Geotechnical and Coastal Hazards Topic Report

Warkworth Structure Plan

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Te Kaunihera o Tāmaki Makaurau

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1 Executive Summary

This is one of a number of topic papers that have been prepared for the Warkworth Structure Plan. This report outlines the existing environment with regards to geotechnical and coastal hazards and summarises the opportunities and constraints of the study area and gaps in information in respect to these topics.

With respect to coastal hazards, the proposed Warkworth Future Urban Zone is 14 km inland from the open coast and extends landward in a northerly, westerly and southerly direction from the upper limit of Mean High Water Springs. The site is outside of the activity controls identified in the Auckland Unitary Plan for coastal erosion, coastal inundation and the future effects of sea-level rise. As a result, there are no identified coastal hazard constraints identified. Given the proximity of the Future Urban Zone to the upper Mahurangi River and the open space conservation zone of the Pahuinui Scenic Reserve, the main opportunity is to ensure a sensitive transition between future developments and coastal margin.

From a geotechnical perspective, the site is underlain by a mixture of geology types that include some of the more challenging conditions encountered within the Auckland Region. Of particular concern are landslide prone rock types, including Northland Allochton (‘Onerahi Chaos’) and large scale block slides within the Pakiri Formation. However, there is some evidence that despite the poor geological conditions in parts of the area, the conditions may be less onerous than other similar areas such as Wellsford, and are therefore the problems encountered are likely to be within the ability of local engineering firms to resolve, with suitably rigorous investigation and design.

2 Introduction

2.1 Purpose and scope of the report

This is one of a number of topic papers that have been prepared for the Warkworth Structure Plan project. This report outlines the existing environment with regards to geotechnical and coastal hazards and summarises the opportunities and constraints of the study area and gaps in information in respect to these topics.

2.2 Study Area

The study area is the Future Urban zone around Warkworth. It comprises around 1,000ha of land. The study area is shown outlined in red on Figure 1 below.

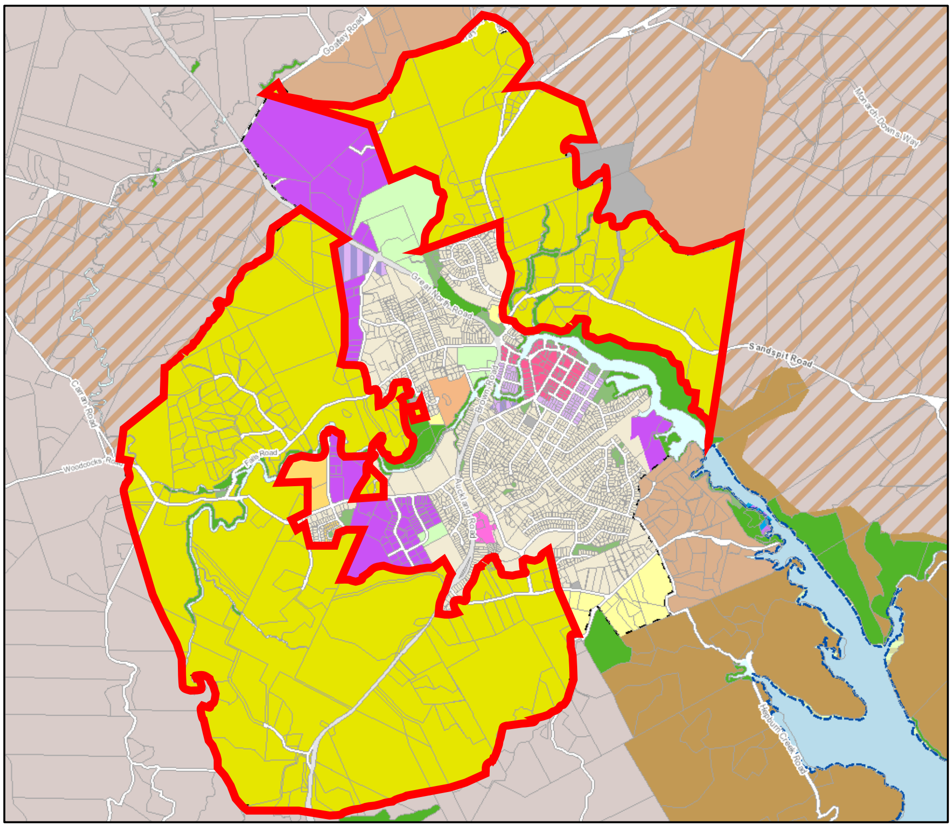

Figure 1: Warkworth structure plan study area (outlined in red)

3 Existing environment

3.1 Description of study area

The Warkworth Future Urban Zone is located upstream of the Mahurangi River, approximately 14 km from the open coast. The boundaries of the future urban zone are adjacent to the Mean High Water Springs (MHWS) boundary, extending further landward in northerly, southerly and westerly directions as demonstrated on Figure 2. As a result the extent of tidal influence and coastal processes on the future urban zone is limited.

The topography of the area is shown in more detail in Map 1 (attached).

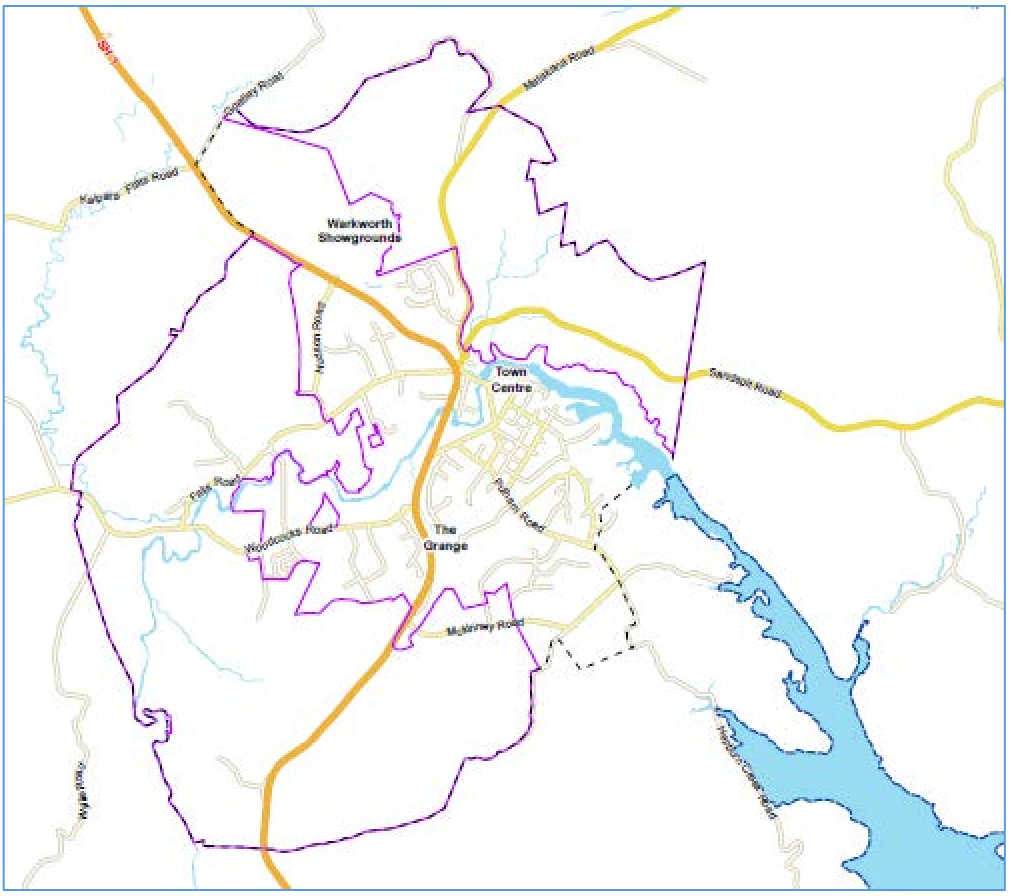

Figure 2: Warkworth FUZ demonstrating distance from MHWS (blue dashed line) and the open coast

3.2 Geology

The 2001 QMap at 1:250,000 scale (Edbrooke S. W., 2001) is the most recent published geological map covering the study area. This shows the following main geological units present in the project region (code letters refer to units shown in Figure 3):

- Northland Allochthon:
    - Motatau Complex – closely fractured limestone (Mahurangi Limestone) and calcareous mudstone (Omm)
    - Mangakahia Complex – closely fractured to sheared mudstone, limestone and sandstone (Kk)
- Waitemata Group:
    - Pakiri Formation – volcanic rich interbedded sandstone and siltstone (Mwp) with thick beds or lenses of coarse conglomerate-breccia (Parnell Grit)
- Tauranga Group Alluvium:

- Holocene floodplain and alluvial fan deposits consisting of unconsolidated to very soft clay, sand and gravel with thin peat or organic lenses (1Qa)
- Colluvium – gravity driven and mass movement (e.g. landslide) deposits derived from parent Waitemata Group and Northland Allochthon rocks (not separately identified on geological maps)

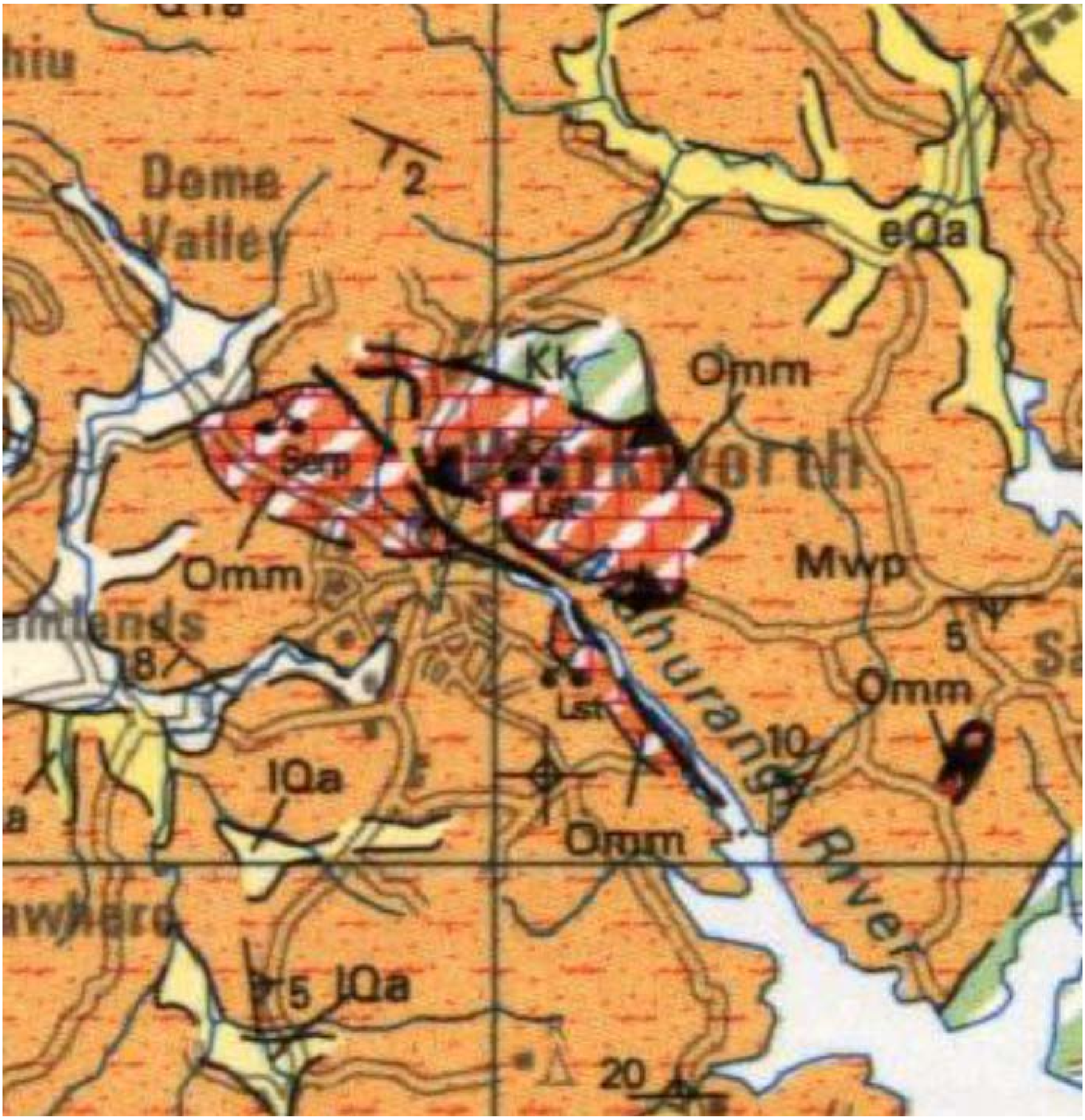

Figure 3: Extract from the 2001 geological map. See bullet points above for legend information. (Edbrooke S. W., 2001)

There is existing information available in the public domain from previous ground investigations, as shown on Map 2 (attached).

The majority of the study area is underlain by rocks of the Waitemata Group, which were deposited in-situ, and rocks of the Northland Allochthon[1] which were scraped off the Pacific plate as it was subducted beneath New Zealand approximately 15 million years ago.

The result is a complex combination of weak to moderately strong sandstones and mudstones (the Waitemata Group), with large lenses or disrupted slices of significantly weaker and highly sheared mudstones, siltstones, sandstones and limestones of the Northland Allochthon (Isaac, Herzer, Brook, & Haywood, 1994), as shown in Figure 4.

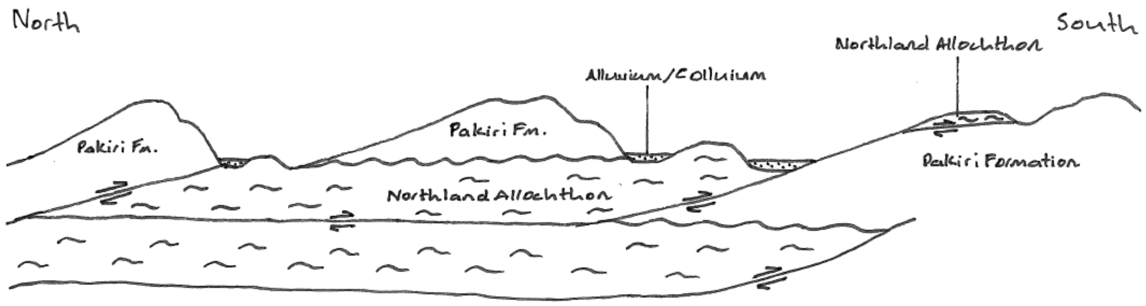

Figure 4: Simplified, inferred geological relationships within the study area, adapted from Issac et al. (1994) and Edbrooke (2001), showing how blocks of the Northland Allochthon and Pakiri Formation were thrust together with geological faults between the units, then alluvium and colluvium deposited into valleys.

3.2.1 Waitemata Group - Pakiri Formation

The Tertiary age Waitemata Group rocks comprise interbedded sandstones and mudstones of the Pakiri Formation, and occasional harder beds of volcaniclastic grit. These rocks were deposited in a deep marine basin formed between two volcanic arcs approximately 15 million years ago (Ballance & Gregory, 1991).

3.2.1.1 Distribution

The Pakiri Formation is believed to lie at depth across the full study area. However, between the existing SH1 and Sandspit Road most of this is obscured by a cap of Northland Allochthon materials (mostly Mahurangi Limestone). There is one notable area of exposure in the north/south aligned valley on the western side of Matakana Road. It appears that in this area the cap of Mahurangi Limestone has been eroded away, exposing the Pakiri Formation beneath. This valley now forms Kowhai Park Reserve.

3.2.1.2 Rock mass description

The Pakiri Formation rocks are predominantly volcanic rich thick-bedded sandstone with interbedded siltstone. It typically includes 10-30 m thick intervals of graded, medium to coarse grained sandstone beds ranging from 1 to 4 m thick. The sandstones alternate

[1] Allochthon: a large block of rock which has been moved from its original site of formation, usually by low angle thrust faulting.

with thinner intervals of laminated siltstone and fine grained sandstone, typically 0.05-0.2 m thick.

Slightly weathered sandstones are often moderately strong, while extremely weathered material may be extremely weak to very weak.

The Pakiri Formation in the study area appears to generally have a regional dip of approximately 20° towards the north-west. However, local deformation is expected throughout the area, with small scale slumping and overturning previously documented.

Extremely weak pre-sheared surfaces are known within the Waitemata Group rocks. These may have formed during tectonic uplift, and in a number of areas have formed the basal shear plane for very large block slides. These have the potential to destroy many buildings if not carefully identified and treated.

3.2.1.3 Weathering

The Pakiri Formation rocks weather to pink, red or orange-brown, soft to very stiff silty clays, clayey silts and sandy silts. The study area was observed to have a significant depth of completely weathered rock and residual soil. The weathered zone will typically be 3 to 10 m deep (Tonkin + Taylor, 2013), although a mantle of residual soil only 1 to 2 m thick is common on steeper slopes (Higham, 2007). Experience on projects in the Warkworth area suggests that weathering zones of 15 m depth are not uncommon, with generally stiff residual soils. The weathering profile is often dependent on the underlying structure (e.g. bedding plane orientation, joint patterns) and exposures commonly display sharp transitions from deep residual soils to relatively unweathered rock masses. Cut slope failures are very common where such sharp transitions are exposed and adversely orientated to the face.

During the Northern Gateway Toll Road construction it was identified that true residual soils developed in situ from the Pakiri Formation had good shear strengths. However, the same materials reworked as colluvium had low shear strength.

3.2.1.4 Geomorphology

Landforms developed on the Pakiri Formation show a degree of structural control. The dominant ridges often reflect major anticline folds. Stream courses tend to parallel the strike of bedding and rectilinear drainage develops in places implying structural defects at high angles (McClean, 1995). Isolated benched topography in steep hillsides often implies the presence of structurally controlled landslide blocks.

Slope movements are controlled by geological structure. However, slope instability appears to be rare on shallow slopes of less than 25 degrees. Translational slides in the Pakiri Formation are often structurally controlled, with rupture planes developing along bedding planes or weathering boundaries. Rotational landslides are unlikely to occur deeper than the residual soils in the Pakiri Formation as shear planes often develop at the soil/rock interface.

3.2.2 Northland Allochthon

The Northland Allochthon rocks are older than the Waitemata Group, and were initially deposited about 15 to 25 million years ago. They were transported and emplaced towards the south or south west into the deepening Waitemata Basin approximately 15 million years ago by a complex process of thrust faulting and submarine landsliding. Consequently, they are severely deformed, crushed and sheared (Winkler, Geotechnical Engineering of the Northland Allochthon, 2003). Rocks of the Northland Allochthon were previously known as the Onerahi Chaos Breccia, but this nomenclature is no longer adopted in geological literature.

The Northland Allochthon rocks have been divided into many lithostratigraphic units, each with a wide variety of rock type, fabric and structure. In the study area, they generally comprise undifferentiated rocks of the Mangakahia Complex (primarily mudstone) and Mahurangi Limestone of the Motatau Complex. Small serpentinite bodies may also be present but known bodies have been worked out in the study area (Rait, 2000). The geological maps of the area show two such bodies immediately north of the Warkworth Showgrounds. Serpentenite is commonly associated with fault zones, which may indicate areas of particularly weak rock prone to instability.

Thrust faults define many of the boundaries between the Pakiri Formation and Northland Allochthon thrust sheets. Deposition of the Pakiri Formation sediments continued above the newly emplaced allochthon sheets. This relationship is shown in . Syn- and post-depositional faults and folds have resulted in additional complex local deformation of the rocks in the area. Allochthonous thrust sheets incorporating blocks of highly deformed Pakiri Formation have also been reported in the region (Tonkin & Taylor, 2004). Within the Northland Allochthon materials, the sequential emplacement of thrust sheets has resulted in large scale fold structures, with the possibility that older materials now overlie younger deposits or rocks have been completely overturned.

The Pakiri Formation rocks display evidence of deformation associated with emplacement of the Northland Allochthon; particularly where the Pakiri Formation lies in close vicinity to allochthonous rocks where it may be complexly folded and faulted.

3.2.2.1 Distribution

The Northland Allochthon forms the surface geology across the majority of the study area between the existing SH1 and Sandspit Road. The distribution of the sub-units is described individually below since their performance is expected to be quite different.

3.2.2.2 Geomorphology

Northland Allochthon materials are notorious for their instability at even the most gentle of slopes. Discrete individual landslides are rare in Northland Allochthon materials, instead numerous lobes displace in turn until they reach equilibrium. Small modifications to the equilibrium conditions can easily reactivate previously stable lobes.

Translational sliding of residual soils and colluvium is common, occurring along low-angle pre-existing failure planes and shear surfaces in the transition zone between the residual soils and underlying rock masses. These failures are often controlled by the very low residual friction angle along sheared surfaces and within the sheared fabric.

In general the non-calcareous Hukerenui Mudstones have the lowest residual friction angles typically between 10 and 13 degrees, and sometimes as low as 8 degrees. Residual friction angles within sheared zones of the more calcareous and siliceous rocks are higher, generally increasing up to 20 degrees. This is due to the increased proportion of sand sized particles and other fragments within the sheared zones within these stronger rock masses (Winkler, 2003). Deep seated landslides with basal shear surfaces within the rock mass are usually much less common than shallow slope instability within the soil mantle; the parent rock mass generally doesn’t have persistent defects due to the pervasive shearing and fracturing from the allochthon emplacement. Where present, deep seated landslides can be difficult to identify due to the tendency of headscarps and lateral scarps to degrade resulting in loss of definition of the original feature. Slide morphology will be strongly influenced by the rock mass structure and defects. Movement can occur on slope angles as low as 8-10 degrees.

The siliceous soils generally display Atterberg Limits typical of highly active and swelling clay minerals. Seasonal wetting and drying leads to swelling and shrinkage, creep movement on slopes and strain softening of the soils. Consideration should be given to adopting foundation depths below levels subject to seasonal wetting and drying (Lentfer, 2007). Fissuring interpreted to be the result of shrink / swell may extend to depths of 2 metres within highly expansive soils. Wide fissures may develop at the ground surface over drying months that allow rapid surface water ingress during heavy rainfall.

The Northland Allochthon is characterised by long, gentle to moderately graded, broad, hummocky slopes with terracettes on most slope angles. Slopes will often have hummocky ground extending all the way from the toe to the ridgeline, with hummocks 5 m to 20 m wide, oval in shape, and parallel to the slope contours. Almost all the slopes have been subject to some form of slope instability and creep over time. Wet or swampy ground is common in the many low lying areas and ridge line depressions (Lentfer, 2007).

3.2.3 Northland Allochthon - Mahurangi Limestone

3.2.3.1 Distribution

Almost all of the Allocthon materials immediately underlying the study area are believed to be Mahurangi Limestone, except under the Warkworth Golf Course.

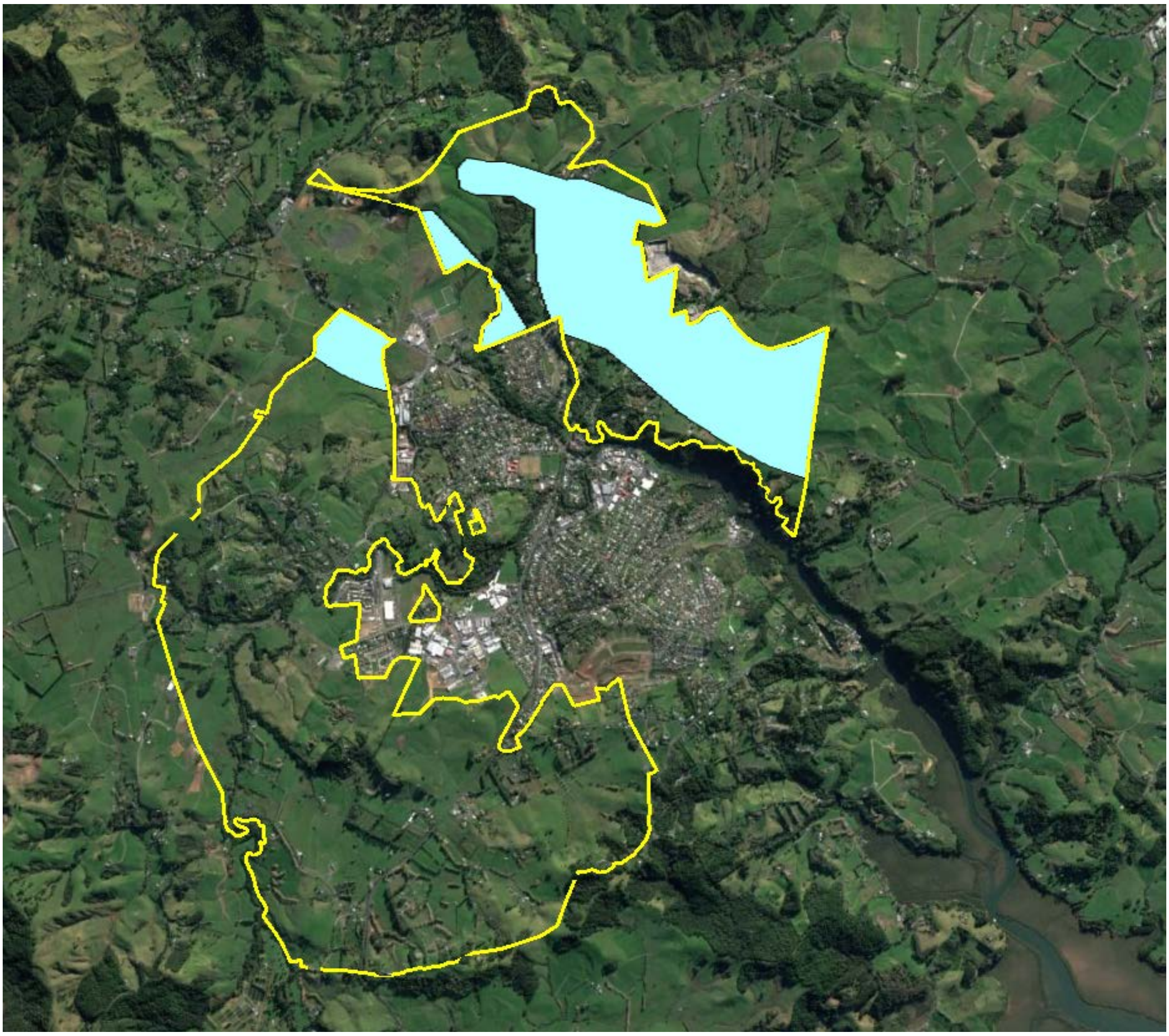

Figure 5: Inferred distribution of Mahurangi Limestone within the study area boundaries. Note that these are slightly different from the mapped distribution shown in Figure 3 as they take into account additional data from boreholes and other sources.

3.2.3.2 Rock mass description

Carbonate-rich Early Eocene to Early Miocene rocks are grouped into the Motatau Complex, of which the Mahurangi Limestone is a sub-unit. The two main sub-units are:

- Mahurangi limestone. Pale grey to white, massive or millimetre-laminated, weak to strong, typically shattered, muddy micritic limestone, locally with intercalated, centimetre- to decimetre-thick graded beds of dark green glauconitic sandstone. The rock mass often includes polished and slickensided surfaces.
- Puriri Mudstone. Massive, unsheared, light grey to white, very calcareous mudstone (Edbrooke S. W., 2001).

Although the geological maps show only Mahurangi Limestone at the study area, a ground investigation at Warkworth Showgrounds reported calcareous Northland Allochthon mudstones which may be indicative of the presence of Puriri Mudstone at this location (Beca, 2004). Alternative interpretations are that these materials may be part of the Mangakahia Complex, or may be mis-logged Mahurangi Limestone.

3.2.3.3 Weathering

Residual soils of the Mahurangi limestone typically comprise firm (occasionally stiff) moderately to highly plastic, orange, cream, brown or grey clayey silts and silty clays. Rare limonite staining may be found. Depths of residual soils range from 0.3 m to 2.5 m. The change from residual soil to rock is often abrupt, with little or no transition zone. However, unweathered material is rarely observed in excavations up to 10 m deep (Lentfer, 2007).

3.2.3.4 Stability

The Mahurangi limestone often forms the steepest slopes of the Northland Allochthon materials, with natural slopes in excess of 20 degrees. These rocks are generally considered to be more stable than the Mangakahia Complex. An active quarry in this material between Sandspit Road and Matakana Road has utilised cut slope angles of 60 degrees which appear to be generally stable. Some of these slopes have been benched. There was some evidence of very shallow slips off these steep faces in isolated locations, and regular frittering of small blocks (<0.1 m) from all the faces.

There was only minor evidence of landslides on natural terrain, manifested as undulating and highly variable terrain with benched slopes and significant seepages or springs in the gullies. These landslides also tend to develop by shearing within a broken transition zone between the residual soils and underlying weak rock. From local experience, transition zones in Mahurangi Limestone in the local area are known to vary from 2 m to over 8 m deep.

Within the Mahurangi limestone piping is common, forming subsurface cylindrical drainage channels along defects. These are typically 1 m wide, 20 m long, and within 2 m of the surface. They may collapse to form sinkholes (McClean, 1995). These features have been observed within calcareous Mangakahia Complex and Mahurangi Limestone terrain in the Silverdale area to the south of the study area where groundwater flows have been concentrated over the less permeable rock surface. No evidence of these was observed during the site walkover.

3.2.4 Northland Allochthon - Mangakahia Complex

3.2.4.1 Distribution

Mangakahia Complex rocks are shown on the geological maps as being present under the Warkworth Golf Course. There is a possibility that they are also present beneath the Warkworth Showgrounds.

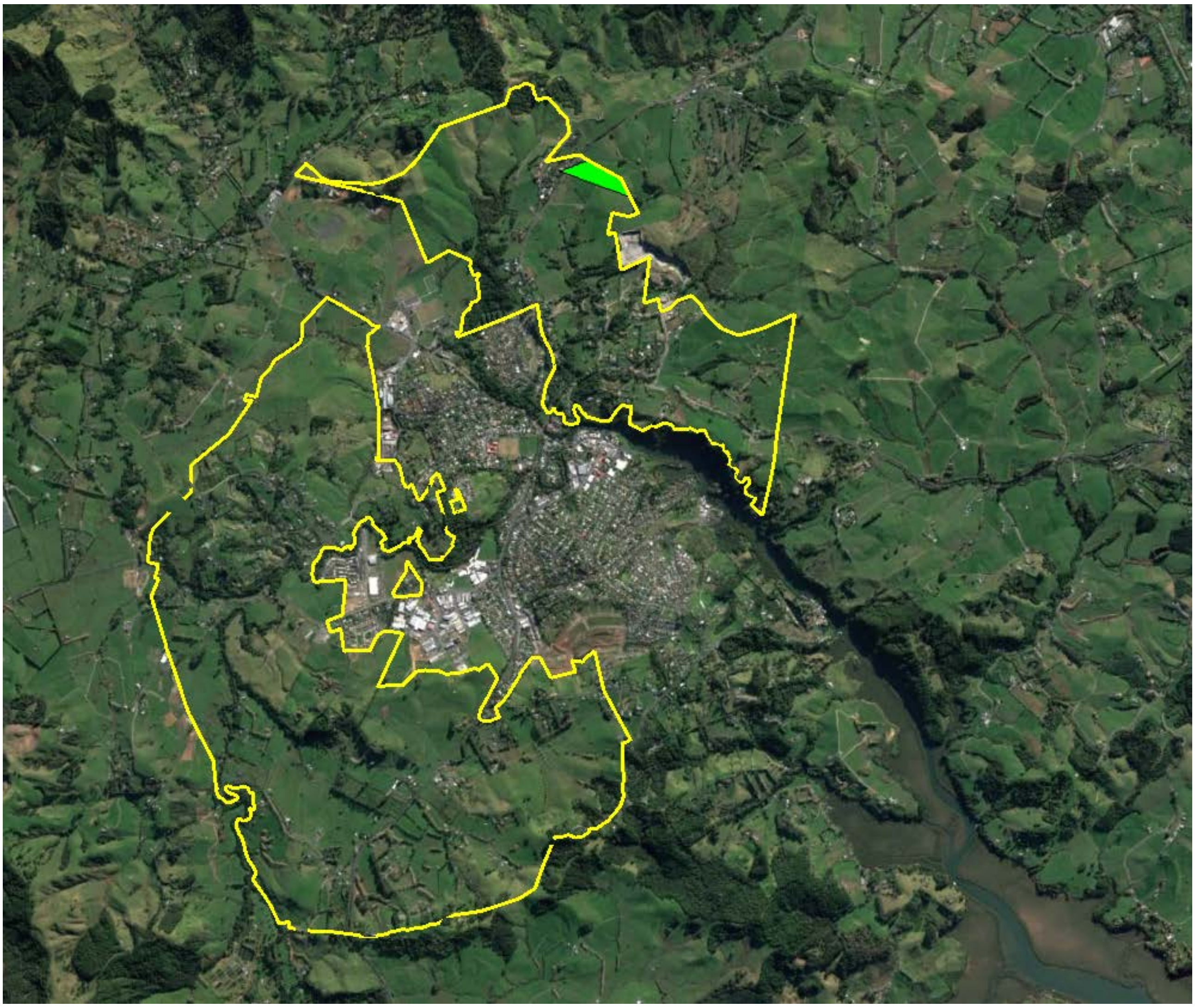

Figure 6: inferred distribution of Mangakahia Complex mudstones within the study area boundaries. Note that these are slightly different from the mapped distribution shown in Figure 3 as they take into account additional data from boreholes and other sources.

3.2.4.2 Rock mass description

These closely fractured to sheared mudstones, limestones and sandstones contain the most deformed group of materials in the Northland Allochthon. The rocks are highly variable, and include:

- Hukerenui Mudstone. Extremely weak to weak non-calcareous grey, green, red, or dark brown, clay rich, typically highly to pervasively sheared mudstone with very high smectite (swelling clay) content.
- Whangai Formation. Dark brownish grey or black siliceous mudstone and dark grey to blueish grey calcareous mudstone to fine sandy siltstone, weathering to cream, light grey and white. Surfaces of rock fragments may be weakly striated to intensely slickensided and polished with thin coatings of silty clay or limonite.

The sheared fabric within the materials is typically at a low angle, due to the low angle of emplacement of the thrust sheets. The rocks typically occur as a melange of mixed lithologies (Edbrooke S. W., 2001).

3.2.4.3 Weathering

The soils that develop above the Northland Allochthon are generally relatively thin, with thickness often controlled by the permeability of the parent rock. More calcareous or siliceous parent rocks often have a higher permeability, and are associated with a thicker depth of weathered soil mantle. The least permeable soils, the non-calcareous Hukerenui mudstones, have a very thin soil mantle of typically 1.5m to 2m thickness (Winkler, 2003) although in the Silverdale area they have been noted as up to 10m thick. The residual soils of the mudstone tend to comprise silts and clays. They are often stiff near the ground surface and soft to very soft near the transition zone as the water content increases (Lentfer, 2007).

The soil is almost always nearly saturated, and grades sharply down into the parent rock with a broken ‘transition’ zone and sheared contact between. Water tends to perch above the parent rock within the sheared low strength transition zone.

The residual soils of the Whangai Formation typically comprise stiff to very stiff, slightly to highly plastic, orange, brown or grey silts and clays with traces of sand. Iron oxide (as limonite) is often evident and gives rise to moderately cemented to well cemented granular material. Soils are highly fissured but permeability is typically very low due to high clay content. The upper soil profile is often saturated during winter months and surface water ponds. Residual soils may be poorly developed or absent on steeper slopes where they have been removed by landsliding or erosion (Lentfer, 2007).

The residual soil of the Mangakahia Complex often has very high water content and may abruptly grade down into the parent rock with a broken ‘transition’ zone and sheared contact. Alternatively a softened/weathered rock layer may exist beneath the transition zone, which grades into fresh and stronger rock with higher frictional strengths. Groundwater tends to perch above the parent rock within the more permeable sheared transition zone.

3.2.4.4 Stability

The geomorphology, and in particular the gradient of the slope, is controlled by the lithology. Slopes underlain by Hukerenui mudstone and melange stand at the lowest gradients (often less than 12 degrees, and sometimes as low as 8 degrees) reflecting the low residual shear strength of the soil/rock interface. Weakly calcareous rocks stand at 12 to 20 degrees, and the calcareous, siliceous, and sandstone allochthonous rocks (such as the Whangai Formation) stand at 20 to 26 degrees or more. The boundaries between the different rocks within the Northland Allochthon can be identified by changes in slope angle, lines of springs, or by the boundary between a smooth, elongated mound surrounded by hummocky ground (Winkler, 2003). Slope movements are particularly apparent for siliceous rocks of the Mangakahia Complex as they typically contain significant proportions of active clays.

Deep seated landslides exist, but are much less common than slope instability within the soil mantle. Discrete individual landslides which are common in other lithologies are rare in Northland Allochthon materials. Instead, numerous lobes form over the slope and displace in turn until they reach equilibrium. Small changes can easily reactivate previously stable lobes. Deep seated landslides can be difficult to identify due to the tendency of headscarps and lateral scarps to degrade resulting in loss of definition of the original feature.

3.2.5 Tauranga Group alluvium and colluvium

Over the last few million years, Northland has been uplifted at a fairly uniform rate of up to a maximum of 0.35 mm per year (Ballance & Williams, 1992), and this is believed to also apply to the Warkworth area. It is thought that this ongoing regional uplift may have been in large part responsible for maintaining a relatively rugged relief, despite ongoing deep and rapid chemical weathering of the rocks and an otherwise stable tectonic situation for the last 10-15 million years.

About 20,000 years ago, during a period of glaciation, sea levels reached a low of about 100 m below current sea level resulting in rivers cutting deep valleys into the landscape. Subsequent sea level rises ‘drowned’ and infilled many of the deep valleys with sediments. These drowned valleys dominate the east coast of Northland, including the Puhoi and Mahurangi valleys. These valleys are infilled with deep, soft estuarine and alluvial sediments, often with terrace levels representing previous, higher sea levels or lower land levels (Ballance & Williams, 1992).

3.2.5.1 Distribution

Colluvium is present on many slopes, typically resulting from translational sliding of residual soils. This slope movement has been exacerbated as a result of human impacts on the landscape since the 1820s, including the changing land use from kauri forest to scrub, pasture, or urban land (Ballance & Williams, 1992). Deforestation also alters hydrology, which may result in channel enlargement and migration. Colluvium has not been separately mapped in the study area.

Alluvium is found in most low-lying valley floors across the study area.

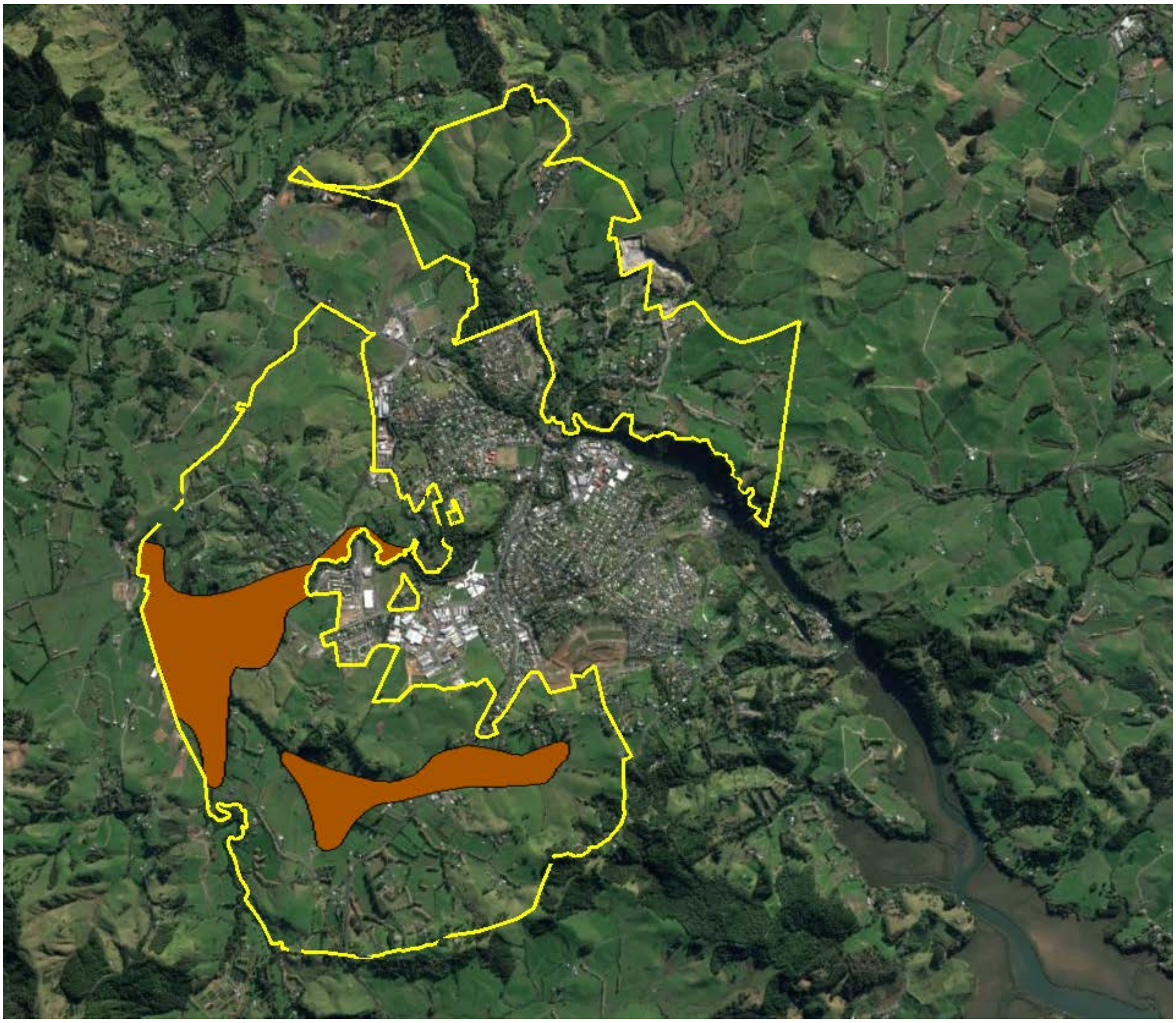

Figure 7: Mapped distribution of alluvium within the study area boundaries

3.2.5.2 Material description

The alluvium is expected to comprise soft to very soft clay and silt, with some sand and possibly lenses of gravel, peat or organic beds, and pumiceous deposits in some of the older Pleistocene deposits. Alluvium is typically reworked deposits of colluvium and eroded soils derived from both the surrounding Northland Allochthon and Waitemata Group rocks. Consequently, the alluvium may contain moderately or highly expansive smectite-rich soils derived from the local Northland Allochthon and weathered Pakiri Formation.

3.2.5.3 Geomorphology

The alluvial deposits are characterised by flat, low lying ground with few or no signs of instability.

3.3 Regional hydrogeology

Subsurface groundwater conditions are an important consideration for any development, and may have a major impact on foundations, services (excavations), earthworks, slope stability and liquefaction potential.

The hydrogeological regimes of the main geological groups encountered along the alignment (the Waitemata Group, Northern Allochthon and Tauranga Group) are fundamentally different.

Northland Allochthon rocks can display highly variable and complex hydrogeological conditions relative to various response zone depths. Northland Allochthon rocks typically comprise poor to very poor permeability rocks with hydraulic conductivity (the ability of the water to transmit water) generally less than 10^{-7} m/s. Both matrix and secondary permeability along bedding planes is typically poor due to secondary infill through either weathering products (clay) or precipitation (limonite or calcite). However, localised zones of high tertiary (conduit) porosity have been experienced in water supply boreholes in the Warkworth area as a result of the presence of fault induced shattering of the rock.

Drainage from the Northland Allochthon rocks is typically observed as a line of seepage or minor springs at geological boundaries between units within the Northland Allochthon rocks.

Waitemata Group Rocks typically have hydraulic conductivity values at the lower end of the 10^{-7} m/s range. Perched and leaky water tables may be present and reflect the interbedded nature of the sandstones and siltstones of varying permeability. Groundwater from the Waitemata Group rocks is used as a resource for stock and domestic water supplies, but generally the yields are low (~2 L/s) for boreholes less than 100 m deep, and the aquifers are not generally conducive within reasonable economic consideration for the higher flows required for broad water supply or irrigation purposes.

The geology and geological structure in the area lends itself to poorly yielding aquifers, with the exception being localised zones of better yields associated with faulting and shallow alluvial deposits infilling valleys. Groundwater use in the Puhoi to Warkworth area is very low with the bore database only providing information on seven bores. These are typically for stock and domestic purposes and consist of 100 mm installations, generally 50-100 m deep.

3.4 Areas of geological significance

A search of the online New Zealand Geopreservation Inventory identified one location of recorded geological significance within the project area. This is unlikely to be impacted by the proposed structure plan as it lies just outside the boundary adjacent to the Mahurangi River south of Sandspit Road.

<table>
<tr><th>• Name</th><th>• Location</th><th>• Reason for significance</th><th>• Classification</th></tr>
<tr><td>Wilsons Cement Works</td><td>Warkworth</td><td>First Portland cement plant in the Southern Hemisphere. Well preserved historic relics.</td><td>A1</td></tr>
<tr><td colspan="4">Note: Classification rates the importance of the geological feature.</td></tr>
<tr><td>Importance:
A = international
B = national
C = regional</td><td colspan="3">Vulnerability:
1 = vulnerable to complete destruction by human actions
2 = vulnerable to significant modifications by human actions
3 = probably not vulnerable to any likely human actions
4 = already destroyed by human actions</td></tr>
</table>

Table 1: Areas of geological significance in the project area

3.5 Regional geohazards

3.5.1 Faulting and seismicity

The Auckland Region is one of the least seismically active regions of New Zealand. The study area is over 200 km from the seismically active boundary between the Australian plate and the subducting Pacific plate. The closest active faults are the Wairoa North Fault (Edbrooke S. W., 2001) and Drury Fault (Williams, et al., 2006), located in the Hunua Ranges south-east of Auckland, approximately 75 km to the south of the study area and the Kerepehi Fault within the Firth of Thames.

The Kerepehi Fault has been estimated to be capable of generating earthquakes of about M 7 with a recurrence interval of 3600 years (Edbrooke, Heron, Stirling, Johnston, & Alloway, No date). Published empirical relationships and recent unpublished studies of fault rupture displacements have suggested single earthquake events on the Wairoa North Fault may give rise to moment magnitudes in the order of Mw6.9-7.1

That being said, there has been negligible seismic activity over the last 100 years in the study area, with the exception of a magnitude 4.5 earthquake which was centred 30 km east of Orewa in the Hauraki Gulf on 21 February 2007. The earthquake was felt from Warkworth in the north through to Waihi at the base of Coromandel Peninsula (GNS News

Release, 22 February 2007). Two smaller earthquakes occurred within hours of the main quake and were of magnitude 3.7 and 3.8.

A set of hazard plans prepared by the ARC indicate the ground shaking hazard within the study area for an earthquake return period of 2000 years is generally low due to the general absence of significant thicknesses of unconsolidated sediments. However, the estuary south of Puhoi and the area of Kaipara Flats to the west of Warkworth are considered to have a high ground shaking hazard due to the presence of soft estuarine deposits.

Ground shaking that is severe enough to damage buildings built to earthquake code standards (~0.26 g) is expected to occur in the Auckland Region, on average, once every two thousand years (ARC, 2010e).

3.5.2 Liquefaction

Liquefaction hazards primarily exist in areas of saturated unconsolidated finer grained soils, although coarse-grained soils may be susceptible to liquefaction under certain seismic conditions. The primary areas of liquefaction hazard in the study area are considered to be alluvial and estuarine sediments in the river valleys.

A study undertaken in 1996 for the Auckland Lifelines Group identified the areas shown in Figure 8 as potentially liquefiable.

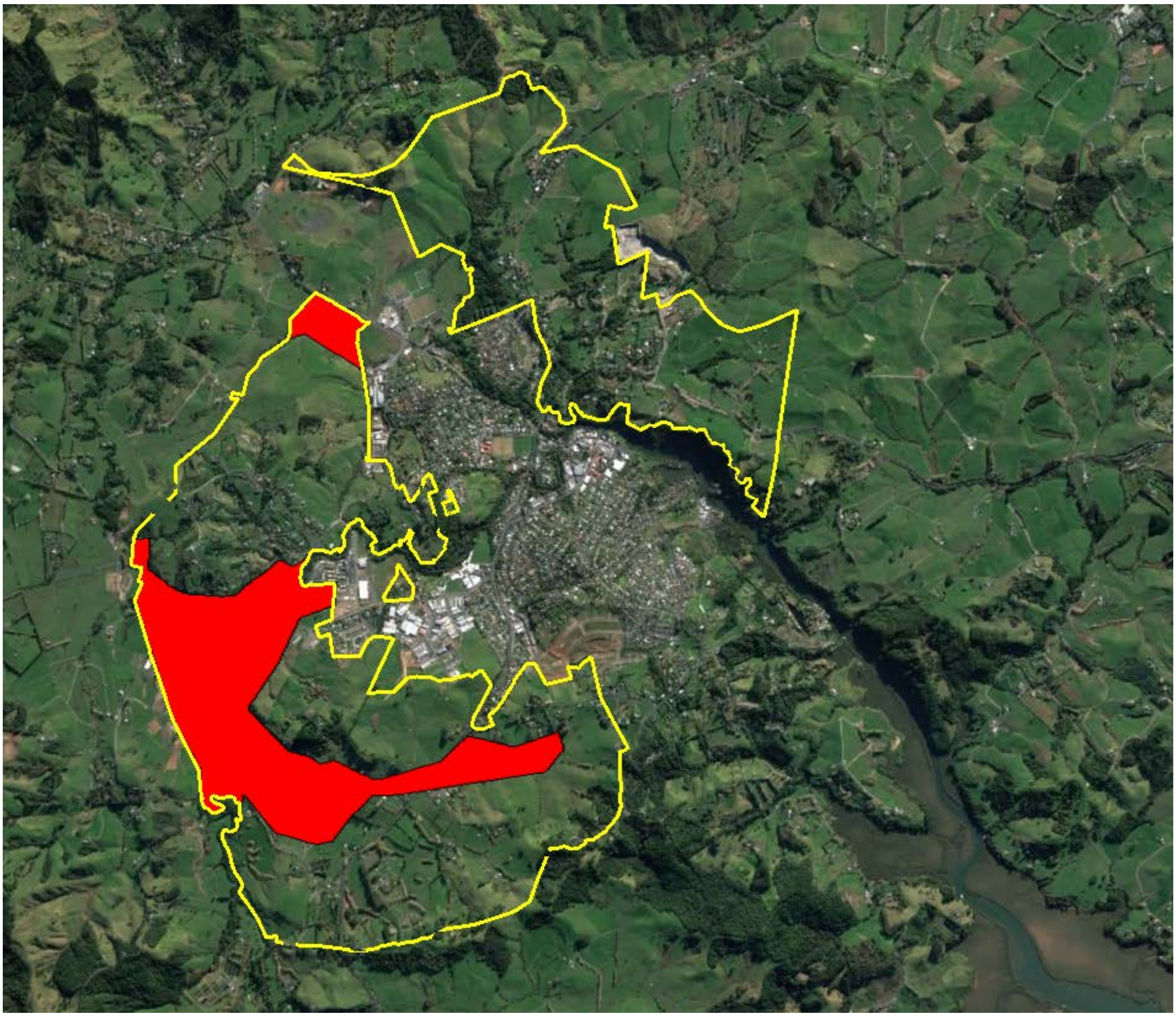

Figure 8: High-level of areas potentially susceptible to liquefaction

However, a new study currently underway at the University of Auckland suggests that this may be over-conservative, and has assigned a low liquefaction vulnerability to the full study area. Because this study takes into account the latest research and lessons learned from the Canterbury earthquake sequence it is considered to be more reliable than the older 1996 study. However, it has yet to undergo peer review and so the findings have not been fully incorporated into this report. It is anticipated that future revisions will show a significantly smaller area that may be susceptible to liquefaction than currently indicated on Figure 8.

3.5.3 Slope instability

The geology and geomorphology are the principal conditioning factors of the region's land instability. The majority of the natural slopes in the study area are typically moderately steep (25-40°) and underlain by deeply weathered materials of the Pakiri Formation. Shallower slopes are formed where underlain by Northland Allochthon materials. There is generally widespread evidence of shallow soil creep and shallow translational landslides across the entire study area and numerous examples of historical and current instability exist along the present road network, including SH1.

The Auckland Council Slope Instability Hazard Map (Williams A. L., 1996) shows that a significant portion of the study area is considered a High hazard[2] for general slope instability.

Figure 9: Mapped distribution of high (orange) and medium (yellow) risk areas for slope instability

Given the relatively low accuracy of the study on which Figure 9 is based, a geomorphological desk study of the area has been undertaken to assess the distribution of identifiable landslides within the area, and the data in Figure 9 has not been used in the definition of development premiums for the study area. The data used in the development premiums is presented in Figure 10

[2] Slope instability hazard is broadly assessed based on a combination of factors incorporating soil/rock type, slope grade, and areas of known instability (Williams, 1996).

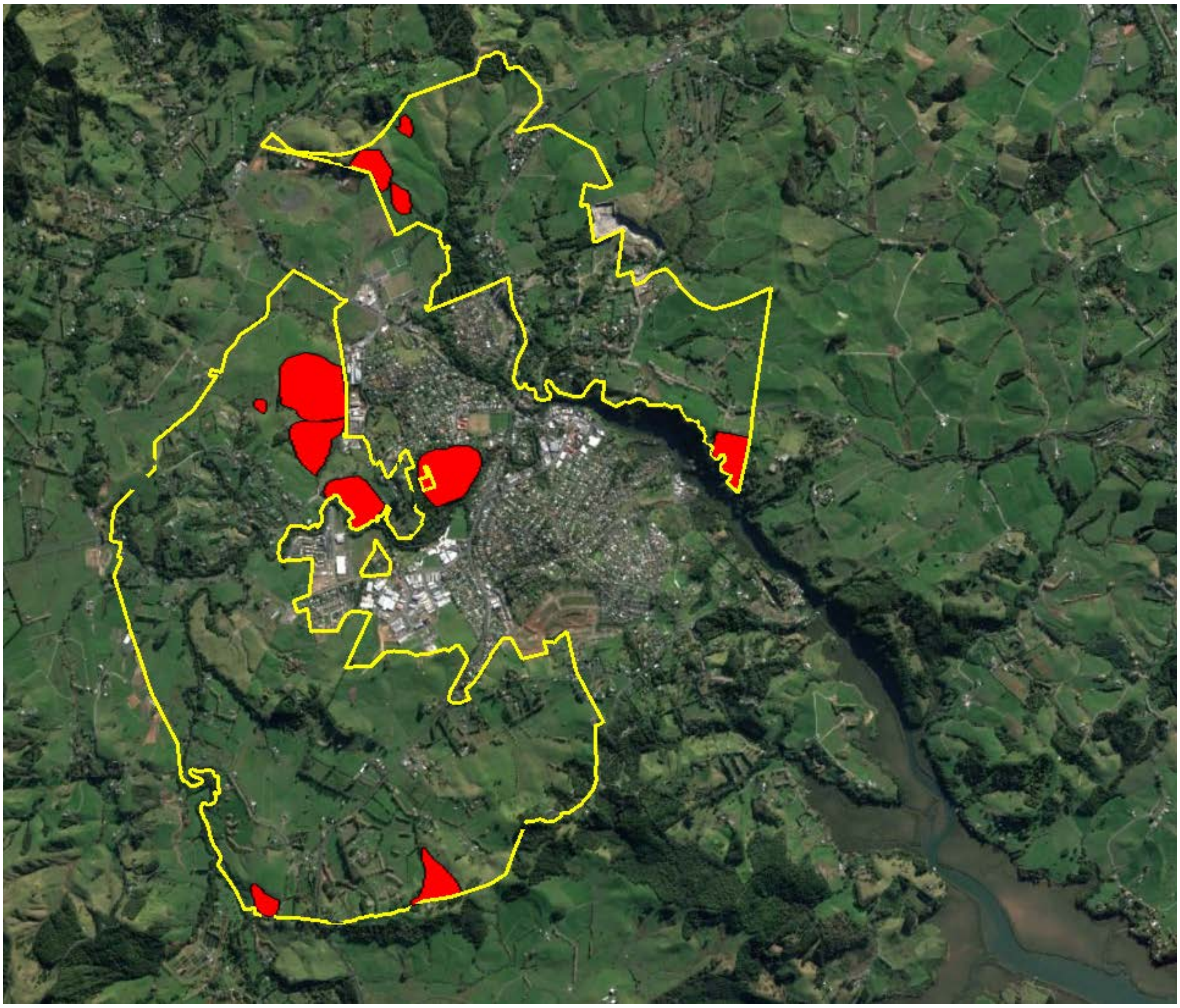

Figure 10: Mapped distribution suspected large-scale active or inactive landslides identifiable from aerial photography

3.5.3.1 Soil creep

Soil creep (very slow seasonal shallow mass movement) is widespread, and is readily observable across many steeper slopes of the Pakiri Formation and moderate slopes of the Northland Allochthon in the form of terracettes. This form of shallow instability suggests that potentially expansive clayey soils are present. In many cases these should not be a significant concern for the project, but will in some areas require additional engineering work to retain slopes or result in ongoing maintenance issues.

3.5.3.2 Shallow landslides

Shallow landslides also commonly form in the Northland Allochthon and Pakiri Formation by creeping or slumping of the soil mantle over the weathered bedrock. Ground water build up at this interface may have a significant destabilising effect.

The majority of the landslides in the region are shallow translational or shallow earthflows, inferred to generally be less than 5 m deep. They are very common in the steeper slopes of weathered Pakiri Formation and in all but the gentlest gradients of Northland Allochthon materials.

It is difficult to distinguish the boundaries of landslide masses within Northland Allochthon materials as they are often a combination of creep, slides and flows.

3.5.3.3 Debris flows

Rainfall-induced channelised debris flows and gully erosion are a hazard for potential road alignments crossing steeply incised gullies, particularly road alignments near the valley floors in the elevated and deeply dissected terrain of the Pakiri Formation. There is extensive evidence of debris within gullies across the entire area and this material is susceptible to capture and channelised transport during significant rainfall events.

3.5.3.4 Deep seated landslides

A number of translational block slides are identified in both Pakiri and Northland Allochthon units. These involve translational slide masses containing blocks which remain relatively intact though the majority are poorly developed as the failed mass tends to have deformed. In particular, failed debris from shallow translational or block landslides is often remobilised as earth flows developing at the toe region.

Deep-seated rotational landslides are generally considered to be rare in the region. Studies by Power (2005), (Tonkin & Taylor, 2004) and (Williams A. , 1989) found that rotational landslides in the Pakiri Formation and Northland Allochthon materials of the region were also either absent or rare. However, (McClean, 1995) noted benched topographic landforms on Mahurangi Peninsula and attributed these to deep-seated movements. Studies undertaken for the Puhoi to Wellsford Road of National Significance identified evidence of significant deep-seated block or translational landslides in both the Pakiri Formation and Northland Allochthon terrains (Sinclair Knight Merz, 2010).

3.5.4 Piping erosion

Within the limestone of the Northland Allochthon piping is reported to be common, forming subsurface cylindrical drainage channels along defects. These are typically 1m wide, 20m long, and within 2m of the surface and may collapse to form sinkholes (McClean, 1995). These features have been observed within calcareous Mangakahia Complex and Mahurangi Limestone terrain in the Silverdale area to the south of the study area where groundwater flows have been concentrated over the less permeable rock surface.

There are no karstic features reported in the limestone and no history of large sinkholes known to the authors.

The extent of this risk is expected to coincide with the extent of the limestone shown in Figure 5.

3.5.5 Climate change

The Intergovernmental Panel on Climate Change (IPCC) latest fifth assessment report (AR5) presents the most recent global climate change and sea-level rise projections. The projections are based on four Representative Concentration Pathways (RCP) scenarios. These cover a range of future global, socio-economic trends considering energy demand, population growth and varying degrees and mitigation controls on Greenhouse Gas (GHG) emissions. The subsequent RCPs reflect of a range of 'paths' that global radiative forcing may take which will influence other climate factors including temperature, sea-level rise and rainfall.

The impacts of climate change on north eastern New Zealand are likely to include:

- Regional reductions in rainfall in south-west and inland Australia and eastern New Zealand.
- Increasing coastal vulnerability to tropical cyclones, storm surges and sea-level rise.
- Increased frequency of high-intensity rainfall, which is likely to increase flood damage and result in greater storm runoff, greater erosion of land surfaces, more landslides, and redistribution of river sediments.

For coastal hazards, justification of an appropriate sea-level rise value to be used in future planning and development needs to be cognisant of future RCP scenarios and their impact. For example, the figure below shows the median estimate and the assessed likely ranges of global-mean sea-level rise for two contrasting RCP scenarios (RCP2.6 and RCP8.5).

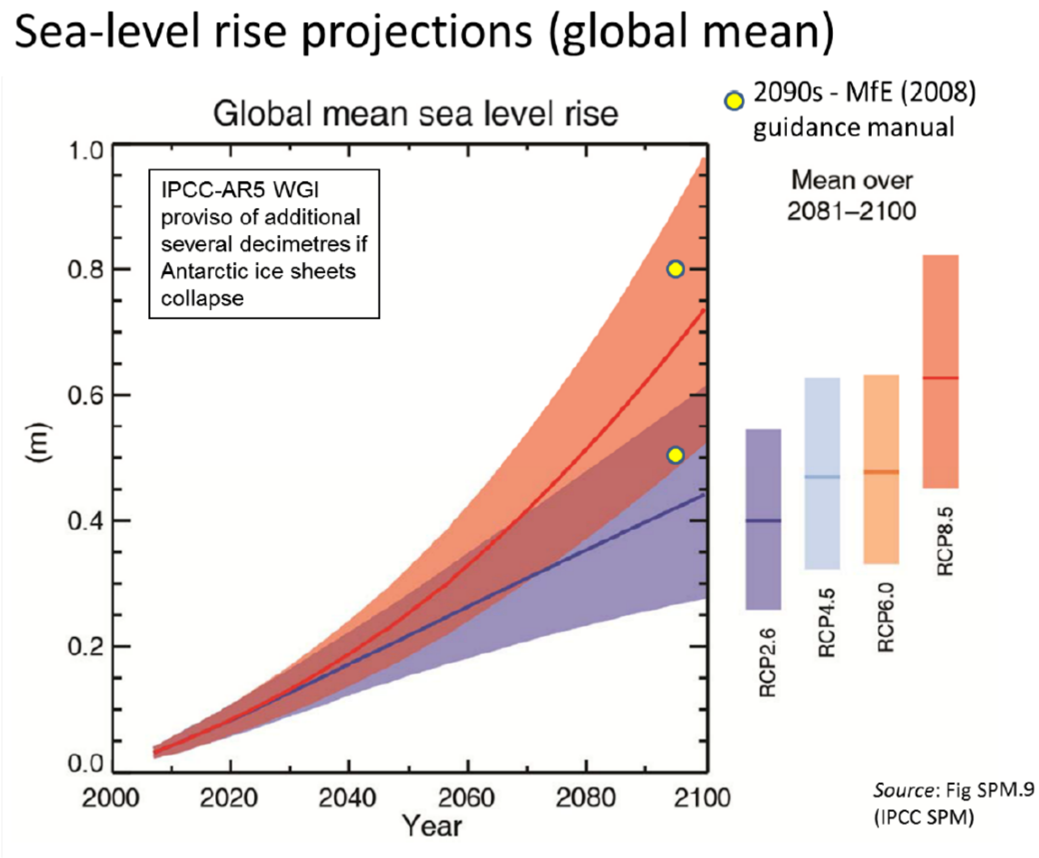

Figure 11: Projections of global mean SLR over the 21st century relative to the 1986 2005 baseline from ensembles of climate-ocean models for the RCP2.6 (blue shading: for severe curbs on emissions) and RCP8.5 (brown shading: for business-as-usual) scenarios, The heavy line is the median estimate from models and the shading represents the assessed 'likely range' of SLR for the RCP[3]. Considering the aforementioned national guidance, the yellow dots represent the SLR values currently specified in the MfE guidance to apply to the mid 2090's. (Bell., 2015)

The Auckland Unitary Plan considers the effects of 1 m sea-level rise over the next 100 years (see Section 4.3). This is based on adoption of the RCP8.5 (upper bound) scenario, extended out to 2115 in alignment with the New Zealand Coastal Policy Statement (2010) and the Ministry for the Environment Guidance on Coastal Hazards and Climate Change (2008/2017) as demonstrated in the figure below.

[3] Based on Figure SPM.9 from the IPCC Summary for Policymakers

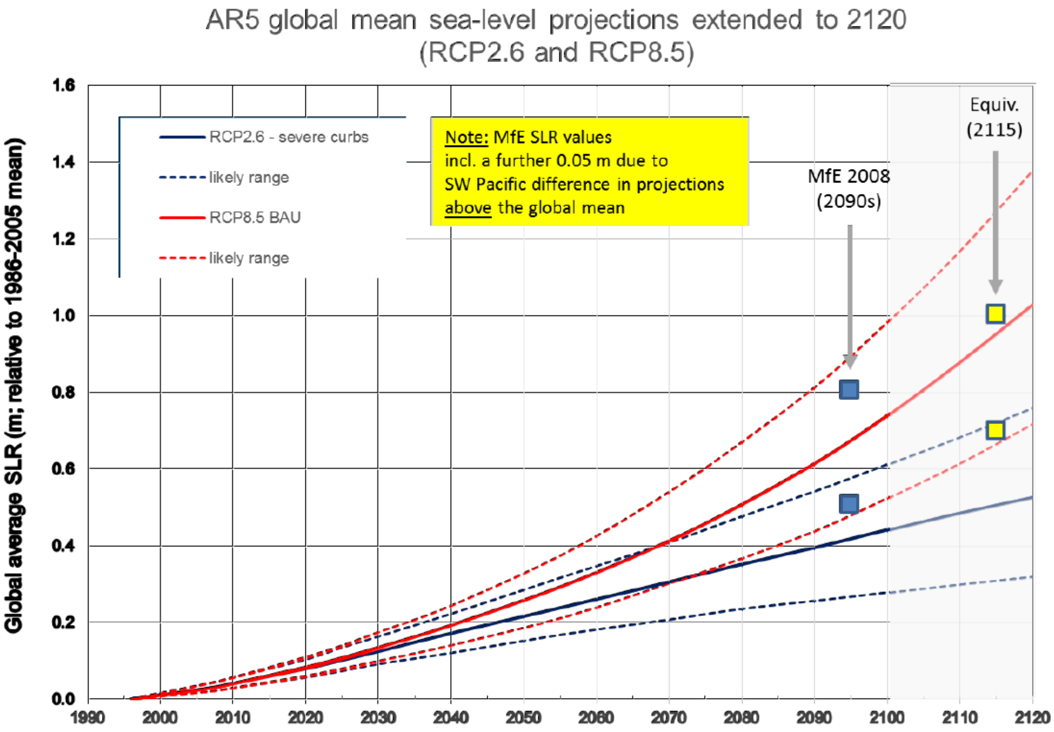

Figure 12: IPCC AR5 projections of global mean sea-level rise over the 21st century relative to the 1986-2005 baseline from ensembles of climate ocean models for the RCP2.6 (dark blue: severe curbs on emissions) and RCP8.5 (red: business-as-usual) pathways, with the likely ranges (dashed-lines) extended out to 2120 to increase the timeframe to 100+ years. Blue square represent SLR to consider in a hazard assessment of 0.5m and at least 0.8m by the mid 2090s (MfE, 2008) and the yellow squares are the extensions through to 2115 of 0.7m and 1.0m, respectively. (Bell., 2015)

- Regarding geotechnical hazards, since landslides are often triggered by extreme rainfall events, the predicted increase in extreme events may lead to an increase in slope instability. The likelihood or potential quantum of this change for the study area is not yet defined.

	2030	2080
Relative temperature change (°C)	+0.2 to +1.4	+0.5 to +3.8
Relative rainfall Change (%)	-19 to +7	-32 to +2

Table 3.2 : Projected changes in New Zealand annual precipitation and mean temperature for the 2030s and 2080s, relative to 1990 (Hennessy, et al., 2007).

4 Planning context

4.1 The Auckland Plan (2012)

The Auckland Plan 2012 sets the overall strategy for Auckland. Key to the plan is the development strategy for accommodating future growth up to 2040, with up to 40 per cent of growth in greenfield areas, satellite towns, rural and coastal towns.

The Plan recognises that Auckland is exposed to a broad and dynamic range of natural hazards and that they are a significant part of our natural environment. As a result, priority 4 of Strategic Direction 7 is to build resilience to natural hazards. This includes in particular, ‘avoid placing communities and critical infrastructure and lifeline utilities in locations at risk from natural hazards, unless the risks are manageable and acceptable.’

4.2 Draft Auckland Plan (2018)

A refresh of the Auckland Plan is being publicly notified in February/March 2018. The draft plan continues/reinforces/changes the direction of the Auckland Plan 2012 in relation to TOPIC AREA in that…

The Draft Auckland Plan 2018 is available using the link below (item 9 of the Planning Committee meeting 28 November 2017):

http://infocouncil.aucklandcouncil.govt.nz/Open/2017/11/PLA_20171128_AGN_6728_AT_WEB.htm

“Approval of draft Auckland Plan for consultation” (File No.: CP2017/22113)

4.3 The Auckland Unitary Plan (Operative in Part) (2016)

The Auckland Unitary Plan recognises that Auckland is affected by a range of hazards including land instability, coastal erosion and coastal inundation. In addition, it considers the effects of climate change and sea-level rise. These matters are predominantly addressed in the Auckland Wide rules of Chapter E.36 Natural Hazards and Flooding. The overarching objectives of which are to ensure that the risks of adverse effects from natural hazards in rural areas are not increased and, where practicable, are reduced.

Policy 1 requires land that may be subject to natural hazards (including land instability, coastal hazards and the likely effect of climate change) to be identified. Policies 5 to 9 specifically relate to coastal hazards to avoid and not increase the risk through subdivision and development. Policies 10 to 12 consider coastal defences and seek to encourage natural systems as defences against coastal hazards over hard protection structures.

Policies 31 to 33 specifically relate to land instability. The policies highlight that land potentially exposed to instability must be identified taking into account; proximity to cliffs, steepness of land, geological characteristics and uncontrolled fill. As a result, risk assessment prior to subdivision, use and development of land is required and results should ensure potential adverse effects are primarily avoided. Where not practicable, effects should be remedied or mitigated.

Activity Controls

Activity controls for coastal erosion (A1 – A5), coastal inundation (A6 – A13), coastal defences (A14 – A22) and land instability (A43-A51) are set out in E36.4.1.

With respect to coastal hazards, this includes the following definitions:

- Activities on land which may be subject to coastal erosion are defined in Chapter J of the AUP. At Warkworth, this relates to land within 40m of MHWS. The FUZ is landward of this definition.
- Activities on land which may be subject to coastal storm inundation 1% Annual Exceedance Probability (AEP). The FUZ at Warkworth is outside of this inundation extent.
- Activities on land which may be subject to coastal storm inundation 1% AEP plus 1m sea-level rise. The FUZ at Warkworth is also outside of this inundation extent.

The Warkwork Future Urban Zone is outside these definitions as further demonstrated in the Figures below. As a result, the further controls for defences against coastal hazards are unlikely to apply.

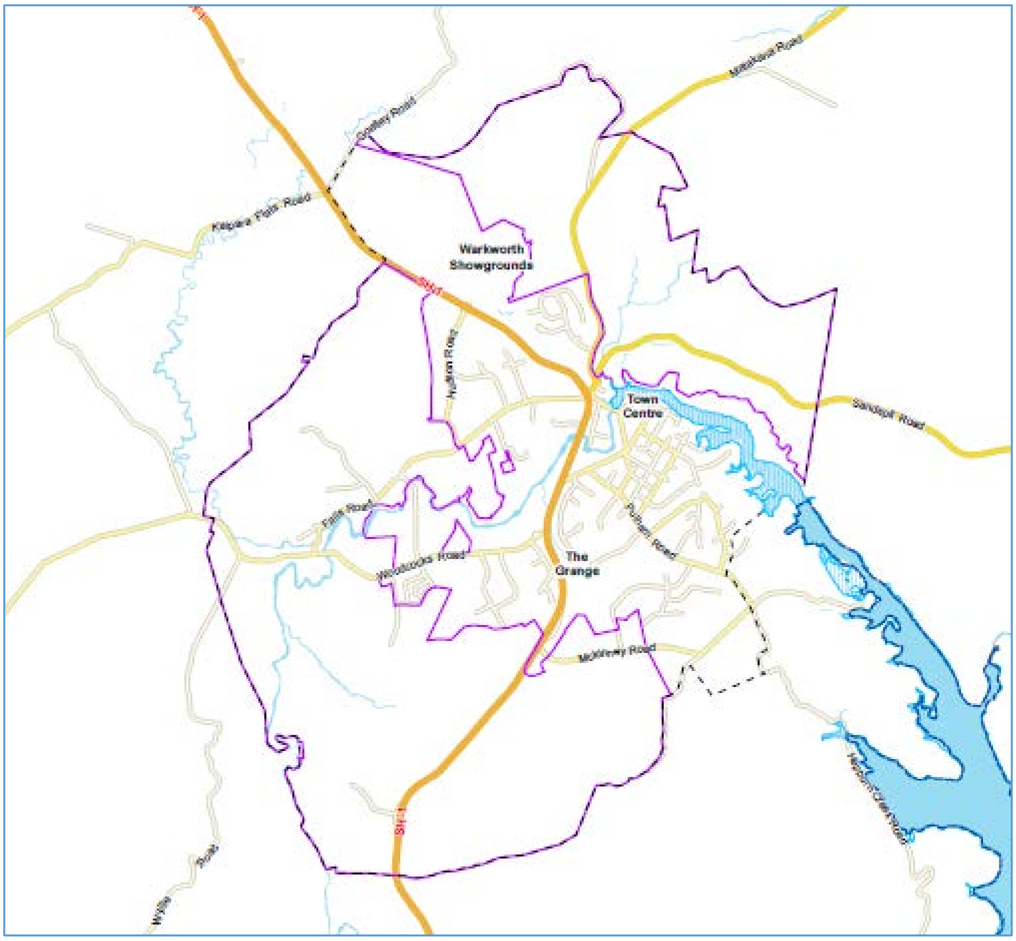

Figure 13: AUP Coastal inundation control layer in relation to the Warkworth FUZ

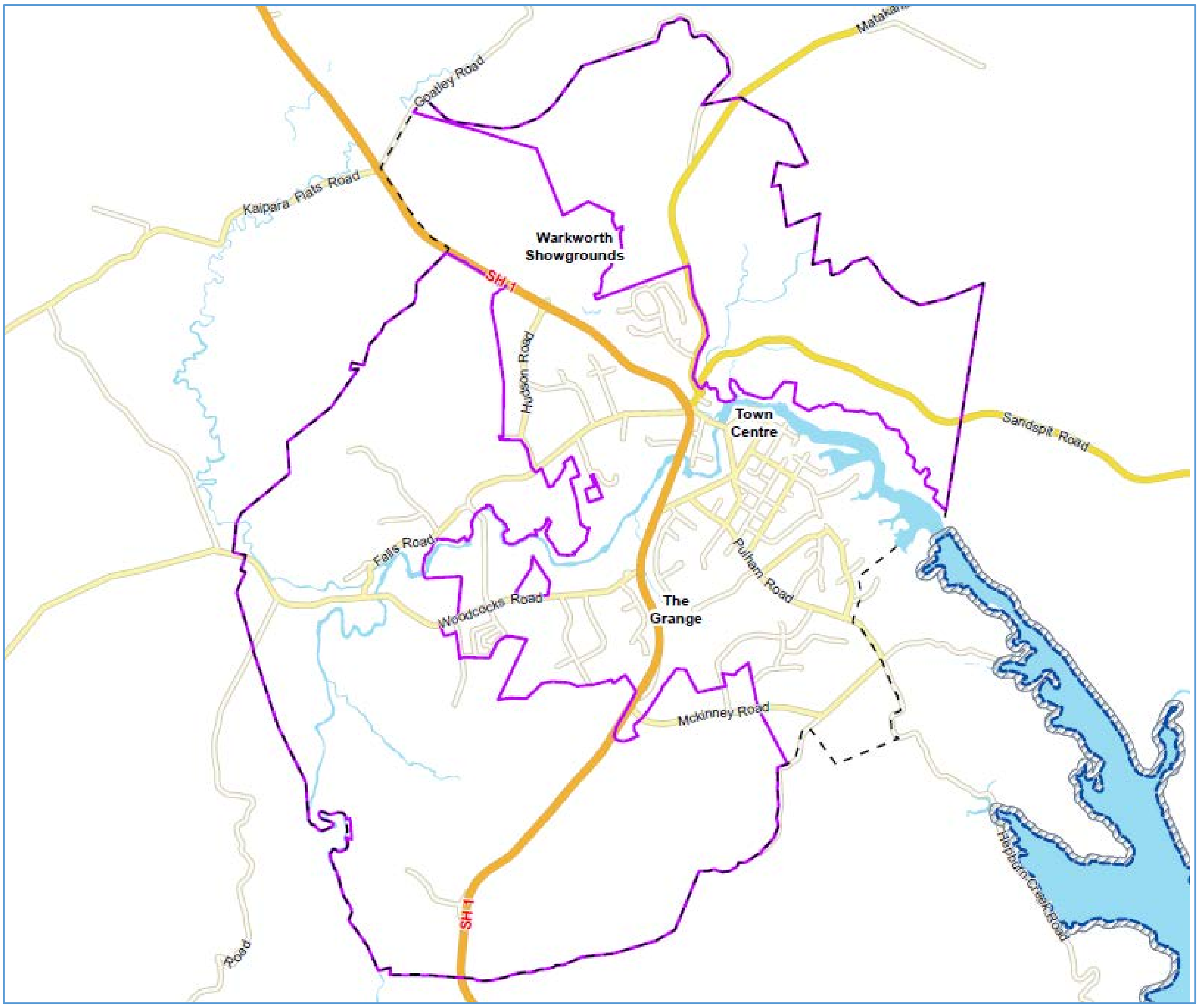

Figure 14: AUP coastal erosion definition in relation to the Warkworth FUZ

With respect to land instability controls, land which may be subject to instability is defined as:

"Any land with one of the following characteristics:

a) Where the land which is underlain by Allochthonous soils has slope angles greater than or equal to 1 vertical to 7 horizontal;

b) Where the land which is underlain by Holocene or Pleistocene sediments which has a slope angle greater than or equal to 1 vertical to 4 horizontal;

c) Where the land is underlain by any other soil type and has a slope angle greater than or equal to 1 vertical to 3 horizontal;

d) On sloping sites where fill greater than 600mm depth has been placed in uncontrolled conditions or not to engineered (certified) standards and where the original underlying natural terrain gradient was greater than or equal to:

   a. *1 vertical to 7 horizontal for slope comprising Allochthonous soils;*
   b. *1 vertical to 4 horizontal for slopes comprising Holocene or Pleistocene soils; or*
   c. *1 vertical or 3 horizontal for slopes comprising any other soil types;*

e) *Within a horizontal distance of 2.5 times the cliff vertical height behind the base of (e)any natural cliff; or*

f) *Within a horizontal distance of 2 times the cliff vertical height in front of the base of (f)any natural cliff."*

Based on this definition, some land in the Warkworth Future Urban Zone is within controlled zones as highlighted on the Development Premium map and explained in later sections.

5 Constraints, opportunities, and information gaps

This section summarises the geotechnical and coastal hazards constraints and opportunities of the structure plan area and information gaps.

5.1 Constraints

5.1.1 Coastal hazards

There are no identified constraints at the Warkworth FUZ in relation to coastal hazards as the site is above MHWS and outside of the 1% AEP plus 1m sea-level rise coastal inundation layer.

5.1.2 Geotechnical hazards

5.1.2.1 Weak, soft and compressible alluvium

At the Warkworth Showgrounds a ground investigation found that the alluvium in this location was particularly weak, with a lower-bound peak shear strength of 40 kPa (Beca, 2004). It noted variable organic content of 0-13 per cent, which may mean that secondary consolidation settlements are unpredictable, slow, and variable across the site. This material was described as being derived from Northland Allochthon sources, and comprising silts and clays of high plasticity. Fill batters may have to be limited to shallow angles to prevent bearing failure during construction. Settlement of embankments is likely to be significant where large volumes of alluvium are present. Experience from the Northern Gateway Toll Road embankments showed the majority of settlement in local alluvial material with less organic material occurs quickly (approximately one month) if suitable wick drains are installed. Where thinner zones of alluvium a few metres thick are present in small gullies these are normally best treated by complete removal.

5.1.2.2 Cuttings and slope stability in the Northland Allochthon materials

It is generally accepted that cut slope gradients in Northland Allochthon materials generally need to be low and as close as possible to the natural slope profile otherwise failures in the cut can be expected. Experiences in road cuttings along the SH1 ALPURT alignment and trial cuts monitored in typically incompetent Northland Allochthon materials show gradients in the order of 1V:4H to 1V:5H are generally considered to be optimal for long term stability (Opus, 1997).

Any excavation in Mangakahia Complex materials can be problematic as trench walls often tend to collapse during construction, even for excavations less than 5 m in length (Winkler, 2003). Temporary construction of shear keys also requires considerable excavations with low batter slope angles and trench support.

There are numerous examples of attempts to stabilise steeper cut slopes in Northland Allochthon materials, particularly around the Wellsford region, using gabion walls or boulders as slope armouring or buttresses. These methods are applied to prevent dilation and bulging at the toe but appear to have had variable and often little success, as many slopes exhibit ongoing movement and impact on the road verge. Cuts steeper than 1V:3H will generally require retaining measures and extensive slope drainage.

Should non-calcareous rock masses be exposed in cut slopes, it is common practice to replace a confining cohesive engineered fill layer over the rock to prevent dilation and slaking which can be significant. Hukerenui Mudstone (which may be present at Warkworth Golf Course and Warkworth Showgrounds) should not be left exposed within cut slopes for any length of time as major degradation and slippage are likely to occur.

Underslips (or failures affecting embankment edges) are common in Mangakahia Complex materials and tend to affect areas of some local roads particularly where the drainage discharges into topographic depressions below the road. As such, fill embankments on sloping ground in Northland Allochthon materials almost always require a shear key to provide the necessary stability. As failure planes are normally relatively shallow, shear keys extending into the underlying competent rock can often be formed by conventional excavation techniques. It must be noted, however, that shear keys up to 5-8 m deep have been required to stabilise earthfill formations for some residential subdivisions in the Wellsford area, requiring considerable staged earthworks. Extensive underfill drainage is generally required. These forms of failures appear to be currently affecting stretches of SH1 in the Windy Ridge area.

Palisade walls are considered to be the most expensive but probably most robust method for stabilising many slope failure problems that develop in the Northland Allochthon (Winkler, 2003), but deep soil mixing may provide an alternate reliable and cost effective solution. Drainage of slopes of Northland Allochthon materials can be difficult as a result of the low permeability of these units, and because of the weak, clay rich nature of the soil and rock. It has been recommended that limited reductions in groundwater levels should be assumed for any remedial drainage design measures (Winkler, 2003).

5.1.2.3 Existing landslides

In areas identified as existing landslides, specific geotechnical investigation and design will be required to ensure that the site is safe for development.

5.1.2.4 Liquefiable soils

There is the potential for localised areas with liquefaction potential, which could lead to significant subsidence.

Where liquefiable soils are present within approximately 200 m of a watercourse or other free face it should be assumed that they area also susceptible to lateral spreading, which may severely compromise foundations.

5.1.2.5 Poorly drained soils and risk of initiating landslides

Ground surface may be generally saturated during winter months due to clay-rich soils.

Design of drainage discharge is critical to avoid exacerbating existing landslide zones below construction areas, or initiating new slope failures in topographic depressions.

5.1.2.6 Cavities and sinkholes

Naturally occurring cavities commonly exist within limestone. However, none are known by the authors in the Warkworth area. If these do exist, they will be extremely difficult to identify during a ground investigation, and are normally managed during construction.

5.2 Development premium

In order to allow a comparison of the constraints described, the area has been divided up into high, medium and low development premium areas. This approach is considered useful in enabling broad scale assessment of development premiums. The selection of these development premium areas incorporates the geotechnical hazards discussed in this report. Development may still occur in high or medium premium areas provided site specific investigation and design is undertaken. However, for economic reasons some land use types may only be suitable in low or medium development premium areas.

The input parameters used for developing the development premium are described below, and presented spatially in Map 3 (attached). The results of this assessment are presented in Map 4 (attached).

5.2.1 Low development premium

These areas are typical of more benign Auckland conditions. They may include areas where material may exhibit shrink swell potential. This is recommended to be mitigated by extending foundations to a minimum of 600mm depth.

5.2.2 Medium development premium

Areas with a medium development premium will require specific investigation and design for the development of multi-storey dwellings, concrete frame structures, commercial buildings, and settlement sensitive structures. These areas include locations which are underlain by:

- Potentially liquefiable ground more than 200 m from a waterway or free face
- soils likely to be compressible, including organic and sensitive soils
- Pakiri Formation soils with slope angles greater than 1 in 3
- Mangakahia Complex materials with slope angles less than 1 in 7
- Mahurangi Limestone, due to the potential presence of cavities

5.2.3 High development premium

These areas have been identified as at risk of slope instability, coastal retreat / erosion and lateral spreading; or in the case of organic soils to be highly compressible. They may require ground improvement, engineering structures, such as retaining walls, rip-rap, earthworks, or drainage. These areas include locations which are underlain by:

- Active or inactive landslides
- Potentially liquefiable ground within 200 m of a waterway or free face
- Mangakahia Complex materials with slopes greater than 1 in 7
- Any slopes with an angle greater than 1 in 2

It should be noted that current research suggests that the assessment of the extent of potentially liquefiable soils may be over-stated by the 1996 study on which the current mapping is based. Once this research is peer reviewed it may be possible to significantly reduce the mapped extent of potentially liquefiable soils in both the medium and high development premium zones.

5.3 Opportunities

5.3.1 Pahuinui Scenic Reserve

There are opportunities to enhance the adjacent Puhinui Scenic Reserve open space conservation zone situated between the Mahurangi River and Warkworth Future Urban Zone to ensure an appropriate transition between the natural and built environment.

5.3.2 Natural resources

The local presence of Mahurangi Limestone, some of which is currently being quarried, may make a useful source for fill. This material will not be suitable for use as a pavement material. Unweathered Limestone can be used as fill but is likely to need to be placed and compacted immediately following excavation, and covered after placement as it may degrade on exposure.

5.3.3 Cuttings and slope stability in the Pakiri Formation

The areas immediately underlain by Pakiri Formation rocks may be able to be cut relatively steeply, making hillsides suitable for development (subject to the absence of deep-seated failure planes). Observations during site walkovers along the existing SH1 alignment from Puhoi to Wellsford identified cut slopes in the weathered Pakiri Formation varying in angles from 45 to 72 degrees, with benches constructed where slopes were formed at 60 degrees or greater. Although the majority of these slopes appeared to be stable, there were a number of failures identified in cut slopes constructed steeper than 60 degrees. These often failed from the level of a bench with a typical resulting (failed) angle of 55 degrees in moderately weathered material, suggesting that the material has a factor of safety of 1 at these angles. Slopes cut at shallower angles were only observed where bedding dipped adversely out of a cut slope. Large cut slopes in the Pakiri Formation along the adjacent Northern Gateway Toll Road were cut to a maximum gradient of 40 to 41 degrees. These angles were adjusted to take into account the local dip of the bedding at each cut location. Cuts steeper than 40 degrees may be prone to rock falls onto or near the carriageway.

5.4 Summary of constraints and opportunities

Overall it is considered that, given the inland location of the Warkworth Future Urban zone, constraints in relation to coastal hazards are limited. However, there are opportunities to retain and enhance the coastal and natural environment of the upper Mahurangi River and Open Space Conservation Zones by careful consideration of the land use transition between these areas and the Future Urban zone.

There are numerous geotechnical issues that will have an effect on the development of the study area. In most cases these issues will be able to be managed with careful planning, investigation and design. The challenges presented in the study area are no more onerous than those experienced in other similar locations around the region (e.g. Silverdale, Wellsford).

5.5 Information gaps

5.5.1 Northland Allochthon stability

Although (as earlier noted under constraints) it is generally accepted that cut slope gradients in Northland Allochthon materials generally need to be low, significantly better stability has been demonstrated by the Mahurangi Limestone believed to be present under the study area, including reasonably stable 60 degree cut slopes up to 20 m high in a quarry. This indicates that normally accepted practice may be overconservative in these materials. Cuts in the Motatau Complex limestones have been successfully constructed at 1V:1H to greater than 20 m height at SH12 near Brynderwyn. However, achieving this will require extensive investigation and careful geotechnical control.

Early results from Auckland Transport's Matakana Link project suggests that the rocks to the north of the Warkworth Showgrounds may be atypical of the Northland Allochthon, and has the potential to be more stable than other similar areas (personal communication, Jacobs). Further investigation of this may allow steeper slopes to be developed than would normally be the case in these materials.

5.5.2 Liquefaction susceptibility

The current assessment of liquefaction susceptibility is based on a high-level desk study based on relatively inaccurate geological maps. A site-specific study, incorporating testing in accordance with the latest MBIE guidelines, will be required prior to development. The MBIE guidelines give suggested investigation intensities at plan chance and resource consent stages.

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