Waikato District Council
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Tuakau Structure Plan

Geotechnical Suitability Assessment

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Geotechnical Suitability Assessment

Client: Waikato District Council

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Executive Summary

The Waikato District Council (WDC) engaged AECOM New Zealand Limited (AECOM) to undertake an assessment of the geotechnical constraints within the study area for the Tuakau Structure Plan. Geotechnical constraints are natural hazards (geohazards) that can impact on developments or be adversely affected by development.

AECOM has undertaken a desk study of the potential geohazards within the Tuakau Structure Plan study area. The desk study has comprised:

- A review of natural hazard regulations related to development,
- A review of relevant geological maps and topographical maps,
- A review of aerial photography within the public domain,
- Experience of development issues within the study area,
- Review of site hazard information supplied by the Waikato District Council.

The Tuakau Structure Plan study area covers approximately 6000 Hectares of predominately rural farmland. The topography can be broadly grouped into gently rolling hills, and steep ridges with plateaus.

The gently rolling hills encompass the township south of the North Island Main Trunk Railway and the land to the south and west.

The steep ridges are to the east of the town and to the north of the North Island Main Trunk Railway Line. In some locations there are broad plateaus on the ridges.

The key geohazards identified within the Tuakau Structure Plan study area are:

- Settlement of soft soils and has potential to damage structures and infrastructure within the areas underlain by alluvial soils.
- Slope instability has the potential to affect both the gently rolling hills and the steep ridges. On the flanks of the steep ridges there is a significant risk of large landslides and debris flows may develop in certain conditions.
- Soil liquefaction is a geohazard applicable to the alluvial soils of the lowlands. Soil liquefaction can result in vertical settlement and horizontal displacement. This hazard has potential to do widespread damage to structures, roads and infrastructure.

A number of development practices have been identified as having potential to instigate, accelerate or make worse geohazards. Earthworks and tracking within the hill country can result in slips and erosion. Discharges to ground for managing stormwater and on-site effluent systems can reduce the stability of slopes and result in erosion.

AECOM has assessed the land within the study areas against four development suitability categories. The suitability categories do not imply that a site is subject to natural hazard, but that the hazard is associated with that area and needs to be specifically assessed. The development suitability categories and the areas assessed as fitting the categories are:

Category A – Low risk – Land on the low gently rolling hills, underlain by volcanic geology and the wide plateaus of the ridges.

Category B – Some risk – Moderately steep slopes of ridges and valleys.

Category C – Moderate risk – The area underlain by young alluvial soils and the steep slopes with some evidence of instability.

Category D – High risk – Steep slopes with evidence of widespread instability.

In addition to the development suitability categories AECOM has made several recommendations for modifications to the Waikato District Plan to address geohazards. AECOM recommends:

- A land instability policy layer is incorporated into the District Plan to guide and restrict development in areas recognised as having a high risk of land instability such as the areas mapped as Category D.

- Liquefaction risk mapping is advisable if the alluvial soils are zoned to anything other than rural. As a minimum, systems to record liquefaction risk assessments that are submitted as part of consent documentation should be put in place.
- The engineering standards within the District Plan should have an increased focus on the importance of geotechnical engineering in the identification and management of geohazards.
- Definitions be added to the District plan for the terms "Natural Hazard" and "Geotechnical Suitability".

1.0 Introduction

Waikato District Council (WDC) engaged AECOM New Zealand Limited (AECOM) to assess geotechnical constraints and issues for the proposed development of a Tuakau Structure Plan. The area of interest was provided by WDC and includes the rural areas around Tuakau township. The study area is shown on Sheet A1 in Appendix A.

The purpose of the Structure Plan is to provide a framework for sustainable development within the district. Recent changes to the District Plan have reduced the potential for further subdivision of rural land; however it is likely that the Structure Plan will result in some areas of rural land adjacent to the township being rezoned to allow for residential and commercial growth.

Geotechnical constraints are a reflection of the potential for a geohazard to impact on land or a land development proposal were the geohazard not to be addressed. A geohazard is a broad term that refers to natural hazards caused by a combination of the structure, type, strength and topography of the land. Geohazards may be obvious, such as a large landslide revealed only by thorough investigation, or unknown such as the settlement potential of buried compressible soil or an earthquake generated by an unknown fault.

The purpose of this assessment is to provide WDC with a high level assessment of the potential geohazards in the area being considered under the Tuakau Structure Plan. The geohazards assessment is intended to inform WDC's decisions regarding the Structure Plan and while guidance is provided regarding the general suitability of different classes of land for development, the information is not suitable for determining the development potential of, and geotechnical constraints applying to individual parcels of land. In addition, identifying the actual location and extent of any geohazard is beyond the scope of this assessment.

2.0 Scope of assessment

This assessment is a desk study and comprises:

- A review of natural hazard regulations related to land development,
- A review of relevant geological maps and topographical maps,
- A review of aerial photography in the public domain,
- Experience of development issues within the study area,
- Review of site hazard information supplied by Waikato District Council.

This assessment focuses on geohazards and therefore excludes other natural hazards such as flooding, surface ponding and wind.

3.0 Legal framework

Geotechnical suitability of land for development is substantially concerned with the avoidance and mitigation of geohazards. The foundation framework is outlined in Legislation, District Plans, and New Zealand Standards.

A brief outline how these documents address natural hazards is provided in the following sections.

3.1 Resource Management Act 1992

The Resource Management Act 1992 gives Territorial Authorities the control of any actual or potential effects of the use, development, or protection of land, including for the purpose of the avoidance or mitigation of natural hazards.

In the case of subdivisions the territorial Authority may refuse to grant subdivision consent, or may grant a subdivision consent subject to conditions, if it considers that:

- *the land in respect of which a consent is sought, or any structure on the land, is or is likely to be subject to material damage by erosion, falling debris, subsidence, slippage, or inundation from any source; or*

- *any subsequent use that is likely to be made of the land is likely to accelerate, worsen, or result in material damage to the land, other land, or structure by erosion, falling debris, subsidence, slippage, or inundation from any source; or*
- *sufficient provision has not been made for legal and physical access to each allotment to be created by the subdivision.*

3.2 Building Act 2004

The Building Act, 2004 defines a Natural Hazard as:

- *erosion (including coastal erosion, bank erosion, and sheet erosion):*
- *falling debris (including soil, rock, snow, and ice):*
- *subsidence:*
- *inundation (including flooding, overland flow, storm surge, tidal effects, and ponding):*
- *slippage.*

The Building Act addresses natural hazards by requiring that the building consent authority refuse to grant a building consent for construction of a building, or major alterations to a building, if:

- *the land on which the building work is to be carried out is subject or is likely to be subject to 1 or more natural hazards or*
- *the building work is likely to accelerate, worsen, or result in a natural hazard on that land or any other property.*

The Building Control Authority can issue a building consent if the building consent authority is satisfied that suitable provision has been or will be made to:

- *protect the land, building work, or other property referred to in that subsection from the natural hazard or hazards or*
- *restore any damage to that land or other property as a result of the building work.*

The Building Act includes all site work within the definition of building work. Site work is defined as "*work on a building site, including earthworks, preparatory to, or associated with, the construction, alteration, demolition, or removal of a building*".

3.3 Waikato District Plan (Franklin Section)

The Waikato District Plan has objectives and policies to manage development in areas prone to natural hazards. Tuakau was part of the Franklin District until 2010. Policy and rules related to the Tuakau area contained in the Waikato District Plan (Franklin Section).

The Waikato District Plan (Franklin Section) makes reference to the following geohazards; instability, earthquakes, volcanism. The Franklin Section contains policies to specifically address land instability and erosion.

Throughout the rules within the Waikato District Plan (Franklin Section) there is frequent reference to how development earthworks and stormwater management can result in instability and erosion, requiring these matters to be assessed as part of a development application.

3.4 NZS4404:2010 Land Development and Subdivision Infrastructure

NZS4404 outlines the geotechnical considerations for assessing the suitability of land for subdivision and designing new landforms (recontouring by earthworks). In addition to addressing the natural hazards that are defined in the RMA, this standard also includes the assessment of special soil types, which includes but is not limited to:

- *Soils with high shrinkage and expansion*
- *Compressible soils*

- *Volcanic soils*
- *Soils subject to liquefaction*
- *Soils prone to dispersion*

3.5 NZS3604:2011 Timber Framed Buildings

NZS3604 provides a definition of "good ground" which is suitable for buildings that are within the scope of the standard and also NZS4229:1999 Concrete Masonry Structures Not Requiring Specific Engineering Design.

The intent of the site requirements section in NZS3604 is to enable compliance with the building code to be readily established for most residential type buildings, without the need for soil bearing capacity and settlement calculations.

Land with instability in the "immediate locality", compressible soil, subsidence, organic soil, and expansive soil are excluded from good ground.

4.0 Study area description

Tuakau is nestled between the Bombay Hills to the north and the Waikato River to the south. A topographic map of the study area is shown on Sheet A2 in Appendix A. The town centre is approximately 3 kilometres north of the Waikato River with urban development up to 1.5 kilometres from the river. The study area encompasses approximately 6000 hectares of rural land surrounding Tuakau.

The town has been established over gently rolling hills south of the North Island Main Trunk Railway, and is elevated between 20 and 40 metres above sea level (RL 20 to RL 40). To the west and southwest topography is similar to the topography within Tuakau.

To the north of the North Island Main Trunk Railway (NIMT) on the eastern side of the study area the hills are higher and steeper as they rise towards the summit of the Bombay Hills, approximately 10 kilometres to the north east. Peaks in the study area are up to RL 240 on the ridges. Slopes are typically steep, and are estimated to be 30 to 35 degrees, particularly adjacent to Waikato River.

The Alexandra Redoubt is atop a prominent ridge adjacent to the Waikato River which is estimated to be approximately RL 70 at the ridge crest.

Stream and gully channels throughout the study area drain to the Waikato River.

5.0 Geology

The geological map for the area is presented on Sheet A3 in Appendix A. The map indicates that the study area is located within the South Auckland Volcanic Field. The South Auckland Volcanic field was active intermittently between 1.6 and 0.5 million years ago and contains basaltic lava, scoria, ash and tuff, sourced from multiple vents within the volcanic field.

The ridge that supports the Alexandria Redoubt is mapped as having outcrops of the Puketoka Formation overlying the Mercer Sandstone member of the Waitemata Group on the river side of the ridge.

The Puketoka Formation was deposited over the period from 1.8 to 0.03 million years ago and interfingers with the lava and tuff of the South Auckland Volcanic Field. Within the South Auckland area, the Puketoka formation is typically 5 to 60 metres thick and can consist of pumiceous sandstone, carbonaceous mudstone, peat, lignite and unwelded rhyolitic ignimbrite.

The Waitemata Group is a sequence of sedimentary rocks that were deposited between 24 and 20 million years ago. The Mercer Sandstone is a massive to thickly bedded calcareous sandstone with interbedded sandy mudstone and occasional conglomerate beds. It is likely that the Waitemata Group underlies the areas mapped as South Auckland Volcanics.

The old geology has been mantled by weathered volcanic ash from more recent volcanic activity in the Auckland Volcanic Field and activity in the mid North Island. The ash typically weathers to a clayey silt or silty clay.

Holocene alluvial and colluvial deposits are mapped to the southwest of Tuakau and extend to the Waikato River. The alluvial deposits are less than 10 thousand years old and contain reworked silt, sand and clay deposited by the Waikato River. Pumice and peat soil may also be present. Alluvial and colluvial deposits are likely in the stream valleys and gullies throughout the study area.

6.0 Geohazards

6.1 Introduction

The geological hazards (Geohazards) considered relevant to the study area include slope instability, river bank erosion, seismicity and liquefaction, volcanic hazard and poor ground conditions (e.g. peat). Related issues such as decommissioned industrial sites and landfills are also addressed.

6.2 Soil strength and characteristics

6.2.1 Overview

The study area is large and encompasses a variety of terrains and soil types. Soil strength is an important consideration when assessing the suitability of land for development, in particular the potential for unacceptable settlement and subsidence of buildings and infrastructure.

6.2.2 Static settlement

Static settlement is due to the ground underlying a structure or fill embankment compressing due to the increased load. Provided uniform settlement occurs then structures typically do not sustain structural damage and the settlement can be undetectable without reference levels. When settlement occurs it is common for the land adjacent to the structure to also be affected as a depression is created towards the loaded area.

Differential settlement occurs when settlement across a structure occurs in way that results in non-uniform settlement. This can be due variable settlement rates or differences in the thickness of the compressible layer.

When differential settlement of a building occurs the walls and cladding are susceptible to cracking, floors become uneven and doors and windows become tight and prone to jamming. The integrity and function of onsite services can also be compromised when settlement affects auxiliary structures such as water tanks.

Roads and buried services are generally at low risk of issues related to static settlement, unless the works include embankments or structures as part of the works or in close proximity to the infrastructure.

6.2.3 Expansive soils

Expansive soils are those that contain clay minerals that shrink and swell significantly upon wetting and drying. These soils can apply significant pressure to foundations, resulting in differential movements and damage similar to that experienced due to settlement. Expansive soils can be mitigated by specific design of foundations; however as laboratory testing is typically required it is more efficient to address the issue of expansive soils as part of investigations for subdivision consent.

6.3 Slope instability

AECOM is not familiar with commonly adopted approaches for assessing land instability for subdivision and building consents in the Tuakau Area. The following comments are based on site observations from public roads and aerial photographs of the area.

Three types of slope instability are readily identifiable in the area.

- Soil creep
- Shallow slumping
- Deep seated instability

Soil creep is common on the slopes in the study area that are steeper than approximately 20 degrees. Soil creep is a gradual downslope movement of the soil profile which is generally limited to the uppermost metre. Land owners typically refer to the visible manifestation of soil creep as sheep or cattle tracks.

The low rolling hills in the vicinity of Tuakau and the land to the west have moderate to gentle slopes that are generally less than 10 metres high and are commonly associated with streams at their toe. Shallow instability is also common. Some isolated large slips are also present, which affect the full height of the slope over a considerable width. These are most common on the high, steep ground adjacent to Waikato River and over the eastern part of the study area. Many of the back scarps are in excess of 50 metres long and they are located near the crests of the ridges. This indicates that there is potential for a significant instability hazard on the flanks of these steep ridges.

Given the size of the slips, the gradient of the slopes and the height of the ridges it is likely that the larger slips would generate a significant volume of debris that would affect the full slope height. Although there is limited evidence for very fluid slope failures, failure mass run-out zones can extend beyond the toe of the slope. Developments can be at risk from material upslope and in some cases the area most likely to generate a landslide may be located beyond the boundary of the property to be developed. Case Study 2 in Appendix C examines a large slip and debris flow in similar terrain.

6.4 Seismic hazard

6.4.1 Introduction

Earthquakes can result widespread damage to land and buildings. Land damage in this context has traditionally been considered as destabilisation of slopes and ground surface movement associated with shaking and fault rupture.

Building codes and standards such as NZS3604 Timber Framed Buildings generally ensure that buildings are structurally designed to withstand specified level earthquake shaking.

Since the Canterbury Earthquake Sequence (2011 to present) there has been heightened awareness of the effects on both buildings and infrastructure of earthquake-induced soil liquefaction. Soil liquefaction is addressed in in Section 6.5.

6.4.2 Tectonic setting

New Zealand straddles the boundary between the Australian and Pacific tectonic plates. Tuakau is approximately 350 kilometres west of the plate boundary.

Two inactive faults are mapped in the study area (Sheet 3, Appendix A). The Waikato Fault trends east to west and passes between Tuakau and Waikato River. A north to south fault through the centre of the study area parallels the Drury Fault mapped just to the east. These and several other faults to the south of the Waikato River and north of the Bombay Hills are mapped as inactive.

The closest faults identified as active are the Turi Fault, Wairoa South Fault and the Kerepehi Fault. The Turi Fault is located off the west coast of the Waikato region, approximately 130km south west of Tuakau, and is estimated to be capable of generating a M7.2 earthquake approximately every 1600 years. The Wairoa South Fault (20km north east of Tuakau) and the Kerepehi Fault (50km east of Tuakau) are estimated to be capable of generating M6.6 earthquakes, with return periods of 22,000 and 2500 years respectively. The Drury Fault has also been identified as possibly having potential for future activity, but evidence is very limited.

6.4.3 Seismic history

Sheet B1 in Appendix B shows the locations of shallow earthquakes M3.5 or greater within and near the Waikato Q-Map area from 1840 to 2003. In addition to this data source the New Zealand Institute of Geological and Nuclear Sciences also have an online earthquake search tool, Quakesearch.

The four significant shallow earthquakes closest to Tuakau Study Area are:

- 1891 Port Waikato M5.9
- 1912 Te Awamutu M5.5
- 1950 Tuakau M4.8 (Quakesearch)
- 1972 Te Aroha M5.3

It is also a feature of both databases that the vast majority of earthquakes have not occurred on the fault lines that are recognised as being active. Although there is a low frequency of earthquakes, the records cover a period much less than the return event that needs to be considered for building code compliance.

6.4.4 Managing the seismic hazard

The Zealand Building Code requires that structures perform to a requisite standard during an earthquake. The design earthquake strength is a factor of a structure's importance level (determines the return event to be considered) and the location. This means that more seismically active regions have stronger earthquake actions in design.

While seismic forces are taken into account as a routine part of structural engineering, it is often overlooked when assessing civil works, land modification, and stability, yet these works can equally affect the structural integrity of the building. Case Study 1 in Appendix C discusses liquefaction knowledge and the lack of mitigation in Canterbury prior to 2010.

6.5 Soil liquefaction

6.5.1 Liquefaction mechanism

The cyclic ground motion induced by earthquakes can cause a build-up of excess pore pressure within the soil. If the excess pore pressure exceeds overburden pressure, liquefaction can occur which causes a loss of strength and commonly ejection of material at the surface (e.g. sand boils). As the excess pore pressure dissipates following cessation of shaking, densification of the soil can occur that, together with the loss of ejected material, causes settlement that may damage structures.

Such liquefaction and densification typically occurs in geologically young, loose, saturated, fine to medium grained, non-cohesive and low plasticity soils.

6.5.2 Potential effects of soil liquefaction

When soil liquefaction occurs there is a significant decrease in the soil strength. While this is a temporary situation, foundation bearing capacity failure can occur if the liquefied soil is sufficiently close to the foundations.

Liquefied material adjacent to a free face, such as a terrace, gully or river, can allow un-liquefied material above it to move towards the free face (lateral spreading). Lateral spreading can result in ground displacement and cracks developing several hundred metres from the slope. Lateral spreading is particularly damaging to buildings, roads and services with the zone of displacement.

Services such as buried pipelines, manholes and tanks can become buoyant resulting in damage to infrastructure. This can also be exasperated by ground surface settlement. Roads can be damaged by ground settlement and lateral spreading.

6.5.3 Soil liquefaction potential

Within the study area the low-lying alluvial soils adjacent to Waikato River (west of Tuakau, Sheet A3, Appendix A) can contain significant layers of saturated, loose sand and silt. As these soils are also geologically young, there is a potential liquefaction hazard.

6.5.4 Soil liquefaction mitigation

Engineering solutions are available to mitigate the effects of soil liquefaction should assessment indicate that the effects are significant and warrant mitigation. Some of the commonly adopted methods are:

- raft foundations,
- ground improvement (replacement, stabilisation, deep soil mixing),
- piles.

The solution adopted will depend on the end use, the estimated deformation and the depth to underlying non-liquefiable material.

Infrastructure can be protected by using non-rigid pipes, slip joins and mass blocks to prevent buoyancy.

6.6 Volcanic hazard

Volcanic activity within the south Auckland Volcanic Field ceased approximately 0.5 million years ago. The nearby Auckland Volcanic Field is characterised by low-frequency, low-magnitude basaltic eruptions. Ash fall from an eruption in the Auckland Volcanic Field is unlikely to mantle the landscape within the study area. Higher magnitude eruptions in the central North Island could also result in ash fallout within the study area.

6.7 Non-engineered fill

Non engineered fill can be prone to settlement and instability. Hazard maps supplied by Waikato District Council show locations were non-engineered fill has been recorded by Council. It is likely that there are many more instances of non-engineered fill though out the study area. It is appropriate to deal with the presence of non-engineered fill during subdivision planning.

7.0 Development issues

With the exception of soft, saturated or peaty ground, development of flat ground generally is straightforward and carries little geotechnical risk. Aside from erosion of exposed soils and potential to alter land drainage paths, there is little risk of subdivision works contributing to natural hazards or environmental issues.

On sloping ground or near gullies certain activities that have the potential to result in environmental damage or alter the stability of the natural ground. Earthworks are typically required for access to lots and the building platforms within the lots.

Cuttings (excavated slopes) have the potential to destabilise land above the cutting and can increase the erosion potential of the site. Cuttings in stiff clay soil can stand steeply and unsupported when initially excavated; however, over time the cutting can fritter back to a flatter angle through erosion processes.

Filling has the potential to increase load on a slope, which can result in instability in the underlying in-situ soil. Side-casting over unprepared ground is inherently unstable increasing both the erosion and instability potential of the slope.

Effluent discharges to ground continually add water to the slope. This can reduce soil strength and lead to slope destabilisation. Effluent discharge fields are building work and are subject to the same requirements to avoid or mitigate natural hazards as the building itself.

Stormwater discharges to ground have the potential to decrease the stability of nearby slopes. Poorly located dispersion systems can increase erosion potential and also result in instability. Where development is intensified the cumulative effect of the discharges to ground need to be addressed.

Tracks or driveways constructed through sloping terrain capture and concentrate stormwater runoff from both the track itself and also the land upslope of the track. Runoff volumes can far exceed what would be generated by the track alone. This concentration of stormwater can lead to soil erosion and instability.

8.0 Development suitability recommendations

8.1 Development suitability categories

8.1.1 Overview

A map has been developed (Sheet A4, Appendix A), that classifies the development suitability of the study area land, based on landforms and geological and geotechnical constraints. Four development suitability categories are proposed. The map provides a high level classification of the land suitable for Structure Planning purposes.

The categorisation does not imply that all of the land within any category is subject to the geohazards typical of the zoning. The intent of the plan is to provide guidance to Council on the general suitability of the land and the starting point for engineering assessment that should accompany development proposals. It is possible that a specific assessment could either upgrade or downgrade the risk.

8.1.2 Category A – Low Risk

Category A represents land that is likely to be suitable for development with minimal geotechnical input. There is little risk to buildings and infrastructure. Residential buildings are likely to be able to be developed using foundation details from NZS3604. There is also little environmental risk from developments within the Category A land; however the cumulative effects of stormwater discharges onto or into the land should be addressed as it may affect land beyond this zone.

8.1.3 Category B – Some Risk

Category B represents land that is likely to be suitable for development with some geotechnical input. Although pockets of land that are unsuitable for development may occur, most land is suitable for residential buildings developed using foundation details from NZS3604, possibly with minor shallow ground improvement (e.g. undercut and replacement or foundations that are deepened to more competent materials).

There is some environmental risk from developments within the Category B land, which will typically be related to earthworks for building sites and accesses. Consideration to the management of development-induced water discharges and the cumulative effects of increased runoff volumes or soakage to ground volumes is required.

8.1.4 Category C – Moderate Risk

Category C land has a moderate development risk. There are likely to be development constraints that will need specific geotechnical assessment to identify the impact on the development of potential hazards. It may be costly and difficult to develop some land in Category C.

There can be significant environmental risk from developments within the Category C land, which will typically be related to earthworks for building sites and accesses. Assessment of the cumulative effects of development induced water discharges in particular increased runoff or soakage to ground volumes and how these may affect the geohazards is required.

8.1.5 Category D – High Risk

Land within Category D is assessed as having a high risk of being subject to a significant geohazard within the zone. Where such hazards are present, mitigation is unlikely to be possible in a safe and economically viable manner. Development is not recommended without extensive engineering assessment and design. Hazards may be due to geological conditions beyond the property boundary and assessment of the wider area is recommended in Category D areas near slopes.

There can be significant environmental risk from developments within the Category D land, which will typically be related to earthworks for building sites and accesses and development induced water discharges. Assessment of the cumulative effects of development induced water discharges in particular increased runoff volumes or the volume discharged to ground and how these may affect the geohazards is required.

8.2 Geomorphological categories

8.2.1 Recent alluvium

The alluvial terraces of the lowlands can generally be considered suitable for urban development or country living zoning, subject to a detailed assessment during the consenting process. Due to variability of soil type and strength, the potential for soil liquefaction and settlement and compression of soft and/or peaty soils, this land will need to be assessed. Assessment will need to address risks to both building and infrastructure. It is likely that engineering solutions to mitigate hazards will be required. The alluvial terraces are therefore generally considered to be Category C.

Development adjacent to the gullies and water bodies (streams, rivers, ponds, open drains) will need to address the stability of the slopes. Due to the potential for soil liquefaction to result in lateral displacements that extend considerable distances from slopes, land within 200 metres of the gullies and waterways is considered to be Category D.

8.2.2 Low gently rolling hills

The low gently rolling hills that occur over a significant part of the study area have a mantle of volcanic ash overlying volcanic rocks. These soils are likely to be stiff clay with minimal risk of settlement for residential type structures. Earthworks may expose lower strength soil which can likely be mitigated during the building consent process.

Slope instability can be present near the stream gullies, however it is generally not deep seated and the slope heights are relatively low.

The low rolling hills are considered to generally fall into Category A and Category B. Category C is applicable for steeper valley slopes.

8.2.3 Hill country

The hill country in the southern and eastern parts of the study area have highly variable topographic and geomorphic features. Consequently the full range of development categories has been applied over this area.

The wide plateaux that are near level to gently sloping have been mapped as category A. At the other end of the scale are generally steep areas with widespread instability that are mapped as category D.

Categories B and C are applicable to sloping ground which is not affected by widespread instability. Category C typically applies to the steeper or higher slopes than Category B.

9.0 Policy Recommendations

9.1 Land instability policy area

It is recommended that the Waikato District Council consider a Land Instability Policy Layer within the District Plan to cover the land assessed as Category D. To be effective the Land Instability Policy Area would need to outline the issues, objectives and policies so that it provides guidance to developers, builders and council officers of the significant potential for land instability within this area. Key to such a policy is additional assessment of the existing instability through mapping using current and historic aerial photos, and an estimation of the magnitude, and frequency of landslides including their potential impact area.

Development proposals for hill country land will need to consider that not all land will be suitable for development and that greater costs will be incurred to develop the land.

It is recommended that consideration is given to requiring a land developer to undertake the all development engineering works, including the formation of building sites and accesses within the policy zone. Wherever possible domestic discharges onto and into slopes should be prevented, and provision may be required during subdivision planning and engineering to establish appropriate discharge locations and easements.

9.2 Liquefaction risk mapping

Many New Zealand Territorial Authorities, particularly those that have alluvial soils now have high level liquefaction risk maps available to guide development. These maps are often accompanied by guidance on the minimum level of assessment for development and building consent. The Tuakau area is likely to have a low risk of soil liquefaction, except in the low-lying alluvial area adjacent to Waikato River. If the structure plan includes the alluvial area within any zone other than rural then preliminary liquefaction mapping is advisable.

As a minimum it is recommended that engineering reports that contain an analytical liquefaction assessment be added to the Hazard Register with a hazard grading. The usefulness of the information would be improved by requiring that all liquefaction assessments be submitted with the raw CPT data in electronic form for future area-wide analysis.

9.3 Increased geotechnical focus

AECOM recommends that the Waikato District Plan and Structure Plans include an update to Appendix B engineering standards to include an increased focus on best practise geotechnical engineering and integration with the other engineering standards.

9.4 Definitions

AECOM recommends that future revisions of the Waikato District Plan and Structure Plans include definitions in for:

- Natural Hazard
- Geotechnical suitability

10.0 References

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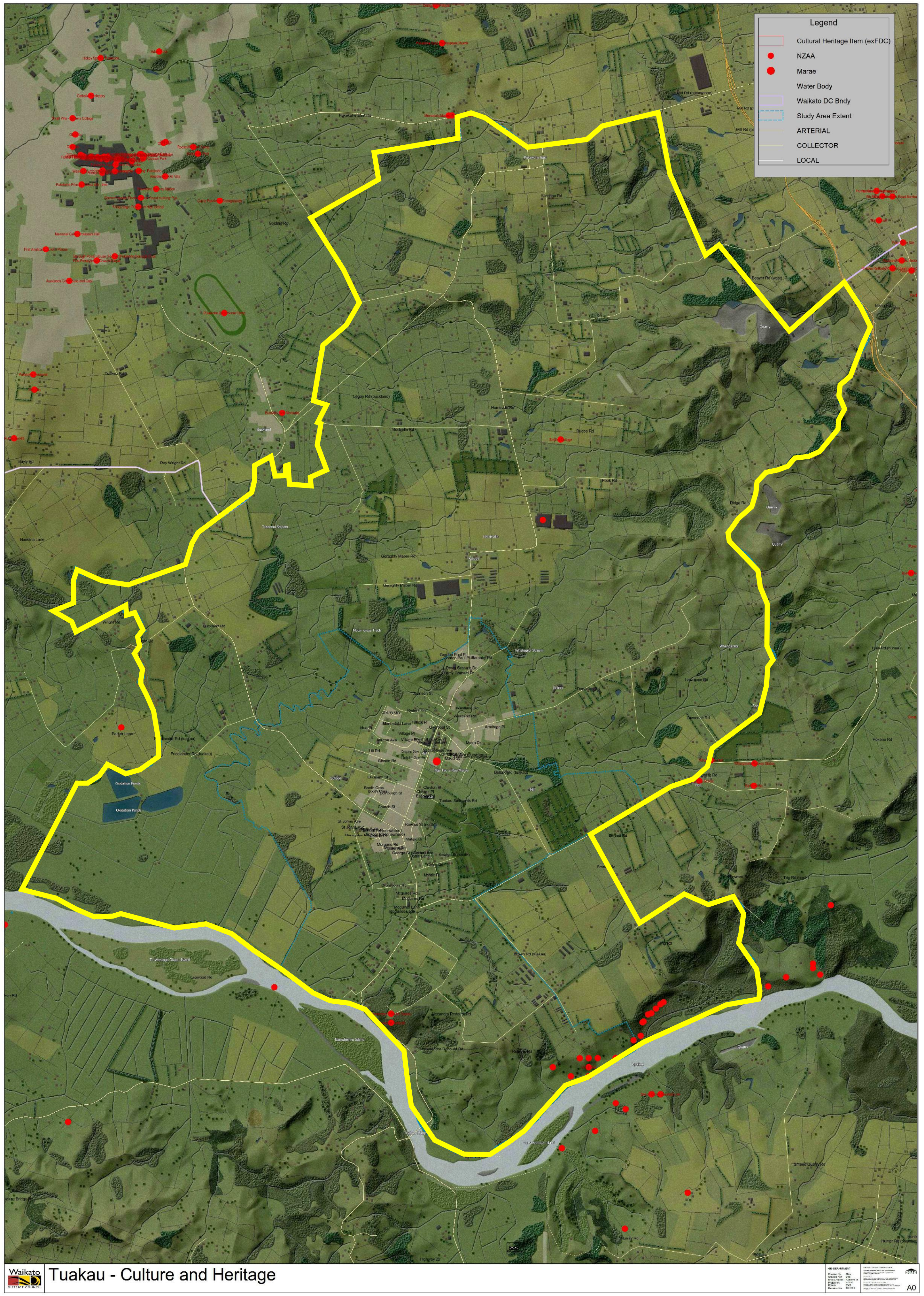
11.0 Limitations

The recommendations and opinions in this report are based upon a review of the topography of the study area, geological maps and engineering experience of the issues within the areas considered. Inferences about the nature and continuity of geohazards are made using geological principles and engineering judgement. However it is possible that ground conditions over the site may vary and therefore it is not possible to guarantee that all hazards have been identified and appropriately zoned.

This report has been prepared for the particular project described in WDC's brief to us and no responsibility is accepted for the use of any part of this report in other contexts or for any other purposes.

Appendix A

Figures



Plan showing the study area
supplied by Waikato District Council

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SHEET TITLE
Study Area

SHEET NUMBER
A1

Topographic Map sourced from
Topomap.co.nz
Land Information New Zealand (LINZ)

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SHEET TITLE

Topographic Map

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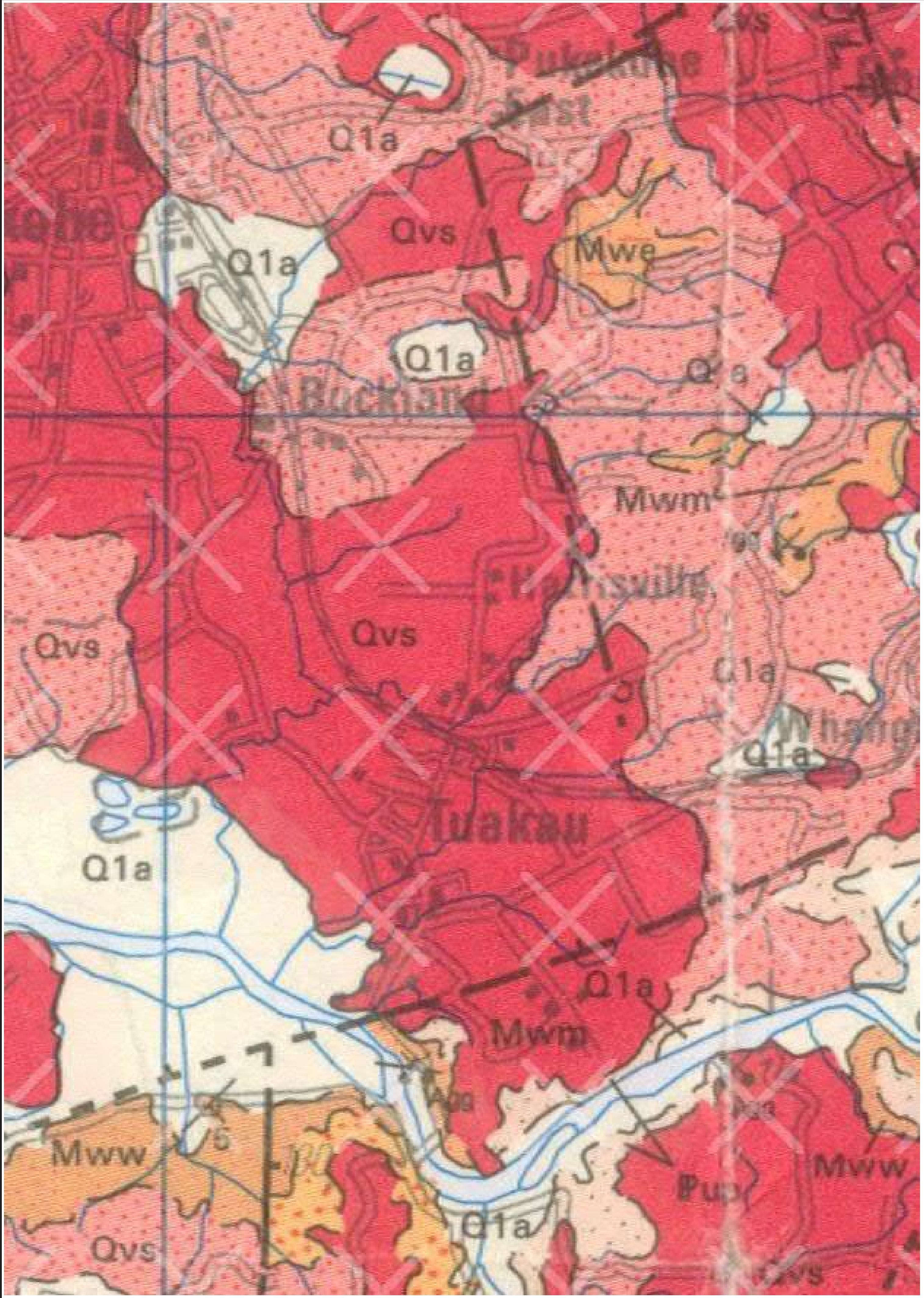
A2



Alluvium/ colluvium

Q1a — Alluvial/colluvial deposits, estuarine deposits, lacustrine/ swamp deposits and fan deposits (Q1a).

Qvs — SOUTH AUCKLAND VOLCANIC FIELD

Basalt lava (Qvs).

Scoria (Qvs).

Ash, lapilli and lithic tuff (Qvs).

Pup — PUKETOKA FORMATION (Pup) Pumiceous mud, sand and gravel with muddy peat and lignite; rhyolite pumice, including non-welded ignimbrite, tephra and alluvial pumice deposits; massive micaceous sand.

Mwe — EAST COAST BAYS FORMATION (Mwe) Alternating sandstone and mudstone with variable volcanic content (volcanic-poor lower in the sequence and mixed volcanic content higher) and interbedded volcaniclastic grit beds.

Mwm — MERCER SANDSTONE (Mwm) Massive sandstone and thin mudstone.

Mww — WAIKAWAU SANDSTONE (Mww) Calcareous, glauconitic sandstone with minor siltstone and tuff.

FAULT *

Fault (tick on downthrown side)

Reference:
Edbrooke, S.W. (compiler) 2001. Geology of the Auckland Area.
Institute of Geological and Nuclear Sciences 1:250:0000 Geological map 3.
1 sheet + 74p. Lower Hutt,
New Zealand: Institute of Geological and Nuclear Sciences Limited.

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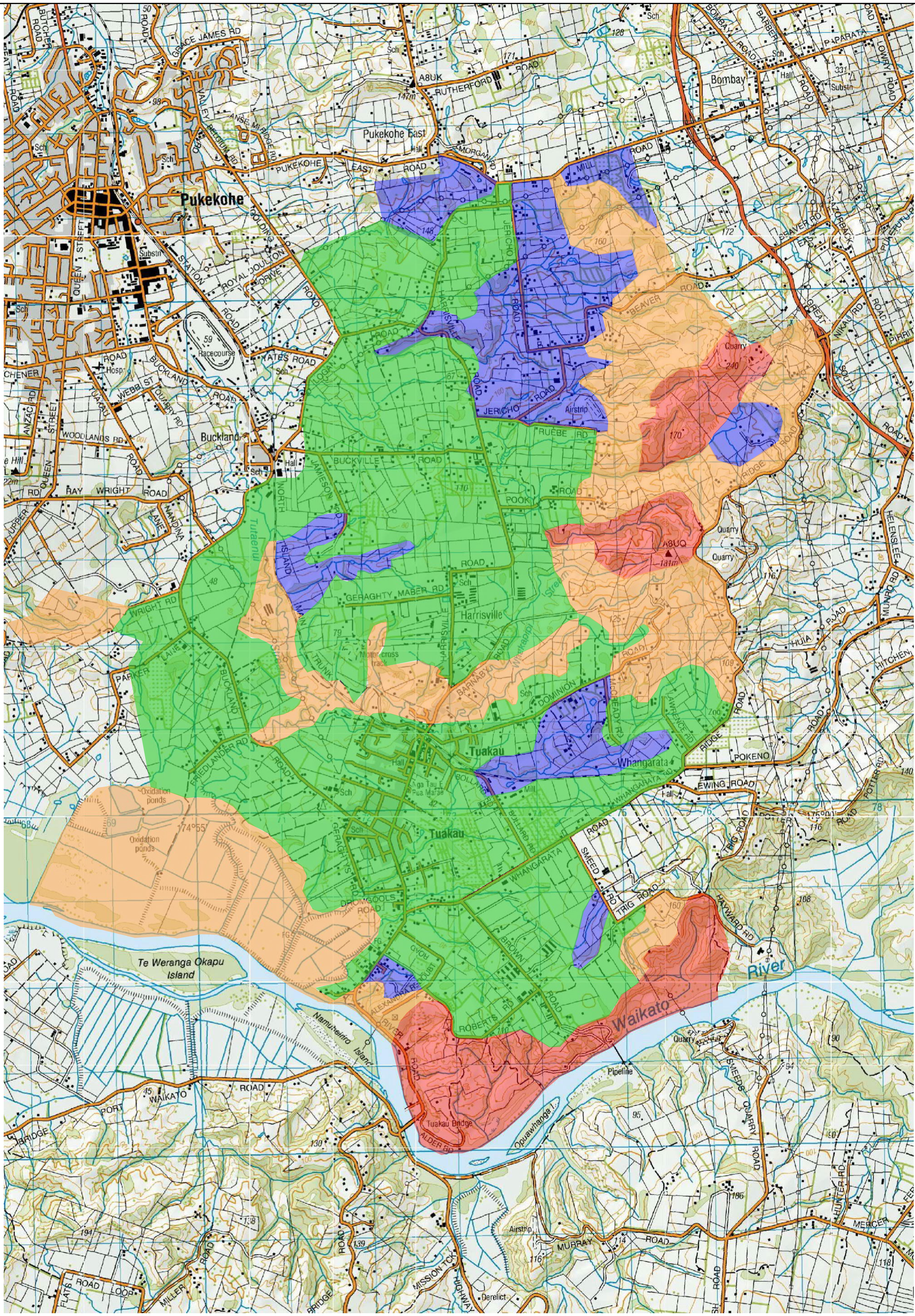
SHEET TITLE
Geological Map

SHEET NUMBER
A3

ISO A1 594mm x 841mm



Land Development Suitability Categories

Category A - Low Risk

- Geohazards unlikely
- Residential buildings likely to adopt NZS3604 with no ground improvement
- Minimal engineering input required
- Bulk earthworks are unlikely or will be minor
- Cumulative effects of stormwater and wastewater discharges require assessment
- Flanks of some hills and gully slopes may include pockets more appropriately considered Category B or C
- Mapped as the land on the low gently rolling hills that are underlain by volcanic geology and the wide plateaux of the ridges

Category B - Some Risk

- Possible for geohazards to be present
- Moderate level of engineering input appropriate
- Residential buildings likely to adopt NZS3604 with shallow ground improvement or foundation deepening away from geohazards
- Minor bulk earthworks may be needed to recontour for development
- Individual and cumulative effects of stormwater and wastewater discharges to be assessed

Category C - Moderate Risk

- Likely for geohazards to be present
- Detailed engineering assessment required to address impacts on buildings roads and infrastructure
- Recountouring likely to be required for development on slopeing sites
- Individual and cumulative effects of stormwater and wastewater discharges to be assessed
- Mapped as the alluvial soil adjacent to the Waikato River and also the moderately steep to steep, ridge and gully slopes

Category D - High Risk

- Likely that significant geohazards are present
- Detailed engineering assessment required to address impacts on buildings roads and infrastructure
- If the potential geohazard is confirmed then mitigation is unlikley to be possible in a safe and economically viable manner
- High environmental risk due to earthworks
- Individual and cumulative effects of stormwater and wastewater discharges to be assessed
- Mapped as steep slopes with widespread evidence of past instability
- Also includes recent alluvial soil within 200m of waterways and gully or terrace slopes (not shown on map)

NOTES:

1. Boundaries are approximate and based on large scale topographic and geological maps
2. Classification zones do not address flood hazard
3. This map does not imply that all of the land within any category is subject to the geohazards typical of the zoning. The intent of the plan is to provide guidance to Council on the general suitability of the land and the starting point for engineering assessment that should accompany development proposals. It is possible that a specific assessment could either upgrade or downgrade the risk within any given property.

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Development Suitability Categories

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Appendix B

Seismic history

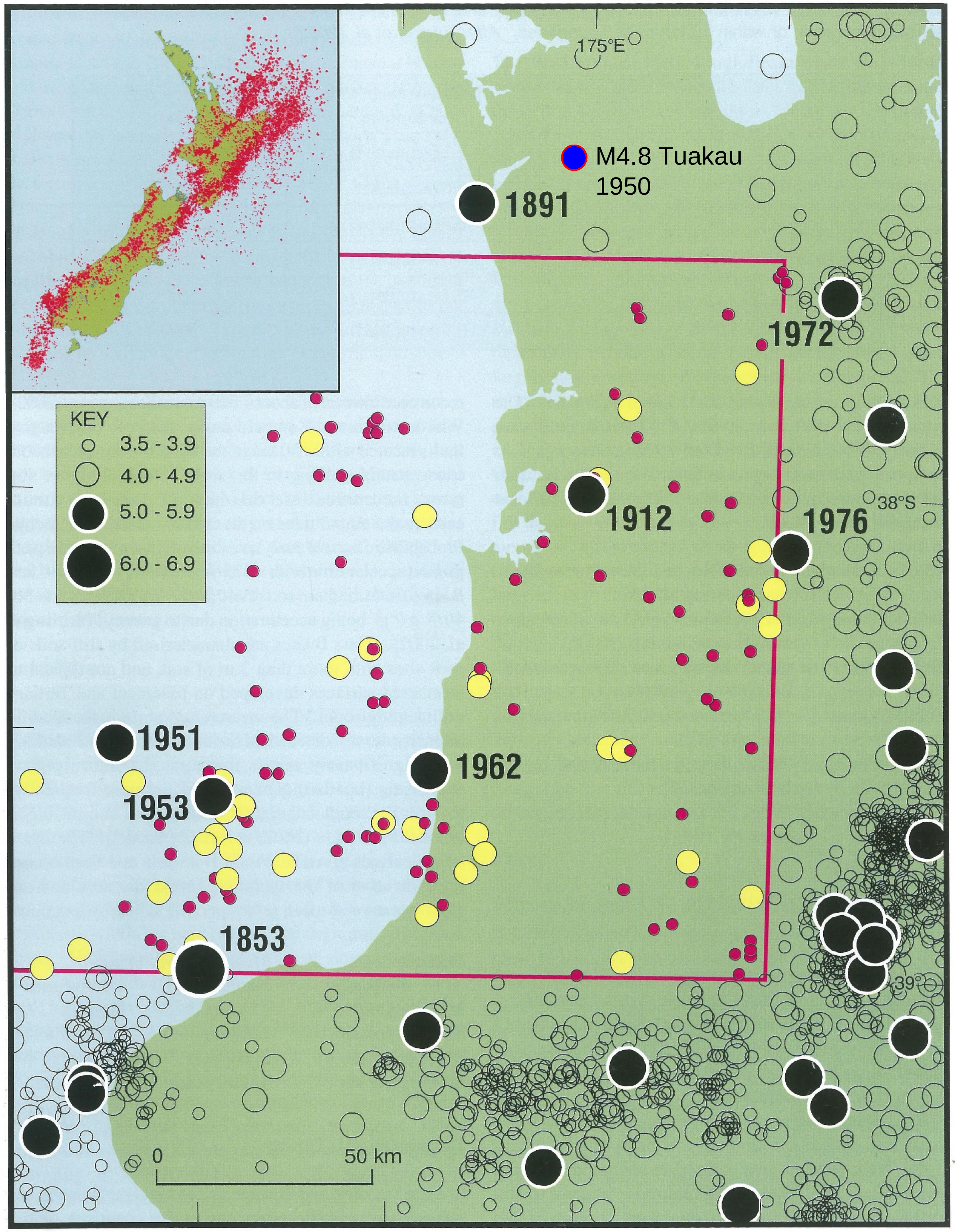

Figure 61 Locations of shallow (depth ≤40 km) earthquakes in the Waikato map and surrounding area, with magnitudes M≥3.5 (January 1840-June 2003). Note that the record of small earthquakes is incomplete before 1964, and the record of moderate to large earthquakes is probably incomplete before 1900. Inset: Shallow earthquakes recorded in the New Zealand region from 1964 to 2002.

Reproduced From:
Edbrooke, S.W. (compiler) 2005. Geology of the Waikato Area.
Institute of Geological and Nuclear Sciences 1:250:0000 Geological map 4.
1 sheet + 68p. Lower Hutt,
New Zealand: Institute of Geological and Nuclear Sciences Limited.

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Seismic History

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Appendix C

Case studies

Appendix C Case Studies

Case Study1 – Canterbury development prior to 2010

Following the Canterbury Earthquake sequence that commenced in September 2010, councils, central government and insurance companies have incurred enormous costs repairing the damage to public and private property.

The New Zealand Geotechnical Society has published a paper by Merrick Taylor which delves into what was known about liquefaction in Canterbury pre 2010 and the processes for development and building consents.

Despite the existence of liquefaction hazard maps produced in the 1990s and the inclusion of these in the Regional Plan, only two developments considered the potential for liquefaction. This was due to the reliance on engineers acting for the developer, and a lack of direction from council officers.

The situation arises from the developers profit motives and desires to do the minimum required to get a consent. The engineers were operating in a competitive market and generally followed their clients brief to do the minimum required. The minimum required was based on the engineers' experience with previous consents.

Taylor concluded that the reliance on individual engineers and the absence of clear direction from council officers resulted in development and building occurring in areas that had been previously identified as hazard prone without addressing the hazard. The developments that did include mitigation measures had engineers that had a "full awareness of such hazards and international best practice with regards to the evaluation and mitigation".

There is potential that local authorities could be exposed to risk if new developments are consented without reasonable consideration of natural hazards, if a reasonably foreseeable hazard occurred.

Hazard avoidance and mitigation requires appropriate zoning, the collection and dissemination of information regarding hazards, and policies and rules that direct developers and their engineers to assess those hazards.

Case Study 2 - Hakarimata Road, Ngaruawahia

Ridge slopes to the south and east of Tuakau have a lot of similar geomorphic features that are visible in aerial photography, to those presented in this case study. They both have steep slopes, and large slips are apparent. This recent slip near Ngaruawahia highlights the danger that large slips can pose.

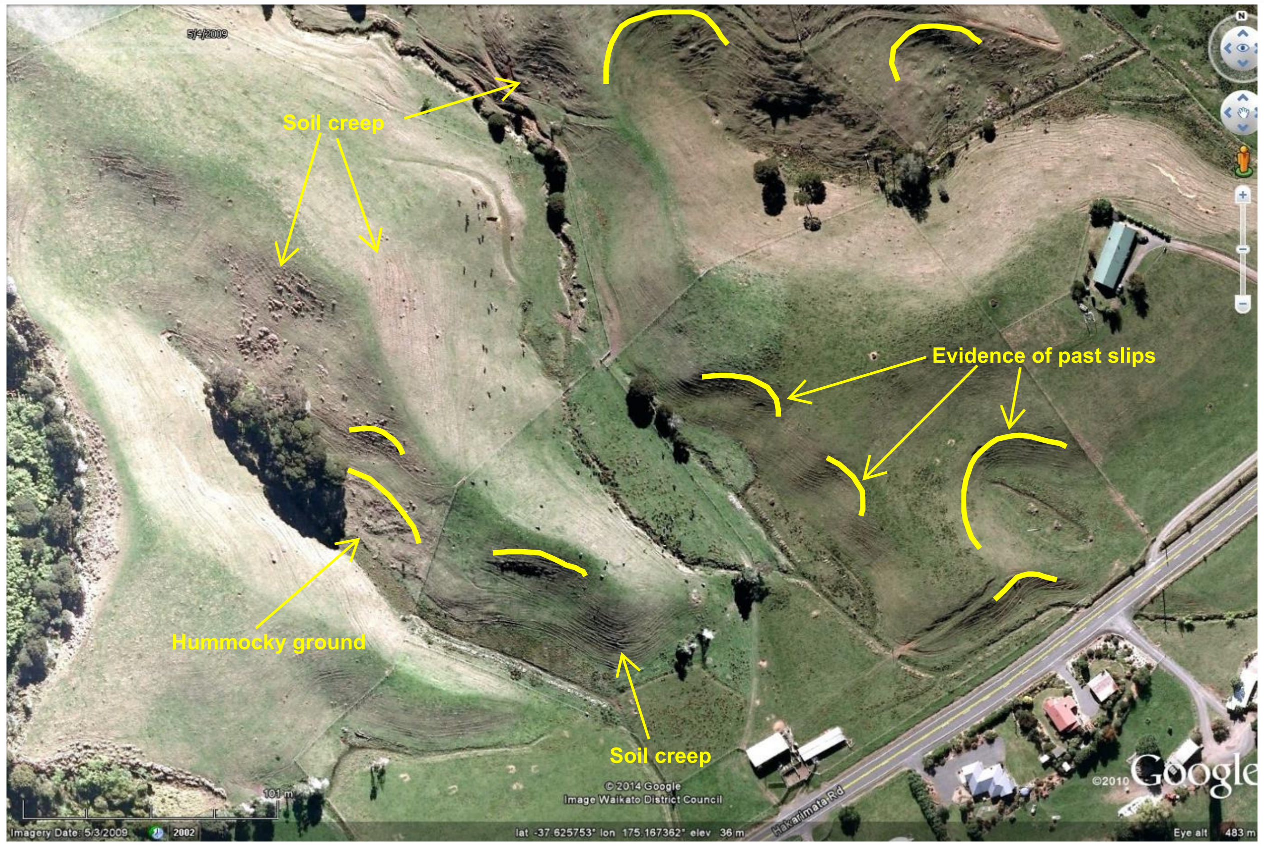
In July 2012 a slip occurred on the ridge supporting a dwelling that had been recently relocated to the site. A series of site photos and also aerial photographs from Google Earth Pro follow this discussion.

The pre-existing ridge slope is estimated to be 30 to 32 degrees. Following a period of normal winter rainfall a slip occurred with a back scarp estimated to be 8 to 10 metres high and 15 to 20 metres long. The resulting debris flow is still visible in the August 2012 image, which shows the debris travelled in excess of 100 metres from the scarp. The debris also had enough velocity to travel up the adjacent ridge. When the debris came to rest it was approximately 2 metres thick at the toe.

Prior to the slip occurring the there was a stream near the toe of the ridge, with a stream bank height of approximately 0.5 metres. The aerial image taken in May 2012, shows the house positioned on the site and the formation of the access driveway up the ridge. Comparing these two photos indicates that the track did not cut into the toe of the slip.

The 2009 aerial photograph is very clear and shows numerous large slips in the vicinity of the site, indicating that slips of this size and magnitude have happened in this area previously and can be expected to happen in the future.

Had this house being positioned on the slip or in the path of debris flow it would have been destroyed and any occupants would have been unlikely to survive.



1. This image was taken in May 2009. It shows multiple slips have occurred in the past. Associated with these slips are evidence of hummocky grounds and soil creep.

2. This image was taken in July 2010. No major change in slope.

3. By May 2012 a house was relocated to the risge. The image indicates that the driveway did not interfere with the toe of the slope, which subsequently failed in July 2012. The image also indicates that no earthworks were undertaken on the slope.

4. This image was taken in August 2012 approximately 6 weeks after the slip occurred. Note the soil has flowed approximately 100 metres from the headscarp. Works have cleared the driveway however surge marks are still visible on the opposite ridge.

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Case Study 2 - Aerial Photos

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5. Looking across slip backscarp towards Hakarimata Road.

7. The size and depth of back scarp is apparent in this photo

6. Note debris flow had sufficient velocity to travel several metres up adjacent slope and topple mature trees.

8. View from Hakarimata Road. Note the thickness of the debris 100m from the source.

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Case Study 2 - Site Photos

SHEET NUMBER

C2