Waiwhetū Aquifer

Source water risk management implications

Version 1.0
22 March 2023

Our water, our future.

Executive Summary

The Waiwhetū aquifer is a critical water resource for the Wellington Region. Groundwater is abstracted from the Waterloo bore field, providing up to 70% of the Wellington Region's water demand during summer.

The Waiwhetū aquifer water supply is vulnerable. A microbiological contamination event at the Colin Grove supply bore in 2016 and subsequent investigations indicate that the aquifer is more vulnerable to contamination that previously assumed. Additionally, water treatment at the Waterloo Water Treatment Plant (WTP) is protective of microbiological contaminants only and is highly sensitive to turbidity. This means the water supply is vulnerable to chemical contamination (e.g., fuel spills) and aquifer disturbances (e.g., seismic activity).

Risks to the Waiwhetū aquifer water supply are likely to increase. These risks can be broadly categorised as contaminant sources, activities that create/exacerbate contaminant pathways and/or water availability risks. Increasing urban intensification in the Lower Hutt Valley, increasing water demand and climate change could all place additional pressure on the Waiwhetū aquifer water supply. This document includes a review of potential risks, their likelihood and consequence.

The Waiwhetū aquifer is not sufficiently protected. Wellington Water, Hutt City Council (HCC) and Greater Wellington Regional Council (GWRC) undertake many approaches and interventions to protect the Waiwhetū Aquifer water supply, including Water Safety Planning, the GWRC Natural Resources Plan and the HCC District Plan. However, the findings of this report suggest that current risk management approaches and interventions are not sufficient to protect the Waiwhetū aquifer from potential risks.

There are many opportunities to improve source water risk management. HCC and GWRC are currently reviewing their District and Natural Resources Plans, respectively. In addition, recent regulatory reform places greater emphasis on multi-barrier approaches to source water protection as well as monitoring and mitigation of potential risks. This presents an opportunity improve the security of the Waiwhetū aquifer water supply.

Recommendations – Based on the risk identification reported in this document, it is recommended that:

- Stricter controls of activities within source water risk management areas be implemented, including piling, excavations, and drilling investigations.
- A more coordinated approach be adopted for source water risk management between Wellington Water, GWRC and HCC, including sharing of information around high-density urban development, hazardous activities, chemical storage and contaminated sites.
- Additional studies be completed to understand groundwater dynamics and contaminant pathways and potential risks in the Waiwhetū aquifer and wider Lower Hutt Valley aquifer system.

Document information

Document history and status

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0.1	11/3/2022	Chris Shanks	Geoff Williams Angela Penfold		Draft
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Revision history

Revision	Description of change
0.1	Initial draft for comment from GWRC and HCC
0.2	Updated draft for internal review
1.0	Final version for to be circulated to GWRC and HCC

Contents

1 Introduction

The Waiwhetū aquifer is a key drinking water source for the Wellington region. However, the aquifer comes under significant stress in summer, and recent technical work has highlighted that areas of the aquifer are vulnerable to surface contamination. Alongside these issues, there is also very little resilience or redundancy in the water supply infrastructure to manage the effects of a reduction in groundwater levels or a chemical contamination event in the Waiwhetū aquifer. This combination of factors means that the security of the drinking water supply is highly sensitive to change.

Wellington Water, on behalf of its client councils, has committed significant resources to increase the resilience of the water supply infrastructure, including expansion, renewal and/or relocation of bore fields, network upgrades and demand forecasting/management. Alongside the infrastructure upgrades, maintaining and improving the security of the Waiwhetū aquifer is also of critical importance to the long-term supply of drinking water for the Wellington metropolitan area.

Hutt City Council (HCC) is revising the Hutt City District Plan and Greater Wellington Regional Council (GWRC) is reviewing its RMA documents' provisions relating to water quality, including community drinking water supplies. This presents an opportunity improve the security of the Waiwhetū aquifer, including the potential impacts associated with building foundations.

This document provides a summary of background information relating to the public water supply bore field supplying the Waterloo Water Treatment Plant (WTP), including the results from recent investigations and source water risk management planning. Also included is an initial summary of potential implications that may be associated with an intensification of development within the Lower Hutt, particularly the installation of pile foundations within proximity of the bore field.

The Intention of this document is to support well informed decisions about the controls placed on activities that have the potential to impact the security of the Waiwhetū aquifer as a critical drinking water source for the Wellington region.

2 Background

2.1 Water supply

The Waiwhetū aquifer is the primary source of water for much of Hutt and Wellington Cities, supplying around 74,000 and 81,000 customers to the respective cites. Groundwater is abstracted from the Waiwhetū aquifer at the Knights Road (Waterloo) and Gear Island bore fields (Figure 2-1), which are critical components of the supply network. The Knights Road bore field supplies the Waterloo WTP and provides around 40% of the region's annual water supply on average but can supply up to 70% of daily demand during the summer months when abstraction from surface water sources is constrained. At times, all eight of the Knights Road bores are operating without redundancy for extended periods.

The Waiwhetū aquifer comprises a layer of sand and gravel deposited during the last glaciation that are highly transmissive (i.e., can sustain high groundwater abstraction rates). The Waiwhetū gravels are overlain by the Petone Marine Beds, a fine-grained layer that acts as a barrier to groundwater flow and contamination. These are then overlain by recent Taita Alluvium and Melling Peat deposits. The Waterloo bores are screened in the Waiwhetū aquifer from around 20 to 40 m below ground surface.

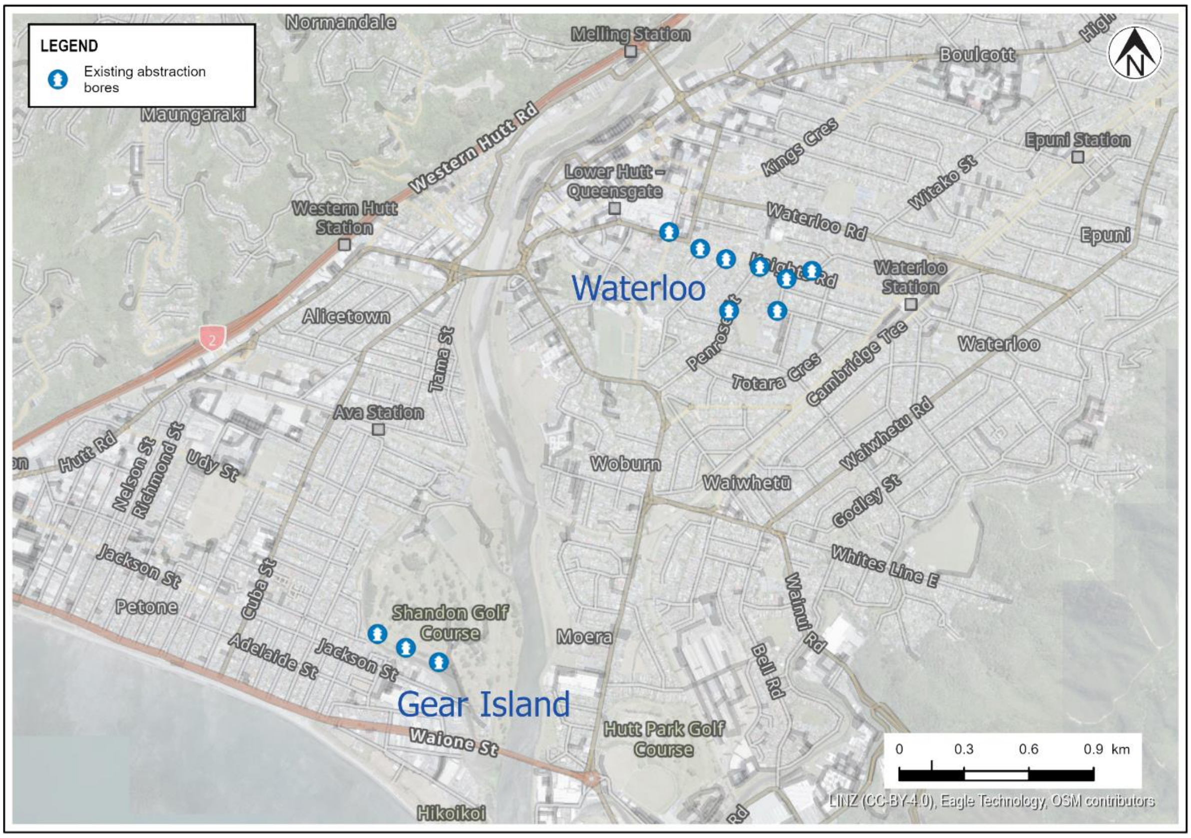

Figure 2-1: Waterloo and Gear Island bore field locations.

Wellington Water is also permitted to abstract groundwater from the Waiwhetū aquifer at the Gear Island bore field. However, the Gear Island bore field is considered to have a lower risk profile (and is not the focus of this document) due to the following:

- Gear Island is a back-up supply, used only when sufficient water volume cannot be achieved from other sources in the supply network.
- The proposed urban intensification areas are not in proximity to the Gear Island bore field.

- The Gear Island bore field abstracts groundwater from a portion of the aquifer system that is overlain by fine-grained sediment (Petone Marine Beds, refer Section 3.2.1) that provide a barrier to contamination issues.
- Although the Gear Island bore field has elevated risk of saline intrusion due to its proximity to the Petone foreshore, however this risk is largely managed through consent limits and Wellington Water operational practices.

2.1.1 2016 Contamination event and subsequent investigations

In late 2016 and early 2017 assets associated with the Waterloo bore field experienced several detections of *E.coli* and a significant increasing trend in total coliforms was observed indicating contamination of the drinking water supply had occurred. The results may have been linked to the Kaikoura earthquake which occurred on 14 November 2016 with enough force to cause significant structural damage to buildings in Wellington City, though it is not possible to confirm the root cause of the contamination issue. A full scientific investigation was launched in response to the contamination events, comprising the following stages (T+T, 2017, p.1):

- **Stage 1: Understand available information and uncertainties** – Review and analysis of existing data to determine contamination causes and identify data gaps.
- **Stage 2: Improve knowledge and confidence** – Undertake additional investigations and analysis, including field investigations and model revision.
- **Stage 3: Understand the implications of that knowledge** – Review existing regulatory and non-regulatory interventions in light of the Stage 2 conclusions.

The Stage 1 summary report (T+T, 2017) concluded that the seismic event had likely exacerbated contaminant pathways between the surface and the Waiwhetū Aquifer; that contaminant sources were likely to be widespread, rather than localised; and that the Petone Marine Beds geological unit was less laterally extensive and more coarse-grained that assumed previously. The investigation recommended that further hydrogeological investigations be undertaken and that the results of these be incorporated into revised conceptual and numerical modelling of the Lower Hutt aquifer system.

Stage 2 investigations are largely complete and include the following activities:

- **Additional hydrogeological field investigations** – These included the drilling and installation of groundwater monitoring wells across the Lower Hutt Valley between November 2020 and October 2021 (Stantec, 2022). The investigations targeted both shallow and deep zones to better understand groundwater dynamics throughout the Lower Hutt Valley.
- **Revision of the three-dimensional geological model** – Following the field investigations, the three-dimensional geological model (developed using Leapfrog software) has been revised to incorporate the additional information collected (J Begg Geo Ltd, 2022).
- **Revision of the Hutt Aquifer Model (HAM5)** – A new numerical groundwater model is being developed to replace the HAM3 model. The new model (HAM5) will predict how the aquifer might behave under a range of various pumping scenarios and will enable contaminant transport modelling. This capability will be used for a range of tasks, including long-term planning, assessing key contamination or recharge risks and climate change resilience modelling.

Stage 3 of the response to the 2016/2017 contamination events will comprise regulatory and non-regulatory activities to increase the resilience of the water supply. These activities will include:

- **Waterloo bore field additional bores** – Wellington Water plans to install two new bores as soon as practicable, to provide resilience and redundancy to the existing bore field (Stantec, 2023).
- **Waterloo bore field replacement project** – The Waterloo bores are nearing the end of (or may have exceeded) their design life. Accordingly, Wellington Water has mapped out a programme for

replacement of the bore field over the next 10 years (Stantec, 2023) and has completed a multi-criteria analysis (MCA) to determine the optimal location for replacement bores (Stantec, 2020). Although the MCA findings were not conclusive, the results indicated that the new bore field will likely extend to the north and south of the existing Waterloo bore field. Once complete, a Stage 2 MCA will be completed, incorporating the HAM5 model to optimise the new bore field's position and layout.

2.1.2 Water Treatment

Following the 2016/2017 microbial contamination events described above and the findings of the subsequent Stage 1 investigation (T+T, 2017), Wellington Water upgraded the Waterloo WTP to include UV treatment and permanently dosed chlorine disinfection to manage the microbial contamination risk as part of a multiple barrier approach to water safety. Raw water abstracted from the Knights Road bores undergoes the following treatment at the Waterloo WTP:

- UV treatment.
- Aeration.
- pH adjustment with lime.
- Dosing with fluoride and chlorine.

This treatment process is effective at treating microbial contamination. However, it will not materially treat chemical or heavy metal contamination. In addition, components of the treatment train are ineffective when the raw water has high turbidity. For this reason, the Waterloo bore field is vulnerable to heavy metals and chemical contamination, or high turbidity. Following the 2016 contamination event, a run-to-waste system was implemented as a mitigation against high turbidity, which often occurs during pump start-up. However, for heavy metals and chemical contaminants, a plant shutdown would be the only mitigation, which would have significant consequences for the security of supply to the Wellington metropolitan area.

2.2 District and Regional Plan updates

The GWRC Natural Resources Regional Plan (NRP, GWRC, 2022) delineates a Community Drinking Water Supply Protection Zone over the Waiwhetū aquifer, recognising the vulnerability of the aquifer to the effects of discharges of contaminants and some land use activities, such as excavation.

HCC is in the process of reviewing and updating the Lower Hutt District Plan to reflect the National Policy Statement in Urban Development (NPS-UD, MfE, 2022). The NPS-UD requires district plans to enable greater height and density of housing, particularly in areas of high demand and access. For Lower Hutt, this means allowing for greater urban development intensity and building height within "intensification areas" that are based on walking catchments of rapid transit stops and city and metropolitan centre zones. We understand that HCC is currently reviewing intensification areas options based on buffer distances of 800m of train stations on the Hutt Valley and Melling lines and 1,200m of Lower Hutt city centre and Petone metropolitan centre.

There is a considerable overlap between the intensification areas, and the Waterloo bore field Source Protection Zone 1 (Figure 2-2). As part of stakeholder engagement, HCC has reached out to Wellington Water to understand the potential implications that intensification could have on the operation of the existing bore field. This document provides an assessment of these potential implications, particularly those associated with potential impacts associated with building foundations.

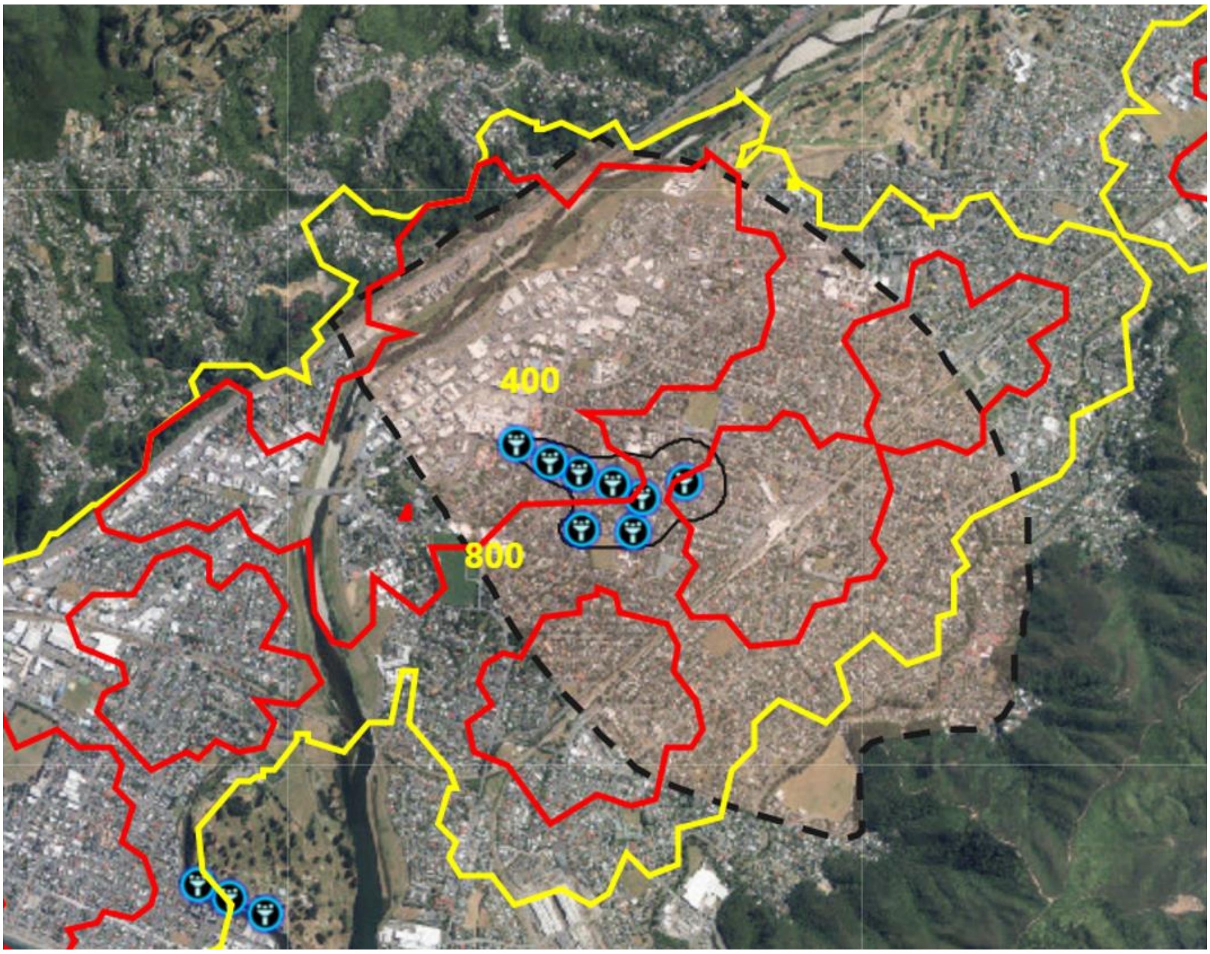

Figure 2-2: 400m and 800m buffer areas (yellow and red respectively) around train stations, Lower Hutt city centre and Petone metropolitan centre and the *Wellington Water SPZ 2a (black line). Wellington Water supply bores are shown in blue.*

At the same time, GWRC is reviewing both the Regional Policy Statement and Natural Resources Plan to address effects of urban intensification on water and give effect to the National Policy Statement for Freshwater Management 2020 (NPS-FM) published by the Ministry for the Environment (MfE, 2023).

Wellington Water faces many challenges to the security of the Waiwhetū aquifer. These challenges play out on local and regional scales and range from identifying and managing activities close to the bores, to regional-scale issues such as long-term aquifer yield and the cumulative effects of population growth. The primary focus of this document is to identify risk to source water quality and provide advice on potential management interventions to mitigate these risks. This document also includes information regarding the types of activities that may impact on its water supply sources in the Waiwhetū aquifer.

2.3 Drinking water regulatory reform

A government review of the 'Three Waters'[1] regulatory system was initiated following an incident in Havelock North in 2016, where four people died and an estimated 5,500 fell ill with gastroenteritis from ingesting bore water contaminated with campylobacter. The subsequent Government Inquiry into Havelock North Drinking Water (GIHNDW, 2017) identified various issues with the regulatory regime, including "significant problems" (p.151) with the National Environmental Standard for Sources of Human Drinking Water (NES-DW, New Zealand Government, 2007) and the 2018 revision of the Drinking-water

[1] Drinking water, wastewater, and stormwater

Standards for New Zealand 2005 (Ministry of Health, 2018). The Havelock North Inquiry determined the "following six fundamental principles of drinking water safety in New Zealand" (GIHNDW, 2017, p.8):

1. A high standard of care must be embraced.
2. Protection of source water is of paramount importance.
3. Maintain multiple barriers against contamination.
4. Change precedes contamination.
5. Suppliers must own the safety of drinking water.
6. Apply a preventive risk management approach.

The multiple barrier approach in principle three above is recommended because "no single barrier is effective against all sources of contamination and any barrier can fail at any time (GIHNDW, 2017, p.8). In addition, a "source to tap" approach should be adopted, whereby barriers should be implemented and monitored at each step in the water supply (i.e., source, treatment, and distribution).

The Three Waters Review[2], undertaken following recommendations from the Havelock North Inquiry, has resulted in the new Water Services Act 2021 and the establishment of a new dedicated regulator, Taumata Arowai. The Water Services Act requires all drinking-water suppliers other than domestic self-suppliers to register with Taumata Arowai and prepare Source Water Risk Management Plans (SWRMP) to identify, manage and monitor risks to source water.

Under the Water Services Act, regional councils are required to contribute information to SWRMP, annually publish information about source water quality and quantity, and report to Taumata Arowai. Regional councils must assess the effectiveness of their interventions every three years. The Water Services Act has also amended the Resource Management Act, requiring consenting authorities to consider risks and effects on source water for registered water supplies (new section 104G). New national standards for drinking water (Water Services (Drinking Water Standards for New Zealand) Regulations 2022) and operational compliance rules (Taumata Arowai, 2022) have also been implemented by Taumata Arowai.

Alongside Taumata Arowai's update of the drinking water rules for water suppliers, MfE is revising the National Environmental Standard for Sources of Human Drinking Water (NES-DW). The NES-DW was first introduced in 2007 and was the sole national direction for source water protection at that time. The revised NES-DW is intended to support the mitigation of risks to drinking water sources. The importance of protecting drinking water sources is also expressed in the National Policy Statement for Freshwater Management 2020 (NPS-FM, MfE, 2023), which requires freshwater management throughout Aotearoa New Zealand to recognise drinking water as the second highest priority for water, after the intrinsic value of the water itself.

While freshwater and drinking water management through the Water Services Act and NPS-FM strengthen the recognition of the hazards and risks to source water, updates to the NES-DW will explicitly ensure plans and resource consents address those risks in a nationally consistent way. These changes will therefore have direct relevance to the scope of revisions to the HCC District Plan and GWRC Natural Resources Plan.

[2] https://www.dia.govt.nz/Three-waters-review

3 Water source characteristics

Groundwater is abstracted from the Waiwhetū aquifer at the Knights Road (Waterloo) and Gear Island borefields. The Waiwhetū aquifer is part of the Lower Hutt groundwater zone that extends from Taita Gorge through to the Wellington Harbour heads. This section describes the conceptual geology and hydrogeology of the groundwater zone, and its relevance to source water protection and urban intensification.

3.1 Geology

The Lower Hutt groundwater zone comprises layers of sediment that have infilled a tectonic basin associated with the Wellington Fault and bounded by the Wellington Belt greywacke basement rock. The Waiwhetū gravels, deposited during the last glaciation, form a productive aquifer within the system. The aquifer is overlain by the following Holocene geological units (Figure 3-1):

- **Taita Alluvium**, consisting mainly of gravel deposits, but also includes sand, silt and clay deposited by the river as flood and over-bank deposits.
- **Melling Peat**, comprising peat/organic material from fossil forest and wetlands, as well as sand, gravel, and silt deposits. This layer grades laterally into the Taita Alluvium.
- **Petone Marine Beds** reach inland from the coastline, terminating slightly north of the Waterloo bores. The Petone Marine Beds are dominated by sands, clays, shelly silts and sandy silts. The marine beds increase in thickness, and transition from coarse-grained material (sands) in the vicinity of the Waterloo bores to finer grained material, such as silts and clays further down-valley, towards the coast and beneath the harbour.

The Waiwhetū gravels are underlain by further alluvial deposits, but these are not immediately relevant to the protection of the drinking water source.

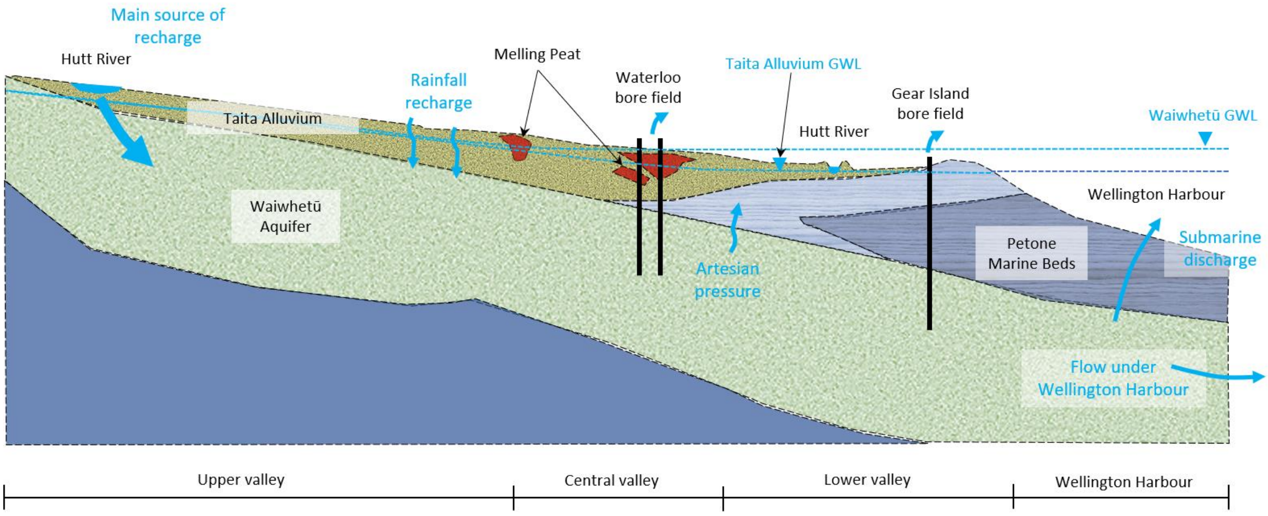

Figure 3-1: Conceptual hydrogeological model. (GWL: approximate groundwater level) NOT TO SCALE.

3.2 Hydrogeology

The hydrogeology of the Lower Hutt Valley is largely controlled by Te Awa Kairangi / Hutt River recharging the aquifer system recharge in the upper valley and the discharge of groundwater into Wellington harbour. The groundwater zone is 'finely balanced', in that groundwater abstraction can cause observable changes to river recharge fluxes and/or groundwater levels in the aquifer system beneath Wellington harbour.

The hydrogeology of the groundwater zone can be broadly grouped into four zones, as depicted in the conceptual hydrogeological model (Figure 3-1):

- **Upper valley** – here, the aquifer is unconfined (i.e., no restriction on vertical groundwater movement) and there is generally little distinction between the different geological units. Recharge to the aquifer predominantly occurs from the Hutt River and from rainfall infiltration over the upper and central Hutt Valley where the aquifer is unconfined.
- **Central valley** – here the Petone Marine Beds and Melling Peat begin to overly the Waiwhetū aquifer. These units have a generally lower hydraulic conductivity which impedes the downward flow of groundwater. Although these layers are likely to be present in this area, their lateral extent, thickness and composition is still uncertain.
- **Lower valley, south of the Waterloo wellfield to Petone foreshore** – the Petone Marine Beds become more laterally extensive and thicker. These beds act as a confining layer (or aquitard) which impedes the vertical movement of groundwater and allows artesian pressures to build in the underlying Waiwhetū aquifer beneath, as well as allow groundwater levels to establish in the Taita Alluvium
- **Beneath Wellington Harbour** – the Petone Marine Beds and Waiwhetū aquifer extend beneath the harbour through to Falcon Shoals at the harbour heads. The aquifer is artesian, with Petone Marine Bed acting as an aquitard. Groundwater is discharged from the aquifer through submarine springs as well as diffuse discharge. Drilling in Wellington Harbour south of Matiu/Somes Island encountered brackish groundwater in the lower part of the Waiwhetū Aquifer (Gyopari, 2018), suggesting that saline intrusion has occurred in that location. However, there is still limited understanding of the interaction of saline and fresh water beneath Wellington Harbour.

This hydrogeological conceptual model is presented in Figure 3-1.

3.2.1 Barriers to groundwater flow and solute transport

Geological layers of differing water-bearing properties (hydrostratigraphic units) influence how groundwater flows through an aquifer system. In the Lower Hutt Valley, the Petone Marine Bed unit (where present) acts as an aquitard. This means that the unit restricts the vertical flow of groundwater, meaning that groundwater cannot migrate downwards (i.e., no recharge) and that groundwater pressure can build in the underlying Waiwhetū gravels (i.e., confined, artesian conditions).

From a water security perspective, the Petone Marine Bed unit acts as a barrier to contamination of the aquifer in the vicinity of the Waterloo bore field. The lateral extent, thickness and composition of the Petone Marine Beds is uncertain but has been subject to a number of investigations and reports. The most recent of these investigations was triggered by the detection of *E.coli* and increasing trends of total coliforms in December 2016, following the Kaikoura Earthquake (refer Section 2.1.1). The summary report (T+T, 2017) concluded the following:

- The earthquake likely worsened or enhanced a previously small contaminant pathway for surface or near-surface pathogen entry in the Waiwhetū aquifer or bores.
- Review of the geological model suggested that the Waterloo bore field lies in an area where the Petone Marine Beds are relatively thin and more coarse-grained than other parts of that unit, but also variable in terms of lateral and vertical permeability. If this is indeed the case, heavy abstraction of groundwater from the Waterloo bore field may activate poorly sealed pathways between unconfined groundwater and the aquifer.
- The two southern bores (Penrose Street South, R27/1179 and Mahoe Street, R27/1180) have screens that extend closer to the surface than the remaining abstraction bores. These bores were also most impacted by total coliform transgressions, which may suggest that the contamination source was at (or near) the ground surface.

- The Colin Grove and Mahoe St bores (both impacted by *E.coli*) are nearly at the opposite ends of the borefield, so it was inferred that a widespread source(s) of faecal contamination was occurring, rather than being one localised source.

According to the subsequent recent analysis (J Begg, Geo Ltd, 2022), the sediments that comprise the Petone Marine Beds are commonly coarse-grained at the stratigraphic contacts but have a core of fine-grained sediment that comprise a thick and laterally reliable aquitard. This is generally the case in the lower valley and beneath Wellington Harbour. Near their inland extent, however, the fine-grained core is largely absent, and groundwater is sometimes recorded within the Petone Marine Beds (Figure 3-2). In addition, the report has indicated that the Petone Marine Beds are not expected to extend as far north (i.e., north of the Waterloo bore field) as had been surmised in previous reports. Therefore, this unit may be less of a barrier to groundwater flow and contaminant transport than assumed previously.

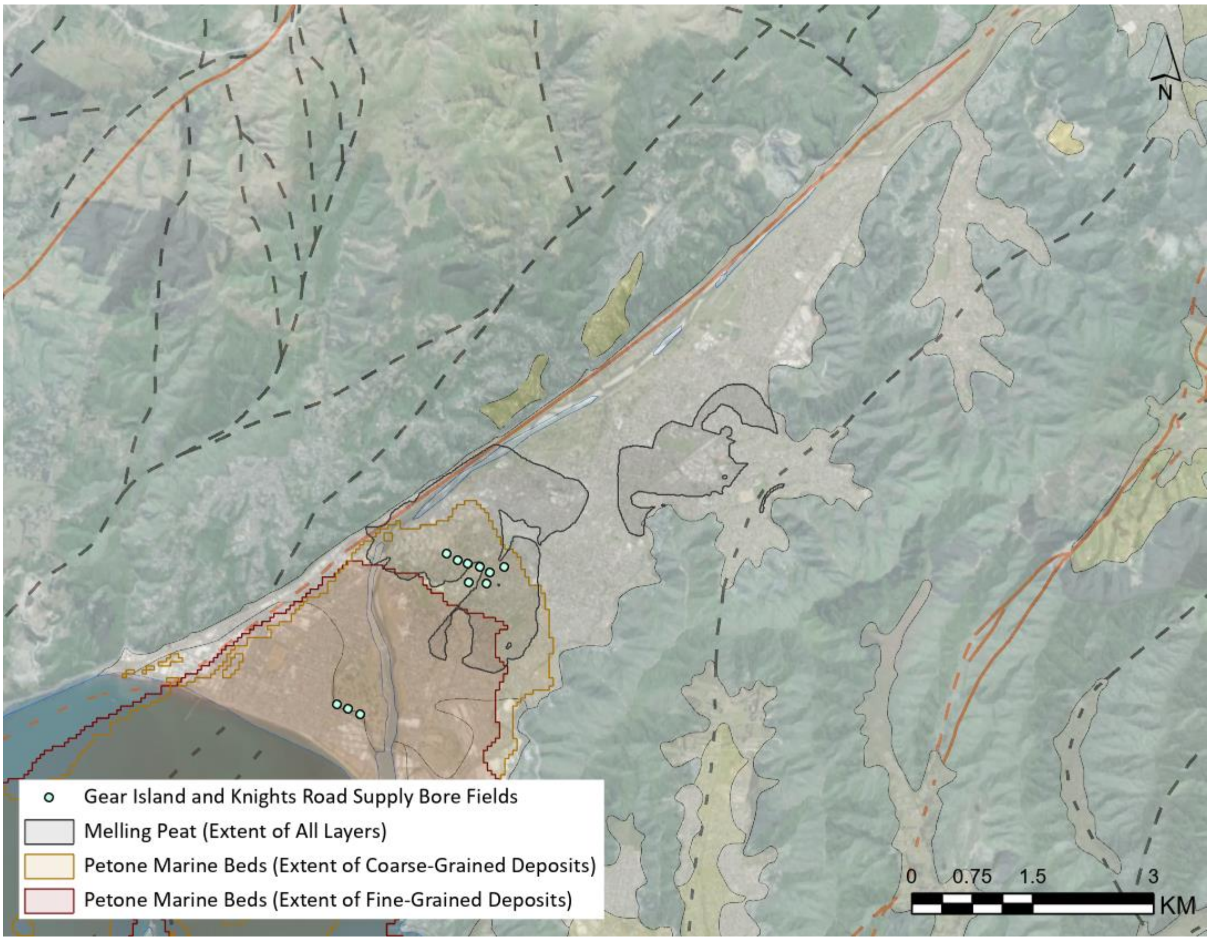

Figure 3-2: Approximate lateral extent of Melling Peat and Petone Marine Beds.

3.2.2 Implications for source water protection

In terms of aquifer vulnerability and implications for source water protection, these results show that:

- The Petone Marine Beds in the vicinity of the Waterloo bore field are relatively coarse-grained, relatively thin and under a negative hydraulic gradient. This means that the aquifer is at greater risk from contaminants being able to migrate downwards into the aquifer/bores from the surface. This is supported by the microbiological contamination event at the Waterloo bore field in 2016.
- Because the Petone Marine Beds are relatively permeable, the attenuation of contaminants during transport from the surface to the water supply bores relies on preserving the greatest thickness of the aquitard possible to protect the water supply from contamination.

- In some areas close to the Waterloo bores, the Taita Alluvium (the uppermost layer) is only approximately 3 m thick and underlain by the Petone Marine Beds unit, which is thin and laterally discontinuous in the Waterloo bore field area. This means that in some areas, excavations deeper than 3 m could start to intercept the Petone Marine Beds unit and therefore increase contamination risks to the aquifer.
- If contaminants were able to enter the aquifer (particularly chemical contaminants that degrade slowly) natural attenuation of the contaminants may take a very long time (i.e., 10-100 years). This could result in significant and extended water supply issues for Wellington and Hutt Cities.
- Significant thicknesses (15-18 m) of fine-grained Petone Marine Beds deposits at the Gear Island bore field are expected to significantly retard the vertical migration of contaminants in combination with slight artesian pressures. This means that minor excavation of the upper portion of the Petone Marine Beds unit in this area is less likely to create contaminant pathways into the aquifer. As such, impacts to the Gear Island bore field have not been considered in detail in this report.

3.3 Source protection zones

Wellington Water has delineated source protection zones (SPZ, also referred to as Source Water Risk Management Areas) around its Waterloo and Gear Island bores to allow for greater regulatory visibility/control of activities within the immediate vicinity of the bores. Of particular concern are potential intrusive activities (such as drilling, or deep excavation), undertaken close to the bore field which increase the risk of creating pathways for contamination to migrate from the surface (or shallow subsurface) to public water supply bores. Wellington Water has provided the SPZs to GWRC and HCC with the intention that the zones will be included within the respective regional and district plan change processes.

Delineation of the three groundwater SPZs for the Gear Island and Waterloo bore fields has been undertaken by GNS (Toews, 2017) and T+T (2018) in accordance with MfE guidance (PDP, 2018). The delineation methodologies and input parameters are based on the conceptual hydrogeology, including groundwater flow direction and hydraulic conductivity. The following approach was adopted to define the three SPZs:

- SPZ 1 – Immediate protection zone around water supply.
- SPZ 2 – Microbiological contamination protection zone.
- SPZ 3 – Entire catchment zone.

3.3.1 SPZ 1 – Immediate protection zone

This zone is intended to protect the water supply from risks immediately adjacent the water supply. For groundwater sources, these zones are generally delineated based on a 5-30 m buffer of the wellhead. Due to the criticality of the Waterloo wellfield for the Wellington region, the SPZ 1 also considered a modified aquifer vulnerability index (DRASTIC, refer T+T, 2018), resulting in an SPZ 1 and that extends between 30 - 170 m from the supply bores (Figure 3-3).

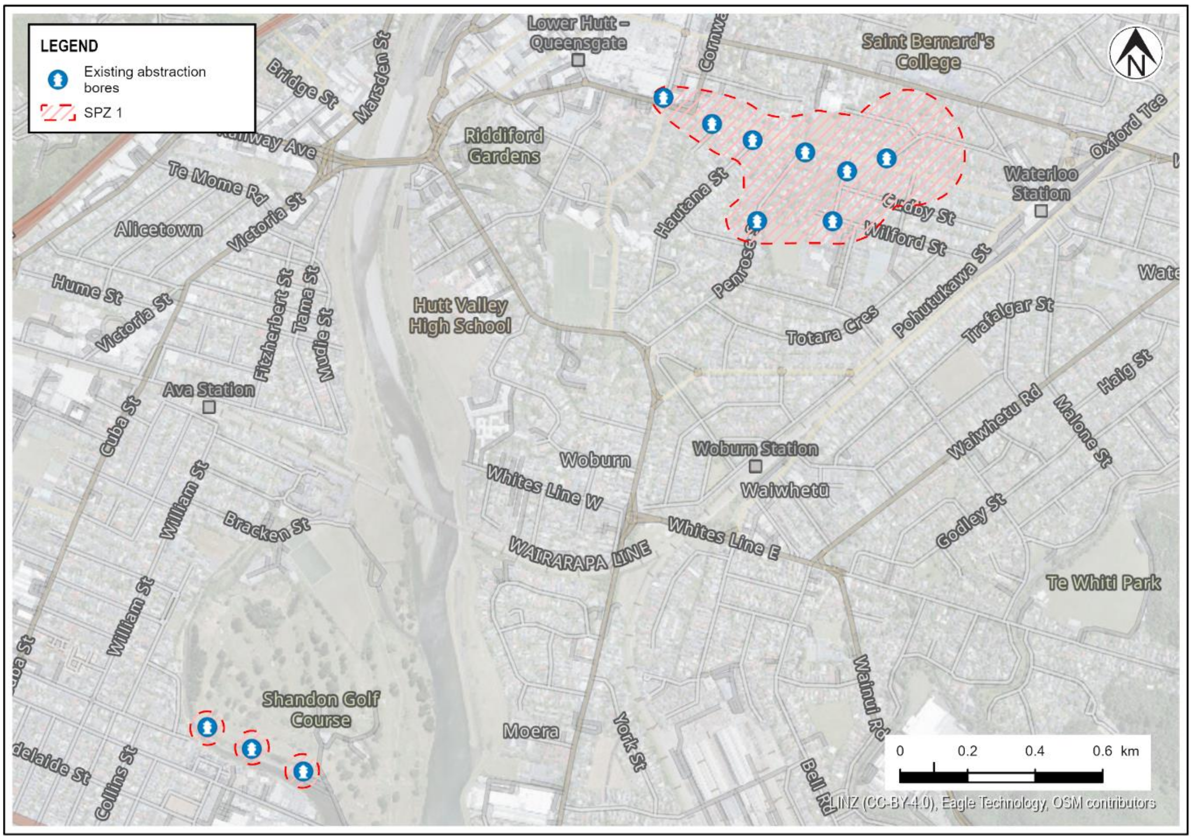

Figure 3-3: SPZ 1 for Waterloo and Gear Island bore fields.

3.3.2 SPZ 2 – Microbiological contamination protection zone

The SPZ 2 is intended to protect against microbiological contamination of the water supply. Where sufficient information is available, these zones can be delineated based on one-year groundwater travel times using a modelling method that tracks the trajectory of particles in a numerical groundwater flow model. For the Waterloo and Gear Island bore fields, the SPZ 2 delineation was based on combined areas of shallow and deep one-year travel time undertaken by GNS (Toews, 2017) using the HAM3 model (Earth in Mind, 2014). The Waterloo and Gear Island SPZ 2 are shown in Figure 3-4 and extend approximately 8.5 km and 11 km upgradient of the water supply bores, respectively.

Note that the current SPZ 2 is truncated at the coastline although it is possible that the capture zone of the Gear Island bores may extend into Wellington Harbour. Additionally, changes in aquifer pressure beneath the harbour could affect abstraction at the Waterloo and Gear Island bore fields.

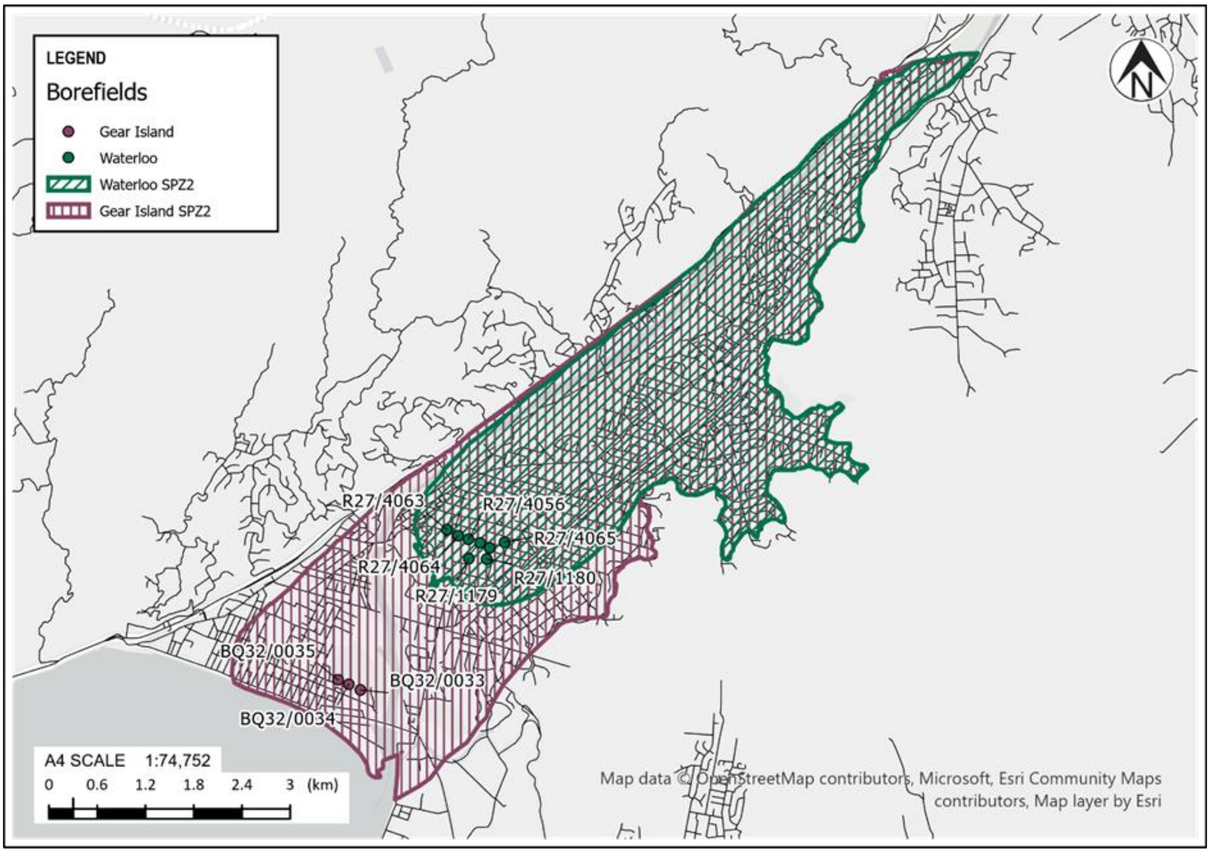

Figure 3-4: SPZ 2 for Waterloo and Gear Island bore fields.

Due to uncertainty in the lateral extent and thickness of the confining Petone Marine Beds (refer Section 3.2.1), as well as the potential for pumping-induced negative gradients around the Waterloo bores (Earth in Mind, 2020), Wellington Water commissioned the delineation of an additional SPZ 2a around the Waterloo bore field. The SPZ 2a considers the potential for groundwater contamination based on aquifer vulnerability mapping, as well as consideration of national and international guidance and practice within the context of the Waiwhetū aquifer.

The SPZ 2a delineation method described above incorporated information from a three-dimensional geological model. This model has since been updated as part of the HAM5 process (J Begg, Geo Ltd, 2022) and Wellington Water are planning to replace the Waterloo bore field, starting with two new bores in 2022/2023 (described in Section 2.1.1). On this basis, the SPZ size, shape and extent is likely to change to reflect the new bores, and an improved geological understanding.

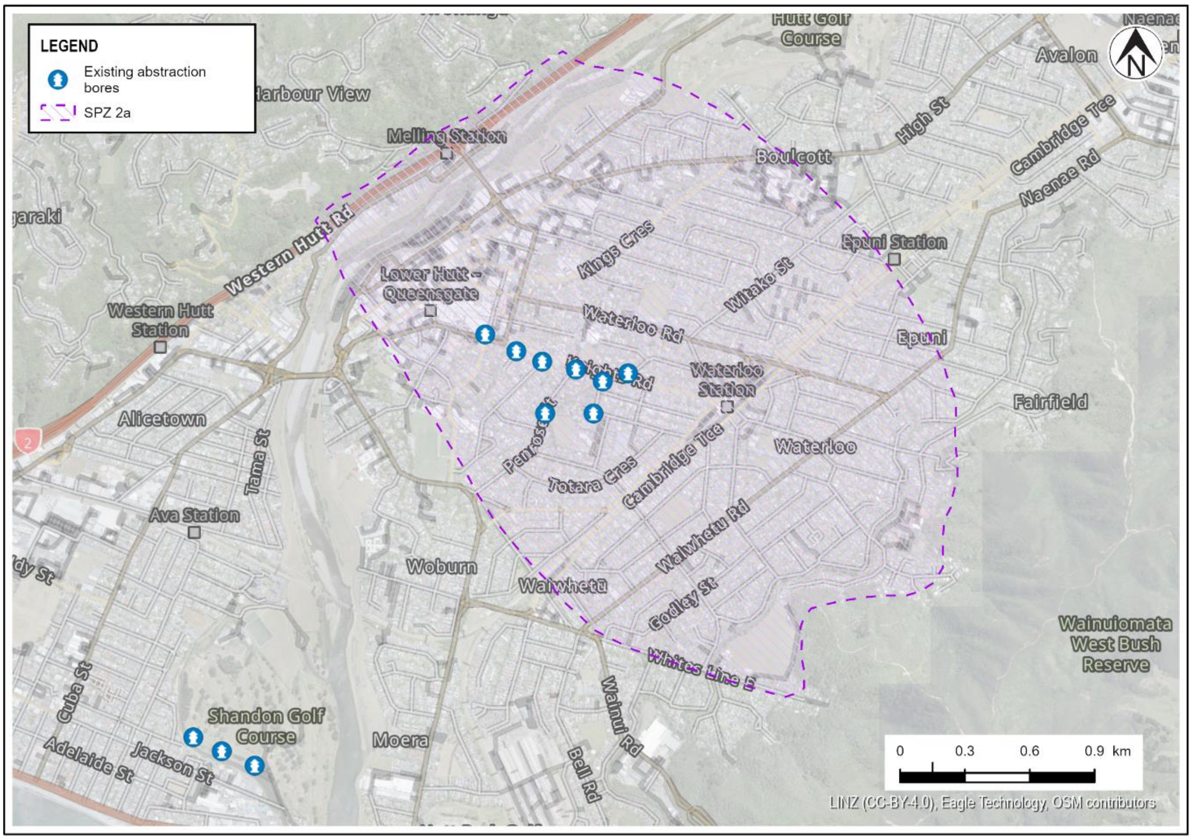

Figure 3-5: SPZ 2a for Waterloo bore fields.

3.3.3 SPZ 3 – Entire catchment zone

This zone for protection against other types of contamination and considered to be the total groundwater catchment. The SPZ 3 boundary for the Gear Island and Waterloo bore fields has been delineated based on hydrogeological boundaries inferred from the catchment characteristics (e.g., geology, topography and surface water catchments). The SPZ 3 is shown Figure 3-6. As for the current SPZ 2, the SPZ 3 is truncated at the coastline although it is possible that the capture zone of the Gear Island bores may extend into Wellington Harbour.

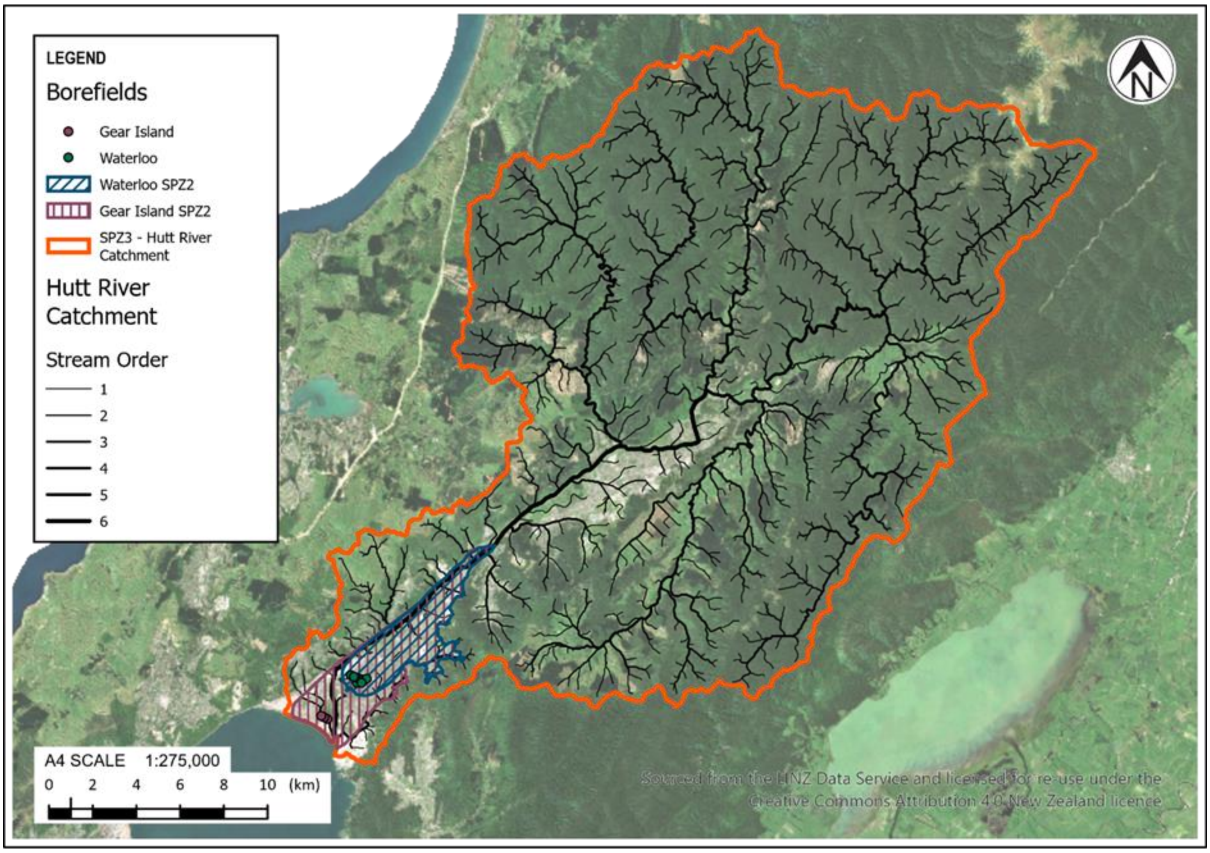

Figure 3-6: SPZ 3 delineation for Waterloo and Gear Island bore fields.

3.4 Summary of key aquifer characteristics and constraints

The following summarises key constraints described in this section:

- At the Waterloo bore field, the Petone Marine Beds unit that protects the aquifer from contamination is relatively permeable, shallow and thin. This allows contaminants to migrate from the surface into the bores. Any disturbance of the aquitard near the bores may exacerbate this issue. Even excavations as shallow as 3 m may start to remove the Petone Marine Beds unit in some areas.
- There is currently UV/chlorination treatment in place to manage the risk of microbial contamination from the Waterloo bores. However this treatment process is susceptible to turbidity and there is little or no treatment protection to chemical contamination (e.g., fuel spills). This makes the supply particularly vulnerable to chemical contamination and elevated turbidity.
- Should one or more supply bores be impacted by a contamination event and shut down, Wellington Water has little to no redundancy in the bore field to abstract additional groundwater. The compact nature of the bore field also means that contamination events are more likely to impact more than one bore. This exacerbates the vulnerability of the water supply.
- If contamination enters the aquifer, natural attenuation could take an extended period of time (10-100 years). This means that a contamination could cause significant and lengthy disruption to the water supply.
- Saline intrusion risks constrain abstraction rates from the Waterloo bores in summer, when they are most needed. Any further impacts to aquifer pressures at the foreshore, such as the cumulative effects of groundwater abstraction, changes to aquifer recharge, or penetrations through the Petone Marine Beds unit could exacerbate this issue. These impacts should be mitigated as far as practicable.
- The Gear Island bores are used as a backup supply only, and the Petone Marine Beds unit in this area is thicker and much less permeable than at Waterloo. This means that the aquifer in this area is significantly less vulnerable to surface contamination and more resilient to impacts from excavation. However, it is much more vulnerable to saline intrusion because the bores are much closer to the foreshore.

This information shows that the Waiwhetū aquifer drinking water source at Waterloo is vulnerable to most activities except shallow (< 3 m) excavations. Any activities beyond shallow excavations may increase contaminant pathways and/or reduce aquifer pressures, which may exacerbate saline intrusion risks.

Given the importance of the Waterloo bore field to Wellington's water supply, it is therefore critical that a high standard of care is exercised when assessing new activities proposed within the Lower Hutt. This is mandated through recent water regulatory changes, such as the Water Services Act 2021 and updates to the NES-DW.

4 Source water risk

As described in the preceding section, the Waiwhetū aquifer is now understood to be more vulnerable than previously thought. This change in perception, alongside a lack of treatment for chemical contamination, mean that protection of the source is vital to maintaining safe drinking water. Accordingly, we have undertaken a high-level assessment of the source water risks that can be broadly categorised as those that could:

- **Be a potential contaminant source to the aquifer:**

  As noted in Section 2.1.2, the raw water abstracted from the Waiwhetū aquifer undergoes treatment for microbiological contamination only. The lack of chemical treatment means that the supply is vulnerable to chemical contamination. Additionally, the treatment processes are sensitive to turbidity.

- **Create permanent/temporary pathways:**

  These activities may compromise the ability of the Petone Marine Beds to act as a barrier to contamination or cause a loss of groundwater pressure in the aquifer that may exacerbate water availability risks.

- **Impact water availability:**

  Water availability also impacts on drinking water security. Maintaining artesian pressure at the foreshore to prevent saline intrusion into the aquifer is a key constraint on water availability from the Waiwhetū aquifer. Thus, activities that reduce aquifer pressure at the foreshore can have a significant impact on Wellington Water's ability to abstract water at both of its bore fields.

These risks have been summarised in the following sub-sections and are depicted in the conceptual diagram below (Figure 4-1).

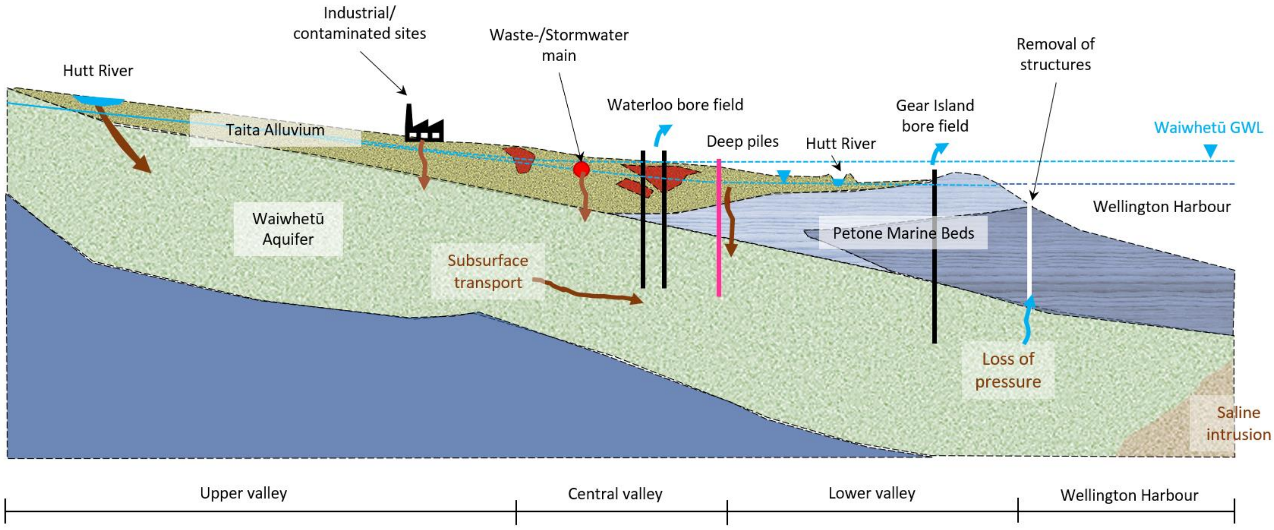

Figure 4-1: Source water risk conceptual model (NOT TO SCALE).

The management of the risks identified can be broadly categorised into regulatory and non-regulatory approaches:

- **Regulatory approaches** in this document are management interventions that are prescribed within the GWRC's region-wide Natural Resources Plan and/or HCC's District Plan (refer Section 2.2). These include rules around permitted and discretionary activities, as well as Wellington Water's status as an Affected Party under s95E of the Resource Management Act.

- **Non-regulatory approaches** in this document are management and interventions that are not directly specified in the NRP or District Plan. However, the approaches may be part of Wellington Water's and GWRC's legal obligations as a water supplier and regional authority, respectively (refer Section 2.3). These approaches include:
  - Source water risk management planning. Following the introduction of the Water Services Act in 2021, Wellington Water has compiled a Source Water Risk Management Plan (SWRMP) for the Waiwhetū aquifer. The SWRMP identifies potential risks to the Waiwhetū aquifer (water quality and quantity) and describes how those risks are monitored, managed or mitigated.
  - Te Whanganui-a-tara Whaitua implementation programme, focussing on improving water quality in the catchment (Te Whanganui-a-tara Whaitua Committee, 2021)
  - Ongoing State of the Environment monitoring undertaken by GWRC.
  - Replacement of the Waterloo water supply bores.

As noted in Section 2, the Lower Hutt Valley aquifer system has been subject to detailed hydrogeological investigation and is under increasing urban pressure. As understanding of the potential risks grows, it is appropriate to reconsider risk management and intervention in both a regulatory and non-regulatory context. This is the objective of the risk identification process described in the following section.

4.1 Risk identification

In this section, we have broadly identified key potential contaminant sources and activities that could increase migration of contaminants from the surface (and subsurface) into the Waiwhetū Aquifer. For each of these, we have:

- Described the risk identified.
- Assigned likelihood and consequence descriptors based on definitions in Guidelines for Drinking-water Quality Management for New Zealand (Ministry of Health, 2017). Further information about the descriptors is included in Appendix A.
- Described how those activities are currently regulated and suggested possible improvements to regulation to support a higher level of management.

The risks outlined in this section and the subsequent tables focus on SPZ 2 and SPZ 2a zones of the Waterloo bore field, as described in Section 3.3. Risks for the immediate SPZ 1 have not been included in detail here as they can be considered low due to the relatively small size of these zones and the existing control measures that are available to Wellington Water in those zones. The risk identification undertaken also assumes that the footprint of the bore fields will not change. Assessment of risks and mitigations through partial relocation of the bore fields is beyond the scope of this document but may be explored in the future.

The following tables provide a brief summary of the results risk identification process described above. **The full risk identification tables are included in Appendix B and should be referred to for further detail.**

Table 4.1: Summary of key contaminants and source

Contaminant/source	Likelihood	Consequence	Current management	Future management
Reticulated wastewater	Possible	Major	Non-regulatory	Non-regulatory
Stormwater reticulation and disposal	Possible	Moderate	Regulatory, monitoring	Regulatory, cumulative effects

Contaminant/source	Likelihood	Consequence	Current management	Future management
Sea water	Almost certain	Catastrophic	Regulatory, monitoring	NRP buffer zone, monitoring
Discharges from contaminated land	Rare	Major	NRP	NRP,
Surface water	Rare	Major	Monitoring	NRP, Whaitua
Chemical storage and use	Rare	Catastrophic	District Plan, HSNO Act	HSNO Act

Table 4.2: Summary of contaminant pathway activities

Activity	Likelihood	Consequence	Current management	Future management
Excavation of building basements	Possible	Major	NRP	Expanded NRP
Dewatering during excavation	Possible	Major	NRP	NRP
Drilling investigations	Possible	Catastrophic	NRP	Expanded NRP
Ground source heating/cooling	Rare	Major	NRP	Expanded NRP
Deep pile foundations	Possible	Catastrophic	NRP	Expanded NRP
Removal/decommissioning of existing structures	Likely	Major	NRP (bores only)	Expanded NRP
Unused/abandoned bores	Possible	Major	NRP	Expanded NRP and records
Earthworks in river/stream beds	Likely	Major	NRP	Better understanding of potential risks

Table 4.3: Summary of water availability risks

Risk	Likelihood	Consequence	Current management	Future management
Saline intrusion	Almost certain	Catastrophic	Water take consents	Better understanding of potential risks
Impacts to recharge	Almost certain	Major	Water take consent	Better understanding of potential risks, Whaitua
Changes to minimum environmental flows	Possible	Moderate	Whaitua recommendations	Whaitua process
Increased groundwater abstraction be other parties	Rare	Major	NRP	Expanded NRP, Additional analysis

Risk	Likelihood	Consequence	Current management	Future management
Climate change and sea level rise	Almost certain	Major	NRP	Expanded NRP, Additional analysis

4.2 Urban Development Intensification Implications

The intensification of urban development described by the NPS-UD (MfE, 2022) references an increase to the density and height of housing. This may translate to an increase in building heights to accommodate 'vertical intensification'. Early advice from HCC suggests that this may be in the form of buildings up to six stories (or more) within urban intensification areas, which overlap with the Waterloo bore field. In general terms, as building heights increase, the scale of the foundations also increases to carry the additional weight of the structure.

The Taita Alluvium that underlies the Lower Hutt Valley is generally suitable in terms of bearing capacity to support most single and double storey buildings. However, the geological unit may not be suitable to support larger structures, depending on the geotechnical properties of the deeper Taita Alluvium at the particular site (which varies significantly across the Hutt Valley). In these instances, foundation designers may look to extend pile foundations into the top of the Waiwhetū aquifer. As outlined earlier, this creates significant risk to Wellington's water supply.

Therefore, the key considerations for intensification of urban development in terms of source water security are:

- An increase of building height could necessitate deeper pile foundations. If deep and/or numerous, the pile foundations may create contaminant pathways to the aquifer/bores. These pathways may be exacerbated during seismic events that frequently occur in the Wellington region.
- Foundation design typically requires site-specific geotechnical information to be gathered from drilling or Cone Penetration Test (CPT) investigations, which may create contaminant pathways close to the water supply bores if not managed appropriately. The cumulative effect of many small penetrations through the Petone Marine Beds and other overlying units may increase risks to the Waiwhetū aquifer water source.
- An increase in population density will increase the pressure on existing wastewater infrastructure which, if not suitably upgraded or maintained, may increase the risk or consequence of a wastewater pipe failure. Such an event could contaminate the aquifer if close to the bores, or if a pathway exists for the wastewater to enter the aquifer.

Wellington Water engaged Tonkin & Taylor to assess the likely type and depth of foundations required to support up to 6-storey buildings in the vicinity of the Waterloo bore field and consider possible impacts of these foundations on the underlying Waiwhetū aquifer (T+T, 2022, Appendix C). Based on available site data, the assessment concluded that:

- A large number of deep piles into the Waiwhetū gravels are likely to be required to support a 5-6 storey building in the vicinity of the Waterloo bore field. For typical ground conditions, a nominal 20 m x 20 m development could require 60-80 piles per building.
- For a 3-4 storey structure, deep piles into the Waiwhetū gravels may only be required if ground conditions are poor.
- Alternatively, deep ground improvement (e.g., jet grouting, deep soil mixing) could be used in place of piles for a 3-4, or 5-6 storey structure (with limited height/width ratio). However, this approach is typically more expensive than pile foundations.

This information indicates that if up to 6-storey buildings were permitted by a future District Plan, there could be a scenario where a large number of deep piles are installed into the Waiwhetū aquifer in close proximity to the Waterloo bore field. This would pose significant risk to water quality within the aquifer and jeopardise the security of the Waterloo bore field. As well as construction-related risk, the presence of deep foundations significantly increases the source risk profile, i.e., creation of numerous preferential flow paths with increased risk of shallow/deep short-circuiting of groundwater.

The risks can also be expected to increase following even moderate ground shaking because piles and the surrounding ground move differently under seismic conditions. This movement between foundation and ground in the presence of negative hydraulic gradients presents increased risk of contamination transport into the Waiwhetū Aquifer.

However, the T+T assessment also indicates that alternatives to pile foundations may exist, such as deep ground improvement. Such alternatives may pose some construction-related risk but may not pose the same longer-term risks as deep pile foundations.

5 Conclusions

The Waiwhetū aquifer beneath the Lower Hutt Valley is a critical water source for the Wellington region. Due to the hydrogeology of the aquifer system and the increasing urbanisation of the Lower Hutt area, the potential risks to the water supply are increasing. These risks can be broadly categorised as sources of contamination, creation of contaminant pathways, and water availability risks. These risks, their likelihood and consequences and management interventions have been identified in this document.

Sources of contamination include reticulated wastewater and stormwater, contaminated sites and chemical storage and surface water. Although many of these contaminants are currently managed by various means, more work is required to create an integrated approach to managing contaminant sources in the Lower Hutt Valley. This may include better communication of contaminant storage and discharge between GWRC, HCC and Wellington Water.

Contaminant pathway risks may be exacerbated as Hutt City intensifies (i.e., piling for urban developments); this is of particular concern close to the Waterloo bore field in the Knights Road area. However, these activities could be managed through additional rules to control specific associated activities, such investigation drilling, excavations and wastewater infrastructure.

Strengthening and expanding regulatory approaches to managing the risks identified should be undertaken, particularly for activities in the intermediate source water risk management areas (SPZ 2/2a). This may require amendment to existing Natural Resources and District Plans. In addition, Wellington Water, GWRC and HCC should collaborate on tools that assist their staff in the enforcement of planning instruments and encourage communication between organisations.

Further investigation and assessment of risks through additional monitoring of groundwater quality across the Lower Hutt Valley, as well as predictive scenario modelling will help to improve the understanding of the potential risks identified. This is particularly relevant for risks that are poorly defined but potentially high impact, such as water availability (i.e., saline intrusion, sea level rise).

The findings of this report highlight the need for stakeholders to work together on an ongoing basis, in accordance with the intentions of the Water Services Act and the NES for drinking water.

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Appendix A: Risk assessment definitions

As described in Section 4.1, we have undertaken a high-level assessment of activities that may be a potential risk to source water security at the Waterloo and Gear Island bore fields. To undertake this assessment for each risk, we have adopted qualitative ratings of likelihood and consequence in the tables below based on descriptions described in the Guidelines for Drinking-water Quality Management for New Zealand (Ministry of Health, 2017).

Appendix A: Table A.1: Likelihood definitions

Likelihood ranking	Description
Rare	Is expected to occur within a 25-year timeframe
Unlikely	Is expected to occur within a 12-year timeframe
Possible	Is expected to occur within a 5-year timeframe
Likely	Is expected to occur within a 2-year timeframe
Almost certain	Is expected to occur within a 1-year timeframe

Appendix A: Table A.2: Consequence definitions

Consequence ranking	Description
Insignificant	Insignificant impact, little disruption to normal operation. Isolated exceedance of aesthetic parameter.
Minor	Minor impact on a sub-population, some manageable disruption to normal operation. Potential local aesthetic issues, isolated exceedance of MAV.
Moderate	Minor impact on most of the population, significant (but manageable) disruption to normal operation, requirement for increased monitoring. Potential widespread aesthetic issues, or repeated breach of maximum acceptable value (MAV).
Major	Major impact on a sub-population, significant compromise of systems and abnormal operation, requirement for high level of monitoring and incident management. Potential acute harm to people, declared outbreak or widespread illness expected.
Catastrophic	Major impact on most of the population, complete failure of systems, requirement for high level of monitoring and incident management. Potential acute harm to people, declared outbreak or widespread illness and possible deaths expected.

Appendix B: Risk assessment tables

B1 Key contamination sources (and activities)

B.1: Reticulated Wastewater

Contaminant description		Reticulated wastewater is a primary source of microbial contamination within urban environments. An increase in urban density will increase the pressure on existing assets, which could increase the frequency and severity of leaks/pipe failures.
Risk assessment	**Likelihood**	**Possible** – If a wastewater pipe located close (within SPZ1 or SPZ1a) to the Waterloo bores were to fail, it is possible that contamination could reach the bores.
	Consequence	**Major** – Treatment is in place for microbial contamination, which significantly reduces the risk to human health. However, reliance on a single contaminant barrier contravenes the multi-barrier approach to water security. Furthermore, there are a number of possible contaminants within domestic wastewater that may not be removed by the existing water treatment processes (such as endocrine disruptors, pharmaceuticals etc).
Risk management	**Current**	Managed by Wellington Water asset management and upgrades to infrastructure to meet customer demand (which is somewhat determined by district planning and building consent processing).
	Wellington Water's desired outcome	Controls: • WWL assets (non-regulatory): – Asset Management Plan – Source Water Risk Management Plan • Private Assets (regulatory): – Regional plan o New wastewater pipes within SPZ 1 should be Non-complying or Discretionary Activity. – Update of the Regional Standard (COP) Wastewater asset condition/risk within the SPZ 2a and SZP 2 should be managed by Wellington Water. However, the demand (and need for increases to capacity/upgrades) is a significant interface point between WWL and HCC when planning for new developments within close proximity of Waterloo bore field (i.e., within SPZ 2a). Further risk assessment can be supported by scenario analysis with the HAM5 model.

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B.2: Stormwater reticulation and disposal

Contaminant description	Cumulative effects of stormwater disposal within the unconfined areas of the aquifer, leading to broad-scale changes to source water quality at the Waterloo bore field. With increased interest in water-sensitive urban design, disposal of stormwater to land may become more common.	
Risk assessment	**Likelihood**	**Possible** – Stormwater is currently reticulated throughout the Lower Hutt Valley. Connection between groundwater and the reticulated network are considered likely, but poorly understood. However, any impacts are likely to have been seen already.
	Consequence	**Moderate** – Stormwater can be high in heavy metals and chemical contaminants (i.e., hydrocarbons), which are not treated at the Waterloo WTP. However, pathways of stormwater contamination are likely to be relatively slow (i.e., moving through the shallow subsurface), resulting in attenuation of contaminant loads.
Risk management	**Current**	• NPS FM Whaitua and regional plan will improve WQ in the Waiwhetū Stream over time, this will benefit source water security (if the Waiwhetū Stream is hydraulically connected to the aquifer). • WWL undertakes monitoring of stormwater quality as part of discharge consent compliance. • NRP Rule R51 – Stormwater to land is a PA if > 20m from a bore.
	Wellington Water's desired outcome	• Amend NRP Rule 51 to remove PA status within SPZ 1. • Cumulative effects of the volume and nature of discharges to ground needs to be considered in NRP, particularly over the unconfined area, where the water recharges to the Waiwhetū Aquifer

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B.3: Sea water

Contaminant description	Sea water is a critical risk to the Waiwhetū Aquifer as a large portion of it is beneath Wellington Harbour. Drilling investigations within the harbour indicate that saline intrusion has already occurred within the seaward extent of the aquifer.	
Risk assessment	**Likelihood**	**Almost certain** – Saline intrusion risk already limits Wellington Water's ability to abstract from the aquifer at times – refer Saline Intrusion risk description Sea water may also enter the aquifer where the Petone Marine Beds unit is compromised through anthropogenic (i.e., piling) or natural (i.e., seismic activity) means.
	Consequence	**Catastrophic** – If the aquifer was to become contaminated with saline water, natural attenuation/flushing of the saline water from the aquifer would likely take an extended period of time (i.e., decades), if possible at all. Depending on the extent of the saline intrusion, it may no longer be possible to extract water for potable supply from the Waiwhetū aquifer.
Risk management	**Current**	• Monitoring and maintenance of aquifer pressures and electrical conductivity at the Petone/Seaview foreshore.
	Wellington Water's desired outcome	Refer Saline Intrusion risk description

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B.4: Discharges from contaminated land

Contaminant description	Although passive discharges from contaminated land could pose a risk to water quality at the Waterloo bore field; these are likely to be ongoing and any effects already observed in current/historic water quality results. Disturbance of contaminated land may pose a contamination risk by mobilising contaminants, particularly if within some kind of containment (for example breaching an underground storage tank) or if the disturbance compromises the aquitard in some way. As such, a high level of care needs to be undertaken when disturbing these sites.	
Risk assessment	**Likelihood**	**Rare –** Passive discharges are unlikely to be migrating to the bore field, as evident by water quality monitoring to date. The impact of earthworks on contaminated sites could pose a risk to the bore field, but the potential for migration in sufficient quantities to cause an impact at the bore field is dependant on a number of factors, such as: • Concentrations and volumes of contaminant at the earthworks site • Migration potential of the particular contaminant(s) • Distance from the bore field • Depth of excavations/impact on the aquitard Given that there are very few known contaminated sites within close proximity of the bore field, the likelihood is considered rare that these factors would align, such that contaminants could migrate to reach the bore field in sufficient concentration to cause a human health risk.
	Consequence	**Major** – No treatment barriers are in place for chemical contaminants
Risk management	**Current**	• No specific controls in NRP on disturbing contaminated land. • Excavation deeper than 5m requires resource consent. • NES-SC, managed by TAs, has controls on disturbance of contaminated land if land use changing or being subdivided. • NRP Rule R82 for discharge from verified SLUR Cat III or IV contaminated land in a community water drinking water supply protection area is a permitted activity provided no exceedance of 50% of any MAV in NZDWS at property boundary or within 50 m of source, or in a water supply well on the property or within 50 m of the source. • If Rule R82 not complied with discharge requires a consent, discretionary activity.
	Wellington Water's desired outcome	• Existing SLUR sites within SPZ 2a should have a risk assessment that is sufficiently robust to reflect the high vulnerability of the public water supply, particularly for Categories I, II, III, and IV. • GWRC complete a survey to identify all HAIL sites within SPZ 2a and categorise them. • "Identified, but not investigated" category sites should be assessed for drinking water contamination risk. • Suggest that SPZ 2a is introduced to strictly control the monitoring and disturbance of contaminated sites within this zone. • Regional rules for bore construction (abstraction and investigation bores), dewatering and soil disturbance on actual or potential HAIL/SLUR sites should consider risks to drinking water supplies.

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B.5: Surface water

<table>
<tr><td>Contaminant Description</td><td colspan="2">Hutt River / Te Awa Kairangi
The Hutt River is ultimately the main source of recharge to the Waiwhetū Aquifer. This means that regional-scale changes to land uses and very large contaminant sources may pose a long-term risk to source water quality. This could include examples such as increases to nitrogen in groundwater from application of fertilisers across the catchment.
Cumulative effects of industrial discharges of persistent/conservative contaminants.
Urban waterways (Waiwhetū Stream, Ōpahu Stream)
The Waiwhetū Stream has relatively low water quality and has been shown to interact with the Waiwhetū aquifer in areas of Lower Hutt (generally within the unconfined area of the aquifer). These exchanges may allow contaminated surface water to reach the aquifer. However, given that these exchanges are likely to already be occurring, any impacts are likely to already have been seen. The exception to this would be if something were to change that might increase the groundwater/surface water interaction, such as:
• Modifications to the stream course or stream bed
• Seismic activity.
Other surface water features in the Lower Hutt valley include the Ōpahu Stream, which meanders through the Waterloo bore field. Little is known about water quality in this waterway, or its connectivity with the underlying aquifer system.</td></tr>
<tr><td rowspan="2">Risk assessment</td><td>Likelihood</td><td>Rare – Source water quality shows relatively stable trends for nitrate and general water chemistry. In addition, any impacts are likely to have been seen already.</td></tr>
<tr><td>Consequence</td><td>Major – Although long term changes are easily identified, they are also often very difficult to mitigate because of the regional-scale changes required and the long timeframes. If nitrate levels were shown to be increasing close to appoint where MAVs may be exceeded (noting that the nitrate MAV is likely to be reduced significantly in coming years)
Microbiological contaminants are less of a risk as there are treatment barriers in place. However, elevated turbidity (as observed in the Waterloo bores following the 2016 Kaikoura earthquake) could also result in a WTP shutdown as it adversely effects components of the raw water treatment train.</td></tr>
<tr><td rowspan="2">Risk management</td><td>Current</td><td>• NPS-FM 2020 requires GWRC to set target attribute states for water quality in all freshwater bodies including aquifers by 2024, and to achieve these by 2040. Must also have a freshwater accounting system to monitor and report changes/improvements to water quality. This is also reflected in the Whaitua implementation process.
• GWRC currently undertakes State of the Environment monitoring of water quality in the Hutt River.
• WWL undertakes monitoring of stormwater quality as part of discharge consent compliance.</td></tr>
<tr><td>Wellington Water's desired outcome</td><td>• Ensure that development of GW's nutrient frameworks for Te Awa Kairangi take account of the connectivity to the bore field.
• Assess hydraulic connection between Waiwhetū Stream and Waiwhetū Aquifer using HAM5 model (and other tools), then use these results to influence regulatory controls if necessary.
• NPS-FM, Whaitua and Regional Plan will improve WQ in the Waiwhetū Stream over time, this will benefit source water security (if the Waiwhetū Stream is hydraulically connected to the aquifer).
• Extend the consideration of the impact of river/stream bed works to potential risks to the aquifer (quality and quantity).</td></tr>
</table>

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B.6: Chemical storage and use (industrial sites)

<table>
<tr><td>Contaminant / Activity description</td><td colspan="2">Storage of large volumes of chemicals can pose a risk to source water quality if leakage occurs. This risk is determined by:
• Concentrations and volumes of contaminant stored at the site
• Mobility of the particular chemical (i.e., how easily a particular chemical moves in the environment)
• Distance of the site from the bore field
• How vulnerable the aquifer beneath the site is (i.e., how thick the aquitard is, and whether the aquifer is artesian or not)
New industrial developments within northern portion of Lower Hutt Valley where the Petone Marine Beds are not present could pose a greater risk due to the lack of a barrier to contamination</td></tr>
<tr><td rowspan="2">Risk assessment</td><td>Likelihood</td><td>Likely – Given the location of existing industrial areas to the Waterloo bore field, it is unlikely that significant chemical storage is occurring within close proximity of the bore field.
However, chemical storage and use could be occurring at some distance from the bore field over the unconfined area (for example, at the hospital or at industrial sites)</td></tr>
<tr><td>Consequence</td><td>Catastrophic – There is no treatment barriers in place to remove chemical contamination. Any contamination of the aquifer may take a very long time to attenuate and treatment barriers are extremely expensive to install.</td></tr>
<tr><td rowspan="2">Risk management</td><td>Current</td><td>• Hazardous substances regulated under HSNO Act, but has been subject to recent amendments.
• District plan has provision for “large scale users of hazardous substances” but uncertainty around notification requirements.
• Worksafe NZ may also hold information regarding chemical storages based on their hazardous substance location compliance certification scheme.
• There appears to be limited linkage between MfE and drinking water suppliers/Regional Councils to communicate where HSNO sites are and how these are managed/monitored.</td></tr>
<tr><td>Wellington Water’s desired outcome</td><td>• Greater linkage between HSNO Act and source water risk planning required, to ensure that drinking water source risk is considered. This could be a policy specific to source water risk management areas that HSNO activities need to register with the relevant water supplier and provide copies of their management plans.
• HCC to review information about chemical storage and volumes and share with GWRC/WWL.
• Consideration of contaminant pathways in industrial land use consenting.
• Development of industrial areas within the Hutt River catchment and aquifer recharge zone should consider cumulative impact of industrial developments.</td></tr>
</table>

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B2 Contaminant pathway activities

B.7: Excavation of building basements

Activity Description	Excavations below 2 m within the SPZ 2a of the Waterloo bore field may start to compromise the aquitard, increasing aquifer vulnerability. Excavations for a building basement could be significant in terms of size and depth. This could create a plume of sediment/high turbidity groundwater and may compromise the upper surface of the aquitard. If this is close enough to the bores, high turbidity groundwater could migrate downwards and into the bores.	
Risk assessment	**Likelihood**	**Possible** –
	Consequence	**Major** – A turbidity spike or increasing trend may require Wellington Water to shut down selected bores or the bore field for a period of time to prevent non-compliance. If this was to occur during a critical supply period (i.e., summer), there could be significant disruption to the supply.
Risk management	**Current**	5 m Permitted Activity rule in PNRP
	Wellington Water's desired outcome	• 5 m PA rule within SPZ 2 remains. • Wellington Water to be notified of proposed activities that may disturb below 2 m within the **SPZ 2a**, and ability for the timing, monitoring and site management to be controlled or managed. • Requirement for the developer to consider/assess the risk of their activity on the water supply.

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B.8: Dewatering during excavation/construction

Activity Description	Dewatering during excavation/construction may also be a risk to the supply bores, both in terms of water quality and water availability.	
Risk assessment	**Likelihood**	**Possible**
	Consequence	**Major**
Risk management	**Current**	• Permitted activity in NRP • Consent required for larger takes
	Wellington Water's desired outcome	• 5 m PA rule within SPZ 2 remains. • Wellington Water to be notified of proposed activities that may disturb below 2 m depth within the **SPZ 2a**, and ability for the timing, monitoring and site management to be controlled or managed. • Dewatering activities near SLUR sites within the SPZ 2a should be a discretionary activity. • Requirement for the developer to consider/assess the risk of their activity on the water supply.

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B.9: Drilling investigations

Activity Description	Drilling investigations are often inadequately controlled. Bore sizes are often small (<200mm), using a rotary wash/mud/sonic methods and temporary casing (which is extracted after drilling is complete). This causes an open hole that can sometimes be difficult to decommission appropriately (bridging and cave-ins routinely occur, creating voids). Absolute care needs to be taken during the process to reduce the risk of this occurring. If a permanent installation is being deployed (e.g., a piezometer or monitoring well), an open annulus between the hole and the instrument must be sealed (which can be difficult to achieve, particularly in granular materials). This method of drilling is also poorly suited to artesian conditions, as artesian flows are difficult to control once started. CPT investigations are almost impossible to seal – so rely on cave-in of the sequence. Under sub-artesian conditions, this is relatively low risk, but uncontrollable flows can develop in artesian conditions	
Risk assessment	**Likelihood**	**Possible –** Any development of a significant structures five stories or higher is likely to require intrusive investigations, which are likely to disturb the aquitard in some way. A flow path through the aquitard close to the bore field could allow a direct pathway for contaminants to enter the aquifer.
	Consequence	**Catastrophic –** Some resilience exists within the treatment system to accommodate microbial contamination, but any chemical release or aquifer pressure reduction could cause both short- and long-term issues for WWL.
Risk management	**Current**	All bores require consent, except for investigation or monitoring bores less than 5m deep, which are a permitted activity, bore log must be supplied to GW. WWL is notified, so has some notice/warning to plan shutdowns etc, but no authority to control. Currently an assumed duty of care from drilling contractors – which relies on trust and is likely not always undertaken.
	Wellington Water's desired outcome	**SPZ 2a:** a requirement for a greater level of control/visibility of the drilling methodology and bore design, to address potential cumulative effects and timing so that shut-downs can be planned if necessary. Wellington Water to be notified of investigation bores >2m depth within the SPZ 2a, and have some ability to influence the bore design/methodology and timing, so that shut-downs can be planned if necessary. **SPZ 2:** Confidence that the drilling and bore construction methodology will not allow contaminants to migrate into the aquifer, either during the drilling, or use of the bore; or after decommissioning.

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B.10: Ground source heating/cooling

<table>
<tr><td>Activity Description</td><td colspan="2">Groundwater abstraction/injection systems for building heating and cooling are typically non-consumptive (i.e., abstracted groundwater is often reinjected, so no net removal of groundwater.

However, the installation of these systems creates a contaminant pathway into the aquifer and often use chemicals (i.e., coolants) in the above-ground infrastructure that could pose a risk to the water supply. This could result in contaminants being introduced directly into the aquifer, if not monitored and maintained appropriately.

Individually these systems are likely to cause only localised changes in groundwater chemistry. However, there is currently some uncertainty regarding cumulative impacts.

Another risk from a source water risk perspective is where groundwater reinjection does not occur into the same aquifer/sub-aquifer as the water was abstracted from. In this case, the system is essentially consumptive, whereby water may be removed from the production aquifer.</td></tr>
<tr><td rowspan="2">Risk assessment</td><td>Likelihood</td><td>Rare – The likelihood of a leak of coolant/refrigerant from a HVAC system is very low, but if a leak did occur it could migrate to the bore field (if the volume of contaminant injected was large enough and the injection was close enough to the bore field).</td></tr>
<tr><td>Consequence</td><td>Major – If a contaminant leak was able to migrate to the bore field, no treatment barriers are in place to manage the risk. The bore field would need to be shut-down (causing water supply issues) either until the contaminant plume passed (which could take decades), or a treatment process installed to remove the contamination (likely extremely expensive). Over and above the absolute risk, there is also a public perception risk.</td></tr>
<tr><td rowspan="2">Risk management</td><td>Current</td><td>• NRP Rule R136 take and use of water permitted activity up to 2.5L/s and 10m^3/day. If exceeded consent required under Rule R142.
• Discharge controlled under NRP Rule R42 minor discharge to (ground)water permitted activity, subject to vague conditions (e.g., no adverse effect beyond the property boundary).
• NRP Policy P132 specifies that “taking of groundwater … shall not result in cross-contamination between aquifers … that may result in adverse effects in water quality”. However, not clear how this is controlled.
• No standard approach to assessing the potential effects as these systems are not widespread in the Lower Hutt Valley.</td></tr>
<tr><td>Wellington Water’s desired outcome</td><td>• SPZ 1: Activity not permitted.
• SPZ 2a: Controlled activity status, with the following conditions:
– Any water chemistry or temperature changes are acceptable.
– The system is adequately monitored over its life span.
– Can be ceased without delay if necessary or be reviewed if unexpected effects occur.
– Abstracts and re-injects into the same aquifer unit.
– Assessment of cumulative impacts related to water chemistry or temperatures is undertaken and the activity can be paused or prevented if necessary due to cumulative effects in relation to any of the above points.
• SPZ 2: Permitted activity, with the following conditions:
– Assessment of cumulative impacts related to water chemistry or temperatures and the ability to prevent the activity if necessary due to cumulative effects.
– Abstracts and re-injects into the same aquifer unit.
• Develop guidance and tools to assist GWRC with consenting.</td></tr>
</table>

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B.11: Deep pile foundations penetrating into the Waiwhetū Aquifer

Activity Description		Construction of deep foundation piles into the Waiwhetū aquifer. These effects may be exacerbated by poor installation practices.	
		Short term	**Long term**
		During construction, the disturbance created by deep pile drilling may pose a turbidity risk to the aquifer/public supply bores. However, this risk is highly dependent on the location of the piles in relation to the bore field (up-gradient and close to the bores is very high risk). During this time, the piles also create potential pathways for contamination to reach the aquifer (depending on the pile design/method).	Longer-term, deep piles could pose a contaminant pathways risk by causing defects in the aquitard. This is of particular concern following seismic events, where new aquitard defects could be created. In situations where large numbers of piles are installed, this could create a cumulative effect, whereby relatively large volumes of low-quality shallow groundwater is able to migrate downwards into the aquifer though a "pin-cushion" effect. This could cause a widespread decline in water quality within the Waiwhetū Aquifer.
Risk assessment	**Likelihood**	**Possible –** If located within close proximity of the Waterloo bores, a turbidity plume and long-term leakage risk is highly likely to impact on the bores to point where shutdowns may be required. The risk becomes more uncertain with distance from Waterloo, with the short-term turbidity risk reducing with distance.	**Unlikely –** Long-term risk from piles during seismic events, particularly where poorly installed. Long-term cumulative risk from a large number of deep piles (but reduces to a lesser degree with distance).
	Consequence	**Major**– If not planned for, short-term turbidity impacts to the Waterloo bore could require bores to be shut-down, which causes water supply issues.	**Catastrophic** – The long-term/cumulative risk could cause a general decline in water quality at Waterloo. Depending on the nature of the resulting water quality, this may pose a human health risk (i.e., if a pulse of contamination was to follow a seismic event), or require WTP upgrades (at significant expense). No treatment in place for chemical contaminants means that any conservative contaminants that are able to migrate (e.g., PFAS) could have catastrophic consequences to the supply
Risk management	**Current**	NRP Policy P132 specifies that "ground disturbance shall not result in cross-contamination between aquifers … that may result in adverse effects in water quality". NRP Rule 168 specifies that these types of activities deeper than 5 m within the community drinking water supply protection area (i.e., SPZ 2/2a) is a discretionary activity.	

	Wellington Water's desired outcome	• Update NRP Policy P132 to include water quantity or aquifer pressures also. • Develop guidance for installation, monitoring and certification of pile structures. • **Both SPZ 2a and SPZ 2:** – Develop installation guidance, including installation certification (Chartered Engineer). – Mitigation of short-term risks through monitoring and shut-down (where necessary). – Mitigation of long-term risk through appropriate installation and certification. – Pile type and installation method will be determined by bearing strength requirements, ground conditions and aquitard thickness/competency, so needs bespoke installation procedures. – Cumulative issues for the water supply are likely for poorly installed piles.

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B.12: Removal or decommissioning of existing structures

Activity Description	Removal or decommissioning of existing structures (e.g., piles)	
Risk assessment	**Likelihood**	**Likely** – Wellington Water sometimes receives Affected Party notifications for removal of structures
	Consequence	**Major** – poorly implemented removal could result in aquifer depressurisation, as well as creation of a contaminant pathway
Risk management	**Current**	R164 – Decommissioning or sealing of bores. Notification as an affected party.
	Wellington Water's desired outcome	Within SPZ 2A and SPZ 2 - An ability to input into decommissioning methods and require as-built records. A requirement for landowner(s) to decommission unused or abandoned structures deeper than 5 m for SPZ 2 and 2 m for SPZ 2A.

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B.13: Unused or abandoned bores/monitoring wells

Activity Description	Unused or abandoned bores/monitoring wells	
Risk assessment	**Likelihood**	**Possible**
	Consequence	**Major** – creation of a contaminant pathway; could result in aquifer depressurisation during seismic events.
Risk management	**Current**	NRP Rule R164
	Wellington Water's desired outcome	• Within SPZ 2A - An ability for Wellington Water to provide input into decommissioning methods and require as-built records. • A requirement for landowner(s) to decommission unused or abandoned bores deeper than 2 m.

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B.14: Earthworks in river/stream beds

Activity description	Earthworks in river/stream beds, which may include extraction of sand and gravel for flood protection purposes. It is considered likely that recharge of the Waiwhetū Aquifer from Te Awa Kairangi is partly controlled by the river morphology and that gravel extraction may, therefore, impact river recharge to the aquifer system. However, this recharge process is only partly understood.	
Risk assessment	**Likelihood**	**Likely** – GWRC occasionally undertakes gravel extraction in the Hutt River as part of flood protection works. In addition, the Riverlink development will require amendment of the Hutt River morphology, although this is expected to occur downstream of the main recharge zone.
	Consequence	**Major** – The effect of gravel extraction in the river recharge zone is unclear, but altered recharge behaviour is expected as hydraulic gradients between the river and aquifer are changed.
Risk management	**Current**	Under NRP Rule 133, gravel extraction for flood protection purposes is a discretionary activity.
	Wellington Water's desired outcome	• Ensure that assessments of effects appropriately consider the potential for impacts on drinking water sources in connected aquifer systems, and that the standard of assessment is proportional with the consequence of the risk materialising. This relates to the principles of high standard of care and the paramount importance of protecting drinking water sources. • Development of guidance about the standard of hydrogeological assessment that would be considered appropriate for this activity. This may incorporate additional modelling using HAM5 to better understand risks and effects of management interventions.

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B3 Water availability risks

B.15: Saline intrusion

<table>
<tr><td>Activity description</td><td colspan="2">Saline intrusion into the Waiwhetū Gravels is considered a significant risk to the aquifer. Recent investigative drilling in the Wellington Harbour has shown that areas of the lower Waiwhetū gravels already has brackish water within it. This suggests that saline intrusion has already occurred within the seaward extent of the aquifer and reinforces the reality of the risk.

Further intrusion of saline water into the aquifer is currently managed by maintaining artesian pressure within the aquifer at the foreshore. If groundwater pressure is decreased (through cumulative effects of abstraction or a confinement failure), saline water could enter the aquifer, which could pose long-term catastrophic water quality issues.</td></tr>
<tr><td rowspan="2">Risk assessment</td><td>Likelihood</td><td>Almost certain – Saline intrusion risk already limits Wellington Water’s ability to abstract from the aquifer at times. These events happen in summer, when the Waterloo source is critical to maintaining drinking water supply. This means that if water levels at the foreshore decline, Wellington Water will continue to be constrained more often, and likely for longer periods of time which could cause significant water supply issues for the region.

Saline intrusion could be further exacerbated by increased groundwater abstraction from the Waiwhetū Aquifer, particularly if abstracted close to the foreshore.</td></tr>
<tr><td>Consequence</td><td>Catastrophic – If the aquifer was to become contaminated with saline water, natural attenuation/flushing of the saline water from the aquifer would likely take an extended period of time (i.e., decades), if possible at all. Depending on the extent of the saline intrusion, it may no longer be possible to extract water for potable supply from the Waiwhetū aquifer.</td></tr>
<tr><td rowspan="2">Risk management</td><td>Current</td><td>Groundwater levels are closely monitored by Wellington Water and GWRC near the Petone foreshore. To manage the risk of saline intrusion, Wellington Water’s consent conditions restrict abstractions when groundwater levels at the foreshore drop below 2.3 m above ground (i.e., to maintain a slight artesian pressure, necessary for operation of the pumps/bore field). However, it is unclear whether these conditions also apply to other groundwater takes close to the foreshore.

Wellington Water and GWRC routinely enter an “alert-level” situation when aquifer levels drop below 2.5 m at the foreshore in summer. During these times, GWRC closely monitors electrical conductivity and sodium chloride levels within monitoring bores along the Petone foreshore to observe any indications that saline intrusion may be occurring. In some instances, Wellington Water have reduced abstraction rates at the Waterloo bore field to prevent aquifer levels at the foreshore from dropping below 2.3 m.</td></tr>
<tr><td>Wellington Water’s desired outcome</td><td>• Establishment of a buffer zone along the Petone and Seaview foreshore area preventing any new abstraction bores from being consented.
• Applying saline intrusion conditions on other groundwater within the foreshore buffer zone.
• Revision of SPZ 2 to include offshore portion of the aquifer
• Review of saline intrusion risks based on additional scenario modelling using HAM5.</td></tr>
</table>

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B.16: Impacts to recharge of the Waiwhetū Aquifer from the Hutt River

Activity description	As described in Section 3.2, the Lower Hutt aquifer system is finely balanced between the amount of water recharging the aquifer, the amount of water being abstracted by Wellington Water, and saline intrusion at the coast. Any disruption of the balance could significantly impact on Wellington Water's ability to abstract from Waterloo. This is because any impact on the amount of water recharging to the aquifer from the Hutt River may impact on aquifer pressures within the confined portion of the aquifer, including at the foreshore and beneath the harbour, which will exacerbate saline intrusion into the aquifer. Along with presenting a water quality risk, this may also significantly limit Wellington Water's ability to abstract groundwater at Waterloo. Greater abstraction from the Hutt River could reduce recharge to the aquifer, as could physical modification of the riverbed. Given the complexity and connected nature of the surface water and groundwater systems, additional care is needed to assess potential impacts. Particular regard is required in the specialist area of uncertainty analysis.	
Risk assessment	**Likelihood**	**Almost certain** – Any impacts to recharge of the aquifer are likely to impact Wellington Water's ability to abstract water from the Waterloo bore field. However, the magnitude of impact relates to the quantum of recharge reduction and when this occurs (summer vs winter**)**
	Consequence	**Major** – Given the current reliance on Waterloo during the summer months, any impact to Wellington Water's access to this resource is likely cause water supply issues for the majority of the Wellington Region.
Risk management	**Current**	• NRP controls certain activities that may impact recharge (i.e., earthworks with the Te Awa Kairangi active channel), but no explicit links with source water risks. • NPS-FM and Whaitua Implementation Programme have implications for how recharge impacts are considered and managed.
	Wellington Water's desired outcome	• Assess potential impacts of river morphology changes on river recharge using HAM5. • Monitor impacts of gravel extraction or river reshaping on recharge. • Linkage between Whaitua implementation programmes and NPS-FM needs to be better understood.

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B.17: Changes to minimum environmental flows or groundwater allocation

Activity description	GWRC Whaitua – redefine minimum low flow. WWL become more reliant on groundwater allocation	
Risk assessment	**Likelihood**	**Possible**
	Consequence	**Moderate**
Risk management	**Current**	• NPS-FM and Whaitua require prioritisation of environmental flows for waterways
	Wellington Water's desired outcome	• Linkage between Whaitua implementation programmes and NPS-FM needs to be better understood. • Water supply impacts to be considered when assessing minimum environmental flows as part of the Whaitua Implementation Programme.

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B.18: Increased groundwater abstraction from other parties

Activity description	Increased groundwater abstraction from the Lower Hutt groundwater zone could result in a reduction of pore water pressures in the aquifer; this may, in turn, impact on Wellington Water's ability to supply water. Although Wellington Water abstracts groundwater from the Waiwhetū Aquifer, it is likely that groundwater abstraction from any of the hydrostratigraphic units in the Lower Hutt groundwater zone would affect the entire aquifer system due to the level of hydraulic connectivity. Any abstraction in summer would have the most impact on Wellington Water, but even abstraction in winter may intercept water that would otherwise contribute to storage within the aquifer, which is taken up during summer.	
Risk assessment	**Likelihood**	**Rare –** Additional groundwater abstraction is prohibited
	Consequence	**Major** – Considerable impacts to Wellington Water's ability to supply water, and increased saline intrusion risks. Impacts would not necessary be permanent, provided that abstraction that was causing the abstraction could be ceased, which somewhat reduces the consequence
Risk management	**Current**	• We understand that the Waiwhetū aquifer is fully allocated, so any further consumptive groundwater abstraction is prohibited. It is not clear how/if groundwater take consents from other hydrostratigraphic units could be considered. • No consideration of river or rainfall recharge in the current NRP.
	Wellington Water's desired outcome	• No additional action required, other than requesting that any future "non-complying activity" applications be considered from this perspective and notified to Wellington Water. • Opportunity to clarify rules that the Hutt River and Lower Hutt aquifer system are fully allocated. • An integrated holistic connectivity approach (cf. Whaitua Implementation Plan) to reflect connection between river, aquifer and saline interface should be undertaken to protect the groundwater resource. This could include a wider capture of activities that have the potential to impact recharge or discharge. • Additional analysis of aquifer system behaviour under full abstraction of the existing groundwater allocations using the HAM5 model.

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B.19: Climate change and sea level rise

Activity description	Given the uncertainty associated with climate change, it is reasonable to expect that changes to weather patterns and increases in sea levels will naturally change the existing balance between recharge, abstraction and saline intrusion within the aquifer. Although not within the mandate of regulatory control, climate change will likely cause a natural increase to the sensitivity of the system and as a result, vulnerability of the Wellington Water supply to impacts from anthropogenic impacts.	
Risk assessment	**Likelihood**	**Almost Certain –** Climate change and associated sea level risk is now widely accepted as inevitable. However the magnitude and timing is uncertain, which will ultimately determine how/when Wellington Water is impacted.
	Consequence	**Major –** Likely a slow decline in water availability, that will present as a greater frequency and duration of events where Wellington Water cannot abstract from the aquifer because of aquifer pressure trigger limits at Petone foreshore. It has been previously assessed that a 1.5m rise in sea level is expected to require a 30% reduction in aquifer yield to compensate for the greater potential for saline intrusion (Earth in Mind Ltd, 2014).
Risk management	**Current**	• We understand that the Waiwhetū aquifer is fully allocated, so any further consumptive groundwater abstraction is prohibited. It is not clear how/if groundwater take consents from other hydrostratigraphic units could be considered. • No consideration of river or rainfall recharge in the current NRP.
	Wellington Water's desired outcome	• Ensure that climate change impacts are considered in future resource allocation planning. This may be incorporated into the water allocation framework as part of Whaitua Implementation Programme (e.g., Whaitua Rec 88.). • Designate exclusion zones for abstraction (Petone/Seaview foreshore) to address increased saline intrusion risks, including under climate change.

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Appendix C: Desktop Geotechnical Seismic Assessment

Tonkin & Taylor Ltd, 18 January 2022. *Knights Road Wellfield, Lower Hutt: Desktop Geotechnical Seismic Assessment (1019079.1000).* Letter report prepared for Wellington Water Ltd. ACT26-1350569271-1247

Tonkin+Taylor

Job No: 1019079.0000
18 January 2022

Wellington Water
Private Bag 39804
Wellington Mail Centre 5045

Attention: Geoff Williams

Dear Geoff

Knights Road Wellfield, Lower Hutt
Desktop Geotechnical Seismic Assessment

1 Introduction

This report presents a geotechnical desktop assessment for possible redevelopment around Knights Road well fields, Lower Hutt (refer Figure A1, “Site Plan” included in Appendix A). The study was undertaken by Tonkin & Taylor Ltd (T+T) at the request of Wellington Water (WW) in accordance with our letter of engagement dated 29 October 2021. T+T have sought structural input to this from their subconsultant, Dunning Thornton Consultants Ltd (DTC).

We understand that Hutt City Council (HCC) is applying for a plan change to allow development of up to 6-storey high buildings in the Lower Hutt area. This report considers the likely type and depth of foundations required to support these taller buildings and the possible impact of these foundations on the underlying Waiwhetu aquifer.

This report presents:

- A summary of findings of a desktop assessment:
  - Likely soil/rock profile at the site.
  - Site seismic subsoil class in terms of NZS1170.5:2004.
- An outline of possible foundation concepts for buildings ranging from single storey up to 6-storeys; particularly where a building height could require consideration of foundations extending into the Hutt aquifer. These foundation concepts have been developed with high-level structural input (possible structural forms) from DTC.

2 Desktop assessment

2.1 Site description

Conclusion	Information reviewed
· Refer Figure A1 (site plan), in Appendix A. · The site is relatively flat and is approximately 650m southeast of the Hutt River. It is adjacent to Queensgate Shopping Centre. · Site area: approx. 280,000m^2 (28 hectares).	· Aerial photograph source: refer Figure A1 in Appendix A.

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- The site is currently occupied by existing residential houses, school buildings, sport fields and roadways. - The site is located within the Hutt aquifer protection zone. - The Opahu (Black Creek) stream meanders through the site. The mainly open channel stream is part of the area stormwater system and begins approx. 1km northeast of the site (near Boulcott Street), meandering southward into the Hutt River at Whites Line West.	- Ground surface elevation (LiDAR) data: LINZ Data Service - Opahu stream: GWRC GIS Database Wellington Water Website

2.2 Ground and groundwater conditions

Conclusion	Information reviewed

- Refer Figure A1 (site plan), in Appendix A and Figure B1 included in Appendix B.
- Available geotechnical data within the site includes:
  - 3 No. boreholes (BH) drilled up to approx. 8m depth
  - 1 No. borehole (BH01) drilled into the Hutt aquifer, to a final depth of 40m.
  - 8 No. Cone Penetration Tests (CPT) to approx. 10m depth.
- The typical soil profile/geological sequence expected at the site (also refer to Figure B1):
  - FILL: Limited available data. Inferred to be mixed granular and cohesive FILL, varies, up to 1m thick.
  - UPPER TAITA ALLUVIUM: Very loose SAND and very soft SILT, extending up to approx. 8m depth below the ground surface. These soils are also referred to as 'river overbank deposits' within floodplain areas.
  - LOWER TAITA ALLUVIUM: Dense GRAVEL, typically 3m to 5m thick.
  - PETONE MARINE DEPOSITS: Medium dense to very dense SAND and GRAVEL, and soft to firm SILT. Up to 9m thick. The aquitard, typically present as predominantly overlapping discontinuous beds of clay/silt, is found within the Petone Marine Deposits stratum.
  - WAIWHETU GRAVEL (HUTT AQUIFER): Very dense GRAVEL, proven in BH01 to 21m thickness.
  - BEDROCK: SANDSTONE (Greywacke), SILTSTONE and MUDSTONE (Argillite). Approximately 150m to 200m below ground surface.
- Groundwater is inferred to be located at 1.5m to 2m depth below the ground surface.
- Beyond the site boundaries data has indicated the Lower Taita alluvium to be locally thin (<3m) or absent. We cannot discount the possibility of similar local effects within the site boundary.
	- 1:50,000 geological map 22 (Begg, J.G.; Mazengarb, C., 1996).
	- "*It's Our Fault – Geological and Geotechnical Characterisation and Site Class Revision of the Lower Hutt Valley*". (D. Boon et al, 2010)
	- New Zealand Geotechnical Database (NZGD).
	- Opahu Stream history: "*Lower Hutt Past and Present (1941)*", Hutt City Online Library

2.3 Other Considerations

In order to develop concept designs of foundations to support buildings up to 6 storeys high it has been necessary to understand the geotechnical issues to be addressed by these foundations. Appendix C presents our evaluation of likely geotechnical issues within the site.

3 Possible foundation concepts

Appendix B presents feasible foundation concepts for three ground scenarios. DTC advised the conceptual structural forms presented (refer Appendix D for the structural basis of the summary sketches presented in Appendix B).

Figure B1 presents the typical ground profile of this site based on limited available ground information. However, given the inherent variable nature of the ground, two other scenarios (i.e. poorer ground (Figure B2) and better ground (Figure B3) compared to the typical ground shown in Figure B1) are also presented to provide an understanding of their impact to the foundation concepts. These ground scenarios may exist as a localised poorer or better ground within this site. The three scenarios presented in Appendix B provide an indication of the range of possible ground conditions for the wider Lower Hutt area.

Any pile type penetrating the aquitard presents a risk of leakage. This includes screw, driven and bored piles. Double casing techniques can be used to reduce this risk but a residual risk of leakage would remain and these systems add considerable cost. It is difficult to detect if leakage has occurred. Water pressure monitoring can be undertaken to provide indications of leakage but this can be costly and include some uncertainty. In the long term if aquifer contamination or other adverse effects occur it can be difficult to identify the cause, i.e. leakage due to pile penetration or other cause.

As indicated in Appendix B it is likely that structural and foundation systems are available to support buildings up to 6 stories high without extending piles through the aquitard, and thus mitigate this risk of leakage.

4 Further work

The following stages of further work are recommended for a typical development at this site:

- Resource consent application for site specific investigations (e.g. boreholes, cone penetrometer testing).
- Site-specific investigations to collect subsoil and groundwater data and identify suitable founding stratums, particularly the presence and thickness of the Lower Taita Alluvium.
- Analyse site investigation data including liquefaction assessment. Foundation optioneering and concept design. Project team (geotechnical engineer, structural engineer and principal/owner) to collaboratively select preferred foundation option.
- Preliminary design including resource consent for foundations where applicable.
- Developed design.
- Detailed design.
- Construction monitoring.

5 Applicability

This report has been prepared for the exclusive use of our client Wellington Water , with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Recommendations and opinions in this report are based on data from BHs and CPTs. The nature and continuity of subsoil away from the BHs and CPTs are inferred, and it must be appreciated that actual conditions could vary from the assumed model.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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Appendix A: Figures

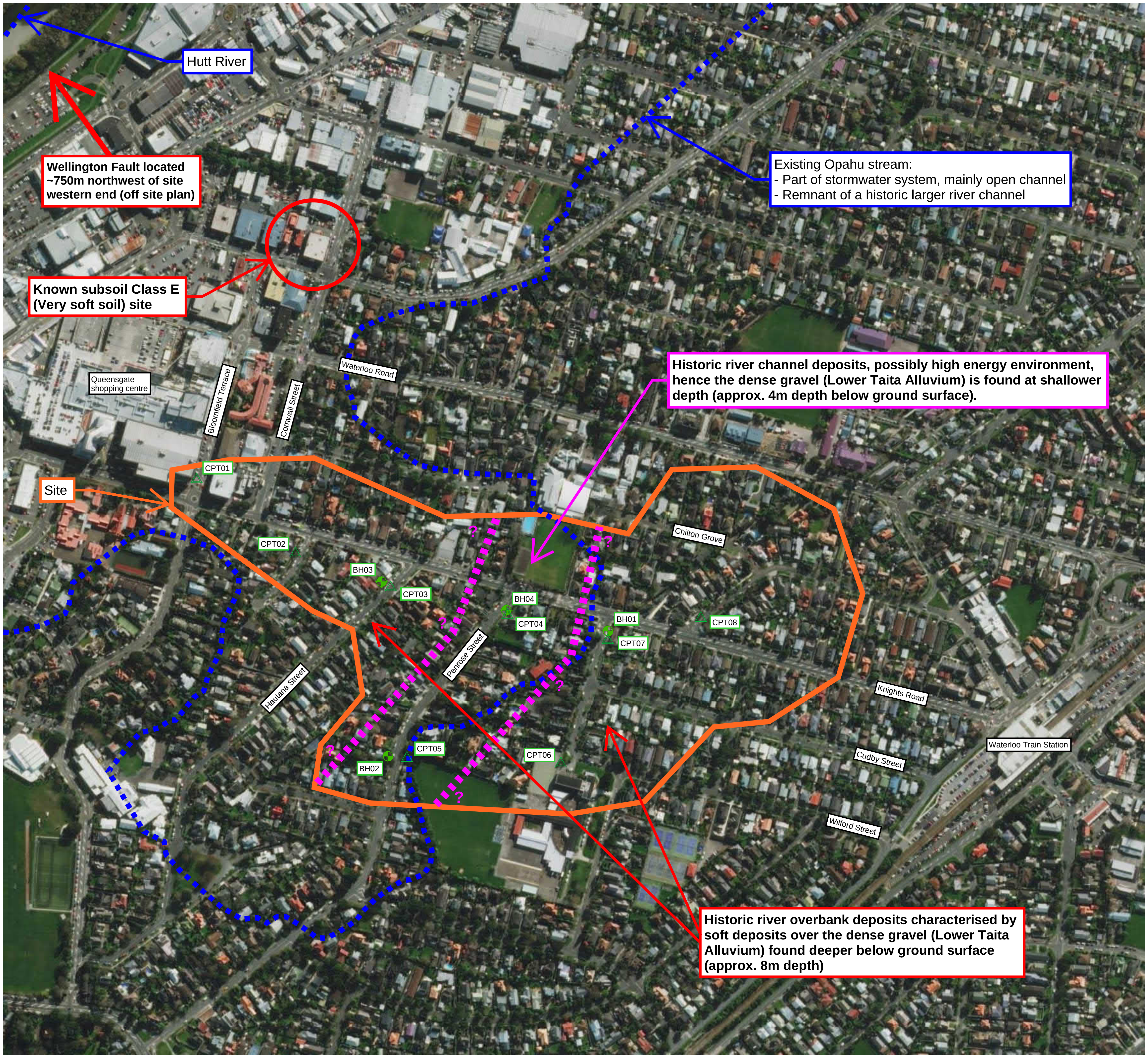
Appendix B: Foundation Concepts

Appendix C: Geotechnical Issues Identified

Appendix D: Structural Basis of Foundation Concepts

Appendix A Figures

- Figure A1 - Site Plan



LEGEND

- Approx. site boundary
- Approx Opahu stream alignment
- Approx. extent of historic river channel based on site geology and GNS description of such feature across Lower Hutt.
- Approx. location of known subsoil Class E site
- Existing T+T borehole (BH)
- Existing T+T CPT

A3 SCALE: 1:5,000

0 50 100 150 200 250 (m)

N

1. World Imagery Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Created On:	16/11/2021
Created By:	ARolfe
Approved By:	
TT Proj Ref:	1019079
TT Map Ref:	TTMAPREF1433463001.902

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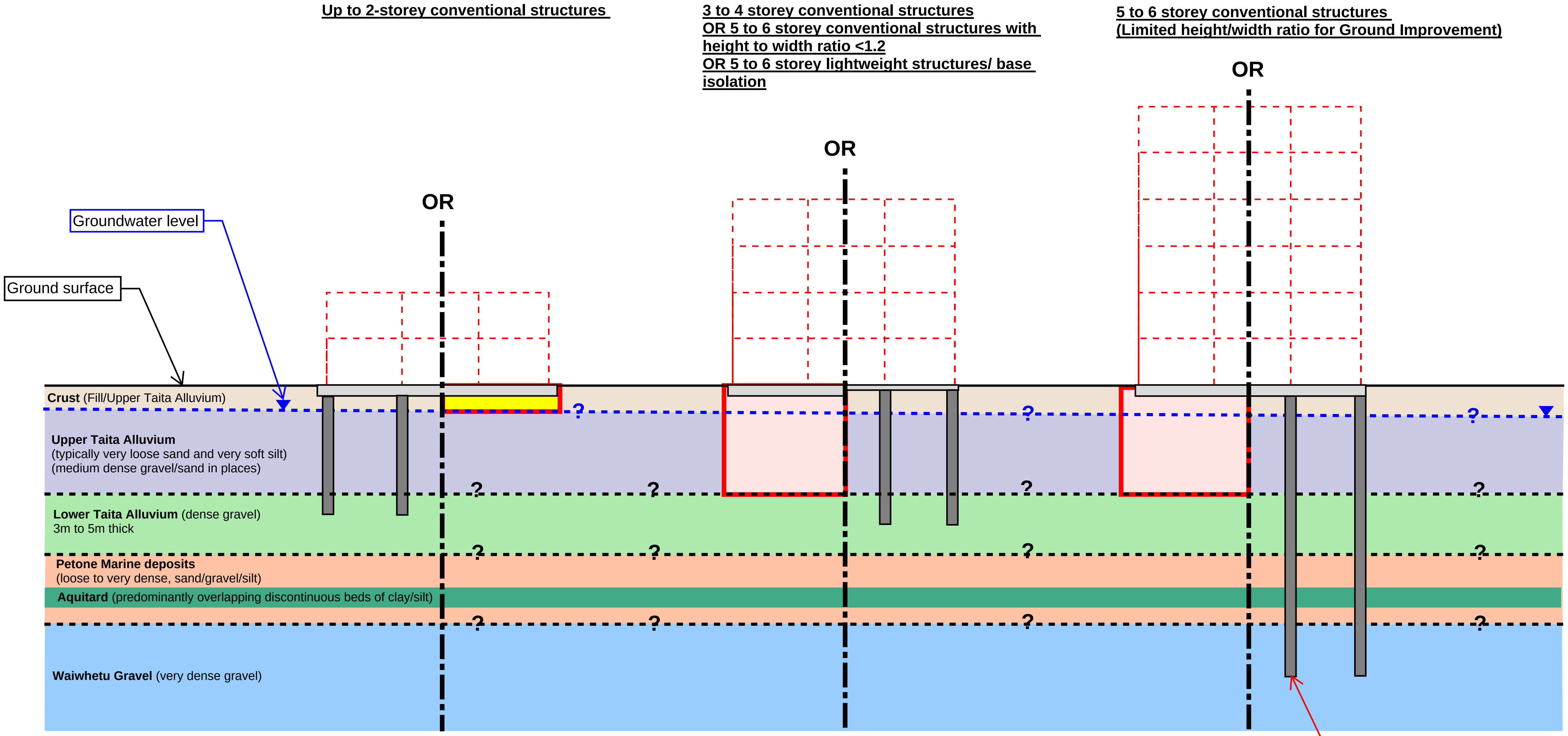
Wellington Water
Knights Road, Wellfield, Lower Hutt
Geotechnical Desktop Assessment
Site Plan

FIGURE No. **A1**

Appendix B: Foundation Concepts

- Figure B1 - Foundation concepts for Ground Scenario 1 (Typical ground based on desktop study)
- Figure B2 - Foundation concepts for Ground Scenario 2 (Possible localised poorer ground)
- Figure B3 - Foundation concepts for Ground Scenario 3 (Possible localised better ground)



Deep foundations to found in Waiwhetu gravels:

1) Expect large diameter bored pile say 0.9m to 1.5m diameter on a 6m to 8m grid; OR
2) Expect 4 to 6 No. smaller diameter piles (say 0.6m to 0.75m diameter) to replace one large diameter bored pile.

For example, for a 20m x 20m development, expect 15 to 20 No. large diameter bored piles or 60 to 80 No. smaller diameter piles.

Ground Scenario 1 : Typical Ground Profile of Site Based on Desktop

= Shallow Ground Improvement (e.g. Geogrid Reinforced Gravel Raft)

= Deep Ground Improvement (e.g. Jet grouting, Deep Soil Mixing)

= Deep Foundation (e.g. Bored Piles, Screw Piles, Driven Steel Piles)

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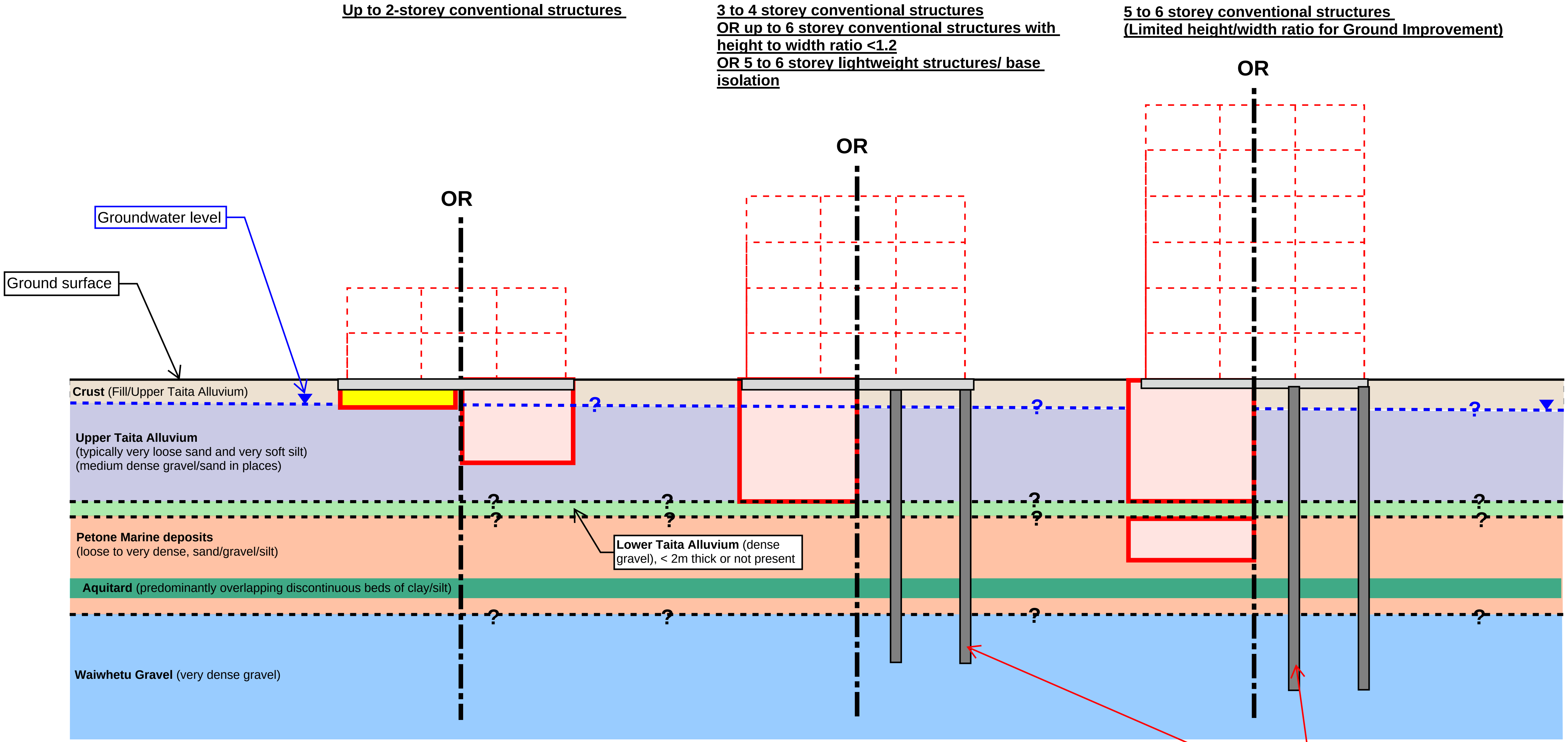
Ground Scenario 1

FIG. No. **B1**

REV. 1



Ground Scenario 2 : Possible Localised Poorer Ground

Deep foundations to found in Waiwhetu gravels:

1) Expect large diameter bored pile say 0.9m to 1.5m diameter on a 6m to 8m grid; OR
2) Expect 4 to 6 No. smaller diameter piles (say 0.6m to 0.75m diameter) to replace one large diameter bored pile.

For example, for a 20m x 20m development, expect 15 to 20 No. large diameter bored piles or 60 to 80 No. smaller diameter piles.

= Shallow Ground Improvement (e.g. Geogrid Reinforced Gravel Raft)

= Deep Ground Improvement (e.g. Jet grouting, Deep Soil Mixing)

= Deep Foundation (e.g. Bored Piles, Screw Piles, Driven Steel Piles)

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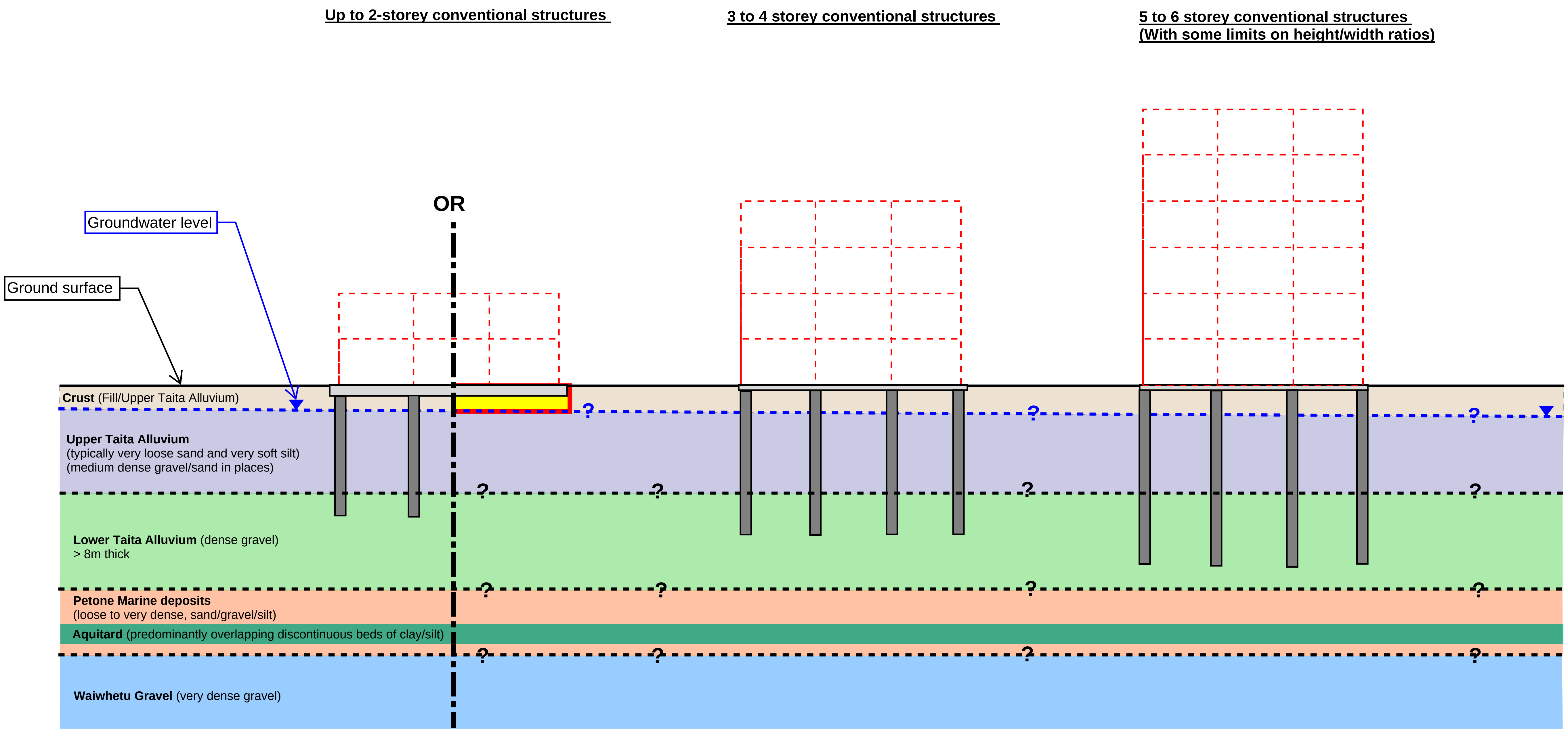
Ground Scenario 2

FIG. No. **B2** REV. 1



Ground Scenario 3 : Possible Localised Better Ground

= Shallow Ground Improvement (e.g. Geogrid Reinforced Gravel Raft)

= Deep Ground Improvement (e.g. Jet grouting, Deep Soil Mixing)

= Deep Foundation (e.g. Bored Piles, Screw Piles, Driven Steel Piles)

Tonkin + Taylor Environmental & Engineering Consultants 2 Hunter Street, Wellington, New Zealand www.tonkintaylor.co.nz	DRAWN ANRO DRAFTING CHECKED APPROVED FILE : - N.T.S	**Wellington Water** Knights Road Well Field, Lower Hutt Geotechnical Desktop Assessment Ground Scenario 3	
	PROJECT No. 1019079	FIG. No. B3	REV. 1

Appendix C: Geotechnical Issues Identified

Geotechnical earthquake engineering assessment

Active Faults

Conclusion	Information reviewed
· The Wellington Fault lies approximately 750m northwest of the site. · The Wellington Fault is included in Table 3.6 of NZS 1170.5:2004 as a major fault requiring near fault factors when assessing structural design actions. · The Whitemans Valley Fault lies approximately 6km southeast of the site.	· GNS Online database of active faults, https://data.gns.cri.nz/af/ · NZS1170.5: 2004 Section 3.1.3 and Table 3.6

Previous earthquakes

Conclusion	Information reviewed
· The following notable earthquakes have been felt at the site since 2013: Cook Strait Earthquake (21 July 2013 at 5.09pm) Location: Cook Strait, approx. 65km from site Magnitude: M_L 6.5 Focal depth: 13km Intensity felt at site: PGA 0.1g recorded at the Lower Hutt Emergency Management Office, approx. 500m west of site Lake Grassmere Earthquake (16 August 2013 at 2.31pm) Location: Lake Grassmere, approx. 80km from site Magnitude: M_L 6.6 Focal depth: 8km Intensity felt at site: PGA 0.07g recorded at the Lower Hutt Emergency Management Office, approx. 500m west of site Kaikōura Earthquake (14 November 2016 at 12:02am) Location: 15km northeast of Culverden Magnitude: M_L 7.8 Focal depth: 15km Intensity felt at site: PGA 0.17g recorded at the Lower Hutt Emergency Management Office, approx. 500m west of site · No known evidence of ground damage at the site as a consequences of these earthquakes.	· Earthquake event characteristics: http://geonet.org.nz/

Seismic site subsoil class

Conclusion	Information reviewed
Site subsoil class is assessed to be Class D (Deep/soft soil site). A known Class E site is located approx. 300m north of the site, refer Figure A1 in Appendix A. Accordingly we cannot discount the possibility of localised Class E (Very soft soil site) within the site area.	· Refer Section 2.2. · NZS1170.5:2004 · "*NZS1170.5:2004 Site Subsoil Classification of Lower Hutt*". (Boon, D. et al, 2011)

Ground shaking hazard

The seismic hazard in terms of peak ground acceleration (PGA) and magnitude (M) for the site has been assessed based on NZGS Module 1 (2021), Method 1. Table C1 presents the return periods for earthquakes with various peak ground accelerations (PGA) with a corresponding earthquake magnitude.

Table C1: Ground shaking hazard

NZS 1170.5 Limit State	PGA (g)	Magnitude (M)	Return period (years)
Ultimate limit state: ULS_{IL2} (ULS_{IL3})	0.68 (0.91)	7.7 (7.7)	500 (1000)
Serviceability limit state: SLS_{IL2} (SLS_{IL3})	0.13 (0.13)	6.5 (6.5)	25 (25)

Note:

PGA and magnitude has been assessed based on NZGS Module 1 (2021), Method 1, for the following:

Building design life	50 years
Building importance level	IL2 and (IL3) (NZS 1170.0:2004, Table 3.2)

The Kaikoura M7.8 earthquake recorded a PGA of 0.17g at the Lower Hutt Emergency Management Office. Applying the magnitude weighting procedure of Idriss and Boulanger (2014)[1] to this record yields a PGA of 0.18g at M_w = 7.7, which is approx. 25% ULS_{IL2} shaking and 20% ULS_{IL3} shaking.

Liquefaction assessment

Liquefaction potential

The triggering of liquefaction, for each soil layer identified as being susceptible to liquefaction, has been assessed in accordance with the procedure of Idriss and Boulanger (2014)[1]. This method is based on empirical relationships with the SPT 'N'/CPT 'q_c' and fines content. The eight CPT and four BH within the site have been assessed. The conclusions are summarised in the table below.

Table C2: Liquefaction potential

Soil Layer	Conclusion
FILL (above groundwater)	This layer is located above the groundwater level therefore liquefaction is not expected.
UPPER TAITA ALLUVIUM (above groundwater)	This layer is located above the groundwater level therefore liquefaction is not expected.
UPPER TAITA ALLUVIUM (below groundwater)	Liquefaction of non to low plastic silt and loose to medium dense sand is possible in an earthquake shaking with PGA > 0.2g, M7.7.
LOWER TAITA ALLUVIUM	This layer is dense and therefore liquefaction is not expected.
PETONE MARINE DEPOSITS	Liquefaction of localised non to low plasticity silt and medium dense sand is possible in earthquake shaking with PGA > 0.3g, M = 7.7. Widespread liquefaction is unlikely.
WAIWHETU GRAVEL	This layer is dense and therefore liquefaction is not expected.
BEDROCK	Not applicable.

[1] Boulanger, R.W. and Idriss, I.M., 2014. CPT and SPT based liquefaction triggering procedures. "Report No. UCD.CGM-14/01, Centre for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, CA, 134pp.

Liquefaction consequences

Considering the potential for liquefaction described above, consequences of liquefaction at the site have been identified as listed in Table C3.

Table C3: Liquefaction consequences

ID	Issue	Comments
1	Lateral spread	For sites close to the Opahu Stream, lateral spreading towards this stream is possible when a continuous layer of liquefaction is present.
2	Cyclic displacement	Possible across areas underlain by soils with widespread liquefaction potential.
3	Free-field settlement	Of the order of 200mm is possible. Less in areas with less thickness of liquefied soils.
4	Sand boils	· Possible as thickness of non-liquefied crust is only 1.5m to 2m thick. · Ground settlement is possible as a result of sand boils. This is in addition to free-field settlement described above.
5	Uplift pressure	Possible for buried vessels (e.g. manholes) located in liquefiable soils.
6	Reduced support to foundations	· Punching failure for foundations founded on or immediately above liquefied soils (e.g. shallow foundations and shallow piles). · Loss of shaft friction for deep foundations adequately founded on non-liquefiable soils.

Geotechnical issues

Several geotechnical issues associated with the site have been identified and are listed in Table C4. These geotechnical issues could impact the possible redevelopment and should be considered in the selection of foundation types.

Table C4: Geotechnical issues

Issue	Comments
Founding conditions	<u>FILL, UPPER TAITA ALLUVIUM and PETONE MARINE DEPOSITS</u> · Due to the variable nature and/or low strength and/or susceptibility to liquefaction of these stratums, they are not considered reliable founding stratum. <u>LOWER TAITA ALLUVIUM</u> · Typically comprises dense to very dense GRAVEL and in sufficient thickness is considered a reliable founding stratum (refer Section 3). Risk exists of this layer being locally too thin as a founding layer. <u>PETONE MARINE BEDS</u> · Generally, too weak as a founding layer <u>WAIWHETU GRAVEL</u> · Typically comprises dense to very dense GRAVEL . A favourable founding stratum (refer Section 3). Aquifer is within these gravels. · Founding in this gravel layer requires piles to extend through the Petone marine beds which form the aquitard confining the aquifer. Risk of creating leakage through the aquitard. · Leakage of the aquitard could lead to contamination (downward water flow). This must be critically considered in deep foundation design.

Issue	Comments
Cyclic displacement and lateral spread	· Foundation and structural design need to consider impacts of liquefaction-induced lateral ground movement.
Liquefaction-induced differential settlement	· Foundation and structural design need to consider impacts of liquefaction-induced total and differential settlement. · Differential settlement between a building (particularly those founded on deep foundations) and adjacent services/hardstanding/landscaping is to be considered.
Negative skin friction (NSF)	· Post-liquefaction settlements as a result of re-consolidation of liquefied soils could impose downdrag forces on deep foundations. · Foundation design to consider NSF effects.
Liquefaction-induced sand boils	· Consequences likely to be low for a building founded on deeper reliable founding layer but could induce additional differential settlement for buildings on shallow foundations. · Damage to services and hardstanding possible.
Uplift pressure	· For manholes and other services, liquefaction induced buoyancy uplift is likely when they are located within liquefied soils. Hydrostatic uplift must be considered. · Building with basement should consider uplift effects (both hydrostatic and liquefaction induced).
Existing foundations	Depending on type, can be an obstruction to future foundations. Options to remove if shallow foundations.
Slope stability	Developments close to the Opahu Stream need to consider the possibility of slope instability affecting the building.
Soil contamination	The FILL soils could contain contaminants requiring management during any excavation and offsite disposal. May need to be addressed as part of Resource Consent.

Appendix D: Structural Basis of Foundation Concepts Presented in Appendix B

The structural guidance for developing on these soil conditions is based around controlling three aspects of structural performance:

1) Building weight associated with vertical load carrying capacity of the ground;
2) Seismic weight and distribution of seismic resisting structure (height/width ratio on the sketches);
3) Building resilience to differential settlements.

These are discussed in more detail below.

With the potential liquefaction conditions, all structures will require well-tied foundations to deal with both cyclic ground movement and base-shear take-out.

When discussing structures "lightweight" structures are assumed to be a seismic weight of 2-4kPa per floor (Steel (no concrete)/timber/mass timber), "conventional" structures 6-10kPa per floor averaged over the total area. Roofs would be typically 0.3-0.5 times these numbers.

Building weight associated with vertical load carrying capacity of the ground

This is simply limited by the weight that can be supported by foundations under gravity loads and distributed suitably to the strata below. The sketches do not envisage large-span structures (>10-15m typically).

Seismic weight and distribution of seismic resisting structure (height/width ratio on the sketches)

Past experience suggests that in these materials, overturning loads on seismic systems more often govern practical founding solutions, rather than vertical loadings as above.

The sketches are based on limiting seismic overturning loads. All medium rise (>2 storey) buildings are assumed to have distributed seismic systems. This means frames that maximise the use of the building's mass to resist overturning. The most simple example of this is moment frames which extend right across the structure, however well positioned lightly loaded K-frames can do a similar job. Traditional short core-type shear walls are likely to concentrate loads too much, but for residential structures, cellular walls (especially lightweight/mass timber) can create distributed resistance.

Base Isolation is assumed to halve base shear loads, reducing overturing demands for conventional buildings more to those of lightweight buildings.

Building resilience to differential settlements

Seismic systems may need to be distributed rather than concentrated (as above) to ensure that ground movements don't become unduly manifest as building lateral movements.

Base-isolated and lightweight buildings are likely to have a capacity for being re-levelled after an earthquake if detailed as such. Some conventional systems may, but the degree of cost/damage will vary with detailing.

In general, we would suggest that all structural systems founded in the Taita Alluvium or shallower should have distributed seismic systems and detailing for Architectural finishes that minimise susceptibility to differential settlements.