses. The assessments provided in this report are based on the latest research, which is summarised in Appendix C. The discussions and the method of assessment provided in this report are based on the experience of mining at depths of cover generally greater than 350 metres, such as the case within the *Study Area*.

The most extensive data has come from the extraction of Tahmoor Longwalls 22 to 25, where over 1,000 residential and significant civil structures have experienced mine subsidence movements. The impacts to houses at Tahmoor Colliery were last analysed in detail following the completion of Longwall 24A. A summary of the observed frequency of impacts for all structures located within the 26½ degree angle of draw line from the extents of mining at that time is provided in Table 5.26.

Table 5.26 Observed Frequency of Impacts for Building Structures Resulting from the Extraction of Tahmoor Longwalls 22 to 24A

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All buildings (total of 1099)	967 (88.0 %)	92 (8.4 %)	37 (3.4 %)	3 (0.3 %)
Buildings directly above goaf (total of 669)	546 (81.6 %)	84 (12.6 %)	36 (5.4 %)	3 (0.4 %)
Buildings directly above solid coal (total of 430)	421 (97.9 %)	8 (1.9 %)	1 (0.2 %)	0 (0.0 %)

The distributions of the maximum predicted conventional hogging and sagging curvatures for the houses, resulting from the extraction of Tahmoor Longwalls 22 to 24A, are provided in Fig. 5.16. It can be seen from this figure, that the houses were predicted to have experienced conventional hogging curvatures of up to 0.10 km^{-1} and conventional sagging curvatures of up to 0.15 km^{-1}.

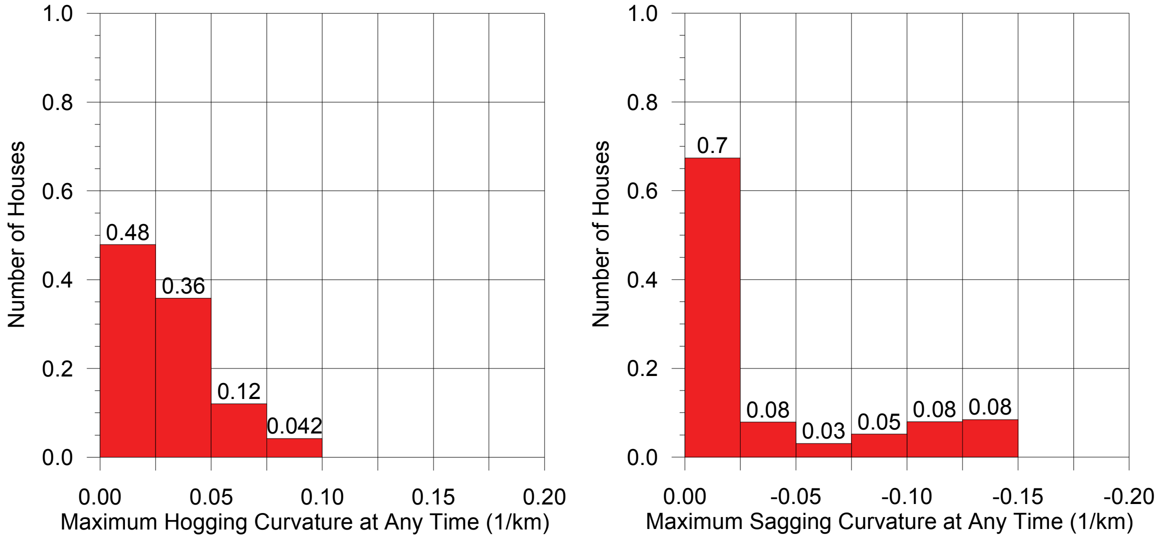

Fig. 5.16 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Houses Located Above Tahmoor Longwalls 22 to 24A

Extensive data has also come from the extraction of Teralba Longwalls 9 and 10, West Cliff Longwalls 5A1 to 5A4 and West Wallsend Longwalls 1 to 10, where approximately 500 houses have experienced mine subsidence movements. A summary of the observed frequency of impacts for the houses located within the 26½ degree angle of draw lines from the extents of mining at these Collieries is provided in Table 5.27.

Table 5.27 Observed Frequency of Impacts for Houses Resulting from the Extraction of Teralba Longwalls 9 and 10, West Cliff Longwalls 5A1 to 5A4 and West Wallsend Longwalls 1 to 10

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All houses (total of 494)	415 (84.0 %)	51 (10.3 %)	26 (5.3 %)	2 (0.4 %)

The repair categories R0 to R5 are described in Table C.4 in Appendix C.

The distributions of the maximum predicted conventional hogging and sagging curvatures for the houses, resulting from the extraction of Teralba Longwalls 9 and 10, West Cliff Longwalls 5A1 to 5A4 and West Wallsend Longwalls 1 to 10, are provided in Fig. 5.17. It can be seen from this figure, that the houses were predicted to have experienced conventional hogging curvatures of up to 0.20 km^{-1} and conventional sagging curvatures of up to 0.25 km^{-1}.

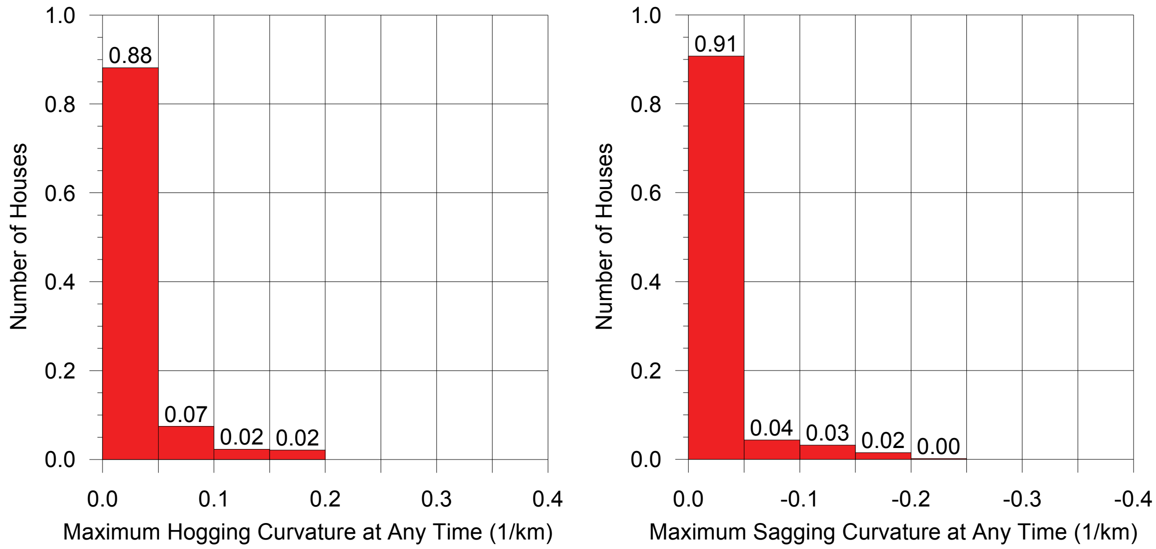

Fig. 5.17 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Houses at Teralba, West Cliff and West Wallsend

The experiences at Tahmoor, Teralba, West Cliff and West Wallsend Collieries indicate that the majority of observed impacts relate to minor effects that are relatively simple to repair, such as sticky doors or windows and cracks to plasterboard linings. In about 5 % of cases, however, substantial or more extensive repairs were required. In less than 1 % of cases, the houses experienced severe impacts, where the Mine Subsidence Board, in consultation with the owners, elected to rebuild the structure as the cost of repair exceeded the cost of replacement.

In all these cases, the residents were not exposed to any immediate and sudden safety hazards as the result of impacts that occurred due to mine subsidence movements. Emphasis is placed on the words "immediate and sudden" as, in rare cases, some structures have experienced severe impacts, but these impacts did not present an immediate risk to public safety as they developed gradually with ample time to relocate residents.

As part of ACARP Research Project C12015, a detailed analysis was undertaken to identify the trends that linked the frequency and severity of impacts with ground strain, ground curvature, type of construction and structure size. A method for assessment was developed for houses, using the primary parameters of ground curvature and type of construction, and further details of this method are provided in Appendix C. The method of assessment developed as part of the ACARP research project has been used to assess the potential impacts on the houses within the *Study Area* which is provided below.

Impact Assessment for Houses within the Study Area

It can be seen from Table D.01, that 194 of the 245 houses within the *Study Area* (i.e. 79 %) are predicted to experience hogging curvatures no greater than 0.10 km^{-1} and experience sagging curvatures no greater than 0.15 km^{-1}, which represent minimum radii of curvature of 10 kilometres and 7 kilometres, respectively. The range of predicted curvatures at these houses, therefore, is similar to that predicted to have occurred for the houses above Tahmoor Longwalls 22 to 24A, which is illustrated in Fig. 5.16.

It can also be seen from Table D.01, that 226 of the 245 houses within the *Study Area* (i.e. 92 %) are predicted to experience hogging curvatures no greater than 0.15 km^{-1} and experience sagging curvatures no greater than 0.25 km^{-1}, which represent minimum radii of curvature of 7 kilometres and 4 kilometres, respectively. The range of predicted curvatures at these houses, therefore, is similar to that predicted to have occurred for the houses above Teralba Longwalls 9 and 10, West Cliff Longwalls 5A1 to 5A4 and West Wallsend Longwalls 1 to 10, which is illustrated in Fig. 5.17.

The overall levels of movement predicted for the houses within the *Study Area* are greater than those predicted to have occurred for the houses at Tahmoor, Teralba, West Cliff and West Wallsend Collieries. It is expected, therefore, that the proportion of houses within the *Study Area* which experience impacts would be greater than those experienced at Tahmoor, Teralba, West Cliff and West Wallsend Collieries.

The higher proportion of impacts, however, would be expected to occur primarily at the lower end of the range, i.e. R0, R1 and R2, rather than at the higher end of the range, i.e. R3, R4 and R5. The reason for this is that experience suggests that, where the depth of cover is greater than 350 metres, such as the case within the *Study Area*, moderate and severe impacts are generally the result of non-conventional movements resulting from near-surface geological features. The potential for impacts resulting from non-conventional movements is dependent on the incidence of the geological features with the houses, rather than the magnitudes of the conventional subsidence movements.

As 79 % of the houses within the *Study Area* are predicted to experience curvatures similar to those experienced at Tahmoor Colliery and 92 % of houses within the *Study Area* are predicted to experience curvatures similar to those experienced at Teralba, West Cliff and West Wallsend Collieries, the observed levels of impact on the houses at these Collieries should provide a reasonable guide to the overall levels of impact on the houses within the *Study Area*.

The probabilities of impacts for each house within the *Study Area* have been assessed using the method developed as part of ACARP Research Project C12015, which is described in Appendix C. This method uses the primary parameters of ground curvature and type of construction. A summary of the predicted movements and the assessed impacts for each house within the *Study Area* is provided in Table D.01 in Appendix D. The overall distribution of the assessed impacts for the houses within the *Study Area* is provided in Table 5.28.

Table 5.28 Assessed Impacts for the Houses within the *Study Area*

Group	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
All houses (total of 245)	202 (82 %)	30 (12 %)	12 (5 %)	≈ 1 (< 0.5 %)

Trend analyses following the mining of Tahmoor Longwalls 22 to 24A indicate that the chance of impact is higher for the following houses:-

- Houses predicted to experience higher strains and curvatures,
- Houses with masonry walls,
- Masonry walled houses that are constructed on strip footings,
- Larger houses, and
- Houses with variable foundations, such as those with extensions added.

The primary risk associated with mining beneath houses is public safety. Residents have not been exposed to immediate and sudden safety hazards as a result of impacts that occur due to mine subsidence movements in the NSW Coalfields, where the depths of cover were greater than 350 metres, such as the case above the proposed longwalls. This includes the recent experience at Tahmoor Colliery, which has affected more than 1,000 houses, and the experiences at Teralba, West Cliff and West Wallsend Collieries, which have affected around 500 houses.

Emphasis is placed on the words “immediate and sudden” as in rare cases, some structures have experienced severe impacts, but the impacts did not present an immediate risk to public safety as they developed gradually with ample time to relocate residents.

All houses within the *Study Area* are expected to remain safe and repairable throughout the mining period, provided that they are in sound structural condition prior to mining. It should be noted, however, that the assessments indicate that the impact to approximately one house within the *Study Area* may be such that the cost of repair may exceeded the cost of replacement.

Potential Impacts Resulting from Downslope Movements

Longwall mining can result in downslope movements, in the locations where the natural surface grades are high, which can result in the increased potential for impacts on houses. The natural surface slopes at each house within the *Study Area* are provided in Table D.01 in Appendix D and is illustrated in Fig. 2.20.

It can be seen from this table and figure, that the natural surface slopes in the locations of the houses are generally less than 200 mm/m (i.e. 20 %), which represents a natural grade of 1 in 5. The maximum natural surface slope at the houses identified within the *Study Area* is 300 mm/m (i.e. 30 %), which represents a natural grade of 1 in 3.

As described in Section 2.4.9, natural slopes of less than 1 in 3 would not normally be considered steep. In many cases, natural slopes much greater than 1 in 3 would be considered stable. It is unlikely, therefore, that there would be any significant increase in the potential for impacts on the houses within the *Study Area* resulting from downslope movements.

The method of assessment for houses developed as part of ACARP Research Project C12015 included the experience of mining beneath houses having a similar range of natural surface slopes. The range of natural surface slopes within the *Study Area* is unlikely, therefore, to affect the probabilities of impact for the houses which have been obtained using this method.

5.31.3. Impact Assessments for the Houses Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum tilts would be less than 7 mm/m at 193 of the houses (i.e. 79 %) at the completion of mining. It would still be expected that only minor serviceability impacts would occur at these houses, as the result of tilt, which could be remediated using normal building techniques.

The maximum tilts would be between 7 mm/m and 10 mm/m at 25 houses (i.e. 10 %) and would be greater than 10 mm/m at 27 houses (i.e. 11 %) at the completion of mining. It would be expected that greater serviceability impacts would occur at these houses which would require more substantial remediation measures including, in some cases, relevelling of the building structures.

It is expected that, in all cases, the houses within the *Study Area* would remain in safe conditions as the result of the mining induced tilts.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, 128 of the 245 houses within the *Study Area* (i.e. 52 %) would be expected to experience hogging curvatures no greater than 0.10 km^{-1} and experience sagging curvatures no greater than 0.15 km^{-1}. The range of curvatures at these houses, therefore, would still be similar to that predicted to have occurred for the houses above Tahmoor Longwalls 22 to 24A.

Similarly, 163 of the 245 houses within the *Study Area* (i.e. 67 %) would be expected to experience hogging curvatures no greater than 0.15 km^{-1} and experience sagging curvatures no greater than 0.25 km^{-1}. The range of predicted curvatures at these houses, therefore, would still be similar to that predicted to have occurred for the houses above Teralba Longwalls 9 and 10, West Cliff Longwalls 5A1 to 5A4 and West Wallsend Longwalls 1 to 10.

The increased curvatures and strains would result in a greater proportion of houses being impacted and greater levels of impact. Based on previous experience, it would still be expected that the houses would remain in safe conditions. The impacts would develop slowly, allowing preventive measures to be undertaken and, where required, relocation of residence if any structures were deemed to become unsafe.

5.31.4. Recommendations for the Houses

It is recommended that management strategies are developed as part of Property Subsidence Management Plans or the Extraction Plans, to manage the potential impacts on the residential and non-residential building structures. The management strategies should include the following where access is provided to the property:-

- Identification of structures and their forms of construction prior to mining,
- Identification by a suitably qualified building inspector of any structures or structural elements that may be potentially unstable prior to mining,
- Consideration of implementing any mitigation measures, where necessary to address specific identified risks to public safety,
- Consideration of undertaking detailed monitoring of ground movements at or around structures, where necessary to address specific identified risks to public safety,
- Periodic inspections of structures that are considered to be at higher risk. These may include:-
  - Structures in close proximity to steep slopes where recommended by a geotechnical or subsidence engineer,
  - Structures identified as being potentially unstable where recommended by a structural or subsidence engineer, and
  - Pool fences.
- Co-ordination and communication with landowners and the Mine Subsidence Board during mining.

It is recommended that the houses are visually monitored during the extraction of the proposed longwalls. With these strategies in place, it is expected that the houses would remain in safe conditions throughout the mining period.

5.32. Tanks

The locations of the water tanks within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for the tanks are provided in the following sections.

5.32.1. Predictions for the Tanks

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at points located around the perimeter of each tank, as well as at points located at a distance of 20 metres from the perimeter of each tank.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the tanks within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.29.

Table 5.29 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Tanks within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Tanks	2350	11	0.25	0.30

The subsidence and tilt provided in the above table are the maximum predicted values at the completion of the proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the tanks within the *Study Area*, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 5.18 and Fig. 5.19.

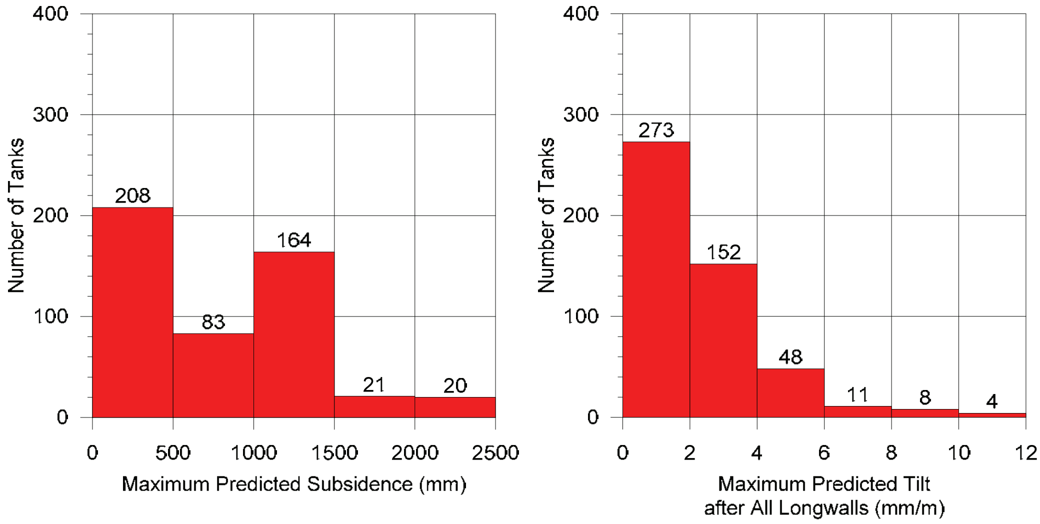

Fig. 5.18 Maximum Predicted Conventional Subsidence and Tilt for the Tanks within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

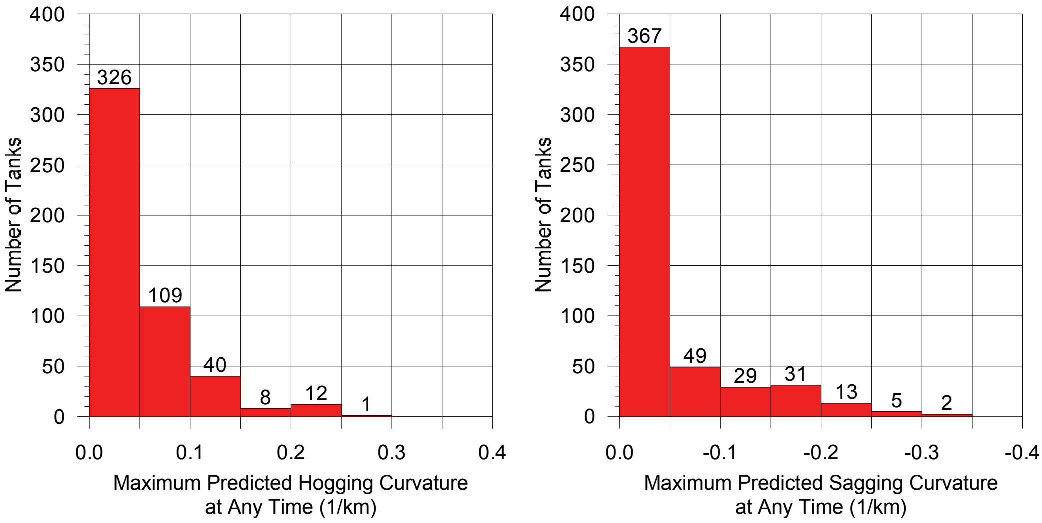

Fig. 5.19 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Tanks Resulting from the Extraction of the Proposed Longwalls

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual tanks would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the tanks across the *Study Area* would not be expected to change significantly.

The maximum predicted conventional strains for the tanks, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4 mm/m tensile and 4.5 mm/m compressive.

The tanks are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.32.2. Impact Assessments for the Tanks

Tilt can potentially affect the serviceability of tanks by altering the water levels in the tanks, which can in turn affect the minimum level of water which can be released from the outlets. The maximum predicted conventional tilt for the tanks within the *Study Area* is 11 mm/m (i.e. 1.1 %), which represents a change in grade of 1 in 90. The predicted changes in grade are small, in the order of 1 % and unlikely, therefore, to result in any significant impacts on the serviceability of the tanks.

The tanks structures are typically constructed above ground level and, therefore, are unlikely to experience the curvatures and ground strains resulting from the extraction of the proposed longwalls. It is possible, that any buried water pipelines associated with the tanks within the *Study Area* could be impacted by the ground strains, if they are anchored by the tanks, or by other structures in the ground.

Any impacts are expected to be of a minor nature, including leaking pipe joints, and could be easily repaired. With these remediation measures in place, it would be unlikely that there would be any significant impacts on the pipelines associated with the tanks.

5.32.3. Impact Assessments for the Tanks Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the incidences of serviceability impacts, such as changes in the minimum water levels which can be released from the outlets, would increase for the tanks which are located directly above the longwalls. Any such impacts would be expected to be easily remediated by relevelling the tanks.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, the incidence of impacts on the tank structures would not be expected to change significantly, as they are not expected to experience these ground movements. The incidence of impacts on the buried pipelines would, however, be expected to increase. Any impacts would still be expected to be of a minor nature which could be readily repaired. With these remediation measures in place, it would be unlikely that there would be any significant long term impacts on the pipelines associated with the tanks.

5.32.4. Recommendations for the Tanks

The assessed impacts on the tanks and associated infrastructure resulting from the extraction of the proposed longwalls are not significant. It is recommended that the tanks are visually monitored during the mining period.

5.33. Gas and Fuel Storages

There are domestic gas and fuel storages on the rural properties across the *Study Area* which are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4.

The storage tanks are generally elevated above ground level and, therefore, are not susceptible to mine subsidence movements. It is unlikely that there would be any significant impacts on the gas and fuel storage tanks themselves, even if the predictions were increased by factors of up to 2 times.

It is possible, however, that any buried gas pipelines associated with the storage tanks within the *Study Area* could be impacted by the ground strains, if they are anchored by the storage tanks, or by other structures in the ground. Any impacts are expected to be of a minor nature, including minor gas leaks, which could be readily repaired.

5.34. Swimming Pools

The locations of the swimming pools within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for the pools are provided in the following sections.

5.34.1. Predictions for the Swimming Pools

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at points located around the perimeter of each pool, as well as at points located at a distance of 20 metres from the perimeter of each pool.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the pools within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.30.

Table 5.30 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Pools within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Pools	2350	11	0.25	0.30

The subsidence and tilt provided in the above table are the maximum predicted values at the completion of the proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the pools within the *Study Area*, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 5.20 and Fig. 5.21.

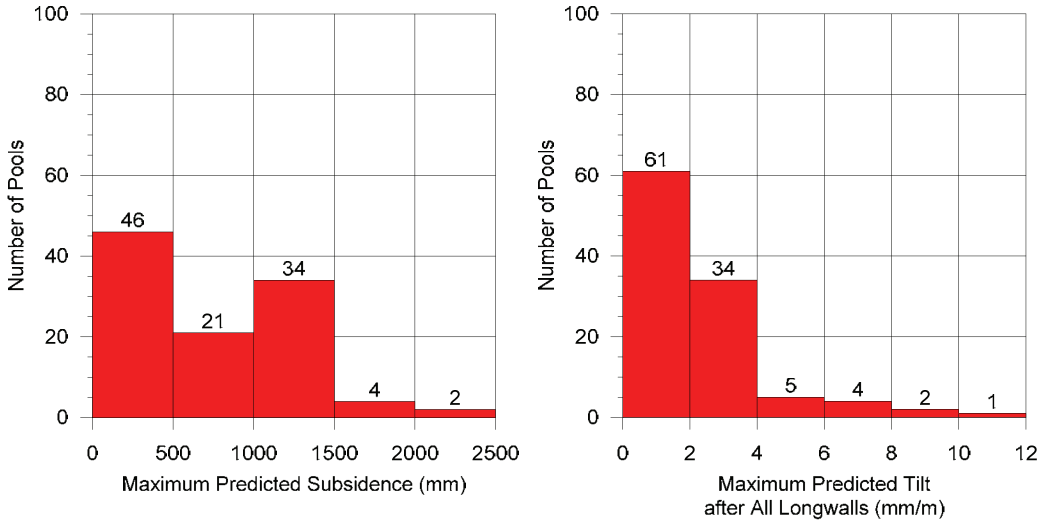

Fig. 5.20 Maximum Predicted Conventional Subsidence and Tilt for the Pools within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

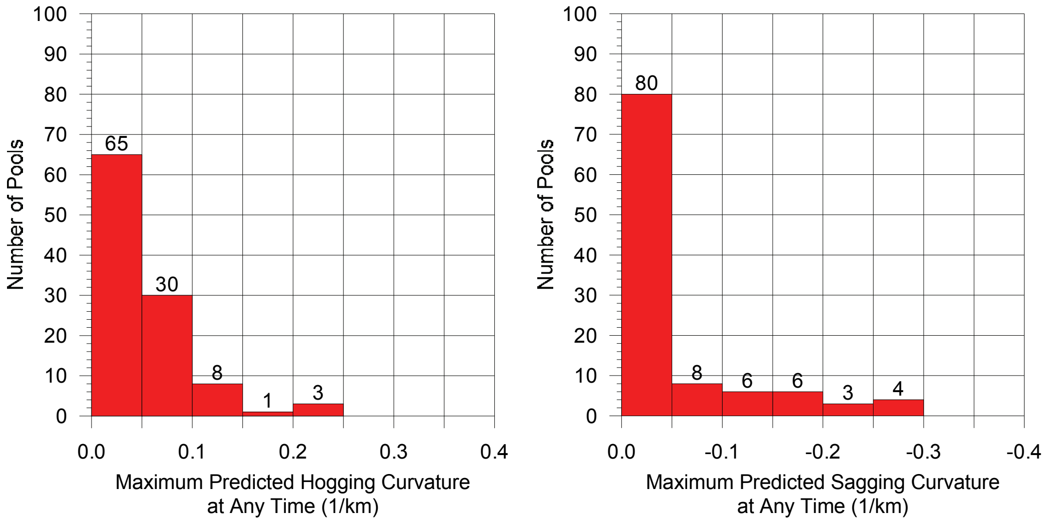

Fig. 5.21 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Pools Resulting from the Extraction of the Proposed Longwalls

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual pools would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the pools across the *Study Area* would not be expected to change significantly.

The maximum predicted conventional strains for the pools, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 4 mm/m tensile and 4.5 mm/m compressive.

The pools are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.34.2. Impact Assessments for the Swimming Pools

Mining-induced tilts are more noticeable in pools than other structures due to the presence of the water line and the small gap to the edge coping, particularly when the pool lining has been tiled. Skimmer boxes are also susceptible of being lifted above the water line due to mining tilt.

The Australian Standard AS2783-1992 (Use of reinforced concrete for small swimming pools) requires that pools be constructed level ± 15 mm from one end to the other. This represents a tilt of approximately 3.3 mm/m for pools that are 10 metres in length. Australian Standard AS/NZS 1839:1994 (Swimming pools – Pre-moulded fibre-reinforced plastics – Installation) also requires that pools be constructed with a tilt of 3 mm/m or less.

At the completion of the proposed longwalls, 82 of the 107 pools within the *Study Area* (i.e. 76 %) are predicted to experience final tilts of less than 3 mm/m, which is similar to or less than the Australian Standard. For the remaining pools within the *Study Area*, the predicted maximum final tilts are between 3 mm/m and 7 mm/m at 21 pools (i.e. 20 %), between 7 mm/m and 10 mm/m at 3 pools (i.e. 3 %), and greater than 10 mm/m at one pool (i.e. 1 %) at the completion of mining. The 25 pools which are predicted to experience final tilts greater than 3 mm/m, at the completion of the proposed longwalls, which may require some remediation of the pool copings.

At the completion of the proposed longwalls, 87 of the 107 pools within the *Study Area* (i.e. 81 %) are predicted to experience hogging curvatures no greater than 0.10 km^{-1} and experience sagging curvatures no greater than 0.15 km^{-1}. The range of predicted curvatures at these pools, therefore, is similar to that predicted to have occurred for the houses and, hence, the pools above Tahmoor Longwalls 22 to 24A, which is illustrated in Fig. 5.16.

Observations during the mining of Tahmoor Colliery Longwalls 22 to 25 have shown that pools, particularly in-ground pools, are more susceptible to severe impacts than houses and other structures. Pools cannot be easily repaired and most of the impacted pools need to be replaced in order to restore them to pre-mining condition or better.

As of February 2011, a total of 130 pools have experienced mine subsidence movements during the mining of Tahmoor Colliery Longwalls 22 to 25, of which 118 were located directly above the extracted longwalls. A total of 18 pools have reported impacts, all of which were located directly above the extracted longwalls. This represents an impact rate of approximately 15 %. A higher proportion of impacts have been observed for in-ground pools, particularly fibreglass pools. The majority of the impacts related to tilt or cracking, though in a small number of cases the impacts were limited to damage to skimmer boxes or the edge coping.

The maximum predicted subsidence parameters for the pools within the *Study Area* are greater than the maxima predicted at Tahmoor Colliery. The incidence and levels of impacts on the pools in the *Study Area*, therefore, are expected to be greater than those experienced at Tahmoor Colliery. As 81 % of the pools within the *Study Area* are predicted to experience curvatures similar to the pools at Tahmoor Colliery, the observed levels of impact on the pools at Tahmoor should provide a reasonable guide to the potential levels of impact on the pools within the *Study Area*.

5.34.3. Impact Assessments for the Swimming Pools Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, 44 of the 107 pools within the *Study Area* (i.e. 41 %) would still be predicted to experience tilts of less than 3 mm/m, at the completion of the proposed longwalls, which is similar to or less than the Australian Standard. The remaining 63 pools within the *Study Area* (i.e. 59 %) would experience tilts greater than 3 mm/m, at the completion of the proposed longwalls, and may require some remediation of the pool copings.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, 59 of the 107 pools within the *Study Area* (i.e. 55 %) would experience hogging curvatures no greater than 0.10 km^{-1} and experience sagging curvatures no greater than 0.15 km^{-1}. The range of curvatures at these pools, therefore, would still be similar to that predicted to have occurred for the pools above Tahmoor Longwalls 22 to 24A. The remaining pools would be predicted to experience hogging curvatures greater than those predicted to have occurred for the pools at Tahmoor.

The increased curvatures would result in a greater proportion of pools being impacted and greater levels of impact when compared to the previous experience at Tahmoor Colliery.

5.34.4. Recommendations for the Swimming Pools

While not strictly related to the pool structure, a number of pool gates have been impacted as the result of the previous extraction of longwalls beneath pools. While the gates can be easily repaired, the consequence of breaching pool fence integrity is considered to be severe. As a result, it is recommended that regular inspections of the integrity of pool fences during the active subsidence period be included in the development of any Management Plan for properties that have pools or are planning to construct a pool during the mining period.

5.35. Tennis Courts

The locations of the tennis courts within the *Study Area* are shown in Drawing No. MSEC515-19. The predictions and impact assessments for the tennis courts are provided in the following sections.

5.35.1. Predictions for the Tennis Courts

Predictions of conventional subsidence, tilt and curvature have been made at the centroid and at points located around the perimeter of each tennis court, as well as at points located at a distance of 20 metres from the perimeter of each tennis court.

A summary of the maximum predicted values of conventional subsidence, tilt and curvatures for the tennis courts within the *Study Area*, resulting from the extraction of the proposed longwalls, is provided in Table 5.31.

Table 5.31 Maximum Predicted Conventional Subsidence, Tilt and Curvatures for the Tennis Courts within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

Location	Maximum Predicted Conventional Subsidence (mm)	Maximum Predicted Conventional Tilt (mm/m)	Maximum Predicted Conventional Hogging Curvature (km^{-1})	Maximum Predicted Conventional Sagging Curvature (km^{-1})
Tennis Courts	1800	9	0.15	0.20

The subsidence and tilt provided in the above table are the maximum predicted values at the completion of the proposed longwalls. The curvatures provided in the above table are the maximum predicted values which occur at any time during or after the extraction of the proposed longwalls.

The distributions of the maximum predicted conventional subsidence, tilt and curvature for the pools within the *Study Area*, resulting from the extraction of the proposed longwalls, are illustrated in Fig. 5.22 and Fig. 5.23.

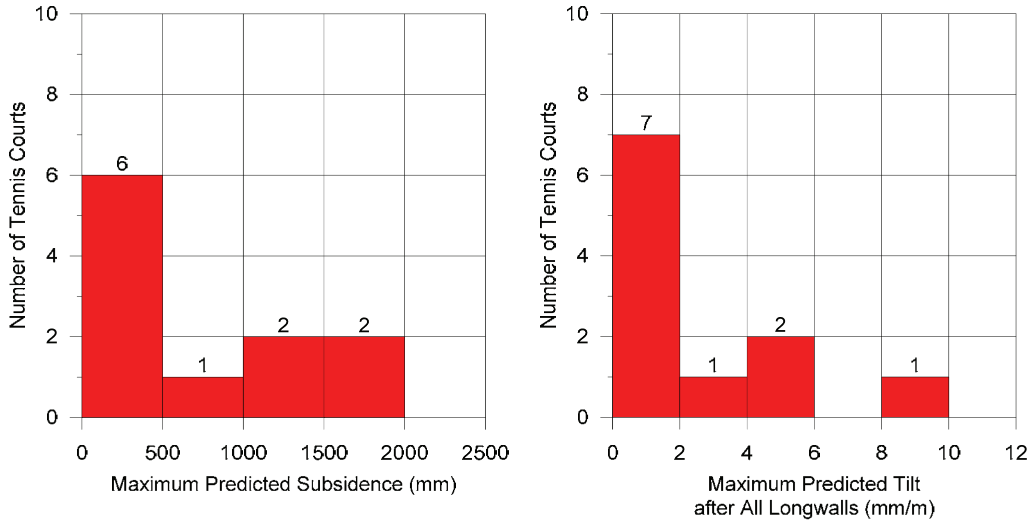

Fig. 5.22 Maximum Predicted Conventional Subsidence and Tilt for the Tennis Courts within the *Study Area* Resulting from the Extraction of the Proposed Longwalls

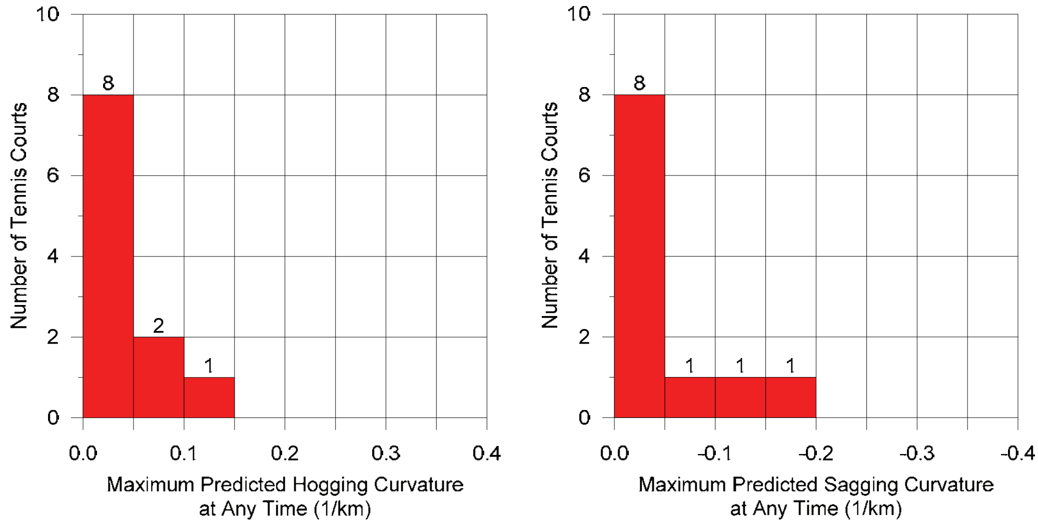

Fig. 5.23 Maximum Predicted Conventional Hogging Curvature (Left) and Sagging Curvature (Right) for the Tennis Courts Resulting from the Extraction of the Proposed Longwalls

If the longwalls were to be shifted or reoriented within the extent of the *Extraction Area*, the individual tennis courts would be predicted to experience greater or lesser movements, depending on their locations relative to the longwalls, but the overall levels of movement for the tennis courts across the *Study Area* would not be expected to change significantly.

The maximum predicted conventional strains for the tennis courts, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 2.5 mm/m tensile and 3 mm/m compressive.

The tennis courts are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

5.35.2. Impact Assessments for the Tennis Courts

The maximum predicted tilt for the tennis courts, resulting from the extraction of the proposed longwalls, is 9 mm/m (i.e. 0.9 %), which represents a change in grade of 1 in 110. The predicted tilts are small, less than 1 % and unlikely, therefore, to result in any significant impacts on the serviceability of the tennis courts.

The maximum predicted curvatures for the tennis courts, resulting from the extraction of the proposed longwalls, are 0.15 km^{-1} hogging and 0.20 km^{-1} sagging, which represent minimum radii of curvature of 7 kilometres and 5 kilometres, respectively. The maximum predicted ground curvatures are similar to or slightly greater than those typically experienced in the Southern Coalfield.

It is possible that the maximum predicted curvatures and ground strains could result in minor cracking in the tennis courts with grass or clay surfaces, however, any cracking would be expected to be minor and readily repairable. It is expected, that the predicted ground strains would arch around the concrete tennis courts and would not be fully transferred into the pavements. It is possible, that some minor surface cracking could occur in the concrete surfaces, but any cracking would be expected to be of a minor nature and readily repairable.

5.35.3. Impact Assessments for the Tennis Courts Based on Increased Predictions

If the actual tilts exceeded those predicted by a factor of 2 times, the maximum change in grade at the tennis courts would be 18 mm/m (i.e. 1.8 %), which is still reasonably small and unlikely to result any significant impacts on the serviceability of the tennis courts.

If the actual curvatures and strains exceeded those predicted by a factor of 2 times, 8 of the 11 tennis courts within the *Study Area* (i.e. 73 %) would experience hogging curvatures no greater than 0.15 km^{-1} and experience sagging curvatures no greater than 0.20 km^{-1}. The maximum ground curvatures for these tennis courts, therefore, would still be similar to or slightly greater than those typically experienced in the Southern Coalfield. The increased curvatures would result in a greater incidence of cracking in the tennis court surfaces. Any impacts would still be expected to be of a minor natural which could be readily repaired

5.35.4. Recommendations for the Tennis Courts

It is recommended that periodic visual inspections of the tennis courts are undertaken during the active subsidence period.

5.36. On-Site Waste Water Systems

The residences on the rural properties within the *Study Area* have on-site waste water systems.

The on-site waste systems are located across the *Study Area* and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the *Study Area* is provided in Chapter 4.

The on-site waste systems are at discrete locations and, therefore, the most relevant distributions of strain are the maximum strains measured in individual survey bays from previous longwall mining. The analysis of strains measured in survey bays during the mining of previous longwalls in the Newcastle Coalfield is discussed in Section 4.3.1. The results for survey bays above goaf are provided in Fig. 4.1 and Table 4.3. The results for survey bays above solid coal are provided in Fig. 4.2 and Table 4.4.

Non-conventional movements can also occur and have occurred in the NSW Coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The maximum predicted change in grade for the on-site waste water systems within the *Study Area* are in the order of 1 % to 2 %. It is unlikely, therefore, that the maximum predicted tilts would result in any significant impacts on the tank systems. The maximum predicted conventional tilts could, however, be of sufficient magnitude to affect the serviceability of the buried pipes between the houses and the on-site waste water systems, if the existing grades of these pipes are very small, say less than 1 %.

The on-site waste water system tanks are generally small, typically less than 3 metres in diameter, are constructed from reinforced concrete, and are usually bedded in sand and backfilled. It is unlikely, therefore, that the maximum predicted curvatures and ground strains would be fully transferred into the tank structures.

It is possible, however, that the buried pipelines associated with the on-site waste water tanks could be impacted by the ground strains if they are anchored by the tanks or other structures in the ground. Any impacts are expected to be of a minor nature, including leaking pipe joints, and could be readily repaired. With the implementation of these remediation measures, it would be unlikely that there would be any significant impacts on the pipelines associated with the on-site waste water systems, even if the predictions were increased by a factor of 2 times.

5.37. Rigid External Pavements

Adverse impacts on rigid external pavements are often reported to the Mine Subsidence Board in the NSW Coalfields. This is because pavements are typically thin relative to their length and width. The design of external pavements is also not regulated by Council or the Mine Subsidence Board.

A study by MSEC of 120 properties at Tahmoor and Thirlmere indicated that 98 % of the properties with external concrete pavements demonstrated some form of cracking prior to mining. These cracks are sometimes difficult to distinguish from cracks caused by mine subsidence. It is therefore uncertain how many claims for damage can be genuinely attributed to mine subsidence impacts.

Residential concrete pavements are typically constructed with tooled joints which do not have the capacity to absorb compressive movements. It is possible that some of the smaller concrete footpaths or pavements within the *Study Area*, in the locations of the larger compressive ground strains, could buckle upwards if there are insufficient movement joints in the pavements. It is expected, however, that the buckling of footpaths and pavements would not be common, given the magnitudes of the predicted ground strains, and could be easily repaired.

5.38. Fences

The predictions and impact assessments for fences are provided in Section 5.25.

APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

Glossary of Terms and Definitions

Some of the more common mining terms used in the report are defined below:-

Angle of draw	The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence).
Chain pillar	A block of coal left unmined between the longwall extraction panels.
Cover depth (H)	The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel.
Closure	The reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining induced movements, valley closure movements, far-field effects, downhill soil slumping and other possible strata mechanisms.
Critical area	The area of extraction at which the maximum possible subsidence of one point on the surface occurs.
Curvature	The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km-1)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*. Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave).
Extracted seam	The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel.
Effective extracted seam thickness (T)	The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel.
Face length	The width of the coalface measured across the longwall panel.
Far-field movements	The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain.
Goaf	The void created by the extraction of the coal into which the immediate roof layers collapse.
Goaf end factor	A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel.
Horizontal displacement	The horizontal movement of a point on the surface of the ground as it settles above an extracted panel.
Inflection point	The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max.
Incremental subsidence	The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel.
Panel	The plan area of coal extraction.
Panel length (L)	The longitudinal distance along a panel measured in the direction of (mining from the commencing rib to the finishing rib.
Panel width (Wv)	The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side.
Panel centre line	An imaginary line drawn down the middle of the panel.
Pillar	A block of coal left unmined.

Pillar width (Wpi)	The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib.
Shear deformations	The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index.
Strain	The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation. **Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines.
Sub-critical area	An area of panel smaller than the critical area.
Subsidence	The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured.
Subsidence Effects	The deformations of the ground mass surrounding a mine, sometimes referred to as 'components' or 'parameters' of mine subsidence induced ground movements including; vertical and horizontal displacements, tilts, curvatures, strains, upsidence and closure
Subsidence Impacts	The physical changes or damage to the fabric or structure of the ground, its surface and natural features, or man-made structures that are caused by the subsidence effects. These impacts considerations can include; tensile and shear cracking of the rock mass, localised buckling of strata bed separation, rock falls, collapse of overhangs, failure of pillars, failure of pillar floors, dilation, slumping and also include subsidence depressions or troughs.
Subsidence Consequences	The knock-on results of subsidence impacts, i.e. any change in the amenity or function of a natural feature or man-made structure that arises from subsidence impacts. Consequence considerations include; public safety, loss of flows, reduction in water quality, damage to artwork, flooding, draining of aquifers, the environment, community, land use, loss of profits, surface improvements and infrastructure. Consequences related to natural features are referred to as environmental consequences.
Super-critical area	An area of panel greater than the critical area.
Tilt	The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
Uplift	An increase in the level of a point relative to its original position.
Upsidence	Upsidence results from the dilation or buckling of near surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of millimetres (mm), is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.

APPENDIX B. REFERENCES

References

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APPENDIX C. METHOD OF IMPACT ASSESSMENTS FOR HOUSES

APPENDIX C METHOD OF IMPACT ASSESSMENT FOR HOUSES

C.1. Introduction

The methods for predicting and assessing impacts on building structures have developed over time as knowledge and experience has grown. MSEC has provided predictions and impact assessments for the building structures within the *Study Area* using the latest methods available at this time.

Longwall mining has occurred directly beneath building structures at a number of Collieries in the Southern Coalfield, including Appin, West Cliff, Tower and Tahmoor Collieries. The most extensive data has come from extraction of Tahmoor Colliery Longwalls 22 to 24A, where more than 1,000 residential and significant civil structures have experienced subsidence movements. The experiences gained during the mining of these longwalls, as well as longwalls at other Collieries in the Southern and Newcastle Coalfields, have provided substantial additional information that has been used to further develop the methods.

The information collected during the mining of Tahmoor Colliery Longwalls 22 to 24A has been reviewed in two parallel studies, one as part of a funded ACARP Research Project C12015, and the other at the request of the then Department of Industry and Investment NSW (I&I).

The outcomes of these studies include:-

- Review of the performance of the previous method,
- Recommendations for improving the method of Impact Classification, and
- Recommendations for improving the method of Impact Assessment.

A summary is provided in the following sections.

C.2. Review of the Performance of the Previous Method

The most extensive data on house impacts has come from extraction of Tahmoor Colliery Longwalls 22 to 25 and a comparison between predicted and observed impacts is provided in Table C.1. The comparison is based on pre-mining predictions that were provided in SMP Applications for these longwalls and the observations of impacts using the previous method of impact classification. The comparison is based on information up to 30th November 2008. At this point in time, the length of extraction of Longwall 25 was 611 metres.

A total of 1,037 houses and civil structures were affected by subsidence due to the mining of Tahmoor Colliery Longwalls 22 to 25 at this time. A total of 175 claims have been received by the Mine Subsidence Board (not including claims that have been refused) of which 14 claims do not relate to the main residence or civil structure.

Table C.1 Summary of Comparison between Observed and Predicted Impacts for each Structure

Strain Impact Category	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 0	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 1	Total No. of Observed Impacts for Structures predicted to be Strain Impact Category 2	Total
No impact	483	373	20	876
Cat 0	31	70	6	107
Cat 1	8	9	1	18
Cat 2	7	11	2	20
Cat 3	2	2	0	4
Cat 4	3	5	0	8
Cat 5	3	1	0	4
Total	537	471	29	1037
% claim	**10 %**	**21 %**	**31 %**	16 %
% Obs > Pred	**4 %**	**4 %**	**0 %**	-
% Obs <= Pred	**96 %**	**96 %**	**100 %**	-

Note: Predicted impacts due to conventional subsidence only, as described in the SMP Application.

Given that observed impacts are less than or equal to predicted impacts in 96 % of cases, it is considered that the previous methods are generally conservative even though non-conventional movements were not taken into account in the predictions and assessments. However, when compared on a house by house basis, the predictions have been substantially exceeded in a small proportion of cases.

The majority, if not all, of the houses that have experienced Category 3, 4 or 5 impacts are considered to have experienced substantial non-conventional subsidence movements. The consideration is based on nearby ground survey results, where upsidence bumps are observed in subsidence profiles and high localised strain is observed. The potential for impact from non-conventional movements were discussed generally and not included in the specific impact assessments for each structure.

The inability to specify the number or probability of impacts due to the potential for non-conventional movements is a shortcoming of the previous method. It is considered that there is significant room for improvement in this area and recommendations are provided later in this report.

The comparison shows a favourable observation that the overall proportion of claims increased for increasing predicted impact categories. This suggests that the main parameters currently used to make impact assessments (namely predicted conventional curvature and maximum plan dimension of each structure) are credible. Please note that we have stated predicted conventional curvature rather than strain, as predictions of strain were directly based on predictions of conventional curvature.

A significant over-prediction is observed at the low end of the spectrum of impacts (Category 0 and 1). A number of causes and/or possible causes for the deviations have been identified:

- Construction methods and standards may mitigate against small differential ground movements.
- The impacts may have occurred but the residents have not made a claim for the following reasons:-
  - All structures contain some existing, pre-mining defects. A pre-mining field investigation of 119 structures showed that it is very rare for all elements of a building to be free of cracks. Cracks up to 3 mm in width are commonly found in buildings. Cracks up to 1 mm in width are very common. There is a higher incidence of cracking in brittle forms of construction such as masonry walls and tiled surfaces.
  - In light of the above, additional very slight Category 0 and 1 impacts may not have been noticed by residents. A forensic investigation of all structures before or after mining may reveal that the number of actual impacts is greater than currently known.
  - Similarly, impacts have been noticed but some residents may consider them to be too trivial to make a claim. While difficult to prove statistically, it is considered that the frequency of claims from tenanted properties is less than the frequency of claims from owner-occupied properties.
- The impacts have been noticed but some residents are yet to make a claim at this stage. It has been observed that there is a noticeable time lag between the moment of impact and the moment of making a claim. More claims are therefore expected to be received in the future within areas that have already been directly mined beneath.
- The predictive method is deliberately conservative in a number of ways.
  - Predicted subsidence movements for each structure are based on the maximum predicted subsidence movements within 20 metres of the structure.
  - An additional 0.2 mm/m of strain was added
  - Maximum strains were applied to the maximum plan dimension, regardless of the maximum predicted strain orientation.
  - The method of impact assessment does not provide for “nil impacts”. The minimum assessed level of impact is Category 0.
  - The impact data was based on double-storey full masonry structures in the UK.

Finally, it is considered that the previous method impact classification has masked the true nature and extent of impacts. It is recommended that an improved method of classification be adopted before embarking on any further analysis. This is discussed in the next chapter of this report.

C.3. Method of Impact Classification

C.3.1. Previous Method

The impacts to structures were previously classified in accordance with Table C1 of Australian Standard 2870-1996, but the Table has been extended by the addition of Category 5 and is reproduced below.

Table C.2 Classification of Damage with Reference to Strain

Impact Category	Description of typical damage to walls and required repair	Approximate crack width limit
0	Hairline cracks.	< 0.1 mm
1	Fine cracks which do not need repair.	0.1 mm to 1.0 mm
2	Cracks noticeable but easily filled. Doors and windows stick slightly	1 mm to 5 mm
3	Cracks can be repaired and possibly a small amount of wall will need to be replaced. Doors and windows stick. Service pipes can fracture. Weather-tightness often impaired	5 mm to 15 mm, or a number of cracks 3 mm to 5 mm in one group
4	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Window or door frames distort. Walls lean or bulge noticeably. Some loss of bearing in beams. Service pipes disrupted.	15 mm to 25 mm but also depends on number of cracks
5	As above but worse, and requiring partial or complete rebuilding. Roof and floor beams lose bearing and need shoring up. Windows broken with distortion. If compressive damage, severe buckling and bulging of the roof and walls.	> 25 mm

Note 1 of Table C1 states that *"Crack width is the main factor by which damage to walls is categorized. The width may be supplemented by other factors, including serviceability, in assessing category of damage.*

Impacts relating to tilt were classified according to matching impacts with the description in Table C.3, not the observed actual tilt. This is because many houses that have experience tilts greater than 5 mm have not made a claim to the MSB.

Table C.3 Classification of Damage with Reference to Tilt

Impact Category	Tilt (mm/m)	Description
A	< 5	Unlikely that remedial work will be required.
B	5 to 7	Adjustment to roof drainage and wet area floors might be required.
C	7 to 10	Minor structural work might be required to rectify tilt. Adjustments to roof drainage and wet area floors will probably be required and remedial work to surface water drainage and sewerage systems might be necessary.
D	> 10	Considerable structural work might be required to rectify tilt. Jacking to level or rebuilding could be necessary in the worst cases. Remedial work to surface water drainage and sewerage systems might be necessary.

C.3.2. Need for Improvement to the Previous Method of Impact Classification

It is very difficult to design a method of impact classification that covers all possible scenarios and permutations. The application of any method is likely to find some instances that do not quite fit within the classification criteria.

Exposure to a large number of affected structures has allowed the mining industry to appreciate where improvements can be made to all aspects including the identification of areas for improvement in the previous method of impact classification.

A number of difficulties have been experienced with the previous method during the mining period. The difficulty centres on the use of crack width as the main classifying factor, as specified in Table C1 of Australian Standard 2870-1996.

A benefit of using crack width as the main factor is that it provides a clear objective measure by which to classify impact. However, experience has shown that crack width is a poor measure of the overall impact and extent of repair to a structure. The previous method of impact classification may be useful for assessing impact to newly built structures in a non-subsidence environment but further improvement and clarification is recommended before it can be effectively applied to houses impacted by mine subsidence.

The following aspects highlight areas where the previous classification system could be improved.-

- *Slippage on Damp Proof Course*

  Approximately 30 houses have experienced slippage along the damp proof course in Tahmoor. Slippage on some houses is relatively small (less than 10 mm) though substantial slippage has been observed in a number of cases, such as shown in Fig. C.1 below.

Fig. C.1 Example of slippage on damp proof course

  Under the previous classification method, the “crack” width of the slippage may be very small (Category 1) but the distortion in the brickwork is substantial. Moreover, the extent of work required to repair the impact is substantial as it usually involves re-lining the whole external skin of the structure. Such impacts would be considered Category 4 based on extent of repair but only Category 1 or 2 based on maximum crack width.

  There is no reference to slippage of damp proof course in the previous method of impact classification. However, if the extent of repair was used instead of using crack width as the main factor, the impact category would be properly classified as either Category 4 or Category 5.

  It was recommended that slippage of damp proof courses be added to the previous impact classification table.

- *Cracks to brickwork*

  In some cases, cracks are observed in mortar only. For example, movement joints in some structures have been improperly filled with mortar instead of a flexible sealant, as shown in Fig. C.2. In these situations, the measured crack width may be significant but the impact is relatively simple to repair regardless of the crack width.

Fig. C.2 Example of crack in mortar only

In other cases, a small number of isolated bricks have been observed to crack or become loose. This is usually straightforward to repair. Under the previous impact classification method, a completely loose brick could be strictly classified as Category 5 as the crack width is infinitely large. This is clearly not the intention of the previous method but clarification is recommended to avoid confusion.

If a panel of brickwork is cracked, the method of repair is the same regardless of the width. While it is considered reasonable to classify large and severe cracks by its width, it is recommended that cracks less than 5 mm in width be treated the same rather than spread across Categories 0, 1 and 2.

If a brick lined structure contains many cracks of width less than 3 mm, the impact would be classified as no more than Category 2 under the previous method of impact classification. The extent of repair may be substantially more than a house that has experienced only one single 5 mm crack. However, it is recognised that it is very difficult to develop a simple method of classifying impacts based on multiple cracks in wall panels. How many cracks are needed to justify an increase in impact category?

- *Structures without masonry walls*

  Timber framed structures with lightweight external linings such weatherboard panels and fibro sheeting are not referenced in the previous classification table. If crack widths were strictly adopted to classify impacts, it may be possible to classify movement in external wall linings beyond Category 3 when in reality the repairs are usually minor.

  It was recommended that the impact classification table be extended to include structures with other types of external linings.

- *Minor impacts such as door swings*

  Experience has shown that one of the earliest signs of impact is the report of a sticking door. In some instances, the only observed impact is one or two sticking doors. It takes less than half an hour to repair a sticking door and impact is considered negligible.

  Such an impact would be rightly classified as Category 0 based on the previous method of impact classification as there is no observed crack. However, the previous classification table suggests that sticking doors and windows occur when Category 2 crack widths develop. It was recommended that the impact classification table be amended in this respect.

C.3.3. Broad Recommendations for Improvement of Previous Method of Impact Classification

It was recommended that crack width no longer be used as the main factor for classifying impacts. This does not mean that the use of crack width should be abandoned altogether. Crack width remains a good indicator of the severity of impacts and should be used to assist classification, particularly for impacts that are moderate or greater.

By focussing on crack width, the previous impact classification table appears to be classifying impacts from a structural stability perspective. It was recommended that a revised impact classification table be more closely aligned with all aspects of a building, including its finishes and services. Residents who are affected by impacts are concerned as much about impacts to internal linings, finishes and services as they are about cracks to their external walls and a revised impact classification method should reflect this.

With crack width no longer used as the main factor, it was recommended that the wording of the descriptions of impact in the classification table be extended to cover impacts to more elements of buildings. In keeping with the previous method of assessment, the level of impact should distinguish between cosmetic, serviceability and stability related impacts:-

- Low impact levels should relate to cosmetic impacts that do affect the structural integrity of the building and are relatively straight-forward to repair,
- Mid-level impact categories should relate to impacts to serviceability and minor structural issues, and
- High level impacts should be reserved for structural stability issues and impacts requiring extensive repairs.

C.3.4. Revised Method of Impact Classification

The following revised method of impact classification has been developed.

Table C.4 Revised Classification based on the Extent of Repairs

Repair Category	Extent of Repairs
Nil	No repairs required
R0 **Adjustment**	One or more of the following, where the damage does not require the removal or replacement of any external or internal claddings or linings:- - **Door** or **window** jams or swings, or - Movement of **cornices**, or - Movement at external or internal **expansion joints**.
R1 **Very Minor Repair**	One or more of the following, where the damage can be repaired by filling, patching or painting without the removal or replacement of any external or internal brickwork, claddings or linings:- - Cracks in **brick mortar** only, or isolated cracked, broken, or loose **bricks** in the external façade, or - Cracks or movement < 5 mm in width in any external or internal wall **claddings**, **linings**, or **finish**, or - Isolated cracked, loose, or drummy floor or wall **tiles**, or - Minor repairs to any **services** or **gutters**.
R2 **Minor Repair**	One or more of the following, where the damage affects a small proportion of external or internal claddings or linings, but does not affect the integrity of external brickwork or structural elements:- - Continuous cracking in **bricks** < 5 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 2 to 5 mm anywhere in the total external façade, or - Cracks or movement ≥ 5 mm in width in any external or internal wall **claddings**, **linings**, **finish**, or - Several cracked, loose or drummy floor or wall **tiles**, or - Replacement of any **services**.
R3 **Substantial Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or affects the stability of isolated structural elements:- - Continuous cracking in **bricks** of 5 to 15 mm in width in one or more locations in the total external façade, or - Slippage along the **damp proof course** of 5 to 15 mm anywhere in the total external façade, or - Loss of bearing to isolated walls, piers, columns, or other load-bearing elements, or - Loss of stability of isolated structural elements.
R4 **Extensive Repair**	One or more of the following, where the damage requires the removal or replacement of a large proportion of external brickwork, or the replacement or repair of several structural elements:- - Continuous cracking in **bricks** > 15 mm in width in one or more locations in the total external façade, or - Slippage along the damp proof course of 15 mm or greater anywhere in the total external façade, or - Relevelling of building, or - Loss of stability of several structural elements.
R5 **Re-build**	Extensive damage to house where the MSB and the owner have agreed to rebuild as the cost of repair is greater than the cost of replacement.

As discussed at the start of this chapter, it is very difficult to design a method of impact classification that covers all possible scenarios and permutations. While the method has been floated among some members of the mining industry, it is recommended that this table be reviewed broadly.

The recommended method has attempted to follow the current Australian Standard in terms of the number of impact categories and crack widths for Categories 3 and 4. The method is based on the extent of repairs required to repair the physical damage that has occurred, and does not include additional work that is occasionally required because replacement finishes cannot match existing damaged ones. It is therefore likely that the actual cost of repairs will vary greatly between houses depending on the nature of the existing level and type of finishes used.

The impacts experienced at Tahmoor Colliery have been classified in accordance with the revised method of classification with good results. The method allowed clearer trends to be found when undertaking statistical analyses.

A comparison between the previous and revised methods is shown in Fig. C.3.

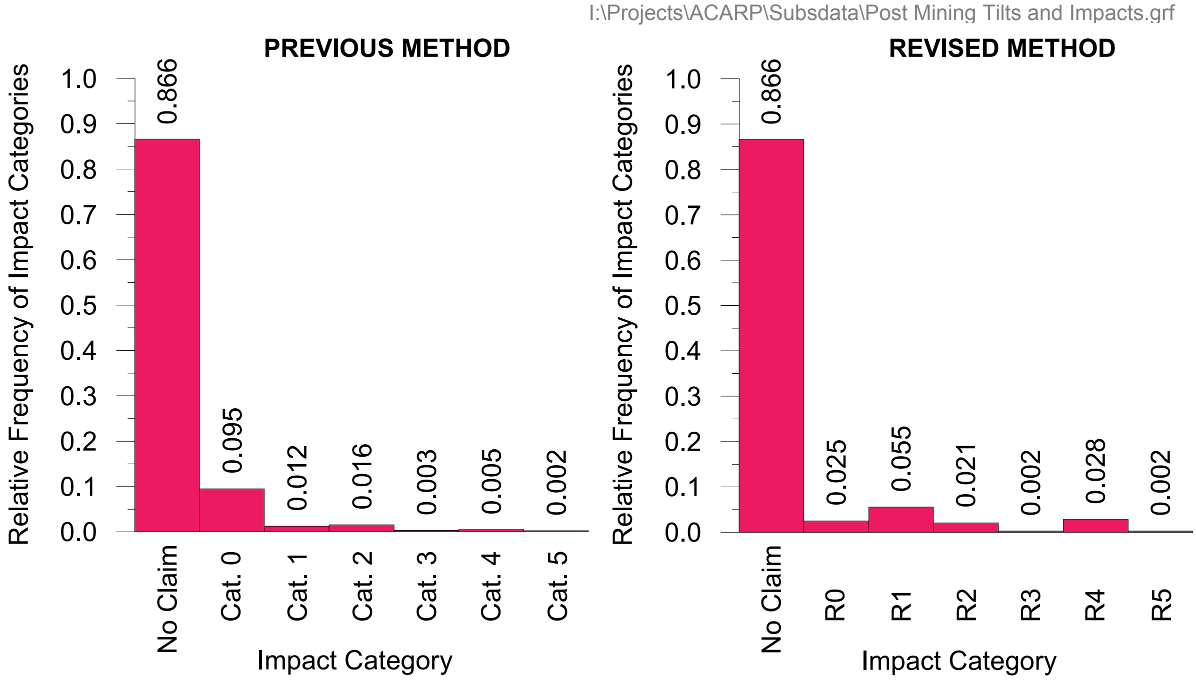


Fig. C.3 Comparison between Previous and Revised Methods of Impact Classification

It can be seen that there was an increased proportion in the higher impact categories using the revised method. This is brought about mainly by the recorded slippage on damp proof courses, which are classified as either Category 3 or Category 4 when they were previously classified as Category 1 or 2.

There was also a noticeable reduction in proportion of Category 0 impacts and noticeable increase in proportion of Category 1 impacts using the revised method. This is because the revised method reserves Category 0 impacts for impacts that did not result in cracking any linings, while the previous method allows hairline cracking to occur.

The consistent low proportion of Category 3 impacts under both the previous and current methods raises questions as to whether this category should be merged with Category 4.

C.4. Method of Impact Assessment

C.4.1. Need for Improvement of the Previous Method

The previous method of impact assessment provided specific quantitative predictions based on predicted conventional subsidence movements and general qualitative statements concerning the potential for impacts due to non-conventional movements. These non-conventional movements are additional to the predicted conventional movements.

This message was quite complex and created the potential for confusion and misunderstanding among members of the community who may easily focus on numbers and letters in a table that deal specifically with their house and misunderstand the message contained in the accompanying words of caution about the low level of reliability concerning predictions of conventional strain and potential for non-conventional movements.

This was unfortunately a necessary shortcoming of the previous method at the time as there was very little statistical information available to quantify the potential for impacts due to non-conventional movement. However, a great deal of statistical information is now available following the mining of Tahmoor Colliery Longwalls 22 to 24A and the method and message to the community can be improved.

While additional statistical information is now available, there remains limited knowledge at this point in time to accurately predict the locations of non-conventional movement. Substantial gains are still to be made in this area.

In the meantime, therefore, a probabilistic method of impact assessment has been developed. The method combines the potential for impacts from both conventional and non-conventional subsidence movement.

C.4.2. Factors that Could be Used to Develop a Probabilistic Method of Prediction

Trend analyses have highlighted a number of factors that could be used to develop a probabilistic method. The trends examined were:-

- *Ground tilt*

  This was found to be an ineffective parameter at Tahmoor Colliery as ground tilts have been relatively benign and a low number of claims have been made in relation to tilt.

- *Ground strain*

  There appears to be a clear link between ground strain and impacts, particularly compressive strain. The difficulty with adopting ground strain as a predictive factor lies in the ability to accurately predict ground strain at a point.

  Another challenge with using strain to develop a probabilistic method is that there is limited information that links maximum observed strains with observed impacts at a structure. Horizontal strain is a two-dimensional parameter and it has been measured along survey lines that are oriented in one direction only.

  The above issues are less problematic for curvature and the statistical analysis on the relationship between strain and curvature shows that the observed frequency of high strains increased with increasing observed curvature.

- *Ground curvature*

  Curvature appears to be the most effective subsidence parameter to develop a probabilistic method. The trend analysis showed that the frequency of impacts increased with increasing observed curvature.

  It should be noted that we are referring to conventional curvature and not curvatures that have developed as a result of non-conventional subsidence behaviour. This is because conventional curvature can be readily predicted with reasonable correlation with observations. It is also a relatively straight-forward exercise to estimate the observed smoothed or “conventional” curvature provided some ground monitoring is undertaken across and along extracted longwalls.

  Non-conventional curvature cannot be predicted prior to mining and is accounted for by using a probabilistic method of impact assessment.

  It has also been shown that the observed frequency of high strains increased with increasing observed curvature.

- *Position of structure relative to longwall*

  A clear trend was understandably found that structures located directly above goaf were substantially more likely to experience impact. The calculated probabilities may be applicable for mining conditions that are similar to those experienced at Tahmoor Colliery but will be less applicable for other mining conditions. An effective probabilistic method should create a link between the magnitude of differential subsidence movements and impact.

- *Construction type*

  Two trends have been observed. Not surprisingly, structures constructed with lightweight flexible external linings are able to accommodate a far greater range of subsidence movements than brittle inflexible linings such as masonry. The analyses merely quantified what was already well known. The second observation was that houses constructed with strip footings were noticeably more likely to experience impacts than houses constructed with a ground slab, particularly in relation to higher levels of impact. This is because houses with strip footings are more susceptible to slippage along the damp proof course.

- *Structure size*

  Trend analysis showed that larger structures attract a higher likelihood of impact. This is understandable as the chance of impacts increases with increasing footprint area. However, it is noted that the probability of severe impacts was not substantially greater for larger structures even though this would be expected if considering probabilities theoretically rather than empirically. It may be worthwhile including structure size as a factor in the development of a probabilistic method, though it is considered that it is a third order effect behind subsidence movements and construction type.

- *Structure age*

  The trend analysis for structure age did not reveal any noticeable trends.

- *Extensions, variable foundations and building joints*

  There is a clear trend of a higher frequency of impacts for structures that include extensions, variable foundations and building joints. The increased frequency appears to be related mainly to lower impact categories.

- *Urban or rural setting*

  While trends were observed, it is considered that they can be explained by other factors. However, consideration can be made to provide a more conservative estimate of probabilities in rural areas if structure size has not been taken into account.

C.4.3. Revised Method of Impact Assessment

A revised method of impact assessment has been developed. The method is probabilistic and currently includes conventional ground curvature and construction type as input factors.

Because of the relatively low number of buildings that suffered damage, the trends in the data were difficult to determine within small ranges of curvature. A decision was therefore taken to analyse the data in a limited number of curvature ranges, so that where possible a reasonable sample size would be available in each range. The ranges of curvature chosen were 5 to 15 kilometres, 15 to 50 kilometres and greater than 50 kilometres.

Because the incidence of damage for different construction types showed strong trends and because the sample size was reasonable for each type of structure, the data were analysed to determine the effect of radius of curvature on the incidence of damage for each of the three structure types and for each of the three curvature ranges.

The following probabilities are proposed in Table C.5.

Table C.5 Probabilities of Impact based on Curvature and Construction Type based on the Revised Method of Impact Classification

R (km)	Repair Category			
	No Repair or R0	R1 or R2	R3 or R4	R5
Brick or brick-veneer houses with Slab on Ground				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	80 ~ 85 %	12 ~ 17 %	2 ~ 5 %	< 0.5 %
5 to 15	70 ~ 75 %	17 ~ 22 %	5 ~ 8 %	< 0.5 %
Brick or brick-veneer houses with Strip Footing				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	80 ~ 85 %	7 ~ 12 %	2 ~ 7 %	< 0.5 %
5 to 15	70 ~ 75 %	15 ~ 20 %	7 ~ 12 %	< 0.5 %
Timber-framed houses with flexible external linings of any foundation type				
> 50	90 ~ 95 %	3 ~ 10 %	1 %	< 0.1 %
15 to 50	85 ~ 90 %	7 ~ 13 %	1 ~ 3 %	< 0.5 %
5 to 15	80 ~ 85 %	10 ~ 15 %	3 ~ 5 %	< 0.5 %

The results have been expressed as a range of values rather than a single number, recognising that the data had considerable scatter within each curvature range. While structure size and building extensions have not been included in the predictive tables, it is recommended to adopt percentages at the higher end of the range for larger structures or those with building extensions.

The percentages stated in each table are the percentages of building structures of that type that would be likely to be damaged to the level indicated within each curvature range. The levels of damage in the tables are indicated with reference to the repair categories described in the damage classification given in Table C.4.

To place these values in context, Table C.6 shows the actual percentages recorded at Tahmoor Colliery for all buildings within the sample.

Table C.6 Observed Frequency of Impacts observed for all buildings at Tahmoor Colliery

R (km)	Repair Category			
	No Claim or R0	R1 or R2	R3 or R4	R5
> 50	94%	4%	1%	0%
15 to 50	86%	9%	4%	0.7%
5 to 15	76%	17%	7%	0%

It can be seen that the proposed probabilities for the higher impact categories have been increased compared to those observed to date. These have been deliberately increased, because it has been noticed that some of the claims for damage have been submitted well after the event and it is possible that the numbers damaged in this category could be increased as further claims are received and investigated. These numbers are particularly sensitive to change because the sample size is very small. In light of the above, it is recommended that the probabilities be revisited in the future as mining progresses.

The ranges provided in Table C.5 have been converted into a set of probability curves to remove artificial discontinuities that are formed by dividing curvatures into three categories. These are shown in Fig. C.4. The probability curves are applicable for all houses and civil structures.

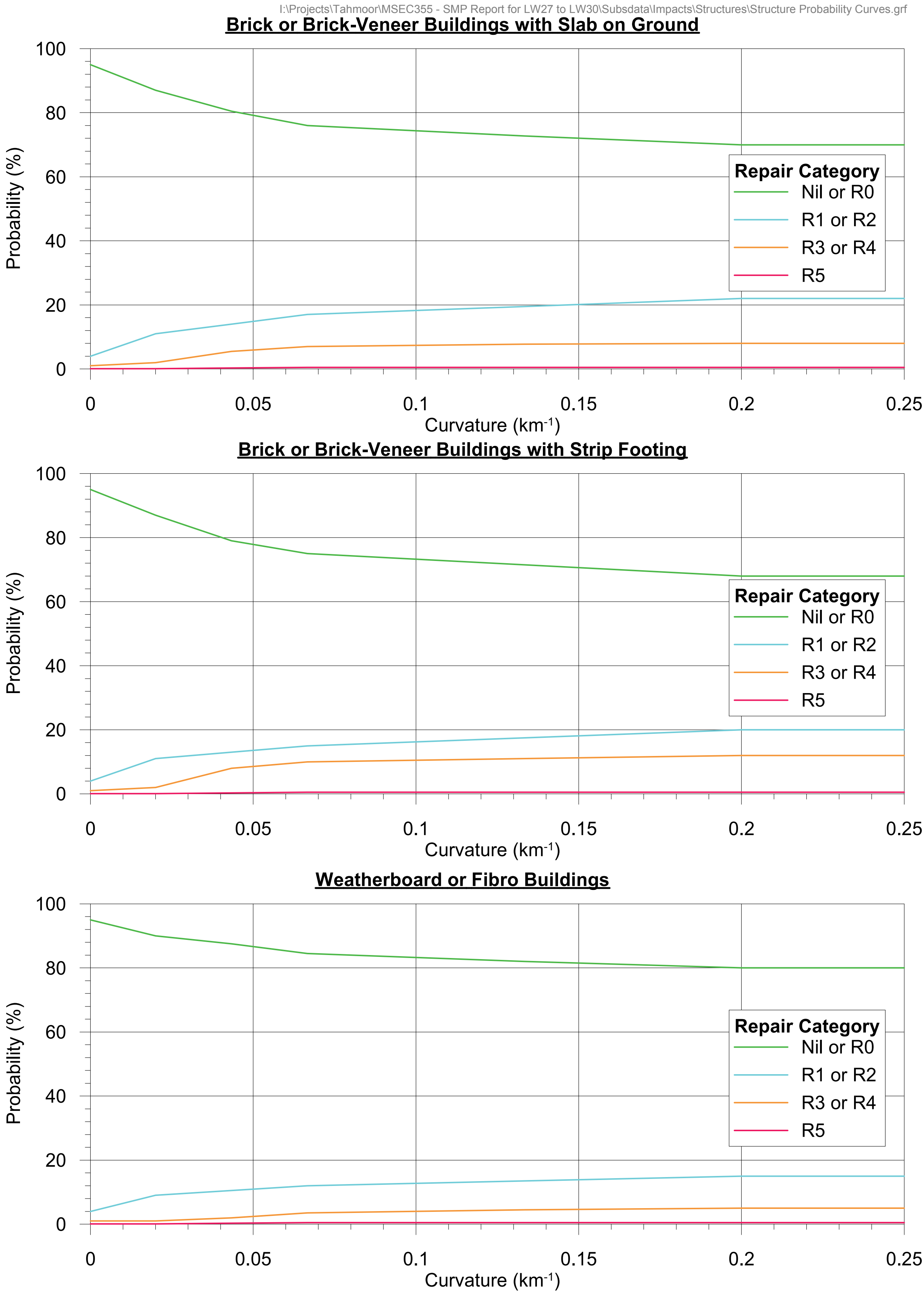


Fig. C.4 Probability Curves for Impacts to Buildings

APPENDIX D. TABLES

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probability of Nil or Category R0 Impact (%)	Predicted Probability of Category R1 or R2 Impact (%)	Predicted Probability of Category R3 or R4 Impact (%)	Predicted Probability of Category R5 Impact (%)
1	Wyong	50	Timber Frame	Suspended	13	1	1500	1.0	0.08	0.04	84	12	4	< 0.5
2	Wyong	< 50	Brick-Veneer	Suspended	37	1	200	1.5	0.01	< 0.01	89	9	2	< 0.1
3	Wyong	< 50	Timber Frame	Suspended	18	1	2250	3.0	0.05	0.04	86	11	3	< 0.4
4	Wyong	250	Brick-Veneer	Not Available	29	2	1200	9.5	0.08	0.06	75	18	7	< 0.5
5	Wyong	150	Not Available	Not Available	26	NA	2250	2.5	0.06	0.18	71	21	8	< 0.5
6	Wyong	100	Brick-Veneer	On Ground	34	1	2100	3.0	0.09	0.04	75	18	7	< 0.5
7	Wyong	< 50	Not Available	Not Available	17	NA	100	1.0	< 0.01	< 0.01	92	7	1	< 0.1
8	Wyong	200	Timber Frame	Suspended	13	1	700	7.5	0.08	< 0.01	84	12	4	< 0.5
9	Wyong	< 50	Brick-Veneer	Suspended	20	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
10	Wyong	50	Timber Frame	Suspended	13	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
11	Wyong	100	Not Available	Not Available	12	1	100	0.5	< 0.01	< 0.01	93	6	1	< 0.1
12	Wyong	150	Brick-Veneer	Not Available	37	1	100	0.5	< 0.01	< 0.01	93	6	1	< 0.1
13	Wyong	50	Timber Frame	Suspended	25	1	2100	3.0	0.09	0.04	84	12	4	< 0.5
14	Wyong	< 50	Brick-Veneer	Suspended	28	1	250	2.0	0.02	< 0.01	87	11	2	< 0.1
15	Wyong	100	Timber Frame	Suspended	19	1	1500	2.0	0.04	0.15	81	14	5	< 0.5
16	Wyong	< 50	Timber Frame	Suspended	18	1	1450	6.0	0.04	0.12	83	13	4	< 0.5
17	Wyong	< 50	Timber Frame	Suspended	19	1	500	4.0	0.03	0.02	89	9	1	< 0.2
18	Wyong	100	Brick-Veneer	Suspended	20	2	1900	3.0	0.07	0.11	73	17	11	< 0.5
19	Wyong	100	Brick-Veneer	Suspended	23	1	1450	4.0	0.09	0.05	74	16	10	< 0.5
20	Wyong	100	Brick-Veneer	Suspended	38	1	1350	2.5	0.10	0.03	73	16	11	< 0.5
21	Wyong	150	Brick-Veneer	On Ground	48	1	1650	3.5	0.09	0.04	75	18	7	< 0.5
22	Wyong	100	Brick-Veneer	Not Available	44	1	2350	4.5	0.17	0.25	67	24	9	< 0.5
23	Wyong	150	Brick-Veneer	Suspended	24	1	1450	2.0	0.04	0.09	74	16	10	< 0.5
24	Wyong	200	Brick-Veneer	On Ground	29	1	550	6.5	0.08	< 0.01	75	18	7	< 0.5
25	Wyong	100	Timber Frame	Suspended	24	1	1200	2.0	0.04	0.03	87	11	2	< 0.3
26	Wyong	< 50	Timber Frame	Suspended	29	1	1050	2.5	0.15	0.04	82	14	5	< 0.5
27	Wyong	150	Brick-Veneer	Suspended	32	1	50	0.5	< 0.01	< 0.01	91	7	1	< 0.1
28	Wyong	100	Brick-Veneer	On Ground	16	1	25	0.5	< 0.01	< 0.01	92	7	1	< 0.1
29	Wyong	100	Timber Frame	Suspended	17	1	1300	4.0	0.14	0.19	80	15	5	< 0.5
30	Wyong	50	Brick-Veneer	Not Available	23	1	1250	10.5	0.19	0.25	68	23	9	< 0.5
31	Wyong	100	Brick-Veneer	Not Available	25	1	1900	5.5	0.08	0.06	75	17	7	< 0.5
32	Wyong	50	Not Available	Not Available	12	NA	350	4.5	0.07	0.01	76	17	7	< 0.5
33	Wyong	50	Timber Frame	Suspended	17	1	950	10.0	0.18	0.09	81	14	5	< 0.5
34	Wyong	100	Brick-Veneer	On Ground	31	1	1250	4.0	0.14	0.18	71	21	8	< 0.5
35	Wyong	50	Brick-Veneer	Not Available	11	1	1400	6.5	0.20	0.25	67	24	9	< 0.5
36	Wyong	50	Brick-Veneer	On Ground	24	1	1150	1.5	0.13	0.04	73	19	8	< 0.5
37	Wyong	100	Brick-Veneer	On Ground	37	1	1100	3.0	0.05	0.04	80	14	6	< 0.3
38	Wyong	50	Brick-Veneer	On Ground	26	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
39	Wyong	100	Brick-Veneer	Suspended	47	1	1200	2.0	0.05	0.03	78	13	8	< 0.3
40	Wyong	100	Brick-Veneer	On Ground	21	1	1350	5.5	0.05	0.20	69	23	8	< 0.5
41	Wyong	100	Brick-Veneer	On Ground	26	1	75	1.0	< 0.01	< 0.01	91	7	1	< 0.1
42	Wyong	< 50	Timber Frame	Suspended	15	1	75	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probability of Nil or Category R0 Impact (%)	Predicted Probability of Category R1 or R2 Impact (%)	Predicted Probability of Category R3 or R4 Impact (%)	Predicted Probability of Category R5 Impact (%)
43	Wyong	100	Brick-Veneer	On Ground	24	1	1250	2.0	0.06	0.03	77	16	7	< 0.4
44	Wyong	< 50	Brick-Veneer	Suspended	19	1	1250	4.5	0.13	0.18	69	19	12	< 0.5
45	Wyong	100	Brick-Veneer	Suspended	23	1	1300	2.0	0.04	0.03	81	13	7	< 0.3
46	Wyong	< 50	Brick-Veneer	Suspended	22	1	1200	1.5	0.05	0.03	78	13	8	< 0.3
47	Wyong	< 50	Timber Frame	Suspended	14	1	1100	2.0	0.08	0.03	84	12	4	< 0.5
48	Wyong	50	Timber Frame	Suspended	20	1	1100	2.0	0.08	0.03	84	12	4	< 0.5
49	Wyong	50	Timber Frame	Suspended	19	1	< 20	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
50	Wyong	< 50	Brick-Veneer	On Ground	20	1	25	< 0.5	< 0.01	< 0.01	93	5	1	< 0.1
51	Wyong	50	Brick-Veneer	On Ground	23	2	50	0.5	< 0.01	< 0.01	92	6	1	< 0.1
52	Wyong	150	Brick-Veneer	On Ground	29	1	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
53	Wyong	100	Brick-Veneer	Suspended	49	1	75	1.0	0.01	< 0.01	90	8	2	< 0.1
54	Wyong	50	Timber Frame	Suspended	20	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
55	Wyong	100	Timber Frame	Suspended	17	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
56	Wyong	100	Brick-Veneer	Not Available	28	1	1400	2.0	0.03	0.09	75	18	7	< 0.5
57	Wyong	50	Brick-Veneer	On Ground	17	2	75	0.5	< 0.01	< 0.01	92	6	1	< 0.1
58	Wyong	300	Brick-Veneer	On Ground	27	2	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
59	Wyong	< 50	Brick-Veneer	On Ground	21	1	1200	1.5	0.05	0.03	79	15	6	< 0.3
60	Wyong	50	Brick-Veneer	On Ground	15	1	1050	2.0	0.08	0.03	76	17	7	< 0.5
61	Wyong	100	Timber Frame	Suspended	24	1	25	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
62	Wyong	150	Brick-Veneer	Not Available	30	1	50	< 0.5	< 0.01	< 0.01	92	7	1	< 0.1
63	Wyong	100	Timber Frame	Suspended	19	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
64	Wyong	100	Timber Frame	Suspended	24	1	200	1.5	0.01	< 0.01	92	7	1	< 0.1
65	Wyong	50	Timber Frame	Suspended	19	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
66	Wyong	100	Brick-Veneer	On Ground	21	1	1300	2.5	0.09	0.15	72	20	8	< 0.5
67	Wyong	100	Timber Frame	Suspended	15	1	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
68	Wyong	200	Brick-Veneer	On Ground	30	1	1450	5.5	0.06	0.06	78	16	6	< 0.4
69	Wyong	100	Brick-Veneer	On Ground	23	1	1650	3.5	0.16	0.04	72	21	8	< 0.5
70	Wyong	150	Brick-Veneer	Suspended	32	1	1700	2.0	0.04	0.05	79	13	8	< 0.3
71	Wyong	< 50	Timber Frame	Suspended	16	1	1250	2.0	0.04	0.03	88	10	2	< 0.3
72	Wyong	< 50	Timber Frame	Suspended	35	1	1150	1.5	0.12	0.03	82	13	4	< 0.5
73	Wyong	50	Timber Frame	Suspended	16	1	1300	2.0	0.04	0.03	88	10	2	< 0.3
74	Wyong	50	Brick-Veneer	On Ground	32	1	1200	2.0	0.12	0.04	73	19	8	< 0.5
75	Wyong	50	Brick-Veneer	On Ground	29	1	450	2.5	0.02	0.01	89	10	2	< 0.1
76	Wyong	100	Timber Frame	Suspended	16	1	25	< 0.5	0.01	< 0.01	92	7	1	< 0.1
77	Wyong	50	Timber Frame	Suspended	16	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
78	Wyong	50	Timber Frame	Suspended	15	1	200	2.0	0.02	< 0.01	90	9	1	< 0.1
79	Wyong	200	Brick-Veneer	On Ground	23	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
80	Wyong	200	Brick-Veneer	Suspended	27	NA	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
81	Wyong	100	Timber Frame	Suspended	15	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
82	Wyong	50	Brick-Veneer	On Ground	24	1	100	1.0	0.02	< 0.01	88	10	2	< 0.1
83	Wyong	100	Timber Frame	On Ground	18	1	1350	7.5	0.25	0.25	75	18	7	< 0.5
84	Wyong	150	Timber Frame	Suspended	20	1	1200	3.0	0.09	0.04	84	12	4	< 0.5

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probability of Nil or Category R0 Impact (%)	Predicted Probability of Category R1 or R2 Impact (%)	Predicted Probability of Category R3 or R4 Impact (%)	Predicted Probability of Category R5 Impact (%)
85	Wyong	100	Brick-Veneer	Suspended	26	1	1350	7.0	0.25	0.25	63	23	14	< 0.5
86	Wyong	100	Brick-Veneer	Suspended	25	1	1200	3.5	0.05	0.04	77	14	9	< 0.4
87	Wyong	< 50	Brick-Veneer	Not Available	26	1	1150	4.5	0.06	0.10	74	18	7	< 0.5
88	Wyong	100	Brick-Veneer	Suspended	26	1	350	4.5	0.07	0.03	75	15	10	< 0.5
89	Wyong	< 50	Timber Frame	On Ground	30	1	450	5.5	0.06	0.02	85	12	3	< 0.5
90	Wyong	< 50	Timber Frame	On Ground	22	1	1100	2.0	0.04	0.08	84	12	4	< 0.5
91	Wyong	50	Timber Frame	Suspended	26	1	1200	3.0	0.18	0.04	81	15	5	< 0.5
92	Wyong	50	Timber Frame	Suspended	19	1	1350	4.0	0.06	0.25	74	19	7	< 0.5
93	Wyong	100	Brick-Veneer	Suspended	23	1	1300	3.5	0.06	0.05	76	15	10	< 0.5
94	Wyong	50	Not Available	Suspended	26	2	1100	5.0	0.25	0.04	68	23	9	< 0.5
95	Wyong	< 50	Brick-Veneer	On Ground	27	1	750	2.5	0.11	0.10	74	19	8	< 0.5
96	Wyong	< 50	Brick-Veneer	On Ground	21	1	750	2.5	0.03	0.05	80	14	6	< 0.3
97	Wyong	50	Brick-Veneer	Suspended	29	1	1350	3.5	0.06	0.25	65	22	13	< 0.5
98	Wyong	50	Brick-Veneer	Suspended	28	1	1350	6.0	0.05	0.25	65	22	13	< 0.5
99	Wyong	100	Brick-Veneer	Suspended	16	1	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
100	Hue Hue	100	Brick-Veneer	On Ground	26	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
101	Hue Hue	50	Brick-Veneer	Suspended	34	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
102	Hue Hue	50	Brick-Veneer	On Ground	34	1	75	0.5	< 0.01	< 0.01	91	7	1	< 0.1
103	Hue Hue	< 50	Brick-Veneer	On Ground	24	1	750	2.0	0.03	0.08	75	18	7	< 0.5
104	Hue Hue	50	Brick-Veneer	On Ground	25	1	700	2.0	0.03	0.04	82	13	5	< 0.3
105	Hue Hue	100	Brick-Veneer	On Ground	22	1	700	2.0	0.03	0.04	81	14	5	< 0.3
106	Hue Hue	< 50	Brick-Veneer	On Ground	24	1	700	2.5	0.03	0.04	81	14	5	< 0.3
107	Hue Hue	100	Brick-Veneer	On Ground	28	1	750	2.0	0.10	0.14	72	20	8	< 0.5
108	Hue Hue	50	Brick-Veneer	On Ground	41	1	750	1.0	0.09	0.14	73	20	8	< 0.5
109	Hue Hue	100	Brick-Veneer	Suspended	32	1	850	2.5	0.09	0.02	74	16	10	< 0.5
110	Hue Hue	50	Brick-Veneer	On Ground	31	1	1000	2.5	0.04	0.03	82	13	5	< 0.3
111	Hue Hue	100	Brick-Veneer	On Ground	29	1	1000	2.5	0.04	0.05	79	15	6	< 0.4
112	Hue Hue	100	Brick-Veneer	On Ground	25	1	1000	3.0	0.10	0.18	71	21	8	< 0.5
113	Hue Hue	100	Brick-Veneer	On Ground	39	1	1000	2.5	0.11	0.15	72	20	8	< 0.5
114	Hue Hue	100	Brick-Veneer	On Ground	23	1	950	1.5	0.09	0.02	75	18	7	< 0.5
115	Hue Hue	100	Brick-Veneer	On Ground	36	1	1000	2.5	0.11	0.15	72	20	8	< 0.5
116	Hue Hue	100	Brick-Veneer	Suspended	17	1	1000	2.0	0.04	0.14	71	18	11	< 0.5
117	Hue Hue	100	Brick-Veneer	Suspended	29	1	900	2.5	0.06	0.03	76	15	10	< 0.5
118	Hue Hue	100	Brick-Veneer	On Ground	33	1	800	2.5	0.08	0.07	75	18	7	< 0.5
119	Hue Hue	100	Brick-Veneer	On Ground	26	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
120	Hue Hue	100	Brick-Veneer	On Ground	36	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
121	Hue Hue	100	Brick-Veneer	Suspended	29	1	700	2.0	0.02	0.10	73	16	10	< 0.5
122	Hue Hue	100	Brick-Veneer	On Ground	26	1	700	1.5	0.07	0.11	74	19	8	< 0.5
123	Hue Hue	50	Brick-Veneer	On Ground	24	1	900	2.5	0.07	0.02	76	17	7	< 0.5
124	Hue Hue	< 50	Brick-Veneer	Suspended	35	1	1000	2.0	0.04	0.12	72	17	11	< 0.5
125	Hue Hue	< 50	Brick-Veneer	On Ground	32	1	1000	2.5	0.10	0.15	72	20	8	< 0.5
126	Hue Hue	50	Brick-Veneer	On Ground	34	1	950	1.5	0.11	0.02	74	18	7	< 0.5

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probability of Nil or Category R0 Impact (%)	Predicted Probability of Category R1 or R2 Impact (%)	Predicted Probability of Category R3 or R4 Impact (%)	Predicted Probability of Category R5 Impact (%)
127	Hue Hue	50	Brick-Veneer	Suspended	28	1	1050	1.5	0.03	0.05	78	14	9	< 0.4
128	Hue Hue	50	Brick-Veneer	On Ground	21	1	1050	1.5	0.03	0.08	76	17	7	< 0.5
129	Hue Hue	100	Brick-Veneer	On Ground	28	1	1050	1.0	0.08	0.02	75	18	7	< 0.5
130	Hue Hue	50	Brick-Veneer	On Ground	30	1	1000	1.5	0.09	0.02	75	18	7	< 0.5
131	Hue Hue	50	Brick-Veneer	Suspended	24	1	1050	1.5	0.09	0.13	72	17	11	< 0.5
132	Hue Hue	100	Brick-Veneer	On Ground	23	1	1050	1.5	0.09	0.08	75	18	7	< 0.5
133	Hue Hue	100	Brick-Veneer	On Ground	30	1	1050	1.5	0.07	0.12	74	19	8	< 0.5
134	Hue Hue	100	Brick-Veneer	On Ground	30	2	1050	1.5	0.03	0.12	74	19	8	< 0.5
135	Hue Hue	150	Brick-Veneer	Suspended	25	2	1050	2.0	0.03	0.12	72	17	11	< 0.5
136	Hue Hue	150	Brick-Veneer	Suspended	19	2	1050	1.5	0.03	0.10	73	16	10	< 0.5
137	Hue Hue	100	Brick-Veneer	Suspended	41	1	1050	1.5	0.05	0.04	78	13	8	< 0.3
138	Hue Hue	50	Brick-Veneer	On Ground	18	1	700	1.0	0.04	0.13	73	19	8	< 0.5
139	Hue Hue	< 50	Brick-Veneer	On Ground	41	1	700	2.5	0.03	0.04	82	13	5	< 0.3
140	Hue Hue	< 50	Brick-Veneer	On Ground	24	1	600	4.0	0.02	0.07	76	17	7	< 0.5
141	Hue Hue	< 50	Brick-Veneer	On Ground	27	1	350	3.5	0.05	0.03	80	15	6	< 0.3
142	Hue Hue	< 50	Brick-Veneer	On Ground	28	1	450	4.0	0.05	0.05	79	15	6	< 0.4
143	Hue Hue	< 50	Brick-Veneer	Suspended	27	1	300	3.0	0.05	0.04	78	13	8	< 0.3
144	Hue Hue	< 50	Brick-Veneer	On Ground	28	1	150	1.5	0.02	< 0.01	87	11	2	< 0.1
145	Hue Hue	< 50	Brick-Veneer	On Ground	24	1	75	0.5	< 0.01	< 0.01	92	6	1	< 0.1
146	Hue Hue	< 50	Brick-Veneer	On Ground	52	2	50	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
147	Hue Hue	< 50	Brick-Veneer	On Ground	23	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
148	Hue Hue	< 50	Brick-Veneer	On Ground	25	NA	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
149	Hue Hue	< 50	Brick-Veneer	On Ground	32	1	200	2.0	0.02	< 0.01	87	11	2	< 0.1
150	Hue Hue	< 50	Brick-Veneer	Suspended	27	1	150	1.5	0.02	< 0.01	88	10	2	< 0.1
151	Wyong	200	Timber Frame	Not Available	17	NA	200	1.5	0.01	< 0.01	92	7	1	< 0.1
152	Wyong	150	Not Available	Not Available	21	NA	50	< 0.5	< 0.01	< 0.01	93	5	1	< 0.1
153	Wyong	50	Timber Frame	Suspended	17	1	1550	3.0	0.07	0.03	84	12	4	< 0.5
154	Wyong	< 50	Timber Frame	Suspended	33	1	1200	9.5	0.09	0.13	82	14	5	< 0.5
155	Wyong	100	Not Available	Not Available	18	NA	350	3.5	0.03	0.03	83	13	4	< 0.2
156	Wyong	100	Timber Frame	Suspended	29	2	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
157	Wyong	100	Brick-Veneer	Not Available	18	2	2200	3.0	0.06	0.25	68	23	9	< 0.5
158	Wyong	150	Not Available	On Ground	32	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
159	Wyong	100	Not Available	Not Available	30	NA	100	0.5	< 0.01	< 0.01	93	6	1	< 0.1
160	Wyong	100	Brick-Veneer	On Ground	22	2	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
161	Wyong	250	Not Available	Not Available	34	2	50	< 0.5	< 0.01	< 0.01	93	5	1	< 0.1
162	Wyong	150	Not Available	Not Available	38	NA	150	1.0	0.01	< 0.01	91	8	2	< 0.1
163	Hue Hue	< 50	Brick-Veneer	On Ground	39	1	100	1.0	0.01	< 0.01	89	9	2	< 0.1
164	Hue Hue	100	Brick-Veneer	On Ground	27	1	1050	1.5	0.03	0.06	77	16	7	< 0.5
165	Hue Hue	50	Brick-Veneer	Suspended	29	1	1000	1.5	0.09	0.02	74	16	10	< 0.5
166	Hue Hue	50	Brick-Veneer	Suspended	26	1	950	1.5	0.09	0.08	74	16	10	< 0.5
167	Hue Hue	100	Brick-Veneer	On Ground	35	1	950	1.5	0.03	0.10	74	18	7	< 0.5
168	Hue Hue	50	Brick-Veneer	On Ground	20	1	700	1.0	0.05	0.09	75	18	7	< 0.5

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probability of Nil or Category R0 Impact (%)	Predicted Probability of Category R1 or R2 Impact (%)	Predicted Probability of Category R3 or R4 Impact (%)	Predicted Probability of Category R5 Impact (%)
169	Hue Hue	50	Brick-Veneer	On Ground	28	1	600	4.0	0.02	0.06	77	16	7	< 0.5
170	Hue Hue	50	Brick-Veneer	On Ground	30	1	100	1.0	0.02	< 0.01	89	10	2	< 0.1
171	Hue Hue	50	Brick-Veneer	On Ground	25	1	50	< 0.5	< 0.01	< 0.01	93	5	1	< 0.1
172	Hue Hue	100	Brick-Veneer	On Ground	25	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
173	Hue Hue	100	Brick-Veneer	On Ground	23	1	75	0.5	0.01	< 0.01	90	8	2	< 0.1
174	Hue Hue	100	Brick-Veneer	Suspended	26	1	150	2.0	0.02	< 0.01	87	11	2	< 0.1
175	Hue Hue	100	Brick-Veneer	Not Available	27	NA	150	1.5	0.02	< 0.01	87	11	2	< 0.1
176	Hue Hue	150	Brick-Veneer	On Ground	45	1	75	0.5	< 0.01	< 0.01	92	7	1	< 0.1
177	Hue Hue	50	Brick-Veneer	On Ground	38	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
178	Hue Hue	50	Brick-Veneer	On Ground	23	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
179	Hue Hue	100	Brick-Veneer	On Ground	24	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
180	Hue Hue	150	Brick-Veneer	On Ground	28	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
181	Hue Hue	100	Brick-Veneer	On Ground	27	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
182	Hue Hue	100	Brick-Veneer	On Ground	23	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
183	Hue Hue	150	Brick-Veneer	On Ground	28	2	75	0.5	< 0.01	< 0.01	92	7	1	< 0.1
184	Wyong	100	Brick-Veneer	On Ground	32	1	200	1.5	0.02	< 0.01	89	9	2	< 0.1
185	Wyong	< 50	Brick-Veneer	On Ground	19	1	25	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
186	Wyong	50	Brick-Veneer	On Ground	34	1	75	1.0	0.02	< 0.01	89	10	2	< 0.1
187	Hue Hue	150	Brick-Veneer	Not Available	29	1	1250	4.0	0.04	0.19	71	21	8	< 0.5
188	Hue Hue	100	Not Available	On Ground	29	1	1250	2.0	0.05	0.05	79	15	6	< 0.4
189	Hue Hue	150	Brick-Veneer	Not Available	25	1	1150	2.0	0.10	0.03	74	18	7	< 0.5
190	Hue Hue	100	Brick-Veneer	On Ground	37	1	50	0.5	< 0.01	< 0.01	91	7	1	< 0.1
191	Wyong	50	Not Available	Not Available	17	NA	1350	6.5	0.06	0.25	67	24	9	< 0.5
192	Wyong	50	Timber Frame	Suspended	17	1	25	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
193	Wyong	100	Timber Frame	Suspended	19	1	150	2.0	0.02	0.02	90	9	1	< 0.1
194	Wyong	100	Brick-Veneer	Suspended	25	1	1250	10.5	0.13	0.30	60	25	15	< 0.5
195	Wyong	50	Timber Frame	Not Available	22	1	1100	6.0	0.25	0.04	76	18	6	< 0.5
196	Hue Hue	100	Brick-Veneer	Suspended	17	2	1100	3.5	0.20	0.03	67	21	12	< 0.5
197	Wyong	< 50	Brick-Veneer	On Ground	31	1	1300	5.5	0.25	0.25	69	23	9	< 0.5
198	Wyong	< 50	Brick-Veneer	Suspended	34	1	50	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
199	Wyong	< 50	Timber Frame	Suspended	19	1	1000	8.5	0.09	0.07	83	13	4	< 0.5
200	Wyong	< 50	Timber Frame	Suspended	22	1	1400	2.0	0.13	0.02	82	13	4	< 0.5
201	Wyong	150	Brick-Veneer	On Ground	33	1	1550	4.0	0.15	0.07	72	20	8	< 0.5
202	Hue Hue	100	Brick-Veneer	On Ground	40	1	1000	1.5	0.11	0.03	74	19	8	< 0.5
203	Hue Hue	150	Timber Frame	Suspended	21	2	1300	2.0	0.04	0.04	87	11	2	< 0.3
204	Wyong	100	Timber Frame	Suspended	18	2	1400	9.5	0.04	0.06	86	11	3	< 0.4
205	Wyong	50	Timber Frame	Suspended	20	1	2000	5.0	0.06	0.10	83	13	4	< 0.5
206	Wyong	100	Timber Frame	Not Available	14	2	2100	3.0	0.17	0.04	81	14	5	< 0.5
207	Wyong	< 50	Timber Frame	Suspended	15	1	75	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
208	Wyong	150	Brick-Veneer	Suspended	23	1	< 20	< 0.5	< 0.01	< 0.01	91	7	1	< 0.1
209	Wyong	300	Timber Frame	Suspended	17	NA	250	2.0	0.02	< 0.01	91	8	1	< 0.1
210	Hue Hue	150	Brick-Veneer	Suspended	26	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1

Table D.01 - Houses within the Study Area
Maximum Predicted Conventional Subsidence Parameters and Impact Assessments

House No.	Mine Subsidence District	Natural Ground Slope (mm/m)	Wall Type	Footing Type	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Predicted Probabulity of Nil or Category R0 Impact (%)	Predicted Probabulity of Category R1 or R2 Impact (%)	Predicted Probabulity of Category R3 or R4 Impact (%)	Predicted Probabulity of Category R5 Impact (%)
211	Hue Hue	100	Brick-Veneer	On Ground	28	1	500	4.0	0.04	0.06	78	16	6	< 0.4
212	Hue Hue	100	Brick-Veneer	On Ground	32	1	700	1.0	0.05	0.10	74	18	7	< 0.5
213	Wyong	< 50	Timber Frame	Suspended	18	1	1500	2.5	0.15	0.03	82	14	5	< 0.5
214	Hue Hue	< 50	Brick-Veneer	On Ground	31	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
215	Wyong	< 50	Brick-Veneer	Not Available	30	1	1500	2.5	0.13	0.20	70	22	8	< 0.5
216	Wyong	< 50	Timber Frame	Suspended	20	1	700	7.5	0.10	0.02	83	13	4	< 0.5
217	Wyong	50	Brick-Veneer	Suspended	30	1	100	1.5	0.02	0.02	88	11	2	< 0.1
218	Wyong	300	Timber Frame	On Ground	26	2	300	3.5	0.03	< 0.01	89	10	2	< 0.2
219	Hue Hue	< 50	Brick-Veneer	Not Available	25	1	300	3.0	0.04	0.03	80	14	6	< 0.3
220	Hue Hue	100	Brick-Veneer	On Ground	32	1	550	4.0	0.02	0.06	77	16	7	< 0.5
221	Hue Hue	100	Timber Frame	On Ground	30	1	700	2.5	0.02	0.05	87	11	2	< 0.3
222	Hue Hue	50	Brick-Veneer	Not Available	39	1	750	1.5	0.07	0.07	76	17	7	< 0.5
223	Hue Hue	100	Brick-Veneer	Not Available	28	1	850	2.5	0.06	0.02	78	16	6	< 0.4
224	Wyong	150	Brick-Veneer	Suspended	33	1	1300	6.5	0.25	0.25	64	22	13	< 0.5
225	Wyong	< 50	Brick-Veneer	Suspended	31	1	1350	2.0	0.05	0.07	75	15	10	< 0.5
226	Wyong	50	Timber Frame	Suspended	41	1	1350	2.0	0.04	0.08	84	12	4	< 0.5
227	Wyong	< 50	Timber Frame	Suspended	18	1	1250	3.0	0.15	0.03	82	14	5	< 0.5
228	Wyong	100	Not Available	On Ground	29	2	1200	1.5	0.10	0.02	74	18	7	< 0.5
229	Wyong	100	Brick-Veneer	On Ground	10	1	< 20	< 0.5	< 0.01	< 0.01	91	7	1	< 0.1
230	Wyong	100	Timber Frame	Suspended	20	1	100	0.5	< 0.01	< 0.01	93	6	1	< 0.1
231	Wyong	100	Timber Frame	Suspended	19	1	25	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
232	Wyong	100	Brick-Veneer	Suspended	14	1	200	2.5	0.03	< 0.01	84	12	4	< 0.2
233	Wyong	150	Timber Frame	Suspended	18	2	2050	13.0	0.07	0.25	75	19	7	< 0.5
234	Wyong	150	Not Available	Not Available	24	NA	2250	11.0	0.07	0.30	65	25	10	< 0.5
235	Wyong	< 50	Timber Frame	Suspended	15	1	1250	4.5	0.11	0.17	81	14	5	< 0.5
236	Wyong	50	Brick-Veneer	On Ground	25	1	< 20	< 0.5	< 0.01	< 0.01	93	6	1	< 0.1
237	Wyong	100	Brick-Veneer	Not Available	30	1	< 20	< 0.5	< 0.01	< 0.01	92	7	1	< 0.1
238	Wyong	< 50	Timber Frame	Suspended	14	1	1400	6.5	0.04	0.13	82	13	4	< 0.5
239	Wyong	150	Timber Frame	Suspended	15	1	1100	8.5	0.04	0.06	86	11	3	< 0.4
240	Wyong	50	Timber Frame	Suspended	14	1	25	< 0.5	< 0.01	< 0.01	94	5	1	< 0.1
241	Wyong	100	Timber Frame	Suspended	30	1	1250	2.0	0.05	0.04	87	11	2	< 0.3
242	Wyong	100	Brick-Veneer	Suspended	27	1	< 20	< 0.5	< 0.01	< 0.01	91	7	1	< 0.1
243	Wyong	150	Brick-Veneer	On Ground	57	1	300	2.5	0.03	< 0.01	85	12	3	< 0.2
244	Wyong	150	Timber Frame	Not Available	23	0	1450	1.5	0.12	0.02	83	13	4	< 0.5
245	Wyong	50	Timber Frame	Not Available	36	0	1450	2.5	0.04	0.18	81	15	5	< 0.5
						Maximums:	**2350**	**13**	**0.25**	**0.30**				

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
1	9	1	600	7.0	0.08	< 0.01
2	5	1	750	8.0	0.08	< 0.01
3	1	1	800	8.5	0.08	< 0.01
4	4	1	25	< 0.5	< 0.01	< 0.01
5	4	1	1700	3.5	0.05	0.03
6	8	1	600	7.0	0.08	0.04
7	7	1	650	7.5	0.08	0.05
8	4	1	550	7.0	0.07	0.04
9	4	1	450	6.0	0.06	0.03
10	4	1	500	6.5	0.06	0.03
11	7	1	1150	3.5	0.05	0.03
12	7	1	300	3.0	0.04	0.02
13	4	1	250	2.5	0.02	0.01
14	8	1	150	1.5	< 0.01	< 0.01
15	4	1	150	1.0	< 0.01	< 0.01
16	3	1	50	0.5	< 0.01	< 0.01
17	4	1	50	0.5	< 0.01	< 0.01
18	4	1	100	1.0	< 0.01	< 0.01
19	8	1	100	0.5	< 0.01	< 0.01
20	8	1	75	0.5	< 0.01	< 0.01
21	4	1	100	1.0	< 0.01	< 0.01
22	13	1	100	1.0	< 0.01	< 0.01
23	7	1	100	1.0	< 0.01	< 0.01
24	16	1	75	0.5	< 0.01	< 0.01
25	11	1	100	1.0	< 0.01	< 0.01
26	11	1	1400	9.0	0.03	0.14
27	10	1	1450	9.5	0.11	0.07
28	6	1	1350	9.5	0.11	0.10
29	24	1	150	1.5	0.02	< 0.01
30	11	1	100	0.5	< 0.01	< 0.01
31	14	1	100	0.5	< 0.01	< 0.01
32	12	1	75	0.5	< 0.01	< 0.01
33	11	1	75	< 0.5	< 0.01	< 0.01
34	2	1	100	1.0	< 0.01	< 0.01
35	13	1	100	1.0	< 0.01	< 0.01
36	8	1	150	1.5	0.01	< 0.01
37	8	1	300	3.0	0.03	< 0.01
38	13	1	200	2.0	0.02	< 0.01
39	3	1	150	1.5	0.02	0.01
40	4	1	400	4.0	0.04	0.03
41	8	1	< 20	< 0.5	< 0.01	< 0.01
42	15	1	< 20	< 0.5	< 0.01	< 0.01
43	21	1	< 20	< 0.5	< 0.01	< 0.01
44	6	1	25	< 0.5	< 0.01	< 0.01
45	10	1	25	< 0.5	< 0.01	< 0.01
46	21	1	< 20	< 0.5	< 0.01	< 0.01
47	5	1	< 20	< 0.5	< 0.01	< 0.01
48	4	1	< 20	< 0.5	< 0.01	< 0.01
49	5	1	200	1.5	0.01	< 0.01
50	13	1	200	1.5	0.01	0.01
51	8	1	300	2.5	0.04	0.01
52	11	1	1600	2.0	0.06	0.03
53	5	1	1550	2.0	0.08	0.03
54	5	1	1700	1.5	0.03	0.10
55	17	1	1700	1.5	0.03	0.08

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
56	9	1	150	1.5	0.02	0.01
57	5	1	150	1.5	0.02	< 0.01
58	8	1	200	2.0	0.03	< 0.01
59	11	1	200	2.0	0.03	< 0.01
60	6	1	200	1.5	0.02	< 0.01
61	22	1	150	1.5	0.02	< 0.01
62	2	1	150	1.5	0.02	< 0.01
63	6	1	50	0.5	< 0.01	< 0.01
64	2	1	50	0.5	< 0.01	< 0.01
65	12	1	< 20	< 0.5	< 0.01	< 0.01
66	13	1	25	< 0.5	< 0.01	< 0.01
67	3	1	< 20	< 0.5	< 0.01	< 0.01
68	15	1	2050	5.0	0.15	0.20
69	18	1	2150	3.0	0.06	0.08
70	14	1	1800	4.0	0.09	0.04
71	10	1	1750	4.0	0.10	0.04
72	7	1	1750	4.0	0.13	0.04
73	11	1	1700	4.0	0.16	0.04
74	4	1	1300	2.0	0.08	0.02
75	26	1	1250	2.0	0.10	0.02
76	8	1	1200	1.5	0.10	0.02
77	27	1	1250	2.5	0.10	0.11
78	12	1	1650	3.0	0.05	0.04
79	7	1	1700	3.0	0.05	0.08
80	31	1	1750	2.5	0.05	0.17
81	11	1	1650	3.0	0.05	0.04
82	19	1	1700	3.0	0.05	0.09
83	16	1	1700	0.5	0.06	0.03
84	10	1	1350	2.0	0.04	0.03
85	46	1	1300	2.0	0.04	0.03
86	10	1	1300	2.0	0.05	0.03
87	24	1	1350	2.0	0.04	0.04
88	8	1	1300	2.0	0.04	0.04
89	6	1	1400	1.5	0.03	0.14
90	9	1	1400	1.5	0.03	0.12
91	4	1	1250	1.5	0.05	0.02
92	15	1	1250	1.5	0.03	0.14
93	24	1	1250	2.0	0.03	0.05
94	8	1	1250	1.5	0.03	0.09
95	5	1	1200	2.0	0.03	0.03
96	17	1	1200	2.0	0.05	0.03
97	5	1	1250	2.0	0.04	0.03
98	10	1	1200	2.0	0.04	0.03
99	10	1	1150	2.0	0.04	0.03
100	10	1	1100	1.5	0.10	0.03
101	5	1	1050	1.5	0.13	0.03
102	8	1	1100	1.5	0.10	0.03
103	6	1	1100	1.5	0.09	0.03
104	8	1	1050	3.0	0.14	0.02
105	8	1	1100	1.5	0.10	0.03
106	5	1	1050	1.5	0.13	0.02
107	9	1	1050	1.5	0.13	0.02
108	8	1	1200	5.0	0.14	0.15
109	5	1	1200	4.5	0.14	0.13
110	5	1	1250	5.0	0.13	0.18

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
111	8	1	1150	4.5	0.14	0.09
112	9	1	1150	4.5	0.14	0.08
113	23	1	1250	4.5	0.13	0.18
114	6	1	1250	4.5	0.14	0.18
115	10	1	1250	1.5	0.04	0.15
116	27	1	1250	3.5	0.04	0.18
117	17	1	1250	4.5	0.06	0.18
118	9	1	1250	4.0	0.04	0.18
119	10	1	1250	2.5	0.04	0.18
120	7	1	1250	2.0	0.04	0.17
121	8	1	1250	4.5	0.11	0.17
122	7	1	1200	4.5	0.13	0.15
123	8	1	1150	1.5	0.09	0.03
124	14	1	1150	2.5	0.13	0.03
125	12	1	1100	2.0	0.12	0.03
126	8	1	1200	1.5	0.03	0.03
127	6	1	1100	1.5	0.09	0.03
128	6	1	1050	2.0	0.09	0.03
129	5	1	1100	2.5	0.03	0.03
130	12	1	1100	2.5	0.03	0.03
131	9	1	1000	3.0	0.07	0.03
132	22	1	1100	5.0	0.03	0.10
133	7	1	400	2.5	0.02	< 0.01
134	18	1	150	1.0	< 0.01	< 0.01
135	9	1	750	5.0	0.02	0.06
136	7	1	350	3.0	0.03	0.02
137	7	1	450	2.5	0.02	0.01
138	2	1	1300	2.0	0.04	0.04
139	25	1	1250	2.0	0.04	0.03
140	23	1	1250	4.0	0.08	0.18
141	8	1	1250	3.5	0.10	0.18
142	20	1	1200	2.0	0.04	0.03
143	3	1	1300	2.0	0.04	0.04
144	16	1	1300	4.0	0.15	0.09
145	9	1	1500	2.0	0.04	0.20
146	22	1	1450	2.0	0.15	0.03
147	18	1	2200	4.5	0.09	0.07
148	53	1	1950	5.5	0.08	0.06
149	3	1	1900	5.5	0.08	0.06
150	3	1	1200	10.5	0.06	0.25
151	3	1	1300	9.0	0.05	0.25
152	14	1	600	7.5	0.16	0.02
153	18	1	1100	2.5	0.05	0.04
154	13	1	1350	4.5	0.05	0.20
155	18	1	1350	4.0	0.05	0.20
156	10	1	1350	2.0	0.05	0.04
157	4	1	1150	2.5	0.14	0.03
158	12	1	1200	3.5	0.14	0.03
159	9	1	1200	4.0	0.14	0.05
160	9	1	1150	2.0	0.05	0.03
161	5	1	1150	2.0	0.04	0.03
162	8	1	1300	6.0	0.17	0.20
163	5	1	1150	2.0	0.06	0.03
164	12	1	1250	2.0	0.04	0.04
165	30	1	1300	3.5	0.04	0.19

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
166	8	1	1300	2.5	0.04	0.19
167	5	1	1300	4.0	0.04	0.19
168	19	1	1300	3.5	0.04	0.19
169	9	1	1300	3.5	0.04	0.19
170	17	1	1300	3.5	0.04	0.19
171	4	1	1300	3.5	0.04	0.19
172	5	1	1300	3.0	0.04	0.19
173	5	1	1300	4.0	0.10	0.19
174	19	1	1300	4.0	0.13	0.19
175	13	1	1150	3.5	0.14	0.03
176	2	1	25	< 0.5	< 0.01	< 0.01
177	15	1	25	< 0.5	< 0.01	< 0.01
178	5	1	100	1.5	0.02	< 0.01
179	9	1	25	< 0.5	< 0.01	< 0.01
180	6	1	50	1.0	< 0.01	< 0.01
181	8	1	50	0.5	< 0.01	< 0.01
182	4	1	100	1.5	0.02	< 0.01
183	14	1	1150	1.5	0.19	0.03
184	14	1	1150	1.5	0.12	0.04
185	6	1	1400	6.5	0.20	0.25
186	15	1	1100	3.5	0.20	0.03
187	21	1	1100	2.0	0.12	0.04
188	10	1	1100	2.0	0.09	0.04
189	5	1	1150	5.0	0.20	0.03
190	18	1	1100	7.5	0.20	0.03
191	11	1	900	4.5	0.05	0.05
192	10	1	950	3.5	0.06	0.05
193	2	1	850	5.5	0.05	0.06
194	11	1	400	5.0	0.07	0.01
195	4	1	400	5.0	0.07	0.01
196	10	1	100	1.5	0.01	0.01
197	11	1	250	5.0	0.07	0.03
198	16	1	200	4.0	0.06	< 0.01
199	12	1	< 20	< 0.5	< 0.01	< 0.01
200	6	1	1150	3.5	0.25	0.04
201	24	1	1200	3.5	0.07	0.04
202	7	1	1250	3.5	0.06	0.05
203	9	1	1350	6.0	0.25	0.25
204	16	1	1300	6.0	0.25	0.20
205	4	1	1150	6.5	0.25	0.03
206	17	1	1100	3.5	0.14	0.19
207	4	1	1100	2.0	0.04	0.17
208	12	1	1100	2.0	0.04	0.11
209	7	1	1100	3.0	0.25	0.04
210	7	1	950	1.5	0.06	0.02
211	10	1	950	2.5	0.11	0.11
212	7	1	1000	2.0	0.04	0.16
213	3	1	1000	2.0	0.04	0.16
214	9	1	1000	3.0	0.12	0.17
215	10	1	1000	2.0	0.04	0.06
216	14	1	900	2.5	0.05	0.03
217	17	1	750	2.0	0.09	0.03
218	4	1	750	2.5	0.09	0.02
219	9	1	700	2.5	0.03	0.03
220	12	1	700	2.0	0.03	0.04

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
221	12	1	700	2.0	0.03	0.04
222	6	1	750	2.5	0.10	0.02
223	13	1	750	1.5	0.03	0.17
224	23	1	750	2.0	0.03	0.10
225	11	1	750	2.0	0.03	0.12
226	16	1	750	1.5	0.03	0.17
227	10	1	100	1.0	0.02	< 0.01
228	9	1	100	1.0	0.01	< 0.01
229	8	1	25	< 0.5	< 0.01	< 0.01
230	19	1	50	< 0.5	< 0.01	< 0.01
231	7	1	50	< 0.5	< 0.01	< 0.01
232	9	1	50	< 0.5	< 0.01	< 0.01
233	7	1	25	< 0.5	< 0.01	< 0.01
234	9	1	300	4.0	0.05	0.02
235	15	1	450	5.0	0.06	0.02
236	4	1	350	4.5	0.06	0.01
237	16	1	100	1.5	0.02	< 0.01
238	5	1	1150	3.0	0.11	0.04
239	12	1	1150	3.5	0.05	0.11
240	6	1	1150	5.5	0.16	0.25
241	18	1	75	1.0	0.01	< 0.01
242	16	1	450	7.0	0.10	0.02
243	13	1	1100	11.0	0.20	0.30
244	12	1	250	3.0	0.04	0.02
245	15	1	400	4.5	0.07	0.05
246	9	1	1150	4.0	0.05	0.04
247	13	1	1050	4.5	0.05	0.04
248	5	1	1300	7.0	0.19	0.25
249	6	1	1350	7.0	0.10	0.25
250	10	1	1150	3.0	0.12	0.04
251	13	1	1350	2.5	0.06	0.05
252	4	1	1250	7.5	0.25	0.14
253	11	1	1350	6.0	0.06	0.25
254	8	1	1000	1.5	0.08	0.02
255	12	1	1050	1.5	0.03	0.10
256	10	1	700	2.0	0.04	0.13
257	12	1	900	2.5	0.04	0.03
258	12	1	150	1.5	0.02	< 0.01
259	8	1	25	< 0.5	< 0.01	< 0.01
260	3	1	25	< 0.5	< 0.01	< 0.01
261	18	1	50	< 0.5	< 0.01	< 0.01
262	9	1	50	< 0.5	< 0.01	< 0.01
263	15	1	50	< 0.5	< 0.01	< 0.01
264	10	1	450	4.0	0.05	0.06
265	13	1	200	2.0	0.02	< 0.01
266	18	1	100	1.0	0.01	< 0.01
267	13	1	25	< 0.5	< 0.01	< 0.01
268	11	1	50	< 0.5	< 0.01	< 0.01
269	6	1	< 20	< 0.5	< 0.01	< 0.01
270	11	1	75	1.0	0.01	< 0.01
271	24	1	75	1.0	0.02	< 0.01
272	7	1	100	1.5	0.01	< 0.01
273	7	1	75	1.0	< 0.01	< 0.01
274	20	1	25	< 0.5	< 0.01	< 0.01
275	6	1	< 20	< 0.5	< 0.01	< 0.01

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
276	9	1	< 20	< 0.5	< 0.01	< 0.01
277	12	1	150	1.5	0.02	< 0.01
278	5	1	75	1.0	< 0.01	< 0.01
279	5	1	200	2.5	0.03	< 0.01
280	15	1	100	1.5	0.02	< 0.01
281	39	1	100	1.0	0.02	< 0.01
282	33	1	50	0.5	< 0.01	< 0.01
283	6	1	50	0.5	< 0.01	< 0.01
284	18	1	50	0.5	< 0.01	< 0.01
285	16	1	50	< 0.5	< 0.01	< 0.01
286	4	1	25	< 0.5	< 0.01	< 0.01
287	9	1	25	< 0.5	< 0.01	< 0.01
288	8	1	50	0.5	< 0.01	< 0.01
289	6	1	50	< 0.5	< 0.01	< 0.01
290	4	1	50	0.5	< 0.01	< 0.01
291	4	1	50	0.5	< 0.01	< 0.01
292	4	1	25	< 0.5	< 0.01	< 0.01
293	6	1	< 20	< 0.5	< 0.01	< 0.01
294	4	1	25	< 0.5	< 0.01	< 0.01
295	12	1	25	< 0.5	< 0.01	< 0.01
296	12	1	25	< 0.5	< 0.01	< 0.01
297	5	1	50	0.5	< 0.01	< 0.01
298	7	1	100	1.0	0.01	< 0.01
299	6	1	25	< 0.5	< 0.01	< 0.01
300	27	1	< 20	< 0.5	< 0.01	< 0.01
301	13	1	< 20	< 0.5	< 0.01	< 0.01
302	16	1	25	< 0.5	< 0.01	< 0.01
303	18	1	< 20	< 0.5	< 0.01	< 0.01
304	8	1	< 20	< 0.5	< 0.01	< 0.01
305	8	1	25	< 0.5	< 0.01	< 0.01
306	11	1	25	< 0.5	< 0.01	< 0.01
307	3	1	25	< 0.5	< 0.01	< 0.01
308	5	1	25	< 0.5	< 0.01	< 0.01
309	9	1	< 20	< 0.5	< 0.01	< 0.01
310	20	1	< 20	< 0.5	< 0.01	< 0.01
311	16	1	25	< 0.5	< 0.01	< 0.01
312	9	1	25	< 0.5	< 0.01	< 0.01
313	26	1	< 20	< 0.5	< 0.01	< 0.01
314	8	1	< 20	< 0.5	< 0.01	< 0.01
315	7	1	25	< 0.5	0.01	< 0.01
316	3	1	< 20	< 0.5	< 0.01	< 0.01
317	12	1	25	< 0.5	< 0.01	< 0.01
318	11	1	25	< 0.5	< 0.01	< 0.01
319	20	1	25	< 0.5	< 0.01	< 0.01
320	11	1	< 20	< 0.5	< 0.01	< 0.01
321	7	1	25	< 0.5	< 0.01	< 0.01
322	10	1	< 20	< 0.5	< 0.01	< 0.01
323	2	1	25	< 0.5	< 0.01	< 0.01
324	16	1	75	1.0	< 0.01	< 0.01
325	13	1	75	1.0	< 0.01	< 0.01
326	4	1	600	6.0	0.09	0.02
327	8	1	550	6.5	0.10	0.02
328	8	1	1950	3.0	0.05	0.17
329	7	1	1800	9.0	0.17	0.19
330	8	1	2350	4.5	0.05	0.25

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
331	20	1	2300	4.5	0.11	0.25
332	7	1	2250	4.5	0.17	0.16
333	2	1	2350	3.5	0.06	0.15
334	6	1	25	< 0.5	< 0.01	< 0.01
335	11	1	50	< 0.5	< 0.01	< 0.01
336	6	1	50	< 0.5	< 0.01	< 0.01
337	7	1	50	< 0.5	< 0.01	< 0.01
338	13	1	25	< 0.5	< 0.01	< 0.01
339	2	1	50	< 0.5	< 0.01	< 0.01
340	5	1	50	< 0.5	< 0.01	< 0.01
341	13	1	25	< 0.5	< 0.01	< 0.01
342	10	1	25	< 0.5	< 0.01	< 0.01
343	6	1	50	< 0.5	< 0.01	< 0.01
344	2	1	100	1.0	< 0.01	< 0.01
345	1	1	75	0.5	< 0.01	< 0.01
346	4	1	25	< 0.5	< 0.01	< 0.01
347	17	1	75	0.5	< 0.01	< 0.01
348	14	1	250	2.0	0.02	0.01
349	4	1	200	2.0	0.01	< 0.01
350	8	1	200	2.0	0.02	< 0.01
351	8	1	200	1.5	0.01	0.01
352	9	1	1700	6.5	0.06	0.07
353	9	1	1550	1.5	0.04	0.13
354	23	1	1500	1.0	0.08	0.05
355	9	1	1500	1.5	0.05	0.09
356	10	1	1500	1.5	0.03	0.11
357	4	1	1900	3.0	0.08	0.09
358	9	1	1900	3.5	0.05	0.09
359	8	1	250	2.5	0.02	< 0.01
360	5	1	300	2.5	0.02	0.01
361	18	1	350	3.0	0.03	0.01
362	14	1	50	< 0.5	< 0.01	< 0.01
363	22	1	2300	3.0	0.05	0.07
364	13	1	2100	3.0	0.05	0.04
365	11	1	2200	3.0	0.05	0.04
366	8	1	2200	3.0	0.05	0.04
367	10	1	1850	3.0	0.05	0.11
368	6	1	1900	3.0	0.07	0.11
369	6	1	1950	2.5	0.09	0.04
370	12	1	2050	3.0	0.08	0.04
371	12	1	2250	3.5	0.05	0.04
372	5	1	2150	3.0	0.05	0.04
373	9	1	2050	1.5	0.15	0.04
374	4	1	2250	3.5	0.06	0.25
375	9	1	2250	4.5	0.06	0.25
376	12	1	2150	3.5	0.06	0.04
377	3	1	200	1.5	0.02	< 0.01
378	13	1	200	2.0	0.02	< 0.01
379	9	1	300	2.5	0.02	< 0.01
380	8	1	850	8.0	0.09	0.04
381	18	1	550	4.0	0.03	0.03
382	8	1	250	2.0	0.02	< 0.01
383	12	1	1100	8.5	0.09	0.11
384	3	1	1500	4.0	0.04	0.05
385	16	1	1550	3.5	0.11	0.10

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
386	11	1	1400	2.0	0.13	0.02
387	8	1	800	4.5	0.02	0.07
388	15	1	200	1.5	0.02	< 0.01
389	14	1	100	1.0	< 0.01	< 0.01
390	3	1	1350	4.0	0.08	0.03
391	25	1	1600	3.0	0.04	0.19
392	10	1	1600	4.0	0.08	0.20
393	9	1	1500	4.5	0.15	0.02
394	13	1	1600	3.5	0.06	0.20
395	11	1	1450	2.0	0.04	0.08
396	11	1	1500	2.0	0.03	0.15
397	10	1	1400	2.0	0.04	0.04
398	12	1	1450	1.5	0.03	0.14
399	9	1	50	< 0.5	< 0.01	< 0.01
400	13	1	50	< 0.5	< 0.01	< 0.01
401	12	1	75	< 0.5	< 0.01	< 0.01
402	18	1	75	< 0.5	< 0.01	< 0.01
403	9	1	150	1.5	0.01	< 0.01
404	2	1	150	1.0	0.01	< 0.01
405	20	1	100	0.5	< 0.01	< 0.01
406	19	1	300	2.5	0.02	0.01
407	14	1	75	< 0.5	< 0.01	< 0.01
408	9	1	25	< 0.5	< 0.01	< 0.01
409	8	1	2250	4.5	0.17	0.13
410	3	1	950	3.0	0.12	0.10
411	7	1	25	< 0.5	< 0.01	< 0.01
412	3	1	350	3.0	0.03	0.01
413	12	1	2150	3.0	0.05	0.04
414	9	1	1500	4.0	0.04	0.06
415	14	1	< 20	< 0.5	0.01	< 0.01
416	9	1	< 20	< 0.5	< 0.01	< 0.01
417	15	1	< 20	< 0.5	0.01	< 0.01
418	4	1	150	2.0	0.02	< 0.01
419	9	1	25	< 0.5	< 0.01	< 0.01
420	5	1	1500	2.0	0.04	0.20
421	7	1	1500	2.0	0.04	0.20
422	4	1	1050	3.0	0.14	0.02
423	6	1	1050	3.0	0.14	0.02
424	3	1	1150	2.0	0.06	0.03
425	10	1	1150	2.0	0.07	0.03
426	4	1	1050	3.5	0.19	0.03
427	16	1	1150	6.0	0.19	0.02
428	9	1	25	< 0.5	< 0.01	< 0.01
429	14	1	1200	3.5	0.08	0.04
430	6	1	1350	5.0	0.06	0.25
431	9	1	1250	6.0	0.25	0.16
432	3	1	1100	5.5	0.20	0.03
433	4	1	850	3.0	0.08	0.03
434	12	1	750	2.5	0.11	0.02
435	7	1	650	3.0	0.03	0.07
436	8	1	650	2.5	0.03	0.04
437	9	1	1000	1.5	0.07	0.02
438	16	1	750	1.5	0.06	0.05
439	17	1	1200	4.5	0.13	0.17
440	9	1	1150	1.5	0.05	0.03

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
441	6	1	450	4.5	0.05	0.01
442	3	1	< 20	< 0.5	< 0.01	< 0.01
443	13	1	25	< 0.5	< 0.01	< 0.01
444	5	1	1100	2.0	0.11	0.03
445	5	1	1750	13.0	0.13	0.19
446	15	1	2150	2.5	0.06	0.05
447	11	1	2250	3.0	0.06	0.25
448	2	1	150	1.5	0.02	< 0.01
449	3	1	< 20	< 0.5	< 0.01	< 0.01
450	11	1	75	< 0.5	< 0.01	< 0.01
451	16	1	50	< 0.5	< 0.01	< 0.01
452	18	1	1050	1.5	0.09	0.13
453	8	1	1100	2.0	0.04	0.08
454	15	1	25	< 0.5	< 0.01	< 0.01
455	11	1	25	< 0.5	< 0.01	< 0.01
456	7	1	< 20	< 0.5	< 0.01	< 0.01
457	8	1	100	0.5	< 0.01	< 0.01
458	8	1	200	1.5	0.01	< 0.01
459	6	1	150	1.5	0.01	< 0.01
460	8	1	2100	5.0	0.05	0.25
461	8	1	2100	2.5	0.05	0.20
462	48	1	50	< 0.5	< 0.01	< 0.01
463	10	1	300	3.5	0.05	0.01
464	7	1	300	3.5	0.05	< 0.01
465	9	1	250	2.0	0.03	< 0.01
466	8	1	250	2.5	0.04	< 0.01
467	6	1	< 20	< 0.5	< 0.01	< 0.01
468	8	1	25	< 0.5	< 0.01	< 0.01
469	18	1	150	1.5	0.02	< 0.01
470	12	1	150	1.5	0.02	0.01
471	11	1	1500	4.0	0.06	0.04
472	6	1	1050	8.5	0.03	0.06
473	8	1	1200	3.0	0.09	0.03
474	4	1	150	1.5	0.02	< 0.01
475	4	1	1300	9.5	0.04	0.05
476	7	1	2050	6.5	0.03	0.06
477	7	1	2300	3.0	0.05	0.06
478	7	1	2300	3.5	0.06	0.11
479	9	1	< 20	< 0.5	< 0.01	< 0.01
480	3	1	< 20	< 0.5	< 0.01	< 0.01
481	5	1	< 20	< 0.5	< 0.01	< 0.01
482	3	1	1350	2.0	0.04	0.04
483	5	1	1400	4.0	0.04	0.20
484	11	1	1000	3.5	0.05	0.04
485	3	1	1200	4.0	0.14	0.08
486	8	1	1300	4.0	0.06	0.19
487	7	1	1100	2.0	0.06	0.03
488	18	1	1250	1.5	0.04	0.03
489	6	1	1250	1.5	0.04	0.16
490	6	1	1250	1.5	0.04	0.10
491	7	1	1250	1.5	0.04	0.06
492	7	1	1200	4.0	0.13	0.06
493	15	1	1250	2.5	0.04	0.03
494	8	1	250	2.0	0.04	< 0.01
495	8	1	50	< 0.5	< 0.01	< 0.01

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
496	5	1	50	< 0.5	< 0.01	< 0.01
497	5	1	25	< 0.5	< 0.01	< 0.01
498	6	1	1850	7.5	0.06	0.25
499	5	1	1600	4.0	0.05	0.20
500	17	1	50	0.5	< 0.01	< 0.01
501	19	1	75	0.5	< 0.01	< 0.01
502	7	1	100	1.0	< 0.01	< 0.01
503	7	1	100	0.5	< 0.01	< 0.01
504	7	1	100	1.0	0.01	< 0.01
505	7	1	150	1.5	0.01	< 0.01
506	7	1	200	2.0	0.02	< 0.01
507	7	1	250	2.5	0.02	0.01
508	6	1	200	1.5	0.01	< 0.01
509	6	1	200	2.0	0.02	< 0.01
510	5	1	250	2.0	0.02	< 0.01
511	2	1	900	8.0	0.09	0.04
512	8	1	1300	2.5	0.04	0.03
513	4	1	1150	1.0	0.15	0.03
514	4	1	1350	2.0	0.05	0.05
515	11	1	1300	6.0	0.17	0.20
516	11	1	1300	6.0	0.19	0.20
517	5	1	1250	4.0	0.13	0.18
518	11	1	700	4.5	0.02	0.04
519	11	1	50	0.5	< 0.01	< 0.01
520	12	1	100	1.5	0.01	0.01
521	6	1	1200	10.5	0.25	0.30
522	3	1	50	0.5	< 0.01	< 0.01
523	6	1	250	2.5	0.02	< 0.01
524	15	1	350	3.0	0.02	0.01
525	5	1	250	2.0	0.02	< 0.01
526	6	1	450	3.5	0.02	0.02
527	9	1	150	1.0	0.01	< 0.01
528	3	1	100	0.5	< 0.01	< 0.01
529	11	1	200	1.5	0.02	< 0.01
530	3	1	25	< 0.5	< 0.01	< 0.01
531	14	1	1100	1.0	0.04	0.03
532	5	1	1350	6.5	0.06	0.25
533	5	1	100	1.5	0.02	0.02
534	6	1	1200	3.5	0.10	0.04
535	3	1	900	1.0	0.09	0.02
536	5	1	1000	1.0	0.09	0.02
537	6	1	1050	1.5	0.03	0.11
538	7	1	1350	2.5	0.06	0.12
539	5	1	950	1.5	0.11	0.02
540	7	1	1000	2.0	0.04	0.06
541	15	1	900	2.5	0.04	0.03
542	6	1	750	2.5	0.08	0.02
543	7	1	900	2.5	0.04	0.03
544	13	1	700	1.5	0.03	0.11
545	9	1	500	3.5	0.04	0.05
546	7	1	25	< 0.5	< 0.01	< 0.01
547	16	1	< 20	< 0.5	< 0.01	< 0.01
548	5	1	500	4.0	0.05	0.06
549	3	1	550	4.0	0.02	0.07
550	16	1	500	4.0	0.05	0.07

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
551	8	1	700	1.5	0.08	0.10
552	5	1	800	2.5	0.09	0.02
553	3	1	950	3.0	0.04	0.03
554	9	1	450	5.0	0.06	0.02
555	14	1	300	4.0	0.05	0.02
556	5	1	750	2.0	0.03	0.11
557	10	1	750	2.5	0.03	0.05
558	13	1	650	2.5	0.03	0.05
559	16	1	700	2.0	0.03	0.04
560	4	1	700	2.0	0.03	0.04
561	8	1	600	3.0	0.02	0.06
562	11	1	200	2.0	0.02	0.02
563	6	1	400	4.0	0.05	0.04
564	5	1	150	1.5	0.02	< 0.01
565	6	1	100	1.0	0.01	< 0.01
566	6	1	75	0.5	0.01	< 0.01
567	17	1	25	< 0.5	< 0.01	< 0.01
568	9	1	25	< 0.5	< 0.01	< 0.01
569	3	1	25	< 0.5	< 0.01	< 0.01
570	10	1	25	< 0.5	< 0.01	< 0.01
571	3	1	25	< 0.5	< 0.01	< 0.01
572	11	1	25	< 0.5	< 0.01	< 0.01
573	3	1	50	< 0.5	< 0.01	< 0.01
574	6	1	100	1.0	0.02	< 0.01
575	5	1	50	< 0.5	< 0.01	< 0.01
576	2	1	25	< 0.5	< 0.01	< 0.01
577	7	1	50	< 0.5	< 0.01	< 0.01
578	4	1	50	< 0.5	< 0.01	< 0.01
579	17	1	1400	1.5	0.03	0.14
580	9	1	1350	1.5	0.03	0.08
581	7	1	400	5.5	0.07	0.05
582	5	1	350	4.5	0.06	0.04
583	6	1	50	0.5	< 0.01	< 0.01
584	3	1	1300	4.0	0.05	0.20
585	3	1	250	2.0	0.02	< 0.01
586	7	1	250	2.0	0.02	< 0.01
587	8	1	850	9.0	0.09	0.02
588	3	1	1000	2.5	0.07	0.16
589	8	1	200	1.5	0.01	< 0.01
590	5	1	150	1.5	< 0.01	< 0.01
591	10	1	150	1.5	< 0.01	< 0.01
592	18	1	750	2.0	0.03	0.11
593	10	1	900	2.5	0.04	0.03
594	10	1	1300	7.5	0.25	0.25
595	3	1	250	3.5	0.07	0.03
596	7	1	1250	3.5	0.06	0.05
597	11	1	1300	6.5	0.05	0.06
598	14	1	1350	5.5	0.05	0.06
599	2	1	75	0.5	< 0.01	< 0.01
600	3	1	200	2.0	0.02	< 0.01
601	5	1	50	< 0.5	< 0.01	< 0.01
602	6	1	1000	1.5	0.09	0.02
603	8	1	1000	1.5	0.03	0.03
604	13	1	100	1.5	0.02	< 0.01
605	12	1	950	2.0	0.08	0.11

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
606	6	1	750	1.0	0.09	0.13
607	7	1	25	< 0.5	< 0.01	< 0.01
608	8	1	75	1.0	< 0.01	< 0.01
609	12	1	75	1.0	< 0.01	< 0.01
610	15	1	1100	5.5	0.25	0.03
611	15	1	800	3.0	0.11	0.02
612	11	1	1050	1.0	0.08	0.02
613	11	1	1350	7.5	0.06	0.25
614	3	1	950	2.5	0.11	0.09
615	4	1	75	0.5	< 0.01	< 0.01
616	10	1	1400	9.5	0.11	0.05
617	9	1	1700	4.0	0.13	0.04
618	5	1	75	0.5	< 0.01	< 0.01
619	3	1	1300	2.5	0.10	0.12
620	3	1	1500	2.0	0.04	0.14
621	13	1	1450	2.5	0.04	0.04
622	4	1	1400	2.5	0.04	0.03
623	3	1	1500	2.0	0.04	0.15
624	3	1	2050	1.5	0.16	0.04
625	3	1	2300	3.0	0.05	0.07
626	11	1	1250	3.0	0.04	0.18
627	3	1	1250	4.5	0.04	0.18
628	4	1	1250	4.5	0.04	0.18
629	3	1	1200	2.0	0.05	0.03
630	3	1	1050	3.0	0.05	0.04
631	3	1	1100	3.0	0.05	0.04
632	6	1	1100	2.5	0.05	0.03
633	3	1	1100	1.5	0.13	0.03
634	5	1	250	2.5	0.02	0.01
635	6	1	25	< 0.5	< 0.01	< 0.01
636	13	1	1300	2.0	0.05	0.18
637	6	1	1250	2.0	0.04	0.06
638	25	1	50	< 0.5	< 0.01	< 0.01
639	7	1	25	< 0.5	< 0.01	< 0.01
640	6	1	25	< 0.5	< 0.01	< 0.01
641	7	1	1000	3.0	0.11	0.18
642	12	1	700	2.0	0.02	0.09
643	6	1	1100	3.0	0.25	0.04
644	21	1	< 20	< 0.5	< 0.01	< 0.01
645	14	1	75	0.5	< 0.01	< 0.01
646	13	1	1350	3.0	0.07	0.05
647	16	1	950	3.5	0.05	0.02
648	22	1	1250	2.0	0.04	0.03
649	12	1	1300	5.5	0.10	0.20
650	10	1	1300	1.0	0.04	0.17
651	4	1	1250	1.5	0.06	0.02
652	4	1	1250	5.0	0.09	0.19
653	8	1	150	1.5	0.02	< 0.01
654	36	1	1450	4.0	0.04	0.19
655	7	1	1300	1.5	0.04	0.03
656	20	1	1250	1.5	0.11	0.02
657	7	1	1300	2.5	0.08	0.15
658	4	1	1300	1.5	0.04	0.04
659	7	1	1300	1.5	0.04	0.04
660	10	1	1400	2.0	0.03	0.04

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
661	8	1	1450	1.0	0.07	0.15
662	11	1	1450	1.0	0.09	0.15
663	11	1	1400	2.0	0.04	0.04
664	11	1	1200	1.5	0.11	0.02
665	11	1	1250	2.0	0.10	0.02
666	4	1	1300	2.0	0.04	0.15
667	34	1	1300	2.0	0.04	0.04
668	7	1	1200	1.5	0.08	0.03
669	7	1	1200	1.5	0.07	0.03
670	6	1	1250	2.0	0.04	0.03
671	7	1	1250	3.0	0.12	0.05
672	5	1	1200	2.5	0.11	0.02
673	8	1	1300	3.0	0.04	0.17
674	7	1	1250	2.0	0.04	0.04
675	8	1	1250	2.0	0.04	0.04
676	8	1	1150	2.0	0.07	0.03
677	7	1	1150	2.0	0.06	0.03
678	6	1	1100	3.5	0.13	0.02
679	7	1	1100	3.5	0.13	0.02
680	8	1	50	0.5	< 0.01	< 0.01
681	7	1	150	1.0	0.01	< 0.01
682	10	1	100	1.0	0.01	< 0.01
683	12	1	1100	2.0	0.14	0.03
684	6	1	1300	4.5	0.12	0.19
685	7	1	1150	1.5	0.12	0.03
686	4	1	1200	1.5	0.05	0.03
687	5	1	1250	1.5	0.04	0.04
688	4	1	1300	1.5	0.05	0.04
689	4	1	1300	5.5	0.04	0.20
690	4	1	1300	5.5	0.06	0.20
691	4	1	1350	1.5	0.05	0.16
692	13	1	1200	4.0	0.14	0.06
693	4	1	1200	1.5	0.10	0.03
694	8	1	1200	2.0	0.05	0.03
695	6	1	1200	2.0	0.07	0.03
696	6	1	25	< 0.5	< 0.01	< 0.01
697	6	1	25	< 0.5	< 0.01	< 0.01
698	8	1	25	< 0.5	< 0.01	< 0.01
699	5	1	1300	2.0	0.05	0.04
700	11	1	50	0.5	< 0.01	< 0.01
701	9	1	1350	7.5	0.07	0.25
702	15	1	1200	7.0	0.25	0.07
703	13	1	1300	7.0	0.25	0.25
704	10	1	950	1.5	0.11	0.02
705	9	1	1100	1.5	0.05	0.03
706	15	1	1050	1.5	0.03	0.05
707	10	1	950	2.0	0.03	0.08
708	8	1	25	< 0.5	< 0.01	< 0.01
709	13	1	2150	12.0	0.06	0.25
710	16	1	1750	5.0	0.07	0.05
711	23	1	1950	2.5	0.09	0.04
712	7	1	1950	2.5	0.09	0.04
713	18	1	2250	10.5	0.07	0.30
714	14	1	200	3.0	0.04	0.02
715	16	1	150	2.0	0.02	0.01

Table D.02 - Rural Building Structures within the Study Area Maximum Predicted Conventional Subsidence Parameters

Structure No.	Longest Side (m)	No. of Storeys	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)
716	17	1	150	1.5	0.01	< 0.01
717	5	1	700	5.5	0.03	0.08
718	8	1	1050	8.5	0.09	0.07
719	3	1	< 20	< 0.5	< 0.01	< 0.01
720	10	1	75	1.0	< 0.01	< 0.01
721	7	1	75	1.0	0.01	< 0.01
722	8	1	100	1.5	0.02	< 0.01
723	4	1	75	< 0.5	< 0.01	< 0.01
724	5	1	250	3.5	0.06	< 0.01
725	14	1	550	6.0	0.07	0.03
726	5	1	150	2.0	0.03	< 0.01
727	6	1	100	1.5	0.02	< 0.01
728	6	1	850	2.5	0.08	0.02
729	5	1	750	2.0	0.08	0.05
730	13	1	900	2.5	0.03	0.02
731	13	1	25	< 0.5	< 0.01	< 0.01
732	5	1	25	< 0.5	< 0.01	< 0.01
733	12	1	50	< 0.5	< 0.01	< 0.01
734	13	1	25	< 0.5	< 0.01	< 0.01
735	12	1	25	< 0.5	< 0.01	< 0.01
736	7	1	600	3.0	0.02	0.05
737	7	1	150	1.5	0.02	< 0.01
738	14	1	1000	2.5	0.07	0.16
739	9	1	1100	8.5	0.09	0.11
740	8	1	< 20	< 0.5	< 0.01	< 0.01
741	18	1	< 20	< 0.5	0.01	< 0.01
742	19	1	< 20	< 0.5	< 0.01	< 0.01
743	17	1	< 20	< 0.5	0.01	< 0.01
744	19	1	< 20	< 0.5	< 0.01	< 0.01
745	33	1	< 20	< 0.5	< 0.01	< 0.01
746	24	1	950	1.5	0.11	0.02
747	8	1	1050	2.0	0.04	0.03
748	18	1	350	3.5	0.05	0.03
749	14	1	1150	1.5	0.07	0.03
750	9	1	1150	1.5	0.12	0.03
751	12	1	1350	3.0	0.05	0.20
752	24	1	25	< 0.5	< 0.01	< 0.01
753	11	1	1300	6.0	0.25	0.25
754	8	1	< 20	< 0.5	< 0.01	< 0.01
755	5	1	< 20	< 0.5	< 0.01	< 0.01
		Maximums:	**2350**	**13**	**0.25**	**0.30**

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
1	33	561	1200	1.5	4.0	0.05	0.04	< 50
2	48	1041	1250	2.0	4.5	0.05	0.16	< 50
3	29	520	1200	1.5	4.0	0.05	0.05	< 50
4	38	1000	1400	2.0	4.5	0.06	0.13	< 50
5	22	295	1400	6.0	10.0	0.05	0.25	75
6	8	47	1400	1.0	4.5	0.06	0.13	< 50
7	39	885	400	4.5	4.5	0.05	0.01	100
8	44	781	550	6.0	6.0	0.15	0.02	200
9	18	190	450	7.5	8.0	0.15	0.04	100
10	17	204	800	8.0	9.5	0.25	0.03	100
11	26	335	1100	5.0	5.0	0.06	0.20	100
12	29	427	1350	2.0	4.0	0.05	0.05	< 50
13	39	891	1350	2.0	4.0	0.05	0.05	< 50
14	22	264	1200	1.5	4.0	0.08	0.03	< 50
15	21	316	1300	2.0	4.0	0.05	0.04	< 50
16	21	237	1250	2.0	4.0	0.06	0.04	< 50
17	74	624	1500	7.5	11.5	0.25	0.30	300
18	11	85	1250	2.5	4.0	0.05	0.04	< 50
19	35	327	1450	2.5	4.5	0.06	0.07	< 50
20	24	660	1400	2.5	4.5	0.06	0.05	50
21	19	184	1250	2.5	4.5	0.06	0.04	< 50
22	24	306	1400	2.0	5.0	0.06	0.20	< 50
23	38	721	1400	2.5	5.0	0.07	0.25	< 50
24	48	984	1350	2.5	4.5	0.07	0.05	75
25	21	224	1050	2.5	7.0	0.25	0.03	< 50
26	31	598	1250	9.5	11.5	0.06	0.30	200
27	26	346	1200	3.5	4.0	0.06	0.04	75
28	24	312	1050	3.0	6.5	0.25	0.04	< 50
29	41	886	1350	2.5	4.5	0.06	0.05	75
30	26	415	1200	2.5	4.0	0.05	0.04	50
31	25	423	950	2.5	7.5	0.20	0.03	< 50
32	25	400	850	5.5	6.0	0.04	0.11	100
33	88	2241	25	0.5	0.5	< 0.01	< 0.01	< 50
34	58	1917	1050	4.5	9.0	0.20	0.25	100
35	25	332	1050	4.0	8.5	0.18	0.13	75
36	81	2094	1250	2.0	4.0	0.05	0.14	100
37	54	763	1050	5.0	9.5	0.25	0.03	75
38	38	818	900	3.0	3.5	0.04	0.14	100
39	34	696	500	5.0	5.0	0.06	0.03	200
40	26	431	50	0.5	0.5	< 0.01	< 0.01	< 50
41	20	247	500	7.5	7.5	0.11	0.03	100
42	11	85	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
43	44	961	50	1.0	1.0	0.01	< 0.01	< 50
44	58	1036	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
45	44	1131	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
46	45	692	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
47	13	49	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
48	34	590	50	0.5	0.5	< 0.01	< 0.01	< 50
49	46	918	25	0.5	0.5	< 0.01	< 0.01	< 50
50	28	375	100	1.0	1.0	0.01	< 0.01	< 50
51	33	661	< 20	< 0.5	< 0.5	0.01	< 0.01	< 50
52	22	284	100	1.5	1.5	0.02	< 0.01	< 50
53	17	124	75	1.0	1.0	0.01	< 0.01	< 50
54	31	507	900	4.0	4.0	0.04	0.05	100
55	20	201	1100	2.0	3.5	0.05	0.03	< 50
56	23	355	1150	1.5	4.0	0.10	0.03	< 50
57	30	506	1250	4.0	8.5	0.05	0.19	75
58	26	304	1200	6.0	10.0	0.19	0.08	100
59	55	724	1350	1.5	4.0	0.05	0.05	< 50
60	20	230	1250	2.0	4.0	0.05	0.04	< 50
61	31	591	1200	2.5	4.5	0.11	0.04	75
62	84	2811	1400	5.5	10.5	0.19	0.25	300
63	76	2362	1400	2.5	3.5	0.04	0.03	100
64	46	485	1500	2.0	4.0	0.04	0.18	< 50
65	83	1347	1500	2.5	9.5	0.15	0.18	75
66	35	460	1400	2.5	4.0	0.05	0.03	100
67	62	2179	1450	3.0	9.5	0.15	0.15	75

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
68	134	5885	1750	4.0	9.0	0.05	0.25	300
69	35	489	1450	9.0	12.5	0.25	0.06	200
70	48	947	1100	12.0	12.0	0.05	0.20	300
71	20	116	1850	9.0	9.0	0.09	0.35	100
72	32	176	1700	5.5	6.5	0.08	0.06	100
73	7	27	1300	4.5	4.5	0.17	0.04	< 50
74	7	22	1250	14.0	15.0	0.17	0.04	75
75	23	362	2150	2.0	6.0	0.07	0.25	< 50
76	26	208	2250	3.5	7.0	0.08	0.17	< 50
77	59	1706	1900	5.5	6.0	0.11	0.06	300
78	30	208	1700	4.5	10.5	0.15	0.15	100
79	28	212	1750	5.0	5.5	0.11	0.05	100
80	39	622	1800	1.0	10.0	0.17	0.04	< 50
81	15	108	1750	2.5	7.0	0.04	0.20	< 50
82	28	516	1750	2.0	6.5	0.04	0.18	< 50
83	49	1053	1750	2.0	8.5	0.08	0.16	50
84	10	34	1550	2.5	3.5	0.04	0.03	< 50
85	7	33	1650	2.5	4.0	0.04	0.03	< 50
86	6	20	1500	1.5	8.5	0.03	0.12	< 50
87	16	163	1200	2.0	8.5	0.14	0.02	< 50
88	55	1582	1600	2.0	7.5	0.03	0.14	50
89	27	356	1250	1.5	5.0	0.11	0.02	< 50
90	72	1033	1250	4.0	9.0	0.14	0.15	100
91	28	418	1300	4.0	9.0	0.08	0.19	100
92	50	594	1200	2.0	3.5	0.04	0.03	100
93	26	329	1250	2.0	4.0	0.05	0.04	< 50
94	21	273	1250	2.0	4.0	0.05	0.04	< 50
95	43	799	1300	2.0	3.5	0.05	0.06	75
96	23	308	1200	2.0	3.5	0.05	0.04	< 50
97	17	199	1150	5.5	9.5	0.17	0.07	75
98	29	362	1300	2.5	4.5	0.06	0.04	75
99	19	196	950	1.5	3.0	0.05	0.03	< 50
100	17	199	1100	1.5	4.5	0.04	0.18	< 50
101	21	336	900	3.0	8.0	0.15	0.02	< 50
102	51	1216	1050	2.0	3.0	0.04	0.03	50
103	34	710	950	1.5	4.0	0.11	0.03	< 50
104	21	286	1000	2.0	3.0	0.04	0.03	< 50
105	67	1831	1000	2.5	3.0	0.04	0.03	100
106	44	766	950	3.5	8.0	0.14	0.13	75
107	35	748	750	1.5	6.0	0.12	0.15	< 50
108	80	1576	650	3.5	3.5	0.03	0.07	200
109	33	473	550	4.0	4.0	0.02	0.07	100
110	22	228	350	3.5	3.5	0.05	0.04	50
111	35	419	150	1.5	1.5	0.02	< 0.01	< 50
112	31	308	700	2.0	2.0	0.03	0.04	< 50
113	28	429	800	3.0	3.5	0.09	0.03	50
114	30	409	750	1.5	6.0	0.10	0.16	< 50
115	19	210	600	3.0	3.0	0.03	0.03	50
116	26	401	250	3.5	3.5	0.04	0.02	75
117	22	287	100	1.0	1.0	0.02	< 0.01	< 50
118	27	460	50	0.5	0.5	< 0.01	< 0.01	< 50
119	33	625	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
120	39	809	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
121	39	523	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
122	29	462	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
123	20	174	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
124	17	160	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
125	36	699	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
126	41	433	200	2.0	2.0	0.02	< 0.01	75
127	54	1157	350	3.5	3.5	0.04	0.03	100
128	76	2082	200	2.0	2.0	0.02	0.01	100
129	23	349	100	0.5	0.5	< 0.01	< 0.01	< 50
130	22	113	150	1.5	1.5	0.01	< 0.01	< 50
131	40	614	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
132	10	47	2100	3.0	5.0	0.06	0.04	< 50
133	47	1169	1700	3.0	8.0	0.04	0.16	< 50
134	36	837	1700	1.5	6.0	0.03	0.11	< 50

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
135	66	854	1700	1.5	7.5	0.08	0.10	< 50
136	16	139	1800	2.0	4.5	0.06	0.03	< 50
137	20	235	1900	3.0	4.5	0.05	0.04	50
138	49	567	400	4.5	4.5	0.07	< 0.01	50
139	8	26	350	4.0	4.0	0.07	< 0.01	< 50
140	11	50	350	3.5	3.5	0.06	0.02	< 50
141	34	613	150	1.5	1.5	0.01	0.01	< 50
142	71	1797	1450	4.0	6.0	0.03	0.10	200
143	9	46	1450	2.5	3.0	0.03	0.05	< 50
144	15	123	75	0.5	0.5	< 0.01	< 0.01	< 50
145	16	166	2300	2.5	4.5	0.03	0.03	< 50
146	20	297	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
147	32	615	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
148	9	60	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
149	33	654	50	0.5	0.5	< 0.01	< 0.01	< 50
150	25	308	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
151	75	661	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
152	28	369	75	1.0	1.0	0.01	< 0.01	< 50
153	9	60	850	5.0	5.5	0.14	0.05	< 50
154	27	352	1350	1.5	4.0	0.09	0.02	< 50
155	9	43	1200	1.5	3.5	0.06	0.03	< 50
156	17	173	1250	2.0	3.5	0.04	0.03	< 50
157	17	134	1350	2.0	3.5	0.04	0.03	< 50
158	21	251	1400	1.5	3.5	0.03	0.10	< 50
159	33	627	1350	1.5	3.5	0.03	0.11	< 50
160	6	23	1250	1.5	3.0	0.04	0.03	< 50
161	38	702	1300	1.5	3.5	0.04	0.11	< 50
162	74	1052	1250	2.5	7.0	0.03	0.15	< 50
163	17	221	75	0.5	0.5	< 0.01	< 0.01	< 50
164	16	110	50	1.0	1.0	0.01	< 0.01	< 50
165	42	726	50	0.5	0.5	< 0.01	< 0.01	< 50
166	114	2295	75	1.0	1.0	0.01	< 0.01	< 50
167	26	424	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
168	32	407	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
169	20	268	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
170	25	367	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
171	41	689	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
172	26	449	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
173	28	415	75	1.0	1.0	0.01	< 0.01	< 50
174	22	279	250	3.0	3.0	0.04	0.02	50
175	31	569	2050	6.0	6.5	0.06	0.25	100
176	36	409	1100	9.5	9.5	0.14	0.02	200
177	70	1917	2250	8.5	13.0	0.06	0.25	200
178	13	135	2350	4.5	13.0	0.04	0.12	50
179	9	48	100	1.0	1.0	< 0.01	< 0.01	< 50
180	23	352	450	4.5	4.5	0.07	< 0.01	75
181	33	593	1050	9.0	9.0	0.03	0.04	300
182	32	735	1400	8.5	8.5	0.03	0.05	200
183	13	102	1500	1.5	4.0	0.03	0.11	< 50
184	5	19	1600	2.5	3.0	0.03	0.03	< 50
185	41	574	2100	2.5	5.0	0.07	0.03	75
186	13	117	1700	2.5	3.5	0.03	0.08	< 50
187	14	155	2250	3.0	5.0	0.05	0.05	< 50
188	16	154	2100	3.0	5.0	0.05	0.04	< 50
189	14	107	1900	2.0	6.5	0.08	0.03	< 50
190	103	3454	1900	3.0	7.0	0.08	0.10	200
191	18	219	2300	4.0	10.5	0.05	0.25	< 50
192	21	109	2050	1.5	5.5	0.08	0.04	< 50
193	17	150	2050	3.5	12.0	0.17	0.03	< 50
194	23	390	2200	5.0	13.5	0.14	0.07	100
195	20	226	2250	3.0	5.5	0.06	0.11	50
196	39	674	2100	6.5	14.0	0.18	0.07	200
197	63	2438	2150	2.5	6.0	0.07	0.05	100
198	48	1303	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
199	46	335	200	1.5	1.5	0.02	< 0.01	< 50
200	24	210	300	2.5	2.5	0.03	< 0.01	< 50
201	26	330	1250	2.5	5.5	0.04	0.17	< 50

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
202	24	310	1150	1.5	3.0	0.04	0.03	< 50
203	22	295	1250	5.5	9.5	0.04	0.20	100
204	29	298	1300	2.0	4.0	0.05	0.04	50
205	32	519	1300	2.5	5.0	0.04	0.19	< 50
206	85	2778	1250	1.5	3.5	0.04	0.05	75
207	25	120	1250	4.5	8.0	0.04	0.19	< 50
208	6	21	1100	1.0	3.5	0.07	0.03	< 50
209	5	19	1150	2.5	8.5	0.13	0.02	< 50
210	3	9	1250	2.0	3.5	0.04	0.03	< 50
211	9	60	1200	3.5	9.5	0.15	0.02	< 50
212	8	46	1150	1.5	3.5	0.04	0.03	< 50
213	61	1021	1300	4.0	8.5	0.04	0.18	100
214	27	127	1250	1.5	3.5	0.04	0.03	50
215	9	41	1150	1.0	3.5	0.05	0.03	< 50
216	15	123	1200	1.5	3.5	0.04	0.03	< 50
217	134	2163	650	7.0	7.0	0.07	0.02	200
218	14	105	200	1.5	1.5	0.02	< 0.01	< 50
219	24	339	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
220	55	1776	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
221	35	744	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
222	7	30	50	0.5	0.5	< 0.01	< 0.01	< 50
223	24	295	150	1.5	1.5	0.01	0.01	< 50
224	41	636	100	1.0	1.0	0.01	< 0.01	< 50
225	31	527	350	4.0	4.0	0.06	0.01	75
226	17	177	850	10.0	10.0	0.03	0.14	100
227	72	2602	650	7.0	7.0	0.13	0.02	300
228	61	1849	1650	5.5	5.5	0.06	0.20	100
229	10	73	1600	3.0	3.5	0.03	0.03	< 50
230	36	512	1950	3.0	5.0	0.09	0.04	100
231	21	291	1800	1.5	8.0	0.04	0.12	< 50
232	42	916	1900	2.5	7.5	0.10	0.04	100
233	103	3974	2150	3.5	5.5	0.09	0.04	300
234	38	1058	1500	4.5	11.0	0.14	0.04	100
235	59	1936	1400	3.0	9.5	0.15	0.02	< 50
236	23	341	1500	2.5	3.0	0.05	0.02	< 50
237	19	52	1650	2.5	3.0	0.03	0.06	< 50
238	72	775	1900	3.0	7.0	0.08	0.11	200
239	22	217	1500	2.5	9.0	0.09	0.02	< 50
240	36	759	1550	3.5	4.0	0.04	0.07	75
241	19	143	200	2.0	2.0	0.02	< 0.01	< 50
242	24	145	500	4.5	4.5	0.05	0.02	75
243	15	158	1350	4.0	4.0	0.04	0.03	50
244	26	335	500	4.0	4.0	0.03	0.02	100
245	37	468	1450	4.0	4.0	0.04	0.04	100
246	21	280	1500	4.0	4.5	0.05	0.07	75
247	12	75	1350	2.5	3.5	0.04	0.03	< 50
248	18	189	1250	4.5	4.5	0.04	0.09	75
249	126	5919	650	5.5	5.5	0.09	0.04	300
250	52	1172	250	3.5	3.5	0.07	0.01	100
251	29	307	900	5.0	5.0	0.05	0.05	75
252	7	33	400	6.0	6.0	0.07	< 0.01	< 50
253	136	13976	1350	3.0	4.5	0.06	0.20	200
254	33	422	1300	4.5	9.0	0.08	0.17	75
255	24	260	1250	3.5	8.0	0.03	0.17	50
256	45	1158	1300	1.5	3.5	0.04	0.16	< 50
257	14	115	1150	2.0	3.0	0.04	0.03	< 50
258	15	158	1050	1.5	3.0	0.05	0.03	< 50
259	30	374	1250	2.0	3.5	0.04	0.04	< 50
260	12	94	1100	1.5	3.5	0.04	0.03	< 50
261	16	171	1400	8.0	10.5	0.06	0.30	100
262	20	272	300	6.0	6.0	0.10	0.02	75
263	69	839	1300	2.5	5.0	0.07	0.05	100
264	80	3345	1250	1.5	3.5	0.05	0.03	100
265	48	1081	1000	2.0	6.0	0.05	0.12	100
266	13	111	900	3.0	4.5	0.06	0.03	< 50
267	25	214	1000	2.0	6.0	0.08	0.02	< 50
268	42	584	800	5.0	5.5	0.10	0.10	200

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
269	37	562	100	1.5	1.5	0.02	< 0.01	< 50
270	28	444	300	3.5	3.5	0.04	< 0.01	75
271	36	261	850	3.0	3.0	0.05	0.05	50
272	22	191	800	3.0	3.0	0.04	0.05	< 50
273	13	89	1350	1.0	4.0	0.04	0.05	< 50
274	69	694	1350	1.5	4.0	0.04	0.05	< 50
275	46	820	1300	3.5	4.5	0.04	0.05	100
276	14	87	300	2.5	2.5	0.02	< 0.01	< 50
277	15	124	350	2.5	2.5	0.01	< 0.01	< 50
278	12	85	650	4.0	4.0	0.02	0.02	50
279	31	458	250	2.0	2.0	0.02	< 0.01	< 50
280	24	164	75	< 0.5	< 0.5	< 0.01	< 0.01	< 50
281	21	149	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
282	28	362	75	< 0.5	< 0.5	< 0.01	< 0.01	< 50
283	24	310	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
284	42	449	75	0.5	0.5	< 0.01	< 0.01	< 50
285	11	86	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
286	27	207	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
287	213	17528	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
288	183	4118	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
289	44	839	350	3.0	3.0	0.03	0.02	100
290	53	1327	200	2.0	2.0	0.02	< 0.01	75
291	30	506	200	1.5	1.5	0.02	< 0.01	< 50
292	119	1448	1250	3.0	4.0	0.04	0.04	100
293	66	1498	1250	2.0	3.0	0.06	0.03	75
294	28	242	1250	2.0	3.0	0.06	0.02	< 50
295	31	241	700	2.5	2.5	0.03	0.06	50
296	37	77	75	1.0	1.0	< 0.01	< 0.01	< 50
297	16	133	1350	2.0	4.5	0.06	0.10	< 50
298	21	213	1100	6.0	10.0	0.16	0.12	75
299	60	1522	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
300	31	583	200	3.0	3.0	0.03	< 0.01	75
301	22	202	1250	1.5	3.5	0.04	0.03	< 50
302	25	436	1000	1.5	3.0	0.04	0.11	< 50
303	27	432	950	2.5	3.0	0.04	0.03	50
304	20	262	500	4.0	4.0	0.02	0.07	75
305	52	661	1000	2.5	7.0	0.06	0.16	75
306	31	450	550	3.0	3.0	0.02	0.07	50
307	22	345	700	< 0.5	3.0	0.05	0.06	< 50
308	44	700	200	1.5	1.5	0.02	0.01	< 50
309	24	356	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
310	12	34	1100	1.0	3.5	0.07	0.03	< 50
311	14	129	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
312	15	158	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
313	24	170	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
314	22	327	50	1.0	1.0	0.01	< 0.01	< 50
315	59	1534	75	1.5	1.5	0.02	< 0.01	50
316	256	24517	450	3.5	3.5	0.02	0.02	400
317	21	290	75	< 0.5	< 0.5	< 0.01	< 0.01	< 50
318	15	110	75	< 0.5	< 0.5	< 0.01	< 0.01	< 50
319	25	346	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
320	35	628	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
321	32	329	75	0.5	0.5	< 0.01	< 0.01	< 50
322	19	236	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
323	53	695	2050	2.5	6.0	0.07	0.08	100
324	10	52	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
325	12	65	1150	9.5	9.5	0.01	0.06	100
326	282	12214	2100	5.0	12.0	0.15	0.25	300
327	25	318	950	1.0	2.5	0.03	0.02	< 50
328	23	353	950	1.0	3.5	0.08	0.02	< 50
329	15	152	1050	1.0	6.0	0.02	0.08	< 50
330	46	688	250	2.0	2.0	0.02	< 0.01	75
331	14	104	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
332	52	1111	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
333	33	345	900	1.0	6.5	0.12	0.02	< 50
334	21	192	1250	1.5	3.5	0.04	0.12	< 50
335	9	59	1350	1.0	4.0	0.05	0.07	< 50

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

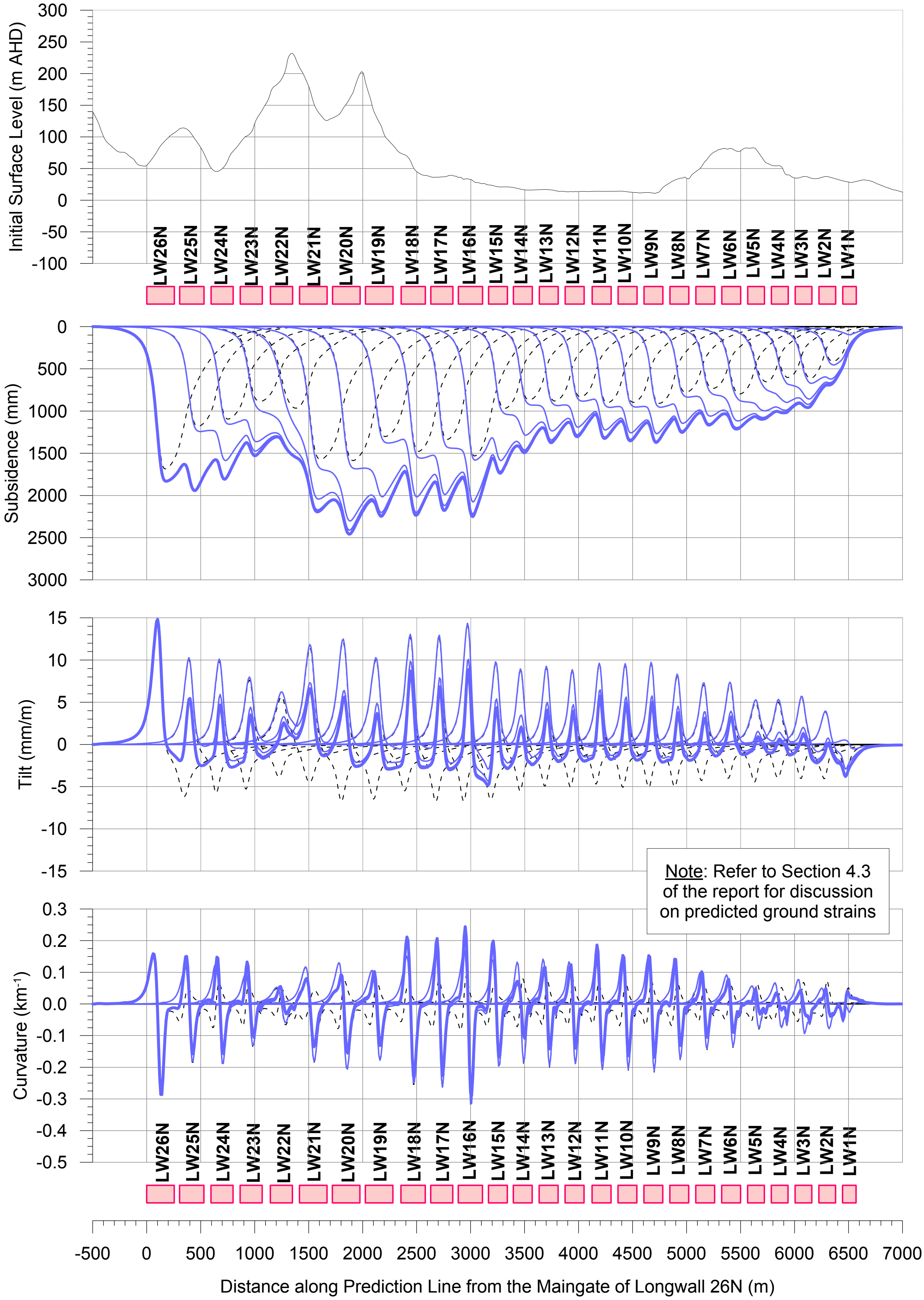
Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
336	13	101	1350	3.5	6.0	0.05	0.20	< 50
337	22	284	1350	2.5	5.0	0.05	0.20	< 50
338	15	135	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
339	7	40	1100	2.0	8.0	0.25	0.03	< 50
340	15	130	950	1.5	2.5	0.06	0.02	< 50
341	24	408	1000	1.5	2.5	0.03	0.03	< 50
342	29	370	1050	1.0	4.5	0.03	0.12	< 50
343	13	84	900	1.0	3.0	0.08	0.02	< 50
344	25	197	750	1.5	4.0	0.05	0.02	< 50
345	15	107	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
346	94	3577	1300	4.0	9.0	0.13	0.18	200
347	16	124	1700	5.0	10.0	0.04	0.20	< 50
348	9	55	100	0.5	0.5	0.01	< 0.01	< 50
349	13	119	250	2.5	2.5	0.02	0.02	< 50
350	24	306	500	4.0	4.0	0.03	0.06	100
351	29	402	1100	6.5	10.5	0.25	0.03	100
352	20	240	1100	3.0	4.0	0.05	0.11	< 50
353	16	135	1100	1.0	6.0	0.10	0.02	< 50
354	41	616	1600	3.5	4.5	0.05	0.04	75
355	13	119	1250	2.5	4.5	0.06	0.04	< 50
356	30	469	2200	3.5	6.5	0.07	0.17	100
357	39	625	1850	5.0	7.0	0.09	0.07	100
358	9	34	1400	2.5	3.5	0.04	0.04	< 50
359	15	57	2200	2.0	5.5	0.06	0.06	< 50
360	51	357	1250	2.0	3.5	0.04	0.04	100
361	13	75	1050	3.5	8.5	0.19	0.02	< 50
362	27	344	1150	1.5	7.5	0.15	0.03	< 50
363	36	701	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
364	16	169	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
365	23	230	200	2.0	2.0	0.02	0.01	< 50
366	24	347	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
367	24	402	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
368	13	97	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
369	10	61	100	1.0	1.0	< 0.01	< 0.01	< 50
370	27	393	1700	1.0	5.0	0.03	0.12	< 50
371	7	22	1500	1.0	5.0	0.03	0.13	< 50
372	8	37	1050	1.0	4.5	0.12	0.02	< 50
373	16	122	1150	1.0	4.0	0.09	0.02	< 50
374	28	367	1300	1.0	3.0	0.03	0.07	< 50
375	17	122	1150	2.0	3.0	0.03	0.03	< 50
376	43	229	1200	4.5	8.5	0.04	0.17	75
377	44	396	1100	2.0	3.0	0.04	0.03	< 50
378	24	144	850	6.5	6.5	0.08	0.02	100
379	54	840	100	1.0	1.0	< 0.01	< 0.01	< 50
380	124	3342	150	1.0	1.0	< 0.01	< 0.01	75
381	36	334	1300	2.5	6.0	0.04	0.19	< 50
382	18	190	1150	1.0	4.5	0.11	0.03	< 50
383	25	285	75	1.0	1.0	< 0.01	< 0.01	< 50
384	22	217	100	1.5	1.5	0.02	< 0.01	< 50
385	56	777	1350	4.0	9.5	0.05	0.20	100
386	32	352	1100	4.5	8.5	0.10	0.13	75
387	47	542	1200	1.5	4.0	0.09	0.03	50
388	29	432	1200	4.0	9.5	0.14	0.05	75
389	106	4204	1400	2.0	4.0	0.05	0.18	75
390	111	3417	1300	2.5	3.5	0.04	0.03	100
391	23	324	1100	1.5	4.0	0.09	0.03	< 50
392	50	909	200	2.5	2.5	0.03	0.02	< 50
393	25	449	550	4.5	4.5	0.04	0.02	100
394	18	195	800	7.5	7.5	0.09	0.02	100
395	33	204	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
396	29	195	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
397	12	89	50	< 0.5	< 0.5	< 0.01	< 0.01	< 50
398	37	703	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
399	12	71	25	< 0.5	< 0.5	< 0.01	< 0.01	< 50
400	173	1685	1250	4.5	4.5	0.06	0.14	400
401	71	511	1200	6.0	10.5	0.15	0.25	300
402	187	2454	550	4.5	4.5	0.04	0.06	500

Table D.03 - Farm Dams within Study Area
Maximum Predicted Conventional Subsidence Parameters

Dam No.	Length (m)	Surface Area (m2)	Maximum Predicted Subsidence after All Longwalls (mm)	Maximum Predicted Tilt after All Longwalls (mm/m)	Maximum Predicted Tilt At Any Time (mm/m)	Maximum Predicted Hogging Curvature At Any Time (1/km)	Maximum Predicted Sagging Curvature At Any Time (1/km)	Maximum Predicted Change in Freeboard after All Longwalls (mm)
403	14	89	600	4.5	4.5	0.04	0.08	75
404	120	1826	500	5.5	5.5	0.08	0.08	400
405	46	816	75	1.5	1.5	0.02	< 0.01	< 50
406	14	153	250	2.5	2.5	0.02	0.03	< 50
407	39	282	1700	4.5	10.0	0.05	0.25	75
408	19	225	1400	1.0	5.0	0.10	0.02	< 50
409	19	94	1400	0.5	4.5	0.04	0.18	< 50
410	37	506	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
411	70	780	< 20	< 0.5	< 0.5	0.01	< 0.01	< 50
412	48	1076	50	0.5	0.5	< 0.01	< 0.01	< 50
413	80	2774	50	0.5	0.5	< 0.01	< 0.01	< 50
414	22	211	< 20	< 0.5	< 0.5	< 0.01	< 0.01	< 50
415	59	1208	1200	3.5	8.0	0.05	0.16	100
416	48	448	1250	4.5	8.5	0.04	0.17	75
417	14	77	1200	1.5	3.5	0.04	0.03	< 50
418	26	325	1100	1.5	5.0	0.09	0.03	< 50
419	42	684	650	5.5	5.5	0.04	0.05	200
420	13	105	1050	0.5	3.5	0.04	0.17	< 50
		Maximums:	**2350**	**14**	**15**	**0.25**	**0.35**	**500**

APPENDIX E. FIGURES

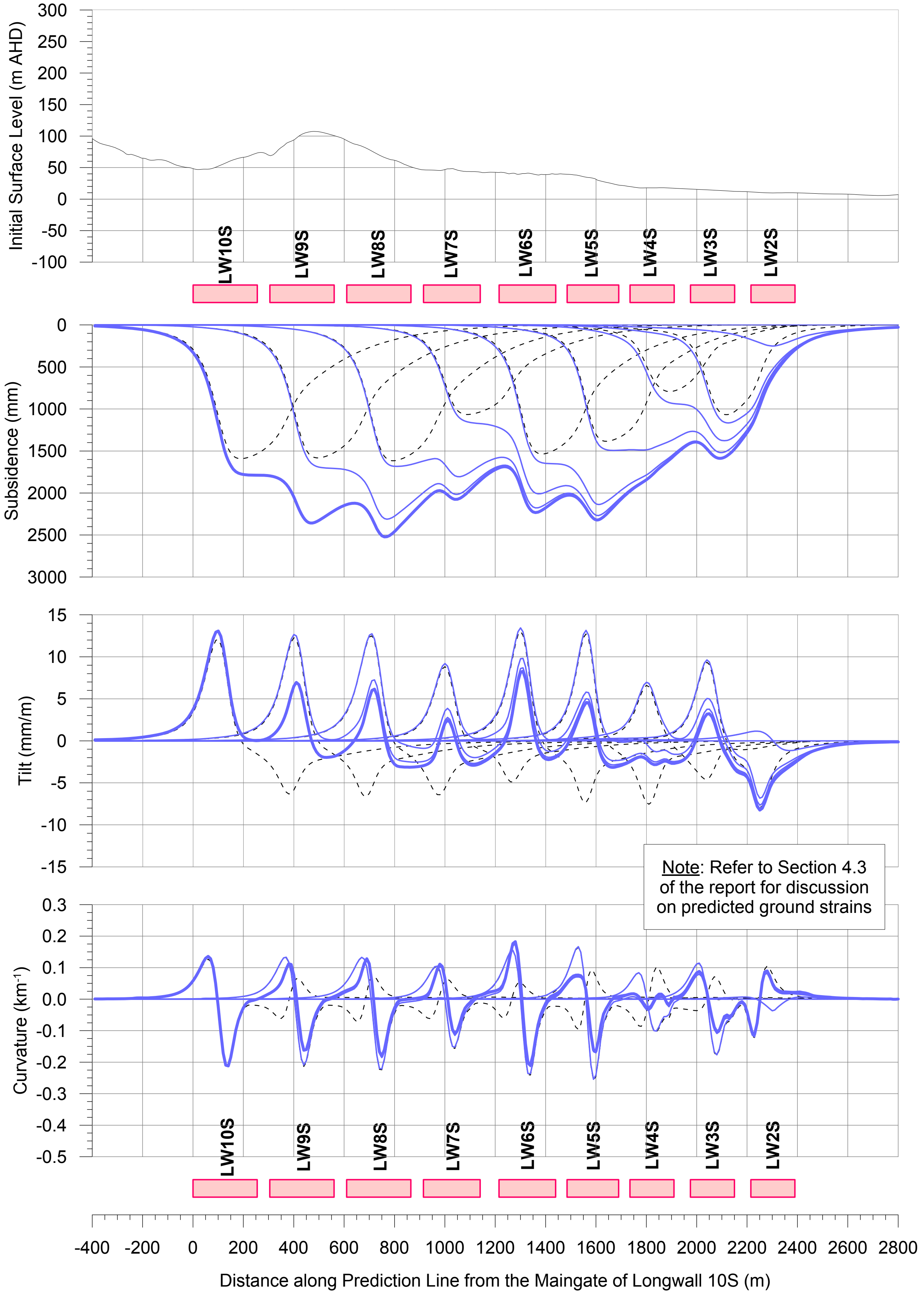
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 1 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.01

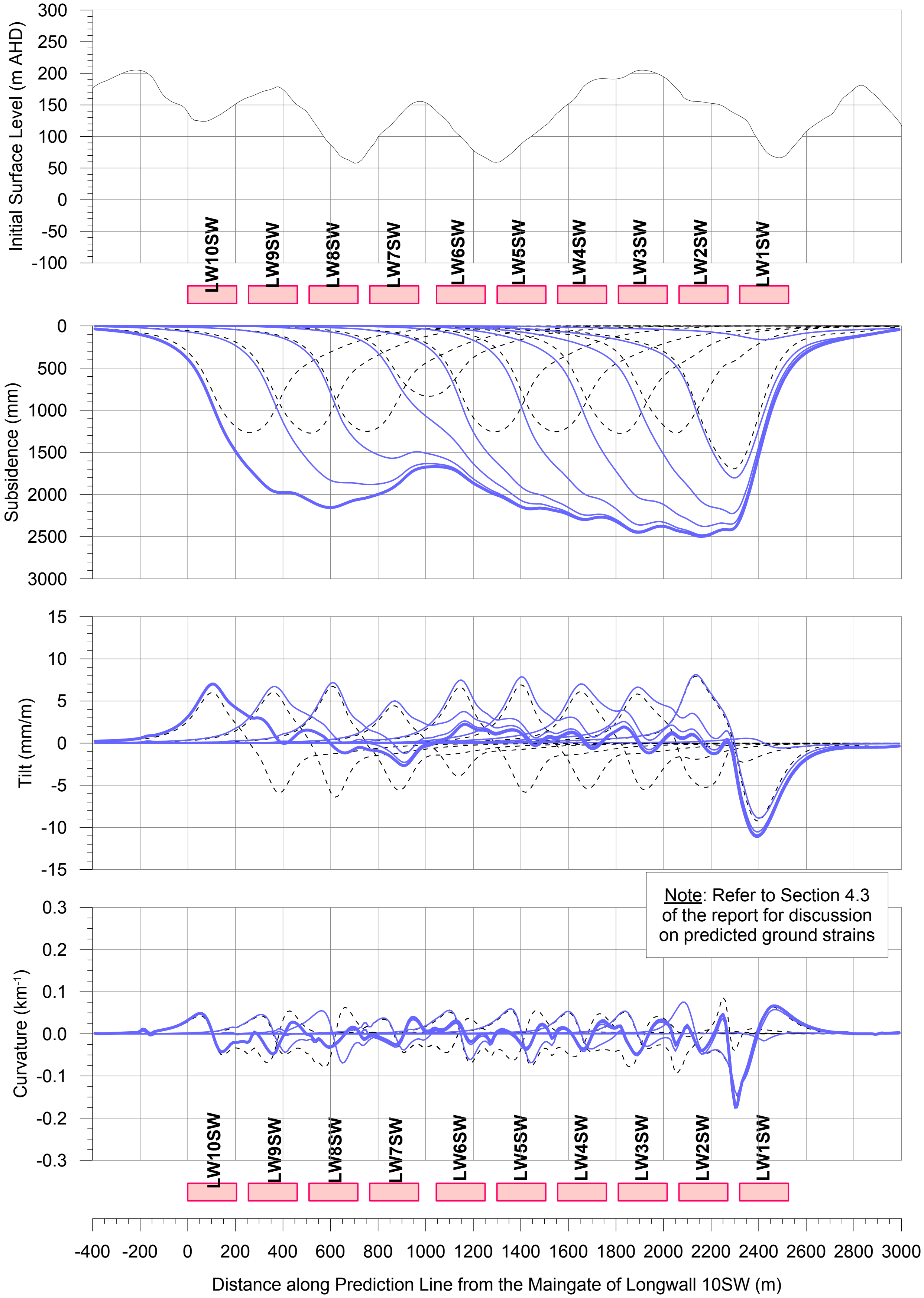
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 2 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.02

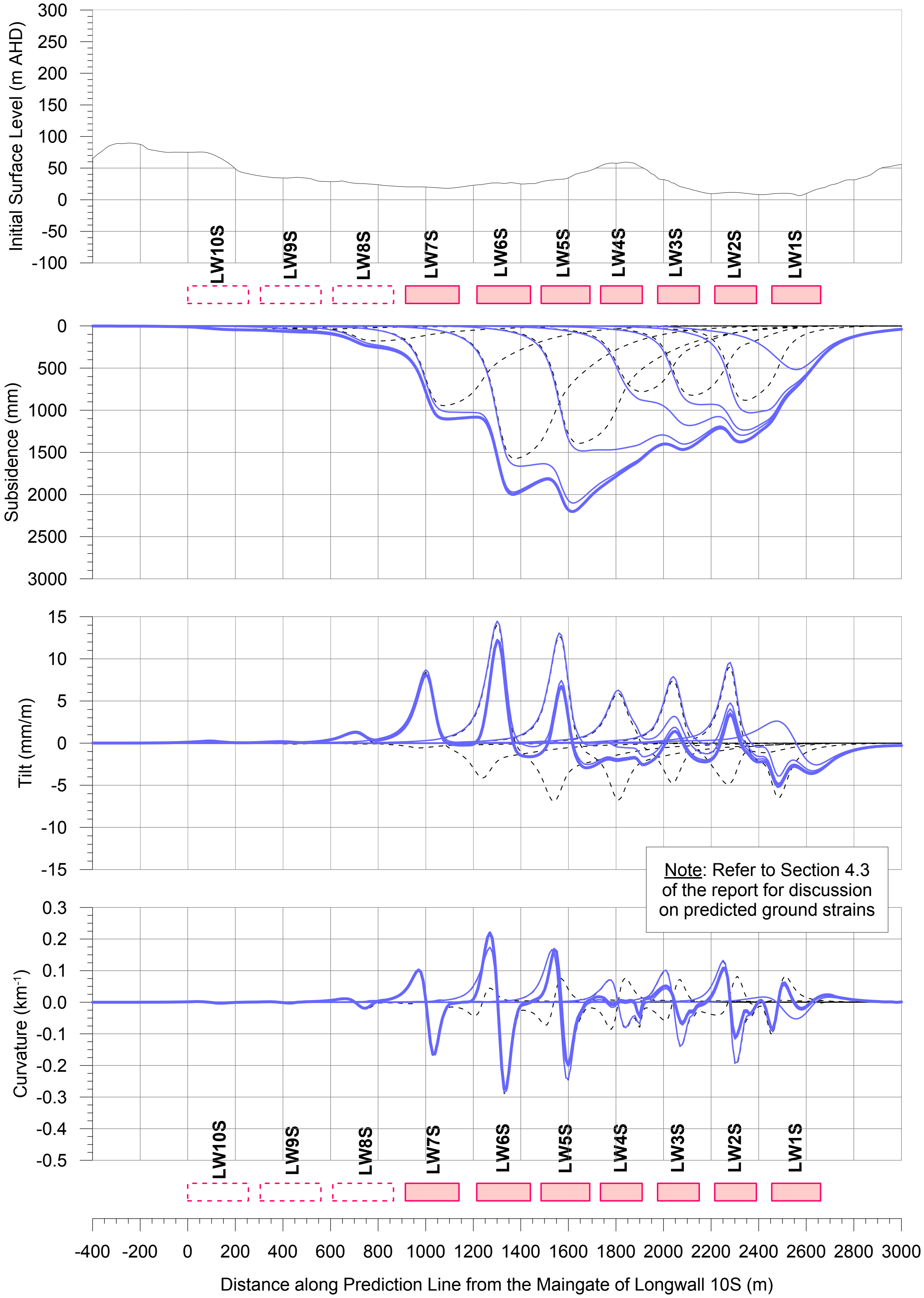
Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 3 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.03

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Prediction Line 4 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.04

Predicted Profiles of Subsidence, Upsidence and Closure along the Wyong River Resulting from the Extraction of the Proposed Longwalls

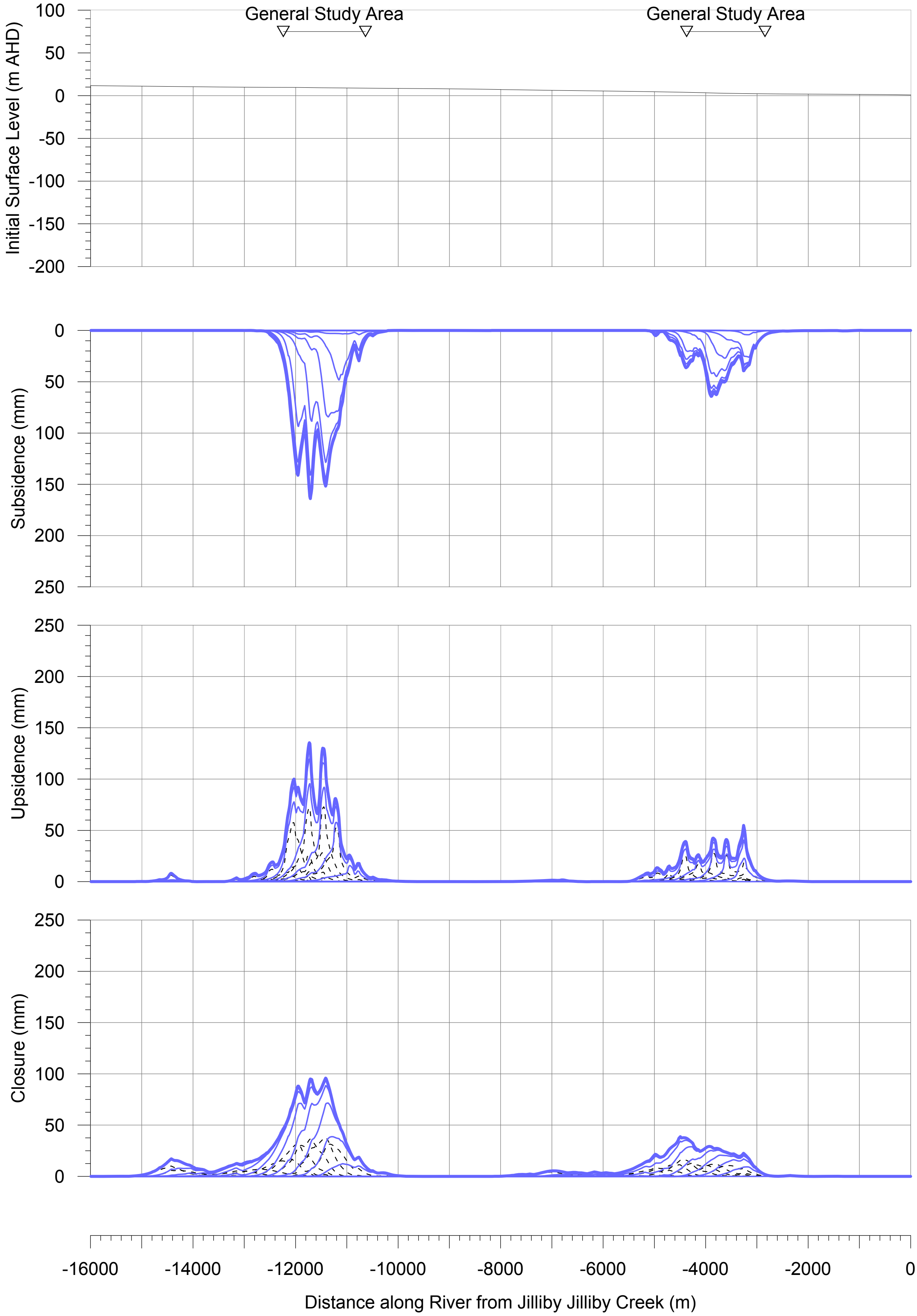
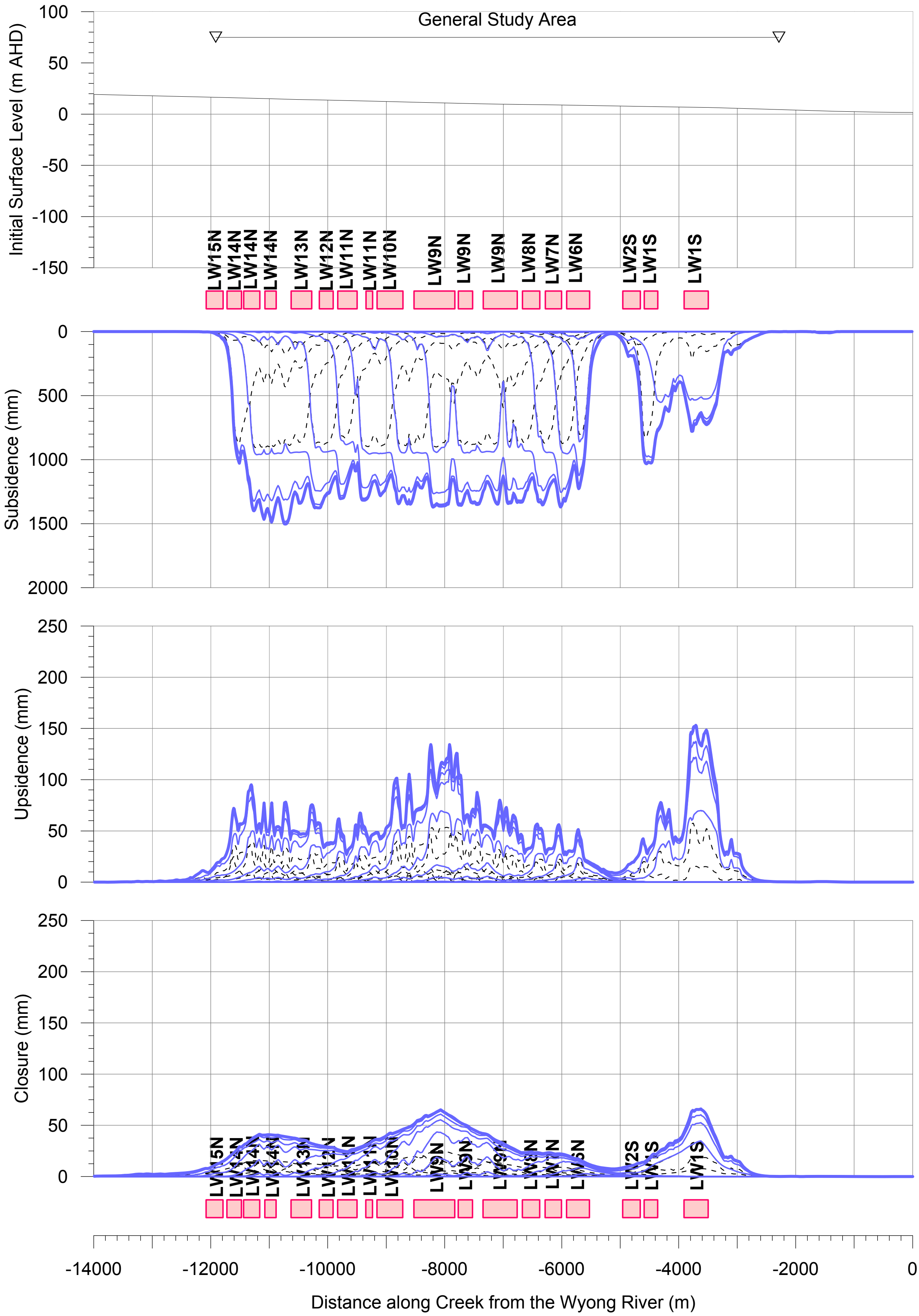


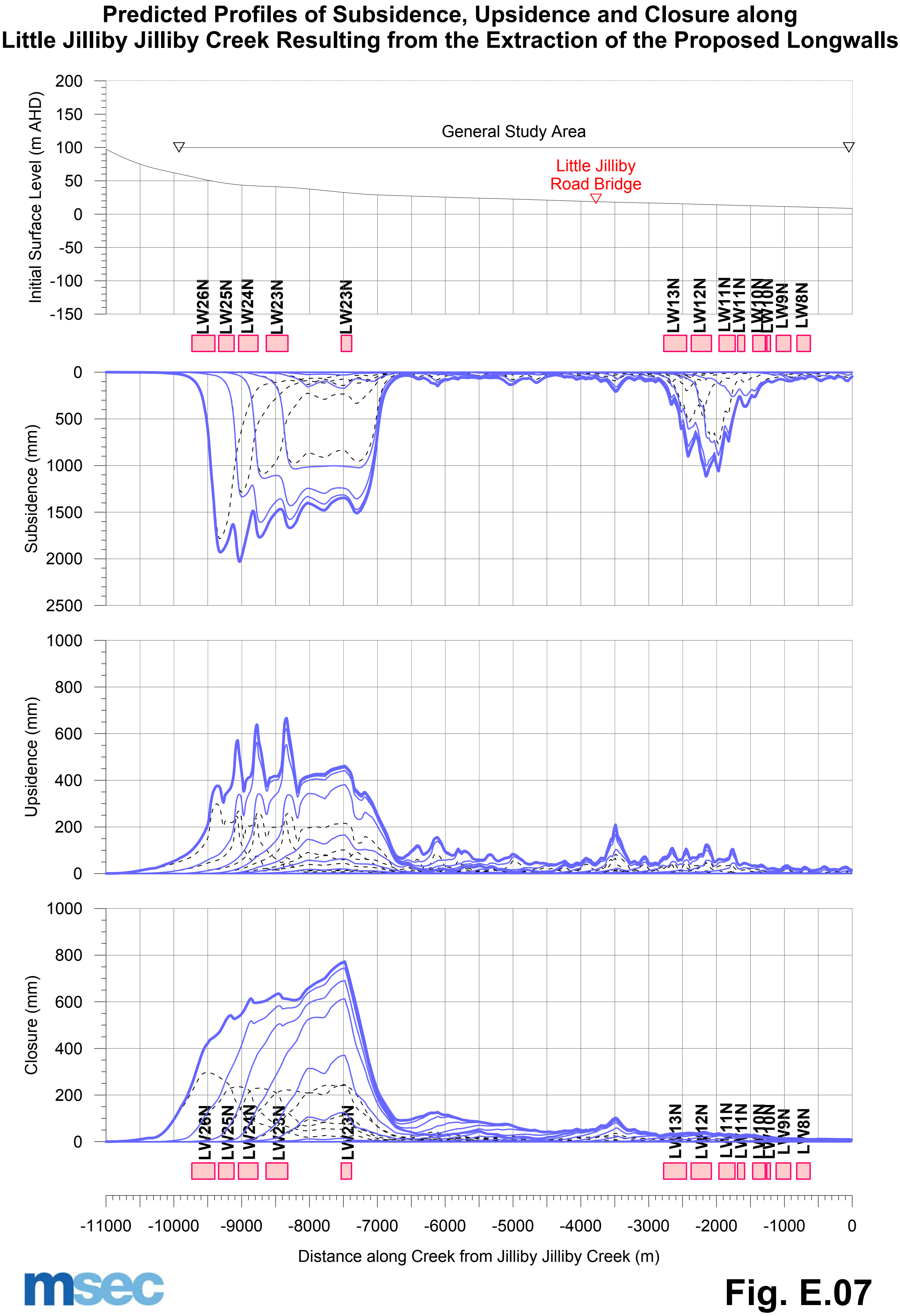
Fig. E.05

Predicted Profiles of Subsidence, Upsidence and Closure along Jilliby Jilliby Creek Resulting from the Extraction of the Proposed Longwalls



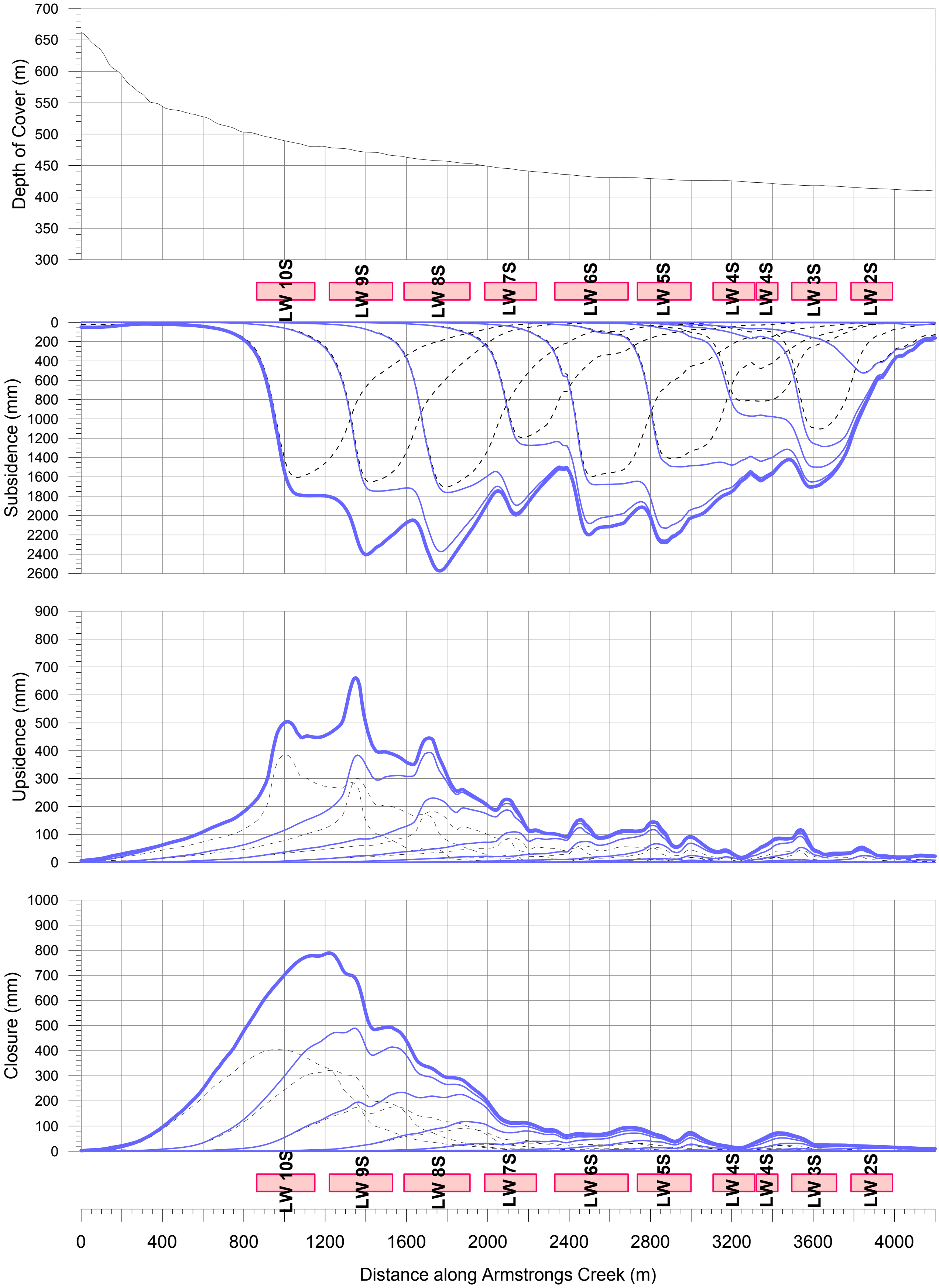
msec

Fig. E.06



Predicted Profiles of Subsidence, Upsidence and Closure along
Little Jilliby Jilliby Creek Resulting from the Extraction of the Proposed Longwalls
Initial Surface Level (m AHD)
General Study Area
Little Jilliby
Road Bridge
LW26N
LW25N
LW24N
LW23N
LW13N
LW12N
LW11N
LW10N
LW9N
LW8N
Subsidence (mm)
Upsidence (mm)
Closure (mm)
Distance along Creek from Jilliby Jilliby Creek (m)
msec
Fig. E.07

Predicted Profiles of Subsidence, Upsidence and Closure along Armstrongs Creek Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.08

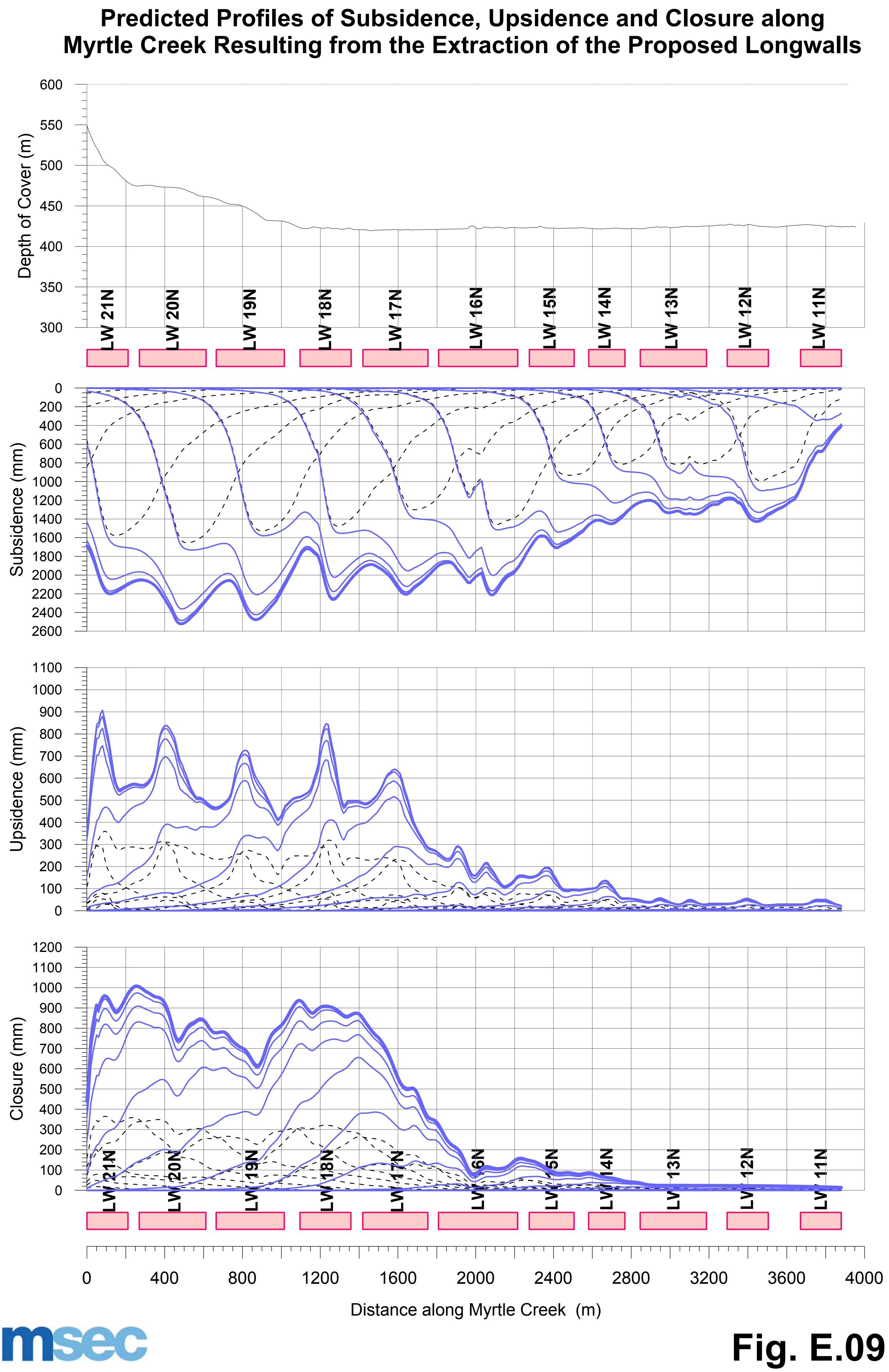
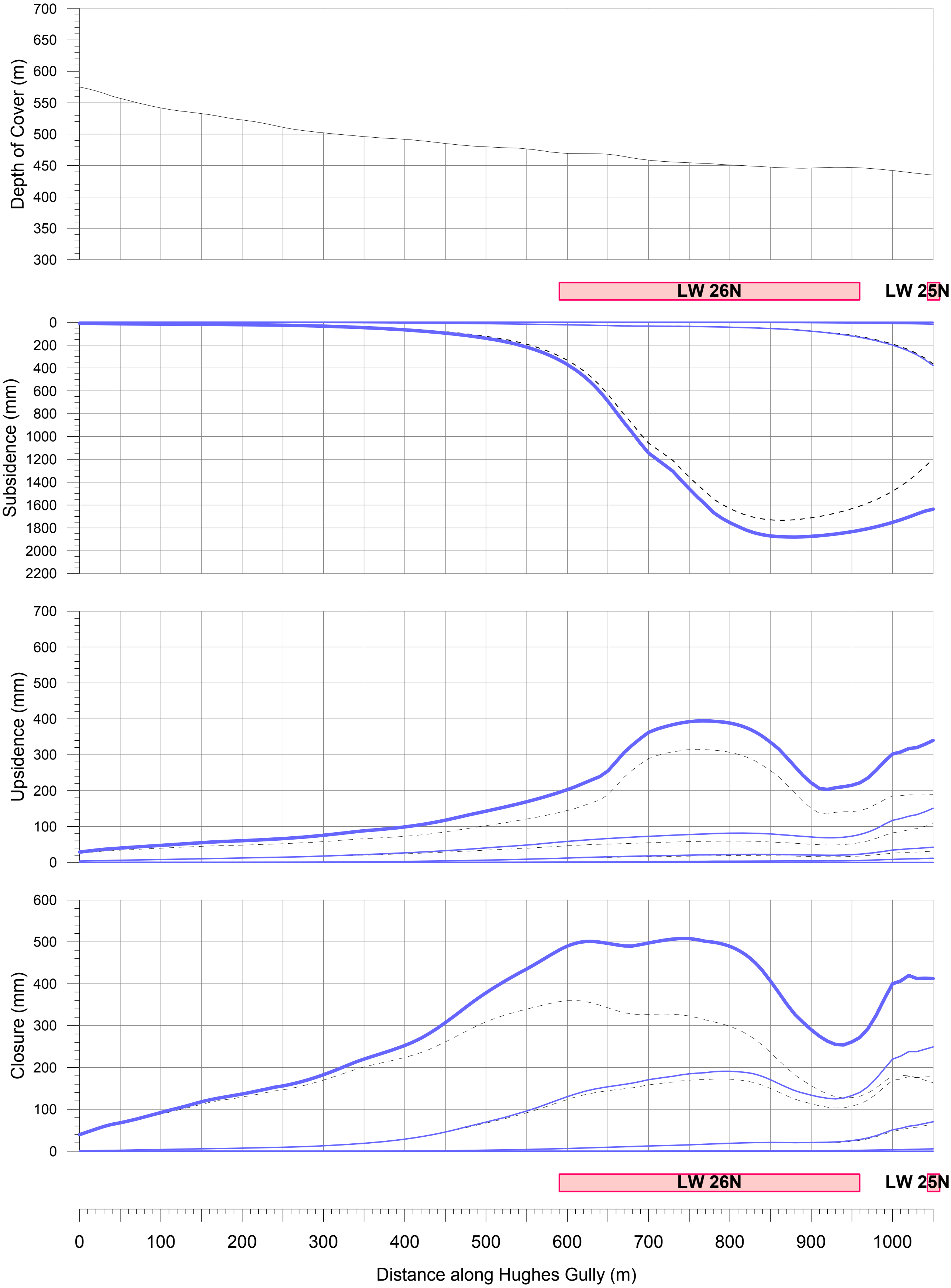

Predicted Profiles of Subsidence, Upsidence and Closure along Myrtle Creek Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
Subsidence (mm)
Upsidence (mm)
Closure (mm)
LW 21N
LW 20N
LW 19N
LW 18N
LW 17N
LW 16N
LW 15N
LW 14N
LW 13N
LW 12N
LW 11N
Distance along Myrtle Creek (m)
msec

Fig. E.09

Predicted Profiles of Subsidence, Upsidence and Closure along Hughes Gully Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.10

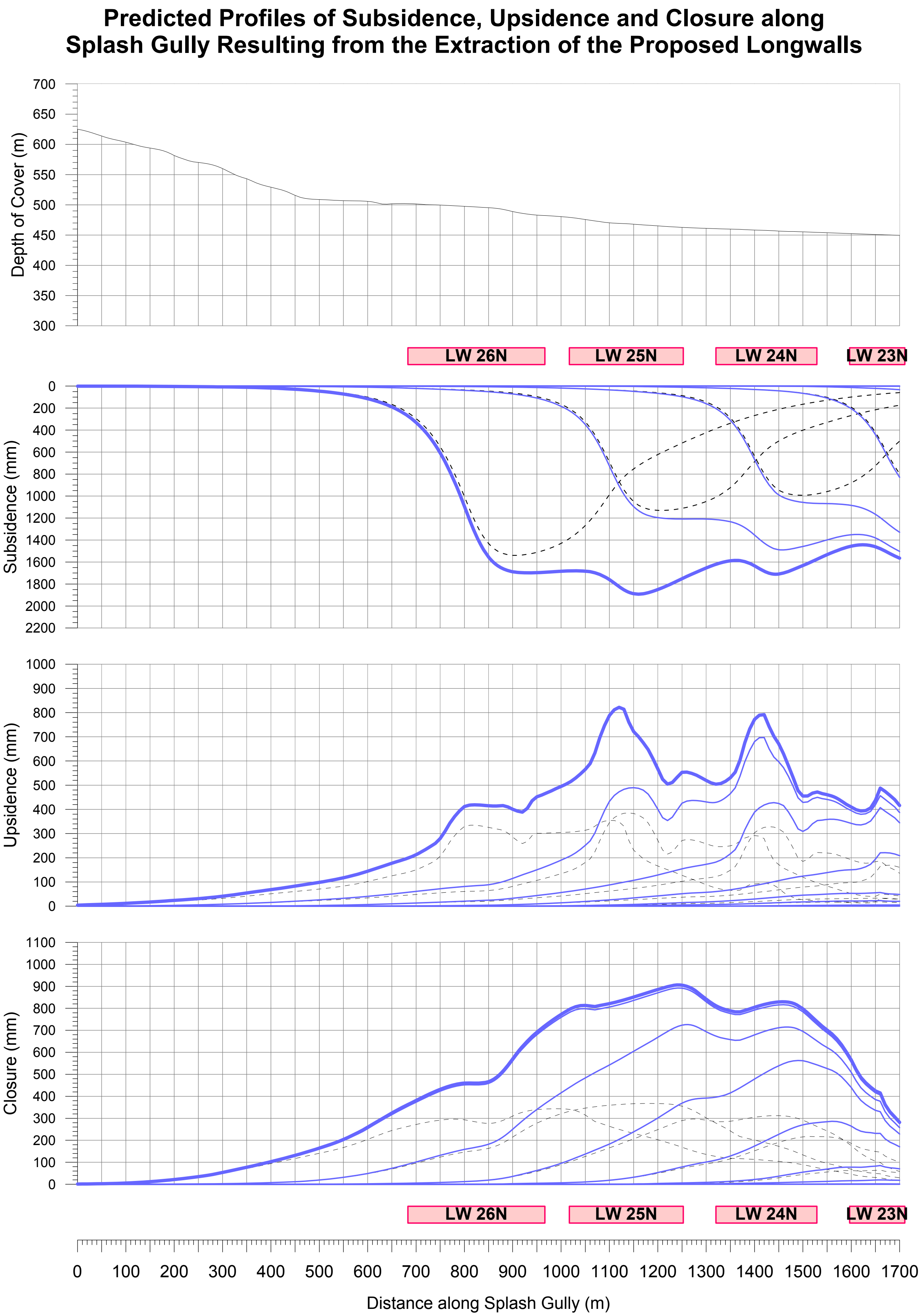

Predicted Profiles of Subsidence, Upsidence and Closure along
Splash Gully Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
700
650
600
550
500
450
400
350
300
LW 26N
LW 25N
LW 24N
LW 23N
Subsidence (mm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Upsidence (mm)
1000
900
800
700
600
500
400
300
200
100
0
Closure (mm)
1100
1000
900
800
700
600
500
400
300
200
100
0
LW 26N
LW 25N
LW 24N
LW 23N
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700
Distance along Splash Gully (m)

Fig. E.11

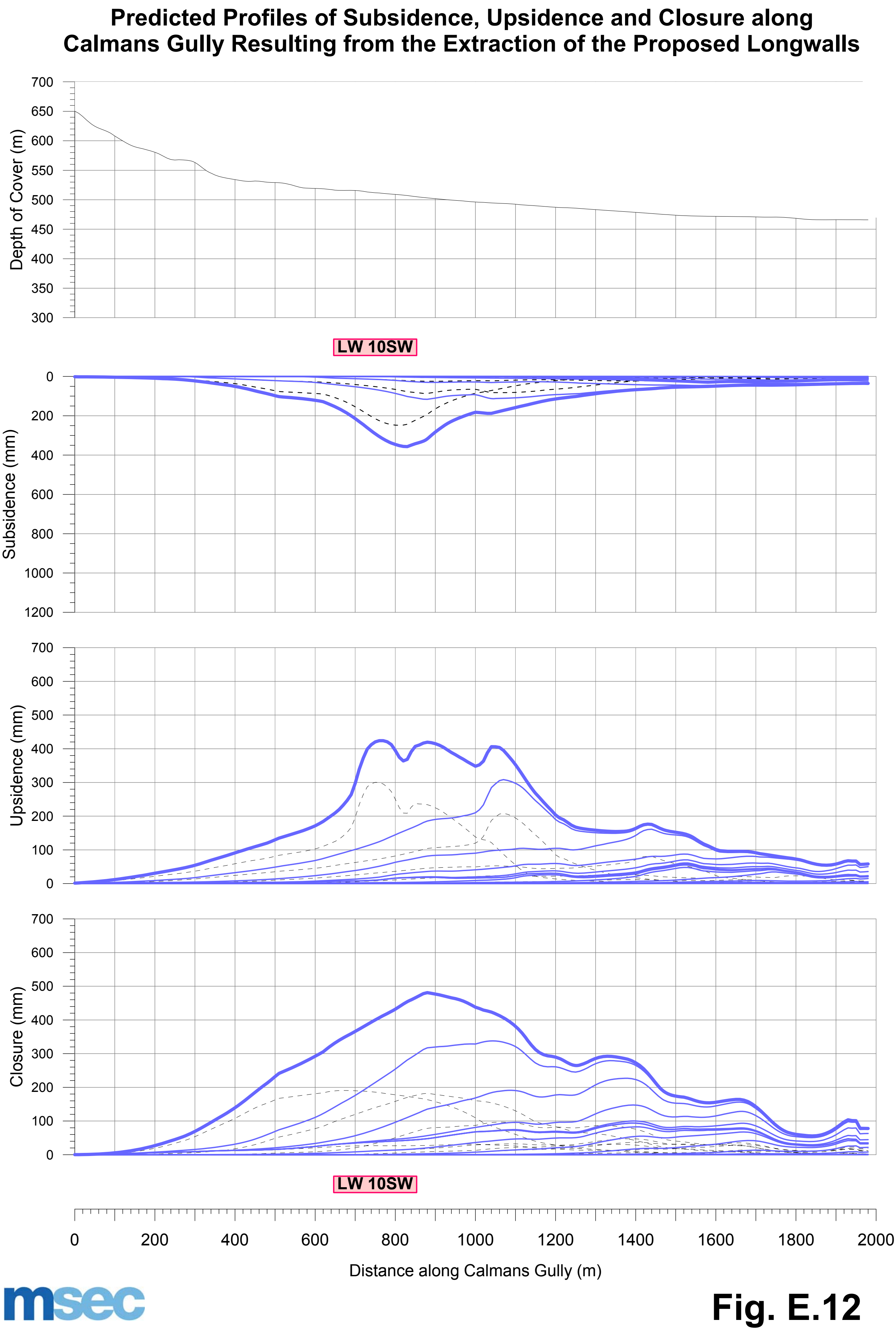
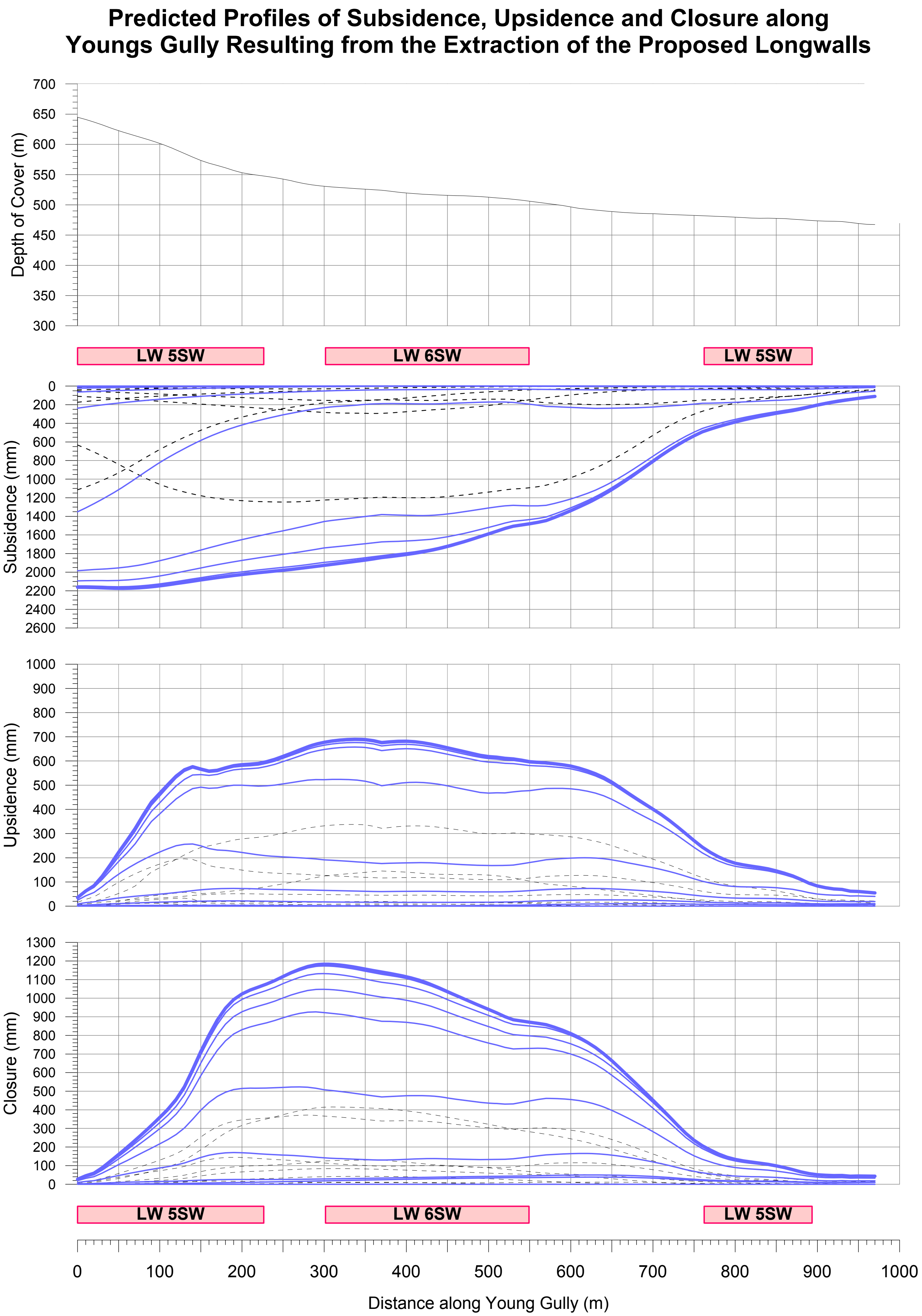

Predicted Profiles of Subsidence, Upsidence and Closure along
Calmans Gully Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
LW 10SW
Subsidence (mm)
Upsidence (mm)
Closure (mm)
LW 10SW
Distance along Calmans Gully (m)
msec

Fig. E.12

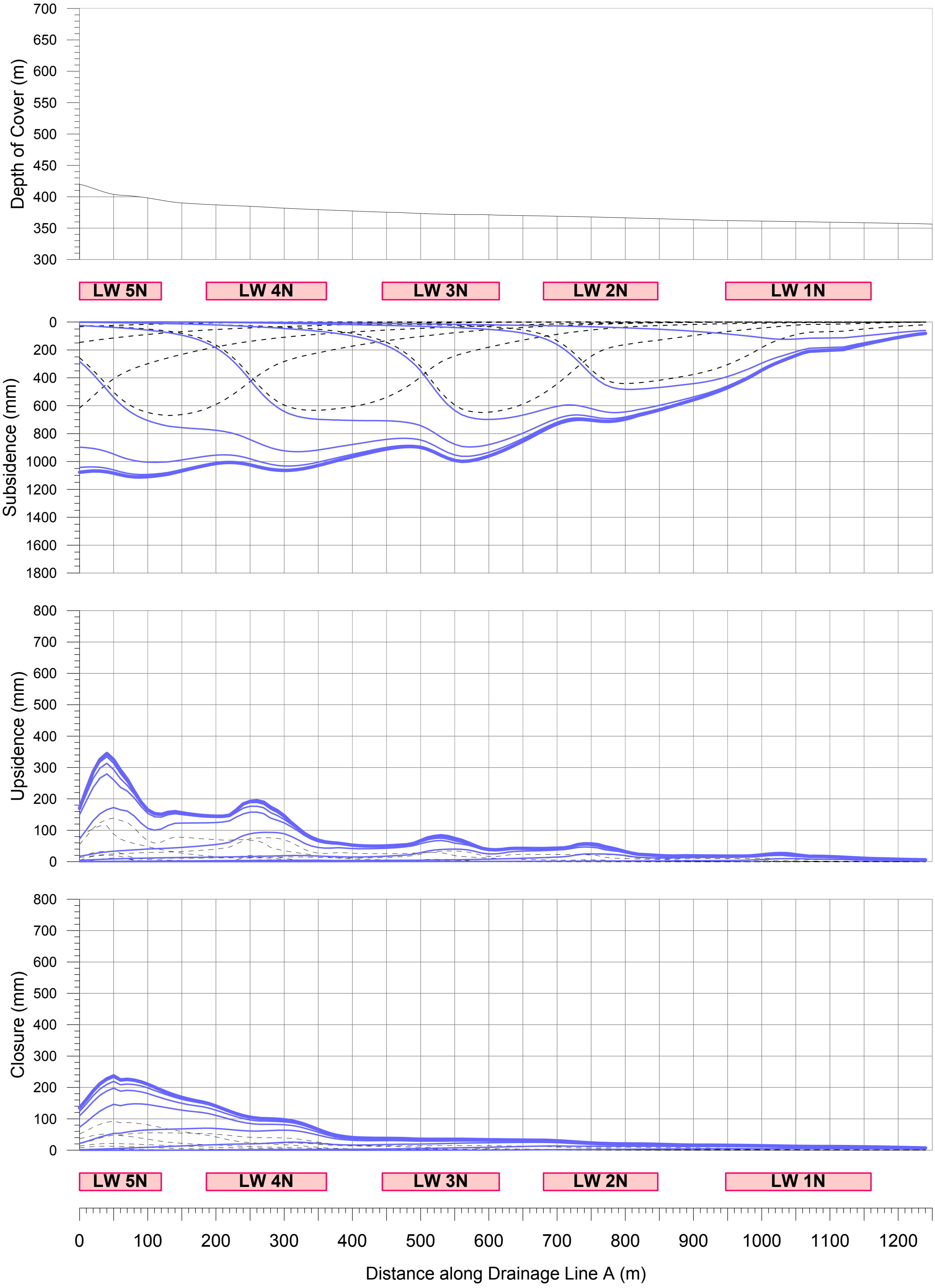


Predicted Profiles of Subsidence, Upsidence and Closure along Youngs Gully Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
LW 5SW
LW 6SW
LW 5SW
Subsidence (mm)
Upsidence (mm)
Closure (mm)
Distance along Young Gully (m)

msec

Fig. E.13

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line A Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.14

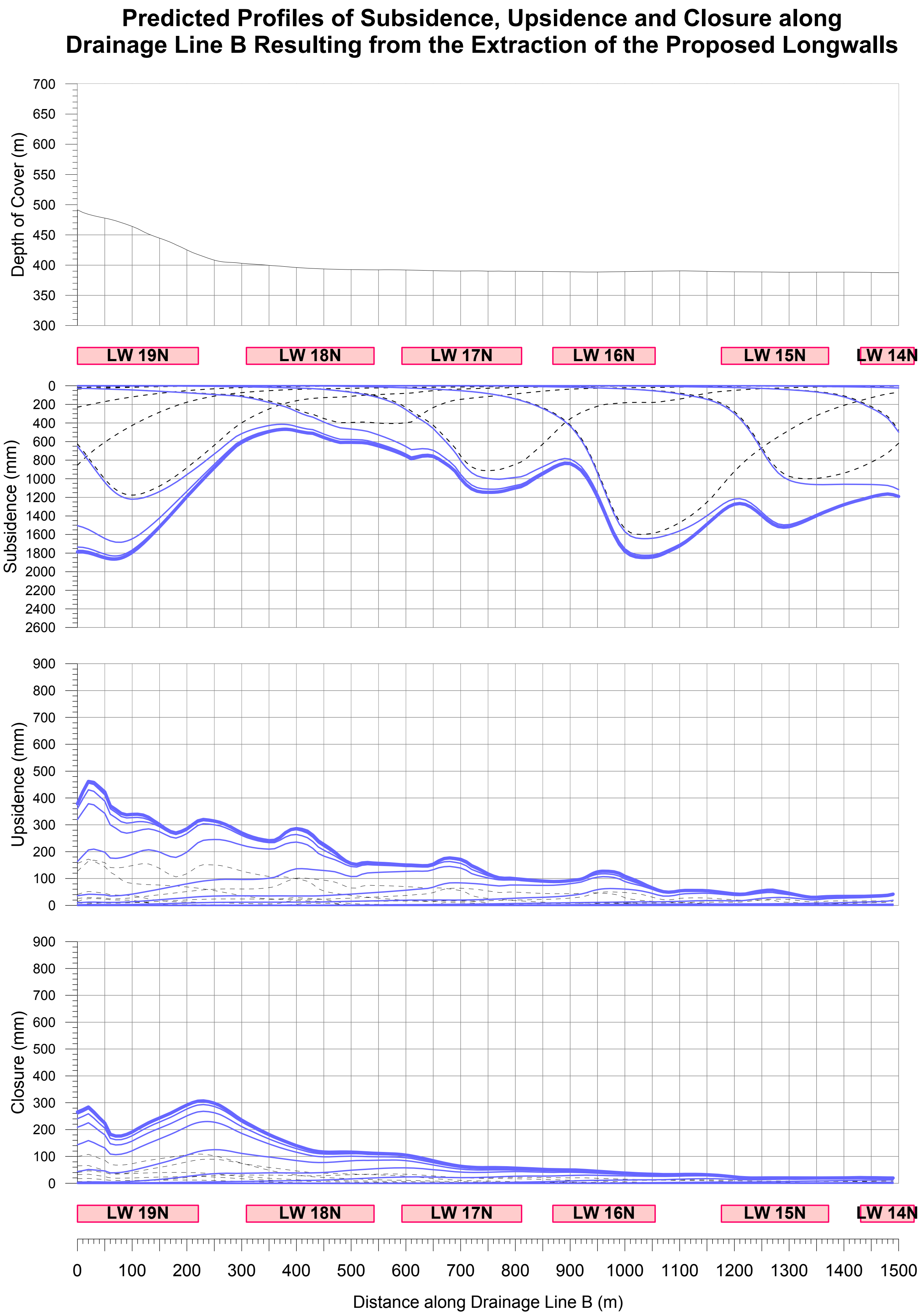
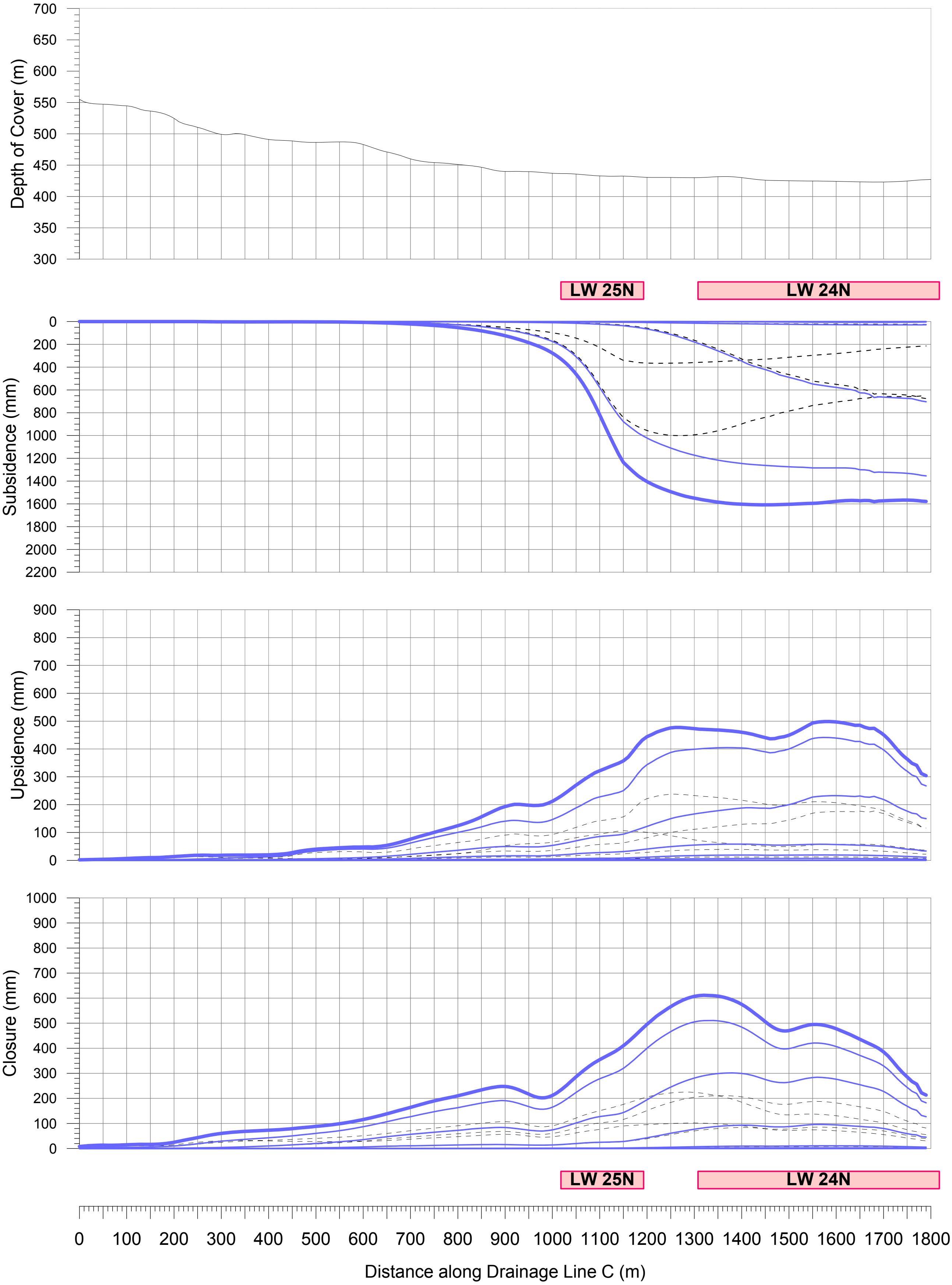

Predicted Profiles of Subsidence, Upsidence and Closure along
Drainage Line B Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
LW 19N
LW 18N
LW 17N
LW 16N
LW 15N
LW 14N
Subsidence (mm)
Upsidence (mm)
Closure (mm)
Distance along Drainage Line B (m)
msec

Fig. E.15

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line C Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.16

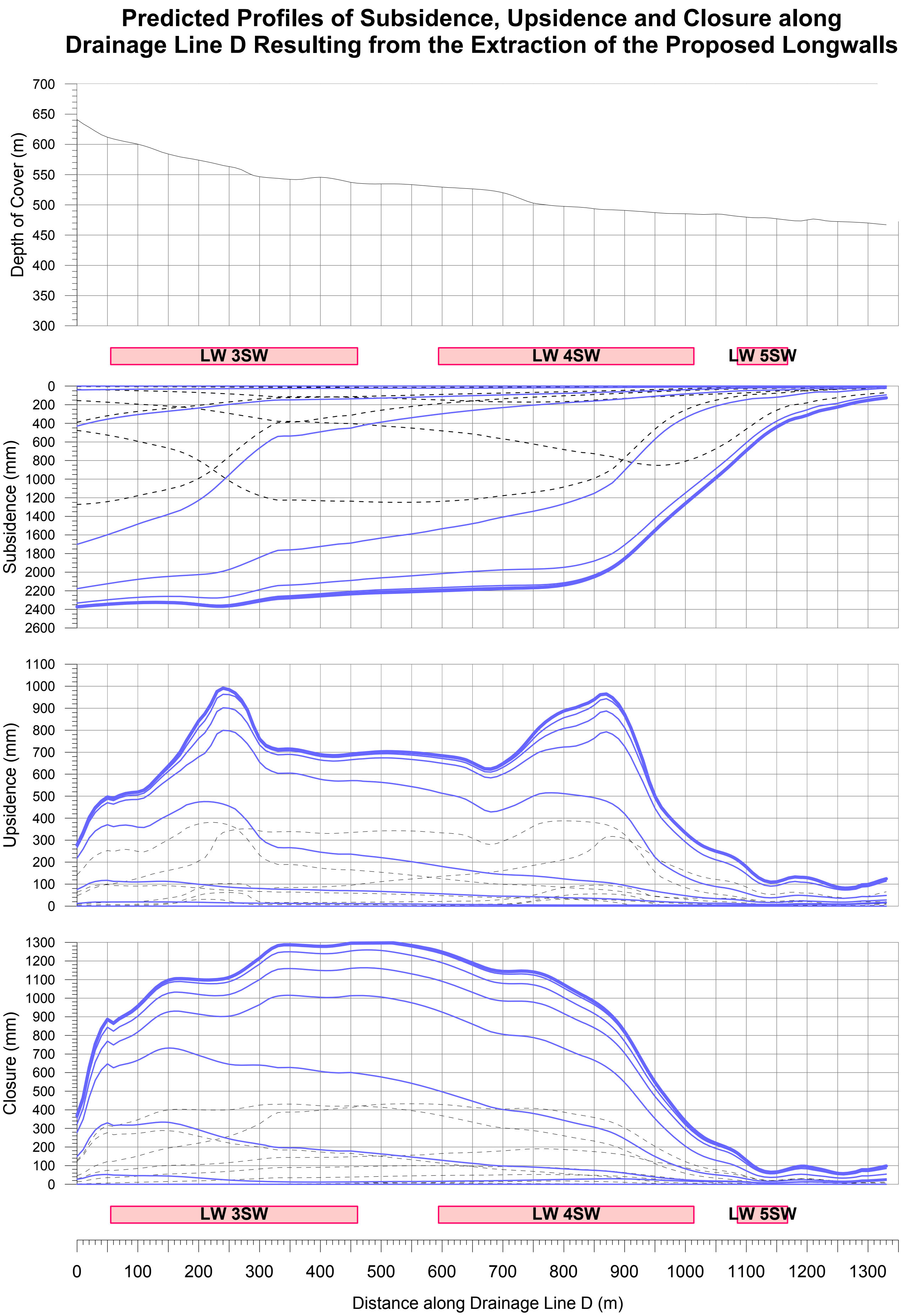
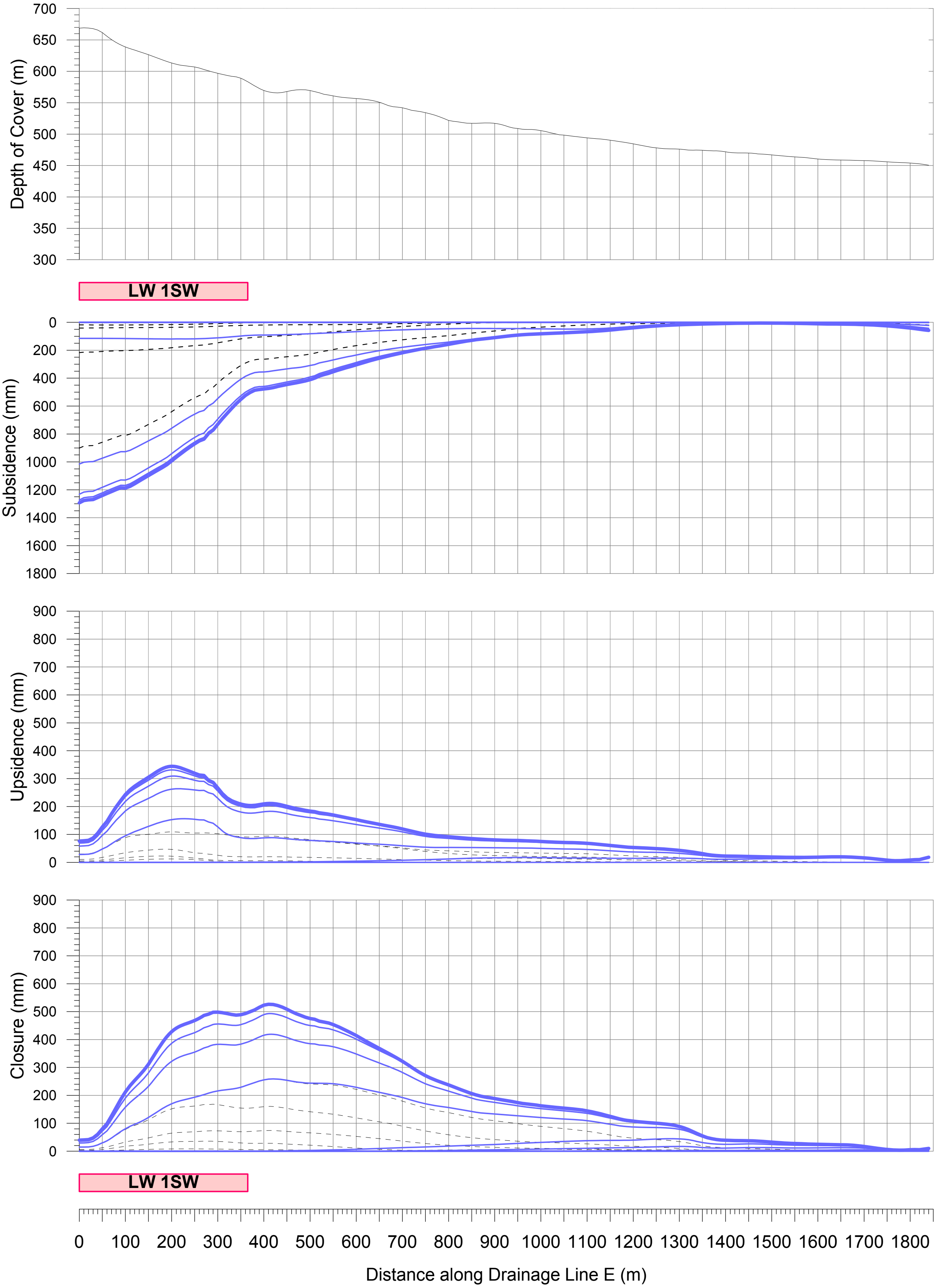

Predicted Profiles of Subsidence, Upsidence and Closure along
Drainage Line D Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
LW 3SW
LW 4SW
LW 5SW
Subsidence (mm)
Upsidence (mm)
Closure (mm)
Distance along Drainage Line D (m)
msec

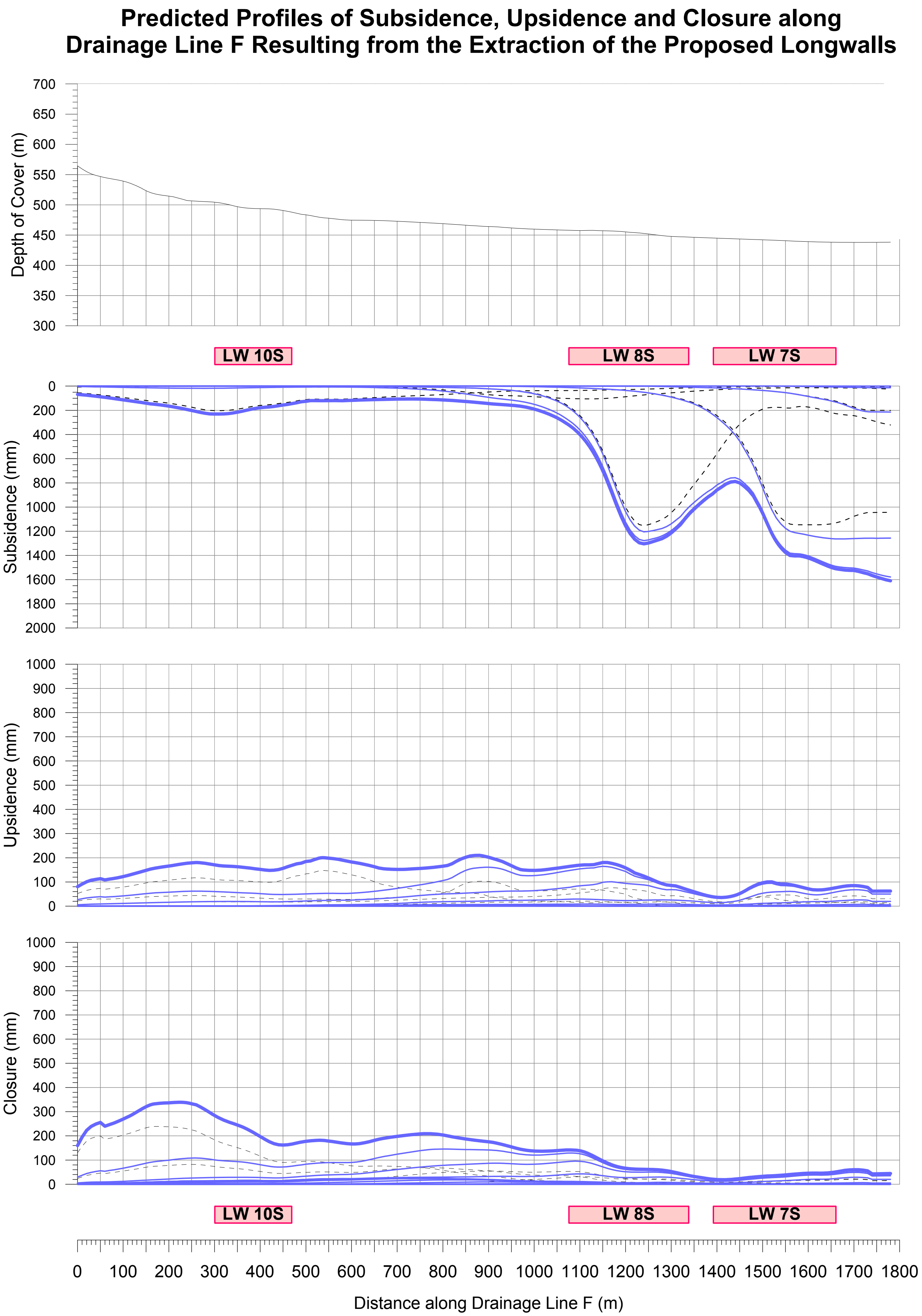
Fig. E.17

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line E Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.18

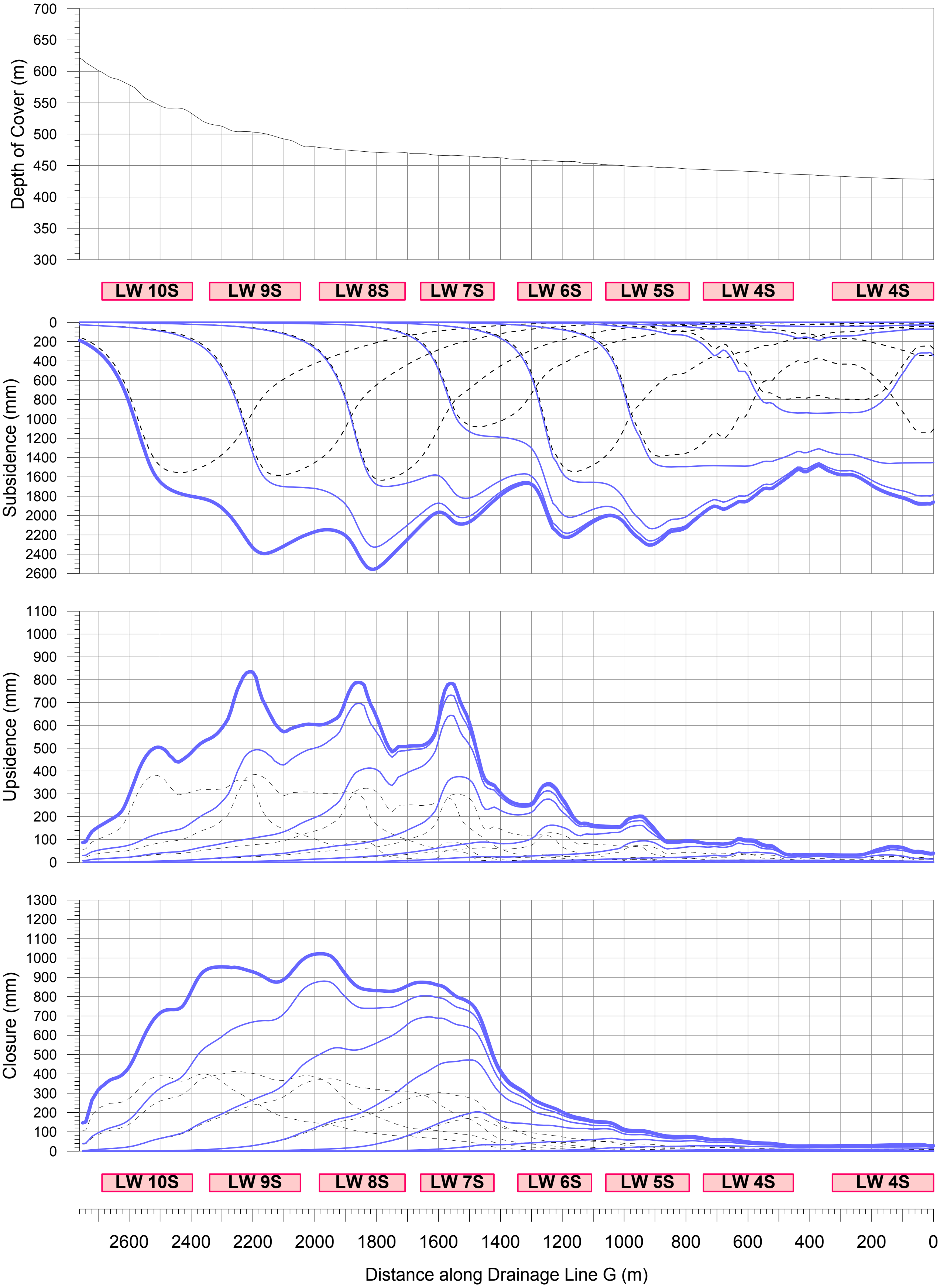


Predicted Profiles of Subsidence, Upsidence and Closure along
Drainage Line F Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
700
650
600
550
500
450
400
350
300
LW 10S
LW 8S
LW 7S
Subsidence (mm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Upsidence (mm)
1000
900
800
700
600
500
400
300
200
100
0
Closure (mm)
1000
900
800
700
600
500
400
300
200
100
0
LW 10S
LW 8S
LW 7S
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800
Distance along Drainage Line F (m)

msec

Fig. E.19

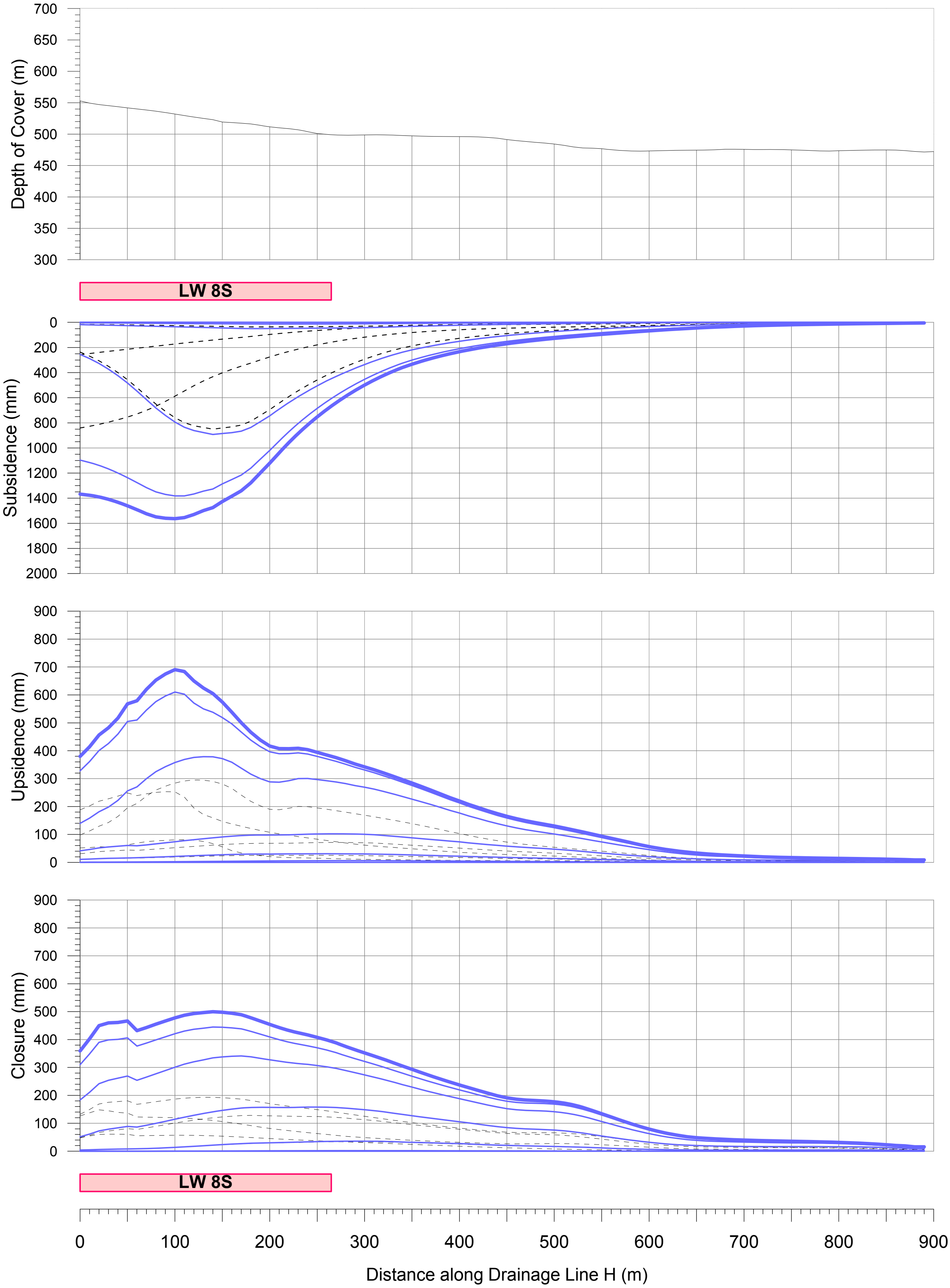
Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line G Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.20

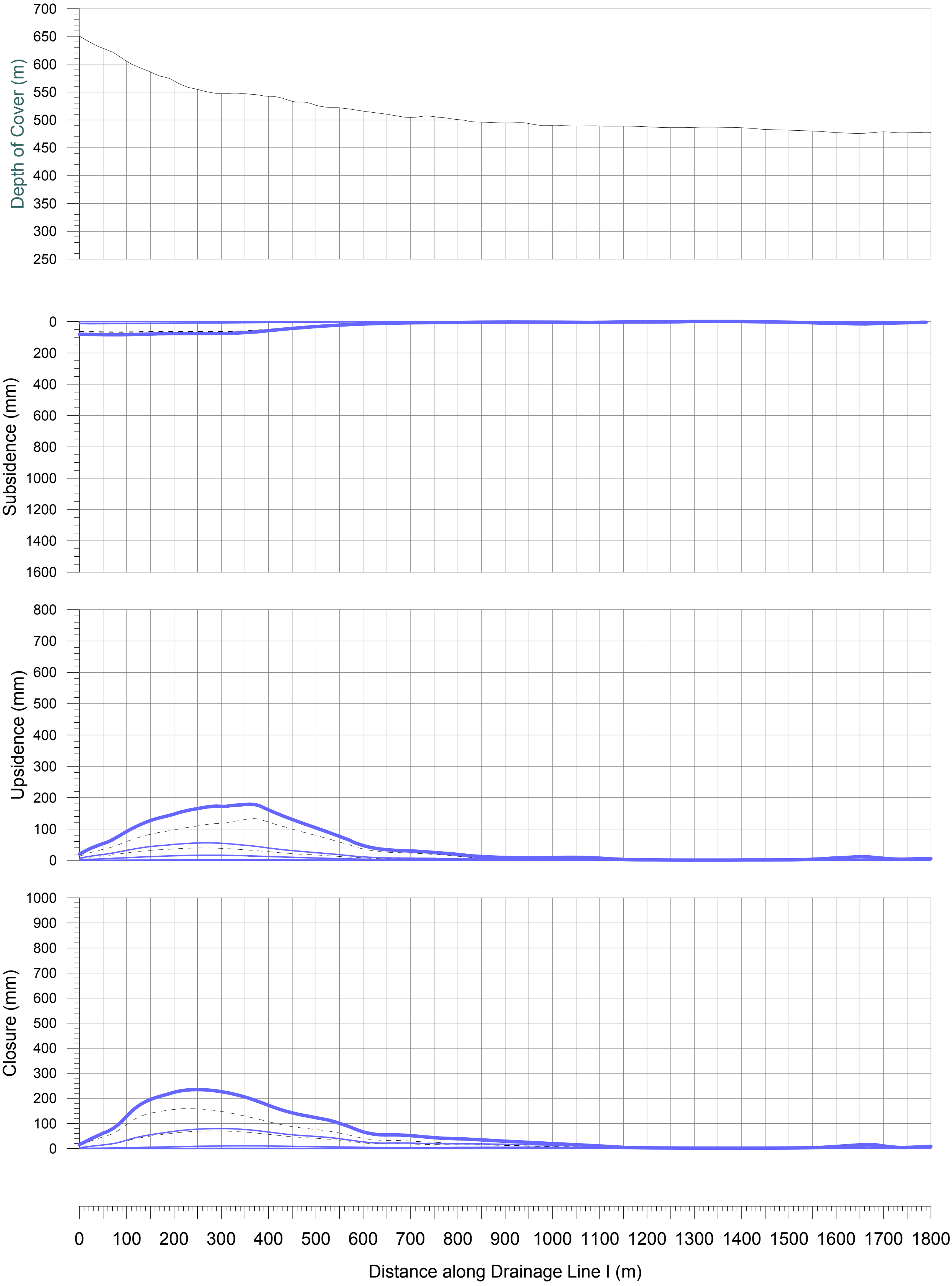
Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line H Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.21

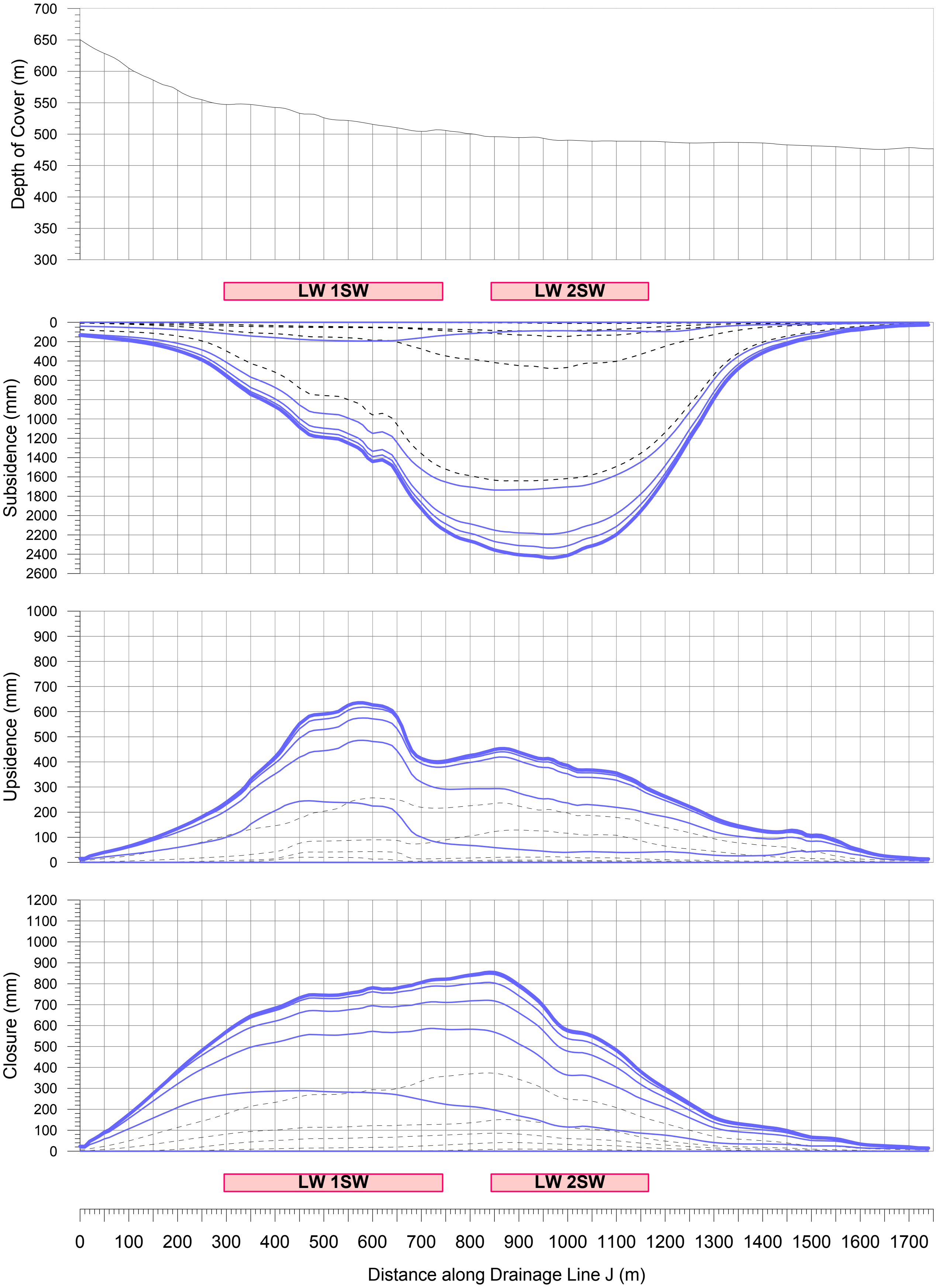
Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line I Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.22

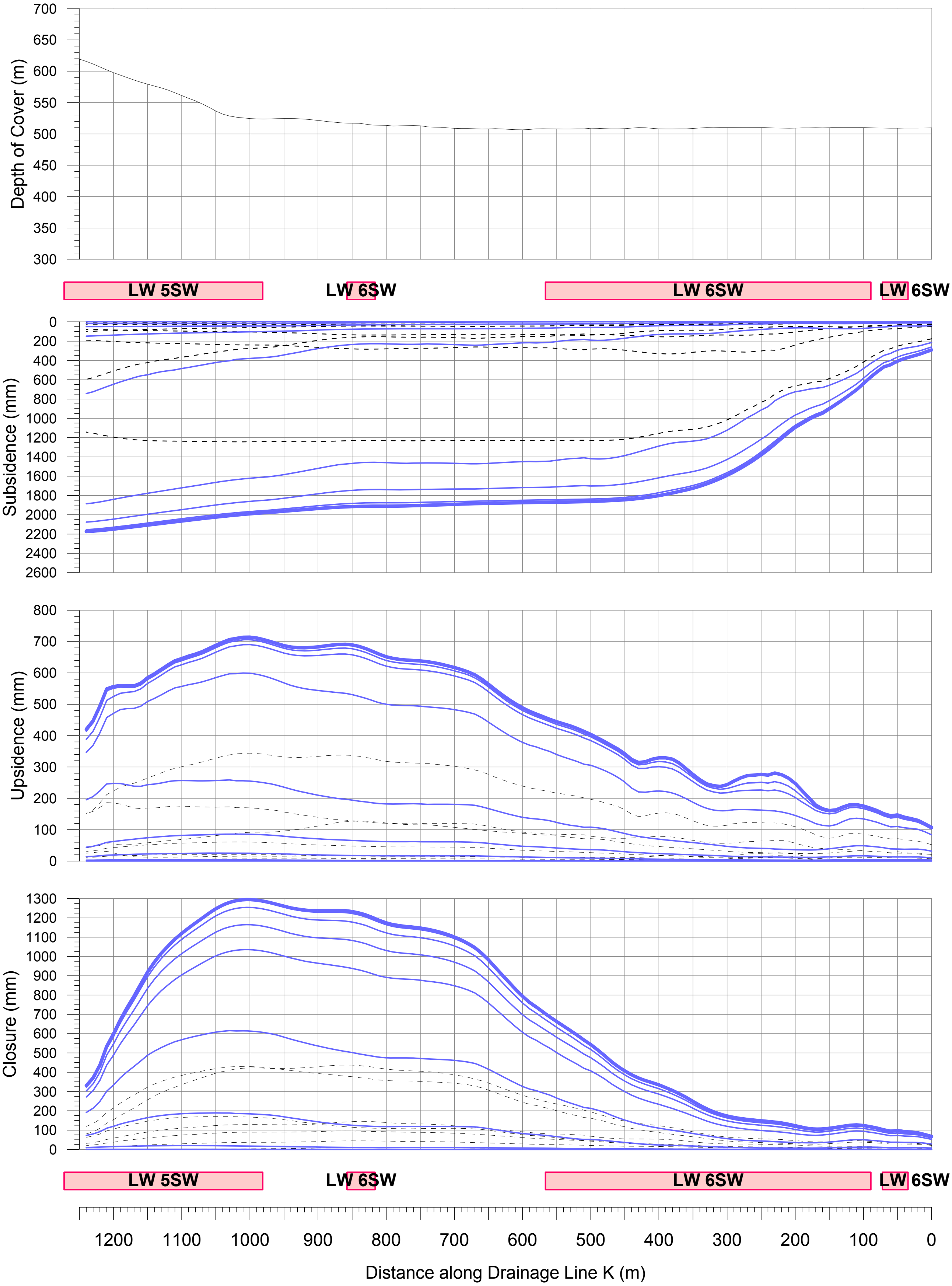
Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line J Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.23

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line K Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.24

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line L Resulting from the Extraction of the Proposed Longwalls

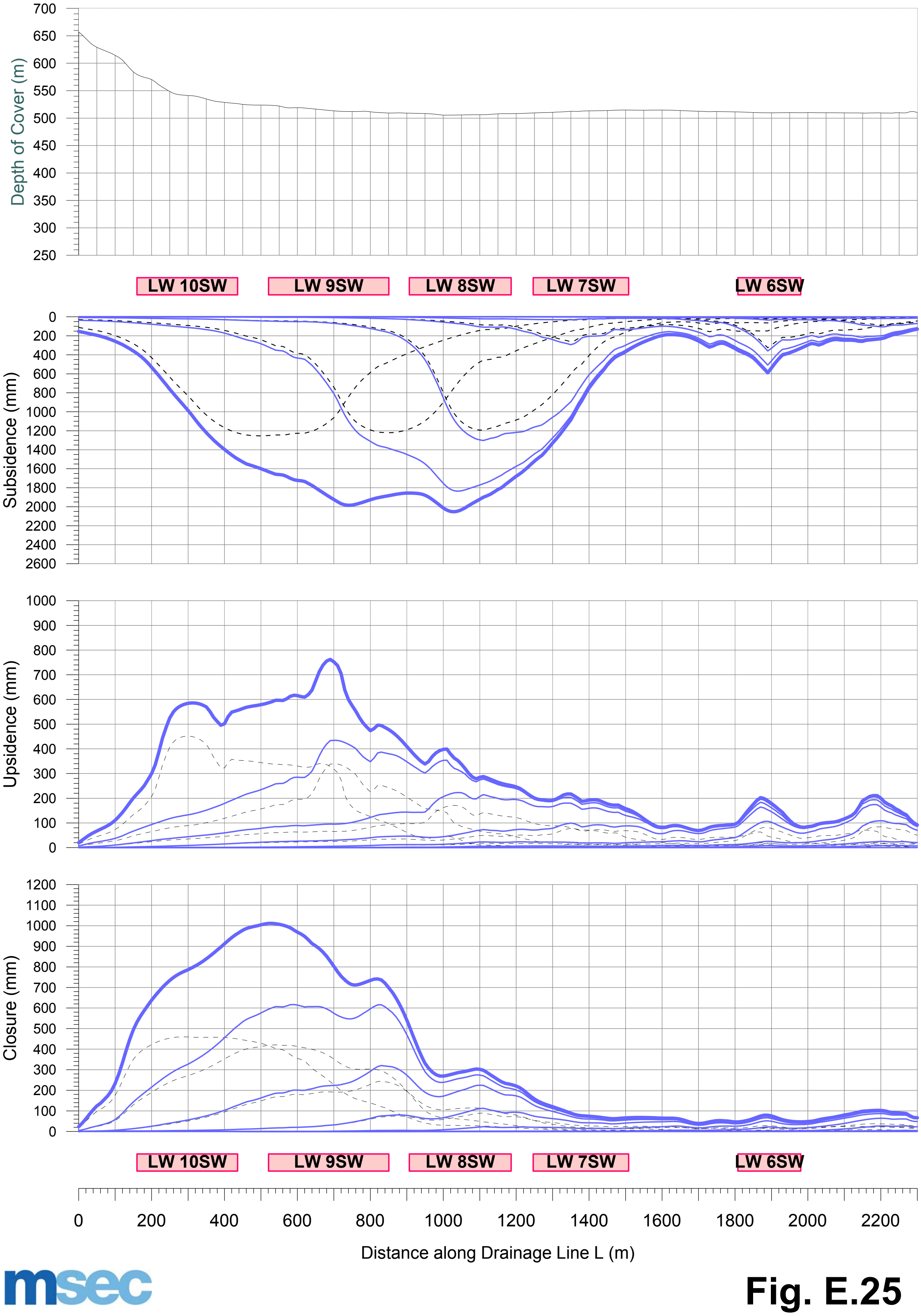


Fig. E.25

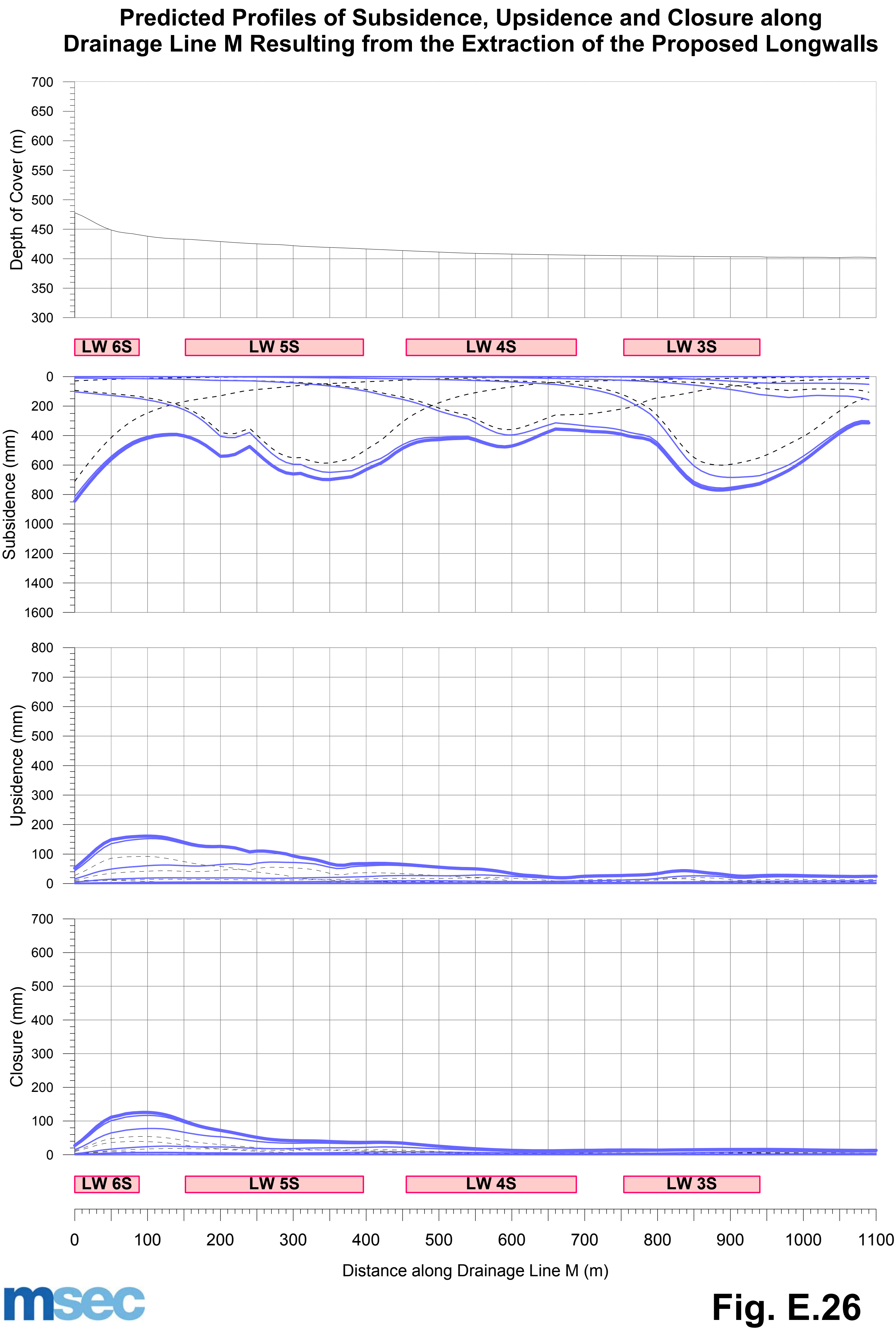
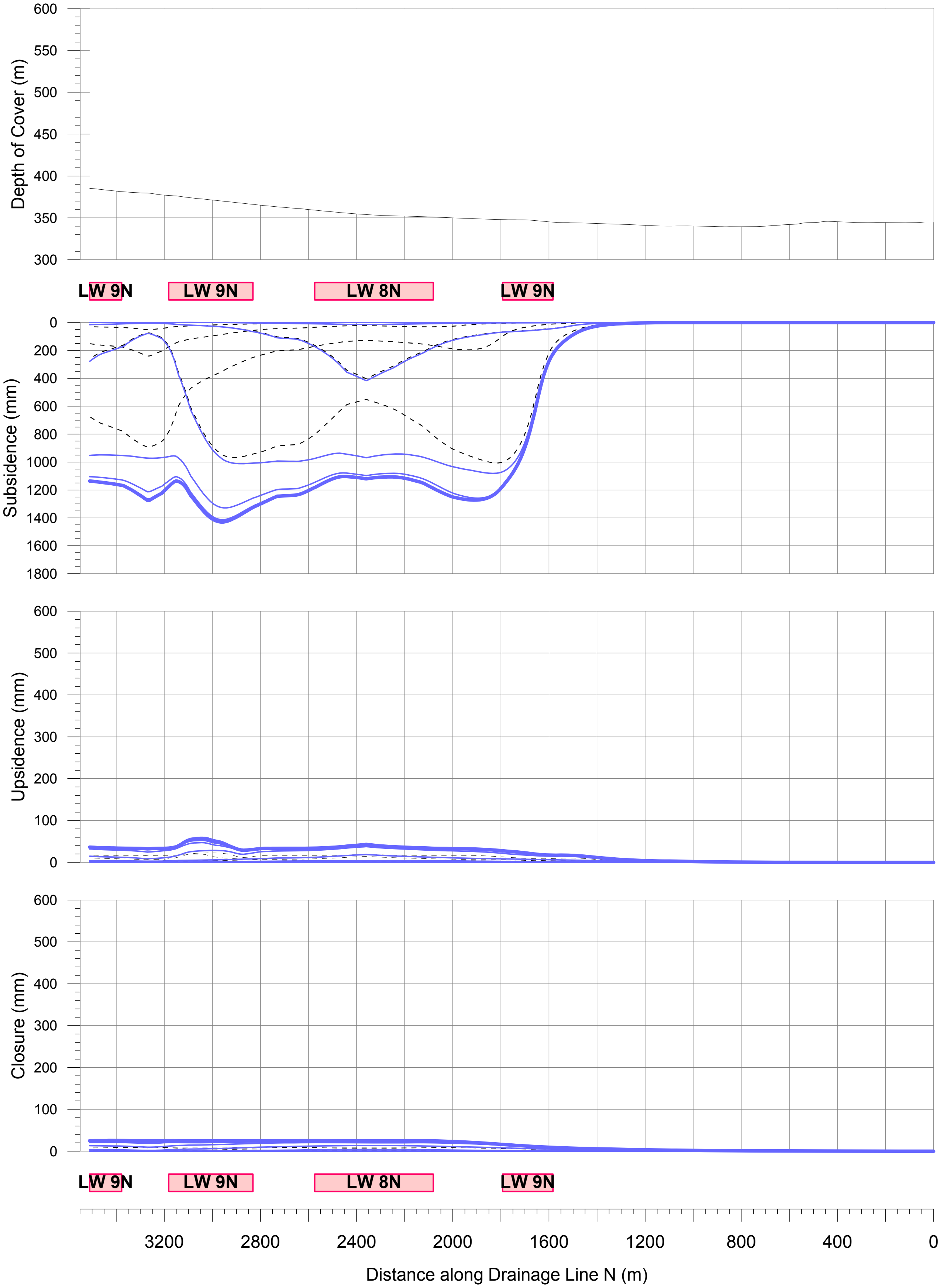

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line M Resulting from the Extraction of the Proposed Longwalls
Depth of Cover (m)
LW 6S
LW 5S
LW 4S
LW 3S
Subsidence (mm)
Upsidence (mm)
Closure (mm)
Distance along Drainage Line M (m)
msec

Fig. E.26

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line N Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.27

Predicted Profiles of Subsidence, Upsidence and Closure along Drainage Line O Resulting from the Extraction of the Proposed Longwalls

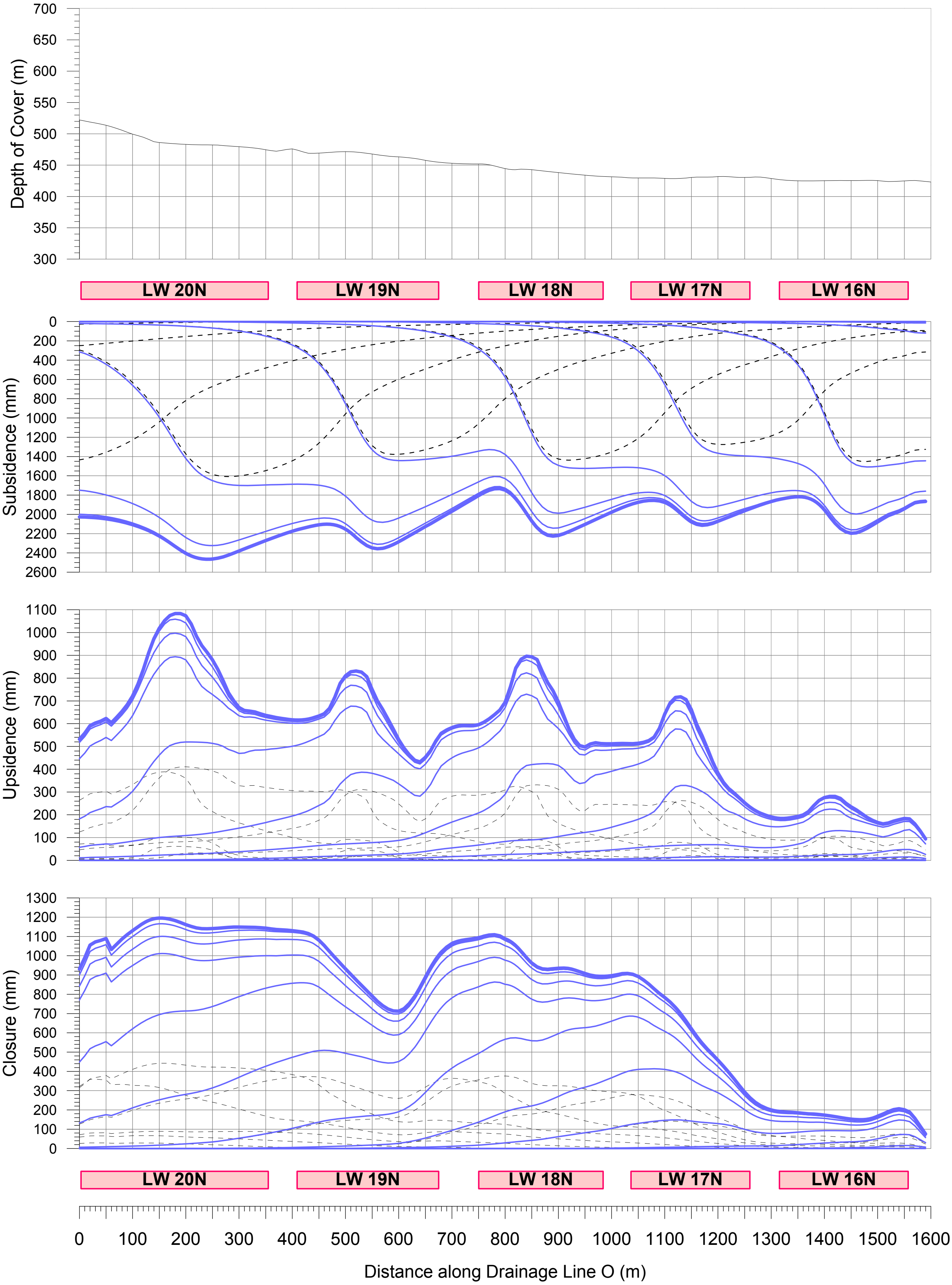


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Fig. E.28

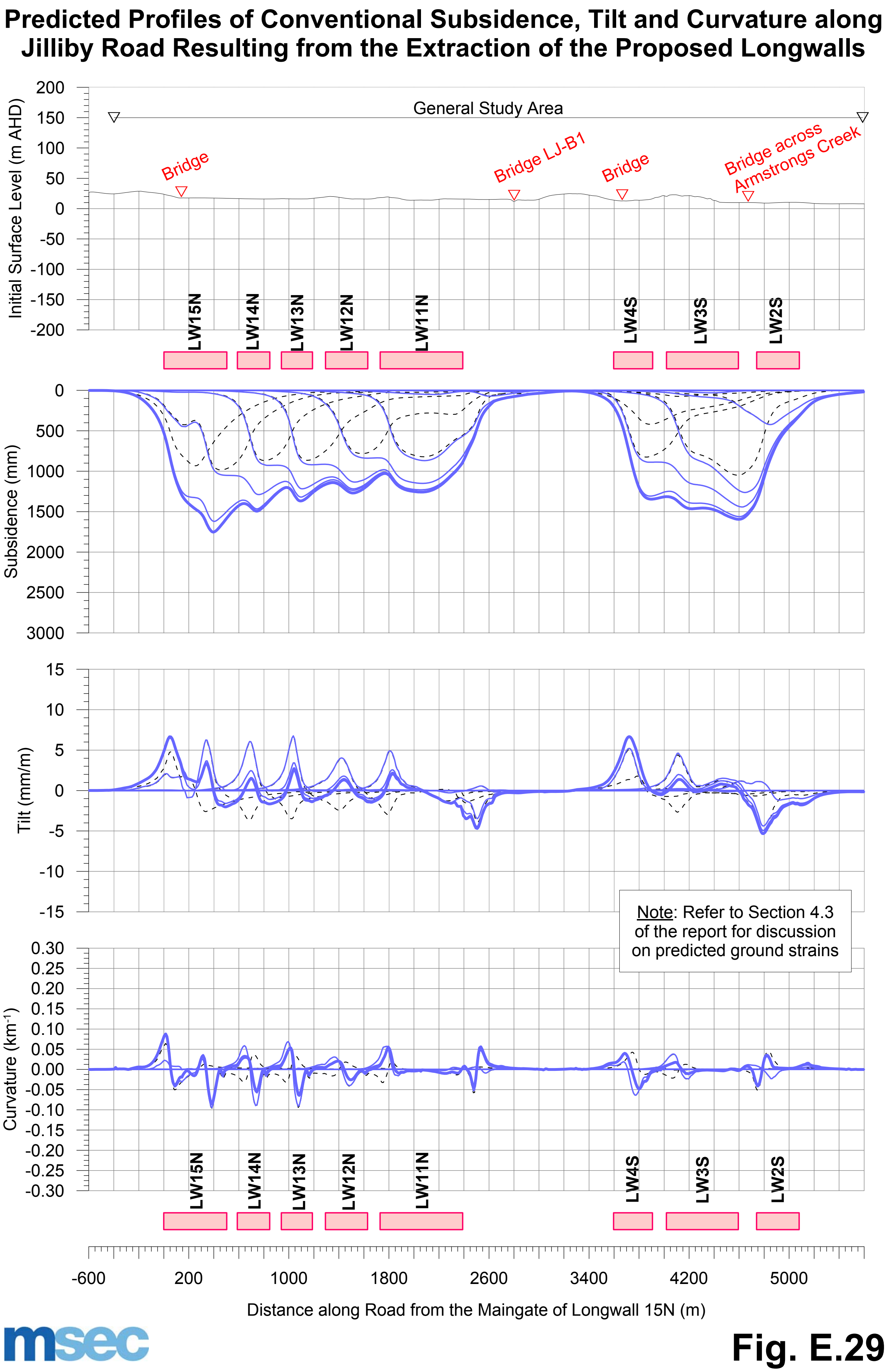
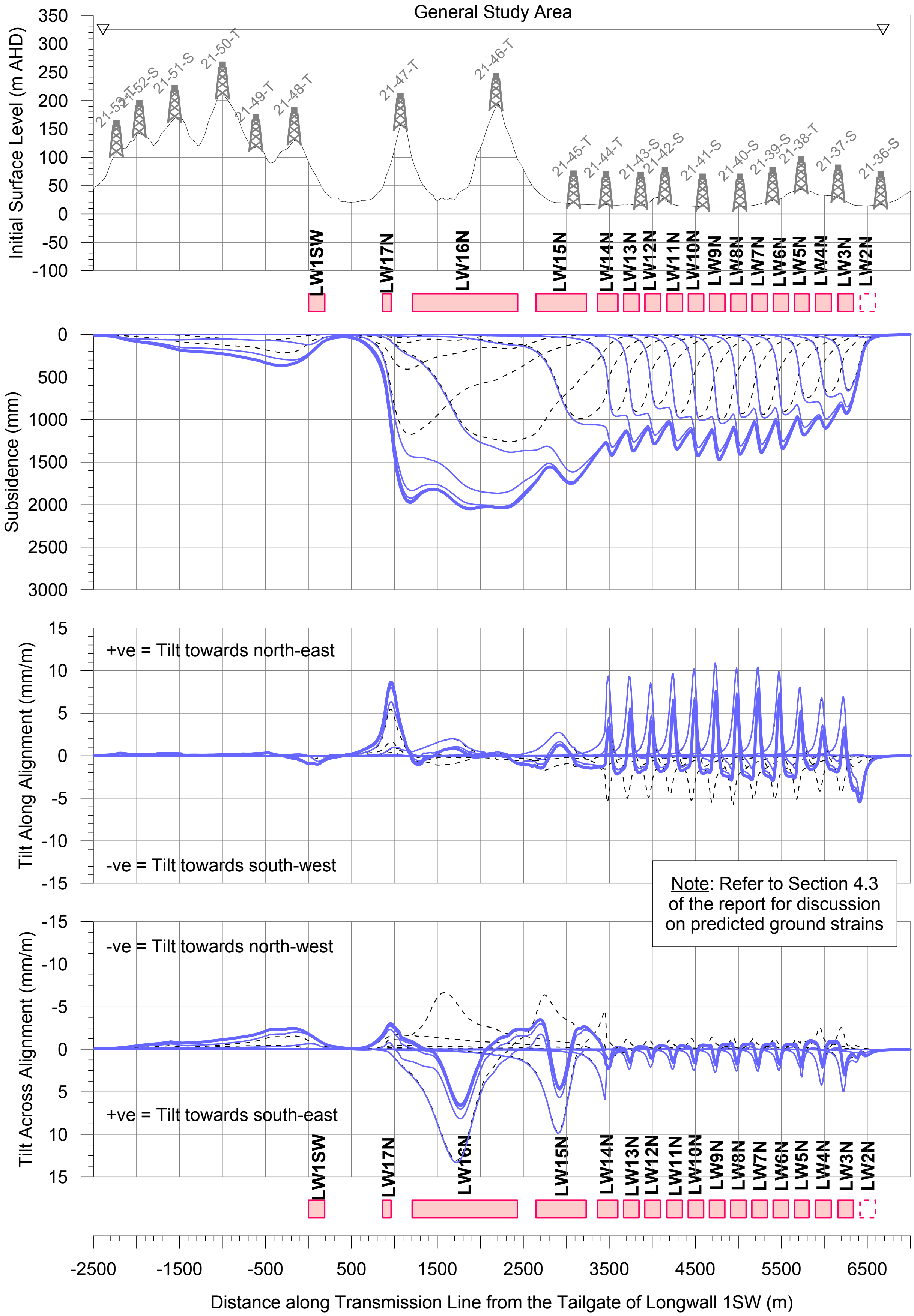

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along Jilliby Road Resulting from the Extraction of the Proposed Longwalls
General Study Area
Bridge
Bridge LJ-B1
Bridge
Bridge across Armstrongs Creek
Initial Surface Level (m AHD)
Subsidence (mm)
Tilt (mm/m)
Curvature (km-1)
LW15N
LW14N
LW13N
LW12N
LW11N
LW4S
LW3S
LW2S
Note: Refer to Section 4.3 of the report for discussion on predicted ground strains
Distance along Road from the Maingate of Longwall 15N (m)
msec

Fig. E.29

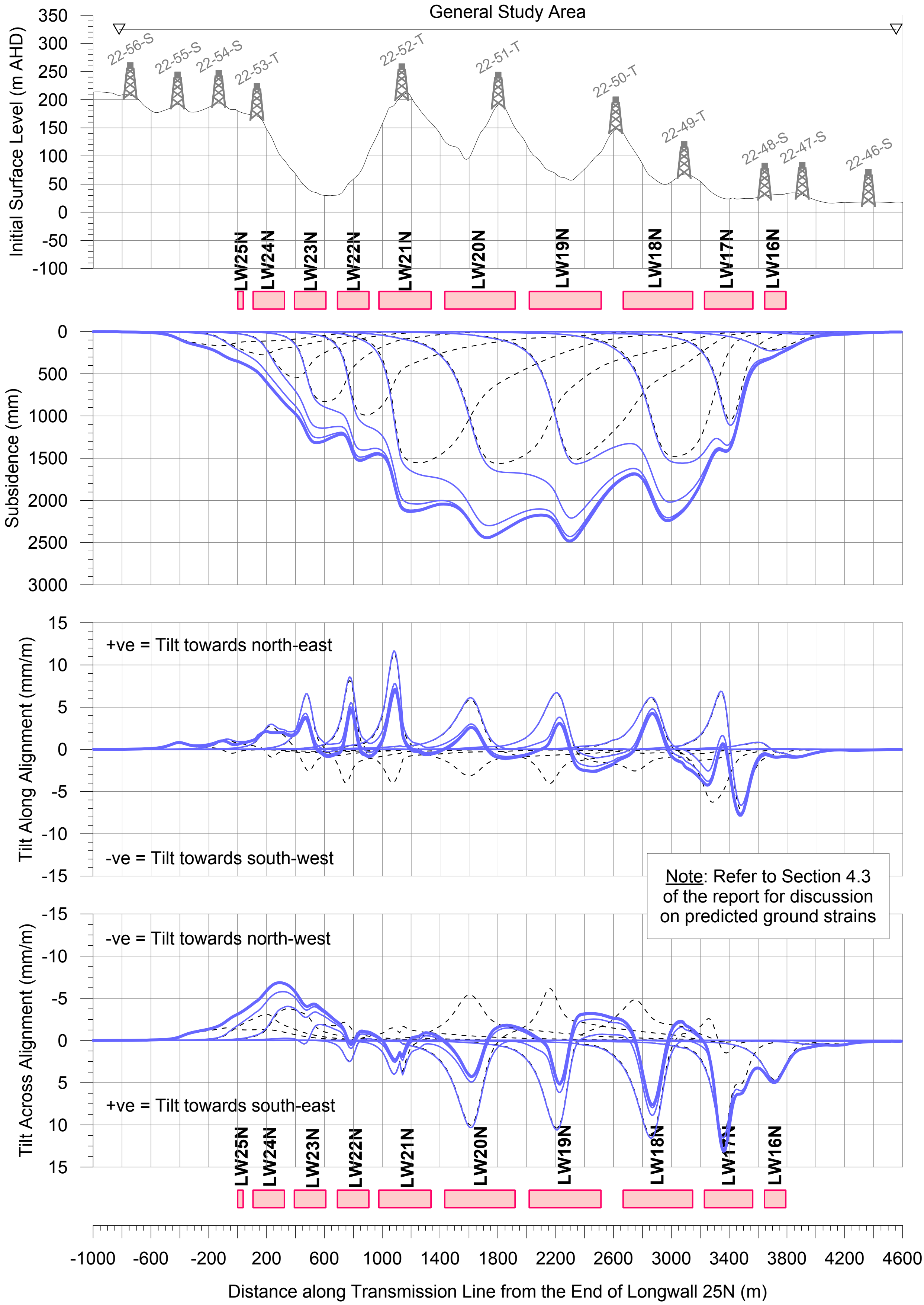
Predicted Profiles of Conventional Subsidence, Tilt Along and Tilt Across the Alignment of the Transmission Line 21 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.30

Predicted Profiles of Conventional Subsidence, Tilt Along and Tilt Across the Alignment of the Transmission Line 22 Resulting from the Extraction of the Proposed Longwalls



msec

Fig. E.31

Predicted Profiles of Conventional Subsidence, Tilt and Curvature along the Optical Fibre Cable Resulting from the Extraction of the Proposed Longwalls

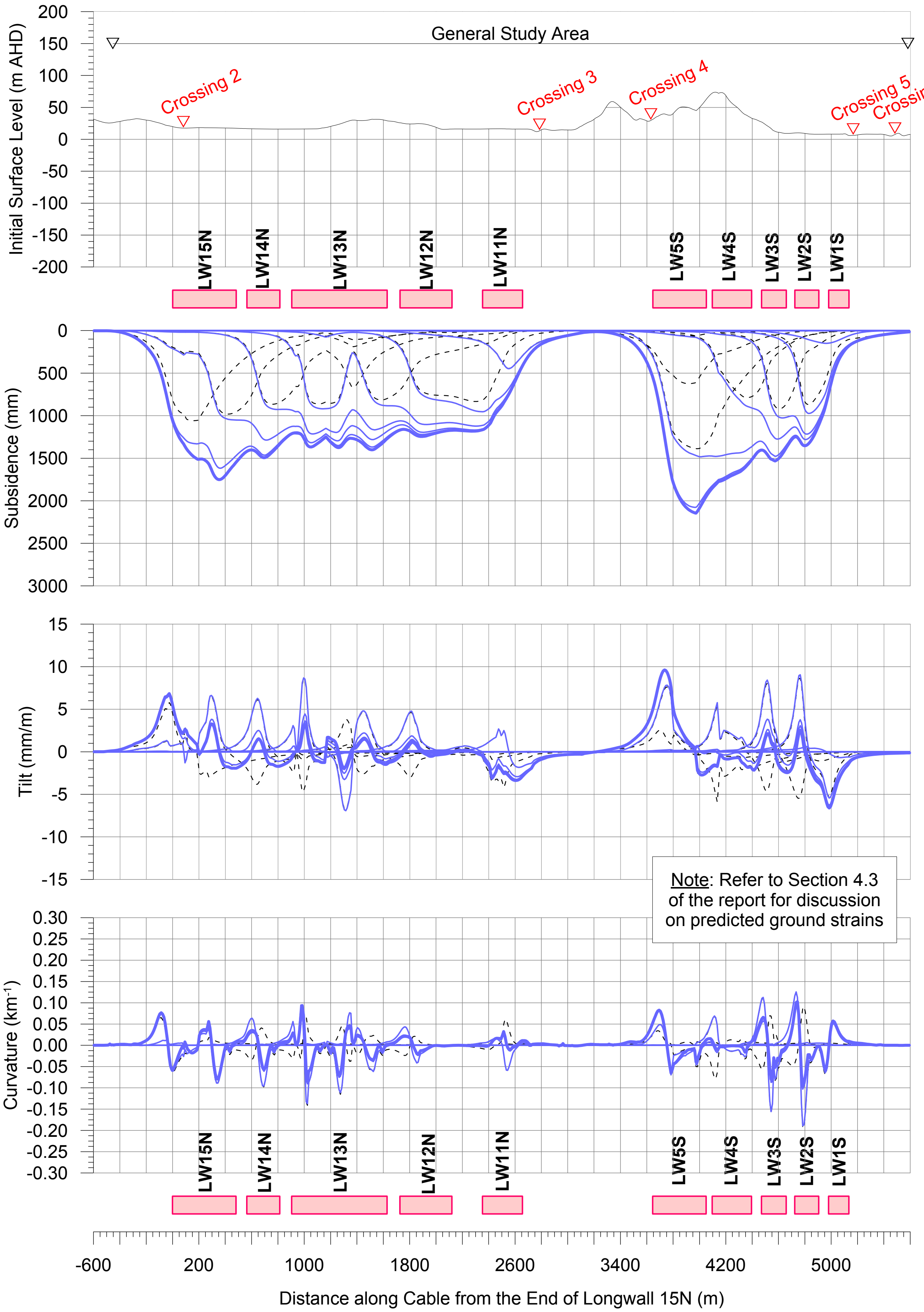
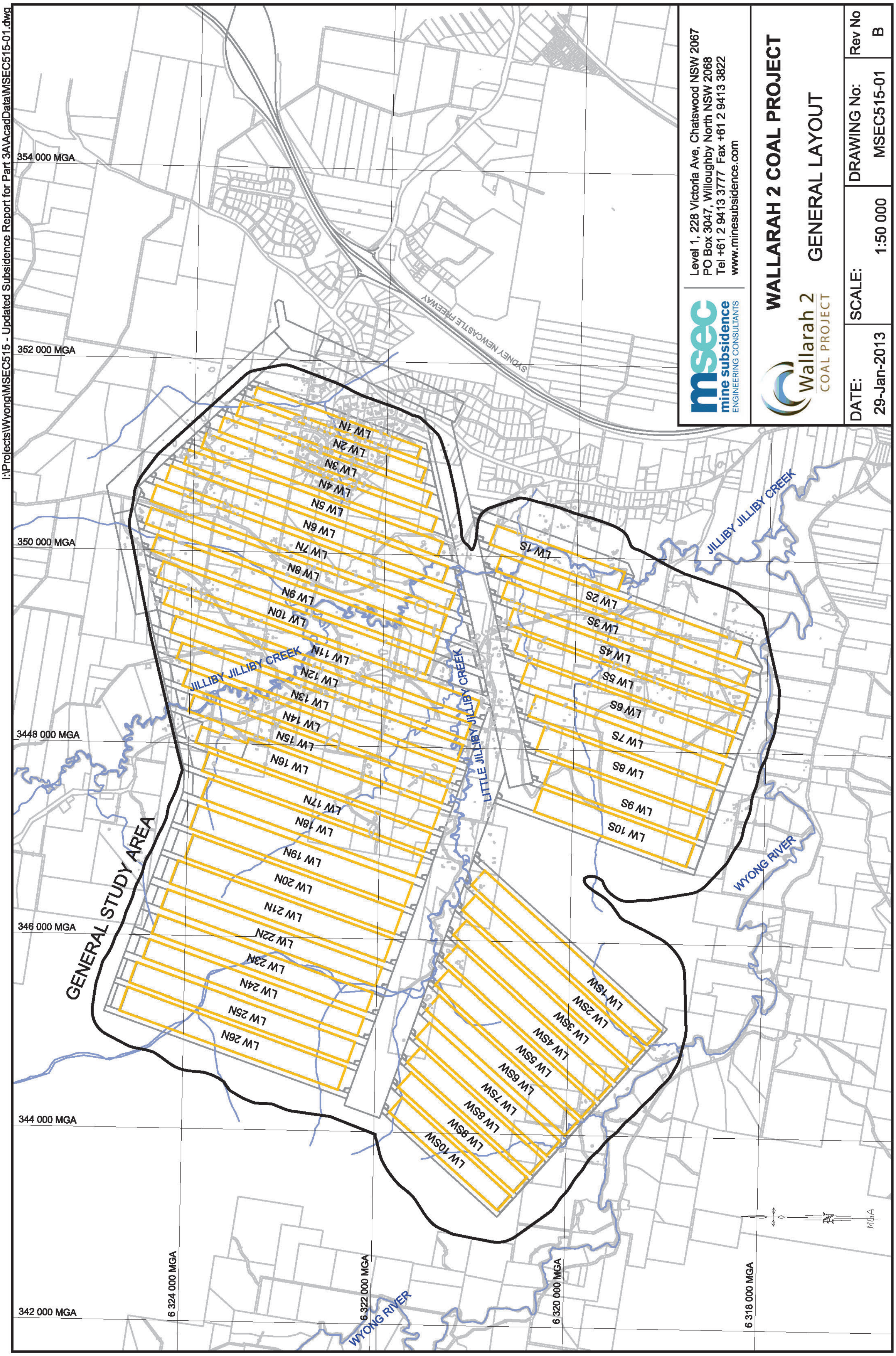


Fig. E.32

APPENDIX F. DRAWINGS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Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
GENERAL LAYOUT
DATE:
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1:50 000
DRAWING No:
MSEC515-01
Rev No
B
SYDNEY NEWCASTLE FREEWAY
JILLIBY JILLIBY CREEK
LITTLE JILLIBY JILLIBY CREEK
WYONG RIVER
GENERAL STUDY AREA
LW 1N
LW 2N
LW 3N
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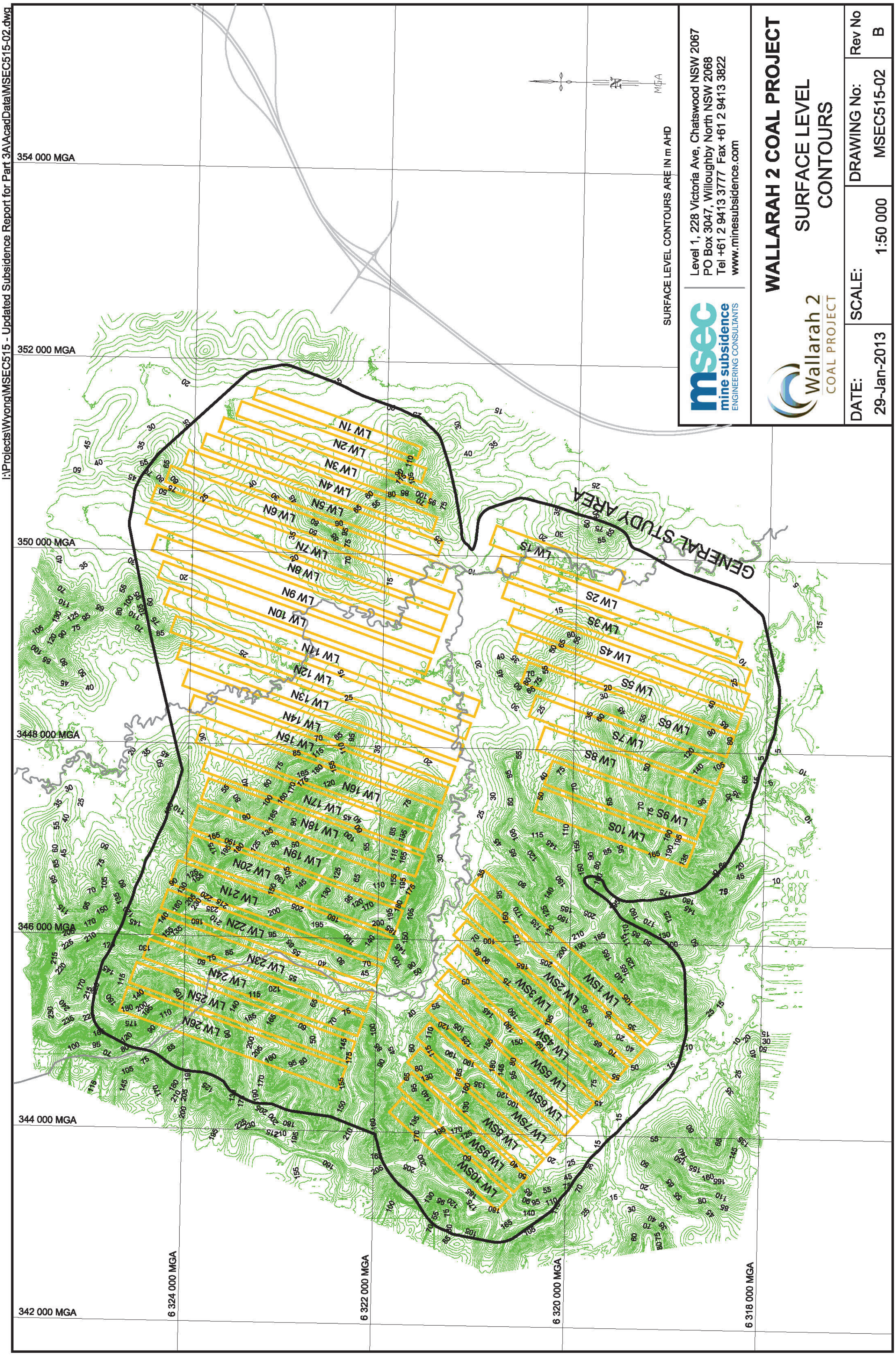
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SURFACE LEVEL CONTOURS ARE IN m AHD
GENERAL STUDY AREA
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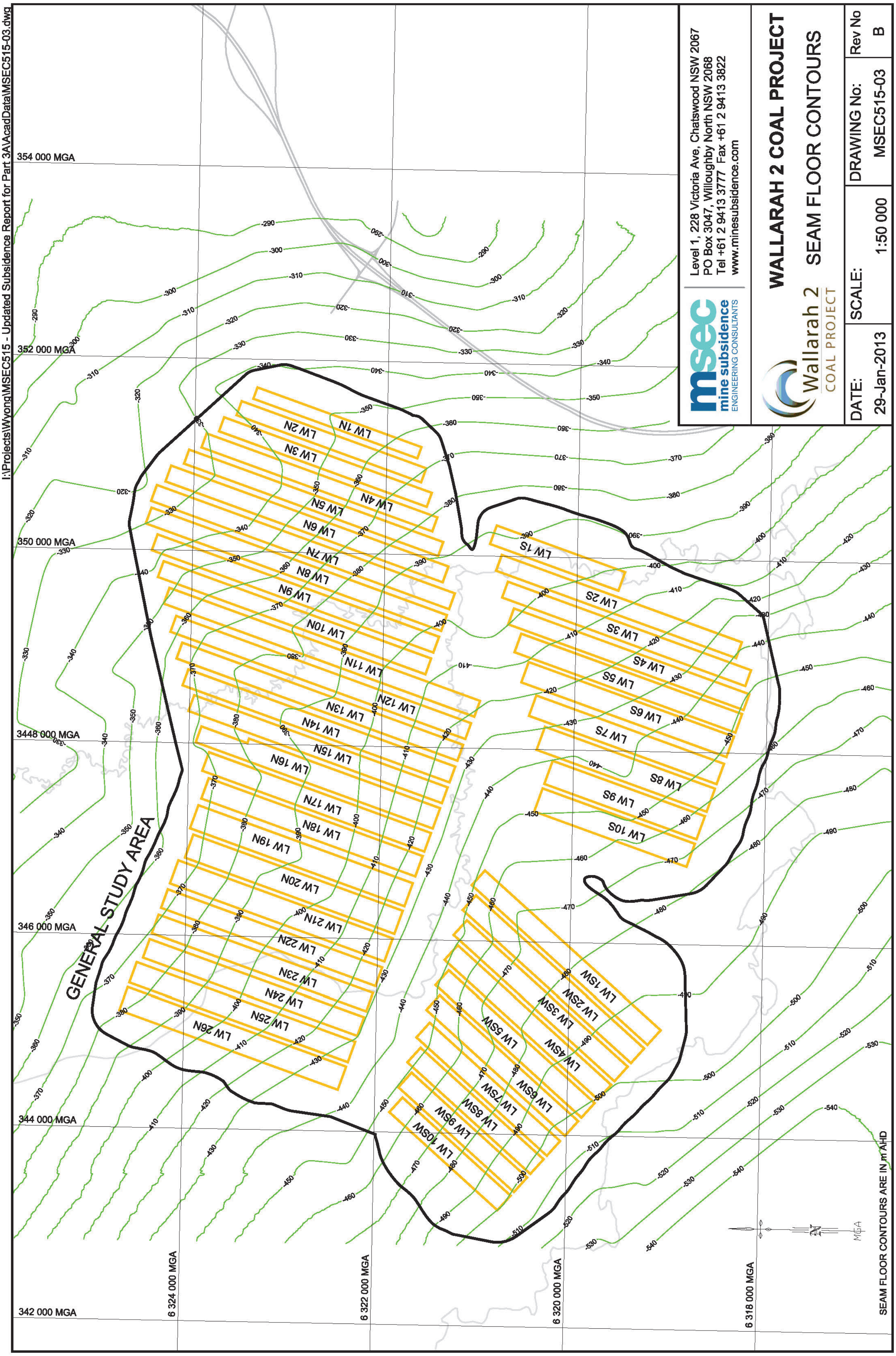
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WALLARAH 2 COAL PROJECT
SEAM FLOOR CONTOURS
DATE:
29-Jan-2013
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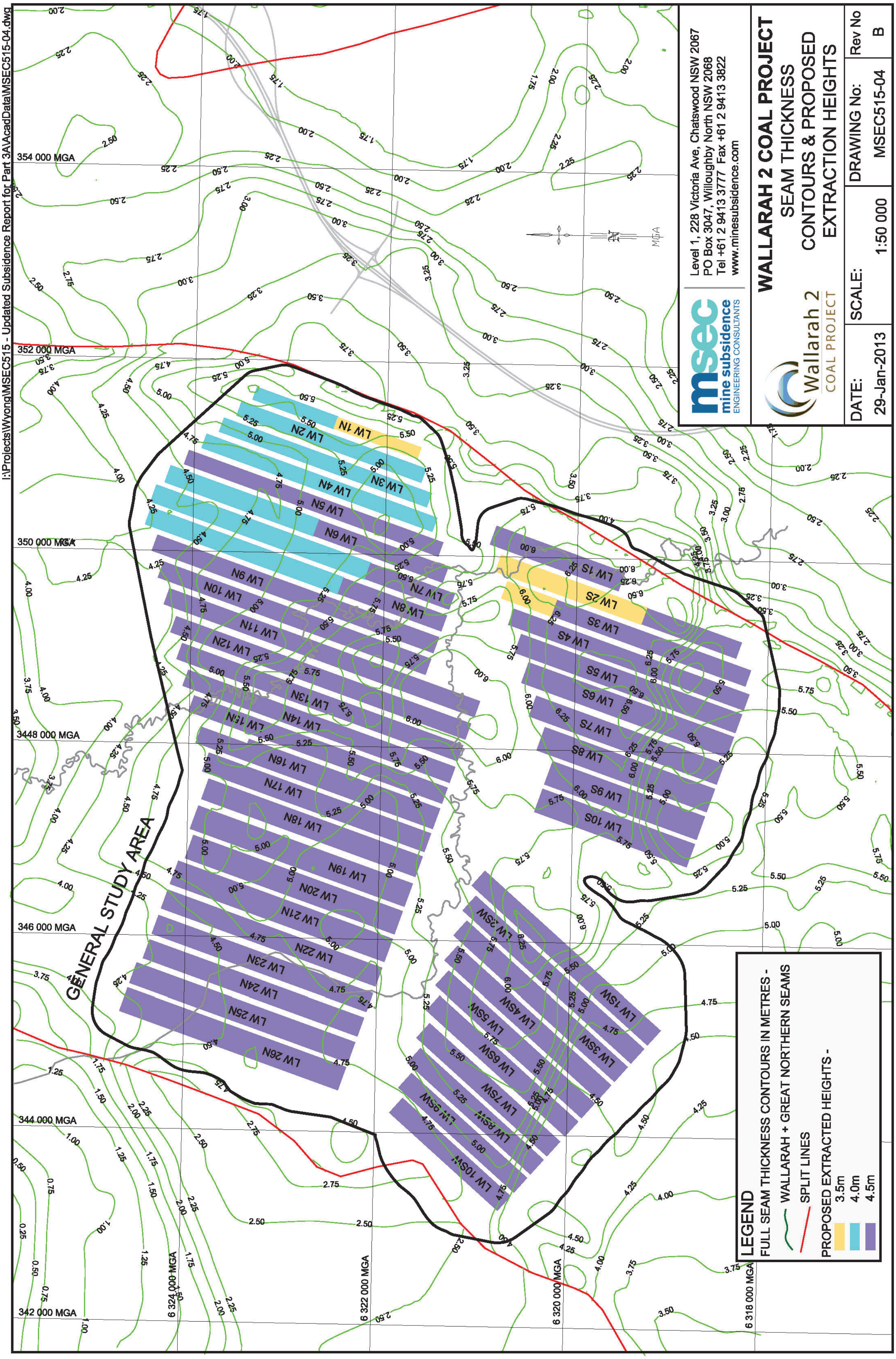

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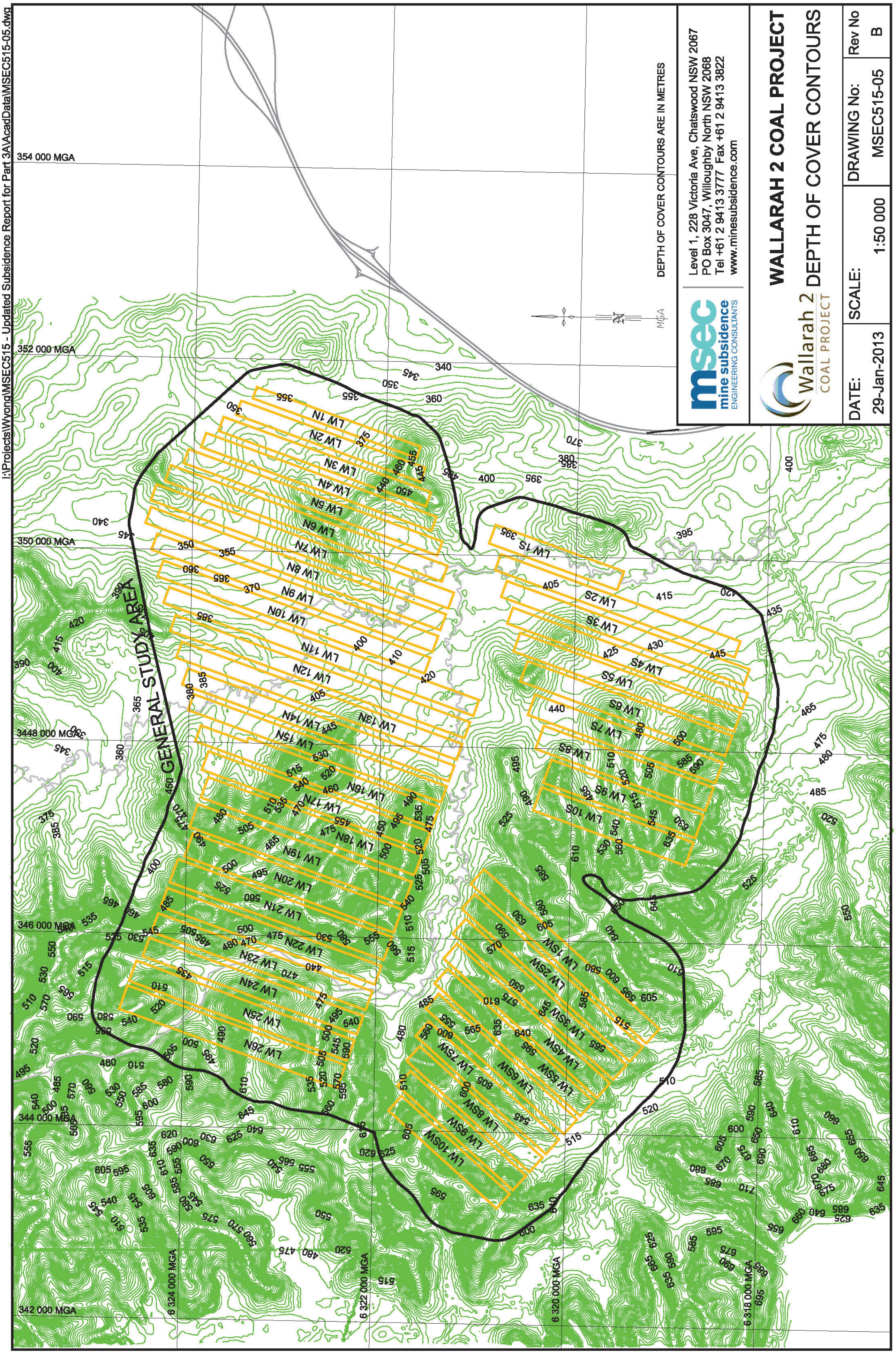
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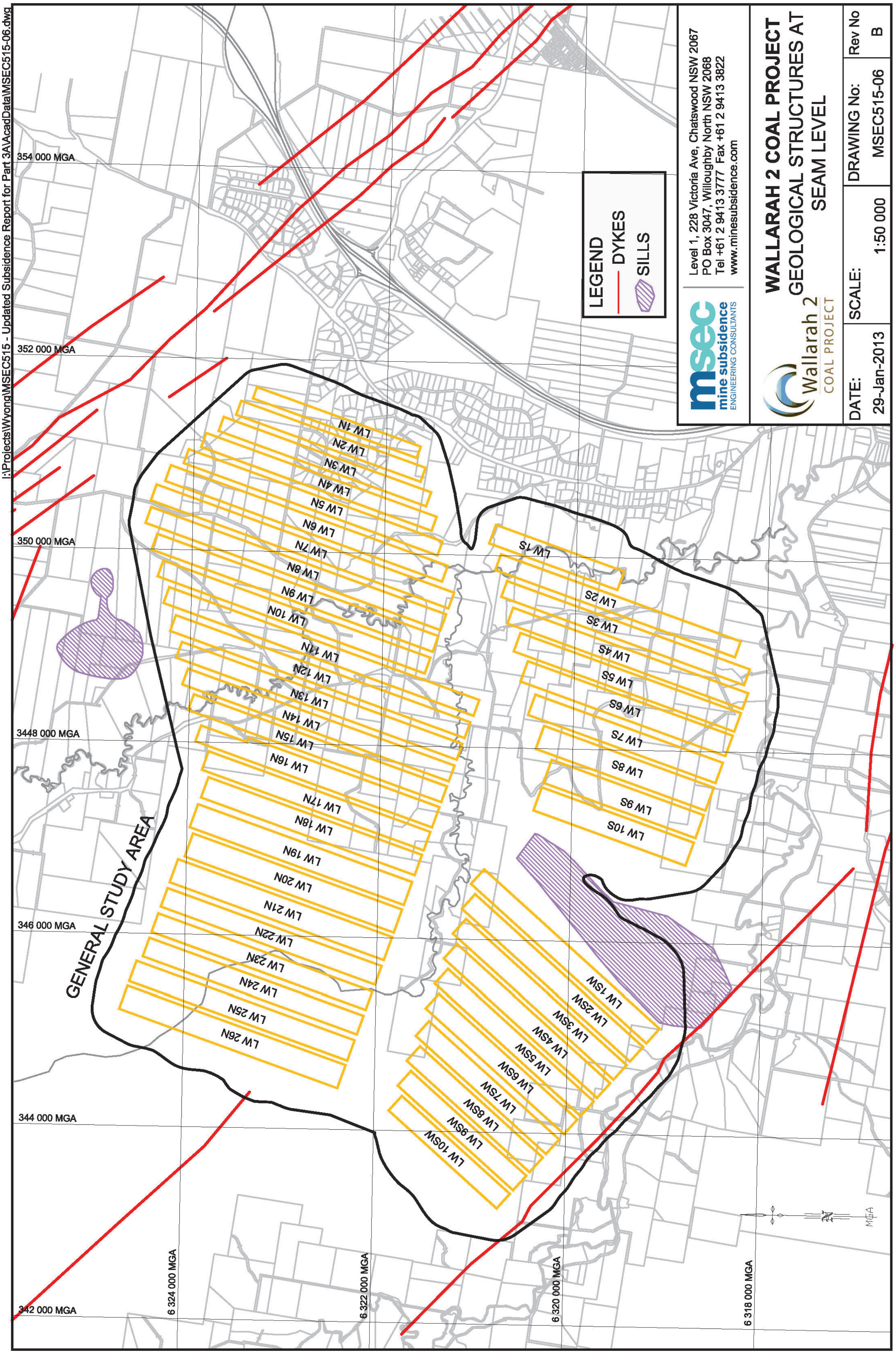

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SILLS
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GEOLOGICAL STRUCTURES AT SEAM LEVEL
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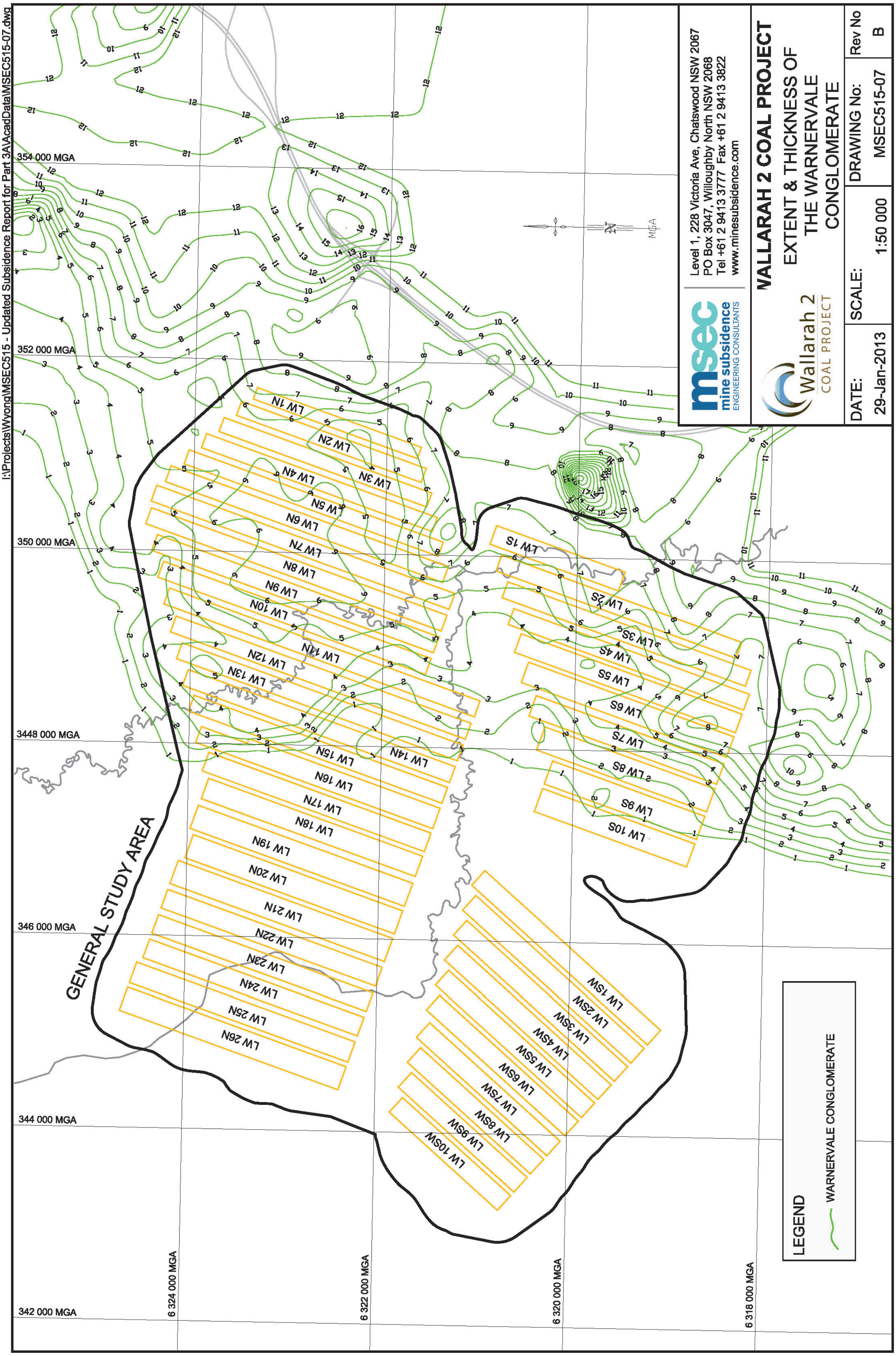
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COAL PROJECT
WALLARAH 2 COAL PROJECT
EXTENT & THICKNESS OF
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CONGLOMERATE
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SCALE:
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Rev No
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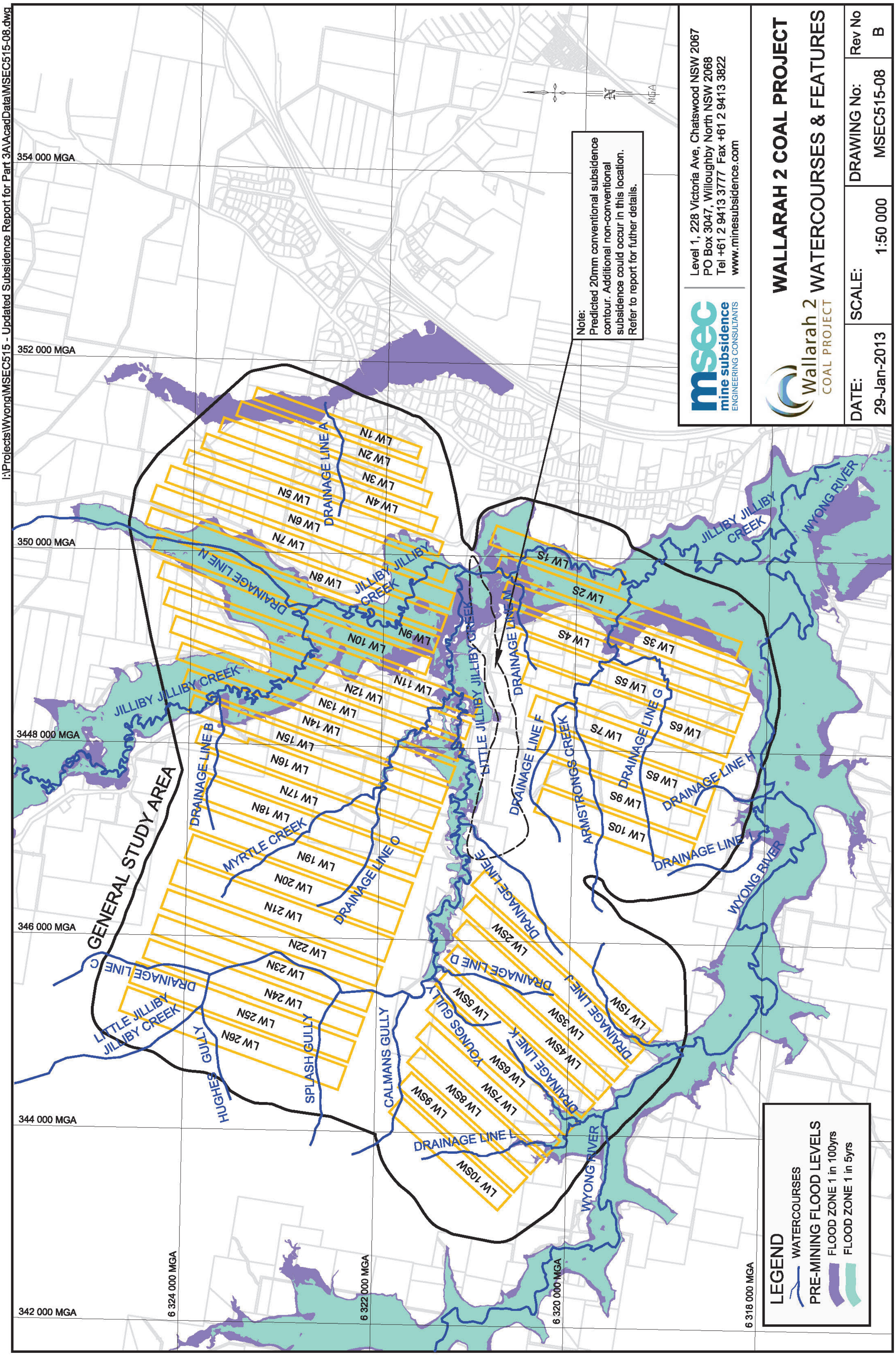
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Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
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LITTLE JILLIBY JILLIBY CREEK
WYONG RIVER
MYRTLE CREEK
ARMSTRONGS CREEK
HUGHES GULLY
SPLASH GULLY
CALMANS GULLY
YOUNGS GULLY
DRAINAGE LINE A
DRAINAGE LINE B
DRAINAGE LINE C
DRAINAGE LINE D
DRAINAGE LINE E
DRAINAGE LINE F
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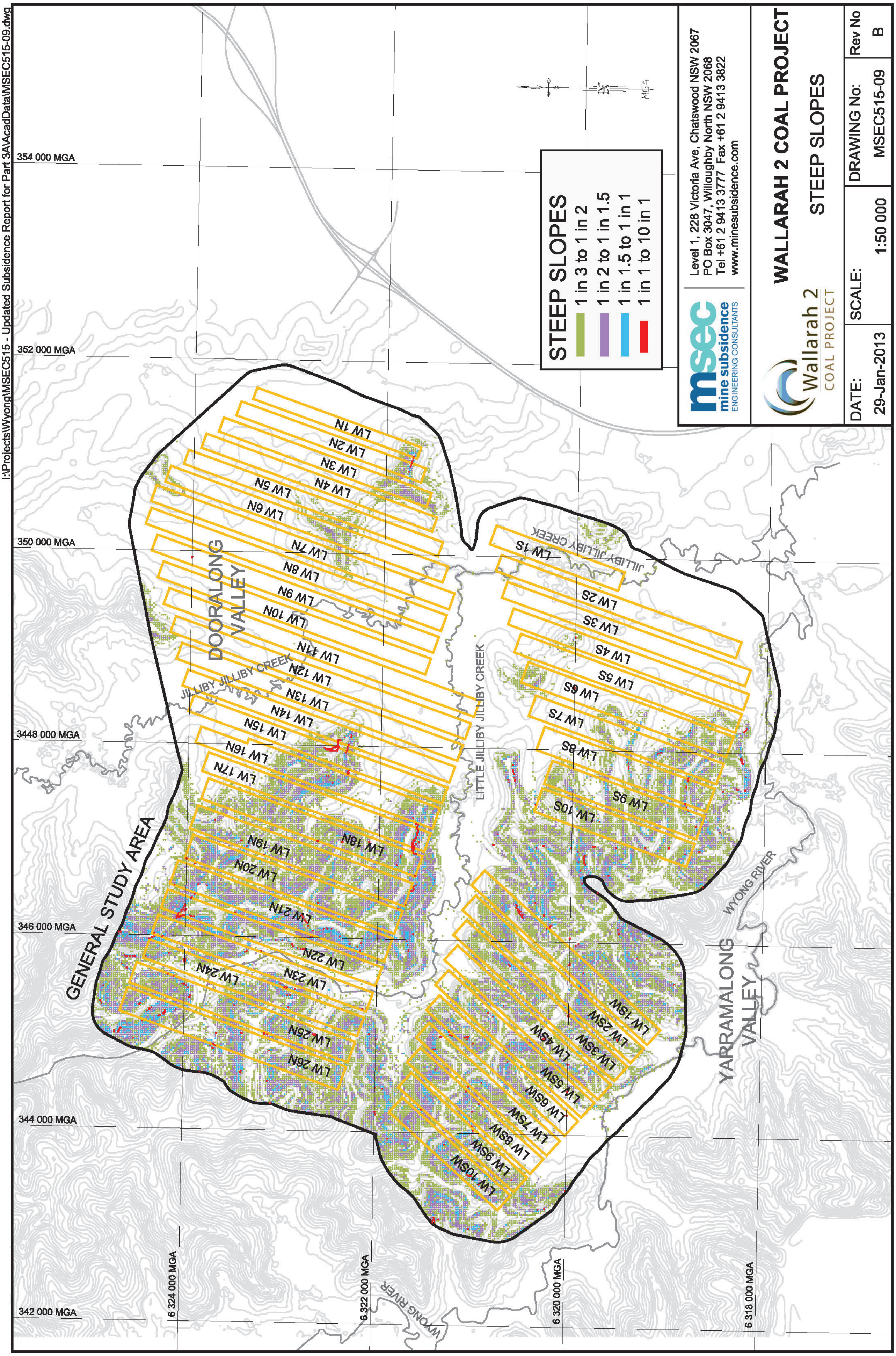
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STEEP SLOPES
1 in 3 to 1 in 2
1 in 2 to 1 in 1.5
1 in 1.5 to 1 in 1
1 in 1 to 10 in 1
msec
mine subsidence
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WALLARAH 2 COAL PROJECT
STEEP SLOPES
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SCALE:
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GENERAL STUDY AREA
DOORALONG VALLEY
JILLIBY JILLIBY CREEK
LITTLE JILLIBY JILLIBY CREEK
YARRAMALONG VALLEY
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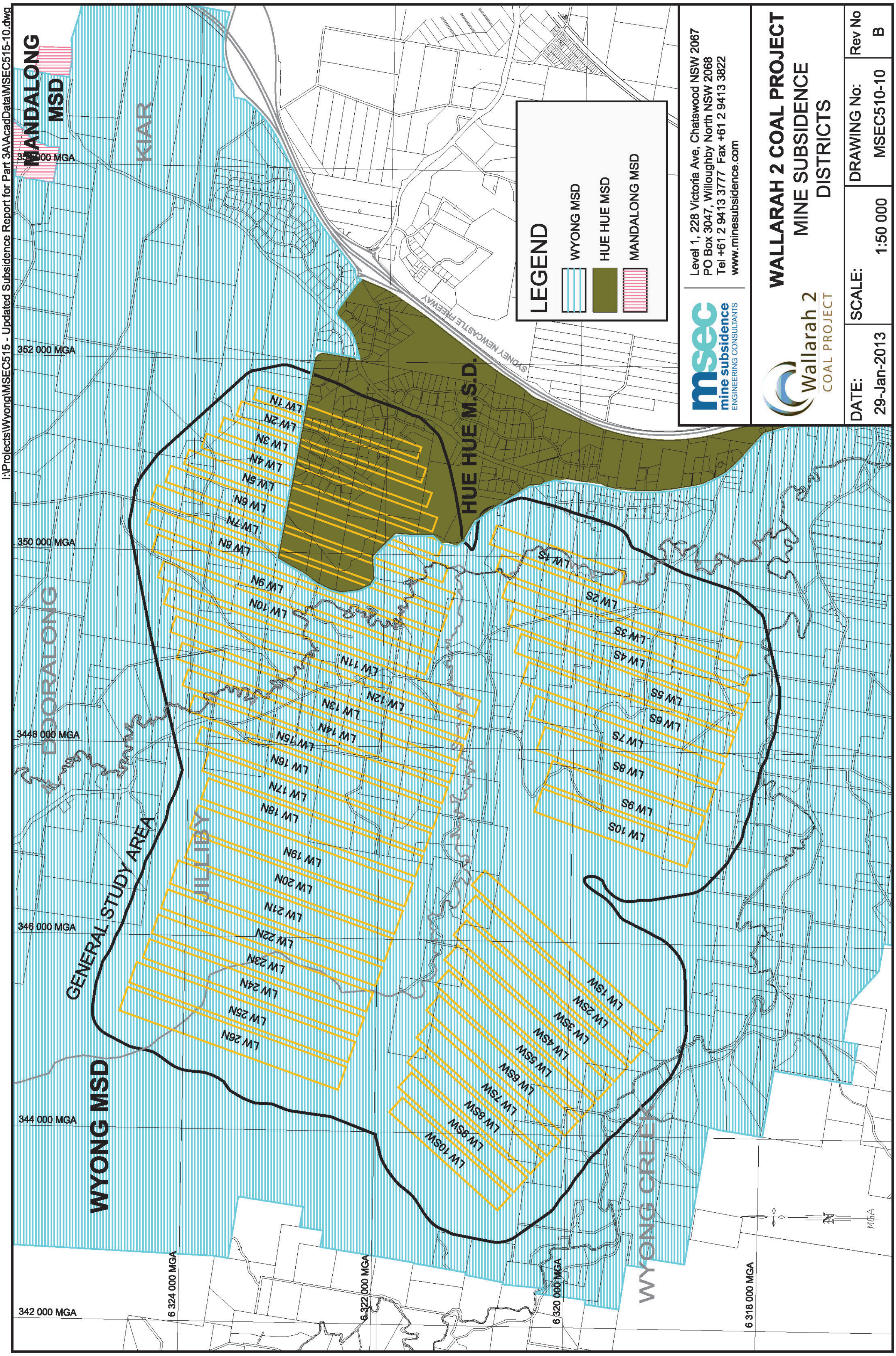

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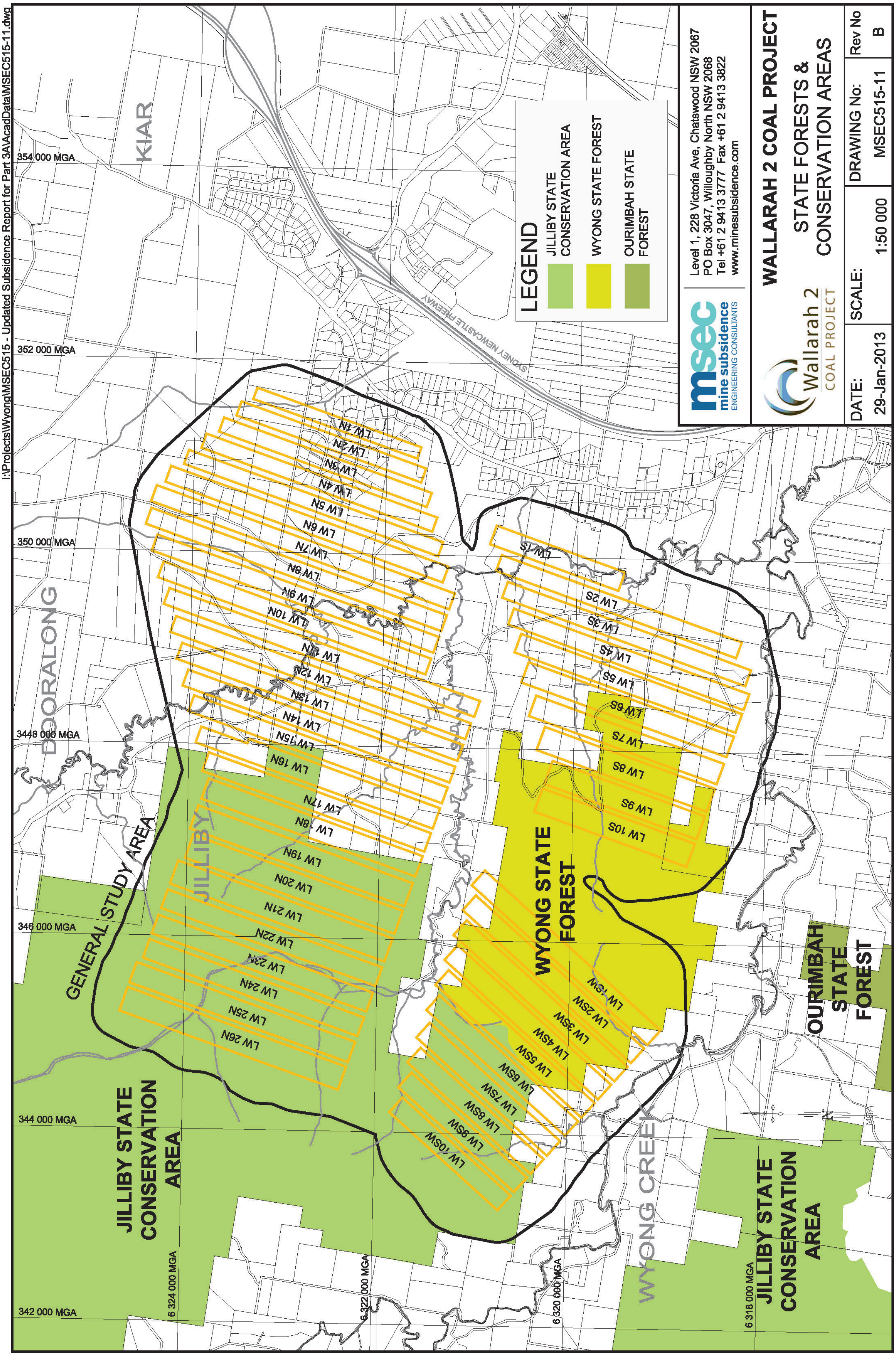
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LEGEND
JILLIBY STATE CONSERVATION AREA
WYONG STATE FOREST
OURIMBAH STATE FOREST
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COAL PROJECT
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DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-11
Rev No
B
KIAR
DOORALONG
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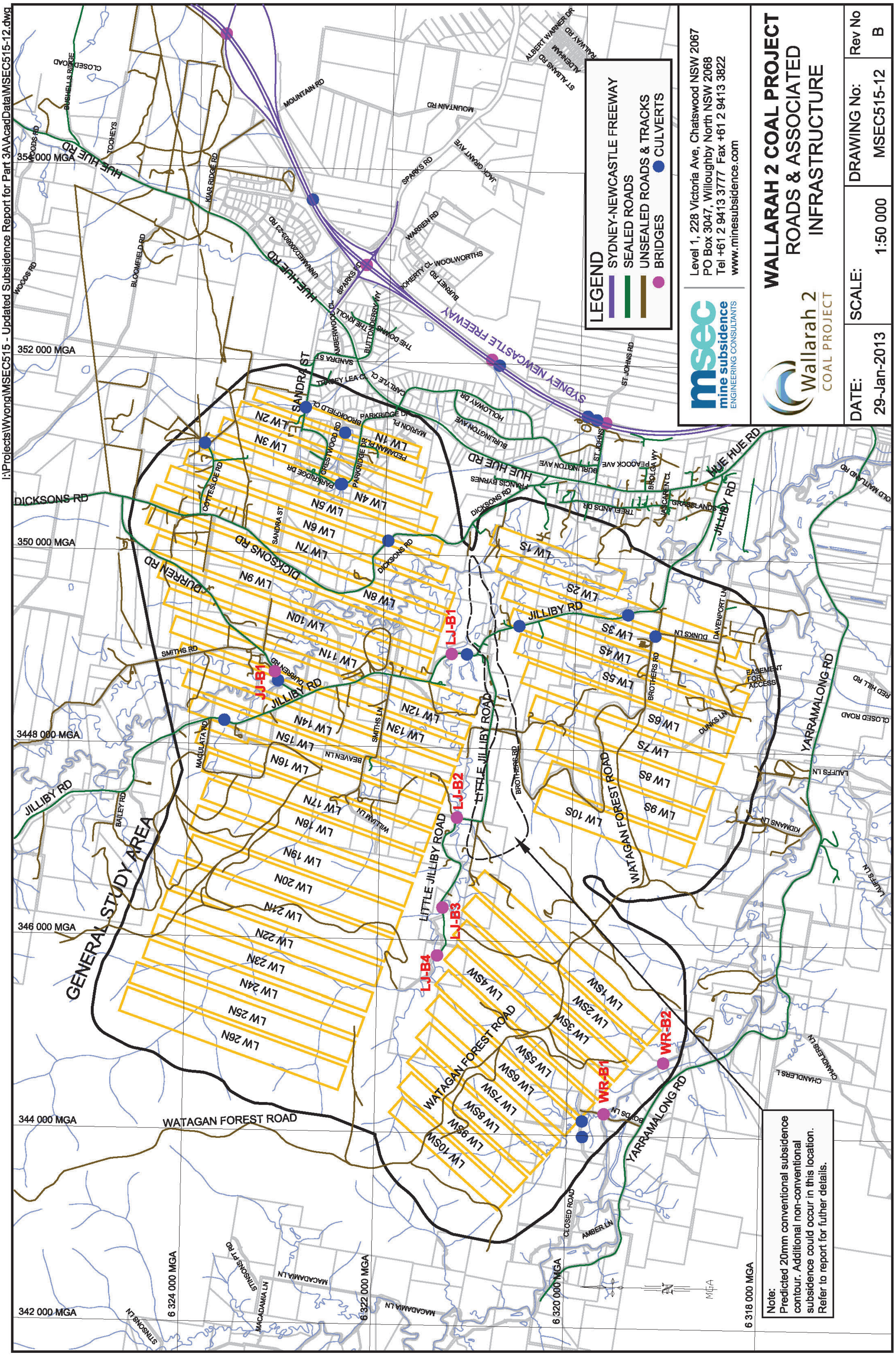

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SYDNEY-NEWCASTLE FREEWAY
SEALED ROADS
UNSEALED ROADS & TRACKS
BRIDGES
CULVERTS
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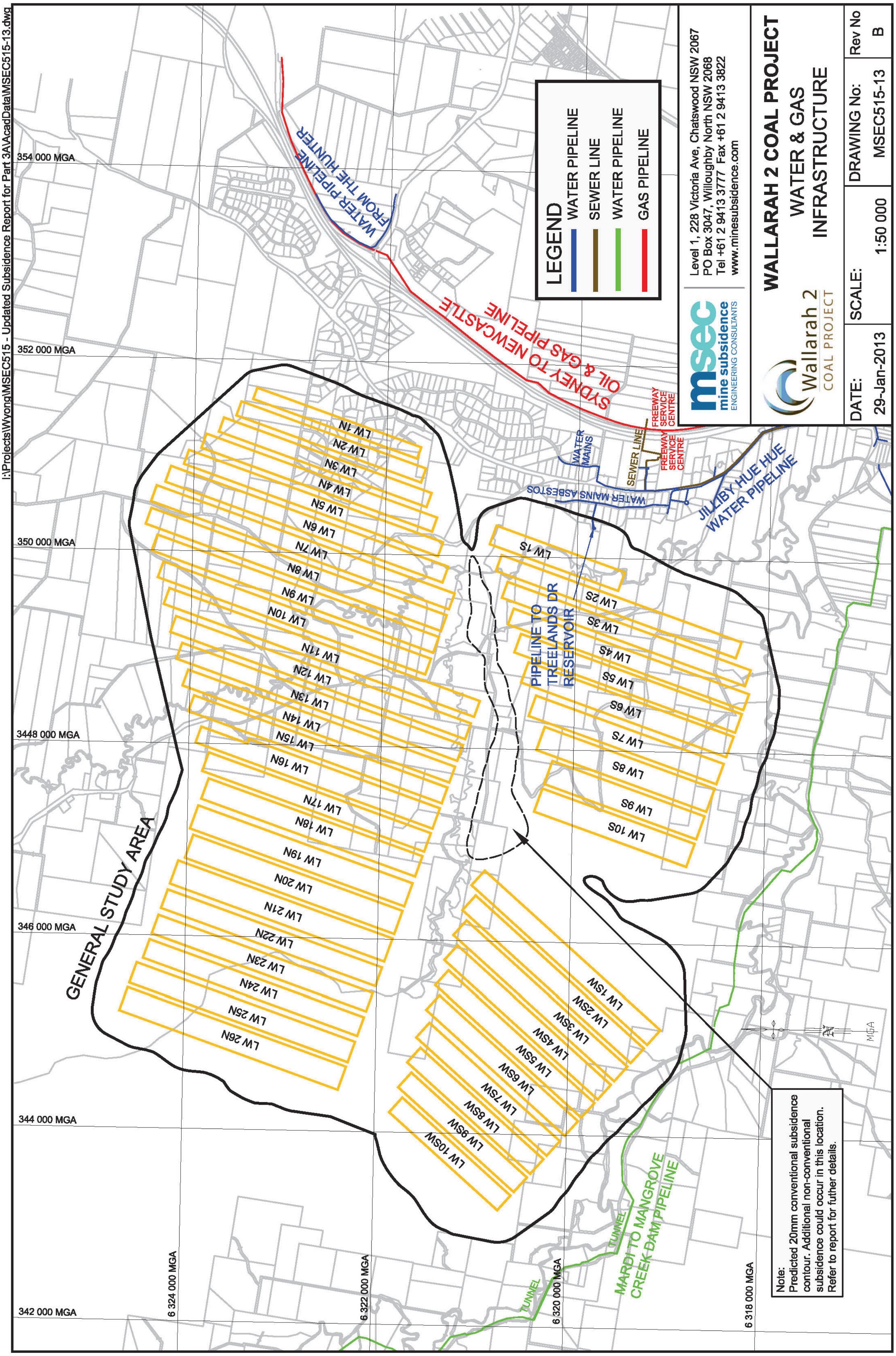
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
ROADS & ASSOCIATED
INFRASTRUCTURE
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-12
Rev No
B
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
GENERAL STUDY AREA
SYDNEY NEWCASTLE FREEWAY
LJ-B1
LJ-B2
LJ-B3
LJ-B4
WR-B1
WR-B2
JJ-B1
HUE HUE RD
DICKSONS RD
JILLIBY RD
LITTLE JILLIBY ROAD
WATAGAN FOREST ROAD
YARRAMALONG RD
354 000 MGA
352 000 MGA
350 000 MGA
3448 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-13.dwg
LEGEND
WATER PIPELINE
SEWER LINE
WATER PIPELINE
GAS PIPELINE
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
msec mine subsidence ENGINEERING CONSULTANTS
Wallarah 2 COAL PROJECT
WALLARAH 2 COAL PROJECT
WATER & GAS
INFRASTRUCTURE
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-13
Rev No
B
WATER PIPELINE FROM THE HUNTER
SYDNEY TO NEWCASTLE OIL & GAS PIPELINE
FREEWAY SERVICE CENTRE
FREEWAY SERVICE CENTRE
SEWER LINE
WATER MAINS
WATER MAINS ASBESTOS
JILLIBY HUE HUE WATER PIPELINE
PIPELINE TO TREELANDS DR RESERVOIR
GENERAL STUDY AREA
MARDI TO MANGROVE CREEK DAM PIPELINE
TUNNEL
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
354 000 MGA
352 000 MGA
350 000 MGA
3448 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA
LW 1N
LW 2N
LW 3N
LW 4N
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LW 7N
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LW 25N
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LW 1S
LW 2S
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LW 4S
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LW 8S
LW 9S
LW 10S
LW 1SW
LW 2SW
LW 3SW
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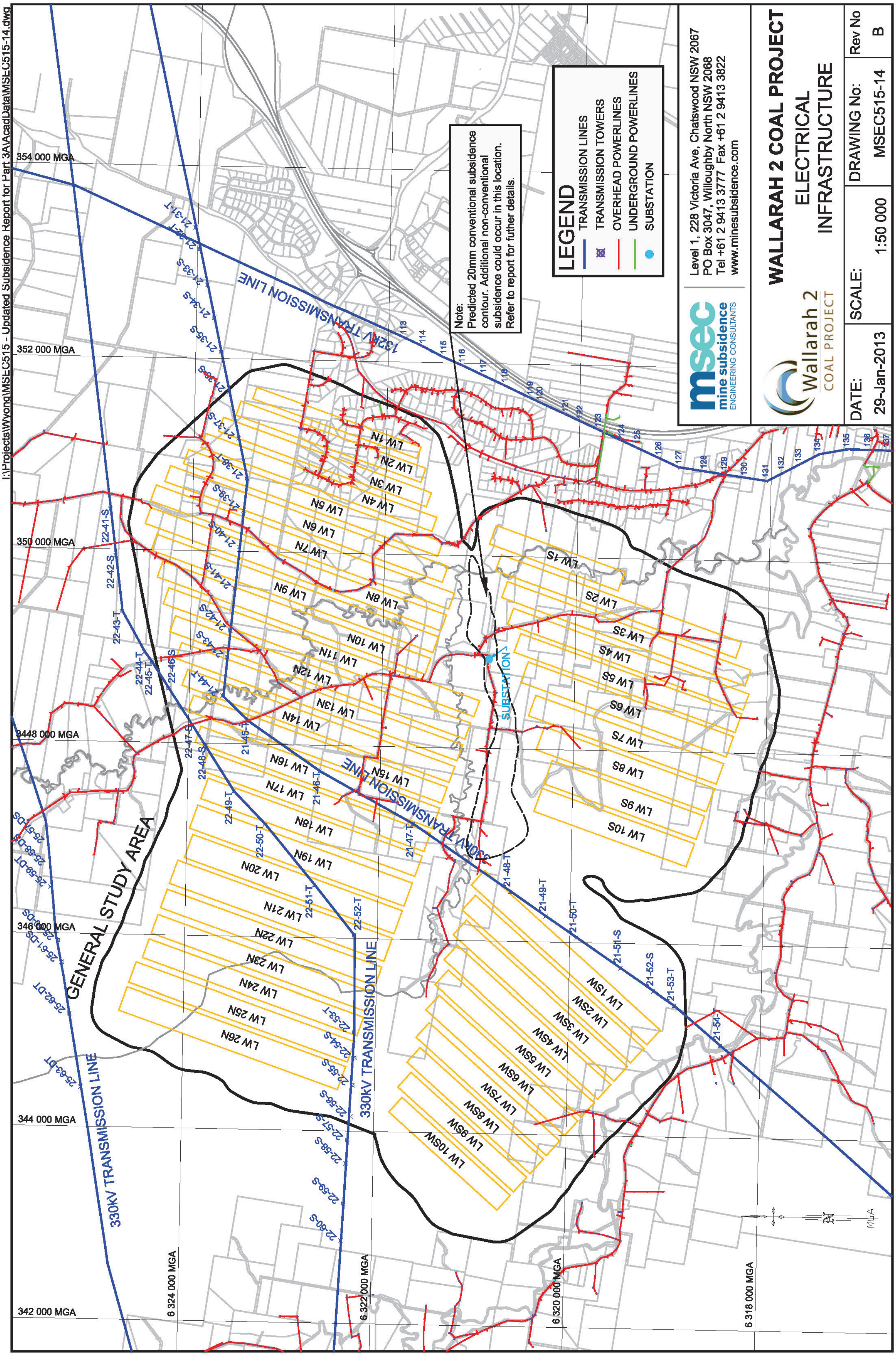
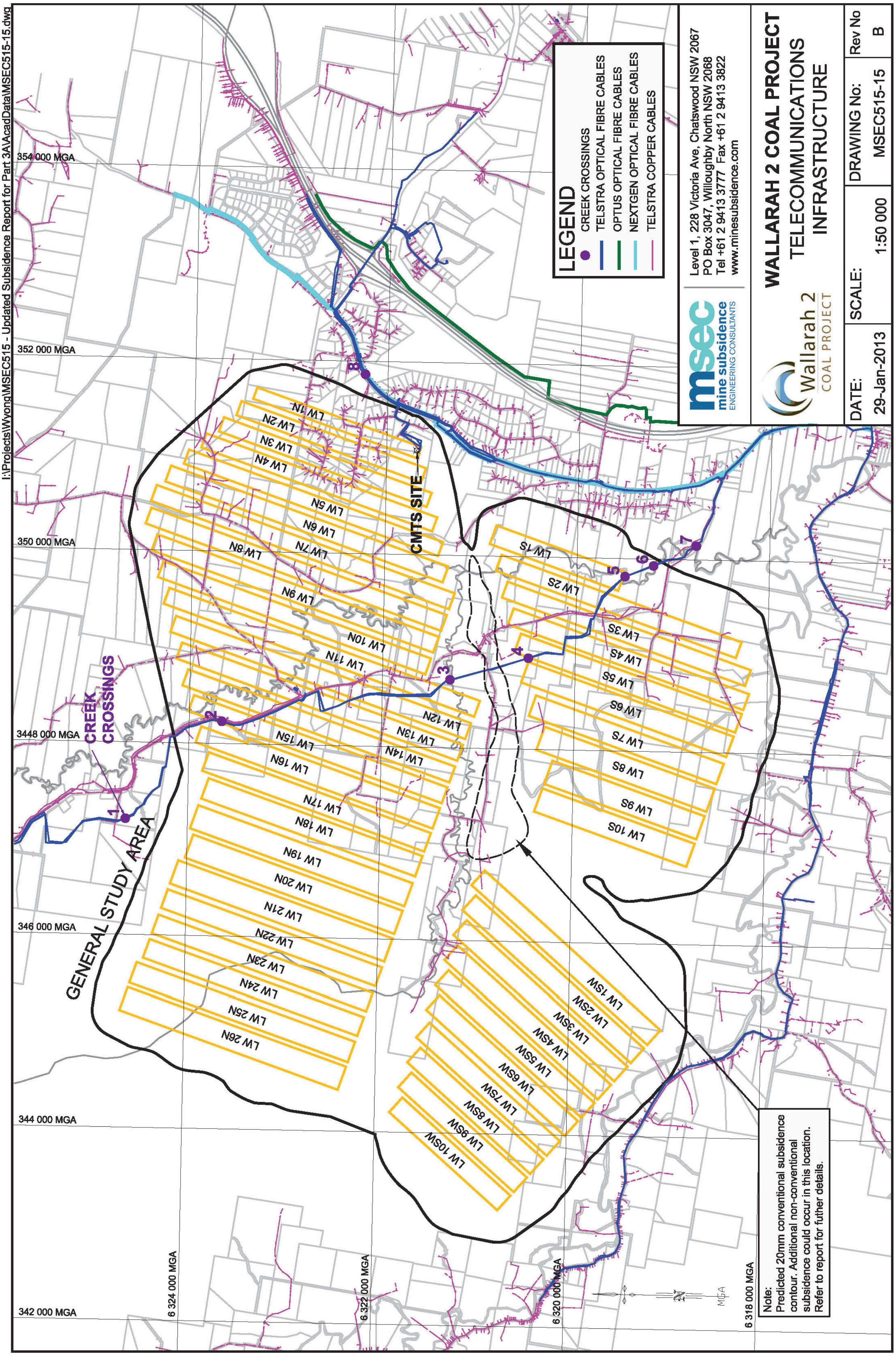
LW 5SW
LW 6SW
LW 7SW
LW 8SW
LW 9SW
LW 10SW



LEGEND
TRANSMISSION LINES
TRANSMISSION TOWERS
OVERHEAD POWERLINES
UNDERGROUND POWERLINES
SUBSTATION
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
msec
mine subsidence
ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
ELECTRICAL
INFRASTRUCTURE
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-14
Rev No
B
132kV TRANSMISSION LINE
330kV TRANSMISSION LINE
GENERAL STUDY AREA
SUBSTATION


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-15.dwg
LEGEND
CREEK CROSSINGS
TELSTRA OPTICAL FIBRE CABLES
OPTUS OPTICAL FIBRE CABLES
NEXTGEN OPTICAL FIBRE CABLES
TELSTRA COPPER CABLES
msec
mine subsidence
ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
TELECOMMUNICATIONS
INFRASTRUCTURE
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-15
Rev No
B
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location.
Refer to report for futher details.
GENERAL STUDY AREA
CREEK CROSSINGS
CMTS SITE
354 000 MGA
352 000 MGA
350 000 MGA
3448 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA
LW 1N
LW 2N
LW 3N
LW 4N
LW 5N
LW 6N
LW 7N
LW 8N
LW 9N
LW 10N
LW 11N
LW 12N
LW 13N
LW 14N
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LW 24N
LW 25N
LW 26N
LW 1S
LW 2S
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LW 4S
LW 5S
LW 6S
LW 7S
LW 8S
LW 9S
LW 10S
LW 1SW
LW 2SW
LW 3SW
LW 4SW
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LW 6SW
LW 7SW
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LW 10SW
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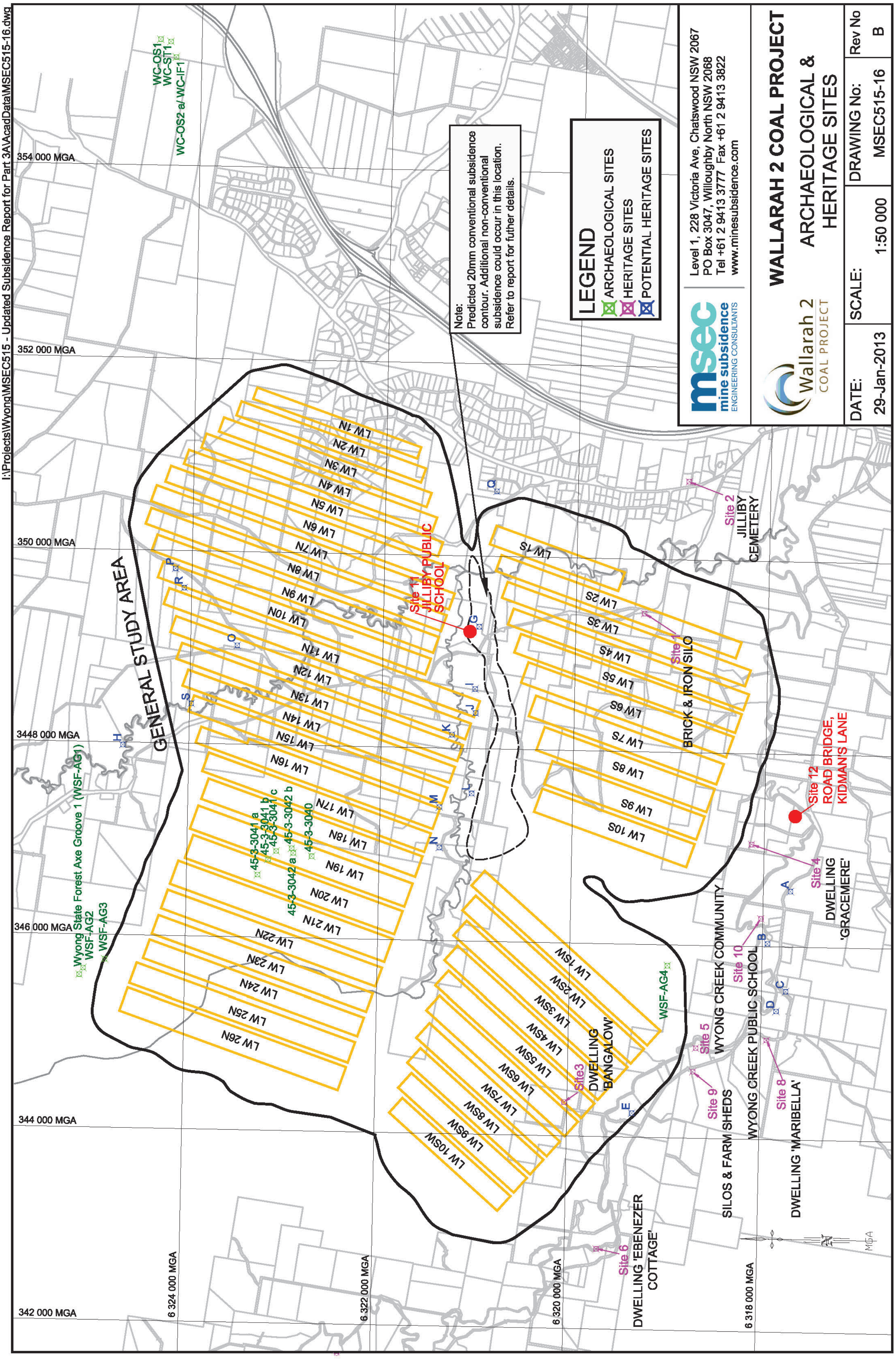
4
5
6
7
8


WALLARAH 2 COAL PROJECT
ARCHAEOLOGICAL & HERITAGE SITES
LEGEND
ARCHAEOLOGICAL SITES
HERITAGE SITES
POTENTIAL HERITAGE SITES
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
msec mine subsidence ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
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Wallarah 2 COAL PROJECT
DATE: 29-Jan-2013
SCALE: 1:50 000
DRAWING No: MSEC515-16
Rev No B
I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-16.dwg
GENERAL STUDY AREA
Site 11 JILLIBY PUBLIC SCHOOL
Site 2 JILLIBY CEMETERY
Site 1 BRICK & IRON SILO
Site 12 ROAD BRIDGE, KIDMAN'S LANE
Site 4 DWELLING 'GRACEMERE'
Site 10 WYONG CREEK PUBLIC SCHOOL
Site 5 WYONG CREEK COMMUNITY
Site 9 SILOS & FARM SHEDS
Site 8 DWELLING 'MARIBELLA'
Site3 DWELLING 'BANGALOW'
Site 6 DWELLING 'EBENEZER COTTAGE'
Wyong State Forest Axe Groove 1 (WSF-AG1)
WSF-AG2
WSF-AG3
WSF-AG4
WC-OS1
WC-ST1
WC-OS2 a/ WC-IF1
45-3-3041 a
45-3-3041 b
45-3-3041 c
45-3-3042 a
45-3-3042 b
45-3-3040
LW 1N
LW 2N
LW 3N
LW 4N
LW 5N
LW 6N
LW 7N
LW 8N
LW 9N
LW 10N
LW 11N
LW 12N
LW 13N
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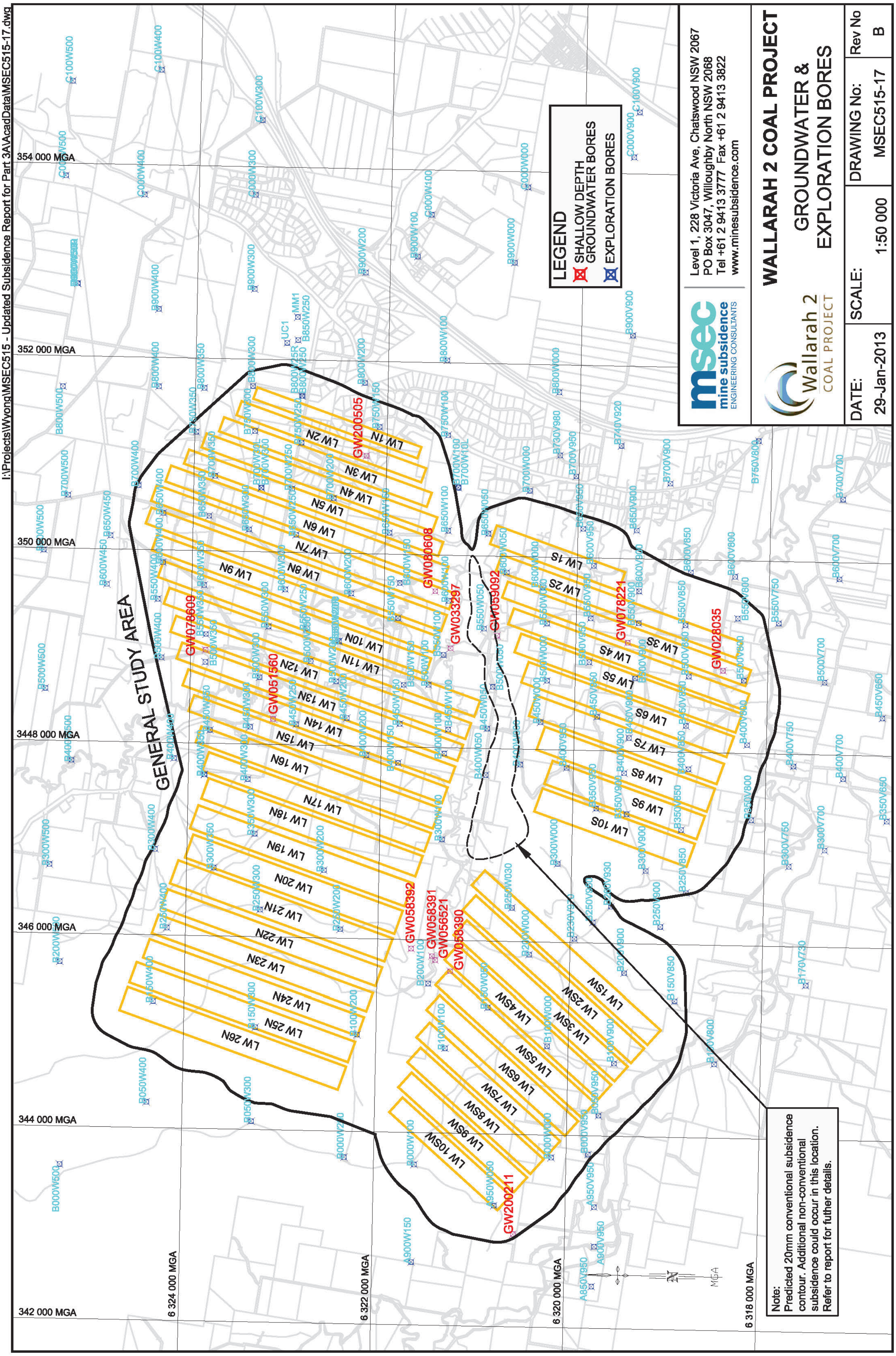
LW 25N
LW 26N
LW 1S
LW 2S
LW 3S
LW 4S
LW 5S
LW 6S
LW 7S
LW 8S
LW 9S
LW 10S
LW 1SW
LW 2SW
LW 3SW
LW 4SW
LW 5SW
LW 6SW
LW 7SW
LW 8SW
LW 9SW
LW 10SW
354 000 MGA
352 000 MGA
350 000 MGA
3448 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-17.dwg
GENERAL STUDY AREA
LEGEND
SHALLOW DEPTH GROUNDWATER BORES
EXPLORATION BORES
msec
mine subsidence
ENGINEERING CONSULTANTS
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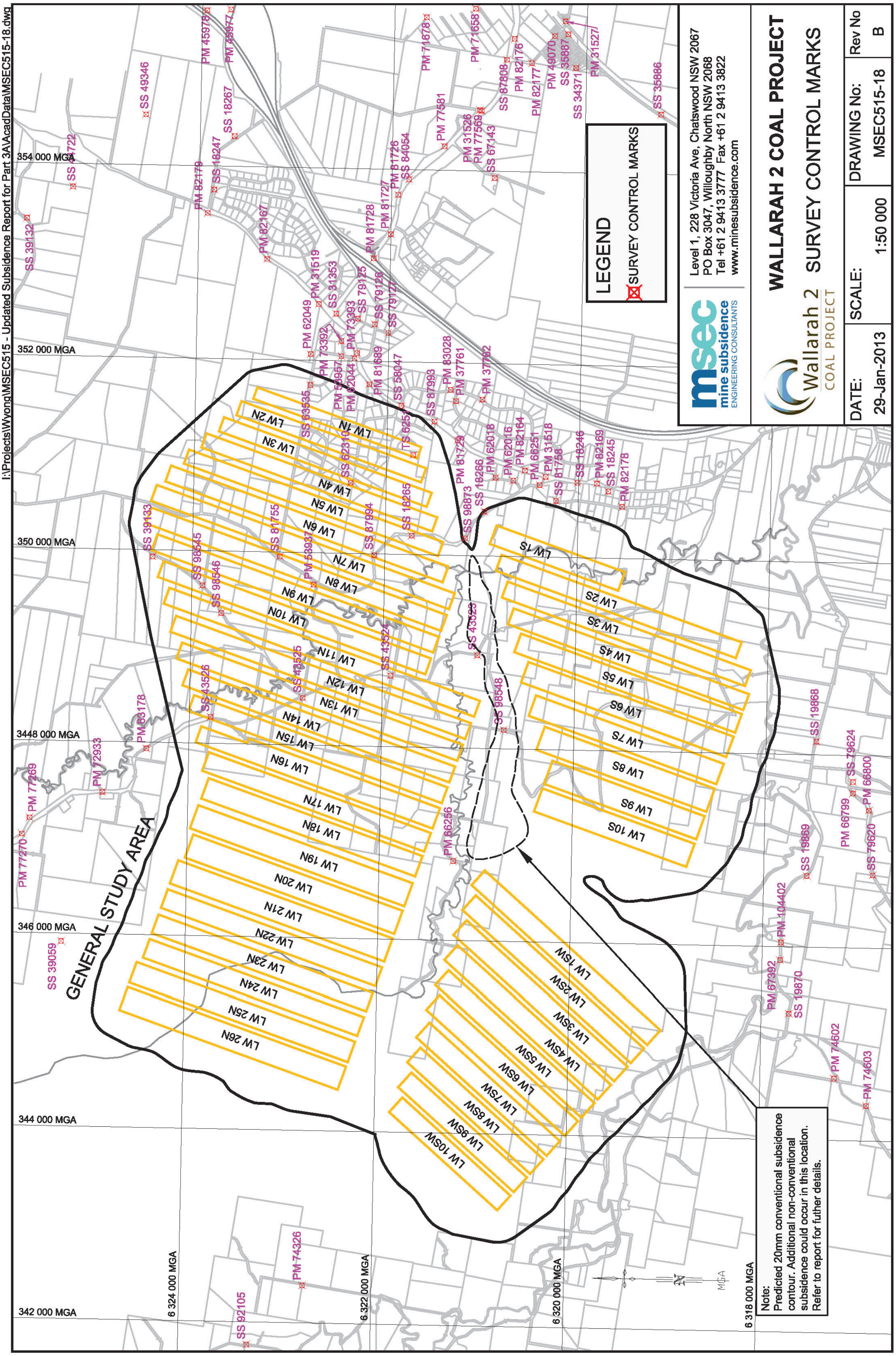
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
GROUNDWATER &
EXPLORATION BORES
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-17
Rev No
B
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location.
Refer to report for futher details.
MGA


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-18.dwg
LEGEND
SURVEY CONTROL MARKS
GENERAL STUDY AREA
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location.
Refer to report for futher details.
msec mine subsidence ENGINEERING CONSULTANTS
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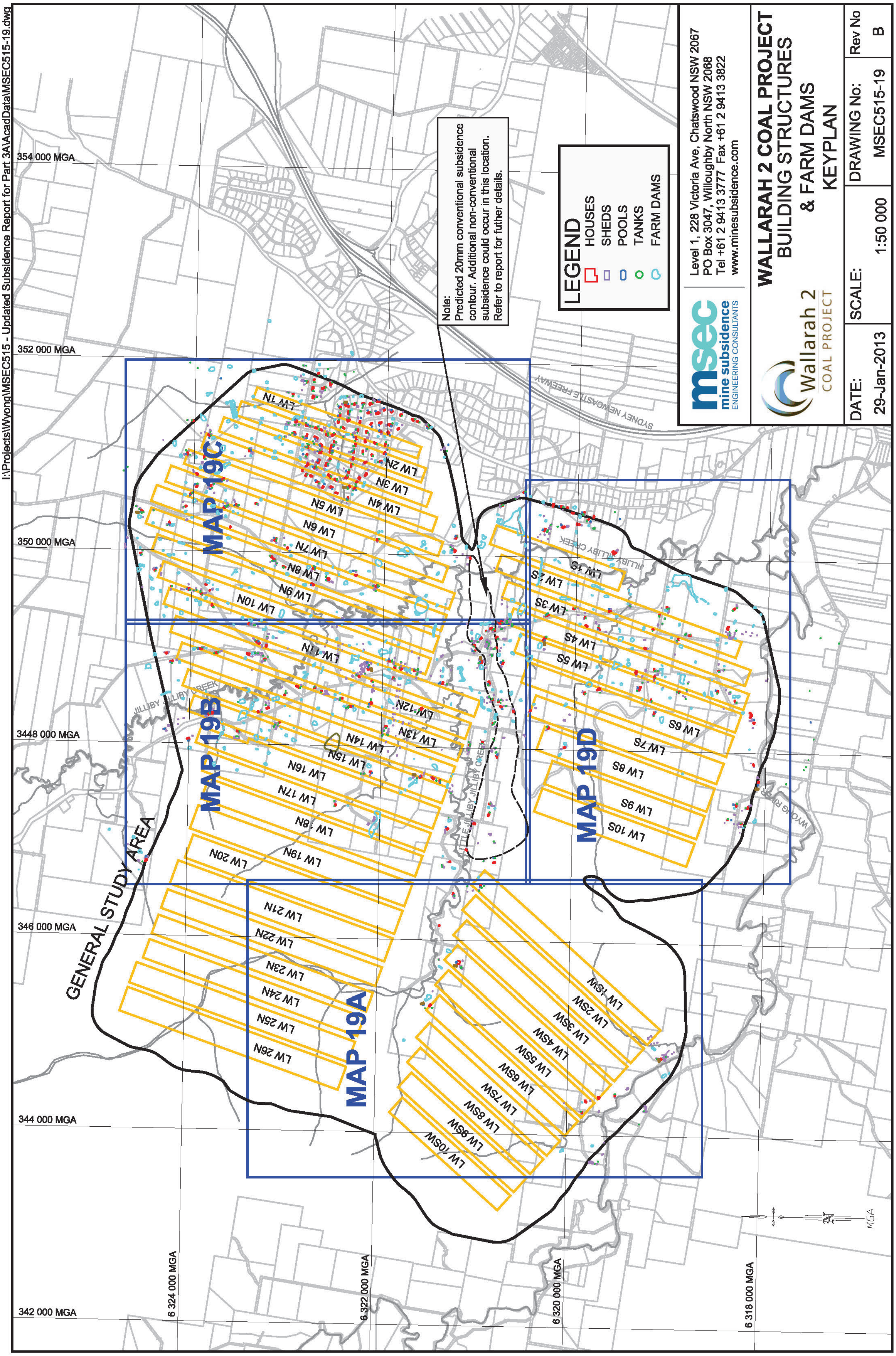
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2 COAL PROJECT
WALLARAH 2 COAL PROJECT
SURVEY CONTROL MARKS
DATE: 29-Jan-2013
SCALE: 1:50 000
DRAWING No: MSEC515-18
Rev No B


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-19.dwg
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
LEGEND
HOUSES
SHEDS
POOLS
TANKS
FARM DAMS
msec
mine subsidence
ENGINEERING CONSULTANTS
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PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
BUILDING STRUCTURES
& FARM DAMS
KEYPLAN
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC515-19
Rev No
B
MAP 19A
MAP 19B
MAP 19C
MAP 19D
GENERAL STUDY AREA
SYDNEY NEWCASTLE FREEWAY
JILLIBY JILLIBY CREEK
LITTLE JILLIBY JILLIBY CREEK
WYONG RIVER
354 000 MGA
352 000 MGA
350 000 MGA
348 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA
LW 1N
LW 2N
LW 3N
LW 4N
LW 5N
LW 6N
LW 7N
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LW 26N
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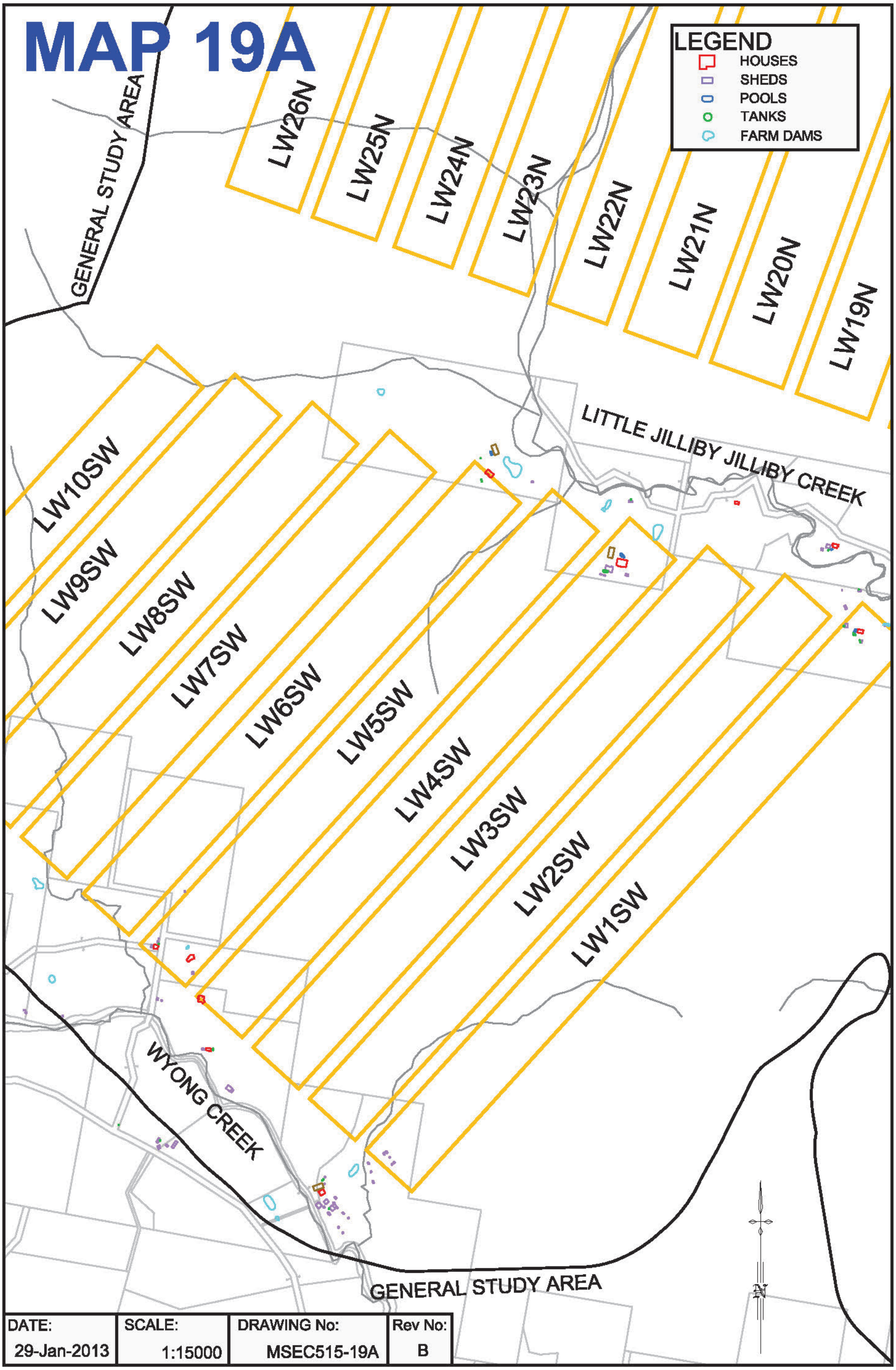
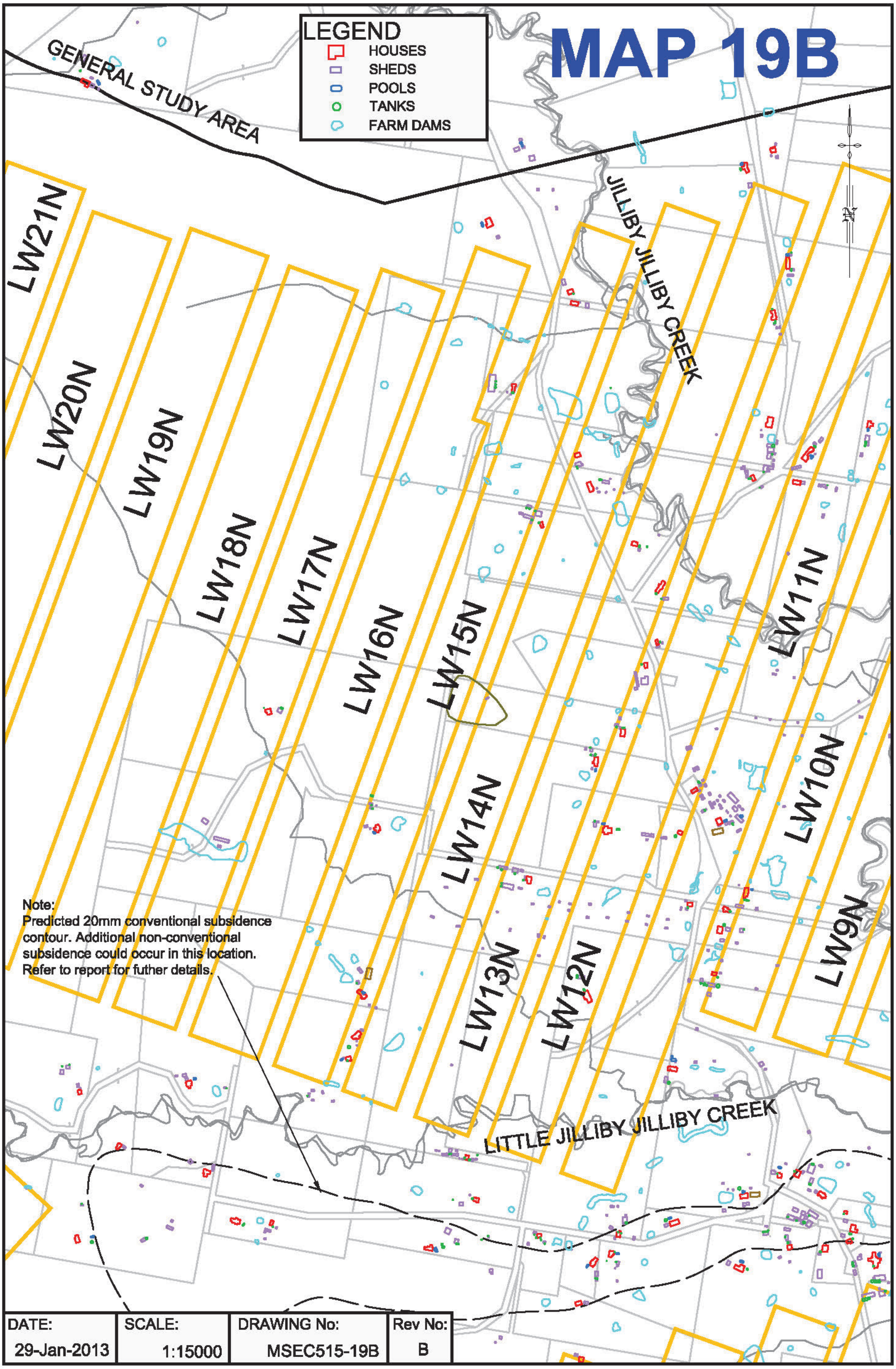
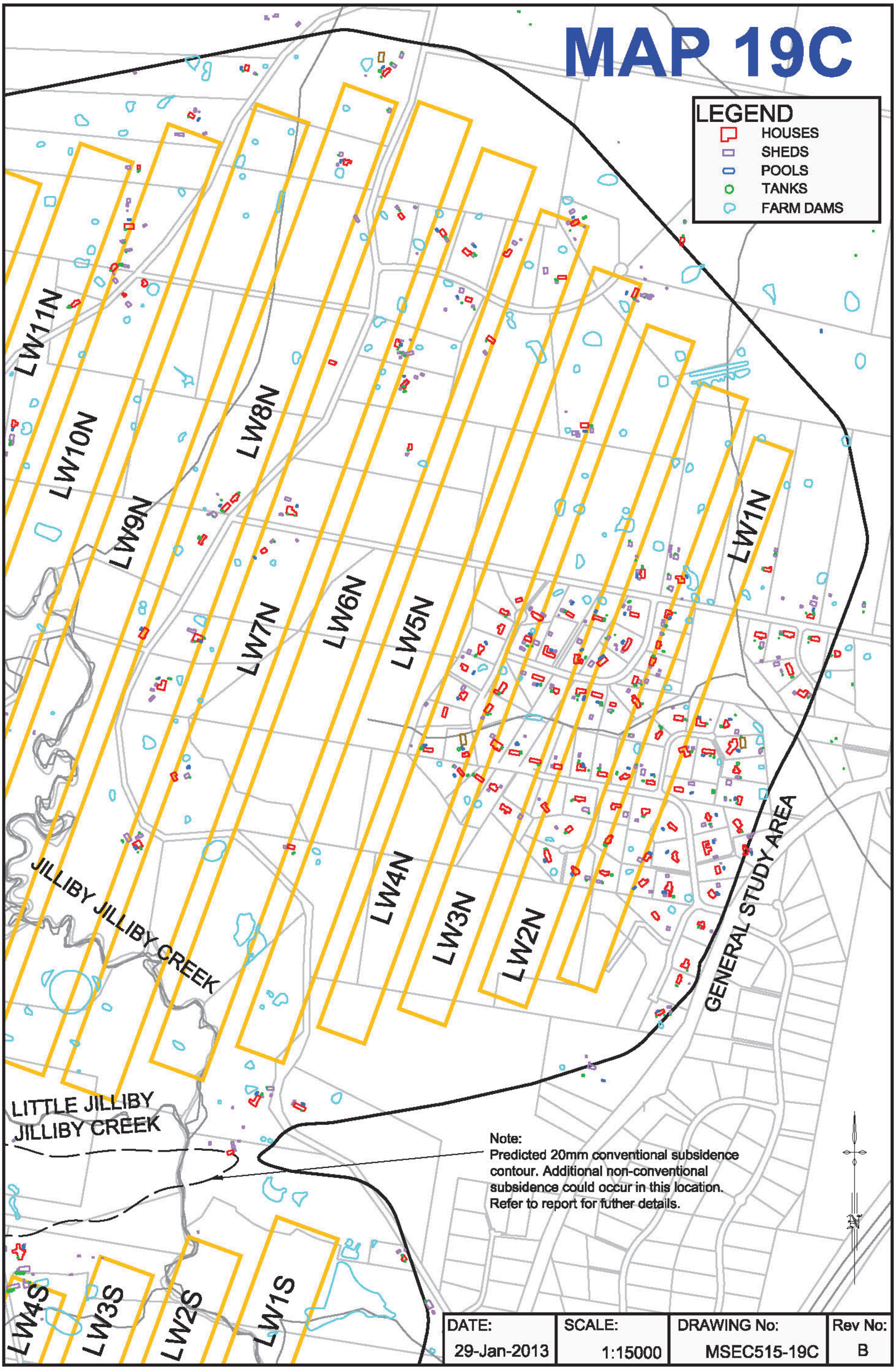
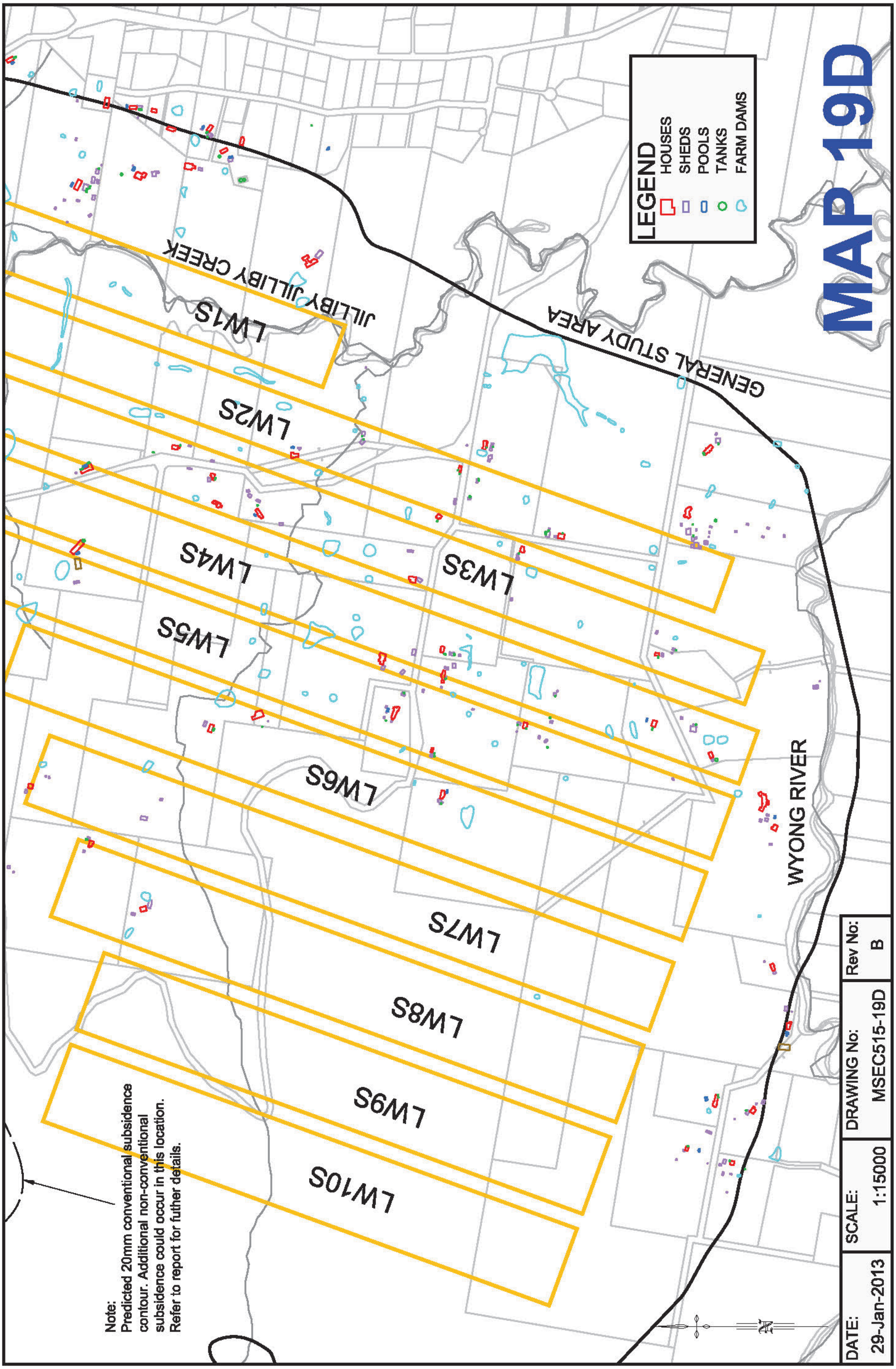
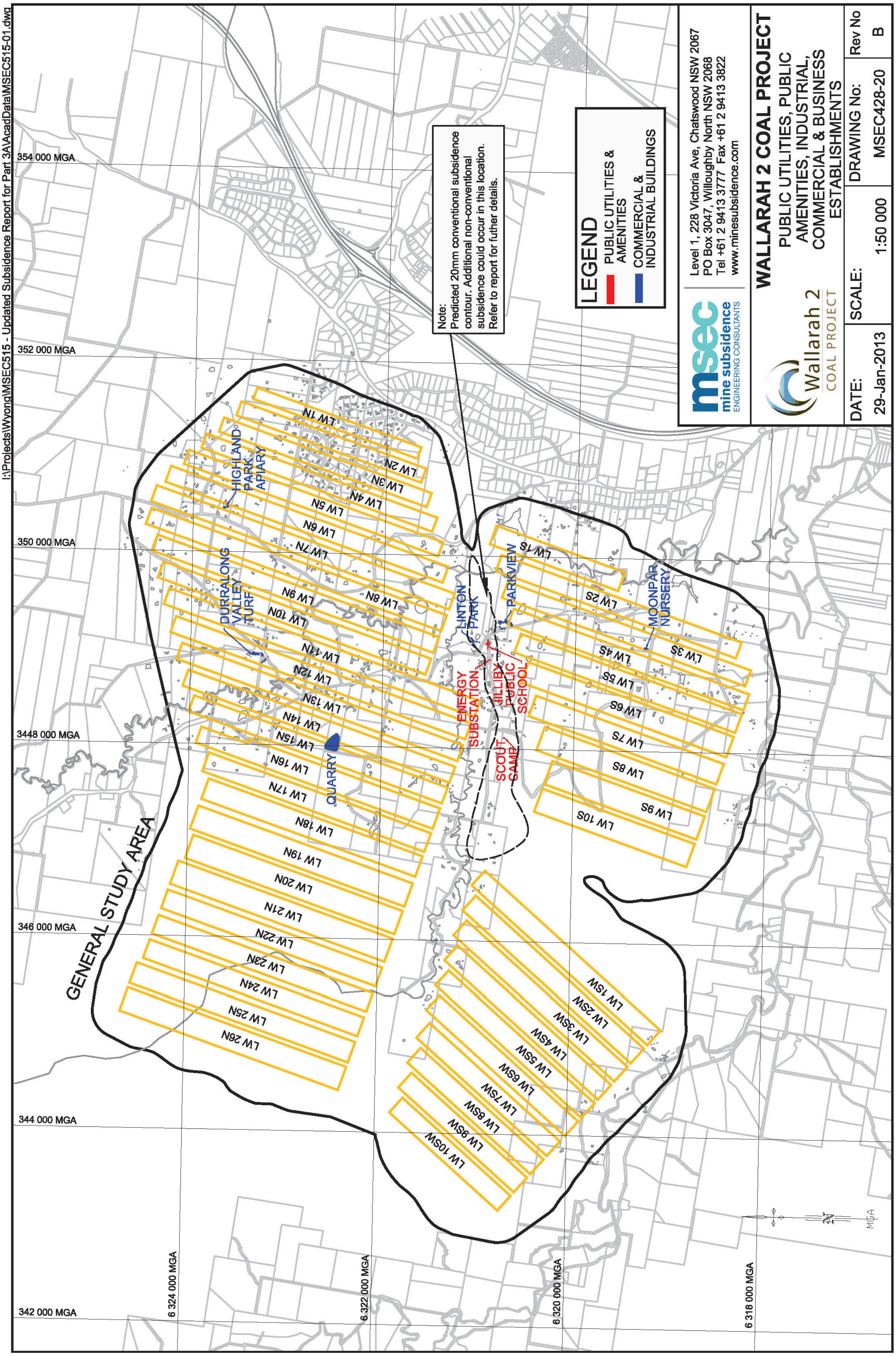
LW 2S
LW 3S
LW 4S
LW 5S
LW 6S
LW 7S
LW 8S
LW 9S
LW 10S
LW 1SW
LW 2SW
LW 3SW
LW 4SW
LW 5SW
LW 6SW
LW 7SW
LW 8SW
LW 9SW
LW 10SW
MGA


MAP 19A
LEGEND
HOUSES
SHEDS
POOLS
TANKS
FARM DAMS
GENERAL STUDY AREA
LW26N
LW25N
LW24N
LW23N
LW22N
LW21N
LW20N
LW19N
LITTLE JILLIBY JILLIBY CREEK
LW10SW
LW9SW
LW8SW
LW7SW
LW6SW
LW5SW
LW4SW
LW3SW
LW2SW
LW1SW
WYONG CREEK
GENERAL STUDY AREA
N
DATE:
29-Jan-2013
SCALE:
1:15000
DRAWING No:
MSEC515-19A
Rev No:
B


MAP 19B
LEGEND
HOUSES
SHEDS
POOLS
TANKS
FARM DAMS
GENERAL STUDY AREA
JILLIBY JILLIBY CREEK
LITTLE JILLIBY JILLIBY CREEK
LW21N
LW20N
LW19N
LW18N
LW17N
LW16N
LW15N
LW14N
LW13N
LW12N
LW11N
LW10N
LW9N
N
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
DATE: 29-Jan-2013
SCALE: 1:15000
DRAWING No: MSEC515-19B
Rev No: B


MAP 19C
LEGEND
HOUSES
SHEDS
POOLS
TANKS
FARM DAMS
LW11N
LW10N
LW9N
LW8N
LW7N
LW6N
LW5N
LW4N
LW3N
LW2N
LW1N
JILLIBY JILLIBY CREEK
LITTLE JILLIBY
JILLIBY CREEK
GENERAL STUDY AREA
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
LW4S
LW3S
LW2S
LW1S
DATE: 29-Jan-2013
SCALE: 1:15000
DRAWING No: MSEC515-19C
Rev No: B


MAP 19D
LEGEND
HOUSES
SHEDS
POOLS
TANKS
FARM DAMS
JILLIBY JILLIBY CREEK
GENERAL STUDY AREA
WYONG RIVER
LW1S
LW2S
LW3S
LW4S
LW5S
LW6S
LW7S
LW8S
LW9S
LW10S
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location.
Refer to report for futher details.
DATE:
29-Jan-2013
SCALE:
1:15000
DRAWING No:
MSEC515-19D
Rev No:
B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354 000 MGA
352 000 MGA
350 000 MGA
3448 000 MGA
346 000 MGA
344 000 MGA
342 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA
Note:
Predicted 20mm conventional subsidence contour. Additional non-conventional subsidence could occur in this location. Refer to report for futher details.
LEGEND
PUBLIC UTILITIES & AMENITIES
COMMERCIAL & INDUSTRIAL BUILDINGS
msec
mine subsidence
ENGINEERING CONSULTANTS
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www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
PUBLIC UTILITIES, PUBLIC AMENITIES, INDUSTRIAL, COMMERCIAL & BUSINESS ESTABLISHMENTS
DATE:
29-Jan-2013
SCALE:
1:50 000
DRAWING No:
MSEC428-20
Rev No
B
HIGHLAND PARK APIARY
DURRALONG VALLEY TURF
QUARRY
LINTON PARK
PARKVIEW
MOONPAR NURSERY
ENERGY SUBSTATION
JILLIBY PUBLIC SCHOOL
SCOUT CAMP
GENERAL STUDY AREA
LW 1N
LW 2N
LW 3N
LW 4N
LW 5N
LW 6N
LW 7N
LW 8N
LW 9N
LW 10N
LW 11N
LW 12N
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LW 4SW
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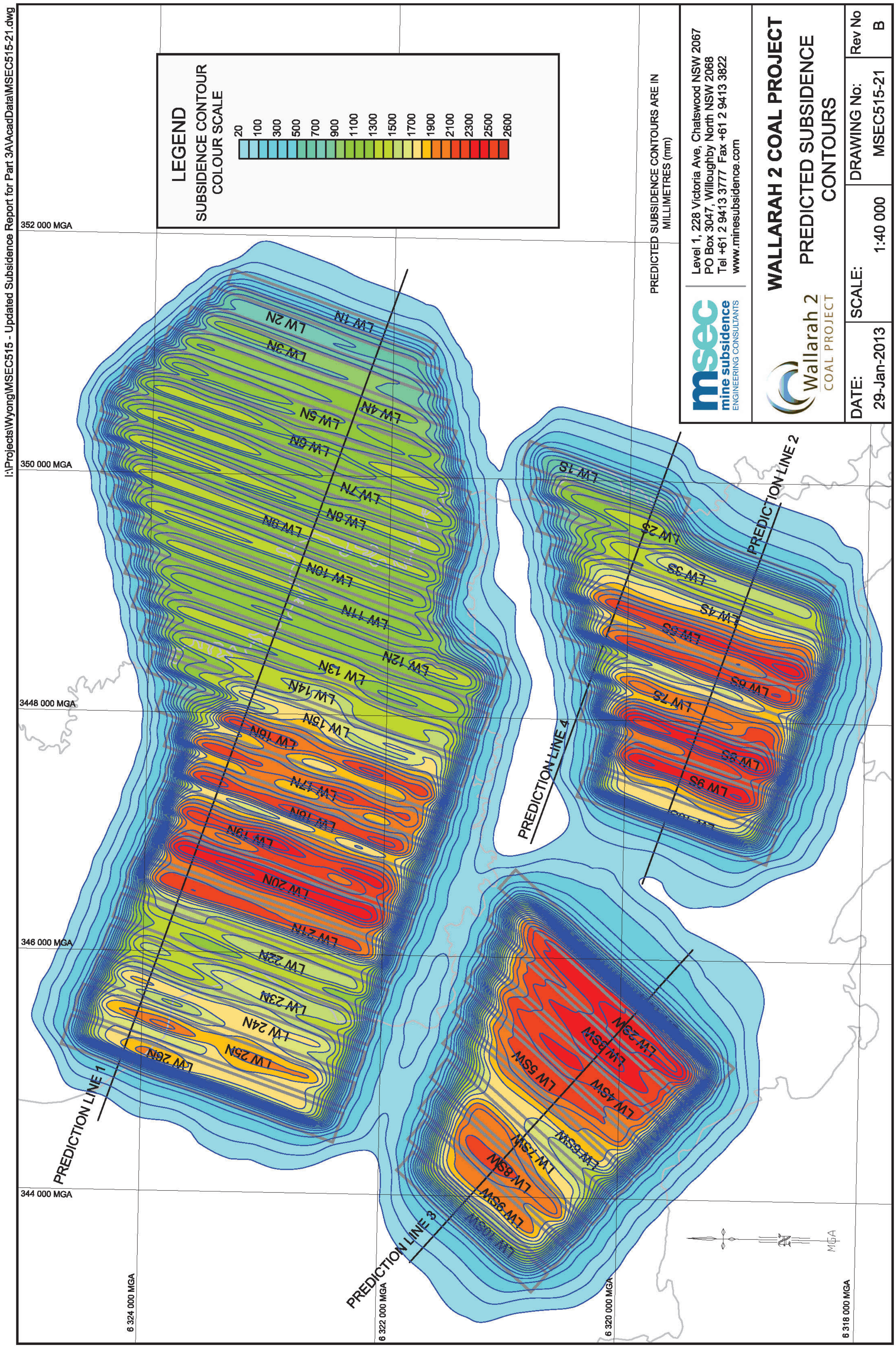
LW 6SW
LW 7SW
LW 8SW
LW 9SW
LW 10SW
MGA


I:\Projects\Wyong\MSEC515 - Updated Subsidence Report for Part 3A\AcadData\MSEC515-21.dwg
LEGEND
SUBSIDENCE CONTOUR COLOUR SCALE
20
100
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
2600
PREDICTED SUBSIDENCE CONTOURS ARE IN MILLIMETRES (mm)
msec
mine subsidence
ENGINEERING CONSULTANTS
Level 1, 228 Victoria Ave, Chatswood NSW 2067
PO Box 3047, Willoughby North NSW 2068
Tel +61 2 9413 3777 Fax +61 2 9413 3822
www.minesubsidence.com
Wallarah 2
COAL PROJECT
WALLARAH 2 COAL PROJECT
PREDICTED SUBSIDENCE CONTOURS
DATE:
29-Jan-2013
SCALE:
1:40 000
DRAWING No:
MSEC515-21
Rev No
B
352 000 MGA
350 000 MGA
348 000 MGA
346 000 MGA
344 000 MGA
6 324 000 MGA
6 322 000 MGA
6 320 000 MGA
6 318 000 MGA
PREDICTION LINE 1
PREDICTION LINE 2
PREDICTION LINE 3
PREDICTION LINE 4
LW 1N
LW 2N
LW 3N
LW 4N
LW 5N
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LW 7N
LW 8N
LW 9N
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LW 24N
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LW 1S
LW 2S
LW 3S
LW 4S
LW 5S
LW 6S
LW 7S
LW 8S
LW 9S
LW 1SW
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LW 5SW
LW 6SW
LW 7SW
LW 8SW
LW 9SW
LW 10SW
MGA

APPENDIX G. WALLARAH 2 COAL PROJECT SUBSIDENCE IMPACT ASSESSMENT PEER REVIEW

B.K. HEBBLEWHITE B.E.(Min.) PhD
Consultant Mining Engineer

ABN 85 036 121 217

46 Beecroft Road
BEECROFT NSW 2119
AUSTRALIA

Ph: +61 2 9484 6791
Mobile: 04172 67876
Fax: +61 2 9484 6791
Email: hebble@bigpond.com
B.Hebblewhite@unsw.edu.au

Ms Belinda Hale
Environmental Scientist
Hansen Bailey

acting on behalf of:
Wyong Areas Coal Joint Venture

My Ref: Report No. 1202/02.1

10 July, 2012

Dear Ms Hale,

Re: Wallarah 2 Coal Project Subsidence Impact Assessment – Peer Review

I have been asked by Hansen Bailey, who is acting on behalf of the Wyong Areas Coal Joint Venture (*WACJV*), to provide an independent peer review of the mine subsidence impact assessment carried out for the Wallarah 2 Coal Project (*"the Project"*).

I have been briefed on the project (on 3 April, 2012) by representatives of the Joint Venture, their environmental consultants (Hansen Bailey), and their subsidence consultants, Mr Don Kay of Mine Subsidence Engineering Consultants (*MSEC*) and Dr Winton Gale, of Strata Control Technology (*SCT*).

1. Scope

The documents provided for this peer review are:

- Table 1 Wallarah 2 Coal Project EIS – Director Generals Requirements & Responsibilities(*DGR*s);
- *Wallarah 2 Coal Project Subsidence Modelling Study*, 120605 EA Subsidence Modelling Study report, WACJV, March 2012 (draft copy);

- WACJV Wallarah 2 Coal Project: *Subsidence Predictions and Impact Assessments: Assessment of mine subsidence impacts on natural features and surface infrastructure for the Wallarah 2 Coal Project*, MSEC Report No. MSEC515, Rev. 3, June 2012.

The particular terms of reference for this peer review are as follows:

- Review of above reports (including draft WACJV report) and review model/assumptions, impacts and findings;
- Assess the modelling components in the draft final report, in consideration of above DGRs, relevant regulatory input and PAC findings;
- Provide a report outlining key findings from the review (this report 1202/02.1); and
- Provision of a letter confirming peer review comments have been addressed or otherwise.

It should be noted that this subsidence review does not include any detailed level of review with respect to groundwater and related hydrogeology matters.

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

2. Background

The following is a brief summary of pertinent site and mining factual parameters associated with the Wallarah 2 Project, as outlined in the various project reports (Hansen Bailey 2011, MSEC 2012, WACJV 2012) and as provided through the project briefing. This factual information is assumed for the purposes of this review, and has not been independently verified:

- The Project area is located 4.7km north-west of central Wyong and approximately 45km south-west of Newcastle.
- Project approval was originally sought under the Part 3A process, but approval was refused by the NSW Minister for Planning, in March 2011.
- *“The Minister’s refusal cited specific issues that required further information to improve certainty of impact assessment conclusions, which included additional:*
    - o *Subsidence prediction modelling, specifically for the western area;*
    - o *Heritage and ecological assessment, particularly in the western areas that are subject to the additional subsidence modelling; and*
    - o *Details of site water management and water balance at the surface facilities sites (particularly the Tooheys Road Site)”,* (Hansen Bailey, 2011).
- Development Consent is now being sought under Part 4 of the EP&A Act for a period of 28 years.
- The site geology is part of the Newcastle Coal Measures.
- Mining is to take place in the Great Northern Seam only, or in regions where the Great Northern Seam has coalesced with the overlying Wallarah Seam to create the thicker seam sections.
- Seam thicknesses range up to 6.8m.
- Depth range: from 345m to 690m.
- Surface topography is variable, but does not include any significant cliff lines or valley floor rock bars. All surface stream beds are located in alluvium geological formations.

- The only freshwater aquifer in the overburden is a near-surface aquifer.
- Overburden includes the Munmorah Conglomerate – characterised across the site by bedded sequences, without evidence of massive units (a sample section of borecore was inspected during the project briefing and confirmed this particular statement for the core observed).
- The floor stratum immediately below the seam is Awaba Tuff which will typically be isolated from the mine workings by leaving a layer of floor coal.
- Mining will take place using the longwall mining system.
- Longwall face mining heights will range up to 4.5m.
- Gate road heights will typically be 3.5m high.
- Longwall face lengths will typically be of the order of 250m, with some face lengths reduced for subsidence control purposes.

Figure 1 shows the regional location of the site.

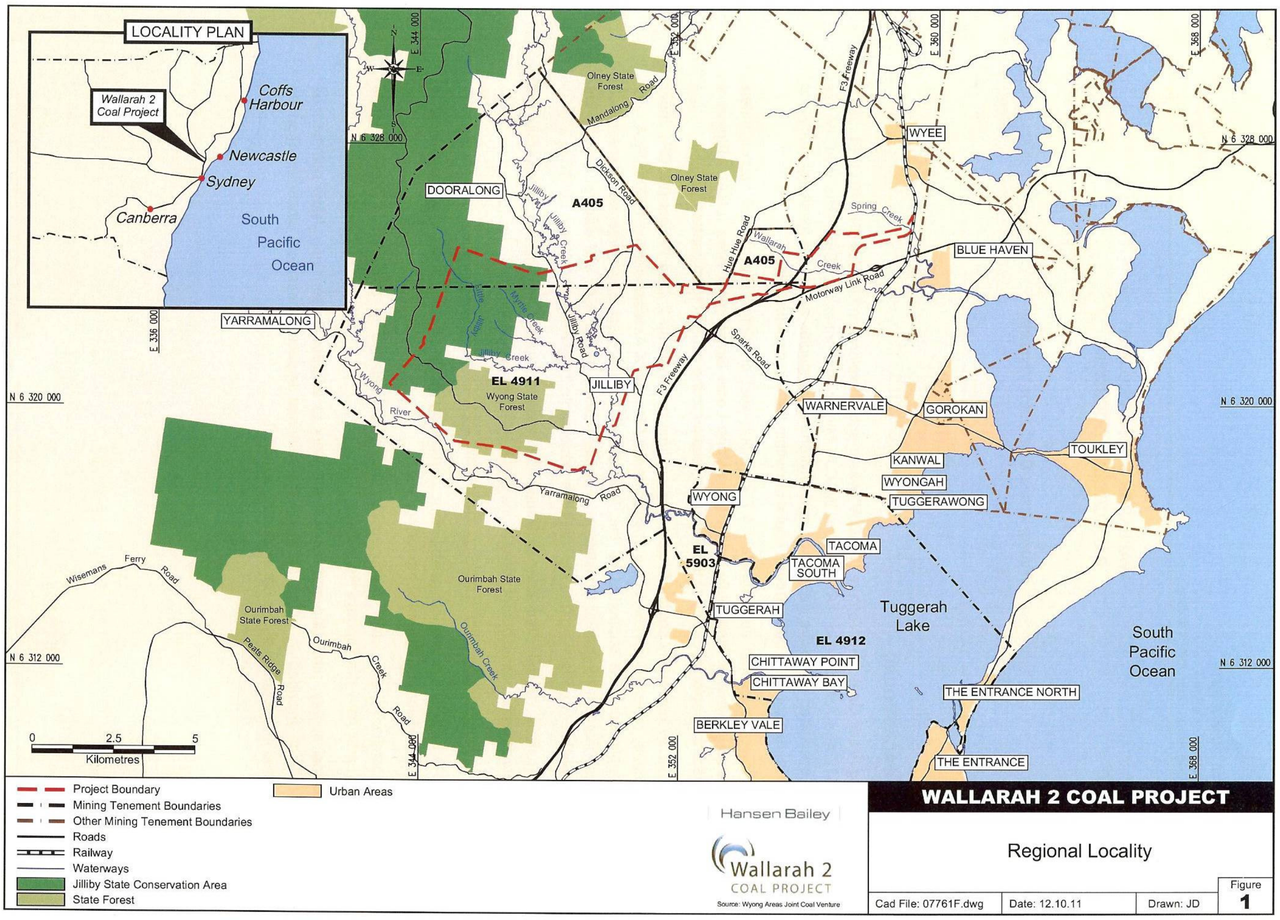

Figure 1. Project location *(after Hansen Bailey, 2011, Fig. 1)*

Figure 2 shows the conceptual mine plan for the Project, consisting of a series of longwall panels.

Figure 3 indicates proposed mining extraction height ranges across the proposed longwall panels.

Figure 1.1 of the MSEC report is also reproduced below as Figure 4. It provides good visual identification of the different surface conditions and topography, relative to the proposed longwall panels.

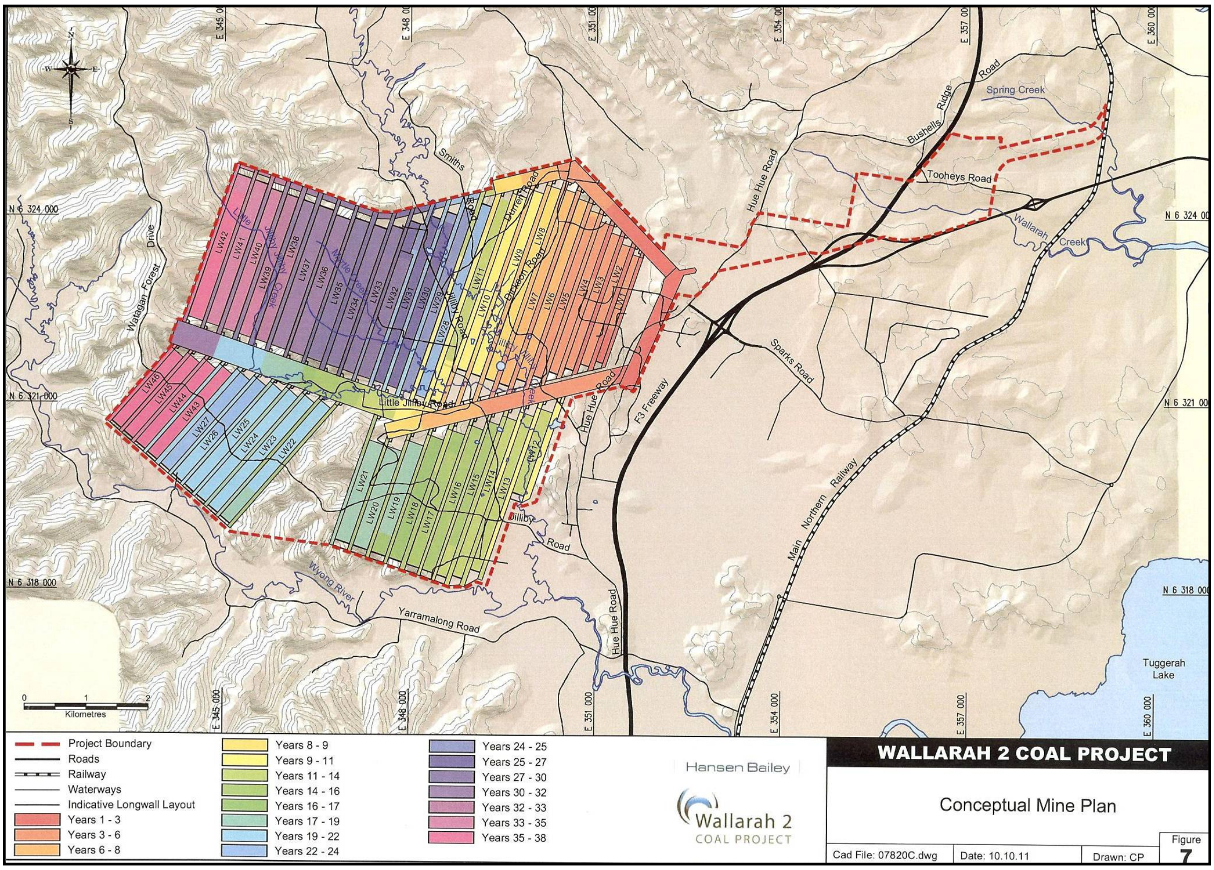

Figure 2. Conceptual mine plan *(after Hansen Bailey, 2011, Fig. 7)*

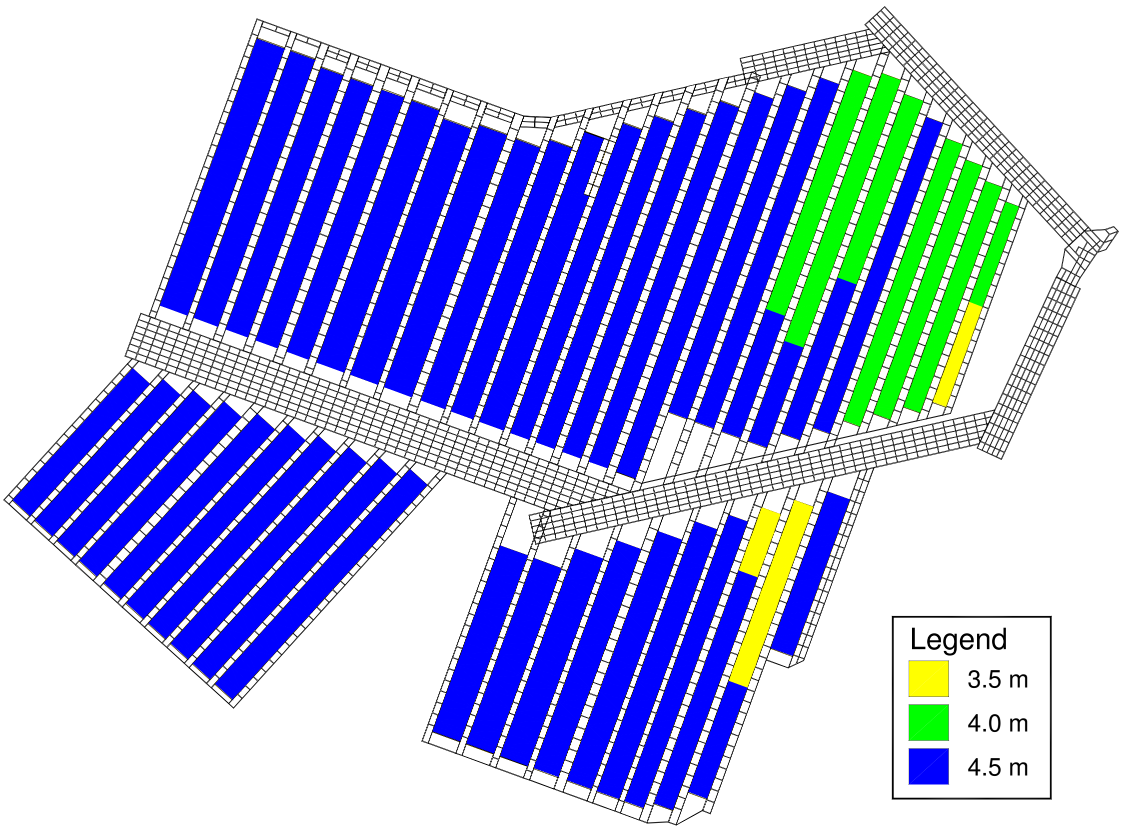

Figure 3. Proposed panel layouts showing extraction heights (*after WACJV, 2012, Fig 4.2*)

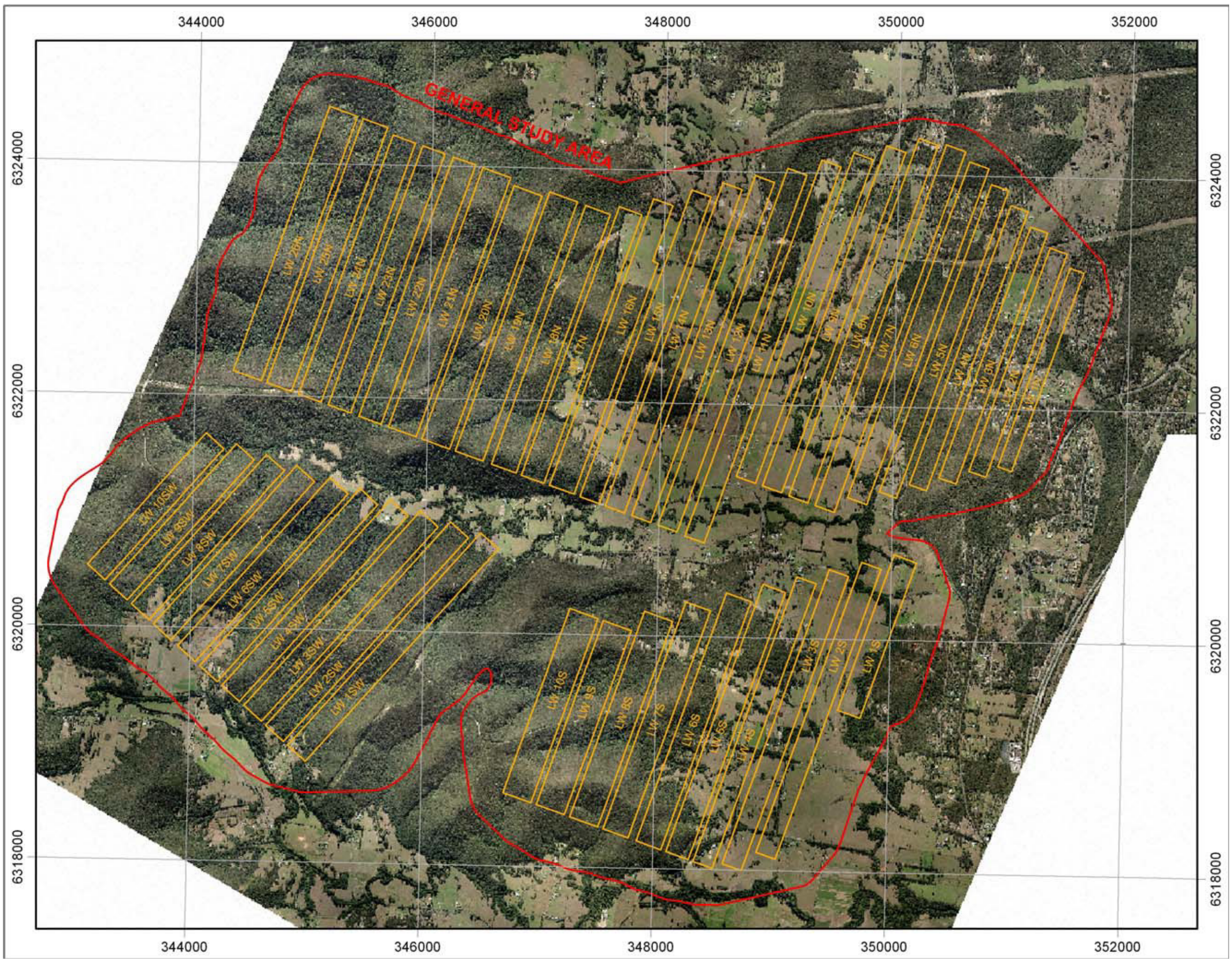

Figure 4. Proposed panel layouts superimposed on surface image (*after MSEC, 2012, Fig 1.1)*

This report is structured in the form of specific comments on the two reports provided, followed by commentary with respect to the DGRs and PAC considerations, and finally an overview commentary covering all aspects of the study and the approach that has been adopted. The MSEC report is reviewed first, followed by the WACJV summary report, which incorporates the findings of the MSEC report, in large part.

In relation to the individual report commentary, specific references are taken in the order they appear in the report texts, and not in any order of priority or importance. Some summary factual data is reproduced for ease of reference to specific issues of subsidence management. Some issues are quite minor and are more in the form of an observational comment rather than a request for any significant alteration in the studies.

3. MSEC Report

Executive Summary

- The Executive Summary notes the different approaches taken to panel design for subsidence control, dependant on surface conditions. These are summarised as follows:
    - Hue Hue District (north-east of project area) – extraction height limited to 3.5m, and panel void widths reduced to between 125m and 175m;
    - Dooralong Valley (Jilliby Jilliby Creek) and Yarramalong Valley (Wyong River) – extraction height limited to 4.0m and panel void widths between 175m and 205m.

- MSEC used their empirical Incremental Profile Method (IPM) of subsidence prediction, based on their existing databases from various NSW coalfield locations. This was followed by engagement of SCT into the project to undertake numerical modelling of the planned extraction panels to take account of the specific site geology and other local conditions of topography etc. SCT modelled three case studies, being: the Hue Hue district; the valley floor area and the forest area to the west of the project lease. (This third case study prediction was carried out subsequent to the earlier Part 3A approval application).

- MSEC then calibrated their predictions based on the SCT modelling – this resulted in a significant increase in predicted subsidence effects on the surface, compared to traditional Newcastle Coalfield predictions (later identified to be up to 150% to 200% of traditional prediction magnitudes). The main sources of such differences was:

    - Softening (compressibility) of Awaba Tuff beneath longwall chain pillars;
    - Deeper depth of cover;
    - Greater extraction heights; and
    - Less massive strata units present in the overburden.

- MSEC notes that the above approach, using a hybrid modelling and prediction methodology is a conservative approach. However they do note that WACJV has committed itself to an adaptive and continuous improvement approach to the longwall panel design, over the course of initial mining and subsidence experience, to *"refine, mitigate and manage the long term impacts of mining".*

- On page iv, it is stated that *"Further changes to the mine plan will be considered as part of the adaptive management approach that will be based on the results of the subsidence monitoring programme. Management measures generally include the recording of the condition and the value of surface natural and built features and the detailed monitoring of ground movements near these features."* It is recommended that this final statement be modified or supplemented with a more precise and appropriate statement of management measures that might be undertaken. To simply record conditions, value surface features and monitor movement near such features is hardly a proactive or adaptive management strategy. The report should refer to further actions that might follow such measures, to provide confidence that the subsidence management plan is indeed adaptive and proactive. (This is more an issue for the WACJV report, rather than MSEC, but given that MSEC has made reference to it here, it needs to be more modified accordingly).

Chapter 1

- Page 1 – reference is made to the underlying Warnervale Conglomerate and Awaba Tuff. Given that these two rock types are geologically and geotechnically quite different, it is suggested that their respective characteristics be described separately, rather than in the one broad statement.

- Page 2 – is the geology actually unique, or is it simply different to other current coalfields where subsidence prediction databases are available? This point about uniqueness is contradicted on the same page where reference is made to calibration of the SCT modelling to data from areas of *"similar geological conditions".* These similar conditions should be identified here, rather than just relying on the SCT work to reference their location.

- Page 3 – at the top of the page is mention of the *"degree of surface constraint and sensitivity that influenced the final mine design".* This is clearly a critical factor in the design, that either warrants some clearer definition here, or at least a reference to another document where such constraints and sensitivities are described/specified or assumed.

- Page 3 – a further question on the adaptive management approach (once again, more of an issue for the WACJV document than MSEC, but given it is discussed here it becomes relevant to the MSEC document). Some examples of the adaptive approach are given here. Do these extend to either prematurely stopping mining or modifying a set of panel dimensions (eg reducing mining height, or in the extreme, reducing the panel width) during the course of that panel extraction, or only for consideration in subsequent panels?

- Page 3 – Commentary from the Independent Inquiry, and the subsequent PAC report is included here and supports the use of the hybrid modelling approach as being technically appropriate, leading practice and able to provide at least as accurate a set of predictions as other methods. These opinions are supported. There is no doubt that correctly applied and validated, this particular hybrid approach using SCT's calibrated numerical modelling and MSEC's IPM empirical methodology is quite appropriate for this application.

- Page 3 – The quoted PAC findings comment on the conservative approach taken, but also then highlight (conclusion 3) that the conservative approach may lead to more adverse outcomes of final tilts and strains if the chain pillars do not offer the level of yield anticipated. This is a quite valid concern which is not directly acknowledged at this point in the MSEC report and should be (it is possibly addressed elsewhere, but to quote these findings and then not respond immediately is considered a deficiency in the case being put). Have this "worst case" scenario been evaluated? Perhaps a response that some "worst case" predictions have been analysed should be mentioned here and included later in the report, to take account of this possible scenario?

- Page 3 - PAC conclusion 4 comments on the level of uncertainty in predicting non-conventional subsidence effects. It does acknowledge that there are currently no better alternatives. However it would be useful to respond briefly to this point by providing some supporting evidence as to what is the current level of confidence in such predictions.

- Further consideration of the PAC findings is included in section 5 of this report.

- Page 5 – the considerations and requirements of the Director General of the NSW Dept of Planning (January 2012) are listed here. These issues are discussed in section 5 of this report.

- Page 10 and following – Section 1.5 describes the geological investigations and findings. It is quite correct to record that the extent of drilling and geological investigation that has been undertaken for this project is extensive, by comparison with any other project of similar magnitude and depth. Whilst not expecting to have identified all potential geological anomalies, this extensive investigation program provides a very good level of confidence in the geological interpretation across the lease area.

- Figure 5 is an excellent cross-sectional summary of the complex geological sequences across the lease area, reproduced from MSEC 2012 (Fig. 1.2).

- Page 15 – Table 1.4 lists mining extraction heights for each longwall panel, as minimum, maximum and average. It is unclear why the average height is provided at all, as it does not offer any useful additional information and should not be used in any design calculations or predictions.
- Page 15 – Table 1.5 provides the depth of cover – again as minimum, maximum and average. In this case, it is useful to understand the average depth. However it would be reassuring to have a statement that actual extraction heights and actual depths were used incrementally along each longwall panel in all predictions. Alternatively, provide a statement that worst case figures were used (i.e. max. height and minimum depth) rather than averages.

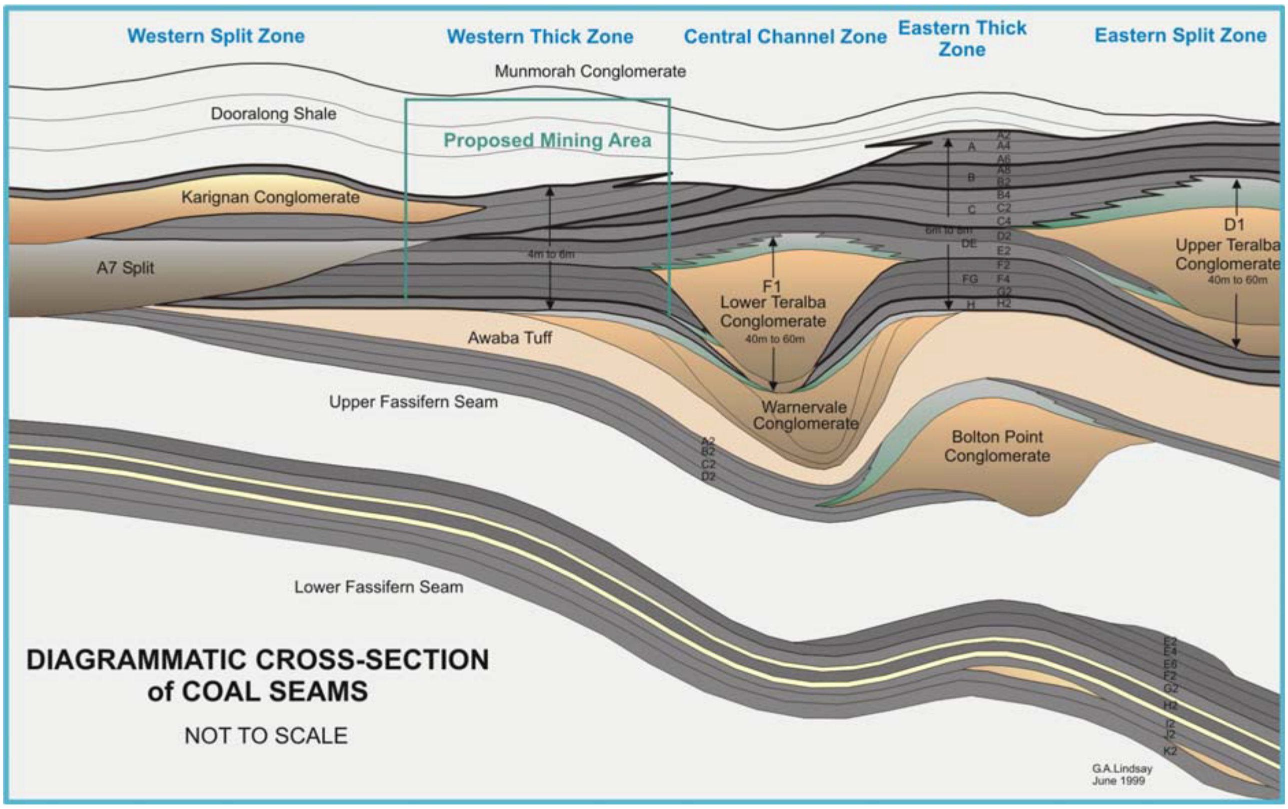

Figure 5. Geological east-west stratigraphic cross-section (*after MSEC, 2012, Fig 1.2)*

<u>Chapter 2</u>

- Page 16 – the report states that the Study Area is defined by three parameters. Two are precisely defined, but there is no definition, or set of criteria put forward to explain how far the "far field movements" might be expected to occur beyond mining – in terms of the identification of sensitive surface features. MSEC states they have identified certain features, but they have not defined how far from mining they have extended their consideration process.

<u>Chapter 3</u>

- Pages 40 and 41 – MSEC discuss the adoption of the terminology put forward originally in the Southern Coalfield Inquiry Report of 2008. This includes the terminology of subsidence effects, impacts and consequences; and also the distinction between conventional and non-conventional subsidence behaviour (the latter being associated with differing or more complex ground behavioural mechanisms associated with irregular topographies. The section has been expanded, as stated, making it unclear what was the original quotation from the reports, and what are the MSEC expansions. It would be more appropriate to directly quote the definitions and attribute them, and then separately add any additional MSEC comments. For example, there is reference in this report to non-conventional subsidence being a misnomer, since only the site conditions have varied. This appears to be an MSEC interpretation. I would challenge this view, in that the whole issue with non-conventional subsidence is that due to the different site conditions, the mechanisms that drive the subsidence effects have changed in a more complex way than with simple conventional behaviour. Furthermore, the MSEC report then reintroduces the terminology of systematic, and non-systematic behaviour – a concept that was rejected by the Southern Coalfield report, and should preferably be removed altogether from this report (both at this point in the report and where it is again used later in the report, e.g. on pages 42 and 45).

- Page 44 – the discussion of horizontal subsidence movements defines any horizontal movements outside the longwall panel boundaries as far field movements. This interpretation is considered incorrect, or at least misleading, insofar as horizontal movements will occur beyond the goaf edge or longwall panel boundary due to conventional subsidence behaviour. However, in certain circumstances, such movements may be supplemented by additional levels of horizontal movement which then extend beyond the angle of draw limit, due to true "far-field" effects. The result is increased levels of horizontal movement, both within the angle of draw, and also beyond it, when far-field effects add a further increment of movement to that induced by conventional subsidence alone.

- Page 45 – the three bullet points describing mechanisms that contribute to horizontal movements should also include valley closure effects as a further example under the third bullet. It should be noted that such movements can in fact lead to horizontal movements occurring away from the direction of the longwall panel, towards an active valley closure location.

- Page 46 – The report is again confusing the issues of conventional and non-conventional subsidence. It describes far-field horizontal movements as conventional because the confidence level in their prediction is improving. This justification is at odds with the whole concept of non-conventional behaviour – which should also eventually be improving in the ability for prediction, but such an improvement does not change it to being conventional behaviour. MSEC seems to be equating non-conventional behaviour with anomalous behaviour. However, returning to the Southern Coalfield report addressing terminology, anomalous behaviour was quite different again, and related to unexpected geological changes such as faults, or joint swarms, where the prediction ability is extremely difficult. Anomalous behaviour should not be confused with non-conventional behaviour. (Any subsequent references to these definitions should also be corrected in the report). So just to repeat, to assist clarity on this point:
  - Subsidence behaviour generally falls into two different forms based on the driving mechanisms – conventional and non-conventional behaviour (both of which could actually be described as systematic, but this term has been rejected as misleading).
  - The other type of subsidence is anomalous subsidence, which does not fit any current behavioural understanding, and is therefore very difficult to predict. It is usually associated with localised changes in conditions such as geological structures, and is usually quite localised in effect, within an otherwise normal subsidence trend.

- Page 46 – Regardless of terminology, the report correctly states that most far-field horizontal movements are characterised by almost rigid-body motion, with very low levels of associated differential strain, and as such, the potential for adverse impacts is low.

- Page 47 – the opening statement of section 3.7.1 may be slightly over-simplistic in terms of potential mechanisms for non-conventional behaviour. At the least, it should state that it is believed that a number of factors influence such behaviour, including mining-induced stress changes. However, if reference is made to mining-induced stresses, it is even more important to also refer to high levels of in situ horizontal stress in the overburden strata (prior to any mining taking place) as being a key factor.

- Page 51 – The opening paragraph of section 3.11 states that the MSEC empirical IPM predictions have been calibrated to mining conditions and site geology using the SCT modelling results, as part of the hybrid modelling approach. Whilst it is correct that the SCT modelling has been used to calibrate the predictions, this is really only a calibration to another prediction method, and not directly to real data. It should therefore be clearly noted that full calibration to mining conditions and site geology will only be achieved after the first set of actual site monitoring data is obtained and analysed.

- Page 52 – The third paragraph of section 3.2 should change the words “level of horizontal in situ stress” to “level and direction of horizontal in situ stress”.

<u>Chapter 4</u>

- Page 55 – The statement in the first paragraph that strain variation can be irregular, even when subsidence profiles are quite uniform, must be strongly emphasised. Anomalous strains leading to very localised fracturing in the ground surface are not uncommon, within an otherwise uniform subsidence distribution.

- Page 55 – In the paragraph commencing “At a point”, it is stated that these variable strains are a result of non-conventional movements. It is considered that this is again a misuse of the terminology, and it would be more appropriate to refer to this point as “as a result of anomalous conditions”. In this same paragraph, the adoption of a statistical reporting system to account for this variability in strain, rather than just a single strain figure, is to be commended.

- Page 61 – Section 4.5 attributes far-field horizontal movements to redistribution of in situ horizontal stress. Whilst this might be the case, I believe that our understanding of this behaviour is not yet fully understood and so this statement may be slightly too definitive at this stage.

- Page 61 – Section 4.5 contains the same confusion regarding the description of far-field horizontal movements as conventional, simply because they are more predictable. This should be corrected, as discussed earlier when the same comments were made in Chapter 3.

- Page 64 – the conclusions regarding unlikely extent of surface cracking as a result of depth and alluvial cover are fully supported.

- Page 64 – the conclusion that the fracturing network that will develop in the caving zone up to 200m above the mining horizon will be isolated from near-surface ground fracturing networks, resulting in no expected surface to seam connectivity – is also supported.

<u>Chapter 5</u>

- Page 69 – Section 5.2 refers to comments made by the 2008 Inquiry. It then provides a quoted set of findings, attributed to “*other previous studies*”, but it does not directly identify these other studies. These quotes must be attributed to some independent authorship. Such authorship needs to be independent of WACJV or its consultants, if the quotes are to have credibility.

- Page 71 – a similar situation exists to the one above. A set of quotations is provided, and only attributed to "*many studies*". Since these are quotations, they must be directly attributed to specific authorship for them to add any potential value to the report. A similar instance of unattributed quotes occurs on page 73 and should be rectified.

- Page 72 – analysis of tilts along Wyong River leads to a conclusion that they are *"unlikely to result in any significant changes in the level of ponding, flooding and scouring".* This statement may be quite correct overall, but the emphasis is clearly on the word "significant". Is it correct to state that there may be localised low level instances of ponding, flooding and scouring? If so, this should be stated; if not, then the word significant should be removed from the earlier statement. On page 73 it appears that some level of ponding and flooding is expected, as the report discusses remedial actions to deal with it.

- Page 73 – a similar issue of semantics occurs when discussing changes to stream alignment. MSEC states that there will be no significant changes, but what is regarded as significant? Can this be quantified at all?

- Page 74 – In discussion of valley floor closure and upsidence, it is noted that such behaviour is expected to occur in a number of valleys, but will be masked by overlying alluvium. It is noted that small zones of increased permeability might develop in the top few metres of the rock head beneath the alluvium, but due to the saturated overlying alluvium, these increased permeability zones will not result in any impact on surface water levels. This conclusion may be correct, but is it not possible that some conditions may exist due to localised geological changes, and changing climatic conditions such that the alluvium is not always saturated and some loss of water level in streams may occur? If so, this point should be conceded, albeit that it is only a very small likelihood and probably only on a very localised scale.

- Page 74 – another unattributed quote needs to be rectified.

- Page 77 – The recommendations regarding management plans to be developed, includes monitoring of stream conditions before mining as well as during/after mining. This is fully supported, especially the need to gather comprehensive, long-term multi-seasonal data ahead of mining.

- Page 78 contains another series of quotations from unspecified authors, which needs to be rectified with appropriate author attribution.

- Page 79 – the final paragraph of section 5.5.1 needs to be rewritten to rectify the confused references to conventional, non-conventional and anomalous movements. (This same paragraph, or similar wordings, occur at other points in the report and should be rectified, e.g. pages 85, 88, 90).

4. WACJV Draft Report

Executive Summary

- Page ES1 – under the dot point summary of the modelling process key stages, there is reference to validation of the numerical modelling by back analysis. However it is unclear how such validation has occurred without any existing subsidence data from the Project. Obviously data from other sites has been used. It is worth commenting on the source of such data and why it is considered appropriate, at least as a summary point here, and then in more detail later in the report (as occurs in Chapter 2). (Based on the evidence in Chapter 2, it would appear that the validation is of the generic capability of the numerical modelling approach to simulate longwall caving and subsidence, rather than validating it specifically with respect to the conditions of the Project).

- Page ES1 – The listed stages of the subsidence design process are considered to be generically appropriate and logical.

- Page ES2 – the conclusion that the subsidence profiles expected will be very similar to those from the Southern Coalfield may not be quite correct, especially given some of the differences then listed. It is stated that the magnitudes will be greater, but the effects of the soft floor/pillar yield system is also a difference which will change profile shape as well as magnitude. It would be more appropriate to comment that there will be some similarities, rather than claiming to be “very similar”.

- Page ES2 – reference is made here to the requirements of the Hue Hue and Wyong Subsidence Districts. There needs to be a reference here to those requirements, which presumably are, or can be contained in an Appendix.

- Page ES2 – Please delete reference to “systematic subsidence”, both here, and anywhere else in this document. This terminology, using the word systematic, should no longer be used (ref. to terminology from the Southern Coalfield Inquiry Report, 2008)).

- Page ES2 – again, a query on how the numerical modelling has been validated yet?

- Page ES2 – It is hard to justify the use of the term “fracture analysis” which implies detailed shape, size, distribution of fracturing. What has been achieved is an understanding of the caving-induced fracture zones within the rock mass.

Chapter 1

- Page 2 – in quoting that the proposed depth of mining, up to 700m, is well beyond current experience in the Newcastle Coalfield, please note that at the Austar Mine, depths are already around 600m and approaching 700m.

Chapter 2

- Page 4 – In Section 2.1, the discussion is an appropriate explanation of the SCT modelling procedure. However it then contains a specific design parameter, being the strength reduction factor of 0.58, without any explanation or justification of the basis of this figure. It is certainly accepted that some form of reduction has to be applied in any numerical modelling, but the basis of the reduction needs to be explained and justified.

- Page 4 and following – the issue of validation of the numerical modelling is a critical one as has already been mentioned. It is clear that extensive calibration modelling has been conducted on a range of different mining/subsidence databases. However, one point which does not come out clearly from the discussion is the ability to model the different overburden geology within the Project, as compared to other Newcastle Coalfield/Hunter valley geology. The case has been made that the geology in the Project area does not contain the massive overburden units seen elsewhere in the Newcastle region. It is therefore critical to validate the model against this different geological sequence. It is not clear from reading this section of the report whether this has been explicitly carried out. The report makes reference to typical overburden sections, from the Project, and then comparison with regional databases of typical Hunter Valley geology, but the argument has already been made that the Project geology is different to elsewhere. These differences are almost certainly going to change the caving and subsidence developmental behaviour (as has already been stated). It would be useful to provide explicit evidence of this situation, if it has been done, and to demonstrate the sensitivity of the model to the different overburden characteristics – with and without massive units.

- Page 11 – In summarising the conclusions of this section in 2.2.3, a similar caution is expressed with regard to stating that rock fracture distributions have been simulated. Certainly zones of different levels and types of rock fracturing have been identified, which is extremely valuable, but it is unlikely that a detailed level of rock fracture distribution can be simulated by any large scale, regional form of numerical modelling (this is simply questioning the level of detail which can be achieved, rather than challenging the principle of the statement).

- Page 11 – Also in section 2.2.3, it is possibly more accurate to report that the modelling has been capable of simulating the chain pillar stress distributions and potential deformational/failure characteristics, rather than specifically stating that pillar strengths have been simulated.

- Page 12 and following – the quantity of borecore drilling and resultant geological/geotechnical data obtained is significant and impressive, for a single project of this nature. Whilst it is never possible to fully define the overburden geological and geotechnical domain, a database of this magnitude significantly improves the confidence levels in the geological and geotechnical models developed.

- Page 14 – The hypothesis adopted with regard to confinement of swelling floor materials (last line of P14 and following) is considered valid and appropriate. The significant benefit that can be gained by even small amounts of confinement with such materials has been seen in soft tuffaceous floor investigations elsewhere, as is referenced in the report (e.g. ACARP investigations at Cooranbong Colliery).

- Page 15 – The design approach for chain pillar yield is discussed here. The yielding pillar approach has been adopted to prevent subsequent adverse impacts from time dependent pillar failure. The approach relies heavily on soft floor foundation failure beneath the pillar coal. The approach is considered to be sound, providing that yield does not occur prematurely. However the other concern that is raised relates to the extreme variability already discussed in terms of the tuffaceous floor strength and variable clay content. This variability will make it difficult to confidently design for yielding pillars to occur throughout the mine. It would be extremely difficult to guarantee that all pillars will yield as designed. Local rock property variations may result in some pillars not actually yielding as designed. The consequence of this may be less overall subsidence, but also more severe tilts over the line of pillars. It is not clear whether any alternative modelling has been conducted to consider this unwanted consequence. Further discussion should address this issue and it would be helpful to provide further subsidence predictions based on lack of pillar yield, to evaluate any changes in subsidence impacts which may occur.

- Page 15 – the stress field data quoted refers to a horizontal stress field of 10 - 12 MPa, and states that it is similar in magnitude to the South Coast, relative to a 10 GPa rock. Some further explanation is required here. Certainly there are a number of South Coast mines with horizontal stress magnitudes much greater than 12 MPa. It is unclear what is meant by "relative to a 12 GPa rock". Is this referring presumably to elastic modulus, in which case it would be worth stating that?

- Page 18 – The approach taken to estimate pillar strengths is reasonable, in particular to allow for the influence of cut-throughs. It is noted that a full 5m mining height is used in the strength calculations. This deemed to be an appropriate and prudent assumption, even with slightly lower extraction heights. The only query relates to the lack of any explanation or justification for the assumed value of yield pillar strength at 24MPa (p19). This should be explained.

- Page 20 – Section 2.3.8 discusses upper and lower bound caving modes and concludes that for the higher mining heights of 4.5m – 5.0m, the pillar strength and caving geometry resulted in an unlikely worst case scenario. However it is unclear which caving mode was being used in this instance and why this particular approach was rejected. This paragraph and the conclusions for subsequent modelling should be more clearly explained.

- Page 22 – in discussion of use of 55m wide chain pillars in the Hue Hue model, some words should be added to confirm that this reduced width is to allow for the strength reduction factor associated with cut-throughs which are not included in the 2D model, as discussed previously.

- Page 27 – the results here support the approach of designing for yielding pillars, but again raise the concerns about (a) what happens to the surface subsidence effects if the pillars do not yield, and (b) what are the consequences of a later time-dependent failure of the chain pillars within an old goaf area?

- Page 27 – Section 2.4.2 provides valuable data on upward caving and rock failure/shear propagation above the longwall goaf areas. This quality of modelling is regarded as "state of the art" in relation to this particular issue of vertical permeability above mining panels.

- Page 30 – Here, and in other modelling scenarios, it is argued that the pillar load bearing capacity increases with confinement support from the goaf. This is accepted, but it is important to realise that this only occurs with a certain amount of further pillar system compression or vertical subsidence, albeit small values.

- Page 36 and following – (Section 2.6). This modelling for the "forest case" is the additional work carried out following the previous submissions made for the project. The modelling approaches used are the same as adopted earlier, but demonstrate some minor changes in results associated with the greater depths, wider panel widths and variable surface topography. It is noteworthy that the modelling reproduces evidence, at least mechanistically, of valley floor shearing and potential closure triggered by early adjacent longwall extraction, peaking when directly undermined (see Figures 2.3.8 and 2.3.9). This provides further evidence of the validity of the modelling approach adopted.

<u>Chapter 3</u>

- Page 43 – as previously mentioned, removal of the use of the term systematic subsidence should occur in this and all subsequent chapters.

- Page 44 – it is noted that the IPM empirical model results were calibrated using the numerical modelling results – both for the magnitude of the vertical subsidence, and also the shape of the profiles with respect to subsidence over the chain pillars. This is valid, but contradicts an earlier statement that the profile shapes did not change (as commented on previously).

- Chapter 3 then continues to discuss the application of the calibration process to the IPM predictions.
- Page 51 – it is concluded that the use of the calibrated IPM method provides a level of conservatism relative to the separate numerical modelling results. This is considered correct and appropriate at this stage of the project.

Chapter 4

- This chapter simply summarises the modelling options processed as part of the iterative mine design process – in accordance with the procedures discussed in earlier chapters.

Chapter 5

- This chapter provides appropriate discussion of the impacts of higher extraction heights and changing geology on the caving and goaf development process leading to differing subsidence results on the surface. Further summarised subsidence results are then presented.

Chapter 6

- This chapter applies the predicted subsidence effects to the surface of the lease area and evaluates the impacts of such effects.
- Page 68 – in discussing shearing/fracturing below valley floors, a depth of up to 10m is quoted. However as discussed in other sections of this report, it has been conceded that the valley floor failure process is likely to occur in the rock strata which is typically overlain by alluvium, so the overall depth limit to where fracturing could extend may be greater than 10m in this case. It is agreed that the presence of the alluvium in the Project area will be advantageous in minimising/masking many of the potential adverse impacts associated with valley closure, valley floor failure and related upsidence.
- Page 69 – the conclusions regarding the 200m zone of fracturing above the mining horizons are appropriate in relation to the design approaches conducted.

5. DGRs and PAC

In regard to subsidence issues, the Director-General's Requirements were stated as follows:

The EIS must address the following specific issues:

- ***Subsidence** - including a detailed quantitative and qualitative assessment of the potential conventional and non-conventional subsidence impacts of the development that includes:*
  - *the identification of the natural and built features (both surface and subsurface) within the area that could be affected by subsidence, and an assessment of the respective values of these features using any relevant statutory or policy documents;*
  - *accurate predictions of the potential subsidence effects and impacts of the development, including a robust sensitivity analysis of these predictions;*
  - *a detailed assessment of the potential environmental consequences of these effects and impacts on both the natural and built environment, paying particular attention to those features that are considered to have significant economic, social, cultural or environmental values; and*

- *a detailed description of the measures that would be implemented to avoid, minimise, remediate and/or offset subsidence impacts and environmental consequences (including adaptive management and proposed performance measures).*

- Many of these issues have been addressed in the preceding review comments. Certainly the two reports include detailed assessment of both conventional and non-conventional subsidence impacts, and provide an assessment of the various natural and built features and how they may be impacted by subsidence effects.

- The predictions made regarding subsidence effects have been carried out using state of the art methodologies and an innovative but appropriate hybrid modelling approach. In regard to robustness of the sensitivity analysis, there is discussion regarding use of limiting and upper and lower bound considerations. In the commentary provided earlier in this report, there are a number of points where further discussion about some sensitivities is recommended.

- Environmental consequences of subsidence impacts on both the natural and built environment have been assessed in the reports.

- Discussion of measures that would be implemented to avoid, minimise or remediate subsidence impacts have been provided, although in earlier commentary, it is suggested that some further discussion of the detailed adaptive management strategies should be included.

In regard to the PAC conclusions, again, these have been discussed in earlier commentary. The specific PAC conclusions, as quoted in the MSEC report are listed below:

1. "The hybrid prediction methodology for conventional subsidence is leading practice but this is not to say that the predictions are accurate or more accurate than those produced by alternative techniques.

2. There is a high degree of conservatism built into the prediction of conventional subsidence effects.

3. An unexpected problem may arise from this conservatism if the interpanel pillars do not yield as designed, thereby resulting in vertical displacements over the interpanel pillars being less than predicted but final tilts and strains possibly being considerably higher, consistent with a final landform more 'wavy' than predicted.

4. There is considerable uncertainty associated with the methodology used to predicted nonconventional subsidence effects. However, currently there is no better alternative technique available and predictions of effects are likely to have been overestimated.

5. The assessment of subsidence effects, impacts and consequences in hilly landform areas of W2CP Study Area is minimal and will need to be defined before mining commences there under well into the proposed life of the proposal.

6. In general, the mine plan is well suited to adaptive management and continuous improvement. However, the opportunity to practice adaptive management in the Hue Hue Subsidence District may be limited and needs to be planned for prior to commencement of any mining operations.

7. For the proposed mine layout, the predicted worst case upsidence and closure values could be expected to result in negligible impacts for the Wyong River and Jilliby Jilliby Creek and for Little Jilliby Jilliby Creek up to the start of LW 23N. Site specific impacts cannot be ruled out but these are likely to be sparsely distributed and of a very localised nature.

8. In the absence of major, unforseen geological anomalies (e.g. faults and dykes), subsidence-induced hydraulic connectivity between Wyong River, Jilliby Jilliby Creek or their alluvial systems and any *underlying mine workings is extremely unlikely.*

9. Geological anomalies are likely to be present in the proposed mining area and to go undetected until they are exposed by mining. The potential for them to impact on surface and subsurface drainage is likely to be low given the considerable depth of mining, the considerable thickness of the alluvium and the drainage characteristics of the alluvium and shallow aquifer systems.

10. If the project is approved, there is a need to validate the longwall caving model, the hybrid subsidence prediction methodology and upsidence and closure predictions very early into the mining process."

Overall, the PAC conclusions are very supportive, or neutral, with respect to the Project and the approach taken for subsidence prediction and impact assessment. The only issue raised by the PAC where some further explanation and possibly additional analysis may be required, relates to conclusion 3 above. This has been discussed in the earlier comments. Given the significant range of floor properties, it is considered that the probably of achieving designed yield conditions in all chain pillar systems is quite low. As a result, there may be some adverse subsidence consequences which could arise immediately, or later in time. It is considered that these require further comment and analysis, if not already available.

6. Summary Comments

As an overall commentary on the subsidence prediction and assessment process undertaken by the WACJV, I offer the following concluding summary remarks:

- The extent of geological investigation carried out to form an initial understanding of the geological domains across the lease area is highly commendable – both in terms of the quantity of information gathered, and the manner in which it has been collated and analysed.

- The selected subsidence prediction methodologies (IPM and calibrated numerical modelling); and the consultants who have applied the methodologies (MSEC and SCT); are both highly reputable and appropriate to the prediction requirements of the Project. It is fair to say that these organisations and the approaches they have applied in this case represent state of the art, not just in Australia, but internationally, for subsidence prediction.

- The adaption of the two methodologies into a hybrid prediction approach is innovative, and has been done in an appropriate manner, making it applicable to the mining conditions anticipated by the Project.

- The preceding reviews of the individual reports contain a number of quite specific comments where it is considered that minor improvements can be made, either in terms of clarity, or content. In a small number of cases, some additional discussion and supporting evidence is called for.

- Regardless of the above comments, it is important to recognise that there are difficulties in subsidence predictions and especially where extensive databases of past practice do not exist or are not directly relevant. As a result, the predictions made are not without a level of uncertainty, albeit that they have been made with a degree of conservatism in most if not all cases.

- It will be absolutely essential to gather a considerable amount of subsidence data over and around the first block of longwall panels, and to ensure that re-evaluation of all predictions occurs as part of a further validation process.

- It is also absolutely essential that the proposed adaptive management approach be quite explicitly defined well in advance, incorporating proactive measures and response to leading indicators, rather than just being a post-mortem after each panel is finished. The adaptive management approach must include clearly defined management decision-making processes at all stages.

7. References

Hansen Bailey, 2011	Wyong Areas Coal Joint Venture: Background Document (Ref. 111013), Oct 2011.
MSEC, 2012	WACJV Wallarah 2 Coal Project: Subsidence Predictions and Impact Assessments: Assessment of mine subsidence impacts on natural features and surface infrastructure for the Wallarah 2 Coal Project, MSEC Report No. MSEC515, Rev. 3, June 2012.
WACJV, 2012	Wallarah 2 Coal Project Subsidence Modelling Study, 120605 EA Subsidence Modelling Study report, March 2012 (draft).

Yours sincerely,

Bruce Hebblewhite

APPENDIX A

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

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

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

Disclaimer

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

SUMMARY CURRICULUM VITAE

Bruce Kenneth Hebblewhite

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Head of School and Research Director,
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DATE OF BIRTH 1951

NATIONALITY Australian

QUALIFICATIONS

1973: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, University of New South Wales

1977: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
1991: Diploma AICD, University of New England

PROFESSIONAL MEMBERSHIPS; APPOINTMENTS & SPECIAL RESPONSIBILITIES

Member - Australasian Institute of Mining and Metallurgy
Member - Australian Geomechanics Society
Member – Society for Mining, Metallurgy and Exploration (USA)
Member - International Society of Rock Mechanics (President – Mining Interest Group (2004 – 2011))
Council Member – International Society of Mining Professors (and President for 2008/09)
Executive Director – Mining Education Australia (July 2006 – December 2009)

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 Northparkes Mine Accident
Member (2005 – 2008): Independent Expert Review Panel (Dendrobium Mine), NSW Dept of Planning
Expert Witness assisting Coroner – Coronial Inquest (2007): 2004 Sydney Cross City Tunnel Fatality
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries)

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2003-present	University of New South Wales, School of Mining Engineering Head of School and Research Director, (Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006); Professor of Mining Engineering (from 2006))
2006 – 2009	Mining Education Australia (a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide) Executive Director (a concurrent appointment with UNSW above).
1995-2002	University of New South Wales, School of Mining Engineering Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC)

1983-1995	ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation.
1981-1983	ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs.
1979-1981	ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods.
1977-1979	ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Also Project Engineer for roof control and numerical modelling stability investigations.
1974-1977	Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis).

SPECIALIST SKILLS & INTERESTS

- Mining geomechanics (including ground control and surface subsidence)
- Mine design and planning
- Mining methods
- Mine safety and training
- Mine system audits and risk assessments
- Education and training

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Ms Belinda Hale
Environmental Scientist
Hansen Bailey

acting on behalf of:
Wyong Areas Coal Joint Venture

My Ref: Report No. 1202/02.2

5th October, 2012

Dear Ms Hale,

Re: Wallarah 2 Coal Project Subsidence Impact Assessment – Peer Review

I have been asked by Hansen Bailey, who is acting on behalf of the Wyong Areas Coal Joint Venture (*WACJV*), to provide an independent peer review of the mine subsidence impact assessment carried out for the Wallarah 2 Coal Project (*"the Project"*).

I was briefed on the project (on 3 April, 2012) by representatives of the Joint Venture, their environmental consultants (Hansen Bailey), and their subsidence consultants, Mr Don Kay of Mine Subsidence Engineering Consultants (*MSEC*) and Dr Winton Gale, of Strata Control Technology (*SCT*).

1. Scope

The documents provided for this peer review were:

- Table 1 Wallarah 2 Coal Project EIS – Director Generals Requirements & Responsibilities(*DGR*s);
- *Wallarah 2 Coal Project Subsidence Modelling Study*, 120605 EA Subsidence Modelling Study report, WACJV, March 2012 (draft copy);

- WACJV Wallarah 2 Coal Project: *Subsidence Predictions and Impact Assessments: Assessment of mine subsidence impacts on natural features and surface infrastructure for the Wallarah 2 Coal Project*, MSEC Report No. MSEC515, Rev. 3, June 2012.

The particular terms of reference for this peer review are as follows:

1. Review of above reports (including draft WACJV report) and review model/assumptions, impacts and findings;
2. Assess the modelling components in the draft final report, in consideration of above DGRs, relevant regulatory input and PAC findings;
3. Provide a report outlining key findings from the review; and
4. Provision of a letter confirming peer review comments have been addressed or otherwise.

It should be noted that this subsidence review does not include any detailed level of review with respect to groundwater and related hydrogeology matters.

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

2. <u>Background</u>

The following is a brief summary of pertinent site and mining factual parameters associated with the Wallarah 2 Project, as outlined in the various project reports (Hansen Bailey 2011, MSEC 2012, WACJV 2012) and as provided through the project briefing. This factual information is assumed for the purposes of this review, and has not been independently verified:

- The Project area is located 4.7km north-west of central Wyong and approximately 45km south-west of Newcastle.
- Project approval was originally sought under the Part 3A process, but approval was refused by the NSW Minister for Planning, in March 2011.
- *"The Minister's refusal cited specific issues that required further information to improve certainty of impact assessment conclusions, which included additional:*
  - *Subsidence prediction modelling, specifically for the western area;*
  - *Heritage and ecological assessment, particularly in the western areas that are subject to the additional subsidence modelling; and*
  - *Details of site water management and water balance at the surface facilities sites (particularly the Tooheys Road Site)",* (Hansen Bailey, 2011).
- Development Consent is now being sought under Part 4 of the EP&A Act for a period of 28 years.
- The site geology is part of the Newcastle Coal Measures.
- Mining is to take place in the Great Northern Seam only, or in regions where the Great Northern Seam has coalesced with the overlying Wallarah Seam to create the thicker seam sections.
- Seam thicknesses range up to 6.8m.
- Depth range: from 345m to 690m.
- Surface topography is variable, but does not include any significant cliff lines or valley floor rock bars. All surface stream beds are located in alluvium geological formations.

- The only freshwater aquifer in the overburden is a near-surface aquifer.
- Overburden includes the Munmorah Conglomerate – characterised across the site by bedded sequences, without evidence of massive units (a sample section of borecore was inspected during the project briefing and confirmed this particular statement for the core observed).
- The floor stratum immediately below the seam is Awaba Tuff which will typically be isolated from the mine workings by leaving a layer of floor coal.
- Mining will take place using the longwall mining system.
- Longwall face mining heights will range up to 4.5m.
- Gate road heights will typically be 3.5m high.
- Longwall face lengths will typically be of the order of 250m, with some face lengths reduced for subsidence control purposes.

3. Peer Review Conclusions (as required under Terms of Reference 4)

The procedure outlined above under the Terms of Reference was followed in relation to review of the various documents provided. I provided WACJV (via Hansen Bailey) with a detailed commentary on the documents in July 2012, addressing Terms of Reference 1, 2 and 3. Subsequent to this I was provided with further amendments to the two documents on 15th August, 2012, and again on 3rd October, 2012 in response to the comments I had provided, and issues raised.

On the basis of the amended documents, I am able to confirm the following:

- The majority of comments, suggestions and requests for further information or clarification made by me in my detailed peer review report have been addressed.

- I am able to restate, with confidence, my preliminary conclusions regarding the investigations undertaken to date:

    - *The extent of geological investigation carried out to form an initial understanding of the geological domains across the lease area is highly commendable – both in terms of the quantity of information gathered, and the manner in which it has been collated and analysed.*

    - *The selected subsidence prediction methodologies (IPM and calibrated numerical modelling); and the consultants who have applied the methodologies (MSEC and SCT); are both highly reputable and appropriate to the prediction requirements of the Project. It is fair to say that these organisations and the approaches they have applied in this case represent state of the art, not just in Australia, but internationally, for subsidence prediction.*

    - *The adaption of the two methodologies into a hybrid prediction approach is innovative, and has been done in an appropriate manner, making it applicable to the mining conditions anticipated by the Project.*

    - *The preceding reviews of the individual reports contain a number of quite specific comments where it is considered that minor improvements can be made, either in terms of clarity, or content. In a small number of cases, some additional discussion and supporting evidence is called for.*

    - *Regardless of the above comments, it is important to recognise that there are difficulties in subsidence predictions and especially where extensive databases of past practice do not exist or are not directly relevant. As a result, the predictions made are not without a level of uncertainty, albeit that they have been made with a degree of conservatism in most if not all cases.*

- *It will be absolutely essential to gather a considerable amount of subsidence data over and around the first block of longwall panels, and to ensure that re-evaluation of all predictions occurs as part of a further validation process.*

- *It is also absolutely essential that the proposed adaptive management approach be quite explicitly defined well in advance, incorporating proactive measures and response to leading indicators, rather than just being a post-mortem after each panel is finished. The adaptive management approach must include clearly defined management decision-making processes at all stages.*

- I am of the opinion that "best-practice" subsidence prediction techniques have been adopted using innovative hybrid empirical and numerical techniques. These techniques have been rigorously evaluated, and validated as far as possible against available databases.

- The techniques used, and hence the predictions made by them, have incorporated appropriate assumptions concerning certain rock characteristics and anticipated modes of ground behaviour.

- It will be absolutely essential that a comprehensive Wallarah site-based validation of the predictions and hence the prediction methodologies is carried out, once data is collected from subsidence associated with the initial longwall panels, to provide an even better level of confidence in the prediction techniques and the underlying assumptions and findings.

- Should such validation processes identify any major inconsistencies or discrepancies between predicted and actual behaviour, then a further re-evaluation of the overall project predictions should be undertaken. (This validation and review process should be an ongoing procedure as part of the subsidence management procedures).

Yours sincerely,

Bruce Hebblewhite

APPENDIX A

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

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(and President for 2008/09)
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