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NZS1170.5:2004 Site Subsoil Classification of Lower Hutt

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ABSTRACT: A 3D engineering geological model of the Quaternary sediments of the Lower Hutt sedimentary basin was constructed from topographic, geological, geophysical, and geotechnical data. The data include 846 borehole records. The three-dimensional geometry of seven basin units was identified based on variations in strength and lithology. Shear-wave velocities measured using a range of geophysical techniques were obtained and compared with the 3D model. Engineering geological boundaries in the 3D model corresponded well with observed changes in shear-wave velocity. This allowed a range of shear-wave velocities to be assigned to each geological unit. The 3D engineering geology model was then used to calculate a shear-wave velocity profile on a 25 m^2 grid to produce a site-period model for Lower Hutt. This model is used to derive a site subsoil class map in accordance with the preferred methods described in NZS 1170.5:2004. The site subsoil class C/D boundary was determined using the 0.6s contour from the site-period model. The minimum and maximum shear-wave velocity values for each unit were used to determine the uncertainty in the location of the C/D boundary. Subsoil class E sites were determined using standard penetration test results and surface geology.

1 INTRODUCTION

The Wellington Region sits on a major plate tectonic boundary and is crossed by several seismically active faults (Begg & Mazengarb, 1996; Van Dissen & Berryman, 1996; Begg *et al.* 2008). The relatively high earthquake hazard (Stirling *et al.* 2002) associated with the several active faults in the Wellington region and the concentrated urban population of the Lower Hutt valley combine to produce an area with a high seismic risk. Recent paleo-seismic studies (Van Dissen *et al.* 2010; Rhoades *et al.* 2011) conclude that there is currently a 10% probability of a magnitude (M) ≥7.3 earthquake being generated by a rupture on the Wellington Fault in the next 100 years.

The earthquake risk is partly managed through the current New Zealand standards for Structural Design Actions, NZS 1170.5:2004 (Part 5: Earthquake actions – New Zealand) which requires determination of the subsoil class at a site. The preferred method is calculation of the low amplitude natural period (hereafter referred to as the *site period*) at a site (McVerry *et al.* 2011). This can be calculated using the depth to bedrock and a shear-wave velocity profile. As part of the larger “It’s Our Fault” programme (Van Dissen *et al.* 2011) to assess and mange the seismic risk in the Wellington region the spatial variation in site period has been determined for Wellington city’s CBD (Semmens *et al.* 2011) and Lower Hutt (Boon *et al.* 2010, this paper). Prior to this study this information was not available for the majority of the Lower Hutt valley.

The Lower Hutt valley is a wedge-shaped, fault-bound, sediment-filled basin adjacent to Wellington Harbour. Sediment fill thickness is ~ 350 m near the Petone foreshore where the basin is 5 km wide and shallows to ~0 m at Taita Gorge, 12 km to the northeast where the basin is less than 1 km wide. In this paper we describe the integration of available pre-existing and newly-acquired topographic, geological, geotechnical and geophysical data into a digital, 7-layer, 3D engineering geological model for Lower Hutt. The modelled engineering geological units are then assigned appropriate shear-wave velocity parameters to derive a 3D pseudo-shear-wave velocity model of the basin. Two of the outputs of the new 3D model are a depth-to-bedrock model and the ability to determine a shear-wave velocity profile for any point in the model. The shear-wave velocity characterisation allows the site period to be determined at any location in the valley. The site period model is used to produce a subsoil-class map of the Lower Hutt valley based on NZS1170.5:2004.

2 GEOLOGICAL AND GEOTECHNICAL CHARACTERISATION

2.1 Topographic data sources for the digital terrain model (DTM)

Three readily-available topographic datasets were used to construct a DTM for the study area. These were: 1) NZMS 260-derived 20 m contours for the valley side topography; 2) LiDAR topographic data collected by Greater Wellington Regional Council for the valley floor topography; and 3) marine chart NZ4633: Wellington Harbour, for the offshore area. The three DTMs were combined to create a composite 25 m (grid size) DTM for seamless coverage of the study area.

2.2 Hutt Valley borehole database

The Hutt Valley borehole database currently contains 846 borehole records, including 237 SPT tests with coverage mainly concentrated in the Lower Hutt central business district and Petone. The borehole database contains logs from various sources and these are of variable quality. The earliest, often poorer-quality logs, are from deeper boreholes drilled for groundwater investigations. Later logs, generally better-quality but shallower, typically originate from ground investigations for civil engineering projects. Borehole locations and collar heights have been determined using available locality information on the logs and heights from the Greater Wellington Regional Council topographic database. Consequently there is some uncertainly in the accuracy of collar heights and borehole locations. Locations are thought to be accurate to ±50 m and collar heights are to ±0.5 m.

2.3 Geology

The Lower Hutt valley lies in a 4.5 km wide, 14 km long wedge-shaped fault bound basin with a maximum depth to basement of 350 m at the Petone foreshore and progressively shallows to the northeast exposing basement greywacke rock in the valley floor at Taita Gorge. On the north-west margin of the basin there is a step in the bedrock caused by offset across the Wellington Fault.

The 1:50 000 geology map of Begg & Mazengarb (1996) is the base geological data used in this study. The basement bedrock in the study area is composed of 280 to 200 Ma (million years) greywacke comprising indurated (hard) sandstone, siltstone and mudstone beds. The greywacke is tightly folded, faulted and locally crushed creating an angular blocky discontinuous rock mass near the surface.

The Quaternary (last 2.5 million years) is represented by a c. 350 m thick wedge-shaped package of alluvial-deltaic-marginal marine sediments that infill the bedrock basin. Stevens (1956) subdivided the Hutt Formation into six Members: Taita Alluvium, Melling Peat, Petone Marine Beds, Waiwhetu Artesian Gravels, Wilford Shell Bed, Moera Basal Gravels (Table 1). Correlation of the geological units is based upon marine and non-marine changes and the international sea level curve. Begg *et al.* (2008) correlated the statigraphy between three pivotal boreholes based on the presence of multiple marine (shelly) incursions that are separated by non-marine intervals. We have extended their correlations to other boreholes by similarly using the presence of marine (shelly) incursions as stratigraphic markers.

2.4 Geotechnical Characterisation

The geotechnical data held in the Lower Hutt borehole database has been used to help characterise the geological materials within the Lower Hutt valley. The geological materials were classified based on their likely geotechnical behaviour which is generally governed by their strength and lithology (a combination of geological origin and grain-size). A litho-technical code was assigned to each layer in a borehole in the Hutt Valley borehole database. Litho-technical codes characterised the strength of the material in terms of loose/soft or dense/stiff (based on SPT 'N' values) their geological origin (e.g marine, alluvial, beach, swamp) and the dominant grain-size (fine or coarse). Litho-technical classifications were displayed in the boreholes used to define the boundaries between engineering geological units when constructing the 3D model (Table 1 & Fig 1).

Table 1: Engineering geological units used in Hutt Valley 3D model.

Engineering Geological Unit	Engineering Geological Description	Stratigraphic Name	Approx Age	Maximum Thickness (m)
Unit 1	Moderately dense engineered fill and non-engineered fill	Reclaimed land	0 to 100 years	~5 to 15
Unit 2	Loose to dense, rounded gravel	Taita Alluvium	< ~10 ka	~40
	Very soft to soft organic sand, silt, clay, peat, wood	Melling Peat & Naenae swamp deposits		
	Soft to firm, shelly, sand, and silt.	Petone Marine Beds		
	Loose to dense, silty sandy angular gravel	Alluvial fans		
Unit 3	Medium to very dense, gravel, sand and silt	Waiwhetu Artesian Gravel	10 to 70 ka	~60
Unit 4	Stiff, shelly, sand, silt and clay.	Wilford Shell Bed	70 to 128 ka	~ 30
Unit 5	Very dense alluvial gravels inter-bedded with, very stiff shelly silts and sands	Waimea Glacial & Karoro Interglacial	128 to 245 ka	~60
Unit 6	Very dense weathered gravel and stiff fine-grained marginal marine beds	Moera Basal Gravels, Nemona Glacial Gravels & older deposits	245 to >380 ka	~210
Unit 7	Strong (50-100 MPa) greywacke	Wellington Greywacke	290 to 159Ma	

2.5 Engineering Geological Model

These datasets were used to characterise the geology and distribution of geotechnical properties in the Lower Hutt valley in a 3D engineering geological model. This model uses topographic data to construct a digital terrain model (DTM), a surface geological map and borehole data to spatially control the 3D distribution of the geological units and geotechnical data to characterise material strengths. An exploded view of the 3D engineering geological model showing 7 units (orientated to face north) is shown in Figure 1. The units are from top downwards, reclaimed land (Unit 1 - brown); soft flexible Holocene deposits (Unit 2 - dark yellow); stiff gravels (Unit 3 - blue); Wilford Shell Bed (Unit 4 - aqua); older glacial and interglacial gravels (Unit 5 - green) and the oldest gravels (Unit 6 - orange). Greywacke bedrock forms the basement (Unit 7 - light grey). The active Wellington Fault bounds the northwest margin of the basin.

The greatest sources of uncertainty in the engineering geological model are the sub-surface unit boundaries where limited data are available. In the model the top and basal boundaries of each unit are represented as smooth surfaces. In reality geological boundaries may be gradational or sharp and may undulate with a surface roughness that varies over different scales. Therefore the accuracy of the surfaces is considered to range from 1 m, where the depth is well constrained by mapping, boreholes and geophysics, to ±50 m in the deepest parts of the basin where little or no information is available.

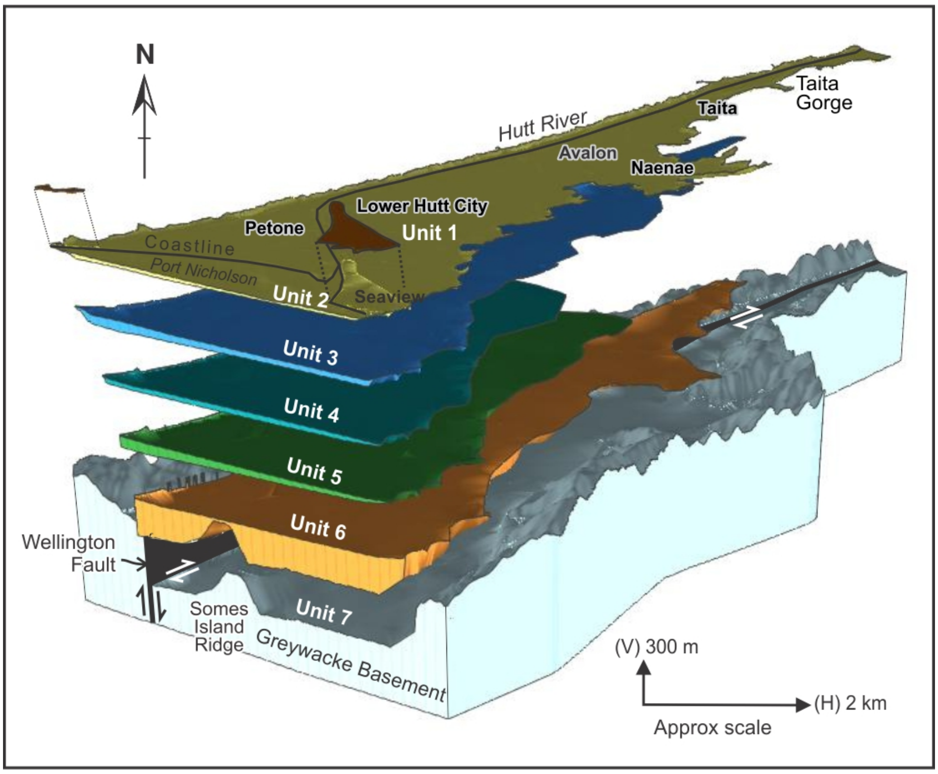

Figure 1: An exploded view of the Lower Hutt valley engineering geological model (viewed obliquely, looking north).

3 SHEAR-WAVE VELOCITY CHARACTERISATION

Earthquake ground motion modelling studies in the Lower Hutt valley require characterisation of the basin fill in terms of shear-wave velocity (Vs) in order to calculate site period. Shear-wave velocity data have been collected using a variety of geophysical techniques in Lower Hutt (Table 2). Because the shear-wave velocity data were not used to construct the 3D engineering geological model a comparison was made between the depths of unit contacts in the 3D model and the depths of changes in shear-wave velocity. It was found that changes in shear-wave velocity corresponded closely to unit boundary depths (Table 2).

Table 2: Unit boundary depths in the deep borehole at Petone were compared with the depths of shear-wave velocity changes near the borehole as determined by a range of geophysical techniques. Depth values are given to the nearest metre with one standard deviation given in square brackets. *indicates only 1 comparison available. The geophysical techniques were Seismic Cone Penetration Test (SCPT), Spatial Autocorrelation (SPAC), Refraction Microtremor (ReMi), and Noise Interferometry (NI)

Model Unit	Depth in borehole (m)	Geophysical technique			
		SCPT	SPAC	ReMi	NI
2	30	±3 [1.6]	±2 [1.2]	±4 [4.2]	±6 [3.9]
3	80		±12*	±12 [13.1]	±6 [5.8]
4	105			-	±7 [7.0]
5	160			±1*	±12 [9.5]
6	300			±27 [19.8]	±38 [26.1]

This allowed a range (minimum, average and maximum) of Vs values to be assigned to each unit and extrapolated across the entire volume for each unit to derive a 3D pseudo-velocity model. The final shear-wave velocity values used to generate the applied maps are summarised in Table 3 and the complete catalogue of values (sorted into 15 m/s bins for clarity) that contribute to the final Vs value range is given in Figure 2. The pseudo-velocity model was used to calculate values for site period on a 25 m grid across the 3D model.

Table 3: Shear-wave velocities of engineering geological units in the Lower Hutt basin. Vs values are rounded to the nearest 5 m/s.

Model Unit	**Material Description**	**Shear-wave velocity (m/s)**			**No. of values**
		min.	ave.	max.	
1	Stiff rock boulder fill	100	200	300	-
2	Soft to firm silt and clay, loose sand, gravels, and very soft peat lenses	150	180	270	22
3	Dense to very dense gravel	270	490	630	25
4	Stiff shelly sand, silt and clay	610	630	650	7
5 & 6	Stiff gravels inter-bedded with stiff silts	715	745	770	15
7	Strong slightly-weathered greywacke	1310	1375	1480	30

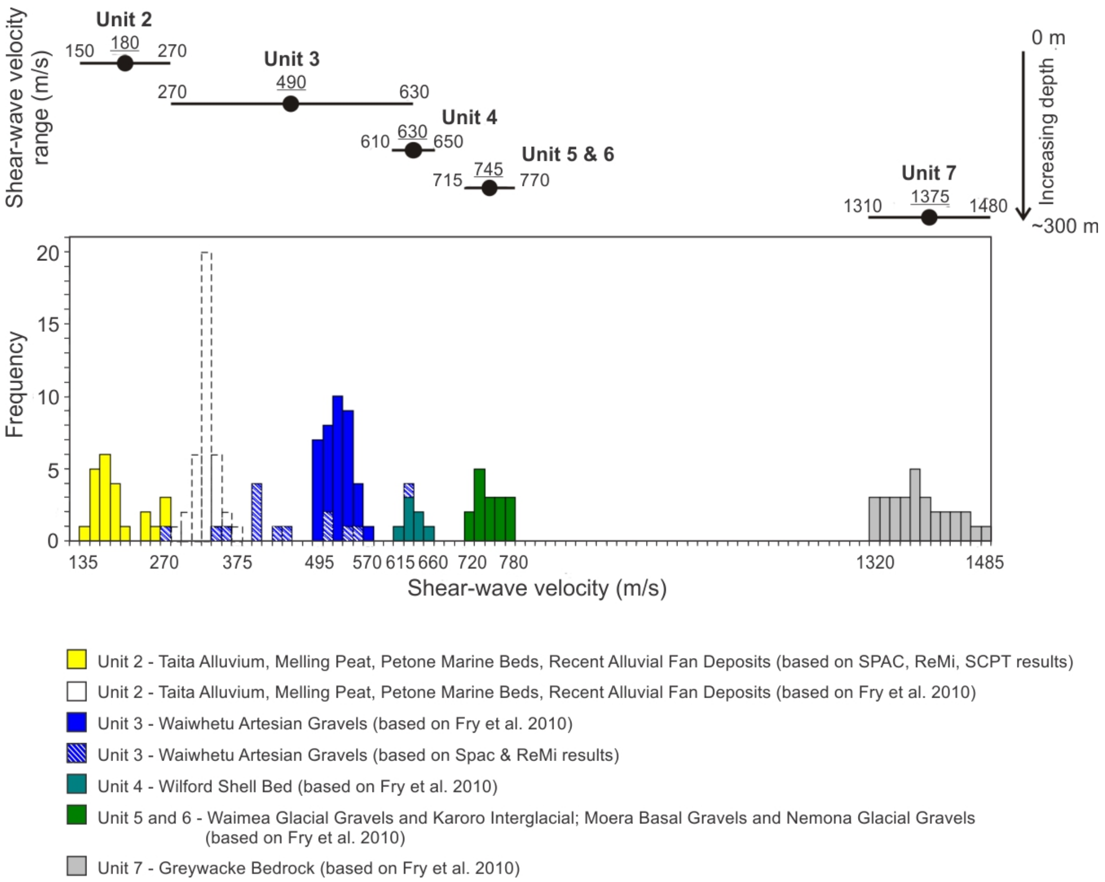

Figure 2: Summary of final shear-wave velocity ranges (top) for engineering geological model units 2–7. Data values summarised into 15 m/s increments and distinguished by colour to indicate unit and data source (bottom).

4 THEMATIC MAPS

4.1 Depth to bedrock map

The depth to bedrock map has been generated by subtracting the bedrock elevation model surface from the digital terrain model. The new map was built using 20 m contours to reflect the average precision of the depth to bedrock in the 3D engineering geology model. Known depth to bedrock points proven in boreholes were used to verify the map.

4.2 Low-amplitude natural period (or site period) map

The NZS 1170.5:2004 preferred method of site classification for determination of site subsoil class is by calculation of the low-amplitude natural period (also known as the *site period*). Measured and pseudo site periods were used to construct the site period map (Fig 3). The site period was calculated on a 25 m^2 grid using the thickness of each unit at a grid point (from the 3D model) and the average shear-wave velocity of the unit (Table 2).

The sensitivity of the 0.6 s site-period contour location was investigated by recalculating the model using the minimum and maximum Vs values summarised in Table 2. Figure 3 shows three contours for the 0.6 s site period boundary. Using minimum Vs values pushes the 0.6 s contour approximately 1 km to the northeast (up-valley) around Taita. Using maximum values pushes the position of the 0.6 s contour southwest (down-valley) by around 1 km at Taita and draws it out of the Naenae area pushing it 1 km northwest into the main valley.

4.3 Site subsoil class map

The site sub-soil class map was generated from the site period map following the preferred methods described in NZS1170.5. The map defines site subsoil class B, C, D and E. The class B area is the area of mapped exposed basement bedrock. The extent of the Class C area is defined by a low-amplitude natural period of less than or equal to 0.6 s (as defined in Figure 3) and where Class B is not present. Class D areas are defined by a low-amplitude natural site period greater than 0.6 s. NZS 1170.5:2004 (Clause 3.1.3.6) defines Class E sites where the results of SPT or CPT tests prove more than 10 m of soils with SPT N-values less than 6. SPT and CPT data have been used to determine Class E sites on a site-specific basis, depicted on Figure 4 as red circles.

Where there are no SPT or CPT data we cannot use this method to determine Class E sites. Based on the lithological descriptions made in the borehole records and from the detailed geological mapping by Stevens (1974), Begg & Mazengarb (1996) and Begg *et al.* (2008) we expect additional localised areas of very soft soil in the Lower Hutt valley. We have accommodated uncertainly in our knowledge of Class E sites (caused by lack of data) by defining a zone that may contain site Class E sites (zone shown as hatched area on the map, Fig 4).

5 CONCLUSIONS

Seven engineering geological units were recognised in the Hutt Valley and their extents have been modelled in 3D. A depth-to-bedrock model has been generated and the sediments of the Hutt Valley basin have been characterised in terms of shear-wave velocity resulting in a 3D shear-wave velocity model of the Lower Hutt Valley basin.

The depth-to-bedrock and shear-wave velocity models have been combined to produce the first site period map of the Hutt Valley that is based on local geology. The depth-to-bedrock and site-period maps have been combined to create the first site subsoil class map for the Lower Hutt Valley, in accordance with the preferred method described in NZS 1170.5:2004, Part 5.

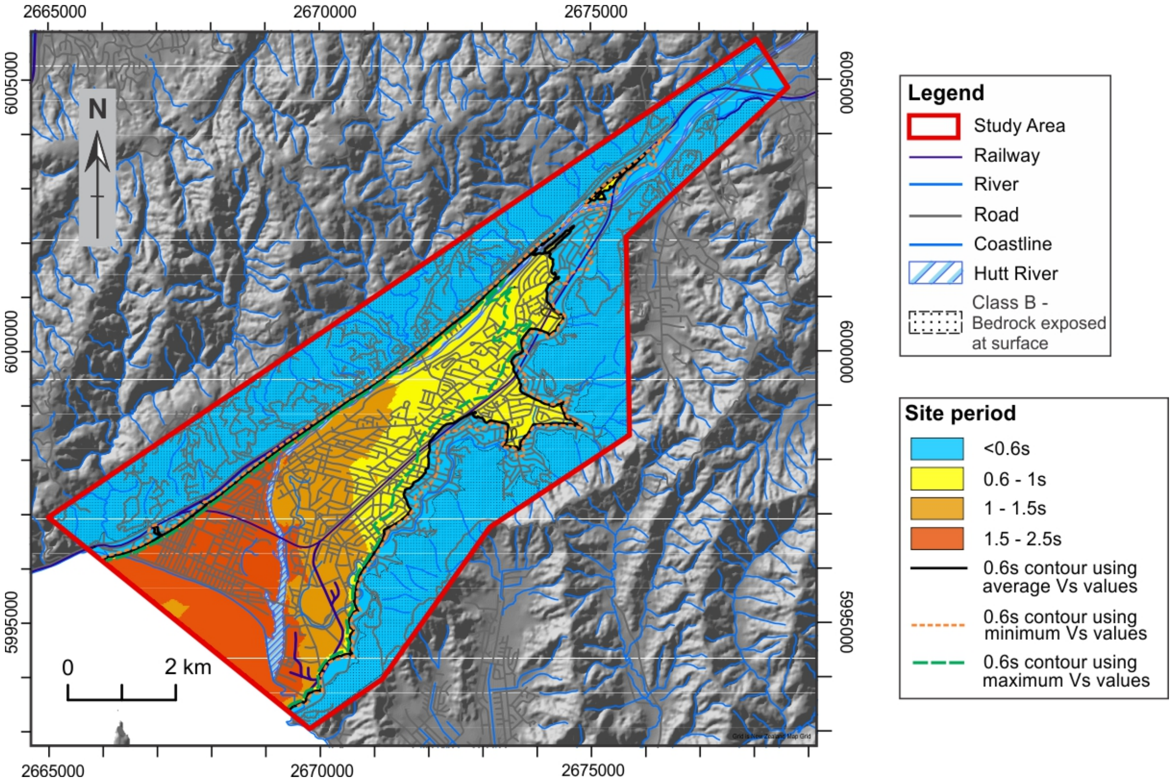

Figure 3: Low-amplitude natural period (site period).

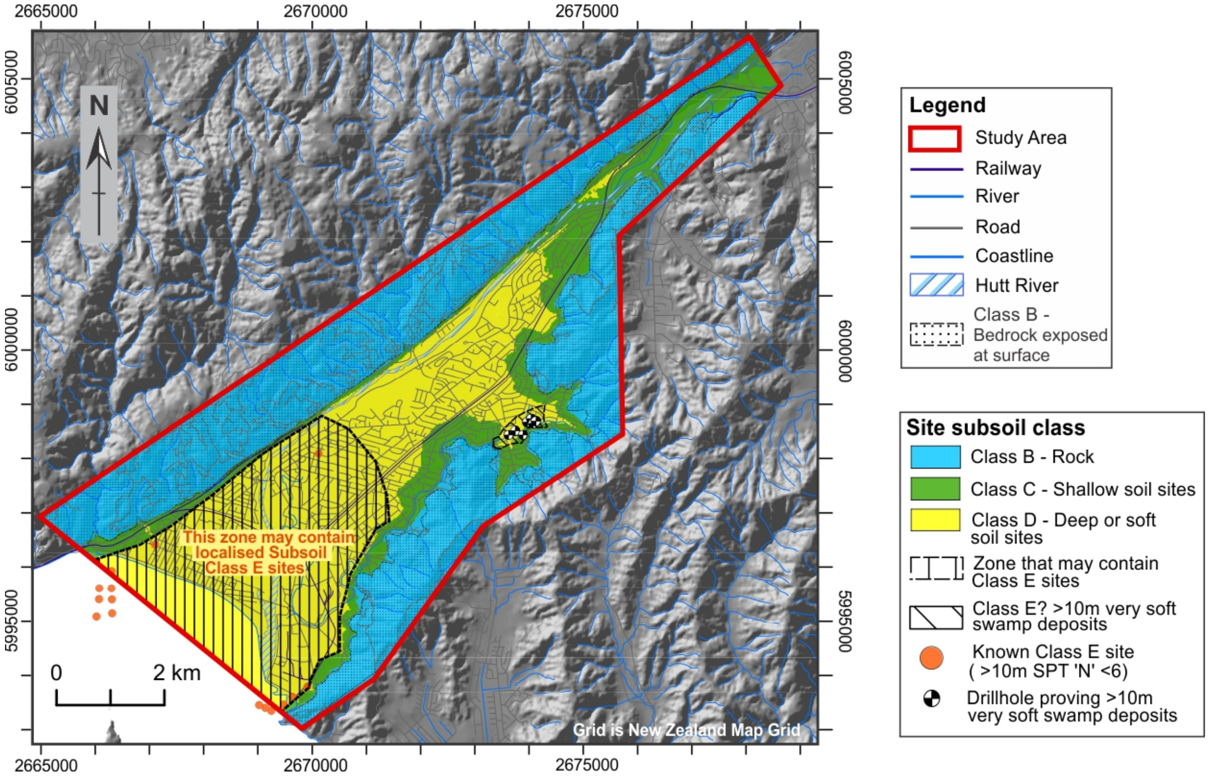

Figure 4: Site subsoil class in Lower Hutt as determined by the methods described in NZS1170.5:2004, Clauses 3.1.3.2 to 3.1.3.6.

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