University of Southern Queensland

Faculty of Health, Engineering and Sciences

Retrospective Resilience of Jamberoo Mountain Road

A dissertation submitted by:

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Abstract

Kiama Municipal Council is responsible for the ongoing maintenance of Jamberoo Mountain Road, a regional road that links the Illawarra to the Southern Highlands. (*Delivery Program and Operational Plan* 2023). This road, like many along the Illawarra Escarpment, suffered from landslides due to the uncharacteristic rainfall in early 2022.

The repair of this road took a substantial amount of time, only reopening in July 2023, some 16 months after the rainfall period started, and impacted the community and Council operations heavily. To minimise the impact in the event of future heavy rainfall events, this dissertation was prepared.

In this study, reviews of the geology of Jamberoo Mountain Road and landslide repairs, both locally and internationally, have been undertaken. These repair methods were then assessed against a criterion developed with respect to the organisational challenges faced by Kiama Municipal Council, as well as, the geographical challenges of Jamberoo Mountain Road.

With the most appropriate design solution identified, a project scope was then developed and explained in chapter 5, along with a cost estimate and program of works for the repairs. These documents are included in the appendix.

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[redacted]

Bryce Hammond

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2. Introduction and Background

2.1. Background

Jamberoo Mountain Road, MR264, is a Regional Road that links the townships of Jamberoo and Robertson, on the south coast of New South Wales. Owned by Transport for New South Wales, and vested to Kiama Municipal Council for maintenance and renewal, this road exists to link state highways to local council managed roads, and was gazetted on 8 January 1884 ('CONFIRMATION OF A PARISH ROAD' 1891; *Schedule of Classified Roads and Unclassified Regional Roads* 2023). This road is one of four roads that link the Illawarra to the Southern Highlands, and then on the Hume Highway, emphasising the road importance to the community. The impact on the communities is very significant when the road is closed as travel between the coast and the highlands takes a greater amount of time and is more congested through the alternative routes. One segment of the road, approximately 6.7 kilometres long, from the intersection of Daltons Road to the Jamberoo Mountain Lookout, has a change in elevation of 537 metres. This segment is shown below in figure 1.

Figure 1: Aerial Image of Jamberoo Mountain Road segment - 11/03/2023

Along the Illawarra Escarpment landslides occur frequently on six of the seven major roads linking the Illawarra to the South Coast, Southern Tablelands, and Sydney regions. Records show that landslides have occurred in 1921, 1931, 1934, and more recently 2020 and 2022 on Jamberoo Mountain Road, where over 200 landslides occurred along the escarpment during the March and July events in 2022 (Flentje et al. 2022). These landslides are frequently caused by high rainfall events (Pierce et al. 2017).

The landslides that occurred in 2022 greatly impacted the transport network in the Illawarra region. Landslides had caused closures on Moss Vale Road, Jamberoo Mountain Road, Macquare Pass, and had damaged Mount Ousely Road, reducing traffic volumes. These roads are at least of regional significance, therefore carrying freight and the travelling public in and out of the region (*Schedule of Classified Roads and Unclassified Regional Roads* 2023).

The monthly rainfall for Jamberoo during March 2022 was 929mm, the highest recorded monthly rainfall for this station. Comparing this to a March mean of 194 mm shows the severity of the rainfall for March 2022 (Bureau of Meteorology, 2023).

Figure two shows the landslide that occurred in 2020 on Jamberoo Mountain Road, approximately 4452 metres past the Daltons Road intersection. Figure three shows the damage at site 3D, approximately 3417 from the Daltons Road intersection, during the 2022 rainfall events.

Figure 2: The 2020 Landslide on Jamberoo Mountain Road (Kiama Municpal Council, 2020)

Figure 3: Site 3D Jamberoo Mountain Road 2022 (Kiama Municpal Council, 2022)

Many of these landslides have not yet been repaired as of May 2023, as the roads have not been designed or constructed in a way that allows a quick recovery, and the road has not been constructed in a way that is resilient to natural disasters, such as, landslides.

2.2. Objective

Due to the effort, cost and disruption caused by landslides and their reactive repair, it is beneficial to research potential methods to reduce these impacts. That is, to determine the most practical and sustainable (financially and environmentally) solution to improve the resilience of the road, and therefore, reduce the closure period for reconstruction of Jamberoo Mountain Road following a natural disaster.

To do this, investigation and further understanding of the following is required:

- Determine the cause and type of landslides along the Illawarra Escarpment;
- Review available bore logs for Jamberoo Mountain Road and compare to other landslides in the region;
- Define ‘practical’ and ‘sustainable’ in the context of this paper;
- Analyse current proposed repairs from interviews and literature reviews;
- Consider which proposed designs fall in the above definitions;
- And select the most applicable design/s to increase resilience of Jamberoo Mountain Road to heavy rainfall events

2.3. Structure of the Document.

This document consists of five chapters that review and determine the solution/s to improve resilience to landslides on Jamberoo Mountain Road.

Chapter two contains a review of the geology of Jamberoo Mountain, what is believed to cause the landslides, introduces landslides that occurred at the same time in the

region, and describes the design solution presently being undertaken on Jamberoo Mountain Road and on other landslides across the region.

The third chapter defines ‘sustainable’ and ‘practical’ in the context of Kiama Municipal Council and Jamberoo Mountain Road; introduces and analyses resilient solutions; and, the methods to determine the most applicable design solutions.

In the fourth chapter I discuss the most appropriate design solutions to implement, as well as the scope, program of works and cost estimate to implement the solutions.

Chapter five contains the conclusion to the research, describes further research to be undertaken, and suggested improvements for this project.

3. Literature Review

3.1. Site Geology

The 6.7-kilometre segment of Jamberoo Mountain Road traverses five bedrock profiles, with recent landslides occurring on interbedded quartz-lithic sandstone, mudrock, carbonaceous claystone and coal, and Bong Bong basalt (Bowman 1974). However, the previously mentioned rock types did not fail, but the colluvium and imported fill overlaying the various rock layers slid at the interface between the soil and rock.

Geotechnical analysis undertaken in 2022 (Trani 2022) and geology mapping in 2020 (Trani 2020a) do not show any basalt through drilling or field observations.

Borehole investigation undertaken in 2022 shows layers of fill (likely to be imported road base or fill from cut when the road alignment was constructed), colluvium, and residual soil layers to a depth of 13 metres below the road surface. Rock layers become progressively less weathered sandstone or shale with increasing depth.

3.2. Impact of landslides

The impact of landslides on the local community, and larger region, was experienced during the closure period on Jamberoo Mountain Road, with the economic impacts summarised into three categories:

- Direct economic impacts
- Direct consequential economic impacts
- Indirect consequential economic impacts.

The direct costs result from the clean-up and repair of the landslide. Easy to estimate and track, these impacts are felt by government bodies that clean the debris flows and repair the infrastructure, as well as private residences, businesses and insurance companies, in the event that houses were damaged (Winter & Bromhead 2012). The direct economic impacts were:

- $61,494.30 for emergency clean up works;
- $105,640.50 for the construction of a temporary access road for resident access only;
- And, $1,681,779.67 quoted for public asset restoration, with a final cost of $2,372,608.56, including variations.

These costs impacted Kiama Municipal Council, who were then repaid by the Federal Government under the Disaster Relief Funding Arrangements (*Ordinary Meeting of Council, June 2023*).

Direct consequential economic impacts are caused by the increase in traveling time due to the road closure, and include changes in accident costs, carbon emissions and the delay to the road users. The costs for this impact were not calculated for this closure, however media articles and press releases from Kiama Municipal Council acknowledge the delays felt by residents, and thanks them for their patience (Zaucer 2023).

Businesses bore the brunt of the indirect consequential economic impacts, through loss of business and loss of staff. Media articles show that two businesses struggled to remain open during the 12-month closure, with one business closing. Jamberoo News Agency states that it lost between 20-25% of its daily customers due to the closure, and Nerilee Antiques had three customers a day on weekends, reduced from 30. (Zaucer 2023)

The environmental impacts of landslides are often overlooked, and have benefits and detriments to the natural environment, as well as having the potential for further socioeconomic impacts such as sediment contamination of drinking water (Geertsema et al. 2009).

The obvious environmental impact of landslides is the destruction of native flora, fauna and habitat. In the context of Jamberoo Mountain Road, this destruction has a higher than usual impact due to the environmentally sensitive land that is adjacent to the road reserve (Geertsema et al. 2009). The land zoning and importance will be discussed further in section 3.4.4 – environmentally sensitive.

There are positive environmental impacts caused by landslides, including the increase in plant diversity and therefore habitat diversity, as well as the creation of habitat in the form of fallen trees. The bare earth left by the landslide allows for various plants to establish, free from light competition from taller, well-established plants. Native grasses and shrubs provide a different habitat compared to taller eucalyptus trees (Gonzalez-Ollauri & Mickovski 2017).

3.3. Failure Causes and Comparison

It is indicated that both the 2020 and 2022 landslides had been caused by heavy and prolonged rainfall. In memos from SLR Consulting to Kiama Municipal Council (Trani, 2020). Trani specifically states that the slides are believed to have been caused by water pore pressure between the extremely weathered and impermeable sandstone layers, and the liquefaction of the colluvial soils above, along with uncontrolled surface water and erosion of the downhill embankment. The failure mode here is a complex sliding action (Trani 2022).

Bunkers Hill Road in Barrengarry, approximately 17 km east of Jamberoo Mountain Road, experienced a failure with a rotational slide and transitional sliding at the downhill face, caused by excess pore pressure between extremely weathered sandstone and colluvial soil. This scenario is very similar to failure mode described at site 3D on Jamberoo Mountain Road.

The proposed repair in this location is a bored pile retaining wall, which follows the same methodology of sites 3B and 3D on Jamberoo Mountain Road below (Gates 2022).

The Site 141 landslide is a landslide under Mount Ousley Road, a segment of the Princes Highway and the main road between Sydney and Wollongong. This slide is 34 km north of Jamberoo Mountain Road, is the largest landslide in the Wollongong Landslide Inventory at 720,000 m^3. This site experienced the same complex failure mode as Bunkers Hill Road. As Mount Ousley Road is a critical piece of infrastructure, linking Sydney to Wollongong, the management of this site is predominately real time

monitoring for early warning, taken at 50kPa pore pressure with movement likely at 60kPa, and the operation of nine dewatering wells (Pierce et al. 2017).

The heavy rainfall through March 2022 caused movement on Site 141, and revised the size of the landslide to 810,000m^3. The reactivated slide impacted the emergency stopping bay and arrestor bed in the southbound direction in the form of tension cracking. Tension cracking in the slopes downhill of Mount Ousley Road were mapped with heights up to 600mm, comparable to the height of the slump at Site 3D, Jamberoo Mountain Road. At the time of writing, one of the six lanes on Mount Ousley Road is closed (Flentje et al. 2022)

The proposed repair Transport for NSW is undertaking involves the installation of 140mm Horizontally Directional Drilled Drains (HDDs), a drainage system composed of slotted pipes in between the colluvial soil of the slip and the rock below. It is stated on the Transport for NSW website that this solution will make Mount Ousley Road more resilient to natural disasters, such as the March storms (*Mount Ousley Road natural disaster recovery repairs* | *Transport for NSW* 2023).

Figure four below show a simplified diagram, describing the construction process. This diagram was used as a part of Transport for NSW's community consultation. Figure five shows a snapshot of the detailed design plans for the installation of 12 HDD drains under Mount Ousley Road.

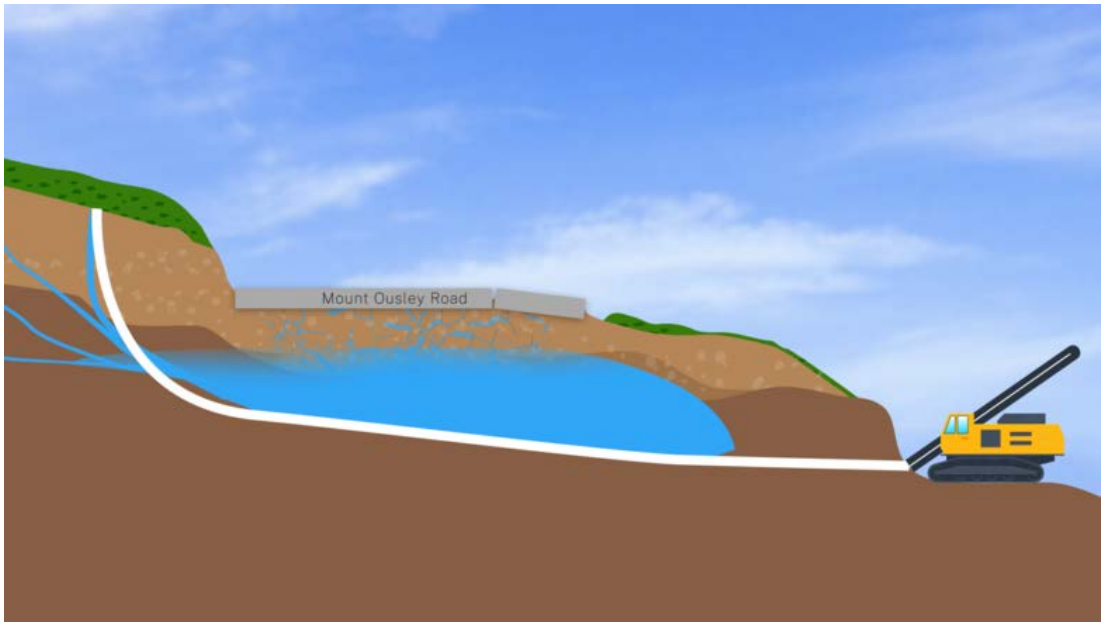

Figure 4: Diagram showing repair on Mount Ousley Road (Transport for NSW 2023)

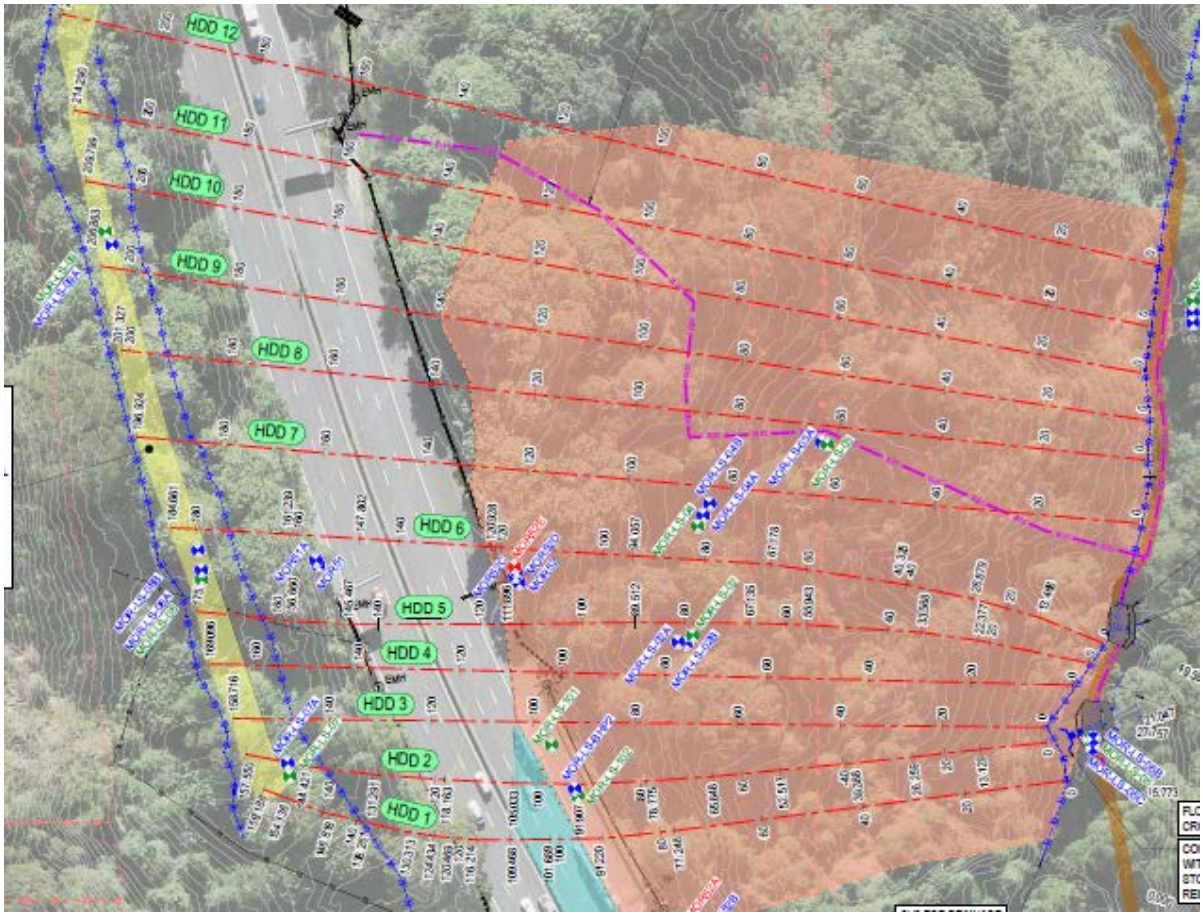

Figure 5: Detailed design showing 12 horizontal drains installed under Mount Ousley Road.

Macquarie Pass, the closest landslide to Jamberoo Mountain Road at 13 km north, was inspected and tension cracks were found on the 9th of March 2022. Flentje et al (2022) undertook analysis through LiDAR and found that this landslide dates back to 1851 and reacitivated due to over 1000 mm of rain in the previous 30 days. Geotechnical analysis was undertaken on Macquarie Pass to determine a design, and found that there was no bedrock encountered while drilling. This differs to Jamberoo Mountain Road where bedrock was found and could provide a suitbale anchor or socket for various desing solutions

The resulting remediation design constisted of benching the slope, providing more stabiliity to the slope and constructing a platform to work off, then backfilling with

150mm basalt rocks, draped in geofabric. The road pavement was then constructed on top. This repair was the quickest of the above repairs, completed in 24 days, but the cost associated with the repair would not be considered financially sustainable for Kiama Municipal Council to deliver along Jamberoo Mountain Road (Flentje et al. 2022)

3.4. Current Remediation Practices on Jamberoo Mountain Road

Figure 6: Aerial image showing the location of each failure.

To repair the landslides that occurred on Jamberoo Mountain Road in 2022, two separate design methodologies were prepared. The two separate design solutions were needed depending on the location of the failure, whether it was above the road, or below the road. Figure 66 above shows the location of the failures, with yellow markers indicating a failure above the road. Green markers indicate failures below the road.

Site 3A and 3C both contain slips that occurred above the road and did not damage or impact the structural components of the road. The material that slid onto the road was cleared away relatively quickly. As the vegetation collapsed during the slide, Site 3A and 3C were repaired using soil nails, that are passive bars inserted into the slope to resist the forces typically experienced in landslides, that is, bending moments, tensile forces and shear forces (Budania et al. 2016).

Sites 3B and D were slips that occurred below the road, resulting in structural damage to all road components. As indicated in Figure 3, a 600mm step occurred down the centreline of Site 3D. Site 3B had evident tension cracking along the outer wheel path, but the road surface had not slumped. These two sites underwent weighted assessment of the benefits of soil nails and stabilising piles, with piles being the preferred option by 0.5%. While the soil nails were cheaper to construct, the environmental impact of the nails was too great, in that they would lead to further destruction of vegetation.

3.4.1. Soil nail anchor system.

Figure 7: Cross section of design at site 3C (Trani 2022).

The soil nail solution involves the installation of soil nails at 2.5 metre spacing, and between three and 4.5 metre embedment for site 3C.

The purpose of soil nailing is to improve the slope stability by reducing the slip driving forces along the slip plane, and increase the force applied to the slip plane. The advantages of soil nailing as lope stabilisation include:

- Quick installation
- Cost effective in remote locations
- Are more redundant than anchored walls due to the number of nails.

Some disadvantages of soil nails include:

- The soil nails allow some flex to the embankment, which could impact utilities such as telecommunication, water and sewer.

- They are not suitable in locations where the soil cannot support itself during construction, such as course grained or clayey soils, or where groundwater is present (Budania et al. 2016).

These are used to attach steel mesh and Grassroots matting to the exposed slope. This method would require additional support to the road shoulder to repair a downslope failure, such as gabion rock baskets and a concrete capping beam, and was considered for sites 3B and D due to cost and construction time, however, the density of the remaining vegetation would have resulted in a challenging construction. The application of soil nails in a slope that is unstable but has not yet failed is possible.

3.4.2. Stabilisation piles with sleeper shutters.

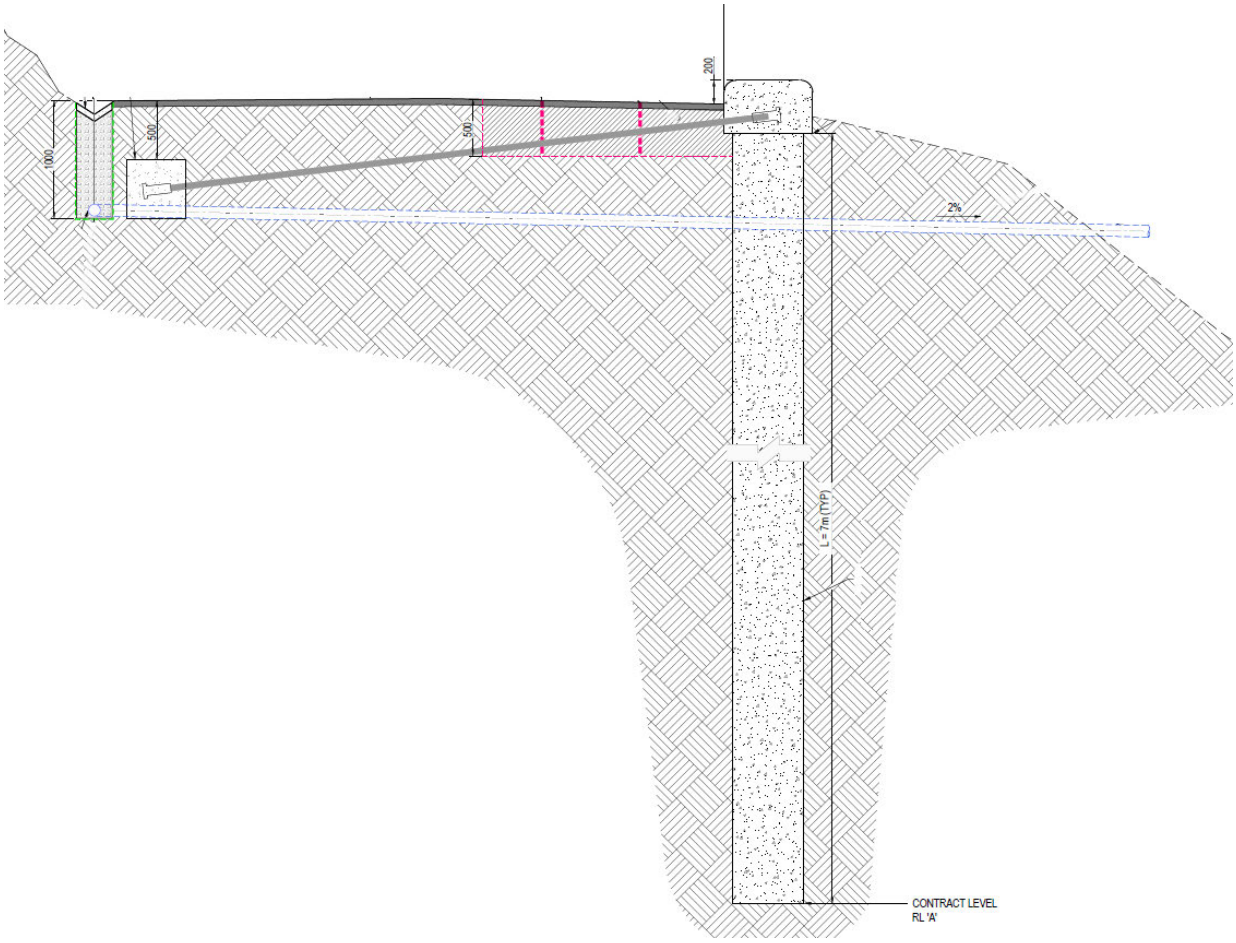

Figure 8: Cross section of design at site 3B (Trani 2022).

The chosen solution for sites 3B and 3D (indicated on figure 6) on Jamberoo Mountain Road was the installation of stabilising piles with sleeper shutter retaining system and

tie-backs to deadman anchor blocks. The piles had between seven- and eight-metre embedment, and a one-metre socket, into the extremely weathered material recovered from the geotechnical investigation.

While this option was estimated to be more expensive, the works were constrained to the road reserve with minimal slope work, the ease of construction and the minimal environmental impact.

3.5. Further research into landslide resilience

Significant research has been undertaken in the Wollongong region into the management of landslide risks at both a policy and land use/zoning level. Such research includes the development of a landslide inventory for the Northern Illawarra, including mapping of existing landslides in a Geographical Information System (GIS), and correlating the landslides with rainfall (Flentje 1998). This has been used to inform land zoning policies for Wollongong City Council, limiting the development that can occur in areas identified as landslide impacted or at risk. The inventory was expanded in 2005 to include the Illawarra escarpment, and in 2012 to cover the Sydney Basin (Flentje & Chowdhury 2005; Flentje et al. 2012).

This research aimed to minimise the impact of these landslides to residential property and increase the safety for the residents of the region, not the selection, design or construction of landslide resilient features.

The current landslide management methods based off the research mentioned in the above paragraphs indicate the region's willingness to accept and mitigate risks. Methods that follow this approach are cheap to implement and effective when it comes to infrastructure protection, and is one of the apexes for the willingness diagram in Figure 9. The other apexes indicate either the willingness to alter the environment, or the willingness to pay. (Winter & Bromhead 2012). Options towards the willingness to pay apex are considered most appropriate for Jamberoo Mountain Road, as simply the infrastructure already exists in the landslide prone area and it is unlikely to alter the alignment of Jamberoo Mountain Road to avoid further slips.

Figure 9: The willingness diagram, comparing different methods of landslide management and remediation (Winter & Bromhead 2012)

A report was authored by the Victorian Government in 1979 pertaining to landslides that affected 20 roads in the Shire of Narracan. This report outlined the causes of landslides in the region, and potential remedial measures. The natural causes for these slides were identified to be intense rainfall, pore water pressure in the soil, and fissures in the high clay soils allowing water infiltration. Human influences for the failure of the slopes were also attributed to cuttings in the slope, for road and railway construction, damming creeks and deforestation (Brumley 1979).

A rather pragmatic remedial approach was proposed from this report, composing of the following categories:

1. Avoid the landslide prone area: this is the approach focused on in the research undertaken in the Wollongong region.

2. Removal of unstable landslide material: this approach is considered for upslope failures that do not impact the structure of the road.
3. Reduction of instigating forces.
4. Increasing the resisting forces.

For option three, the factor of slope safety is increased by increasing drainage and reducing the pore pressure in the slope through improving surface and sub-surface drainage. The repair of Mount Ousley Road follows this repair principle through the installation of its HDD drains, but other solutions include slotted PVC pipe, no or low-fines concrete and vertical drains.

Electro-osmosis was also suggested in this study, where a voltage is applied to soil to produce a flow of water to reduce the pore pressure of the soil (Bjerrum et al. 1967). This approach is similar to the HDD drains installed under Mount Ousley Road, albeit a distinctly different methodology. However, the implementation of this to protect a 6.7-kilometre stretch of road is impractical and cost prohibitive. Tree planting to stabilise the slopes is also mentioned in the report. The vegetation assists in the reduction of soil pore pressure through the transpiration of ground water and the binding of the topsoil to prevent erosion. The replanting of trees removed during construction will be considered in the project scope for the construction phase of this project, however, with the dense vegetation shown in figures one, two and three, there is no benefit to undertaking additional tree planting. This repair and prevention approach is suitable for areas cleared of mature trees such as farmland.

Option 4 includes the construction of physical structures such as gabion basket retaining walls, piles, and soil nails, all of which have been mentioned earlier in this chapter. This option also lists methods of improving the internal strength and cohesion of the soil, such as chemical stabilisation.

In the location for which this report was created for, the soils have a high clay content and benefit from chemical stabilisation by mixing gypsum through the soil, improving the binding of the soil particles and improving the materials strength (Ahmed & Issa 2014). This was beneficial for the stabilisation of exposed embankments, such as post slip when the vegetation has been removed.

Comparing the willingness diagram to the Brumley report shows the development of landslide management methods in recent times, with the land use and zoning approach is a relatively new method of landslide management.

4. Methodology

4.1. Methodology Outline

1. Undertake a literature review to identify and understand the causes, and solutions, to the landslides on Jamberoo Mountain Road and the nearby escarpment.
2. Define ‘sustainable’ and ‘practical’ in the context of Kiama Municipal Council and Jamberoo Mountain Road; analyse resilient solutions introduced in the literature review; create an assessment methodology; and, determine the most applicable design solutions.
3. The successful solution will then be included in a scope of works, program of works and cost estimate.

The literature review undertaken on Jamberoo Mountain Road provides an understanding of the geology of the area and helps to provide direction into which design solutions are appropriate for the road. The review of landslides and their design solutions in the nearby area could provide options to improve the resilience. A wider literature review is to be undertaken, focusing on international resilient and resistant landslide designs to identify their strengths and ascertain if they can be implemented on Jamberoo Mountain Road.

With a completed literature review, an assessment and evaluation method to rank the design solutions previously introduced was developed. This took into consideration the estimated price of the solution, its ability to be maintained, resilience to storms, environmental impact, and residual risk to motorists and the community. The definitions around the assessable criteria are also developed and defined.

The design solutions were then assessed using the previously developed evaluation matrix, based on the information gathered in the literature reviews. Once assessed, the solutions were ranked, a project scope of works was developed for the targeted segment of Jamberoo Mountain Road using the most appropriate design solution, as well a multi-year program for the works, with a high priority assigned to sections of the

road with tension cracking and slip evidence. A cost estimate was also developed as part of the program of works.

4.2. Consequential effects of the project

This dissertation aims to reduce the consequences of landslides on Jamberoo Mountain Road. While this is a benefit to the community and connectivity in a resilient road, there may be some environmental impacts that occur due to the result of the research if implemented. This will be considered and assessed in detail through the pre-planning phase of the works using a review of environmental factors.

Impact may be experienced by residents adjacent to Jamberoo Mountain Road if works proceed. Due to the topography of Jamberoo Mountain, access to private property may need to be arranged during the pre-planning stages of the works project to undertake spatial survey, geotechnical inspections or to undertake physical works.

With the above considered, and the long-term benefits of the resilience and reduced closure periods of the road, the research will have a positive effect on Kiama Municipal Council as managers of the road, the Federal Government and taxpayers through reduced disaster repair payments, and the community of Jamberoo with an improved road providing robust and reliable accessibility in order to maintain economic, educational and social connections with neighbouring communities.

4.3. Safety considerations

The research and preparation of this dissertation do not produce any physical products, and as such, hazards are reduced. The risks applicable to this project are tabulated below and expanded upon in Appendix B – Risk Assessment.

Risk	Risk rating before management	Management	Risk rating after management

Extended periods of sitting	Low	Take regular breaks stand up and stretch muscles in the lower back	Very Low
Eye fatigue from long periods of looking at digital displays	Low	Implementation of the 20-20-20 rule to minimise digital eye strain	Very Low
Stress caused by extended periods of mental effort (12+ hours)	Low	Plan activities outside of work and research to alleviate stress. Implement planning to reduce stress	Very Low
Traffic during site inspections		Undertake site inspections during road closure periods or have traffic control onsite. Wear proper safety equipment	Low

Table 1: Risk summary

As site visits were undertaken after the initial development of the risk assessments, a review of the risk assessment in table 3 and in appendix A was undertaken to include the risk that traffic posed during the site inspection, and the remedial actions to mitigate that risk.

4.4. Sustainable definitions

4.4.3. Financially sustainable

Considering the last two years, and the current financial year, the roads and bridges capital budget of Kiama Municipal Council has been an average of $2,285,543 (*Delivery Program and Operational Plan* 2023) to maintain, renew or upgrade the roads and bridges across the local government area.

To ensure that other roads in the Kiama Municipality are still maintained to the communities expected level of service, and to ensure that the annual program of works is deliverable by Kiama Municipal Council staff, the annual budget for this project will be set at $450,000. It is assumed that grant funding, such as the Regional Road Block Grant, and the Regional and Local Road Repair Program, both administered by Transport for NSW, will also be dedicated towards this project, however as that is a competitive process, these funds will be used to accelerate the program, not any increase of scope (*Regional Road Block Grant* | *Transport for NSW* 2022; *Regional and Local Roads Repair Program* | *Transport for NSW* 2023).

This is a conservative approach, as it is likely that grant funding will be available for this project, and also likely that Council will vote to allow additional funding to be made available to improve the quality of the assets they maintain.

4.4.4. Environmentally sustainable

The identified stretch of Jamberoo Mountain Road that is susceptible to landslides is bounded by land zoned C1, C2 and C3 under the Kiama Local Environmental Plan 2011 (*Kiama Local Environmental Plan 2011*). These zones, C1 National Parks and Nature Reserves, C2 Environmental Conservation and C3 Environmental Management, have the purpose of protecting, managing, and restoring areas with either high or special ecological and aesthetic values. Therefore, while the landslide design solutions can be implemented in the road reserve as “development permitted without consent” under the NSW State Environmental Planning Policy (Transport and

Infrastructure) 2021 (*State Environmental Planning Policy (Transport and Infrastructure) 2021*), special consideration should be given to the environmental impacts of the design.

To be considered environmentally sustainable, the design solutions:

- should be as compact as possible, to stay within the road reserve where possible.
- should not cause further destruction to vegetation or native wildlife habitats.
- should not detract from the natural aesthetics of the area.

To ensure that the selected design solutions are environmentally sustainable, a Review of Environmental Factors will be undertaken, however this document is not a part of this research.

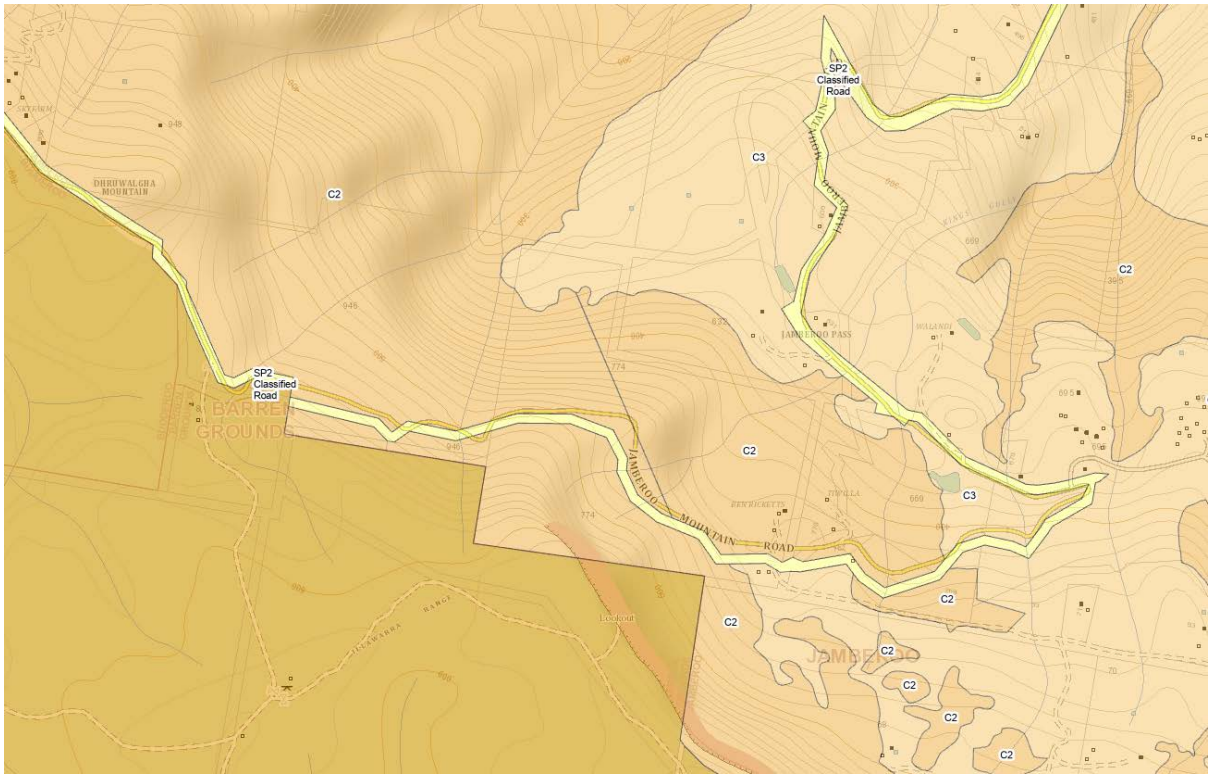

Figure 1010: Kiama Local Environmental Plan mapping showing Land Use Zones C1 (darkest), C2 and C3 (lightest) (NSW Planning Portal Spatial Viewer 2023).

4.5. Assessment and evaluation criteria

To evaluate the different design solutions, the below assessment criteria has been developed:

1. Resilience to storm events
2. Environmentally sustainable
3. Price of solution
4. Ability to be maintained
5. Safety of workers during construction

The scoring was determined by the author's onsite experience.

As the purpose of this research is to determine a solution to improve the resilience of Jamberoo Mountain Road to storm events and the resulting landslides, this criterion has the highest weighting at 35%.

The solutions are required to be environmentally sustainable, that is, the works are not to damage threatened ecological communities of vegetation or destroy the habitat of native animals. This category is weighted 20% of the total score.

Financial sustainability has also been considered, with solutions that fall within Council's current capital budget allocated to roads and bridges. This will be scored by comparing the solutions estimated price with the average price of all considered estimates from the submitted tenders for the 2022 Jamberoo Mountain Road restoration, as well as *Rawlinson's Australian Construction Handbook (2018)* with regional and inflation factors considered. As these tenders are considered confidential, the names of the tenderers will be redacted. This comparison will then be converted to a score out of 10 by normalising it. The price score is also worth 20% of the assessment.

With 15% of the weighting, the risk to workers during construction will also be considered. This is to ensure that whatever solution is implemented, that the safety of the workers improving the road is considered.

The final 10% of the evaluation criteria will be used to assess if the solution is maintainable.

Criteria	Weighting (Percentage)
Price	20%
Ability to be maintained	10%
Resilience to storms	35%
Environmental impact	20%
Safety during construction	15%

Table 2: Assessment criteria and weighting.

4.6. Potential solutions for improved resilience

From the literature review, six potential solutions have been selected for further investigation into their suitability to improve resilience on Jamberoo Mountain Road. They are:

- Increased drainage only – The construction of subsurface drains such as longitudinal subsoils, culverts, and concrete dish drains along the road edges to minimise water infiltration under the road pavement.
- Bored piles and sleeper shutters at identified locations – Similar to the approach at Site 3B on Jamberoo Mountain Road, bored piles with a retaining system. This will be implemented at locations identified that are at risk of impact from natural disasters.
- Soil nail anchor system at identified locations – Similar to the approach at Site 3C on Jamberoo Mountain Road, soil nails will be implemented at the same locations as above.
- Increased drainage and bored piles at select locations – this solution is a combination of the increased drainage and bored piles solutions above. This

will reinforce the identified at risk sections, while also minimising the risk to the road as a whole.

- Increased drainage and soil nails at select locations – Also a combination of the above solutions including drainage and soil nails at identified locations.
- Do nothing – No engineered solutions to be implemented, repairs to the road are to be reactive and funded under Disaster Recovery Funding Arrangements (*Disaster Assist Website* 2023).

While avoiding the landslide hazard as mentioned in Brumley (1979) and Winter and Bromhead (2012) is the most cost effective and technically effective option, it is an unfeasible approach for Jamberoo Mountain Road due to the residents of Jamberoo Mountain Road and Misty Lane. Access to the properties will need to be maintained, and therefore a road must follow this alignment.

4.7. Solution analysis

To effectively compare the costs for each of the six solutions, the four submitted tenders have been converted to a unit rate suitable for the item of work e.g., bored piles and sub-soil drains are converted to a per linear metre rate and pavement reconstruction and soil nailing is converted to per square metre rate. *Rawlinson's Australian Construction Handbook (2018)* was also considered, with the regional factor for the handbook applied, as well as applying the Producer Price Index 3109 Other Heavy and Civil Engineering Construction from September 2018 to June 2023 (*Australian Bureau of Statistics 2006-revision-2.0, 3109 Other Heavy and Civil Engineering Construction* 2006). These costs are then to be averaged, considered for each of the six potential solutions, then scored.

Tenderer 1:

	3A ($)	3B ($)	3C ($)	3D ($)	Additional works ($)
Surface drains					130/m
Subsoil drains					250/m
Piles (capping beam and guardrails		7,344/m		8,624/m	
Soil nails	1,206/m^2		519/m^2		
Vegetation repair					80/m^2
Pavement					550/m^2

Table 3: Tenderer 1 submitted prices for 2022 Jamberoo Mountain Road repair.

Tenderer 2:

	3A ($)	3B ($)	3C ($)	3D ($)	Additional works ($)
Surface drains					700/m
Subsoil drains					79/m
Piles (capping beam and guardrails)		7,527/m		13,825/m	
Soil nails	2,532/m^2		1,259/m^2		
Vegetation repair					25/m^2
Pavement					220/m^2

Table 4:Tenderer 2 submitted prices for 2022 Jamberoo Mountain Road repair.

Tenderer 3:

	3A ($)	3B ($)	3C ($)	3D ($)	Additional works ($)
Surface drains					353/m
Subsoil drains					263/m
Piles (capping beam and guardrails		5,582/m		7,670/m	
Soil nails	3,243/m^2		901/m^2		
Vegetation repair					
Pavement					

Table 5: Tenderer 3 submitted prices for 2022 Jamberoo Mountain Road repair.

Tenderer 4:

	3A ($)	3B ($)	3C ($)	3D ($)	Additional works ($)
Surface drains					160/m
Subsoil drains					154/m
Piles (capping beam and guardrails		9,385/m		13,537/m	
Soil nails	2,771/m^2		1,227/m^2		
Vegetation repair					
Pavement					166/m^2

Table 6: Tenderer 4 submitted prices for 2022 Jamberoo Mountain Road repair.

Rawlinson's Australian Construction Handbook 2018:

	2018 cost ($)	Regional increase factor (Wollongong)	Producer Price Index	2023 Wollongong Cost ($)
Surface drains	72.00	101%	122%	88.35/m
Subsoil drains	77.90	101%	122%	95.59/m
Pavement	58.90	101%	122%	72.28/m^2

Table 7: Rawlinson's Australian Construction Handbook 2018 cost estimates

Average costs:

Surface drains	$286.33/m
Subsoil drains	$168.40/m
Piles (capping beam and guardrails	$9,187.13/$m^2$
Soil nails	$1,707.77/$m^2$
Vegetation repair	$52.50/$m^2$
Pavement	$252.28/$m^2$

Table 8: Average costs for each portion of the six solutions

4.7.1. Cost scoring for all options

	Increased drainage only	Bored piles with sleeper shutter	Soil nail anchor system	Increased drainage and piles	Increased drainage and soil nails	Do Nothing
Surface drains	286			286	286	
Subsoil drains	168			168	168	
Piles (capping beam and guardrails		9,187		9,187		
Soil nails			1,707		1,707	
Vegetation repair			52		52	
Pavement		252		252		
Total	454	9,439	1,760	9,894	2,215	-
Average Fee	3,960	3,960	3,960	3,960	3,960	3,960
Price Score	188.5	-38.3	155.6	-49.8	144.1	200.0
Normalised Price Score	9.4	-1.9	7.8	-2.5	7.2	10.0

Table 9: Price score for each solution

4.7.2. Option 1 – Increased drainage only

The option to increase drainage would include, catch drains upslope of the road, 5 to 10 metres from the edge of the road, to reduce water infiltration to the upslope cutting that lead to existing culverts under the road; concrete v-drains on the upslope shoulder to catch water flowing off the cutting and subsoil drains, approximately one metre deep, filled with drainage aggregate, geotextile; and, 90mm diameter slotted PVC pipe to intercept any water below the surface of the road. Horizontal directional drilled slotted pipe will be installed at 13 metres below the road surface to reduce the landslide instigation pore pressure.

Based on similar projects and submitted tenders for the Jamberoo Mountain Road 2022 restoration, the estimated cost for this method is at $454.73 per linear metre of road, with surface drains at $286.33/metre and subsoil drains costing $168.40/metre. This solution has been given 9.4 out of 10 possible points, calculated using a normalised price score.

The maintenance of Jamberoo Mountain Road is currently treated as reactive, due to distance from the Kiama Municipal Council depot, and the available resources to Council. The increased drainage option will require additional maintenance if the horizontal drains do not achieve a self-cleaning velocity, as well as clearing of the catch drains. It is expected that there will be increased leaf litter in the culverts, due to the catch drains, that will reduce the effectiveness of the drainage systems uphill from the road. The concrete v-drains will also require cleaning by a street sweeper to improve the flow velocity and prevent unsafe flow widths. This has been given 3 out of 10 points for maintainability.

For this solution and its resilience to future natural disasters, it has scored 7 out of 10 points. The increase in drainage will improve the roads resilience by reducing the pore water pressure between the colluvial soil and rock layers, through the prevention of water infiltration. This solution is different to the other built solutions in that it aims to prevent the slide from happening, instead of resisting the slide action.

This solution is almost entirely retained to the road reserve with the exclusion of the catch drains, which will require vegetation removal for the optimum protection of the slope, resulting in a score of 7out of 10.

It will be difficult to undertake a full road closure for the construction of the various drainage systems, through the expectations for the community. As such, it is assumed that the construction of the subsoil and v-drain systems will be undertaken with one travel lane closed. Water filled barriers should be used in this circumstance, however the traffic still poses a risk to the workers onsite. Further to this, some machinery and worker will be required to construct the catch drain at the top of the upslope, potentially destabilising it when the drain is dug. This results in a score of 6 out of 10.

When the weightings are applied, the increased drainage option scores 6.9 out of 10.

Criterion	Weighting	Score
Price	20%	9.4
Ability to be maintained	10%	3
Resilience to storms	35%	7
Environmental impact	20%	7
Safety during construction	15%	6
Total		6.9/10

Table 10: Scores for option 1 - Increased drainage

4.7.3. Option 2 – Bored Piles with sleeper shutters.

Option 2 is the construction of bored piles with a sleeper shutter retaining system, to be constructed at locations identified as at risk of slipping, through visual inspection of longitudinal tension cracks. The piles are to be drilled and constructed to a depth that intercepts the slump failure to improve the slopes factor of safety. The retaining system is constructed to support the construction of, and ongoing pressures, of the road pavement. This solution resists the instigating forces of the slide and reduces the pressure of the batter of the slope. Deadman blocks with tiebacks and subsoil drains are also included in this solution but are limited to the identified weak spots.

The bored piles are expensive, with an average price of the summitted tenders for Jamberoo Mountain Road 2022 reconstruction project being $9,187.13 per linear metre. A one-metre-wide stretch of pavement reconstruction is included in this repair with a cost of $252.28 per linear metre. As the total price of $9,439.41 is more than double the average price of all solutions, it has resulted in a negative score for price, -1.9 out of 10.

As 90% of the structure is below the surface of the ground, the concrete piles have been given 8 out of 10 for their ability to be maintained. It is expected that the piles will not require any maintenance to maintain the stability of the slope, however some maintenance will be required to ensure motorists safety, such as replacement of guardrail or reflective chevrons.

The concrete piles are designed to stabilise the road above an existing slip, reducing the soil pressure on the downslope batter, and the piles will only serve to build resilience at the location the piles were constructed. This results in a score of 7 out of 10.

The environmental impact of the construction of this solution is relatively minor, due to the vertical nature of the piles, the construction is retained to the previously disturbed road. Environmental impacts may be felt if large boulders or groundwater is encountered. This method scores an 8 in environmental impact.

The construction of the piles is considered the safest option present for the onsite workers. No work is required on the slopes, instead the works are undertaken primarily by machinery within the road alignment. Due to this, bored piles score a safety during construction score of 9 out of 10.

The installation of piles with a retaining structure scores a 5.8 out of 10. While this solution has high scores in most areas, it is cost prohibitive for Kiama Municipal Council to undertake.

Criterion	Weighting	Score
Price	20%	-1.9
Ability to be maintained	10%	8
Resilience to storms	35%	7
Environmental impact	20%	8
Safety during construction	15%	9
Total		5.8/10

Table 11: Scores for option 2 - Bored piles.

4.7.4. Option 3 – Soil Nail Anchor System

Similar to the above option, this option considers the installation of soil nails and matting or mesh at the same identified locations to transfer the loads of the slide to more competent material. The nails are typically installed at 15-degree angle, with one to two metre spacings. The meshing will allow revegetation after construction, further improving the slopes factor of safety.

This method is cost effective, with the market rate averaging $1,707.77 per square metre of embankment nailed. As this method will remove low lying vegetation to enable construction, a rate of $52 per square metre is added to cover revegetation to the environmentally sensitive land. The normalised score for the cost of this method is 7.8 out of 10.

The maintenance of the soil nails is similar to the bored piles, in that minimal maintenance will be required to ensure slope stability. However, all assets should be inspected, including the matting and anchor heads. Due to this, the soil nail system scores 8 for ability to be maintained.

The soil nail anchor system works well to stabilise the bank in the area in which they are installed, however, as the nail heads are exposed, they could be damaged by falling trees. The nails could be impacted by groundwater, both by eroding the embankment around the nails and by allowing the nails to creep out of clayey soils. (Budania et al. 2016).

There is vegetation removal associated with soil nailing embankments, this has been considered in the costing of this project with a revegetation component included and is considered beneficial to the factor of safety on the slope. Bo et al. (2015) undertook analysis of soil nailed slopes in Canada and found the slopes had a higher factor of safety in SLOPEW with up to 350mm deep grass rooting and 450mm deep tree root systems than without. Due to the benefits of having vegetation within the soil nailed area, this method scores a 7.

For the workers safety during construction, soil nailing score an 8 out of 10. The nails are installed by machinery from above the slope. Unfortunately, some works of foot access is required on the slope to install matting and tension the nail heads.

When all weightings are applied, the soil nail anchor system option scores 7.1 out of 10.

Criterion	Weighting	Score
Price	20%	7.8
Ability to be maintained	10%	8
Resilience to storms	35%	6
Environmental impact	20%	7
Safety during construction	15%	8
Total		7.1/10

Table 12: Scores for option 3 - Soil nail anchor system

4.7.5. Option 4 – Increased drainage and piles.

This option is a combination of options one and two and therefore includes the construction of a bored pile retaining wall system at locations identified at risk of further slippage, and increased surface and subsurface drainage for the length of the segment.

As this solution is the combination of two options, the price is the summation of the two prices for those options. The increased drainage market cost is $454.73 per metre, and the market rate of the bored pile retaining wall is $9,439.41 per linear metre. The resulting cost for option four is $9,849.14 per linear metre and is the most expensive option of the six options considered. The normalised price score for this option is -2.5 out of 10.

The ability to maintain the combined solution is scored a 6 out of 10. This is due to the maintenance burden caused by the increased drainage. While the piles and capping beam are still relatively maintenance free, there is still an operational impact to Kiama Municipal Council for the ongoing cleaning of surface and subsurface drains.

This solution's resilience to storm events is higher than both the increased drainage and bored piles solutions independently, as both the instigating forces are reduced through the reduction in soil pore pressure, and the resisting forces are increased from the pile retaining wall. The resulting score is 8 out of 10.

The environmental impact of this solution is quite low. The retaining wall works are kept within the road reserve, and minor drainage works will be required outside of the road reserve to minimise water in the pavement. This might result in some minor vegetation removal, and so is scored 8 out of 10.

During construction, the road will need to be closed to undertake the piling. As such, the drainage works can be completed in conjunction with the road closure, increasing the safety score from 6 that was for drainage only. The construction is still not as safe as piling only, as works will be required on the slopes.

The overall result for this option is a score of 5.7 out of 10.

Criterion	**Weighting**	**Score**
Price	20%	-2.5
Ability to be maintained	10%	6
Resilience to storms	35%	8
Environmental impact	20%	8
Safety during construction	15%	8
Total		5.7/10

Table 13: Scores for option 4 - Increased drainage and piles

4.7.6. Option 5 – Increased drainage and soil nails.

Option 5, similar to option four, is a combination of increased surface and subsurface drainage along the segment and the soil nail retaining system at identified at risk locations.

The price score is 7.2 out of 10, and follows the same evaluation method as option four. The cost for drainage is estimated at $454.73 per linear metre, added to the estimate for the soil nails, $1,760.27 per square metre gives a final estimate of $2,215.00/$m^2$.

This option suffers from the same drawbacks as option four in that the increased drainage will be impacted by Council's current resourcing and limited budgets, leading to insufficient maintenance. The soil nails require routine inspections, which can be covered under existing inspection and maintenance practices.

The remaining three factors all have the same characteristics as option four, however they all score one point less, resulting in seven points for each category. This is due to the differences in the bored piles and the soil nails that is discussed in the analysis of options two and three.

Criterion	Weighting	Score
Price	20%	7.2
Ability to be maintained	10%	6
Resilience to storms	35%	7
Environmental impact	20%	7

Safety during construction	15%	7
Total		6.9/10

Table 14: Scores for option 5 - Increased drainage and soil nails.

4.7.7. Option 6 – Do nothing.

The last option, do nothing, is the consideration of the ongoing, reactive process of reacting to a landslide by closing the road, undertaking survey, investigation into suitable design options, the design process, tendering then construction. This is a drawn out and frustrating period for the residents of nearby towns and along Jamberoo Mountain Road due to the extended period of time that the road is closed, however the resulting solution stabilises the landslide and reopens the road

Given that the road is in a usable condition, and restored to the same condition from funding under the Disaster Relief Funding Arrangements, there is no cost to Council under the do-nothing option. Therefore, this option has been given a 10 out of 10. The cost score is determined by the design cost, which is influenced by the location of the slip, the exact soil profile, and access to the location (*Disaster Assist Website* 2023).

Jamberoo Mountain Road is currently not resilient to large scale storms. The road has a history of landslides as mentioned in the introduction, and several locations that exhibit early slope failure through longitudinal tension cracking, to be identified in the project scoping phase. Due to the evidence of unstable sections of road, the do-nothing option scores 0 out of 10 for resilience.

If the do-nothing option is chosen the current impact on the vegetation and habitat would be negligible. However, as mentioned above, when future landslides occur, the damage to vegetation and habitat will be significant, but not catastrophic. Also, the impact is unknown with the number of variables that would influence the slide. As such, two points have been given to this.

This option includes no construction, maintenance, or inspection in line with the current management methods for Jamberoo Mountain Road, there is no risk to workers with this method and so, are not considered in the assessment.

When the unstable sections of the road are damaged due to future weather events, there will be some safety considerations for the repair method and this would determine the safety score.

Criterion	Weighting	Score
Price	20%	10
Ability to be maintained	10%	0
Resilience to storms	35%	0
Environmental impact	20%	2
Safety during construction	15%	10
Total		3.9/10

Table 15: Scores for option 6 - do nothing

5. Results

5.1. Design solutions

The assessment undertaken on the six separate solutions in chapter 4 has resulted in the below scores (Table 18). Option 3 – Soil Nailing Anchor System having the highest score at 7.1 out of 10, scoring slightly better than Option 1 - Increased Drainage only and Option 5 – Soil Nailing and Increased Drainage.

From the scoring, Option 3, while slightly less resistant to future storm events, has a significantly lower impact on Council's day-to-day operations and maintenance, as there are no requirements for continuous cleaning of drains.

The two options that involve the bored pile retaining walls are more resilient and require no maintenance compared to the remaining solutions, however the project would be cost prohibitive. This solution remains valid for stretches of road that have experienced a slip, as it allows for pavement reconstruction behind the retaining wall.

Option 6 - Do Nothing provides no resilience to Jamberoo Mountain Road, even though undertaking no works was cheaper and safer, giving the score of 3.9 out of 10.

Increased drainage only	6.9
Bored piles with sleeper shutter	5.8
Soil nail anchor system	**7.1**
Increased drainage and piles	5.7
Increased drainage and soil nails	6.9
Do Nothing	3.9

Table 16: Scores of all options

5.2. Outputs

With the design solution identified, significant progress has been made towards making Jamberoo Mountain Road resilient to rainfall and storm events. However, the remaining work is to develop the solution using the Kiama Municipal Council's project documents into a shovel ready project for when funding becomes available.

To do this, and to ensure the success of the project in a classical approach, a project scope, a cost estimate and an annual program of works are to be developed. These three documents will assist in the control pf the project and ensure its delivery is on time, under budget and to specifications.

The documents found in appendices C, D and E have been developed by Kiama Municipal Council's Infrastructure section, and are internal templates that have been completed only for the purpose of this dissertation.

5.2.1. Project Scope

The project scope in appendix C outlines the following pieces of information:

- Location of the project.
- Development pathway through the *Environmental Planning and Assessment Act, 1979.*
- An investigation of Aboriginal heritage artefacts as part of the *Due Diligence Code of Practice for the Protection of Aboriginal Objects in New South Wales (2010).*
- The project background and detailed scope.
- Consultation contacts (internal to Council and external to the public) and;
- The project budget over the duration of the project.

The locations for soil nailing were identified through two methods. Sites 1, 2, 3 and 5 from the list below were identified and recorded through site inspections by the Kiama Municipal Council Infrastructure section in August 2023, with sites 4 and 5 detected

by SLR consulting engineers in September 2020 through their Hazard Mapping Outside of the Current Landslide Site memo to Kiama Municipal Council (Trani 2020b).

These sites, known by their chainage from the Daltons Road intersection are listed below with their approximate size.

1. CH1390: 55m long, 5m wide
2. CH1674: 30m long, 10m wide
3. CH1775: 32m long, 12m wide
4. CH4576: 27m long, 4m wide
5. CH4893: 70 m long, 6m wide
6. CH4978: 15m long, 4m wide

The total area of embankment to be stabilised is 1347m^2.

The development pathway was previously mentioned in section 3.4.4 regarding the environmental approval pathway for the project, and will be expanded upon here. Council is not exempt from the *Environmental Planning and Assessment Act*,*1979* however there is other legislation that applies if Council is the roads authority, such as Kiama Municipal Council is for Jamberoo Mountain Road. The State Environmental Planning Policy (Transport and Infrastructure) allows roads authorities to undertake development without a Development Application, but gives less onerous and quicker pathways. For this project, section 2.109 is applicable, in which Council can undertake work for the purpose of a road on any land without consent.

Under the *National Parks and Wildlife Act, 1974*, an organisation can be prosecuted for the destruction of Aboriginal heritage artefacts, however, if the organisation follows the Due Diligence Code of Practice for the Protection of Aboriginal Objects in New South Wales, some protection is provided. Page 10 of the document covers a generic process to undertake due diligence and determine if an Aboriginal Heritage Impact Permit is needed.

Step 2 of the Due Diligence process asks if there are any confirmed site records within the construction site. The Aboriginal Heritage Information Management System (AHIMS) search, undertaken during project scoping, shows five items, approximately 1 km away on Barren Grounds, but as the works are contained to previously disturbed

land, the project is identified as low risk and to proceed with caution. If artefacts are found, the relevant authorities are to be contacted and works are to stop.

The project details section of the project scope includes the background to the project, similar to a condensed version of this document's introduction, the detailed scope for the design and construction phases, any exclusions from the project, and community consultation details. The detailed scop for this project includes the design phase and the construction phase, with an overall scope for all six locations and site-specific inclusions.

The project budget lists the appropriate cost codes for the project, with the ledger being unique for the project. The project code and the work orders are used to track the costs across Council business units, and compare internal project management costs to external contractor costs. The annual budget for the project is also included in the section, being developed from both the cost estimate in appendix D and the program of works in appendix E.

Consultation is also to be undertaken prior to the start of the project, as well as during, to keep interested stakeholders and the community informed of the progress of the project, any key dates including construction commencement, road closures, and estimated completion date. For the majority of project that Kiama Municipal Council undertakes, a letter sent to nearby residents is sufficient, but with the duration that this project is expected to take, a more extensive social media consultation plan is recommended to keep the larger community informed.

The remaining three sections are Variations, Handover checklist and Capitalisation. These sections are included in the scoping document for tracking of any cost or scope variations of the project during construction, records of defect walks and transmission of works as executed drawings to Council, as well as the individual assets transferred to Council at the end of the construction phase, as well as their associated costs.

The project scope can be found in appendix C.

5.2.2. Cost Estimates

The detailed cost estimate, found in appendix D, is separated into each of the six sites, grouped by stage of the project before each line item was estimated. Unit rates were taken from works undertaken to repair the 2022 landslides on Jamberoo Mountain Road, then for the purpose of budgeting, each line item was rounded up to the next $1,000. This added approximately $30,000 to the total project budget as contingency.

The soil nail spacing has been assumed to be 1.5 metres horizontally and vertically, and the cost is for a 4-metre-long nail. During detailed design, the spacing and embedment depth of the nails will be confirmed for each of the sites, and if any adjustments are required to the budget, they will be made at this point.

Contingency and project management have been added to each site at 20% and 10% respectively.

5.2.3. Program of Works

The program of works, found in appendix E, refers back to section 4.4.3 – financially sustainable. With the annual budget set at $450,000 to ensure Council has the resources to maintain other roads within its asset portfolio and the total project budget sitting at $1,683,000, the project could be completed in three years and nine months.

The first year of the program includes the detailed design and approvals for all sites, as well as the completion of site CH4978. Year two lists the completion of CH1775, and the preliminaries of CH1674. With the proximity of these two sites, efficiencies can be gained by undertaking the work in one contract, and moving to CH1674 early in year three.

Year three includes the construction and remediations phases of CH1674, and the whole program of CH1390.

Year four includes CH4576, as well and the preliminaries and starting construction of CH4893. CH4893 is completed early in year five, as the construction spans over the end of financial year four

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6. Conclusion

6.1. Overview

The need for this research was driven by self-reflection of the author's involvement in the 2022 landslides on Jamberoo Mountain Road, the resulting impacts to the community, and how this impact could be mitigated in the future. This was completed in the following three steps:

1. The introduction of, through literature review, the cause of the landslides, and the design solutions being implemented locally and internationally on slopes with a similar geology.
2. Next, the limitations unique to Kiama Municipal Council and Jamberoo Mountain Road were defined, such as financial and environmental limitations. The various design solutions were also assessed in this step.
3. Finally, with the most appropriate design solution identified, a project scope, cost estimate, and program of works were developed for six locations showing distress indicators that are likely to suffer from landslides in future periods of heavy rainfall.

Five of the six solutions assessed in this dissertation would improve the resilience of the road when compared to option 6 – do nothing, as there are significant unknowns to the extent and severity of future landslides.

The Soil Nailing Anchor system had the highest score of the six solutions, striking a balance between cost, environmental impact, and further burdens to an already under resourced maintenance team, while still improving the stability of the road.

From the identified solution, the project scope, cost estimate and program of works makes this research into a shovel ready project, awaiting the allocation of funding and resources.

6.2. Further work

Prior to the implementation of this research and slope stabilisation methodology, further work is required in major areas. Firstly, a detailed design is required to determine the spacing and depth of the soils nails for the soil profiles found on Jamberoo Mountain, and for the required slope factor of safety.

Secondly, the environmental impacts must be assessed by a qualified environmental scientist. As slope stabilisation works are considered development permitted without consent under the State Environment Planning Policy (Transport and Infrastructure) 2021, a Review of Environmental Factors should be undertaken to ensure that the design and construction phases consider their impact to the natural environment.

Both of the above steps could place conditions or could vary the detail of the work to be undertaken, as such, at the completion of the above documents, the project scope, cost estimate and program should be reviewed to ensure that the documents are still relevant and comply with relevant legislation.

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Appendix A - Project Specification

ENG4111/4112 Research Project

Project Specification

For: Bryce Hammond

Title: The Retrospective Resilience of Jamberoo Mountain Road.

Major: Civil Engineering

Supervisors: Dr David Thorpe

Enrolment: ENG4111 – EXT S1, 2023, ENG4112 – EXT S2, 2023

Project Aim: To consider a sustainable and realistic method of providing resilience to Jamberoo Mountain Road and prepare a plan prioritising the sections most at risk.

Communication: Preferred communication is through email, with scheduled teams/zoom calls if required to quickly discuss numerous items

Program: Version 3, 30th June 2023

1. Research historical data and undertake a literature review on Jamberoo Mountain Road, including:
    a. Its alignment
    b. When it was initially constructed
    c. The geology of the mountain.
    d. Past natural disasters in the Jamberoo Region
    e. Impact of the natural disasters on Jamberoo Mountain Road.
2. Undertake a literature review, as well as consider past repairs undertaken on Jamberoo Mountain Road to determine the most practical and sustainable (financially and environmentally) solution to improve the resilience and therefore reduce the closure period for Jamberoo Mountain Road following a natural disaster.
3. Prepare a plan to implement the proposed solution over a realistic period of time.

Resources:

No physical resources are required at this time. If the documents required to complete the project are required to be purchased, this will be discussed with the supervisor at that time.

Appendix B – Risk assessment

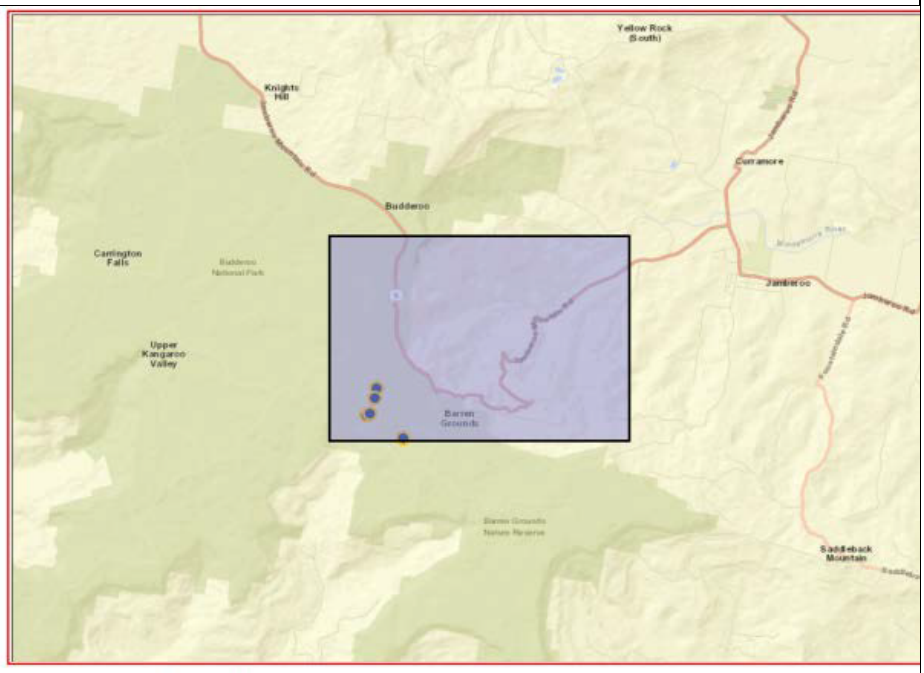
NUMBER	RISK DESCRIPTION	TREND	CURRENT	RESIDUAL
2459	ENG4111 and ENG4112 - Retrospective resilience of Jamberoo Mountain Road		Low	Very Low
DOCUMENTS REFERENCED				

RISK OWNER	RISK IDENTIFIED ON	LAST REVIEWED ON	NEXT SCHEDULED REVIEW
Bryce Hammond	20/05/2023	10/10/2023	10/10/2024

RISK FACTOR(S)	EXISTING CONTROL(S)	PROPOSED CONTROL(S)	DUE DATE
Extended periods of sitting.	**Control:** No existing controls in place.	**Control:** Take regular breaks stand up and stretch muscles in the lower back	16/10/2023
Eye fatigue from long periods of looking at digital displays	**Control:** No existing controls in place.	**Control:** For every 20 minutes that you use a digital device, take a 20 second break to look at objects 20 feet (6 metres) away.	16/10/2023
Stress caused by extended periods of mental effort (12+ hours)	**Control:** No existing controls in place.	**Control:** Plan activities outside of work and research to alleviate stress. Implement planning to reduce stress.	16/10/2023
Traffic during site inspection	**Control:** No existing controls in place.	**Control:** Undertake inspections during road closures or with traffic control in place	

Appendix C – Project Scope

Project Name	Jamberoo Mountain Road slope stabilisation
TRIM Container and folder reference	SC3620
Brief	To stabilise 6 identified unstable sections of Jamberoo Mountain Road using soil nails to make the road more resilient to natural disasters such as rainfall events.
Location	Jamberoo Mountain Road, between Daltons Road and the Jamberoo Mountain Lookout, Jamberoo
Images	 Sites are identified by their chainage from Dalton Road intersection.
Development Pathway	State Environmental Planning Policy (Transport and Infrastructure) 2021 **2.109 Development permitted without consent—general.**

	(1) Development for the purpose of a road or road infrastructure facilities may be carried out by or on behalf of a public authority without consent on any land. However, such development may be carried out without consent on land reserved under the *National Parks and Wildlife Act, 1974* only if the development— (a) is authorised by or under the *National Parks and Wildlife Act 1974*, or (b) is, or is the subject of, an existing interest within the meaning of section 39 of that Act, or (c) is on land to which that Act applies over which an easement has been granted and is not contrary to the terms or nature of the easement.
Aboriginal Heritage Information Management System (AHIMS) (https://www.environment.nsw.gov.au/awssapp/Login.aspx?ReturnUrl=%2fawssapp)	 A search of Heritage NSW AHIMS Web Services (Aboriginal Heritage Information Management System) has shown that: 5 Aboriginal sites are recorded in or near the above location. 0 Aboriginal places have been declared in or near the above location. * 5 Aboriginal sites have been found on the Barren Ground Plateau, approximately 1 km from Jamberoo Mountain Road at its closet point.

	As works are contained to previously disturbed land, such as cuttings for the road formation, risk is assessed at low – works to proceed. If any Aboriginal objects are found, stop work and notify the Department of Climate Change, Energy, the Environment and Water. If human remains are found, stop work, secure the site and notify the NSW Police and Department of Climate Change, Energy, the Environment and Water.		
Part 5 Assessment	No	REF	Yes
SOHI or ADDA	No	Development Application	No

Project Details

Project Background	Jamberoo Mountain Road is susceptible to landslides during periods of high rainfall. In recent memory, landslides have occurred in 2017, 2020, 2022, and there are sections of the road identified as at risk of further slips. These slides have since been repaired, but the stability of the road has been questioned, as well as the impact to residents during the 14-month repair process in 2022, which the road was closed. This project has two parts: 1. Detailed design of various solutions 4. Construction of the detailed design.

	This project aims to build resilience in Jamberoo Mountain Road from natural disasters and reduce the impact that these disasters have on the community.		
Detailed Scope (include any assumptions or risks)	The following sites will be identified by their distance from the Dalton Road/Jamberoo Mountain Road intersection. FOR ALL SITES: Engage a suitably qualified geotechnical engineering design firm to: - Undertake geotechnical investigation of the site. - Design a soil nail retaining system to provide a slope Factor of Safety suitable for a Regional Road. - Provide onsite supervision up to 8 hours a week during the construction phase - Undertake testing at the completion of the construction phase to confirm soil nail pull out forces meet the relevant standards. THEN; Engage a suitably experienced construction contractor to: - Clear vegetation less than 1 metre and 100mm of topsoil in accordance with the REF - Install soil nailing system and meshing as indicated in the detailed design - Revegetate with native plants		
Exclusions	Road pavement reconstruction.		
Notification Letter	Yes	Date Letter was sent	

Additional Communication Notes	Social media consultation plan to be developed during the design phase of this project to inform the residents to the extent of work and any impact to them.

Project Contacts

Contact	Infrastructure Engineer	Involvement	Project Client/Asset Owner
Comments	To be included in all design progress meetings, community engagement, tender assessment, and meetings with impact to scope or budget.		
Contact	Asset Officer	Involvement	Asset Owner/inspector
Comments	Liaison for all onsite inspections and meetings		

Project Budget

Project Ledger	201129	Project Code	1780
WO – Project Management	60201	WO – Construction	61120

Total Project Budget	$1,603,000		
FY	2024/25	Budget	$304,000
FY	2025/26	Budget	$394,000
FY	2026/27	Budget	$413,000

FY	2027/28	Budget	$391,000
FY	2028/29	Budget	$101,000
Funding Acknowledgement	Funding acknowledgement signage is not needed at this time as the project is funded from Internally restricted funds.		

Variations – as needed.

Details of Variations:	Requested By:	Date:	Signature:

Handover Checklist – at completion.

Handover Task	Status	TRIM Reference
Defect Walk		
Product Warranties		
Works as Executed (pdf)		
Designs		
Any compliance measures met per DA requirements		

Capitalisation – post completion.

Asset ID	Asset Type	Asset Status (Dispose/Commission/Improve)	Percentage Allocation

Appendix D – Cost Estimates

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH1390	Approvals	REF	m^2	275	$48	$13,277	(Niche Environment, 2022)
CH1390	Construction	Geotech supervision and testing (8 hours/week)	Hour	64	$320	$20,480	(SLR Consulting, 2023)
CH1390	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH1390	Design	Investigation and detailed design	m^2	275	$47	$12,885	(SLR Consulting, 2022)
CH1390	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH1390	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH1390	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH1390	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH1390	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH1390	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH1390	Construction	Soil Nails	Ea.	108	$450	$48,600	(Civil and Civic, 2022)
CH1390	Construction	Tecco Mesh	m^2	275	$40	$11,000	(Civil and Civic, 2022)
CH1390	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	275	$30	$8,250	(Civil and Civic, 2022)
CH1390	Construction	Spoil Removal	m^3	27.5	$55	$1,513	(Civil and Civic, 2022)
CH1390	Remediation	Vegetation remediation	m^2	275	$80	$22,000	(Proust Land Services, 2023)
CH1390	Construction	Project management			10%	$18,069	
CH1390	Construction	Contingency			20%	$36,138	
CH1390 Total						**$283,537**	

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH1674	Approvals	REF	m^2	300	$48	$14,484	(Niche Environment, 2022)
CH1674	Construction	Geotech supervision and testing (8 hours/week)	Hour	64	$320	$20,480	(SLR Consulting, 2023)
CH1674	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH1674	Design	Investigation and detailed design	m^2	300	$47	$14,057	(SLR Consulting, 2022)
CH1674	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH1674	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH1674	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH1674	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH1674	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH1674	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH1674	Construction	Soil Nails	Ea.	120	$450	$54,000	(Civil and Civic, 2022)
CH1674	Construction	Tecco Mesh	m^2	300	$40	$12,000	(Civil and Civic, 2022)
CH1674	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	300	$30	$9,000	(Civil and Civic, 2022)
CH1674	Construction	Spoil Removal	m^3	30	$55	$1,650	(Civil and Civic, 2022)
CH1674	Remediation	Vegetation remediation	m^2	300	$80	$24,000	(Proust Land Services, 2023)
CH1674	Construction	Project management	%		10%	$18,998	
CH1674	Construction	Contingency	%		20%	$37,995	
CH1674 Total						**$297,989**	

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH1775	Approvals	REF	m^2	384	$48	$18,539	(Niche Environment, 2022)
CH1775	Construction	Geotech supervision and testing (8 hours/week)	Hour	96	$320	$30,720	(SLR Consulting, 2023)
CH1775	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH1775	Design	Investigation and detailed design	m^2	384	$47	$17,993	(SLR Consulting, 2022)
CH1775	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH1775	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH1775	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH1775	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH1775	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH1775	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH1775	Construction	Soil Nails	Ea.	168	$450	$75,600	(Civil and Civic, 2022)
CH1775	Construction	Tecco Mesh	m^2	384	$40	$15,360	(Civil and Civic, 2022)
CH1775	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	384	$30	$11,520	(Civil and Civic, 2022)
CH1775	Construction	Spoil Removal	m^3	38.4	$55	$2,112	(Civil and Civic, 2022)
CH1775	Remediation	Vegetation remediation	m^2	384	$80	$30,720	(Proust Land Services, 2023)
CH1775	Construction	Project management	%		10%	$22,464	
CH1775	Construction	Contingency	%		20%	$44,928	
CH1775 Total						**$361,281**	

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH4576	Approvals	REF	m^2	108	$48	$5,214	(Niche Environment, 2022)
CH4576	Construction	Geotech supervision and testing (8 hours/week)	Hour	16	$320	$5,120	(SLR Consulting, 2023)
CH4576	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH4576	Design	Investigation and detailed design	m^2	108	$47	$5,060	(SLR Consulting, 2022)
CH4576	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH4576	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH4576	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH4576	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH4576	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH4576	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH4576	Construction	Soil Nails	Ea.	36	$450	$16,200	(Civil and Civic, 2022)
CH4576	Construction	Tecco Mesh	m^2	108	$40	$4,320	(Civil and Civic, 2022)
CH4576	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	108	$30	$3,240	(Civil and Civic, 2022)
CH4576	Construction	Spoil Removal	m^3	10.8	$55	$594	(Civil and Civic, 2022)
CH4576	Remediation	Vegetation remediation	m^2	108	$80	$8,640	(Proust Land Services, 2023)
CH4576	Construction	Project management	%		10%	$12,232	
CH4576	Construction	Contingency	%		20%	$24,464	
CH4576 Total						**$176 411**	

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH4893	Approvals	REF	m^2	420	$48	$20,277	(Niche Environment, 2022)
CH4893	Construction	Geotech supervision and testing (8 hours/week)	Hour	96	$320	$30,720	(SLR Consulting, 2023)
CH4893	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH4893	Design	Investigation and detailed design	m^2	420	$47	$19,679	(SLR Consulting, 2022)
CH4893	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH4893	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH4893	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH4893	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH4893	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH4893	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH4893	Construction	Soil Nails	Ea.	184	$450	$82,800	(Civil and Civic, 2022)
CH4893	Construction	Tecco Mesh	m^2	420	$40	$16,800	(Civil and Civic, 2022)
CH4893	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	420	$30	$12,600	(Civil and Civic, 2022)
CH4893	Construction	Spoil Removal	m^3	42	$55	$2,310	(Civil and Civic, 2022)
CH4893	Remediation	Vegetation remediation	m^2	420	$80	$33,600	(Proust Land Services, 2023)
CH4893	Construction	Project management	%		10%	$23,744	
CH4893	Construction	Contingency	%		20%	$47,487	
CH4893 Total						**$381,344**	

Site	Group	Item	UOM	Quantity	unit rate ($/UOM)	cost ($)	Reference for unit rates
CH4978	Approvals	REF	m^2	60	$48	$2,897	(Niche Environment, 2022)
CH4978	Construction	Geotech supervision and testing (8 hours/week)	Hour	16	$320	$5,120	(SLR Consulting, 2023)
CH4978	Remediation	Technical Memo to confirm soil nails comply with relevant	Ea.	1	$2,000	$2,000	(SLR Consulting, 2023)
CH4978	Design	Investigation and detailed design	m^2	60	$47	$2,811	(SLR Consulting, 2022)
CH4978	Preliminaries	Overheads and margin	Ea.	1	$16,447	$16,447	(Civil and Civic, 2022)
CH4978	Preliminaries	Onsite staff costs	Ea.	1	$15,000	$15,000	(Civil and Civic, 2022)
CH4978	Preliminaries	Long Service Levy	Ea.	1	$37,879	$37,879	(Civil and Civic, 2022)
CH4978	Preliminaries	Onsite Preliminaries	Ea.	1	$10,000	$10,000	(Civil and Civic, 2022)
CH4978	Preliminaries	Sediment and Erosion Control	Ea.	1	$6,000	$6,000	(Civil and Civic, 2022)
CH4978	Preliminaries	Traffic Control	Ea.	1	$4,000	$4,000	(Civil and Civic, 2022)
CH4978	Construction	Soil Nails	Ea.	20	$450	$9,000	(Civil and Civic, 2022)
CH4978	Construction	Tecco Mesh	m^2	60	$40	$2,400	(Civil and Civic, 2022)
CH4978	Construction	Grass roots geotextile matting including reinforcement pins and earth anchors	m^2	60	$30	$1,800	(Civil and Civic, 2022)
CH4978	Construction	Spoil Removal	m^3	6	$55	$330	(Civil and Civic, 2022)
CH4978	Remediation	Vegetation remediation	m^2	60	$80	$4,800	(Proust Land Services, 2023)
CH4978	Construction	Project management	%		10%	$10,766	
CH4978	Construction	Contingency	%		20%	$21,531	
CH1390 Total						**$152,781**	
Project Total						**$1,653,343**	

Appendix E – Program of Works

	2024/25	*2025/26*	*2026/27*	*2027/28*	*2028/29*
All	Design and Approvals for All sites.				
CH4978	Preliminaries, Construction and Remediation.				
CH1775		Preliminaries, Construction and Remediation.			
CH1674		Preliminaries.	Construction and Remediation.		
CH1390			Preliminaries, Construction and Remediation.		
CH4576				Preliminaries, Construction and Remediation.	
CH4893				Preliminaries and Construction.	Construction and Remediation.