Waitākere Coastal Communities Landslide Risk Assessment

Piha and Karekare landslide hazards-overarching summary report

Auckland Council

10 January 2024

→ The Power of Commitment

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1. Introduction

1.1 Background

Two significant rainfall events affected the Waitākere area in late January and early February 2023, resulting from the impacts of ex-tropical cyclones Hale and Gabrielle, respectively.

Cyclone Gabrielle resulted in widespread catastrophic flooding and slope instability in the coastal settlements of Piha and Karekare where numerous landslides, debris avalanches and rockfalls occurred. In many cases these resulted in damage to buildings and infrastructure. Several other, smaller scale, landslide hazards were observed including:

– Shallow failures of road cuttings and embankments
– Rotational slumping
– Translational sliding
– Minor rockfalls
– Apparent reactivation of larger slow-moving landslips.

Following the event, a rapid building assessment of residential properties was undertaken in Piha and Karekare by Auckland Council (AC or Council), with some houses having access by owners restricted (a yellow placard – e.g., limited property access) and some for which no access was permitted (a red placard). It is understood that placards were assigned to properties where it was judged there was an immediate and significant risk to life.

AC subsequently requested GHD to undertake quantitative risk assessments of the Piha and Karekare residential areas to identify areas where there may be a risk to life in a similar future event on properties currently impacted or placarded from Cyclone Gabrielle.

1.2 Purpose of this report

The purpose of this report is to set out the basis for and approach that has determined which properties within the settlements of Piha and Karekare have received a site-specific Quantitative Landslide Risk Assessment (QRA) for loss of life risk. In addition, it provides a detailed overview of the setting in which the landslides occurred.

1.3 Scope

This report is focussed on the settled areas of Piha and Karekare.

The scope of work agreed by AC is as follows:-

– Provide general geo-characterisation of the Piha and Karekare areas.
– Provide characterisation of the landslides that occurred in Cyclone Gabrielle.
– Document the data utilised for risk assessment.
– Set out the GHD approach to adopted for QRA at each property group affected by landslide hazard (see Section 1.4).
– Discuss why the QRA process undertaken has been restricted to those properties that were impacted directly from landslides resulting from Cyclone Gabrielle, as opposed to assessing all properties within the Piha and Karekare settlement.
– Provide an umbrella report suitable for non-placarded properties.

Specifically excluded from the scope is an assessment of property risk, subsurface geotechnical investigations, service inspections, and groundwater monitoring.

The focus in this report is geotechnical only. There may be other non-geotechnical considerations that could affect the loss of life or property risk which are not included in GHD's scope, such as flood risk and structural damage to property.

Although considered unlikely, GHD reserves the right to amend the opinions, conclusions and recommendations provided within this report, should additional geotechnical information become available.

1.4 Our approach to Piha and Karekare

The landslides at Piha and Karekare are typically smaller in size compared to those observed elsewhere in the Waitākere Ranges. However, evidence suggests they still have the potential to generate considerable damage to dwellings and subsequently pose a risk to life for residents, partly due to the relatively steep topography and subsequent velocity at which they travel.

The approach of identifying landslide hazard over large and common source areas, such as that used at Muriwai, is not appropriate for most Piha and Karekare sites due to the smaller scale and distributed nature of the February 2023 landslides, which are contained within smaller catchments. For this reason, it has not been appropriate to develop a single QRA report for the Piha and Karekare built environment as undertaken for Muriwai.

For Piha and Karekare QRA reports have been developed for either an individual property or a group of properties with a common landslide hazard source from the Cyclone Gabrielle event. A list of properties or property groupings is presented in Appendix D. An individual property or group of properties is known as a “site” for the purposes of specific property-based discussion.

The primary criteria for the selection of properties to receive individual QRA assessments were the following:-

– Properties that were directly impacted by landslide hazard from Cyclone Gabrielle, and
– Properties where Council required a technical basis to assign property risk categorisation and building placard designation review.

The assessment that has been undertaken for each site included a combination of site observations and desktop review of available information. These results informed the QRA with regards to the presence of existing and historical landslide hazards, site-specific slope conditions, and any on-site stormwater and wastewater infrastructure. Description of the GHD QRA methodology is presented in Appendix E for information only.

We note that there are a small number of sites impacted by landslides from Cyclone Gabrielle which we consider atypical of the slips in Piha and Karekare. These are either located on preexisting slow-moving landslides which reactivated or resulted from scour associated with sand dune deposits.

It is acknowledged that there is evidence of larger historical landslides above or below the properties within some of the catchments (as is evidenced from surface geomorphology). Where relevant, these have also been identified through mapping and, in some cases, these have been considered in the QRA for that property/property group. Generally, there is no observed evidence of movement of these historical landslide features.

Auckland Council has commissioned a separate slope stability susceptibility report for the Auckland region. This report will identify regions of Auckland where slope angles, soil, rock and groundwater conditions may combine to have an adverse impact on slope stability.

2. Site setting

2.1 Location and topography

2.1.1 Introduction

Piha and Karekare are coastal settlements situated on the west coast of the Waitākere Ranges, bounded by the Tasman Sea to the west. The settlements are located approximately 20 km southwest of Henderson, Auckland, and approximately 10 km north of the Manukau Harbour inlet. Both Piha and Karekare can be accessed off SH 24 via Piha Road and Karekare Road respectively. The general location of the Piha and Karekare settlements is shown in Figure 2.1.

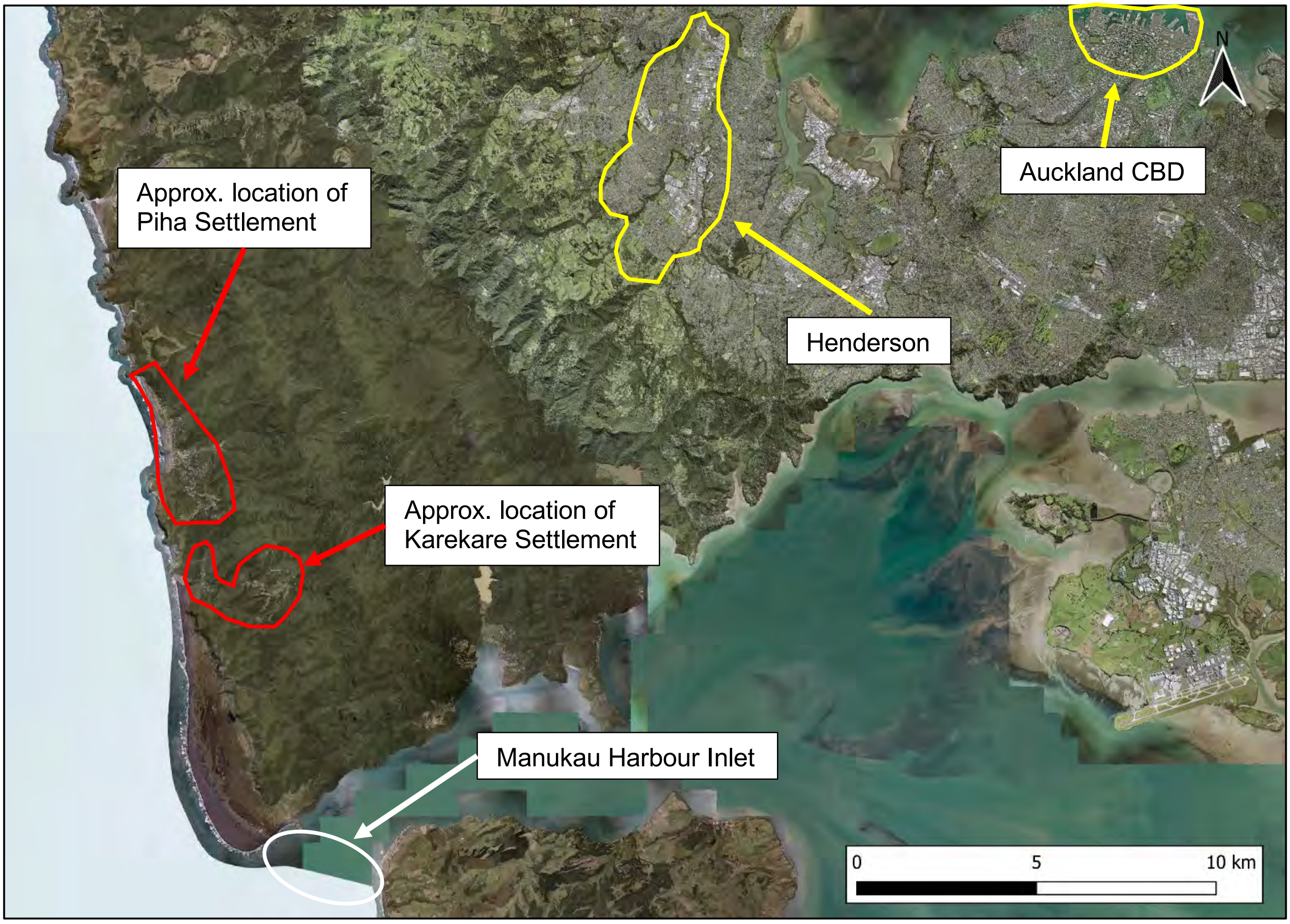


Figure 2.1: General Piha and Karekare settlement location (basemap: New Zealand Aerial Imagery, source: LINZ, date: 2016 - 2022).

2.1.2 Piha

The northern of the two settlements, Piha, is situated on the western sloping margin of the Waitākere Ranges. The settlement is bisected by the Piha Stream, which flows from east to west and divides the southern and central portions of the settlement. Two further streams, named the Melville and Marawhara Streams, are located in the northern portion of the settlement. They flow northeast to southwest and divide the northern and central portions of the settlement. All three streams discharge into the Tasman Sea.

The built environment occupies much of the coastal backshore and associated elevated sand dunes along the western extent of the settlement. The built environment also occupies much of the gently sloping, low lying stream flood plains in the central portion of the settlement, as well as the steep, undulating hill sides in the southern portion of the settlement. Elevation of the settlement ranges from 5 m RL to 280 m RL, with the majority of properties located on the hillside around the southern portion of the settlement. A plan of the Piha area is presented in Figure 2.2.

A belt of sand dunes in the central portion of the settlement trends north - south at an elevation of approximately 10 – 40 m RL. These sand dunes are well vegetated and well developed; they divide Marine Parade North in the west from Garden Road in the east. Garden Road follows a topographic low between the sand dunes to the west and the toe of a ridgeline to the east. The low-lying area acts as a confining basin with a pond (Claude Able Reserve Forebay, locally known as “the Duck Pond”) running parallel to the toe of the ridgeline. This 400 m long pond collects local stormwater runoff. It does not have a natural outlet and appears to drain via seepage through the sand dunes. An oblique aerial of the Claude Able Reserve Forebay is presented in Figure 2.3.

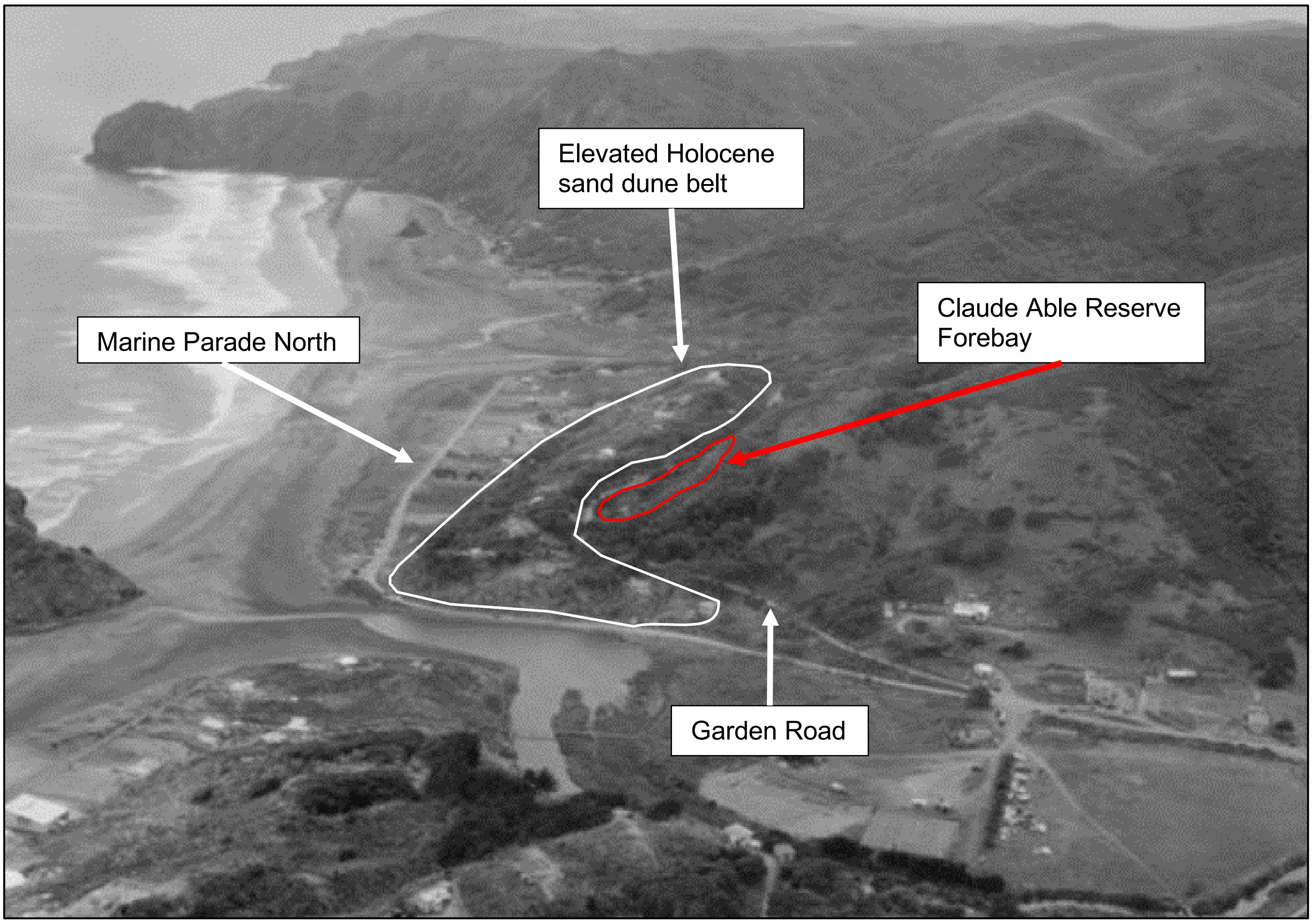


Figure 2.2: ***Oblique aerial image taken in 1955 showing the elevated, Holocene sand dune belt and the approximate location of the Claude Able Reserve Forebay (source: White Aviation Ltd).***

Figure 2.3 *Overview of the Piha area (basemap: New Zealand Aerial Imagery 2016 - 2022, source: LINZ).*

2.1.3 Karekare

The southern of the two settlements, Karekare, is also situated on the western sloping margin of the Waitākere Ranges. This settlement is located within a heavily incised landscape, with prominent ridgelines of varying orientations and lengths. The settlement is located at the mouth and upstream of the Company Stream, Karekare Stream and Opal Pools Stream. Company Stream originates from Lone Kauri Road in the east and transects the width of the settlement, flowing from east to west and separating the northern and southern portions of the settlement. Karekare Stream, located in the northwestern portion of the settlement, at the base of the main valley, flows north to south and is a tributary of Company Stream; their intersection is located at the Karekare Beach Carpark. Opal Pools Stream parallels Lone Kauri Road and separates the southern portion from the central portion of the settlement. Opal Pools Stream intersects Company Stream adjacent to 6 Lone Kauri Road. Company Stream forms its own tributary to the Karekare Stream, intersecting at the Karekare Beach carpark. Karekare Stream then discharges into the Tasman Sea.

The built environment is linearly distributed along the lengths of Karekare Road and Lone Kauri Road and generally occupies the low-lying flood plain of the Karekare Stream (which parallels Karekare Road) in the main valley in the north and west of the Settlement, and the steep undulating hillside along Lone Kauri Road in the south and east of the settlement. The elevation of the properties along Karekare Road varies between 4 and 30 m RL, whereas the elevation of the properties along Lone Kauri Road varies between 5 and 320 m RL. An overview plan of the Karekare area is presented in Figure 2.4.

2.2 Overland flow and flood plains

Auckland Council GeoMaps presents publicly available hydrological data, including the size and location of overland flow paths and flood plains, for the settlements of Piha and Karekare. In addition, the recently updated flood plain map is also available for both areas. Figure 2.5 (Piha) and Figure 2.6 (Karekare) show the predicted extent of flood inundation for a storm event that has a 1% or greater probability of occurrence in any given year, assuming a maximum probable development and future climate change.

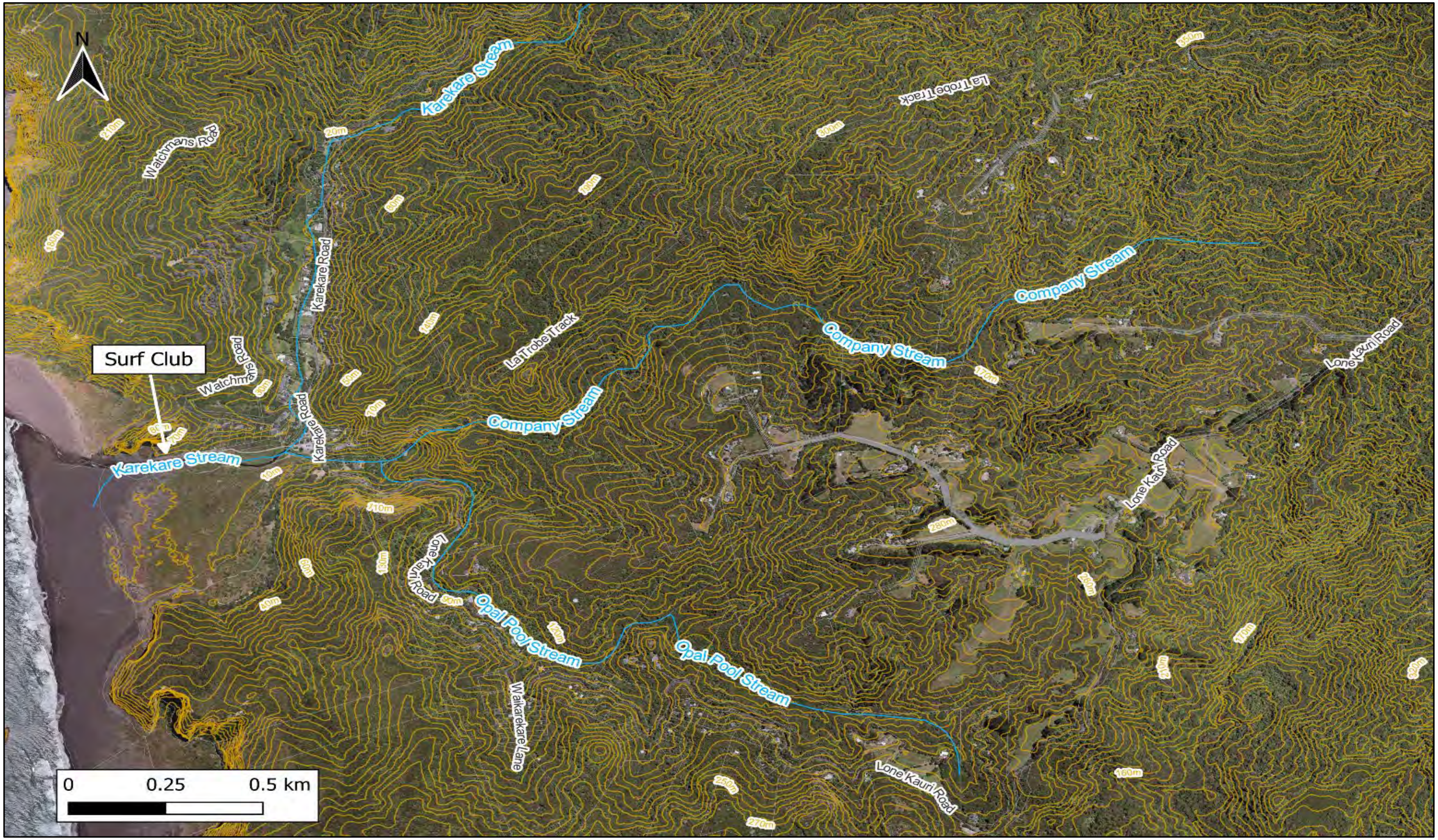


Figure 2.4 Overview of the Karekare area (basemap: New Zealand Aerial Imagery 2016 - 2022, source: LINZ).

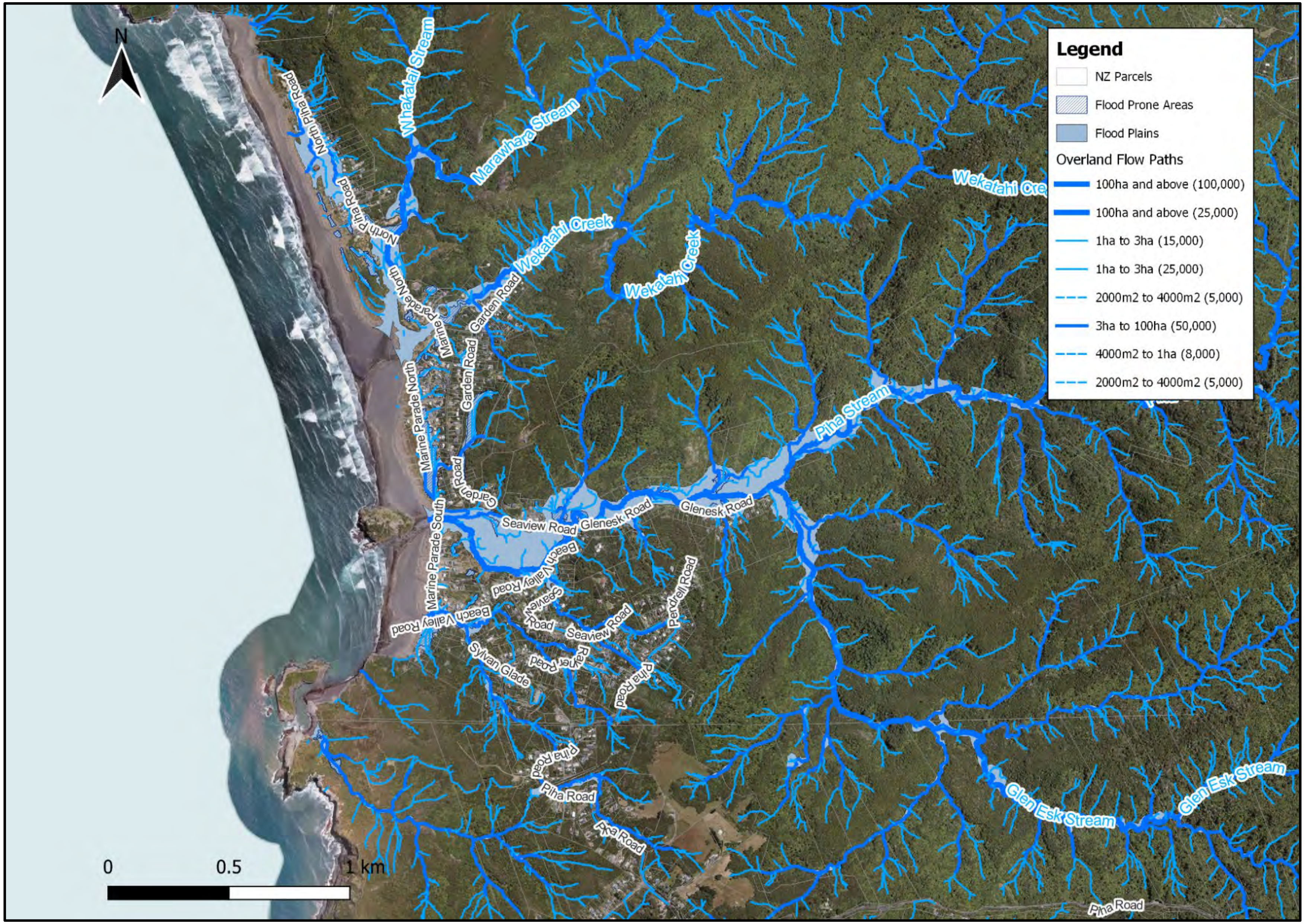


Figure 2.5 *Overland flow path and flood plain map of the Piha settlement (basemap: Feb 2023 Aerial Imagery, source: Auckland Council).*

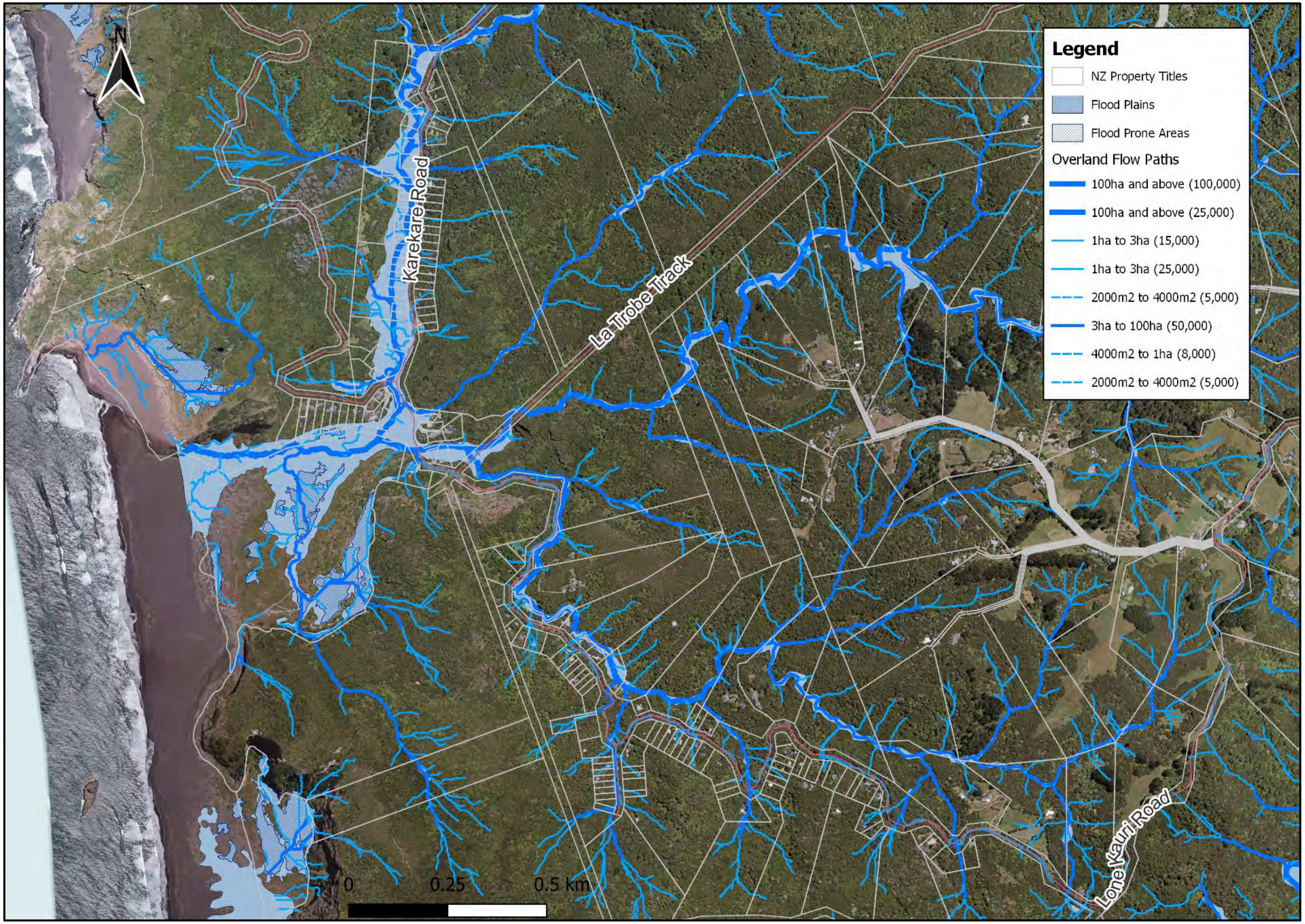


Figure 2.6 ***Overland flow path and flood plain map of the Karekare settlement (basemap: LINZ aerial imagery).***

2.3 Three waters infrastructure

Auckland Council GeoMaps also presents information on the stormwater, wastewater and drinking water services present within the settlements of Piha and Karekare. An excerpt of the data presented in GeoMaps that shows the registered infrastructure across the central Piha area is included in Figure 2.7.

Both the settlements of Piha and Karekare lack large scale, reticulated infrastructure for stormwater, wastewater and drinking water. As such, most properties rely on water tanks and soakage pits for the management of stormwater, septic tanks and effluent dispersal fields for the collection and management of wastewater, and water tanks for the collection and treatment of drinking water.

Minor reticulated infrastructure is present on some of the roads in the settlements (e.g. the Karekare Beach carpark or Marine Parade South; see example in Figure 2.7) for the management of stormwater. This infrastructure can comprise small culverts, catchpits, manholes and concrete pipes. This infrastructure is usually no longer than 100 m in length.

It is generally not clear whether these public or private utilities contributed to the landslides in February 2023.

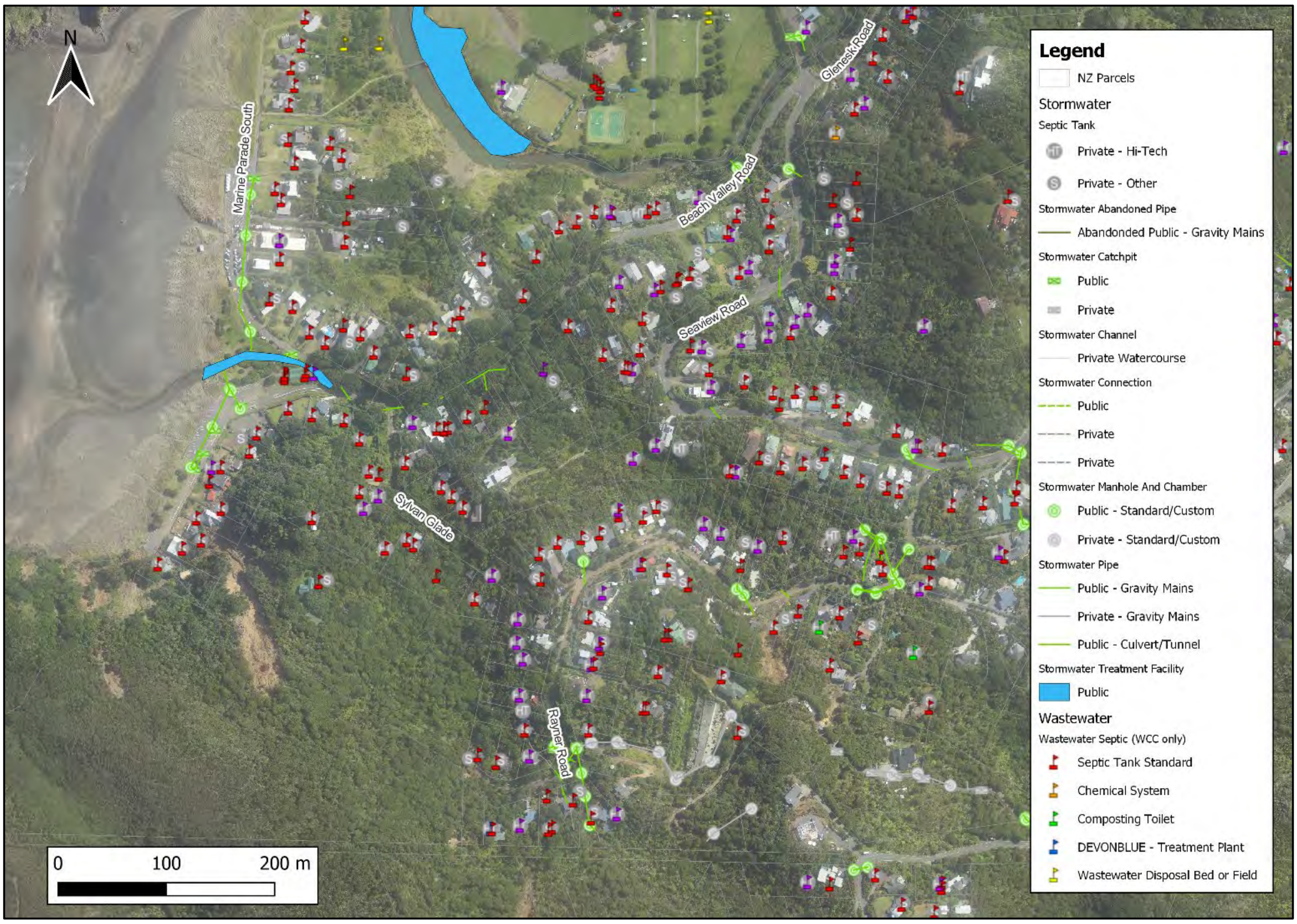


Figure 2.7: Excerpt of utilities data from Auckland Council GeoMaps. Showing typical layout of stormwater and wastewater infrastructure in Piha (basemap: Feb 2023 Aerial Imagery, source: Auckland Council).

2.4 Geology

2.4.1 Mapped Geology

The published 1:50,000 scale geological map of the area (Hayward, 1983[1]) indicates the identified geological units and geological structure of the areas. An excerpt is presented in Figure 2.8.

The main geological units are (from oldest to youngest):

– **Piha Formation**, which comprises stratified andesitic breccio-conglomerate with minor grit, sandstone and siltstone, and makes up a large proportion of the hills surrounding Karekare and Piha

– **Lone Kauri Formation**, which comprises andesite flows and pyroclastics, plugs, diatremes, clastic dikes, shallow intrusives and crater fills, and is present in the hills to the south and east of the Piha settlement.

– **Mitiwai Sand Formation**, which is Holocene in age (< 11,000 years) and comprises alluvial and swamp deposits associated with the Piha and Karekare Streams and their tributaries, and mobile, aeolian, dune sands forming the beachfront coastal landscape and lower lying regions of the Piha and Karekare townships.

The geological units encountered, including individual members within them, are described and shown below in Table 2.1.

[1] Hayward, B.W. 1983. Sheet Q11, Waitakere. Geological Map of New Zealand 1:50,000. DSIR

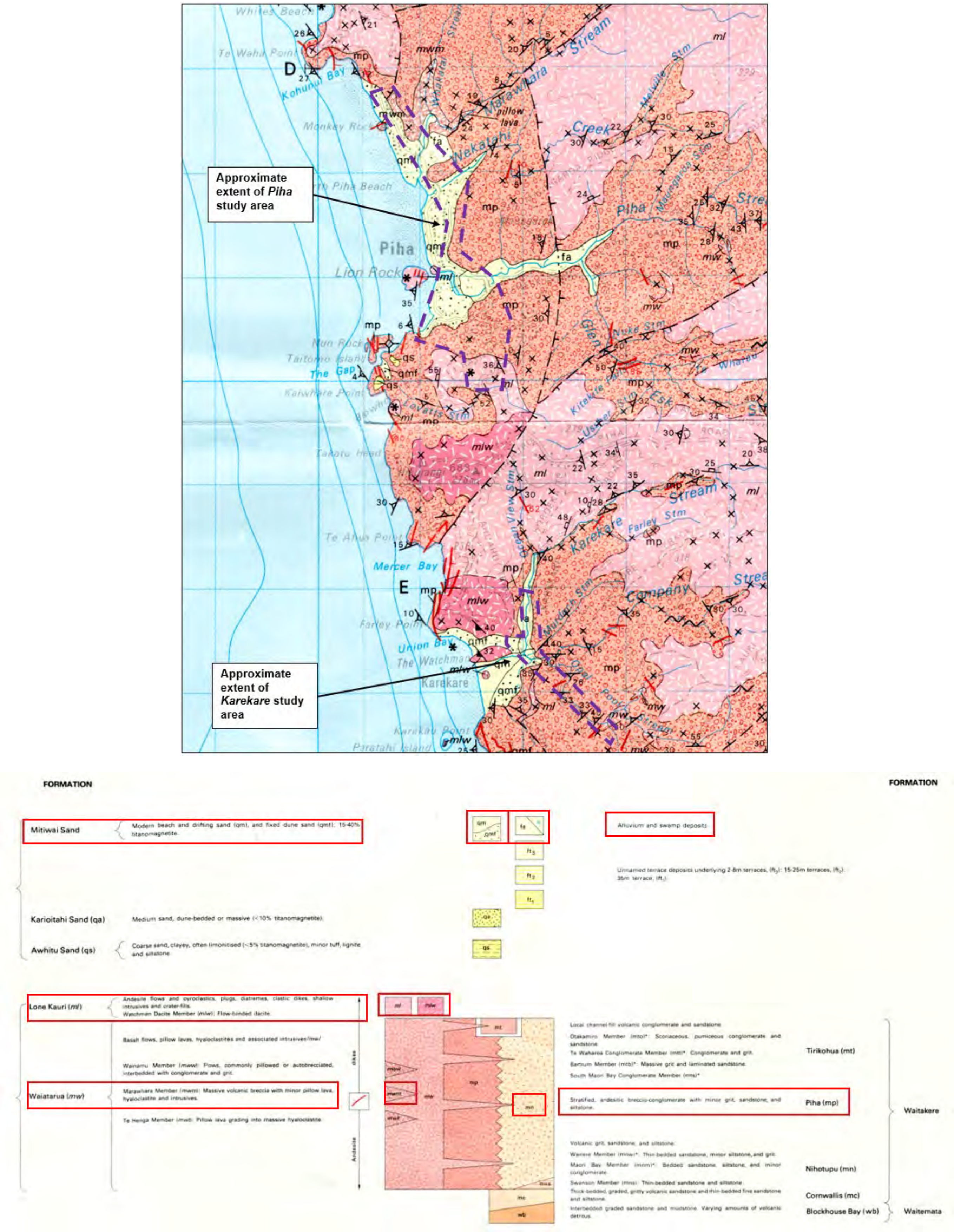


Figure 2.8 ***Published geology - combined excerpt from Hayward, B.W 1983: Sheet Q11, Waitākere. Geological Map of New Zealand 1:50,000. NZGS. Red boxes indicate the geological units relevant to the study area.***

Table 2.1: Summary of geological units.

Geological Unit	Map Symbol	Description	Observed in Piha and/or Karekare	Example Photograph of Geological Unit
Alluvium and Swamp Deposits	fa	Holocene aged (less than 10 kya) colluvium, alluvium and swamp deposits. Alluvium comprises silt, sands and gravels – usually encountered in riverbeds and banks. While the swamp deposits mainly comprise peat and organic clays / silts usually encountered within river floodplains.	Piha and Karekare	
Mitiwai Formation	qm	Modern beach and drifting sands	Piha and Karekare	

Geological Unit	Map Symbol	Description	Observed in Piha and/or Karekare	Example Photograph of Geological Unit
	qmf	Holocene aged (less than 10 kya) aeolian, dune sands forming the beachfront coastal landscape. Generally, 10 – 30 m RL	Piha and Karekare	
Lone Kauri Formation	ml	Terrestrial extrusives and shallow intrusive rocks. Extrusives comprise subaerial basaltic andesite flows and pyroclastics (e.g. breccia, diatremes, bombs, ash etc.). Intrusives comprise volcanic plugs, dykes and sills. Forms a cap along the tall ridges of the central and western Waitakere Ranges A weathered outcrop of Lone Kauri Formation is presented in the photo.	Piha	

Geological Unit	Map Symbol	Description	Observed in Piha and/or Karekare	Example Photograph of Geological Unit
Lone Kauri Formation (Watchman Dacite Member)	mlw	A large flow banded dacite neck and associated breccia. Forms its name's sake, the "The Watchman" adjacent to the surf club at Karekare Beach. Dacite dikes are also encountered within other portions of Karekare and Piha.	Karekare	
Waiatarua Formation (Marawhara Member)	mwm	Massive submarine volcanic breccia with minor pillow lava, hyaloclastite and intrusives. Mainly encountered along the western escarpment of the North Piha Road ridgeline.	Piha	

Geological Unit	Map Symbol	Description	Observed in Piha and/or Karekare	Example Photograph of Geological Unit
Piha Formation	mp	Submarine volcanic breccia conglomerate comprised of cobble to pebble sized material locally interbedded with volcaniclastic grit and rarely sandstone and siltstone. Lenses of cobble and boulder conglomerate, massive beds of volcanic breccia and120m thick slump units occur throughout the formation Early Miocene in age (16 – 23 million years)	Piha and Karekare	

2.4.2 Weathered rock profile

Exposed rock formations naturally degrade through weathering processes; this generally results in a weathered rock profile and overlying soil regolith. The weathering profile is not usually shown on published geological maps.

The typical weathering profile consists of residual soil[2] overlying completely weathered and highly weathered rock. Gravel to boulder sized lithics of less weathered material may also be present in the completely weathered soils. Based on our site observations in both Piha and Karekare, the weathered rock profile and overlying soils can be several meters thick. The residual soils are typically multi-coloured silts and clays, which are typically firm to very stiff in strength.

Examples of the typical weathering profiles in Piha Formation and Lone Kauri Formation are shown below in Figure 2.9 and Figure 2.10, respectively.

Figure 2.9 Example of the typical weathering profile in Piha Formation.

[2] Rock that has been weathered *in situ* to the point that it no longer has any rock-like characteristics and is now a soil.

Figure 2.10 Example of weathered Lone Kauri Formation in road cut.

2.4.3 Colluvium

In addition, colluvium is present on some slopes in both the Piha and Karekare settlements and is associated with erosion and/or historic landsliding. Colluvium is not usually shown on published geological mapping due to scale constraints and the extent of historic colluvium has not been mapped as part of these risk assessments. Based on our site observations in both Piha and Karekare, colluvium is of varied thickness and usually comprises angular gravels in a soil matrix. An example image is presented below in Figure 2.11.

Historic colluvium has been encountered in discrete locations across Piha and Karekare. Areas of historic colluvium associated with old landslides exhibit some or all of the following geomorphological features:

– Hummocky ground
– Toe bulging
– Semi-circular ridgeline
– Mid-slope benching
– Young(er) vegetation
– Incised drainage channels

Figure 2.11 Example of historic landslide colluvium within the headscarp of landslide P-LS94.

2.5 Geological Structure

The Waitākere Ranges formed approximately 25 million years ago and are the remnants of a large volcanic system, the centre of which was approximately 200 km offshore to the west of the Ranges present day location. The volcanic system comprised a large main cone in the centre with many smaller vents and smaller semi-detached systems surrounding it. The Waitākere Ranges formed on the eastern flank of this large volcanic system, which resulted in a regional east to northeastern inclined bedding structure. On a local scale, however, this structure can vary due to local depositional environments and influences from tectonic uplift/deformation.

The 1:50,000 scale geological map of the Waitākere area (Hayward, 1983) presents information on the dip and dip direction of the geological units and maps the locations of inferred faults. The local geological structure mapped in Piha tends to be westward dipping at approximately 25 – 35˚. This structure is reflected in both the Piha Formation and the Lone Kauri Formation in the area. The local geological structure mapped in Karekare, however, tends to be more varied, dipping northwest in the northern portion of site, north to northwest in the southern portion of site, northeast in the eastern portion of site, and northwest, southwest and south in the western portion of site. Dip angle in Karekare also varies more, generally ranging from 20 – 50˚.

There are eight inferred faults mapped within Piha and three inferred faults mapped within the Karekare area. The orientation of these faults is generally northwest at Karekare and north or northeast at Piha (see Figure 2.8).

Joint sets have not been mapped in rock exposure for the areas of interest to this study. A few joints are shown on Figure 2.8, dipping to the NW at 45 to 55˚.

There is no apparent relationship between the geological structure (bedding, faults and joints) and the prevalence or otherwise of the 2023 storm event landslides.

3. Landslide characterisation

3.1 2023 Landslides

The location and extent of the landslides (present and historic) for the Piha and Karekare built environment are presented in Appendix B and Appendix C. A glossary of terminology is provided in Appendix A.

As the maps show, the landslides that occurred during Cyclone Gabrielle were mainly small debris flows. These were widely distributed across the built environments and apart from a few exceptions typically not clustered.

In addition to debris flow hazard, rockfall, translational landslip and fill embankment failures occurred.

For each landslide the location of the head scarp, and the extent of the depletion zone, zone of accumulation and silt discharge zones have been mapped from aerial photography and drone footage with ground truthing as needed. The naming convention for each landslide utilises abbreviations for the Area – landslide and unique number. An example is P-LS092 which is a Piha landslide number 092. An abbreviation of K is used for Karekare.

Examples of the types of 2023 landslides that occurred in Piha and Karekare are presented below in Figure 3.1.

	
North Piha – Debris Flow (landslide P-LS65)	**North Piha - Rockfall (debris)**

	
Road subsidence – Headscarp of Large Translational Slide – Karekare (landslide K-LS66)	**Translational failure – retaining wall failure – Piha**
	
Translational Road Cut Failure Lone Kauri Road (landslide K-LS63)	**Failure within Building Platform Fill – Piha (landslide P-LS87)**

Figure 3.1 Examples of typical landslides from 2023 in Piha and Karekare

3.1.1 Debris Flow characterisation

3.1.1.1 Type and trigger

The observed landslides within the Karekare and Piha areas were generally noted to be shallow translational failures developed in the upper residual/weathered profile of the Piha or Lone Kauri Formations. Apart from triggering on steep (>25 degree) slopes with thin soil cover, there appears to be no other obvious correlation with geology, groundwater or vegetation cover.

Deep seated release of material was not observed in the built environments of Piha and Karekare although there is geomorphic evidence to suggest that such failures have occurred in the surrounding hills in the past.

Failure occurred when shallow soils became saturated due to the excessive rainfall and surface water flow, and in most cases the failures transitioned from translational failures into debris flows that travelled for tens of metres downslope.

An indicative geological cross section of a debris flow is presented in Figure 3.2 below. For illustration purposes the thickness of the residual soils has been exaggerated and the house location is fictitious. However, it demonstrates the steep natural slope angles, and relative locations of the landslide source area (zone of depletion) and debris deposition (zone of accumulation) and the extent that the debris travelled.

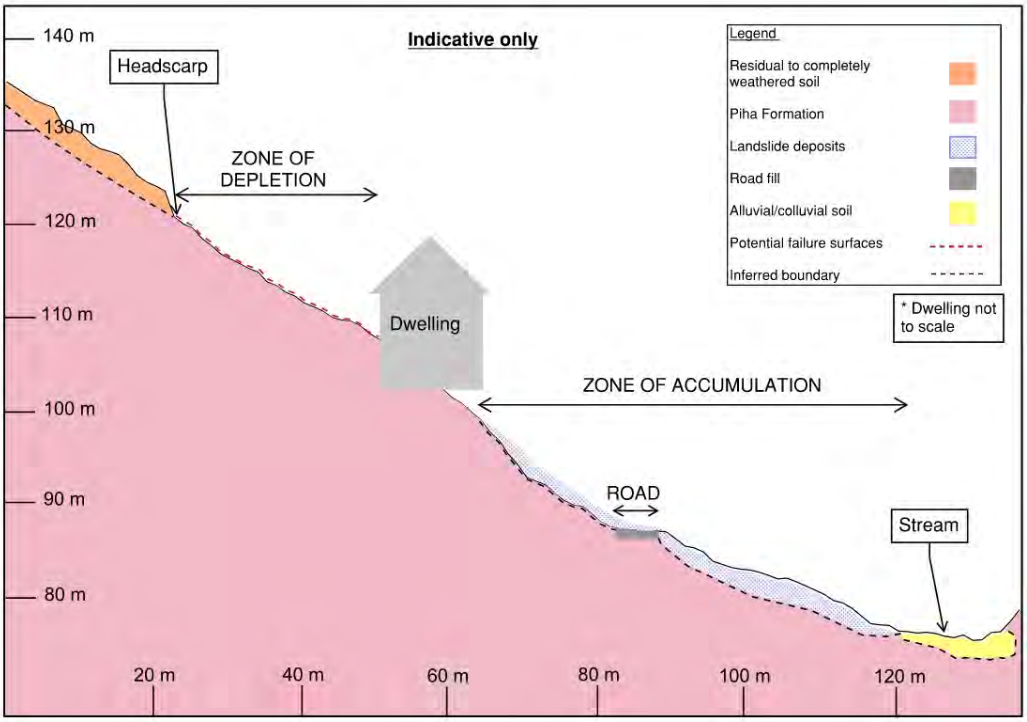


Figure 3.2 ***Indicative cross section and geological model of a debris flow formed from translational failure of residual soils***

Intense and prolonged rainfall was the trigger event responsible for the landslides in Piha and Karekare in February 2023 event with the ground already significantly saturated from the earlier Cyclone Hale event in January 2023. In addition to the saturated ground conditions, concentration of surface water flow within the existing gullies and roads related stormwater flow will have also contributed to saturation the surficial soils during peak rainfall intensity.

There are other factors that may have contributed to the 2023 landslides. In most cases there is no direct evidence that these are due to modification of the natural landscape and urban occupation. Progressive development of both Karekare and Piha since the early 1900's has resulted in progressively more extensive impermeable surfaces from roads and dwellings including their paved areas. Neither community has any significant reticulated stormwater or wastewater management systems. The urban environment tends to collect and concentrate stormwater flows on roadways, driveways, from building roofs and water tank overflows. Generally, these systems drain to low points and discharge to ground or into natural water courses but they are less effective in times of saturated ground conditions.

The effects of saturation of the soil from private septic waste-water systems and/or stormwater drainage systems and associated overflow may also have a negative influence. While both of these factors could conceivably induce or worsen existing slope stability hazards in Piha and Karekare, there has been no evidence to date to indicate they are wholly responsible for the landslides impacting on private property.

3.1.1.2 Event characterisation

Our analysis of the mapped landslides within the Karekare and Piha built environment, which included size, estimated volume, travel distance and travel angle, was undertaken to characterise the nature and distribution of landslides following the rainfall events that occurred in early 2023, particularly the Cyclone Gabrielle rainfall event.

A total of 80 landslides were mapped throughout Karekare and Piha following the storm events in January and February 2023. These landslides were grouped into categories of estimated volume in 50 m^3 increments. Results for an assessment of “frequency as categorised by volume” are shown in Figure 3.3 below. The volumes have been estimated based on the measured area of depletion and the observed thickness soils/ rock in the failure.

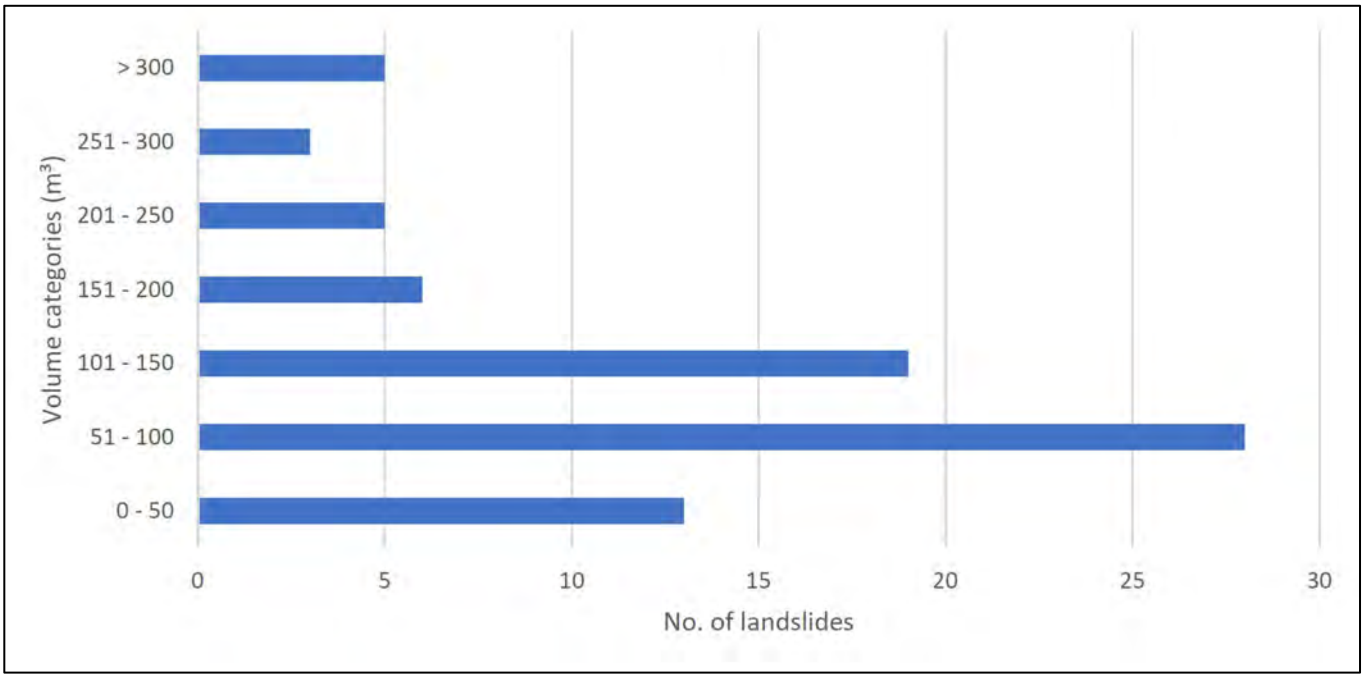


Figure 3.3 The number of mapped debris flows (on the x axis) categorised by volume increments (on the y axis in m^3) in Karekare and Piha.

In addition, detailed information regarding confinement (either unconfined or channelized) and the degree of damage caused by slides impacting dwellings and building was collated.

Figure 3.4 below plots the travel angle against estimated volume and separates the data based on whether the debris flow was channelised or unconfined. The landslides resulting in damage to dwellings are also highlighted.

The data shows that unconfined landslides typically had a higher travel angle (i.e travelled less distance) than channelised flows. The travel angle is the angle from the crest of the source area to the distal toe of the debris (run out zone). The lower the travel angle the further the debris will run out and this was observed with those landslides that were confined or channelised.

Figure 3.5 focuses on the volume and travel angle for dwellings that were damaged. Class 3, which is damage to buildings that did not collapse or had no inundation, or damage is other property infrastructure e.g., access stairs, is limited to landslide volumes of typically less than 100m^3 from Figure 3.5.

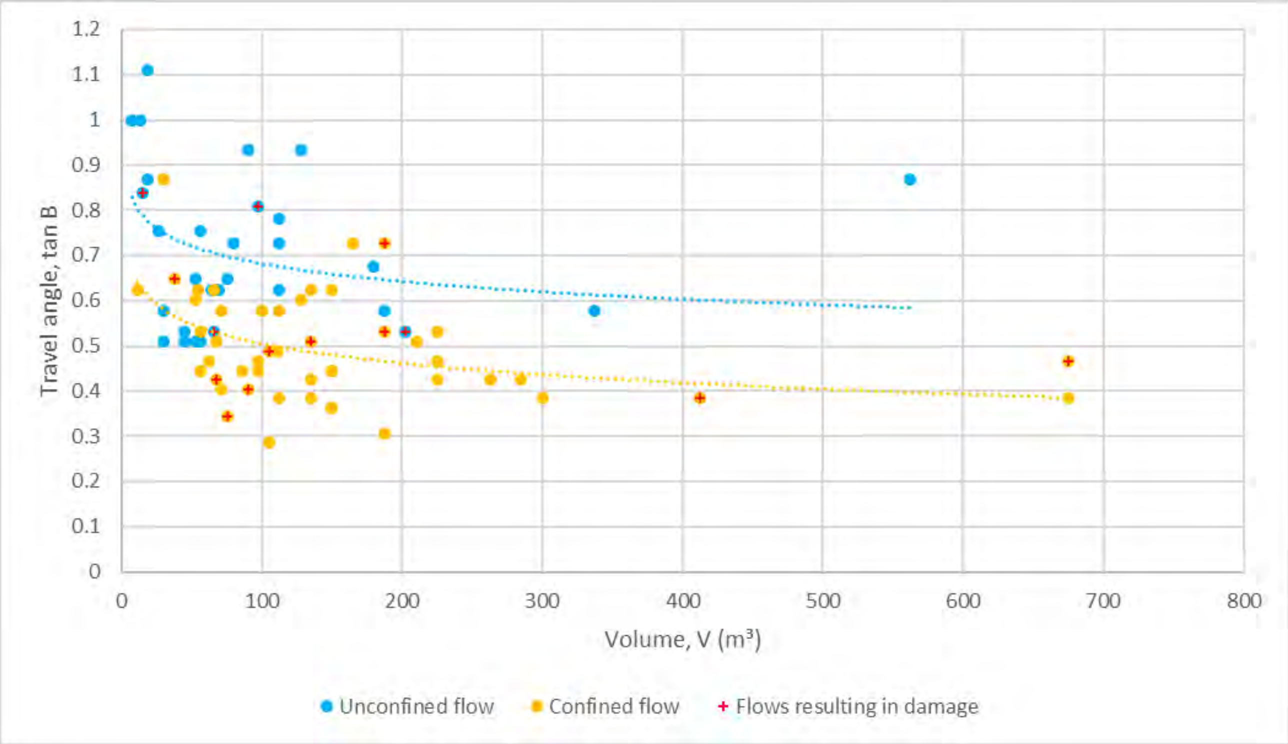


Figure 3.4 *Travel angle vs volume of source area for the Karekare and Piha debris flows*

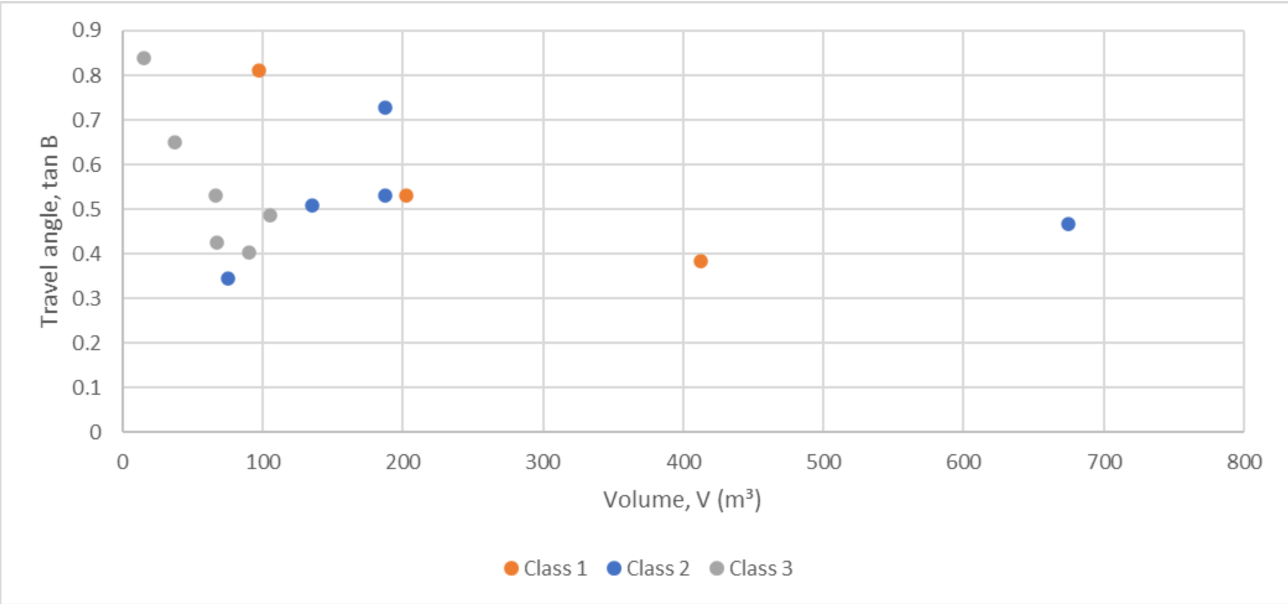


Figure 3.5 *Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.*

This assessment of the Piha and Karekare landslide data highlighted some key characteristics relating to the nature of these landslides. In summary these are:-

– Whilst a range of volumes of source areas for debris flow was noted, the most common volume was about 50-100 m^3 as determined by the frequency plot.
– Many smaller volume source areas for debris flows (less than $75m^3$) typically caused less damage to buildings than volumes above 100 m^3, when the vast majority of debris flows caused partial or full collapse of dwellings and other impacted buildings.

– The greater the volume of the source area, the lower the travel angle and the greater the runout or travel distance.
– Unconfined debris flows generally have a higher travel angle compared to confined or channelized debris flows of the same volume. This means that confined or channelised debris flows have a longer runout or travel distance and hence have more potential to impact elements at risk further down the slope.

The specific Piha and Karekare data assessment above was then used to define the *most likely significant landslide* for specific risk assessments of individual or groups of dwellings.

The working definition adopted for the **most likely significant landslide** is as follows:

– The volume of most likely significant landslides is assumed to be 100 $m^{3.}$
– This volume has been shown to cause significant building damage resulting in partial to full dwelling and building collapse.
– As a result, this hazard is considered to have a high probability for causing loss of life.
– Where this hazard is unconfined, the adopted travel angle is taken as Tan (B) = 0.69 or approx. = 35°.
– Where this hazard is confined or channelised the adopted travel angle is taken as Tan (B) = 0.50 or approx. 26.5°.

The definition of the **most likely significant landslide** is considered a reasonably conservative but not overly cautious estimate of the potential hazard that may affect the site.

3.1.2 Other types of landslides

In addition to debris flows, other landslides forms recognised in the Piha and Karekare area were:

– Large-scale slow-moving landslides
– Rockfall
– Sand scour resulting in soil voids and collapse.

These are atypical of the landslides observed across the region.

3.1.2.1 Larger scale slow moving landslides

There are a few instances in the Piha and Karekare area where damage to roads and buildings suggests the presence of larger slow-moving landslides that responded to the significant rainfall event. There was no associated catastrophic evacuation of the headscarp or inundation of dwellings from debris.

Headscarp movement is most easily seen as new tension cracking and subsidence of a roadway or driveway (an example is presented in Figure 3.1). Buildings located on such landslides will undergo foundation movement, twisting and racking of the building such that doors and windows don't open or close, floors are not level and the wall linings crack. Ancillary structures such as stairs may detach.

Detailed mapping, intrusive investigations and monitoring instrumentation will be required to provide sufficient information to understand the size, depth and complexity of these landslides.

3.1.2.2 Rockfall

Rockfall hazard is applicable to properties at the base of steep rock slopes and cliffs where there is minimal vegetation and soil cover. Rockfall evidence observed to date has resulted from boulders releasing from the weathered rock and residual soil profile, predominantly in the Piha Formation as a function of its broader extent across the study area, but also in isolated outcrops of Lone Kauri Formation (at both Piha and Karekare) and Waiatarua Formation (Marawhara Member) at North Piha.

At North Piha, the jointed nature of the rock mass creates additional potential for blocks of rock to detach from the steep cliff faces.

Isolated rockfall was observed in north and south Piha with a record of boulder sized blocks of rock detaching from the cliff and being lodged in a shed (Figure 3.1). It is therefore considered that the Piha, Lone Kauri, Waiatarua

Formation and Watchman Dacite Formations, in Piha and Karekare, have the potential to generate a rockfall hazard.

In addition, rockfall also includes rocks dislodging from the remaining upslope debris. To date there is evidence that this occurring at North Piha.

3.1.2.3 Sand dune piping or scour

There are two instances in Piha of scour in the Mitiwai Formation associated with Cyclone Gabrielle. In one case the water movement through old sand dunes, combined with ponded water behind the dune, resulted in sand dune scour and failure at the low point of the dune. The mechanism for this is unusual. It is a combination of excessive subterranean water flow through the dune moving the sand particles until a void is formed (known as piping). Continued water movement created significant scour and an associated void under the dwelling.

The second case was related to scour of the dune sands during the flood event oversteepening the toe of the sand dune formation. The scour coupled with likely high pore pressures in the sands once the flood waters had receded (i.e. a rapid draw down type scenario) resulted in a landslide extending back to a house.

3.1.3 Failure of built structures

In addition to the landslides discussed above, failure of built structures and modified slopes (i.e. human made) was also observed. The following were observed in the Piha and Karekare area:

– Road cutting failures
– Road or building platform fill failures
– Retaining wall failures.

Examples of these are presented in Figure 3.1.

In some cases, such as road cuttings and sidling road fills, the failure mechanism is a shallow translational failure of the underlying residual soils or road fill accompanied by subsequent mobilisation of saturated debris.

There are a number of residential house sites on sloping ground where the building platform has been formed by cut and fill placement with shallow foundations as opposed to pole houses. Several properties have been impacted by failure of the fill platform close to or under the dwelling. The trigger for these failures is the same as discussed above – saturated soils and accompanying loss of soil strength. These failures are either translational failures on the fill / natural rock boundary or rotational failures within the fill that have only presented as a significant hazard where either the debris and run out, or the head scarp has impacted a dwelling.

Retaining wall failure or deformation is also observed at some sites across Piha and Karekare. In many cases, shallow translational failures of the retained soils are responsible and are often associated with the failure of fill platforms. An example can be cited in Karekare, Landslide ID 'K-LS98' where a timber retaining wall supporting the base of a cut slope has both rotated and translated forward from what was interpretated to be a shallow translational landslide approximately 20m^2 in area, above.

3.2 Historic landslides

Interpretation of vertical and oblique aerial photograph imagery from 1940 to the present day, coupled with the assessment of topography and hill shade models developed from LiDAR, has been undertaken to recognise and map any geomorphic evidence of historic landslides in the immediate built environments of Piha and Karekare.

Aerial photos were obtained from the following sources:

– AC Geomaps
– Google Earth
– Retrolens
– LINZ NZ Aerial Imagery
– White Aviation Ltd Collection (NZ National Library)
– Auckland Council supplied drone footage

– Auckland Council supplied ortho photo flight, March 2023

The following topographic survey data was also sourced and used

– 2023 Piha and Karekare digital terrain model

Examples of the type and quality of vertical and oblique aerial imagery for Piha and Karekare are presented below in Figure 3.6.

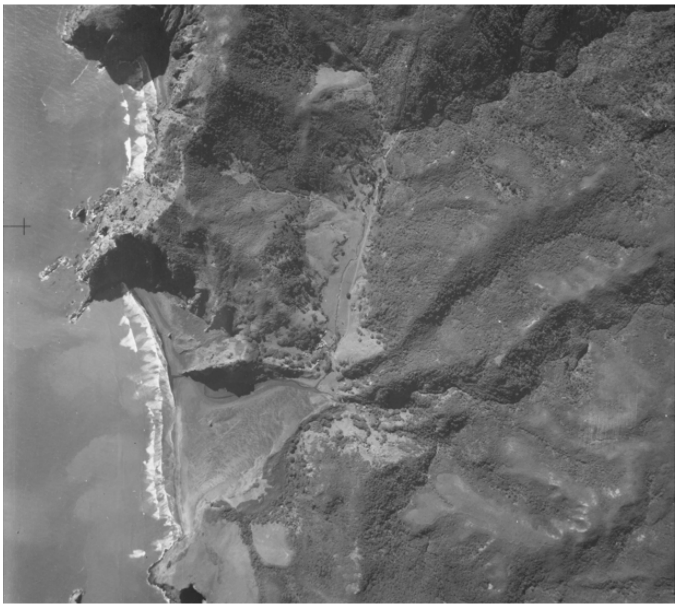
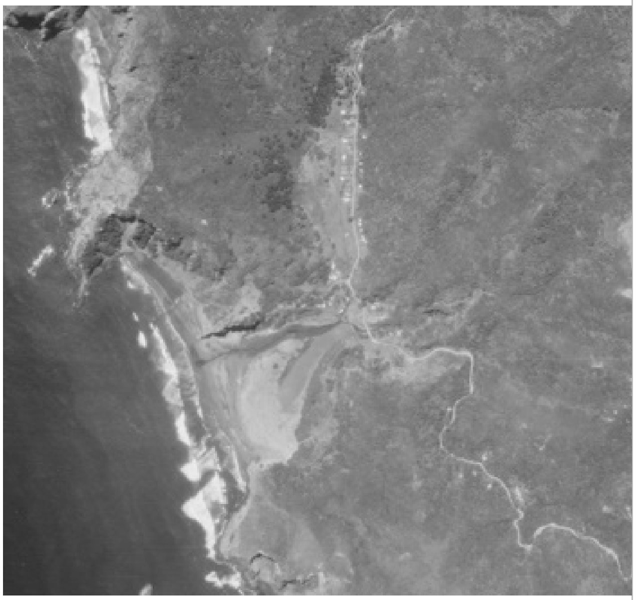
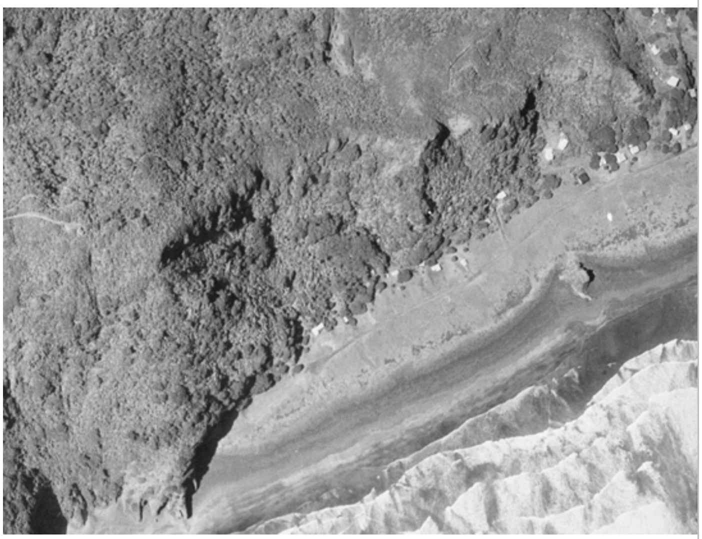
	
Vertical Aerial – Karekare- 1940 – run100/2 (source Retrolens)	Vertical Aerial – Karekare- 1940 – SN5782 Q/2 (source Retrolens)
	
Aerial Oblique – North Piha 1940 (sourced White Aviation Ltd)	Aerial Oblique – North Piha 1957 (sourced White Aviation Ltd)

Figure 3.6 Examples of vertical and oblique aerial imagery

The mapped historic landslides are included on the plans presented in Appendices B and C. For this study the mapping has been restricted to the surrounds of the built environments for both townships. Without a doubt there will be evidence of other historic landslides in the landscape in the surrounding Waitākere Ranges but mapping of these is outside the scope of this study.

The geomorphic features considered to represent evidence of historic landslides includes:-

– Hummocky topography and associated wet ground
– Concave headscarps
– Diverted stream channels
– Evidence of debris and rockfall accumulation at the toe of slopes.

The assessment has identified head scarps of past large landslides as well as debris flows run out zones. The age of these features is unknown. From the aerial photography we did not observe any evidence (such as unvegetated scarps or scars) that indicated reactivation of the historic landslides since at least 1940.

GHD is not aware of any evidence of reactivation of the large historic landslides in 2023. It is clear from the maps presented in the Appendices that both historic and the modern (2023) landslides are spatially distributed across the area. We note that some of the modern landslides formed within the footprint of historic landslides, most likely because colluvium remaining within the footprint of the historic landslide became oversaturated (eg. due to concentrated runoff or ponding) and remobilised in 2023.

4. Basis for assessments

4.1 Site specific risk assessments

Site specific Quantitative Landslide Risk Assessment's (QRA) were undertaken by GHD at the request of Auckland Council for individual or groups of properties in Piha and Karekare. The QRA was undertaken specifically to estimate the **risk of Loss of Life** to individuals at these properties and our methodology follows that of the "Practice Note Guidelines for Landslide Risk Management" (AGS 2007c). The QRA will be used by Council to inform the property risk categorisation and building placard designation review.

The criteria for selection of properties for QRA are briefly summarised below:-

- Dwellings which were placarded or impacted by known landslides from the February 2023 storm event
- Properties adjacent to a landslip or in the same catchment and may have been initially placarded
- Impacted properties which have continued risk of future landslide impact.

A summary of the QRA outcomes for properties across the study area is as follows:

– The properties in North Piha and Marine Parade were each grouped to enable a broader assessment as they have a common geomorphology that could indicate further landslide hazard. This grouping may include properties that may not have been immediately impacted by the 2023 landslides but may be considered at risk from landslide hazard.
– Properties which were impacted by 2023 landslides but have no dwelling may be included in adjacent groups of properties given a QRA assessment but will have no loss of life risk calculation.
– Properties initially considered for QRA and then found to have no damage from the 2023 storm event. These will have received a non-assessment letter documenting the reasoning for no further risk assessment.

The QRA's are related only to the risk posed to the life of the main dwelling occupant(s) from the corresponding landslide hazard(s) and specifically exclude assessments of property structure risk, subsurface geotechnical investigations, service inspections, and groundwater monitoring. There may be other non-geotechnical considerations that affect the final property risk categorisation or placard designation of which GHD are not aware, such as flood risk and structural damage to property.

A list of properties considered by the QRA assessments is presented in Appendix D. The GHD approach to the risk assessment is documented in Appendix E. This appendix is included in all induvial/grouped property risk assessment reports and is provided in this report for information only.

4.2 Properties with no QRA risk assessment

The reasons that the majority of the Dwellings dwelling in the Piha and Karekare study area are not receiving site specific assessments are:

– Not directly impacted by landslides caused by Cyclone Gabrielle (landslides and/or their debris did not originate on or travel onto the property)
– Did not receive a Rapid Building Assessment placard associated with landslide hazard following Cyclone Gabrielle
– Show no credible evidence for the presence of a pre-existing or on-going landslide hazard that could reasonably be expected to impact the dwelling. Specifically, for these properties:
    - Aerial photograph review from the 1940's to the present day did not indicate any fresh scars on the landscape that would suggest a recent past or on ongoing landslide activity
    - No anecdotal evidence of historic landslides was identified
    - No evidence of ground deformation (pre or post Cyclone Gabrielle) associated with landslides was identified.

5. Limitations

This report has been prepared by GHD for Auckland Council and may only be used and relied on by Auckland Council for the purpose agreed between GHD and Auckland Council as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Auckland Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.2 of this report). GHD disclaims liability arising from any of these assumptions being incorrect.

GHD does not accept responsibility arising from, or in connection with, varied conditions and any change in conditions. GHD is also not responsible for updating this report if the conditions change.

An understanding of the geotechnical site conditions depends on the integration of many pieces of information, some regional, some site specific, some structure specific and some experienced based. Hence this report should not be altered, amended, abbreviated, or issued in part in any way without prior written approval by GHD. GHD does not accept liability in connection with the issuing of an unapproved or modified version of this report.

Verification of the geotechnical assumptions and/or model is an integral part of the design process - investigation, construction verification, and performance monitoring. If the revealed ground or groundwater conditions vary from those assumed or described in this report the matter should be referred back to GHD.

This risk assessment does not mean that there will be no further landsliding impacting this property or group of properties.

Appendix A

Glossary

DEFINITION OF TERMS

Acceptable Risk – A risk which, for the purposes of life or work, society is prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

Authority or **Council** having statutory responsibility for community activities, community safety and development approval or management of development within its defined area/region

Consequence – The outcomes or potential outcomes arising from the occurrence of a landslide expressed qualitatively or quantitatively, in terms of loss, disadvantage or gain, damage, injury or loss of life.

Creep Failure – A time-dependant deformation mechanism where constant stress is applied to a material. Creep failure can be identified by ridges the ground surface and curved tree trunks.

Dropout – A landslide feature occurring along the length of the road-side on the downslope edge. Drop outs can result in the undermining the road carriageway.

Elements at Risk – The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by landslides.

Entrainment – The process of surface sediment transportation through water and mass movement.

Frequency – A measure of likelihood expressed as the number of occurrences of an event in a given time. See also Likelihood and Probability of Occurrence.

Hazard – A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material, and the probability of their occurrence within a given period of time.

Individual Risk to Life – The risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide or who follows a particular pattern of life that might subject him or her to the consequences of the landslide.

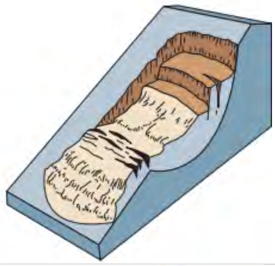
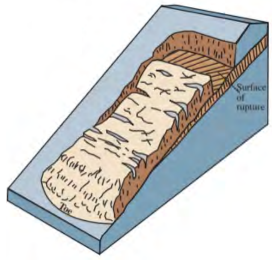
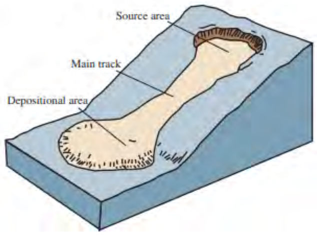
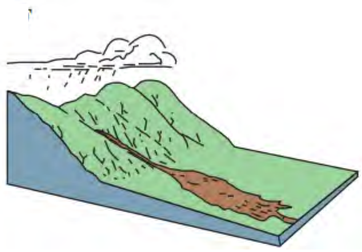
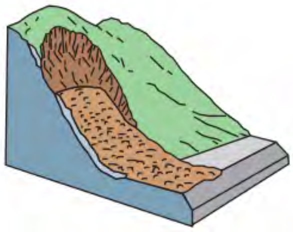
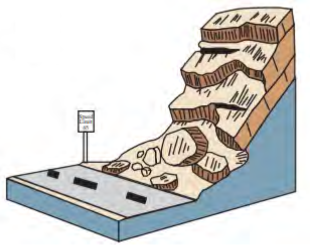
Landslide - A landslide is defined as the movement of a mass of rock, debris, or earth down a slope. The most widely used landslide classification system is that proposed by Cruden and Varnes in 1996 (after Varnes 1954 and Varnes 1978). This has been updated by Hungr, et al., 2014. In its most simple form two nouns are used to describe, firstly the type of material involved and secondly, the mechanism of failure, i.e., rockfall, debris flow.

Landslide inventory – An inventory of the location, classification, volume, activity and date of occurrence of landsliding

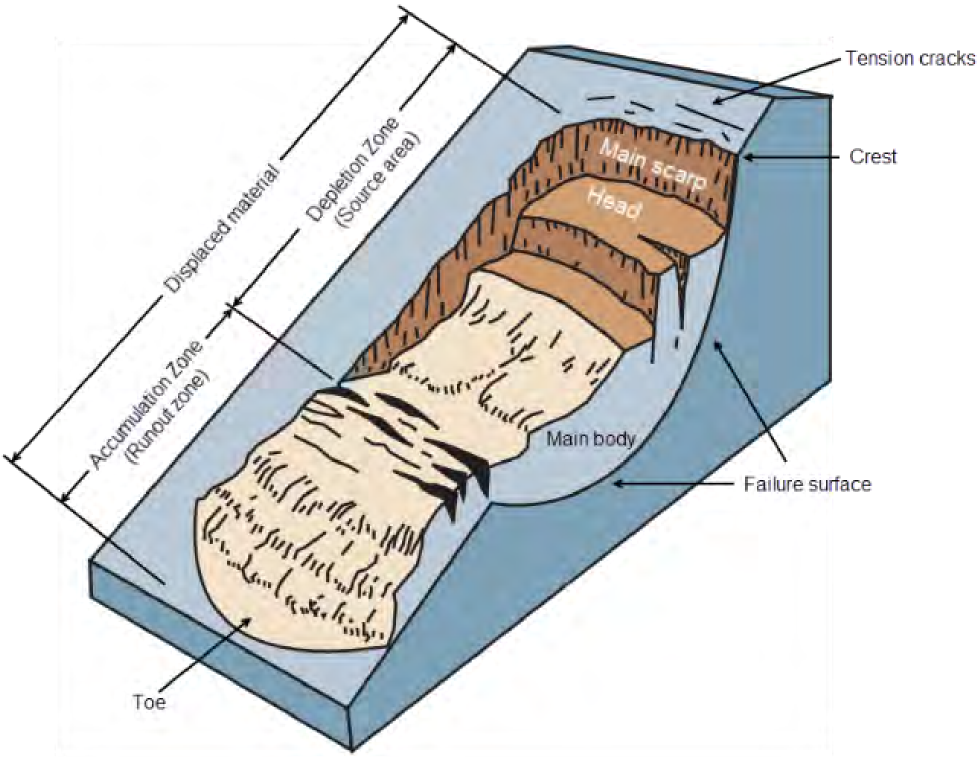
Landslide Risk - Landslide risk is defined herein as the likelihood that a particular landslide will occur and the possible consequences to a specific element at risk (property or human life) taking account of both spatial and temporal considerations.

Landslide Susceptibility – A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

Landslide Classification – Referenced from Varnes, 1978.

Landslide Type	Landslide Description	Illustration
Rotational sliding	The landslide failure surface is curved concavely upward and the movement of mass is mainly rotational. Rotational movement causes back tilting of the displaced material near the headscarp.	
Translational sliding	The landslide mass moves along a planar failure surface with minor rotational movement.	
Earth flow	The movement of saturated fine-grained materials or clay bearing rocks. The displaced material forms a characteristic hourglass shape with an elongated flow path.	
Debris flow	The rapid movement of saturated, loose material caused by heavy precipitation and surface water flow. Commonly occurring on steep slopes.	
Debris avalanche	A type of debris flow that is *extremely* rapid.	
Rockfall	The separation of rocks and boulders along fractures, joints and bedding planes on steep slopes or cliffs. The movement is heavily influenced by mechanical weathering of the rock mass and gravity.	

Landslide characteristics – Modified after Varnes, 1978.



Likelihood – Used as a qualitative description of probability or frequency of the event/landslide.

Overland Flow Path – The predicated flow path of stormwater over the topography.

Permeability – The capacity of a material to allow water to pass through it. Clay materials are impermeable whereas gravels and sands are porous and therefore permeable.

Probability – A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity or the likelihood of the occurrence of the uncertain future event. There are two main interpretations:

(i) *Statistical – frequency or fraction* – The outcome of a repetitive experiment of some kind like flipping coins. It also includes the idea of population variability. Such a number is called an “objective” or relative frequentist probability because it exists in the real world and is in principle measurable by doing the experiment.
(ii) *Subjective probability (degree of belief)* – Quantified measure of belief, judgement, or confidence in the likelihood of a outcome, obtained by considering all available information honestly, fairly and with a minimum of bias. Subjective probability is affected by the state of understanding of a process, judgement regarding an evaluation or the quality and quantity of information. It may change over time as the state of knowledge changes.

Probability of Occurrence – used interchangeably with Likelihood.

Quantitative Risk Analysis – an analysis based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

Recurrence Interval (repeat period) – An estimated value of how often an event occurs based on the average time between passed events.

Regression – The continual movement of a landslide downslope and or widening/retreat of the headscarp.

The **Regulator** will be the responsible body/authority for setting Acceptable/Tolerable Risk Criteria to be adopted for the community/region/activity, which will be the basis for setting levels for Acceptable and Tolerable Risk in the application of the risk assessment guidelines.

Risk – A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability x consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

Risk Analysis – The use of available information to estimate the risk to individuals, population, property or the environment from hazards. Risk analyses generally contain the following steps: scope definition, hazard identification and risk estimation.

Risk Assessment – The process of risk analysis and risk evaluation.

Risk Control or Risk Treatment – The process of decision making for managing risk and the implementation or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Risk Estimation – The process used to produce a measure of the level of health, property or environmental risks being analysed. Risk estimation contains the following steps: frequency analysis, consequence analysis and their integration.

Risk Evaluation – The stage at which values and judgements enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk Management – The complete process of risk assessment and risk control (*or risk treatment*).

Runout Distance – The horizontal distance from the source area to the distal toe.

Susceptibility – see Landslide Susceptibility

Temporal-Spatial Probability – The probability that the element at risk is in the affected area at the time of the landslide.

Tolerable Risk – A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if possible.

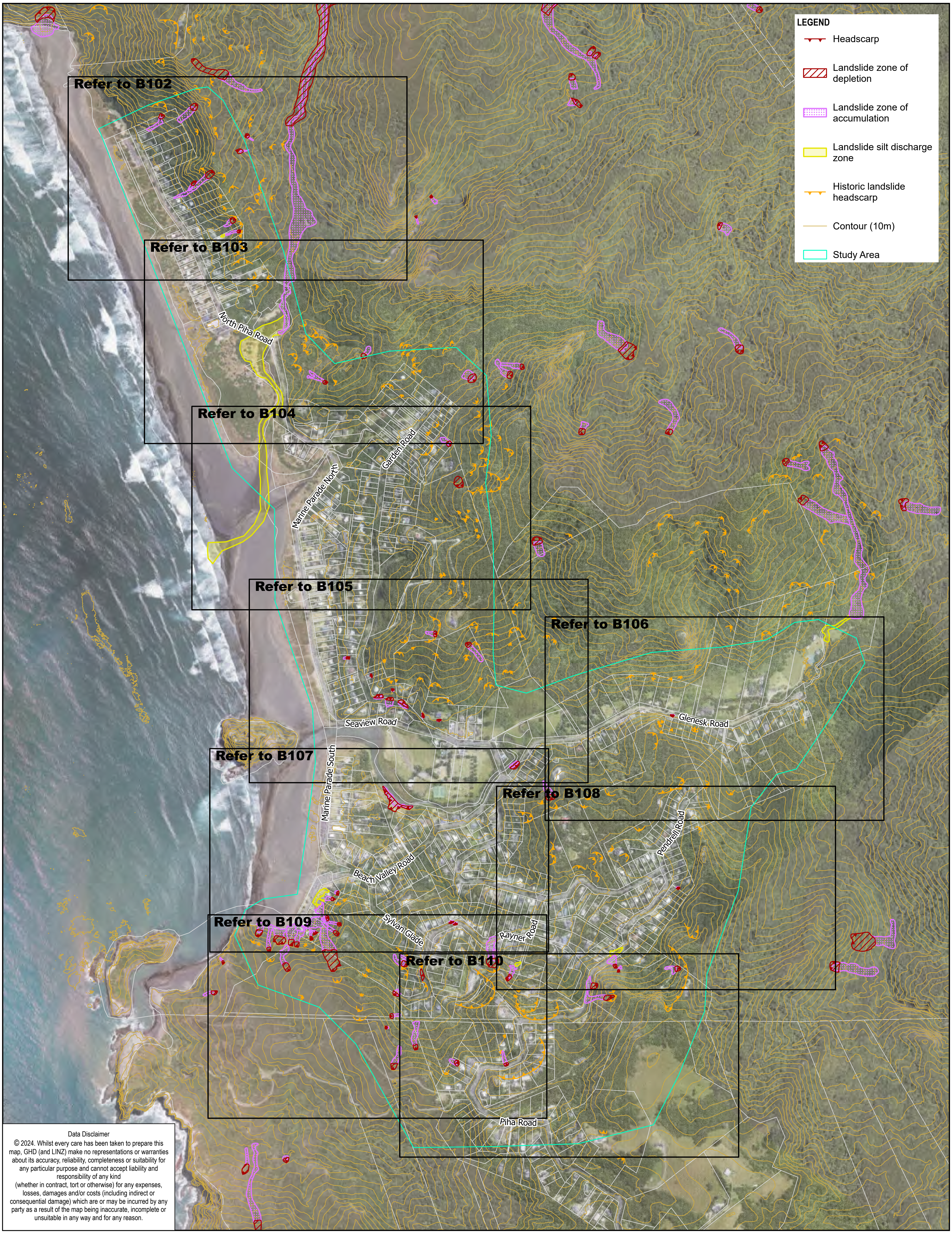
Transgression-regression cycles – Sedimentary deposits formed from cycles of sea level rise and fall.

Travel Angle – The angle from the crest of the source area to the distal toe of the debris (run out zone)

Vulnerability – The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is affected by the landslide.

Appendix B

Landslide Maps for Piha



Paper Size ISO A3

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Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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AUCKLAND COUNCIL
WAITAKERE COASTAL COMMUNITIES LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING-OVERVIEW

Project No.	12612462
Revision No.	0
Date	9/01/24

APPENDIX B101

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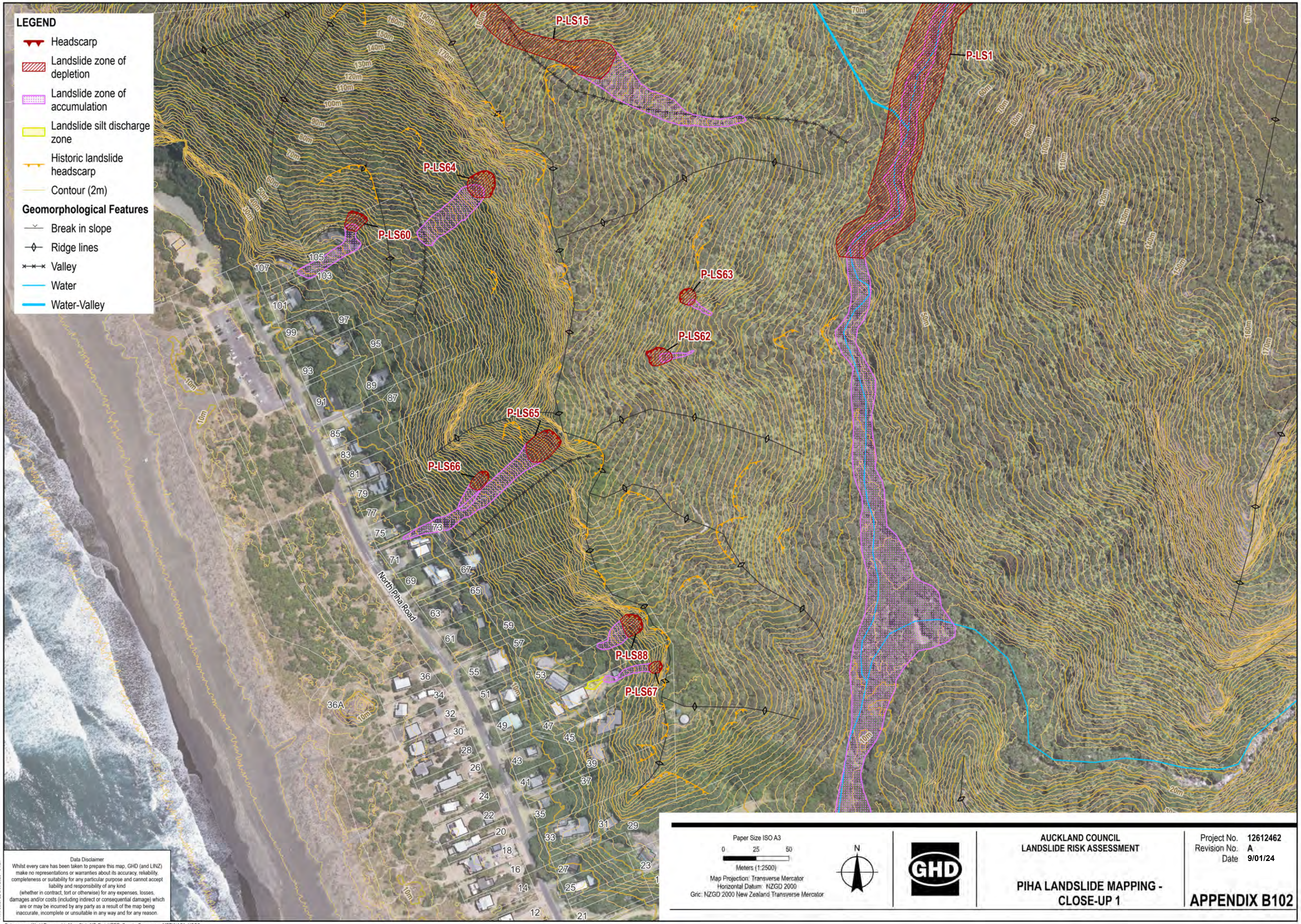

AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 1

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B102

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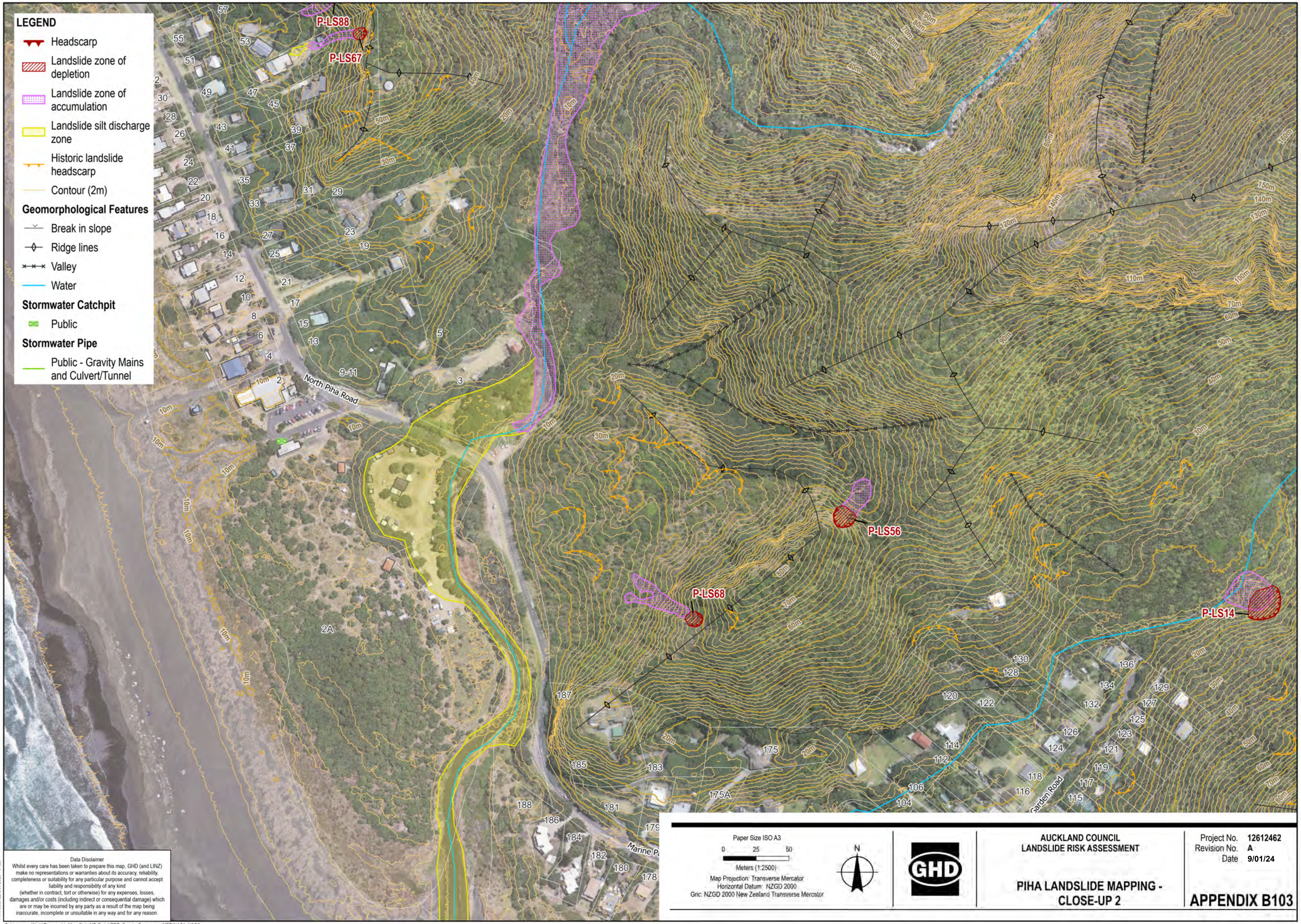
Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



Paper Size ISO A3

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Meters (1:2500)

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 2

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B103

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imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama

Paper Size ISO A3

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Meters (1:2500)

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 3

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B104

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama

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LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 4

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B105

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imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama

Data Disclaimer
Whilst every care has been taken to prepare this map, GHD (and LINZ) make no representations or warranties about its accuracy, reliability, completeness or suitability for any particular purpose and cannot accept liability and responsibility of any kind (whether in contract, tort or otherwise) for any expenses, losses, damages and/or costs (including indirect or consequential damage) which are or may be incurred by any party as a result of the map being inaccurate, incomplete or unsuitable in any way and for any reason.

Paper Size ISO A3
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Meters (1:2500)
Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 5

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B106

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Print date: 22 Dec 2023 - 04:28

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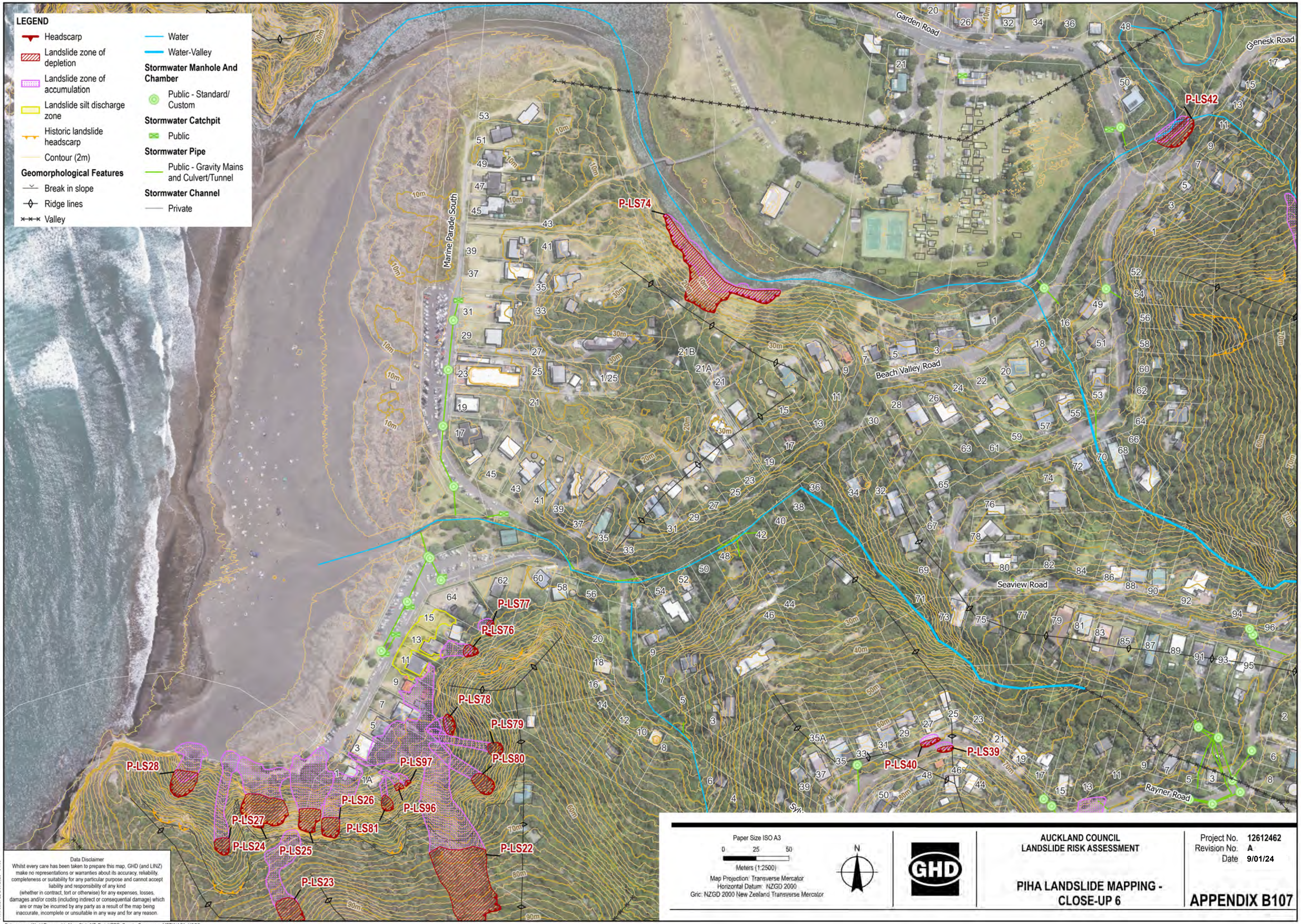

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AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 6

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B107

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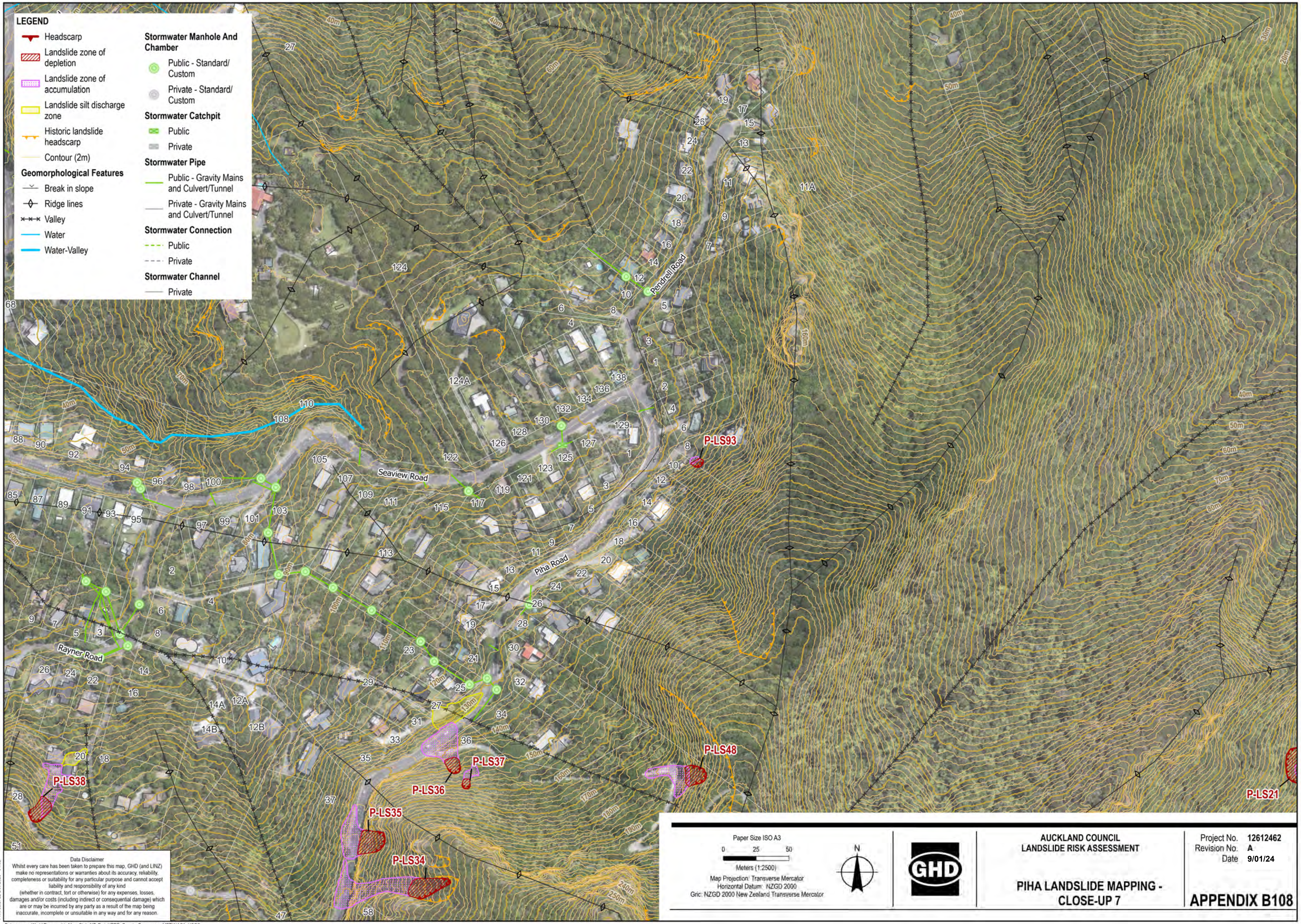

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LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 7

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B108

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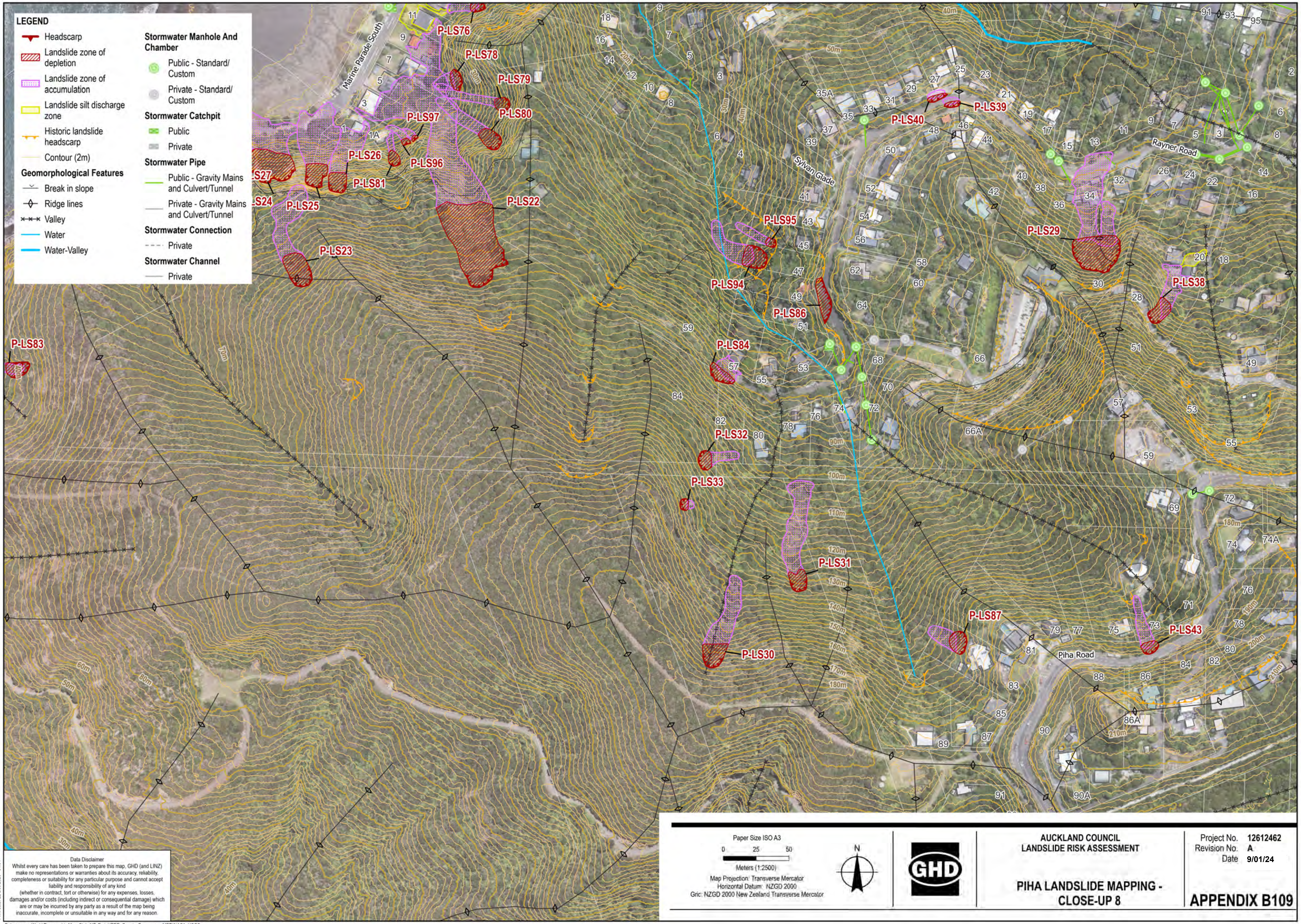

LEGEND

- Headscarp
- Landslide zone of depletion
- Landslide zone of accumulation
- Landslide silt discharge zone
- Historic landslide headscarp
- Contour (2m)

Geomorphological Features

- Break in slope
- Ridge lines
- Valley
- Water
- Water-Valley

Stormwater Manhole And Chamber

- Public - Standard/ Custom
- Private - Standard/ Custom

Stormwater Catchpit

- Public
- Private

Stormwater Pipe

- Public - Gravity Mains and Culvert/Tunnel
- Private - Gravity Mains and Culvert/Tunnel

Stormwater Connection

- Private

Stormwater Channel

- Private

Paper Size ISO A3
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Meters (1:2500)
Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 8

Project No. **12612462**
Revision No. **A**
Date **9/01/24**

APPENDIX B109

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Print date: 22 Dec 2023 - 04:34

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
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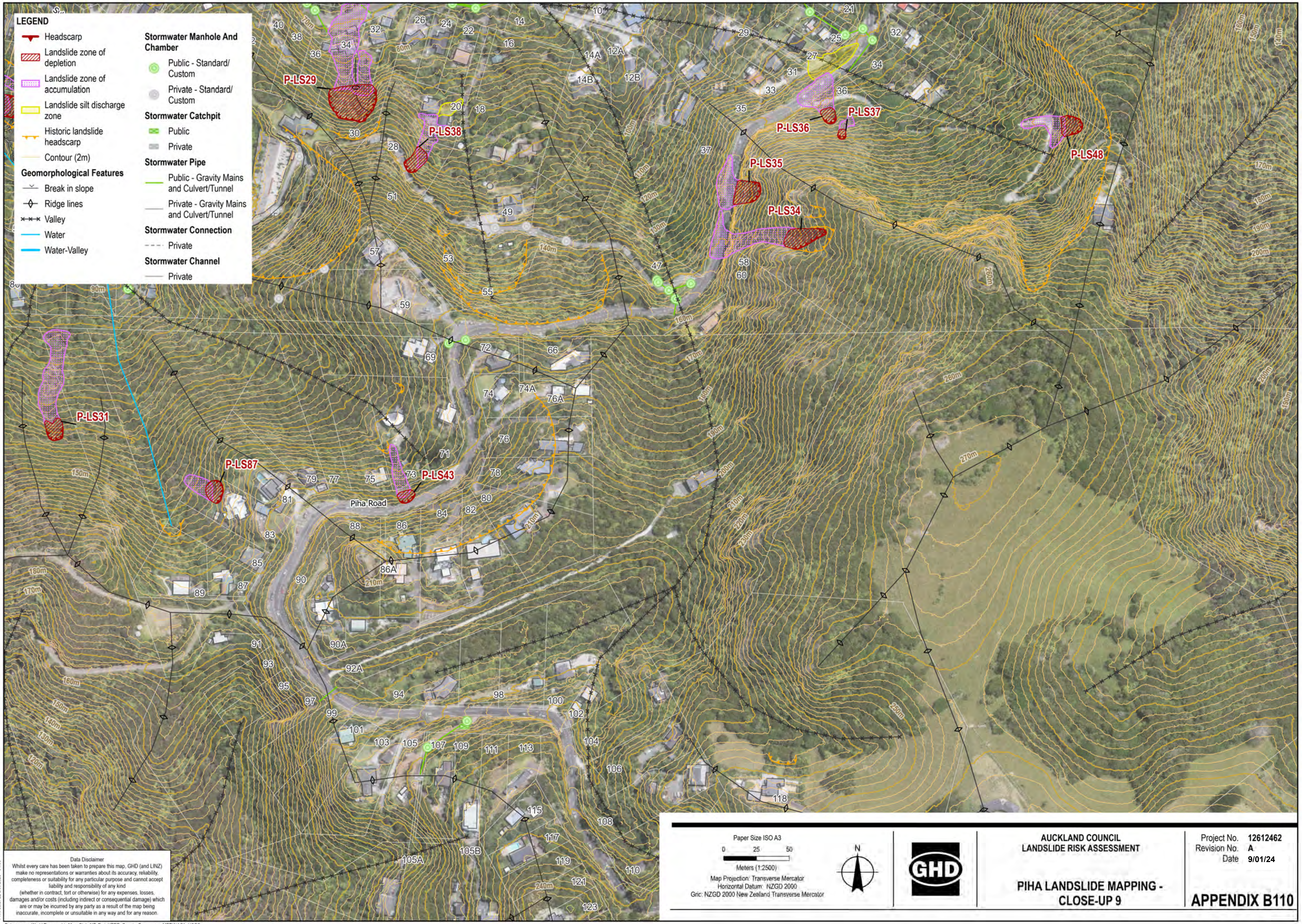
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



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AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

PIHA LANDSLIDE MAPPING - CLOSE-UP 9

Project No. 12612462
Revision No. A
Date 9/01/24

APPENDIX B110

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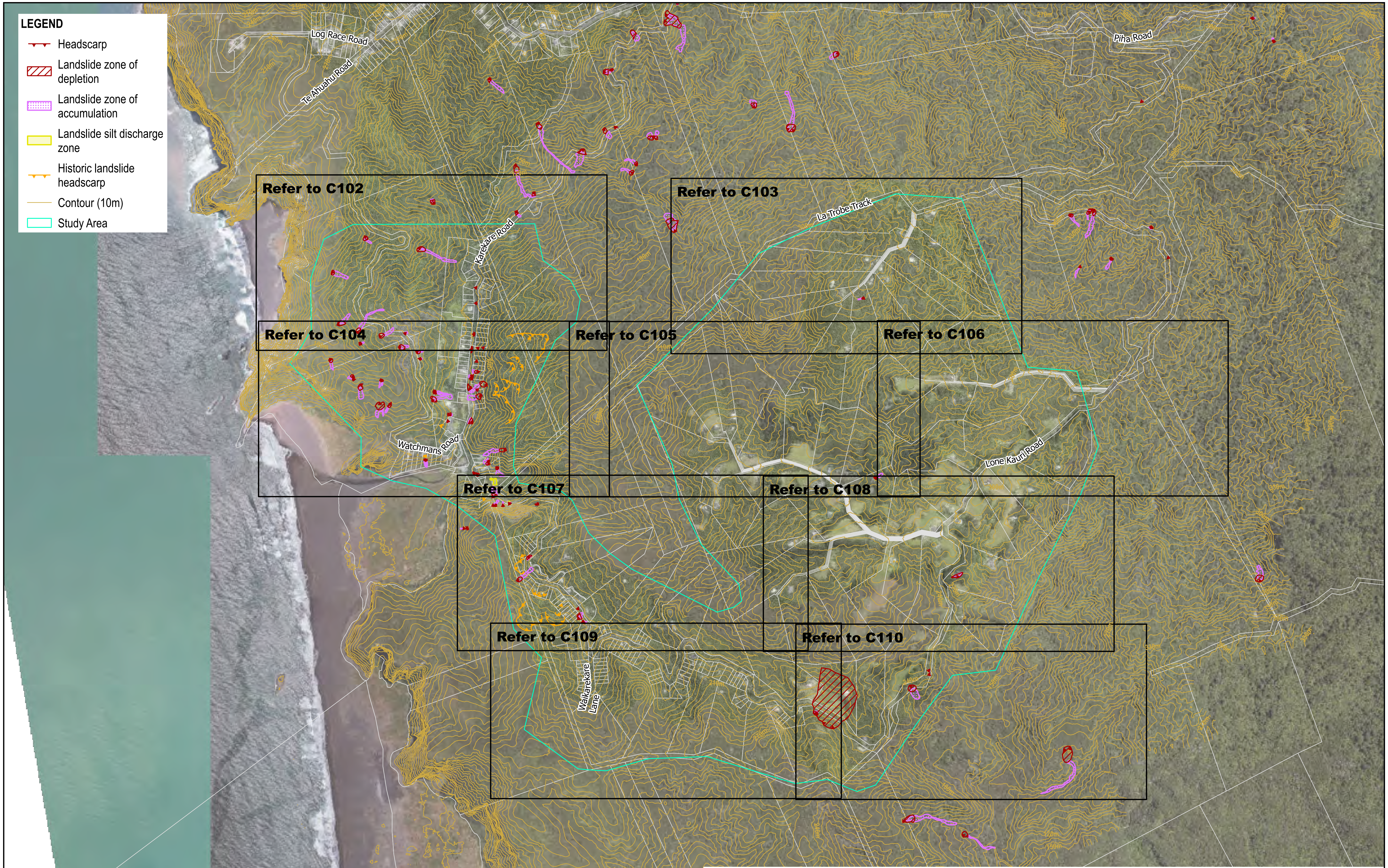
Print date: 22 Dec 2023 - 04:36

Appendix C

Landslide Maps for Karekare



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LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING- OVERVIEW

Project No. **12612462**
Revision No. **0**
Date **22/12/2023**

APPENDIX C101

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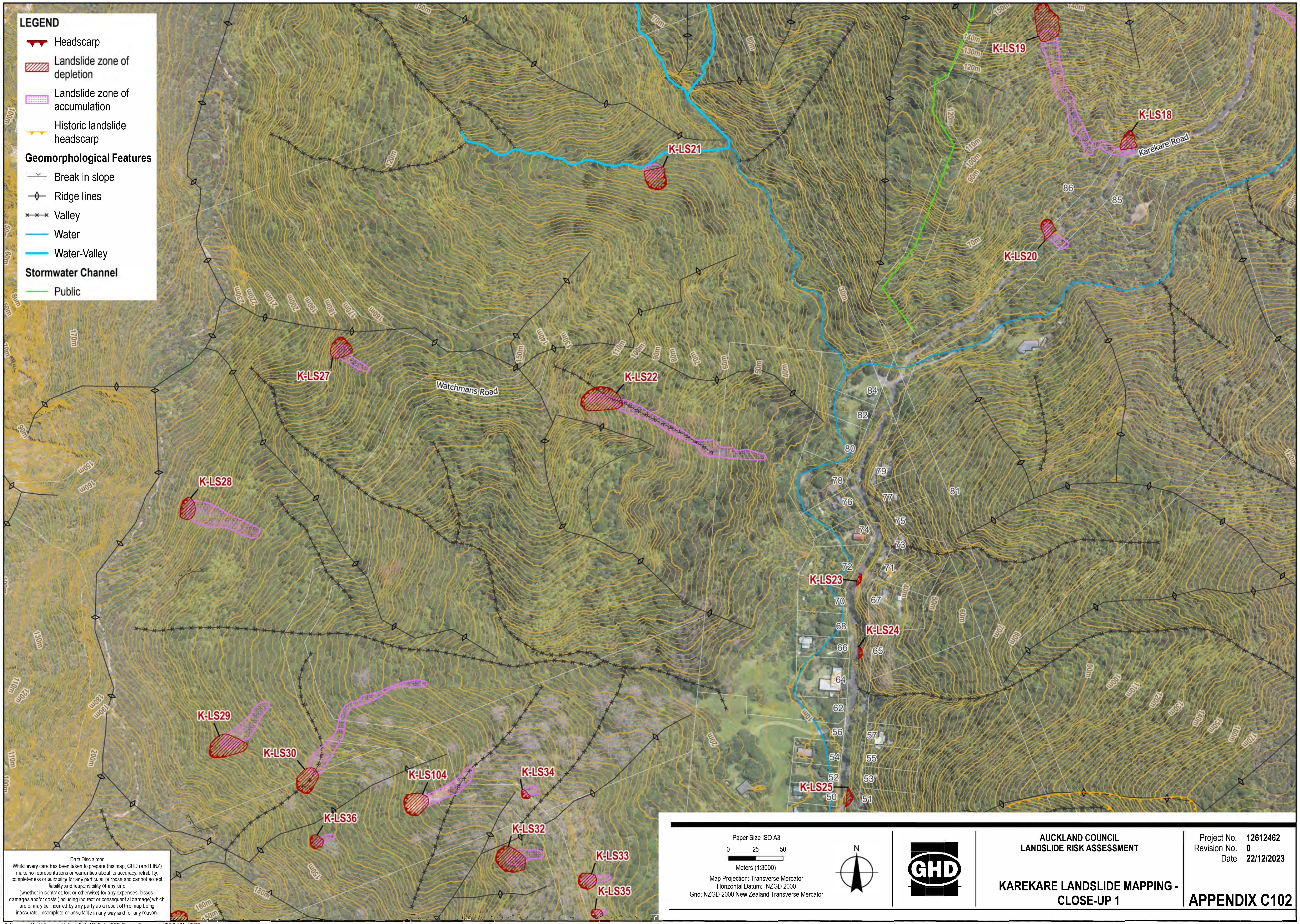
Print date: 09 Jan 2024 - 17:35

Data source: World Topographic Map: Stats NZ, Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS
imagery: Deprecated Basemap - Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: schen4



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Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 1

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C102

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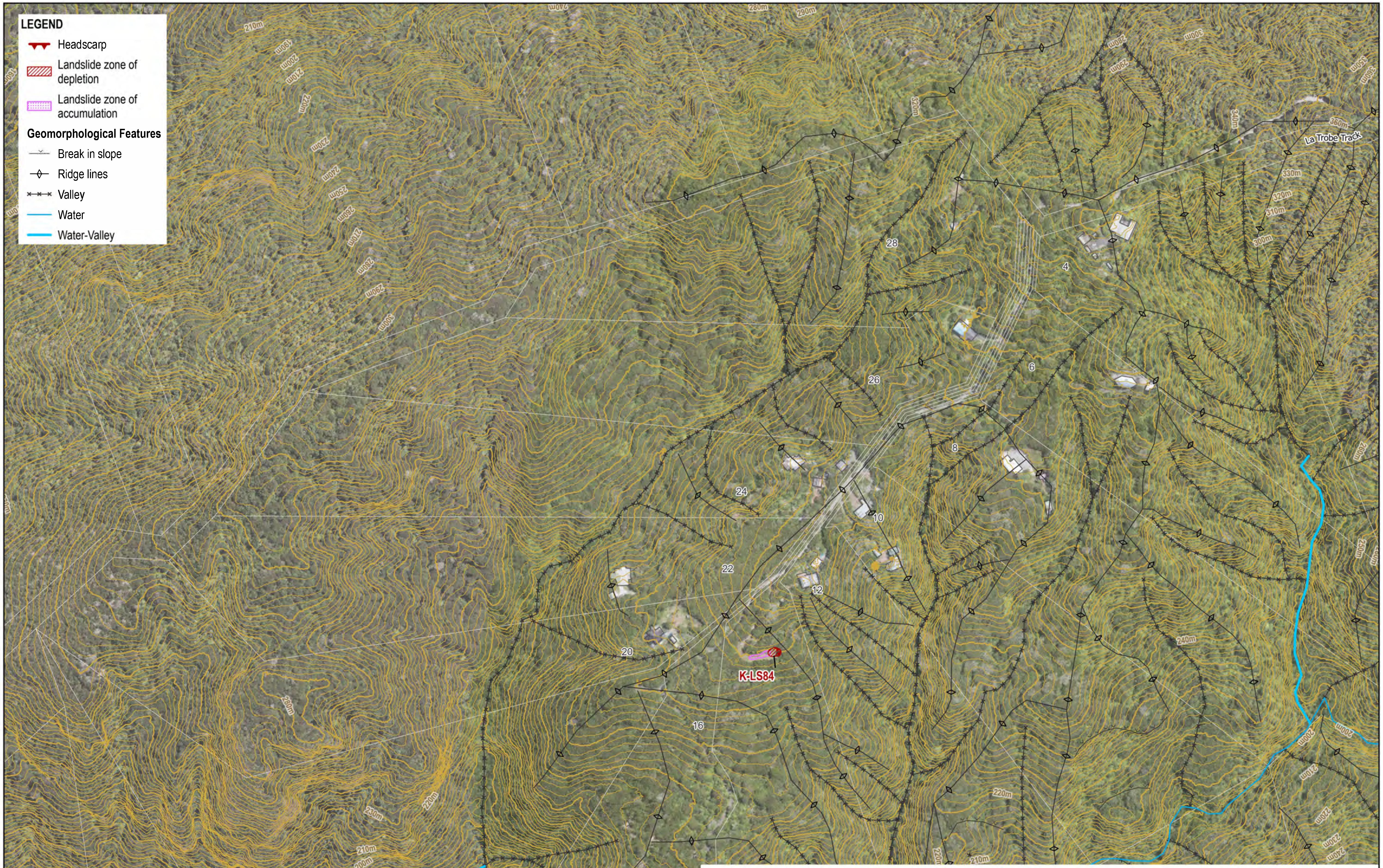
Print date: 22 Dec 2023 - 11:46

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 2

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C103

Paper Size ISO A3
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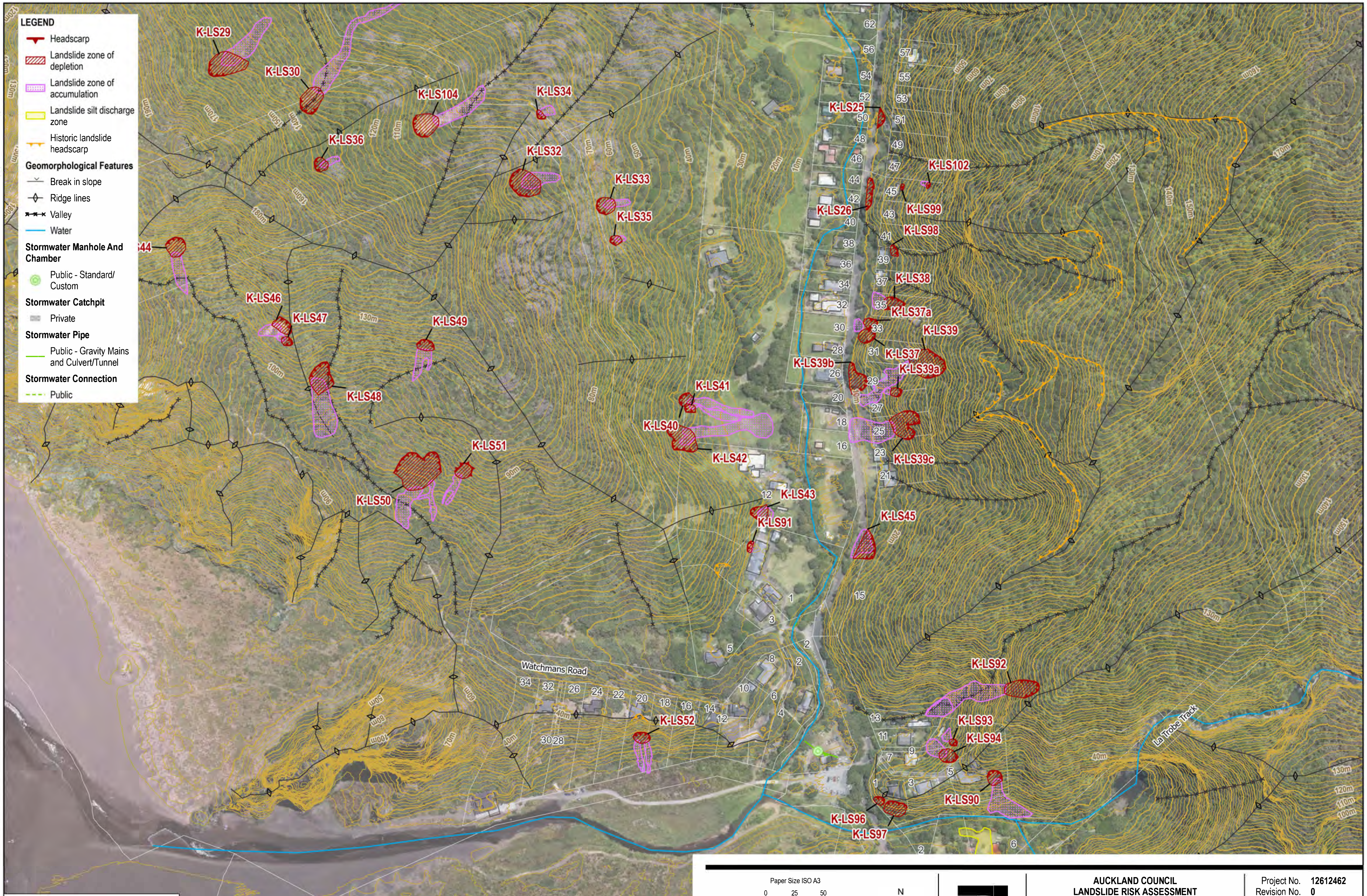
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 3

Paper Size ISO A3
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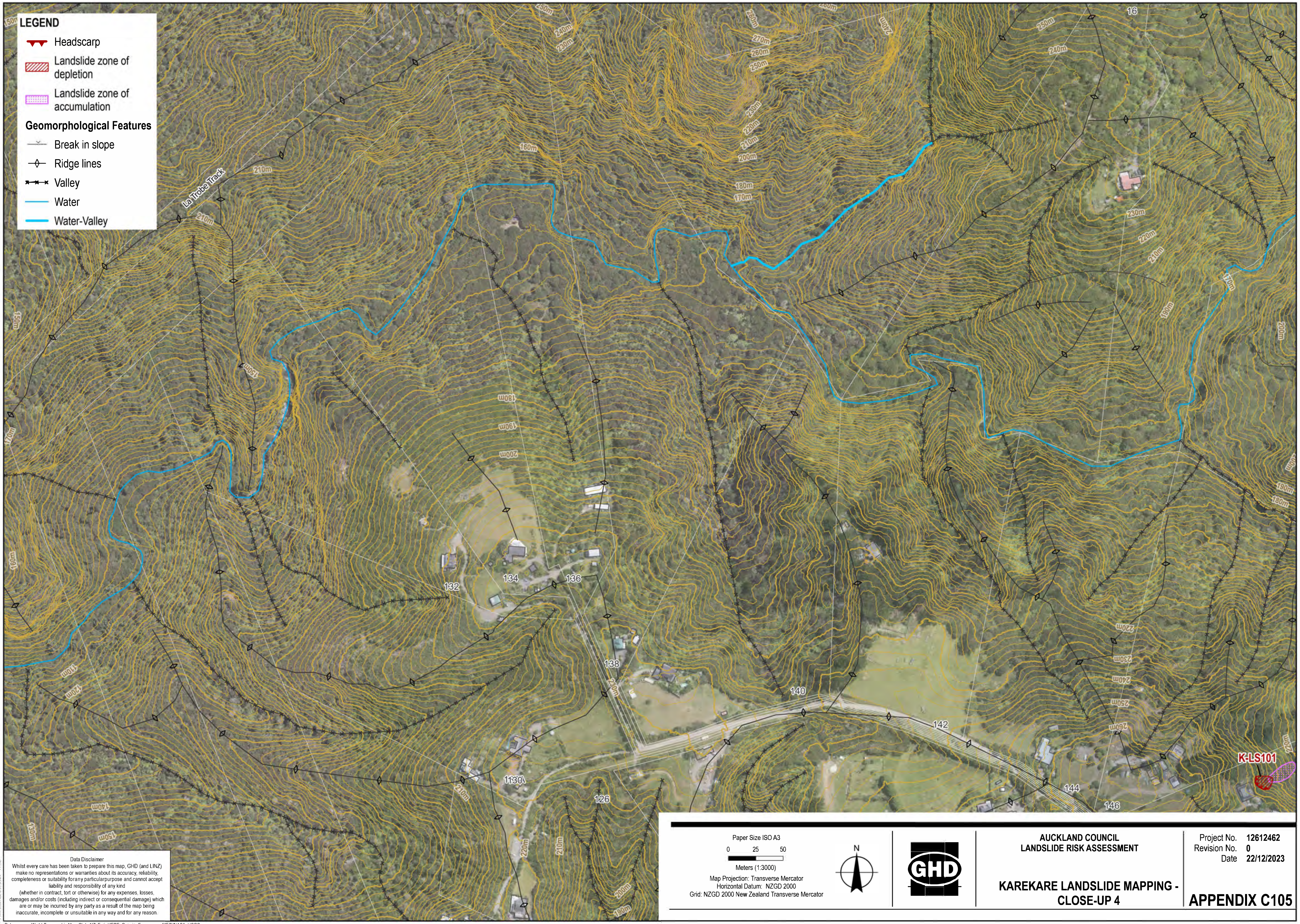
Meters (1:3000)
Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C104

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



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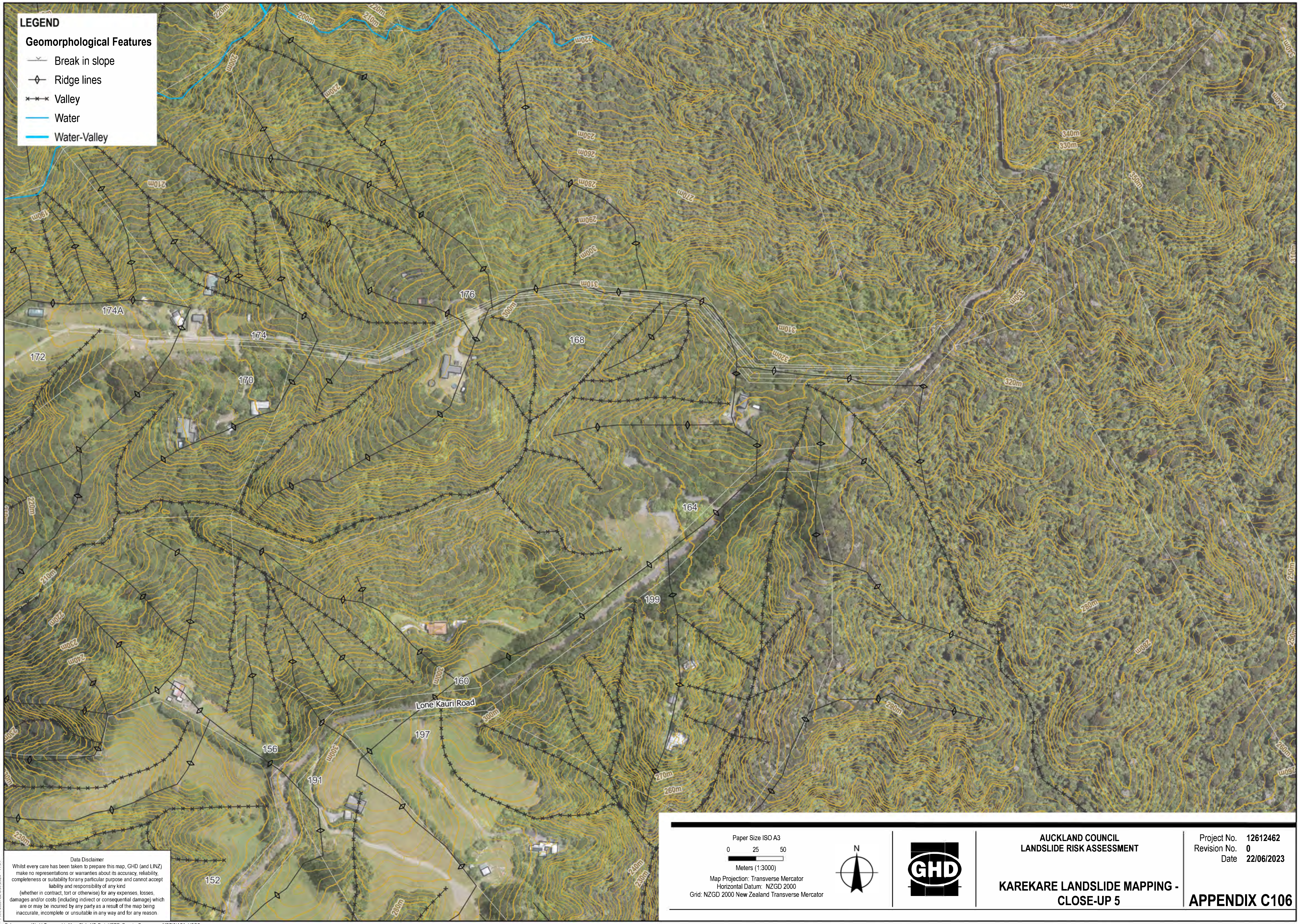
AUCKLAND COUNCIL
LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 4

Project No. **12612462**
Revision No. **0**
Date **22/12/2023**

APPENDIX C105

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



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Paper Size ISO A3
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Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

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LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 5

Project No. 12612462
Revision No. 0
Date 22/06/2023

APPENDIX C106

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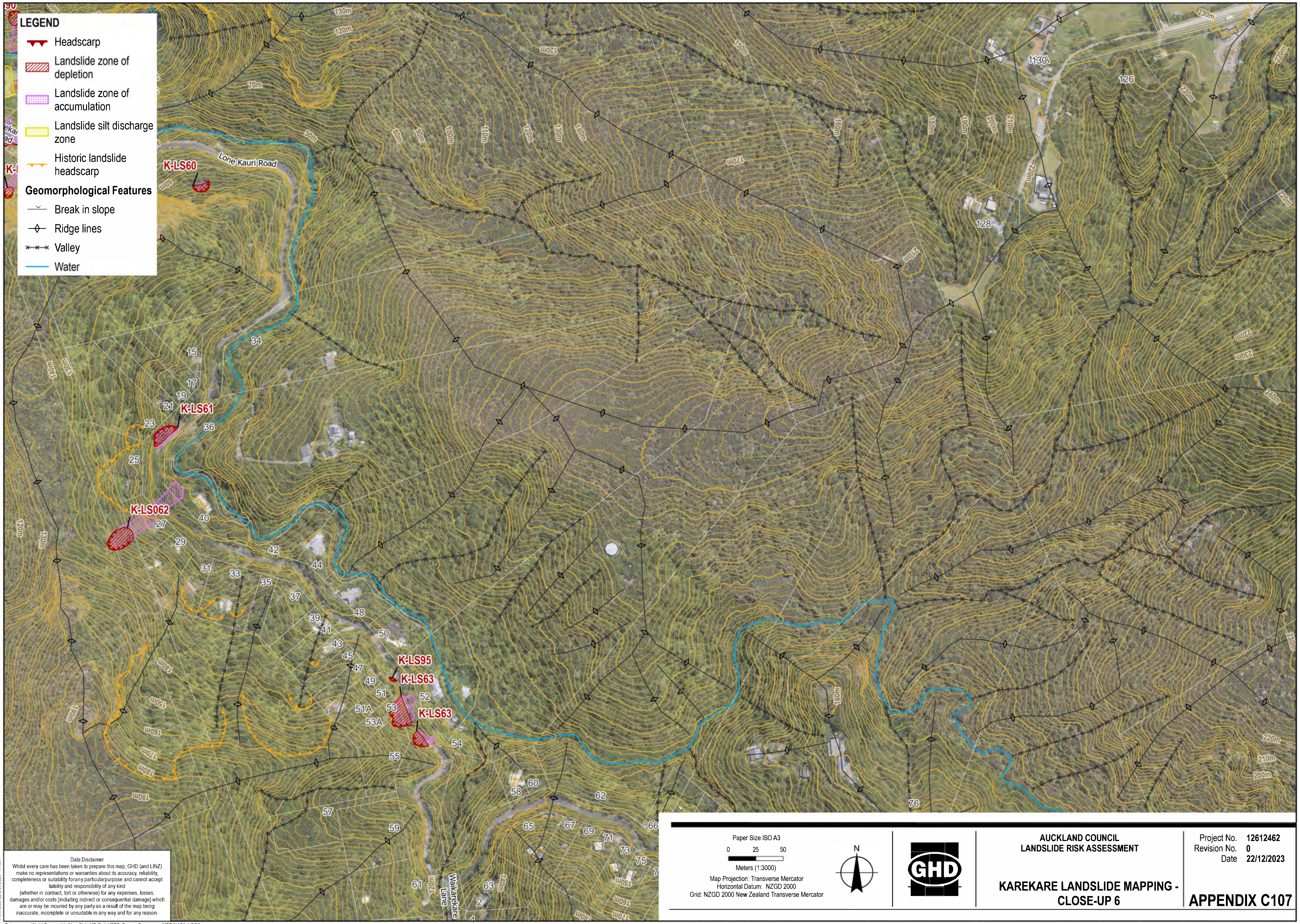
imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama



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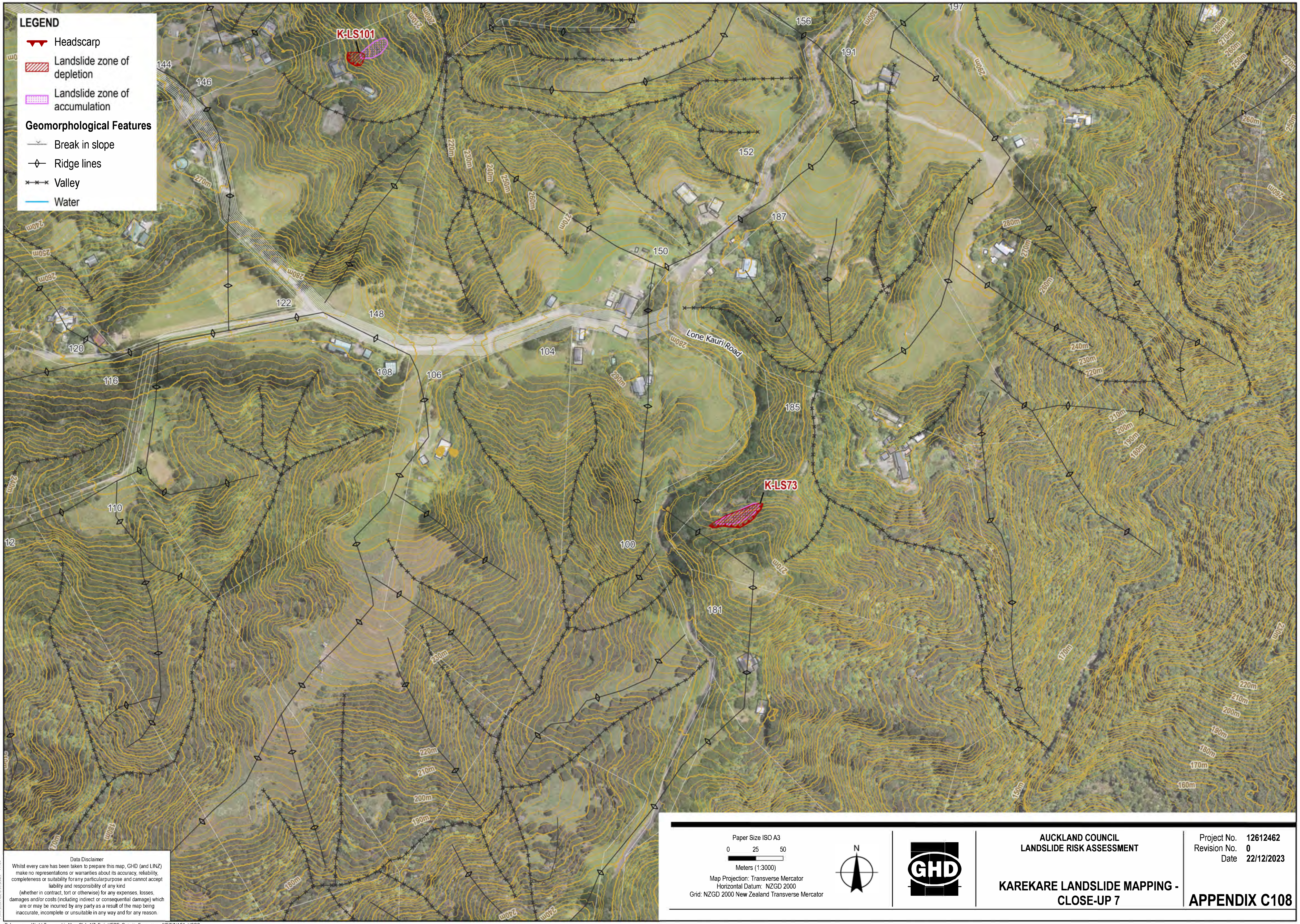

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LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 7

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C108

Print date: 22 Dec 2023 - 11:58

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Meters (1:3000)
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LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 8

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C109

Data source: World Topographic Map: Stats NZ, Esri, HERE, Garmin, Foursquare, METI/NASA, USGS
Imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
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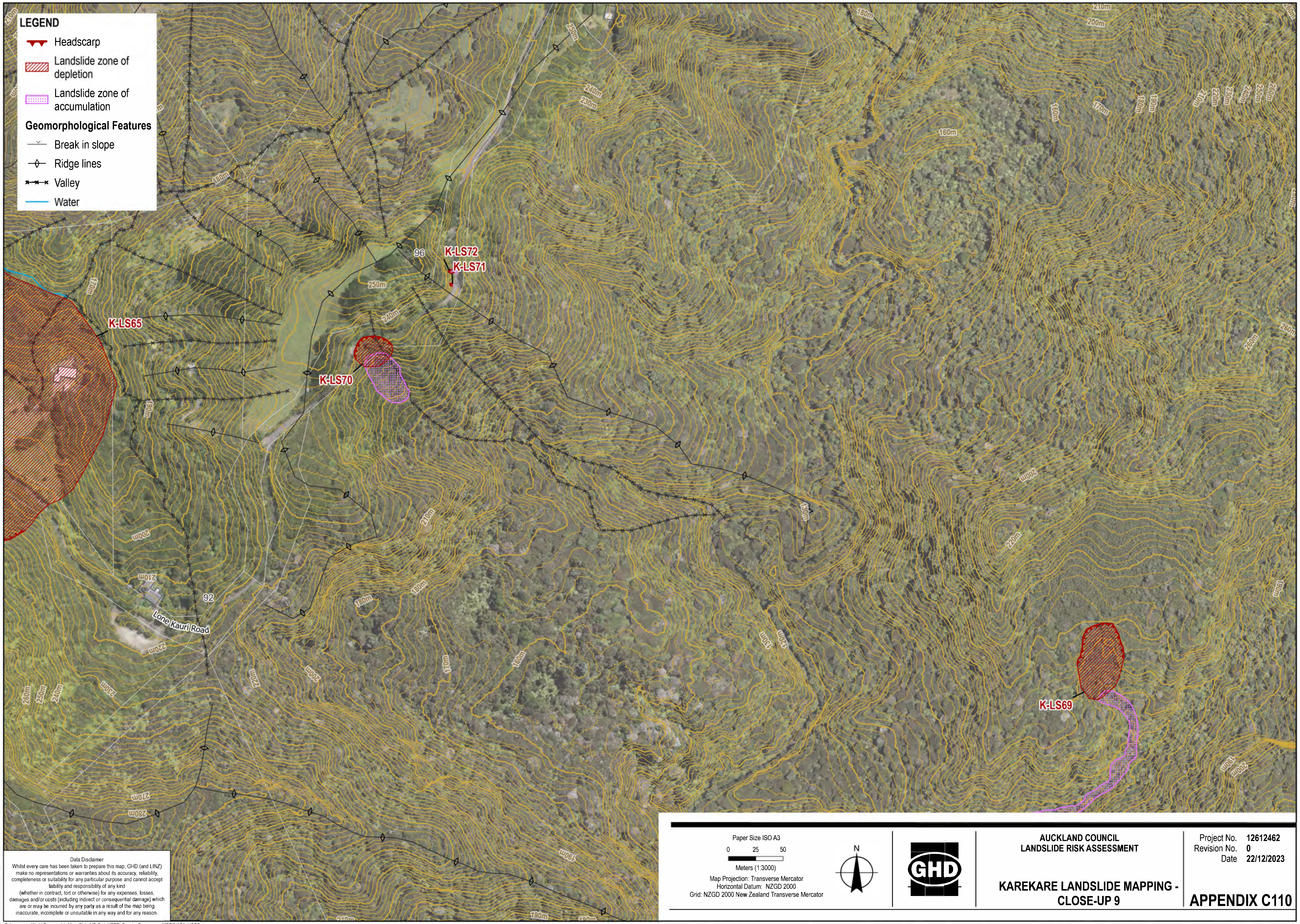

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LANDSLIDE RISK ASSESSMENT

KAREKARE LANDSLIDE MAPPING - CLOSE-UP 9

Project No. 12612462
Revision No. 0
Date 22/12/2023

APPENDIX C110

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Print date: 22 Dec 2023 - 12:01

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imagery: Eagle Technology, Land Information New Zealand, GEBCO, Community maps contributors
World Hillshade: Esri, NASA, NGA, USGS; GHD - Site boundary, Placard status, Cross Sections - 20230626. AC-DTM -20230626, LINZ - Parce, road - 20230626 Created by: nrama

Appendix D

Properties receiving site specific risk assessments

Properties/property groups receiving specific risk assessments.

Piha (single report for each property or group of properties)

Property Name
28 Garden Road
35, 39, 41 Garden Road
113 Garden Road
51 Glenesk Road
8 & 10 Seaview Road
16-18 Seaview Road
20 Rayner Road
32,34,36, Rayner Road
43, 45, 47 Rayner Road
49,51 Rayner Road
57 Rayner Road
8,10 Piha Road
73,75 Piha Road
81 and 83 Piha Road
21B Beach Valley Road

Marine Parade (single report including all of the properties listed below)

1 Marine Parade South
1a Marine Parade South
3 Marine Parade South
5 Marine Parade South
7 Marine Parade South
9 Marine Parade South
11 Marine Parade South
13 Marine Parade South
15 Marine Parade South
64 Beach Valley Road

North Piha (single report including all of the properties listed below)

45 North Piha Road
47 North Piha Road
65 North Piha Road
67 North Piha Road
69 North Piha Road
71 North Piha Road
73 North Piha Road
75 North Piha Road
77 North Piha Road
103 North Piha Road
105 North Piha Road
31 North Piha Road
33 North Piha Road
35 North Piha Road
37 North Piha Road
39 North Piha Road
41 North Piha Road
43 North Piha Road
49 North Piha Road
51 North Piha Road
53 North Piha Road
55 North Piha Road
57 North Piha Road
59 North Piha Road
61 North Piha Road
63 North Piha Road
79 North Piha Road
81 North Piha Road
83 North Piha Road
85 North Piha Road
87 North Piha Road
89 North Piha Road
91 North Piha Road
93 North Piha Road
99 North Piha Road
101 North Piha Road
107 North Piha Road

Karekare

1 Karekare Road
5 Karekare Road
7,11 Karekare Road
9 Karekare Road
13 Karekare Road
21, 23, 25 Karekare Road
27, 29, 31 Karekare Road
33, 35 Karekare Road
37, 39 Karekare Road
43, 45 Karekare Road
51 Karekare Road
1 Watchmans Road
20, 22 Watchmans Road
6 Lone Kauri Road
25,27, 29 Lone Kauri Road
40 Lone Kauri Road
47, 49 Lone Kauri Road
52 Lone Kauri Road
90 Lone Kauri Road
92 Lone Kauri Road
148 Lone Kauri Road

Appendix E

Risk Assessment Methodology

E-1 Overview

This appendix document outlines the methods and procedures used to estimate risks to loss of life for the person-most-at-risk at the site described in the covering report. This document should be read in conjunction with the covering report as it contains information not presented in the covering report. This document should not be separated from the main report.

E-2 Landslide Risk Management Framework

E-2-1 Background

The 1998 Thredbo landslide, in which 18 persons were killed, highlighted the challenges faced from building upon steep slopes and led to the development of the Australian Geomechanics Society Landslide Risk Management guidelines, published in 2007 and now commonly referred to as AGS (2007). The suite of guidelines is recognised nationally (Australia) and internationally as world-leading practice. The reader of this report is encouraged to consult the freely available LRM resources which can be accessed at: https://landsliderisk.org/.

The ”Practice Note Guidelines for Landslide Risk Management” (AGS 2007c), provide technical guidance in relation to the processes and tasks undertaken by geotechnical practitioners who prepare LRM reports including appropriate methods and techniques. The Practice Note is a statement of what constitutes good practice by a competent practitioner for LRM, including defensible and up to date methodologies and provides guidance on the quality of assessment and reporting, including the outcomes to be achieved and how they are to be achieved.

The framework for landslide risk management is presented in the figure below and represents a framework widely used internationally.

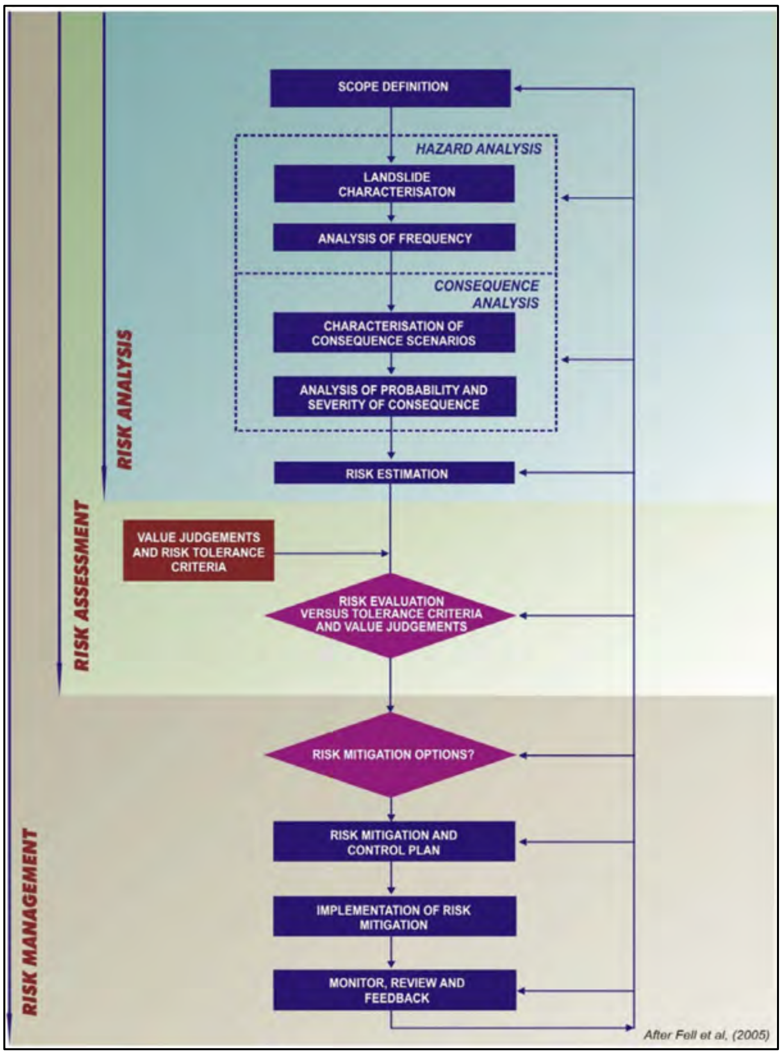

Figure E.1 Framework for landslide risk management.

E-2-2 Risk Estimation Methodology

AGS (2007c) requires risks to loss of life to be estimated quantitatively for the person-most-at-risk. The person-most-at-risk will often but not always be the person with the greatest spatial temporal probability (i.e. the person most exposed to the risk). The Individual Risk-to-Life is defined as the risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the landslide; or who follows a particular pattern of life that might subject him or her to the consequences of the landslide. The risk of ‘loss-of-life’ to an individual is calculated from:

$$\mathbf{R}_{(LoL)} = \mathbf{P}_{(H)} \times \mathbf{P}_{(S:H)} \times \mathbf{P}_{(T:S)} \times \mathbf{V}_{(D:T)}$$

Where:

$\mathbf{R}_{(LoL)}$ is the risk (annual probability of death of an individual).

$\mathbf{P}_{(H)}$ is the annual probability of the landslide (event).

$\mathbf{P}_{(S:H)}$ is the probability of spatial impact of the event impacting an individual taking into account the travel distance and travel direction given the event. For example, the probability of an individual in a building or in the open being impacted by a rockfall / landslide at a given location.

$\mathbf{P}_{(T:S)}$ is the temporal spatial probability (e.g. of the building or location being occupied by the individual at the time of impact) given the spatial impact and allowing for the possibility of evacuation given there is warning of the event occurrence.

$\mathbf{V}_{(D:T)}$ is the vulnerability of the individual (probability of loss of life of the individual given the impact).

E-2-3 Landslide Risk Assessment Uncertainty

The process of risk assessment involves estimation of likelihood, consequence and risks based on available information for the study site. By its very nature, much of the data, including historical and current inventories may be incomplete whilst an understanding of the triggering events has a degree of uncertainty attached to it. Judgement is required to estimate the nature and size of potential hazards, their frequency of occurrence and their impact on a variety of elements at risk. As these judgements are based on the knowledge, experience and understanding of the assessor, it is not unusual for different assessors to make different judgements about the level of risk.

The thought process used in establishing likelihoods, consequences and determining spatial and temporal factors for properties in Piha and Karekare has been documented for transparency. The structure of the risk assessment process is well defined and values for some input parameters have been tabulated to guide standard approaches by different assessors. However, this should not be mistaken for precision given the limitations of the inputs outlined above. Generally, the levels of likelihoods and risks should be thought of as being within a range of typically +/- half an order of magnitude.

While the basis for the judgements contained in this report are well documented, and the levels of risk considered to be good representations of reality, the accuracy and precision of the process should not be overestimated and should always be used in an appropriate manner in combination with risk management including mitigation and treatment options.

E-3 Hazard Characterisation

AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This is generally a predictive exercise based on knowledge and understanding of the geological and geomorphological setting with a view to assembling historical evidence for past hazard events.

E-3-1 Defining the Most Likely Significant Landslide

The observed landslides within the Karakare and Piha areas were generally noted to be shallow translational slides developed in the upper residual profile of the Piha Formation which, under saturation, transition into debris flows. An analysis by GHD of the mapped landslides within the Karekare and Piha areas, which included size, estimated volume, travel distance and travel angle, was undertaken to characterise the nature and distribution of landslides following the rainfall events that occurred in early 2023, particularly the Cyclone Gabrielle rainfall event.

A total of 80 landslides were mapped throughout Karekare and Piha following the storm events in Jan and Feb 2023. These landslides were then grouped into categories of volume in 50 m^3 increments. Results for an assessment of “frequency as categorised by volume” is shown in the graph below.

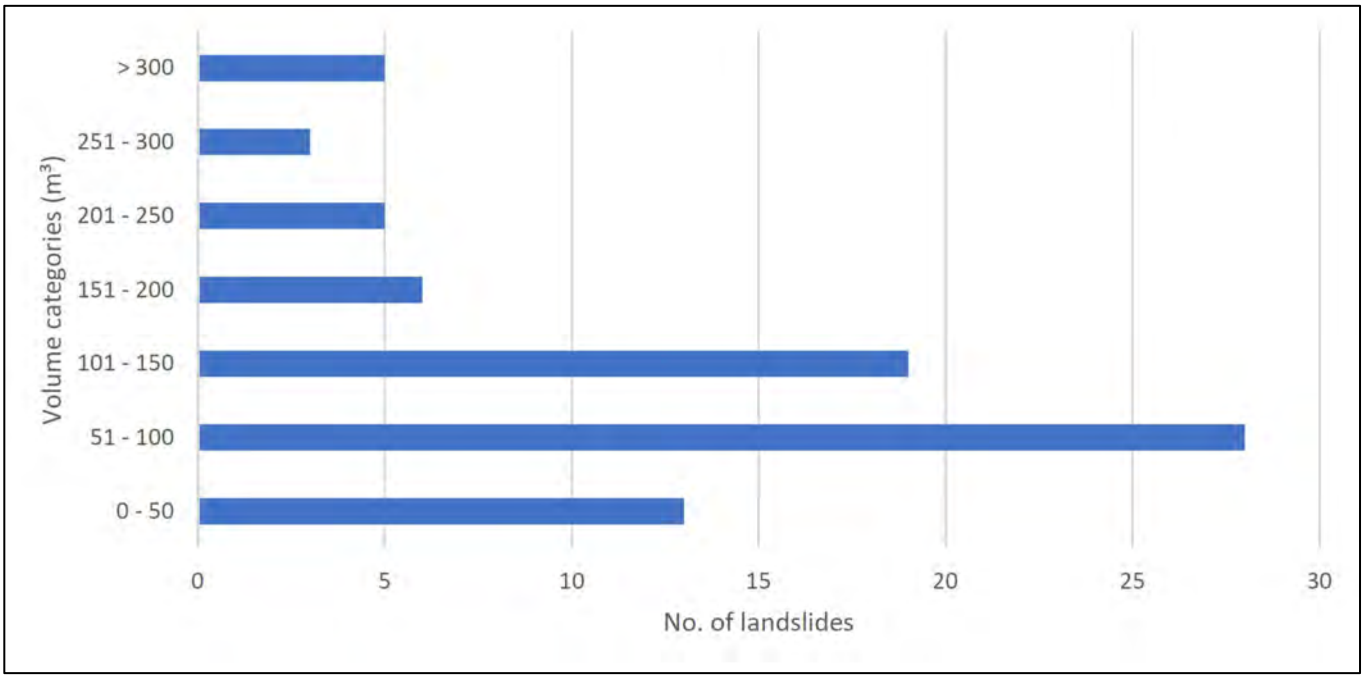

Figure E.2 The number or frequency of mapped debris flows (on the x axis) as categorised by volume increments for mapped source areas of debris flows (on the y axis in m^3) in Karekare and Piha.

In addition, detailed information regarding volume size, travel angle, travel distance, confinement (either unconfined or channelized) and the degree of damage caused by slides impacting dwellings and building was also collated and a number of additional graphs were developed as below:

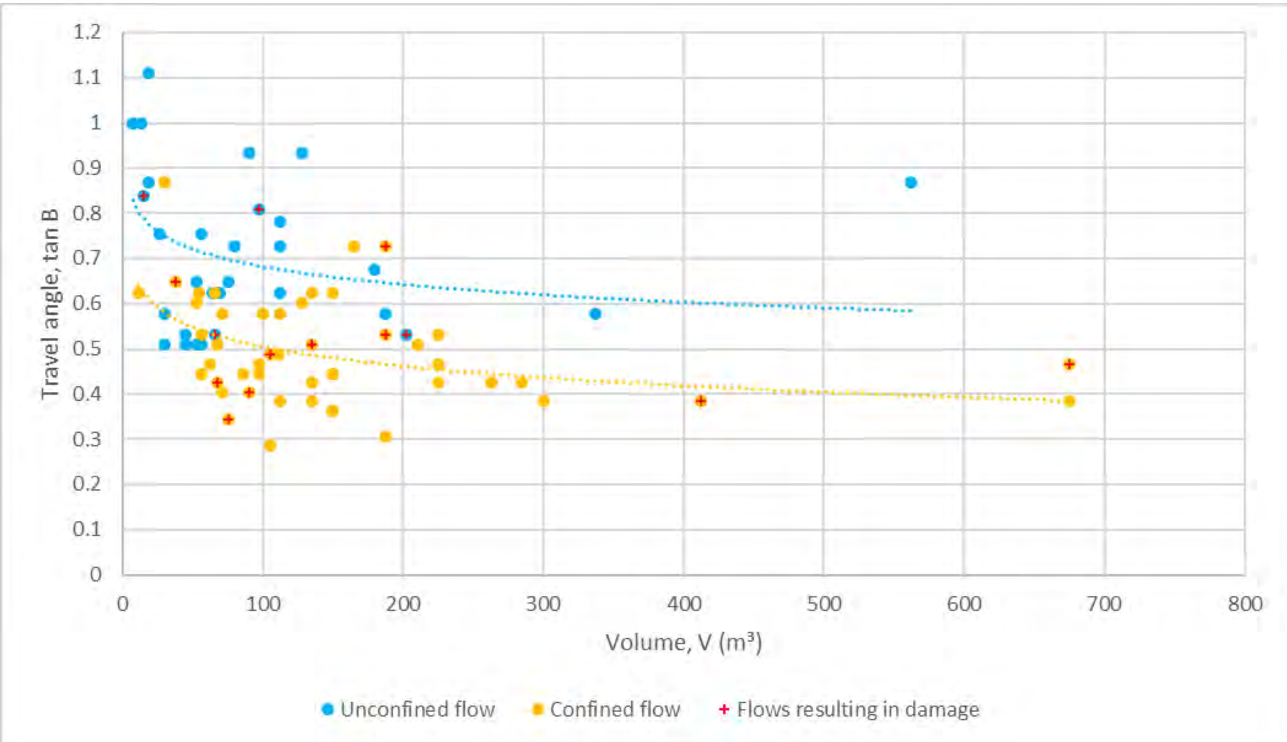

Figure E.3 Travel angle vs volume of source area for the Karekare and Piha debris flows

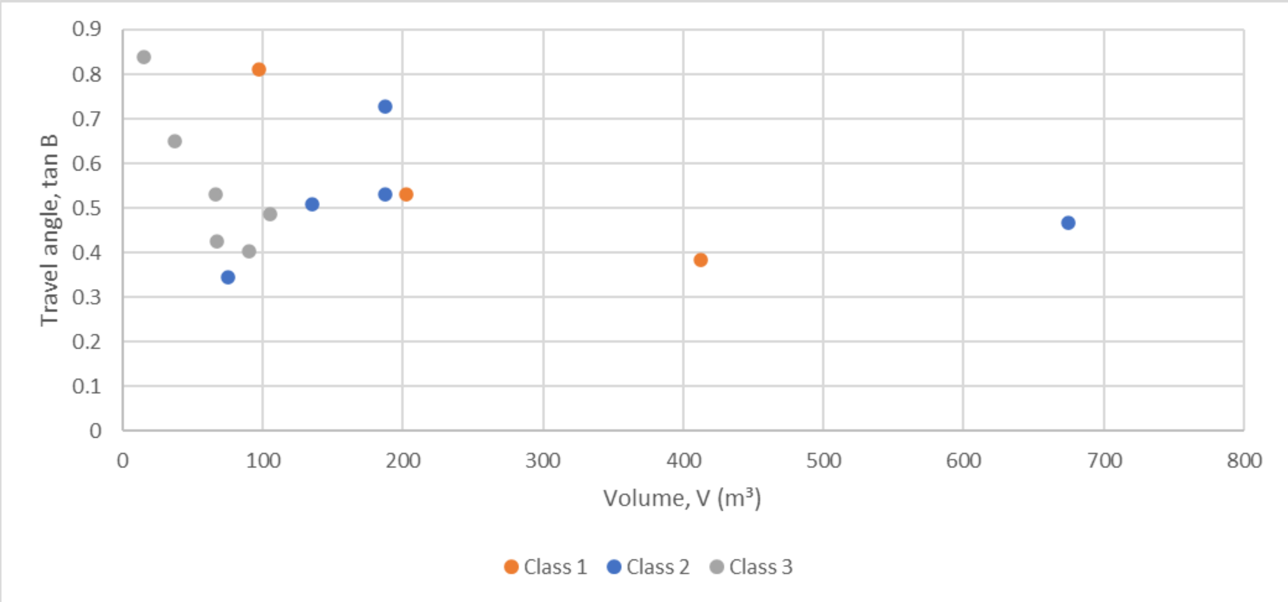

Figure E.4 ***Plot of only those debris flows known to have caused some degree of damage to dwellings and buildings. Note Class 1 = Complete destruction/collapse of building, Class 2 = Partial destruction/collapse of building, significant inundation and Class 3 = Limited damage to building but no collapse or inundation, damage is other property infrastructure e.g., access stairs.***

This assessment highlights a number of important points relating the nature of these hazards including:

– Whilst a range of volumes of source areas for debris flow was noted, the most common or likely sized event was of the order of 50-100 m^3 as determined by the frequency plot.
– Many smaller volume source areas for debris flows (less than $75m^3$) typically only caused some lesser damage to buildings but once the volume increased above 100 m^3, then the vast majority of debris flows were noted to have caused partial or full collapse of dwellings and buildings.
– The greater the volume of the source area, the lower the travel angle and the greater the runout or travel distance.
– Unconfined debris flows generally have a higher travel angle compared to confined or channelized debris flows of the same volume. This means that confined or channelised debris flows have a longer runout or travel distance and hence have more potential to impact elements at risk further down the slope.

Based on this site-specific data and analysis, GHD has adopted a working definition for these risk assessments of what is termed the **most likely significant landslide** as follows:

– The volume of most likely significant landslides is assumed to be 100 m^3.
– This volume has been shown to cause significant building damage resulting in partial to full dwelling and building collapse.
– As a result, this hazard is considered to have a high probability for causing loss of life.
– Where this hazard is unconfined, the adopted travel angle based on Figure E.3 has been taken as Tan (B) = 0.69 or approx. = 35°
– Where this hazard is confined or channelised the adopted travel angle based on Figure E.3 has been taken as Tan (B) = 0.50 or approx. = 26.5°
– Comparison with Figure 6 from Hunter and Fell (2002) suggests the site derived travel angles are generally consistent with other data presented in that plot.

The definition of the **most likely significant landslide** is considered to be a reasonably conservative but not overly cautious estimate of the potential hazard that may affect the site. This is based on an assessment of an overview of landslides that occurred at Karekare and Piha during the previous event.

It is noted however that in some specific circumstances, larger recent debris flows may have occurred in close proximity to the site under investigation. As such, where there is evidence for a larger hazard, the assessor may choose to adopt a larger volume event based on judgement and knowledge of that particular site. In this case other values for travel angle can be read from Figure E.3.

IMPORTANT NOTE: It is duly acknowledged that volume alone does not necessarily account for the full potential of a debris flow to cause significant damage and other factors such as the degree of channelization, the additional entrainment of volume within a channel, the degree of saturation of the debris materials, the location of the source area on the hillslope, the direction of travel, the distance of travel and the velocity of the hazard at the point of impact all play important roles in the destructive capacity of any debris flow. Some of these factors are considered within the risk assessment process as conditional probabilities in spatial considerations.

E-3-2 Description of Other Landslide Types

As discussed in the scope of the covering report, other landslide hazards may exist at the site under assessment. These may include existing geohazards that have resulted from recent failures with the potential to pose risk to life in the immediate short-term (i.e. within the next few years) such as regression of translational failures to occur downslope of dwelling, failure of over-steepened fill and cut slopes, rockfall hazards associated with exposed rock faces/headscarps and/or loose debris remaining upslope of dwellings.

In addition, other possible geotechnical slope instability hazards relating to modified slopes (i.e. human made) may also exist and have potential to pose a risk to life - such as failures of fills, cuttings and failed retaining walls. This represents hazards that may have a range of likelihood from almost certain to possible.

Where appropriate, descriptions and definitions for each of these hazards are provided in the covering report on a case-by-case basis and will be specific to the observed hazard and actual conditions at this site.

E-3-3 General Descriptors for Size Classification of Landslides.

Generalized or relative descriptions of size classification systems for landslides vary significantly depending on the country of origin and the nature of the landslide hazards typically encountered. For the purposes of these assessments, GHD proposes to use the following size classification descriptions adopted from the Transport for New South Wales (TfNSW) Guide to Slope Risk Analysis Version 4 (TfNSW 2014).

Table E3.1 Landslide size classification

Relative size term	Volume range	Typical mid-range dimensions (width x length x depth in metres)
Very small	<20 m3	4 x 4 x 0.5
Small	20 to 200 m3	10 x 10 x1
Medium	200 to 2000 m3	20 x 20 x 2.5
Large	2000 to 20000 m3	40 x 40 x 5
Very large	>20,000 m3	60 x 60 x 8

E-4 Likelihood $P_{(H)}$

Likelihood or annual probability of occurrence of the landslide, $P_{(H)}$, is one of the most critical but difficult to estimate factors as part of the risk assessment process.

E-4-1 The Most Likely Significant Landslide

The recent flood / storm events, the estimation of recurrence intervals for that event and the occurrence of the observed hazards form the basis for the current estimated probability of occurrence for the most likely significant landslide hazard. However, observations of the recent events noted that not all similar slopes failed as a result of the initiating storm event and as such, an additional consideration for probability of occurrence has been included within the analysis by using conditional probabilities as follows:

$$P_{(H)} = P_{(H'1)} \times P_{(H'2)}$$

Where:

$P_{(H'1)}$ = Probability that the rainfall threshold for the most credible significant landslide is exceeded which is taken as a proxy for landslide initiation. This is assumed to be 1 in 100 or 0.01 (see analysis and discussion by Auckland Council below) or 1 in 50 or 0.02 under the influence of future climate change.

$P_{(H'2)}$ =Probability that the slope for the specific assessment fails, which relates to how many of the actual slopes failed out of the total number of all slopes present. This probability is typically based a on spatial analysis of the total area of failed landslides slopes compared to the total area of all slopes for the geomorphic setting in which the site is located.

E-4-2 Auckland Council Guidance on Frequency for Most Likely Significant Landslide

Council provided GHD with an assessment of available rainfall data associated with Cyclone Gabrielle (Auckland Council 2023) (AC memo). During Cyclone Gabrielle, the physical tipping bucket rain gauge at Piha recorded 349.5mm of rain. The AC memo also provided rainfall analysis using AC's Quantitative Precipitation Estimate (QPE) Rain Radar System, which is a real-time rainfall product which utilises the Metservice radar. The rainfall data presented by AC suggests that for the 6 to 24-hour duration the Annual Recurrence Interval (ARI) is >100 years and may be in the order of 250 years. However, we understand that the calculation above the 100-year assessment becomes increasingly unreliable, primarily as a result of the relatively short statistical rainfall records available in New Zealand.

The AC memo recommended that an envelope of "risk" is estimated as the ARI figures will change over time and as these events are incorporated into the statistical record. The AC memo states that in general, it is considered reasonable to consider the Cyclone Gabrielle event to be in the range of 100-250 year ARI. For this assessment we have assumed that the annual likelihood of a landslide event occurring that is similar in magnitude to the February 2023 event, is about 1 in 100 (i.e., 0.01). This is considered to have a *likely* probability of occurrence.

The assumption of 1 in 100 based on rainfall frequency is a simplifying and possibly conservative assumption that we consider reasonable. It does not consider other factors that could potentially affect stability (antecedent conditions, geology, groundwater conditions, slope height and angle, vegetation, surface water management-overland flow path, overflow from water storage tanks, effect of effluent disposal field), all of which are difficult to quantify.

The AC memo further recommended that risk assessment reports consider the potential for climate change to increase the frequency of high intensity rainfall. We understand that the National Institute of Water and Atmospheric Research (NIWA) has projected a 20% increase in rainfall intensity over the next 100 years which suggests that a 250-year ARI event could increase to a 50-year ARI event. Consequently, we have also included a sensitivity check based on a 50-year ARI event.

We draw the reader's attention to Section E-3 of this report and reiterate that AGS (2007c) generally states that all credible hazards originating on, above and below the sites should be assessed. This report has conformed to this requirement and assessed landslide hazards that were observable during the site mapping and/or able to be interpreted via other means such as readily available aerial photographs, lidar data etc. It should be recognised that specific hazards such as rockfalls, failed retaining walls, over-steepened cuts/fill batters may have likelihoods in the *Certain to Almost Certain* range and are more likely to occur in the short term.

E-4-3 Other Landslide Hazards

Where other slope failures and instabilities as described in Section E-3-2 are considered, individual assessments of $P_{(H)}$, the probability of occurrence, are made on the basis of expert judgment, performance of similar landslides in the area and recent site observations.

When considering hazards that may pose immediate or short-term risks to life it is probable that such hazards will have high likelihoods of occurrence that could be triggered by relatively frequent events. As a result, such hazard may have likelihoods in the *Certain to Almost Certain* range as per the ASGS2007 qualitative descriptors for likelihood.

E-5 Probability of Spatial Impact $P_{(S:H)}$

The AGS definition of spatial probability is represented by single term $P_{(S:H)}$ and is described as the probability of spatial impact by the landslide on the element at risk, given the landslide occurs and taking into account the travel distance and travel direction.

E-5-1 The Most Likely Significant Landslide - Upslope of Site

A number of conditional factors may be involved in the spatial distribution for the most likely significant landslide, and for further transparency, the following methodology has been adopted:

$$P_{(S:H)} = P_{(S':H'1)} \times P_{(S':H'2)}$$

Where:

– $P_{(S':H'1)}$ = The probability that if the landslide occurs it travels in the direction of the site under assessment. If the slopes above are consistent, and planar then probability is assumed to be 0.8 to 1.0 depending on the topography; if the originating landslide enters a channel that is directed onto the property then probability is assumed to be 1.0, or if the landslide enters a channel that is directed away from the sites then the probability is assumed to be 0.05 taking account of a small probability that the landslide may super elevate and leave the channel.

– $P_{(S':H'2)}$ = The Probability that if the landslide occurs it will travel to at least the site under assessment and will impact the property. This is to be based on two considerations as follows:

1. Modelled Behaviour based on travel distance analysis undertaken by GHD for 80 observed landslides slides in the Karekare and Piha areas (see Figure). Either probability = 1.0 if the travel angle projects past the dwelling, = 0.5 if the travel angle projects to the rear of the dwelling or = 0.0 if the travel angle falls short of the dwelling.

And/or

2. Observational behaviour: based on site observations of whether the previous landslides within close proximity to the study site, travelled sufficient distance to reach the site under assessment; if yes Probability = 1.0, if no, then probability = 0

– NOTE 1: The GHD analysis of travel distance highlights the effect of channelisation which shows confined debris flows travel further (i.e., they have a lower travel angle) than those which are unconfined on consistent or planar slopes. Such considerations are included on a site-by-site basis. Interestingly, this event-specific analysis also generally agrees with findings presented in Hunter and Fell (2002).

– NOTE 2: Where significant debris flows have occurred in close proximity to the site under assessment, and the observed travel distance is greater than that estimated using the modelled approach, the preferred GHD approach is to use the greater of the two travel distances to assess spatial impact.

E-5-2 The Most Likely Significant Landslide – Under the Dwelling/Building and/or Downslope Below the Dwelling/Building

Based on the possible failure area:

- If the failure area is > ~5 m from the dwelling then the value for $P_{(S:H)}$ will be 0 as a landslide occurring at that location will not impact dwelling. (The general assumption is that the landslide headscarp would have a length of 5m based on size of most likely significant landslide)
- If the failure area is within ~5m from the dwelling (like above) then the value for $P_{(S:H)}$ will be 0.5 to account for uncertainty of it encroaching within the footprint of the dwelling.
- If the failure area encompasses a significant portion of the dwelling then the value for $P_{(S:H)}$ will be 1.0 as there is a certain probability it will impact the dwelling.

Estimates of how far back the most significant landslide will regress are difficult to model without a detailed slope stability analysis and sufficiently accurate soil and rock inputs. This would require an intrusive geotechnical investigation which is outside the scope of this study.

GHD has adopted a more empirical approach that assesses the spatial extent of lateral downslope movement of the most likely significant landslide based on direct observations of existing landslides in close proximity to the site under assessment. In the absence of other information, a similar extent of regression has been applied to any future slides. An estimate of $P_{(S:H)}$ can then be made as to the potential interaction with the element at risk.

E-5-3 Other landslides – Upslope of the study site

Other types of potential landslides situated above dwellings and buildings on the site under assessment, should be assessed in a similar manner to the most likely significant landslide. Estimates of travel distance are taken from Hunter and Fell (2002) and/or previous local knowledge and/or observation of similar landslides in the area.

When undertaking short term assessments, hazards involving reactivation of existing landslides that are located upslope of the study site that didn't previously reach the site must be taken account. In addition, remobilisation of debris from any upslope landslides must also be assessed for their potential of runout or travel distance using Hunter and Fell (2002).

Similarly potential failures of modified slopes such as cuttings or fills located above or directly adjacent to dwellings and buildings must also be assessed for their spatial impact and the methods of assessment follow the same approach.

E-5-4 Other landslides – under buildings and downslope of the building

A similar approach to that taken for other landslides upslope has been adopted. Observation of existing failures and how much lateral downslope movement can be used as a proxy for what may occur in the future under a regression type scenario.

E-5-5 Temporal Spatial Probability $P_{(T:H)}$

These risk assessments have not considered specific occupancy scenarios for each individual residence. We acknowledge that the occupancy of each residence could vary significantly depending on the demographics of the residents and the usage of the residence. For example, some residences may be predominantly used as holiday accommodation, occupied mainly on weekends, whereas other residences could be permanently occupied by working families.

This assessment has assumed the following occupancies:

- Residences are typically occupied for 15 hours each day during weekdays;
- On weekends, residences are occupied for about 20 hours each day;
- The percentage of time a residence is occupied is therefore about 68%.

Any further delineation of the spatial variations in occupancy (i.e. if a bedroom is at the front or the rear of the house etc) are not considered feasible or warranted within the context of the precision of this assessment.

E-6 Vulnerability $V_{(D:T)}$

E-6-1 Most likely significant Landslide

AGS (2007c) includes a table of vulnerability values for various inundation and building damage scenarios as adapted by Finlay et al (1999). It is important to note that the AGS (2007c) vulnerability table doesn't adequately cater for all the building damage scenarios GHD has observed in Karekare and Piha. GHD has therefore further adapted this table and combined it with information from the TfNSW Guide to Slope Risk Analysis (2014) as well as observations of damage to buildings and structures resulting from the recent landslides in Karekare and Piha.

The table of vulnerability values used in this assessment is presented in Table E6.1. These values have been used as a guide and expert judgement has been applied to select a value within the range of values where appropriate on a site-specific basis.

Table E6.1 Summary of Vulnerability Values adopted for Karekare and Piha

Case	Range	Typical value to be used in this assessment	Comments
Person in a building that collapses under impact from debris flow	0.8 -1.0	0.9	Death is almost certain. Evacuation unlikely to occur
If building is inundated with debris and the person is buried	0.8 -1.0	0.8	Very high potential for death Evacuation unlikely to occur
If building is inundated with debris but no collapse occurs and the person is not buried	0.01 -0.1	0.1	High chance of survival Evacuation unlikely to occur
If the debris strikes the building only	0.001-0.05	0.01	Very high chance of survival
If failure occurs below the building and results in significant collapse	0.5-0.8	0.6	Moderate to high potential for death. No forewarning signs with evacuation unlikely to occur.
If failure occurs below the building and results in partial collapse	0.01 -0.1	0.05	High chance of survival. Signs of building distress should provide occupants with opportunity to take evasive action.
If failure occurs below the building and results in damage. No collapse occurs.	0.001-0.05	0.005	Very high chance of survival. Evacuation almost certain.

E-7 Risk Evaluation

The main objectives of risk evaluation are usually to compare the assessed risk to risk levels that are acceptable or tolerable to the community, and therefore to decide whether to accept, tolerate or treat the risks and to set priorities for remediation. The Tolerable Risk Criteria are usually imposed by the regulator, unless agreed otherwise with the owner/client. AGS (2007d) provides discussion and gives the AGS recommendations in relation to tolerable risk for loss of life. These are summarized in the table below.

Table E7.1 AGS Suggested Tolerable loss of life individual risk.

Situation	Suggested Tolerable Loss of Life Risk for the person most at risk
Existing Slope / Existing Development	10^{-4} per annum (1E-4 pa) or 1 in 10,000 pa
New Constructed Slope / New Development / Existing Landslide	10^{-5} per annum (1E-5 pa) or 1 in 100,000 pa

It is important to distinguish between “acceptable risks” and “tolerable risks”. AGS (2007c) states that tolerable risks are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable. Acceptable risks are risks which everyone affected is prepared to accept. Acceptable risks are usually considered to be one order of magnitude lower than the Tolerable risks.

E-8 References

Auckland Council (2023). ‘Guidelines on the use of AGS (2007) for landslide risk assessment in Auckland following the 2023 flooding and cyclone’. Memorandum dated 20 September 2023.

P J Finlay, G R Mostyn & R Fell (1999). ‘Landslides: Prediction of Travel Distance and Guidelines for Vulnerability of Persons’. Proc 8th. Australia New Zealand Conference on Geomechanics, Hobart. Australian Geomechanics Society, ISBN 1 86445 0029, Vol 1, pp.105-113.

Hunter. G., & Fell. R. (2002).’ Estimation of Travel Distance for Landslides in Soil Slopes’. Australian Geomechanics, Vol 37, No2.

New South Wales Government, Transport for New South Wales ‘Guide to Slope Risk Analysis’ Version 4, April 2014.

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