Gisborne District Council

WAIHAU ROAD

POST-SLIP RISK ASSESSMENT

7 DECEMBER 2023

CONFIDENTIAL

wsp

WAIHAU ROAD
POST-SLIP RISK ASSESSMENT

Gisborne District Council

WSP
Gisborne
Hardy Lane
PO Box 49, Gisborne 4040
New Zealand
+64 6 868 5199
wsp.com/nz

REV	DATE	DETAILS
1	28.11.2023	FINAL
2	07.12.2023	UPDATED TARP FOLLOWING CLIENT COMMENTS (APPENDIX C)

	NAME	DATE	SIGNATURE
Prepared by:	Maddison Phillips	07.12.2023	
Reviewed by:	Rob Bond	07.12.2023	
Approved by:	Pete Sims	07.12.2023	

WSP
Gisborne
Hardy Lane
PO Box 49, Gisborne 4040
New Zealand
+64 6 868 5199
wsp.com/nz

TABLE OF CONTENTS

1 INTRODUCTION

1.1 PROJECT BACKGROUND

A significant landslide (slip) occurred on Waihau Road, Waihau Bay, Gisborne following an extended period of heavy rainfall in June 2023. The Pouawa Rural Fire Rain Gauge[1] recorded up to 366.6mm of rainfall during the fortnight prior to the landslide occurring.

Consulting company LDE completed an initial inspection of the site[2] shortly after it was first observed and described a 5m wide dropout which had resulted in loss of the road surface and cut off vehicle access. LDE completed a second inspection in July 2023 and captured UAV aerial imagery of the site to further inform their assessment of the site and inform remedial recommendations.

Contracting company Downer has recently completed remedial works at the dropout and the road is now passable by vehicles but remains restricted to residents only.

WSP understands that Gisborne District Council (GDC) is considering opening the road to public vehicles again but would first like to better understand the residual risks posed to the travelling public associated with land movement at the site.

1.2 SCOPE OF WORK

WSP has been engaged by GDC to:

- Complete a site inspection of the section of Waihau Road affected by the June 2023 slip;
- Review slip remediation information provided by Downer and consider information contained in LDE's Memorandum dated 27.07.2023;
- Complete a high-level risk assessment for the slip site, taking into account the risk posed to road users at other areas along Waihau Road;
- Provide recommendations for any further works, monitoring and/or emergency planning for GDC to consider in the context of reinstating public vehicle access to Waihau Road.

[1] Harvest.com, Rural Fire Pouawa - POA [accessed 24.11.2023]

[2] LDE, Memorandum, Waihau Road RP 4.8, 27.07.2023, ref:24813

2 SITE DESCRIPTION

2.1 SITE LOCATION

Waihau Road is a single lane, mostly unsealed road that connects State Highway (SH) 35 to a small beachside settlement at Waihau Bay (also known as Loisel's). Waihau Bay is approximately 33km northeast of the Gisborne CBD. A site location plan is included as Figure 1.

The section of the road affected by the June 2023 slip is approximately 4.8km from the intersection with SH35. Waihau Road is the only land access for properties located at Waihau Bay and is also an important link for a community camping area during the summer months as well as stock trucks. Average Daily Traffic (ADT) for Waihau Road is estimated to be 75 according to Mobile Roads[3].

The road is cut along the top of a series of steep sea cliffs formed of Tolaga Group sandstone and mudstone. Numerous dropouts have occurred below the road (prior to the current dropout) and the average carriageway width is 4.0m – although much narrower in places. The cliffs of mudstone and banded sandstone typically stand at 70° or steeper. Photo 1 is included below to show the general context of the road environment, this photo was taken within a section of road that was not affected by the June 2023 slip.

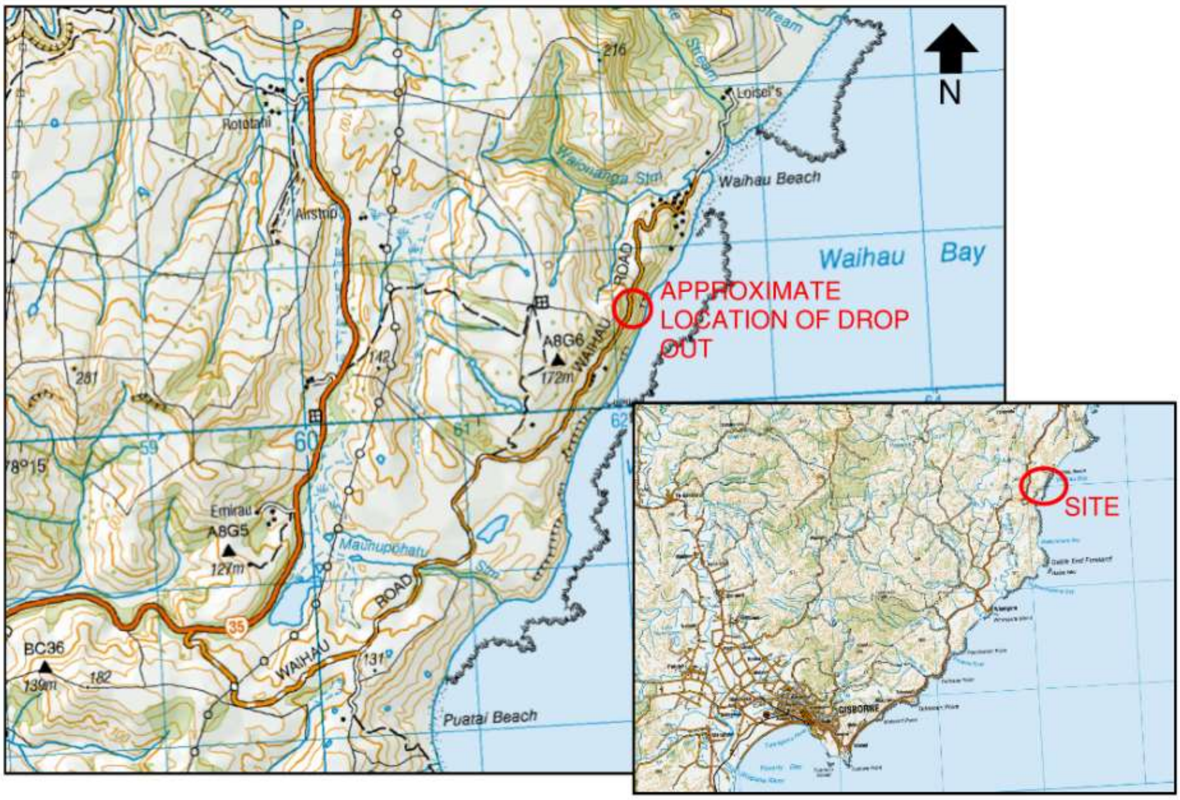

Figure 1: Site location plan (base map from NZ Topo Map)

[3] Mobile Roads website, https://mobileroad.org/desktop.html, accessed 24.11.2023

Photo 1: Typical cross section of Waihau Road

2.2 SUMMARY OF DAMAGE

LDE's Memorandum provides a comprehensive summary of the damage that was sustained as a result of the June 2023 rainfall event and should be referred to for a complete description. A summary is included below for ease of reference:

- A dropout, approximately 5m wide, occurred within the roadway and impacted the entire formed road width, refer Photo 3. A debris flow occurred from the slope directly above the dropout.
- The dropout is interpreted as being the northern most extent of a much larger landslide in the order of 110m wide. The landslide feature was identified by LDE during their initial inspection and later confirmed with aerial imagery, refer Photo 2.
- Cracking at several other locations along Waihau road within the landslide extent also occurred.
- A large wedge failure occurred within the bluffs beneath the road. Additionally, several cracks, defects and rock features were identified by LDE within the slopes and sandstone bluffs above the roadway.

Photo 2: Aerial imagery captured by LDE in July 2023, with extent of larger landslide shown

Photo 3: Photo taken by LDE showing the dropout at Waihau Road (temporary foot access created by locals)

3 SITE INSPECTION

WSP completed a site inspection on 15 November 2023 with representatives from Downer and DS Project Solutions. The purpose of the site inspection was to observe the current state of the road and to gain a better understanding of the remedial work that has been completed since June 2023. Observations made during the site inspection were used to inform a high-level risk assessment for the potential re-opening of the road to the public.

3.1 SUMMARY OF REMEDIAL WORKS COMPLETED

Downer was engaged by GDC to repair the dropout and reinstate road access to a condition similar to pre-June 2023.

During the site inspection, WSP confirmed the following work to have been completed:

- Bulk earthworks were completed to widen the existing road to the west, by cutting into the steep upslope. Cut slopes (within extremely weathered sandstone and mudstone) are standing steeply at approximately 70° or steeper in some places. Bare slopes were recently hydroseeded, with varying degrees of growth. Some shallow slope failures can be seen on the face of the cut slopes in places. The earthworks have resulted in the road retreating from the seaward cliffs between 1.5m and 2.0m within the extent of works.
- A large V-drain has been formed at the top of the main cut slope to direct water from the area affected by debris flow, into the newly formed drain beside the widened road.
- The dropout has been repaired with bulk earthworks and a cantilevered timber pole retaining wall has been constructed at the toe of the dropout. The retaining wall is approximately 12m long and consists of 250mm dia. SED timber poles embedded in concrete footings. Two subsoil drain outlets can be seen at the toe of the retaining wall. The retaining wall has not been engineered.
- The culvert which was previously discharging directly onto the dropout has been blocked-off/de-commissioned.
- The road has been re-shaped and levelled to move the low point in the road to the south, away from the dropout. A new 375mm dia. corrugated pipe culvert has been installed at the new low point, which directs stormwater from the newly formed roadside drain over the seaward cliffs. A long outlet flume, formed with corrugated pipe, has been installed on the end of the culvert.
- A long timber sight rail has been installed the length of the work extent on the seaward side.

A collection of photos taken during the site visit are included as Appendix A.

3.2 SITE INSPECTION CONCLUSIONS

The remedial works were completed approximately three weeks prior to WSP's site inspection and WSP was not involved during the construction phase of work. The remedial works appear to have been completed to a good standard and have successfully reinstated road access for residents.

The road itself is in a generally good condition through the repaired section and the minor road realignment/widening has resulted in road users being further from the seaward drop-off hazard when compared to pre-June conditions.

Cut slopes are steeper than would likely have been recommended if stability analysis had been completed, and therefore residual or existing Factors of Safety against global instability are likely to be less than 1.5 under static conditions. Shallow fretting of the cut slope will likely continue, as shown by the shallow failures observed on the cut slopes during the site inspection. Many of these shallow failures will be caught by the roadside drain. 'Shallow' in this instance is defined as a failure that only affects the near surface soils of the slope.

Drainage has been improved when compared to pre-June 2023 conditions but will need to be maintained to remain effective. Scour from the V-drain and fretting from the slopes will lead to blockage of the roadside drain and the new culvert if they are not maintained or periodically cleared.

A large debris flow and several small dropouts on the seaward side of the road were observed along Waihau Road outside the extent of recently completed remedial works. Many of the dropouts look to pre-date the June 2023 rainfall event.

The inspection was completed from the road only, and therefore inspection of the uphill slopes and rockfall risk areas identified by LDE was not possible. There was no evidence of recent rockfall or landslide activity on the roadway at the time of the site visit.

4 RISK ASSESSMENT

4.1 INTRODUCTION

Risk is a measure of the probability and severity of an adverse effect to health, property or the environment and can be calculated by multiplying the probability of occurrence by the consequences[4]. The process of defining and assessing rockfall and landslide risk can be complex, relies on consistent collection of historic data and almost without exception requires broad assumptions to be made. In cases where a full-scale risk assessment is not warranted or not possible, simplification to the process is generally accepted.

There are three distinct hazards that should be considered for this section of Waihau Road:

- Rockfall from the sandstone bluffs above the road;
- Landslide or debris flow mobilisation;
- Wedge failure of the sandstones and mudstones below the road.

All three hazards would require a trigger to occur. Earthquake induced shaking and persistent heavy rainfall are the two main triggers likely to instigate a failure at this site.

4.2 RISK ANALYSIS

4.2.1 ROCKFALL RISK – QUALITATIVE ANALYSIS

Waka Kotahi developed a Rockfall Hazard Rating Procedure[5] which is a qualitative assessment tool. The system allocates points to a rockfall hazard for items such as slope height, roadway width and block size. The site is then scored out of a total possible score of 891, the higher the score the greater the risk of rockfall. The method is generally used to rank rockfall sites in relation to others and prioritise funding. In this instance where the risk of rockfall is being assessed for a single site, Waka Kotahi provide commentary for score ranges which can be used to inform decisions about mitigation measures.

The following inputs have been assumed for the rockfall hazard rating:

- Nominal Average Daily Traffic (ADT) of 75 vehicle movements, also noting that traffic movements are generally greater in summer and much less in winter.
- Posted speed limit at rockfall hazard site of 100km/h.
- Sight distance is limited by the road geometry over the length of the rockfall hazard.
- There is no recorded history of rockfalls at the site.
- Primary mechanism for rockfall is differential erosion of the over steepened sandstone bluffs, more than 30m above the roadway.

---

[4] AGS, Australian Geomechanics Society Practice Note 2007, Landslide Risk Management

[5] Waka Kotahi, Rockfall Hazard Rating Procedure (previously SMO18 Appendix C), 11 October 2023, Version 1

The rockfall hazard rating has been determined as 285 out of a possible score of 891, the rating sheet is included in Appendix B for reference. The rating system describes sites with a score less than 275 as 'no action needed, continue to check' and a score less than 325 as 'should be inspected by an experienced geotechnical engineer'.

For context, on the State Highway network a score of 285 is unlikely to attract funding attention and monitoring would likely remain annual with special inspections following a large storm or earthquake event.

Rockfall risk from the sandstone bluffs above the section of road in question has been present for an extended period prior to June 2023.

Based on the limited assessment completed and the preliminary assessment of RHR for rockfall risk from above the road the site is not considered to be at a high or extreme risk of rockfall. The site warrants periodic inspection and monitoring post rainfall events.

No further action with respect to rockfall is currently considered necessary.

4.2.2 LANDSLIDE AND DEBRIS FLOW RISK – QUANTITATIVE ANALYSIS

The Australian Geomechanics Society guideline for Landslide Risk Management (AGS, 2007) includes several methods for quantitatively estimating the risk for loss of life from rockfall/landslide. The risk estimation process originally developed by Bunce et. al (1997)[6], and summarised by AGS, has been used to estimate the annual probability of a landslide or debris flow causing death.

The risk estimation relies on an assumption that both traffic and landslides are uniformly distributed in time and space and independent of one another. The calculation inputs include the annual probability of a landslide or debris flow impacting the road, the temporal spatial probability of a vehicle occupying a length of road and the vulnerability of a person within the vehicle. Records about landslides/debris flow events historically impacting the road are scarce, therefore some conservative assumptions have been made in relation to frequency of events.

The scenarios of a landslide/debris flow mobilising and hitting a moving vehicle, and a moving vehicle driving into a landslide/debris flow have been considered. The scenario of a landslide/debris flow hitting a stationary car has been ignored as there is no reason for a vehicle to be stopped or queuing beneath the hazard. Calculations are provided in Appendix C for reference.

Conventional risk analysis in New Zealand considers thresholds of risk to be based on unacceptable, As Low As Reasonably Practicable (ALARP), tolerable and acceptable levels.

For new road construction Waka Kotahi expects the residual risk (post risk mitigation) to be of the order of 1 x10^{-5} for State Highways. For existing roads where a hazard has been identified the risk should be mitigated or reduced to a level of at least 1 x 10^{-4} (ALARP) for State Highways.

Based on the limited inspection and data available for this site a preliminary risk assessment has been completed to ascertain the residual risk level and to aid in understanding the risks posed to road users.

The calculation completed has determined:

[6] Bunce et al., Assessment of the hazard from rock fall on a highway, Can. Geotech. J. 34: 344-356 (1997)

- The annual probability of any vehicle-landslide/debris flow interaction is estimated to be in the order of 4×10^{-4}, or a return period of 2,577 years.
- The annual probability of fatality caused by vehicle-landslide/debris flow interaction for a single trip on the road is estimated to be in the order of 6×10^{-9}, or a return period much greater than 10,000 years.

It is important to note that the quantitative analysis used to determine the probabilities listed above was completed with very limited information, generally based on observations from a single event in the history of the site. This is not considered best practice. Keeping accurate records of slope instability at this site is important so that risk-based decisions can be made going forward.

An acceptable level of risk will need to be established by GDC, however as noted above the generally accepted levels for existing State Highways post mitigation would be circa 1×10^{-4}. Risks of this order would be considered to have been mitigated to ALARP. This does, however, require a level of maintenance and management through periodic inspection and planned action should conditions change.

In addition to the risk to personal safety, it is also important to consider the risk to community access or resilience. If a landslide or debris flow event were to occur, it is likely that the road would be impassable, i.e. total loss of service. The ability to recover from the event or to reinstate the road should be considered and an appropriate level of preparedness be put in place.

4.2.3 WEDGE FAILURE BELOW THE ROAD – QUALITATIVE ANALYSIS

It is very difficult to determine whether the wedge type failure that occurred below the road in June 2023 was within the rock bluffs or caused by evacuation of the overlying colluvial soils. The wedge failure did not directly impact the road but given the general landform it is feasible that a similar failure could occur at any point along the seaward side of Waihau Road.

Moving the road away from the seaward bluffs has, in our opinion, slightly reduced the risk of future wedge failures impacting the road when compared to pre-June 2023 conditions.

Further rock mass analysis and structural geology mapping and assessment would be required to fully assess the implications of wedge failure and the potential impact on the road.

At this stage of the assessment the occurrence of wedge failures is not considered to be the primary form of failure or highest rated hazard at this site.

5 CONCLUSIONS AND RECOMMENDATIONS

The dropout that cut of Waihau Road in June 2023 was the direct result of a landslide and debris flow that occurred more than 30m above the roadway. The debris flow washed over the road and blocked the existing road drainage. As a result of the loss of drainage the road was washed out by the resultant flood and debris.

The landslide and debris flow occurred at the northernmost extent of what appears to be a larger landslide feature, previously identified by LDE.

In addition, a wedge type failure also occurred beneath the road towards the middle of the landslide feature, however this did not directly impact the roadway and would likely not have been identified if the northern dropout had not occurred.

The assessed trigger for the slope failures observed on Waihau Road was an extended period of heavy rainfall in June 2023. The event triggered the landslide which resulted in a debris flow blocking the drainage and washing out the road.

Post event remedial works have been completed to reinstate Waihau Road at the dropout site which included mass earthworks, reconstruction of the road away from the seaward bluffs and installation of new side drainage and a culvert.

High-level qualitative and quantitative risk analysis methods have been used to help assess the risk posed to road users associated with future landslide and debris flow events. The following bullet points summarise the findings from the risk analysis:

— Rockfall risk from the bluffs above the road has been scored 285 out of 891 based on Waka Kotahi's Rockfall Hazard Rating Procedure. A score of 285 warrants ongoing monitoring by a geotechnical engineer but no immediate actions or physical mitigation is generally required.

— The probability of a landslide or debris flow event interacting with any vehicle on the road is estimated to be in the order of 4×10^{-4} and the probability of a fatality caused by a landslide or debris flow event on a single trip is estimated to be in the order of 6×10^{-9}.

— The risk of wedge failure from beneath the road resulting in complete loss of access is no greater than pre-June 2023 conditions. The risk is likely to have slightly reduced at the site where the road has been realigned away from the seaward bluffs.

Based on national approaches to landslide and debris flow risk the calculated risk scores are considered to place the site within the ALARP category. The observations made on site regarding the works completed and the calculated assessment of residual risk posed to road users would indicate that sufficient works have been completed to reduce the risk to an acceptable level. However, the site still requires a level of management and maintenance to be applied to ensure the risk does not increase.

On this basis WSP recommends the following:

— A Trigger Action Response Plan (TARP) is implemented for the site, so that clear and efficient decisions can be made about any future road closures. A TARP for the site has been prepared in collaboration with GDC and is included as Appendix C. This TARP is a live document and should be reviewed on a regular basis against observations made on site.

- A telemetric rain gauge should be installed on site to help inform the TARP. Rainfall location and intensity is known to vary significantly over the region and therefore making decisions about a specific site based on regional data should be avoided if possible. The TARP should be updated based on site observations linked to site rainfall measurements.
- A detailed site inspection is completed 6 monthly and should include the use of UAV imagery to identify any changes to the uphill and downhill slopes that are not readily visible from road level.
- 'No Stopping' signage could be installed at both ends of the landslide feature to discourage vehicles from parking within the hazard extend. It would also be reasonable to enforce 'no stopping' along the entire length of road that is exposed to the seaward bluffs.

6 LIMITATIONS

This report ('Report') has been prepared by WSP New Zealand Limited ('WSP') exclusively for Gisborne District Council ('Client') in relation to Waihau Road Slip ('Purpose') and in accordance with the Short Form Agreement with the Client dated 20.07.2023('Agreement') and the emailed scope of work dated 13.11.2023. The findings in this Report are based on and are subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any use or reliance on this Report, in whole or in part, for any purpose other than the Purpose or for any use or reliance on this Report by any third party.

In preparing this Report, WSP has relied upon data, surveys, analyses, designs, plans and/or other information ('Client Data') provided by or on behalf of the Client. Except as otherwise stated in this Report, WSP has not verified the accuracy or completeness of the Client Data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in this Report are based in whole or part on the Client Data, those conclusions are contingent upon the accuracy and completeness of the Client Data. WSP will not be liable for any incorrect conclusions or findings in the Report should any Client Data be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP.

Disclaimer

No warranty, undertaking or guarantee whether expressed or implied, is made with respect to the data reported or the Conclusions drawn. To the fullest extent permitted at law, WSP, its related bodies corporate and its officers, employees and agents assumes no liability and will not be liable to any third party for, or in relation to any losses, damages or expenses (including any indirect, consequential or punitive losses or damages or any amounts for loss of profit, loss of revenue, loss of opportunity to earn profit, loss of production, loss of contract, increased operational costs, loss of business opportunity, site depredation costs, business interruption or economic loss) of any kind whatsoever, suffered on incurred by a third party.

APPENDIX A

SITE VISIT PHOTOS – 15 NOVEMBER 2023

Photo 1: Debris flow hazard, outside extent of works, unrelated to landslide hazard discussed in this report. Typical of geotechnical hazards present along Waihau Road.

Photo 2: Road surface reinstated, minor excavation into landward slopes to form drainage channel

Photo 3: Sight rail reinstated above historic slip site (outside landslide feature extent discussed in this report)

Photo 4: Road surface reinstated, road moved away from seaward cliffs, example of typical cut slope angles in the background recently hydroseeded.

Photo 5: Large V drain and cut slope constructed and hydroseeded, shallow slope failures evident on steep faces. Road is 1.5m to 2.0m away from seaward cliff crest.

Photo 6: New culvert outlet with rigid flume over cliff edge.

Photo 7: View south along extent of works

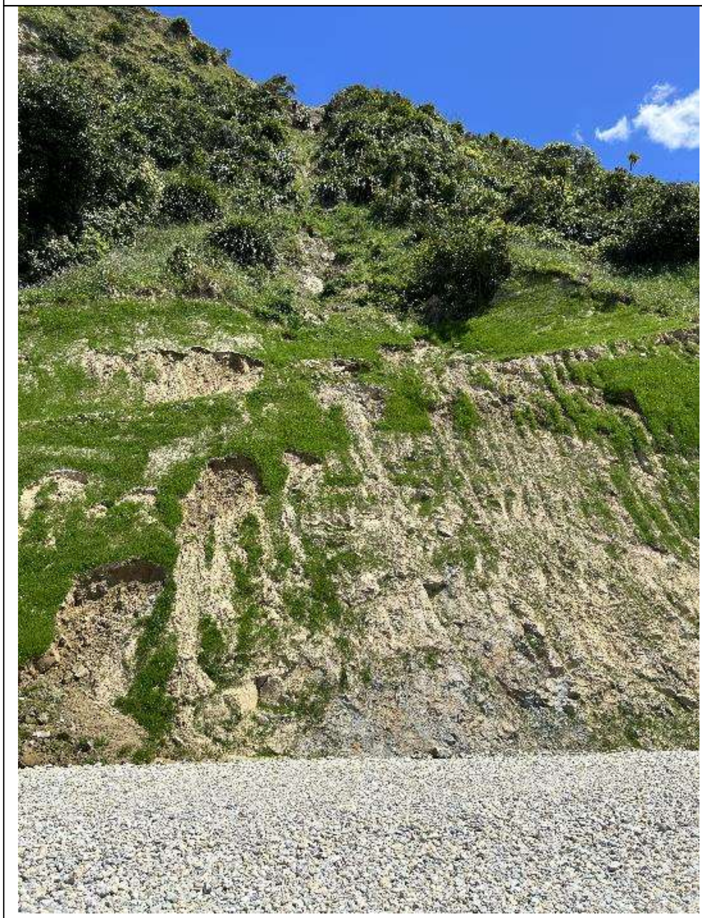

Photo 8: View towards source of debris flow, now directed by V-drain. Cut slope in extremely weathered sandstone/mudstone with surficial failures evident.

Photo 9: Road reinstated at drop out location, timber retaining wall at toe of reinstatement. Old culvert outlet visible in background, culvert is de-comissioned with no water outletting anymore.

Photo 10: Cut slopes within similar material standing steeply just north of the site

Photo 11: General road enviornment north of the extent of works, narrow road width with steep drop off to the coast below.

APPENDIX B

ROCKFALL RATING FIELDSHEET

Rockfall Hazard Rating Fieldsheet				
SH: WAIHAU ROAD	RP: APPROX. 4.7 - 5.7	Area: WAIHAU BAY	RHS/LHS	Length ~300m
Category	Rating Criteria and Score			
	Points 3	Points 9	Points 27	Points 81
Slope Height	7.6m	15.2m	22.9m	30.5m
Ditch effectiveness	Good catchment: all or nearly all of falling rocks are retained in the catch ditch	Moderate catchment: falling blocks occasionally reach the roadway	Limited catchment: falling rocks frequently reach the roadway	No catchment: no ditch or ditch totally ineffective
Average vehicle risk	25%	50%	75%	100%
% of decision sight distance	Adequate sight distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited sight distance, 60% of low design value	Very limited sight distance, 40% of low design value
Roadway width including paved shoulders	13.4m	11.0 m	8.5m	6.1m
Geological Character – Case 1	CASE 1: for slopes where discontinuities are the dominant structural feature			
Case 1 – Structural condition	Discontinuous joints, favourable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints (joint persistency >3m), adverse orientation
Case 1 – Rock Friction	Rough, irregular	Undulating	Planar	Clay infilling, slickensided or low friction mineral coating
Geological Character – Case 2	CASE 2: for slopes where differential erosion or over steepened slopes is the dominant condition that controls rockfall. Common slopes that are susceptible to this condition are: layered units containing easily weathered rock that erodes undermining more durable rock.			
Case 2 – Structural Condition	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
Case 2 – Difference in Erosion Rates	Small difference; erosion features develop over many years	Moderate difference; erosion features develop over a few years	Many erosion features; erosion features develop annually	Major erosion features; erosion features develop rapidly
Block size	300mm	600mm	900mm	1500 mm
Quantity of rockfall/event	1 m³	1.5 m³	2.5 m³	3.0 m³ or greater
Climate and presence of water on slope (adjusted for NZ conditions)	Low to moderate precipitation eg<450mm /year; no freezing, no water on slope	Moderate precipitation 450-2m/yr or short freezing (<1 week) periods or intermittent water on slope (seasonal or in response to rainfall)	High precipitation >2m/yr or long freezing periods (>1 week frozen) or continual water on slope	High precipitation >2m/year and long freezing periods or continual water on slope and long freezing periods (>1week frozen)
Rockfall history	Few falls; rockfall only occurs a few times a year or less	Occasional falls; rockfall can be expected several times a year	Many falls; frequent rockfalls during a certain season, e.g. winter freeze-thaw	Constant rockfalls; rockfalls occur frequently throughout the year
AAHT = AADT/Z4 =75/24 = 3.125	Posted Speed Limit (km/h) 100km/h	Measured Sight Distance m ~50m	Decision Sight Distance m 300m	Total Score **285**

Risk Analysis for Personal Safety (after Bunce et al. 1997)

Average frequency of landslides and debris flows is unknown, but certainly less frequent than one event impacting the road every 10 years.

$$R_f := \frac{1}{10} = 0.1$$

$$R := 1.0$$

Therefore, annual number of landslide or debris flow events for use in the risk analysis:

$$N_R := R_f \cdot R = 0.1$$

Case 1: Impact of landslide/debris flow onto a moving vehicle

Average annual daily traffic according to Mobile Roads (as at 26.11.2023) $AADT := 75$

Assumed average number of vehicles per day in summer $N_v := AADT \cdot 2 = 150$

Average length of vehicle using the road $L_v := 6.$

Posted speed limit $V_v := 100$

$$P_{SH} := \frac{\frac{N_v}{24} \cdot \frac{L_v}{1000}}{V_v} = 3.75 \cdot 10^{-4}$$

Probability that one or more vehicles are impacted by a landslide or debris flow event:

$$P_S := 1 - \left(1 - P_{SH}\right)^{N_R} = 3.751 \cdot 10^{-5}$$

Traffic is assumed to be uniformly distributed in time and space through out the year, therefore annual probability of an accident to one or more vehicles:

$$P_{TS} := 1$$

$$P_{A1} := P_{TS} \cdot P_S = 3.751 \cdot 10^{-5}$$

Probability of an accident on a single trip past the landslide/debris flow hazard (PA1/total trips per year):

$$PAV_1 := \frac{P_{A1}}{365 \cdot 100} = 1.028 \cdot 10^{-9}$$

Probability of fatality (assumed that if a vehicle is struck by a landslide there is no possibility of survival):

$$P_{LT} := 1.0$$

Probability of one or more death per year: $P_{D1} := P_{LT} \cdot P_{A1} = 3.751 \cdot 10^{-5}$

Probability of a death on an individual trip: $P_{DT1} := P_{LT} \cdot PAV_1 = 1.028 \cdot 10^{-9}$

Case 2: Impact of a moving vehicle into a landslide/debris flow event

Calculation of decision sight distance based on AASHTO

Assumed premaneuver time: $t := 3.0\ s$

Deceleration rate: $a := 3.4\ \frac{m}{s^2}$

Posted Speed: $V_{posted} := 100\ kph$

Decision sight distance of a vehicle travelling at 100km/h: $L_{dsd} := 0.278 \cdot V_{posted} \cdot t + \left(0.39 \cdot \frac{V_{posted}^2}{a}\right) = 112\ m$

$L_{dsd} := 112$

Assume, on average, a vehicle crash will occur if a landslide/debris flow occurs within half the sight distance: $P_{SH} := \frac{\frac{N_v}{24} \cdot \frac{L_{dsd}}{2000}}{V_v} = 4 \cdot 10^{-3}$

Probability that a landslide/debris flow event occurs and one or more vehicles are affected:

$P_S := 1 - \left(1 - P_{SH}\right)^{N_R} = 3.506 \cdot 10^{-4}$

Traffic is assumed to be uniformly distributed in time and space through out the year, therefore annual probability of an accident to one or more vehicles:

$P_{TS} := 1$

$P_{A2} := P_{TS} \cdot P_S = 3.506 \cdot 10^{-4}$

Probability of an accident on a single trip past the landslide/debris flow hazard (PA1/total trips per year):

$PAV_2 := \frac{P_{A2}}{365 \cdot 100} = 9.604 \cdot 10^{-9}$

Probability of fatality (assumed that 50% of vehicles will be able to maneauvre so that death does not occur):

$P_{LT} := 0.5$

Probability of one or more death per year: $P_{D2} := P_{LT} \cdot P_{A2} = 1.753 \cdot 10^{-4}$

Probability of a death on an individual trip: $P_{DT2} := P_{LT} \cdot PAV_2 = 4.802 \cdot 10^{-9}$

Summary

Sum of probabilities of a vehicle crash per year caused by landslide/debris flow event:

$$P_{Asum} := P_{A1} + P_{A2} = 3.881 \cdot 10^{-4}$$

$$ReturnPeriod := \frac{1}{P_{Asum}} = 2577 \quad years$$

Sum of probabilities of a vehicle crash caused by landslide/debris flow event on a single trip:

$$P_{AVsum} := PAV_1 + PAV_2 = 1.063 \cdot 10^{-8}$$

$$ReturnPeriod := \frac{1}{P_{AVsum}} = 94057910 \quad years$$

Sum of probabilities of one or more deaths caused by landslide/debris flow event per year (regular road user):

$$P_{Dsum} := P_{D1} + P_{D2} = 2.128 \cdot 10^{-4}$$

$$ReturnPeriod := \frac{1}{P_{Dsum}} = 4700 \quad years$$

Sum of probabilities of one or more deaths caused by landslide/debris flow event per year (one off user):

$$P_{DTsum} := P_{DT1} + P_{DT2} = 5.83 \cdot 10^{-9}$$

$$ReturnPeriod := \frac{1}{P_{DTsum}} = 171536609 \quad years$$

APPENDIX C

Te Kaunihera o Te Tairāwhiti GISBORNE DISTRICT COUNCIL

Waihau Road – Trigger Action Response Plan (TARP)

LAST UPDATE: 05.12.2023

	SITE CONDITIONS	BUSINESS AS USUAL	ORANGE ALERT	RED ALERT
TRIGGER*	RAINFALL	Rainfall less than 50mm in 24hr period	Rainfall between 50mm and 100mm in 24hr period And/or rainfall intensity is greater than 10mm per hour for more than 3 hours And/or NZ MetService issue Orange Severe Weather Warning	Rainfall over 100mm in 24hr period And/or greater than 300mm in any 7-day period And/or NZ MetService issue Red Severe Weather Warning
RESPONSE PLAN	ROAD ACCESS	No restrictions	Alert sent to residents and campground. Road remains open.	Evacuate Waihau Bay. Full road closure.
	ACTIONS	Not applicable	Maintenance contractor to check culvert and roadside drains are clear. Geotechnical Engineer advised. Instigate RED ALERT preparedness i.e. warn of potential evacuations if situation worsens. Closely monitor weather forecast.	Civil Defence advised. Maintenance contractor to install closure. Geotechnical Engineer advised.
	POST-EVENT ASSESSMENT AND RE-OPENING ROAD	Not Applicable	Not applicable	Once trigger conditions ease: 1. 12hr cool-down time, site is likely to be too high-risk for immediate inspection. 2. Geotechnical inspection, including UAV aerial imagery. 3. Geotechnical engineer to advise GDC if risk assessment has changed and advise on remediation plan (if required). 4. GDC to decide on road opening.
RESPONSIBILITY PLAN	MAINTENANCE CONTRACTOR	Routine inspections	Daily monitoring	Install road closure.
	GDC	BAU	Frequent (weekly / or as required) contact with the Maintenance Contractor and Geotechnical Engineer Sending alerts and media updates	Constant contact with Civil Defence, the Maintenance Contractor, and Geotechnical Engineer Notify Regional Management / National Management / Communications & Engagement Team Sending closure notice and media updates
	GEOTECHNICAL ENGINEER	Not applicable	Advise Maintenance Contractor and GDC on alert details. Weekly reporting (or as needed).	Complete inspections as required. Advise Maintenance Contractor and GDC on alert details. Daily reporting (or as needed).

Notes:
*Earthquake trigger is not specifically addressed under this TARP as trigger levels are yet to be defined. An inspection of the site should be completed following an earthquake that is observed to cause damage elsewhere in the region.