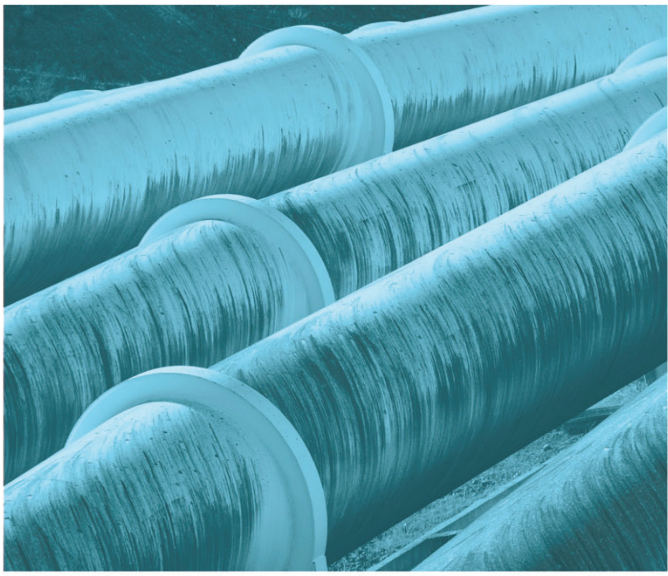



Statement of Environmental Effects

Chain Valley Colliery - Modification 3

Prepared for Great Southern Energy Pty Ltd (trading as Delta Coal)
May 2019

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Chain Valley Colliery - Modification 3

Report Number

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Client

Great Southern Energy Pty Ltd (trading as Delta Coal)

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29 May 2019

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Final

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29 May 2019

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29 May 2019

Executive Summary

Chain Valley Colliery (CVC) is an underground coal mine on the southern end of Lake Macquarie, approximately 60 kilometres (km) south of Newcastle. Great Southern Energy Pty Ltd (trading as Delta Coal) took over as owner and operator of CVC and as the operator of neighbouring Mannering Colliery (MC) on 1 April 2019. Prior to the purchase by Great Southern Energy Pty Ltd, CVC was owned and operated by LakeCoal Pty Ltd (LakeCoal). LakeCoal also operated MC under an agreement with the owners of the mine; Centennial Mannering Pty Limited, a wholly owned subsidiary of Centennial Coal Company (Centennial).

CVC operates under State significant development (SSD) consent (SSD-5465), as modified, which was originally granted on 23 December 2013 by the then Minister for Planning and Infrastructure under Part 4, Division 4.1 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act). Delta Coal is seeking to modify SSD-5465 pursuant to Section 4.55(1A) of the EP&A Act to allow for:

- the transport of product coal from CVC to Mannering Colliery (MC) via the approved underground linkage between the two operations at a rate up to the annual production level approved under SSD-5465, as modified, which is currently 2.1 million tonnes per annum (Mtpa). The current approved rate of product coal transfer from CVC to MC is 1.3 Mtpa; and
- a change in the definition of 'first workings' in SSD-5465 to allow the broader use of bord and pillar mining methods within the approved consent boundary.

An underground linkage within the Fassifern Seam between CVC and MC enables coal extracted at CVC to be transferred and handled at MC. Increasing the amount of coal extracted at CVC that is handled and transported via utilisation of the existing MC coal clearance system will result in a reduction in capital and operating costs across Delta Coal's operations. This is because the existing infrastructure at MC has the proven ability to supply coal to Vales Point Power Station (VPPS) at a higher and more efficient rate than directly from CVC due to more advanced coal clearance infrastructure. As noted above, Great Southern Energy Pty Ltd recently became the owner and operator of CVC and the operator of MC. The common management of the two sites enables them to be managed as a combined operation, resulting in operational efficiencies.

In relation to the proposed change to the definition of first workings, the approved mine design process at CVC uses an adaptive management approach where appropriate mining methods are identified for an area based on geological and surface features, as well as geotechnical conditions and designs. CVC has encountered significant geological faulting. This has resulted in increased geotechnical and geological constraints and a greatly reduced ability for the mine to continue miniwall operations in approved mining areas. Currently approved operations at CVC contemplated miniwall extraction only, with the use of first workings primarily limited to mains headings and gate roads. This is reflected in the current definition of 'first workings' in SSD-5465 and the requirement in Schedule 4 Condition 6 for the Secretary's approval for any changes to the layout of these first working from that specified in Appendix 3 of SSD-5465. Whilst bord and pillar mining methods have historically been used at CVC, the predominant mining method used since 2011 has been miniwall mining.

Bord and pillar mining is a reliable and consistent mining method that would provide operational flexibility at CVC to navigate geological structures, adverse geotechnical conditions and sensitive surface features. First workings bord and pillar mining involves the formation of roadways and pillars that are geotechnically designed to be long-term stable resulting in negligible subsidence effects (ie vertical subsidence of ≤20 mm).

The proposed modification is not seeking to change the approved annual coal extraction limit at CVC, nor is it seeking any change to pit top infrastructure at CVC, or approved trucking rates, routes or hours on the public road network. A separate modification of MC's project approval (MP 06_0311) is being sought to permit an increase in the rate of ROM coal handled at, and transport from MC, from 1.3 Mtpa up to the approved extraction limit at CVC.

This Statement of Environmental Effects and supporting technical assessments examine the potential impacts from the proposed modification. The NSW Department of Planning and Environment (DPE) and key stakeholders have been consulted. The purpose of this consultation has been to notify them of the proposed modification and to assist to identify all of the relevant issues to be assessed.

The proposed modification will not result in significant biophysical, social or economic impacts and any residual impacts can be appropriately managed in accordance with CVC's existing approved environmental management system. Further, the increased use of bord and pillar mining methods rather than solely relying on miniwall mining for production will result in reduced subsidence related impacts and reduced risks to production interruptions. The increased transfer of coal to VPPS via the MC surface infrastructure will also result in a reduction in coal transported via trucks through the increased use of the MC coal clearance system.

The proposed modification of SSD-5465 is of minimal environmental impact and will remain substantially the same development for which consent was originally granted. As such it is considered the modification can be approved pursuant to Section 4.55(1A) of the EP&A Act.

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1 Introduction

1.1 Background

Chain Valley Colliery (CVC) is an underground coal mine located on the southern end of Lake Macquarie, approximately 60 kilometres (km) south of Newcastle (Figure 1.1). CVC is owned and operated by Great Southern Energy Pty Ltd (trading as Delta Coal). Underground mining at CVC commenced in 1962, and since that time has extracted coal from three seams; namely, the Wallarah Seam, the Great Northern Seam and the Fassifern Seam, using a combination of bord and pillar and miniwall mining methods. Current mining activities are generally within the Fassifern Seam.

CVC operates under Development Consent SSD-5465, as modified, which was originally granted on 23 December 2013 by the then Minister for Planning and Infrastructure under Part 4, Division 4.1 of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act), which relates to State significant development (SSD). The consent permits underground miniwall mining in the Fassifern Seam at a maximum rate of 2.1 million tonnes per annum (Mtpa) of run-of-mine (ROM) coal, with all secondary extraction confined to areas under the Lake Macquarie water body.

Adjacent to and south-west of CVC is Mannering Colliery (MC), an underground coal mine also located on the southern end of Lake Macquarie. MC's pit top (Figure 1.2) is located approximately 1.1 km south of CVC's pit top area. MC operates under major project approval MP 06_0311.

Great Southern Energy Pty Ltd (trading as Delta Coal) took over as owner and operator of CVC and as operator of MC on 1 April 2019. Prior to the purchase by Great Southern Energy Pty Ltd, CVC was owned and operated by LakeCoal Pty Ltd (LakeCoal). LakeCoal also operated MC under an agreement with the owners of the mine; Centennial Mannering Pty Limited, a wholly owned subsidiary of Centennial Coal Company (Centennial).

1.2 Site and surrounds

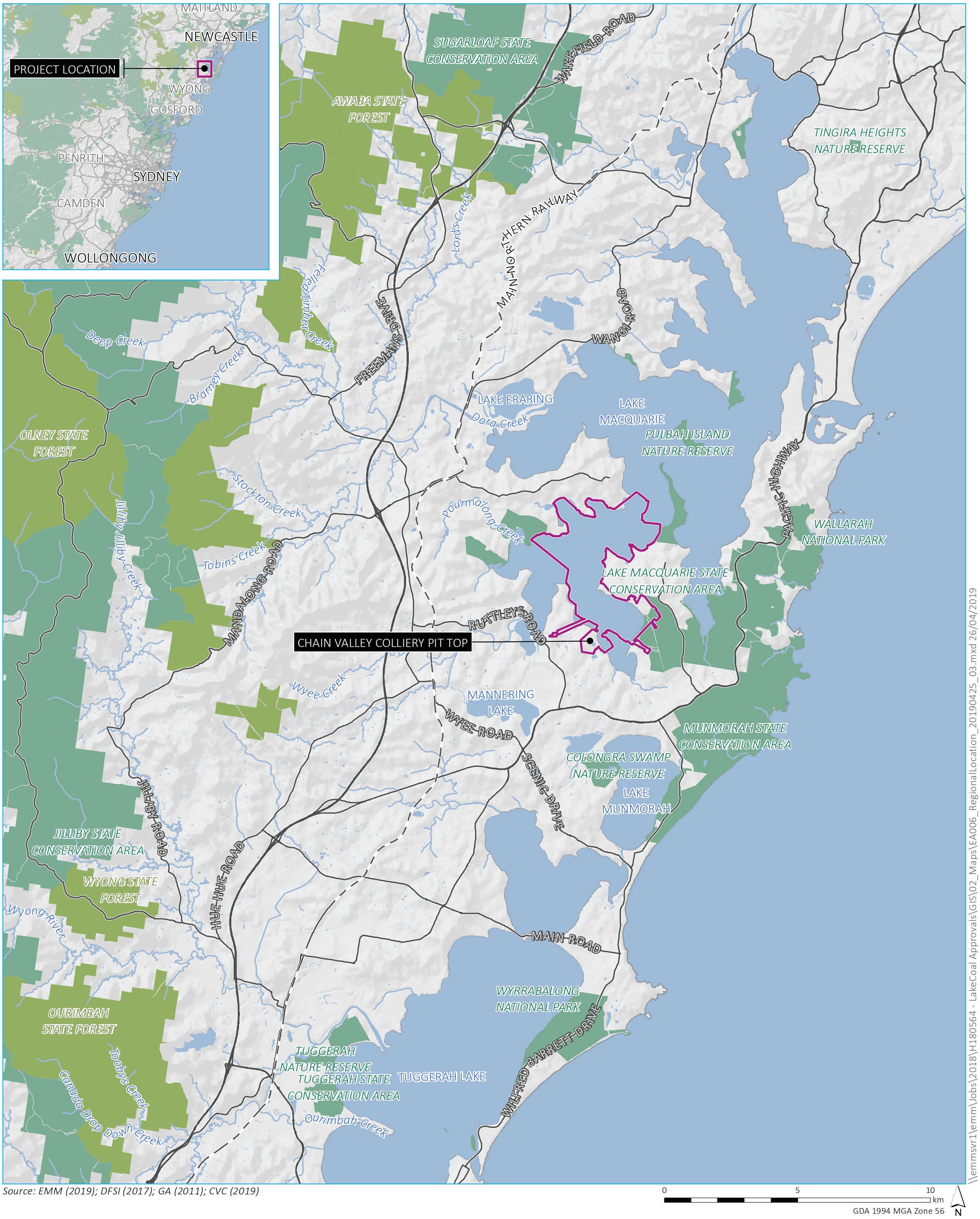
CVC is located near Mannering Park and is accessed via the public Ruttleys Road and Construction Road, a private road which services CVC and Vales Point Power Station (VPPS). The current development consent boundary includes an area of approximately 1,425 hectares (ha) which straddles the boundary of Lake Macquarie and Central Coast local government areas (LGAs). CVC's pit top area is located within the Central Coast LGA, adjacent to VPPS, in an existing industrial area on the southern end of Lake Macquarie and west of Chain Valley Bay.

Nearby residential areas include Macquarie Shores home village, Kingfisher Shores and Chain Valley Bay to the south-east, Mannering Park to the north-west and Summerland Point and Gwandalan to the north-east. CVC's ventilation fan site is located at Summerland Point, north-east of the pit top area across Chain Valley Bay. A site plan is provided as Figure 1.2.

1.3 Proposed modification overview and justification

Delta Coal is seeking to modify SSD-5465 (Modification 3, referred to herein as the proposed modification) under Section 4.55(1A) of the EP&A Act, primarily to enable two main changes:

- the transport of product coal from CVC to MC via the existing underground linkage at a rate of 2.1 Mtpa consistent with the annual production level approved under SSD-5465 (note the current approved rate of product coal transport is 1.3 Mtpa); and
- a change in the definition of 'first workings' in SSD-5465 to allow the broader use of bord and pillar mining methods within the approved consent boundary.



Source: EMM (2019); DFSI (2017); GA (2011); CVC (2019)

KEY

- Chain Valley Colliery development consent boundary
- Rail line
- Main road
- Watercourse/drainage line
- Waterbody
- NPWS reserve
- State forest

Regional context

Chain Valley Colliery
Modification 3
Figure 1.1

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Source: EMM (2019); DFSI (2017); GA (2011); CVC (2019)

0 0.5 1 km

GDA 1994 MGA Zone 56

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KEY

- Chain Valley Colliery development consent boundary
- Mannering Colliery project approval boundary
- Main road
- Local road
- Watercourse/drainage line
- Waterbody

Site plan

Chain Valley Colliery
Modification 3
Figure 1.2

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An underground linkage within the Fassifern Seam between CVC and MC enables coal extracted at CVC to be transferred and handled at MC. There is currently no prescribed limit in the conditions of SSD-5465 on the volume of coal that can be transferred to MC via the underground linkage. However, the Statement of Environment Effects (SEE) prepared by EMM Consulting Pty Limited (EMM) in support of Modification 1 (herein referred to as the Mod 1 SEE) specified an upper limit of 1.3 Mtpa consistent with the limit stipulated in MC's project approval (MP 06_0311). It is proposed to modify SSD-5465 to allow the transport of product coal from CVC to MC via the approved underground linkage at a rate up to the annual extraction level approved under SSD-5465.

The increase to the amount of coal transported via the underground linkage is sought to be consistent with the approved extraction limit applicable at CVC. Increasing the amount of coal that is handled and transported via utilisation of the existing MC coal clearance system will result in a reduction in capital and operating costs across Delta Coal's operations, as the existing infrastructure at MC has the proven ability to supply coal to VPPS at a higher and more efficient rate than directly from CVC due to more advanced coal clearance infrastructure. It would also reduce the number of truck movements from CVC to VPPS via private roads and associated amenity impacts. As noted above, Great Southern Energy Pty Ltd recently became the owner and operator of CVC and the operator of MC. The common management of the two sites enables them to be managed as a combined operation, resulting in operational efficiencies.

A separate modification of MC's project approval (MP 06_0311) is being sought to permit an increase in the rate of ROM coal handled at, and transported from MC, from 1.3 Mtpa up to 2.1 Mtpa to be consistent with the approved extraction limit at CVC.

In relation to the proposed change to the definition of first workings, the approved mine design process at CVC uses an adaptive management approach where appropriate mining methods are identified for an area based on geological and surface features, as well as geotechnical conditions and designs. CVC has encountered significant geological faulting. This has resulted in increased geotechnical and geological constraints and a greatly reduced ability for the mine to continue miniwall operations in approved mining areas. Currently approved operations at CVC contemplated miniwall extraction only, with the use of first workings primarily limited to mains headings and gate roads. This is reflected in the current definition of 'first workings' in SSD-5465 and the requirement in Schedule 4 Condition 6 for the Secretary's approval for any changes to the layout of these first working from that specified in Appendix 3 of SSD-5465.

Whilst bord and pillar mining methods have historically been used at CVC, the predominant mining method used since 2011 has been miniwall mining. First workings bord and pillar mining involves the formation of roadways and pillars that are geotechnically designed to be long-term stable resulting in negligible subsidence effects (ie vertical subsidence of ≤ 20mm). It is a reliable and consistent mining method that would provide operational flexibility at CVC to navigate geological structures and sensitive surface features.

A review of SSD-5465 has identified a number of consent conditions that limit the use of first workings bord and pillar mining methods in areas where negligible subsidence first workings are approved to be undertaken. Amendment of these conditions is proposed to increase flexibility in these areas in accordance with the adaptive management approach. This would also allow for greater resource recovery of an approved mining resource and reduced environmental impacts compared to those currently approved under miniwall mining methods at CVC.

The proposed modification is not seeking to change to the approved annual coal extraction limit at CVC, nor is it seeking any change to pit top infrastructure, approved trucking rates, routes or hours on the public road network.

1.4 The applicant

The applicant is Great Southern Energy Pty Ltd and the relevant contact details are as follows:

Great Southern Energy Pty Ltd (trading as Delta Coal)
ACN: 621 409 201
ABN: 40 621 409 201
Level 7
287 Elizabeth St
Sydney NSW 2000

Further information on CVC and its operations can be found at deltacoal.com.au or chainvalleymine.com.au.

1.5 Report purpose

Delta Coal engaged EMM to prepare this Statement of Environmental Effects (SEE), which is required to accompany an application to the NSW Department of Planning and Environment (DPE) to modify SSD-5465. This SEE provides the background to and description of the proposed modification, an assessment of its potential impacts, management considerations and consultation undertaken.

2 Existing operations and proposed modification

2.1 Approved operations

2.1.1 Approved product coal transport

CVC is currently approved to transport:

- a maximum of 660,000 tonnes (t) of product coal per annum on public roads to the Port of Newcastle for export;
- a maximum of 180,000 t of product coal per annum on public roads to domestic customers; and
- product coal to VPPS via trucks on private roads only.

Currently, trucks transporting export product coal produced at CVC are loaded at the CVC pit top and weighed at CVC's weighbridge prior to departure via the approved haulage route to the Port of Newcastle. Product coal from CVC is approved to be hauled by truck to the Port Waratah Coal Services (PWCS) Carrington Coal Terminal where it is loaded onto ships destined for international customers.

An underground linkage between CVC and the adjacent MC, as permitted under SSD-5465 (Modification 1) and MP 06_0311 (Modification 2), was completed in August 2017 enabling ROM coal from CVC's current operations to be handled at MC's pit top and transferred to VPPS via the existing conveyors. This linkage is currently used preferentially in place of transport via private haul road. There is currently no prescribed limit in the conditions of SSD-5465 on the volume of coal that can be transferred via the underground linkage. However, as noted in Section 1.3, the Mod 1 SEE specified an upper limit of 1.3 Mtpa consistent with the limit stipulated in MC's consent.

2.1.2 Approved CVC mining method

Historically, mining methods at CVC have included both bord and pillar and miniwall mining. Further detail on these mining methods is provided in Section 5.2. Since miniwall mining commenced at CVC in 2011, it has been the preferred method of extraction, and previous applications and the approved mining layout plans under SSD-5465 have focussed on a miniwall layout. Further, previous applications for CVC only contemplated first workings which involved the development of mains headings and gate roads. This is reflected in the current definition of 'first workings' in SSD-5465.

Modification 2 to SSD-5465 introduced an adaptive management process to the mine design at CVC. This process allows for mining changes to the proposed panel layout that may be required as mining progresses in response to geological features, available development float for miniwall mining, strata conditions, or other safety or operational considerations which may impact the estimated reserves available for extraction (see Section 3.2.1 of the Mod 2 SEE). This approach involves the monitoring, periodic evaluation and remediation of the consequences of mining, with possible adjustment of the mining layout and/or methods to achieve the required measures of performance.

A protocol was introduced in Mod 2 where three possible classifications would apply to future changes to the proposed panel layout identified via the adaptive management approach. These included:

1. minor changes within the scope of the modified mine plan;

2. changes that require further notification/approval via CVC's Subsidence Management Plan (SMP) and extraction plan process; and

3. changes that require development consent.

2.1.3 Mining parameters

The currently approved mining layout (Appendix 3 of SSD-5465) and subsidence performance measures specified in Conditions 1 and 2 of Schedule 4 of SSD-5465 have been specifically designed to ensure protection of:

- the Lake Macquarie foreshore – by the use of the High Water Mark Subsidence Barrier (HWMSB), consistent with the requirements of the relevant mining leases;
- seagrass communities – by the use of a Seagrass Protection Barrier (SPB) and implementation of a seagrass management plan, consistent with CVC's prior commitments and extraction plan requirements of SSD-5465; and
- land-based infrastructure – through the adoption of the HWSMB and confining secondary extraction to areas underlying Lake Macquarie.

First workings only are approved to be carried out within the HWMSB and SPB (refer to Figure 2.1). Subsidence associated with first workings is generally less than 20 mm. Subsidence less than 20 mm is commonly referred to as 'zero' subsidence. Subsidence of this magnitude or less is widely adopted as being imperceptible for all practical purposes because the magnitude of natural, seasonal variations in ground level is commonly greater than 20 mm.

The application of the HWMSB is a condition of the relevant mining tenements and has been developed to protect foreshore areas and the boundary of water bodies from mining-induced subsidence. The width of the HWMSB is defined by a 35^{o} angle of draw lakewards from the High Water Mark to the depth of the workings and from the point 2.44 m Australian Height Datum (AHD) above the High Water Mark landward to the depth of the workings.

The SPB was adopted by the previous mine operator, LakeCoal, to protect the seagrass beds of Lake Macquarie from any potential impacts from underground mining at CVC. The width of the SPB is routinely determined by a 26.5^{o} angle of draw from the surveyed boundary of the seagrass beds to the depth of the workings.

2.1.4 Environmental management

Environmental management at CVC is undertaken in accordance with:

- Development Consent SSD-5465 (as modified);
- commitments made in previous applications prepared for CVC;
- CVC's Environmental Management Strategy and associated documents;
- various environmental management plans, including CVC's SMP and approved extraction plans;
- CVC's Environment Protection Licence (EPL) 1770; and
- CVC's and MC's combined Mining Operations Plan (MOP).

The existing environmental management processes and procedures are referred to where relevant in the environmental assessment and management chapter (Chapter 5).

2.2 Proposed modification

A summary of the approved CVC operations and a comparison with the corresponding components of the proposed modification is provided in Table 2.1. The individual components of the proposed modification are further described in the following sub-sections.

Table 2.1 Approved CVC operations and proposed modification

Project aspect	Approved operations	Proposed modification
ROM coal extraction	Extraction of up to 2.1 Mtpa of ROM coal from the Fassifern Seam.	No change.
Mining methods	Underground mining undertaken using continuous miner and miniwall mining methods.	Underground mining undertaken using continuous miner (bord and pillar and pillar extraction) and miniwall mining methods.
Life of mine	Mining operations are approved until 31 December 2027.	No change.
Development consent boundary	As shown in Appendix 2 to SSD-5465	No change.
Underground mining area	As shown in Appendix 3 to SSD-5465	Proposed to be replaced with Figure 2.1. See Section 2.2.2 for further details.
Existing surface infrastructure	Utilisation of existing surface infrastructure, including but not limited to: • personnel-and-material drifts, ROM coal conveyor drift; • upcast and downcast ventilation shaft and fans; • coal handling facilities for breaking, crushing, sizing and storing product coal; • administration and workshop facilities; and • water management infrastructure. • APZs around some items of surface infrastructure.	No change to, or intensification of, existing surface infrastructure.
Coal processing	Screening and crushing of ROM coal at CVC.	No change.
Water demand and supply	160 megalitres (ML) per annum in water use, drawn from Wyong Shire Council's potable water supply mains.	No change.
Coal reject management	No coal rejects are generated.	No change.
Product coal transport	CVC is approved to transport: • a maximum of 660,000 tonnes of product coal per annum on public roads to PWCS for export; • a maximum of 180,000 tonnes of product coal per annum on public roads to domestic customers (other than VPPS); • product coal to VPPS via truck on private roads only; and • 1.3 Mtpa to MC (MP06_0311) via the underground linkage for subsequent delivery to VPPS. Note: restrictions on both the hours and frequency of dispatch for coal laden trucks also apply.	No change to the transport of product coal via public roads. No change to the restrictions on both the hours and frequency of dispatch for coal laden trucks. Transport of product coal to MC via the existing underground linkage up 2.1 Mtpa, for subsequent delivery to VPPS, subject to receipt of requisite approvals for MC (refer to Section 2.4). Options to use CVC pit top for product coal handling will remain as approved, up to current approved tonnages.
Hours of operation	Mining operations are approved 24 hours a day, 7 days a week.	No change.

Table 2.1 Approved CVC operations and proposed modification

Project aspect	Approved operations	Proposed modification
Mine access	Existing road access from Construction Road, off Ruttleys Road.	No change.
Environmental Performance Measures	Less than 20mm subsidence within the HWMSB and within seagrass beds. Performance measures as set out in Condition 2 of Schedule 4 of SSD-5465.	No change
Rehabilitation	Decommissioning of surface facilities and final rehabilitation following mine closure.	No change.
Employment	Employment of approximately 220 full time equivalent personnel in total (including approximately 40 full time equivalent contractors).	No change.

2.2.1 Increase in product coal transport via the underground linkage

As stated above, the numerical limit on the amount of coal transported from CVC to MC via the underground linkage is sought to be increased to 2.1 Mtpa to be consistent with the approved extraction limit applicable at CVC.

As a result of the proposed modification, and requisite approvals for MC (see Section 2.4), there is expected to be a net reduction in the volume of coal being trucked from CVC to VPPS via internal access roads (as the primary transfer of coal to VPPS is expected to be via the overland conveyor from MC). Coal haulage truck movements from the CVC pit top to the public road network would be no greater than currently approved under SSD-5465.

2.2.2 Changes to development consent conditions relating to the mining method

Currently approved operations at CVC contemplated miniwall extraction only with the use of first workings primarily limited only to mains headings and gate roads. This is reflected in the current definition of 'first workings' in SSD-5465 and the requirement in Schedule 4 Condition 6 for the Secretary's approval for any changes to the layout of these first working from that specified in Appendix 3 of SSD-5465. Whilst bord and pillar mining methods have historically been used at CVC, miniwall mining has solely been used since 2011.

It is proposed that future mining within approved mining areas at CVC will consider the use of either miniwall or bord and pillar mining methods depending on the geological conditions of the area. Bord and pillar mining provides increased recovery in areas not suited to miniwall mining such as small resource areas preventing economic miniwall operation, or areas that will not and/or are unlikely to be approved for secondary extraction due to certain constraints (ie sensitive surface features, shallow depths, and/or multi-seam areas). The type of mining method to be used in particular areas would be confirmed in CVC's MOP. Different bord and pillar configurations are possible; however, a 'herringbone' layout similar to that currently used at Myuna Colliery is considered the most likely for use at CVC. This method is discussed further in consideration of potential subsidence impacts in Section 5.2.

The approved adaptive management approach to mine design at CVC allows for the use of alternative mining methods within the approved mining area, as described in Section 2.1.2. It is considered that the use of bord and pillar mining methods could fall under the second category (ie 'changes that require further notification').

Notwithstanding, SSD-5465 includes a definition of 'first workings' that limits it to 'development of the main headings and gateroads in the underground mining area'.

Therefore, to allow CVC the flexibility to use either miniwall or bord and pillar mining methods throughout the approved mining area, it is proposed to amend certain conditions of SSD-5465 that relate to mining methods. These are detailed in Table 2.2.

Table 2.2 Proposed changes to SSD-5465 mining method consent conditions

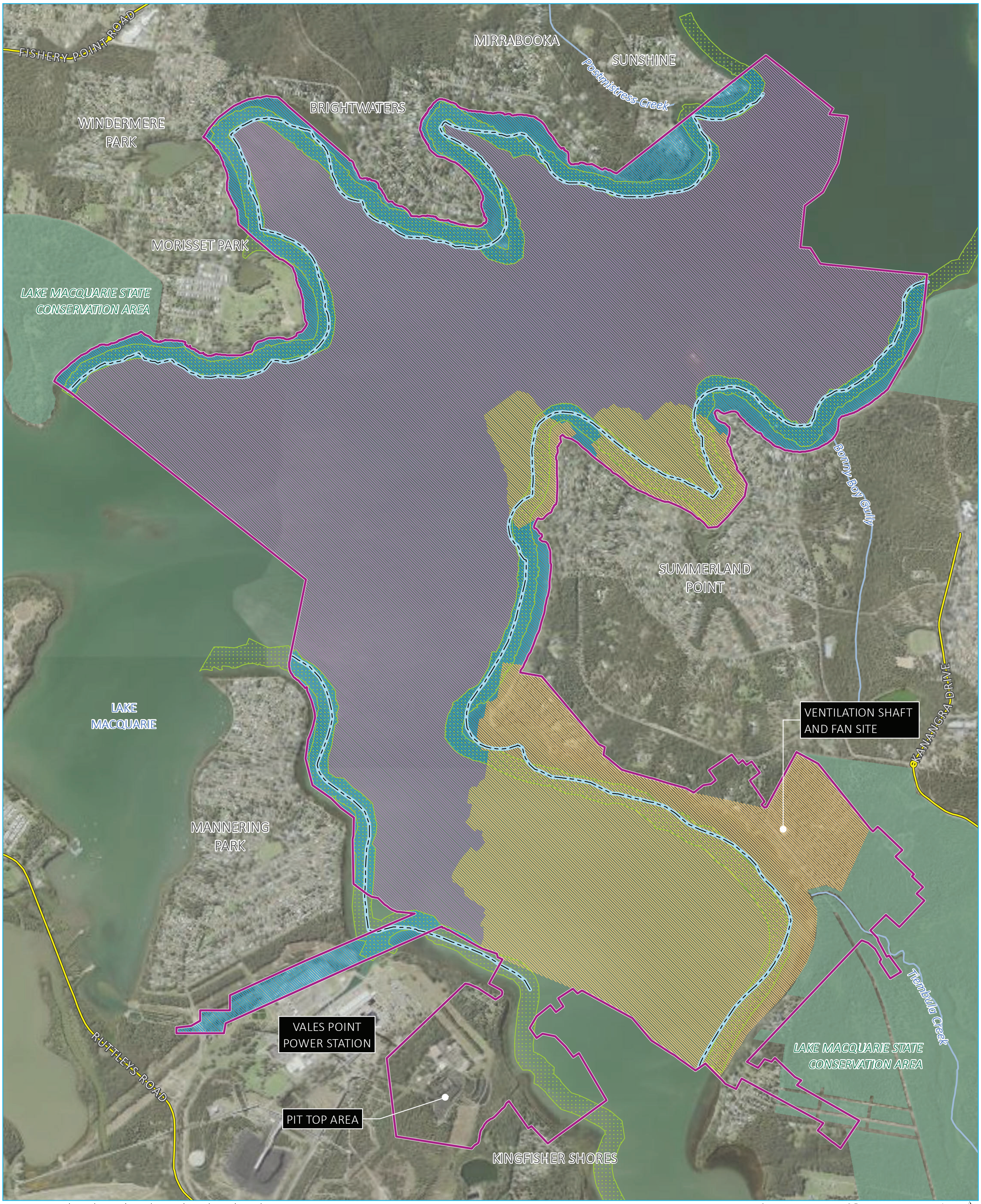
Condition	Current content	Proposed content	Justification for change
Definition of 'first workings'	Development of the main headings and gateroads in the underground mining area.	Development of the main headings and gateroads, and the use of bord and pillar mining methods and the like, in the underground mining area.	To allow CVC to use bord and pillar mining methods and the like throughout the underground mining area.
Definition of 'second workings'	Extraction of coal by miniwall or pillar extraction methods.	Extraction of coal by miniwall, or by pillar extraction, pillar splitting and pillar reduction methods.	To align the definition of secondary workings in SSD-5465 with the definition in the NSW Work Health and Safety (Mines and Petroleum Sites) Regulation 2014.
Schedule 4, Condition 9	The Applicant shall not carry out first workings on site that are not generally in accordance with the approved mine plan without written approval of the Secretary.	The Applicant may carry out first workings within the site, other than in accordance with an approved Extraction Plan, provided that the Resources Regulator is satisfied that the first workings are designed to remain stable and non-subsiding, except insofar as they may be impacted by approved second workings.	The definition of 'Approved mine plan' in SSD-5465 is 'The mine plan show(n) in Appendix 3, as varied by an Extraction Plan approved under this consent'. Therefore, without this modification the use of bord and pillar mining methods throughout the underground mining area would require additional approval.
Appendix 3	Development layout figure illustrating a miniwall layout	Replace with a figure illustrating the 'subsidence/mining zone' approach (refer to Figure 2.1).	The change to a 'subsidence zone' approach would allow the identification of several domains for mining via secondary extraction (such as using miniwalls) and/or first workings bord and pillar methods and the like, thereby, providing flexibility in mining methods at CVC. The use of a first workings mining method would not require any further approval other than through approval of the MOP, and secondary workings would be subject to an Extraction Plan.

The proposed mining zone figure referenced in Table 2.2 is shown in Figure 2.1 and includes three types of zones:

1. Zone A – Long-term stable mining systems generating up to 20 mm surface subsidence (ie areas of 'zero' subsidence);

2. Zone B – Mining systems generating up to a maximum of 780 mm vertical subsidence consistent with the subsidence levels currently approved for CVC (ie areas where first and secondary workings would be undertaken); and

3. Zone C – Long-term stable mining systems, considering multi-seam interaction (ie areas that have historic multi-seam mine workings).



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Source: EMM (2019); CVC (2019); DFSI (2017); GA (2011)

0 0.5 1 km
GDA 1994 MGA Zone 56
N

KEY

- Chain Valley Colliery development consent boundary
- High water mark subsidence barrier
- Main road
- Watercourse/drainage line
- NPWS reserve
- Seagrass protection barrier
- Zone A - Long-term stable mining systems generating up to 20 mm surface subsidence
- Zone B - Mining systems generating up to a maximum of 780 mm vertical subsidence
- Zone C - Long-term stable mining systems (considering multi-seam interaction)

Proposed subsidence zones

Chain Valley Colliery
Modification 3
Figure 2.1

creating opportunities

A geotechnically engineered mine design would be developed for underground mining within the proposed subsidence zones. Any secondary extraction to be undertaken in Zone B would continue to be subject to the requirement for an Extraction Plan being approved, which will require consideration of threats of serious or irreversible environmental damage.

2.3 Alternatives

Alternatives to the proposed removal of a numerical limit on the amount of coal transported from CVC to MC via the underground linkage would be for the limit to remain as per the currently approved limit, or for the limit to be increased but not to the approved extraction limit at CVC. Neither of these options would result in the improvement of potential environmental impacts as per the proposed modification. Both of these options would mean that trucking of product coal from CVC to VPPS would still be required via internal access roads rather than via MC's overland conveyor, with which there are associated operational costs and environmental impacts.

Another alternative to sending coal to VPPS via the underground link road and MC's coal clearance system would be to reconstruct/refurbish required components of the former overland conveyor and transfer system between CVC and the VPPS coal stockpile, a section of which is located immediately adjacent to CVC's access road. This alternative was previously considered under Modification 2 to SSD-5465 and was discounted due to the significant capital investment required to upgrade the former overland conveyor transfer system. The same considerations apply for the proposed modification and it is considered that this would not be a suitable alternative.

Alternatives to the flexibility in mining methods at CVC would be for the currently approved mining methods to remain, with miniwall mining being the primary method of coal extraction. This would potentially result in higher levels of subsidence beneath Lake Macquarie and groundwater inflows to the CVC underground workings. The restrictions on operational flexibility would also potentially result in reduced resource recovery and associated decrease in royalties to the NSW government.

2.4 Mannering Colliery

MC was granted major project approval (MP 06_0311) on 12 March 2008, with subsequent modifications permitting the handling of up to 1.3 Mtpa of ROM coal until 30 January 2022. All coal handled at MC is transported via a dedicated overland conveyor to VPPS.

To increase the rate of coal handling via the underground linkage between CVC and MC, modification to MC's MP 06_0311 will also be required. A modification application (Mod 5) to MC's project approval MP 06_0311 to permit an increase in the rate of coal handling at, and transport from MC, from 1.3 Mtpa up to the annual production level at CVC approved under SSD-5465 will be submitted separately to this application.

MC's Mod 5, together with this proposed modification, will provide Delta Coal with the ability, if required, to transport coal extracted at CVC under SSD-5465 to VPPS via the underground linkage and MC's facilities and conveyor system. As explained above, there will be no change to approved trucking rates, routes or hours on the public road network.

3 Statutory approval framework

3.1 Introduction

This chapter describes the relevant Commonwealth and State legislation and regulatory framework under which the proposed modification will be assessed and determined.

3.2 Planning approval history

A Part 3A planning approval for CVC (MP 10_0161) was granted on 23 January 2012 by the then Minister for Planning and Infrastructure for the Domains 1 and 2 Continuation Project, allowing the continuation of operations at CVC. This approval was subsequently modified on one occasion (30 August 2012) to enable the revision of the miniwall panel layout and an increase in the maximum extraction width of miniwall panels.

The current development consent for CVC, SSD-5465, was granted by the then Minister for Planning and Infrastructure on 23 December 2013. The development consent allows for continued mining within the Fassifern Seam and incorporates the operations approved under the previous project approval (MP 10_0161), as modified.

SSD-5465 was modified (Modification 1) on 27 November 2014 to allow construction of an underground linkage within the Fassifern Seam between CVC and the adjacent MC.

A subsequent modification (Modification 2) to SSD-5465 was approved on 16 December 2015 to permit:

- an increase in the maximum rate of ROM coal extraction at the mine from 1.5 Mtpa to 2.1 Mtpa;
- mine design changes in the mine's northern area;
- an increase in full-time personnel from approximately 160 to approximately 220; and
- minor vegetation clearing adjacent to infrastructure for the purpose of asset protection from bushfires.

3.3 State approvals

3.3.1 NSW Environmental Planning and Assessment Act 1979

i Modification applications

Modification to development consent SSD-5465 is required under Section 4.55 of the EP&A Act.

It is considered that the development consent is able to be modified under Section 4.55(1A), which states:

> (1A) Modifications involving minimal environmental impact
>
> A consent authority may, on application being made by the applicant or any other person entitled to act on a consent granted by the consent authority and subject to and in accordance with the regulations, modify the consent if:
>
> (a) it is satisfied that the proposed modification is of minimal environmental impact, and
>
> (b) it is satisfied that the development to which the consent as modified relates is substantially the same development as the development for which the consent was originally granted and before that consent as originally granted was modified (if at all), and

(c) it has notified the application in accordance with:

(i) the regulations, if the regulations so require, or

(ii) a development control plan, if the consent authority is a council that has made a development control plan that requires the notification or advertising of applications for modification of a development consent, and

(d) it has considered any submissions made concerning the proposed modification within any period prescribed by the regulations or provided by the development control plan, as the case may be.

Subsections (1), (2) and (5) do not apply to such a modification.

To determine whether a proposed modification to a development consent is substantially the same development for which the consent was originally granted, a comparison between the originally approved development and the proposed modified development is required to ascertain whether the modified development is essentially or materially the same as that which was originally approved. Section 7.2 of this SEE provides such a comparison in consideration of the proposed modification and the potential environmental impacts.

Further, Section 4.55(1A) requires the proposed modification to be of minimal environmental impact. This is demonstrated in Chapter 5 and summarised in Section 5.5 of this SEE.

ii Matters for consideration

Section 4.55(3) requires a consent authority to take into consideration relevant matters referred to in Section 4.15(1) of the EP&A Act when determining an application for modification of a consent under Section 4.55. The Section 4.15(1) matters, and where they are addressed in this SEE, are detailed in Table 3.1.

Table 3.1 EP&A Act Section 4.15(1) matters for consideration

Matter	Where addressed
(a) the provisions of:	
(i) any environmental planning instrument, and	Section 3.3.2
(ii) any proposed instrument that is or has been the subject of public consultation under this Act and that has been notified to the consent authority (unless the Planning Secretary has notified the consent authority that the making of the proposed instrument has been deferred definitely or has not been approved), and	Section 3.3.2
(iii) any development control plan, and	Development control plans do not apply to SSD projects.
(iv) any planning agreement that has been entered into under section 7.4, or any draft planning agreement that a developer has offered to enter into under section 7.4, and	Not applicable to the proposed modification.
(v) the regulations (to the extent that they prescribe matters for the purposes of this paragraph)	Sections 3.3.1.iii and 3.3.1.iv
that apply to the land to which the development application relates,	
(b) the likely impacts of that development, including environmental impacts on both the natural and built environments, and social and economic impacts in the locality,	Chapter 5
(c) the suitability of the site for the development,	Section 7.4

Table 3.1 EP&A Act Section 4.15(1) matters for consideration

Matter	Where addressed
(d) any submissions made in accordance with this Act or the regulations,	The local community and relevant government agencies will be invited to make submissions on the proposed modification following submission of this SEE to DPE. The Minister for Planning (or delegate) will consider any submissions received during determination of the application.
(e) the public interest.	Section 7.5

iii Form of application

The required content of a Section 4.55(1A) application is detailed under Clause 115(1) of the EP&A Regulation. The Clause 115(1) requirements and where they are addressed in this document are detailed in Table 3.2.

Table 3.2 EP&A Regulation Clause 115(1) requirements

Requirement	Where addressed
(a) the name and address of the applicant	Section 1.4
(b) a description of the development to be carried out under the consent (as previously modified)	Section 2.1
(c) the address, and formal particulars of title, of the land on which the development is to be carried out,	The address of CVC is: Off Construction Rd Off Ruttleys Rd Mannering Park NSW 2259 For title details see Appendix 1 to SSD-5465.
(d) a description of the proposed modification to the development consent	Section 2.2
(e) a statement that indicates either; (i) that the modification is merely intended to correct a minor error, misdescription or miscalculation, or; (ii) that the modification is intended to have some other effect, as specified in the statement,	Section 1.3
(f) a description of the expected impacts of the modification;	Chapter 5
(g) an undertaking to the effect that the development (as to be modified) will remain substantially the same as the development that was originally approved;	Section 7.2
(g1) in the case of an application that is accompanied by a biodiversity development assessment report, the reasonable steps taken to obtain the like-for-like biodiversity credits required to be retired under the report under the report to offset the residual impacts on biodiversity values if different biodiversity credits are proposed to be used as offsets in accordance with the variation rules under the *Biodiversity Conservation Act 2016,*	The application is not required to be accompanied by a biodiversity development assessment report.

Table 3.2 EP&A Regulation Clause 115(1) requirements

Requirement	Where addressed
(h) if the applicant is not the owner of the land, a statement signed by the owner of the land to the effect that the owner consents to the making of the application (except where the application for the consent the subject of the modification was made, or could have been made, without the consent of the owner),	The application for the consent the subject of the modification was made, or could have been made, without the consent of the owner, as per clause 49 of the EP&A Regulation (see Section 3.3.1 iv).
(i) a statement as to whether the application is being made to the Court (under Section 4.55) or to the consent authority (under Section 4.56),	The application is being made to the consent authority.
and, if the consent authority so requires, must be in the form approved by that authority.	The form of this application is consistent with DPE's requirements.

iv Landowners consent

Clause 49 of the EP&A Regulation details the requirements for land owners consent.

Under Clause 49(2) of the EP&A Regulation, landowner's consent is not required for an application for public notification development if the application instead gives notice of the application:

> (a) by written notice to the owner of the land before the application is made, or
>
> (b) by advertisement published in a newspaper circulating in the area in which the development is to be carried out no later than 14 days after the application is made.

Clause 49(5) defines public notification development to include:

> (i) State significant development set out in clause 5 (Mining) or 6 (Petroleum (oil and gas)) of Schedule 1 to State Environmental Planning Policy (State and Regional Development) 2011 but it does not include development to the extent that it is carried out on land that is a state conservation area reserved under the National Parks and Wildlife Act 1974

The development meets the definition of public notification development.

A portion of the Lake Macquarie State Conservation Area (SCA) lies within CVC's development consent boundary (refer Figure 2.1). Delta Coal has sought landowner's consent from National Parks and Wildlife Services (NPWS) for lodgement of this modification application and SEE.

3.3.2 Environmental planning instruments

i State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007

Mining operations at CVC are permissible by virtue of Clause 7 of State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007 (the Mining SEPP) which states that development for the purposes of underground coal mining is permissible on any land.

Part 3 of the Mining SEPP details the matters for consideration within development applications for mining purposes. Clause 12AB, within Part 3 of the Mining SEPP identifies non-discretionary development standards for mining. Subclause (1) states that if a proposed development for the purposes of mining satisfies a development standard set out in that clause, the consent authority cannot require more onerous standards for those matters but does not prevent the consent authority granting consent even though any such standard is not complied with. The proposed modification satisfies the non-discretionary development standards for mining as detailed in Table 3.3.

Table 3.3 Assessment of the proposed modification against Mining SEPP non-discretionary development standards for mining

Development standard	Comments on compliance
The development does not result in a cumulative amenity noise level greater than the acceptable noise levels, as determined in accordance with Table 2.1 of the Industrial Noise Policy, for residences that are private dwellings.	The proposed modification will not result in additional noise emissions that will result in a cumulative amenity noise level greater than the acceptable noise levels. See Section 5.4 for further information. Therefore, this development standard is satisfied.
The development does not result in a cumulative annual average level greater than 30 µg/m^3 of PM_{10} for private dwellings.	The proposed modification will not result in additional dust emissions that would result in a cumulative annual average level greater than 30 µg/m^3 of PM_{10} for private dwellings. See Section 5.4 for further information. Therefore, this development standard is satisfied.
Air blast overpressure caused by the development does not exceed: (a) 120 dB (Lin Peak) at any time, and (b) 115 dB (Lin Peak) for more than 5% of the total number of blasts over any period of 12 months, measured at any private dwelling or sensitive receiver.	The proposed modification does not involve activities that could cause ground vibration in excess of the development standards.
Ground vibration caused by the development does not exceed: (a) 10 mm/sec (peak particle velocity) at any time, and (b) 5 mm/sec (peak particle velocity) for more than 5% of the total number of blasts over any period of 12 months, measured at any private dwelling or sensitive receiver.	As above.
Any interference with an aquifer caused by the development does not exceed the respective water table, water pressure and water quality requirements specified for item 1 in columns 2, 3 and 4 of Table 1 of the Aquifer Interference Policy for each relevant water source listed in column 1 of that Table.	The groundwater impacts associated with using a first workings mining method across the approved mining area, rather than miniwall, will result in a small reduction in impacts across the site compared to those currently approved due to the elimination of overburden fracturing. Any secondary workings undertaken within Zone B will have similar or reduced groundwater impacts relative to the currently approved miniwall panels located within this area. Refer to Section 5.3 for further information.

The remaining Part 3 matters for consideration are detailed in Table 3.4 where relevant to the proposed modification.

Table 3.4 Mining SEPP Part 3 matters for consideration

Matter	Proposed modification
12 Compatibility of proposed mine, petroleum production or extractive industry with other land uses	
Before determining an application for consent for development for the purposes of mining, petroleum production or extractive industry, the consent authority must: (a) consider: (i) the existing uses and approved uses of land in the vicinity of the development, and (ii) whether or not the development is likely to have a significant impact on the uses that, in the opinion of the consent authority having regard to land use trends, are likely to be the preferred uses of land in the vicinity of the development, and (iii) any ways in which the development may be incompatible with any of those existing, approved or likely preferred uses, and (b) evaluate and compare the respective public benefits of the development and the land uses referred to in paragraph (a) (i) and (ii), and (c) evaluate any measures proposed by the applicant to avoid or minimise any incompatibility, as referred to in paragraph (a) (iii).	Existing and approved uses of land in the vicinity of the development are detailed in Section 1.2. The proposed modification would not have a significant impact on these uses given that it is in relation to an existing underground mine, and there would be no change to the approved mining area, pit top infrastructure, operating hours or traffic generation. The proposed modification is likely to have a positive benefit on surrounding land uses by reducing the number of trucks transporting coal to VPPS.
12A Consideration of voluntary land acquisition and mitigation policy	
(2) Before determining an application for consent for State significant development for the purposes of mining, petroleum production or extractive industry, the consent authority must consider any applicable provisions of the voluntary land acquisition and mitigation policy and, in particular: (a) any applicable provisions of the policy for the mitigation or avoidance of noise or particulate matter impacts outside the land on which the development is to be carried out, and (b) any applicable provisions of the policy relating to the developer making an offer to acquire land affected by those impacts.	The proposed modification would not result in a change in approved noise or particulate matter impacts.
13 Compatibility of proposed development with mining, petroleum production or extractive industry	The proposed modification relates to an existing underground mine. Further, it will enable greater efficiencies across both of Delta Coal's operations (CVC and MC) due to more advanced coal clearance infrastructure at MC.
14 Natural resource management and environmental management	
(1) Before granting consent for development for the purposes of mining, petroleum production or extractive industry, the consent authority must consider whether or not the consent should be issued subject to conditions aimed at ensuring that the development is undertaken in an environmentally responsible manner, including conditions to ensure the following:	

Table 3.4 Mining SEPP Part 3 matters for consideration

Matter	Proposed modification
(a) that impacts on significant water resources, including surface and groundwater resources, are avoided, or are minimised to the greatest extent practicable,	The groundwater impacts associated with using a first workings mining method across the approved mining area, rather than miniwall, will result in a small reduction in impacts across the site compared to those currently approved due to the elimination of overburden fracturing and the resulting groundwater inflow associated with the miniwall method. Any secondary workings undertaken with Zone B will have similar groundwater impacts relative to the currently approved miniwall panels located within this area. Refer to Section 5.3 for further information.
(b) that impacts on threatened species and biodiversity, are avoided, or are minimised to the greatest extent practicable,	The projects impacts on threatened species and biodiversity generally will be unchanged or slightly reduced as a result of the proposed modification.
(c) that greenhouse gas emissions are minimised to the greatest extent practicable.	The proposed modification would not result in an increase in greenhouse gas emissions.
15 Resource recovery	
(1) Before granting consent for development for the purposes of mining, petroleum production or extractive industry, the consent authority must consider the efficiency or otherwise of the development in terms of resource recovery.	The proposed modification provides for flexibility in mining methods used at CVC and would allow for increased recovery of the coal resource.
16 Transport	The proposed modification does not propose to increase the volume of materials transported on public roads.
17 Rehabilitation	The proposed modification would not result in additional surface disturbance that would require rehabilitation of land.

ii Wyong Local Environmental Plan 2013

The relevant zones within the project approval boundary are shown on Figure 3.1. CVC's pit top area and the ventilation fan site are within the Central Coast LGA and are zoned SP2 Electricity generating works and E2 Environmental Conservation pursuant to the Wyong Local Environmental Plan (LEP) 2013. The majority of CVC's underground mining area is within the Lake Macquarie LGA and is zoned W1 Natural Waterways pursuant to the Lake Macquarie LEP 2014. Mining is not listed as being permissible with or without consent in any of these zones.

However, as mentioned above, underground mining on any land is permissible under the Mining SEPP. In the event of an inconsistency, Section 36 of the EP&A Act stipulates that there is a general presumption that a State Environmental Planning Policy prevails over a Local Environmental Plan. Therefore, the prohibition under both LEPs does not affect permissibility.

A Draft Central Coast Local Environmental Plan was released for public exhibition from 6 December 2018 to 28 February 2019. Under the draft instrument CVC's pit top area and the ventilation fan site remains zoned as SP2 and E2.

No further provisions of the Wyong LEP 2013 or the Draft Central Coast Local Environmental Plan are relevant to the proposed modification.

3.3.3 Other State legislation

The following Acts are relevant to the proposed modification.

i Water Act 1912 and Water Management Act 2000

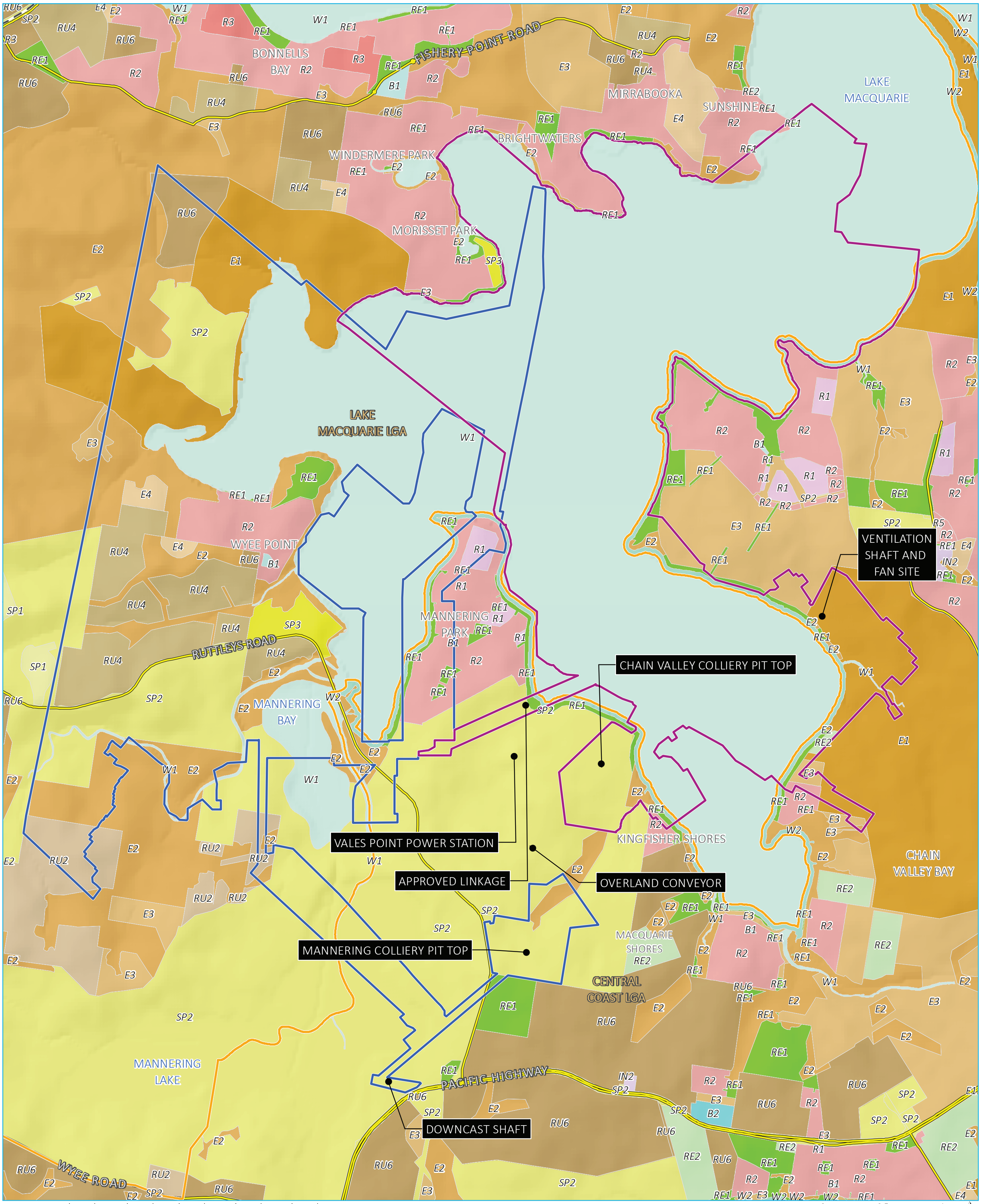
The *Water Act 1912* (Water Act) and *Water Management Act 2000* (WM Act) regulate the use and interference with surface and groundwater in NSW. As described in Section 5.3, it is anticipated that the use of alternative mining methods would result in a decrease in the inflow of groundwater to mine workings. Accordingly, the impacts as a result of the proposed modification on water resources regulated under these acts will be within, or less than those currently approved under SSD-5465.

ii Mining Act 1992

The modification to the mining layout will occur within CVC's colliery holding, with changes occurring within consolidated coal lease (CCL) 707 and mining leases (MLs) 1051, 1052, 1370 and 1632, administered under the Mining Act. A lease plan is provided as Figure 3.2.

The proposed modification will adhere to the existing mining parameters at CVC as described in Section 2.1.2 which, in summary, include confining secondary extraction to areas underlying Lake Macquarie (Zone B) and maintaining the HWMSB and the SPB (as shown on Figure 2.1).

Following approval of the proposed modification, an extraction plan will be prepared, if required by the relevant conditions of the MLs and CCLs, prior to the commencement of any underground mining operations involving secondary extraction that could potentially lead to subsidence of the land surface. Delta Coal has advised the NSW Resources Regulator of the nature of the proposed modification (refer Table 4.1).



Source: EMM (2019); DFSI (2017); GA (2011); DPE (2017); CVC (2019)

0 0.5 1 km
GDA 1994 MGA Zone 56
N

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KEY

- Chain Valley Colliery development consent boundary
- Mannering Colliery project approval boundary
- Local government area
- Rail line
- Main road

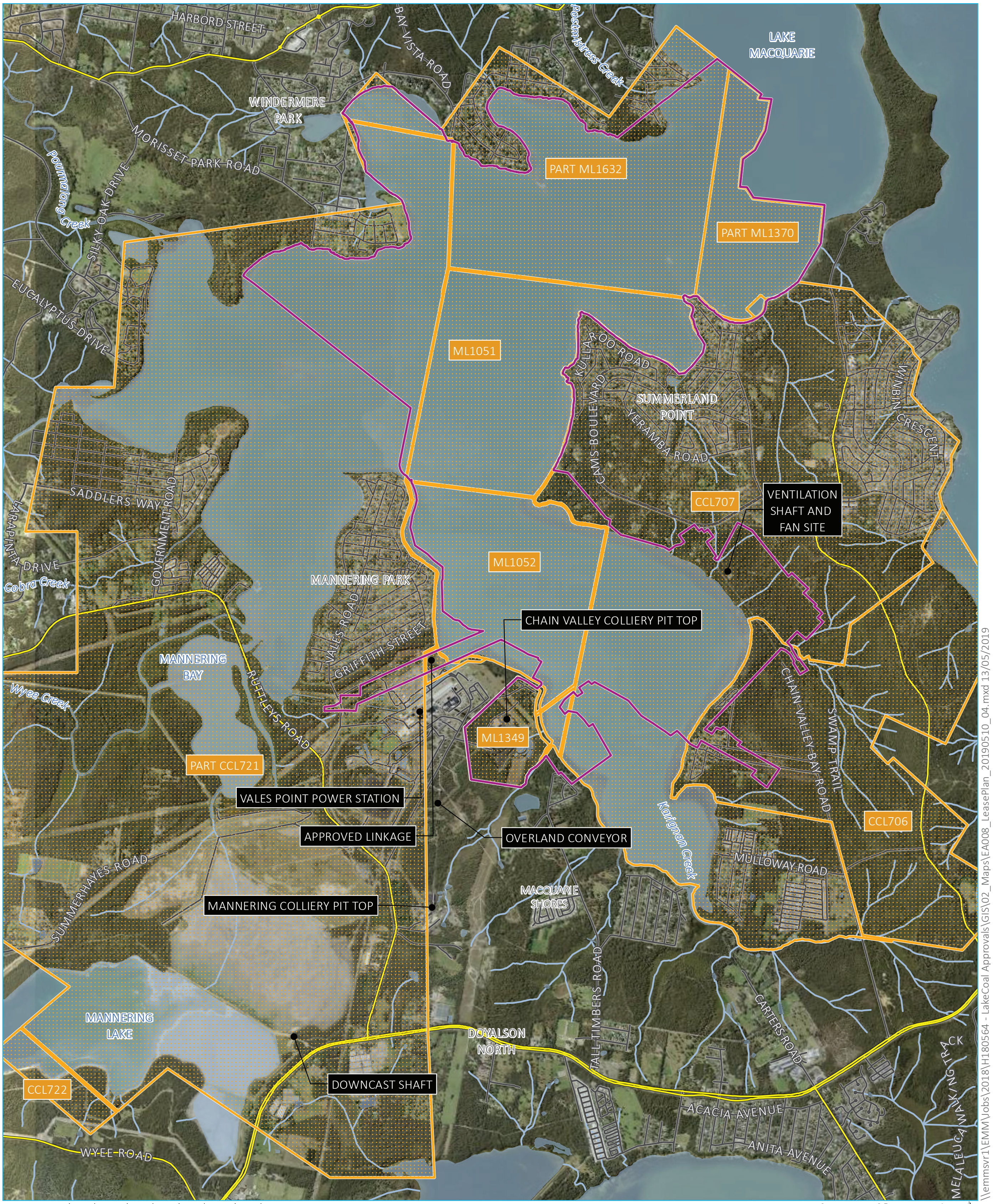
Lake Macquarie/Central Coast LEP zoning

- B1 Neighbourhood Centre
- B2 Local Centre
- E1 National Parks and Nature Reserves
- E2 Environmental Conservation
- E3 Environmental Management
- E4 Environmental Living
- IN2 Light Industrial
- R1 General Residential
- R2 Low Density Residential
- R3 Medium Density Residential
- R5 Large Lot Residential
- RE1 Public Recreation
- RE2 Private Recreation
- RU2 Rural Landscape
- RU4 Primary Production Small Lots
- RU6 Transition
- SP1 Special Activities
- SP2 Infrastructure
- SP3 Tourist
- W1 Natural Waterways
- W2 Recreational Waterways

Land use zoning

Chain Valley Colliery
Modification 3
Figure 3.1

EMM
creating opportunities



Source: EMM (2019); DFSI (2017); GA (2011); CVC (2019)

0 0.5 1 km
GDA 1994 MGA Zone 56
N

KEY

- Chain Valley Colliery development consent boundary
- Lease boundary
- Main road
- Local road
- Watercourse/drainage line
- Waterbody

Lease plan

Chain Valley Colliery
Modification 3
Figure 3.2

EMM
creating opportunities

3.4 Commonwealth approvals

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) aims to protect matters deemed to be of national environmental significance (NES), namely:

- world heritage properties;
- places listed on the National Heritage Register;
- Ramsar wetlands of international significance;
- threatened flora and fauna species and ecological communities;
- migratory species;
- Commonwealth marine areas;
- the Great Barrier Reef Marine Park;
- nuclear actions (including uranium mining); and
- actions of development for coal seam gas or large coal mining on water resources.

If an action (or proposal) will, or is likely to, have a significant impact on any matters of NES, it is deemed to be a Controlled Action and requires approval from the Commonwealth Environment Minister or the Minister's delegate. To determine whether a proposed action would or is likely to be a Controlled Action, an action may be referred to the Department of the Environment and Energy.

As substantiated in Chapter 5, there are no matters of NES that have the potential to be impacted by the proposed modification. Therefore, a referral to the Commonwealth Department of the Environment and Energy is not required.

4 Consultation

4.1 Introduction

As stated in its Environment and Community Policy, Delta Coal is committed to communicating and engaging with the community and other stakeholders regarding its activities. Consistent with this commitment, community consultation for CVC is ongoing and includes a community consultative committee (CCC), CVC's website (chainvalleymine.com.au or deltacoal.com.au), and information line (1800 687 557).

As outlined in the subsequent sections, consultation has been, and will continue to be supplemented by activities that relate specifically to the proposed modification. The nature and extent of these stakeholder consultation activities reflect the modest nature and scale of the proposed modification and its potential impacts.

4.2 Consultation with government

A summary of consultation undertaken with government agencies regarding the proposed modification is given in Table 4.1. The outcomes of this consultation are reflected in the proposed modification's scope and matters addressed in this SEE.

Table 4.1 Summary of government consultation

Agency	Date and method of consultation	Description of outcomes
DPE	Face-to-face meeting held 31 August 2016.	Items discussed during the meeting included project briefing, planning pathway, stakeholder engagement, and matters requiring consideration.
	Phone calls	Numerous phone calls to provide regular updates on the progression of the environmental assessment and modification.
	Face-to-face meetings held 14 January and 13 March 2019	Items discussed during the meetings included an update on the project, in particular the change to the definition of first workings.
Environment Protection Authority	Briefing letter sent 15 April 2019	Confirmation of receipt received 18 April 2019. No comments provided at this stage.
Resources Regulator	Face-to-face meetings held 8 April 2019.	Items discussed during the meeting included an update on the project.
	Briefing letter sent 15 April 2019 to both Subsidence and Compliance departments.	Email received in response from Subsidence department. Further discussion about the proposed modification was had via phone call with Delta Coal on 16 April 2019. Confirmed that further information would be provided as part of this SEE including the proposed zone plan.
Central Coast Council	CCC meetings.	Items discussed during the meetings included an update on the project.
	Briefing letter sent 15 April 2019.	No response received to date.
Lake Macquarie City Council	CCC meetings.	Items discussed during the meetings included an update on the project.
	Briefing letter sent 15 April 2019.	No response received to date.

Table 4.1 Summary of government consultation

Agency	Date and method of consultation	Description of outcomes
NPWS Hunter Central Coast Branch	Request for landowner's consent sent 30 April 2019.	No response received to date.
	Phone call with Delta Coal on 14 April 2019.	Items discussed included an update on the project which may impact the applicable State Conservation Areas (SCAs).
	Briefing letter sent 15 April 2019.	No response received to date.
Department of Industry – Land and Water	Briefing letter sent to Natural Resources Access Regulator.	No response received to date.

4.3 Consultation with community and special interest groups

The proposed modification was raised with the CVC and MC CCCs on several occasions with the most recent occasion being the meeting held on 13 February 2019. No formal objections were raised regarding the proposed modification by community representatives or Central Coast Council or Lake Macquarie City Council representatives during these meetings.

Due to the minor changes in operations proposed, extensive community consultation for the proposed modification was not considered necessary. A briefing information sheet on the proposed modification is available for view on CVC's website. The broader community will also be notified of the proposed modification through an advertisement placed in a local newspaper following lodgement and through the public exhibition process where community members will be invited to make comment by way of formal submissions.

Further consultation is proposed to be undertaken with the community during exhibition of the proposed modification. Delta Coal will also continue to consult with the community during operation of CVC through its CCC.

5 Impact assessment

5.1 Introduction

This chapter assesses the potential environmental, social and economic impacts arising as a consequence of the proposed modification. Whilst the change in mining method is expected to provide a reduced level of environmental impacts, assessments were undertaken to identify the likely extent of these reductions for subsidence and groundwater.

5.2 Subsidence

5.2.1 Proposed subsidence zones

It is proposed for mining operations at CVC to be undertaken within three subsidence zones shown in Figure 2.1. These zones generally align with the currently approved underground mining area and are within the approved development consent boundary. A geotechnically engineered mine design would be developed for underground mining within the proposed subsidence zones.

i Zone A

This zone contains areas where first workings are currently approved to be undertaken and relates to the alignment of SPB and HWMSB (refer Figure 5.1). Long-term stable mining systems that generate negligible surface subsidence (ie up to 20 mm) would be undertaken within this zone.

ii Zone B

This zone contains areas currently approved for secondary extraction where no historic workings overlie. The previous subsidence assessment for CVC (Ditton Geotechnical Services 2015) predicted maximum vertical subsidence of up to 780 mm within these areas. It is proposed that mining systems including both first and secondary workings which would generate up to a maximum of 780 mm vertical subsidence, consistent with the subsidence levels currently approved for CVC, be undertaken within this zone. Any secondary extraction to be undertaken in Zone B would continue to be subject to the requirement for an Extraction Plan, supported by a geotechnical mine design, which will require consideration of vertical subsidence and threats of serious or irreversible environmental damage.

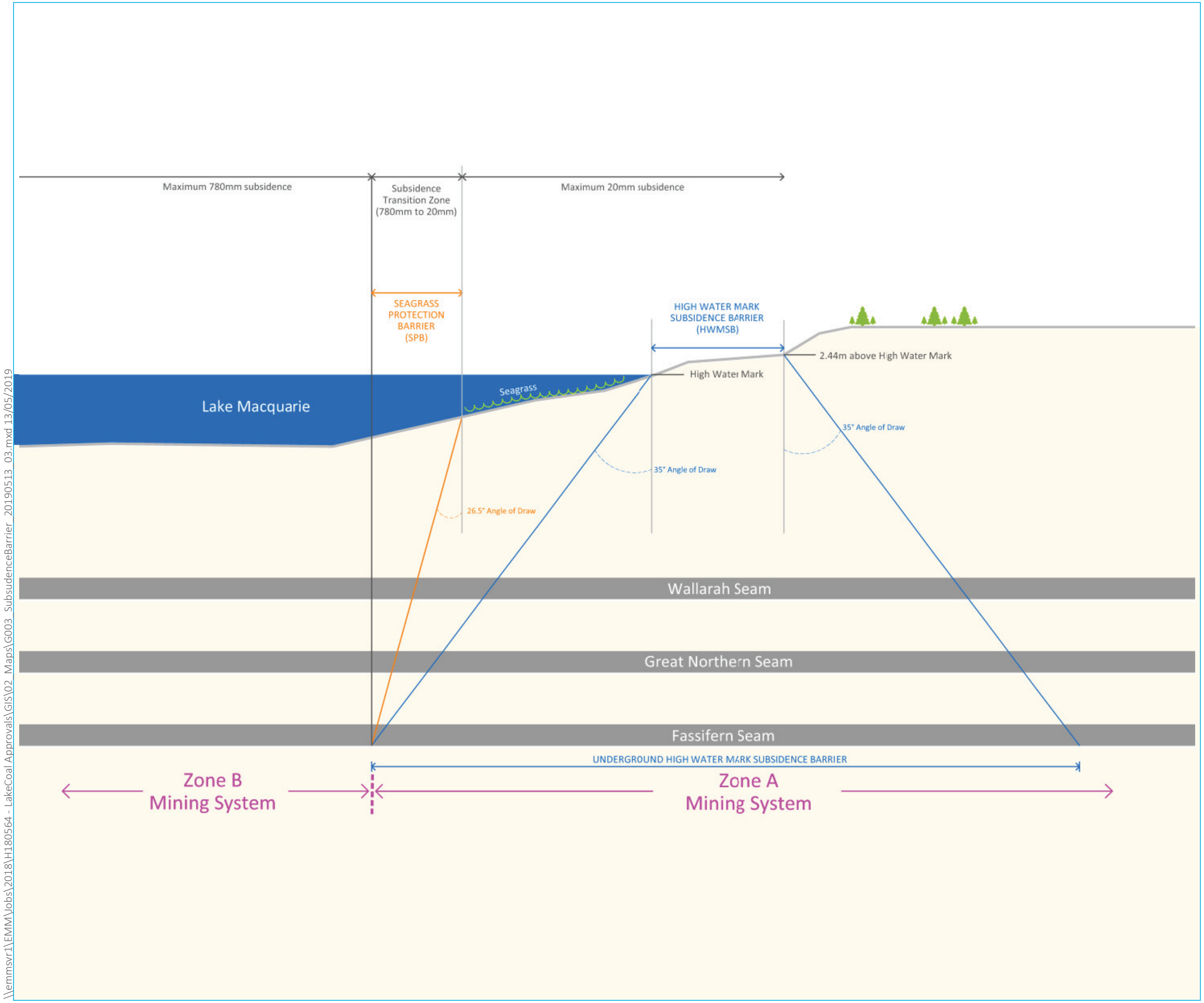
iii Zone C

This zone contains areas that contain historic multi-seam mine workings. It is proposed that long-term stable mining systems, considering multi-seam interaction, would be undertaken within this zone.

5.2.2 Proposed mining methods

i Overview

Both secondary extraction (in the form of miniwalls) and first workings (bord and pillar) mining methods have historically been undertaken at CVC. Secondary extraction (subject to the approval of an Extraction Plan), and first workings in the form of bord and pillar mining and the like, would continue to be undertaken under the proposed modification. A further discussion on the proposed first workings mining method is provided below.



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Source: EMM (2019); Delta (2019)

Conceptual cross section of the mining zones with subsidence barriers

Chain Valley Colliery
Modification 3
Figure 5.1

EMM
creating opportunities

ii Bord and pillar mining

Bord and pillar mining is a method of underground coal mining where bords/headings and cut-throughs are driven to form pillars. The roadways and pillars formed are geotechnically designed to be long-term stable and, therefore, are considered a type of 'first workings' mining.

The mining method would initially involve the drivage of a mains panel up to five headings wide, with individual panels then developed either side of the mains by driving a 'sub-mains' generally three-headings-wide. From the sub-mains, 'run-out' roadways are driven. Finally, stubs or 'free cuts' are driven from these run-out roadways to form the final pillars. Depending on the ground conditions and serviceability requirements of these free cuts, they may or may not remain unsupported (for example, some are bolted to facilitate long-term return airway ventilation).

The subsidence effects of bord and pillar mining are well understood, with a similar mining method and pattern being undertaken at the nearby Myuna Colliery, which also provide a high level of confidence in subsidence predictions (see Section 5.2.3).

If pillars were proposed to be partially or fully extracted, being a form of secondary extraction, this would be subject to an Extraction Plan approval.

5.2.3 Pillar design considerations for negligible subsidence effects

A report considering design criteria for a bord and pillar mining method using a likely herringbone pattern, so as to achieve negligible surface subsidence effects, was prepared by Strata[2] (2019). This report is attached as Appendix A. The design process employed by Strata[2] was based on data obtained from other mines, most notably the herringbone operation at the adjacent Myuna Colliery, where similar systems have been employed successfully for over 30 years.

Strata[2] identify the most significant design constraints for a bord and pillar mining system at CVC as follows:

1. Depth of cover ranges from approximately 120 m–250 m, although the range could extend in future mining areas (both shallower and deeper). Whilst it would be ideal to maintain one pillar geometry throughout the mining area thereby facilitating a simple, repetitive mining process, this depth range means that the design will need to be flexible and suited to the specific conditions of the area.

2. The system entails the development of large areas of permanent, first workings pillars. It follows that the pillars should be designed in a manner that is considered to preclude the potential for any form of sudden or rapid deterioration (primarily from an underground safety perspective). In this regard, pillar width to height (w/h) ratios of >4 are considered likely to result in a 'strain hardening' pillar deformation characteristic and, at worst, a gradual 'squeezing' or 'creep' mode of deterioration, in the event of any overloading.

3. Stable unsupported stubs are critical to the performance of the system, and therefore a typical stub width of 5.5 m is assumed.

4. The interval between stubs is partly a function of the required pillar size, but also dictated by the need to separate the adjacent alternating stubs for roof control purposes, thereby forming isolated three-way intersections. Practically, allowing for break-offs, this dictates a stub (solid) interval of around 20 m.

Strata[2] (2019) referenced case studies undertaken of mining around Lake Macquarie in the Fassifern, Great Northern and Wallarah coal seams, encompassing 62 case studies. Based on the results of this review, Strata[2] recommend the following criteria for a bord and pillar style mining method at CVC, in a herringbone layout similar to that adopted at Myuna, to ensure less than 20 mm subsidence occurs:

- average final pillar stresses of <12 Mpa; and
- factors of safety of ≥2.3.

As described in Section 2.2.2, CVC is seeking approval to maintain the flexibility to use either miniwall or bord and pillar (and the like) mining methods throughout the approved mining area. A detailed geotechnical assessment will be undertaken by a suitably qualified geotechnical engineer as part of the detailed mine plan design process which would confirm the applicable pillar design criteria for each mining area.

5.3 Groundwater

5.3.1 Method and model design

A semi-quantitative groundwater assessment was undertaken by EMM to investigate the potential groundwater impacts related to the proposed change in mining method from miniwall to a bord and pillar style first workings method within the approved development consent boundary (refer to Appendix B). The objective of the assessment was to identify whether impacts to the groundwater system from the use of a bord and pillar mining method will be substantially the same as the development originally approved under CVC's development consent, incorporating the use of a miniwall mining method.

As described in Section 5.2.2, a first workings bord and pillar mining method involves the formation of roadways and pillars that are geotechnically designed to be long-term stable, resulting in negligible subsidence (ie vertical subsidence of ≤20 mm). An approach was adopted in the groundwater assessment whereby potential groundwater impacts were identified by comparing modelled groundwater inflows to a section of the mine for the approved miniwall mining method and for the proposed first workings, bord and pillar style mining method. This 'type model' is largely based on the modelling conducted by Geoterra (2013) but does not simulate the full-scale geometry or transient operation of the life of the mine. Instead, it is simplified to simulate potential inflow to a generic mined section of the Fassifern Seam, regardless of exact location and timing within the mine footprint and schedule. This method allows a comparative assessment of the two mining methods.

The model employed the MODFLOW-USG (Panday et al 2013) simulation code via the Groundwater Vistas version 7 (Environmental Simulations Incorporated) graphical interface. The modelling undertaken best aligns with a Class 1 model as described in the *Australian Groundwater Modelling Guidelines* (Barnett et al 2012).

5.3.2 Modelling results

The groundwater modelling results suggest a reduction in groundwater inflows to mine workings of around 1.9%–2.3% for a bord and pillar style first workings mining method, compared to a miniwall mining operation. Importantly, the proposed change in mining method from miniwall to a bord and pillar style first workings is not expected to cause an increase in impacts to the groundwater system.

5.3.3 Management and monitoring

Water management and monitoring will continue to be undertaken in accordance with CVC's Water Management Plan, which was prepared in accordance with Schedule 3, Condition 18 of SSD-5465. The plan contains a site water balance, erosion and sediment control measures, surface water management plan and groundwater management plan (including a groundwater monitoring program).

5.4 Other aspects

An assessment of the other environmental, social and economic aspects as a consequence of the proposed modification is provided in Table 5.1.

It is noted that the increase in the maximum volume of product coal that can be transported from CVC, via the approved underground linkage, to MC for subsequent delivery to VPPS will not change other aspects of approved operations at CVC. The increase in the rate of coal handling at, and transport from MC, is regulated under MC's project approval (MP 06_0311), as modified.

Table 5.1 Environmental, social and economic aspects

Environmental aspect	Assessment
Noise	There are no changes to surface infrastructure, operating hours, or intensification of CVC operations proposed by the modification. The approval to permit the transport of coal via the underground linkage, subject to increased throughput at MC being approved, may result in a net reduction of truck movements from CVC. Therefore, noise emissions from the proposed modification would be within the predictions made in the *Mining Extension 1 Project EIS* (EMM 2013) and reflected in SSD-5465. No additional measures are therefore warranted. Noise emissions will continue to be managed in accordance with CVC's Noise Management Plan, which was prepared in accordance with the requirements of Condition 9, Schedule 3 of SSD-5465.
Air quality	There are no changes to surface infrastructure or intensification of CVC operations proposed by the modification. The changes to underground mining methods will not result in any changes to ventilation arrangements or any increase in particulate emissions from existing infrastructure used to ventilate the workings. The approval to permit the transport of coal via the underground linkage, may result in a net reduction of truck movements from CVC. Particulate emissions from the proposed modification would be within the predictions made in the *Mining Extension 1 Project EIS* (EMM 2013) and reflected in SSD-5465. No additional measures are therefore warranted. Dust emissions will continue to be managed in accordance with CVC's Air Quality Management Plan, which was prepared in accordance with Condition 13, Schedule 3 of SSD-5465.
Greenhouse gases	There will be no mine life extension or increase in approved production rates under the proposed modification. Therefore, Scope 1 and 2 emissions will be unchanged as a result of the proposed modification. The proposed modification will not affect the level of Scope 3 emissions associated with the approved operations other than potential reductions in transport related emissions due to increased transport of CVC coal to VPPS via MC's conveyor system. Greenhouse gas emissions reporting will continue to be undertaken in accordance with the requirements of the *National Greenhouse and Energy Reporting Act 2007*.
Transport	No changes are proposed to the approved coal extraction limit at CVC or employee numbers. There would be no change to approved trucking rates, routes or hours on the public road network. The transport of coal via the underground linkage, subject to increased throughput at MC being approved, may result in a net reduction of truck movements from CVC via private roads.
Surface water	There are no changes to extraction rates or surface infrastructure, or intensification of activities proposed by the modification and, therefore, water resources will not be impacted. There will be no secondary extraction outside areas currently approved for extraction meaning potential surface water impacts associated with subsidence remain unaffected by the proposed modification. Water management will continue to be undertaken in accordance with CVC's Water Management Plan which was prepared in accordance with Schedule 3, Condition 18 of SSD-5465.

Table 5.1 Environmental, social and economic aspects

Environmental aspect	Assessment
Visibility	The proposed modification will not result in new surface infrastructure or intensification of activities at CVC. Increased transport of coal from CVC to VPPS via the underground linkage, subject to increased throughput at MC being approved, may result in a net reduction of truck movements on existing private haul roads, which would have an improved impact on visual amenity.
Social and economic	The *Mining Extension 1 Project EIS* (EMM 2013) assessed potential social and economic impacts from the continued operation of CVC. The reduction in capital and operating costs associated with utilisation of the MC coal clearance system for coal extracted at CVC, together with the ability to mine in areas where geotechnical constraints previously limited the viable recovery of coal using the approved miniwall methods, will improve the productivity of CVC's operations and result in greater financial certainty for both CVC and MC. This, in turn, will provide increased job security for Delta Coal employees and associated ongoing social and economic benefits. The reduction in haulage vehicle movements to and from VPPS associated with any increased transfer via MC will result in a reduction of potential social amenity impacts from air quality, noise and visual. The increased flexibility in permitted mining methods would result in improved resource recovery and associated royalties to the NSW government which provide socio-economic benefits to NSW.
Waste management	CVC's waste streams and management procedures were described in the *Mining Extension 1 Project EIS* (EMM 2013). The proposed modification will not generate any additional waste streams nor result in any material increase in the volumes of wastes generated at CVC. Waste will continue to be managed in accordance with OEH guidelines and Schedule 3, Condition 23 of SSD-5465.
Hazards/risks	The proposed modification will comply with the provisions of the *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014.* The increased use of bord and pillar mining methods and the like are expected to provide a more stable system, long-term, than miniwall mining methods, thereby reducing the current level of hazards and risks as a result of the proposed modification.
Biodiversity	There will be no surface disturbance associated with the proposed modification and, therefore, no impact on native vegetation, fauna and fauna habitat including Commonwealth listed threated species, communities or migratory birds. Biodiversity will continue to be managed in accordance with CVC's Biodiversity Management Plan, which was prepared in accordance with Schedule 3, Condition 20 of SSD-5465.
Heritage	There will be no surface disturbance associated with the proposed modification and, accordingly, no potential to adversely impact on any item or feature of Aboriginal heritage or historically significant heritage that may be present. The management of Aboriginal and historic heritage at CVC will continue to be undertaken in accordance with CVC's Heritage Management Plan, which was prepared in accordance with Schedule 3, Condition 21 of SSD-5465.
Rehabilitation	The mine closure and rehabilitation measures for CVC are described in the *Mining Extension 1 Project EIS* (EMM 2013) and CVC's MOP and Rehabilitation Management Plan. Mine closure and rehabilitation will be undertaken in accordance with Condition 25 of Schedule 3 of SSD-5465, with the surface facilities to be rehabilitated to the satisfaction of the Executive Director Mineral Resources. There will be no change to mine rehabilitation as a result of the proposed modification.

5.5 Environmental impact summary

As detailed above, due to the minor nature of the proposed modification, it is anticipated that there would be no additional environmental impacts (beyond those existing impacts approved under SSD-5465) as a result of the proposed modification. Further, there is potential for environmental impacts to be improved beyond those existing impacts approved under SSD-5465, primarily as a result of the reduced level of subsidence associated with a first workings mining system, and a reduction in coal transported via trucks through the increased use of the MC coal clearance system.

Therefore, the proposed modification would satisfy the requirements of Section 4.55(1A) of the EP&A Act.

6 Commitments

All aspects relating to environmental management at CVC will continue in accordance with SSD-5465, as modified, EPL 1770, the various approved plans and other elements of the development consent.

A detailed geotechnical assessment will be undertaken by a suitably qualified geotechnical engineer as part of the detailed mine plan design process.

7 Justification and conclusion

7.1 Introduction

This chapter considers the proposed modification against the relevant objects of the EP&A Act and provides a justification for its approval.

7.2 Substantially the same development

The proposed modification constitutes a minor change to an existing approved underground mine that has been operating successfully for over 50 years. The change in mining methods as an adaptive management measure was specifically contemplated and approved in a previous modification application. Consequently, only minor administrative type changes to the wording of the consent are proposed. The underground linkage between CVC and MC was also previously approved and has been constructed. Whilst the development consent does not specify a maximum throughput for the linkage, a previous modification application specified a limit of 1.3 Mtpa consistent with the approved handling limit stipulated in MC's consent (MP 06_0311). It is proposed to align the throughput of the linkage with CVC's maximum extraction rate. This increase would not result in any changes to CVC's existing surface operations or approved level of impacts as the linkage is an existing component of the underground CVC workings. This would result in positive impacts from a reduction in trucks hauling coal from CVC to VPPS via private roads. Any impacts related to increased transport of coal via MC's conveyor system are subject to a separate application to modify MC's consent.

There will be no change to the existing CVC surface infrastructure, maximum road coal haulage or development consent period. The changes proposed would have no additional environmental impacts as there would be no change in surface infrastructure and, therefore, no additional surface disturbance or changes to noise and air emissions. Further, there is potential for environmental impacts to be improved beyond those existing impacts approved under SSD-5465, primarily as a result of the reduced level of subsidence and groundwater inflows associated with the more extensive use of a first workings mining system, and a reduction in coal transported via trucks through the increased use of the MC coal clearance system.

The proposed modification is, therefore, considered substantially the same as the approved development.

7.3 Objects of the EP&A Act

The relevant objects of the EP&A Act are presented below, followed by a discussion on their application with regard to the proposed modification.

(a) to promote the social and economic welfare of the community and a better environment by the proper management, development and conservation of the State's natural and other resources,

The reduction in capital and operating costs associated with utilisation of the MC coal clearance system for coal extracted at CVC, together with the maximisation of resource recovery through the use of a mining system that will enable mining in areas where geotechnical constraints previously limited the viable recovery of coal using the approved miniwall methods, will result in greater financial certainty for CVC and MC. This, in turn, will provide increased job security for Delta Coal employees and associated ongoing social and economic benefits. In addition, the proposed modification would result in greater security of coal supply to VPPS which is important in meeting power supply demand in NSW. By obtaining coal from local sources, impacts related to coal deliveries to VPPS from more distant locations would also be decreased.

The minimal/negligible potential environmental impacts associated with the proposed modification will be managed in accordance with CVC's existing environmental management processes.

(b) to facilitate ecologically sustainable development by integrating relevant economic, environmental and social considerations in decision-making about environmental planning and assessment,

The principles of Ecologically Sustainable Development (ESD) are outlined in Section 6 of the NSW *Protection of the Environment Administration Act 1991* and Schedule 2 of the EP&A Regulation. The consistency of the proposed modification with each of these principles is discussed below.

i) Precautionary principle:

The precautionary principle states that, if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

Assessments of subsidence and groundwater were completed in accordance with current government policies and guidelines by leading technical specialists. The subsidence effects of bord and pillar mining methods are well understood within the Lake Macquarie region and wider NSW. A high level of confidence in the capability of the system can be derived from this knowledge base. On this basis, the proposed modification is consistent with the precautionary principle.

Any secondary extraction to be undertaken in Zone B will continue to be subject to the requirement for an Extraction Plan being approved, which will require consideration of threats of serious or irreversible environmental damage.

ii) Inter-generational equity:

The principle of inter-generational equity puts an onus on society to ensure that the health, diversity and productivity of the environment are maintained, or enhanced, for the benefit of current and future generations. The approved impacts on the health, diversity or productivity of the environment will remain unchanged as a result of the proposed modification and, therefore, will not adversely impact the current or future generations.

iii) Conservation of biological diversity and maintenance of ecological integrity:

The approved impacts on biodiversity and ecological integrity will remain unchanged as a result of the proposed modification.

iv) Improved valuation and pricing of environmental resources:

No potential adverse environmental impacts from the proposed modification are expected. It is anticipated that enabling the transportation of additional coal from CVC to VPPS via MC surface facilities and overland conveyor will provide for an improved amenity outcome when compared with the truck haulage alternative.

Continued operation of CVC in accordance with SSD-5465 will ensure that environmental resources are valued both during and post mining.

(c) to promote the orderly and economic use and development of land,

The proposed modification is a minor alteration to an approved and operating coal mine which represents an orderly and economic use of a resource approved for extraction for use in domestic power generation. The proposed modification will not impinge on land uses within and surrounding CVC.

(d) to promote the delivery and maintenance of affordable housing,

The proposed modification relates to a coal mining operation and, therefore, this object is not relevant.

(e) to protect the environment, including the conservation of threatened and other species of native animals and plants, ecological communities and their habitats,

The proposed modification would not involve any additional disturbance of native vegetation that would impact the conservation of threatened and other species or ecological communities. The proposed modification would utilise existing infrastructure and, therefore, no indirect impacts to ecological communities through light spill or noise and vibration are expected to occur. The current mining parameters and performance measures for seagrass beds would be maintained under the proposed modification.

(f) to promote the sustainable management of built and cultural heritage (including Aboriginal cultural heritage),

The proposed modification would not involve the disturbance of identified heritage items or any additional disturbance of previously undisturbed land that could contain unidentified cultural heritage.

(g) to promote good design and amenity of the built environment,

The proposed modification does not involve the construction of any new built elements. Approved built elements will remain unchanged under the proposed modification.

(h) to promote the proper construction and maintenance of buildings, including the protection of the health and safety of their occupants,

The approved construction and maintenance requirements for existing buildings will remain unchanged under the proposed modification.

(i) to promote the sharing of the responsibility for environmental planning and assessment between the different levels of government in the State, and

The preparation of this SEE has involved engagement with relevant State and local government bodies as described in Chapter 4.

(j) to provide increased opportunity for community participation in environmental planning and assessment.

The community has been consulted during the preparation of the SEE through existing engagement tools and provision of briefing information and will continue to be involved and consulted through CVC's CCC and other mechanisms. The community will also have the chance to comment on the application during the public exhibition process.

7.4 Suitability of the site

The site is an existing underground coal mine with established infrastructure and workforce. The proposed modification would not require variation to any operational aspects of the mine and, therefore, is considered to be suitable for the site.

7.5 Conclusion

The proposed modification is a minor alteration to the approved development and is considered to be in the public interest as it:

- provides operational flexibility and increased resource recovery potential;
- will lower capital and operating costs across Delta Coal's operations, as the existing infrastructure at MC has the proven ability to supply coal to VPPS at a higher and more efficient rate than directly from CVC due to more advanced coal clearance infrastructure;

- improves the overall financial viability of CVC, promoting the continuation of CVC's social and economic benefits;
- supports the continued supply of coal to VPPS for local power generation;
- the benefits can be achieved with no increase in adverse environmental impacts over and above those already approved at CVC via development consent SSD-5465;
- is aligned with the principles of ESD; and
- meets all relevant government policies.

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Appendix A

Design criteria for negligible surface effects

DELTA COAL
CHAIN VALLEY COLLIERY

Proposed Herringbone Layout - Design Criteria for Negligible Surface Effects

APRIL 2019

Report No: CHV-008-Rev0

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First Floor, Building B, Edgeworth Town Square
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REPORT TO : Dave McLean
General Manager
Chain Valley Colliery

REPORT ON : Proposed Herringbone Layout - Design Criteria for Negligible Surface Effects

REPORT NO : CHV-008-Rev0

REFERENCE : PO 604735/1

Rev	Date	Prepared	Status	Signature
A	01/03/2019	D. Hill	Draft	
B	03/03/2019	D. Hill	Second draft	
C	28/03/2019	D. Hill	Third draft	
0	15/04/2019	D. Hill	Final	[signature]

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1.0 INTRODUCTION

This report addresses the design of a "herringbone" pillar layout for future Fassifern Seam workings at Chain Valley Colliery ("CVC") that is considered long-term stable and results in negligible subsidence effects (defined for this purpose as vertical subsidence of ≤ 20mm). The layout is shown schematically in **Figure 1**. The system initially involves the drivage of a mains panel up to five headings wide. Either side of this mains, individual panels are developed by driving a "sub-mains" three-headings wide. From the sub-mains, "run-out" roadways are driven, typically 80m long (mainly limited by wheeling distances). Finally, stubs or "free cuts" are driven from these run-out roadways to form the final pillars; depending on the ground conditions and serviceability requirements of these free cuts, they may or may not remain unsupported (for example, some are bolted to facilitate long-term return airway ventilation).

The most significant geotechnical design constraints for this system at CVC are as follows:

i) Depth of cover ranges from approximately 120m to 250m, although the range could extend in future mining areas (both shallower and deeper). This significant depth range creates a challenge, in that it would generally be considered ideal to maintain one pillar geometry, thereby facilitating a simple, repetitive mining process.

ii) The system entails the development of large areas of permanent, first workings pillars. It follows that the pillars should be designed in a manner that is considered to preclude the potential for any form of sudden or rapid deterioration (primarily from an underground safety perspective). In this regard, pillar w/h ratios of >4 are considered likely to result in a "strain hardening" pillar deformation characteristic and, at worst, a gradual "squeezing" or "creep" mode of deterioration, in the event of any overloading.

iii) Stable unsupported stubs are critical to the performance of the system. This issue was addressed in previous **Strata2 Report No. CHV-005** and a typical stub width of 5.5m is assumed herein.

iv) The interval between stubs is partly a function of the required pillar size, but also dictated by the need to separate the adjacent alternating stubs for roof control purposes, thereby forming isolated three-way intersections. Practically, allowing for break-offs, this dictates a stub (solid) interval of around 20m.

It should be apparent from the preceding points that design of a herringbone panel geometry requires some compromise and also a focus on maintaining flexibility wherever possible. In this regard, the design process summarised herein has sought to learn from the relevant experiences of other mines, most notably the herringbone operation at the adjacent Myuna Colliery, where the system has been employed successfully for a number of years.

2.0 GEOLOGICAL / GEOTECHNICAL ENVIRONMENT

The geological and geotechnical environment in the Fassifern Seam has been described in detail in **LDO Report CHV-016: Chain Valley Bay – Geotechnical Review (2017)**. Familiarity with that report is assumed herein.

From a pillar design perspective, a key issue is the presence of weak claystone layers within the first 2m of the working floor. The cumulative thickness of claystone bands with a UCS of approximately 5 MPa is around 1m over the previous MWs 7 to 12 and in the Northern Mining Domain (**DGS, 2018**). For the purpose of this and previous studies, "weak floor" has been defined simply as a total thickness of ≥ 1m of rock with a UCS of ≤ 5MPa, within 2m of the immediate floor. Although the floor strength is therefore regarded as only “marginally weak”, a conservative approach is warranted, given that the interpretation of “weak claystone” thickness in the Northern Mining Domain is based very largely on the interpretation of widely spaced lithological logs, without supporting geomechanical or geophysical data. The pillar design methodology therefore recognises and addresses this aspect.

3.0 PILLAR DESIGN METHODOLOGY

The pillar design methodology adopted herein builds on the methodology summarised in **Hill (2010)** and the Stability Index “SI” approach put forward for Lake Macquarie Coalfield soft (predominantly claystone) floor environments by **SCT (1993)**. The SI methodology was most recently applied in the Chain Valley Bay area of CVC **(SCT, 2018)**. For convenience, **Hill (2010)** is attached as **Appendix A** and the relevant extract from **SCT (2018)** is attached as **Appendix B**.

The key finding of **Hill (2010)** is as follows:

> *“For Australian conditions, an ARMPS Stability Factor of ≥ 1.5, coupled to a w/h ratio of ≥ 5, would effectively obviate the potential for long-term failure (i.e. collapse due to the failure of any element, roof, floor or the pillar, in the overall structural system).”*

The ARMPS Stability Factor is calculated using **Bieniawski’s (1967)** pillar strength equation, namely:

$$\sigma_{PS} = k(0.64+0.36w/h)$$

where:

σ_{PS} = pillar strength (MPa)
k = unit coal strength (MPa)
and w/h is the pillar width to height ratio.

In Australia, a k value of 6.2MPa is commonly applied **(Colwell, 1998)**.

SCT (1993) arbitrarily increased the k value to 8MPa, to distinguish their Stability Index (SI) from **Bieniawski’s** Stability Factor (SF).

Therefore: SF = 6.2 x SI / 8

The critical Stability Factor of 1.5 suggested in **Hill (2010)** equates to a Stability Index of 1.9. SCT use the approach to define Stability Indices that equate to different subsidence outcomes (see **Table 1** of **Appendix B**). Long-term stability, subsidence and surface impacts are all important considerations in this environment. Even if the pillar system is regarded as long-term stable, the magnitude of subsidence may be unacceptable in a given circumstance (e.g. foreshore areas).

Therefore, the **Hill (2010)** pillar design conclusion has been calibrated against the Lake Macquarie “weak floor” data, focusing on the subsidence outcomes. The case studies encompass the Great Northern, Wallarah and Fassifern Seams, encompassing four decades of local experience. The total number of Lake Macquarie case histories is 62, including 15 of the original SCT case histories (the remaining 25 could not be verified and / or acceptably reproduced). In general, those cases involving complex geometries and significant uncertainty with regard to the caving environment were discarded.

Figure 2 reproduces the failed pillar database, plus the Lake Macquarie weak floor data. The following comments are made regarding **Figure 2**:

i) The Lake Macquarie weak floor cases have initially been divided into stable and failed on the basis of the subsidence outcomes. The 39 cases associated with ≤ 200mm of subsidence have been classed as stable (i.e. strata deformation largely due to elastic system compression), whereas the 23 cases that resulted in >200mm of subsidence have been classed as failed (i.e. higher deformation, more typical of an overloaded system).

ii) The Lake Macquarie failed cases have Stability Factors ranging from 0.91 to 2.23.

iii) The Lake Macquarie stable cases have Stability Factors ranging from 1.34 to 21.60.

iv) The overlap between the failed and the stable cases is largely a function of the natural variability in the geotechnical properties of the strata (i.e. some of the failures are associated with particularly weak rock, whilst some of the stable cases are associated with relatively stronger strata).

v) The case with the highest Stability Factor of 2.23 involved 220mm of subsidence (i.e. marginal in terms of the 200mm failed / stable criterion). The associated data point is from Chain Valley MG4 (Fassifern Seam) and is highlighted on the graph.

vi) **Figure 2** suggests that a revised design criterion for long-term pillar stability in weak floor conditions could be defined by a higher Stability Factor of ≥ 2.3.

vii) The database is dominated by the Great Northern Seam (37 case histories), followed by 16 Fassifern Seam and 9 Wallarah Seam case studies. **Figure 3** presents the Lake Macquarie database on a seam-specific basis. Accepting the limited size of the sub-sets for the Fassifern and Wallarah Seam, there is no obvious evidence of a difference in behaviour of any of the three seams (i.e. one seam does not appear to be either stronger or weaker than the others).

viii) **Figure 4** reproduces **Figure 3**, with the exclusion of the CVC Fassifern Seam miniwall panels, which involved relatively large (30m to 40m wide) and highly stressed pillars (typical final average stresses of 14 to 18MPa). The "limiting" value for failure equates to a Stability Factor of 2.15.

Figure 5 presents all the Lake Macquarie data in histogram form. Subsidence is negligible (≤ 20mm) at a Stability Factor of ≥ 2.3.

Therefore, a Stability Factor of ≥ 2.3 is recommended for the herringbone pillar layout in situations requiring negligible (≤ 20mm) subsidence.

3.1 UNSW Pillar Methodology

Apart from Bieniawski's Stability Factor, the other empirical coal pillar design formulae widely used in Australia are those developed at the UNSW (**Salamon *et al*, 1996**). When applying the "UNSW Formulae", it is common in Australia to use the term "Factor of Safety" (FoS), to differentiate the approach and outcomes from those related to the use of Bieniawski's coal pillar strength formula. However, Factor of Safety is analogous to Stability Factor (i.e. FoS = pillar strength / pillar stress).

The UNSW formulae are founded on extensively researched and broadly-based databases of mining experience. These formulae represent the culmination to-date of work commenced some 40 years ago in South Africa after the 1960 Coalbrook disaster (**Salamon and Munro, 1967**). A combined Australian and South African database has been applied to the derivation of formulae that are considered widely applicable.

The range of parameters within the UNSW combined failed and intact pillar database can be summarised as follows:

- Depth: 20m to 510m
- Mining Height: 1.0m to 9.2m
- Smallest Pillar Dimension: 2m to 32m
- Bord Width: 3.7m to 15.0m
- Percentage Extraction: 30% to 90%
- Width to Height (w/h) Ratio: 0.9 to 11.2
- Time to Failure: 0 to >80 years

The strength formula for Australian coal pillars with w/h ratios of >5 is as follows:

Strength, $\sigma_s = 27.63^{0.51}(0.29*((w_m/5h)^{2.5} - 1) + 1)/(w^{0.22} \times h^{0.11})$

where:

w_m = minimum pillar width (m)
h = roadway height (m)
Θ = a dimensionless 'aspect ratio' factor for rectangular pillars defined by **Salamon *et al,* 1996**.

For pillars with w/h ratios of ≤ 5, the strength formula is as follows:

$\sigma_s = 8.6(w_m\Theta)^{0.51}/h^{0.84}$

FoS can be related to the nominal probability of failure of a panel of pillars. A probability of stability of 99.9% is attained at a Factor of Safety of 1.63, see **Figure 6**, and further increases in FoS have little effect, as the probability of stability curve approaches 100% asymptotically. From a risk management perspective, increasing the FoS beyond 1.63 can only reduce the failure probability by <0.1%.

The consequences of collapse are a key consideration, as these determine the acceptable probability of failure, which in turn allows an appropriate FoS to be determined. For example, prudent risk management suggests that the probability of failure for long-term first workings panels beneath sensitive surface structures should be negligible. In Australia, long-life critical pillars (e.g. in main headings and for the protection of surface infrastructure) are often designed to an FoS of ≥ 2.11, which equates to a nominal failure probability of one panel in a million. This reduces the probability of failure to a level that would be considered acceptable in other key fields of public interest.

It should be understood that the nominal probability of failure is related to the life-time of the pillar database that underpins the design methodology; currently this averages approximately fifty years (i.e. of the order of 100 years of coal pillar history is available). The annualised probability of failure (a concept more commonly applied in engineering practice) is therefore about one-fiftieth of the nominal failure probability.

The South African and Australian databases from which the UNSW formulae were derived cover a broad range of roof and floor materials, including mudrocks, coal, siltstones and sandstones. Therefore, these materials and the variability in strength that may be associated with them are implicitly recognised and largely catered for in the FoS approach. Uncertainty associated with the natural variability in coal measures strata often prohibits design to low FoS values. Geological variability partly accounts for the scatter in the population of failed pillar cases and usually necessitates design to FoS values of >1.5, equivalent to low failure probabilities. Back analysis indicates that incidences of pillar instability traditionally associated with weak floor, for example, can very often be explained in terms of 'conventional' empirical design criteria.

Similarly, the database encompasses pillars in a significant number of seams in different geotechnical environments; consequently, the existence of pillar weaknesses is very largely reflected and implicit within the variability in the failed and intact pillar cases, such that these weaknesses are again very largely catered for by adopting appropriate FoS values.

Figure 7a/b reproduces the Lake Macquarie database outcomes from **Figures 3** and **4**, but according to the FoS values. The overall picture is very similar; there is no evidence of one seam performing better of worse than another and, if the highly stressed CVC chain pillars are excluded, the highest FoS of a "failed" case is 2.08.

The database is reproduced in histogram form in **Figure 8** and the following comments are made regarding the outcomes:

i) Almost all the failures (>200mm of subsidence) are associated with Factors of Safety of <2.11 (i.e. 22 out of 23 failed cases, or 96%).

ii) A rapid transition occurs at Factors of 2.11 to 2.7. The average subsidence magnitude is 93mm, with a maximum of 220mm. Such magnitudes of subsidence would generally be associated with minimal surface impacts.

iii) However, if the CVC chain pillars are excluded, subsidence is negligible (≤ 20mm) at FoS values of >2.3.

Therefore, the following criteria are recommended for the herringbone pillar layout in situations requiring negligible (≤ 20mm) subsidence:

- **average final pillar stresses of <12MPa,**
- **Factors of Safety of ≥ 2.3.**

3.2 Pillar Design Outcomes

3.2.1 Depth Sensitivity

The design outcomes are summarised in **Table 1**.

Table 1: Herringbone Pillar Design for <20mm of Subsidence

Roadway Width (m)	Depth (m)	Pillar							Stub		Bieniawski Stability Factor	Pillar FoS (Salamon)
		Height (m)	Width (m)	Length (m)	w/h Ratio	Stress	Strength		Interval (m)	Length (m)		
							Bieniawski	Salamon				
5.5	100	4.2	16.8	24.5	4.0	4.1	12.9	11.2	19.4	14.1	3.2	2.8
5.5	110	4.2	16.8	24.5	4.0	4.5	12.9	11.2	19.4	14.1	2.9	2.5
5.5	120	4.2	16.9	24.5	4.0	4.9	13.0	11.2	19.5	14.1	2.7	2.3
5.5	130	4.0	17.6	24.5	4.4	5.2	13.8	12.0	20.3	14.1	2.6	2.3
5.5	140	3.8	18.2	24.5	4.8	5.6	14.7	12.8	21.0	14.1	2.6	2.3
5.5	150	3.7	19.6	24.5	5.3	5.9	15.8	13.5	22.6	14.1	2.7	2.3
5.5	160	3.7	21.4	24.5	5.8	6.2	16.9	14.2	24.7	14.1	2.7	2.3
5.5	170	3.7	23.2	24.5	6.3	6.4	18.0	14.8	26.8	14.1	2.8	2.3
5.5	180	3.6	23.9	24.5	6.6	6.8	18.8	15.6	27.6	14.1	2.8	2.3
5.2	190	3.6	24.8	24.8	6.9	7.0	19.3	16.1	28.6	14.3	2.8	2.3
5.2	200	3.4	24.0	24.8	7.1	7.4	19.7	16.9	27.7	14.3	2.7	2.3
5.2	210	3.3	24.2	24.8	7.3	7.7	20.3	17.7	27.9	14.3	2.6	2.3
5.2	220	3.2	24.3	24.8	7.6	8.1	20.9	18.6	28.1	14.3	2.6	2.3
5.5	150	3.5	18.2	24.5	5.2	6.0	15.6	13.8	21.0	14.1	2.6	2.3
5.5	160	3.3	18.2	24.5	5.5	6.4	16.3	14.7	21.0	14.1	2.5	2.3
5.5	170	3.1	18.2	24.5	5.9	6.8	17.1	15.8	21.0	14.1	2.5	2.3
5.5	180	3.0	18.2	24.5	6.1	7.2	17.5	16.4	21.0	14.1	2.4	2.3
5.5	190	2.8	18.2	24.5	6.5	7.6	18.5	17.7	21.0	14.1	2.4	2.3
5.5	200	2.7	18.2	24.5	6.7	8.0	19.0	18.6	21.0	14.1	2.4	2.3
5.5	120	3.1	12.5	24,5	4.0	5.3	13.0	12.7	Mains - rectangular pillars		2.5	2.4
5.5	120	3.6	14.3	24.5	4.0	5.1	12.8	11.8	Mains - rectangular pillars		2.5	2.3
5.5	150	3.1	15.4	24.5	5.0	6.2	15.1	14.4	Mains - rectangular pillars		2.4	2.3
5.5	150	3.6	18.8	24.5	5.2	5.9	15.6	13.6	Mains - rectangular pillars		2.6	2.3
5.5	180	3.1	19.2	24.5	6.2	7.1	17.8	16.3	Mains - rectangular pillars		2.5	2.3
5.5	180	3.6	24.5	24.5	6.8	6.8	19.2	15.9	Mains - square pillars		2.8	2.4
5.5	200	3.1	21.5	24.5	6.9	7.7	19.5	17.5	Mains - rectangular pillars		2.5	2.3
5.5	200	3.4	24.5	24.5	7.2	7.5	20.1	17.1	Mains - square pillars		2.7	2.3
5.2	190	3.6	24.8	24.8	6.9	7.0	19.3	16.1	Mains - square pillars		2.8	2.3
5.2	200	3.4	24.8	24.8	7.3	7.3	20.3	17.3	Mains - square pillars		2.8	2.4
5.2	210	3.3	24.8	24.8	7.5	7.7	20.7	18.1	Mains - square pillars		2.7	2.4
5.2	220	3.2	24.8	24.8	7.8	8.1	21.3	18.9	Mains - square pillars		2.6	2.4

The following comments are made regarding these results:

i) A uniform roadway and stub width of 5.5m is generally assumed, although the effect of reducing the roadway width to 5.2m at depths of ≥ 190m is also highlighted. In practice, it is likely that reduced stub widths of ≤ 5.2m would promote improved stub roof stability during cutting at depths of >170m and stub widths of ≤ 5m are likely to be necessary at depths of >200m.

ii) The table is structured in a manner that illustrates the effect on pillar width of attempting to maximise mining height, as well as the effect on mining height of attempting to maintain a constant stub interval of 21m.

iii) It would be possible to increase the current design drivage height of 3.2m.

iv) The maximum overall height of 4.2m is achievable at depths of <120m. At these shallow depths, the pillar geometry becomes constrained by the minimum suggest stub interval of around 20m.

v) A maximum (solid) pillar length of 24.5m is generally stipulated, consistent with the Myuna practice. The solid pillar width increases to 24.8m at a 5.2m roadway width. This facilitates a consistent design stub length of 14.1-14.3m, again as per Myuna.

vi) The stub interval is the solid dimension between stubs, whereas pillar width is the minimum solid (plan) dimension (i.e. the perpendicular distance between adjacent stubs, allowing for the 60° stub angle).

vii) At a depth of 120m, the stub interval is 19.5m, slightly lower than Myuna (20.6m).

viii) Pillar stresses are low (<7MPa), consistent with the design criteria.

ix) Bieniawski Stability Factors range from 2.6 to 3.2, consistent with the design criteria.

x) UNSW Factors of Safety range from 2.3 to 2.8, again consistent with the design criteria.

3.2.2 Comparison with Previous Design Approaches from Adjacent Mines

In designing the "Zone A" pillars for a maximum of 20mm of subsidence at Myuna Colliery to the north, **Seedsman (2010)** stipulated a minimum pillar Factor of Safety of 2.11, equivalent to a nominal probability of failure of one panel in a million, according to the power law formulae of **Salamon *et al* (1996)**. As noted in **Section 3.2.1** above, the proposed CVC FoS values range upwards from 2.3. The approach recommended herein is therefore more conservative than the Myuna approach.

In designing pillars for a maximum of 20mm of subsidence to the south at Mannering Colliery, **Seedsman (2011)** assessed the performance of panels based on the standard Mannering layout, which involves:

- first workings only on 30m centres,
- a nominal roadway width of 5.5m,
- a height of 2.9m and
- depths of around 180m to 190m.

Seedsman (2011) concluded that in a single seam only situation, such a layout would continue to result in around 8-15mm of surface subsidence in the long-term. This conclusion relates to pillars with Stability Factors of around 3.2 and Factors of Safety of around 3.0, which is higher than the minimum values adopted herein. However, the database indicates that the proposed criteria would maintain the design requirement of slightly greater (≤ 20mm) of subsidence.

It is concluded that the design criteria adopted herein are rational and consistent with ≤ 20mm of subsidence in the long-term.

3.2.3 "Dog-Kennel" Pillar Design

The smaller "dog-kennel" pillars at the start of each successive run-out should be designed according to **Table 2**, where the stub interval is the solid dimension defined in **Figure 9** for an example. This will ensure that the design criteria are met across the potential depth and mining height range. Note that the solid stub intervals result in minimum plan dimensions that are consistent with the regulatory "10m or one-tenth of the depth, whichever is the greater" rule.

Table 2: Solid Stub Interval Dimensions for "Dog Kennel" Pillars

Depth (m)	Mining Height (m)			
	2.8	3.2	3.6	4.0
100	6.4	6.8	8.1	9.4
120	8.4	8.9	10.5	12.4
140	10.4	11.1	13.4	15.9
160	12.4	13.9	16.9	20.4
180	14.4	16.5	20.3	28.2
200	16.4	19.1	26.2	39.9
220	18.4	21.4	35.9	N/A

3.2.4 Benched Pillar Option

An option under consideration is the potential to adopt a benched profile during bottom coaling, an approach that can assist with rib control during mining. The concept is shown schematically in **Figure 10** and the design outcomes are summarised in **Table 3**.

Table 3: Benched Pillar Design for <20mm of Subsidence

Roadway Width (m)	Depth (m)	Pillar							Stub		Bieniawski Stability Factor	Pillar FoS (Salamon)	Bottom Coal (m)
		Height (m)	Width (m)	Length (m)	w/h Ratio	Stress	Strength		Interval (m)	Length (m)			
							Bieniawski	Salamon					
5.3	100	4.05	16.2	24.7	4.0	4.0	12.9	11.4	18.7	14.3	3.2	2.8	1.4
5.3	120	4.05	16.2	24.7	4.0	4.8	12.9	11.4	18.7	14.3	2.7	2.4	1.4
5.3	125	4.05	18.2	24.7	4.5	5.2	14.0	11.8	21.0	14.3	2.7	2.3	1.4
5.3	140	4.05	19.4	24.7	4.8	5.4	14.7	12.5	22.4	14.3	2.7	2.3	1.4
5.3	160	4.05	23.8	24.7	5.9	5.9	17.1	13.6	27.5	14.3	2.9	2.3	1.4
5.3	180	3.70	24.4	24.7	6.6	6.7	18.7	15.3	28.2	14.3	2.8	2.3	1.0
5.4	200	3.40	24.6	24.6	7.2	7.4	20.1	17.2	28.4	14.2	2.7	2.3	0.7
5.3	140	3.90	18.2	24.7	4.7	5.5	14.4	12.5	21.0	14.3	2.6	2.3	1.2
5.4	150	3.60	18.2	24.7	5.1	5.9	15.3	13.4	21.0	14.3	2.6	2.3	0.9
5.4	160	3.30	18.2	24.7	5.5	6.3	16.3	14.7	21.0	14.3	2.6	2.3	0.6
5.5	180	3.00	18.2	24.5	6.1	7.2	17.5	16.4	21.0	14.1	2.4	2.3	0.2
5.5	200	2.80	19.0	24.5	6.8	7.9	19.1	18.3	21.9	14.1	2.4	2.3	0.0
5.3	180	3.70	24.7	24.7	6.7	6.6	18.9	15.5	Mains - square pillars		2.8	2.3	1.0

The following comments are made regarding these results:

i) The design roadway width is the weighted average of the 5.5m and 4.9m wide sections.

ii) Similarly, the design height is the weighted average for the benched profile, assuming a constant 2.8m high first pass.

iii) At depths of up to 160m, the design height of 4.05m facilitates the extraction of up to 1.4m of bottoms, as per **Figure 10**. At a depth of 180m, the reduced design height of 3.7m entails a reduction in the thickness of bottom coal mined to 1.0m.

iv) At depths of >180m, the final design height of 3.2-3.6m does not appear to warrant the adoption of a benched profile.

v) The table also illustrates the effect on average height and the available bottom coal height of attempting to maintain a constant stub solid interval of 21m. This approach is considered practicable at depths of up to 160m.

vi) Average pillar stresses are below 8MPa, consistent with the design criteria.

vii) Bieniawski Stability Factor ranges from 2.7 to 3.2, consistent with the design criteria.

viii) UNSW Factors of Safety range from 2.3 to 2.8, consistent with the design criteria.

3.2.5 Alternative Main Headings Options

A further option under consideration is to reduce the main headings roadway width and height, with the main aim of increasing the drivage rate and overall mine productivity. Obviously, such reductions would also tend to enhance roadway stability. **Table 4** illustrates the design results for a main headings roadway width of 4.8m, at two potential design heights, 2.8m and 3.1m. An attempt has been made to maintain the pillar length constant, at 30m centres.

Table 4: Main Headings Pillar Design for a Roadway Width of 4.8m

Roadway Width (m)	Depth (m)	Pillar							Bieniawski Stability Factor	Pillar FoS (Salamon)
		Height (m)	Width (m)	Length (m)	w/h Ratio	Stress	Strength			
							Bieniawski	Salamon		
4.8	100	2.8	11.2	25.2	4.0	4.3	12.9	13.1	3.0	3.1
4.8	140	2.8	11.7	25.2	4.2	5.9	13.3	13.5	2.3	2.3
4.8	180	2.8	15.6	25.2	5.6	7.0	16.4	16.1	2.3	2.3
4.8	220	2.8	19.5	25.2	7.0	8.2	19.5	18.8	2.4	2.3
4.8	100	3.1	12.4	25.2	4.0	4.1	12.9	12.6	3.1	3.1
4.8	140	3.1	13.1	25.2	4.2	5.7	13.4	13.1	2.4	2.3
4.8	180	3.1	17.8	25.2	5.7	6.8	16.8	15.6	2.5	2.3
4.8	220	3.1	22.5	25.8	7.3	7.9	20.2	18.3	2.5	2.3

The following comments are made regarding these results:

i) Pillar width reduces significantly with depth.

ii) In places, the required pillar width falls below the "1/10 of depth rule" and it would probably be expedient to simply adopt the latter in those cases.

iii) Average pillar stresses are below 8MPa, consistent with the design criteria.

iv) Bieniawski Stability Factor ranges from 2.3 to 3.1, consistent with the design criteria.

v) UNSW Factors of Safety also range from 2.3 to 3.1, consistent with the design criteria.

4.0 CONCLUDING REMARKS

This report has addressed pillar design requirements to achieve ≤ 20mm of subsidence across the depth range relevant to the Northern Mining Domain. It should be noted that the design specifications are such that it should be possible to readily transition from the recommended geometry to an alternative design, in the areas that are not subject to the 20mm subsidence limit.

The proposed design criteria are considered conservative and there would be the potential for some optimisation, based on:

- additional subsidence monitoring data from areas of specific interest (e.g. foreshore areas) and
- a programme of floor coring, to better define the thickness and properties of the claystone within the first 3m of floor.

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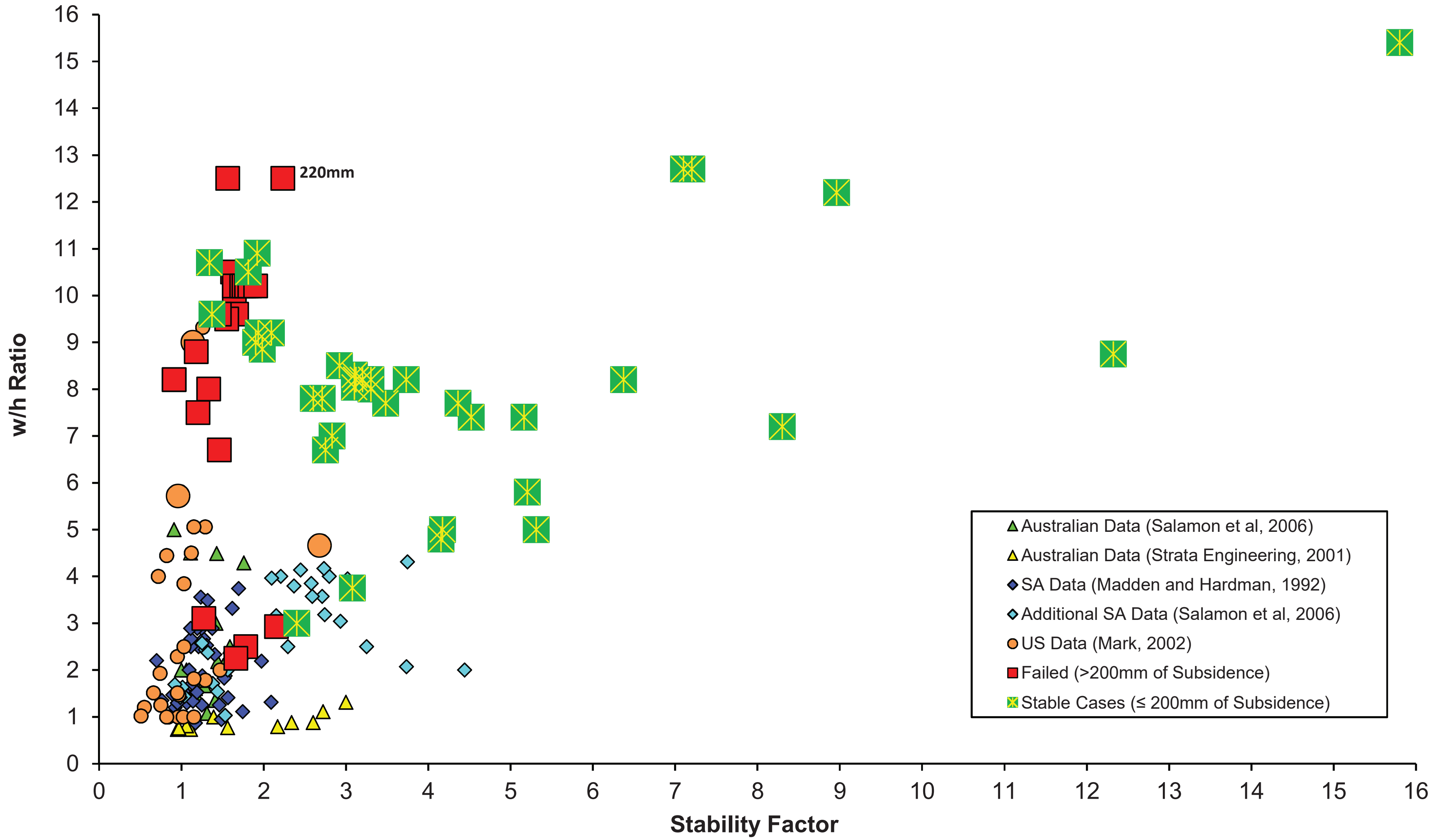
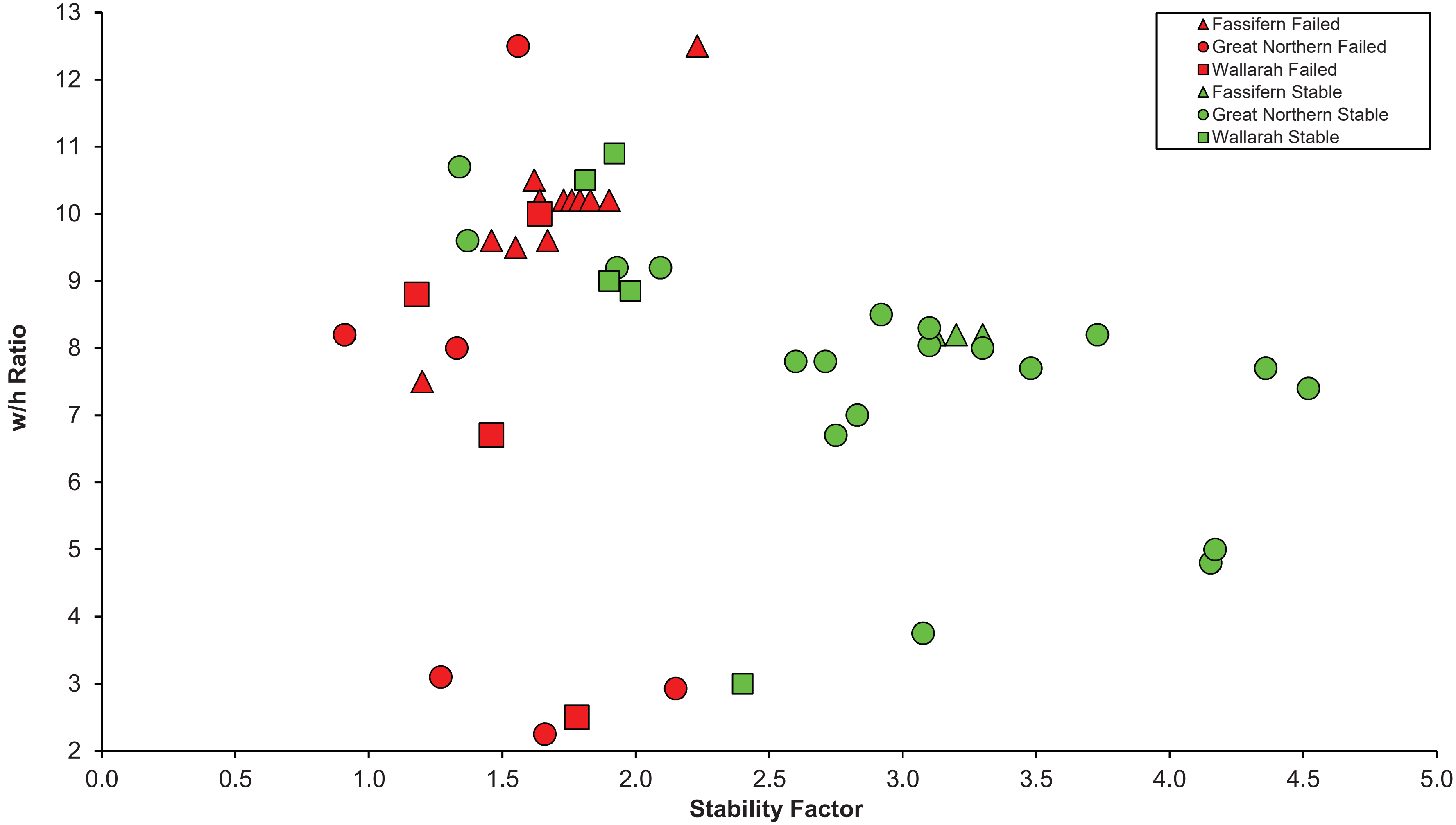
Engineer:	D. Hill	**Client:**	Chain Valley Colliery		
Drawn:	I. Saliamon	**Title:**	Schematic Showing Typical Herringbone Pillar Layout, as Applied at Myuna Colliery		
Date:	01.03.19				
STRATA²		**Ref:**	CHV-008	**Revision No:**	0
		Scale:	NTS	**Figure No:**	1



Engineer:	D. Hill	**Client:**	Chain Valley Colliery
Drawn:	D. Hill	**Title:**	Failed Coal Pillar Database - Bieniawki Stability Factor versus Pillar Width to Height Ratio; including Stable and Failed Weak Floor Cases from the Lake Macquarie Area
Date:	15.04.2019		

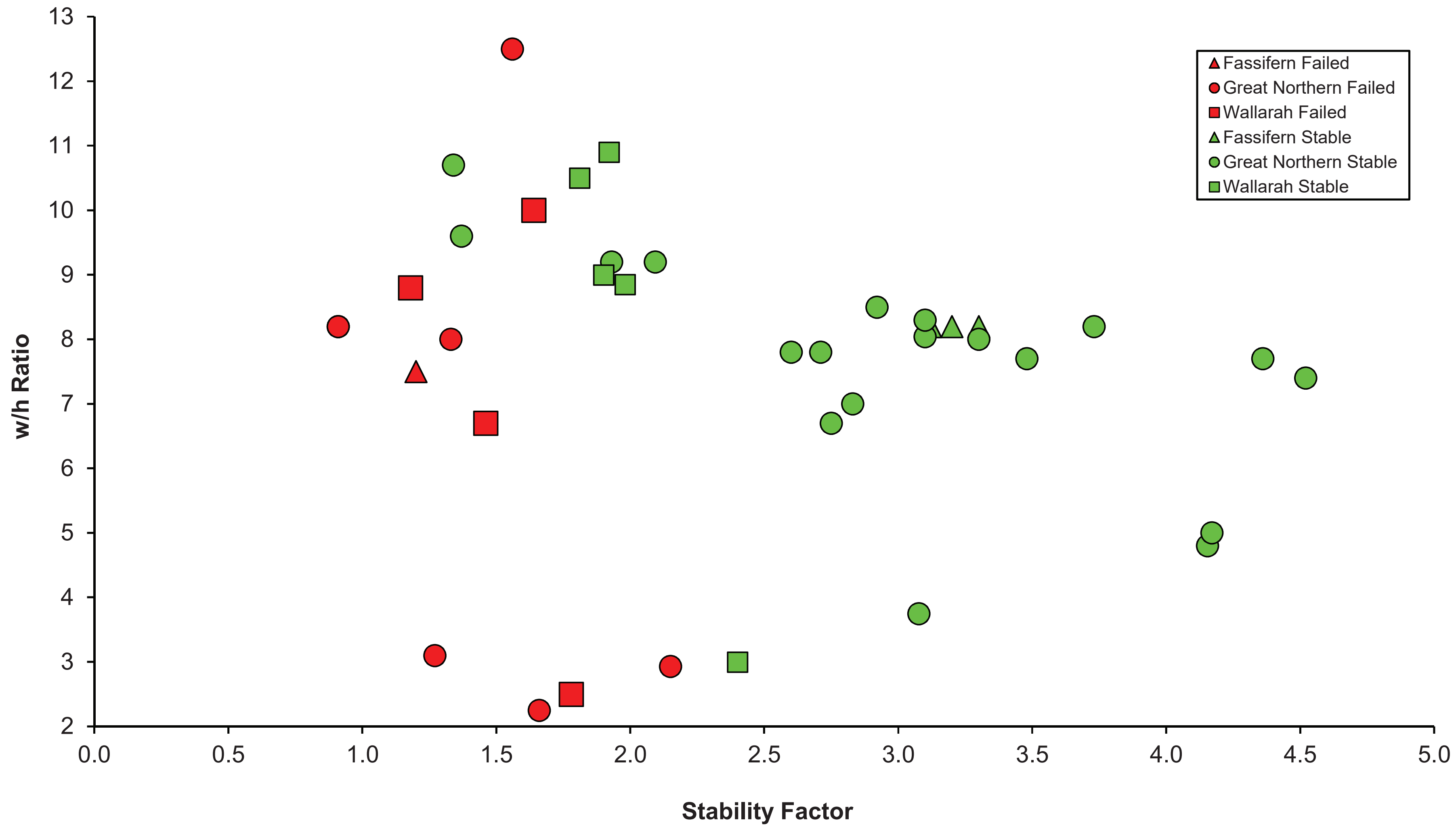
STRATA²

Ref:	CHV-008	**Revision No:**	0
Scale:	N/A	**Figure No:**	2



Note: Cases with Stability Factors >5 excluded (practically irrelevant)

Engineer:	D. Hill	**Client:**	Chain Valley Colliery
Drawn:	D. Hill	**Title:**	Stability Factor versus w/h Ratio: Stable and Failed Weak Floor Cases from the Lake Macquarie Area on a Seam-Specific Basis
Date:	27.03.2019		
STRATA²		**Ref:**	CHV-008
		Revision No:	0
		Scale:	N/A
		Figure No:	3

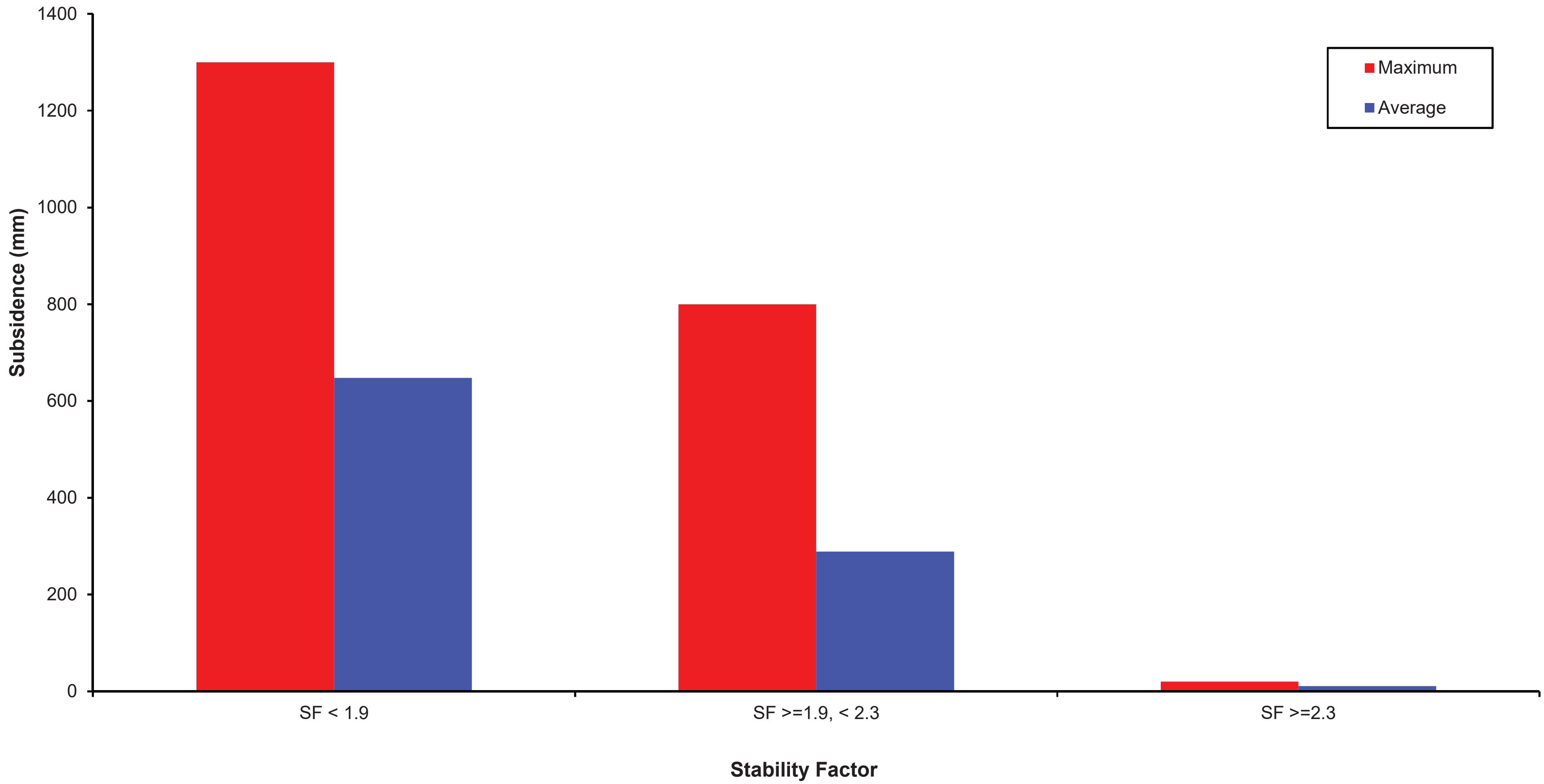


Note: Cases with Stability Factors >5 excluded (practically irrelevant)

Engineer:	D. Hill
Drawn:	D. Hill
Date:	15.04.2019

STRATA[2]

Client:	Chain Valley Colliery		
Title:	Stability Factor versus w/h Ratio: Stable and Failed Weak Floor Cases from the Lake Macquarie Area on a Seam-Specific Basis, excluding the CVC Miniwalls		
Ref:	CHV-008	**Revision No:**	0
Scale:	N/A	**Figure No:**	4



Engineer:	D. Hill	**Client:**	Chain Valley Colliery		
Drawn:	D. Hill	**Title:**	Lake Macquarie Case Histories - Subsidence versus Bieniawski Stability Factor		
Date:	15.04.2019				
STRATA²		**Ref:**	CHV-008	**Revision No:**	0
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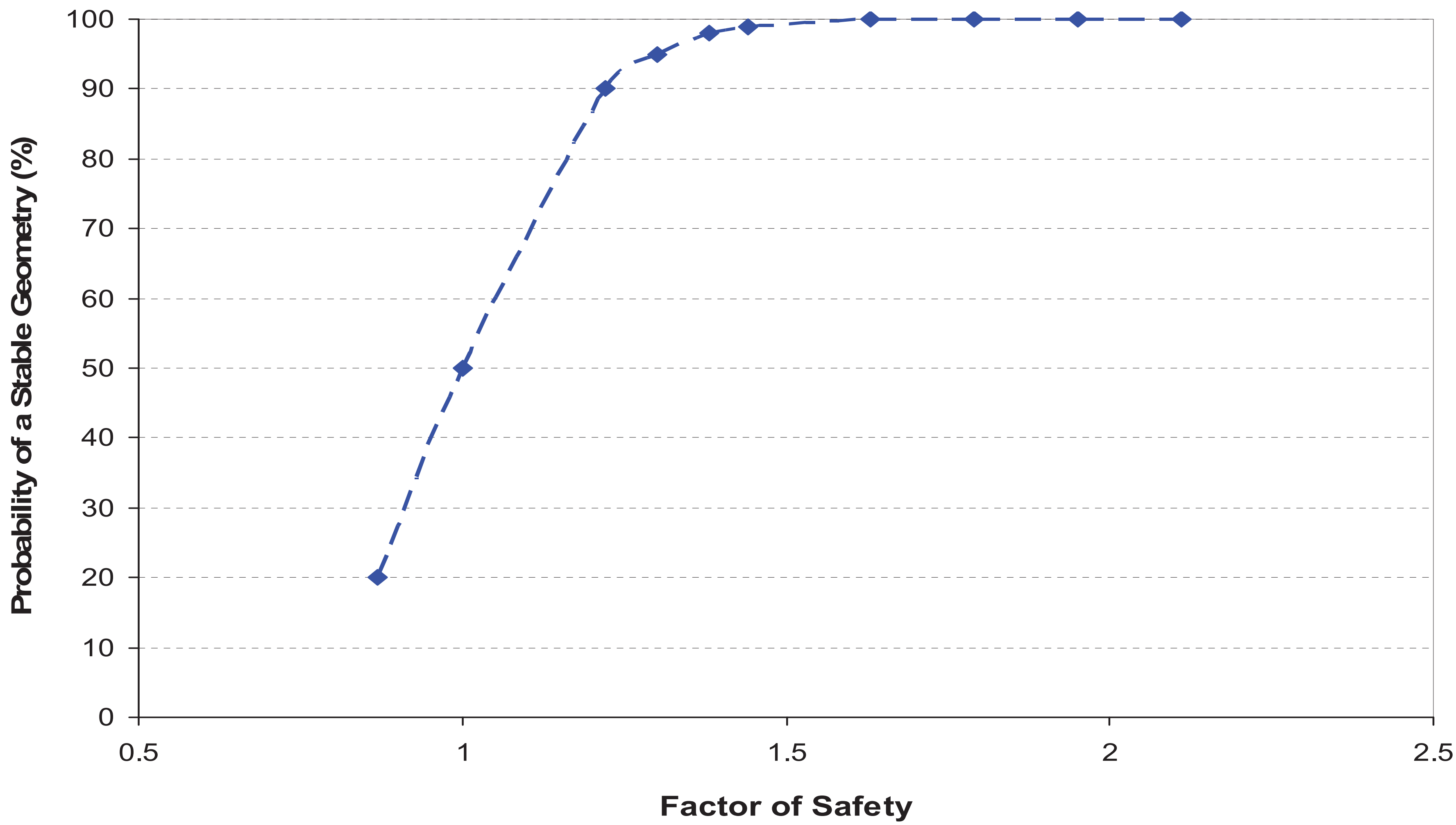


Engineer:	D. Hill	**Client:**	Chain Valley Colliery
Drawn:	D. Hill	**Title:**	Salamon Factor of Safety versus Probability of Stability
Date:	27.03.2019		
STRATA²		**Ref:**	CHV-008
		Scale:	N/A

Revision No:	0
Figure No:	6

Figure 7a: Lake Macquarie Failed and Stable Cases Database - Factor of Safety versus Pillar w/h Ratio

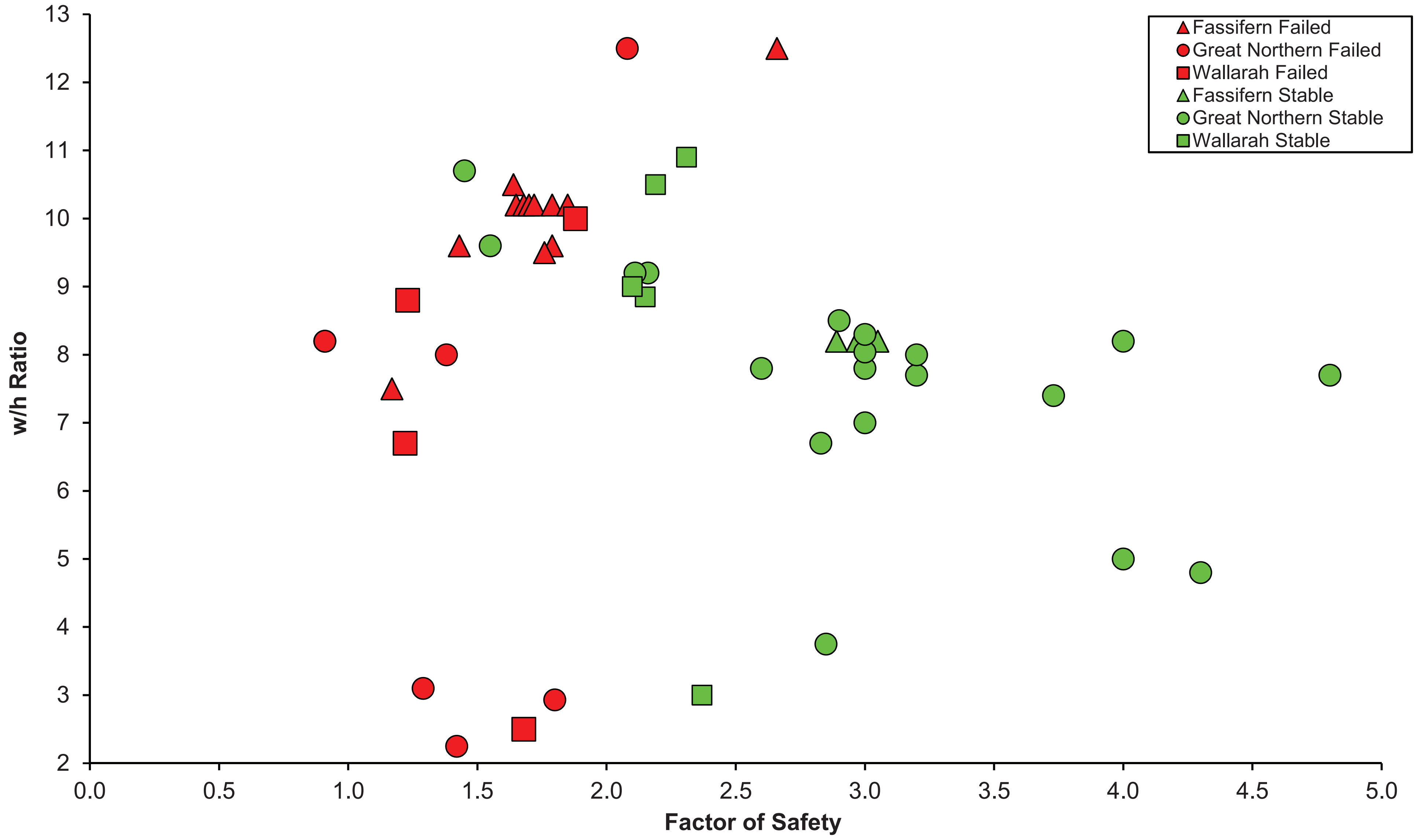
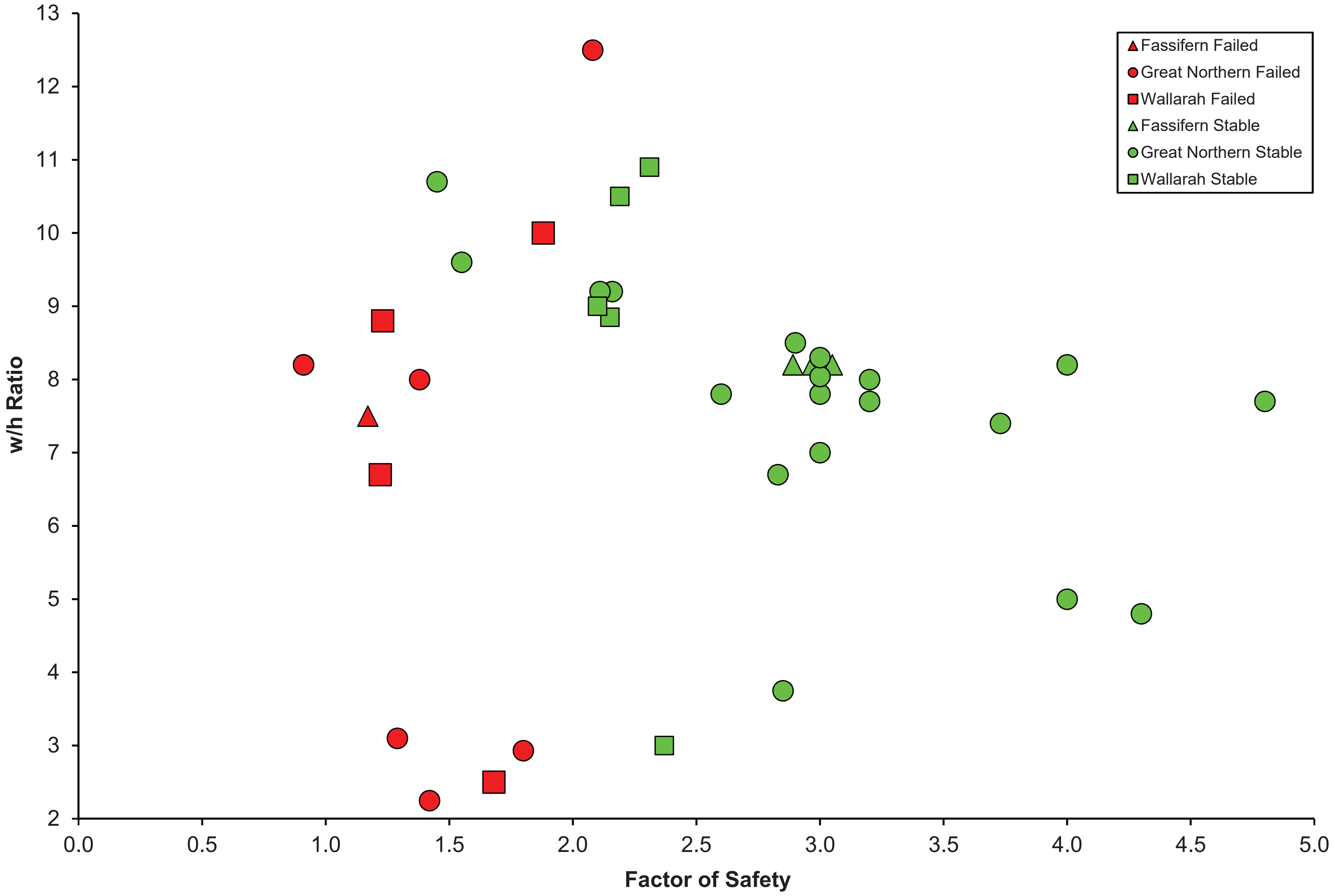
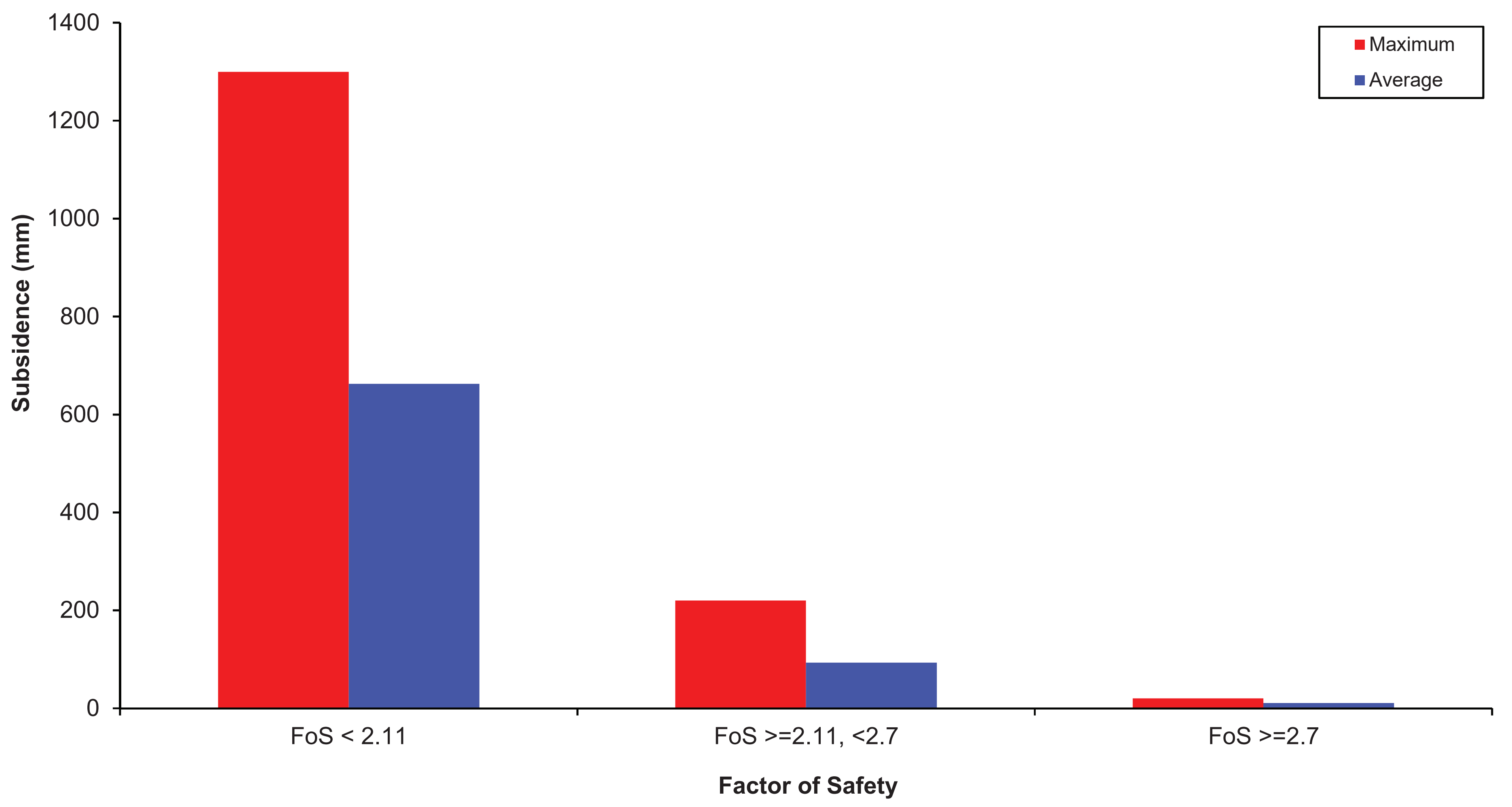


Figure 7b: Lake Macquarie Failed and Stable Cases Database - Factor of Safety versus Pillar w/h Ratio; CVC Miniwalls Excluded



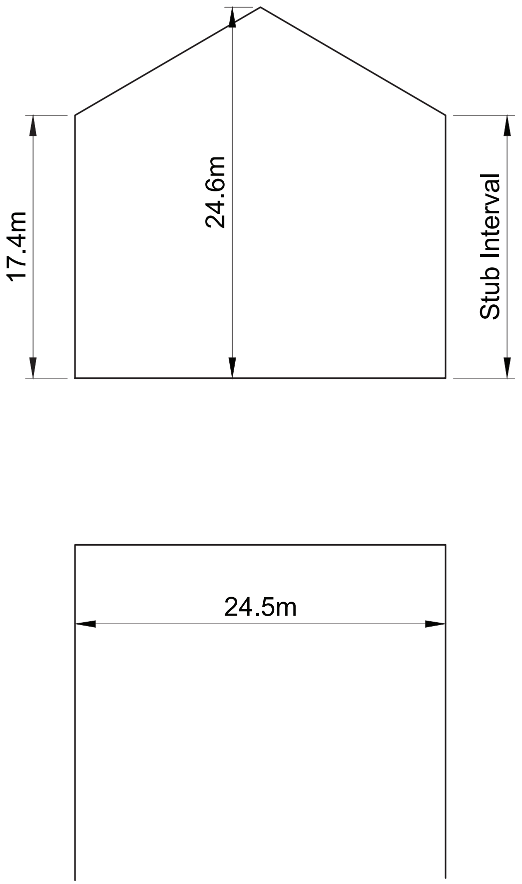
Engineer:	D. Hill	**Client:**	Chain Valley Colliery		
Drawn:	D. Hill	**Title:**	Lake Macquarie Database reproduced using Salamon Factor of Safety		
Date:	15.04.2019				
STRATA²		**Ref:**	CHV-008	**Revision No:**	0
		Scale:	N/A	**Figure No:**	7a/b



Engineer:	D. Hill	**Client:**	Chain Valley Colliery
Drawn:	D. Hill	**Title:**	Lake Macquarie Case Histories - Subsidence versus Salamon Factor of Safety
Date:	15.04.2019		

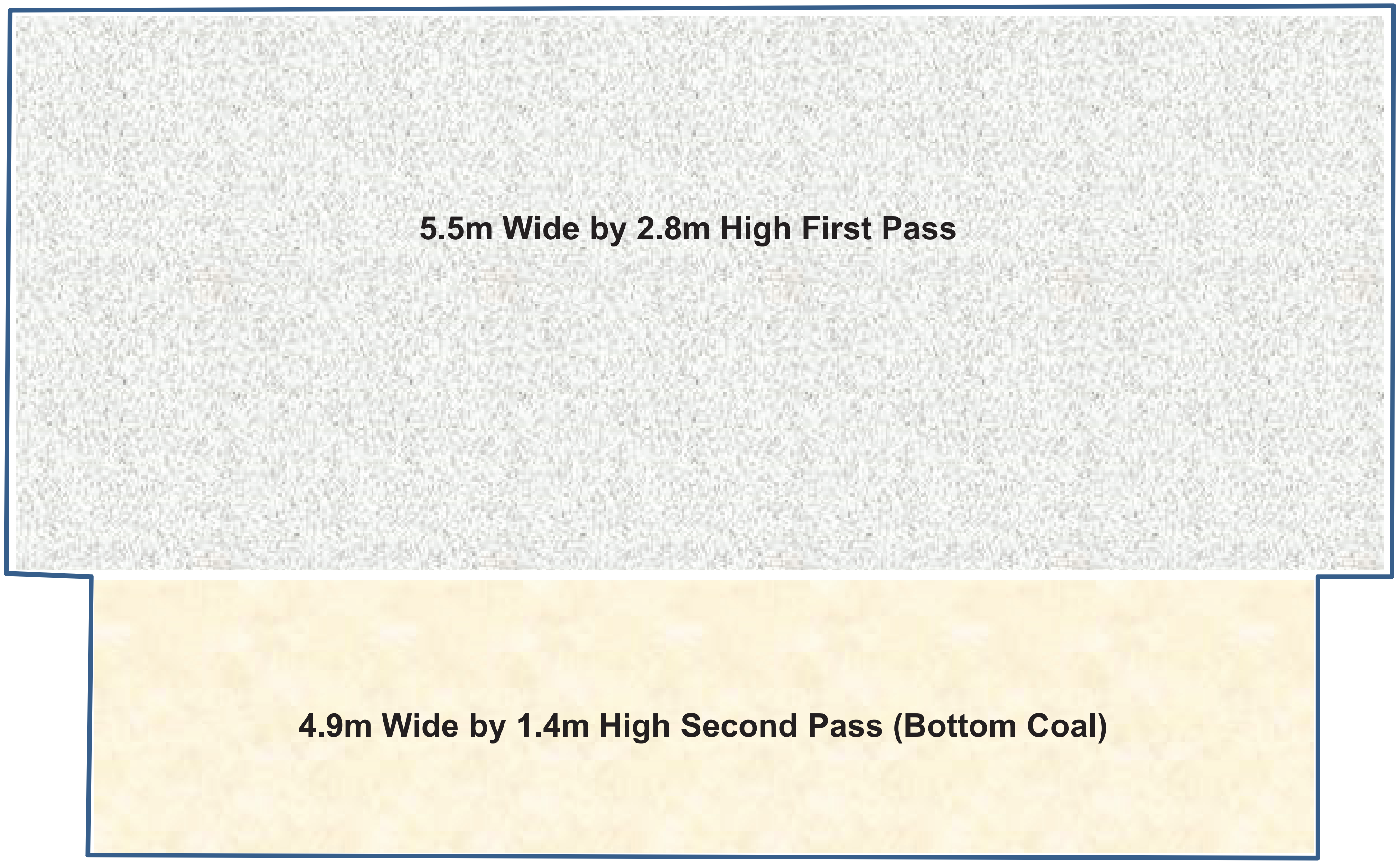
STRATA[2]

Ref:	CHV-008	**Revision No:**	0
Scale:	N/A	**Figure No:**	8



Average Pillar Width
= (17.4+24.6) / 2
= 21m

Engineer:	D. Hill	**Client:**	Mannering Colliery		
Drawn:	I. Saliamon	**Title:**	Example of Configuration of "Dog-Kennel" Pillar (Plan Dimensions)		
Date:	09.04.19				
		Ref:	CHV-008	**Revision No:**	0
		Scale:	NTS	**Figure No:**	9



Average Roadway Width = 5.3m
Average Roadway Height = 4.05m

Engineer:	D. Hill	**Client:**	Chain Valley Colliery		
Drawn:	D. Hill	**Title:**	Benched Roadway Profile		
Date:	15.04.2019				
STRATA2		**Ref:**	CHV-008	**Revision No:**	0
		Scale:	N/A	**Figure No:**	10

Appendix A: Hill (2010)

Long-Term Stability of Bord and Pillar Workings

David Hill, Principal, Strata Engineering (Australia) Pty Ltd

ABSTRACT

In Australia, large surface areas are permanently supported on coal pillars, both in extensive old workings and current drivages in active operations. The continued growth of civil infrastructure is resulting in more surface development above old mines and an increased need for underground development beneath existing, potentially sensitive, surface structures and features. The result is a greater likelihood of conflict between miners, developers and regulatory bodies.

However, over the last fifty years there has been significant improvement in the general level of understanding of bord (room) and pillar behaviour, both in Australia and overseas. This paper examines some of the design issues to be considered when undermining surface structures.

The Factor of Safety (FoS) methodology widely employed for the assessment of pillar stability is reviewed, including the key geometrical, geological and statistical concepts associated with the probability of coal pillar failure. Relevant Australian and international experiences are examined and significant parameters isolated. Common concerns are addressed in the context of practical experience, utilising a risk management approach. Tools for assessing the long-term stability of bord and pillar workings are put forward, along with criteria for arriving at rational design outcomes.

INTRODUCTION

Pillars serve two main roles: promoting the serviceability of underground roadways adjacent to areas of extraction (eg longwall chain pillars) and maintaining long-term regional stability (eg main heading pillars). These pillars are an operational constraint determining the amount of roadway development required. As such, the general need is to minimise pillar widths wherever possible, noting that overly-large coal pillars do not result in significant improvements in serviceability or enhanced regional stability. On the other hand, inadequately-sized pillars can cause major operational difficulties and large-scale rock mass instability, which may be manifested as discernible surface ground movement (i.e. subsidence), with impacts on other stakeholders.

Over 200 years of underground coal mining in Australia has resulted in large areas of ground supported on coal pillars, including very extensive old workings in generally inaccessible redundant mines and current drivages in active mining operations. Also, the continuing growth in the size and complexity of civil infrastructure is resulting in more surface development above old bord and pillar mines, as well as the increasing need for mine development beneath existing, frequently sensitive, surface structures or features. The result is greater potential for conflict between coal miners, developers and regulatory bodies, with the potential for sterilisation of underground resources and / or escalating surface development and infrastructure protection costs.

Coal pillar sizes in New South Wales (NSW) are regulated primarily by Clause 88 of the NSW Coal Mine Health and Safety Regulation (CMHSR) 2006, which contains a long-standing provision that the plan dimension of a coal pillar should be not less than one-tenth of the cover depth or 10 m, whichever is the greater. Given a representative maximum drivage height of around 3.5m and a prescribed maximum bord width of 5.5m in NSW, this is akin to specifying a Factor of Safety (FoS) of ≥ 1.6, assuming full tributary area loading and based on the Australian coal pillar strength formulae given in **Salamon *et al*, 1996**, as well as a minimum width to height (w/h) ratio of 2.9. Clause 32 of the CMHSR 2006 goes further in addressing the content of strata failure management plans, requiring a description of any coal pillars with a width to height ratio of 4:1 or less, together with any special provisions made for them.

EMPIRICAL PILLAR DESIGN METHODOLOGIES

Empirically-based coal pillar design techniques are in widespread use in Australia, South Africa and the US. The underpinning databases of experience have guided the derivation of the various strength formulae and the selection of appropriate Factors of Safety for specific circumstances. These databases also offer considerable insight with regard to the mechanics of pillar behaviour.

For example, it is widely appreciated that pillar strength increases with pillar width (w) and decreases with height (h), such that pillar w/h ratio is a commonly quoted key parameter, as reflected in the comments regarding the NSW regulatory framework. **Figure 1** presents a combined database of bord and pillar panel failures with respect to w/h ratio. The US data (**Mark, Personal Communication, 2002**) is a sub-set taken from the ARMPS database that relates to first workings only (i.e. ARMPS Loading Condition 1); failure data related to secondary extraction was deliberately excluded. The exclusion of failures associated with abutment loading from adjacent areas is intended to be consistent with the Australian and South African data, which are taken from **Salamon *et al*, 1996** and **Salamon *et al*, 2006** respectively. It is apparent from the figure that in all three countries there is a concentration of failures at w/h ratios of ≤ 2, noting that 2.0 is the median w/h value for the 124 failed cases and the median values for the individual countries vary only between 1.9 (USA), 2.0 (S. Africa) and 2.1 (Australia). Also, 95% of the failed cases involve w/h ratios of ≤ 5 and the maximum w/h ratio of a failed case is 9.32.

Considering the South African and US data in more detail, **Figures 2** and **3** illustrate the respective cumulative frequency distributions of the failed cases. Prominent in the South African data, **Figure 2**, is the slope change at a w/h ratio of 1.6; 38% of the 77 failures involve w/h ratios of 0.87 to 1.56. A similar pattern is seen in **Figure 3** for the US data, with a distinct change in slope at a w/h ratio of between 2 and 2.5 and 37% of the data falling within a w/h ratio range of 1.00 to 1.52.

These distributions for the failed cases should be seen in the context of the equivalent distributions for the recorded intact cases, which are presented in **Figures 4** and **5** for South Africa and the US respectively. The intact cases in the South African database cover a w/h ratio range of 1.00 to 15.45, with a median value of 3.67, see **Figure 4**. Although there is a concentration of South African data in a w/h ratio range of 2.6 to 5.2, there are significant numbers of intact cases at low w/h ratios; for example, there are 13 intact cases (i.e. 5% of the total) at w/h ratios of ≤ 1.75. The intact cases for the US mainly involve higher w/h ratios, with a concentration in the 4.5 to 8.4 range, see **Figure 5**; this partly reflects a lower average mining height of 2.2m, in comparison to both Australia and South Africa (i.e. around 3m). There are few US intact cases at w/h ratios of ≤ 3 (i.e. <4% of the total) and the minimum value for an intact case is 1.52 (noting again that 37% of the US failed cases involve w/h ratios of ≤ 1.52).

The associated ranges of pillar widths for the failed and intact cases are illustrated in **Figures 6** and **7** respectively, for all three databases.

With regard to the failed cases, **Figure 6**:

- 21.8% involve minimum pillar widths of ≤ 4m,
- the median value is 6.4m,
- 75% of the failed cases involve pillar widths of ≤ 10m, the NSW regulatory minimum and
- 95% of the failures involve pillar widths of ≤ 16.5m.

With regard to the intact cases, **Figure 7**:

- only 4.5% involve pillar widths of ≤ 6m,
- 75% involve minimum pillar widths of >9m,
- the median value is 12.0m and
- 95% of the intact cases involve pillar widths of ≤ 21.3m.

The median pillar widths of 6.4m for the failures and 12.0m for the intact cases reflect a concentration of data points at these geometries, which for the South African data in turn reflects a widespread industry shift from driving on 40’ (12.2m) to 60’ (18.3m) centres following the Coalbrook disaster.

The concentration of failed cases at small pillar widths is the most prominent feature of the data. **Salamon and Oravecz 1976** urged caution in the case of low pillar widths, pointing out that the potential discrepancy between ‘nominal’ and ‘as built’ pillar dimensions increases as the design dimensions get smaller. They concluded that:

“It is therefore recommended that special care should be taken if small pillars are used and, also, that no pillar width of less than 3 metres should be used. Moreover, the safety factor of pillars between 3.0 and 4.5m in width should be at least 1.7”.

It is often stated that caution should be adopted in applying the results of an empirical study outside of the range of the underpinning data. In this regard, the data ranges for the three countries are summarised in **Tables 1** to **3** below.

Table 1: Australian Data

Parameter	Failed	Intact
Depth (m)	58 – 336	22 – 510
Mining Height (m)	1.8 – 9.2	1.0 – 6.0
Minimum Pillar Width (m)	3.5 – 25.0	2.0 – 32.0
Bord Width (m)	5.5 – 15.0	5.0 – 15.0
Percentage Extraction (%)	42 – 84	30 – 89
w/h Ratio	1.1 – 8.2	1.7 – 11.2

Table 2: South African Data

Parameter	Failed	Intact
Depth (m)	19 – 205	13 – 254
Mining Height (m)	1.3 – 6.2	1.1 – 6.4
Minimum Pillar Width (m)	3.2 – 17.0	4.3 – 35.0
Bord Width (m)	4.8 – 8.5	4.9 – 10.0
Percentage Extraction (%)	44 – 91	23 – 89
w/h Ratio	0.9 – 4.3	1.0 – 15.4

Table 3: US Data

Parameter	Failed	Intact
Depth (m)	53 – 396	61 – 610
Mining Height (m)	0.8 – 5.3	0.8 – 4.0
Minimum Pillar Width (m)	1.5 – 16.5	1.5 – 33.5
Bord Width (m)	5.5 – 11.1	4.3 – 6.1
Percentage Extraction (%)	37 – 89	28 – 89
w/h Ratio	1.0 – 9.3	1.5 – 18.3

The three databases are complimentary in nature. For example, the US data includes five failed cases with w/h ratios of >5, whereas the combined Australian and South African database has just one. Also, the US data includes failed and intact cases with mining heights of <1m, which are not represented in the other data sets, as well as a significant proportion of rectangular and parallelepiped pillars. As previously noted, the South African database contains significant numbers of intact cases at w/h ratios of <1.75.

The US failed cases encompass several failure modes, as shown in **Figure 8** (noting again that the data relates to ARMPS Loading Condition 1). Sudden collapses were characterised by air blasts and are associated with w/h ratios of ≤ 2.5. Progressive (ie slow) pillar failures ("squeezes") occur across the full range of w/h ratios, but become the predominant mode of failure at w/h ratios of >3.5. There is a bump case at a w/h ratio of 5.7 (with an associated depth of 305m) and a single floor-related failure at a w/h ratio of 4.7 (involving a minimum pillar width of 7.1m). Finally, there is one case classed as borderline / marginal, at a w/h ratio of 9.0.

The South African database focuses specifically on cases of pillar collapse resulting in surface subsidence. The original study by **Salamon and Munro (1967)** and that of **Madden and Hardman (1992)** covered most of the South African coalfields and seams. The more recent investigation by **Salamon *et al* (2006)** focussed on deriving seam-specific strength formulae and included more data from seams in the Vaal Basin and Natal, with weaker coal and / or weaker surrounding strata. **Figure 9** illustrates the progressive development of the South African database in terms of the distribution of failed cases versus pillar w/h ratio. It can be seen that the 1992 update by **Madden and Hardman** had minimal impact on the distribution of the data, with the average w/h ratio increasing from just 1.9 to 2.0. However, the addition of data from seams with weaker coal and roof / floor contacts in the 2006 study by **Salamon *et al*** results in a small, but distinct shift in the distribution towards higher w/h ratios; the average increases again, from 2.0 to 2.2 and the maximum w/h ratio for a failed case increases from 3.7 to 4.3.

The Australian database is relatively small and understood to be limited to collapses of the pillar element, excluding failures associated with weak contacts or the bearing capacity of the roof and floor. Although the locations of the individual case histories remain unpublished, it is understood that the intact and failed cases cover a number of coalfields and seams, with a variety of associated adjacent strata. There is nothing in the distributions of the failed and intact cases that would appear to demonstrate an appreciable difference in pillar behaviour, or any other inconsistency, in comparison to the South African and US databases.

The preceding summary of Australian, South African and US experience confirms the role of increasing pillar width and w/h ratio in promoting enhanced pillar stability. Furthermore, back analysis of case histories from elsewhere has also shown that w/h ratio exerts a major influence on coal pillar strength. At low ratios (<3) overloaded pillars tend to fail in a brittle, uncontrolled fashion, whereas at higher ratios (>4) the coal pillars demonstrate a more plastic form of deformation: significant displacement may take place in the form of convergence of the roof and floor, as well as rib spall, but the pillar core remains confined and tends to retain some load carrying ability, such that a 'squeeze' occurs.

The w/h ratio effect was illustrated in the laboratory by **Das (1986)** in tests on Indian coals, see **Figure 10** and also by **Madden (1987)** in tests on sandstone discs during the development of the squat pillar formula (Madden used sandstone, as coal samples are more heterogeneous and difficult to prepare), see **Figure 11**. Back analysis of the results of *in situ* tests by **Van Heerden (1975)** suggests that the post-peak modulus of coal pillars becomes zero or positive at w/h ratios of >4.08 (**Madden and van der Merwe, 2002**), obviating the potential for violent failure. **Zipf (2005)** demonstrated the same change in pillar behaviour with increasing w/h ratio using finite difference modelling.

Referring to the South African and US failed cases shown in **Figures 2** and **3**, the disproportionate number of failures at w/h ratios of <2 reflects a lack of confinement to the core of the pillars. Apart from reducing confinement, the potential impact of discontinuities (i.e. localised structural defects, such as faults) also increases rapidly as w/h ratio decreases. Similarly, the influence of weak bands reduces as their aspect ratio (i.e. length / width) increases with increasing pillar width. Recognition of the vulnerability of small pillars led **Madden (1989a)** to suggest that at shallow depths (i.e. <40m), pillars be designed to a width of >5m and a w/h ratio of >2; in addition, the Factor of Safety was to be >1.6 (according to the **1967 Salamon and Munro** formula).

A great variety of coal pillar strength formulae have been derived either directly from the back analysis of case histories, or from approaches involving laboratory and / or *in situ* testing, generally coupled to reviews of practical experience. The formulae enable the estimation of strength according to the pillar dimensions and generally incorporate w/h ratio as a key element. In South Africa, for example, the original **Salamon and Munro (1967)** formula, as well as the subsequent extension for 'squat' (w/h ratio >5) pillars (**Madden, 1989b**) have proven effective in preventing catastrophic failures in active workings. In the mid-1980s, the author personally mined panels in the Witbank Coalfield involving pillar widths of typically 6m to 6.5m and final heights of around 6m; the workings were designed using the **Salamon and Munro** formula and remain intact to this day.

As more experience becomes available, better estimates of coal pillar strength become possible. Both **Madden (1989a)** and **van der Merwe (1999)** found that the **Salamon and Munro (1967)** formula over-predicted coal pillar strength at w/h ratios of <3 and derived alternative formulae for general South African use. As previously noted, seam -specific formulae have now been developed in South Africa. The definition of the constants within both the Australian and South African squat pillar formulae remains an unresolved issue, noting that conservative values were originally adopted in the face of limited information (i.e. at the time of derivation, the maximum w/h ratio for a South African failed case was 3.74). There is now over 20 years experience with the application of the original squat pillar strength formula, with no known significant incident.

In Australia, both the **Bieniawski (1967)** and the **Salamon *et al* (1996)** formulae are currently in widespread use. **Salamon *et al* (1996)** developed both Australian and joint Australian / South African formulae, concluding that the application of the joint Australian / South African formulae was preferred, due to the limited size of the Australian database in isolation. However, the use of these combined formulae is not ideal, as the underpinning database is composed largely of failed cases with w/h ratios of <5, whereas the Australian norm involves squat pillars (i.e. w/h ratios of >5).

With specific regard to the **Salamon *et al* (1996)** formulae, given:

- the reservations that have been expressed with respect to the use of these formulae at low w/h ratios,
- the limited data at a w/h ratio of >5 and
- their limitation to pillars with "good" roof and floor contacts,

it is considered that these formulae should only be used in conjunction with additional controls. The Australian industry would benefit significantly from an expanded local database and would have much to gain from the derivation of updated formulae that incorporate and build on US experiences with pillars at w/h ratios of >5.

Recognising the limitations of the Australian strength formulae, one initial approach was to "quarantine" the failed cases (**Strata Engineering, 2000**). **Figure 12** illustrates the Factor of Safety versus w/h ratio relationship for the Australian (**UNSW, 1995**) and South African (**Madden and Hardman, 1992**) failed cases. The Australian intact cases are also shown for interest.

The following comments are made with regard to **Figure 12**:

i) There are no failed cases in the combined South African / Australian database with a w/h ratio of greater than 8 (according to **UNSW 1995**, although this was later corrected to 8.16 by **Salamon *et al* 1996**) even at a very low Factor of Safety, and there is only one failed case at a w/h ratio of greater than 5.

ii) The highest Factor of Safety assigned to a pillar collapse is 2.1 and this was associated with a w/h ratio of only 2.2.

iii) A limit envelope was defined for the database of failed cases, illustrated by the curve and given by the following equation:

$$\text{w/h ratio} = 19.328e^{-1.047*(\text{Factor of Safety})}$$

iv) If it is reasonable to assume that the pillars are, or will at some point in the future, be subjected to full tributary loading, then it is considered prudent to design the pillars to be outside (above) the failed case envelope, even though there are many examples of stable pillars that fall within it.

This approach has been used successfully for over ten years and was subsequently refined to the design nomogram shown in **Figure 13 (Hill and Buddery**, **2004)** which adds a third database derived from the back analysis of failed Australian highwall mining cases (**Strata Engineering, 2001**). The highwall mining cases cover the lower end of the range of w/h ratios, from 0.7 to 1.3. Although there are failed highwall mining pillars with Factors of Safety of 2.2 to 2.4, the pillars involved have w/h ratios of only 1.1 to 1.3.

The current limit envelope for the database of failed cases is defined by the following equation:

$$\text{w/h ratio} = 22.419e^{-1.148*(\text{Factor of Safety})}$$

Beyond this envelope, there is no precedent for failure within these databases. Note that the inclusion of the highwall mining pillar data does not materially change the shape of this limit envelope.

In the case of important long-life pillars (e.g. main headings), it is considered prudent to allow an additional margin beyond this envelope. A margin of 20% is the suggested minimum, which is defined by the second, outer curve in **Figure 13** and the following equation:

$$\text{w/h ratio} = 26.903e^{-0.957*(\text{Factor of Safety})}$$

In the case of pillars required for the permanent protection of critical surface features or structures, a broader review of coal pillar behaviour suggested, even in extreme circumstances involving unusually weak floor, coal and / or roof, that the potential for failure could be effectively excluded by designing to a Factor of Safety of ≥ 2.11, coupled to a w/h ratio of ≥ 5. Note that in this context, "failure" means panel collapse due to the failure of any element (i.e. roof, floor or the pillar) in the overall structural system.

Also shown in **Figure 13** are the practical design restrictions that flow from the NSW regulatory framework (i.e. Clauses 32 and 88 of the CMHSR (2006), as discussed previously). It can be seen that the regulatory approach is logical and, to an extent, mimics the Strata Engineering methodology, effectively placing design restrictions on both pillar Factor of Safety and w/h ratio.

The question then arises as to the possibility of incorporating and learning from the US experience, with particular regard to the behaviour of pillars with high w/h ratios. Of the various available approaches, only the Mark-Bieniawski formula (**Mark and Chase, 1997**) is considered appropriate for use across the full range of the data. The Australian and South African data have therefore been reprocessed and the combined database is presented in **Figure 14**, in terms of ARMPS Stability Factor (SF) versus w/h ratio.

The following comments are made with regard to **Figure 14**:

i) Excluding the single US floor failure, 70% of the failed cases have Stability Factors of <1.5.

ii) Again excluding the one floor failure, 90% of the failed cases involved w/h ratios of ≤ 4. This is consistent with the previously outlined studies of the positive impact of increasing w/h ratio on pillar strength and deformation.

iii) All of the failed cases with Stability Factors of >1.5 have w/h ratios of <4.5, apart from the floor failure, which had a w/h ratio of 4.66.

This broader, updated database is regarded as consistent with the previously described design methodology, as illustrated in **Figure 13**. In particular, for the purpose of long-term surface protection, there is no precedent for pillar failure at a Stability Factor of ≥ 1.5, coupled to a w/h ratio of ≥ 5.

The single US floor failure case raises the wider issue of the potential for surface impacts due to bearing capacity failure of the roof and / or floor, as opposed to failure of the pillar element. When pillar failure occurs, the physical manifestations very often include roof damage and floor heave, as pillar deformation and spall result in increases in both excavation span and bearing stress. The degree to which one aspect of this overall deformation (i.e. rib spall, roof falls or floor heave) is more prevalent than the other elements is a function of the geometry and the competency of the roof, seam and floor. Environments in which one aspect is evident in virtual isolation are very rare. The division, therefore, between pillar collapse and bearing capacity failure of the roof and / or floor is not as well defined as is often simplistically portrayed.

The previously discussed databases of pillar behaviour cover a broad range of roof and floor materials, including mudrocks, coal, siltstones and sandstones. Therefore, these materials and the variability in pillar strength that may be associated with them are implicitly recognised and should be very largely catered for within a Stability Factor approach. The uncertainty associated with the natural variability in Coal Measures strata often prohibits design to low Stability Factors (e.g. designing to a SF of 1.01 is not usually acceptable, even though strength nominally exceeds stress). Geological variability partly accounts for the scatter in the population of failed pillar cases and generally results in design Stability Factors of ≥ 1.5, equivalent to very low probabilities of failure.

Within the Australian and South African coal industries, there remain no known panel collapses (i.e. involving the structural failure of the roof, pillar or floor elements) that cannot be explained in terms of the combined Factor of Safety and w/h ratio criteria illustrated previously in **Figure 13**. This includes, for example, collapses in the Great Northern Seam (Lake Macquarie area, Australia), which historically have often been attributed to bearing failure of the Awaba Tuff floor. This often has a high smectite content, with an associated tendency to swell and degrade in the presence of moisture. It should be noted that those practical design parameters with a positive impact on pillar stability also invariably enhance bearing capacity (the obvious example being increasing pillar width), such that pillar and bearing capacity Factors of Safety tend to align closely. Even in known very weak floor environments, incidences of coal pillar collapse are concentrated at low w/h ratios (**Marino and Bauer, 1989**).

Nonetheless, there are geotechnical environments that warrant specific consideration of the behaviour of extremely weak floor materials. The prime example is the weak underclay of the Illinois Basin, where bearing capacity failure has been experienced at very high pillar Stability Factors, coupled to w/h ratios of up to 6.3 (**Gadde, 2009**). Similarly, there are very shallow workings that require specific consideration of overburden properties and the potential for sinkhole development.

The issue of potential long-term deterioration of workings leading to eventual failure is an important consideration, particularly if surface features warrant protection. In the Australian and South African databases, apart from one uncertain Australian case (i.e. at between 80 and 170 years) the maximum recorded time interval from mining to subsequent pillar failure is 52 years and the average time to failure is seven years. US experience appears generally consistent with this, even in weak floor conditions.

Expressed in the context of ARMPS SF and w/h ratio values, it can be shown that the failure probability reduces with time. **Figure 15** indicates that after an elapsed period of 14 years, there is only one Australian or S. African case of collapse at a Stability Factor of >1.6. The exception case involved a w/h ratio of 2. Referring to **Figure 16**, it is seen that after a period of 14 years, there are no cases of collapse at pillar w/h ratios of >2.5. After 40 years, there are no failed cases at w/h ratios of >2.

The industry databases illustrate that the majority of failures occur within a short time of mining, due either to inappropriate design or some form of local anomaly. As time progresses, the actual likelihood of failure decreases and those collapses that do occur involve designs that would be considered increasingly marginal. There is no evidence to suggest that pillar failure becomes inevitable or even more likely over time. On the contrary, the historical data suggests that pillar deterioration (e.g. associated with spall and weathering) tends to a limit over time.

CONCLUDING REMARKS

None of the empirically derived formulae in common use are considered to provide accurate estimates of coal pillar strength in Australian conditions. In particular, these formulae tend to overestimate pillar strength at w/h ratios of <4.

The Australian industry would benefit greatly from improved, updated pillar strength formulae based on expanded local databases, incorporating also US experiences with regard to pillar behaviour at w/h ratios of >5. This is of particular interest, given that NIOSH has recently been updating the ARMPS database.

In the interim, coal pillar designs that take cognisance of both w/h ratio and Stability Factor (or FoS) are considered most appropriate for ensuring the stability of workings. In this regard, both the NSW regulatory approach and the methodology developed by Strata Engineering over the last ten years are considered to remain rational.

For Australian conditions, an ARMPS Stability Factor of ≥ 1.5, coupled to a w/h ratio of ≥ 5, would effectively obviate the potential for long-term failure (i.e. collapse due to the failure of any element, roof, floor or the pillar, in the overall structural system).

Finally, it is re-iterated that the comments herein refer solely to the “first workings” or ARMPS “Loading Condition 1” situation. Obviously, the impacts of any secondary extraction are more complex and would require further consideration.

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LIST OF FIGURES

Figure 1

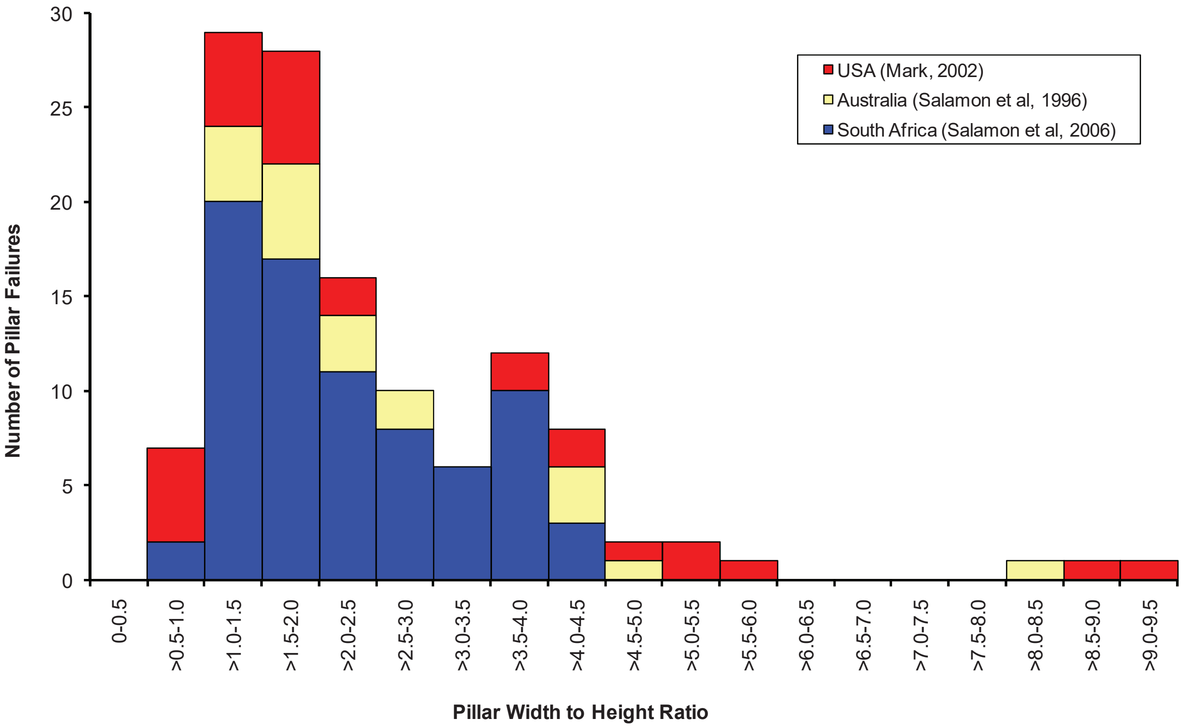
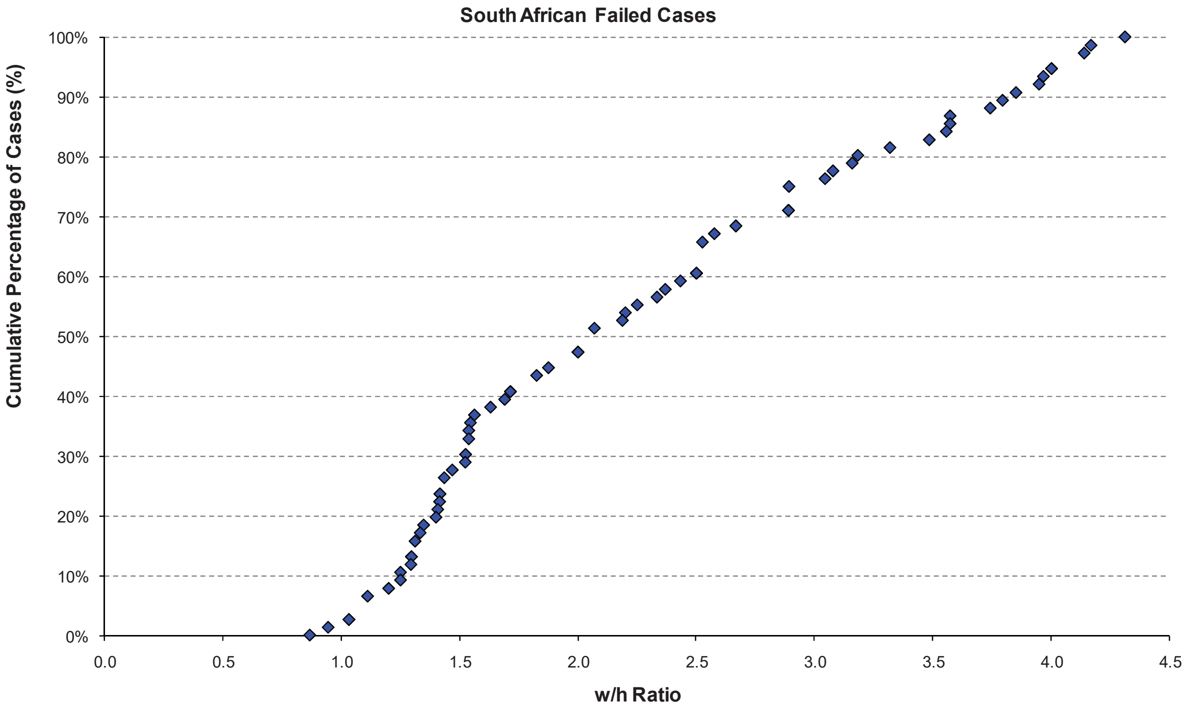
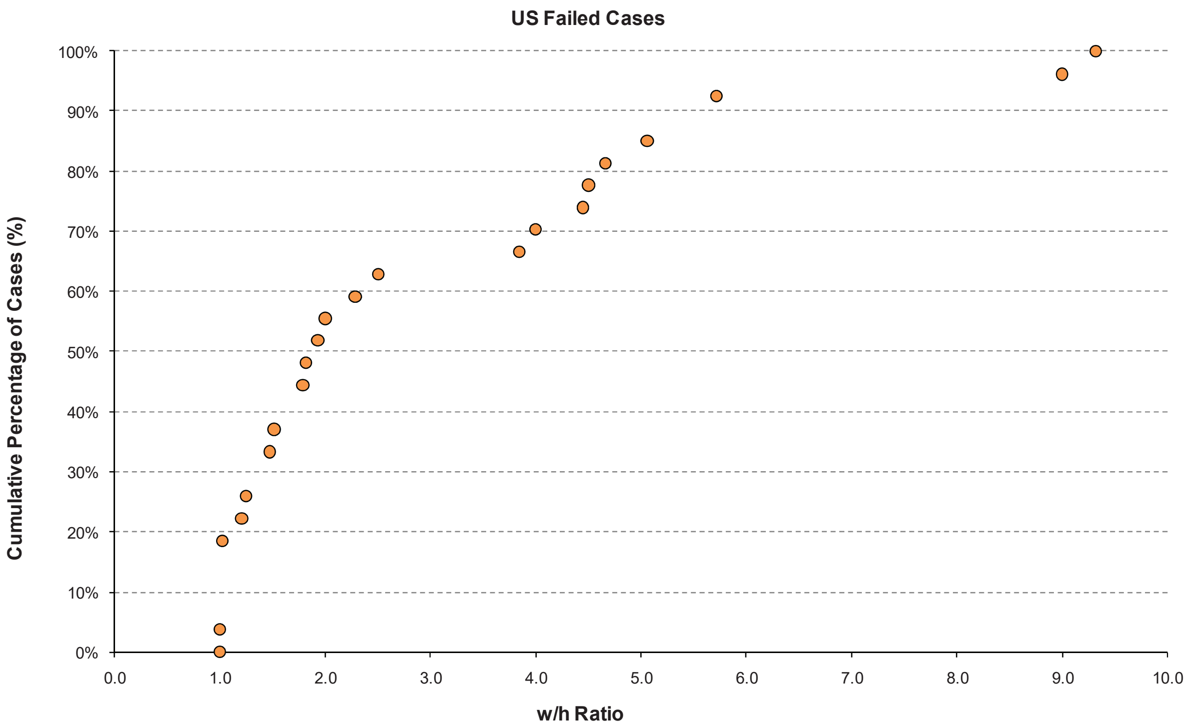

USA (Mark, 2002)
Australia (Salamon et al, 1996)
South Africa (Salamon et al, 2006)
Number of Pillar Failures
30
25
20
15
10
5
0
0-0.5
>0.5-1.0
>1.0-1.5
>1.5-2.0
>2.0-2.5
>2.5-3.0
>3.0-3.5
>3.5-4.0
>4.0-4.5
>4.5-5.0
>5.0-5.5
>5.5-6.0
>6.0-6.5
>6.5-7.0
>7.0-7.5
>7.5-8.0
>8.0-8.5
>8.5-9.0
>9.0-9.5
Pillar Width to Height Ratio

Figure 2



South African Failed Cases
Cumulative Percentage of Cases (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
w/h Ratio

Figure 3



US Failed Cases
Cumulative Percentage of Cases (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
w/h Ratio

Figure 4

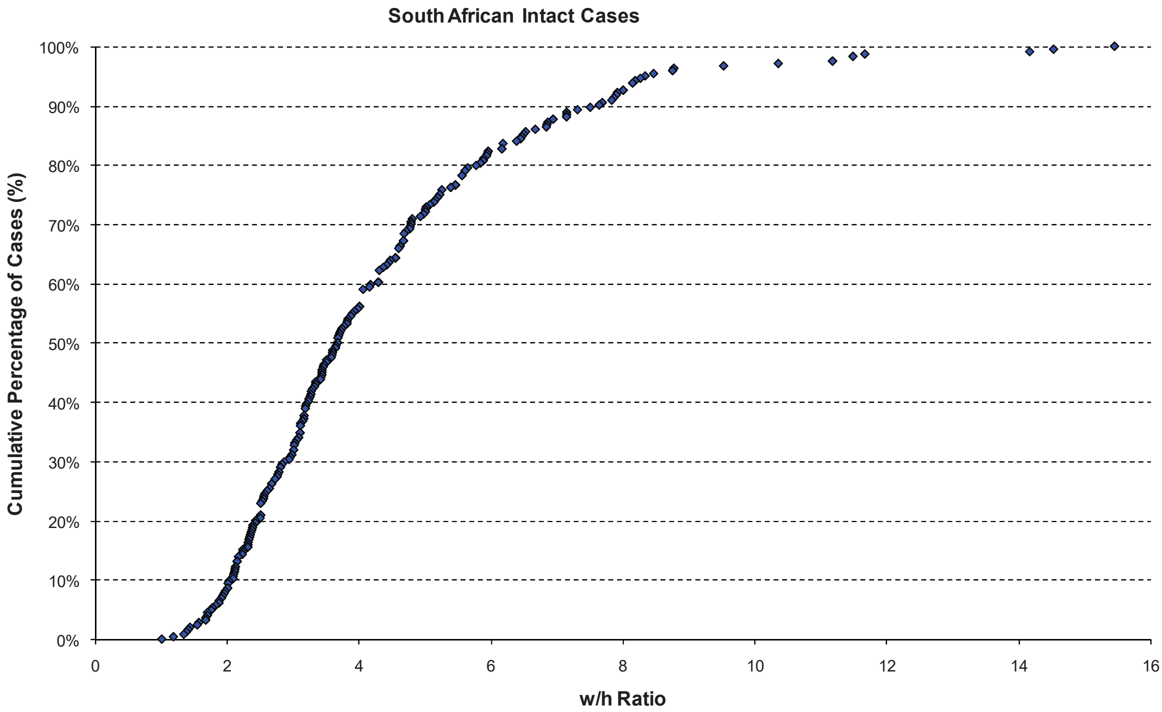

South African Intact Cases
Cumulative Percentage of Cases (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
14
16
w/h Ratio

Figure 5

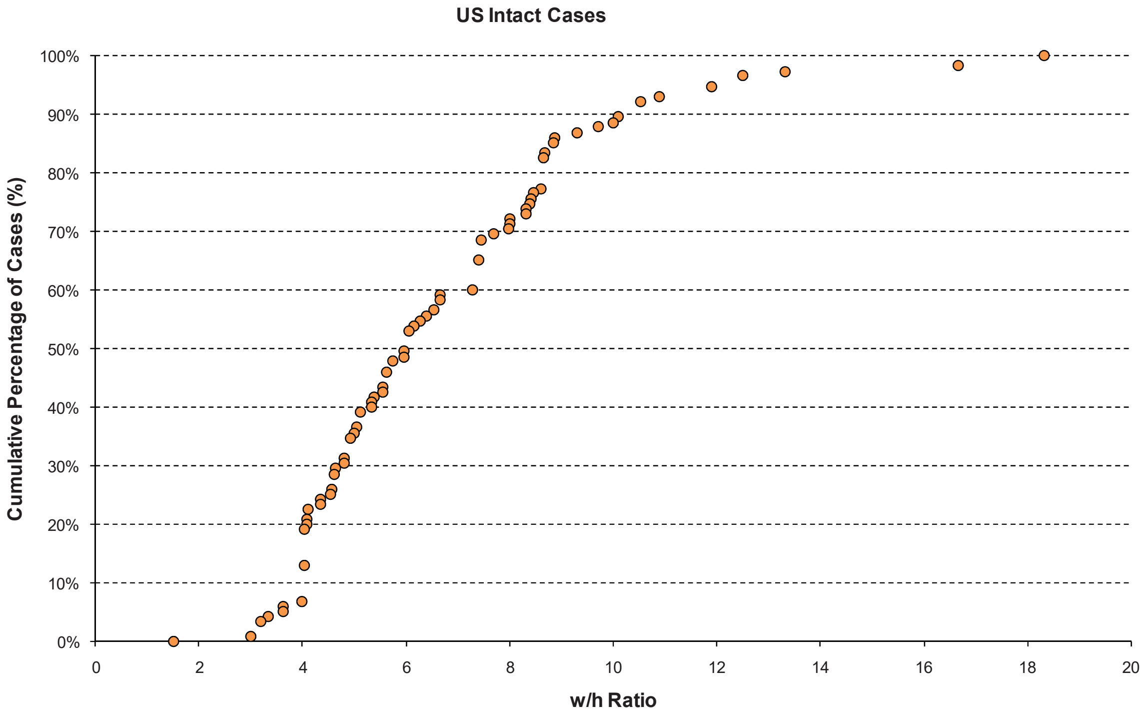

US Intact Cases
Cumulative Percentage of Cases (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
2
4
6
8
10
12
14
16
18
20
w/h Ratio

Figure 6

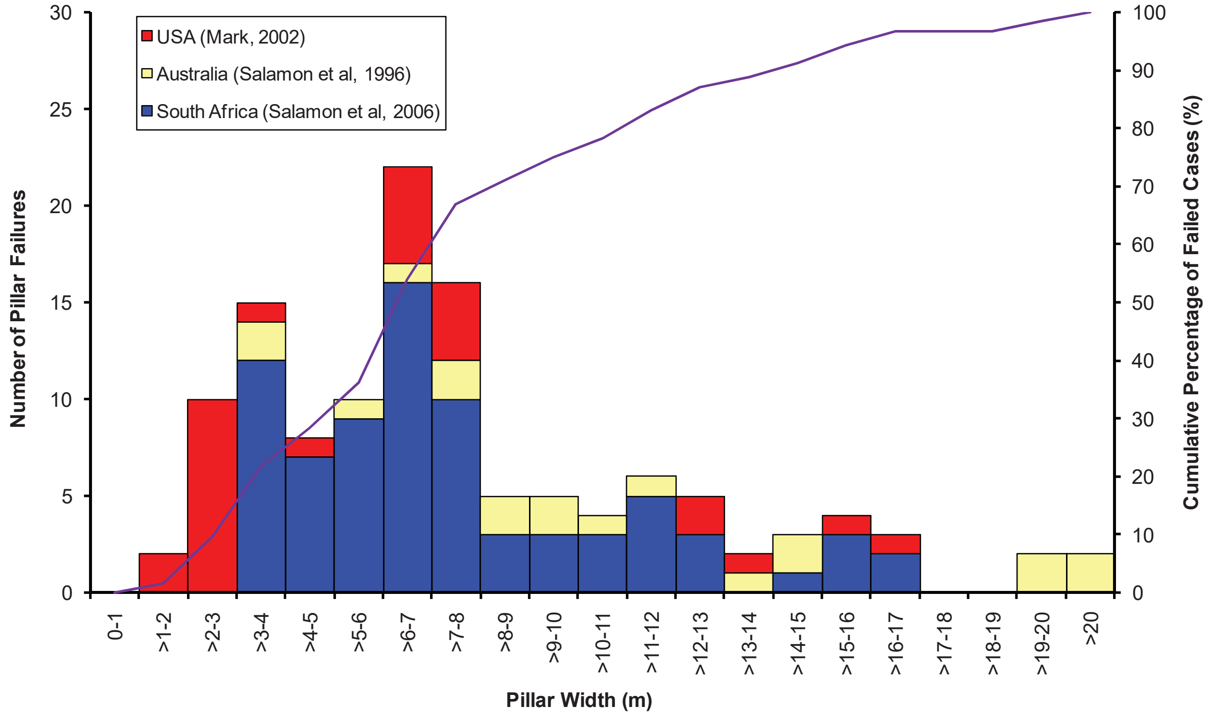

USA (Mark, 2002)
Australia (Salamon et al, 1996)
South Africa (Salamon et al, 2006)
Number of Pillar Failures
Cumulative Percentage of Failed Cases (%)
Pillar Width (m)
30
25
20
15
10
5
0
100
90
80
70
60
50
40
30
20
10
0
0-1
>1-2
>2-3
>3-4
>4-5
>5-6
>6-7
>7-8
>8-9
>9-10
>10-11
>11-12
>12-13
>13-14
>14-15
>15-16
>16-17
>17-18
>18-19
>19-20
>20

Figure 7

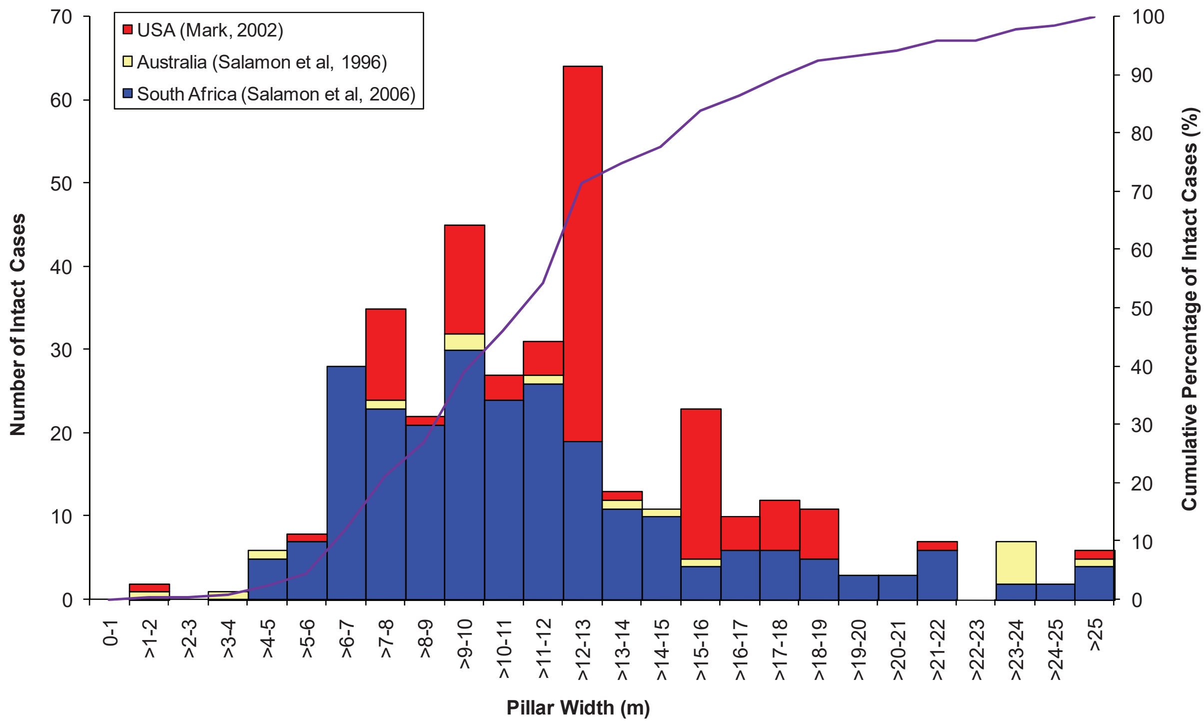

USA (Mark, 2002)
Australia (Salamon et al, 1996)
South Africa (Salamon et al, 2006)
Number of Intact Cases
Cumulative Percentage of Intact Cases (%)
Pillar Width (m)
0
10
20
30
40
50
60
70
80
90
100
0-1
>1-2
>2-3
>3-4
>4-5
>5-6
>6-7
>7-8
>8-9
>9-10
>10-11
>11-12
>12-13
>13-14
>14-15
>15-16
>16-17
>17-18
>18-19
>19-20
>20-21
>21-22
>22-23
>23-24
>24-25
>25

Figure 8

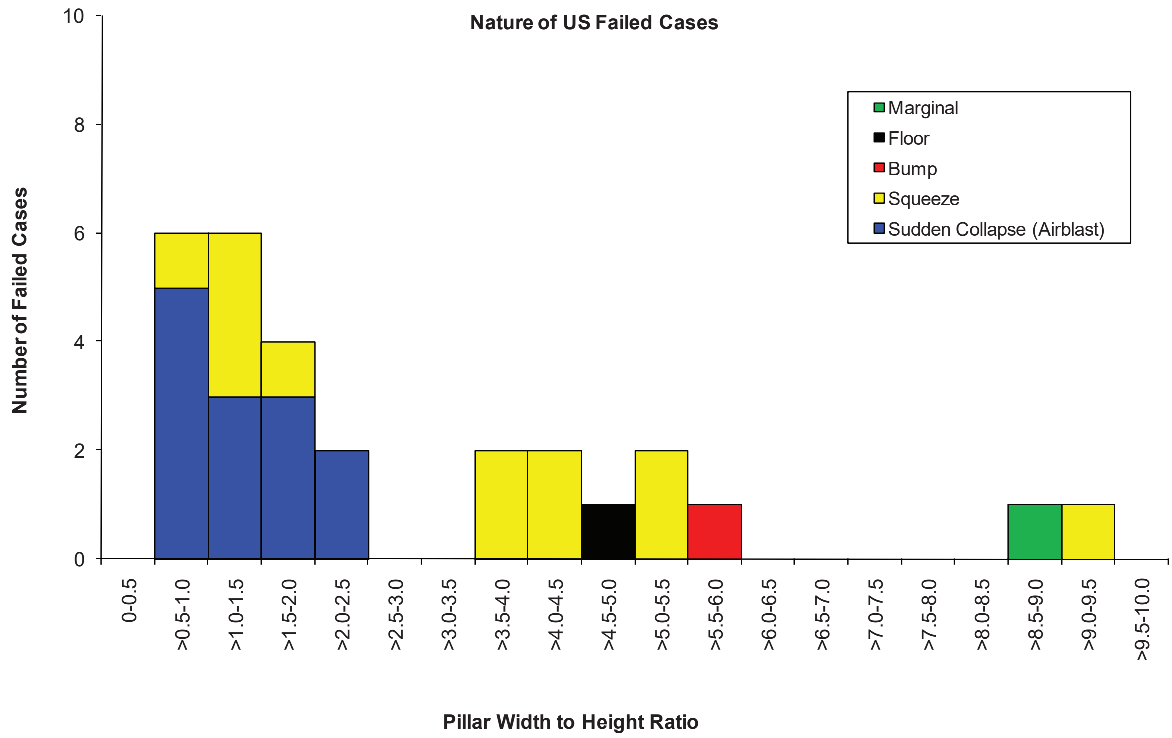

Nature of US Failed Cases
Number of Failed Cases
10
8
6
4
2
0
Marginal
Floor
Bump
Squeeze
Sudden Collapse (Airblast)
0-0.5
>0.5-1.0
>1.0-1.5
>1.5-2.0
>2.0-2.5
>2.5-3.0
>3.0-3.5
>3.5-4.0
>4.0-4.5
>4.5-5.0
>5.0-5.5
>5.5-6.0
>6.0-6.5
>6.5-7.0
>7.0-7.5
>7.5-8.0
>8.0-8.5
>8.5-9.0
>9.0-9.5
>9.5-10.0
Pillar Width to Height Ratio

Figure 9

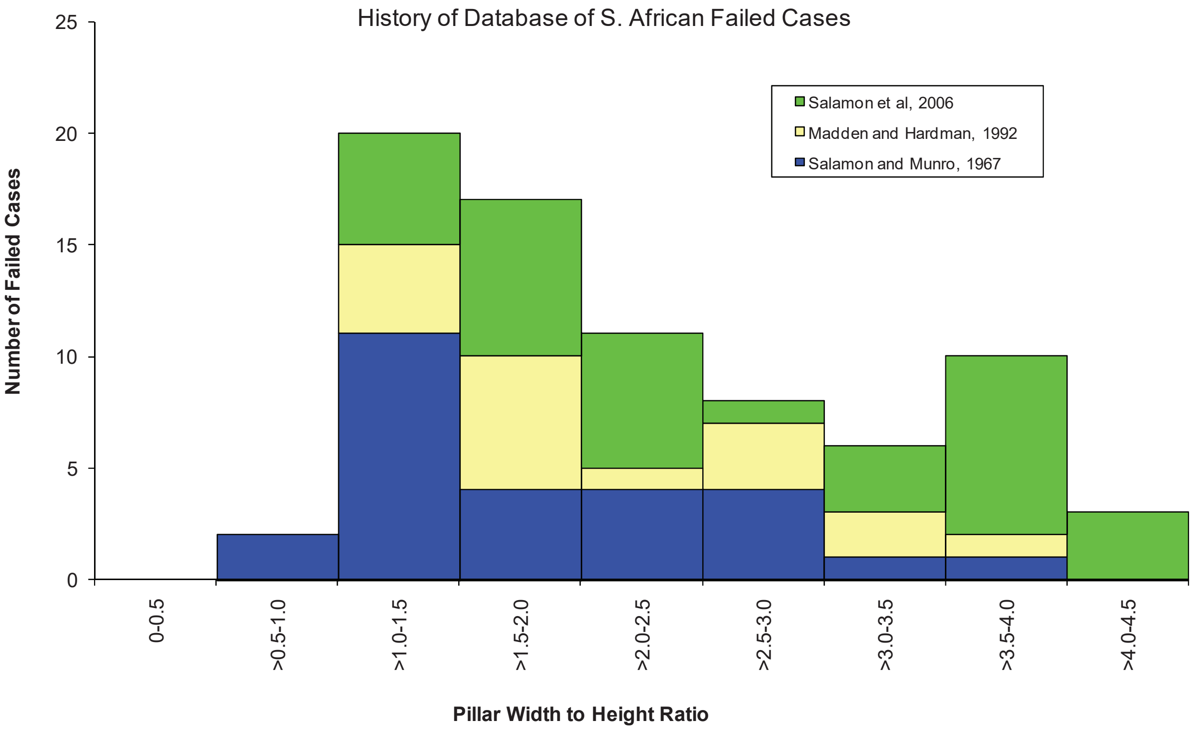

History of Database of S. African Failed Cases
Salamon et al, 2006
Madden and Hardman, 1992
Salamon and Munro, 1967
Number of Failed Cases
0
5
10
15
20
25
0-0.5
>0.5-1.0
>1.0-1.5
>1.5-2.0
>2.0-2.5
>2.5-3.0
>3.0-3.5
>3.5-4.0
>4.0-4.5
Pillar Width to Height Ratio

Figure 10

UCS Test Results on Coal Samples (Das, 1986)

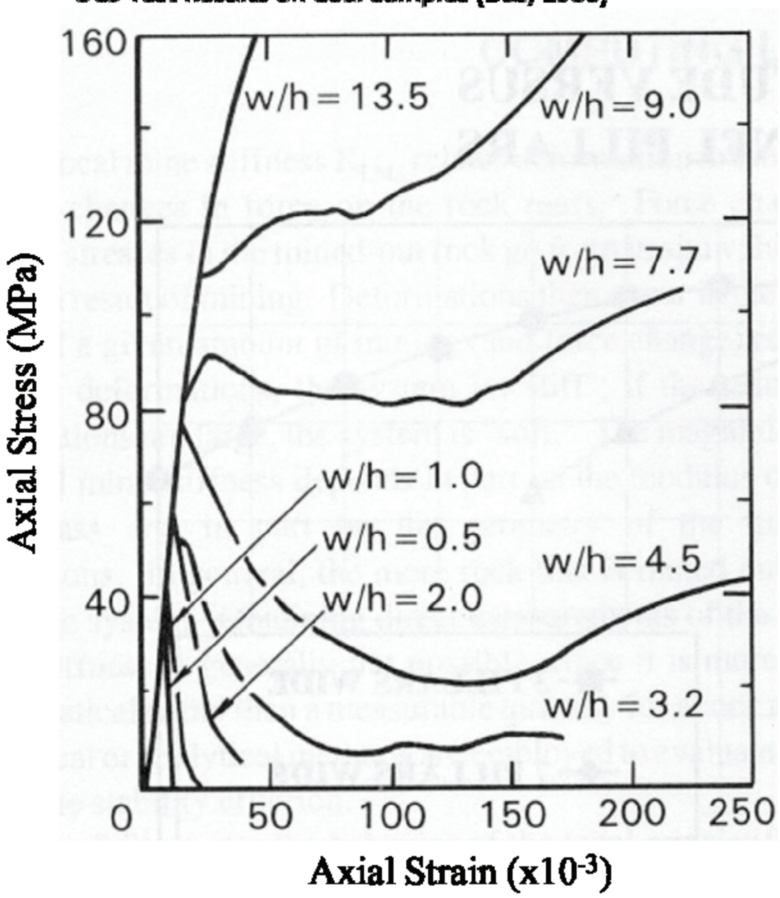
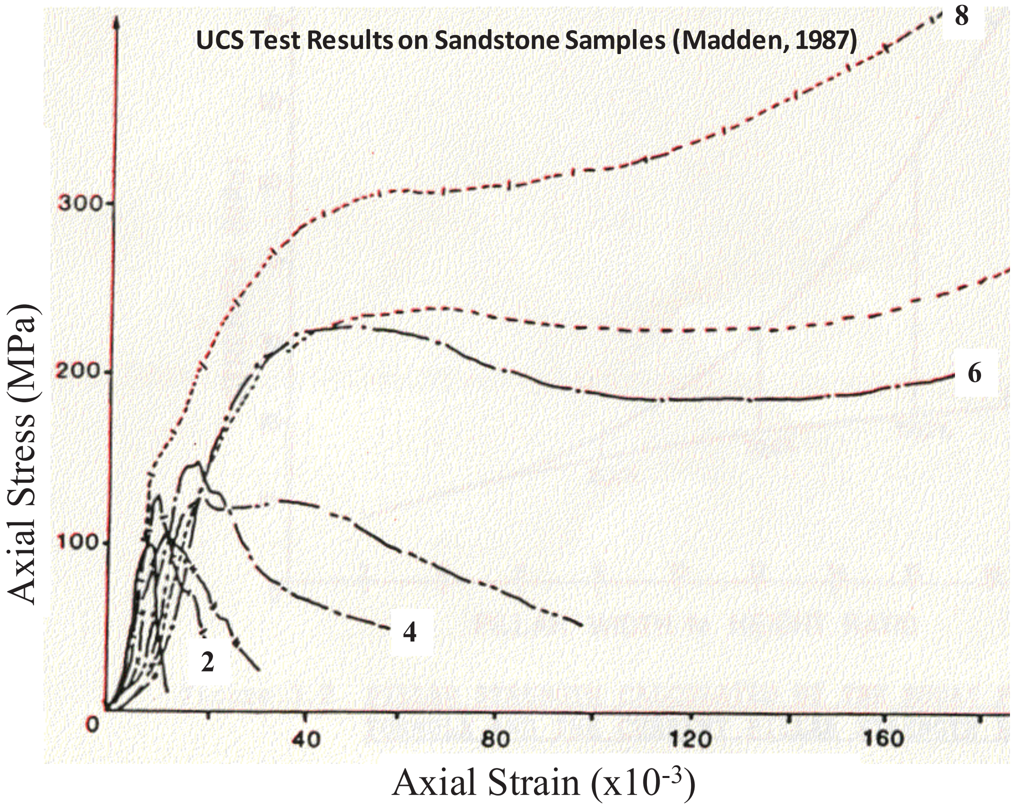


Figure 11



UCS Test Results on Sandstone Samples (Madden, 1987)
Axial Stress (MPa)
300
200
100
0
40
80
120
160
Axial Strain (x10-3)
8
6
4
2

Figure 12

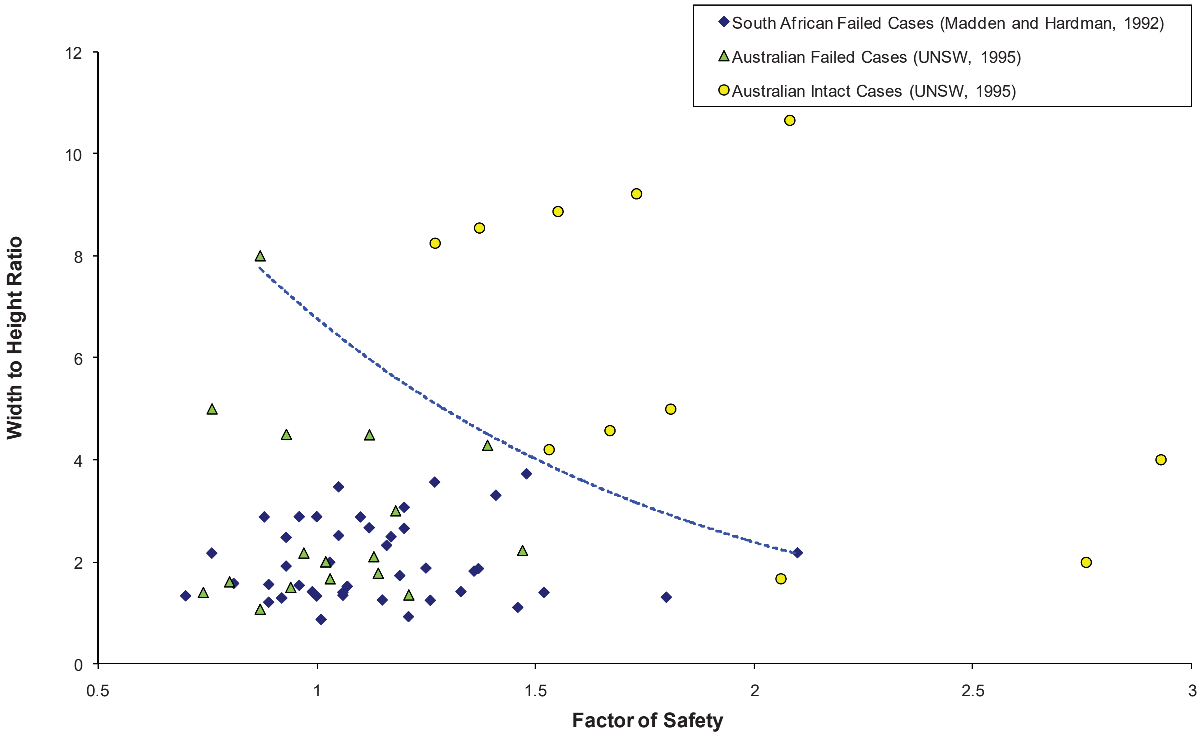
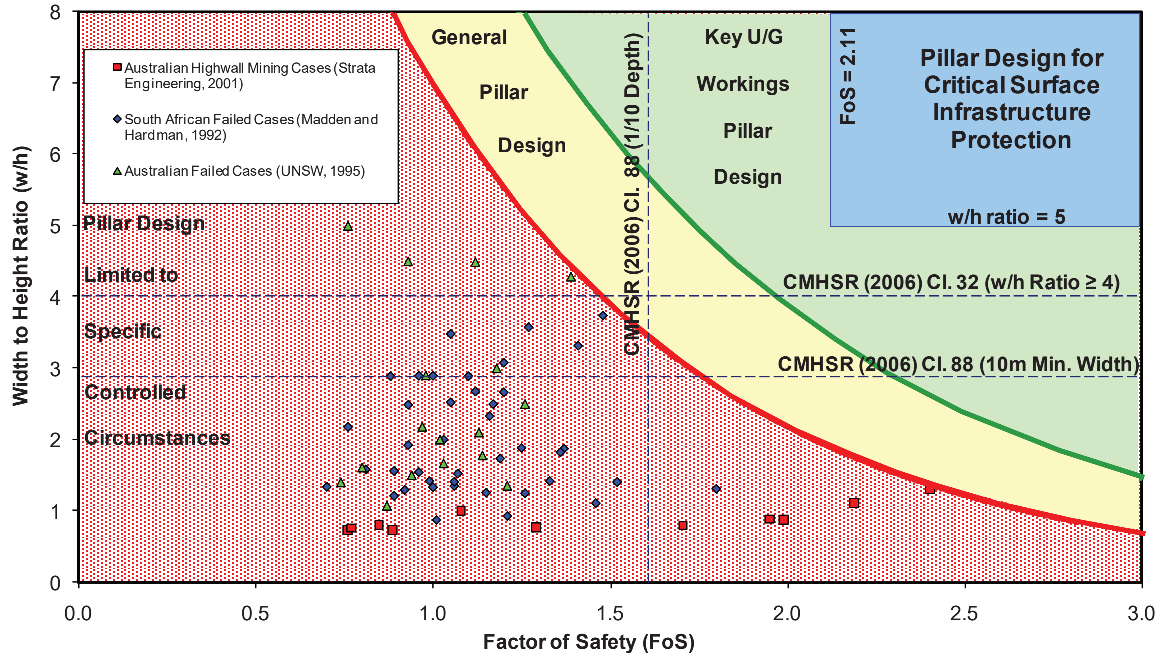
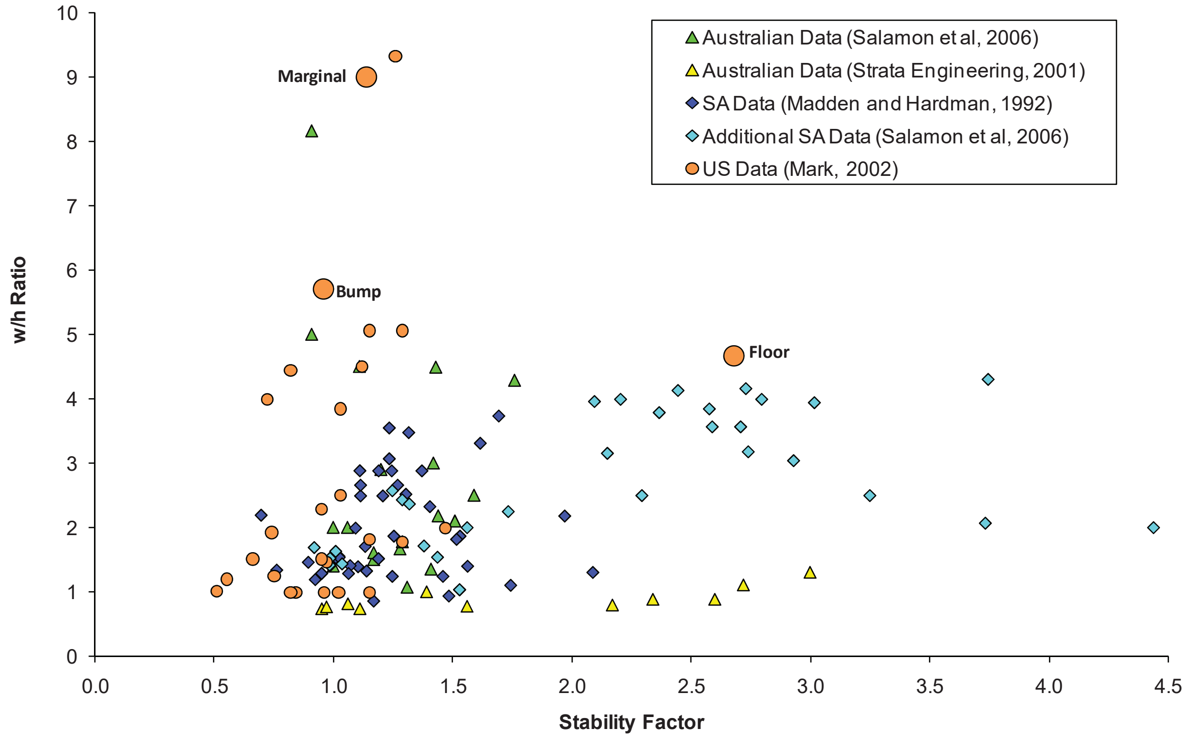

South African Failed Cases (Madden and Hardman, 1992)
Australian Failed Cases (UNSW, 1995)
Australian Intact Cases (UNSW, 1995)
Width to Height Ratio
Factor of Safety
0
2
4
6
8
10
12
0.5
1
1.5
2
2.5
3

Figure 13



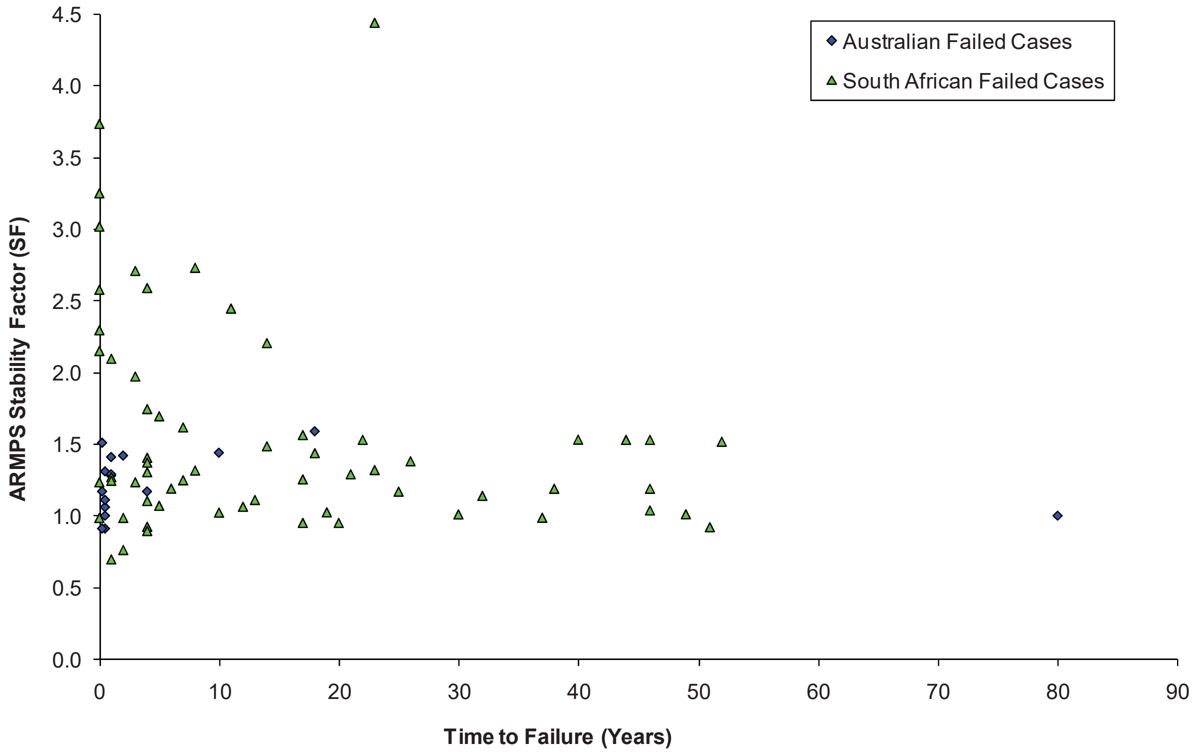
Width to Height Ratio (w/h)
Factor of Safety (FoS)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
1
2
3
4
5
6
7
8
Australian Highwall Mining Cases (Strata Engineering, 2001)
South African Failed Cases (Madden and Hardman, 1992)
Australian Failed Cases (UNSW, 1995)
Pillar Design Limited to Specific Controlled Circumstances
General Pillar Design
Key U/G Workings Pillar Design
FoS = 2.11
Pillar Design for Critical Surface Infrastructure Protection
w/h ratio = 5
CMHSR (2006) Cl. 88 (1/10 Depth)
CMHSR (2006) Cl. 32 (w/h Ratio ≥ 4)
CMHSR (2006) Cl. 88 (10m Min. Width)

Figure 14



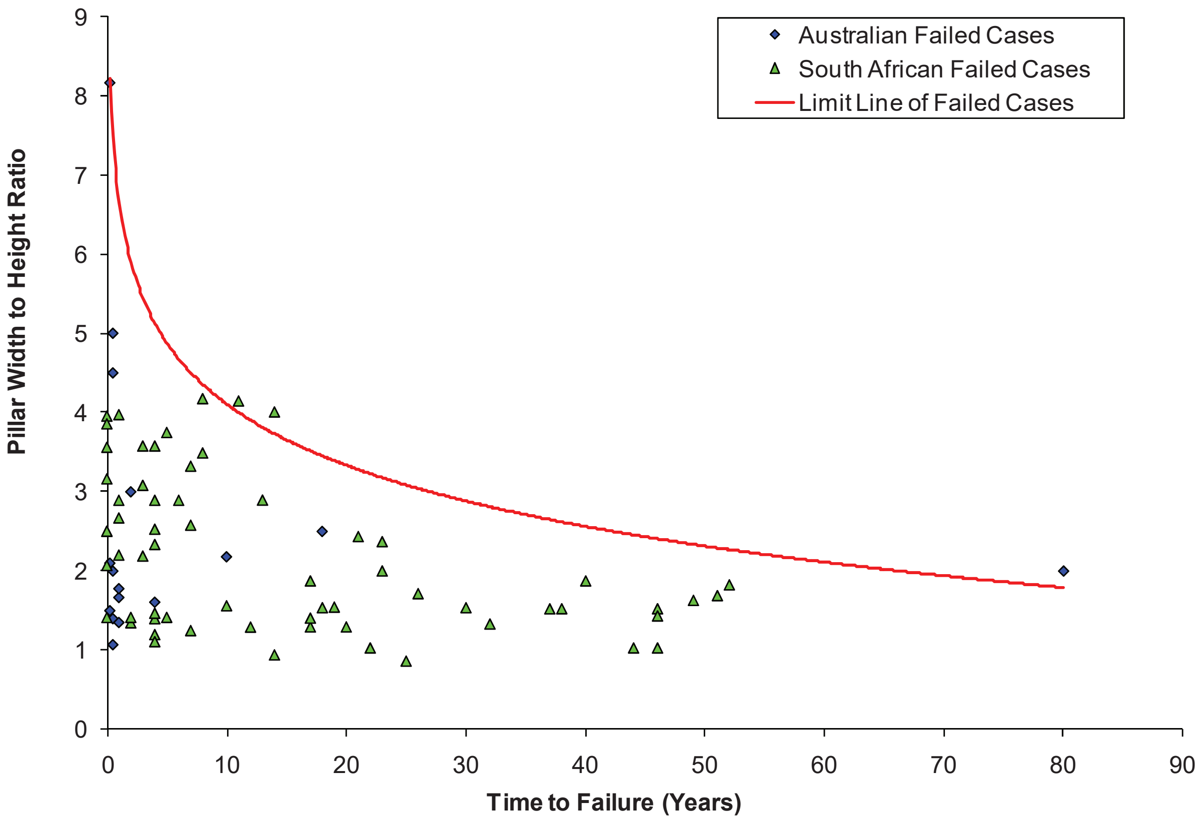
w/h Ratio
Stability Factor
Marginal
Bump
Floor
Australian Data (Salamon et al, 2006)
Australian Data (Strata Engineering, 2001)
SA Data (Madden and Hardman, 1992)
Additional SA Data (Salamon et al, 2006)
US Data (Mark, 2002)
0
1
2
3
4
5
6
7
8
9
10
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5

Figure 15



Australian Failed Cases
South African Failed Cases
ARMPS Stability Factor (SF)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
Time to Failure (Years)

Figure 16


Australian Failed Cases
South African Failed Cases
Limit Line of Failed Cases
Pillar Width to Height Ratio
Time to Failure (Years)
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
70
80
90

Appendix B: Extract from SCT (2018)

The Stability Index approach is based on the widely used pillar design approach of comparing load against an estimate of pillar strength. The load is calculated as the weight of overburden strata tributary to the pillar. Pillar strength is estimated using a formula that varies linearly with pillar width to height ratio.

The difference with the Stability Index approach is that the pillar strength formula was based on an arbitrarily chosen variant of Bieniawski's pillar design formula so as not to be confused with Factor of Safety and to step away from debates that were occurring at the time as to which pillar design formula was the best. The ratio of nominal strength versus loading was compared to experience of surface subsidence above the various panels reviewed. In all but three of the panels reviewed, the panels were of supercritical width. In supercritical width panels, surface subsidence clearly reflects pillar stability.

The variant of the Bieniawski pillar formula used in the Stability Index approach is:

$$Q_P = 8\ (0.64+0.36\ W/H)$$

where Q_P is the nominal pillar strength, W is the pillar width and H is the mining height. No allowance is made for pillar shape but it is common practice for individual pillars in partial panels to be square or very nearly so.

Tributary area loading is calculated on a plan area basis. The overburden density is assumed to be 2,500kg/m^3. In most cases, the tributary area load is calculated on the basis that the overburden strata is able to fully bridge across the extracted panels. This approach is valid where there is significant conglomerate strata in the immediate roof and the void widths are less than about 70m. An allowance for caving can be made when caving is expected to occur.

Abutment loading adjacent to a fully extracted goaf or area of failing pillars is calculated using the approach described in **Mills (2001)**. Total abutment load is estimated based on the weight of a triangle of overburden strata extending from the goaf edge to a point indicated by subsidence monitoring experience as the furthest distance at the surface that can be supported on the abutment. In practice, this distance is typically observed to be in the range 0.6-0.7 times depth. This total abutment weight is then distributed over the abutment pillars based on SCT's experience of monitoring experience of the stress distributions about goaf edges at multiple sites.

Given the generally regular layout of partial extraction panels used in the Southern Lake Macquarie area, a representative Stability Index can be calculated for each row of pillars. Alternatively, the nominal load bearing capacity of each individual pillar can be calculated and compared for the full row or for more irregular geometries. For a regular row of pillars, there is no difference and both approaches were used to develop the database presented in **SCT (1993)**.

The Stability Index is calculated using representative pillar geometries for each row. Pillar instability is observed to initiate in areas of low Stability Index and to propagate outward from there. Occasional larger pillars or small remnant stooks are typically ignored in the calculation of Stability Index because at the scale of the panel they do not contribute significantly to estimating the stability of the pillar system where a domino type failure process can develop. Although larger individual pillars can contribute more load bearing while all other pillars remain stable, their effectiveness at preventing failure of the overall system is limited should the more regular groups of pillars become overloaded.

Experience of using the Stability Index approach to compare observed subsidence behaviour with pillar stability is summarised in **Table 1** and **Figure 3** reproduced from **Figure 6** in **SCT (1993)**.

Table 1: Summary of Stability Index as an Indicator of Subsidence Behaviour in the Southern Lake Macquarie area.

Stability Index Range	Subsidence Experience
< 2.0	Subsidence event occurs soon after mining with maximum subsidence in the range 0.25 to 0.36 times mining height
2.0-2.5	Subsidence event occurs after some time. Perceptible surface movements are typically evident at an increasing Rate prior to a rapid acceleration and onset of a subsidence event.
2.5-4.0	Ongoing movements are evident at very slow rates but stability is maintained at least for some decades. Panel stability is not sufficient to control or halt the progress of subsidence associated with nearby instability or goaf creation (e.g. Sites 20 & 21).
>4.0	Low level subsidence in the order of 0.02 times seam thickness is evident but long term stability is maintained and adjacent subsidence events are able to be controlled.

It should be recognised that the Stability Index approach is only a guide to allow past experience to guide future expectations of pillar behaviour. It is not a design methodology as such and should not be regarded so. The claystone materials that exist within the floor strata below pillar systems in the Southern Lake Macquarie area is known to deteriorate with time. Any long-term assessment of stability needs to recognise this deterioration.

Appendix B

Groundwater assessment

Memorandum

EMM creating opportunities
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E info@emmconsulting.com.au
www.emmconsulting.com.au

30 April 2019

To: Great Southern Energy Pty Ltd (trading as Delta Coal)
From: Doug Weatherill
Subject: Chain Valley Colliery Modification 3: Groundwater impacts of mining method change

1 Introduction

Chain Valley Colliery (CVC) is an underground coal mine approximately 60 km south of Newcastle in New South Wales. The mine is at the southern end of Lake Macquarie and extends underneath the lake.

CVC is seeking approval to modify development consent SSD 5465 under Section 4.55(1A) of the *Environmental Planning and Assessment Act 1979* (EP&A Act) to allow the following:

- the transport of product coal from CVC to the neighbouring Mannering Colliery (MC) via an approved underground linkage at a rate up to the annual production level approved under SSD-5465, as modified. The current approved rate of product coal transport is 1.3 million tonnes per annum (Mtpa);
- a change in the definition of 'first workings' in SSD-5465 to allow the use of bord and pillar mining methods within the approved consent boundary; and
- replacement of the development layout figure in Appendix 3 to SSD-5465.

The following memorandum outlines the results of a semi-quantitative groundwater assessment of the potential groundwater impacts related to the proposed change of mining method from miniwall to a bord and pillar style first workings method. This work forms part of the environmental assessment being conducted to support the application to modify CVC's development consent.

Specifically, the objective of this groundwater assessment is to identify whether impacts to the groundwater system from the use of a bord and pillar mining method are substantially the same as for the development originally approved under CVC's development consent.

2 Method and model design

A first workings bord and pillar mining method involves the formation of roadways and pillars that are geotechnically designed to be long term stable, resulting in negligible subsidence effects (ie vertical subsidence of ≤20 mm).

Given that negligible subsidence above the mined coal seams is associated with a bord and pillar mining method, an approach was adopted whereby potential groundwater impacts were identified by comparing modelled groundwater inflows to a section of mine for the approved miniwall mining method and for the proposed first workings mining method. These "type models" are largely based on the modelling conducted by Geoterra (2013) but do not simulate the full-scale geometry or transient operation of the life of the mine. Instead, they are simplified to simulate potential inflow to a generic mined section of the Fassifern Seam, regardless of exact location and timing within the mine footprint and schedule. This method allows a comparative assessment of the two mining methods. The modelling presented in this study best aligns with a Class 1 model as described in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

The model employs the MODFLOW-USG (Panday et al, 2013) simulation code via the Groundwater Vistas version 7 (Environmental Simulations Incorporated) graphical interface.

A model domain of 20 km east-west by 20 km north-south was employed in order to be sufficiently large so that the model boundaries would not significantly influence the outcomes around the mining area. The domain was discretised by 200 m by 200 m model cells regionally with refinement to 12.5 m by 12.5 m in the vicinity of the modelled mining operations. Cell refinement employed the quadtree mesh technique for unstructured grids. This enables reduced model computational time and file sizes when compared with a structured grid as employed in standard MODFLOW codes.

Model layers were assigned to represent the hydrostratigraphy as per GeoTerra (2013) but, for simplicity, layers were assigned to be horizontal with uniform thickness based on the lithological log of bore JCV3. Layer thicknesses are documented in Table 2.1.

A River (RIV) package boundary condition was assigned uniformly across the model surface with head assigned 2 m below topography to simulate the potential for seepage into underlying strata from Lake Macquarie. River bottom elevation was set at the base of the cells (8 m below topography and 6 m below the assigned head) and a conductance of 2500 square metres per day (m^2/d) was assigned based on regional cell widths and lengths of 200 m, sediment thickness of 8 m and the calibrated vertical hydraulic conductivity of Lake Macquarie sediment of 0.5 metres per day (m/d) reported by GeoTerra (2013).

Constant Head (CH) boundary conditions were assigned around the model edges, in all model layers except layer 1, with hydraulic head set 2 m below ground surface.

Recharge from rainfall and evapotranspiration were not simulated explicitly.

For the purpose of comparing potential groundwater impacts of the miniwall and first workings only mining methods, the proposed first workings were simulated using the Drain (DRN) package. Drain stage was set 0.5 m above the base of the Fassifern Seam and a conductance of 10,000 m^2/d was assigned to ensure the seam was dewatered to the desired drain stage elevation.

Hydraulic conductivity values used by GeoTerra (2013) were calibrated in steady state against hydraulic head measurements from 10 groundwater monitoring bores and used to make steady state predictions of impacts of mining on the groundwater system. The calibrated "host rock" horizontal and vertical hydraulic conductivities presented by Geoterra (2013) were adopted for this study (see Table 2.1).

Geoterra (2013) documented modelled hydraulic conductivity values assigned to the goaf and fracture zones that occur following mining (see Table 2.1). The goaf zone is the region of collapse within and immediately above the mined coal seam. Above this zone, fracturing can propagate upward towards the ground surface, increasing the bulk hydraulic conductivity of the relevant stratigraphic units. The height and extent of fracturing depend on several factors, including the properties of the strata and the geometry of the mined sections. The GeoTerra (2013) properties for fracturing above the Fassifern Seam were adopted for "scenario 1: miniwall". Fracture zone properties were assigned to the mined area and that directly above and below for the proposed bord and pillar workings. GeoTerra (2013) also documented modelled increased specific yield for the mined sections of coal seam. However, it should be noted that both specific yield (unconfined storage) and specific storage (confined storage) have no impact on groundwater flows or pressures in steady state simulations. Therefore, the values assigned for these properties are irrelevant.

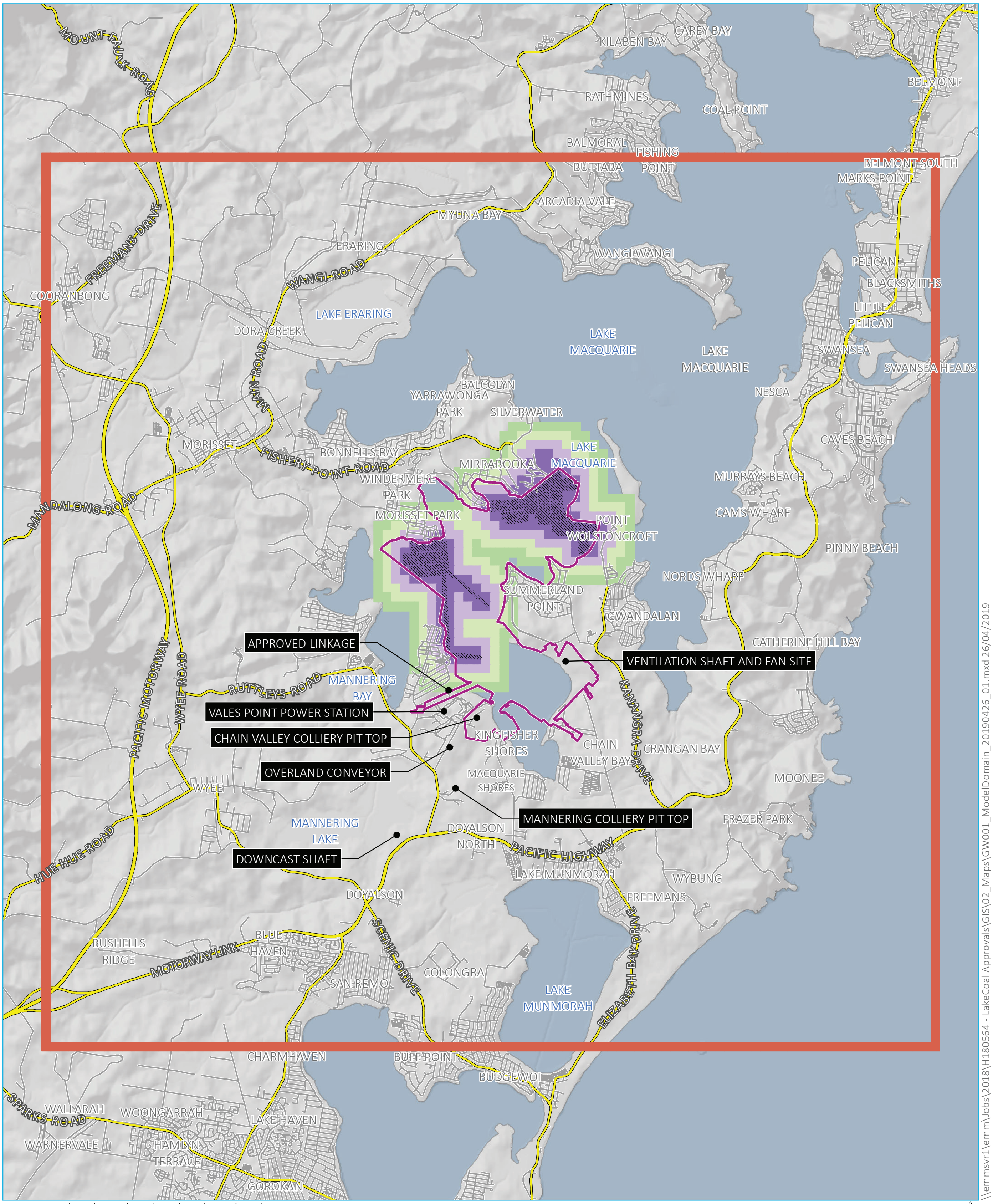
A second miniwall scenario was developed, based on the parameters adopted for scenario 1 but with one modification. Geoterra (2013) decreased the vertical hydraulic conductivity of model layer 3 (Triassic Narrabeen Group) from 6×10^{-4} to 5.5×10^{-5} in the fracture zone above the mine workings. This is inconsistent with the now generally accepted conceptual understanding of the impact of fracturing and/or subsidence above mine workings. Hence, "scenario 2: miniwall – no k reduction" was developed in which all other fracture zone hydraulic properties were simulated as per GeoTerra (2013) but the vertical hydraulic conductivity of model layer 3 (Triassic Narrabeen Group) was maintained at 6 x 10^{-4} m/d.

"Scenario 3: bord and pillar" simulates the proposed first workings mining method with the assumption that long-term stable pillars will be left in place such that negligible subsidence or fracturing will occur above the mine workings. This scenario maintains all hydraulic conductivities at the GeoTerra (2013) calibrated host rock values (see Table 2.1).

Table 2.1 Modelled hydraulic properties, based on Table 4.1 and supporting text in GeoTerra (2013)

			Geoterra (2013) calibrated host rock		Geoterra (2013) Fassifern Seam miniwall fracture zone		"No k reduction" Fassifern Seam miniwall fracture zone		Fassifern Seam bord and pillar (no fracturing)	
Model layer	**Lithology**	**Layer thickness (m)**	**kh (m/d)**	**kv (m/d)**	**kh (m/d)**	**kv (m/d)**	**kh (m/d)**	**kv (m/d)**	**kh (m/d)**	**kv (m/d)**
1	Alluvium		5×10^{-1}	1×10^{-2}	5×10^{-1}	1×10^{-2}	5×10^{-1}	1×10^{-2}	-	-
	Colluvium		2×10^{-1}	1×10^{-4}	2×10^{-1}	1×10^{-4}	2×10^{-1}	1×10^{-4}	-	-
	Lake Macquarie Sediment	8	5	5×10^{-1}	5	5×10^{-1}	5	5×10^{-1}	5	5×10^{-1}
2	Triassic Narrabeen Group	83	1×10^{-2}	3×10^{-5}	1×10^{-2}	3×10^{-5}	1×10^{-2}	3×10^{-5}	1×10^{-2}	3×10^{-5}
3	Triassic Narrabeen Group	3	1×10^{-3}	6×10^{-4}	2×10^{-3}	***5.5×10^{-5}***	2×10^{-3}	***6×10^{-4}***	1×10^{-3}	6×10^{-4}
4	Permian Overburden	21	1×10^{-2}	2×10^{-4}	2×10^{-2}	1×10^{-3}	2×10^{-2}	1×10^{-3}	1×10^{-2}	2×10^{-4}
5	Wallarah Seam	2	1×10^{-2}	1×10^{-3}	2×10^{-2}	2×10^{-3}	2×10^{-2}	2×10^{-3}	1×10^{-2}	1×10^{-3}
6	Teralba Conglomerate	62	1×10^{-3}	1×10^{-3}	2×10^{-3}	1×10^{-3}	2×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}
7	Great Northern Seam	1	1×10^{-2}	1×10^{-3}	2×10^{-2}	5×10^{-3}	2×10^{-2}	5×10^{-3}	1×10^{-2}	1×10^{-3}
8	Awaba Tuff	10	1×10^{-4}	5×10^{-4}	2×10^{-4}	5×10^{-2}	2×10^{-4}	5×10^{-2}	1×10^{-4}	5×10^{-4}
9	Awaba Tuff	11	1×10^{-4}	1×10^{-5}	2×10^{-4}	5×10^{-2}	2×10^{-4}	5×10^{-2}	1×10^{-4}	1×10^{-5}
10	Fassifern Seam	6	1×10^{-2}	1×10^{-3}	2×10^{-2}	5	2×10^{-2}	5	1×10^{-2}	1×10^{-3}
11	Basal Layer	93	1×10^{-5}	1×10^{-6}	2×10^{-5}	3×10^{-6}	2×10^{-5}	3×10^{-6}	1×10^{-5}	1×10^{-6}

Notes: 1. Geoterra (2013) modelled values for host rock and Fassifern Seam fracture zone taken from Table 4.1 and supporting text.
2. Errors/inconsistencies were found between Table 4.1 and the supporting text in GeoTerra (2013). Where descriptive text outlined an approach or value this was adopted, and it was assumed the value/s entered in the table were erroneous.



Source: EMM (2019); DFSI (2017); GA (2011); CVC (2019)

0 2.5 5 km

GDA 1994 MGA Zone 56

N

KEY

- Chain Valley Colliery development consent boundary
- Main road
- Local road
- Drain (DRN) boundary condition
- Constant head (CH) boundary condition
- Cells refined to 12.5 m by 12.5 m
- Cells refined to 25 m by 25 m
- Cells refined to 50 m by 50 m
- Cells refined to 100 m by 100 m

Model domain, grid and boundary conditions

Chain Valley Colliery
Modification 3
Figure 2.1

EMM
creating opportunities

3 Predictive modelling results

Results of the three scenarios are presented in Figure 3.1. Scenario 1: miniwall, using GeoTerra (2013) hydraulic properties to simulate fracturing occurring above and below the simulated mine workings results in modelled steady state inflow to the workings of 1,221 kilolitres per day (kL/d). Scenario 2: miniwall, which used the same fracture zone properties as scenario 1 but with no reduction in hydraulic conductivity, resulted in the highest modelled inflow (as expected) of 1,227 kL/d. Scenario 3, representing the bord and pillar mining method, assumed to cause no fracturing, resulted in the lowest modelled inflow of 1,198 kL/d.

As a proportion of scenario 1 (Geoterra, 2013 fracture zone properties) a change in mining method from miniwall, with a fracture zone, to first workings only, with an assumption no fracturing, results in a 1.9 % reduction in predicted steady state inflow to the mine workings. When compared to scenario 2 (the highest modelled inflow) this reduction increases to 2.3 %. Therefore, the presence or absence of a fracture zone associated with mining of the Fassifern seam has little impact on the modelled inflow to mine workings.

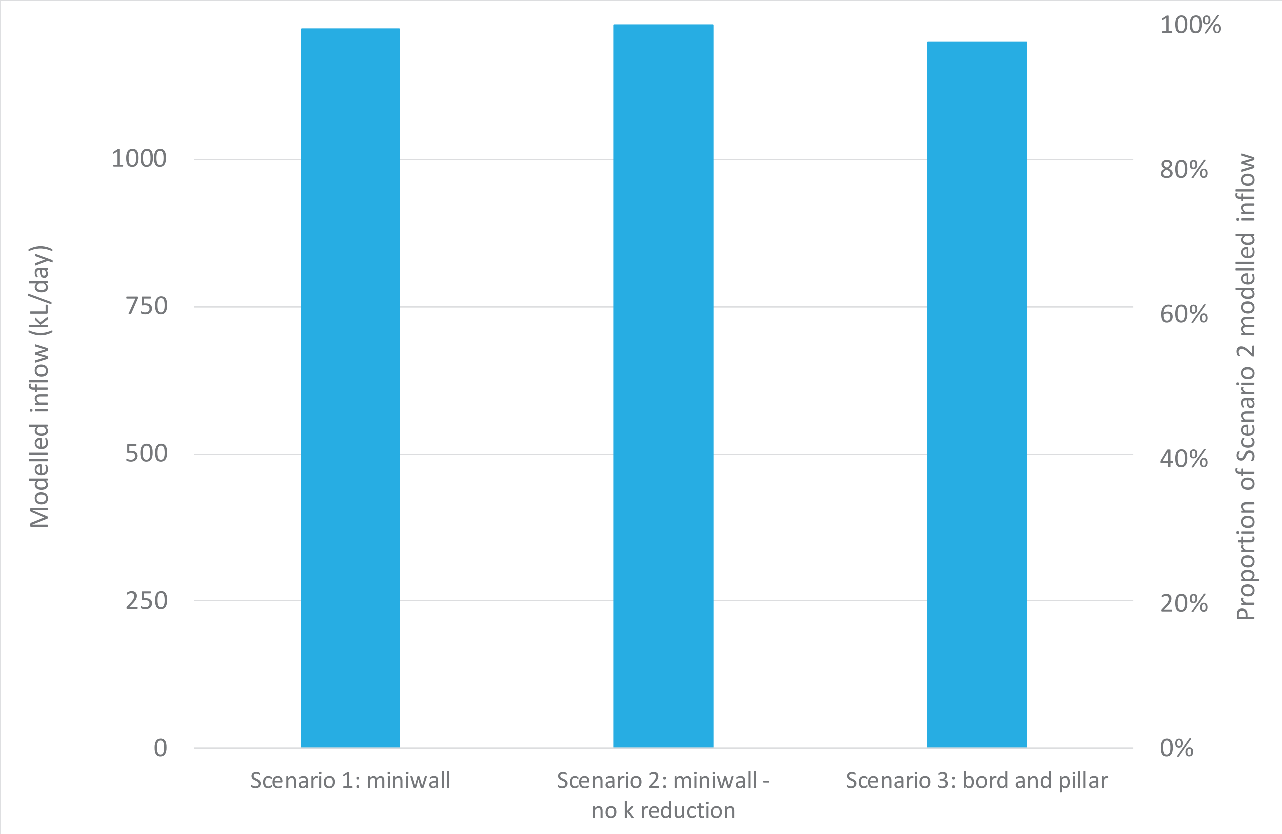


Figure 3.1 Modelled inflow for scenario 1: miniwall, scenario 2: miniwall - no k reduction and scenario 3: bord and pillar

4 Model limitations

The model scenarios presented in this study best align with a Class 1 model as described in the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). As such, the results are intended to provide comparative potential impacts of the two mining methods rather than absolute inflow volumes.

No field investigations were conducted as part of this study and, therefore, the modelled hydraulic properties were based solely on the calibrated hydraulic conductivity values presented by GeoTerra (2013). Properties were assigned uniformly within model layers, except in the modelled fracture zones. In reality, hydraulic properties will vary across the domain, affecting the propagation of impacts.

Model layers were assigned to be horizontal with uniform thickness, based on the log of bore JCV3. Hydrostratigraphic units will vary in thickness across the modelled domain, affecting the propagation of impacts and distribution of inflow to mine workings.

Predictions were made in steady state only and therefore do not provide any indication of the transient nature of potential impacts. In practice the mined areas will not be dewatered indefinitely.

5 Summary and conclusions

Numerical groundwater modelling has provided an indicative assessment of impacts of the difference between employing a miniwall mining method and a proposed first workings bord and pillar mining method at CVC. Provided the bord and pillar mining method maintains hydraulic properties of the host rock at their current estimated values, results suggest a reduction in groundwater inflows to mine workings of around 1.9 % to 2.3 % compared to a miniwall mining operation. Importantly, the proposed change in mining method from miniwall to a bord and pillar style first workings is not expected to cause an increase in impacts to the groundwater system.

6 References

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Yours sincerely

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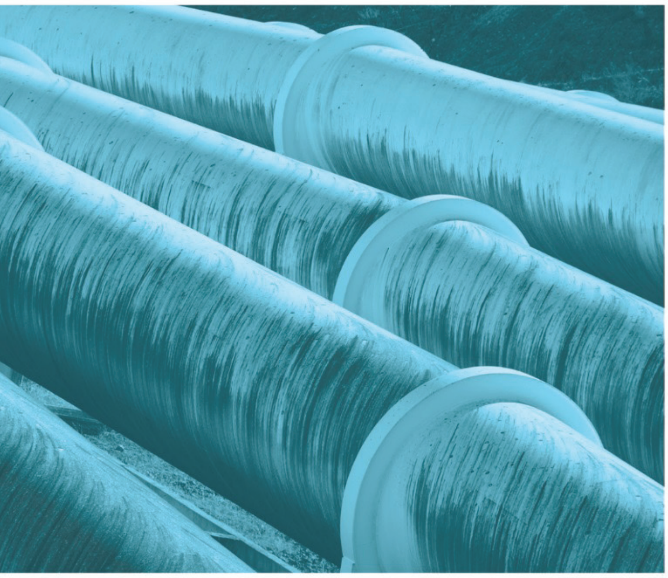

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