THE LOWER HUTT – WELLINGTON HARBOUR (TE WHANGANUI A TARA) GEOLOGICAL MODEL

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June 2020

1 Introduction

1.1 Purpose of building a 3D Geological Model

The Waiwhetu Aquifer is one of the Wellington region's most valuable natural resources. It provides a significant proportion of the water supply to Wellington and Lower Hutt Valley and there have been recent indications that there may be some issues regarding its capacity and security. Parts of the Waterloo Wellfield are approaching the end of their operational life and decisions on reinvestment in the infrastructure must be well informed.

It is now routine to construct digital 3D geological models based on available data that also incorporate a geologically logical conceptual framework. Recent work updating the Hutt Valley Drillhole Log Database (HVDL17) has placed Greater Wellington Regional Council (GWRC) and Wellington Water Limited (WWL) in a strong position to build a high-quality 3D geological model of materials beneath the Hutt Valley floor. The development of such a geological model and better understand the subsurface materials is a vital precursor to quality groundwater modelling.

This work was designed to produce a reliable geological model upon which to base groundwater modelling, but the model also includes basic geological information for informing resource consent decisions.

The area covered by the Geological Model (Figure 1) is from the Taita Gorge across the Lower Hutt Valley and Wellington Harbour to Kilbirnie and the Miramar valley. It explicitly excludes the Wellington City area, as a geotechnical model for Wellington City is currently under development. In the near future it would be desirable for all interested parties (GWRC, WWL), Hutt City Council and Wellington City Council, to fuse these two models. In addition, a 3D geological model may be developed for the

Upper Hutt Basin during the coming years and combining these areas within a single model will carry multiple benefits.

Greater Wellington Regional Council and Wellington Water contracted J Begg Geo Ltd to produce a 3D geological model of the Lower Hutt Valley/Wellington Harbour area to resolve, as well as available data allows, the following:

- Task 1. Define the spatial distribution of Holocene aquitard materials;
- Task 2. The extent and nature of Waiwhetu Artesian Gravels beneath the harbour floor; and
- Task 3. Finalise a Leapfrog Geological model of the Lower Hutt/Wellington Harbour area.

This report provides background information to assist users of the Geological Model understand these materials, the depositional environment and their relationship to climatic and tectonic change. The project was completed during a period when extensive exploratory work was being undertaken by various consultants working for GWRC and WWL to better understand the groundwater system of the area. In particular, work by Stantec (Stantec 2017, 2018) and subcontractors (NIWA, GNS Science, Earth in Mind, Tonkin & Taylor and J Begg Geo Ltd) on the potential for groundwater abstraction from beneath Wellington Harbour and subsequently work towards a cross-harbour pipeline as well as work testing options for upgrading the Waterloo Wellfield have provided new information constraining parts of the model. More information on parts of these projects (and more) is available in the following reports:
Begg (2018), Gyopari (2014), Gyopari et al. (2018), Tonkin & Taylor (2017), Wellington Water Ltd (2017), van der Raaij & Martindale (2017), Nodder et al. (2015, 2020), Nodder & Woelz (2019), Woelz & Nodder (2018), Barnes et al. (2018), Begg & Morgenstern (2017) and Close et al. (2017).

1.2 Background

The Lower Hutt/Wellington Harbour basin is one of a series of basins that have developed along the south-eastern side of the active Wellington Fault during the last c. 1 Ma (million years), directly as a result of accumulated strain across the fault. The focus of this work is to attempt to build a 3D model of the lithological units from the Quaternary Period, materials that unconformably overlie, or are faulted against the basement Torlesse (composite) terrane "greywacke". The units selected in characterising the lithologies are the members of the Hutt Formation (as defined by Stevens 1956), with a small number of subunits that are informally defined in this report. Each member comprises a series of lithologies, but the member is characterised by its predominant lithology/lithologies. The lithologies of each member contrasts with those underlying and overlying it.

There are few constraints on the age of the oldest materials deposited in the Lower Hutt/Wellington Harbour basin, but evidence from further afield (the Wellington region and beyond) suggests that growth of the basin is unlikely to pre-date c. 1 Ma (see Begg & Mazengarb 1996). Counting back through marine incursions into the Hutt Valley using the international sea level curve (here, that of Lisiecki & Raymo 2005) as a chronology suggests that at Petone, deposition has been more or less continuous for at least 350 kyr (thousand years) and that significantly additional time is involved in deposition of underlying deposits.

Task 1: Work description

Define the spatial distribution of reliable Holocene aquitard materials across the Lower Hutt Valley.
In general, materials beneath the Hutt Valley vary in a spatially consistent manner. Holocene lithologies in the upper valley, between Taita Gorge and Boulcott consist of gravel, grit and coarse sand. Between Boulcott and Melling Bridge Holocene materials are laterally variable, ranging from gravel, sand, silt, clay and peat. Between Melling Bridge and Ewen Bridge Holocene materials include beach sand and gravelly sand below gravelly sand and sand of alluvial origin. Southeast of Ewen Bridge to The Esplanade, Holocene surface materials are underlain by a laterally continuous clay or silty clay of marine origin that may be overlain by marginal marine sandy gravel, alluvial silt, sand and/or gravel. While small-scale local variations in these lithologies are present, the broader characteristics are consistent with a conceptual model proposed in Begg & Morgenstern (2017; see below).

The target of this work component is understanding the lateral and vertical distribution of Holocene materials; the aim is to constrain the boundaries of generalised lithologic units, locate any significant volumes that do not conform with the general model and to locate data gaps. The work was well served by close collaboration with a hydrological modeller who will have responsibility for ensuring the value of the geological model to that discipline.

Task 2: The extent and nature of Waiwhetu Gravels beneath Wellington Harbour

The Waiwhetu Gravels (I drop part of the formal unit name as the term "Artesian" suggests that all parts of the Waiwhetu Gravel are not only water-bearing, but artesian) extend south beneath the shoreline at Petone, as indicated by submarine springs near the Hutt River mouth and Point Howard and at Falcon Shoals, by seismic reflection lines, by presence of fresh water at Somes Island bore and also in two deep boreholes within Te Whanganui a Tara/Wellington Harbour. Based on logs from the two harbour boreholes, E3 and E8, and from seismic reflection profiles, the Waiwhetu Aquifer splits into upper and lower members, separated by a fine-grained unit. Mapping the extents of these two aquifers and the intervening aquitard is the goal of this part of the project.

Although there are limited borehole logs that penetrate deeper than the base of the Waiwhetu Gravels (16 within the Lower Hutt Valley and Wellington Harbour, plus a cluster of logs from Kilbirnie and Miramar), the base of the aquifer can still be modelled base on the seismic reflection profiles, although it location will be less well constrained than that of shallower materials. Despite this data issue, the spatial distribution of Waiwhetu Gravel and aquitard is an important factor in understanding and modelling the groundwater system.

Completion of this task extends the model of the Waiwhetu Aquifer from Taita Gorge to the Falcon Shoals near the Harbour Heads. As currently conceived, this extent encompasses the entire Waiwhetu Aquifer System.

Task 3: Making the Geological Model information usable and useful

The Lower Hutt-Wellington Harbour Geological Model provides a basic geological framework detailing the spatial distribution of all differentiated materials beneath the Hutt Valley.

To maximise the utility of the model, it has been transferred into a Leapfrog Viewer project that allows more widespread visualisation of the model to users (this software is freely available at https://www.seequent.com/products-solutions/software-downloads/#viewers).
In addition, data has been extracted from the Leapfrog Geo Geological Model in the forms of:

- Basal geological unit surfaces
- Structure contours
- Isopachs for volumes
- Volumes

for each surface in shapefile format that can be used in a GIS. This data makes the model more readily accessible to GIS users and useful for testing this information against new or different data sets.
These data are essential for adequately managing such an important resource such as the Waiwhetu Artesian System.

Comments on aquifer recharge

The model identifies areas that may be regarded as a recharge zones for the aquifer. It also identifies the location of frailties in the groundwater system, including aquitards, and provides opportunities to test them. The work has been coordinated with GWRC, Wellington Water Limited (WWL) and Earth in Mind to ensure consistency in understanding and approach to the groundwater system.

A resource in Land Use Planning

Knowing the spatial distribution of Holocene materials of contrasting lithological properties should provide a valuable tool in estimating costs and impact of planned development, key components in land use planning. Planning changes may be required to land-use in recharge zones of the aquifer, but the model will inform a wide range of other planning tasks, such as resource consent applications.

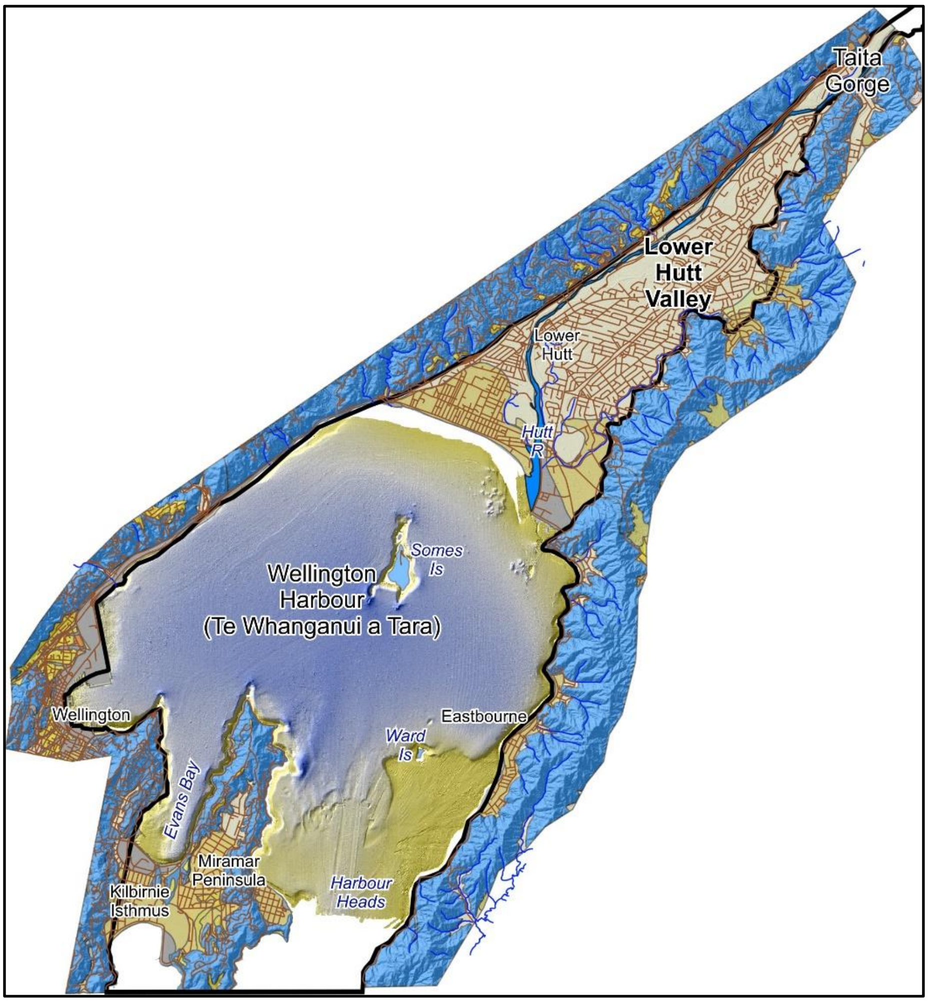

Figure 1: Map illustrating the area covered by the Leapfrog Geological Model of Lower Hutt Valley and Wellington Harbour (heavy black line). Note that Wellington City is excluded from the model. Topo50 (LINZ) data include roads (brown), streams (blue), river polys (blue). The colour-ramped NIWA digital elevation model (DEM; blue = deep, yellow = shallow) of the harbour floor is overlain by a hillshade derivative. Above sea level, the image comprises a hillshade derived from the GWRC LiDAR-derived 1 m DEM. The onshore part of the map area is overlain by the 1:50,000 scale geological map data of Begg & Mazengarb (1996) (blue = Torlesse composite terrane, light yellow = Holocene alluvium, dark yellow = Holocene marginal marine deposits, grey = reclamation).

2. Conceptual Stratigraphic Model

This conceptual stratigraphic model has its origins rooted in the first investigations of Hutt Valley stratigraphy by Dr. G.R. Stevens and Mr. Tom Grant-Taylor. In a paper published in 1956 Stevens formally described the stratigraphy of the Lower Hutt Valley (Figure 2). Other than fan and colluvial materials on the peripheral slopes of the valley, he defined the Quaternary materials beneath the basin floor as belonging to the Hutt Formation. Further, he defined a series of members within the Hutt Formation that include the Taita Alluvium, Melling Peat, Petone Marine Beds, Waiwhetu Artesian Gravels, Wilford Shell Bed and Moera Basal Gravels, listed here approximately in order of increasing age.

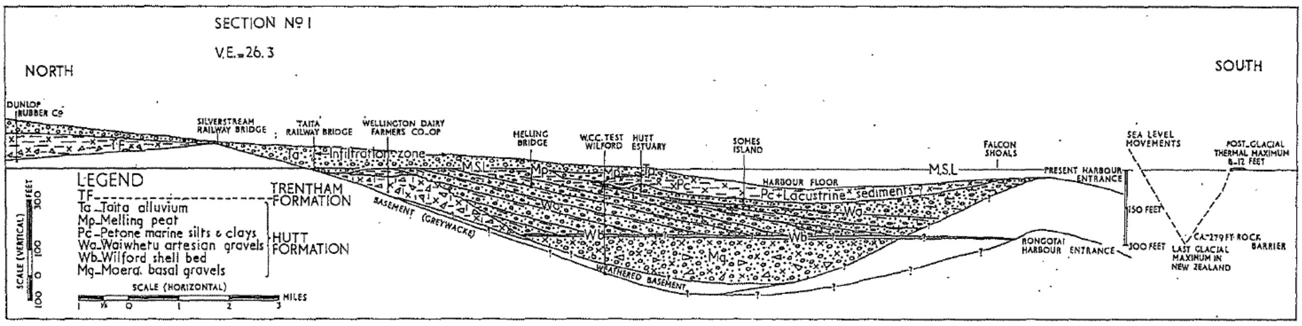

Figure 2: Stevens' (1956) conceptual stratigraphic illustration of the stratigraphy of the Lower Hutt basin and Wellington Harbour.

Since the publication of Stevens' paper a growing appreciation of the activity and location of the Wellington Fault has resulted in some modifications to his conceptual stratigraphic concept, with growing awareness of the significance of its vertical component of slip, down to the southeast. Work by Len Brown, Bryan Davy and Ray Wood and the present author (GNS Science), and Phil Barnes and Scott Nodder (NIWA) have helped build a broader view of the stratigraphic response to vertical deformation associated with the Wellington Fault and other active faults in the area.

The following section presents an outline of a current conceptual stratigraphic model of late Quaternary deposition in the Lower Hutt/Te Whanganui a Tara area (Figure 3). The time scale, sea level and depositional regimes inherent in this model are derived from published oxygen isotope sea level curve and elevation data (primarily Lisiecki & Raymo 2005; Antonioli et al. 2004), borehole logs (HVDL17; Begg & Morgenstern 2017), available radiocarbon ages and a suite of seismic reflection profiles across Te Whanganui a Tara (GNS Science and NIWA).

2.1 Sea level change in response to climatic variation

The latter c. 700-800 kyr of the Quaternary Period is characterised by repeated cycles of sea level change with a period of c. 100 kyr (Lisiecki & Raymo 2004; PAGES 2015; range: 68 to 130 kyr; median 99 kyr; ave c. 92 kyr) that is presumed to be a response to orbitally induced climatic changes as described originally by Milankovitch (1941) and Hays et al. (1976). Extensive research from around the world indicates that peaks of sea levels occurred during warm climatic intervals that approximate the present day sea level (± 10 m), while during cold climatic regimes, sea level may have been up to 125 m (± 10 m) lower than today's (e.g. Imbrie et al. 1984; Martinson et al. 1987; Pillans et al. 1998; Pisias et al. 1984; Rabineau et al. 2006; Shackleton et al. 2000; Siddall et al. 2005; Antonioli et al. 2004; Bintania et al. 2005; PAGES 2015). Transitions, particularly between low sea level stands and high sea levels stands may be extremely rapid (e.g. Lisiecki & Raymo 2005; PAGES 2015). Overall, notwithstanding short-term fluctuations, long-term sea level drop following high sea level stands tend to last for 50 kyr or more, while sea level rise to sea level maximums from extreme minimums tend to be short and rapid, lasting c. 10 kyr.

Isotopic analysis of marine benthic foraminifera through sequences captured by deep sea coring provides the fundamental tool for understanding past marine temperatures. Such analyses from a wide number of deep-sea cores shows a repeated pattern of variation through time (e.g. Rabineau et al. 2006; Lisiecki & Raymo 2005; Railsback et al. 2015; Figure 4). Independent observations from many locations around the world (e.g. Antonioli et al. 2004) have been linked with the marine oxygen isotope curve providing empirical estimates of sea level elevation through the last 500 kyr. In addition, oxygen isotope records from ice cores and atmospheric greenhouse gas concentrations in air bubbles preserved in ice cores from Antarctic (e.g. Lūthi et al. 2008) and Greenland (Barker et al. 2011) reveal changes through time providing a paleoclimatic record that relates well (although are slightly offset from) the marine oxygen isotope data. This body of work provides a vital component of understanding in linkages between marine oxygen isotopes, marine temperature, atmospheric greenhouse gases, absolute sea level and climate.

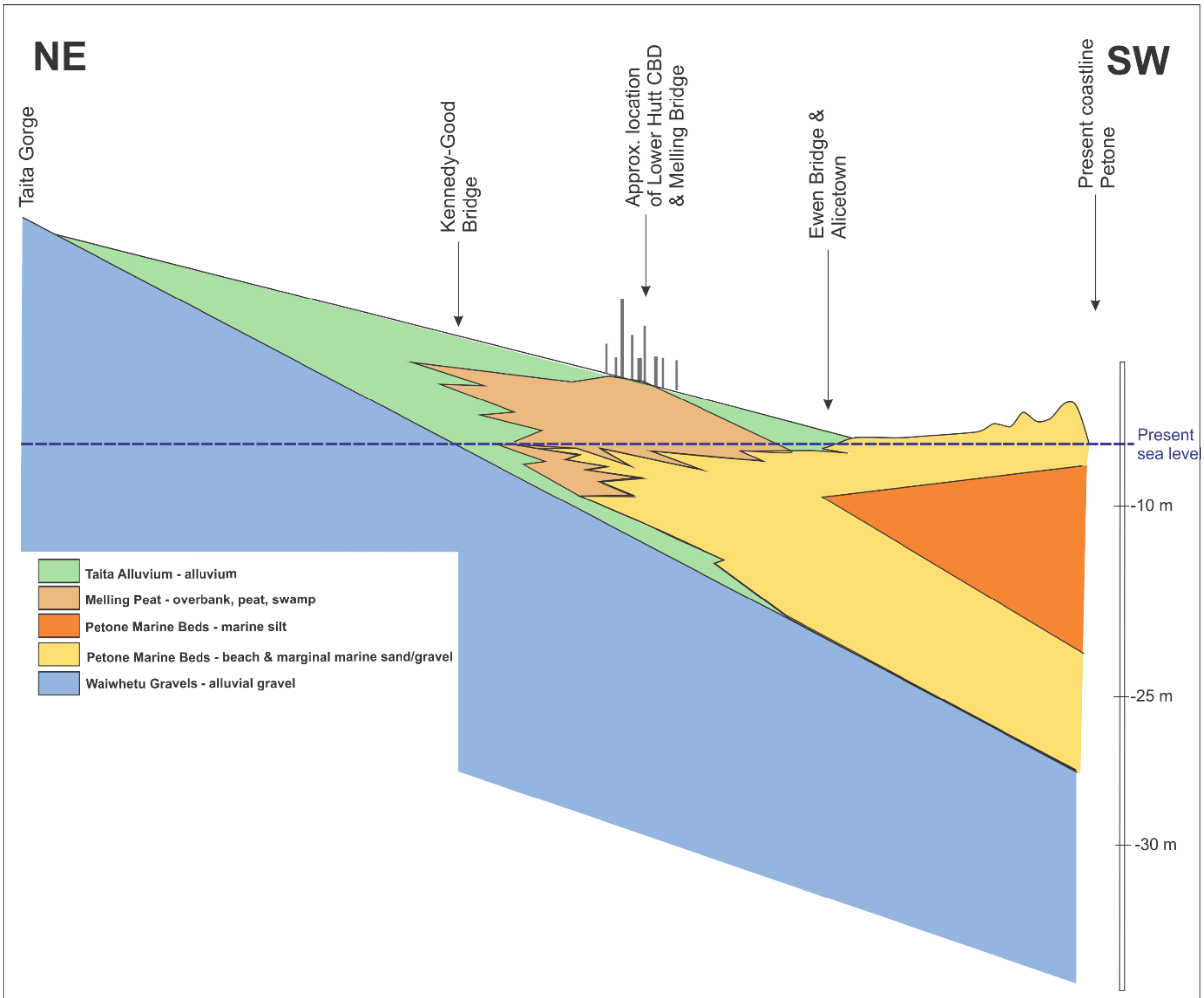

Figure 3: A conceptual model of post-last glacial stratigraphy of the Lower Hutt Valley presented in Begg & Morgenstern (2017).

Of the sea level cycles of the last 700 kyr, the most recent, the Holocene is the best known (see references cited above). Given the broad similarities of the last sea level/climatic cycle (Marine Isotope Stages (MIS) 5 to 1) with previous cycles it is reasonable to use it as an analogue for the others.

The most recent sea level/climatic cycle commenced about 130 kyr at the transition between MIS 6 & 5; in the period between 121 to 126 kyr (MIS 5e) sea level was briefly slightly higher than modern sea level (up to 5-7 m; e.g. Lisiecki & Raymo 2005).

The Wellington hinterland was well vegetated during the mild MIS 5 interval (Biozone P6 of Mildenhall 1995) and the presence of marine shells within interglacial deposits across the Lower Hutt/Kilbirnie/Miramar area are indicative of high sea level at the time. These are key elements in establishing stratigraphic correlation. Similarly, these characteristics can be used to define the lateral and vertical extent of marine inundation for the Holocene (<12 kyr; Biozone P9 of Mildenhall 1995) and penultimate interglacial (191-243 kyr; Biozone P4 of Mildenhall 1995).

Sediments deposited during these periods of marine inundation contrast with those deposited in the terrestrial (including alluvial) environments that prevailed during the intervening glacial periods. Marine deposits are dominated by silt and marginal marine gravelly sands and fine gravels. During low sea level stands (cool climatic episodes), deposits across the valley floors are dominated by alluvial gravel, sandy gravel, silty sand and clayey silt. These lithological cycles can be identified in drillhole logs across the area of interest (Figure 5).

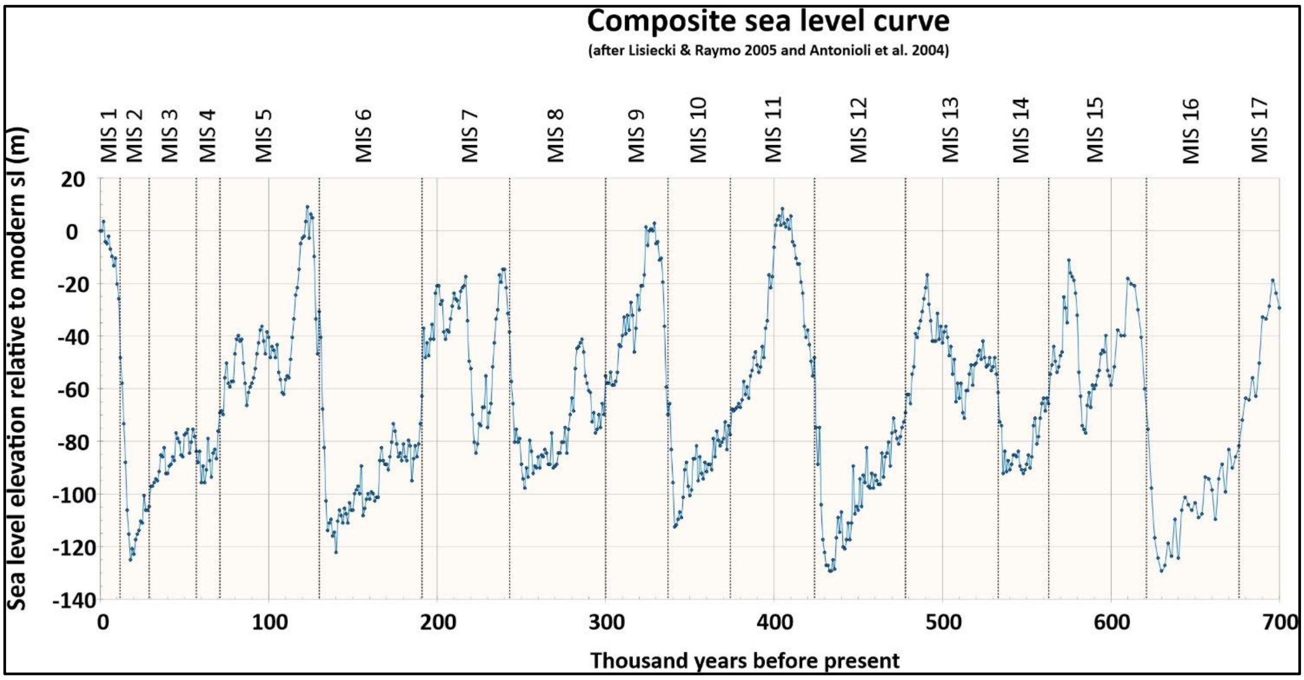

Figure 4: Annotated graph (derived from oxygen isotope data of Lisiecki & Raymo 2005 combined with sea level elevations from Antonioli et al. 2004) illustrating changes in sea level from 240 kyr (right side of horizontal axis; MIS 7) to the present day (left side of horizontal axis).

Oxygen isotope data record three sub-units during the last glaciation, MIS 4, a cool climatic period between c. 71 and 57 kyr during which sea level dropped to c. -90 m relative to its present level. The shoreline retreated to >10 km seaward of Wellington Harbour heads across the gently sloping continental shelf. It is likely that the cooling climate resulted in resetting of vegetation extents and coverage (e.g. McGlone et al. 1988; Mildenhall 1994, 1995; Newnham et al. 2013) in the hinterland and increasing frost shattering and heave in the hill country, mobilising sediment supply to the major rivers (e.g. Dravid & Brown 1997).

The Hutt River likely responded to this high sediment load by propagating as a braided alluvial system across the Wellington Harbour basin floor towards the coastline of the time. This was followed by a period of slight climatic amelioration (MIS 3, between 57 and 44 kyr) followed by a progressive deterioration from 29 kyr, during which relative sea level elevation reduced from c. -80 m to c. -100 m. The following stage, MIS 2 (from 29 to 17 kyr) represents the last glacial climatic maximum with sea levels of up to -125 m (see Barrell et al. 2013 for a New Zealand perspective on this period).

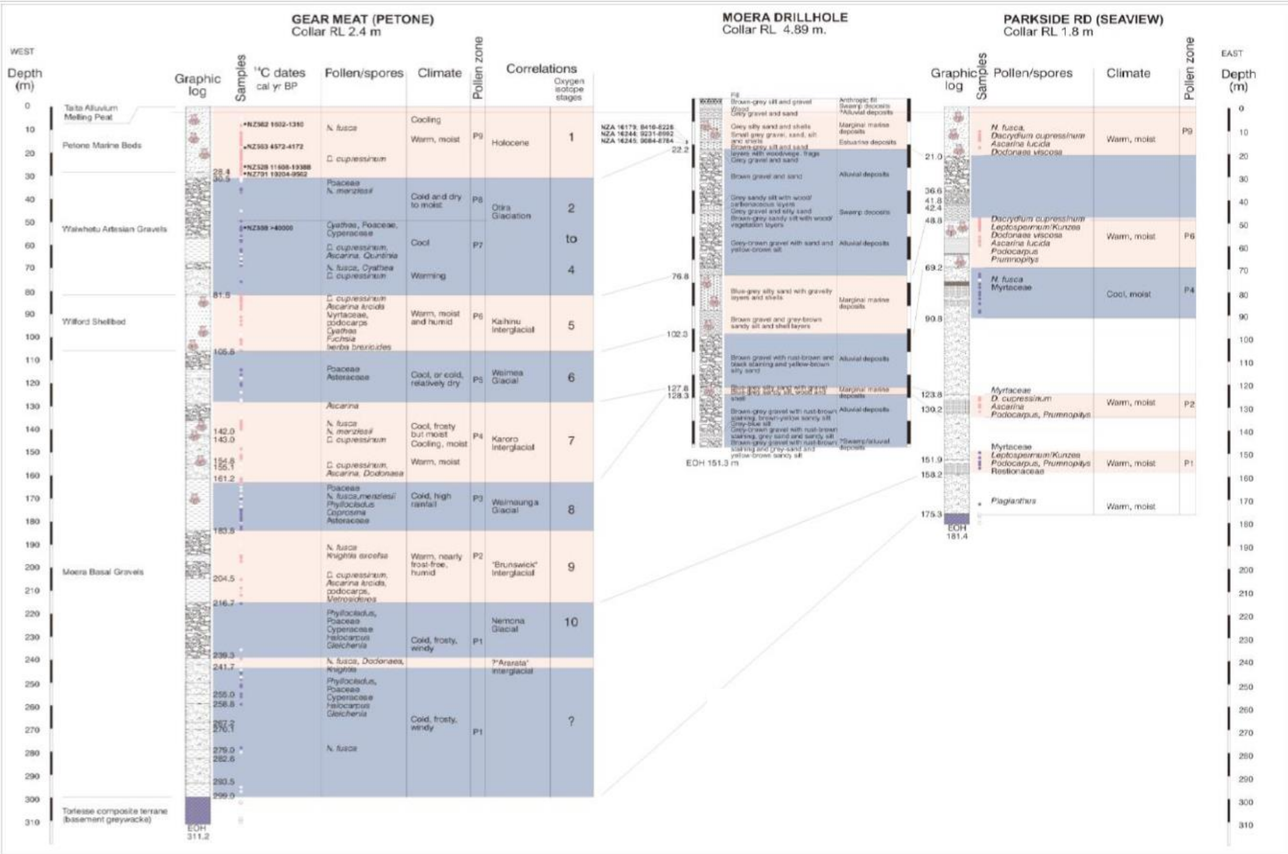

Figure 5: Stratigraphy and correlations of three well-studied borehole logs in the Lower Hutt area (from Begg & Mazengarb 1996). From left to right, logs from the Gear Meat site near the corner of The Espanade and Victoria Street in Petone (R27/151), the Moera Gravel Investigation Bore log (R27/6386) and Parkside Road (R27/1086). Pink intervals are correlated with warm climatic conditions based on the presence of shells, warm climatic pollen and/or marine deposits. Cool climatic intervals are blue in colour and comprise alluvial or terrestrial deposits.

At the height of the last glaciation the shoreline lay >15 km south of the Wellington Harbour heads. Climate was substantially cooler then and the Tararua Range and much of the low country to the south were stripped of most vegetation (e.g. McGlone et al. 2010), so the cold climatic erosive processes of freeze and thaw and mass flow were far more active than today (e.g. Eden 2003). Debris generated by these processes made its way from the hill country into the drainage systems of the time and eventually into the Hutt River.

Where the river emerged from hill country onto the tectonic depressions of the Upper Hutt and Lower Hutt basins, high sediment supply, water flows and river gradients resulted in a broad, braided river plain that extended far into the Wellington Harbour basin. A bedrock high at the harbour heads formed a gorge, through which the river had to actively incise its course before debouching onto the coastal plain to the south. Streams from minor tributaries within the hill country surrounding the plains deposited fans that were graded to the local elevation of the braided plain.

From c. 18 kyr sea level rose rapidly at rates exceeding 10 m/1000 years (Lisiecki & Raymo 2005). As sea level rose drainage from the hinterland was progressively impeded, resulting in deposition of a zone of finer-grained, loose, sandy gravel, sand and increased swampiness (silt and peat deposits) that migrated inland in front of an advancing shoreline. As the seaward margin of this landward-migrating zone was inundated, marine superseded alluvial deposition.

Rapid sea level rise was accompanied by climatic amelioration (at times at least, probably involving increased precipitation), decreased sediment supply (as revegetation stabilised the hinterland) and increased river sediment transport capability resulting in river degradation (downcutting) into Last Glacial gravels, leaving terrace treads often separated from river courses by significant risers. In the Lower Hutt valley these terraces lie above the valley floor only at Silverstream.

The sea rapidly advanced landward across the continental shelf, reaching the present shoreline between c. 11 and 10 kyr (Dravid & Brown 1997) and onward to a few hundred metres north of Melling Bridge by 6.5 kyr. At about this time sea level stabilised at close to its present level. The embayment that resulted from this sea level rise was probably influenced by active tectonic structures in the region (particularly the Wellington and Wairarapa faults). The Hutt Valley embayment is elongated along the NE-SW orientation of the Wellington Fault.

Following sea level stabilisation the Hutt River continued to deliver its (albeit smaller) bedload to the shoreline resulting in development of a delta where it entered the harbour. Longshore drift ensured distribution of this river-borne sediment supply along the shoreline, where the gravelly sands of the littoral zone accumulated. In areas of the harbour deeper than about 7-10 m, sedimentation was, as it is now, fine grained (dominated by silt) during this period following sea level stabilisation.

Shoreline progradation due to Hutt River-borne sediment supply continues to the present day. In the c. 6.5 kyr since sea level stabilisation, the shoreline has migrated southwards from north of Melling Bridge to its present position at Petone. Throughout this period deposition of swamp and overbank deposits have buried the underlying marine materials across much of the valley.

Throughout this entire period of sedimentation the Wellington Fault, and likely other faults within the area (e.g. Aotea, Evans Bay and the Somes Island faults), contributed varying increments of vertical deformation that resulted in continuing development of the Lower Hutt - Wellington Harbour basin. The basin itself is entirely the result of sea level change and tectonics (Figure 6).

2.1 Relationship between stratigraphy and the Waiwhetu Artesian System

The marine materials present in the Hutt Valley-Wellington Harbour basin provide an opportunity to correlate units using borehole logs, but where these marine materials are missing (through non-deposition or erosion, commonly the case in the northern Lower Hutt Valley) such correlation is currently impossible. Borehole logs north of Melling Bridge for example mostly record alluvial gravel resting on older alluvial gravels. This is a very important characteristic for the Waiwhetu and Moera aquifers, as it identifies their recharge zones and the downstream extent of this connection between gravels of differing ages (i.e. the upstream extent of potential aquitards) represents the upstream extent of the confined aquifer.

3 The Lower Hutt – Wellington Harbour Geological Model

3.1 Overview

The Lower Hutt – Wellington Harbour Geological Model was built within Leapfrog Geo vs 4.5.0 in the New Zealand Transverse Mercator 2000 coordinate system.

Topography was clipped from GWRC 1 m DEM derived from 2013 LiDAR and NIWA bathymetric model of Wellington Harbour.

Drillhole data: Updated from HVDL17 (see Begg & Morgenstern 2017), including Kilbirnie and Miramar borehole logs, harbour basin borehole logs and new logs from Seaview and from NZGD.

Surfaces and other data are reconciled as reasonably as possible. Sources include Begg & Mazengarb 1996, Boon et al. (2011) model, Gyopari (2014) HAM3 model surfaces, Wood and Davy (1992), Davy and Wood (1993) seismic lines and derivative maps, Hochstein & Davey (1974) seismic lines, Alpine Geophysical seismic lines (1972) and Davey 1971), available NIWA seismic lines and their interpretation (Nodder & Woelz), Evans Bay and Aotea faults of Barnes et al. (2018), NIWA bathymetric grid, gravity contours of Cowan & Hatherton (1968), Evans Bay harbour floor sediment map of Carter (1977) and Carter & Lewis (1995), Matthews (1980), the Wellington Harbour chart, Hutt Valley geomorphological data (Begg, unpublished), Point Howard and Evans Bay geomorphological maps (Begg unpublished) and the Pillans & Huber (1995) map of Miramar Peninsula.

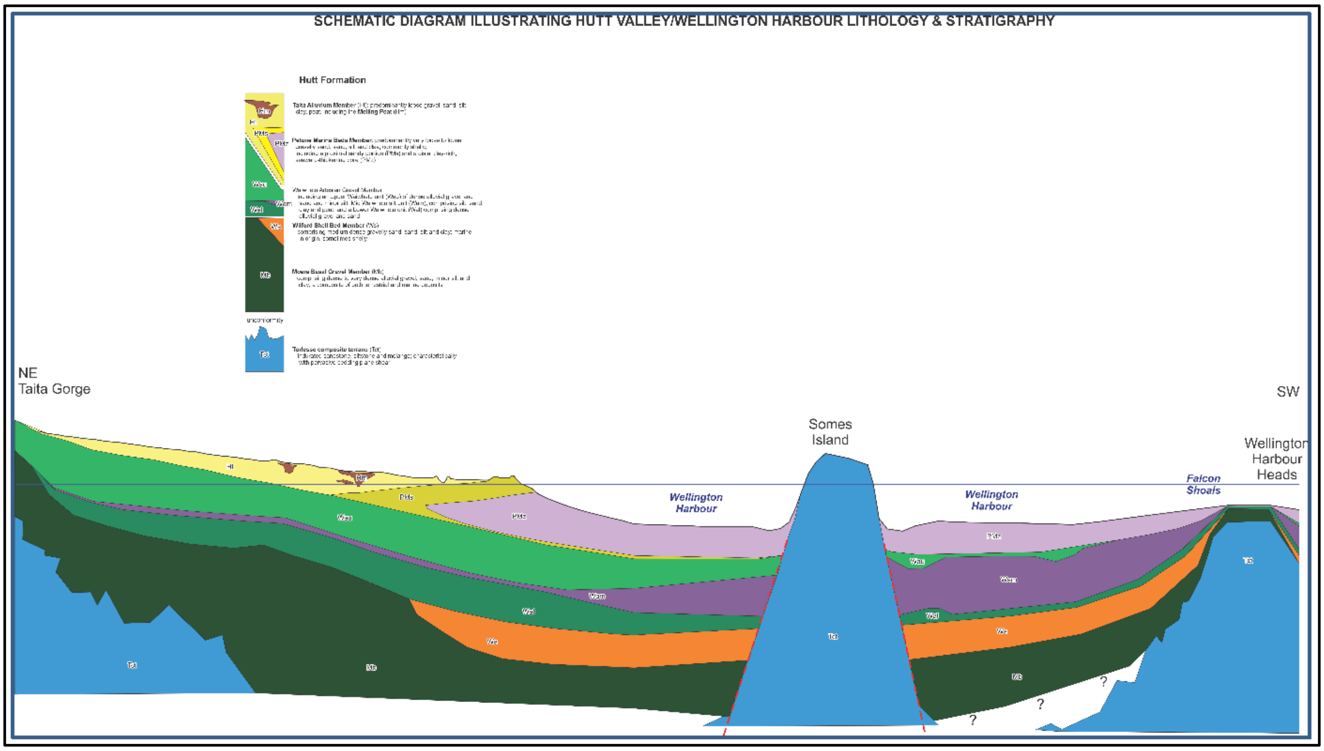

Figure 6: Schematic diagram illustrating the lithological units used in this work and their stratigraphic relationships. This conceptual model underpins the units differentiated within the Lower Hutt/Wellington Harbour Geological Model.

In the model, the bases of each geological unit are defined as a surface, and the base of the stratigraphically overlying unit defines the top. The stratigraphic units modelled, formal and informal, are listed in Tables 1 & 2.

With the exception of Melling Peat and the Petone Marine Beds (distal), each surface is defined by point picks contained within a polyline. The picks are based on all available data plus geologically reasonable interpolants (not differentiated within the polyline layer). Melling Peat is defined using an enclosing arc polyline. The top and base of the Petone Marine Beds (distal) are defined.

Table 1: Formally defined stratigraphic units of the Hutt Formation, Lower Hutt – Wellington basin, and their representation in the Lower Hutt – Wellington Geological Model (see also Table 2).

Member	Definition	Comments
Taita Alluvium Member	Stevens 1956	Retained in model
Melling Peat Member	Stevens 1956	Retained in model
Petone Marine Beds Member	Stevens 1956	Informally differentiated into 3 subunits within model
Waiwhetu Artesian Gravels Member	Stevens 1956	Revised name, informally differentiated into 3 subunits in model
Wilford Shell Bed Member	Stevens 1956	Retained in model
Moera Basal Gravels Member	Stevens 1956	Informally differentiated into 2 subunits in model

Table 2: Stratigraphic units differentiated in the Leapfrog Lower Hutt/Wellington Harbour Geological Model.

Geological Unit	Defining Polyline	Type	Age
Taita Alluvium	Base_Taita See also, Base_Holocene	Deposit	MIS 1 (6.5-0 ka)
Melling Peat	Base_Melling	Intrusion	MIS 1 (6.5-0 ka)
Petone Marine Beds (proximal, upper and lower)	Base_Petone_Marine See also, Base_Holocene	Deposit	MIS 1 (6.5-0 ka) MIS 1 (~10-6.5 ka)
Petone Marine Beds (distal)	Top_Petone_Marine_distal, Base_Petone_Marine_distal See also, Base_Holocene	Intrusion	MIS 1 (~10-0 ka)
Upper Waiwhetu Gravel	Base_upper_Waiwhetu	Deposit	MIS 2 (29-12 ka)
Mid Waiwhetu silt	Base_mid_Waiwhetu	Deposit	MIS 3 (71-12 ka)
Lower Waiwhetu Gravel	Base_lower_Waiwhetu	Deposit	MIS 4 (71-59 ka)
Wilford Shell Bed	Base_Wilford	Deposit	MIS 5 (130-71 ka)
Moera Basal Gravels Informal upper sub-unit MIS 7-6)	Base_Moera Base_MIS7_6	Deposit Deposit	MIS 29-6 (1014-130 ka) MIS 7-6 (243-130 ka)
Torlesse (composite) terrane	Top defined by Base_Moera	Deposit	260-209 Ma

3.2 Lithological descriptions

This section includes a description of each geological unit (volume) used in the Hutt Valley-Wellington Harbour Geological Model. In general, descriptions commence with the youngest unit and end with the oldest unit, although some units are diachronous and overlap in age with those units above and/or below.

3.2.1 Taita Alluvium

Definition: Stevens 1956 defined the Taita Alluvium thus: "The Taita Alluvium is the fluviatile veneer of the Hutt Delta and consists of cobbles and pebbles, admixed with silts and clays. The gravel size decreases and silt and clay content increases correspondingly from Taita Gorge south. The member has an average thickness of 40 ft [12.2 m], thickening towards the Taita Gorge, and dips gently to the south-west, with an average gradient of 1 in 369."

Type Locality: The designated type section for the Taita Alluvium Member of the Hutt Formation (Stevens 1956) is the old Wellington City Water Bore at Wilford (GWRC well number R27/0142).

Distribution: Taita Gorge to Petone across most of the Lower Hutt valley floor, except for an area between Alicetown and The Esplanade, which has remained free from these alluvial deposits since at least the late Holocene (>c. 3 kyrs).

Lithological content: Gravel, sandy gravel, grit, sand, minor silt and clay

Relationship with underlying unit: Lies conformably on upper Waiwhetu Gravel between Taita Gorge and Melling Bridge; and conformably on Petone Marine Beds (proximal) from Melling Bridge to Petone.

Age; Mostly late Holocene in age, though there may be some older parts of the unit beneath the Petone Marine Beds and/or above the upper Waiwhetu Gravel. MIS (Marine Isotope Stage) 1; mostly <6.5 kyrs but locally may be up to 12 kyrs.

3.2.2 Melling Peat

Definition: Melling Peat was described by Stevens (1956). His description included reference to a fossil forest near the Melling Bridge with stumps of matai and puketea in growth position and overlain by gravel. His illustration of a small section of the exposure at the type locality indicates lithologies include silt, clay and minor sand and gravel channels. The description includes a freshwater mussel bed.

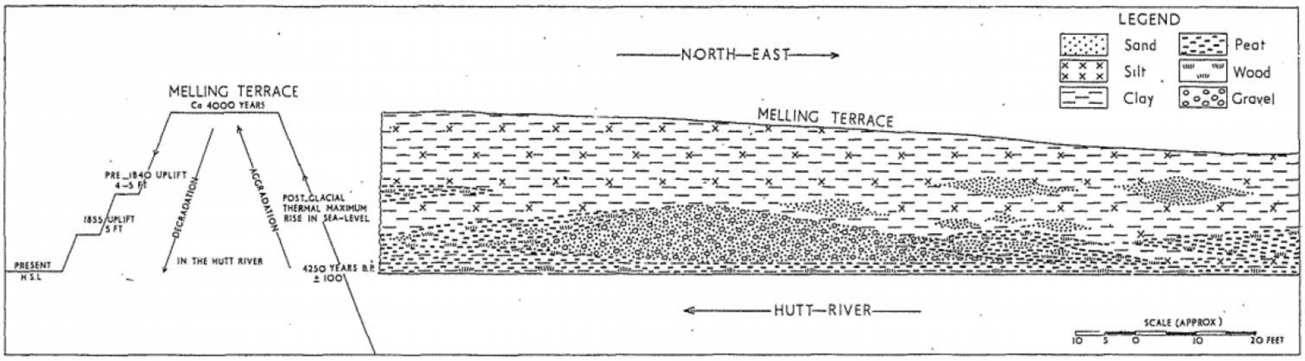

Figure 7: The schematic illustration of the stratigraphic relationships of the Melling Peat near Melling Bridge in the Lower Hutt area (from Stevens 1956).

Type Locality: (from Stevens 1956): "The Melling Peat, outcropping in the bed of the Hutt River for a quarter of a mile [400 m] upstream from Melling Bridge, consists of a fossil forest and associated beds of wood debris (Figs 13. to 15)".

Distribution: Melling Peat lies within Taita Alluvium; borehole logs from Lower Hutt City centre commonly contain materials from this unit resting on underlying Petone Marine Beds. The thickest and apparently most laterally continuous occurrence of the unit currently known extends between the Wellington Fault near Ewen Bridge to the southern end of Harcourt Werry Drive to Mitchell Park and Sacred Heart College. Thinner and less laterally persistent components of the unit are found in logs from the Hutt Hospital area and across much of Waiwhetu. A further area of Melling Peat is known from the Naenae area, although here, it is likely that Melling Peat rests directly on older materials of similar lithology.

Lithological content: Stevens (1956) does not provide a comprehensive lithological description of the unit, but it is reasonable to assume that he considered peat to be a substantial component. His illustration indicates inclusion of silt, clay and channelized gravels are an integral part of the member. Bore logs from the Lower Hutt City Centre commonly record sand and fine sandy gravel and laminated clay and sand.

Relationship with underlying unit: Melling Peat may rest directly on Petone Marine Beds (proximal) or on Taita Alluvium and may even rest directly on upper Waiwhetu Gravels in the Hutt Hospital area.

Age: A number of radiocarbon ages are available from wood collected from Melling Peat near Melling Bridge. Calibrated radiocarbon dates range from c. 5400 to 4800 years. Melling Peat was deposited as a lateral correlative of Taita Alluvium close to the shoreline following the period of sea level stabilisation (c. 6.5 kyrs). It is possible that the swampy area known to early settlers by the name Alicetown Swamp is equivalent in its depositional environment.

3.2.3 Petone Marine Beds

Definition: Stevens (1956) defined the Petone Marine Beds as a member of the Hutt Formation.

Type Locality: The Wellington City Test Bore at Wilford (GWRC borehole database R27/0142) is the nominated type locality for Petone Marine Beds Member, although he described the beds as best developed at the Hutt Estuary Bridge. At the type locality the Petone Marine Beds are represented by materials between 12.2 m and 18.3 m depth (beneath the collar at 1.9 m elevation).

Distribution: Petone Marine Beds underlie the Lower Hutt Valley from c. 300 m northeast of Melling Bridge and from Waterloo to the Petone foreshore and are present at the surface across the floor of Wellington Harbour. Marginal marine materials at the surface of the Kilbirnie Isthmus are considered part of this geological unit.

Lithological content: The original description (Stevens 1956) indicated the member comprised "…silts and clays are sub-horizontal; when traced up the valley they became less constant, and at Hutt City they interdigitate with the overlying deltaic sediments (Melling Peat and Taita Alluvium)."

Relationship with underlying unit: Petone Marine Beds lie conformably upon Upper Waiwhetu Gravel. In some instances, the lowermost Petone Marine Beds are coarse grained (sand, pebbly sand and/or pebbly sand), while in some places fine grained (silt, silty clay and clayey silt) lie directly on underlying materials. Elsewhere, the upper part of Petone Marine Beds is coarse grained, with sand, pebbly sand and/or gravelly sand lying directly upon silt, clayey silt or silty clay of older Petone Marine Beds. In places, these material differences are visible in high resolution seismic lines across the harbour basin. This has prompted some differentiation between coarse grained early Petone Marine Beds (lower), fine grained (deeper water) Petone Marine Beds (distal), and younger coarse grained (shallow marine) Petone Marine Beds (upper).

Age: Holocene; shells from lowermost Petone Marine Beds have been dated from Evans Bay (borehole) SB1, Kaiwharawhara (Barnes et al. 2018) and from BH3a (Harbour borehole; Stantec 2017; NZA64456; unpublished data) all indicate an age of c. 10,000 years before present. A shell from the base of the Petone Marine Beds at the Penrose Street bore (15 m depth, RL=-9.7 m; R27/1179) provided a conventional radiocarbon age of 7297±118 years. These ages are further constrained by radiocarbon ages from wood within the overlying Melling Peat at Melling Bridge that yielded conventional radiocarbon ages of 4350.0 ±100 and 4275.0±100 years. Radiocarbon ages from shells exposed close to the surface in Petone (from beach ridges on William, Collins and Heretaunga streets) provide conventional radiocarbon ages of 2350±70 (Beach Ridge D, William St; NZ1577), 2350±70 (Beach Ridge D, William St; NZ1578) and 2210±53 (Beach Ridge C, Heretaunga St; NZ8141).

Petone Marine Beds (proximal)

In the model two sub-units of Petone Marine Beds are discriminated. The first of these is a proximal facies comprising near shore sandy gravels, gravelly sand and sand. This facies is found commonly near the top of Petone Marine Beds (Petone Marine upper) across the Lower Hutt Valley from 300 m north of Melling Bridge, but also sometimes at its base (Petone Marine lower) south of a line from Ewen Bridge to Waiwhetu. This sub-unit was deposited in marginal marine environments including as aeolian dunes, beach deposits and marginal marine deposits to a depth of c. 6-10 m. Proximal Petone Marine lower is a unit that was deposited upon older non-marine materials as sea level transgressed across the Lower Hutt Valley during the early part of the Holocene (prior to c. 6500 years ago). In the Lower Hutt Valley, proximal Petone Marine upper was deposited following c. 6500 years as terrestrial deposits (Taita Alluvium) pushed the shoreline southwards. Modern beach sands, beach ridges and marginal marine fans at Petone and around the harbour margin (including the Kilbirnie Isthmus and at Seatoun) are considered to belong to this unit.

Petone Marine Beds (distal)

The second discrete sub-unit of Petone Marine Beds is a distal facies composed of marine silt, mud and clay. These deposits are widely distributed across the Lower Hutt Valley south of Alicetown and Woburn and are progressively thicker from the northeast to the southwest (southeast of the Wellington Fault). The materials were deposited below the wave base (c. 6-10 m water depth) in the marine basin that is now Wellington Harbour. In the Lower Hutt Valley, distal Petone Marine Beds are thickest close to the Petone foreshore and commonly lie upon proximal Petone Marine Beds lower. They are commonly overlain by proximal Petone Marine Beds upper. Silts, sandy silt clayey silt and clay accumulating at the present sea floor of Wellington Harbour at depths >6-10 m comprise predominantly distal facies Petone Marine Beds.

3.2.4 Waiwhetu (Artesian) Gravels

Definition: Stevens (1956) defined Waiwhetu Artesian Gravels, a member within the Hutt Formation. In this report and in the model, the member is informally renamed by dropping the descriptive term "Artesian" from the name. The intention of this minor change is to eliminate any confusion between the name of the aquifer, the Waiwhetu Aquifer, from that of the geological unit that commonly hosts it, the Waiwhetu Gravels. Although the Waiwhetu Gravels are predominantly gravel in many places, they also include other lithologies including sand, silt and minor peat.

Type Locality: The designated type section for the Waiwhetu Artesian Gravels Member is the old Wellington City Water Bore at Wilford (GWRC well number R27/0142) between 18.3 m and 81 m depth (beneath the collar elevation, 1.9 m).

Distribution: Waiwhetu Gravels are distributed across the Lower Hutt – Port Nicholson Basin between Taita Gorge to the south of Somes Island. In the upper Lower Hutt Valley the unit lies at (or close to the surface) while in the southern Lower Hutt Valley is overlain by Holocene deposits (Taita Alluvium, Melling Peat and Petone Marine Beds) up to >25 m thick along the western Petone foreshore. The presence of artesian water at Somes Island and in the exploratory harbour boreholes confirms its presence beneath Holocene deposits within the harbour basin, at least as far as E3 and E8.

Lithological content: Stevens describes lithologies as gravel and sand, commonly water saturated, and borehole logs reveal that lithologies also include scattered peat, silt and clay.

Relationship with underlying unit: Borehole data indicate that Waiwhetu Gravels rest conformably upon Wilford Shell Bed across the southern part of the Lower Hutt Valley and seismic data and the borehole logs E3 and E8 confirm that it rests on Wilford Shell Bed across the harbour basin.

Age: Waiwhetu Gravel is non-marine in origin and underlies materials containing well dated marine shells of Holocene age. It also overlies marine materials of the Wilford Shell Bed. Composite international sea level curve data point to correlations with Marine Isotope Stages (MIS) 4-2. Waiwhetu Gravel is last glaciation in age (c. 71-12 kyr).

Modern workers (particularly L.J. Brown, A Jones and M Gyopari) have favoured an informal three-way subdivision of Waiwhetu Gravel into two gravel units separated by a fine-grained unit comprising silt, peat and sand. In the northern part of the Lower Hutt Valley the fine-grained intermediate unit is largely missing and the upper gravel unit rests conformably on the lower gravel unit. Where this is the case, it is impossible to reliably distinguish between the upper and lower gravels.

A number of borehole logs in the southern Lower Hutt basin record the fine grained intermediate sub-unit and the exploratory harbour boreholes (E3 and E8) encountered significant thicknesses. On this basis, the Waiwhetu Gravel is subdivided into three, although the certainty of the presence of the intermediate unit increases down valley and towards the southwest across Wellington Harbour.

The rationale for discriminating the mid Waiwhetu silt is supported by paleoclimatic data that indicate a period of climatic amelioration (MIS 3; 57 to 29 ka) between the early last glacial (MIS 4; 71 to 59 kyr) and the late last glacial maximum (MIS 2; 29 to 12 kyr) periods.

Note that the units are not formally defined here, so upper-case letters are not appropriate (other than for the formal name, Waiwhetu) and the descriptive term "Artesian" is dropped to accommodate correlative gravels that are not artesian.

Upper Waiwhetu gravel

The sub-unit probably lies beneath most of the Lower Hutt Valley floor and much of Wellington Harbour.

The gravel was probably mostly deposited during the last glacial maximum, between 29 and c. 12 kyr; however, in areas where the mid Waiwhetu silt is absent, it is likely that upper Waiwhetu gravel was being deposited, making the unit somewhat diachronous.

The upper Waiwhetu gravel comprises loose, cobble gravel and sandy gravel of alluvial origin (sub-rounded to well-rounded) that is commonly poor in fine matrix and thus heavily water-bearing. The upper part of the gravel may be brown in colour suggesting some exposure to oxidising conditions before burial beneath impermeable silts. Otherwise, although gravels may be interbedded with thin fine silty units, the upper gravel itself is commonly grey in colour and is relatively depleted in silty matrix.

Mid Waiwhetu silt

The sub-unit is distributed broadly across the valley near the Petone foreshore but is probably only locally present north of Moera.

The mid Waiwhetu silt was probably deposited, where present, during the interstadial (MIS3) between the cool climatic stages of the early and late last glacial periods (MIS 4 and 2). The best-developed example of the mid Waiwhetu silt so far recorded was in the Wellington Harbour exploratory borehole E3 (Stantec 2017) where 7.2 m of silt, clayey silt, sandy silt and minor sand are reported.

Lower Waiwhetu gravel

Lower Waiwhetu gravel is probably present across most of the Lower Hutt Valley floor but its distribution is probably more restricted beneath the harbour floor to the east of Somes Island. It comprises subrounded to subangular alluvial gravel, commonly with a higher proportion of silt within its matrix than the upper Waiwhetu gravel. As a consequence, it is considered a lesser aquifer than the upper Waiwhetu gravel. The age of the lower Waiwhetu gravel is likely to be early last glacial (MIS4, 71 to 57 kyr) although it may span through MIS3.

3.2.5 Wilford Shell Bed

Definition: Stevens (1956) defined Wilford Shell Bed, a member within the Hutt Formation.

Type Locality: The designated type section for the Wilford Shell Bed Member is the old Wellington City Water Bore at Wilford (GWRC well number R27/0142) between 18.3 m and 81 m depth (beneath the collar elevation, 1.9 m).

Distribution: Wilford Shell Bed extends up the Lower Hutt Valley to a few hundred metres north of Ewen Bridge and almost as far as Woburn Station in the east. It underlies Waiwhetu gravels within the harbour basin (Stantec 2017) and is found in boreholes within the Kilbirnie and Miramar basins.

Lithological content: Stevens (1956) described the unit as coarse sand containing Chione (cockle) fragments in the Wilford borehole. In the harbour boreholes (E3 and E8; Stantec 2017) the unit comprises stiff sandy silt, clayey silt and silty clay, commonly fossiliferous.

Relationship with underlying unit: The Wilford Shell Bed Member, where present, lies conformably upon gravels of the Moera Basal Gravel Member.

Age: The Wilford Shell Bed, as a marine incursion represents a high sea level stand of the late Quaternary. It is correlated with MIS 5, 128-71 kyr.

3.2.6 Moera Basal Gravels

Definition: Stevens (1956) defined Moera Basal Gravels as comprising all materials beneath Wilford Shell Bed and above Wellington Greywacke as belonging to Moera Basal Gravels Member of the Hutt Formation.

Type Locality: The type locality of Moera Basal Gravels was designated as the Wellington City Council Wilford borehole (GWRC well number R27/0142) from 86 m to the base of the hole at 128 m. No older Quaternary materials are known from the Lower Hutt Valley.

Distribution: Moera Basal Gravels are present between Taita Gorge and the Petone foreshore. They extend out beneath Wellington Harbour at least as far as the exploratory bore E8 where the upper boundary of the member is at about -83.6 m below sea level.

Lithological content: The Moera Basal Gravels is dominated by alluvial gravels but lithologies also include sand, silt, clay and peat. Of the members of the Hutt Formation, this is the most variable in lithology as it includes a number of warm and cool climatic periods and probably includes some marine incursions. For the purposes of the geological model, the upper part of the Moera Basal Gravels has been differentiated informally as “MIS 7-8” (see below).

Relationship with underlying unit: Moera Basal Gravels lies directly on weathered and unweathered basement greywacke rocks of the Torlesse Composite terrane.

Age: There is little doubt that the upper part of unit is correlative with MIS 6 (191-130 ka). However, the age of the oldest part of Moera Basal Gravels is unknown. On the basis of estimates explained in Begg & Mazengarb (1996) it is thought to be somewhere between 1 Ma and c. 750 ka.

MIS 7-6

The engineering geological model of the Lower Hutt Valley of Boon et al. (2011) includes an informal unit, MIS 7-6 that he excluded from the Moera Basal Gravels Member; this resulted in unintentional confusion in the definition of Moera Basal Gravels. The Boon et al. (2011) publication does not formally define this unit and this model recognises its value by including it as an informal subdivision of Moera Basal Gravels.

The rationale for the unit is that alternation of warm and cool climatic deposits (marine and alluvial deposits) shown in the upper part of the Hutt Formation is repeated in the upper part of the Moera Basal Gravels Member. The number of borehole logs that penetrate this deep in the area is limited so no attempt has been made to distinguish the warm and cool climatic deposits and the unit is modelled as a single informal entity.

3.2.7 Torlesse (composite) terrane

Distribution: Torlesse (composite) terrane (Begg and Johnston 2000) is distributed widely across the South and North islands of New Zealand and underlies much of the Southern Alps and Tararua, Ruahine, Kaimanawa and Kaweka ranges.

Lithological content: It comprises predominantly hard (lithified) quartzofeldspathic sandstone (“greywacke”) and siltstone (argillite) that is commonly thoroughly sheared, faulted and folded.

Age: Torlesse composite terrane was deposited largely in a submarine environment between the Permian and early Cretaceous. Most of the rocks in the area are thought to be Triassic or Jurassic in age.

3.3 Likely geotechnical properties of subsurface geological units

Boon et al. (2011) published a table in their paper that characterises the geotechnical properties of many of the units they used in a model of the Lower Hutt Valley. Their Unit 2 (including Taita Alluvium, Melling Peat, Petone Marine Beds, Recent alluvial fan deposits) are regarded as generally soft to firm and shear wave velocities range from 150 to 270 m/s, with an average of 180 m/s. This contrasts with velocities for their Unit 3 (Waiwhetu Artesian Gravels; dense to very dense) which ranges from 270-630 m/s, with an average of 490 m/s. Their Unit 4 comprises Wilford Shell Bed which they characterise as stiff and assign shear wave velocities ranging from 610 to 650 m/s, with an average of 630 m/s.

Table 2: Slightly modified table of Boon et al. (2011) indicating the approximate characteristics of their geotechnical units. Note the correlation with units within the Lower Hutt-Wellington Harbour Geological Model (column 2).

Boon unit	Strat name	Engineering geological description	Approx age	Maximum thickness	Shear wave velocity		
					min	ave	max
Unit 1	Reclaimed	Moderately dense engineered fill and non-engineered fill	0-100 yrs	~5-15	100	200	300
Unit 2	Taita Alluvium	Loose to dense, rounded gravel	<~10 ka	~40	150	180	270
	Melling Peat, Naenae Swamp	Very soft to soft organic sand, silt, clay, peat, wood					
	Petone Marine Beds	Soft to firm, shelly, sand, and silt.					
	Alluvial fans	Loose to dense, silty sandy angular gravel					
Unit 3	Waiwhetu Artesian Gravel	Medium to very dense, gravel, sand and silt	10-70 ka	~60	270	490	630
Unit 4	Wilford Shell Bed	Stiff, shelly, sand, silt and clay.	70-128 ka	~30	610	630	650
Unit 5	Waimea Glacial	Very dense alluvial gravels inter-bedded with, very stiff shelly silts and sands	128-245 ka	~60	715	745	770
	Karoro Interglacial						
Unit 6	Moera Basal Gravels	Very dense weathered gravel and stiff fine-grained marginal marine beds	245->380 ka	~210	715	745	770
	Nemona Glacial Gravels						
Unit 7	Wellington Greywacke	Strong (50-100 MPa) greywacke	290-159 Ma		1310	1375	1480

4 Summary and Geological Synthesis

This report accompanies a three-dimensional geological model of the Lower Hutt – Wellington Harbour area that has been developed for Greater Wellington Regional Council and Wellington Water Ltd. The intention of the report is to present a background explaining the stratigraphy and unit lithologies used in the model. The model incorporates exploratory borehole data within Wellington Harbour for the Cross-Harbour Pipeline project and relies heavily on borehole logs held by GWRC and seismic reflection data collected by GNS Science and NIWA.

The Lower Hutt – Wellington Harbour is an actively subsiding basin that has been accumulating sediments through the Quaternary. Basement rock in the area is Torlesse (composite) terrane, dominated by sandstone and argillite of Triassic to Jurassic age. The rocks were faulted, folded and sheared throughout deposition and deformation over most of the period since.

Changes in the plate boundary conditions within the last few million years resulted initially in emergence of the Wellington area from the sea and subsequently, probably at about 1 million years, with initiation of activity on the Wellington Fault. For the last c. 1 million years, the Wellington Fault has been the locus of dextral (right lateral) strike slip faulting with a small component of vertical slip, involving uplift on its northwest side in the Lower Hutt – Wellington Harbour area and subsidence on its southeast side. Subsidence may grade into uplift near the Wellington Harbour Heads, because it is further from the Wellington Fault than other parts of the basin, and closer to the uplift associated with the active Wairarapa Fault. The presence of the Wellington Fault, perhaps in conjunction with a number of smaller active faults with a more northerly strike, has been the driving influence in development of the basin and deposition within it.

Deposition in the basin has also been heavily influenced by sea level change associated with climatic fluctuation through the part of the Quaternary Period (c. 1 Ma to the present day) during which sedimentation has taken place. Global data indicate that climate has changed cyclically with an average period of c. 100,000 years for the last c.650,000 years. During warm climatic periods marine conditions have flooded the basin through the Wellington Harbour Heads at least three times and probably more during warm climatic periods. During the intervening cool climatic regimes, the sea retreated from Wellington Harbour, at times nearly as far as the edge of the continental shelf, between 10 and 25 km south of the harbour heads. During warm climatic periods marine incursions into Wellington Harbour and the Lower Hutt Valley can be identified, while cool climatic alluvial conditions prevailed during cool climatic periods.

Quaternary deposits of the Lower Hutt valley were formally defined as the Hutt Formation, which was differentiated into six members, by Stevens (1956). Stevens' stratigraphy is adopted in this report and in the model, although distribution of his units is extended southwards into Wellington Harbour. Knowledge of the stratigraphy hangs heavily on six well-studied borehole logs, the Gear Meat deep log (R27/151), The Parkside Road log (R27/1086), the Wilford Wellington City Council log (R27/142), the Moera Gravel Investigation Bore log (R27/6386) and now the two Cross Harbour Pipeline exploratory bores, E3 and E8. While only two of these (R27/151 and R27/1086) ended in bedrock. each records several cycles of marine and non-marine deposition, providing a reasonable level of confidence for correlations. Other logs within the GWRC drillhole database mostly provide correlative information for horizons mostly shallower than the Wilford Shell Bed (see below).

The uppermost unit of the Hutt Formation in the northern Lower Hutt basin is the Taita Alluvium Member that comprises largely of alluvial gravel, gravelly sand and grit. Some pockets of peat, clay, silt, sand and gravelly sand within the Taita Alluvium were defined as a distinct member, Melling Peat. South of Melling Bridge, Taita Alluvium and Melling Peat are underlain by marine gravelly sand, silt and clay deposits of the Petone Marine Beds Member. Across parts of the valley floor, particularly between Alicetown and the Petone shoreline, Petone Marine Beds directly underlie the ground surface. For the purposes of the model, three informal sub-units of the Petone Marine Beds Member are differentiated. A lower gravelly sand, often shelly, is present in some places; this is differentiated as the Petone Marine lower proximal beds. They are marginal marine in origin and overlie the terrestrial (last glacial) beds underlying them, and in the southern part of Lower Hutt, underlie Petone Marines Beds that comprise deeper water marine silt and clay (Petone Marine Beds distal). Sandy gravel and sand of marine and marginal origin commonly overlie the distal Petone Marine Beds, or in the Melling Bridge area, overlie Petone Marine Beds lower proximal deposits; these are differentiated as the Petone Marine proximal upper sub-unit. Differentiation of these sub-units within the Petone Marine Beds is designed to help identify the poorly sealed areas of the aquitard for the Waiwhetu Aquifer.

In general, Petone Marine Beds, Taita Alluvium and Melling Peat are thicker on the western side of the valley closest to the Wellington Fault. These units are all Holocene (<12 kyrs) in age and the youngest part of each is <240 yrs.

Underlying the Holocene members of the Hutt Formation is the Waiwhetu Gravel, a last glacial alluvial gravel that underlies much of the area between the Taita Gorge to south of Somes Island. The Waiwhetu Gravel is dominated by alluvial gravel but includes a wide range of lithologies. It is commonly water bearing, particularly in its upper parts and hosts the Waiwhetu Artesian System (Waiwhetu Aquifer). Recent workers have recognised the presence of a fine-grained sub-unit within the Waiwhetu Gravel that separates the Member into three, an upper Waiwhetu gravel, a mid-Waiwhetu silt and a lower Waiwhetu gravel. The lower Waiwhetu gravel commonly contains more fine-grained matrix than the upper Waiwhetu gravel and the fine-grained mid-Waiwhetu silt is particularly thick and well developed to the southeast of Somes Island.

The Waiwhetu Gravel is modelled as being thicker beneath the western side of the Lower Hutt Valley close to the Wellington Fault. The two gravel sub-units thin southwards between the Petone foreshore and the two Cross Harbour bores, E3 and E8 (particularly west of Somes Island), and probably pinch out altogether (or at least extremely limited in distribution) between these bores and the harbour heads.

Underlying the Waiwhetu Gravel in the lower parts of the Lower Hutt Valley (from the Lower Hutt City Centre and Gracefield southwards) and beneath the harbour is a marine sandy, silty unit, the Wilford Shell Bed, that is correlated with the Last Interglacial (MIS 5). As with the Waiwhetu Gravel, this unit is probably thicker and deeper on the western side of the Lower Hutt Valley close to the Wellington Fault. The materials of the Wilford are significantly finer grained than the Waiwhetu Gravel and at least the upper part of the underlying Moera Basal Gravels and is the major contributor to the confinement (or semi-confinement) of a discrete aquifer(s) beneath the Waiwhetu Aquifer, collectively named the Moera aquifer.

All materials beneath the Wilford Shell Bed Member belong to the Moera Basal Gravels Member of the Hutt Formation. This unit is thick and heterogeneous, comprising alternating marine and/or marginal marine and alluvial deposits. In this model an informal subunit of the member is discriminated that represents materials correlated with the cool climatic MIS 6 and the underlying warm climatic deposits of MIS 7.

The lower Moera Basal Gravels lithologies are only known from logs of the Gear Meat and Parkside Road bores. They suggest that the materials beneath the lower part of Lower Hutt Valley are increasingly alluvial in origin indicating that the basin was largely (or totally) terrestrial through this period of deposition.

Availability of Data

The Lower Hutt – Wellington Harbour Geological Model was completed under contract to GWRC and Wellington Water Limited. Because they are publicly funded organisations the model and its derivative data are publicly available.

Acknowledgements

The authors wishes to thank a number of scientists and specialists who provided advice historically, and/or during development of this model. Not in any order, these include Bryan Davy, Julie Lee, Nick Perrin, Dallas Mildenhall, Russ Van Dissen, Bill Fry, Sally Dellow, Dougal Townsend, Bill Stevenson, Rafael Benites and Peter Barker (GNS Science), Len Brown (retired), Phil Huber. Some members of this group contributed insights through discussion. They are not included in the authorship purely because they may not agree with the content. All interpretations presented here are those of the primary author.

Katie Jones applied her expert Leapfrog modelling skills to turn my draft model into a rational and consistent one.

We wish to thank staff at GWRC (particularly Doug Mzila), Wellington Water Limited (particularly Duheine Myburgh) for the support tendered throughout the project.

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Appendix

Model and modelling

Topography

- GWRC_DTM_1 m_imported at 100 m resolution
- Created 10 m contours in Cross Sections and Contours
- Extracted vertices, (see points folder)
- GWRC_DTM_1 m_imported 100 m_vertices
- Topography includes bathymetry in Wellington Harbour
- Topography exported and NIWA bathymetry inverted (negative values; i.e. elevation relative to sea level, as opposed to depth) vertices
- Topography clipped to remove vertices outside of Topo50 coastline to create a hole in the harbour = onshore topography vertices
- Combined onshore topography and bathymetry vertices (wh250cm_neg)
- Imported combined vertices and use to generate Topography
- GWRC_DTM_1m_with_wh250cm_neg

Geological Model

- Refined HV_HH model
- Model boundary uses GIS polyline called Model_extent
- This is a hybrid of Topo250 coastline (modified around Wellington wharf and airport), topography contours up the Hutt Valley (digitised to smooth), and cuts through Rongotai

Wellington Fault

- Wellington_Fault produced using a GIS polyline

Surfaces & Stratigraphy

- The geological model is a refined model
- HV_HH model revised = basement only
- Undifferentiated = everything above basement volume
- Basement: includes offset topography contours (100 m above the surface) to lift this surface up around Miramar peninsula and Matiu/Somes Island
- Base of lower_Waiwhetu is erosional so that is cuts below the Wilford surface up the Hutt Valley
- Petone Marine is split into lower and upper as separate surfaces and volumes

- Melling Peat is modelled as an intrusion, the minimum Ellipsoid ratio for this surface is 0.004.

Table A.1: Modelled surface definitions:

Modelled surface	Surface name	Defining polyline
Topography	GWRC_DTM_1m_Waiwhetu1 wh250cm_neg	N/A
Melling Peat		Melling
Base of Holocene	Base_Holocene	Base_Holocene
Base of Taita	Base_Taita	Base_Taita
Base of Petone Marine	Base_Petone_Marine	Base_Petone_Marine
Base of Petone Marine distal	Base_Petone_Marine_distal	Base_Petone_Marine_distal
Top of Petone Marine distal	Top_Petone_Marine_distal	Top_Petone_Marine_distal
Base of Upper Waiwhetu Gravels	Base_upper_Waiwhetu	Base_upper_Waiwhetu
Base of mid Waiwhetu	Base_mid_Waiwhetu	Base_mid_Waiwhetu
Base of Lower Waiwhetu Gravels	Base_lower_Waiwhetu	Base_lower_Waiwhetui
Base of Wilford Shell Bed	Base_Wilford	Base_Wilford
Base of MIS 6_7	Base_MIS6_7	Base_MIS6_7
Base of Moera = top of basement	Base_Moera	Base_Moera Davey_Pt_Howard_bedrock_cont

Model Reliability

Within the Lower Hutt Valley modelling is predominantly based on constraints offered by surface geology and borehole logs. Surface geology used is the 1:50,000 scale data of Begg & Mazengarb (1996). The density of the borehole collars across the valley floor varies is indicated in Figure A.1 (see also Figure A.2). There are gaps in the density of collars, notably in the Woburn-Waiwhetu and the Avalon areas. Here, triangulation between logs outside the logical geological principles are used to control the distribution of the geological units.

There are a very small number of borehole logs covering the entire Wellington Harbour area, but here a large number of seismic reflection profiles that record reflectors to depths of up to 100 m provide information. Seismic reflection profiles collected by Hochstein and Davey (1974), Wood and Davy (1992) and interpreted by Davy and Wood (1993), Lewis and Carter (1976), Barnes et al. (2018) and Nodder et al. (2020).

Data density for modelling drops off with depth across the entire area, resulting in decreasing reliability with depth. Many of the borehole logs across the Lower Hutt Valley target the Waiwhetu Aquifer so reliability of the model drops of rapidly below the upper parts of the Waiwhetu Gravels. Only a handful of logs are available for modelling the lower boundary of the Waiwhetu Gravels and even fewer constrain the base of the Wilford Shell Bed.

Table A.2 indicates statistical information characterising the borehole log dataset used in modelling (HVDL17; Begg & Morgenstern 2017).

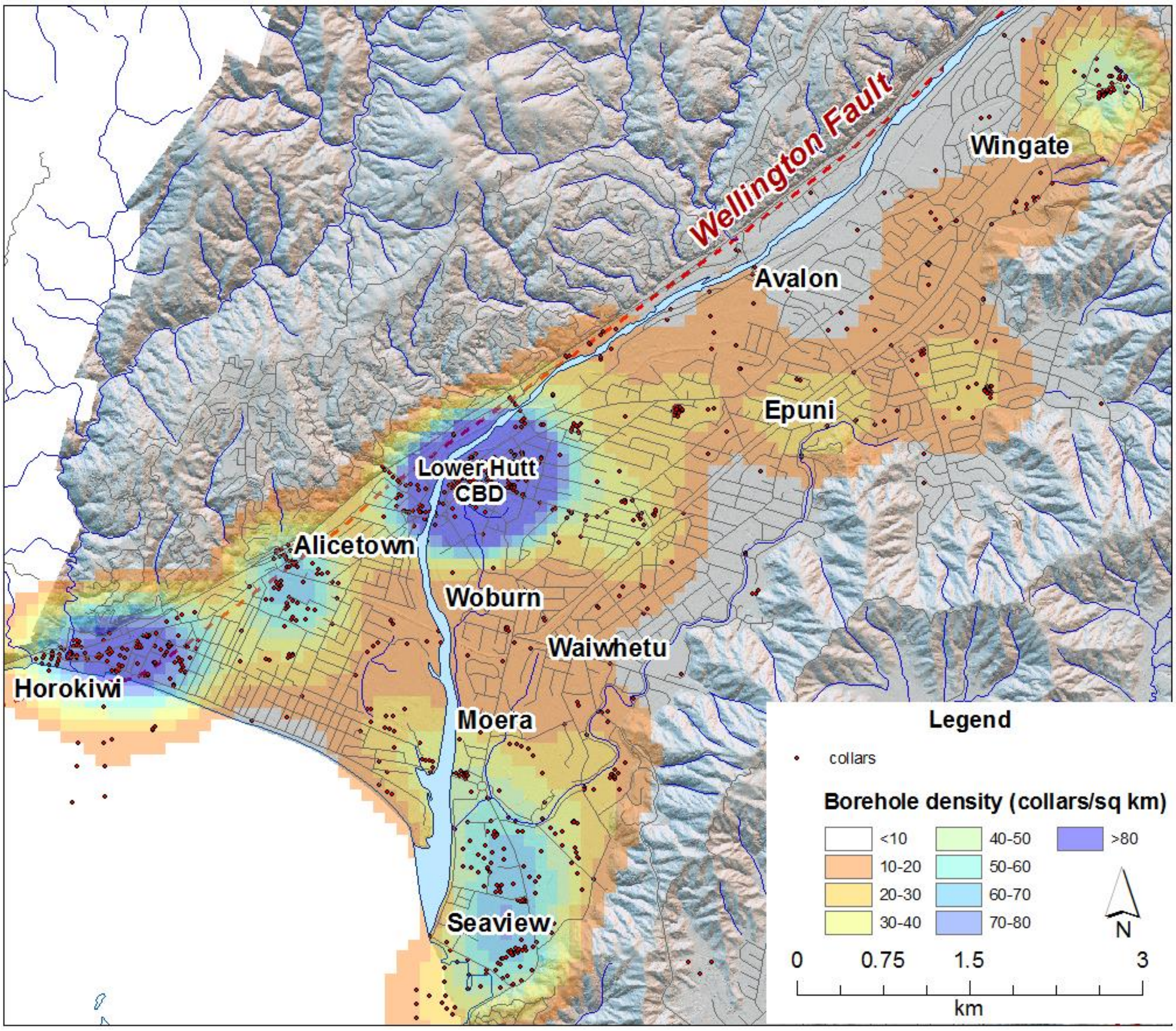

Figure A.1: Map illustrating density of drillhole collars across the Lower Hutt Valley and included in HVDL17. Drillhole collar density (collars/km^2) is illustrated in the colour ramp. Note the areas of relatively poor data (coloured orange) in the Woburn/Waiwhetu area and at Avalon.

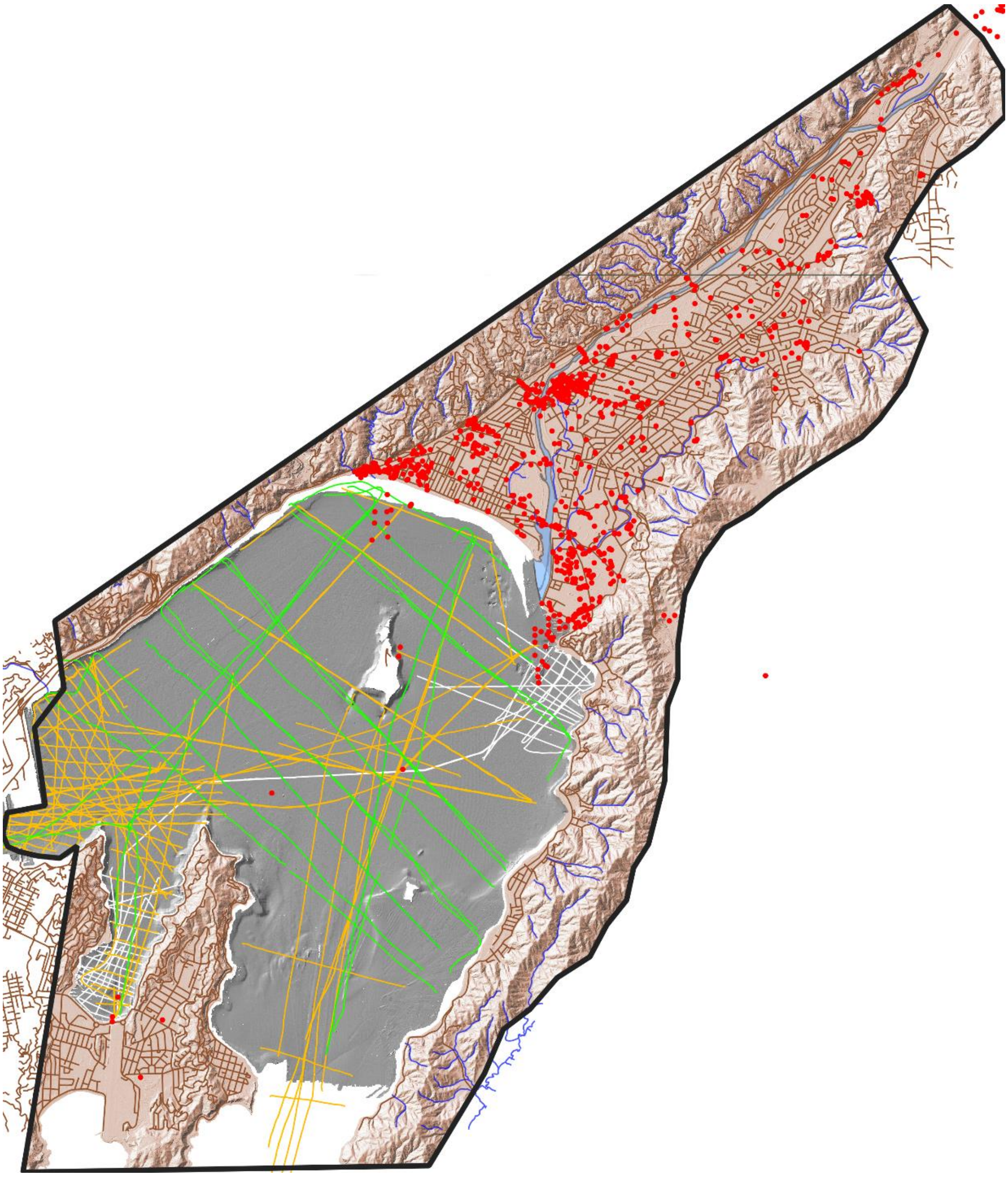

Figure A.2: Data used in compiling the Lower Hutt – Wellington Harbour Geological Model includes borehole logs (red points) and seismic reflection profiles (green, GNS; yellow and white, NIWA; white lines are high resolution TOPAS profiler lines). The background for onshore areas comprises hillshades derived from the GWRC 1 m lidar data overlain by LINZ Topo50 roads, stream centrelines and river polygons. For the harbour area the hillshade is derived from the NIWA 0.25 m DEM.

Table A.2: Statistical information characterising the borehole dataset used in building the Lower Hutt – Wellington Harbour Geological Model.

Borehole log statistics	
Count	1144
Unique values	344
Minimum depth	0.2 m
Maximum depth	311.2 m
Range	311.0 m
Sum of drilled depths	18330.64 m
Mean depth	16.02 m
Median depth	11.0 m
Standard deviation	21.39 m
Coefficient of Variation	1.34
Minority (rarest occurring depth)	0.2 m
Majority (most frequently occurring depth)	12.0 m
First quartile: 6.6 m	6.6 m
Third quartile: 18.15 m	18.15 m
Interquartile Range (IQR): 11.55 m	11.55 m