Dr M. R. JOHNSTON

Consulting Geologist

395 Trafalgar Street
NELSON 7010

An Assessment of Areas of Lower Risk of Potential Settlement due to Seismic-induced Ground Shaking, Tahunanui, Nelson City

Prepared for Nelson City Council

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EXECUTIVE SUMMARY

- Tahunanui, lying west of the Port Hills and north of a line extending from near Annesbrook to Monaco, is the largest area of natural ground in Nelson City that could potentially settle as a result of severe seismic-induced ground shaking.
- The area contains a high proportion of uncompacted, water saturated, sand.
- In the east, marine Rabbit Island Gravel is dominant and extends, from the toe of the Port Hills, westward a variable distance before giving way to Tahunanui Sand.
- The variability in the distribution of the gravel and sand is due to deposition by longshore drift to form beach ridges parallel to, and north of, an abandoned 7,000 year old sea cliff extending from Annesbrook to the Monaco peninsula.
- Between the beach ridges are peat-rich deposits, and estuarine deposits occur in the tidal Jenkins Creek. Adjacent to the Port Hills, the gravel is locally overlain by terrestrial gravel, including fan gravel at the mouth of Jenkins Creek.
- The contact between the gravel units and the sand is complex and would require intensive subsurface investigations, such as auguring and/or geophysical methods, to precisely define. Consequently, it is only possible to delineate a generalised contact between dominantly gravel and dominantly sand.
- The likelihood of significant seismic-induced settlement in the area dominated by gravel units to the east of contact, even in an Ultimate Limit State (ULS) event, is low. Although isolated pockets of sediment that are more prone to settlement could be present, this area is little different, from a foundation design perspective, than other gravel areas in the city.
- To the west of the contact, water saturated sand predominates and, where present, there is a significantly higher risk of settlement during intense seismic ground shaking.
- The amount of settlement in the water saturated sand has been calculated by Tonkin & Taylor, in reports prepared for Council in 2013 and 2014. In a ULS event, settlement of up to 300 mm could occur and this may be exacerbated by lateral spreading adjacent to unsupported stream and tidal channel banks. Under a Serviceability Limit State (SLS) event, settlement could be up to 100 mm.
- The settlements predicted by Tonkin & Taylor do not preclude development, provided certain recommended investigation and foundation design are adopted. Foundation design is similar to what has been adopted in Christchurch.
- For ULS settlement to occur would require a major earthquake originating within or close to Nelson City. Such earthquakes, likely to result from rupture of a local component of the Waimea-Flaxmore Fault System, occur very infrequently. However, the fault system is still poorly understood.
- SLS events can be expected every 50 to 80 years and will likely originate on a fault distant from Tahunanui, such as occurred in 1855, 1929 and 1968. The closest known active fault, beyond the Waimea-Flaxmore Fault System, to Nelson City is the Wairau Section of the Alpine Fault, some is 35 km to the southeast.
- It is recommended that the area dominated by water saturated sand be identified in the Nelson Plan as a Tahunanui Liquefaction Risk Overlay.

Fig. 1. Tahunanui area. The red line (left) is the 7,000 year sea cliff extending from the Annesbrook roundabouts to the base of the spit forming Monaco. North of the sea cliff the low-lying land is dominantly marine sands with gravel adjacent to the toe of the Port Hills.

1. SCOPE OF REPORT

1.1 This report, prepared as part of Nelson City Council Contract PO Number: 240665, considers from data currently available the risk of seismic-induced settlement in the Tahunanui area (Fig. 1).

1.2 As part of the report an area is delineated in which there is a low probability of significant ground settlement arising from liquefaction during a major earthquake impacting on the Tahunanui area.

1.3 This information will assist in identifying where there is a potential for liquefaction thereby allowing for the development of an appropriate overlay in the Nelson Plan (resource management plan). This will assist in managing the risk, and building resilience, by managing development occurring within the overlay.

1.4 This report is based on published geological maps[1] supplemented by unpublished information known to the contractor, principally reports prepared for the Nelson City Council by Tonkin & Taylor Ltd, and feedback from four public meetings initiated by the Nelson City Council as part of community engagement on liquefaction, fault rupture and flood hazards during April-June 2017. No additional subsurface investigations have been undertaken.

2. INTRODUCTION

2.1 The Tahunanui area, from Tahunanui Beach south to a line approximately extending from the Annesbrook roundabouts to the start of the Monaco peninsula or spit, has been identified as the largest area in Nelson City containing natural, dominantly water saturated, sediments that could potentially liquefy in a severe earthquake resulting in variable ground settlement and localised inundation (Fig. 2)[2].

2.2 The risk of ground settlement will be greatest in sandy material and lessens considerably in gravel and others sediments. Gravel is dominant in the east of the Tahunanui area fronting the toe of the Port Hills.

2.3 To further quantify the risk, the Nelson City Council engaged Tonkin & Taylor (2013) to assess the Tahunanui area[3]. That firm demonstrated that there would be significant settlement during severe seismic ground shaking in the west, where thick water-saturated sand dominates, and significantly less in the east where gravel predominates. Council further engaged Tonkin & Taylor to investigate

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[1] Johnston, M. R. 1979: Geology of the Nelson Urban Area (1:25 000). *New Zealand Geological Survey urban series Map 1*.
Johnston, M. R. 1981: Sheet O27AC – Dun Mountain. *Geological Map of New Zealand 1:50 000*.
Johnston, M. R. 1982: Part sheet N27 – Richmond. *Geological Map of New Zealand 1:50 000*.
Rattenbury, M. S.; Cooper, R. A.; Johnston, M. R. 1998: Geology of the Nelson Area. *Institute of Geological & Nuclear Sciences 1:250 000 geological map 9*.

[2] Johnston, M. R. 2013: *Revised Preliminary Assessment of the Liquefaction Hazard in Tasman and Nelson Regions*.

[3] Tonkin & Taylor 2013: *Tahunanui Liquefaction Assessment*. Unpublished report, prepared for Nelson City Council, dated November 2013 (ref. T & T 871023).

the gravel in the northeast of the Tahunanui area (2014), which confirmed the low risk of significant seismic-induced settlement[4].

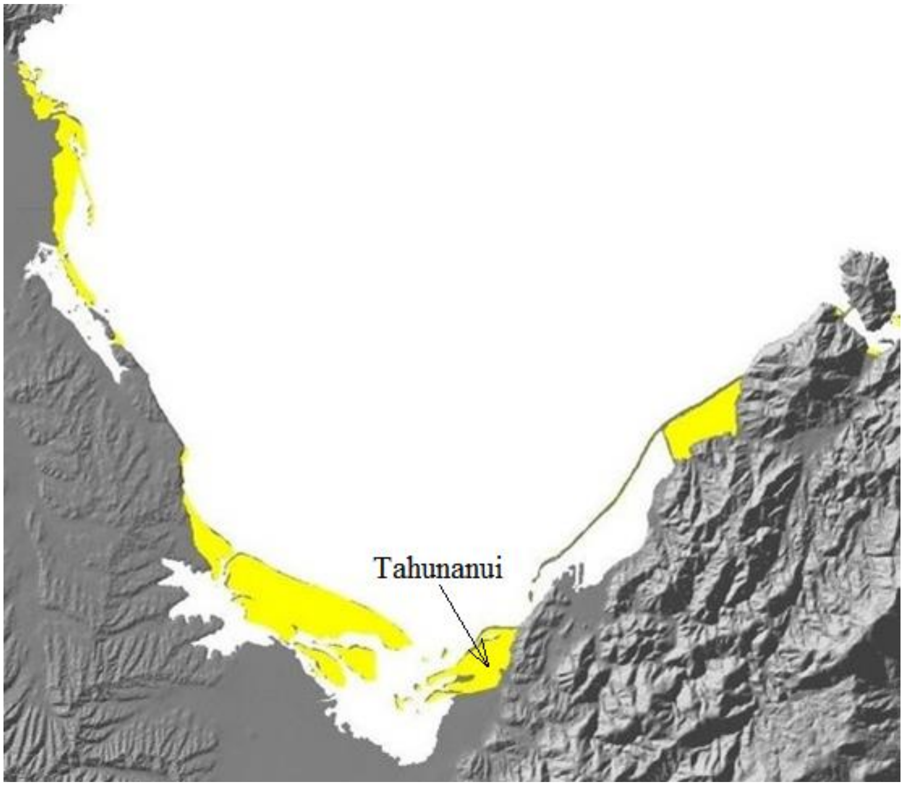

Fig. 2. Natural sediments (yellow) adjacent to Tasman Bay of geologically young age (Holocene, Q1) that potentially contain materials that could liquefy under severe seismic ground shaking.

3. GEOLOGICAL SETTING

3.1 The sediments, in the Tahunanui area, to the north of the Stoke Fan Gravel (Fig. 3) are mostly of marine origin, which are dominated by sand but in the east, adjacent to the Port Hills, gravel is relatively extensive.

3.2 These two geological units have been formally mapped as Tahunanui Sand and Rabbit Island Gravel respectively.

3.3 Overlying the marine deposits at the mouth of Jenkins Creek is a fan gravel deposit, here informally identified as "Jenkins Creek fan", and locally elsewhere in the east are alluvial slope wash, slope failure and minor fan gravel deposits derived from the now abandoned sea cliff cut in the Port Hills that bound the Tahunanui area.

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[4] Tonkin & Taylor 2014: *Tahunanui Liquefaction Assessment Stage 2 –Assessment of Eastern Margin*. Unpublished report, prepared for Nelson City Council, dated September 2014 (ref. T & T 871023).

3.4 Peat deposits are also present, commonly forming linear, approximately east-west trending, strips[5]. Estuarine sediments are present in the tidal section of Jenkins Creek.

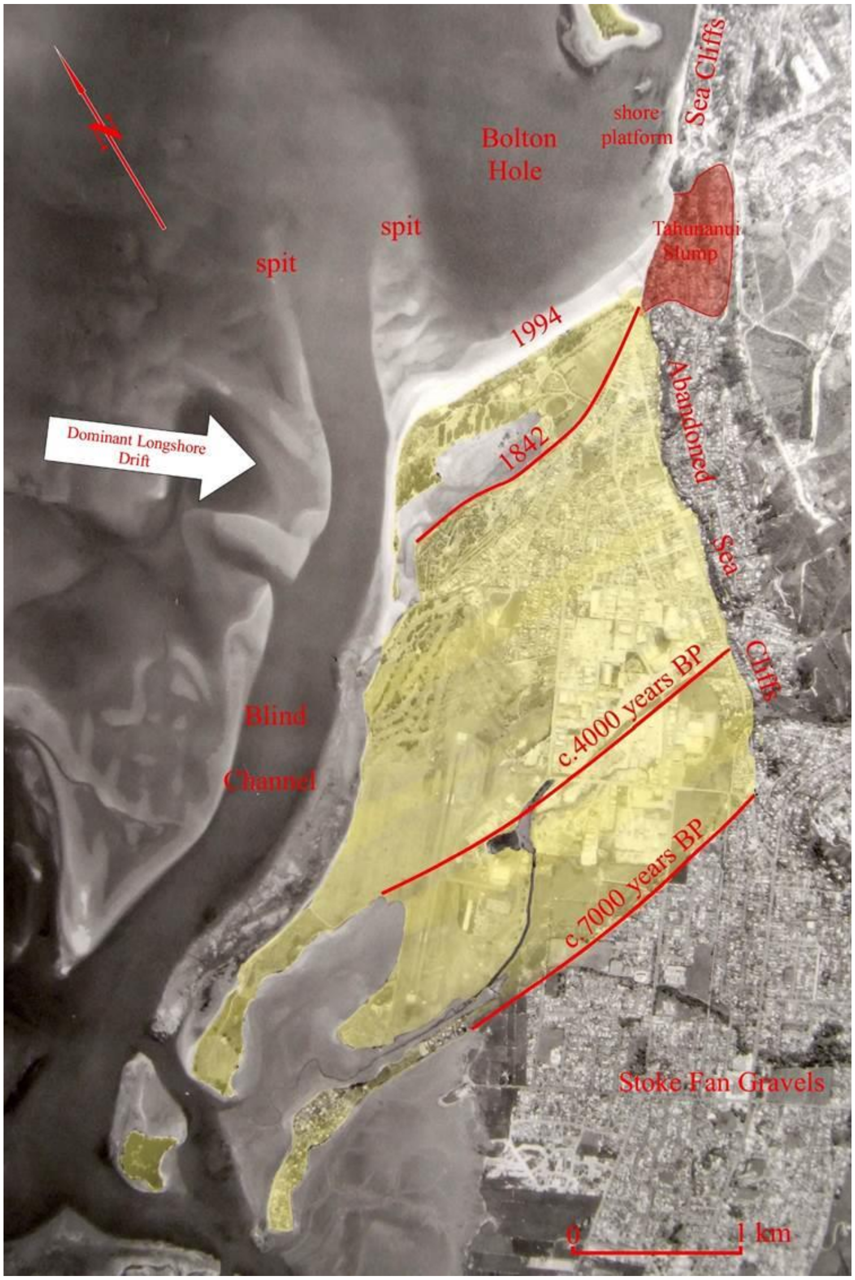

Fig. 3. Tahunanui area (yellow) comprising dominantly marine sediments to the north of the 7,000 year old sea cliff cut in Stoke Fan Gravel. Sand is widespread in the west but gravel, of both marine and locally terrestrial origin, occurs in the east of the area. Shorelines, c.4,000 years before present and in 1842, are also shown.

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[5] Johnston, M. R. 1982.

4. ORIGIN OF THE TAHUNANUI SEDIMENTS

4.1 The geology of the Tahunanui area is relatively straightforward in that it largely formed by the sea depositing materials in a series of beach ridges that parallel a now abandoned sea cliff extending east-west from Annesbrook to the start of the Monaco spit. The sea cliff was cut when the sea, approximately 7,000 years ago, reached its present level following the Last Glaciation (Fig. 3). The cliff is cut in Stoke Fan Gravel formation, but in the east it has been buried beneath younger gravel of the Jenkins Creek fan and further west it has been largely destroyed by urbanisation. However modified remnants of it remain, the best being at the southern abutment of the Nayland Road overbridge.

4.2 The material removed by the cutting of the 7,000 year sea cliff now forms the backbone to the Monaco spit.

4.3 Material transported by southwesterly longshore drift, and largely eroded from the now abandoned sea cliff cut in the Port Hills from Annesbrook to Port Nelson, was progressively deposited as beach ridges parallel to the sea cliff. Once a beach ridge had formed, another would then accumulate on its northern side so that, from about 7,000 years ago to the 1870s, the sea had retreated north to Beach Road.

4.4 The deposition of the beach ridges was interrupted when, about 4,000 years ago, the sea temporarily rose above its present level resulting in a period of erosion. The products of this erosion formed the spit of Aerodrome Point before beach ridge deposition resumed.

4.5 After their formation, the beach ridges in the west were extensively overtopped by wind-blown sand accumulated as dune fields adjacent to the coast from the airport to Tahunanui Beach. Except at the golf course, and locally elsewhere, the dune morphology has been destroyed by construction of the airport and industrial and residential development.

4.6 During the deposition of the beach ridges the outflow from Jenkins Creek formed estuarine areas that, with the exception of where it was infilled as part of Nelson Airport and locally elsewhere, largely remain.

4.7 The beach ridges have been eroded in the west by the Blind Channel, draining the Waimea Inlet, and which, at times, has included the water of the Waimea River.

4.8 All of the sediments forming the Tahunanui area thus accumulated in geologically recent time, known as the Holocene. Although separated into the Rabbit Island Gravel and Tahunanui Sand, these formations include undifferentiated estuarine and peat sediments. The Holocene and Late Pleistocene deposits, collectively part of the Late Quaternary, are also classified according to their oxygen isotope age. Holocene deposits are assigned to Q1 whereas last Glaciation deposits are Q2.

4.9 Areas of fill also exist, the largest being at the airport where part of the estuary of Jenkins Creek has been reclaimed. The airport fill is dominantly, if not entirely, Tahunanui Sand but in the industrial area there is sawdust and other materials.

4.10 The Holocene marine sediments are anticipated to overlie a generally planar, wave cut, surface that dips gently north. The marine sediments are around 8 m thick adjacent to the 7,000 year-old sea cliff, where they rest on Stoke Fan Gravel, but are 29 m thick at the western end of Tahunanui Beach[6] where they overlie alluvial Hope Gravel contiguous with that forming much of the older part of the Waimea Plains. Deeper still is Moutere Gravel and, close to the Port Hills, sandstone and siltstone of the Magazine Point Formation. The latter two units are separated by an unnamed, northeast-trending fault, whose position is not known. The fault is part of the Waimea-Flaxmore Fault System, which separates the Moutere Depression — flooded in the north by the sea to form Tasman Bay — from the eastern Nelson ranges.

5. THE BEACH RIDGES

5.1 The beach ridges have largely formed of material carried in a southwest direction by longshore drift. However, currents moving in the opposite direction from the west of Tasman Bay have also contributed sand, more particularly in the west of the Tahunanui area.

5.2 The area north of Beach Road accumulated after a shift in the position of the Blind Channel in the 1870s released a large amount of sand that was deposited to form the present day Tahunanui Beach. The Blind Channel, being pushed by the currents from the west, is now eroding the western end of the beach. On either side of the entrance to the channel large spits are building and one or both of these are expected to collapse, releasing in a large amount of sand that will result in further changes to the beach of a similar magnitude to what occurred post 1870s.

5.3 A major characteristic of the ridges is that each one becomes finer-grained towards the west. In the east, gravel is mostly eroded from the Port Hills Gravel, particularly from the Tahunanui Slump, a large active rotational landslide whose toe stretches from the Tahunanui shops to Magazine Point (Fig. 3). This landslide was being eroded by the sea until the construction of Rocks Road in the 1890s. The pebbles and small boulders eroded from the Port Hills Gravel, along with sand, were carried by longshore drift south along the toe of the sea cliff cut in the Port Hills before being deposited as beach ridges.

5.4 As the pebbles and gravel were deposited an increasing amount of sand was, in a westward direction, incorporated into the ridge. Consequently the change from gravel to sand, if it could be plotted from the materials that formed the crest of the beach ridges, would in plan view look a little like a saw. The tops of the gravel teeth of the saw would project further west than the intervening troughs filled with sand and in places capped by peat.

5.5 While the deposition of the ridges was a relatively uniform process, the amount of gravel in each ridge is more variable. Thus the change from gravel to sand in each ridge is not necessarily at a regular distance from the sea cliff at the toe of the Port Hills to which each ridge is tied. Consequently the last appearance of

[6] It is possible that the Blind Channel has eroded into the planar surface and, in which case, the base of the marine sediments further east would be at a shallower depth.

gravel in the crest of the ridges may not, when seen in plan view, form a straight line that parallels the toe of the Port Hills.

5.6 In addition, when the gravel disappears from the crest of a ridge it will extend westward for some distance beneath the ridge. The net result is that the interface — or more correctly zone — between dominantly gravel and dominantly sand will vary both horizontally (both along individual ridges and between ridges) and vertically.

6. THE GRAVEL-SAND INTERFACE

6.1 From the above it follows that the contact between Rabbit Island Gravel and Tahunanui Sand is not simple. To fully define this contact would require extensive investigation by invasive auguring or test-pitting and/or by geophysical methods, including ground penetrating radar. Geophysical methods could be compromised by the extensive human ground disturbance.

6.2 Examination of the oldest vertical stereoscopic photographs, taken in 1948 at approximate scale of 1: 15,000, would allow many of the now destroyed beach ridges to be plotted but this would not differentiate between sand and gravel.

6.3 A further complication is that where the gravel disappears below the surface the covering sand will for some distance to the west be, for most of the time, above the water table and therefore not prone to seismic-induced settlement. This further increases the difficulty in the delineating between ground that is at low risk of settlement in the east and the ground to the west at higher risk.

6.4 Thus the contact is a complex diffuse zone, likely in the order of 50 to 75 m or more wide. It includes sand, generally up to 1 m thick overlying the gravel, and being above the normal water table is, except temporarily, unsaturated.

6.5 Nevertheless the contact, on the ground surface, between gravel (both Rabbit Island Gravel and, at the Annesbrook, the Holocene Jenkins Creek fan) and sand has been approximately defined on geological maps and this position, from the eastern end of Parkers Road northwards, has been further refined by Tonkin & Taylor (2014).

6.6 On the map forming part of this report (Fig. 4), a geological contact has been delineated between dominantly gravel, but including the thin layer of sand overlying the gravel that is generally above the water table, and thick, water-logged sand. It is stressed that this contact, because of the complexities referred to above, is a generalised one.

6.7 Although the contact is generalised, there is overall a low risk of significant settlement to the east of it although the presence of pockets of susceptible material (water-logged sand) cannot be dismissed.

6.8 West of the contact water-logged sand predominates, and therefore at greater susceptibility to settlement during a major earthquake. It is possible that areas of beach ridge gravel, with a much lower risk of settlement, are present. The Jenkins Creek fan also extends further west than the generalised geological contact shown on Fig. 4 suggests. However, it overlies marine deposits, which may include water-logged sand and, consequently, without detailed subsurface information a conservative approach has been taken. Gravel is also anticipated to exist at the toe of the 7,000 year old sea cliff extending from Annesbrook to Monaco but there is insufficient data to confirm its extent. These areas are industrial and for any development within it, it is anticipated that there would be a geotechnical investigation of the subsurface materials.

6.9 It is recommended that the area dominated by water saturated sand in the west of is identified on the Nelson Plan as a 'Tahunanui Liquefaction Risk Overlay' so any risk of liquefaction can be managed at the time of new subdivision and development.

7. SEISMIC-INDUCED SETTLEMENT –TAHUNANUI SAND

7.1 Tonkin & Taylor (2013), in its assessment of the Tahunanui area, concluded that seismic-induced settlement could occur. Where water saturated sand dominates, settlement is likely to be between 5 and 25 mm for a "Serviceability Limit State" (SLS) event [building structurally sound but may be uninhabitable] and between 130 and 290 mm for an "Ultimate Limit State" (ULS) event. Settlement in such an ULS event may be accompanied by lateral ground movement of 300 mm or more if adjacent to unsupported banks at the coast or bordering creeks.

7.2 Under a ULS event structures, unless appropriately designed, would lose structural integrity. Settlement could be accompanied by inundation, albeit likely temporary, of low-lying ground.

8. SEISMIC-INDUCED SETTLEMENT – GRAVEL UNITS

8.1 The gravel dominated ground in the northeast that was assessed by Tonkin & Taylor (2014), comprises what was informally identified as the "Muritai Gravel Deposit"[7]. This marine gravel forms a roughly semi-circular area from the foot of Maire Street to approximately the traffic lights at the northern end of Tahunanui Drive.

8.2 SLS and ULS settlement rates determined as part of the Stage 2 assessment are in the order of <10 mm to <100 mm respectively. Lateral spreading is unlikely.

8.3 Although the gravel areas further south, including the Holocene Jenkins Creek fan that overlies the dominantly Rabbit Island Gravel, were not assessed by Tonkin & Taylor, they will have similar properties.

8.4 The consequences of SLS and ULS, as well as an "intermediate" 1/100 AEP event[8], are provided in Table 5 in the Tonkin & Taylor (2014) (attached as Appendix 2 in this report).

[7] An informal part of the Rabbit Island Gravel formation.

[8] Annual exceedance probability is 1%.

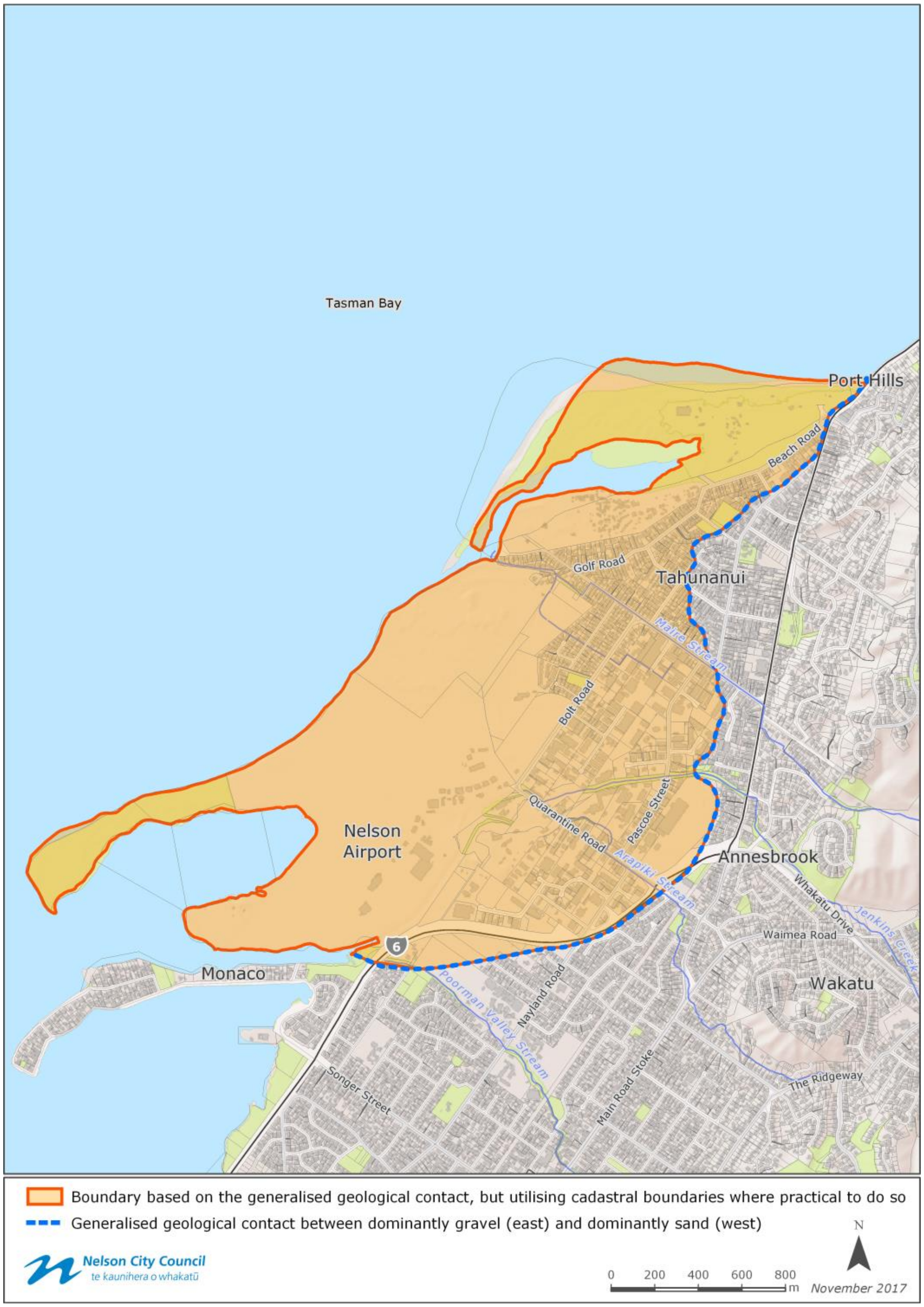

Fig. 4. Generalised geological contact (dotted) between gravel (in the east) with a low risk of seismic-induced settlement and (in the west) sand with a higher risk. The orange area in the west is the recommended Tahunanui Liquefaction Risk Overlay.

9. GROUNDWATER EJECTED FROM DEEP GEOLOGICAL UNITS

9.1 In Christchurch, areas that suffered extensive liquefaction were underlain not only by water-logged fine sediments but also extensive confined aquifers. Consequently, it is possible that these aquifers may have contributed to some of the water ejected.

9.2 In Tahunanui the units beneath the marine sediments are unlikely to contain significant aquifers. Therefore any liquefaction that might occur will be associated entirely with the marine sands, which increase in thickness from about 8 m in the south to 29 m at the northwestern end of Tahunanui Beach.

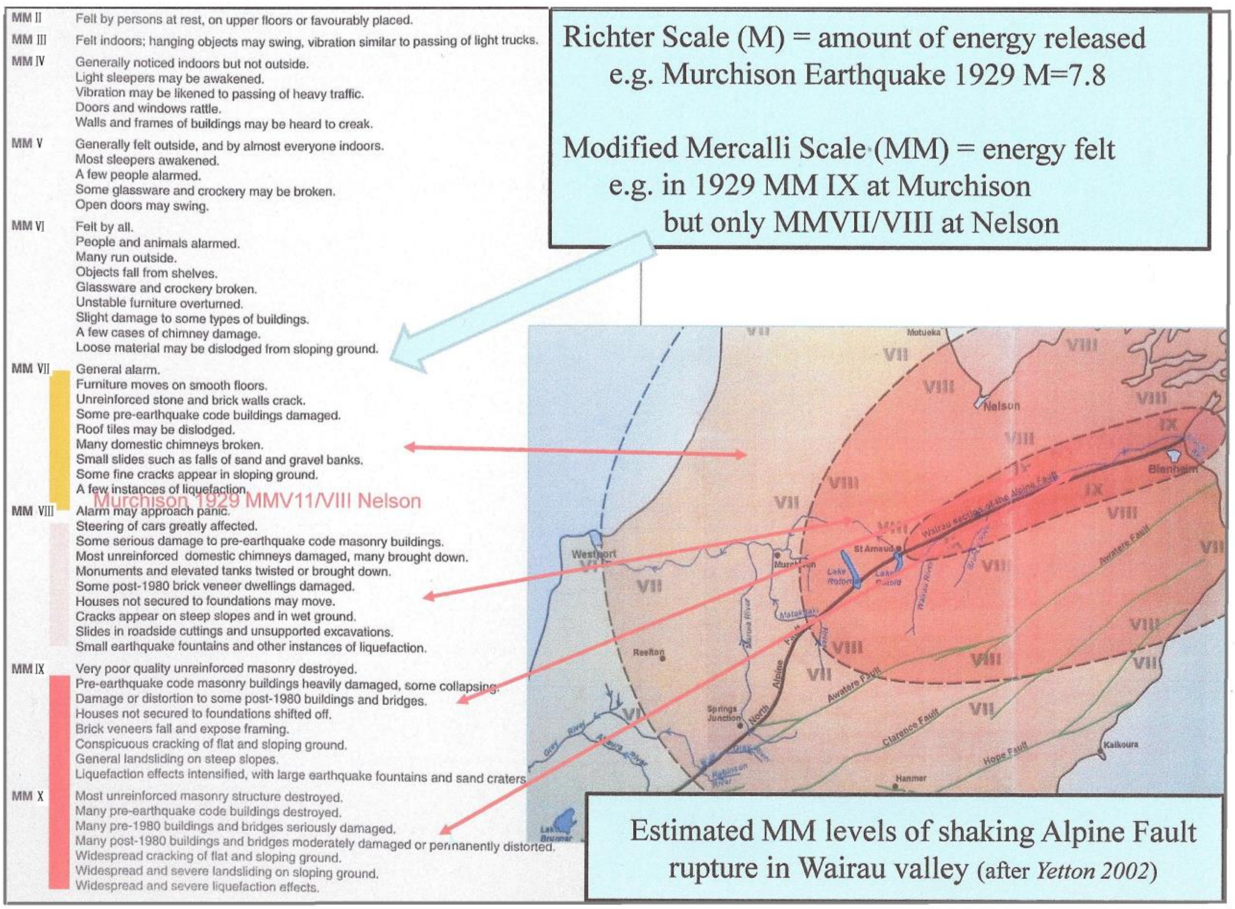

Fig. 5. Estimated levels of ground shaking on the Modified Mercalli (MM) Scale following rupture on the Alpine Fault (Wairau Section). If a fault belonging to the Waimea-Flaxmore Fault System local to Tahunanui ruptured, ground shaking levels could reach MM IX or above in a relatively small area.

10. COMMUNITY ENGAGEMENT ON THE POTENTIAL LIQUEFACTION HAZARD

10.1 As part of the public consultation process, which included four public meetings held at various locations throughout the city in April-June 2017, a number of submissions were received specifically in relation to the liquefaction hazard. Some of the submissions were accompanied by geotechnical reports or provided details of engineering work undertaken on land.

10.2 On review it was found that vast majority of the residential properties referred to in the submissions are underlain by gravel, or can reasonably be inferred to do so, and are east of the geological contact depicted on Fig. 4.

11. SEISMIC RISK

11.1 Seismic-induced settlement requires a significant earthquake.

11.2 In Tahunanui this would likely involve an event with an epicentre within a relatively close distance of Tahunanui.

11.3 Such a seismic event, causing widespread settlement (a ULS event), is likely to originate from movement on one of the local faults of the Waimea-Flaxmore Fault System.

11.4 The seismic activity on the Waimea-Flaxmore Fault System has been investigated in recent years but, in comparison with many active faults in New Zealand, is still poorly understood. Nevertheless, ruptures on faults within the fault system in proximity to Nelson City are rare events, with on any one fault, thousands of years separating them. Because of the nature of the fault system (a reverse fault system – i.e. dominantly vertical movement with a small horizontal component) it is unlikely that earthquakes occur regularly, making it even more difficult to determine the risk the fault system poses. The length of rupture, from geological evidence in Nelson City and the adjacent Richmond area, appears to be relatively short (about 2 to 10 km) compared to other more distant faults, such as the Wairau Fault, that may be 100 kms or more. An assessment of the hazard the fault system presents has been prepared for the Nelson and Tasman councils by GNS Science and others, including this contractor[9].

11.5 An earthquake arising on the Waimea-Flaxmore Fault System in the vicinity of Nelson City (assuming that only a short length of fault ruptures), would produce relatively localised levels of ground shaking equating to MM IX or even MM X on the Modified Mercalli Scale and would therefore be a ULS event.

11.6 From what is known of the earthquake risk impacting on the Tahunanui area, it appears that the risk of severe seismic ground shaking resulting in a ULS event is low but nevertheless real.

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[9] Johnston, M. R.; Nicol, A. 2012: *Assessment of the location and paleoearthquake history of the Waimea-Flaxmore Fault System in the Nelson-Richmond area with recommendations to mitigate the hazard arising from fault rupture of the ground surface*. Unpublished GNS Consultancy Report 2007/64 prepared for Nelson City and Tasman District councils, dated December 2012.
Nicol, A., Johnston, M. R., Wopereis, P. J., Stevens, G.: 2014: *Interim summary of paleoearthquake trenching investigation on the Waimea-Flaxmore Fault System, Nelson-Tasman region*. Unpublished report, prepared for Nelson City and Tasman District, councils, May 2014.

11.7 Nelson City will likely experience, on a crude average of 50 to 80 years, levels of ground shaking equating to MM VII to MM VIII. Such shaking would emanate from a rupture on a fault some distance away, such as occurred in 1848 (Awatere Earthquake), 1929 (Murchison) and 1968 (Inangahua). A rupture on the Wairau section of the Alpine Fault (also referred to as the Wairau Fault) in the Wairau valley 35 km southeast of the Tahunanui would give rise to ground shaking in the lower part of MM VIII (Fig. 5)[10]. Such shaking would be in the realms of a SLS event.

12. DEVELOPMENT CONSIDERATIONS

12.1 The Council has, under the Resource Management Act, a duty to make known the results and recommendations in the Tonkin & Taylor reports and to introduce measures that encourage mitigation of the potential effects of seismic-induced settlement in the Tahunanui area.

12.2 From the above there is no reason not to allow, in relation to possible seismic-induced settlement, future development in the Tahunanui area although a possible rise of sea level resulting from climate change may need to be considered in the longer term, as in other coastal areas of New Zealand.

12.3 Within the dominantly gravel area in the east, comprising Rabbit Island Gravel and Jenkins Creek fan gravel, there is a low risk of significant settlement due to liquefaction and new residential and other subdivisions for building can be assessed in the usual manner[11]. In the extreme east of this area, where it abuts the abandoned sea cliff at the toe of the Port Hills, there may be a need to include a geotechnical assessment of the stability of the sea cliff.

12.4 While in the eastern gravel area NZS 3604[12] structures are appropriate, because the possibility of areas of water saturated sand being present, it would be prudent for foundation excavations to be inspected by a chartered professional engineering practicing in foundations or by an experienced engineering geologist to confirm the suitability of the ground. For buildings not meeting NZS 3604 then foundation design and the suitability of that design for the ground conditions should be under the supervision of a chartered professional engineer practicing in foundation design.

12.5 In the remaining area, dominated by Tahunanui Sand and comprising the recommended Tahunanui Liquefaction Risk Overlay[13], new subdivisions should have each building lot certified as being suitable for that purpose by a chartered professional engineer practicing in geotechnical engineering and experienced in foundation design in ground that may be subject to settlement due to severe seismic shaking. Alternatively as part of the design process the ground could be

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[10] Yetton, M. D. 2002: *Paleoseismic investigation of the North and West Wairau Sections of the Alpine Fault, South Island, New Zealand*. Unpublished report prepared for Earthquake Commission Research Foundation and Tasman District Council, August 2002.

[11] Broadly this area has been equated by Tonkin & Taylor with Technical Categories (TC) TC1 and TC2 Appendix 3). Technical categories TC1 toTC3 have been prepared in the aftermath of the Christchurch earthquakes.

[12] NZS 3604: 2011 – *Timber Framed Buildings*.

[13] Broadly this area has been equated by Tonkin & Taylor with Technical Categories TC2 and TC3.

assessed by an engineering geologist experienced in seismic-induced ground settlement. Certification should also address potential inundation risks arising from severe seismic ground shaking or other natural events. Cognizance should be taken of the recommendations and conclusions in the Tonkin & Taylor reports (2013, 2014) and any subsequent relevant geotechnical investigations in the Tahunanui area.

13. CONCLUSIONS

13.1 Significant parts of the Tahunanui area are underlain by water saturated Tahunanui Sand that would be subject to liquefaction as a result of severe seismic ground shaking.

13.2 Tonkin & Taylor (2013, 2014) concluded that in an extreme seismic event (ULS), liquefaction could result in settlement of up to 300 mm in the sand dominated area with the potential for lateral spreading along unsupported banks of streams and tidal channels.

13.3 A ULS event is not likely to result unless rupture occurs on a fault adjacent to or within Tahunanui, such as a component of the Waimea-Flaxmore Fault System. The resulting level of ground shaking would equate to MM IX or even MM X over a relatively small area around the epicentre. The activity on the fault system, from existing knowledge of it, is low, but nevertheless exists.

13.4 A more distant severe earthquake producing ground shaking levels bordering on MM VII/MM VIII, which Tahunanui can expect roughly every 50-80 years, would not be expected to result in an ULS event.

13.5 Provided foundation design meets the criteria specified by Tonkin & Taylor (2013, 2014), then development on the Tahunanui Sand need not be further constrained.

13.6 The dominantly gravel area, mostly Rabbit Island Gravel, is not expected to suffer significant damage from liquefaction in ULS event and therefore can be developed in a manner similar to many other such areas in the city.

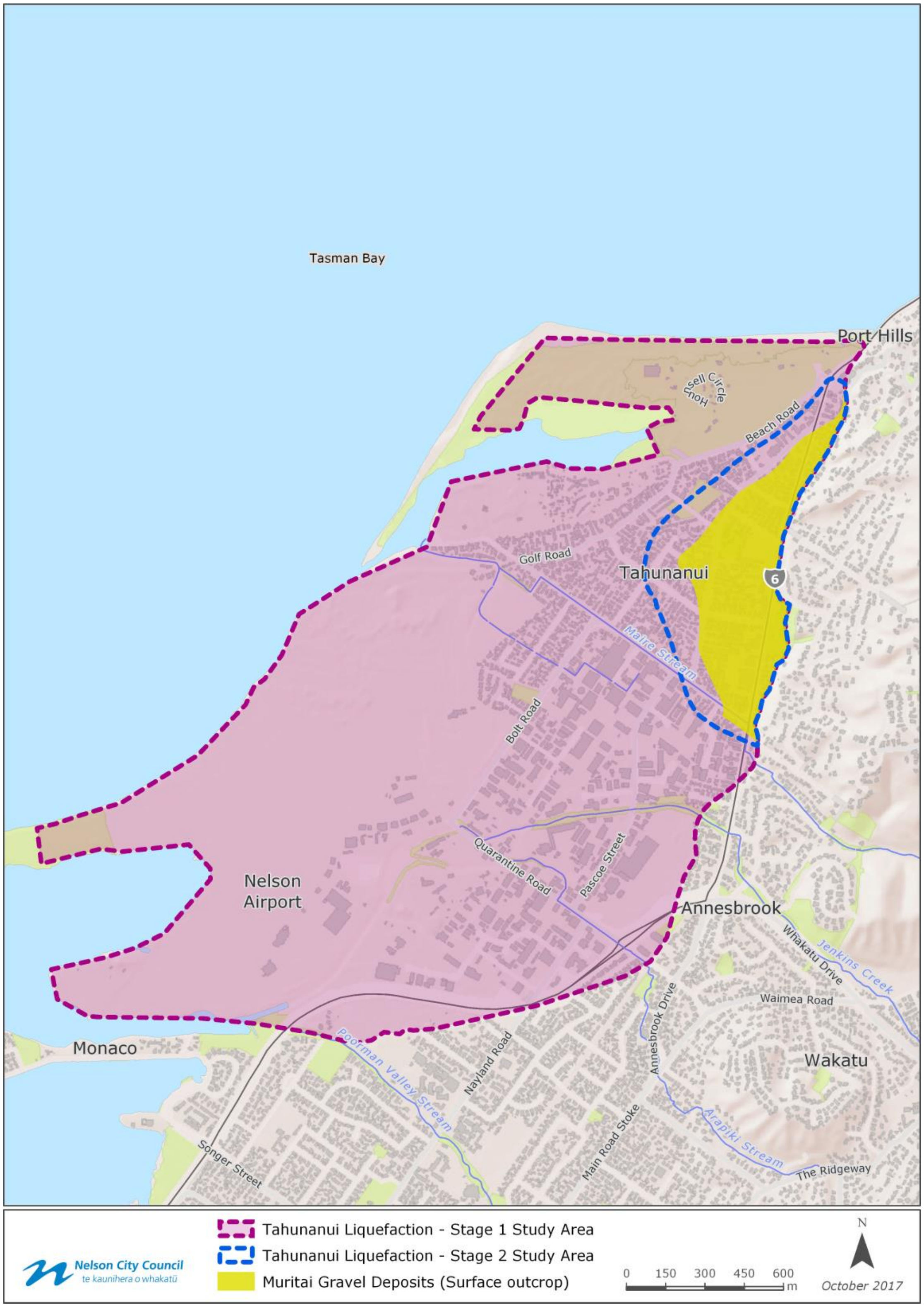
13.7 The inclusion of the dominantly sand area in a planning overlay should take into account that the overlay area could contain, more particularly in the east, ground that would not significantly settle during a severe earthquake affecting Tahunanui. A recommended name could be Tahunanui Liquefaction Risk Overlay.

LIMITATIONS

This report, primarily to identify the area dominated by gravel in which significant settlement during severe seismic ground shaking is unlikely, has been prepared solely for the Nelson City Council. It is based on existing published geological maps, reports prepared by Tonkin & Taylor for the Nelson City Council and a limited amount of unpublished data. No site specific investigations have been undertaken as part of this report.

APPENDICES

Appendix 1. Areas investigated by Tonkin & Taylor (2013, 2014).



Appendix 2 (Tonkin & Taylor 2014, table 5)

Table 5 - Summary of potential liquefaction consequences within the Stage 2 Study Area

Liquefaction Consequence	*Likelihood** and Consequences within the Stage 2 Study Area		
	SLS	**1/100 AEP**	**ULS**
Sand Boils	***Rare***	***Unlikely*** in Muritai gravel. Localised sand boils ***possible*** around the western edge of the Muritai gravel where Tahunanui Sands are present on top of the Muritai gravel sediments.	Localised sand boils across the Muritai gravel ***possible***. Widespread sand boils ***likely*** around the edge of the Muritai gravel where Tahunanui Sands are present above the Muritai gravel sediments.
Buoyancy and uplift of buried pipes and manholes	***Rare***	***Unlikely*** within Muritai gravel. Localised buoyancy and uplift ***Possible*** in saturated Tahunanui Sands (i.e. around the western edge of the Muritai gravel).	Some minor localised buoyancy and uplift of buried manholes and pipes is ***possible*** in the Muritai gravel, and ***likely*** around the western edge of the Muritai gravel where these works are constructed below the groundwater table.
Free-field settlement of the ground surface	***Barely credible***	***Likely*** free-field liquefaction induced ground surface settlements of 0 - 50 mm are currently predicted under this seismic scenario. Larger settlements ***likely*** where building loads are applied at foundation locations. Differential settlements resulting in significant damage to underground services and paved surfaces is ***Barely Credible*** within Muritai gravel, and ***Rare*** around the edge of the Muritai gravel.	***Likely*** free-field liquefaction induced ground surface settlements of typically 0 - 100 mm are currently predicted for the Muritai gravel and surrounding area. Larger settlements are ***likely*** to occur where building loads are applied at foundation locations. Differential settlements ***possible*** within Muritai gravel, and ***likely*** around its western edge, and could result in damage to underground services and paved surfaces (i.e. inadequate fall at some locations on pipelines) and to buildings.
Bearing capacity failure of shallow foundations	***Barely credible***	***Rare*** on Muritai gravel. Localised bearing capacity failures ***possible*** where foundations bear in saturated Tahunanui Sands (i.e. around the western edge of the Muritai gravel).	Some bearing capacity failure of shallow foundations is ***possible*** within the Muritai gravel and ***likely*** around its western edge. ***Likely*** differential settlement of foundations of up to 50 mm is predicted within the Muritai gravel. Bearing capacity failures ***possible*** for heavily loaded foundations within the Muritai gravel, and ***likely*** around its western edge
Lateral spreading	***Barely credible*** - The risk of lateral displacement is assessed to be ***barely credible*** within the Stage 2 Study Area under all design seismic events		

* Likelihood in general accordance with the 'Practice Note Guidelines for Landslide risk management 2007 – Appendix C

Appendix 3.

C1 Broad Classification of Land

MBIE Guidance: Repairing and rebuilding houses affected by the Canterbury earthquakes, December 2012, Part O – Subdivisions table 16.1 broadly classifies land on the basis of assessed liquefaction deformations and types foundations (technical categories) required to address these deformations. Table 16.1 is reproduced below.

Table 16.1: Liquefaction deformation limits and house foundation implications

Technical Category	Liquefaction deformation index limits				Likely implications for house foundation (subject to individual assessment)
	Vertical settlement		Lateral spread (across a house site)		
	SLS	ULS	SLS	ULS	
TC1	15 mm	25 mm	nil	nil	Standard NZS 3604 – like foundations with tied slabs*
TC2	50 mm	100 mm	50 mm	100 mm	The Ministry's enhanced foundation solutions (section 5.2) of the 2011 *Repairing and rebuilding houses affected by the Canterbury earthquakes*
TC3	>50 mm	>100 mm	>50 mm	>100 mm	The Ministry's TC3 foundation solutions, but preferably ground treatment to upgrade land to align with TC2 characteristics.

Note: Certain foundation details included in NZS 3604 are precluded from use (refer to Building Code Acceptable Solution B1/AS1 at www.dbh.govt.nz/compliance-documents#b1.