Marlborough Sounds Future Access Study

Preliminary Natural Hazard Susceptibility, Implications and Interventions

PREPARED FOR MARLBOROUGH DISTRICT COUNCIL | JUNE 2023

We design with community in mind

Stantec

Revision schedule

Rev No	Date	Description				
			Prepared by	**Checked by**	**Reviewed by**	**Approved by**
1	14/06/2023	Final	KC/RA/RC/KB	AC	AH/KOR	AM

Tonkin + Taylor have provided review and comment regarding the method and wider report as part of the formal review process.

Quality statement

Project manager	Project technical lead
Sarah Pownall	Andrew Maughan

PREPARED BY

Ken Clapcott / Ryan Abrey / Roy Ching / Kate Bozek .... 15 / 06 / 2023

CHECKED BY

Andrew Craig .... 15 / 06 / 2023

REVIEWED BY

Avik Halder / Kevin O'Rourke .... 15 / 06 / 2023

APPROVED FOR ISSUE BY

Andrew Maughan .... 15 / 06 / 2023

Level 1, 66 Oxford Street, Richmond, Nelson 7020
P.O Box 13502, Armagh, Christchurch 8141
Tel 03 546 8728
STATUS FINAL / Project No 310205564

Executive Summary

This report is to inform and support the Marlborough Sounds Future Access Program Business Case, currently being completed by Stantec for Marlborough District Council.

This natural hazard report identifies, describes and compiles natural hazard information and presents their corresponding implications to the roading network. Knowledge of the spatial distribution of the natural hazard susceptibility allows informed decision making during the future transport network option development and evaluation.

The assessment considers seven types of natural hazards that are applicable for the Marlborough Sounds road network, namely natural slope instability, human induced slope instability, debris flows, liquefaction, flood inundation, coastal inundation, and tsunami. These hazards are triggered by three key triggering mechanisms, namely storm events (including predicted effects of climate change on rainfall), coastal events (including predicted relative sea level rise due to climate change and vertical land movement) and seismic activity.

An output of the natural hazard task is the development of natural hazard susceptibility maps for the current Marlborough Sounds Road transport network. Natural hazard susceptibility statistics are summarised for each natural hazard and presented per road corridor segment. The summary table enables identification of road corridor segments that have large exposure to high or very high natural hazard susceptibility (i.e., more vulnerable to future disruption or closure). This allows comparison with other road corridor segments along the same route.

A summary of the implications of the natural hazards on the roading network is presented. Potential mitigations are developed utilising the Waka Kotahi adaptation plan strategies:

- Avoid
- Protect
- Accommodate
- Retreat

The report concludes by providing discussion and recommendations to feed into the wider study activities and reports. This is a factual report with recommendations on how those facts can be used or interpreted to inform option development and evaluation.

A study which includes resilience as a direct or indirect outcome should ideally be mindful of the wider system context, however the scope and timescales of this project did not allow for this. For example, various lifeline networks may be reliant on one another to provide their services (for example, water, power, communications networks and fuel providers may all be reliant on road networks and one another to provide or repair service in a major event). In a similar way, local communities should ideally be aware of what they can do themselves to reduce risk and respond in an event, but ideally also what they can reasonably expect from lifeline providers and emergency responders, so that there are fewer uncertainties or gaps. Whilst some resilience pointers are provided where they became apparent during the assessment, this does not imply that the multi-domain resilience of the communities or region have been fully considered.

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Abbreviations

Abbreviation	Full Name
AEP	Annual Exceedance Probability
DEM	Digital Elevation Model
GIS	Geographic Information System
IPCC	International Panel of Climate Change
MHWS	Mean High Water Spring
MDC	Marlborough District Council
RAMM	Road Assessment and Maintenance Management
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
Sounds	Marlborough Sounds
SSP	Shared Socioeconomic Pathways
VLM	Vertical Land Movement

Glossary

Term	Definition
Waka Kotahi Business Case Approach	Waka Kotahi NZ Transport Agency and investment partners use the Business Case Approach (BCA) to guide their planning, investment and project development processes. Any request for funding from the National Land Transport Fund (NLTF) must be supported by a fit-for-purpose investment proposal that uses the principles of the BCA.
Marlborough Sounds Future Access Program Business Case	A Programme Business Case (PBC) is the initial step in the BCA. The purpose of a programme business case (PBC) is to find the combination of activities that represent the best-value-for-money response to the case for change identified. Marlborough Sounds Future Access Program Business Case Study is being completed to fulfil the Waka Kotahi's process and provide analysis of the Marlborough Sounds August 2022 Storm Recovery Long Term Options.
Natural Hazard	Natural hazards are atmospheric, earth or water-related processes or phenomena that may negatively impact human life, property or other parts of the environment.
Geohazard	A geologic hazard or geohazard is an adverse geologic condition capable of causing widespread damage or loss of property/assets and life. These hazards are geological and environmental conditions and can involve long-term and/or short-term geological processes.
Natural hazard Susceptibility	A qualitative assessment of the classification and spatial distribution (of a selected natural hazard type) which exists or potentially may occur at an identified location.
Natural hazard risk	The risk evaluation of natural hazards in which likelihood (frequency and magnitude) and consequence (impact) is taken into consideration.
Annual Exceedance Probability	The estimated probability that an event of specified magnitude will be exceeded in any one year.
Resilience	Resilience in the transport context is defined by Waka Kotahi as the system's ability to enable communities to withstand and absorb impacts of unplanned disruptive events, perform effectively during disruptions, and respond and recover functionality quickly.
Human Induced (Slope Instability)	Effectively anthropogenic related instability issues. The term human induced has been used within this study as provides a more instinctive terminology that a wider audience understands.

1 Introduction

1.1 Purpose

The objective of this document is to inform and support the Marlborough Sounds Future Access Program Business Case, currently being completed by Stantec for Marlborough District Council. This is part of Stantec's December 2022 engagement for Services in connection with August 2022 Storm Recovery Long Term Options Analysis.

The report compiles natural hazard information and presents their corresponding implications to the roading network to help quantify the problem statements of the study. These statements include but are not limited to:

- **Problem One – Disrupted Access:** The impacts of climate change are increasing the frequency and duration of disrupted access (30%).
- **Problem Two – Lack of Alternatives:** Reliance on roads for access to services and lack of alternatives has led to increased vulnerability to the community during road closures (20%).
- **Problem Three – Asset Vulnerability:** Poor construction standards and unstable geology means the Marlborough Sounds roads have a high maintenance cost and safety risk (50%).

This report collates relevant information and presents a preliminary natural hazard desktop assessment. A project specific methodology is developed which includes division of the project into five geo-spatial zones and further division into numerous road segments. Natural hazard types are identified, and the road segments are assigned a susceptibility rating for each natural hazard. Partial validation/verification of the assigned hazard susceptibility is completed by comparison against historical road-fault data.

Earthquake and Storm triggering mechanisms are discussed, with a range of intensities selected. This informs a discussion on the implications (from each natural hazard) to the network's assets.

Potential options to manage the natural hazard implications to the transport network area are developed utilising the Waka Kotahi adaptation plan[1]:

- Avoid
- Protect
- Accommodate
- Retreat.

The purpose of this report is to document the natural hazard susceptibility assessment process, present the derived maps and corresponding data, provide a summary of the implications of the natural hazards and present natural hazard mitigation options. It concludes by providing discussion and recommendations to feed into the wider study activities and reports.

1.2 Study extent

The extent of the study area is shown in Figure 1-1 and encompasses the Sounds. As shown the Sounds are split into five zones according to the primary access road for each area. All public roads were considered within each zone.
The five zones are as follows:

- **French Pass:** access to the Sounds from Ronga Road (Rai Valley).
- **Pelorus:** access to the Sounds from Kaiuma Bay Road.
- **Queen Charlotte Drive:** Queen Charlotte Drive as an alternative for SH6 between Havelock and Blenheim.
- **Kenepuru:** access to the Sounds from Queen Charlotte Drive, Kenepuru Road and outer Sounds.
- **Port Underwood:** access to the Sounds from Port Underwood Road (Picton to Rarangi).

[1] Waka Kotahi: Tiro Rangi: our climate adaptation plan 2022-24

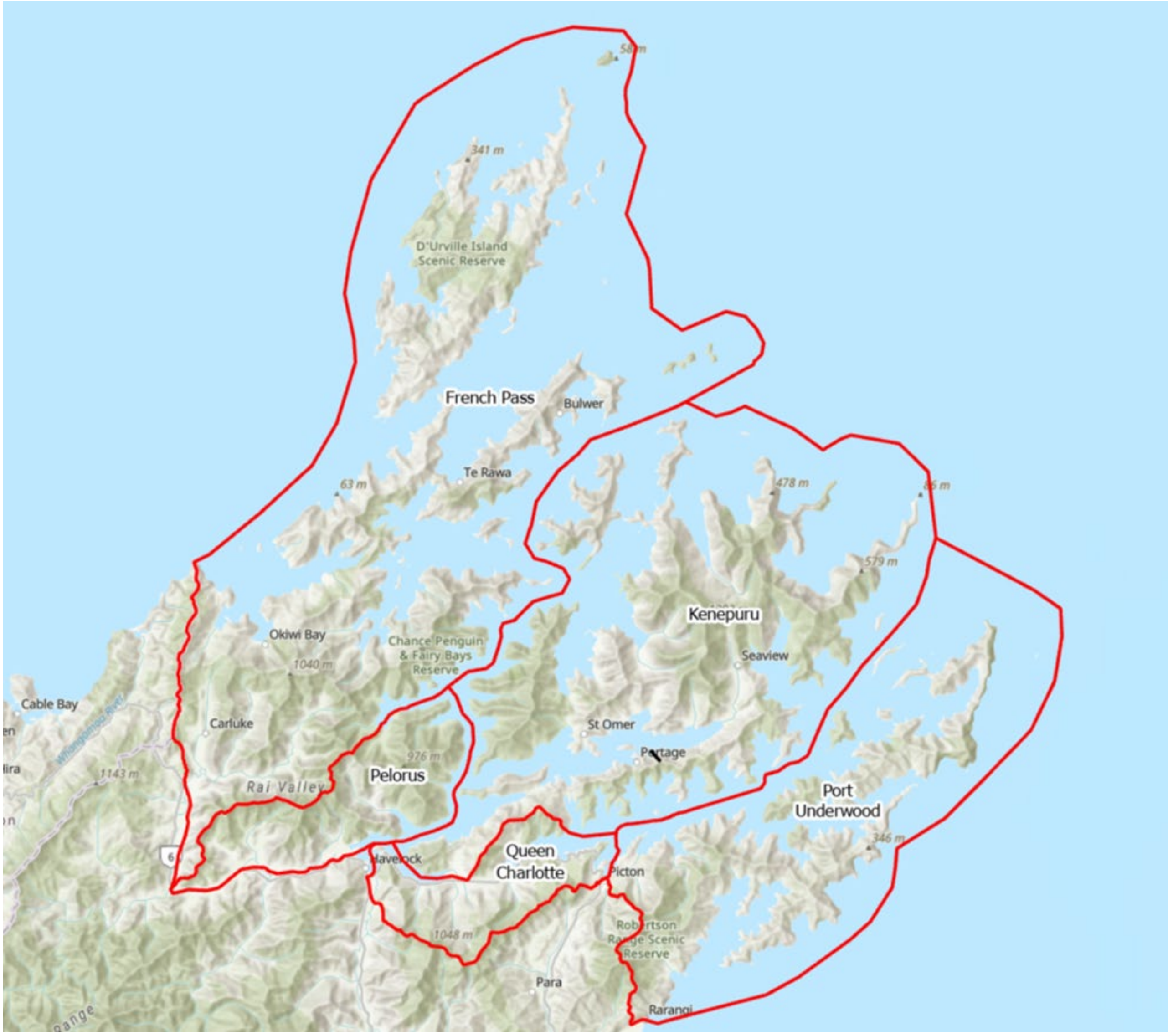

Figure 1-1: Study extent and zones

1.3 Study limitations

The methodology has been developed to fit the program/funding of the Marlborough Sounds Future Access Program Business Case. It is considered high level and therefore defined as a preliminary desktop natural hazard susceptibility assessment.

The assessment relies heavily on the available existing information (some not published or verified) and the accuracy of the information utilised cannot be guaranteed. However, Stantec has used professional judgement in determining what is reasonably appropriate to use for this high-level study.

Although the susceptibility classification has been undertaken by qualified geo-professionals, and verified/validated by data where possible, there is still an element of subjectiveness. Therefore, the hazard maps produced should not be utilised to inform hazard susceptibility at site-specific locations. The intent was to classify a road network of approximately 500km and the level of investigation reflects this broad scale. The desired output was to understand the differing levels and geographical concentrations of natural hazard susceptibility within the network. Some additional subject-specific limitations are discussed within the assessment sections.

A study which includes resilience as a direct or indirect outcome should ideally be mindful of the wider system context, however the scope and timescales of this project did not allow for this. For example, various lifeline networks may be reliant on one another to provide their services (for example, water, power, communications networks and fuel providers may all be reliant on road networks and one another to provide or repair service in a major event). In a similar way, local communities should ideally be aware of what they can do themselves to reduce risk and respond in an event, but ideally also what they can reasonably expect from lifeline providers and emergency responders, so that there are fewer uncertainties or gaps. Whilst some resilience pointers are provided where they became apparent during the assessment, this does not imply that the multi-domain resilience of the communities or region have been fully considered.

This study excludes some anecdotal evidence gathered as part of the consultation process due to the parallel timing of the tasks and information not available during report compilation. The impacts on the road surface from heavy vehicles, and/or from road maintenance practices, are not included in this natural hazard assessment.

2 Methodology

The methodology used in this study included includes:

- Segmentation of transport network
- Desktop natural hazard literature review
- Identification and categorisation of natural hazards
- Identification of natural hazard triggering mechanisms, including development of intensity bands
- Natural hazard assessment, which included:
    - Susceptibility classification, map generation, and data summarisation
    - Summarisation of likely implications (per hazard type) to the transport network, utilising intensity bands where appropriate
    - Development of potential interventions.

Each component of the methodology is further discussed below.

2.1 Project study area and segmentation of transport network

As discussed in Section 1.2, the project study area has been divided into five zones, namely French Pass, Pelorus, Queen Charlotte, Kenepuru and Port Underwood. In some instances (e.g., some maps) Pelorus, Kenepuru and Queen Charlotte have been combined. The roading network in each of these zones are further divided into segments based on road classification and journey types/volumes. The division of the project study area into zones and segments is illustrated in Figure 1-1 and in greater detail in Appendix B .

2.2 Desktop natural hazard literature review

A desktop natural hazard literature review involved identifying and compiling readily available historical information to inform this study. This review identified a series of technical reports, published maps, LiDAR terrain information, historical aerial photography and other relevant information. Key findings are presented throughout the report, and source references are provided.

Where possible, data was obtained as GIS layers (or digitised within GIS) and a project GIS webmap was prepared and is currented hosted by Stantec's ArcGIS interface. The data collection included GIS layers associated with the network faults observed after the 2021 and 2022 storm events.
The literature review highlighted the absence of any existing resilience related studies for any of the Marlborough Sounds transport network infrastructure (either roading or marine hub related).

2.3 Identification and categorisation of natural hazards

The identified natural hazards include:

- Natural Slope Instability
- Human Induced Slope Instability (Modified Terrain)
- Debris Flows
- Liquefaction
- Flood Inundation
- Coastal Inundation and Erosion
- Tsunami.

Refer to Section 4 for the description of each natural hazard and an explanation of the intent/application of the natural hazard to this study.

Although not considered a natural hazard, stormwater management also has implications to the resilience of the roading network. Stantec was unable to gather enough data to enable a justifiable assessment on stormwater management and its implications. However, it is intertwined with and therefore indirectly represented within three of the natural hazards that were evaluated, namely:

- Flood Hazard (captures implications of flood plain inundation).
- Debris Flows (captures road corridor asset susceptibility at the intersection of natural waterways during rainfall).
- Human Induced Slope Stability (captures implications of uncontrolled stormwater as one of the contributors to slope failure).

Severe winds (associated with storms) and fire can both present a hazard to driving (this is a road safety issue, rather than a ground level / roading infrastructure issue). Severe winds and fire can contribute to tree fall which may exacerbate slope instabilities, assumed to be covered under the slope instability topics. Severe winds and fire can also damage other infrastructure such as above-ground power or communication infrastructure, which are outside the scope of this assessment. Therefore, wind and fire are not specifically discussed in the hazard assessment.

2.4 Identification of natural hazard triggering mechanisms

Hazard triggering mechanisms are the natural processes that trigger the initiation of a natural hazard. Three main types of triggering mechanisms are considered in the assessment, namely storm events, coastal events, and seismic events. Each of the triggering mechanisms can have events of different magnitude or intensity. The triggering mechanisms are discussed further in section 5, and adopted intensities are developed for use in the discussion of hazard implications to the transport network.

2.5 Hazard assessment process

To inform the business case, the natural hazard assessment included:

- Susceptibility classification, map generation, and data summarisation
- Summarisation of likely implications (per hazard type) to the transport network
- Development of potential interventions

Each step of the process is further discussed below.

2.5.1 Hazard susceptibility

To produce the hazard susceptibility maps and derive statistical outputs on the road network exposure, a four-level natural hazard susceptibility classification was adopted where feasible (very high, high, medium and low). Classification logic is explained in the respective hazard assessment sections (Section 6 to Section 12).

The following process was applied to each natural hazard:

- Development of project specific logic to classify asset susceptibility (i.e., the four-level system).
- Implement logic to systematically classify susceptibility rating.
- Verify the developed logic/process where feasible (refer section 3).
- Use GIS to produce hazard susceptibility maps.
- Derive statistical outputs on exposure of each road segment to each hazard.

The statistical output is tabulated within Appendix D . This table comprises of:

- Segmentation of network
- Details of segment including road name, surface type and total distance
- Percentage of each road segment per natural hazard susceptibility rating (only select classification categories shown)
- Number of Debris Flows per kilometre (only select classification categories shown)
- Weighted susceptibility scores (to provide a consolidated high-level visual overview, not used quantitatively).

The 2021 and 2022 storm event fault database statistics are provided to allow direct comparison.

2.5.2 Hazard implications

Hazard implications are summarised to provide the likely effects (damage, outages, etc) to the transport network. Hazard implications are tabulated in the respective hazard assessment sections (Section 6 to Section 12).

The following process was applied to each natural hazard:

- General discussions on the likely generic implications.
- Tabulation of implications per triggering mechanism, based on an intensity band. The intent is to provide the likely effects (damage, outages etc) to the roading network and not the impact to the network users. The interpretation of economic and other impacts on end users is addressed in the business case rather than this report.

2.5.3 Hazard interventions

Potential interventions to manage the hazard implications to the transport networks are developed utilising the Waka Kotahi adaptation plan[2] strategies of:

- Avoid
- Protect
- Accommodate
- Retreat.

3 Hazard Assessment Verification / Validation

Verification/validation is desirable to confirm the accuracy or at least sensibility of the outputs of the hazard assessment. Site based verification was not possible due to the wide geographical extent in addition to the programme and financial constraints of the project. Partial validation was undertaking by holistically comparing the defined hazard susceptibility classification against historical network fault data. These are listed below and further described in the following sections.

- 2021 storm event database
- 2022 storm event database
- David Miller Flood Damages Documentation – 1980's to 2005.

Input was also provided by current Marlborough Roads personnel, who shared knowledge of the network gained over the last 25 years.

If further refinement and validation is required, the following could be considered, depending on the risk associated with decisions being made:

- Further desktop validation by comparing site specific information.
- Further review and inclusion of David Miller documentation.
- Improvement and integration of RAMM database maintenance records.
- Ground truthing via a comprehensive site reconnaissance program.

3.1 2021 storm event database

The 2021 storm event network fault database is hosted by a Marlborough District Council ArcGIS interface.

Post storm event, site inspections were completed by zone managers (i.e., supervisors for road maintenance and construction contracts). Typically, the personnel were members of the Network Outcome Contract (NOC) or personnel with similar skillset brought in from other areas. They undertook visual inspections, took photographs, and recorded locations. This data (i.e., brief description, typically accompanied with a photograph) was loaded via a quick capture database process.

The original purpose was to record all the network faults to allow planning and management of recovery.

It should be noted that these were rapid initial inspections and require post verification to confirm the extent of the fault. In terms of Stantec natural hazard susceptibility assessment – the raw data provides direct evidence of location and quantity – and this assists in verifying the preliminary natural hazard susceptibility rating developed in the assessment.

The observed network faults were categorised into the following:

- Asset Damage
- Culvert Issue
- Overslip
- Scour
- Structure Issue
- Surface Flooding
- Tree issues
- Trees/Debris
- Underslip.

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[2] Waka Kotahi: Tiro Rangi: our climate adaptation plan 2022-24

A figure is provided within Appendix E which illustrates the locations of the 2021 storm event fault locations. A breakdown of the data of interest is also provided.

3.2 2022 storm event database

The 2022 storm event database is effectively the 2022 network fault database similar to the 2021 database described above. Notable differences include:

- Hosted by a NOC Contractor ArcGIS interface.
- The team was better equipped to undertake the job promptly and more thoroughly – and therefore the 2022 data is considered slightly more robust.

A figure is provided within Appendix E which illustrates the locations of the 2022 storm event fault locations. A breakdown of the data of interest is also provided.

3.3 David Miller documentation – 1980's to 2010

Retired Marlborough Roads roading engineer David Miller was involved in maintaining the Kenepuru Road and Queen Charlotte Drive from the 1980s to the early 2000s. He was commissioned by MDC to compile a report[3] in 2015 to input into an environmental study with an objective to provide an estimate the volume of sediment entering coastal water from road related instabilities.

In a report to the council environmental committee (16th Feb 2016), it was documented:
"There were significantly more slips along the Kenepuru Road with a total of 36 recorded (Figure 1). These dated from 1982-2005, with an approximate frequency also of one every 9 months. Slips were on average approx. 2400 m3 on the Kenepuru Road (Figure 2), and ranged in volume from 200-8000 m3 with one extreme event of ~35,000 m3 in the mid-1990s on the northern side of the Kenepuru above Mills Bay".

"Mr Miller in his report documented 12 slips along Queen Charlotte Drive from 1990-2003 (Figure 1). These occurred periodically over that 14-year period, at an average frequency of approximately one every year. Estimated volumes of these slips ranged from 300-3000 m3 (Figure 2), with an average slip volume of approximately 1250 m3".

The two figures mentioned are included in Appendix E .

4 Natural Hazard Descriptions

4.1 Natural slope instability

In the Sounds, much of the underlying geology is deeply weathered semi-schist with limited topsoil. This type of land is naturally unstable where it occurs on steep slopes. The natural slope instability hazard classification is intended to capture large volume natural slope instabilities. They typically have deep seated failure mechanisms which result from the natural environment (geology, faults, historical global slope failures, etc). In the Marlborough Sounds, these are typically rotational and translational landslides. Although Debris Flows are a form of natural instability, these are treated as a separate instability mechanism for this study.
These type of slope failures are naturally present and would occur, even if the terrain wasn't altered by humans. The factors that influence slope instability include:

- Antecedent soil moisture
- Slope angle
- Weathering of regolith
- Depth to bedrock
- Vegetation anchoring versus burden.

The two common forms of natural slope instability are illustrated in Figure 4-1 below.

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[3] Some Impacts of Roading and Flood Damage on Sounds Road. Part Only – Queen Charlotte Drive and Kenepuru Road (Period 1985 to 2010)

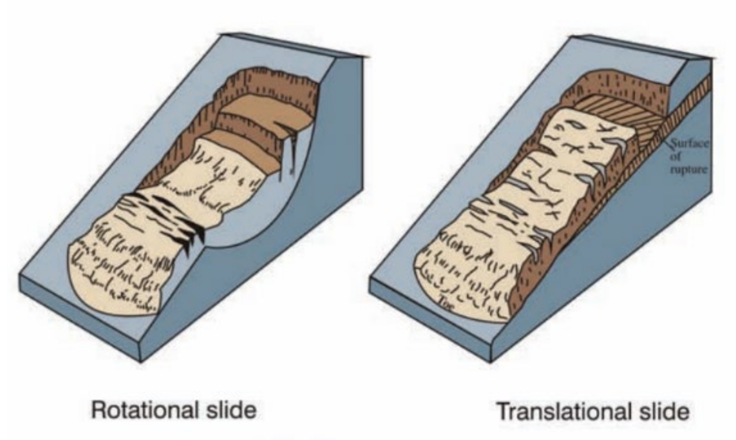

Figure 4-1: Diagram of Rotational and Translational Slide (Modified by GNS 2007, from Highland, 2004)

Figure 4-2: Natural Slope Instability on French Pass Road (2022)

4.2 Human induced slope instability

The human induced slope instability hazard classification is intended to capture low to medium volume instabilities of terrain that has been altered/modified by human activities.
These type of slope instabilities are typically localised to modified terrain and include:

- Road cut batter failure (i.e., Over slips).
- Roadside dropouts and failure of fill slopes (i.e., Under slips).
- Upslope failures (i.e., access tracks, forestry skids, etc).
- Failure of retaining systems.

Vegetation removal from the terrain can be contributing instability factor. Vegetation removal can lead to increased water flows due to reduced canopy interception, concentration of flows to certain parts of the landscape, loosening of surface sediment and reduction in root reinforcement. Vegetation removal is commonly associated with forestry, livestock farming, forming of roads/tracks, stormwater redirection, or other human disturbance.

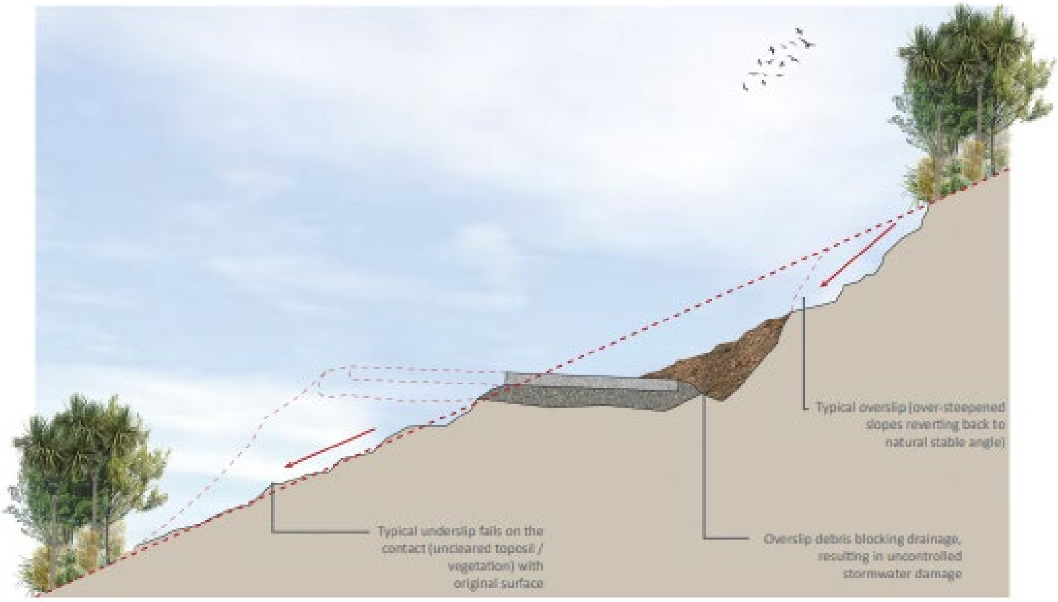

Figure 4-3: Example of human induced slope instability

Figure 4-4: Human Induced Slope Instability (underslip and overslip on Kenepuru Road, 2022).

These instabilities can be typically associated to the inadequate design or poor construction techniques (which correspond to the standards utilised at time of construction). Over steepened cut batters and non-benched side-cast fill slopes are a common feature of Marlborough Sounds roads (as they were predominantly constructed with bull dozers). They can be associated with the main roads, or with smaller access tracks on farms or forestry blocks.

The alteration of drainage patterns associated with reshaping the land tend to accumulate and focus water discharge which can adversely affect terrain stability. Roading, forestry and residential development can all contribute to changes in drainage patterns.

4.3 Debris flows

The Debris Flows hazard classification is intended to capture slope instabilities which are confined to natural waterway flow paths (i.e., valleys, streams, channels etc). This results in the hazard being typically constrained to site specific locations where these valleys or streams cross the existing road corridor.

Debris Flows are water laden masses of soil (and can contain other debris such as vegetation and fragmented rock) that rush down hillsides in a fluid-like manner. Landslides, such as those discussed in Sections 4.1 and 4.2 can also become entrained by rapidly flowing water in a stream to create a hyper-concentrated flow of sediment, rocks and woody debris. Such debris flows are capable of carrying large boulders >1m diameter and can move at speeds of up to 70km/h. Such flows can be extremely destructive to downslope roads, buildings or other infrastructure.

Although damage to culverts can be caused by scour from “clearwater” flows, it is the debris laden water that typically results in greater damage implications.

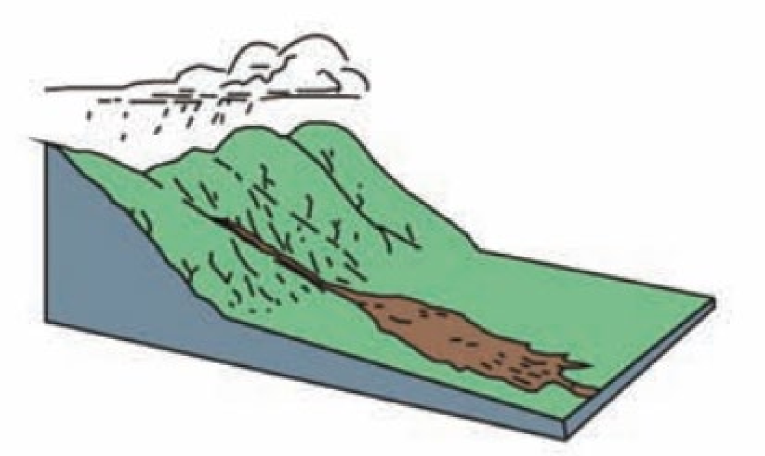

Figure 4-5: Diagram of a Debris Flow (Modified by GNS 2007, from Highland, 2004).

4.4 Liquefaction

Liquefaction is one of the principal hazards associated with strong seismic shaking. Liquefaction is caused by excess pore pressures within a soil, causing a significant loss of stiffness and strength in the soil. This can result in ground surface disruption including surface cracking, dislocation, ground distortion, slumping, large settlements and lateral spreading. Lateral spreading is the displacement of material in the downslope direction or towards waterways or open ditches/drains.

The liquefaction hazard in this assessment includes all the ground deformations that may impact the infrastructure within the project area.

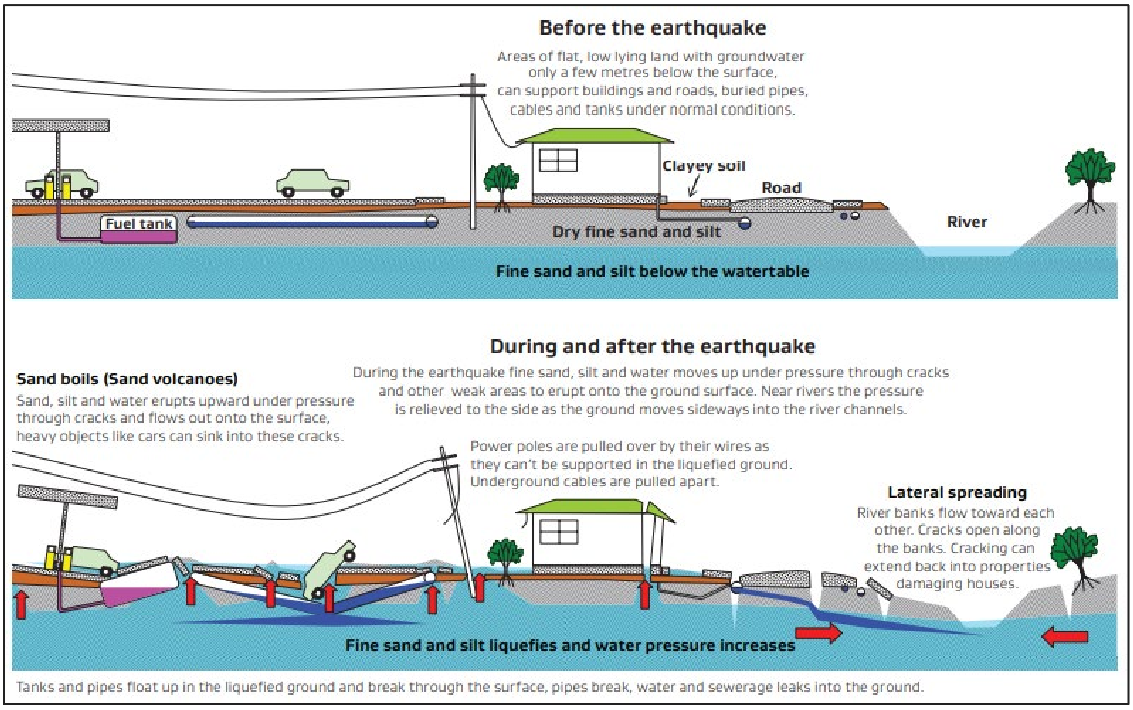

Figure 4-6: Liquefaction and its effects (Source IPENZ)

Figure 4-7: Liquefaction and Lateral Spreading implications to a bridge and a marine hub facility (Source unknown)

4.5 Flood inundation

The flood inundation hazard classification is intended to capture rainfall-related flooding of roads. The 'clear water' inundation can interrupt the serviceability of the road, making it unsafe for driving. Waterlogging of the pavement layers can contribute to direct damage, or indirect damage when the road is trafficked. Due to the geology and soils, heavy rainfall is often accompanied by debris flows. This debris can cause damage through scour and by blocking culverts which leads to overtopping and further damage through scour associated with overtopping.

Figure 4-8: Section of Queen Charlotte Drive flooded with water and debris (2021)

4.6 Coastal inundation and erosion

The coastal hazard classification captures exposure to the coastal environment that could lead to erosion and/or inundation, either currently or in future with climate change and rising sea levels. The main factors for coastal erosion and inundation are:

- Tide levels, including relative sea level rise.
- Storm surge.
- Wave run-up.

Tide range and associated maximum tide levels vary along the exposed coastline and within the Sounds. The risk is anticipated to increase in future due to Sea Level Rise (SLR) triggered by climate change, and Vertical Land Movement (VLM) associated with seismic/tectonic activity. These may result in more frequent and/or greater magnitude of inundation. Furthermore, areas that are currently not at risk might become vulnerable in the future.

Storm surge (a change in sea level that is caused by a storm, generally associated with low pressure weather systems) poses risk particularly when it coincides with the highest spring tides (perigean spring) commonly known as King Tides.

Waves can be generated by distant weather systems (swell waves) or local wind (wind waves). When arriving at the coastline, wave run-up can result in erosion and/or inundation. The significance of wave run-up is dependent on the wind fetch and wave conditions and the shape of the receiving coastline. Steeper shores with deep water receive more incident energy, which may cause higher runup and erosion if the soil or rock is susceptible. Erosion of steep coastlines may pose risk to the road through slope instability, even if the road is significantly higher than the direct wave runup. Gently sloped beaches typically dissipate wave energy over a larger area but are commonly formed of softer sand that can be more easily eroded, whether in individual storm events or over a long period of time.

Each of these factors can act in isolation, or in combination, with different ‘combined probability’ for different combinations of forcing conditions and different amounts of damage potentially rendered to different locations.

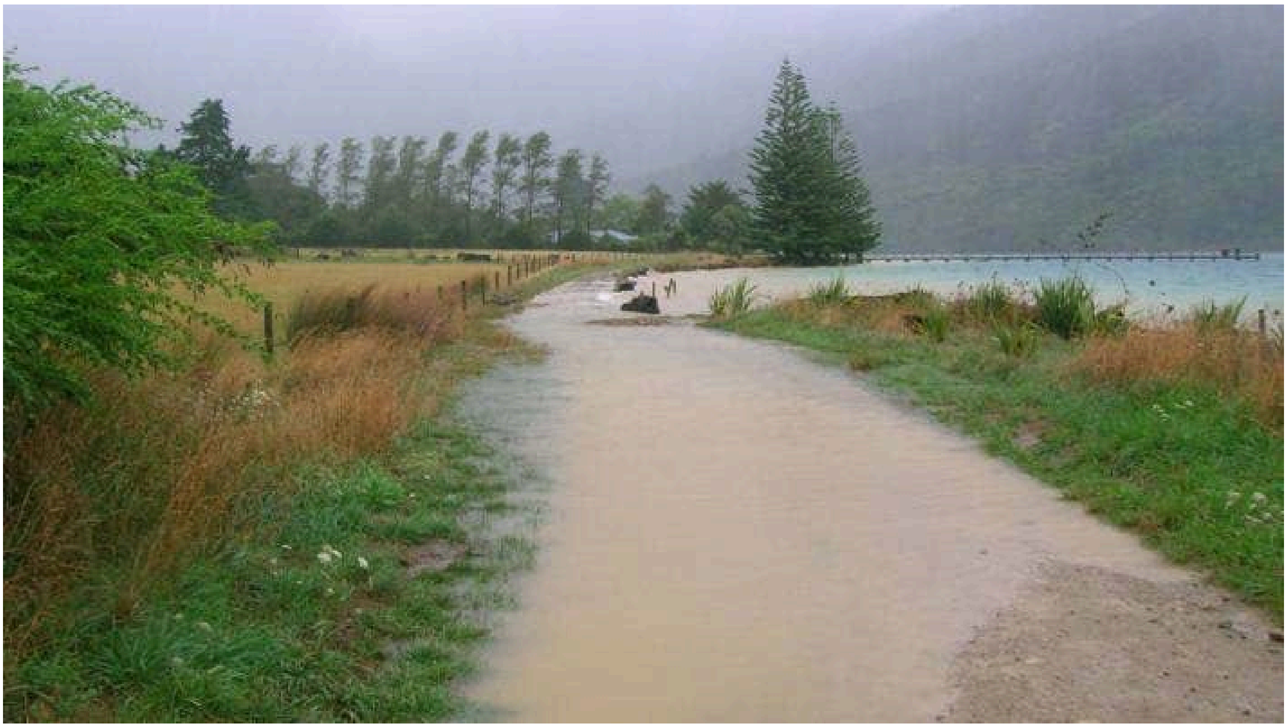

Figure 4-9: Coastal flooding over Elie Bay Road

4.7 Tsunami

A tsunami consists of a series of waves generated when a large volume of water in the ocean, sea or lake is rapidly displaced. The principal sources of tsunami are:

- Earthquakes (submarine or coastal) resulting in significant uplift or subsidence of the seabed or coast.
- Underwater landslides triggered by an earthquake or volcanic activity.
- Landslides from coastal or lakeside cliffs.
- Submarine volcanic eruptions.
- Meteor (bolide) splashdown or burst near the ocean surface.

In a tsunami, depending on the source, the whole water column from the ocean floor to the surface is affected and generates waves travelling in all directions from the source, often with great speed and with periods from few minutes to tens of minutes. When approaching the shallow waters, tsunami waves compress, their speed slows down and as a result they increase in height, as illustrated in Figure 4-10:. This often results in significant inundation of the coastlines, posing great risk to people, property and other infrastructure assets located along the coast.

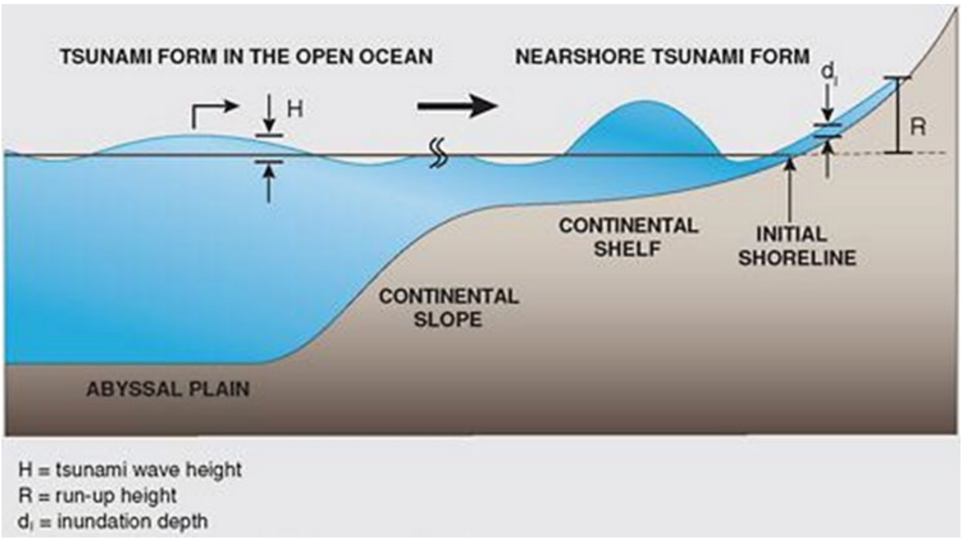

Figure 4-10: Tsunami wave diagram

5 Hazard Triggering Mechanisms

Hazard triggering events are the natural processes that trigger the initiation of a natural hazard. For example, an earthquake depending on its location and magnitude may trigger any combination of shaking, liquefaction, slope instabilities and possibly tsunami. Triggering events may be “sudden” events like earthquakes and storms, or more “slow onset” changes like climate change that gradually changes the frequency or intensity of other triggering mechanisms. We identified three main types of triggering mechanism, namely storm events, coastal events, and seismic events that were then used in the hazard assessment. Triggering mechanisms associated with the natural hazards are presented in Table 1:

Table 1: Natural Hazard Triggering Events

Triggering Mechanisms	Natural Hazards						
	Geological Hazards				Other Hazards		
	Natural Slope Instability	Human Induced Slope Instability	Debris Flows	Liquefaction	Flood Inundation	Coastal Inundation and Erosion	Tsunami
Storm events	X	X	X	◊	X	X	
Coastal events				◊	◊	X	◊
Seismic events	X	X	X	X			X

X – Trigger

◊ – Contributing Factor

In the sections that follow, we will look at the three main types of triggering mechanism, namely storm events, coastal events, and seismic events. These provide general discussion of each of the triggering events and adopted intensities utilised in the hazard implication assessment. More in depth discussion on the triggering mechanism is provided in Appendix A .

5.1 Storm events

5.1.1 General discussion

The mean annual rainfall within Marlborough Sounds varies between 800 and 2000 mm. Within any individual rainfall event, the rainfall intensity and depth may vary significantly spatially, temporally and by elevation.

Short duration storms (e.g., summer thundershowers, up to a few hours in duration) generally produce the highest intensity rainfall and typically produce less damage per storm event but occur more frequently than long duration storms.

Long storms in the order of 24 hours, or a sequence of events over multiple days (such as occurred in August 2022) generally tend to produce more widespread damage through both flooding and triggering of slope instabilities. These longer events also cause larger peak flows on the larger river systems such as the Te Hoiere / Pelorus River.

Whilst seldom directly responsible for triggering slope instability in isolation, wind can trigger tree fall which can compound slope instabilities along with rainfall. Wind also has a direct influence on wind driven wave action in the Sounds, which can contribute to erosion on susceptible shores. Within the Sounds, there can be localised concentration or attenuation of wind, due the height and orientation of the mountains relative the wind.

The effects of climate change are already being experienced in Marlborough and we anticipate that the frequency and intensity of storms will increase into the future. While there is little data yet supporting the increasing frequency of events, there is data supporting the increasing intensity of these events. Analysis of the recent August 2022 event compared to other August events recorded in previous years shows that the latest August 2022 event was not only larger than previous August events, but it was also larger than the historic August average and greater than the previous recorded monthly maximum.

It is predicted the recent trend of extreme rain events will continue, albeit sporadically, on account of climate change. Short duration high intensity rainfall is expected to experience greater increases than long duration events.

5.1.2 Adopted intensities utilised in assessment

Whilst there is always spatial variability in rainfall coverage and temporal intensity, it is useful to provide indicative or simplified storm descriptors that tend to correlate to differing levels of implications on the transport network. We have therefore simplified storms into the following bands of intensity as shown within Table 2.

Table 2: Storm Event Intensity Bands

Adopted Intensity Band	Description
100-150mm/24h or 150-200mm/72h	Rainfall with approximately 50% annual exceedance probability under current climate, which may trigger minor slips on highly susceptible slopes, with limited debris flows. This frequency is consistent with the approximately annual slips reported in the David Miller documentation. Rainfall totals may vary from low to high elevations respectively. Damage or service interruption due to river flooding is not typically expected in these events.
150-200mm/24h or 200-300mm/72h.	Rainfall with approximately 10% annual exceedance probability under current climate, which may trigger slips and debris flows at many locations. Rainfall totals may vary from low to high elevations respectively River flooding may flood over road at known low points ('very high risk' sites susceptible to river flooding identified based on the MDC Flood Hazard layer).
200-300mm+/24h or 300-400mm+/72h	Rainfall with approximately 2% annual exceedance probability or higher under current climate, which are likely to trigger widespread slips and damaging debris flows. Rainfall totals may vary from low to high elevations respectively. River flooding likely to cause road interruption at high and medium risk locations (based on the MDC Flood Hazard layer).

Events with these implications are expected to become more frequent and/or more damaging due to climate change, as discussed above in Section 5.1.1.

5.2 Coastal events

5.2.1 General discussion

Water levels relative to land may compromise several components with interrelated probability, namely:

- Astronomical Tides
- Storm Surge
- Nearshore Wave Effects (a function of many variables)
- Long-Term Trends (Sea Level Rise and vertical land movement).

Storm Surge, i.e. rise in the still water level (excluding waves) due to meteorological effects, in combination with astronomical tide leads to a storm tide water level. Port Nelson experienced a Storm Tide of approximately 0.6m above Mean High Water Spring (MHWS) during the remnants of the 2018 Cyclone Fehi event[4] which was estimated to be a 1% AEP event. It would be anticipated that the Sounds would experience storm tide components, however it should be noted that the probability of these events are dependent on the combined probability of storm surge and astronomical tides which may not peak at the same time. We understand that MDC have contracted NIWA to map future coastal inundation (spatially varying MHWS and 1% annual exceedance sea levels, with an estimate for wave setup, plus vertical land movement from NZ searise, for various epochs under different SSP emissions scenarios) utilising the latest LiDAR data. These results should be incorporated into subsequent detailed business case and design.

The nearshore wave effects such as wave height, wave set-up and run-up will be highly dependent on the exposure to open ocean swell, and whether there is sufficient fetch within a sound to generate significant wind waves, and to the local bathymetry/topography which influences local exposure and wave transformation.

Rising sea levels will exacerbate future coastal risks, with some parts of the road network being exposed more frequently or earlier than other areas. The land and road may be subject to changes in absolute sea level on account of climate change, and to additional effects due to vertical land movement (relative to a fixed geodetic datum).

The long-term predictions of absolute sea level rise show that sea levels will continue to rise well beyond reaching net zero emissions or even maximum global surface temperatures. Uncertainty of the predictions significantly increases over time. Sea-level rise by 2300 could be between 1.2 m and 3.5 m (SSP2-4.5, 17 and 83 percentile uncertainty bands), or anywhere from 5.3 m to 15.1 m under the more conservative high emissions scenario (SSP5-8.5, 50 and 83 percentiles respectively). Stated differently, a sea level rise of say 1.2m could be reached much earlier under high emissions scenarios compared to medium emissions scenarios.

[4] Tonkin & Taylor Ltd (2020). *Coastal Inundation in Nelson City.*

Vertical land movement also needs to be considered when planning for ‘net’ sea-level rise effects. New Zealand is on a dynamic plate boundary which means the land is always moving. As well as tectonic movement, sedimentary basins compact over time and subside. Human influences such as land reclamation and drainage, groundwater extraction, and petroleum reservoir depletion can also cause the land to subside. In areas with subsidence, the relative sea level rise is accelerated, and impacts will be experienced sooner.

The predicted vertical land movement from the NZ Sea Rise website shows that, while most places around the Marlborough Sounds are sinking up to 6 mm/year, some are rising at a rate of 5 mm/year. These vertical land movement estimates carry some inherent uncertainty when projecting these rates far into the future since they are based on relatively short records (predominantly an 8 year period from 2003 to 2011, which excludes major fault rupture events).

Tidal range and high tide levels vary within the Marlborough Sounds due to the different locations at which they connect to the Cook Strait. Figure 5-1 presents the future Storm Tide levels for main port locations around Marlborough Sounds. These were derived combining MHWS (and storm surge for storm tide) with sea level rise allowances (medium emissions scenario up to 2150), also including allowance for vertical land movement.

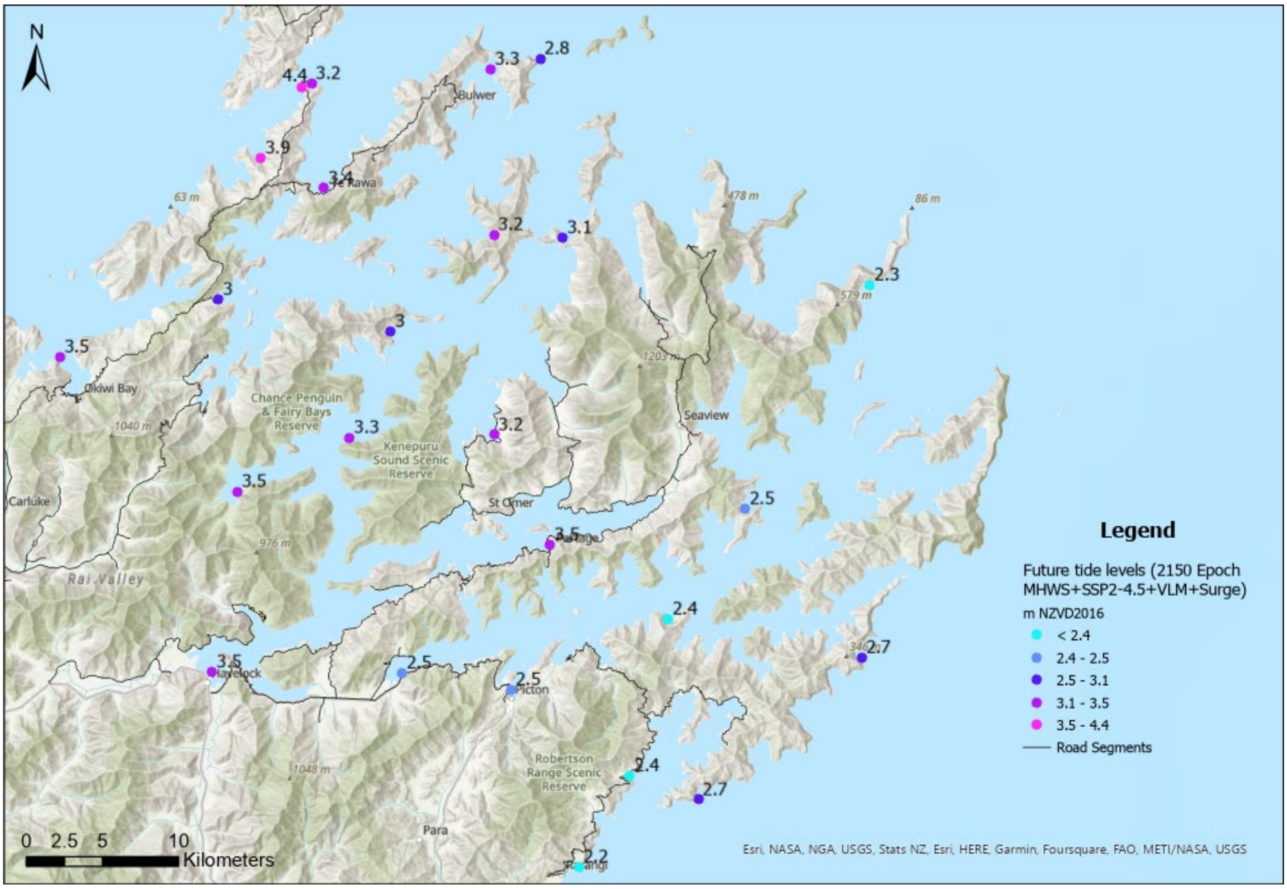

Figure 5-1: Future tide levels at 2150 epoch in meters above NZVD2016 (MHWS + SSP2-4.5[5] + VLM + Surge)

Climate change is also anticipated to impact storminess which may influence the severity of surge, wind and waves. However, these changes are expected to be lesser in magnitude, and have not been considered within this high-level study.

[5] NZ Sea Rise Map, Takiwā. Sea Level Rise Predictions by Decade for site 6768, https://searise.takiwa.co/ (11/01/2023)

5.2.2 Adopted intensities utilised in assessment

There are a variety of potential event intensities that could be used to describe existing coastal triggering events, from MHWS to King Tides, or the estimated 1% surge (applied on top of MHWS), plus potential inclusion of wave action with combined probability adding to the complexity. Any of these reference intensities change over time with sea level rise and vertical land movement, and there is also substantial uncertainty especially under different emissions scenarios for long term future epochs. For this high-level screening exercise, rather than computing many combinations and permutations of event intensities, a simplified level-based screening has been used in the classification, recognising that the results will require spatial and temporal interpretation. Some further information to support the interpretation is provided in Appendix A (Section A.2). It is anticipated that future stages of investment planning would require further spatial disaggregation and vertical refinement to support detailed business case and design. We understand that MDC have contracted NIWA to map future coastal inundation (spatially varying MHWS and 1% annual exceedance sea levels, with an estimate for wave setup, plus vertical land movement from NZ searise, for various epochs under different SSP emissions scenarios) utilising the latest LiDAR data. These results should be incorporated into subsequent detailed business case and design.

To screen for potential impacts of coastal hazard on the road network, road elevations divided into three risk classes:

- High – roads below 3m elevation (NZVD2016), noting that some areas within this will experience impacts sooner or later than others based on spatial tidal and wave exposure;
- Medium – roads between 3m and 5m elevation (NZVD2016) or within 100m of the coastline; and
- Low – roads higher than 5m elevation (NZVD2016) and/or more than 100m form the coastline.

The above classification allowed for a rapid screening of future susceptibility of all roads in the Sounds to coastal inundation. By reference to Figure 5-1, Queen Charlotte Sound / Picton and Port Underwood areas have future storm tide elevations below 3m, although these could still be impacted by wave action and therefore still have the potential to be considered high susceptibility in the future.

Most other road segments have future storm tide levels of approximately 3.5m, indicating that they are likely to be exposed to some coastal hazards much earlier than the year 2150. In these areas, road portions between 3-5m elevation identified as ‘medium’ susceptibility have the potential to be high risk if assessed in more detail. The onset and intensity of coastal impacts will vary by site depending on local topographic influences (wind fetch, bathymetry, slope of beach/cliff), soil/rock material and road formation (angle, and susceptibility of road to damage by waterlogging, wave action or erosion and underslips). The onset will also vary depending on the actual severity of event (combinations of astronomical tide, storm surge and wind/wave conditions), the actual rate of climate change (sea level rise) and actual vertical land movement over time.

The medium susceptibility category is not intended to be definitive, but to overlay with other risk factors such as the spatial variability in future storm tide, geology/soil/erodibility, etc, to shape further localised investigation and site specific design in later stages.

5.3 Seismic hazard

5.3.1 General discussion

The Marlborough Sounds lie in an area of high seismicity near the southern limit of the Pacific plate, with the Wairau (Alpine) fault to the south and the Waimea-Whangamoa fault to the west. The area is subject to frequent deep earthquakes and numerous shallow earthquakes.

The Marlborough district is crossed by a series of fault lines. The Wairau, Awatere and Clarence faults are extensions/offshoots of the Alpine Fault, as are a number of other active faults of limited extent. There are also several important faults offshore to the east of Marlborough. Ground shaking will occur from ruptures on these fault lines.

The largest historical earthquake experienced in Marlborough that generated ground rupture occurred on the Awatere Fault in 1848. It had an estimated magnitude of 7.5.

In 2017, Geonet published forecast probabilities for large events in central NZ. These are presented in Table 3: .

Table 3: Geonet Forecast Probabilities for Large Seismic Events in Central New Zealand

	Magnitude Range	Chance of Occurrence
Within next Decade	M7.8 or Greater	2 to 20%
	M7.0 or greater	10 to 60%

Seismic design criteria for geotechnical elements of infrastructure can be derived using guidelines presented in either the NZTA Bridge Manual[6] or MBIE's Earthquake Geotechnical Engineering Practice guidelines – Module 1[7]. Table 4: presents current seismic design criteria for Picton, based on MBIE Module 1.

Table 4: Current Seismic Design Criteria for a Picton Site

50yr Return Period		250yr Return Period		500yr Return Period	
Magnitude	(Horizontal PGA, g)	Magnitude	(Horizontal PGA, g)	Magnitude	(Horizontal PGA, g)
6.6	0.18	7.1	0.39	7.3	0.52

The New Zealand Seismic Hazard Model (NZSHM) is currently being revised, with preliminary outputs suggesting that the MBIE Module seismic design criteria are considerably underestimating the frequency and intensity of future seismic events in central NZ.

5.3.2 Adopted intensities utilised in assessment

Table 5 presents earthquake shaking intensities (horizontal PGA, g) that are utilised to discuss resulting natural hazard implications to the transport network.

Table 5: Earthquake Event Intensity Bands

Adopted Intensity Band	Description
0.18g to 0.39g	Approximately relates to a 2% to 0.4% AEP, i.e. 50 to 250yr return period event).
>0.39g	>0.39g (approximately relates to a greater than 0.4% AEP, i.e. 250yr return period event).

It is important to note that earthquake shaking less than 0.18g can trigger natural hazards to occur (slope instabilities and liquefaction), however it is not perceived that resultant implications would be widespread across the transport system and therefore not considered further.

[6] Waka Kotahi NZ Transport Agency, Bridge manual SP/M/022, Third Edition 2022
[7] Ministry of Business, Innovation and Employment (MBIE) - Earthquake Geotechnical Engineering Practice guidelines – Module 1, 2021

6 Hazard Assessment – Natural Slope Instability

6.1 Desktop assessment methodology

Historical slips and areas susceptible to instability have been previously mapped. The following publicly available GIS polygon layers were used in the analysis:

- GNS Geological Maps; Geology of the Wellington Area[8], Geology of the Nelson Area[9] – Landslide Units.
- GNS Landslide Database[10].
- MDC Unstable Land[11].

In conjunction, Stantec compiled the following:

- Stantec historic slope instabilities: this layer was created by digitising slope failures in historic aerial imagery hosted by MDC in the project area: The aerial surveys that were used were taken in the following years: 1958, 1983, 1994, 2002, 2012, 2018. The aerial surveys vary in extent, resolution, clarity, time of year and date of survey.

The GIS polygon layers were then intersected with the road centrelines (taken from MDC RAMM database) to identify where the road corridor traverses these features. Table 6 presents the logic used to assign the Natural Slope Instability hazard susceptibility ratings.

Table 6: Natural Slope Instability Hazard Susceptibility Classification Methodology

Natural hazard Susceptibility Classification	Natural hazard Susceptibility Classification Methodology
Very high	Assigned to road sections which are located within GNS mapped landslide units or had evidence of global failures within the Stantec historic slope instabilities and may include some of the criteria listed in the lower classifications.
High	Assigned to road sections which are located within a landslide on the GNS Landslide Database, and may include some of the criteria listed in the lower classifications.
Medium	Assigned to road sections which are located within the MDC Unstable Land layer.
Low	Assigned to road sections which are not located within any of the GIS landslide or unstable land layers.
Not Applicable	Not used.

6.2 Assessment outputs

Natural Slope Instability Hazard Susceptibility maps (covering different areas) have been generated and are presented within Appendix C . A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

Some initial observations include:

- In general, the Kenepuru area has the greatest lengths of roads that have high to very high natural slope instability susceptibilities.

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[8] Begg, J.G, Johnston, M.R. (compilers) 2000. Geology of the Wellington Area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 10, 1 sheet + 64p. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences Limited.
[9] Rattenbury, M.S, Cooper, R.A., Johnston, M.R. (compilers) 1998. Geology of the Nelson area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 9, 1 sheet + text. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences Limited.
[10] Institute of Geological and Nuclear Sciences, New Zealand's National Landslide Database (2017), accessed December 2022, http://data.gns.cri.nz/landslides/about.html
[11] Marlborough Sounds Resource Management Plan (MSRMP), 2020, accessed December 2022, https://eplan.marlborough.govt.nz/eplan/property/1746416/1555838/5520323/5278272/0/145

- Four road segments have notably higher proportions (>40% of segment length) of very high natural slope instability susceptibility compared to anywhere else in the Sounds. These segments are:
    - Moetapu tunrnoff to Mahau turnoff
    - Mahau turnoff to Portage
    - Portage to Kenepuru Heads
    - Moetapu.

6.3 Implications to transport network assets

Large slope instability failures typically cause severe damage to the roading corridor, resulting in road closures for long timeframes. Remediation of global slope failures are typically challenging, long-duration and expensive.

Large slope instability failures could also affect shoreline infrastructure (e.g., jetties) located at the base of slopes via global movement or landslide debris runout.

Table 7: Summary of Natural Slope Instability Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
Storm	100-150mm/24h or 150-200mm/72h	• Typically no implications, as not enough to trigger large global slope instabilities. • Potential to reactivate existing global slope instabilities but would be few in numbers with minimal disruption to service levels.
	150-200mm/24h or 200-300mm/72h	• Expected to cause remobilisation of existing global slope instabilities (i.e., very high and high susceptibility areas). Could involve: ○ minor slumping (of a global slip/stick type global failure) which would involve some short timeframe road closures, and long durations where traffic flow is reduced to one lane. • Complete failure of roading corridor (rare), resulting in road closure for long durations.
	200-300mm+/24h or 300-400mm+/72h	• Numerous global slope instability failures (comparable to 2022 storm event) would occur throughout the majority of the network, resulting in widespread severe damage to the roading corridor. • Major damage especially likely in very high and high susceptibility areas. Long term road closure expected.
Coastal	Not applicable	Not applicable.
EQ	0.18 to 0.39g shaking	• Expected to cause remobilisation of existing global slope instabilities (i.e., very high and high susceptibility areas). • Some new global slope failures would be likely. More likely to occur in the very high and high susceptibility areas – but could occur anywhere. Long duration road closure likely, and other service levels severely affected.
	>0.39g shaking	• Extensive global slope instability failures (comparable to induced slope failures of the Kaikoura 2016 earthquake) would occur throughout the complete network, resulting in widespread severe damage to the roading corridor. Major damage especially likely in very high and high susceptibility areas. • Roading network likely to be left in a condition that rebuild would be unfeasible in numerous places.

7 Hazard Assessment – Human Induced Slope Instability

7.1 Desktop assessment methodology

The following layers were used and edited for the analysis:

- Road Centrelines (taken from RAMM Database).
- LINZ Tracks (Vehicles and Walking)[12]: The layer was further edited by digitising forestry tracks from recent aerial imagery from 2012 and 2018.
- LINZ 1m DEM[13] (2020-2021).
- Stantec slope angle GIS raster layer: This layer was developed utilising the DEM to create a slope shade layer of the project area. The generated layer included colour shading of the terrain into the following slope angle categories:
    - < 7 degrees
    - 7 to 27 degrees
    - 27 to 33 degrees
    - 33 to 45 degrees
    - >45 degrees.

- Stantec historic slope instabilities: this layer was created by digitising slope failures in historic aerial imagery hosted by MDC in the project area[14]: The aerial surveys that were used were taken in the following years: 1958, 1983, 1994, 2002, 2012, 2018. The aerial surveys vary in extent, resolution, clarity, time of year and date of survey.

The Stantec digitised slope instability layer was used to determine sections of the road corridor which had evidence of previous slope failures, typically cut and fill failures. The supplemented LINZ Tracks layer was used to determine areas of the road corridor, above and below the present road centreline, in which vehicle tracks may have altered the drainage patterns associated with reshaping the land.

The slope raster GIS layer, derived from the 1m DEM of the project area, was then used to assess sections of the road corridor which had over-steepened slopes above and below each road. The oversteepening is typically due to the abrupt truncation of the natural hill slope to accommodate the placement of the road.

Table 8 presents the logic used to assign the human induced slope instability susceptibility ratings.

Table 8: Human Induced Slope Instability Hazard Susceptibility Classification Methodology

Natural Hazard Susceptibility Classification	Natural Hazard Susceptibility Classification Methodology
Very high	Assigned to road sections which have evidence of historic slope instabilities, within close proximity to tracks, significant sections of over-steepened slopes (above and below the road).
High	Assigned to road sections which have evidence of some historic slope instabilities, near to tracks, some sections of over-steepened slopes (above and below the road).
Medium	Assigned to road sections which have evidence of few historic slope instabilities, near some tracks, minimal sections of over-steepened slopes (above and below the road).
Low	Assigned to road sections which have no evidence of few historic slope instabilities, not located near tracks, minimal to no sections of over-steepened slopes (above and below the road).
Not Applicable	Not used.

[12] LINZ Data Service – NZ Track Centrelines (Topo, 1:50k), accessed December 2022, https://data.linz.govt.nz/layer/50364-nz-track-centrelines-topo-150k/
[13] LINZ Data Service - Marlborough LiDAR 1m DEM (2020-2021), accessed December 2022, https://data.linz.govt.nz/layer/105911-marlborough-lidar-1m-dem-2020-2021/
[14] MDC Smart Maps – Historic aerial imagery, accessed December 2022, https://marlborough.maps.arcgis.com/apps/webappviewer/index.html?id=b8bddfb24c294a6f9a9ce6cf3c3cfbd2

7.2 Assessment outputs

Human Induced Slope Instability Hazard Susceptibility maps (covering different areas) have been generated and are presented within Appendix C . A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

Some initial observations include:

- All road segments within the Sounds except two (Anikiwa and Bulwer Bay turnoff to French Pass) have significant (>50% of segment length) proportions that have either high or very high susceptibility to human induced slope instability.
- The following roads segments have significant proportions that that have either high or very high susceptibility to human induced slope instability.
    - Bulwer Bay turnoff to Bulwer Bay
    - Havelock to Linkwater
    - Link water to Picton
    - Moetapu tunrnoff to Mahau turnoff
    - Mahau turnoff to Portage
    - Portage to Kenepuru Heads
    - Moetapu
    - Waikawa to Hakahaka Bay
    - Fighting Bay to end of road.

7.3 Implications to transport network assets

Localised low to medium volume slope instability failures can cause a wide range of damage to the roading corridor.

Road cut batter failure (i.e., over slips) occur regularly and can vary in size from minor failures that block roadside ditches to larger failures that can block both lanes. For the larger cut slope failures – the duration of road disruption is typically dependant on the time taken to remove the debris (especially the haul distance to a dump site). Engineer input is required when slopes require benching or alternative slope stabilisation remediations such as rock bolting (although very rare in the Sounds network).

Roadside dropouts and failure of fill slopes (i.e., Under slips) can vary in size from minor road shoulder dropouts to slumping of outer lane, to complete loss of the outside lane. These types of failures occur regularly and are suspected to cause the most disruption to the roading network. Slumping of the shoulder/outer lane are frequently remediated by topping up the road pavement (and not addressing the root instability cause). This remedial solution has a proven "maintenance solution" track record, but eventually the material failures resulting in complete loss of the outer lane. Due to steep downslope conditions, these failures tend to require complex, time consuming and expensive retaining solutions. These result in single lane access for long time durations.

Although upslope failures of modified terrain (i.e., access tracks, forestry skids, etc) commonly occur, it is more likely that the associated uncontrolled stormwater flows will adversely affect the road (rather than the earth debris themselves). Culvert/drainage ditches get blocked, and stormwater is discharged on the already susceptible cut or fill slopes, compounding instability issues.

Failure of retaining systems typically disrupt the outer lane and result in long durations of one-way traffic whilst a remedial solution is designed and constructed.

Table 9: Summary of Human Induced Slope Instability Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
Storm	100-150mm/24h or 150-200mm/72h	• "Typical" year of usual road network Level of Service restrictions, and the requirement to undertake the corresponding maintenance activities.
	150-200mm/24h or 200-300mm/72h	• In very high and high susceptibility areas: ○ Over steepened cut slopes become saturated and fail (over slips). ○ Fill slopes become saturated, and uncontrolled stormwater promotes localised scour, which all combines to slope failures. • Short to medium duration road closure likely, and other service levels severely affected. Prolonged time when one lane traffic flow is required at location where outer lanes have failed.

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
	200-300mm+/24h or 300-400mm+/72h	• Widespread slope instability failures (comparable to 2021 and 2022 storm event) would occur throughout the majority of the network, resulting in widespread severe damage to the roading corridor. • Major damage especially likely in very high and high susceptibility areas. Long term road closure expected.
Coastal	Not Applicable	Not Applicable.
Earthquake	0.18 to 0.39g shaking	• Based on available accelerometer information – it is unlikely that much of the human modified terrain has experienced shaking >0.2g. It is therefore expected that widespread slope failures would occur, especially concentrated within very high and high susceptibility areas. • Few, if any retaining structure in the Sounds have been designed for >0.2g, therefore widespread structure damage of retaining systems is expected. Short to medium duration road closure likely, and other service levels severely affected. Prolonged time when one lane traffic flow is required at location where outer lanes have failed.
	>0.39g shaking	• Extensive slope instability failures would occur throughout the complete network, resulting in widespread severe damage to the roading corridor. Major damage especially likely in very high and high susceptibility areas. • Roading network likely to be left in a condition that rebuild would be unfeasible in numerous places.

8 Hazard Assessment – Debris Flows

8.1 Desktop assessment methodology

Stantec's assessment of debris flow susceptibility assessment relies heavily upon the MDC commissioned Debris Flow Study[15]. The following data was used for the assessment:

- Road Centrelines (taken from MDC RAMM database).
- GIS layers extracted from Bloomberg and Palmer's Debris Flow Study (2022) including a polyline GIS layer of stream segments with corresponding Melton ratios (a metric for vaulting debris flow potential), within the project area. It is noted that this study has been undertaken at a desktop level, and recommendations within the report include the need to undertake additional verification. Verification work is currently underway with results expected toward the end of 2023.

Potential debris flow locations (along the road corridor) were derived by identifying the intersection of the road centrelines with the stream segments identified (and classified) by Bloomberg and Palmer.

Table 10 presents the logic used to assign the debris flow susceptibility ratings. A simple relationship was assigned between susceptibility classification and the Melton ratios (a metric for evaluating debris flow potential). The Melton ratio is considered a screening level indicator of a creek's propensity (or susceptibility) to produce debris floods or debris flows. It is a measure of the catchments ability to capture enough water and move it downslope fast enough to carry dense flows of sediment and woody debris. The threshold values may be conservative, i.e., values below 0.3 may still trigger debris flows in some catchments.

Table 10: Debris Flow Instability Hazard Susceptibility Classification Methodology

Natural Hazard Susceptibility Classification	Natural Hazard Susceptibility Classification Methodology
Very high	Debris Flow Melton ratio >0.9
High	Debris Flow: Melton ratio 0.6 – 0.9
Medium	Debris Flood: Melton ratio 0.3 – 0.6
Low	Clearwater Flood: Melton ratio <0.3
Not Applicable	Not used.

8.2 Assessment outputs

Natural Slope Instability Hazard Susceptibility maps (covering different areas) have been generated and are presented within Appendix C . A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

8.3 Implications to transport network assets

Debris flows hazard are confined to natural waterway flow paths (i.e.gullies, valleys, streams, channels etc) and therefore the implication to the road corridor assets are normally confined to site specific locations where these flow paths cross the road corridor. Typically, in the Marlborough Sounds, the configuration of the road corridor at these locations consists of a non-engineered embankment fill (filling in the natural depression) and a buried pipe to convey the water under the road. Sometimes a retaining wall is present on the downslope side.

From experience and post 2021 and 2022 flood event observation, there are three common road corridor implication scenarios:

- Small debris flow block (or partially block) the culvert entrance, which results in a secondary flow path over the road, resulting in localised scour, especially on the downslope side of the fill. This could include minor damage to any retaining structures that are present. Often, these sites can be temporary reinstated to one or two-lane traffic within a short timeframe. Permanent fixes typically are undertaken as part of maintenance programs.

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[15] Bloomberg, M., Palmer, D., 2022, Estimation of catchment susceptibility to debris flows and debris floods – Marlborough Sounds, Pelorus Catchment and Wairau Northbank, Te Kura Ngahere – School of Forestry, University of Canterbury, Scion Research.

- Small to medium debris flows block the culvert entrance (sometime even depositing material onto the carriageway), which results in a secondary flow path over the road. However due to greater exposure (greater or prolonged secondary flows and more rocky debris being transported), the resulting effects induce more damage. Embankment fill could be entirely evacuated from the site, retaining structures damaged and culverts severely compromised. These types of failures can take up to a week (once the site can be accessed) to be temporarily reinstated to one or two-lane traffic. Permanent fixes require site specific design and construction which could take months.

- Large debris flows are typically terrain altering events. They originate in the upper extents of catchments and can flow down the natural flow path as a high energy fluidised mass. It has the potential to carve a new channel into the landscape. Depending on the volume of debris mass and its energy, it has the potential to destroy most things in its path (including vehicles, buildings and parts of road embankments). This could result in a channel-like void across the road corridor (with the channel being deeper than the natural depression during original road construction). These are devastating natural hazard events and could take a few weeks to temporarily restore. Permanent fixes require site specific design and construction which could take months.

Debris flows are typically triggered by storm events but can also be triggered by earthquakes, or combinations of storm and earthquake. Earthquake triggered debris flows require the ground to have higher levels of saturation (i.e., more likely to be triggered if earthquake occurred during winter months). However, the larger the shaking intensity, the less dependent on saturation levels. After an earthquake has mobilised material, subsequent rainfall may be able to re-initiate debris flows at lower rainfall intensities than usual.

Table 11: Summary of Debris Flow Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
Storm	100-150mm/24h or 150-200mm/72h	• Typical" year of usual road network Level of Service restrictions, and the requirement to undertake the corresponding maintenance activities.
	150-200mm/24h or 200-300mm/72h	• In very high and high susceptibility debris flow locations, some small to medium sized debris flows are expected. • Always a chance that a large debris flow could also occur.
	200-300mm+/24h or 300-400mm+/72h	• Numerous small to medium sized debris flows (comparable to 2021 and 2022 storm event) would occur throughout the majority of the network, resulting in widespread damage to the roading corridor. Damage especially likely at very high and high susceptibility locations. • One (at minimum) large debris flow is likely, which would result in a period of road closure.
Coastal	Not Applicable	Not Applicable
EQ	0.18 to 0.39g shaking	• In very high and high susceptibility debris flow locations, some small to medium sized debris flows could occur. • Always a chance that a large debris flow could also occur.
	>0.39g shaking	• Numerous small to medium sized debris flows could occur throughout the complete network, resulting in damage to the roading corridor. Damage especially likely at very high and high susceptibility locations. • One (at minimum) large debris flow is likely, which would result in a period of road closure.

9 Hazard Assessment – Liquefaction

9.1 Desktop assessment methodology

The liquefaction hazard assessment used the following data sources:

- GNS Geological Maps: Geology of the Wellington Area[16], Geology of the Nelson Area[17].

The geology maps were used to create an adapted methodology in line with the MBIE Liquefaction Assessment, Level A – Basic Desktop Assessment[18]. Due to the lack of additional supporting information within the project area, the primary focus of the assessment was to identify land with a high degree of certainty that "Liquefaction damage is unlikely". There is a high level of residual uncertainty regarding the other hazard classifications, as there are no recent regional scale assessments of liquefaction, groundwater, paleo-seismicity and minimal subsurface information within the project area.

Table 12 presents the logic used to assign Liquefaction susceptibility ratings. The geological maps were discretized based on their geological criteria, adapted from MBIE Geotechnical Module 3.

Table 12: Debris Flow Hazard Susceptibility Classification Methodology

Natural hazard Susceptibility Classification	Natural hazard Susceptibility Classification Methodology
Very High	Not used
High	Not used
Medium	Assigned to road sections which traverse over Holocene aged units (which are considered susceptible to liquefaction). Excludes landslide units.
Low	Assigned to road sections which traverse over Pleistocene aged units (which are considered to possibly result in liquefaction damage).
Not Applicable	Assigned to road sections which traverse over all units older than Pleistocene (in which liquefaction damage is unlikely).

Note: the primary focus of the assessment was to identify land with a high degree of certainty that "Liquefaction damage is unlikely"

Port Marlborough Ltd indicated (per comms) that they expect the assets located on reclaimed land (Havelock and Picton) are likely to be susceptible to liquefaction and lateral spreading. It was also advised that during the 2016 Kaikoura, liquefaction was observed at a location within the Havelock Port.

9.2 Assessment outputs

Liquefaction Hazard Susceptibility maps (covering different areas) have been generated and are presented within Appendix C . A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

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[16] Begg, J.G, Johnston, M.R. (compilers) 2000. Geology of the Wellington Area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 10,. 1 sheet + 64p. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences Limited.
[17] Rattenbury, M.S, Cooper, R.A., Johnston, M.R. (compilers) 1998. Geology of the Nelson area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 9, 1 sheet + text. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences Limited.
[18] Ministry of Business, Innovation and Employment (MBIE), 2017, Planning and engineering guidance for potentially liquefaction-prone land – Resource Management Act and Building Act aspects, MBIE, Wellington, New Zealand.

9.3 Implications to transport network assets

The greatest liquefaction implications are expected where assets are located upon Holocene aged geological units.

Liquefaction implications to existing road corridors within NZ are rarely mitigated in advanced, with the typical approach to fix the damage after the event. Liquefaction induced damage to the road corridor can normally be repaired relatively quickly to a basic level of service. However, liquefaction induced effects to the foundations of the network's structural assets can result in considerable damage and could result in significant network disruption. These structural assets could include bridges, major culverts, retaining walls, and coastal marine infrastructure (wharfs, jetties, marinas, ramps, coastal revetments).

These types of structures are also typically located on or adjacent to sloping ground, so are also exposed to the dual effects of liquefaction and lateral spreading. Typically, the effects from lateral spreading cause the most damage to the structures.

Key transport network infrastructure located within areas of expected liquefaction include (but not limited to):

- Waikawa Marina (and other Picton marine hub facilities)
- Havelock Marina (and adjacent facilities)
- Okiwi Bay foreshore/settlement area
- French Pass wharf and Ramp
- All the bridges listed with Section 10.3 (which are also susceptible to flood inundation related impacts).

Table 13: Summary of Liquefaction Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Network Assets
Storm	100-150mm/24h or 150-200mm/72h	Not Applicable.
	150-200mm/24h or 200-300mm/72h	Not Applicable.
	200-300mm+/24h or 300-400mm+/72h	Not Applicable
Coastal		It is noted there is a cascading effect to liquefaction/lateral spreading susceptibility of coastal areas as sea level rises. As groundwater levels increases, the extent and depth of ground that is susceptible to liquefaction increases.
EQ	0.18 to 0.39g shaking	• Although liquefaction can be triggered during <0.18g events, liquefaction triggering (in most scenarios) is expected to occur above 0.18g. • Road corridors may experience liquefaction induced effects including sand boils, differential vertical deformation and lateral spreading (when on a slope adjacent to a free face). Typically, roads can be restored to a usable state within a couple of days. • Lateral Spreading at bridge abutments can result in the abutments moving inwards and the bridge foundations and superstructure being offset or severely damaged. This has the potential to close the road for a significant timeframe (generally requiring a temporary bailey bridge whilst a new bridge is constructed). Lateral spreading at numerous marine hubs is expected and widespread damage should be expected. This is likely to disrupt operations: emergency ramps could be out of actions for a few days and wharf/marinas closed for weeks. Vessel fuel supply is likely to be affected.
	>0.39g shaking	As above, but damage more severe and widespread.

10 Hazard Assessment – Flood Inundation

10.1 Desktop assessment methodology

The MDC Flood Hazard overlay addresses mainly the larger valleys, and its accuracy may vary based on the data used to generate it at the time. This assessment used the MDC Flood Hazard[19] layer as a starting point for identifying segments of road likely to be susceptible to flooding, i.e. potential of the roads to be exposed to flood inundation. However, given the uncertainties associated with this layer, and the paucity of information regarding culvert dimensions, the flood inundation hazard should be interpreted together with the debris flow risk for sites away from the main rivers. In other words, the presence of debris flows is considered an indicator of locations where flooding or damage related to flooding is a potential risk. Once the programme business case sets out the direction of travel, further data collection and assessment of flooding and debris flow risk to the current and future road network is recommended.

Table 14 presents the logic used to assign flood inundation susceptibility ratings assigned from the MDC Flood Hazard layer. It should be noted that Level 4 of the MDC Flood Hazard layer was excluded from this assessment due to lack of raised defences within the study area.

Table 14: Flood Inundation Hazard Susceptibility Classification Methodology

Natural hazard Susceptibility Classification	Natural hazard Susceptibility Classification Methodology
Very High	Level 3 (dangerous)
High	Level 2
Medium	Level 1 (shallow) or Level R (residual).
Low	Not used.
Not Applicable	Not used.

10.2 Assessment outputs

Flood Inundation Susceptibility maps (covering different areas) have been generated based on MDC flood hazard overlay, and are presented within Appendix C A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

Some initial observations include:

- The Dalton Road to Kaiuma/Te Hoiere Road segment contains the highest proportion (>30%) of corridor length that have high susceptibility to flooding.
- The SH6 to Okiwi Bay, Havelock to Linkwater, and Portage to Kenuperu Heads also have notable proportions (>5%) of corridor length that have high susceptibility to flooding.

10.3 Implications to transport network assets

Flood inundation is typically quite localised, short lived. The resulting short-term implications caused by flood inundation could include temporary and/or partial road closures to clear debris and make road repairs where applicable (for example due to scour). Typically, a road can be opened relatively quickly if no major damage has occurred.

The resulting longer-term implications caused by flood inundations could include:

- damage to pavement layers if trafficked by heavy vehicles during or too soon after the event
- damage to road shoulders / outer lanes from scour
- damage to culverts, ranging from inlet/outlet damage to complete washout
- damage to bridge approaches
- damage to bridges
- sedimentation of navigable water.

[19] Marlborough District Council, 2020, Marlborough Environment Plan, Volume 4 – Maps, Flood Hazard, https://www.marlborough.govt.nz/your-council/resource-management-policy-and-plans/proposed-marlborough-environment-plan/decisions-on-the-pmep/pmep-tracked-changes-version/volume-4-maps/flood-hazard

The timeframe of road disruption/outrages is dependent on the level of damage to the network asset, with damage to bridges having the potential of causing the most disruption.

A selection of bridges (or major culverts) located within known areas of flood inundation on main roads include:
French Pass Area:

- Ronga Road Bridges (x2 over Ronga River)
- Hope Drive Bridge (Okiwi Bay)
- Opouri Road Bridge (over Rai River)
- Opouri Road Bridge (x3 over Opouri River).

Pelorus Area:

- Daltons Road Bridge (over Pelorus River)
- Te Hoiere Road Bridge (over Pelorus River).

Kenepuru Area:

- Queen Charlotte Dr Bridge (over Kaituna River)
- Kenepuru Rd Bridge (near Kenepuru Heads).

Port Underwood Area

- Port Underwood Road (over Graham River).

Table 15: Summary of Flood Inundation Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Network Assets
Storm	100-150mm/24h or 150-200mm/72h	Typical year of usual LoS restriction and corresponding maintenance activities.
	150-200mm/24h or 200-300mm/72h	• Road closure during the event. • Short term implications as listed above, likely resulting in short-duration lane or road closures.
	200-300mm+/24h or 300-400mm+/72h	• Road closure during the event. • Short term implications as listed above, likely resulting in short-duration lane or road closures. • Longer-term implications as listed above. Site specific assessment of each inundation area is required to understand potential localised effects and ascertain likely implication to the assets. Serious damage or failure of one of the bridges mentioned would cause road closure resulting in the greatest impact to the roading network.
Coastal*		Near to where rivers flow into the sea, flood levels will be impacted by sea level rise, including potential backwater and sediment deposition occurring further upstream. Refer to the section on coastal risks for these locations.
EQ	0.18 to 0.39g shaking	Not Applicable
	>0.39g shaking	Not Applicable

*Note: Sea level rise is not strictly a triggering event for flood inundation, but it is rather a contributing factor that may increase flood inundation hazard in the future.

11 Hazard Assessment – Coastal

11.1 Desktop assessment methodology

A GIS assessment has been carried out to highlight sections of the road network at risk from coastal sources, using the criteria described in Section 5.2.2.

The following layers were used in the coastal assessment:

- Road centrelines (from MDC RAMM database).
- LINZ NZ Coastlines[20].
- LINZ Marlborough 1m DEM (2020-2021)[21].

Table 16 presents the logic used to discretize the coastal hazard susceptibility.

Table 16: Coastal Hazard Susceptibility Classification Methodology

Natural Hazard Susceptibility Classification	Natural Hazard Susceptibility Classification Methodology
Very High	Not used.
High	All road centrelines with an elevation of less than 3m (NZVD2016).
Medium	Road centrelines between 3m and 5m elevation (NZVD2016) or located within 100m of the coastline
Low	All other road centrelines
Not Applicable	Not used.

11.2 Assessment outputs

Coastal hazard susceptibility maps (covering different areas) have been generated and are presented within Appendix C A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

Extract from the GIS assessment is presented in Figure 11-1 which indicates that the longest portions of roads susceptible to future coastal flooding sit around Kenepuru Sound, with some sections along the northern shoreline being of high susceptibility. Whilst some of these are locations known to flood during king tides, some locations may only later be susceptible due to sea level rise. It is worth reiterating that due to the topography and the linear nature of the road network, any one location at risk may impact the entire network beyond that point if the road is closed due to flooding or damage.

[20] LINZ Data Service, NZ Coastlines (Topo, 1:50k), accessed December 2022, https://data.linz.govt.nz/layer/50258-nz-coastlines-topo-150k/
[21] LINZ Data Service, Marlborough LiDAR 1m DEM (2020-2021), accessed December 2022, https://data.linz.govt.nz/layer/105911-marlborough-lidar-1m-dem-2020-2021/

Figure 11-1: GIS Coastal Hazard Assessment extract for Kenepuru Sound

11.3 Implications to transport network assets

Table 17 below presents the estimated implications to the existing road network associated with the screening criteria described in Section 5.2.2.

Table 17: Summary of Coastal Hazard Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
Storm	Not Applicable	Not Applicable
Coastal	High: Road level < 3m MSL	• Road inundation in some known locations during king tide events currently, becoming deeper, more frequent or more widespread at other locations in future. • Potential for erosion due to wave action during storm events. • Risk of wave overtopping onto the roads during future storm events. • Short to medium duration road closures likely, to limit risk to drivers and limit damage to waterlogged pavement layers, and/or to allow for repairs. Prolonged time when one lane traffic flow is required at locations where outer lanes have been damaged.
	Medium: Road level between 3m and 5m MSL and/or <100m to shore	• Road inundation or wave overtopping during king tide or storm surge events may be possible under some future climate conditions, particularly in the northern Sounds (Kenepuru Sound, Pelorus Sound, French Pass and Ōkiwi Bay). • Potential for erosion due to wave action contributing to underslips. • Short to medium duration road closures possible to allow for repairs. Prolonged time when one lane traffic flow is required at location where outer lanes have been damaged.
	Medium: Road level > 5m MSL and <100m to shore	• Road inundation unlikely (except for very high emissions scenarios in the long term future). • Potential for erosion to the coastline due to wave action, might not reach the road level but might undermine stability of the ground below where it is weaker or more exposed. • Short duration closure of outer lane possible in the event of significant erosion.
	Low: Road level > 5m MSL and >100m to shore	• Low risk of direct consequences from coastal flooding, wave action or erosion.
EQ	Not Applicable	Not Applicable

12 Hazard Assessment – Tsunami

12.1 Desktop assessment methodology

GIS was used to identify segments of the road that lie within the MDC evacuation zone overlay. These were based on the report Tsunami evacuation zone boundary mapping for Marlborough District (GNS 2015). The road segments were classified as presented in Table 18.

Table 18: Tsunami Hazard Susceptibility Classification Methodology

Natural Hazard Susceptibility Classification	Natural Hazard Susceptibility Classification Methodology
Very High	Not used.
High	Not used.
Medium	Orange zone (1-3 and 3-5m / 0.2% AEP, i.e. 1 in 500-year return period)
Low	Yellow zone (>5m, 0.04% AEP, i.e. 1 in 2,500-year return period)
Not Applicable	Not used.

12.2 Assessment outputs

Tsunami susceptibility maps (covering different areas) have been generated and are presented within Appendix C . A summary table of each natural hazard statistics per road zone/segment is presented with Appendix D in conjunction with other data tables.

The probabilities associated with very large tsunami are rare. Depending on local bathymetry and topography, the classified road segments may not suffer significant damage. However, it is worth being aware of those segments of road at risk from moderate events, which are also likely to be more significantly damaged in an extreme event. The emergency management approach needs to consider a whole of system approach to response.

There is significant variation in maximum amplitude of tsunami risk around the Cook Strait, and there is limited information on wave focussing or dissipation within the Sounds. Depending on the outcomes of the programme business case, further detailed assessment may be required to understand local risks from tsunami waves for key infrastructure such as marine hubs, particularly if they are pivotal to emergency response.

When compared to the coastal hazard assessment presented in Section 11, it was found that some sections of the road network classified at risk of inundation from tsunami are not necessarily classified at risk from other coastal hazards, or vice versa. This indicates potential limitations of the high-level assessment and adopted general assumptions in both assessments, and that a different DEM would likely have been used by the GNS study.

In the GNS study, for Marlborough Sounds the risk associated with tsunami waves as a result of landslides, both submarine and coastal, was deemed much lower than tsunami generated from earthquakes and therefore was not explicitly assessed. Whilst significant landslide-induced tsunami may have a lower probability, and be highly localised, their potential for substantial local wave height can still cause local impact.

12.3 Implications to transport network assets

Generic summary of the tsunami hazard impact on transport network assets is provided in Table 19.

Table 19: Summary of Tsunami Hazard Impacts on Transport Network Assets

Triggering Mechanism	Intensity	Potential Generic Implications to Transport Network Assets
Storm	Not Applicable	Not Applicable.
Coastal	Tsunami Evacuation Zone: Yellow/Low - 0.04% AEP (1 in 2,500-years)	- Actual wave run up will vary depending on local exposure angles, bathymetry and above-water topography. - Damage to road assets is possible from both the initial runup and from the wash of water back out to sea. - Assets at or near sea level will likely be subject to high waves and strong currents, and significant damage may result if not designed accordingly.
	Tsunami Evacuation Zone: Orange/Medium 0.2% AEP (1 in 500-years)	- Actual wave run up will vary depending on local exposure angles, bathymetry and above-water topography. - Damage to road assets is likely from both the initial runup and from the wash of water back out to sea. - Assets at or near sea level will likely be subject to high waves and strong currents, and damage may result if not designed accordingly.
EQ	Refer Coastal	Refer Coastal

13 Natural Hazard Interventions

Natural hazard interventions (or mitigations) aim to reduce the transport implications associated with natural hazard triggering events. These actions can be targeted at different levels (e.g., system-wide transport network, road corridor segment, or site specific). Interventions can be a mixture of policy-based and engineering-based solutions.

Table 20 presents a collection of natural hazard interventions for each of Waka Kotahi adaptation plan 'strategies'. The table showcases multiple strategies with the intent that a collection of options are considered and evaluated in the programme business case. The interventions presented are initial examples to illustrate the concepts and the list is not considered to be comprehensive. Additional development of the table and broadened concepts are expected as part of the programme business case and future studies or projects that derive from it.

Table 20: Natural Hazard Intervention Strategies

	Intervention for Different Strategies			
Natural Hazard Type	**Avoid**	**Protect**	**Accommodate**	**Retreat**
Natural Slope Stability	Avoid building new roads or facilities (i.e., marine hubs) upon or below natural unstable slopes.	Very challenging and expensive to protect infrastructure from natural slope instability. Consider subsoil drainage or deep shear piles where applicable (site by site basis). Vegetation of slopes	Repair damage post hazard event to same or lower level of service, as likely prone to continued damage in the future when exposed to an EQ or storm triggering event.	New road alignment (outside of hazard area), reduce levels of service, marine options.
Human Induced Slope Stability	Avoid building new roads, tracks, or facilities (i.e., marine hubs) upon known areas of human induced stability. Ensure new earthworks are engineered and undertaken adequately, to avoid creating new terrain susceptible to human induced instabilities (including for new roading, tracking, farm and forest earthworks and residential development).	Review stormwater design of road corridor and other tracks, and implement dedicated improvement program (including strengthened exceedance or overtopping pathways rather than allowing excess to run along the road causing further damage). Target geotechnical improvements (retaining walls, cut slope improvements etc) through a dedicated improvement program. Investigation of options to minimise the impact of tree felling by forestry companies Vegetation of Slopes	Repair damage post hazard event to same standard as before (reactive maintenance). Alternatively, consider repairing roading corridors to a reduced level of service (i.e., one lane or vehicle restriction). Consider repairing roading corridors to a reduced resilience standard (e.g., not seismically designed). Plan and undertake a robust maintenance program.	New road alignment (outside of hazard area), reduce levels of service, marine options.
Debris Flow	Avoid building new assets in the potential flow paths of debris flows.	The installation of debris flow barriers is not considered economically feasible to protect linear infrastructure in the Sounds. However, in some locations, the road embankment may provide a measure of debris capture, therefore interventions to the road should also consider risks to	Prepare Trigger Action Response Plan (TARP) for operation of marine facilities post hazard event. Understand and plan for the rapid repair of lifeline assets (i.e., emergency marine ramps) and plan for redundancy. Option to reduce lane width during repair.	New road alignment (outside of hazard area), reduce levels of service, marine options.

	Intervention for Different Strategies			
Natural Hazard Type	**Avoid**	**Protect**	**Accommodate**	**Retreat**
		downslope infrastructure.		
Liquefaction	Avoid building new facilities (e.g., marine hubs) upon susceptible ground conditions. Remediate ground conditions if no other options.	Understand extent and scale of risk by undertaking further studies. Undertake remedial improvements on existing facilities (where possible) to increase resilience to hazard.	Prepare Trigger Action Response Plan (TARP) for operation of marine facilities post hazard event. Understand and plan for the rapid repair of lifeline assets (e.g emergency ramps) and plan for redundancy options	New road alignment (outside of hazard area), reduce levels of service, marine options.
Flood Inundation	Avoid building new roads or facilities within areas of inundation.	River related works to reduce the extent or frequency of flooding (i.e., stop banks, river training, retaining walls, raise or strengthen key bridges, etc).	Prepare Trigger Action Response Plan (TARP) for roads closures during/after events. Understand detour routes (if available). Repair damage post hazard event to same or reduced level of service. If bridge/major culvert fails – build back stronger (to accommodate future flow predictions). Reduce heavy traffic on waterlogged pavements.	New road alignment (outside of hazard area), reduce levels of service, marine options.
Coastal Hazard	Put restrictions on construction within exposed areas.	Raise or protect critical sections with seawalls.	Prepare Trigger Action Response Plan (TARP) for roads closures during/after events. Understand detour routes (if available). Repair damage post hazard event to same or reduced level of service, or build back stronger (to accommodate. Future coastal predictions). Reduce heavy traffic on waterlogged pavements.	New road alignment (outside of hazard area), reduce levels of service, marine options.
Tsunami Hazard	Put restrictions on construction within exposed areas.	N/a (disproportionately expensive for rare occurrence).	Prepare Trigger Action Response Plan (TARP) for roads closures during/after events. Understand detour routes (if available). Work with communities to improve integrated resilience and response. Toughen key assets to reduce damage.	N/a (disproportionately expensive for rare occurrence).

14 Discussion and Recommendations

14.1 Business case considerations

14.1.1 Hazard susceptibility summary

Knowledge of the spatial distribution of the natural hazard susceptibility allows informed decision making during the future transport network option development and evaluation.

An output of this study is the development of natural hazard susceptibility maps for the current Marlborough Sounds Road transport network (Appendix C). Natural hazard susceptibility statistics are summarised for each natural hazard and presented per road corridor segment (Appendix D). The summary table enables identification of road corridor segments that have large exposure to high or very high natural hazard susceptibility (i.e., more vulnerable to future disruption or closure). It also allows comparison to other road corridor segments.

It is important to understand that individual natural hazards have different triggers and a range of transport network implications. Slope stability hazards (natural, human-induced, debris flow) are triggered by storm and/or earthquake events. These are “sudden” events with corresponding immediate implications. Due to the nature of the terrain in the Sounds, it is recommended that additional emphasis/weighting be placed on slope instability hazards during transport network option development and evaluation.

14.1.2 Future frequency of hazard triggering events

Storm and earthquake events are the most common natural hazard trigger. Historical and future predictions for these events have been presented and discussed within Appendix A .

Traditionally, engineering assessment relies partly on past statistics and observation to predict the frequency and intensity of future events. This results in science-derived probability estimates (i.e., Annual Exceedance Probability, or X-year return events). However, in reality the actual events can vary considerably, and we do not know when the next storm or earthquake event will occur, and what the corresponding intensity will be for differing spatial areas. An extreme event could occur that exceeds the magnitude of previously recorded data in the area. And then the effects of climate change further influence the distribution of future events.

Due to the uncertainty of the future occurrence of damaging triggering events, it is recommended that a range of scenarios are used in the business case to evaluate sensitivity of investment strategy options. For example, slope stability hazards, it is proposed that events of 50%, 10% and 2% AEP are analysed.

Some economic analysis annualises damages from potential trigger events. This can mask the different outcomes and decisions if more extreme trigger events occur early or late within the evaluation period. It is suggested that sensitivity testing may help to test for the robustness of decisions. Refer to discussion on Dynamic Adaptive Policy Pathways (DAPP) below.

14.1.3 Implications of future natural hazard events

Predicting future potential implications for a range of natural hazards over a transport network of considerable length is challenging.

Implications are largely dependent on the magnitude (intensity) of the triggering event and site-specific details. This study has provided a holistic discussion on hazard implications based on ‘step-change’ triggering event intensities over wide areas.

It only takes “one” major site-specific slope instability failure to close a road for a considerable period of time, and this “one” failure could occur on any number of slope instability (global, human-induced, debris flow) sites, although more likely those sites rated high to very high hazard susceptibility.
It is therefore proposed that the business case assumes widespread network corridor slope stability implications when significant triggering events occur. This includes assuming long periods of road disruption and at least one prolonged road closure. It is recommended to assume a reasonable worst-case scenario in which any road closure occurs as the start of a spine road so that further segments are impacted by the same closure.

Future transport network option development and evaluation needs to consider likely continued natural hazard induced implications, with climate change tending to increase the frequency and severity of damaging trigger storm events. It is noted that the implications caused by the 2022 storm event provides a good basis to formulate assumptions of the recovery effort required in the future.

The hazard engineers and business case team responsible for economic assessment should discuss and agree the approach to assigning the frequency and severity of damages for future events, in terms of financial damages or benefits (damages avoided). This should include consideration for sensitivity testing (e.g., the adaptation potential or robustness of the preferred pathway to more frequent or extreme events in the earlier or latter parts of the economic evaluation period).

14.1.4 Build back "stronger/better"

The terms "build back stronger" and "build back better" are frequently referred to in the media. If these terms are incorporated into the business case, it is important to define what they actual mean. These terms could be applied to a transport system as a whole, where resilience is aided by providing alternatives. The terms could also be applied with an engineering design philosophy context, in which the engineering provides more robust or resilient solutions regardless of other systems or redundancies.

Resilience in the land transport context is defined by Waka Kotahi as the system's ability to enable communities to withstand and absorb impacts of unplanned disruptive events, perform effectively during disruptions, and respond and recover functionality quickly.

14.1.5 Lifelines in the context of emergency management

According to the MDC website[22], lifelines projects take an all-hazards approach, with the objectives being to:

- Reduce damage following a major disaster.
- Reduce the time lifeline utilities will take to restore their usual level of service after such an event.

The transport system within the Marlborough Sounds is pivotal to lifeline provision due to the areas' remoteness and the inter-dependencies of other lifeline services on transport systems. It is important to consider these lifeline interdependencies during transport system option development and evaluation. However, the transport system is not the only part of a set of physical or engineered lifelines. Resilient communities and responder agencies can also contribute to the effectiveness of risk Reduction, Readiness, Response and Recovery (sometimes referred to as the 4R's of emergency management). The 4R's are not solely the responsibility of Civil Defence and/or lifeline providers. There are various domains in which the 4R's can operate, as illustrated in the matrix table below. Effective resilience and emergency management relies on all domains performing their role across all 4R's. Each cell's function shown should be aware of and function in collaboration with adjacent cells. This awareness improves clarity of communication, exchange of useful information, and reduces the opportunities for gaps or potentially unintentional overlaps or over-investment. This Table 21 is not intended to be exhaustive but illustrates the concept of the four domains of 4R's (4x4R's). The level of detail, and appropriate mitigations or actions can be tailored or expanded for different audiences according to their function, and the relevant hazards in any location and at any scale.

Table 21: Four Domains of Resilience (4x4R's)

Domain	Reduction (of risk)	Readiness	Response	Recovery
Household	Review hazards info collated by local gov/LIM (including beyond property boundary), consider structural or minor mitigation works where feasible (consider overland flows paths, minimise or mitigate human induced slope instability, work with neighbours where applicable).	Have at least 7 days of water and food for household, have a household plan (and where applicable boating safety plan, EPIRB) with meeting strategy if away from home, FM radio, consider usability of different boats in emergencies. Find out if recognised community Emergency Hub nearby or consider forming one, consider fire or first aid training (e.g. at work, to be able support community), be aware of vulnerable neighbours (old, young, disabled, higher risk houses)	Drop-cover-hold, long-strong-get-gone, check on each other, check on neighbours, if able help at the emergency hub, if away from home ask locals for nearest emergency hub to get advice or help getting home, etc.	Help with the recovery directly or indirectly according to your skills and capacity.

[22] https://www.marlborough.govt.nz/civil-defence-emergency-management/engineering-lifelines

Domain	Reduction (of risk)	Readiness	Response	Recovery
		and visitors (airBnB, bachcare etc).		
Community, local businesses & marae networks	Maintain community connections and trust, understand community risks and work with lifeline organisations to improve or manage gaps where feasible.	Monitor community level of preparedness (first aiders, 4x4's, tools, emergency hub training, wellbeing training, etc), identify potential leaders or influencers in community (consider ways to work with professionals on potential negative influencers to reduce risk of looting, etc).	Run local emergency hub, triage, communicate community needs with EOC, help keep community informed, promote community security and collaborate with police, steer sharing of community and incoming resources according to needs, where appropriate.	Help with recovery in collaboration with local gov, convey information on local household/community needs.
Lifeline providers, responders, local gov (CDEM, FENZ, hospitals, water, food, power, comms/ radio/ internet, roads, fuel, wastewater, waste, police/ security, etc).	Lifelines criticality and vulnerability assessments, system robustness, redundancy, skills/tools to shorten recovery times to partial or full service.	Exercising emergency situations, flood forecasting, comms (content and multiple modes), resourced rotas for critical functions, partnerships and MOU's.	Responders are champions, assess and triage, coordinate response, work with providers to restore emergency/partial service, needs and gaps assessments to inform recovery.	Phased handover and cooperate with local and central gov, providers, rebuild *smarter.*
Central gov (NEMA, NZDF, various gov departments, etc).	National resilience strategy, understand and reduce regional lifeline vulnerabilities where possible.	NEMA/CIMS/Beehive bunker, comms plans, clear established relationships, MOU's with lifeline providers and neighbouring countries, etc.	Aggregate understanding of scale of need, declare state of emergency as required, coordinate inter-regional and international support at scale as required, start to plan recovery.	EQC, funding and strategy for major event recovery, rebuild *smarter.*

In Section 0 (natural hazard interventions) a common approach is to accommodate the hazard is via an appropriate level of emergency response planning. This includes developing tools in advance such as Trigger Action Response Plan (TARP), especially for key infrastructure (for example, Havelock marine facilitates). Understanding the role of emergency response and resilience/redundancy measures will help to balance the load and not place potentially unrealistic reliance on a fragile road network (for example). Where future transport systems differ from their current state, it will be important to revaluate the emergency response for the new system as a whole, including intermediate forms in periods of transition.

14.1.6 Dynamic adaptive policy pathways

The Marlborough Sounds roading networks have considerable susceptibility to natural hazards, which can result in substantial implications when triggering event/s occur. The timing of these tiggering events, the intensities and the scale of these implications are challenging to predict over time (i.e., there is significant temporal uncertainty). This is further compounded by uncertainties in future rates of global greenhouse gas emissions and the associated impacts on climate change (such as sea level rise and storms).

Dynamic Adaptive Policy Pathways (DAPP[23],[24]) offers a conceptual approach to decision making under uncertainty, incorporating Adaptation Tipping Points and Adaptation Pathways. DAPP acknowledges that change is inevitable and supports the need to plan for it, to avoid or minimise investment in potentially abortive pathways. Some metrics usually require monitoring to inform a shift between investment pathways, whereas some triggers may be temporally unpredictable events such as major floods or earthquakes. There may also be significant lead time required to further develop appropriate designs and consents to enable adaptation. Early investment toward future pathways may enable more rapid recovery and adaptation after the appropriate triggering event/s.

It is not practical to fully apply DAPP to each element or programme during MCA, since many of the elements or boundary conditions have a wide range of uncertainty. However, to address the major investment outcome of improving the resilience of the transport network, consideration must at least be given to adaptation *potential*. One way to do this is during the MCA scoring of options, for example under the category of resilience, to include adaptation potential (as opposed to programmes that hit a threshold and cannot easily adapt).

Another useful approach, after the initial MCA scoring, is to sensitivity test the ability of the shortlisted programmes to cope with or recover from an envelope of possible future conditions. For example, under a reasonable worst case (including severe storms and earthquake sequences early in the evaluation period, plus conservative relative sea level rise over time), could the programme or pathway be adapted by accelerating or upscaling investment, or does it become untenable? If so, are there other pathways that could cope better with this scenario? Does investing early provide significant resilience benefits (damages avoided and/or accelerated recovery)? The sensitivity testing results and DAPP can then be used to test and help manage investment and pathway transitions between say a ‘medium’ scenario and a more extreme scenario. The most pertinent adaptation signals (such as greenhouse gas concentrations and global surface temperatures) can serve as intermediate indicators of where we are tracking against IPCC emissions trajectories. These should be identified and tracked early to steer toward the best action in response to the passage of time, climate change and triggering events. This may reduce the potential for abortive investment. Development of the upper and medium scenarios can also be useful in engaging with the community and stakeholders on how their choices and actions can contribute to better integrated and more sustainable community resilience. These concepts should be carried into the programme business case, as the interpretation and application of DAPP cannot be finalised on the basis of hazard susceptibility alone, but must consider social, economic and environmental resilience.

14.1.7 Potential changes in land use activity management

It is widely accepted that vegetation removal typically increases susceptibility of slope instabilities. It has also been widely observed that vegetation debris can compound negative impacts on the transport system assets from storm events (e.g., debris blocking culverts and bridges resulting in overtopping, scour and/or failure). At time of report preparation, the government is undertaking a Ministerial Inquiry into Land Use practice and the outcomes or lessons arising may have implications in Marlborough Sounds.

Upslope terrain modification and land use practices can result in higher human induced terrain instability with negative implications to the road network. Policy changes could be considered, to tighten consenting for earthworks within an offset of road corridors, to provide greater protection of transport assets and reduce road corridor disruption and maintenance efforts.

Land use and management practices can also have an influence on the interception, infiltration, and attenuation of rainfall runoff. Positive land use management could potentially be encouraged or incentivised.

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[23] Haasnoot, M., Kwakkel, J. H., Walker, W. E. & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change 23, 485-498, http://dx.doi.org/10.1016/j.gloenvcha.2012.12.006.

[24] Lawrence, J., Bell, R., Blackett, P., Stephens, S., Collins, D., Cradock-Henry, N., Hardcastle, M. (2020). Supporting decision making through adaptive tools in a changing climate: practice guidance on signals and triggers.

14.2 Recommended future technical activities

14.2.1 Hazard susceptibility assessment

As previously mentioned, this natural hazard assessment has been developed to fit the programme/funding of the Marlborough Sounds Future Access Program Business Case. It is considered high level and therefore defined as a preliminary desktop natural hazard susceptibility assessment.

If there is a need to provide more evidence behind key or marginal decisions, or to advance to subsequent stages of Business Case, additional technical assessment should be considered. This could include:

- Ground truthing of susceptibility classification ratings via comprehensive site reconnaissance.
- Incorporating site specific geotechnical assessment currently being undertaken in parallel as part of the recovery/rebuild effort.
- Identifying and undertaking specific geo-science assessments to develop further technical understanding to enable more informed hazard classification ratings.
- Further review and inclusion of David Miller documentation, including assigning rainfall probabilities to the reported events, where feasible.
- Future integration of RAMM database, especially focusing on maintenance records at site specific location.

If required, additional technical work should be scoped to achieve the future business case objectives. Furthermore, when developing and evaluating transport network options, additional emphasis/weighting should be placed on slope instability hazards due to the nature of the terrain in the Sounds.

14.2.2 Natural hazard site-specific resilience studies

The desktop literature search found limited site-specific resilience studies. Understanding the natural hazard vulnerability of critical marine hubs (e.g., Havelock, Waikawa, Elaine Bay) will be important if the future transport becomes more reliant on water-based transport systems.

Identification and prioritisation of resilience studies for key sites will be required, and therefore it is recommended that these are incorporated into future programming/funding.

14.2.3 Road corridor stormwater and maintenance effects

A limitation of this natural hazard assessment has been the inability to incorporate the current state of the road corridor stormwater management, and the potential effects of maintenance practices. Inadequate stormwater capacity is likely to be one of the key contributors to human induced sloped instabilities (i.e., saturation of side cast fill resulting in underslip, or water flowing over the road and scouring on the downslope side).

Depending on key decisions around preferred pathways forward, consideration should be given to further assessment of the current state of the road corridor stormwater measures. An objective of this assessment would be to identify the extent to which stormwater measures, or lack thereof, contribute to direct impacts or compound debris flow issues. This may allow stormwater improvements to be prioritised and incorporated into a stormwater upgrade program.

Appendices

We design with community in mind

Appendix A Hazard Triggering Mechanisms

Hazard triggering events mechanisms are the natural processes that trigger the initiation of natural hazard. Three main types of triggering events mechanisms are considered in the assessment, namely storm events, coastal events, and seismic events. These are discussed in detail below.

A.1 Storm events

A.1.1 General discussion on rainfall environment

The mean annual rainfall coverage over the Marlborough District is shown in Figure A 1 below. Within any individual rainfall event, the rainfall intensity and resulting depth may vary significantly spatially, temporally and by elevation.

Short duration storms (e.g., summer thundershowers, up to a few hours in duration) generally produce the highest intensity rainfall. Overtopping of any undersized culverts would tend to be short-lived, and therefore short duration storms typically produce less damage per storm event but occur more frequently than long duration storms.

Long storms in the order of 24 hours, or a sequence of events over multiple days (such as occurred in August 2022) generally tend to produce more widespread damage through both flooding and triggering of slope instabilities. These longer events also cause larger peak flows on the larger river systems such as the Te Hoiere / Pelorus River.

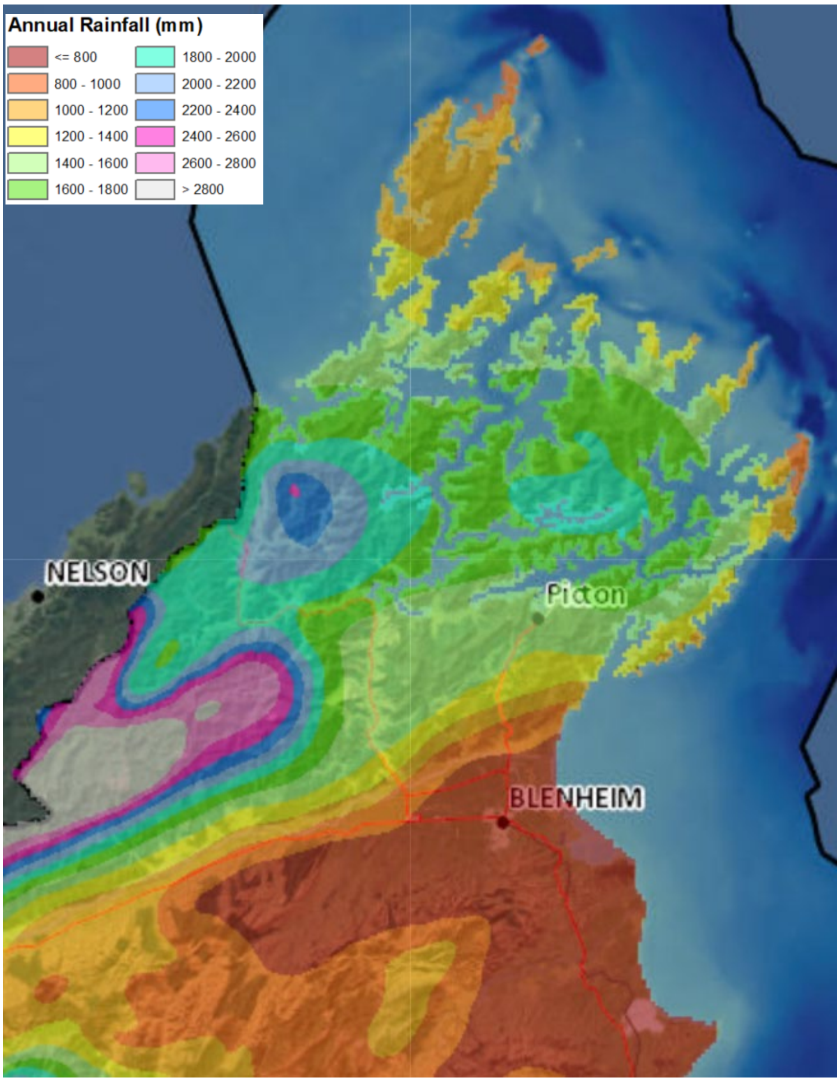

Figure A 1: Mean annual rainfall (NIWA/MDC)

A long-term overview of daily and 3-day rainfall accumulation is provided in Figure A 2 below. This shows at least 5 discrete 3-day periods where more than 250mm has fallen (i.e., approximately 7% AEP event), including the July 2021 and August 2022 events. The daily plot illustrates that the July 2021 event had substantially higher daily rainfall compared to the August 2022 event, although they had different total event durations and are more comparable at 72 hours. The daily rainfall plot also shows that over the 84 years of record, there are many events with higher daily rainfall than the August 2022 event.

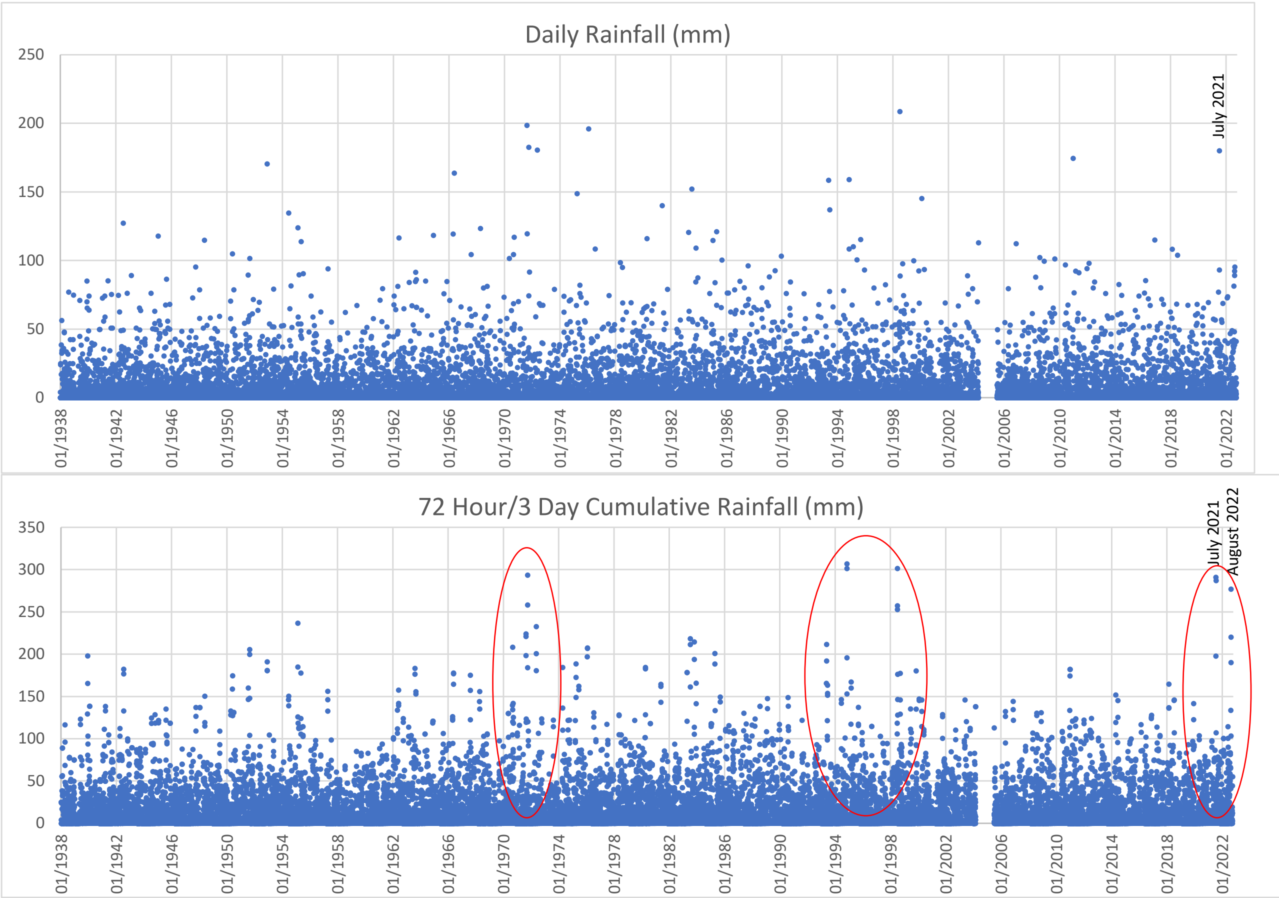

Figure A 2: Long term daily and 3-day rainfall accumulation at Linkwater (1938-2022)

A.1.2 Summary of historical events / rainfall intensities

In the July 2021 event, the AEP was approximately 2.5% AEP over a 24-hour duration at Linkwater, while in August 2022 the AEP was 2.5% over a 96-hour duration at the same site. The calculated AEP varies spatially across the study area, and relatively sparse rain gauges make it difficult to accurately estimate the annual exceedance probabilities for other locations. Radar-derived rainfall provides more spatial detail between raingauges, although there can be inaccuracies in total depths and the available radar records are much shorter than most raingauges.

Section 3 of the main report contains information on the damages / faults reported during these events. We anticipate that the frequency and intensity of storms will increase due to climate change.

The MDC Flood Hazard overlay is confined mainly to the larger valleys, and its accuracy may vary based on the data used to generate it at the time.

A.1.3 Wind

Whilst seldom directly responsible for triggering slope instability in isolation, wind can trigger tree fall which can compound slope instabilities along with rainfall. Wind also has a direct influence on wind driven wave action in the Sounds, which can contribute to erosion on susceptible shores. NIWA (2016) indicated that Brothers Island is highly exposed to gale force winds, as would be expected due to its location adjacent to the Cook Strait, with an average of 51 days per year with gusts over 96km/h. The following Table A 1 summarises some extreme gusts from the record period extracted from NIWA (2016) report. Within the Sounds, there can be localised concentration or attenuation of wind, due the height and orientation of the mountains relative to the wind.

Table A 1: Recorded wind gusts across Marlborough (from NIWA 2016)

Location	Gust (km/hr)	Direction	Date
Awatere Valley, Dashwood RAWS	134	NW	5/10/2000
Blenheim Aero	118	W	6/02/1975
Brothers Island AWS	171	S	14/07/2013
Grassmere Salt Works	131	W	19/11/1982
Vernon Lagoon	115	SSE	20/05/1981

A.1.4 Climate change

The effects of climate change are already being experienced in Marlborough. While there is little data yet supporting the increasing frequency of events, there is data supporting the increasing intensity of these events. Figure A 3 shows a comparison of the August rainfall at the Tunakino and Rai Falls rain gauges. It shows that the total rainfall for August 2022 was:

- At Tunakino (data from 1979 to 2022):
  - More than two and a half times larger than the previous August maximum recorded in 2017.
  - 37% increase from the previous monthly maximum recorded in October 1998.
  - More than five times larger than the average August rainfall total.
- At Rai Falls (data from 2000 to 2022):
  - double the previous August maximum recorded in 2010.
  - A 52% increase from the previous monthly maximum recorded in December 2010.
  - More than four times the average August rainfall total.

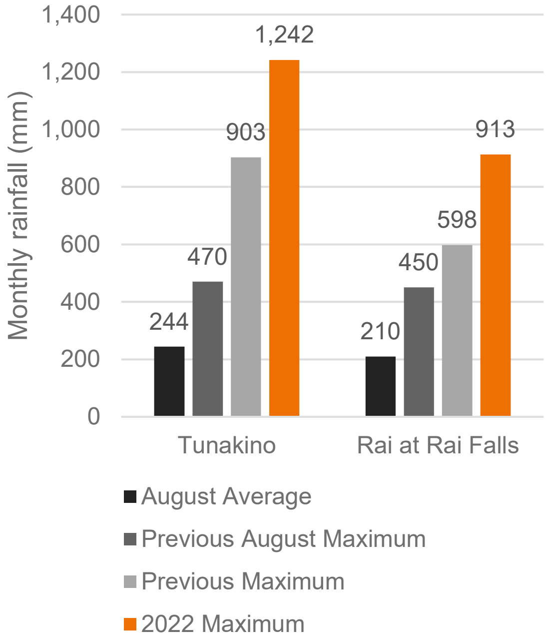

Figure A 3: Comparison of August 2022 rainfall totals at Tunakino and Rai Falls sites

It is predicted the recent trend of extreme rain events will continue, albeit sporadically, on account of climate change. Short duration high intensity rainfall is expected to experience greater increases than long duration events. This is illustrated in the Table A 2 below for the 1% AEP event, showing two emissions scenarios, based on HIRDS version 4.

Table A 2: Change in Rainfall on Account of Climate Change for 1% AEP Rainfall Events

Duration	1h	2h	6h	12h	24h	48h	72h	96h
Rainfall increase (%): RCP**4.5** for the period 2081-2100								
	16.4%	15.8%	14.1%	12.1%	10.2%	9.1%	8.3%	7.9%
Rainfall increase (%): RCP**8.5** for the period 2081-2100								
	35.0%	33.7%	30.4%	26.3%	22.0%	19.2%	17.7%	16.5%

Based on the climate change factors from HIRDS version 4, it is anticipated that:

- Under RCP4.5 2081-2100, the 1% AEP future event will be about as intense as the 0.5% AEP historic intensity.
- Under RCP4.5 2081-2100, the 1% AEP historic event will be roughly twice as frequent (~2% AEP).
- Under RCP8.5 2081-2100, the 1% AEP historic event will be roughly three times as frequent (~3% AEP) for long duration storms, and five times as frequent (~5% AEP) for short duration storms.
- Short duration storms generally produce the highest intensity rainfall, and the highest peak water flow from small catchments. Climate change impacts on these events will be higher than on longer duration storms, as illustrated above.
- Water levels in the lower reaches of rivers will also be influenced by relative sea level rise, through backwater effects and consequential sediment deposition and raising of the riverbed. This may further exacerbate the onset and impacts of flooding from future rainfall events in these overlapping locations.

A.2 Coastal events

A.2.1 Extreme water levels

Water levels relative to land may compromise several components with interrelated probability, namely:

- Astronomical Tides
- Storm Surge
- Nearshore Wave Effects
- Long-Term Trends (Sea Level Rise).

The astronomical tidal range (between mean high-water springs / MHWS and mean low water springs / MLWS) varies around the Sounds from around 1.4m at Picton to approximately 3.3m west of French Pass (Man-o-War Bay, Coppermine Bay, and the southwest portion of D'Urville Island coastline).

In addition to tide levels, the still water level (excluding waves) is further influenced by meteorological effects such as barometric pressure and wind shear on the surface which together comprise the Storm Surge and in combination with astronomical tide leads to a storm tide water level. Port Nelson experienced a Storm Tide of approximately 0.6m above MHWS during the remnants of the 2018 Cyclone Fehi event[25] which was estimated to be a 1% AEP event. It would be anticipated that the Sounds would experience storm surge components between these two conditions however it should be noted that the probability of these events are dependent on the combined probability of storm surge and astronomical tides which may not peak at the same time.

The nearshore wave effects such as wave height, wave set-up or run-up will be highly dependent on the exposure to open ocean swell, and whether there is sufficient fetch within a sound to generate significant wind waves, and to the local bathymetry/topography which influences local exposure and wave transformation.

A.2.2 Climate change and vertical land movement

Rising sea levels will exacerbate future coastal risks to some parts of the road network. The land and road may be subject to changes in absolute sea level on account of climate change, and to additional effects due to vertical land movement (relative to a fixed geodetic datum).

Figure A 4 shows the long term predicted absolute sea level rise at Portage under the IPCC SSP2-4.5[26] and SSP5-8.5[27] scenarios. It shows that sea levels continue to rise well beyond reaching net zero emissions or even maximum global surface temperatures, due to legacy greenhouse gases in the atmosphere. It also shows that uncertainty significantly increases over time. Under SSP2-4.5 the sea-level rise by 2300 could be between 1.2 m and 3.5 m, but under SSP5-8.5 it could be anywhere from 5.3 m to 15.1 m. Stated differently, a sea level rise of say 1.2m could be reached much earlier under high emissions scenarios such as SSP5-8.5 compared to medium emissions scenarios such as SSP2-4.5.

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[25] Tonkin & Taylor Ltd (2020). *Coastal Inundation in Nelson City.*

[26] This is a world with moderate emissions (+2.7°C warmer world). This approximates the path associated with current global policy settings.

[27] This is a worst-case scenario world with very high emissions (>4°C warmer world). It is unlikely to materialize given ongoing climate mitigation.

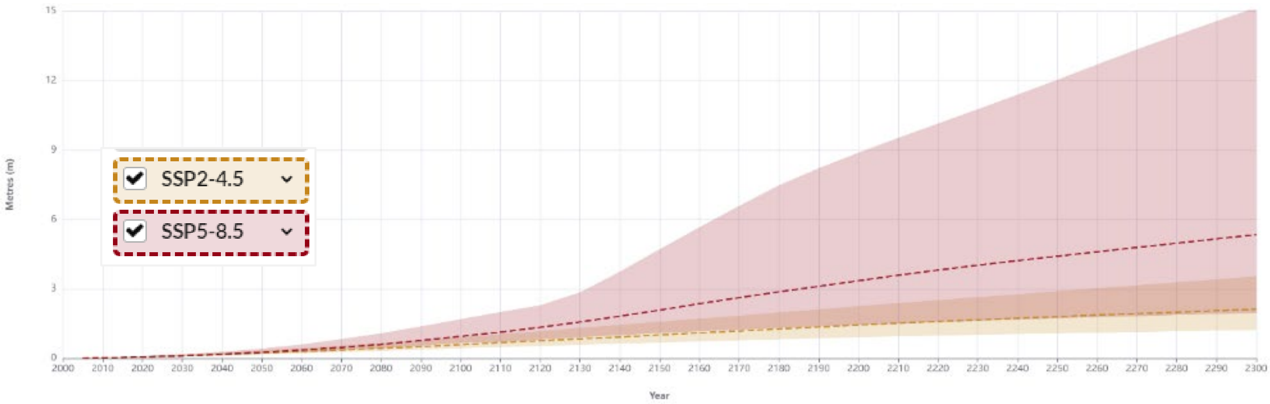


Figure A 4: Long-term sea-level rise projections for Portage

Vertical land movement also needs to be considered when planning for 'net' sea-level rise effects. New Zealand is on a dynamic plate boundary which means the land is always moving. As well as tectonic movement, sedimentary basins compact over time and subside. Human influences such as land reclamation and drainage, groundwater extraction, and petroleum reservoir depletion can also cause the land to subside. In areas with subsidence, the impacts of sea-level rise are accelerated, and impacts will be experienced sooner.

Figure A 5 shows the predicted vertical land movement for various points around the Marlborough Sounds, from the NZ Sea Rise website. It shows that while most places are sinking up to 6 mm/year, some are rising at a rate of 5 mm/year. This has been based on comparatively recent observations (predominantly 2003-2011) which reflect ongoing 'creep' adjustments but not major surface rupture events on say the Alpine or Wellington faults. There is therefore some inherent uncertainty in vertical land movement when projecting these rates far into the future.

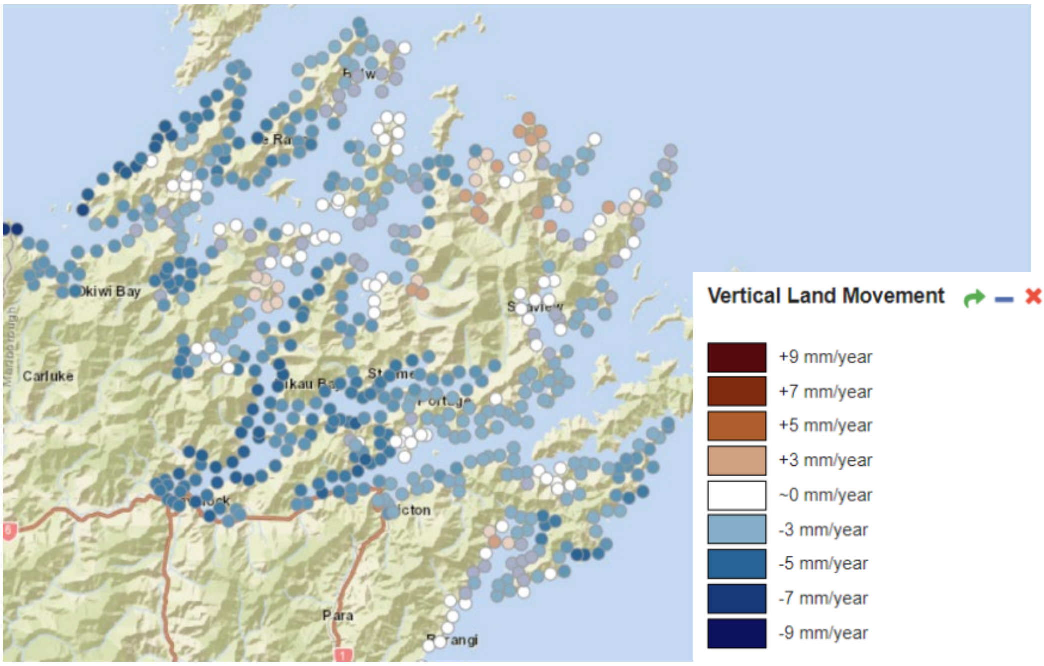


Figure A 5: Vertical land movement for Marlborough Sounds[28]

Figure A 6 shows the expected sea level rise under the SSP2-4.5 scenario combined with the vertical land movement for Portage. The land at Portage is sinking at a rate of 1.6 mm/year. The land movement combined with the anticipated sea level rise under SSP2-4.5 means that the total seal level rise could be 73 cm by 2100. Under SSP5-8.5 the total sea level rise by 2100 could be up to 1 m. The total sea level rise in places with faster rates of vertical land movement will be greater than what is detailed above. The spatial integration of sea level rise and vertical land movement is discussed after Figure A 6.

[28] NZ Sea Rise Map, Takiwā. https://searise.takiwa.co/ (11/01/2023)

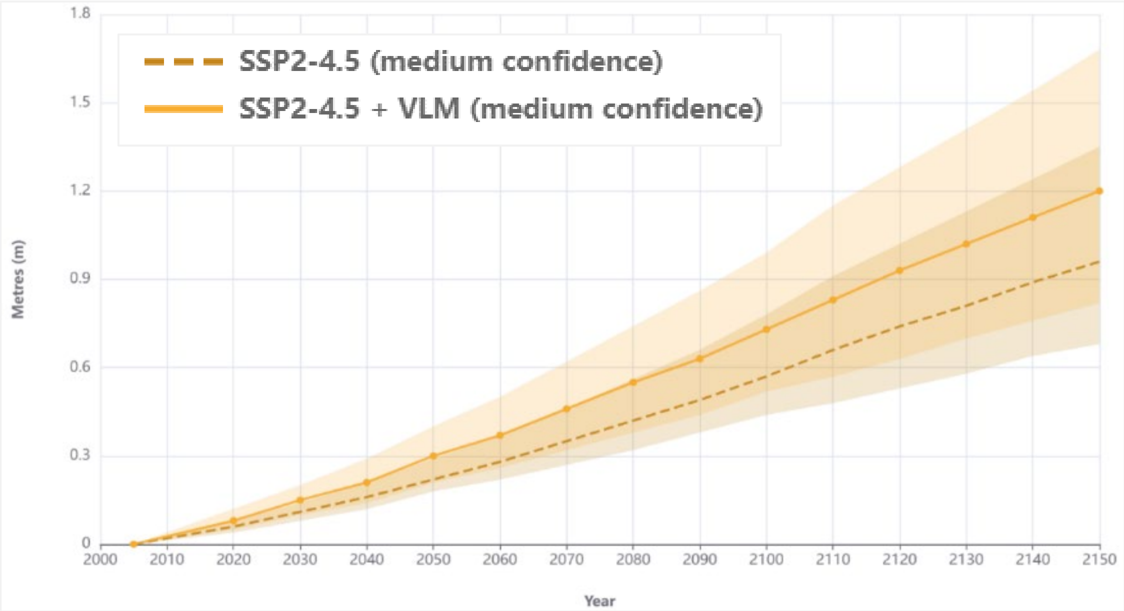


Figure A 6: Total sea-level rise with vertical land movement for Portage SSP2-4.5[29]

Tidal range and high tide levels vary within the Marlborough Sounds due to the different locations at which they connect to the Cook Strait. Table A 3 presents the present day and future tidal levels for main ports within the Sounds derived from LINZ. The levels were adjusted to NZVD2016 datum, assuming that NZVD2016 is reasonably equivalent to MSL. Tide levels are presented only for ports that are relevant to the study road network segments. A simplified storm surge allowance of 0.6m above MHWS has been included to the regions of the Sounds to account for both barometric as well as wind/wave setup, in Table A 3 to derive 'Storm Tide' levels. Future tide levels combined MHWS (and storm surge for storm tide) with sea level rise allowances for the SSP2-4.5 climate change scenario at the 2150 epoch, also including allowance for VLM. The future Storm Tide levels are presented spatially in Figure A 7.

Table A 3 below shows that, of the ports most relevant to the assessed road segments, the greatest tidal range of 2.9m is within Portage and Croisilles Harbour, whereas the smallest tidal range is within Okukari Bay. For the coastal susceptibility, only the road segments are assessed, so some of the future elevations at marine locations on Figure A 7 are not reflected in Table A 3. Relative sea level rise will also impact levels in the lower reaches of rivers, due to backwater and sediment deposition effects, which will project further upstream than for current sea levels.

Table A 3: Tide levels within Marlborough Sounds

Road Segments	Closest Port Location	Tidal Range (m)	Present Day Tide Levels (m NZVD2016)		Future* Tide Levels (m NZVD2016)	
			MHWS	Storm Tide	MHWS	Storm Tide
French Pass Area						
SH6 to Okiwi Bay	Croisilles Harbour - Kotiro Point	2.9	1.5	2.1	2.9	3.5
Okiwi Bay to Elaine Bay Opouri Road/ Tollgate Bridge to Duncan / Penzance Bay	Elaine Bay	2.4	1.3	1.9	2.4	3.0
Port Ligar turnoff to French Pass	Elmslie Bay	2.3	1.2	1.8	2.6	3.2
Port Ligar turnoff to Bulwer Bay	Hamilton Bay	2.3	1.3	1.9	2.8	3.4
Kenepuru and Pelorus Area						

29 NZ Sea Rise Map, Takiwā. Sea Level Rise Predictions by Decade for site 6768, https://searise.takiwa.co/ (11/01/2023)

Road Segments	Closest Port Location	Tidal Range (m)	Present Day Tide Levels (m NZVD2016)		Future* Tide Levels (m NZVD2016)	
			MHWS	Storm Tide	MHWS	Storm Tide
Havelock to Linkwater Moetapu turnoff to Mahau turnoff Moetapu Daltons Road to Kaiuma Bay/Te Hoiere Road Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay	Havelock	2.8	1.5	2.1	2.9	3.5
Mahau turnoff to Portage Portage to Kenepuru Heads Kenepuru Heads to Waitaria Bay Waitaria Bay to road ends	Portage	2.9	1.7	2.3	2.9	3.5
Waitaria Bay to Clova Bay	Elie Bay	2.4	1.3	1.9	2.6	3.2
Kenepuru Heads to Titirangi	Whakatahuri	2.2	1.4	2.0	2.5	3.1
Anikiwa	Okiwa Bay	1.5	0.6	1.2	1.9	2.5
Linkwater to Picton	Picton	1.4	0.6	1.2	1.9	2.5
Port Underwood Area						
Waikawa to Hakahaka Bay	Picton	1.4	0.6	1.2	1.9	2.5
Hakahaka Bay to Rarangi Hakahaka Bay to Fighting Bay entrance Fighting Bay to road end	Ocean Bay	1.2	0.7	1.3	1.8	2.4

*Note: Future tide levels combine MHWS with storm surge and sea level rise allowances for SSP2-4.5 scenario for 2150 epoch and including VLM.

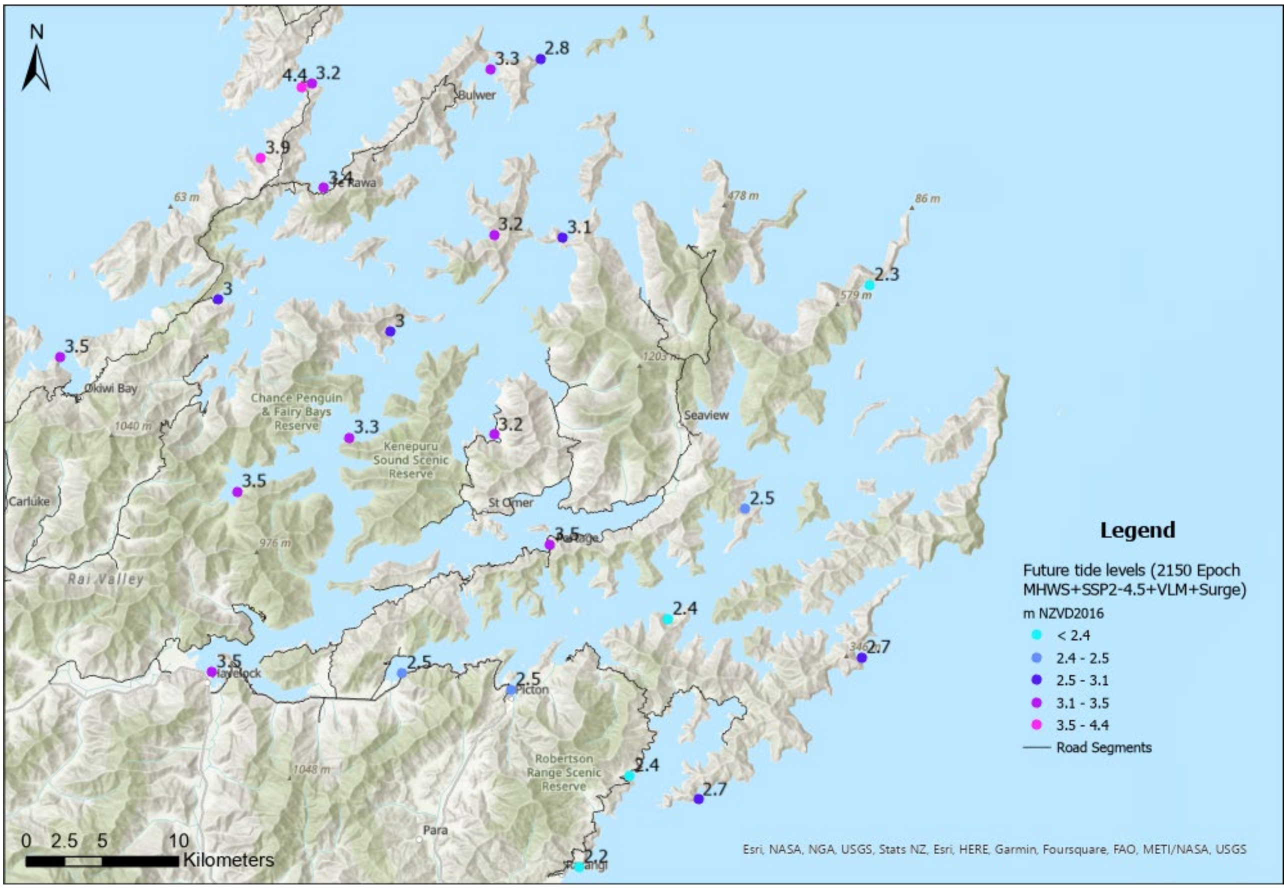


Figure A 7: Future tide levels at 2150 epoch in meters above NZVD2016 (MHWS + SSP2-4.5[30] + VLM + Surge)

Climate change is also anticipated to impact storminess which may influence surge, wind and waves. However, these changes tend to be lesser in magnitude, and have not been considered within this high-level study.

We understand that MDC have contracted NIWA to map future coastal inundation (spatially varying MHWS and 1% annual exceedance sea levels, with an estimate for wave setup, plus vertical land movement from NZ searise, for various epochs under different SSP emissions scenarios) utilising the latest LiDAR data. These results should be incorporated into subsequent detailed business case and design.

A.3 Seismic hazard

A.3.1 General discussion on seismic environment

The Marlborough Sounds lie in an area of high seismicity near the southern limit of the Pacific plate, with the Wairau (Alpine) fault to the south and the Waimea-Whangamoa fault to the west. The area is subject to frequent deep earthquakes and numerous shallow earthquakes.

The Marlborough district is crossed by a series of fault lines. The Wairau, Awatere and Clarence faults are extensions/offshoots of the Alpine Fault, as are a number of other active faults of limited extent. There are also several important faults offshore to the east of Marlborough. Ground shaking will occur from ruptures on these fault lines. All published faults within the project area, extracted from GNS are presented in Figure A 8.

The largest historical earthquake experienced in Marlborough that generated ground rupture occurred on the Awatere Fault in 1848. It had an estimated magnitude of 7.5. The lack of recent significant earthquakes can lead to a false sense of security. Earthquake events causing serious structural damage can be expected every 55 to 60 years.[31]

[30] NZ Sea Rise Map, Takiwā. Sea Level Rise Predictions by Decade for site 6768, https://searise.takiwa.co/ (11/01/2023)
[31] Marlborough District Council (2003) "Natural Hazards." In *Marlborough Sounds Resource Management Plan Volume 1*., https://www.marlborough.govt.nz/repository/libraries/id:2ifzri1o01cxbymxkvwz/hierarchy/documents/your-council/environmental-policy-and-plans/msrmp-volume-1-list/Chapter_16_Natural_Hazards.pdf

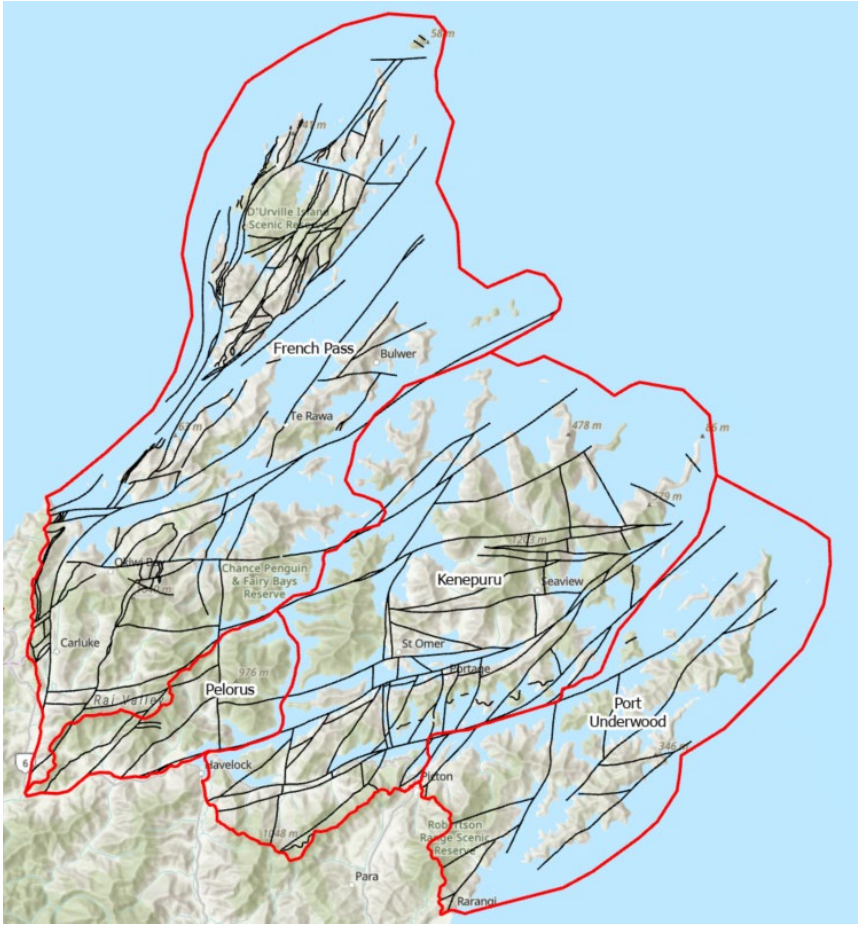


Figure A 8: All published faults within the project area, extracted from GNS[32]

A.3.2 Summary of historical events / shaking intensities

A summary of relevant historical earthquakes events and their corresponding shaking intensities are summarised in Table A 4 below.

Table A 4: Summary of Relevant Historical Earthquake Events

Earthquake (& Location)	Earthquake Details			Earthquake (horizontal PGA, g)				Modified Mercalli Intensity
	Date	Magnitude	Depth (km)	Near source	D'Urville	Havelock	Picton	
Marlborough	16/10/1848	~7.5						8+
Murchison	09/03/1929	7.1						7
Darfield (2010)	09/04/2010	7.2	11	0.49			0.01	
Offshore Seddon	07/21/2013	6.5	16				0.14	
Lake Grassmere	08/06/2013	6.5	7	0.73			0.12	
Kaikoura	11/15/2016	7.8	15	1.04		0.12	0.25	6
French Pass	09/22/2022	5.8	53		0.03	0.02	0.04	
Offshore Levin	02/15/2023	6.0	54		0.03	0.05	0.08	

Notes
1. Blanks cells in the table are due to information being unavailable.
2.The earthquakes displayed have been selected as considered pertinent examples.

[32] Begg, J.G, Johnston, M.R. (compilers) 2000. Geology of the Wellington Area. Institute of Geological and Nuclear Sciences 1:250,000 geological map 10, 1 sheet + 64p. Lower Hutt, New Zealand, Institute of Geological and Nuclear Sciences Limited.

3. Earthquake details obtained from GeoNet: Home, except the Marlborough and Murchison which are from https://teara.govt.nz/
4. Horizontal Peak Ground Acceleration (PGA) data captured by strong motion sensors, from GeoNet: Home
5. Modified Mercalli Intensity scale is used to describe the felt intensity of shaking produced by an earthquake (at a given location, with this location being Marlborough Sound in the table.). Values from https://teara.govt.nz/, except Kaikoura which is from Geonet. Definition of Modified Mercalli Intensities include:

- **MMI 6** – Strong - Felt by all, and many are frightened. Some heavy furniture is moved; a few instances of fallen plaster occur. Damage is slight.
- **MMI 7** – Very Strong - Damage is negligible in buildings of good design and construction; but slight to moderate in well-built ordinary structures; damage is considerable in poorly built or badly designed structures; some chimneys are broken. Noticed by motorists.
- **MMI 8** – Severe - Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Motorists are disturbed.

In 2017, Geonet published forecast probabilities for large events in central NZ. These are presented in Table A 5.

Table A 5: Geonet Forecast Probabilities for Large Events in Central New Zealand

	Magnitude Range	Chance of Occurrence
Within next Decade	M7.8 or Greater	2 to 20%
	M7.0 or greater	10 to 60%

Seismic design criteria for geotechnical elements of infrastructure can be derived using guidelines presented in either the NZTA Bridge Manual[33] or MBIE's Earthquake Geotechnical Engineering Practice guidelines – Module 1[34]. Table A 6 presents current seismic design criteria for Picton, based on MBIE Module 1.

Table A 6: Current Seismic Design Criteria for a Picton Site

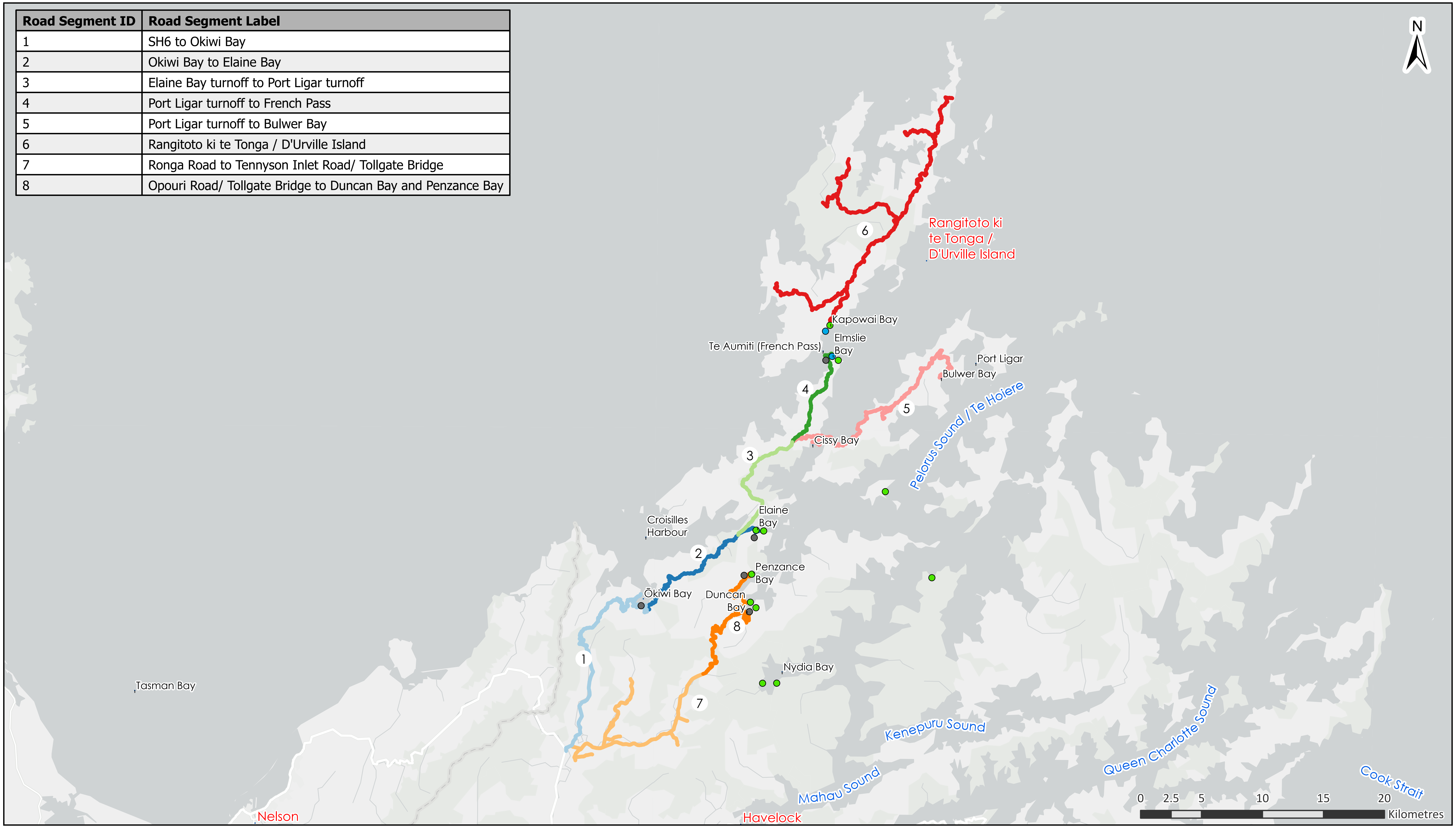
2% AEP (1 in 50yr Return Period)		0.4% AEP (1 in 250yr Return Period)		0.2% AEP (1 in 500yr Return Period)	
Magnitude	(horizontal PGA, g)	Magnitude	(horizontal PGA, g)	Magnitude	(horizontal PGA, g)
6.6	0.18	7.1	0.39	7.3	0.52

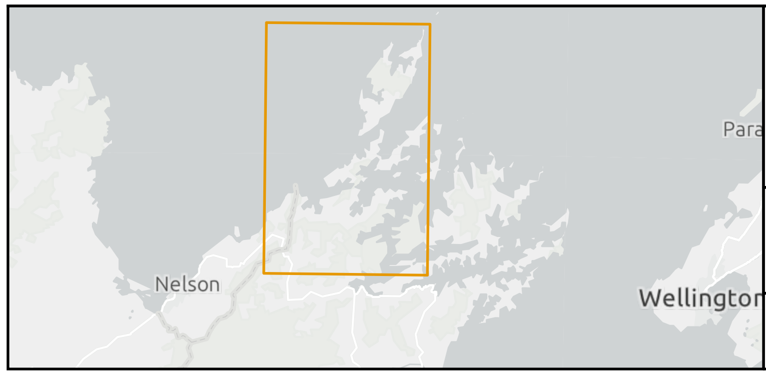
The New Zealand Seismic Hazard Model (NZSHM) is currently being revised, with preliminary outputs suggesting that the MBIE Module seismic design criteria are considerably underestimating the frequency and intensity of future seismic events in central NZ.

[33] Waka Kotahi NZ Transport Agency, Bridge manual SP/M/022, Third Edition 2022
[34] Ministry of Business, Innovation and Employment (MBIE) - Earthquake Geotechnical Engineering Practice guidelines – Module 1, 2021

Appendix B Project Area Figures

Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





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Marlborough Future Access Study

French Pass Area - Overview Plan

Segmentation of Transport Network

MDC

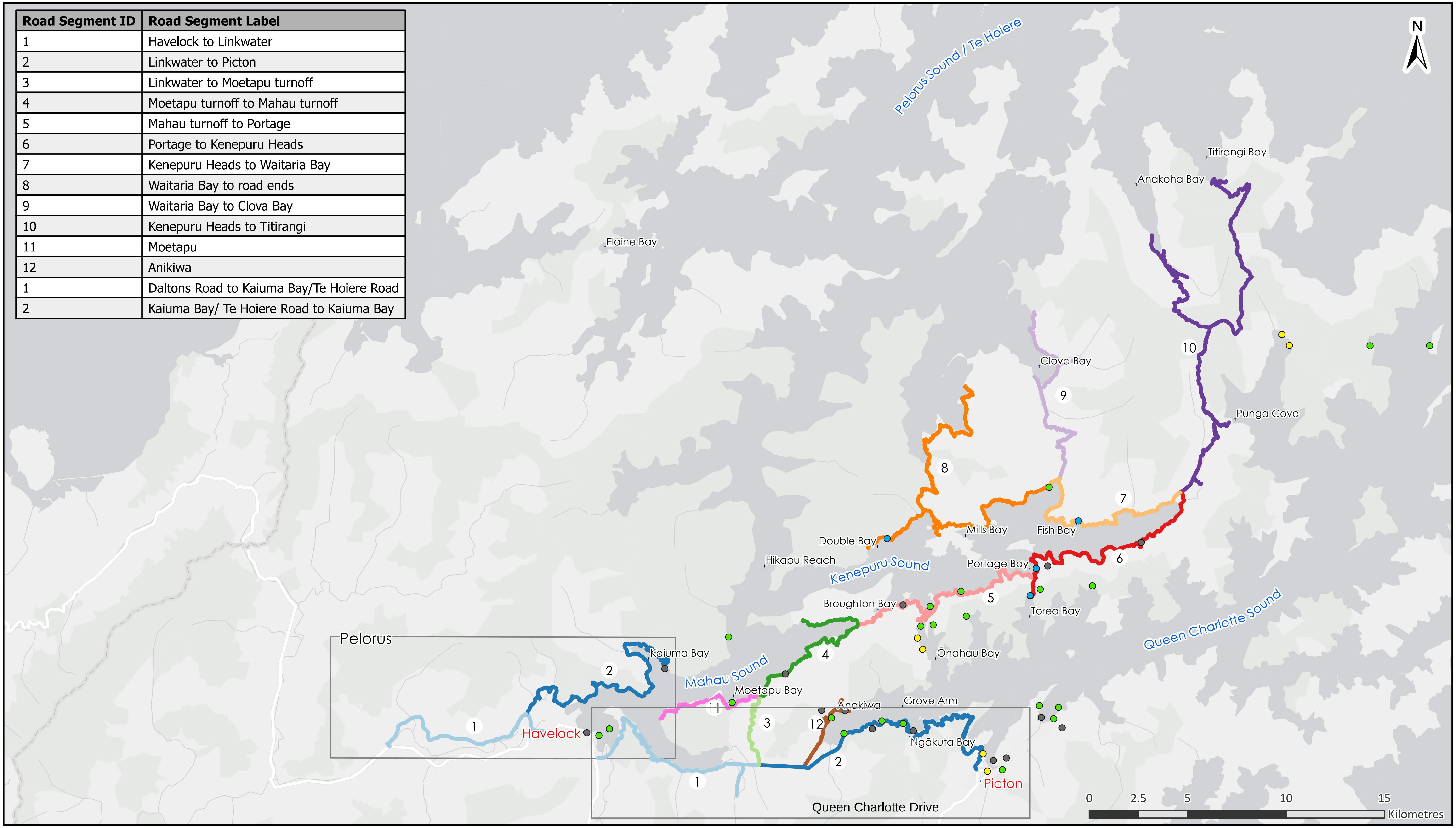
Barge Sites
Boat Ramp (Public)
Jetty - Community / Public

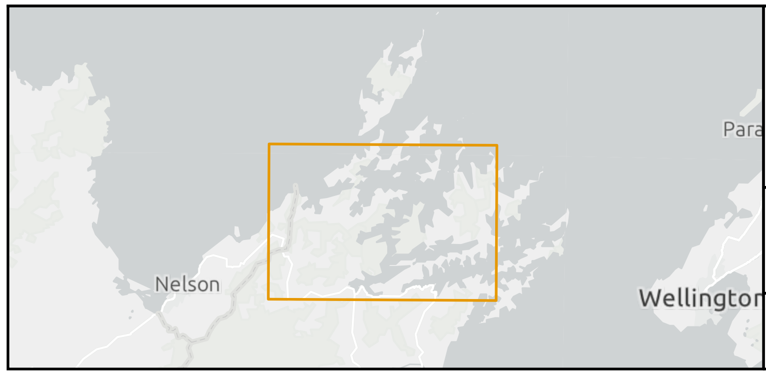
Road Segments
1
2
3
4
5
6
7
8

Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
Basemap Service Credits: Stats NZ, Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

Kenepuru, Pelorus & Queen Charlotte Area - Overview Plan

Segmentation of Transport Network

MDC

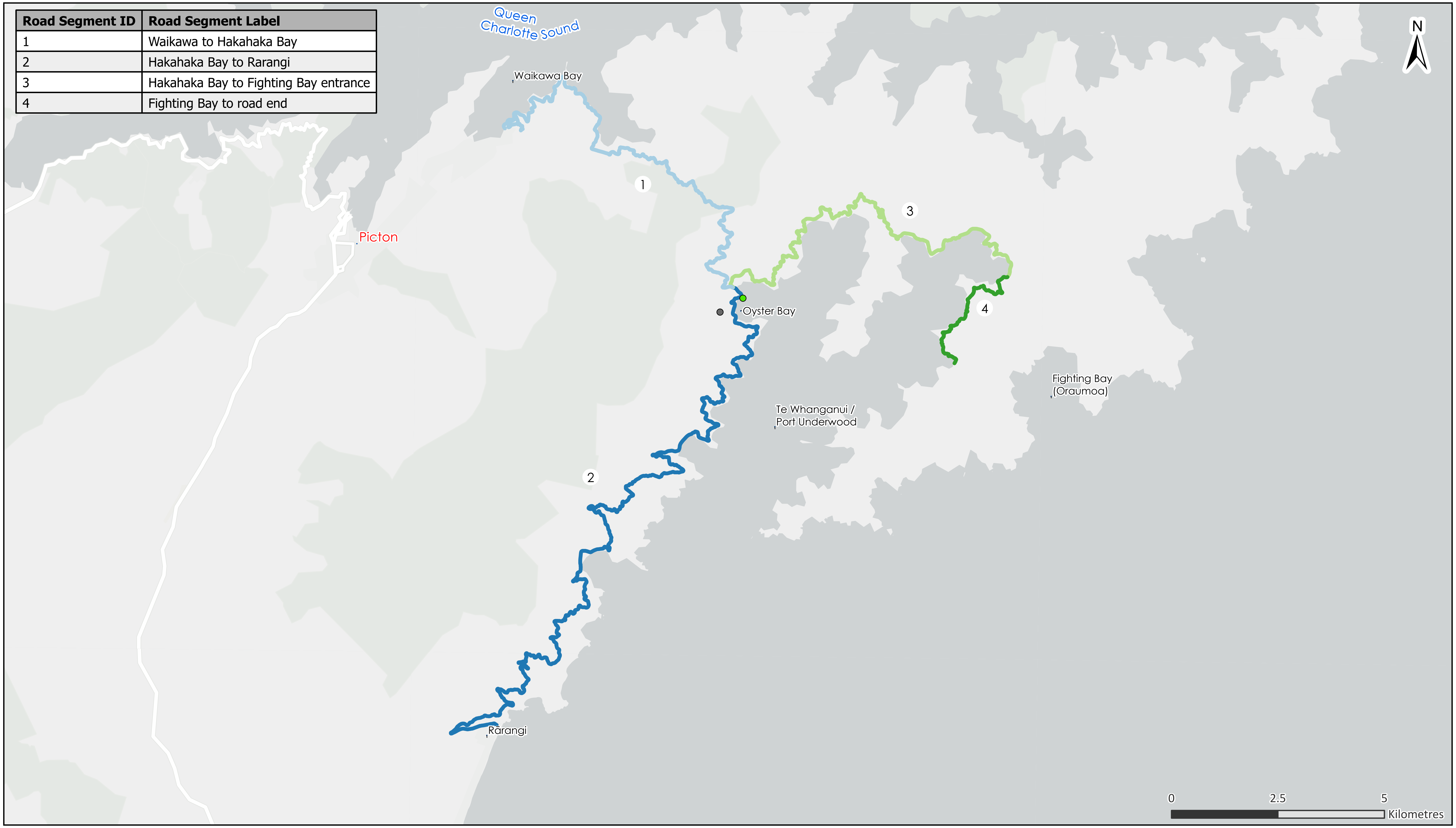
Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
Basemap Service Credits: Esri, HERE, Garmin, FAO, NOAA, USGS, Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

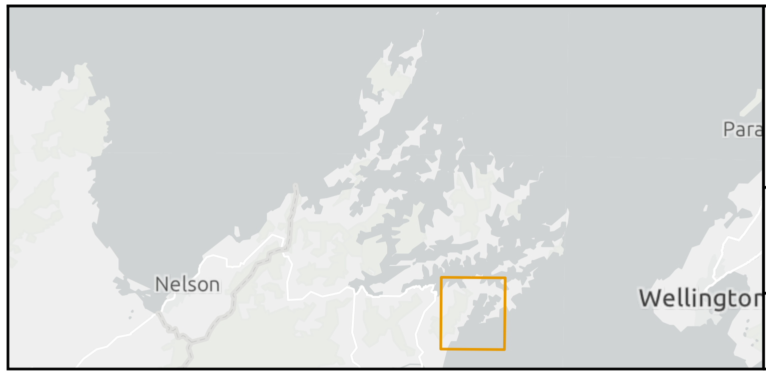
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Barge Sites
Boat Ramp (Public)
Jetty - Commercial
Jetty - Community / Public

Road Segments
1
2
3
4
5
6
7
8
9
10
11
12

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





Marlborough Future Access Study

Port Underwood Area - Overview Plan

Segmentation of Transport Network

- Boat Ramp (Public)
- Jetty - Community / Public

Road Segments
- 1
- 2
- 3
- 4

Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
Basemap Service Credits: LINZ, Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS, Esri, HERE, Garmin, FAO, NOAA, USGS
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
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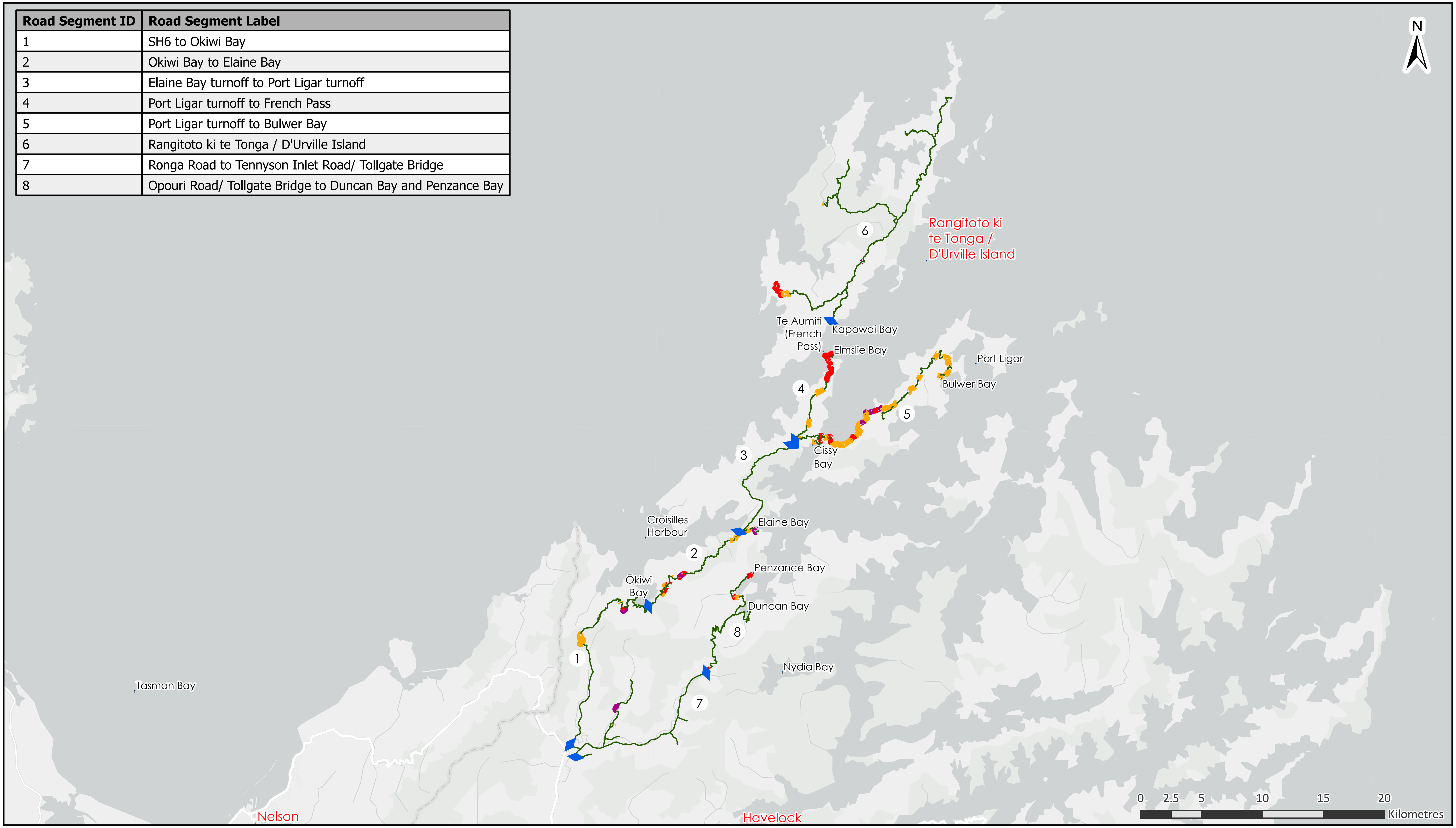
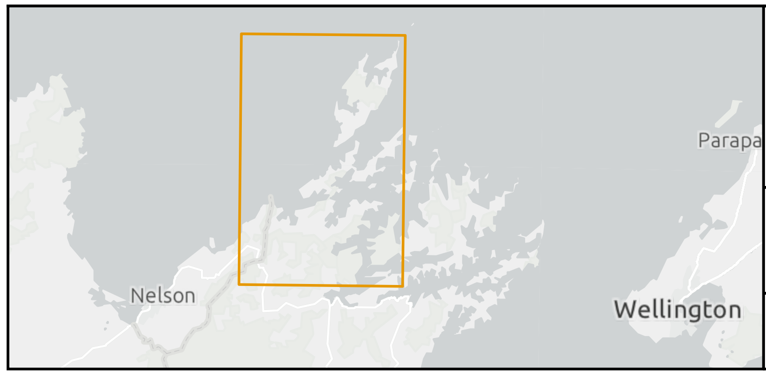
Appendix C Preliminary Hazard Maps

Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





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Marlborough Future Access Study

French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Natural Slope Instability Hazard

Disclaimer: Figures to be read only in conjunction with Stantec's 2023 'Marlborough Sounds Future Access Study - Preliminary Natural Hazard Susceptibility, Implications and Interventions Report
Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
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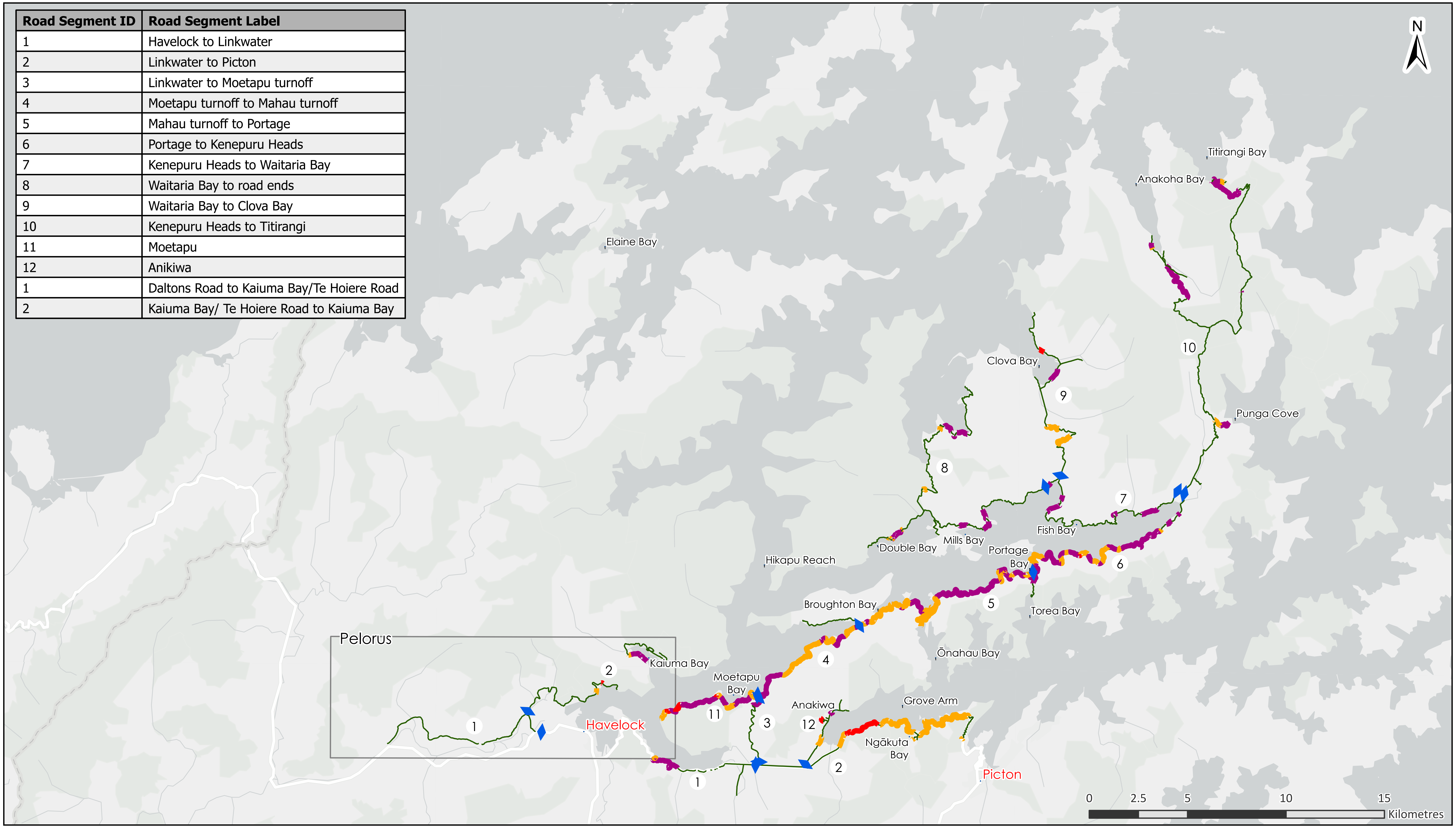
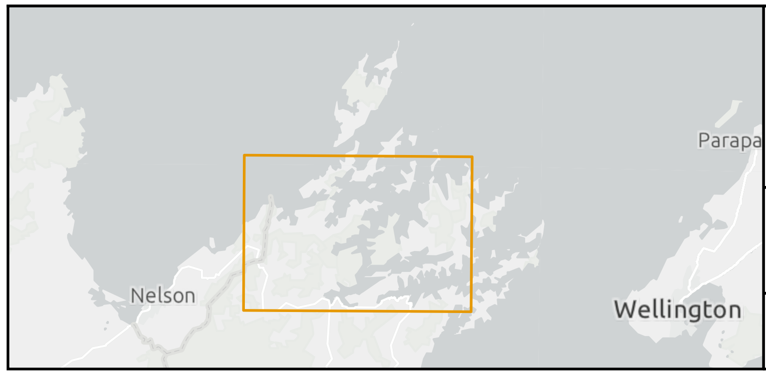
Natural Slope Instability Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

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Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Natural Slope Instability Hazard

Natural Slope Instability Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

Disclaimer: Figures to be read only in conjunction with Stantec's 2023 'Marlborough Sounds Future Access Study - Preliminary Natural Hazard Susceptibility, Implications and Interventions Report

Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
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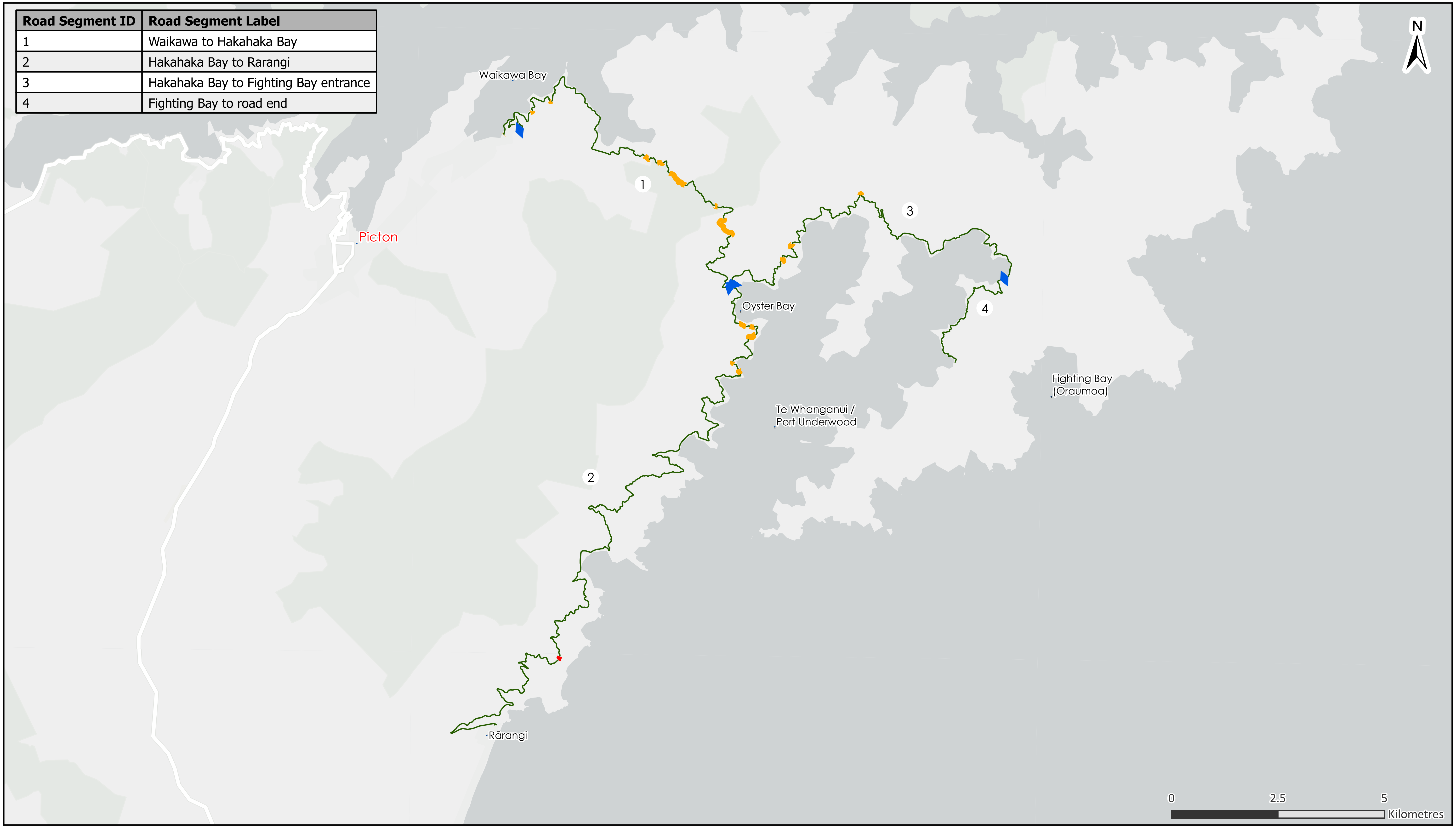
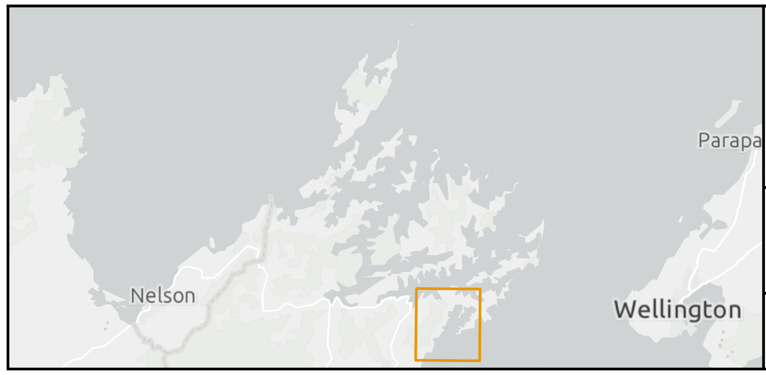
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





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Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Natural Slope Instability Hazard

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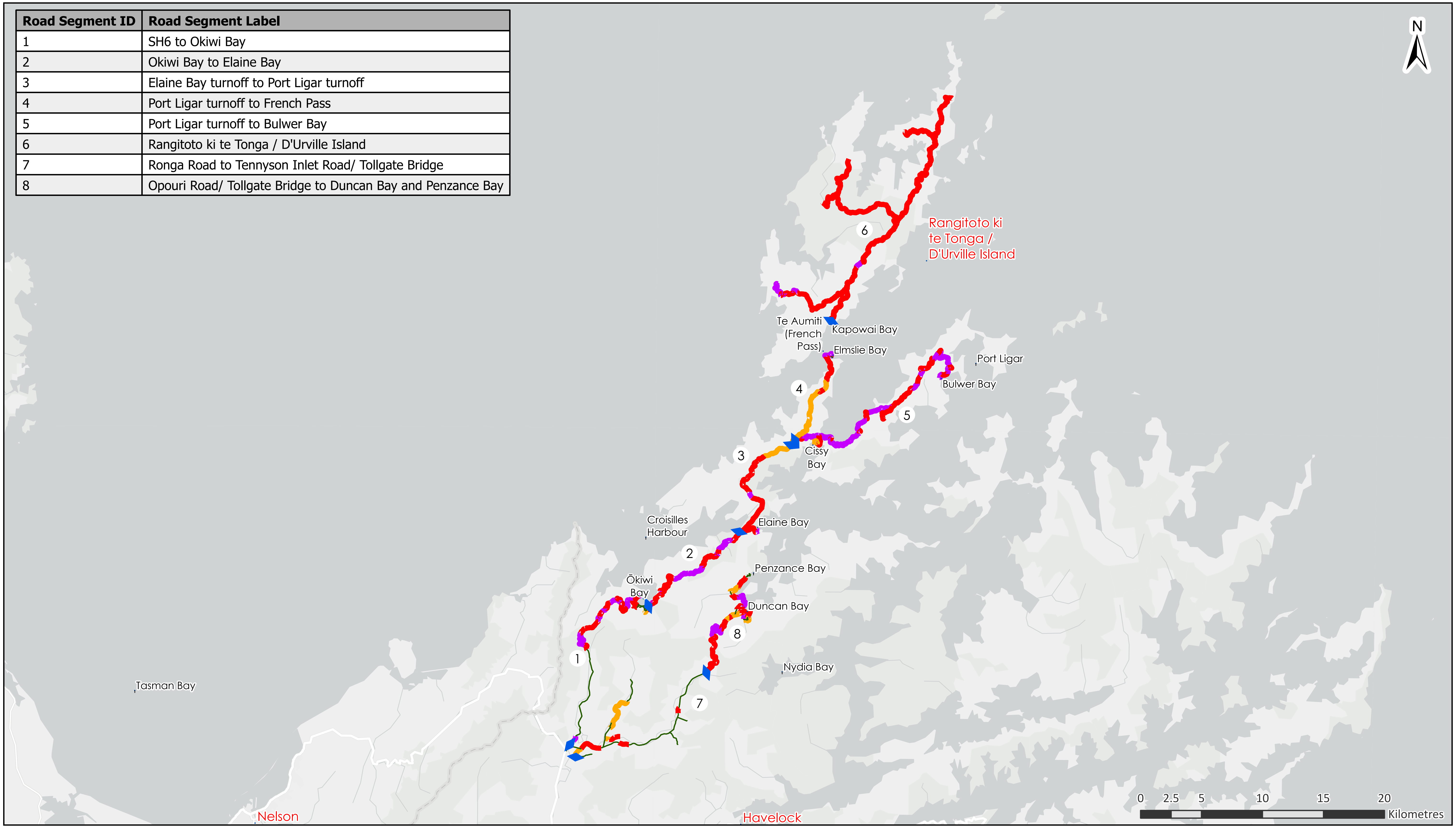
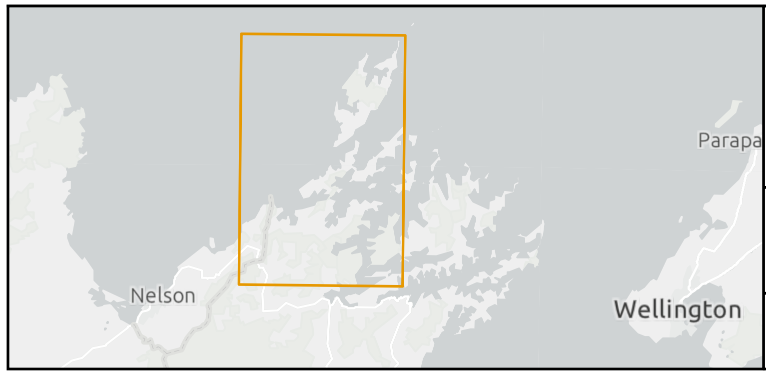
Project Code: 310205564
Export Date: 12/04/2023

Natural Slope Instability Hazard

- Very High
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





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French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Human Induced Slope Instability Hazard

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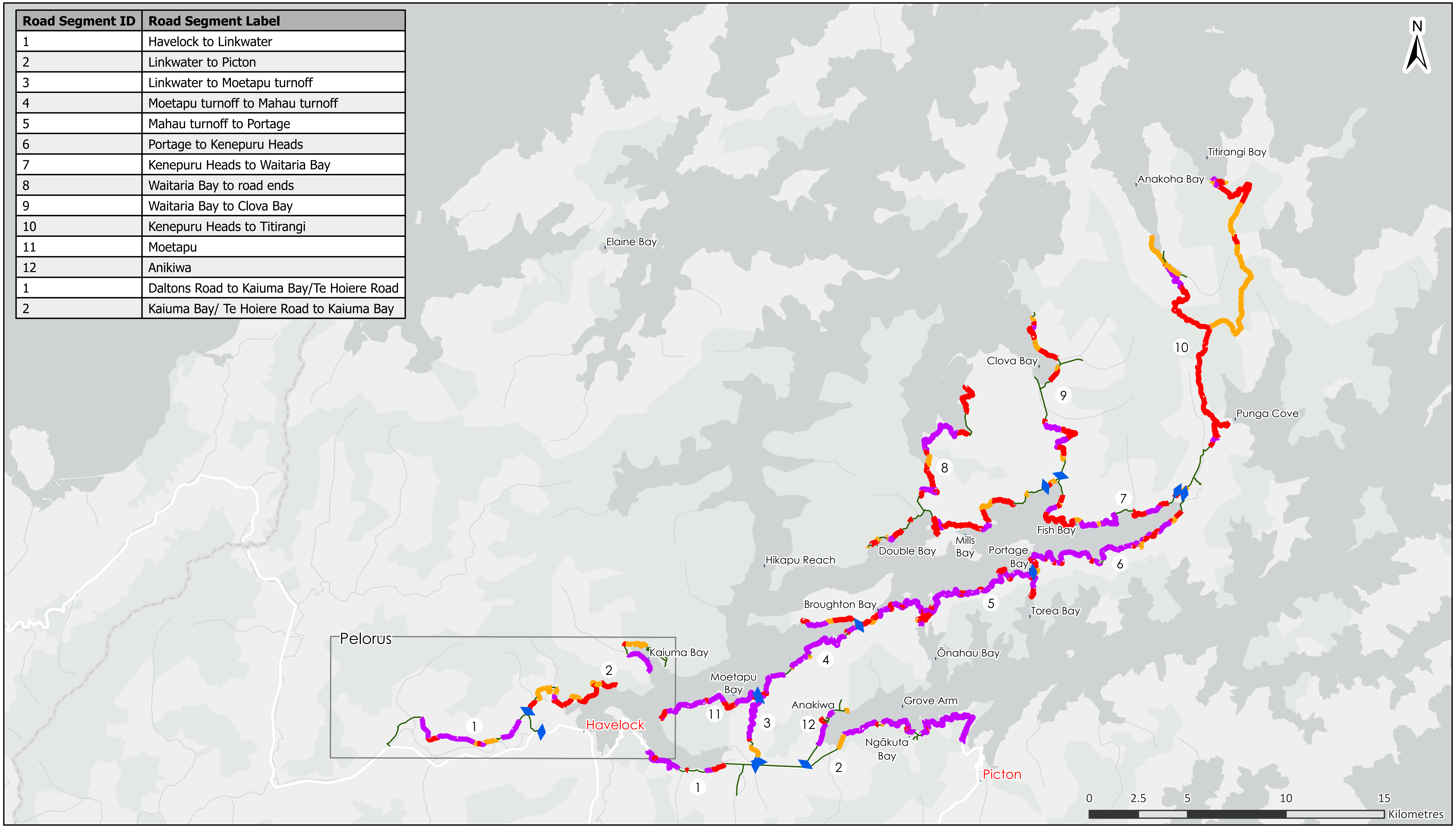
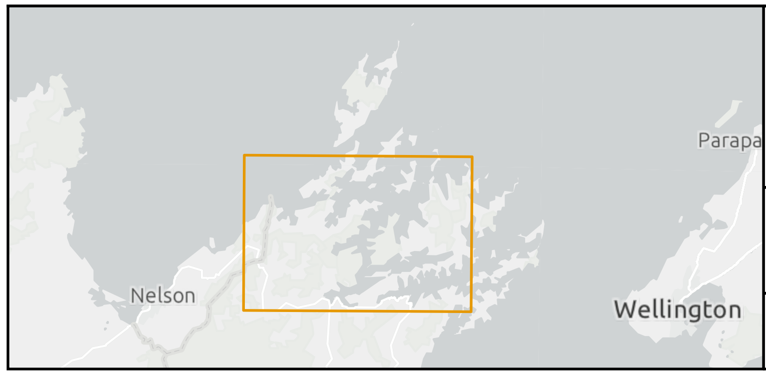
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Human Slope Instability Hazard

- Very High
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

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Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Human Induced Slope Instability Hazard

Human Slope Instability Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

Disclaimer: Figures to be read only in conjunction with Stantec's 2023 'Marlborough Sounds Future Access Study - Preliminary Natural Hazard Susceptibility, Implications and Interventions Report

Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
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Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
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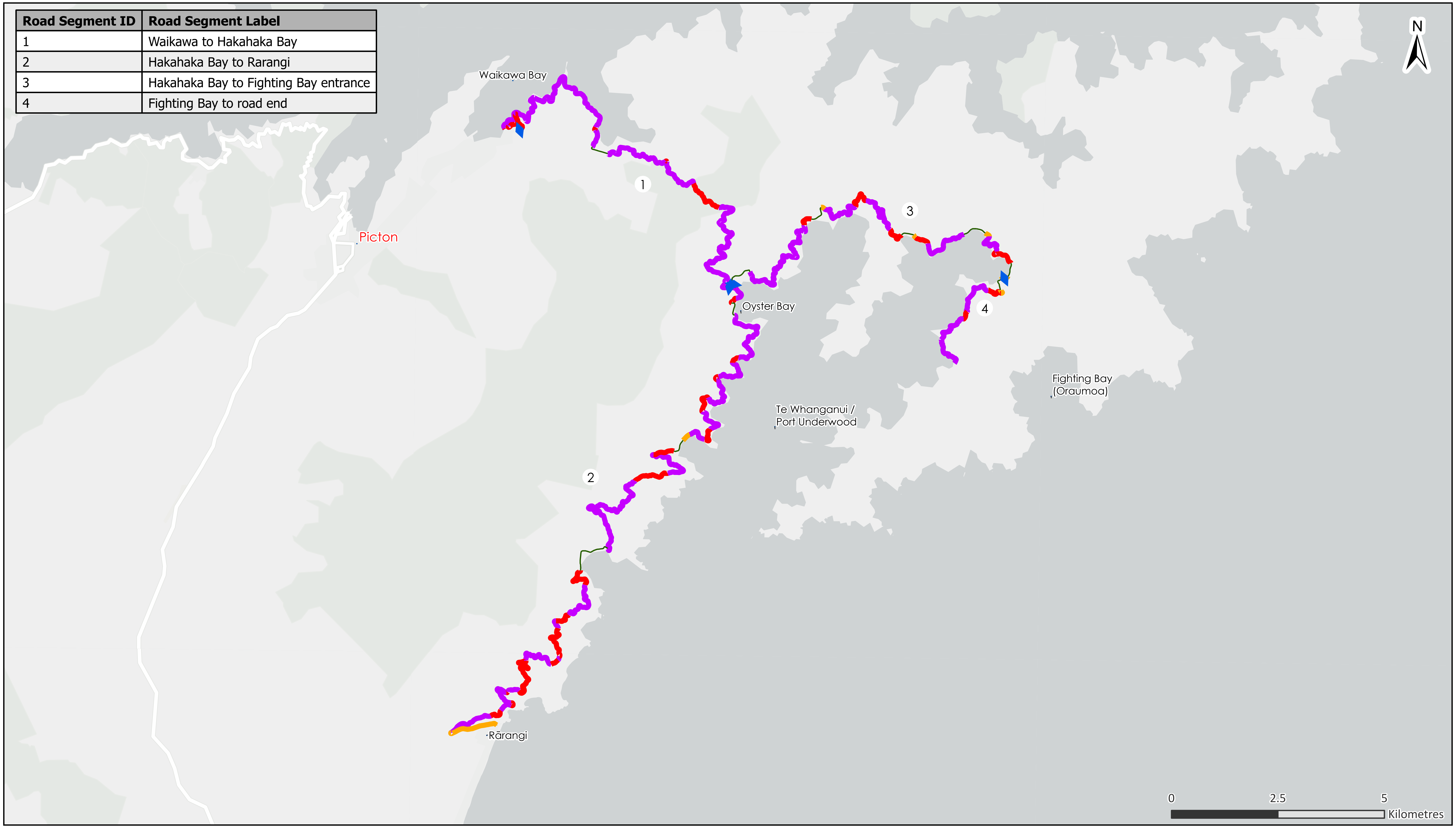
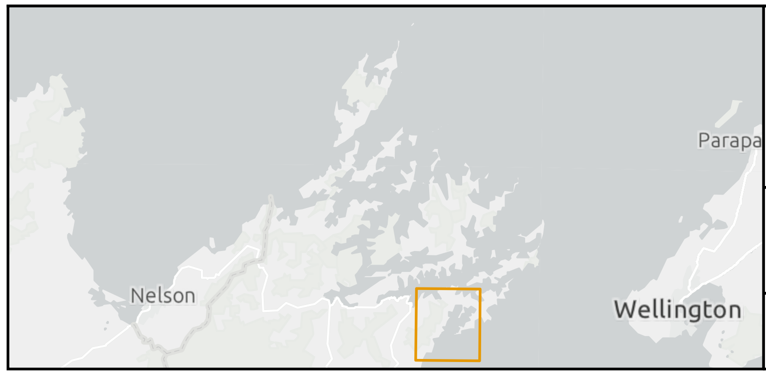
Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





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Marlborough Future Access Study

Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Human Induced Slope Instability Hazard

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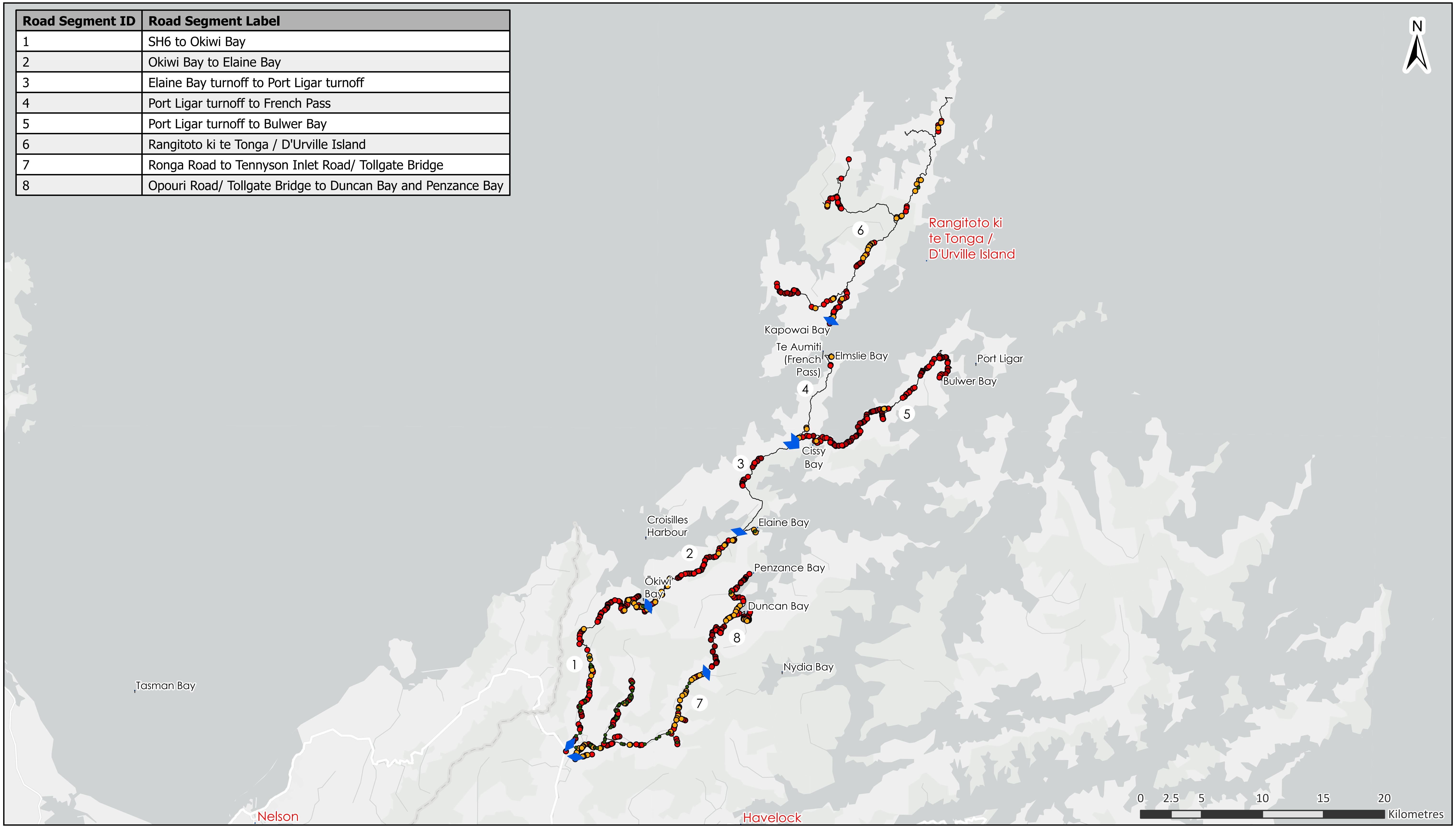
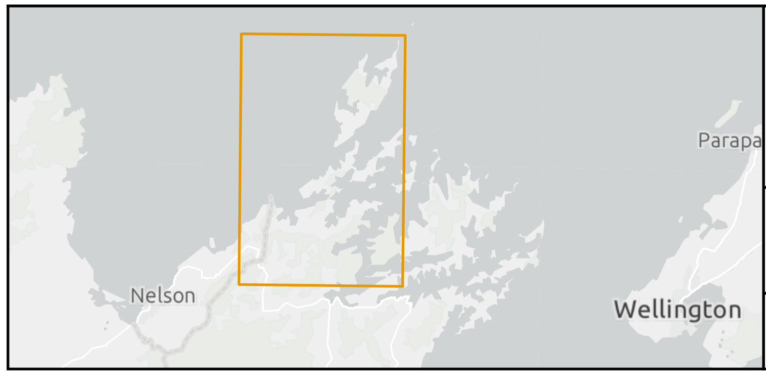
Human Slope Instability Hazard

- Very High
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





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Marlborough Future Access Study

MDC

French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Debris Flow Hazard

Debris Flow Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

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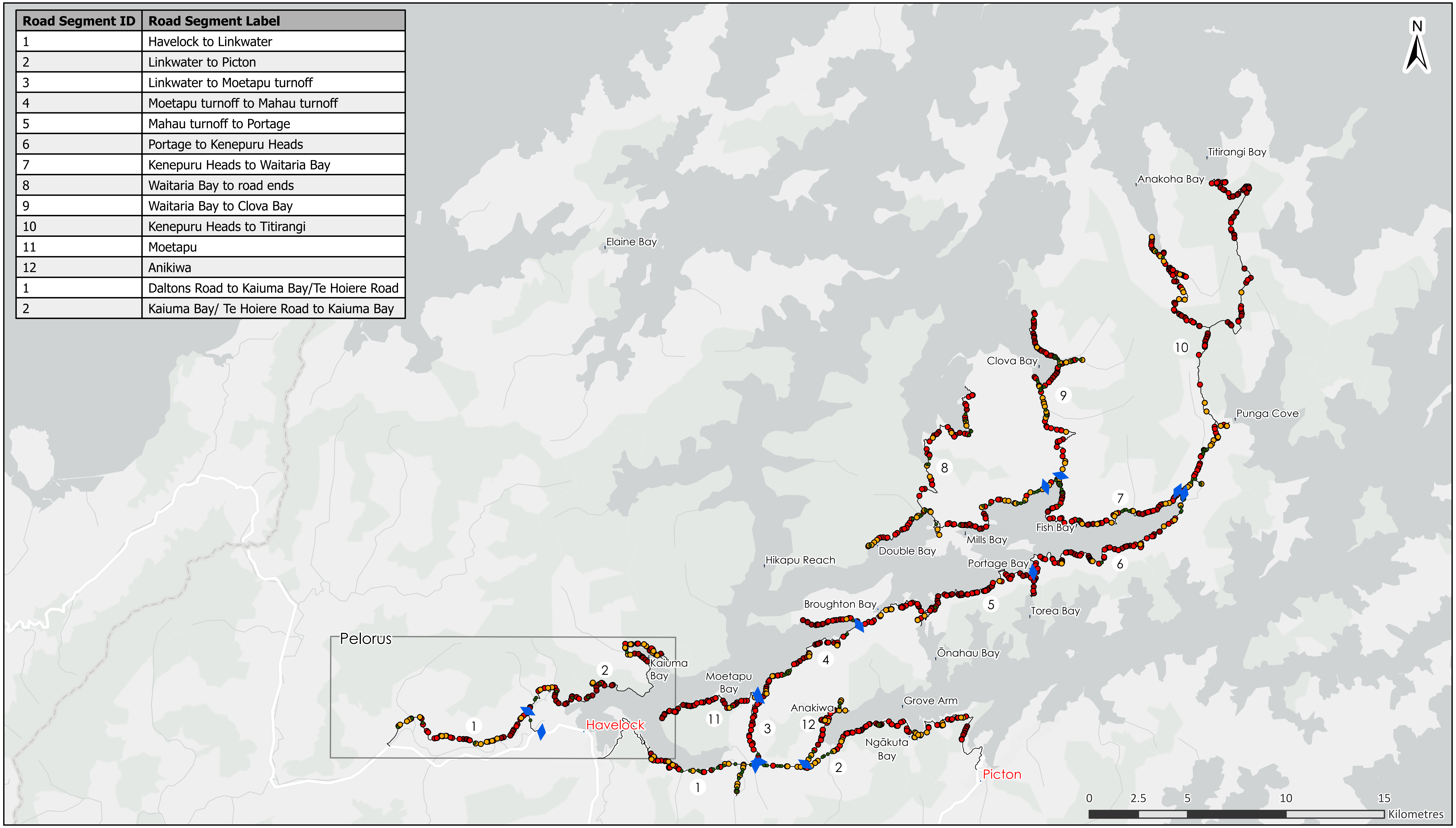
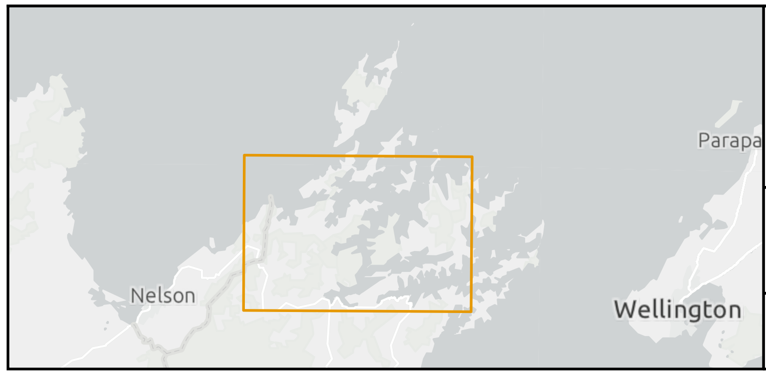
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

MDC

Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Debris Flow Hazard

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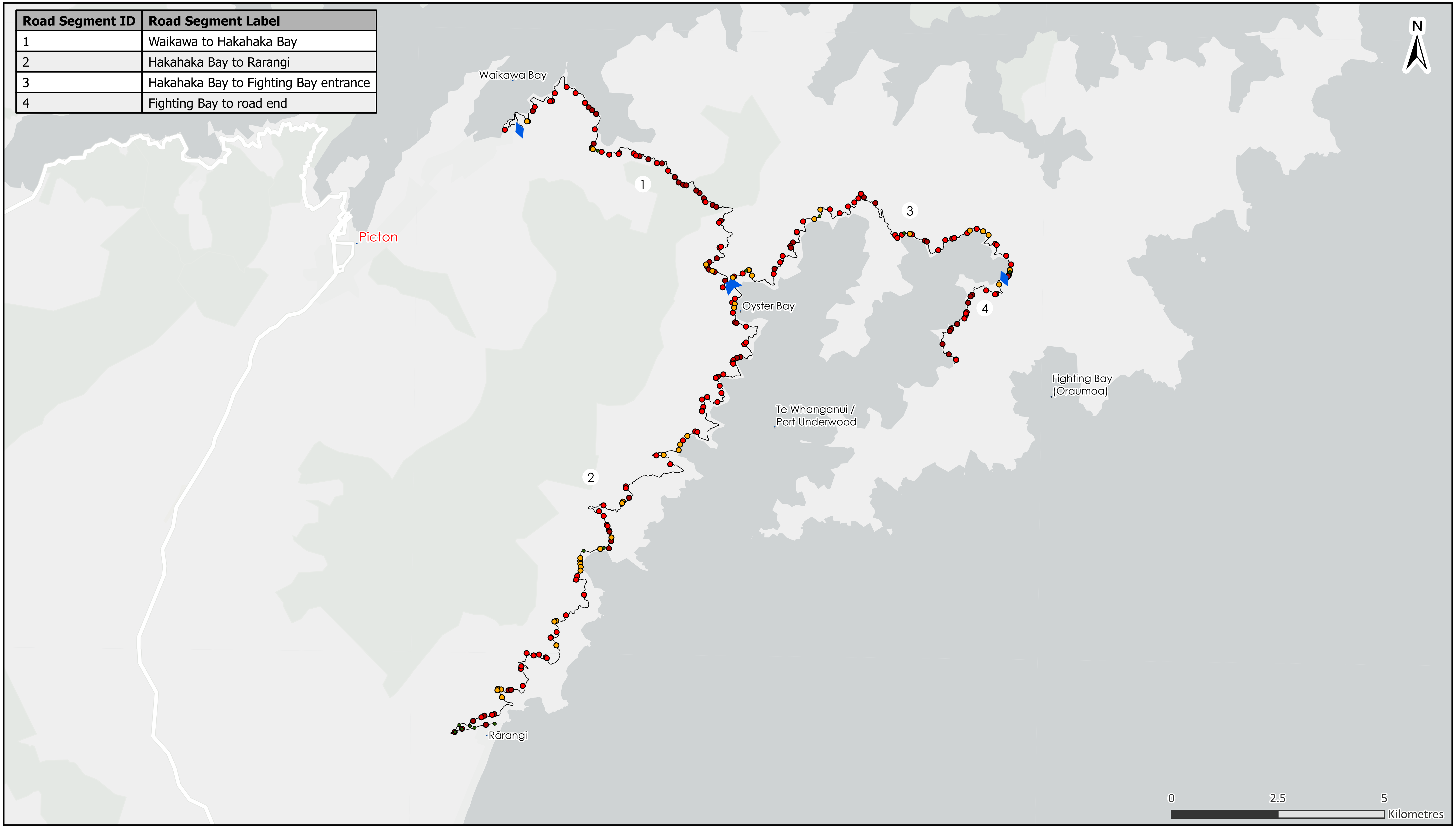
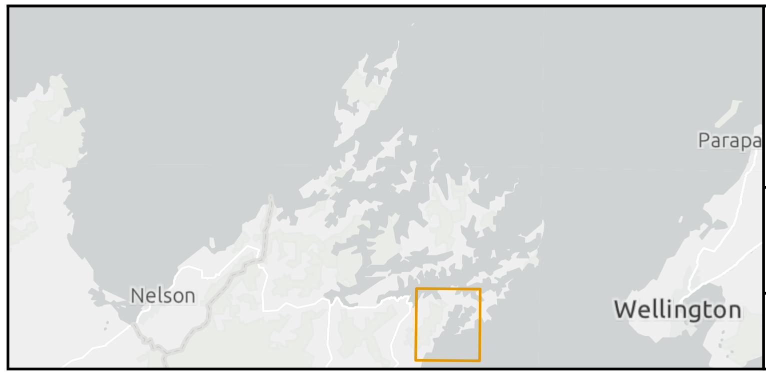
Project Code: 310205564
Export Date: 12/04/2023

Debris Flow Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





Marlborough Future Access Study

Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Debris Flow Hazard

Debris Flow Hazard
- Very High
- High
- Medium
- Low
- Division of Road Segment

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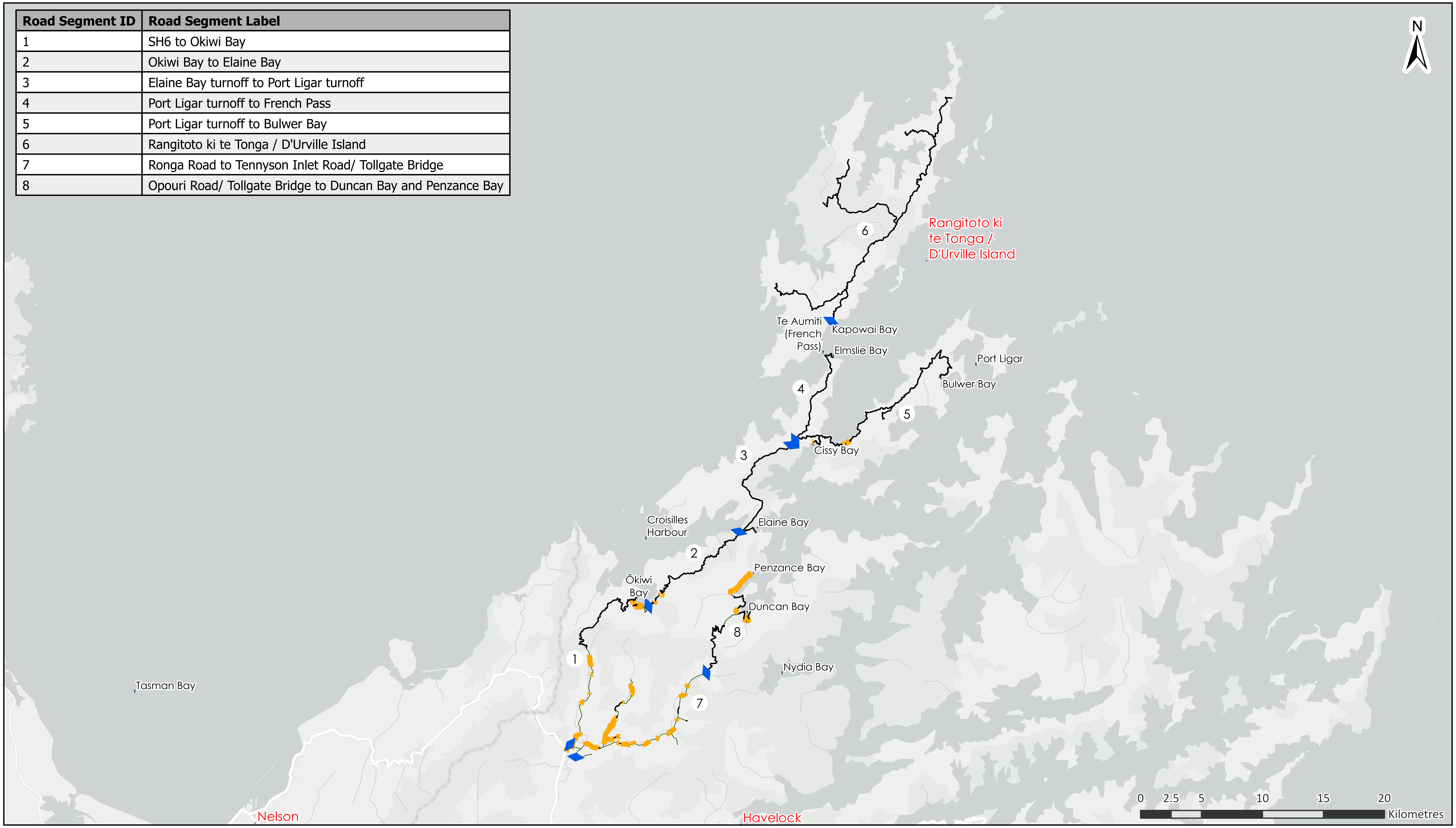
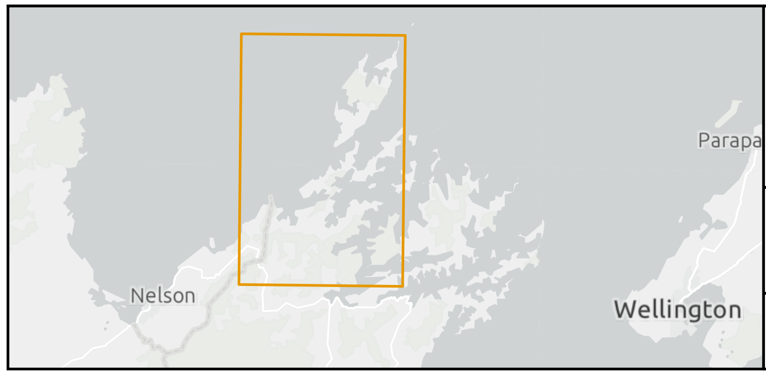
Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





Marlborough Future Access Study

French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Liquefaction Hazard

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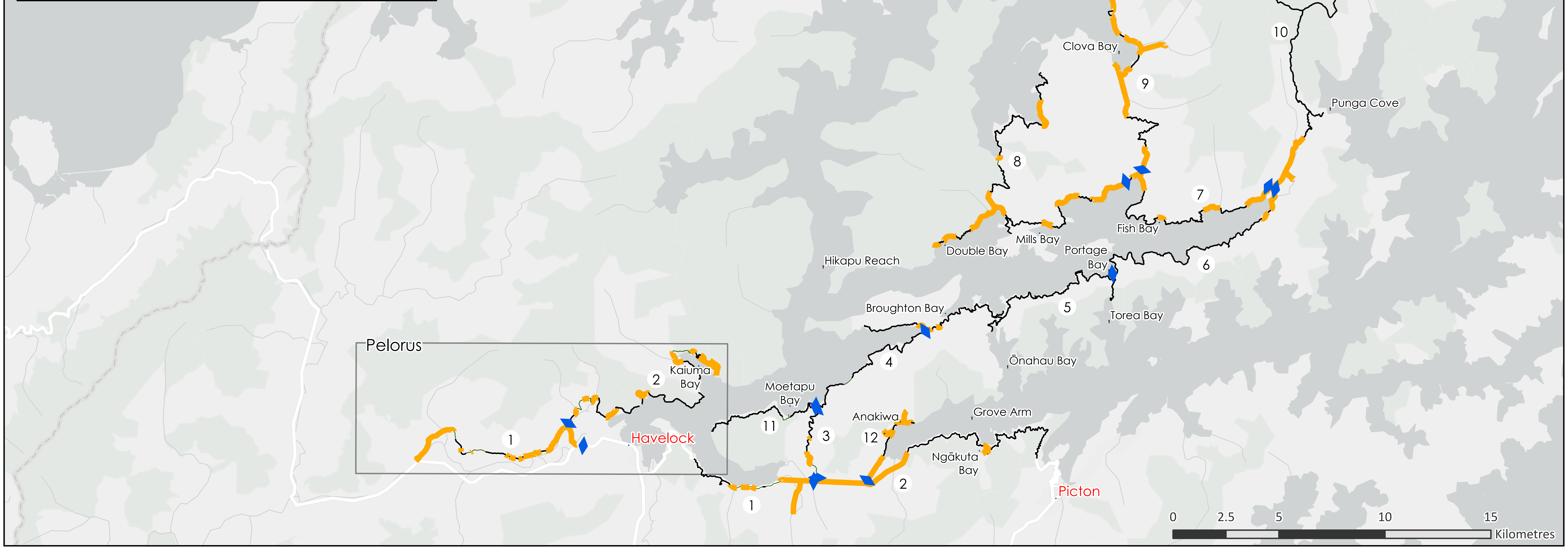
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

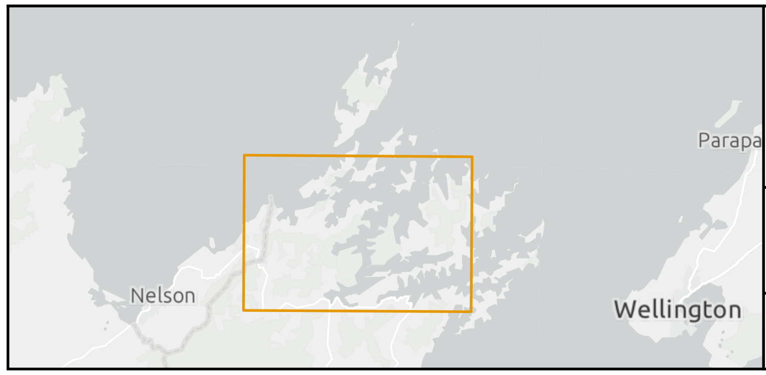
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Liquefaction Hazard

- Medium
- Low
- NA
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

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Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Liquefaction Hazard

Disclaimer: Figures to be read only in conjunction with Stantec's 2023 'Marlborough Sounds Future Access Study - Preliminary Natural Hazard Susceptibility, Implications and Interventions Report
Data Sources: LINZ Data Service, Marlborough District Council Smart Maps, Stantec
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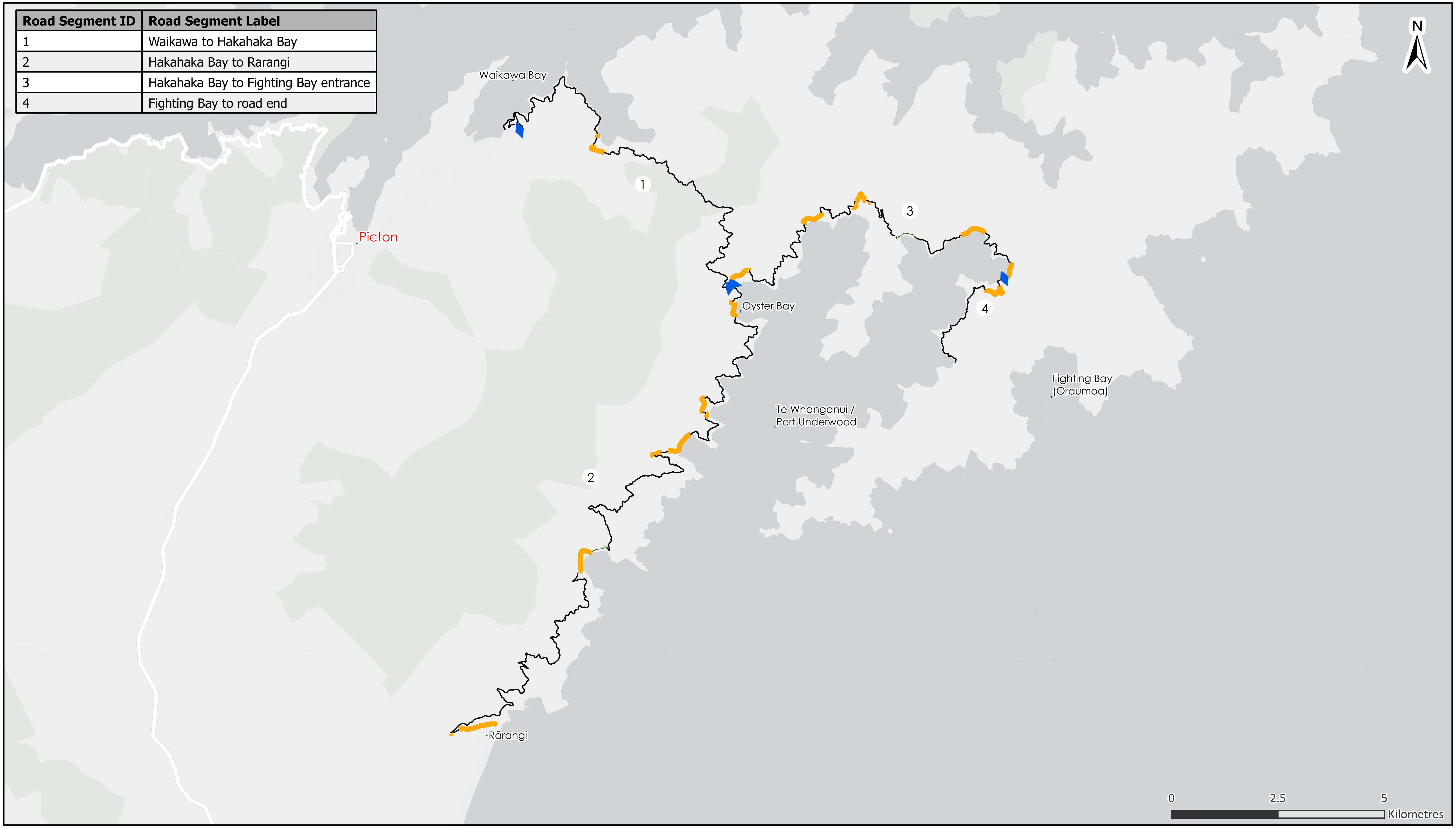
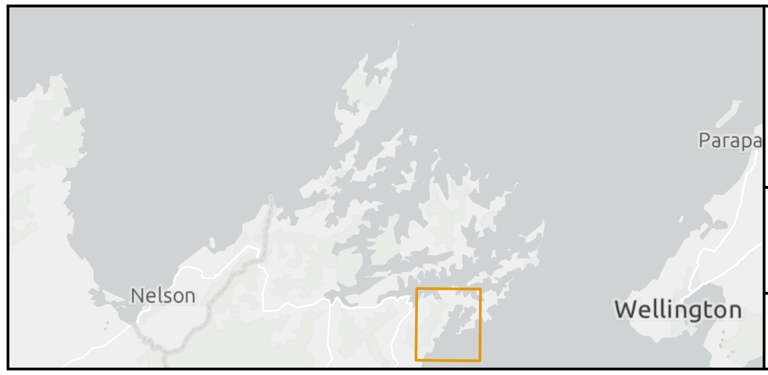
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Liquefaction Hazard
- Medium
- Low
- NA
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





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Marlborough Future Access Study

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Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment
Liquefaction Hazard

Liquefaction Hazard
- Medium
- Low
- NA
- Division of Road Segment

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Author: caharris, Stantec (2023)
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Project Code: 310205564
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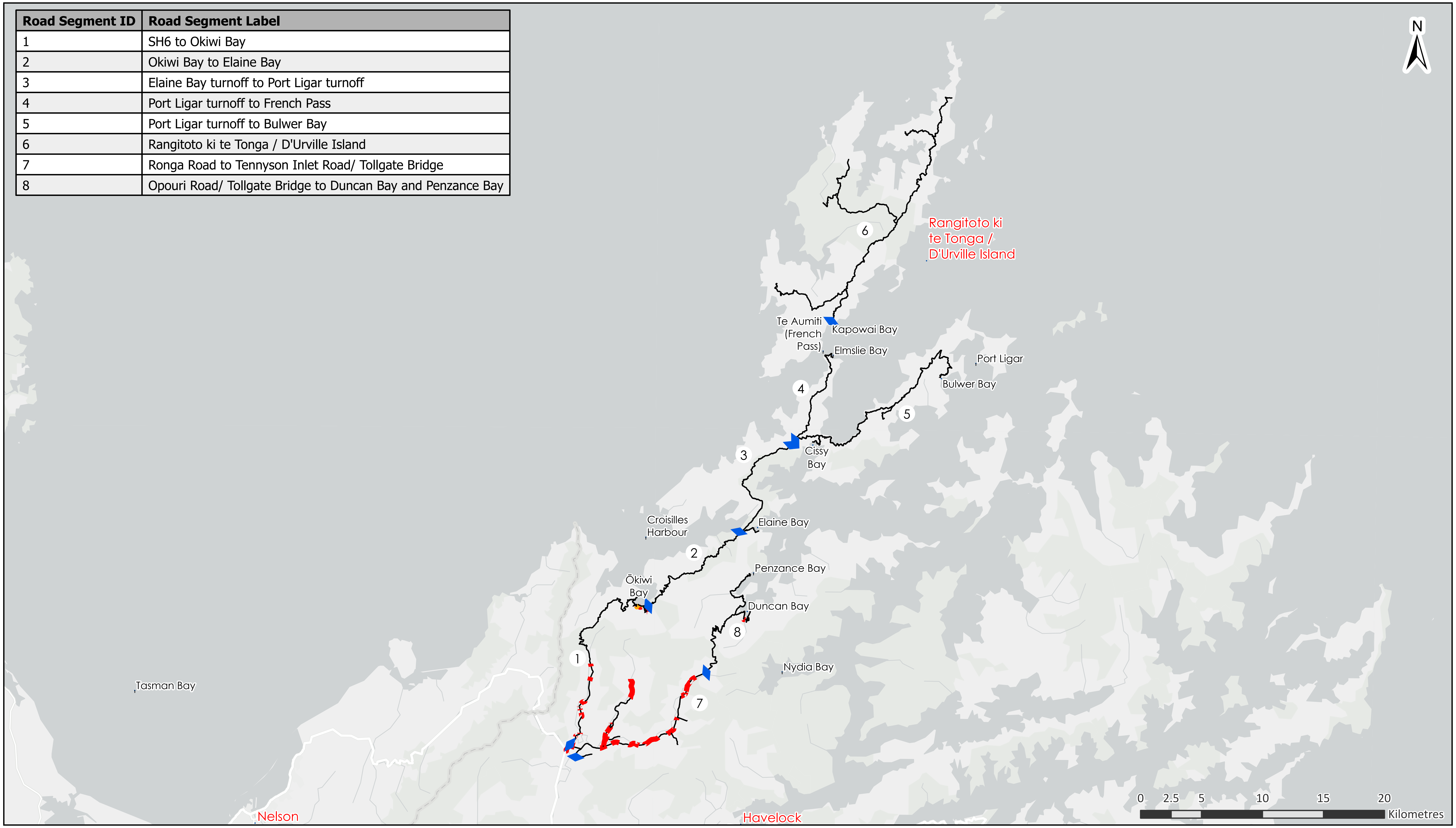
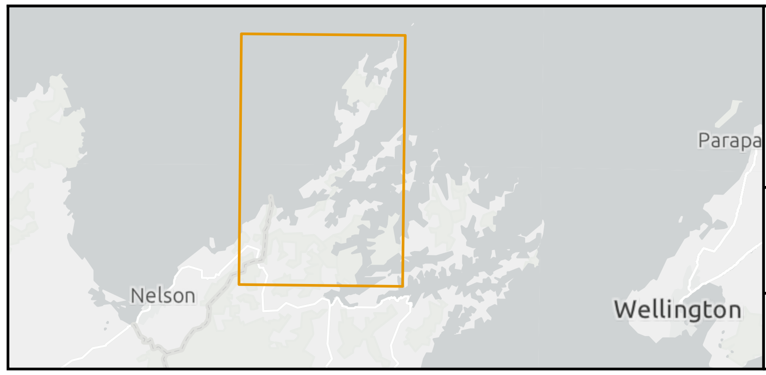
Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





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French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Flood Hazard

MDC

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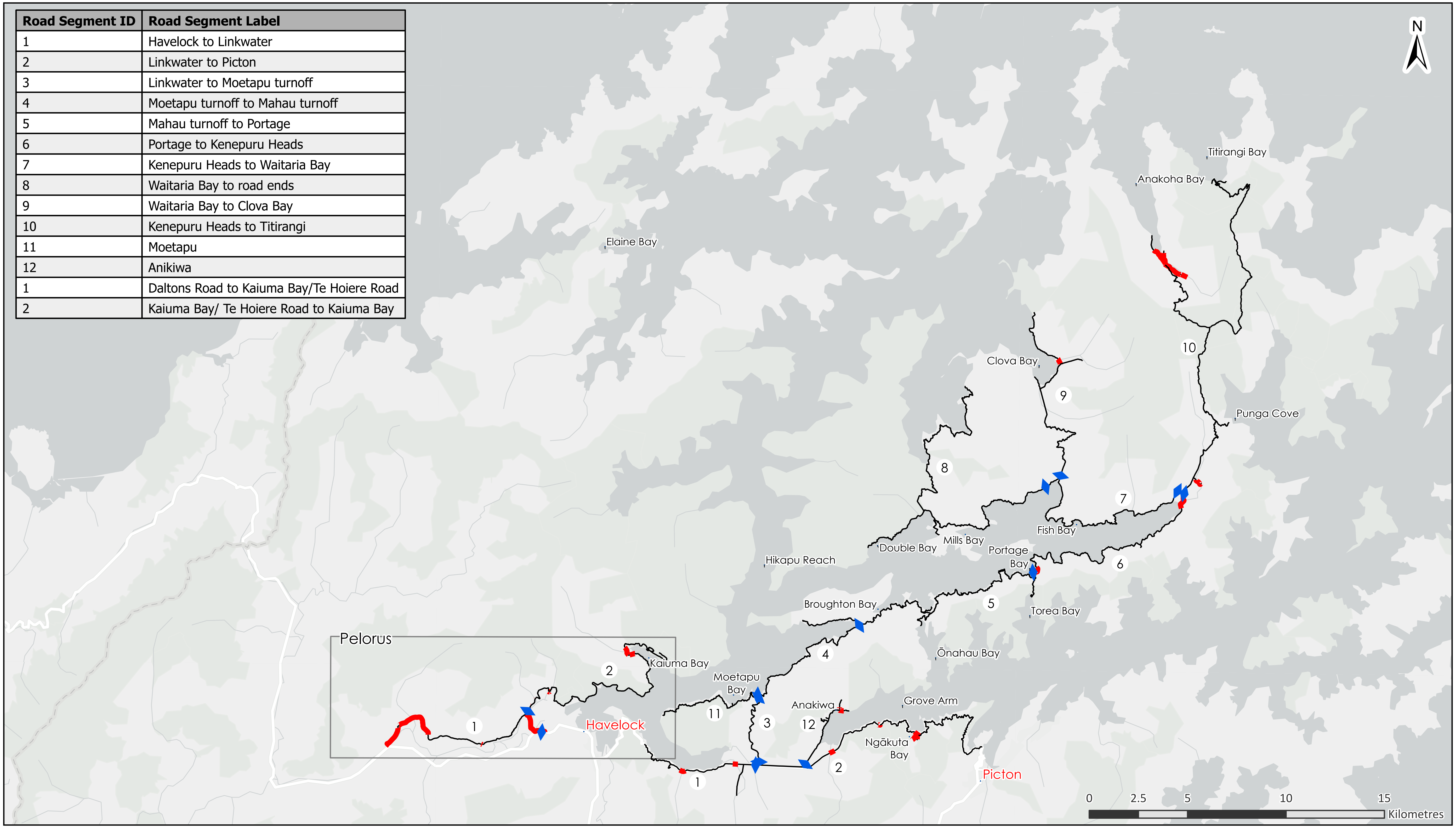
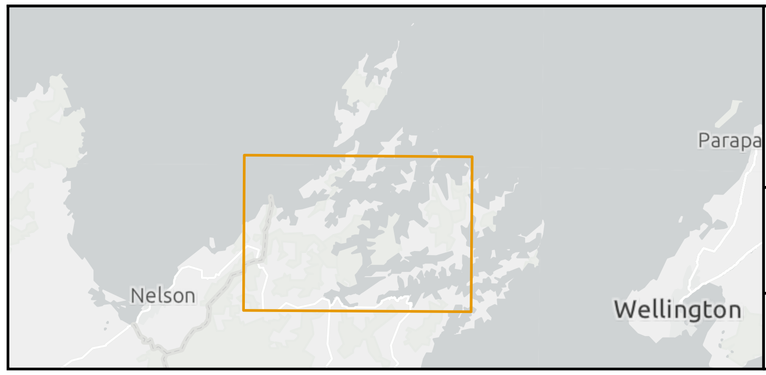
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Flood Hazard
- Very High
- High
- Medium
- Not within Flood Hazard Overlay
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

MDC

Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Flood Hazard

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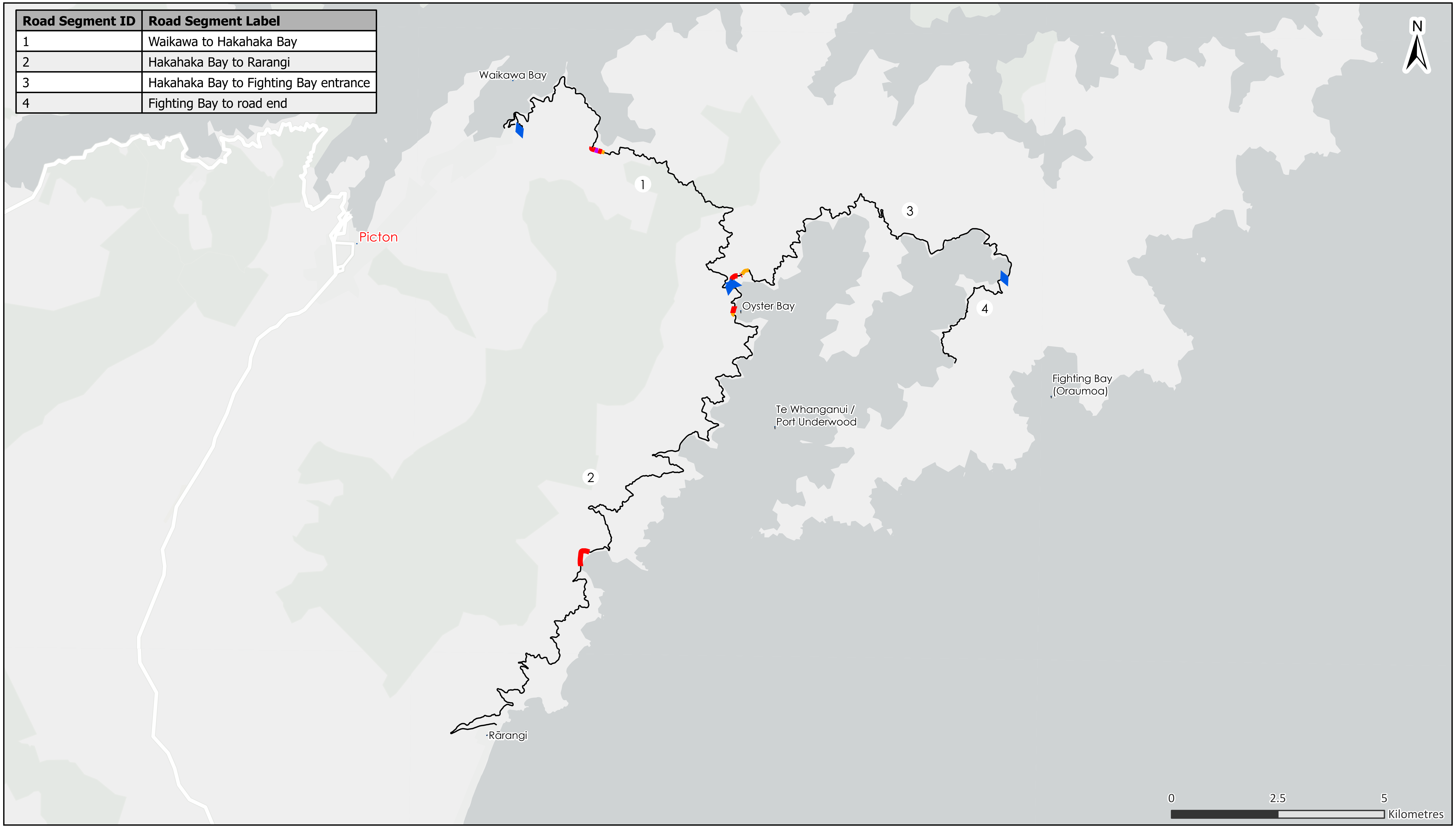
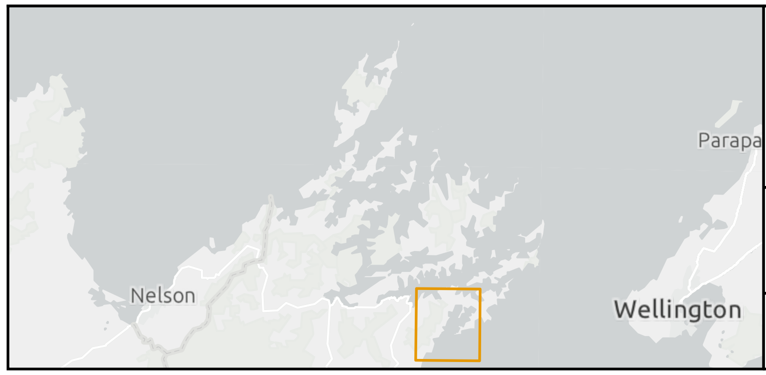
Coordinate System: NZGD 2000 New Zealand Transverse Mercator

Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Flood Hazard
- Very High
- High
- Medium
- Not within Flood Hazard Overlay
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





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Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Flood Hazard

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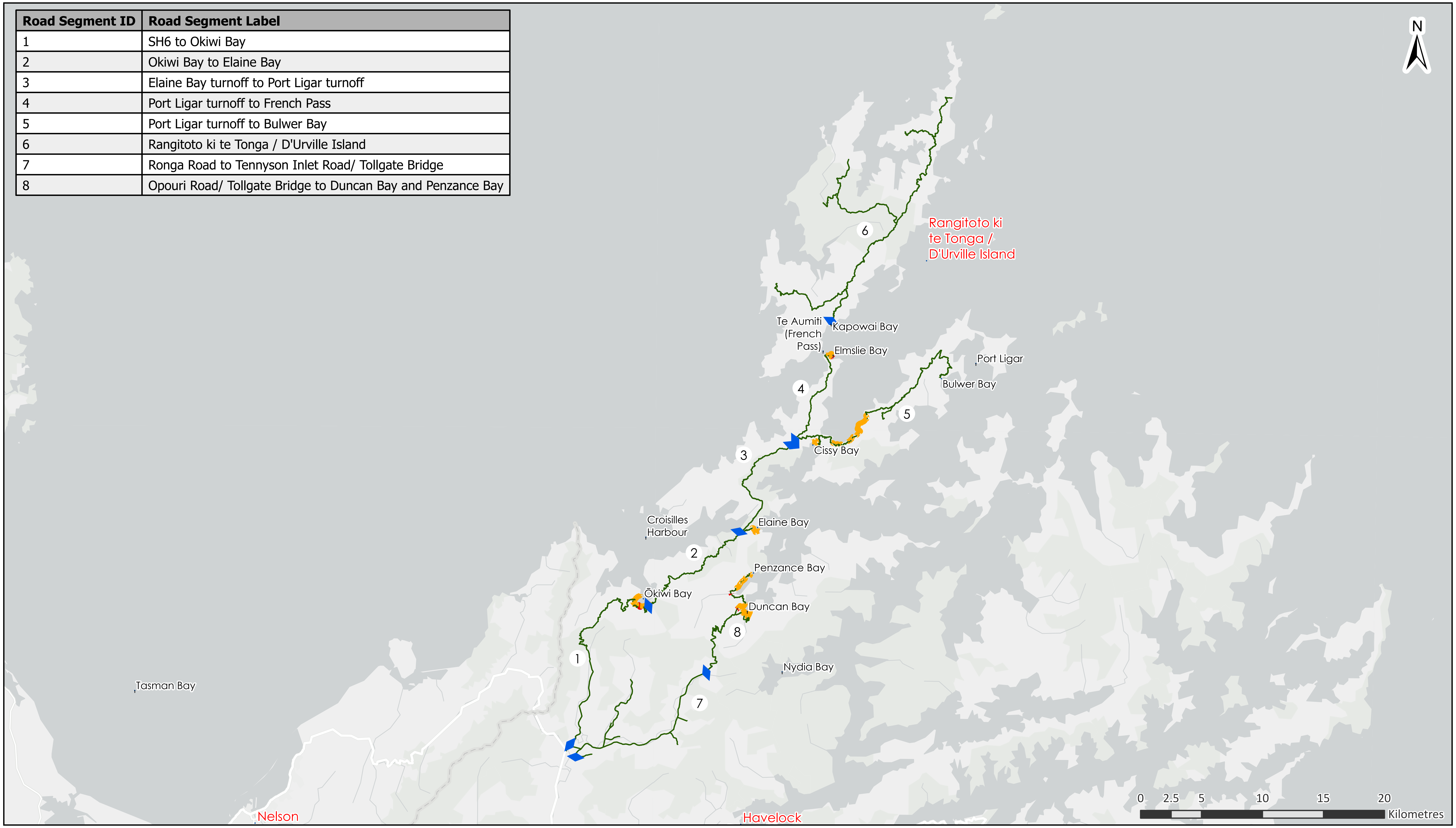
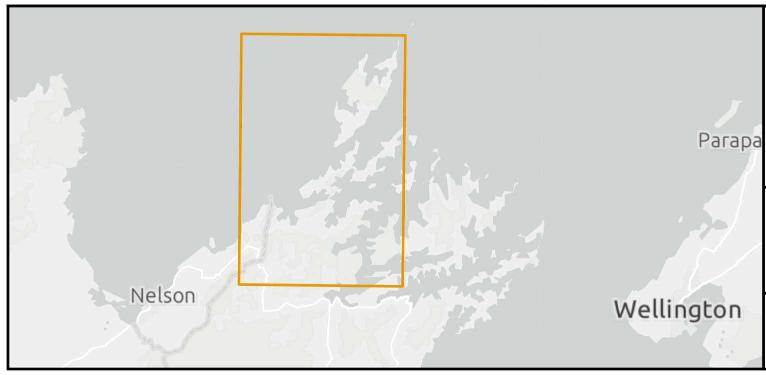
Flood Hazard
- Very High
- High
- Medium
- Not within Flood Hazard Overlay
- Division of Road Segment

Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





Marlborough Future Access Study

French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Coastal Hazard

Coastal Hazard
- High
- Medium
- Low

Division of Road Segment

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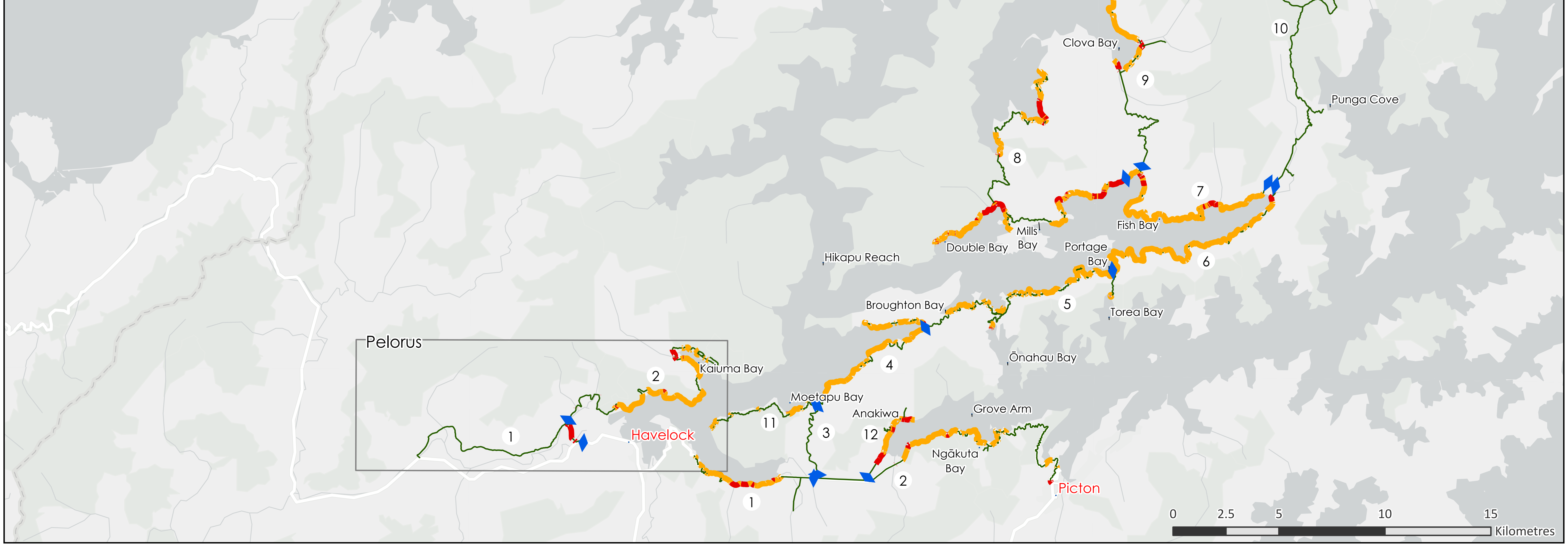
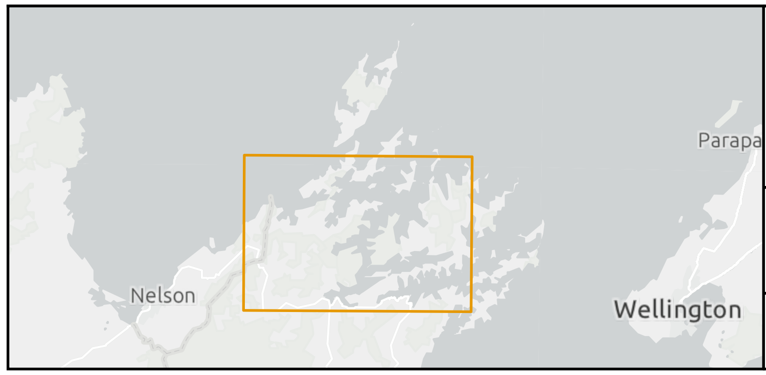
Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





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Marlborough Future Access Study

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Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Coastal Hazard

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Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
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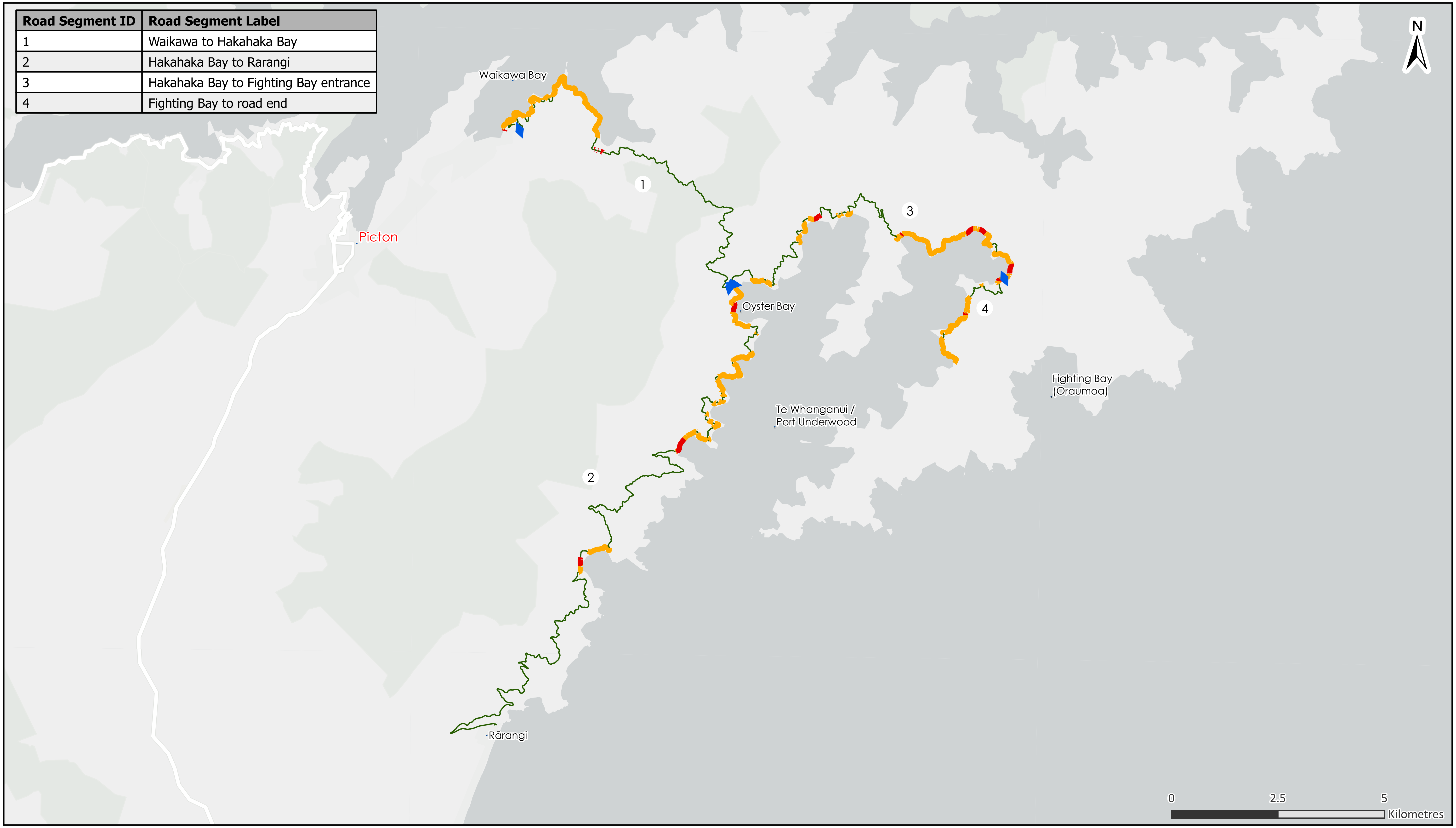
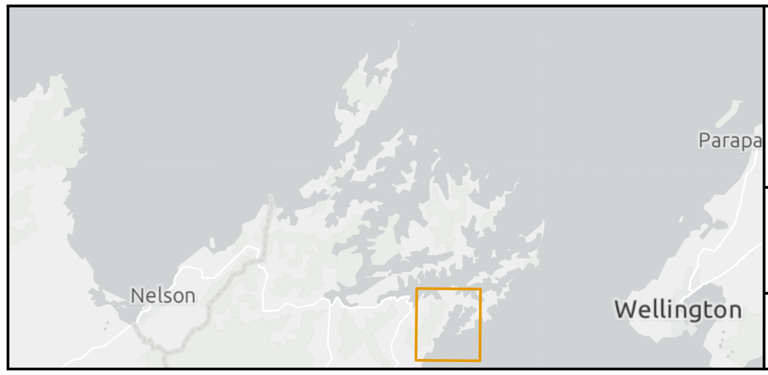
Coastal Hazard
- High
- Medium
- Low
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





Marlborough Future Access Study

Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Coastal Hazard

Coastal Hazard
- High
- Medium
- Low
- Division of Road Segment

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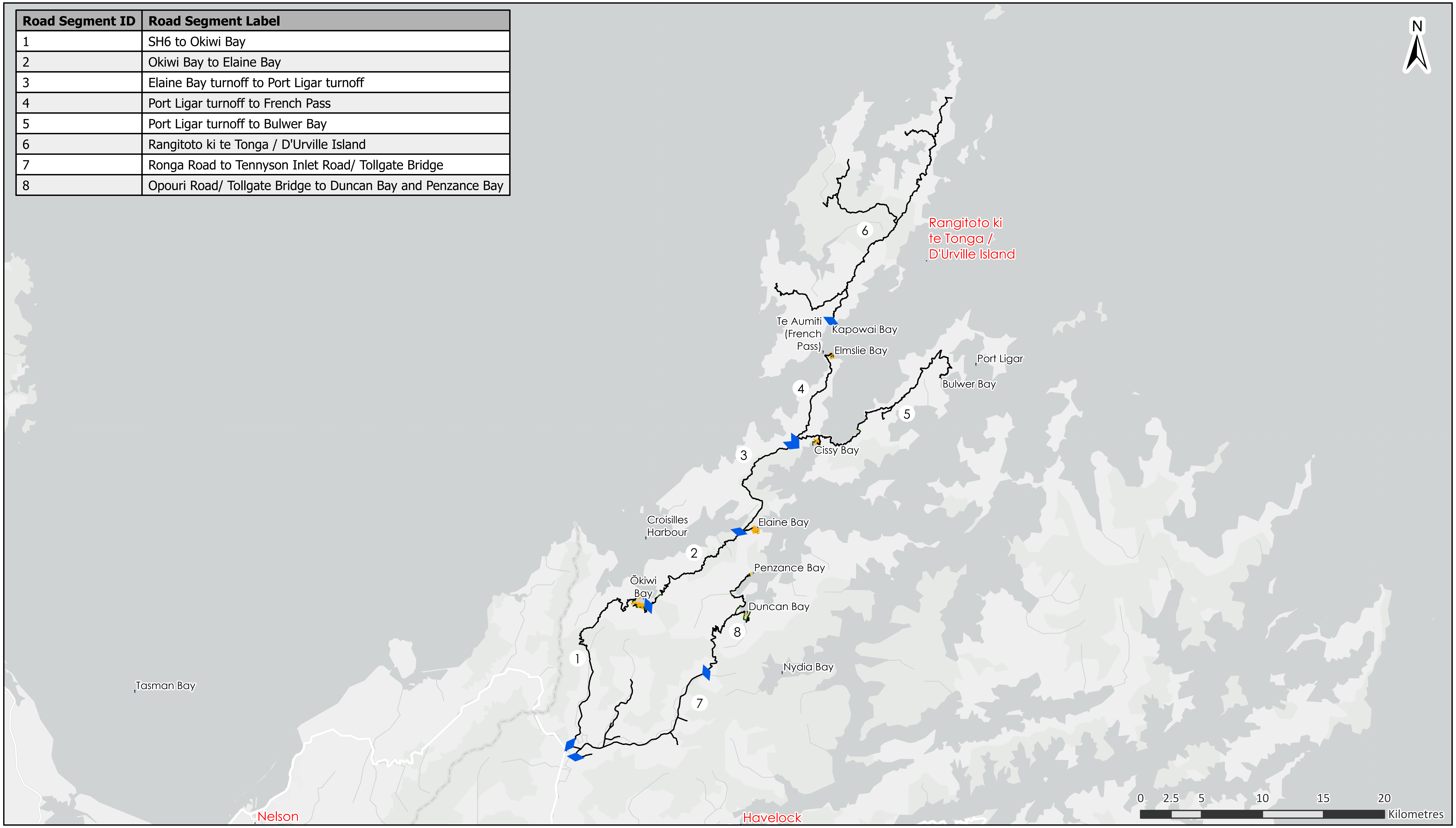
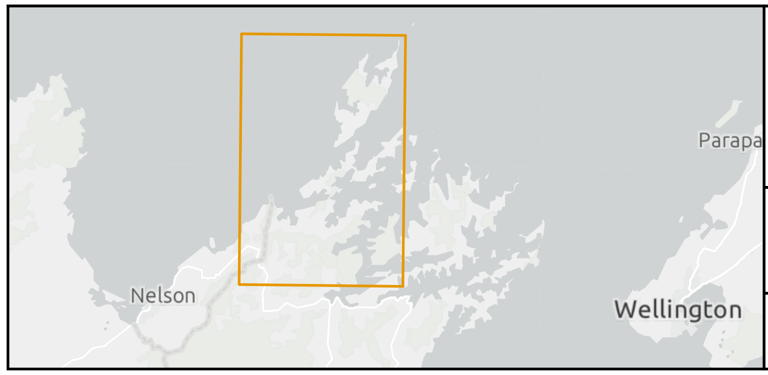
Road Segment ID	Road Segment Label
1	SH6 to Okiwi Bay
2	Okiwi Bay to Elaine Bay
3	Elaine Bay turnoff to Port Ligar turnoff
4	Port Ligar turnoff to French Pass
5	Port Ligar turnoff to Bulwer Bay
6	Rangitoto ki te Tonga / D'Urville Island
7	Ronga Road to Tennyson Inlet Road/ Tollgate Bridge
8	Opouri Road/ Tollgate Bridge to Duncan Bay and Penzance Bay





Stantec

Marlborough Future Access Study

French Pass Area - Preliminary Natural Hazard Susceptibility Assessment

Tsunami Hazard

MDC

Tsunami Hazard
- Medium
- Low
- Not within Evacuation Area
- Division of Road Segment

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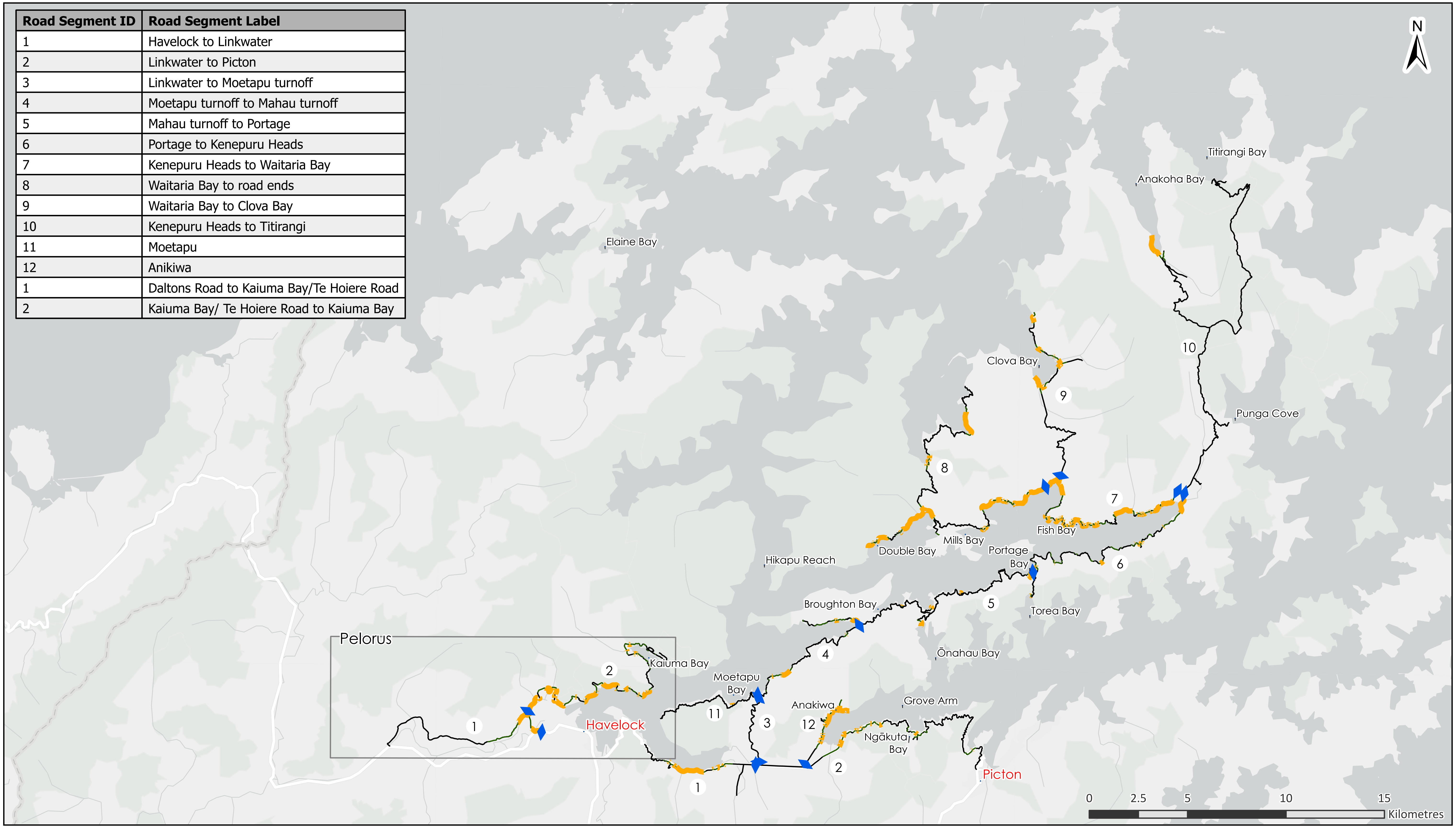
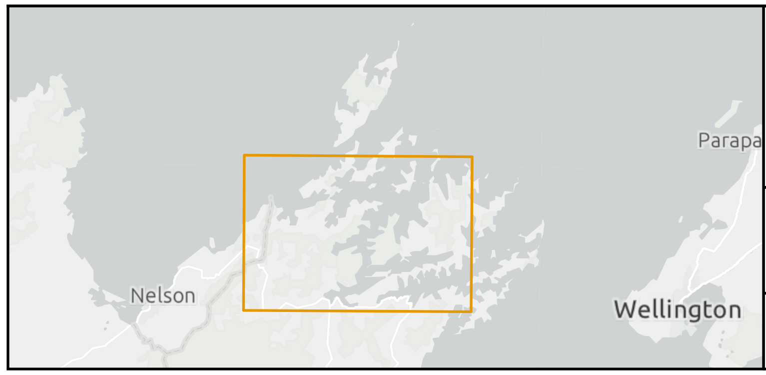
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Road Segment ID	Road Segment Label
1	Havelock to Linkwater
2	Linkwater to Picton
3	Linkwater to Moetapu turnoff
4	Moetapu turnoff to Mahau turnoff
5	Mahau turnoff to Portage
6	Portage to Kenepuru Heads
7	Kenepuru Heads to Waitaria Bay
8	Waitaria Bay to road ends
9	Waitaria Bay to Clova Bay
10	Kenepuru Heads to Titirangi
11	Moetapu
12	Anikiwa
1	Daltons Road to Kaiuma Bay/Te Hoiere Road
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma Bay





Marlborough Future Access Study

Kenepuru, Pelorus & Queen Charlotte Area - Preliminary Natural Hazard Susceptibility Assessment

Tsunami Hazard

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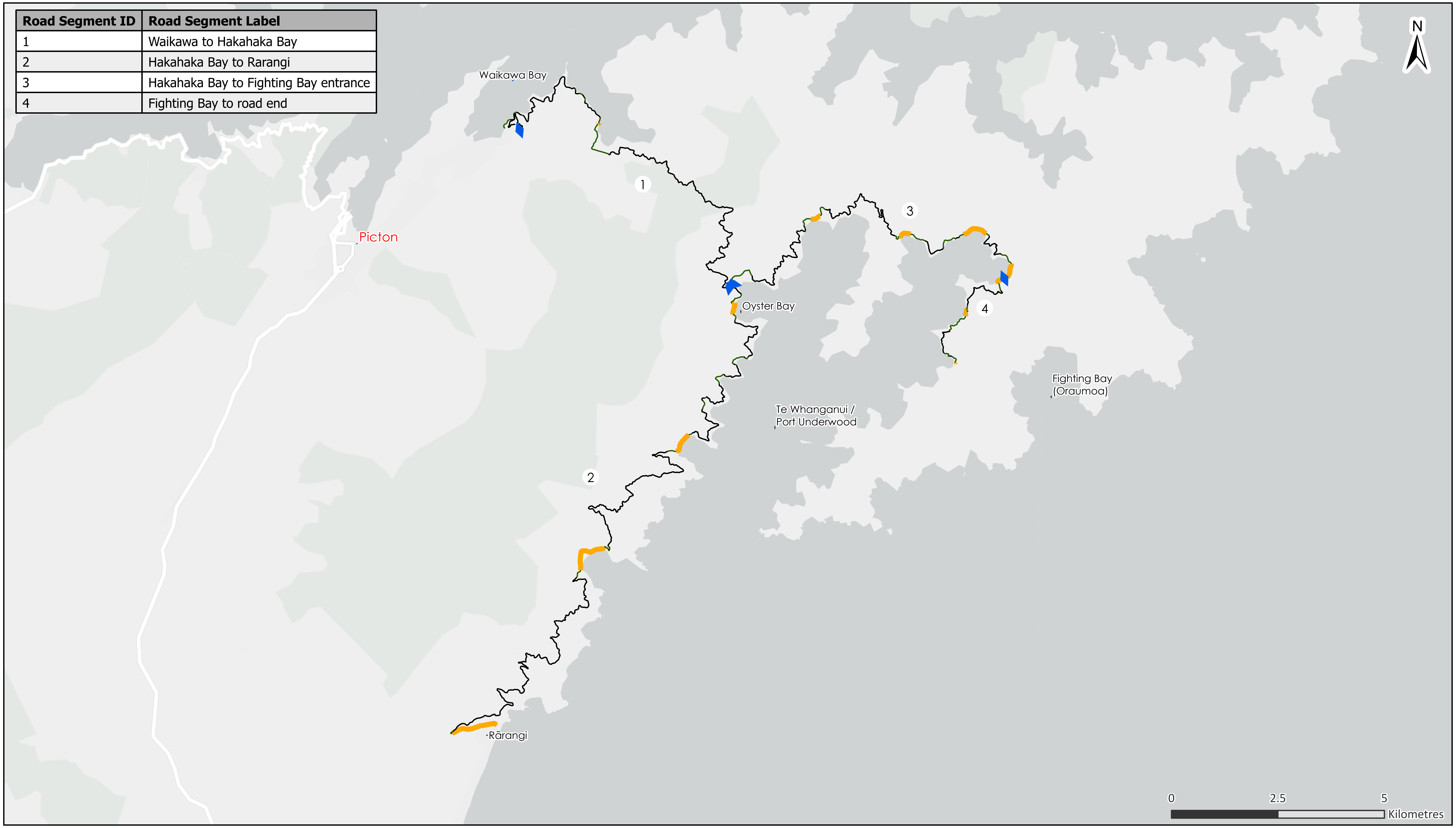
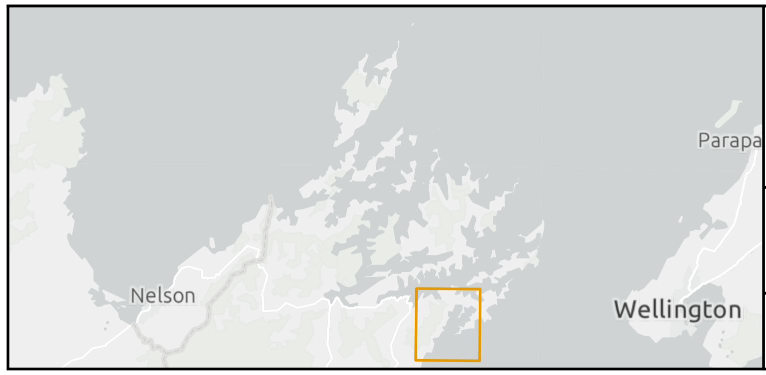
Author: caharris, Stantec (2023)
Reviewed by: rmcpherson, 12/04/2023
Project Code: 310205564
Export Date: 12/04/2023

Tsunami Hazard

- Medium
- Low
- Not within Evacuation Area
- Division of Road Segment

Road Segment ID	Road Segment Label
1	Waikawa to Hakahaka Bay
2	Hakahaka Bay to Rarangi
3	Hakahaka Bay to Fighting Bay entrance
4	Fighting Bay to road end





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Marlborough Future Access Study

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Port Underwood Area - Preliminary Natural Hazard Susceptibility Assessment

Tsunami Hazard

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Export Date: 12/04/2023

Tsunami Hazard
- Medium
- Low
- Not within Evacuation Area
- Division of Road Segment

Appendix D Preliminary Hazard Summary Table

MARLBOROUGH ROADS FUTURE ACCESS STUDY

FAULT / HAZARD SUCEPTIBILITY SUMMARY

Segment #	Segment Name	Road Name	Surfacing: Sealed (km)	Unsealed (km)	Total Distance (km)	% of road segment exposed per natural hazard susceptibility rating: Natural Slope Stability Very High (%)	Natural Slope Stability High (%)	Human Induced Slope Stability Very High (%)	Human Induced Slope Stability High (%)	Liquefaction Medium (%)	Flood inundation Very High (%)	Flood inundation High (%)	Coastal High (%)	Tsunami Medium (%)	# per km: Debris Flow Very High (#)	Debris Flow High (#)
FRENCH PASS AREA																
1	SH6 to Okiwi Bay	Ronga And Croilles	25	1	26	2%	1%	28%	27%	21%	0%	11%	3%	6%	1.5	1.9
2	Okiwi Bay to Elaine Bay	Croisilles-French Pass Road	17	0	17	6%	3%	39%	60%	3%	0%	1%	0%	4%	1.4	1.5
3	Elaine Bay turnoff to Port Ligar turnoff	Croisilles-French Pass Road	7	6	13	0%	0%	4%	73%	0%	0%	0%	0%	0%	1.2	0.2
4	Port Ligar turnoff to French Pass	Croisilles-French Pass Road	3	8	11	0%	34%	10%	29%	2%	0%	0%	2%	2%	0.1	0.4
5	Port Ligar turnoff to Bulwer Bay	Te Towaka-Port Ligar Road2	1	29	30	6%	7%	57%	40%	3%	0%	0%	0%	1%	2.4	1.2
6	Rangitoto ki te Tonga / D'Urville Island	Not Summarised	0	57	57	0%	3%	6%	94%	0%	0%	0%	0%	0%	0.6	0.7
7	Ronga Road to Tennyson Inlet Road/ T	Opouri Road	19	10	29	2%	0%	0%	15%	38%	0%	35%	0%	0%	0.8	1.4
8	Opouri Road/ Tollgate Bridge to Dunca	Tennyson Inlet Road	21	0	21	0%	5%	28%	46%	22%	0%	1%	1%	1%	2.1	1.2
QUEEN CHARLOTTE DRIVE																
1	Havelock to Linkwater	Mahakipawa Hill	13	2	15	11%	0%	48%	16%	40%	0%	8%	10%	19%	1.5	1.7
2	Linkwater to Picton	Queen Charlotte Drive	21	0	21	0%	10%	62%	3%	35%	0%	6%	3%	5%	0.8	2.2
KENEPERU AREA																
3	Linkwater to Moetapu turnoff	Kenepuru Road (Linkwater-Hea	5	0	5	14%	0%	66%	3%	25%	0%	0%	0%	0%	1.3	2.9
4	Moetapu turnoff to Mahau turnoff	Kenepuru Road (Linkwater-Hea	8	4	12	29%	0%	70%	15%	5%	0%	0%	1%	10%	2.5	1.3
5	Mahau turnoff to Portage	Kenepuru Road (Linkwater-Hea	17	2	19	52%	0%	74%	24%	4%	0%	0%	0%	4%	2.1	1.9
6	Portage to Kenepuru Heads	Kenepuru Road (Linkwater-Hea	16	0	16	54%	1%	64%	22%	11%	0%	7%	2%	9%	2.2	2.1
7	Kenepuru Heads to Waitaria Bay	Kenepuru Road (Heads-Raetihi	14	0	14	17%	0%	34%	42%	31%	0%	0%	9%	50%	1.8	2.6
8	Waitaria Bay to road ends	Kenepuru Road (Heads-Raetihi	5	24	29	14%	0%	23%	47%	36%	0%	0%	18%	31%	1.1	1.7
9	Waitaria Bay to Clova Bay	Manaroa Road	2	14	15	5%	2%	17%	35%	62%	0%	2%	6%	15%	2.1	1.9
10	Kenepuru Heads to Titirangi	Titirangi Road	1	37	38	18%	0%	10%	47%	21%	0%	9%	1%	3%	2.2	1.5
11	Moetapu	Moetapu Bay Road	7	1	8	60%	12%	71%	29%	0%	0%	0%	0%	1%	3.7	2.0
12	Anikiwa	Anakiwa Road	5	0	6	4%	5%	30%	7%	73%	0%	5%	26%	44%	0.7	2.6
PERLOROUS AREA																
1	Daltons Road to Kaiuma Bay/Te Hoiere	Kaiuma Bay Road	3	9	11	0%	0%	43%	6%	68%	0%	45%	8%	12%	1.4	1.7
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma	Kaiuma Bay Road	3	17	20	7%	0%	28%	25%	38%	0%	4%	4%	31%	3.4	1.0
PORT UNDERWOOD AREA																
1	Waikawa to Hakahaka Bay	Port Underwood Road	15	0	15	0%	0%	85%	12%	3%	1%	1%	1%	0%	1.6	1.6
2	Hakahaka Bay to Rarangi	Port Underwood Road	9	18	27	0%	0%	60%	27%	14%	0%	3%	3%	11%	0.6	1.8
3	Hakahaka Bay to Fighting Bay entrance	Tumbledown Bay Road	4	9	13	0%	0%	62%	18%	22%	0%	1%	6%	11%	1.0	2.0
4	Fighting Bay to road end	Tumbledown Bay Road	0	4	4	0%	0%	71%	15%	20%	0%	0%	4%	10%	3.0	1.7
TOTAL PROJECT AREA			241	249	491											
		Colour scales:	0	20	60			0%	20%						0.0	4.0

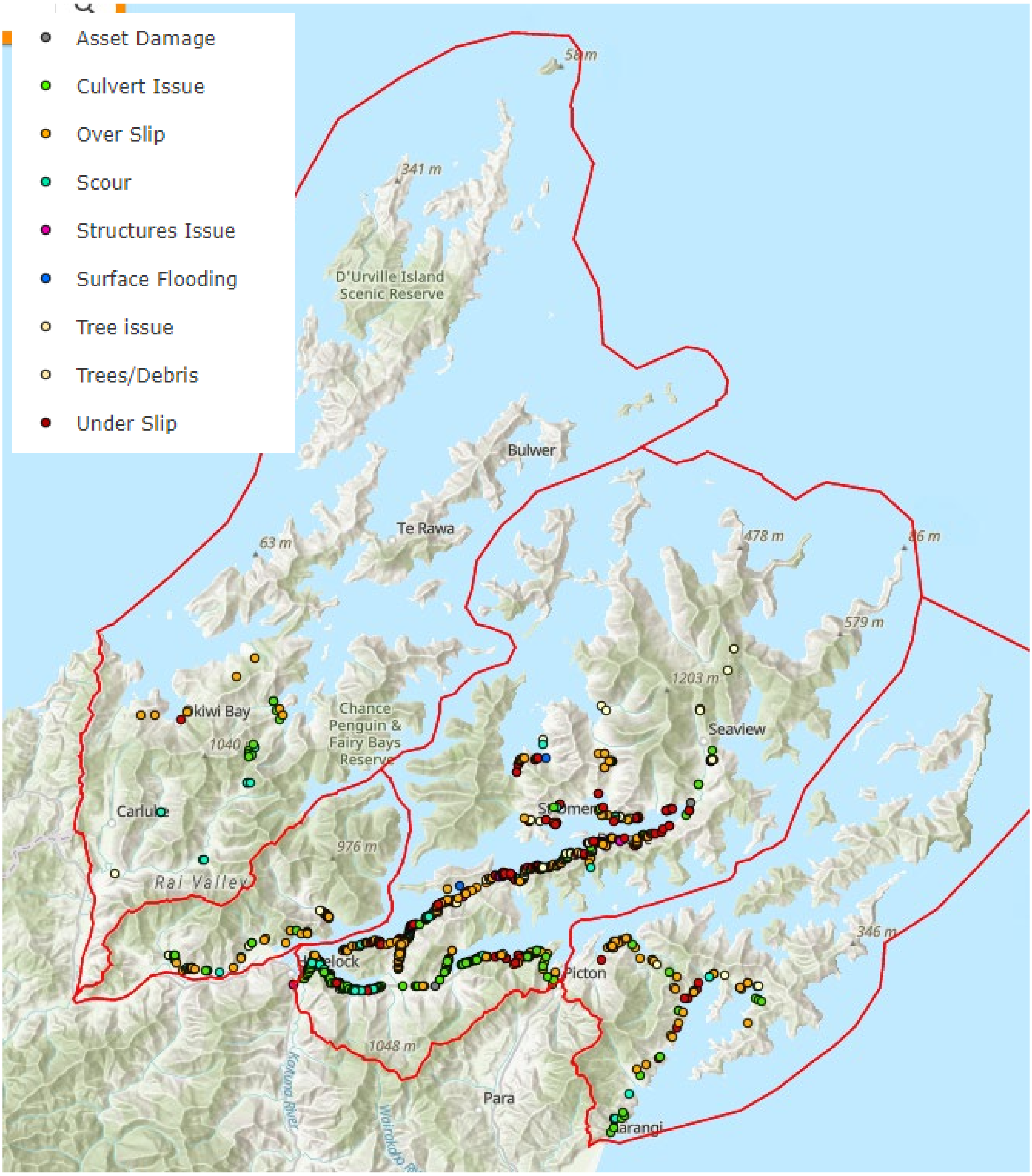
Segment #	Segment Name	2021 Storm Event - Faults Database: # Total	# per Sub Classification (only relevant listed): Culvert Issue	Over slip	Surface Flooding	Scour	Underslip	2022 Storm Event - Faults Database: # Total	# per Sub Classification (only relevant listed): Culverts	Over slip	Surface Flooding	Scour	Underslip
FRENCH PASS AREA													
1	SH6 to Okiwi Bay	2	0	2	0	0	0	139	44	22	18	20	23
2	Okiwi Bay to Elaine Bay	4	0	3	0	0	1	83	21	29	2	8	18
3	Elaine Bay turnoff to Port Ligar turnoff	0	0	0	0	0	0	38	9	9	0	4	12
4	Port Ligar turnoff to French Pass	0	0	0	0	0	0	62	13	32	0	2	9
5	Port Ligar turnoff to Bulwer Bay	0	0	0	0	0	0	153	28	78	0	13	28
6	Rangitoto ki te Tonga / D'Urville Island	0	0	0	0	0	0	3	0	2	0	0	1
7	Ronga Road to Tennyson Inlet Road/ T	5	1	0	0	3	0	67	16	13	14	15	4
8	Opouri Road/ Tollgate Bridge to Dunca	15	9	2	0	4	0	76	36	13	0	12	12
QUEEN CHARLOTTE DRIVE													
1	Havelock to Linkwater	147	49	49	0	18	25	96	34	28	0	6	14
2	Linkwater to Picton	84	19	42	1	3	15	200	10	124	0	2	53
KENEPERU AREA													
3	Linkwater to Moetapu turnoff	53	7	36	0	5	3	37	8	17	0	8	2
4	Moetapu turnoff to Mahau turnoff	117	7	59	2	7	26	172	47	65	0	20	33
5	Mahau turnoff to Portage	141	10	51	0	7	39	419	84	142	0	49	113
6	Portage to Kenepuru Heads	71	5	24	0	3	29	279	45	106	0	17	95
7	Kenepuru Heads to Waitaria Bay	37	1	16	0	1	10	79	15	21	0	12	29
8	Waitaria Bay to road ends	39	2	15	1	3	13	152	39	51	0	25	36
9	Waitaria Bay to Clova Bay	16	2	5	0	1	3	40	13	14	0	12	1
10	Kenepuru Heads to Titirangi	14	2	4	0	1	2	91	47	19	0	11	6
11	Moetapu	36	4	20	0	1	11	67	7	29	0	13	16
12	Anikiwa	19	6	8	0	0	4	27	10	7	0	1	4
PERLOROUS AREA													
1	Daltons Road to Kaiuma Bay/Te Hoiere	33	8	15	0	7	0	34	8	15	0	7	0
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma	30	3	20	0	3	2	71	16	46	0	4	2
PORT UNDERWOOD AREA													
1	Waikawa to Hakahaka Bay	30	3	25	0	0	0	151	34	86	0	10	9
2	Hakahaka Bay to Rarangi	21	10	6	0	2	3	199	23	114	0	19	21
3	Hakahaka Bay to Fighting Bay entrance	20	0	11	0	2	4	132	4	83	0	4	17
4	Fighting Bay to road end	4	3	1	0	0	0	19	1	13	0	0	4
	Colour scales:				0	40	400						

Segment #	Segment Name	Weighted Susceptibility Score: Natural Slope Stability	Human Induced Slope Stability	Liquefaction	Flood inundation	Coastal	Tsunami	Debris Flow
FRENCH PASS AREA								
1	SH6 to Okiwi Bay	0.2	1.4	0.3	0.3	0.1	0.0	0.8
2	Okiwi Bay to Elaine Bay	0.6	2.6	0.0	0.0	0.0	0.0	0.7
3	Elaine Bay turnoff to Port Ligar turnoff	0.0	2.3	0.0	0.0	0.0	0.0	0.4
4	Port Ligar turnoff to French Pass	1.4	1.1	0.0	0.0	0.1	0.0	0.1
5	Port Ligar turnoff to Bulwer Bay	0.7	2.3	0.0	0.0	0.0	0.0	1.0
6	Rangitoto ki te Tonga / D'Urville Island	0.1	2.9	0.0	0.0	0.0	0.0	0.3
7	Ronga Road to Tennyson Inlet Road/ T	0.2	0.4	0.6	0.9	0.0	0.0	0.5
8	Opouri Road/ Tollgate Bridge to Dunca	0.2	2.0	0.3	0.0	0.0	0.0	0.9
QUEEN CHARLOTTE DRIVE								
1	Havelock to Linkwater	0.8	1.4	0.6	0.2	0.4	0.1	0.8
2	Linkwater to Picton	0.4	1.3	0.5	0.1	0.1	0.0	0.7
KENEPERU AREA								
3	Linkwater to Moetapu turnoff	1.1	1.4	0.4	0.0	0.0	0.0	1.0
4	Moetapu turnoff to Mahau turnoff	2.2	1.9	0.1	0.0	0.0	0.1	1.0
5	Mahau turnoff to Portage	3.9	2.2	0.1	0.0	0.0	0.0	1.0
6	Portage to Kenepuru Heads	4.1	2.0	0.2	0.2	0.1	0.0	1.1
7	Kenepuru Heads to Waitaria Bay	1.3	1.9	0.5	0.0	0.3	0.2	1.0
8	Waitaria Bay to road ends	1.0	1.9	0.5	0.0	0.7	0.2	0.7
9	Waitaria Bay to Clova Bay	0.4	1.4	0.9	0.1	0.2	0.1	1.0
10	Kenepuru Heads to Titirangi	1.3	1.6	0.3	0.2	0.0	0.0	1.0
11	Moetapu	5.0	2.3	0.0	0.0	0.0	0.0	1.5
12	Anikiwa	0.5	0.8	1.1	0.1	1.1	0.2	0.7
PERLOROUS AREA								
1	Daltons Road to Kaiuma Bay/Te Hoiere	0.0	1.0	1.0	1.1	0.3	0.1	0.8
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma	0.6	1.3	0.6	0.1	0.1	0.2	1.2
PORT UNDERWOOD AREA								
1	Waikawa to Hakahaka Bay	0.0	2.1	0.0	0.1	0.0	0.0	0.8
2	Hakahaka Bay to Rarangi	0.0	2.0	0.2	0.1	0.1	0.1	0.5
3	Hakahaka Bay to Fighting Bay entrance	0.0	1.8	0.3	0.0	0.3	0.1	0.7
4	Fighting Bay to road end	0.0	1.9	0.3	0.0	0.1	0.0	1.2
	Colour scales:		0.0	1.0	5.0			

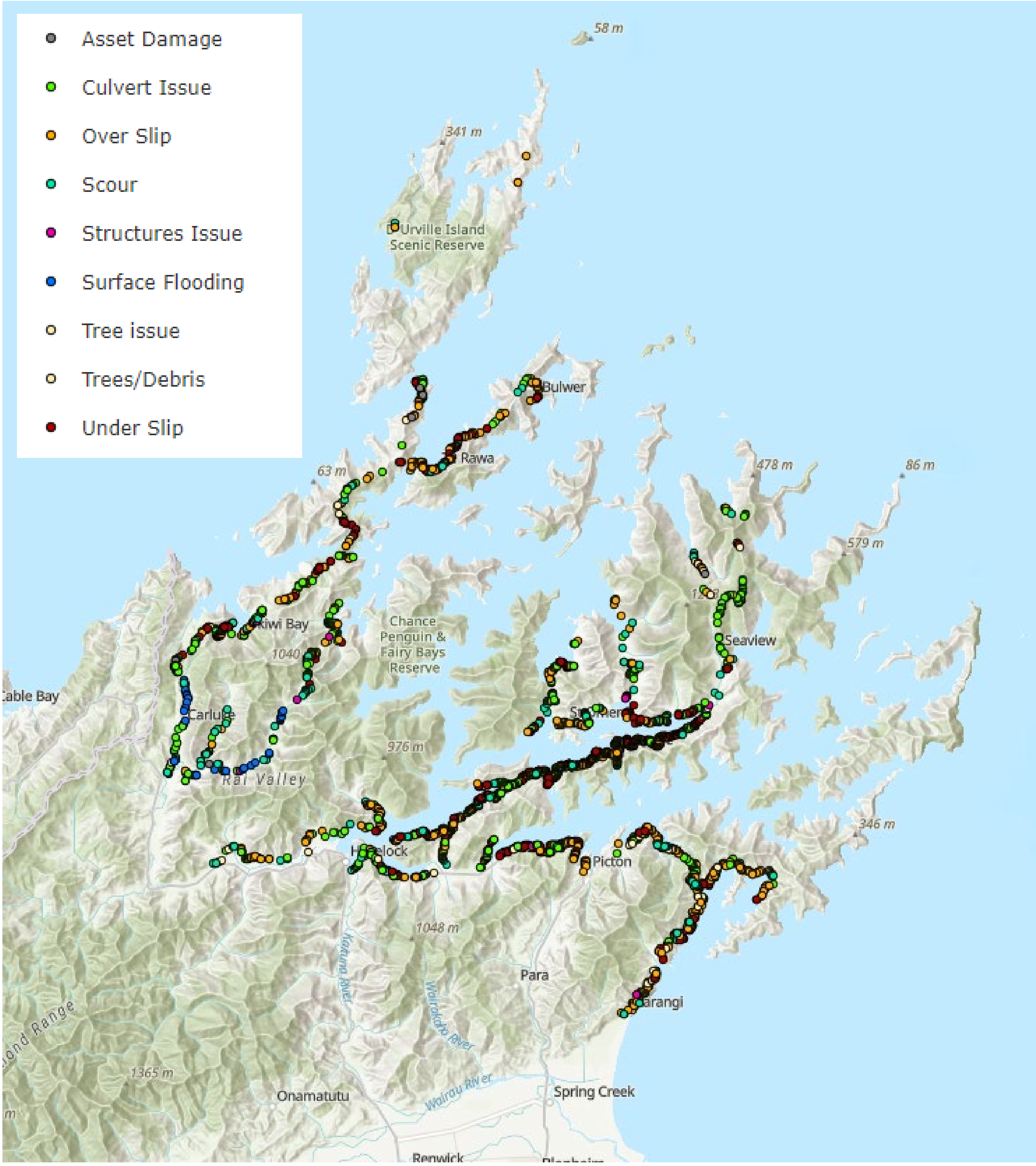
1/05/2023

Appendix E Road Network Fault Figures

E.1 2021 Storm Event – Road Network Fault Map



E.2 2022 Storm Event – Road Network Fault Map



E.3 2021 and 2022 Fault Database Summary

			Surfacing			2021 Storm Event - Faults Database						2022 Storm Event - Faults Database					
Segment #	Segment Name	Road Name	Sealed	Unsealed	Total Distance	# Total	# per Sub Classification (only relevant listed)					# Total	# per Sub Classification (only relevant listed)				
			(km)	(km)	(km)		Culvert Issue	Over slip	Surface Flooding	Scour	Underslip		Culverts	Over slip	Surface Flooding	Scour	Underslip
FRENCH PASS AREA																	
1	SH6 to Okiwi Bay	Ronga And Croilles	25	1	26	2	0	2	0	0	0	139	44	22	18	20	23
2	Okiwi Bay to Elaine Bay	Croisilles-French Pass Road	17	0	17	4	0	3	0	0	1	83	21	29	2	8	18
3	Elaine Bay turnoff to Port Ligar turnoff	Croisilles-French Pass Road	7	6	13	0	0	0	0	0	0	38	9	9	0	4	12
4	Port Ligar turnoff to French Pass	Croisilles-French Pass Road	3	8	11	0	0	0	0	0	0	62	13	32	0	2	9
5	Port Ligar turnoff to Bulwer Bay	Te Towaka-Port Ligar Road2	1	29	30	0	0	0	0	0	0	153	28	78	0	13	28
6	Rangitoto ki te Tonga / D'Urville Island	Not Summarised	0	57	57	0	0	0	0	0	0	3	0	2	0	0	1
7	Ronga Road to Tennyson Inlet Road/ Toll	Opouri Road	19	10	29	5	1	0	0	3	0	67	16	13	14	15	4
8	Opouri Road/ Tollgate Bridge to Duncan	Tennyson Inlet Road	21	0	21	15	9	2	0	4	0	76	36	13	0	12	12
QUEEN CHARLOTTE DRIVE																	
1	Havelock to Linkwater	Mahakipawa Hill	13	2	15	147	49	49	0	18	25	96	34	28	0	6	14
2	Linkwater to Picton	Queen Charlotte Drive	21	0	21	84	19	42	1	3	15	200	10	124	0	2	53
KENEPERU AREA																	
3	Linkwater to Moetapu turnoff	Kenepuru Road (Linkwater-Head	5	0	5	53	7	36	0	5	3	37	8	17	0	8	2
4	Moetapu turnoff to Mahau turnoff	Kenepuru Road (Linkwater-Head	8	4	12	117	7	59	2	7	26	172	47	65	0	20	33
5	Mahau turnoff to Portage	Kenepuru Road (Linkwater-Head	17	2	19	141	10	51	0	7	39	419	84	142	0	49	113
6	Portage to Kenepuru Heads	Kenepuru Road (Linkwater-Head	16	0	16	71	5	24	0	3	29	279	45	106	0	17	95
7	Kenepuru Heads to Waitaria Bay	Kenepuru Road (Heads-Raetihi)	14	0	14	37	1	16	0	1	10	79	15	21	0	12	29
8	Waitaria Bay to road ends	Kenepuru Road (Heads-Raetihi)	5	24	29	39	2	15	1	3	13	152	39	51	0	25	36
9	Waitaria Bay to Clova Bay	Manaroa Road	2	14	15	16	2	5	0	1	3	40	13	14	0	12	1
10	Kenepuru Heads to Titirangi	Titirangi Road	1	37	38	14	2	4	0	1	2	91	47	19	0	11	6
11	Moetapu	Moetapu Bay Road	7	1	8	36	4	20	0	1	11	67	7	29	0	13	16
12	Anikiwa	Anakiwa Road	5	0	6	19	6	8	0	0	4	27	10	7	0	1	4
PERLOROUS AREA																	
1	Daltons Road to Kaiuma Bay/Te Hoiere R	Kaiuma Bay Road	3	9	11	33	8	15	0	7	0	34	8	15	0	7	0
2	Kaiuma Bay/ Te Hoiere Road to Kaiuma B	Kaiuma Bay Road	3	17	20	30	3	20	0	3	2	71	16	46	0	4	2
PORT UNDERWOOD AREA																	
1	Waikawa to Hakahaka Bay	Port Underwood Road	15	0	15	30	3	25	0	0	0	151	34	86	0	10	9
2	Hakahaka Bay to Rarangi	Port Underwood Road	9	18	27	21	10	6	0	2	3	199	23	114	0	19	21
3	Hakahaka Bay to Fighting Bay entrance	Tumbledown Bay Road	4	9	13	20	0	11	0	2	4	132	4	83	0	4	17
4	Fighting Bay to road end	Tumbledown Bay Road	0	4	4	4	3	1	0	0	0	19	1	13	0	0	4
TOTAL PROJECT AREA			241	249	491												
		Colour scales:	0	20	60				0	40	400						

E.4 2016 MDC Figure generated by MDC from David Miller Documentation

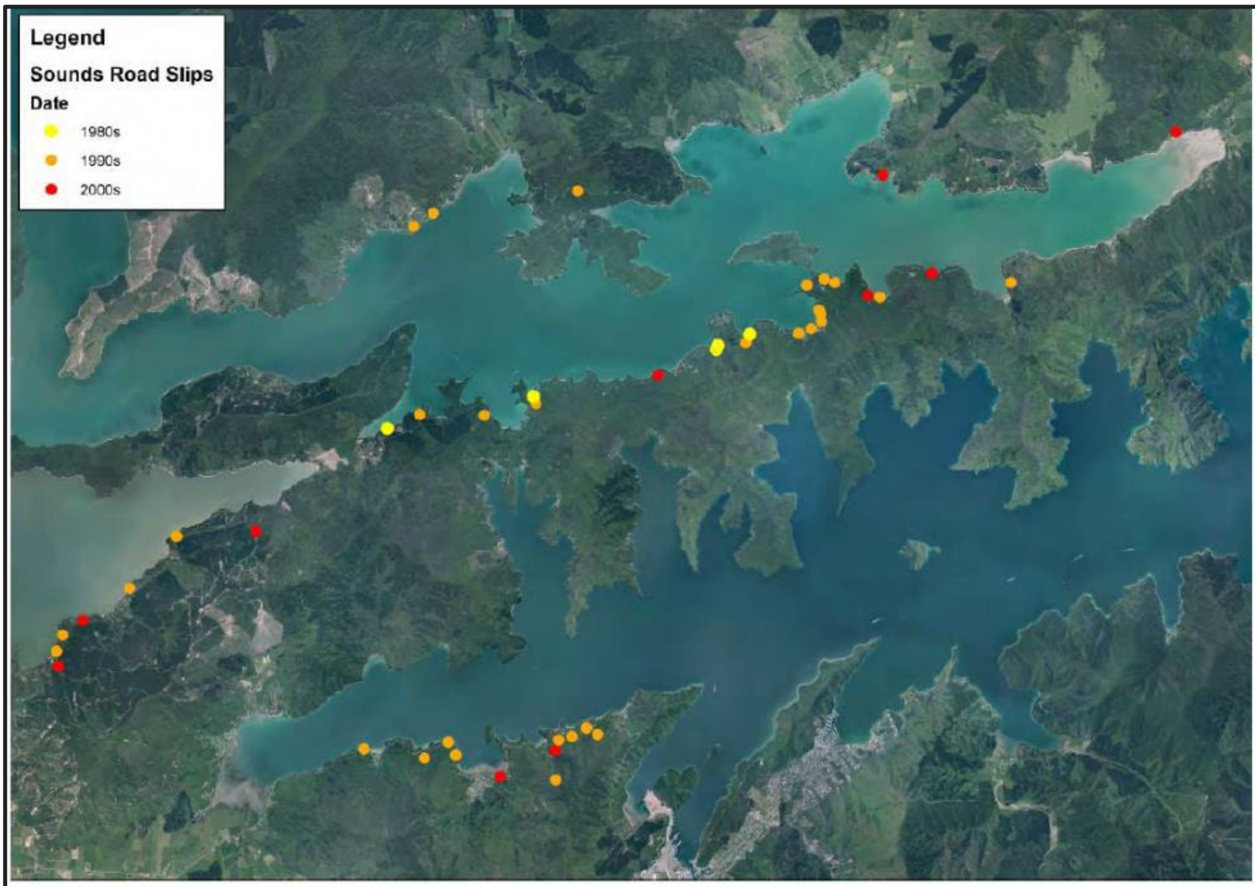


Figure 1: Slips that entered coastal waters associated with the transport road network on Queen Charlotte Drive (bottom centre – 12 dots) and the Kenepuru Road. Source Miller 2015.

FIGURE D4.1: Figure 1 generated by MDC from David Miller Documentation

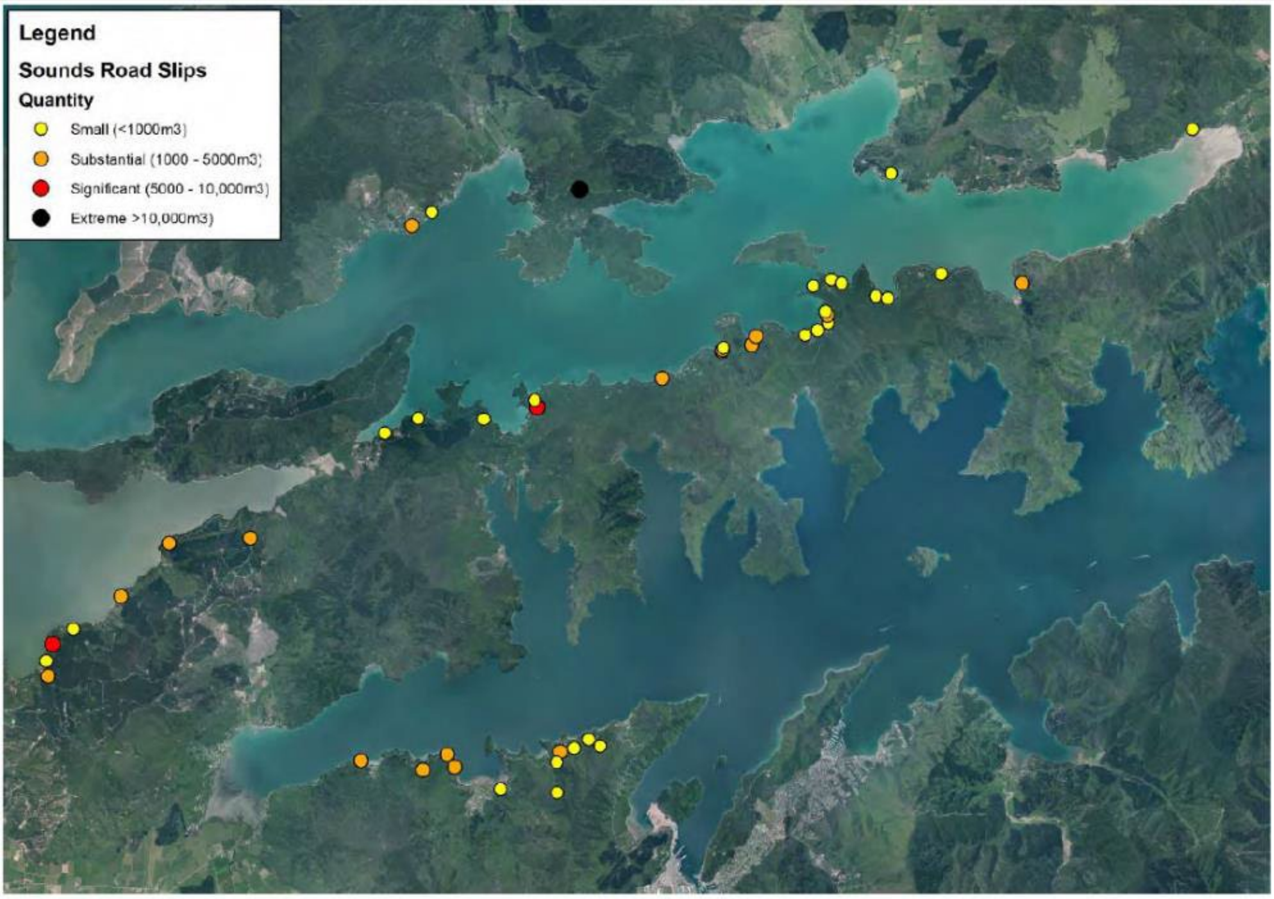


Figure 2: Estimated volume of slip material associated with the slips identifed in Figure 1. Source: Miller 2015

FIGURE D4.2: Figure 2 generated by MDC from David Miller Documentation

DESIGN WITH COMMUNITY IN MIND

Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of place and of belonging. That's why at Stantec, we always design with community in mind.

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Level 1, 66 Oxford Street, Richmond, Nelson 7020
PO Box 13052, Armagh, Christchurch 8141
Tel 3 546 8728 | www.stantec.com