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Wairakei Research Centre
114 Karetoto Road
RD 4
Taupo 3384
Private Bag 2000
Taupo Mail Centre
Taupo 3352
New Zealand
T +64-7-374 8211
F +64-7-374 8199
www.gns.cri.nz

Marlborough District Council
PO Box 443
Blenheim, 7240

Attention: Peter Davidson

Dear Peter,

Scoping for the proposed scientific/monitoring drill hole, Wairau Plain, Marlborough

1.0 INTRODUCTION

The Wairau Plain groundwater system is a key water resource for the Marlborough district as it is the sole source of municipal supply for Blenheim and Renwick, providing water for domestic/industrial use, and much of the water for agriculture and agricultural processing (Davidson and Wilson 2011; White et al. 2016a).

The system faces multiple pressures. The demand for groundwater, particularly from agricultural processing, is increasing. Groundwater use probably impacts on flow in spring-fed streams (Davidson and Wilson 2011; White et al. 2016a). Land use intensification has been identified as a risk to groundwater quality (Davidson and Wilson 2011; Raiber et al. 2012 White et al. 2016a; White et al. 2018) and to water quality in spring-fed streams (i.e., Spring Creek and Blenheim urban streams), White et al. (2016a).

To address these issues, Marlborough District Council (MDC) has long-supported groundwater investigation programmes in the Wairau Plains including: geological mapping (Brown 1981); resource characterisation (Davidson and Wilson 2011; Wilson 2016); three-dimensional geological modelling (e.g., White and Tschritter 2009; White et al. 2016a; White et al. 2018); the Wairau River as a source of groundwater (Wohling et al. 2017); groundwater-surface water interaction (White et al. 2016a); and assessment of groundwater quality associated with land use (e.g., Raiber et al. 2012).

Together, this work has led to numerous research questions about the Wairau Plains groundwater system, in the following topic areas:

1. Geological structure and aquifer location:
   - do deeper aquifers exist below the known groundwater system? These aquifers could include Pleistocene gravels older than the known Late Pleistocene units, as with the Christchurch groundwater system (White and Tschritter 2009; Murray et al. 1998)?
   - what is the depth of basement under the Wairau Plains (White and Tschritter 2009)?
2. Geology and groundwater flow:
   - what is the cause of the complex groundwater flow directions in the area east of the historic Wairau River channel (White et al. 2016a)?
   - how does Holocene development of the estuary influence pre-historic groundwater flow in the coastal area of the wider Wairau Plains and drainage in the area (White et al. 2016b 2018)?
   - how does the Wairau Fault influence groundwater flow in the area east of the historic Wairau River channel?
3. Co-management of land and water by MDC:
   - what information is required by MDC to protect the groundwater resource and sustain the flow and quality of spring-fed streams (White et al. 2016a)?
4. Management of future risks:
   - how can MDC manage future risks to the Wairau groundwater system, e.g., land use and groundwater quality; sea water intrusion, groundwater use, and liquefaction?
5. Ground motion and liquefaction:
   - what are the implications of basement depth and rock properties to the behaviour of seismic shock waves and the management of the built environment?

Assessment of these questions is the focus of current and future investigations by MDC. Data from drill holes is a key information source in the assessment of the Wairau Plain groundwater system. For example, the MDC drill-hole database provided significant new information about the structure of the Wairau groundwater system and the Holocene palaeoestuary east of Blenheim (White et al. 2016a).

These research questions require new sub-surface data from drill holes, in particularly a deep well, which is a key next step in the investigation of Wairau Plain groundwater. At the request of MDC, GNS Science (GNS) completed this scoping report for the drilling of a deep well in the Wairau Plain.

This report considers possible deep-well options, including location, drilling depth and drilling methods. The project should aim to get as much scientific information as possible from the well. Therefore, the report also considers in-drilling sampling, associated science that could be completed based on drilling results, and MDC operational use of the well, e.g., for monitoring sea water intrusion.

2.0 POTENTIAL AIMS OF A DEEP-WELL INVESTIGATION

Potential aims of a deep-well investigation come from Wairau Plain research projects and from national research projects, particularly as associated with New Zealand's coastal aquifer systems (e.g., White et al. 2016a).

2.1 Geological Structure and Aquifer Location

Deep Pleistocene aquifers may exist below the Wairau Plain. The Wairau Plain is a coastal aquifer that shares much in common with the Christchurch aquifer system (e.g., White and Tschritter 2009; White et al. 2016a; White et al. 2018); and multiple Pleistocene gravels have been mapped at the ground surface in the Wairau Plain (Brown 1981; Table 2.1). The Christchurch aquifers owe their origin to gravels deposited in glacial periods within an alternating sequence of glacial and interglacial intervals in the Pleistocene period (e.g., Figure 2.1). Importantly, most of Christchurch groundwater is sourced from aquifers that are deeper than the Pleistocene Riccarton Aquifer (White 2008).

However, only two major aquifers have been conclusively identified in the Wairau Plain, whereas multiple aquifers have been identified in the Christchurch aquifer system (Brown 1981; Brown et al. 1995), Table 2.1. White and Tschritter (2009) noted that several Wairau Plain well logs possibility identify a marine incursion that pre-dates the Speargrass Formation, i.e., aquifers that pre-date Speargrass Formation may occur below the Wairau Plain (Table 2.1).

A deep drill hole will be key to the investigation of possible Pleistocene aquifers below the Speargrass Formation. This well would ideally be located near the coast, where the alternating inter-glacial/glacial sequence has the best chance of detection in the sedimentary record, as observed in Christchurch by Brown et al. (1995).

The drill hole could best be located south of the Wairau Fault where the depth to contiguous gravel sediments is greater, consistent with relative downthrow on the Fault, approximately south and east of the Grovetown drain (White et al. 2016a; Figures 2.2 and 2.3). Thicker Pleistocene sediments south of the fault are consistent with a broad thickening of Quaternary sediments in a southerly direction that was interpreted from off-shore seismic sections (Holdgate and Grapes 2015). Such relative 'subsidence' provides, as in Christchurch, tectonic conditions that are more likely to preserve a sequence of Pleistocene marine incursions.

Wairau Fault offsets are visible at the ground surface west of the study area (Begg and Johnston 2000; Zachariasen et al. 2006). The northern side of the Wairau Fault is upthrown by 2 m at Marshlands, but fault offsets are not observed within 800 m of the coast, indicating that there has been no movement of the Wairau Fault in the area within the last 770 years (Grapes and Wellman 1986).

Table 2.1 Major Holocene and Pleistocene units identified in the Wairau Plain and Christchurch.

Wairau Plain			Christchurch Aquifer system[2]		
Unit	**Aquifer/ aquiclude**	**Approximate depth at coast (m)**	**Unit**	**Aquifer/ aquiclude**	**Approximate depth at coast (m)**
Dillons Point[1]	Aquiclude	40	Christchurch	Aquiclude	40
Rapaura Formation[1]	Aquifer	42	Springston	Aquifer	-
Speargrass Formation[1]	Aquifer	44	Riccarton	Aquifer	50
?[3]	Aquiclude?	?	Bromley	Aquiclude	70
Tophouse Formation[1]	?	?	Linwood	Aquifer	90
?	?	?	Heathcote	Aquiclude	110
Manuka Formation[1]	?	?	Burwood	Aquifer	120
?	?	?	Shirley	Aquiclude	140
?	?	?	Wainoi	Aquifer	160

[1] Brown (1981).

[2] Brown et al. (1995).

[3] White and Tschritter (2009).

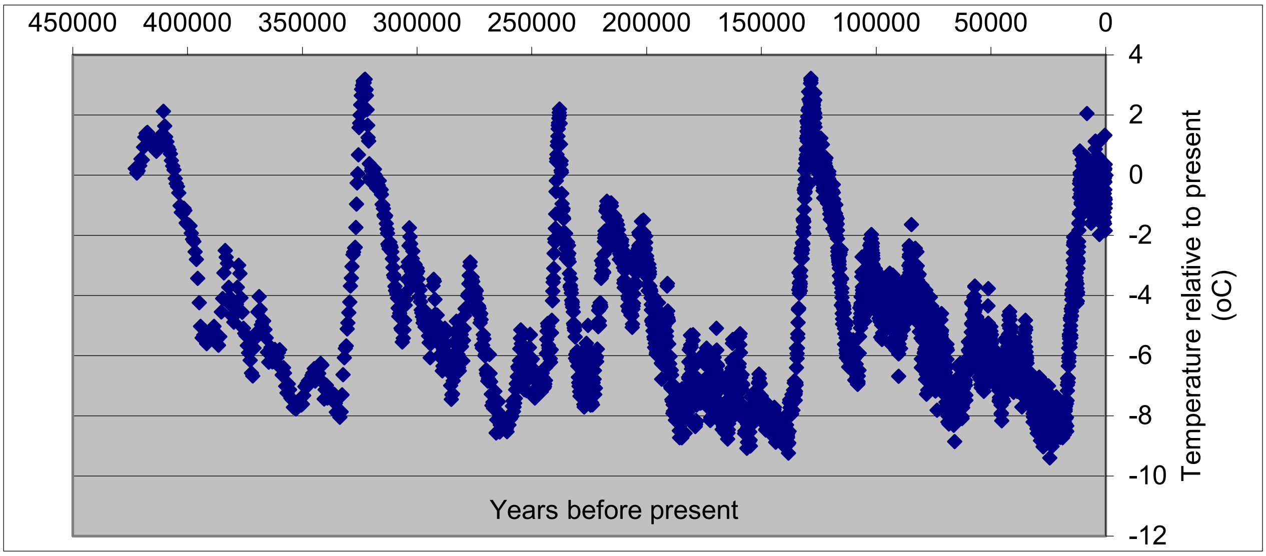

Figure 2.1 Earth temperature as calculated at the Vostok ice core in the last 420,000 years (Petit et al. 1999).

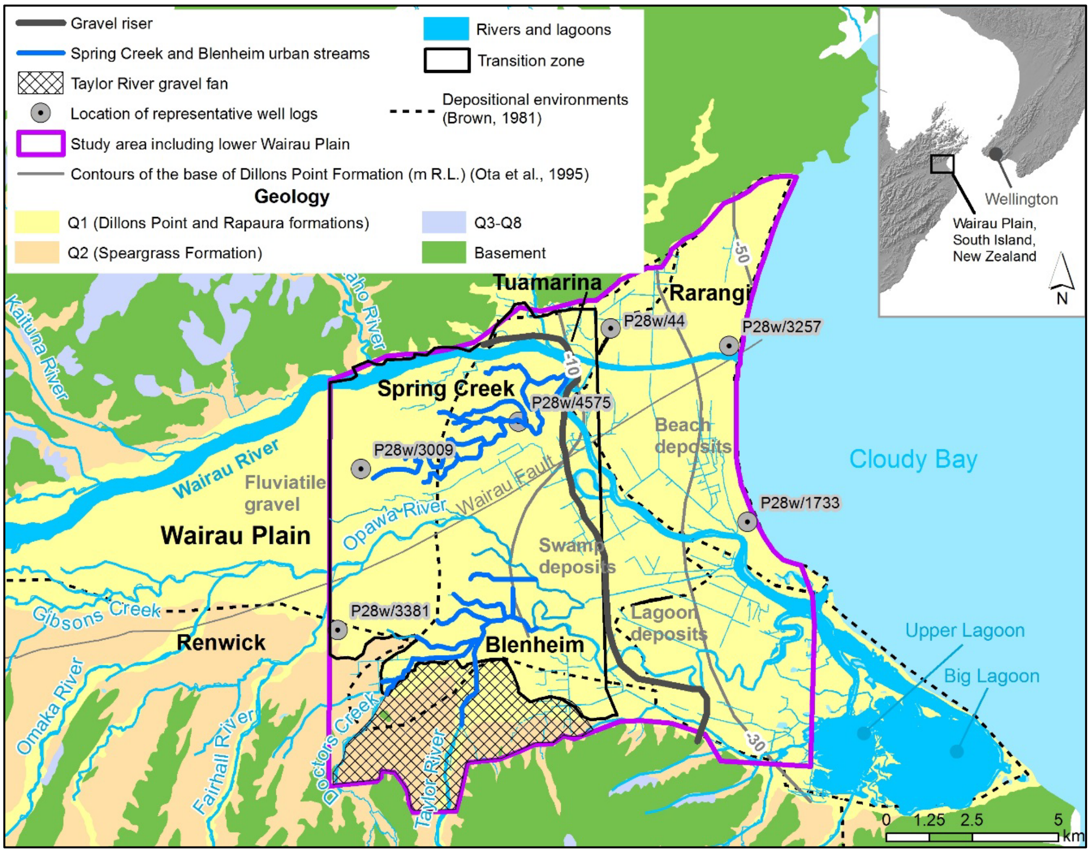

Figure 2.2 Geological map of Wairau Plain and environs showing the location of Wairau Fault (after Begg and Johnston 2000 and White et al. 2016a).

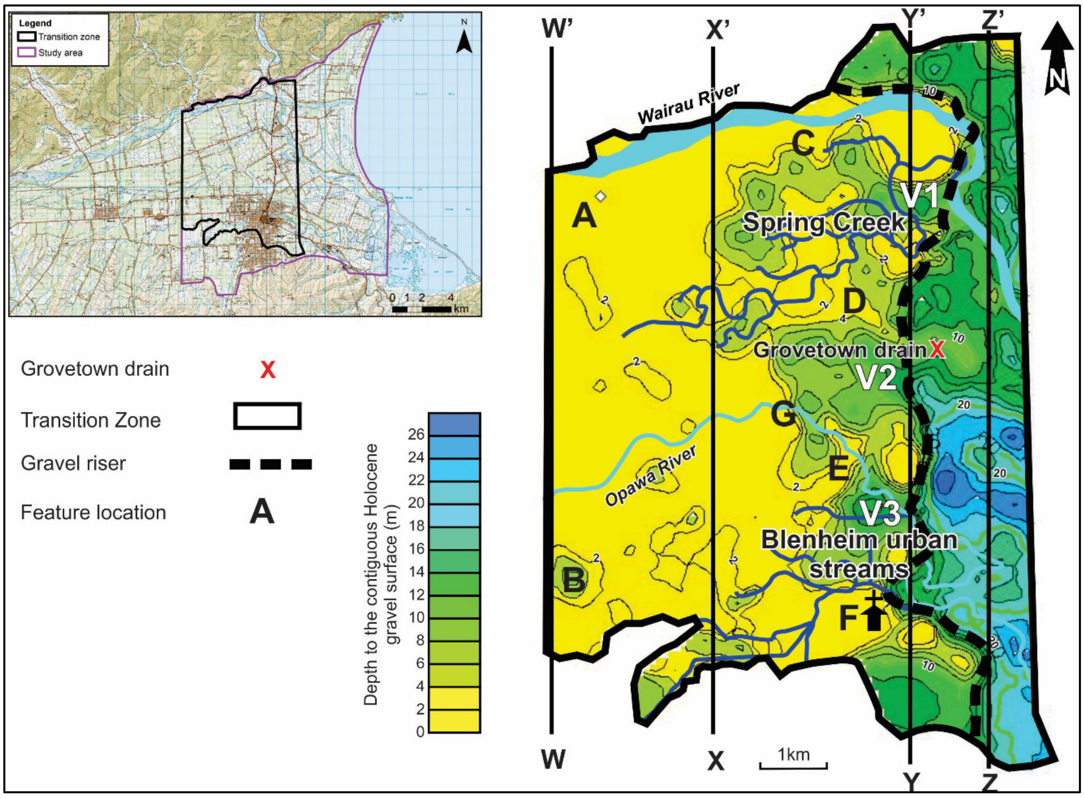

Figure 2.3 Depth to Holocene contiguous gravel sediments. These sediments are deeper south of the Wairau Fault (after White et al. 2016a).

2.2 Geology and Groundwater Flow

White et al. (2016a) made the case that all groundwater recharge in the west, i.e., rainfall recharge and river recharge, flows to spring-fed streams, such as Spring Creek and Blenheim urban streams. Coastal sediments provide the hydraulic barrier that forces groundwater to flow to springs. Therefore, coastal sediments, and their hydraulic properties, are of prime importance to the Wairau Plains groundwater system.

Well logs and groundwater pressures in the coastal area were assessed by White et al. (2016a). However, well logs and piezometric contours are complex in the area between Spring Creek, Tuamarina, and the coast, possibly because of Wairau River channel movement from its Pleistocene position to its 'pre-European' position, Holocene development of the Boulder Bank/Rarangi Gravel and offsets associated with the Wairau Fault (White and Tschritter 2009), Figure 2.2.

Certainly, drilling in the area between Spring Creek, Tuamarina, and the coast will lead to further understanding of the key controls on local deposition and aquifer distribution within the coastal sediments. These controls include Holocene movement of Wairau Plains facies: the Wairau River, the Boulder Bank and evolution of Rarangi Gravel (White et al. 2018). Understanding the evolution, and permeability, of these facies is a part of the planned GNS SSIF programme, which will include national coastal aquifer characterisation in the Wairau Plain for the period 2019–2021.

2.3 Co-management of Land and Water by MDC

Measurements of the water quality of groundwater outflow are an indicator of future water quality in spring-fed streams, for example, vertically-upwards groundwater flow was observed in the vicinity of Grovetown drain (Figure 2.3; White et al. 2016a). Therefore, groundwater discharge to surface catchments is a key indicator of the sustainability of groundwater and spring-fed streams. Deep drilling could target the groundwater discharge zone of the Wairau Plain groundwater system with a well located, broadly, a little east of the gravel riser (Figure 2.3).

2.4 Management of Future Risks

Deep drilling could assist with the assessment of future risks to the Wairau Plain groundwater system including: water quantity (groundwater and spring-fed streams), land use and water quality (groundwater and spring-fed streams), climate change (e.g., Zemansky et al. 2010), sea water intrusion and sea level rise. Investigation information relevant to each risk will be maximised by targeting of the drill hole location (Table 2.2).

Table 2.2 Future risks and well location criteria.

Risk	Deep drilling location criteria	Monitoring purpose
Water quantity (groundwater and spring-fed streams)	Outflow of the Wairau Plain groundwater system	Groundwater outflow sustainability
Water quality (groundwater and spring-fed streams)	Outflow of the Wairau Plain groundwater system	Early-warning of declines in stream quality
Water quality (groundwater and spring-fed streams)	Coastal investigation of deep aquifers and natural salinity	Deep aquifers at the coast
Climate change	Outflow of the Wairau Plain groundwater system	Groundwater outflow sustainability
Sea water intrusion and sea level rise	Coastal investigation of deep aquifers and natural salinity	Early-warning of salinity change; groundwater-level management criteria

Importantly, the drill hole should be designed to allow for future monitoring associated with these risks.

2.5 Ground Motion and Liquefaction

QuakeCoRE has been undertaking research across New Zealand to better understand the characteristics of deep sedimentary basins, and how they may influence potential ground motions in future earthquakes (Wotherspoon 2019). This has helped to understand the shaking that was experienced across Canterbury and Christchurch during the Canterbury earthquake sequence and is starting to better inform the more recent events that have affected Wellington. The Wairau Plain is an area of interest for research, and initial investigations have begun (through Auckland University, MDC and GNS) to understand the depth of the basin and the properties of the deposits within the basin. These methods rely on surface-based investigation approaches; however, key to any of this work is deep subsurface data that can provide clear evidence of the depth to rock. With this information, the surface-based investigations and the deep subsurface investigations can be combined to form a model of the basin to use as part of ground-motion simulation studies. This can assess a range of different earthquake events and quantify the effect of the Wairau Basin structure on potential amplification of ground motion. This will all combine to better understand the hazard across the region, forming the basis for improved assessment of the risk and exposure to the built environment.

3.0 PROPOSED DEEP DRILL HOLE

Deep drilling has been used before to produce key understandings of coastal aquifer systems (Dravid and Brown 1997). For example, three deep wells were drilled the Heretaunga Plains to identify aquifer structure and assemble geological information including the depositional environments. The wells included:

- Flaxmere well which was drilled by the cable tool method to a depth of 64.3 m and by rotary drilling to a depth of 137.34 m;
- Tollemache Orchard which was drilled by the cable tool method to a depth of 222.1 m and by rotary drilling to a depth of 256.5 m;
- Awatoto well which was 254.0 m deep and drilled by the cable tool method.

Sampling that was completed included: lithology, groundwater level, water quality, radiocarbon, macro-fauna, micro-fauna, macro-flora, micro-flora and tephra.

3.1 Location Options

Four general locations for deep-well drilling are identified that aim to address investigation targets (Figures 3.1, 3.2 and Table 3.1), with primary aims associated with potential investigation aims (Section 2), i.e.:

- area ‘A’, primarily to assess geological structure and aquifer location;
- area ‘B’, primarily to understand facies development relative to aquifer distribution;
- area ‘C’, primarily to assess groundwater discharge from the Wairau Plain to spring-fed streams and drains;
- area ‘D’, primarily to assess the risks of salt water intrusion and sea level rise.

Table 3.1 Deep-well investigation targets and priority areas.

Area	Investigation target
A	Deep aquifer potential, depth to basement, near-coastal zone
B	Facies distribution (Wairau River, Boulder Bank and Rarangi gravel), near-coastal zone
C	Groundwater outflow from the Wairau Plain
D	Near-coastal zone, deep aquifer potential, depth to basement

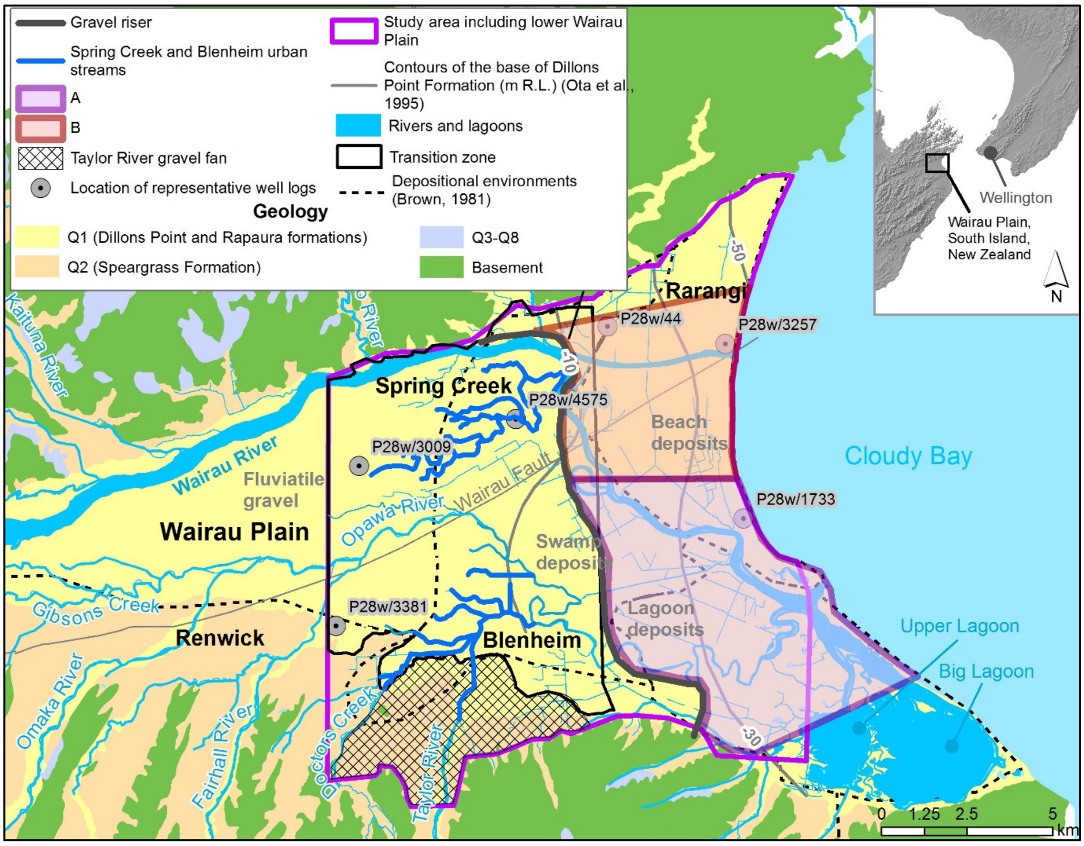

Figure 3.1 General deep-well location options ‘A’ and ‘B’.

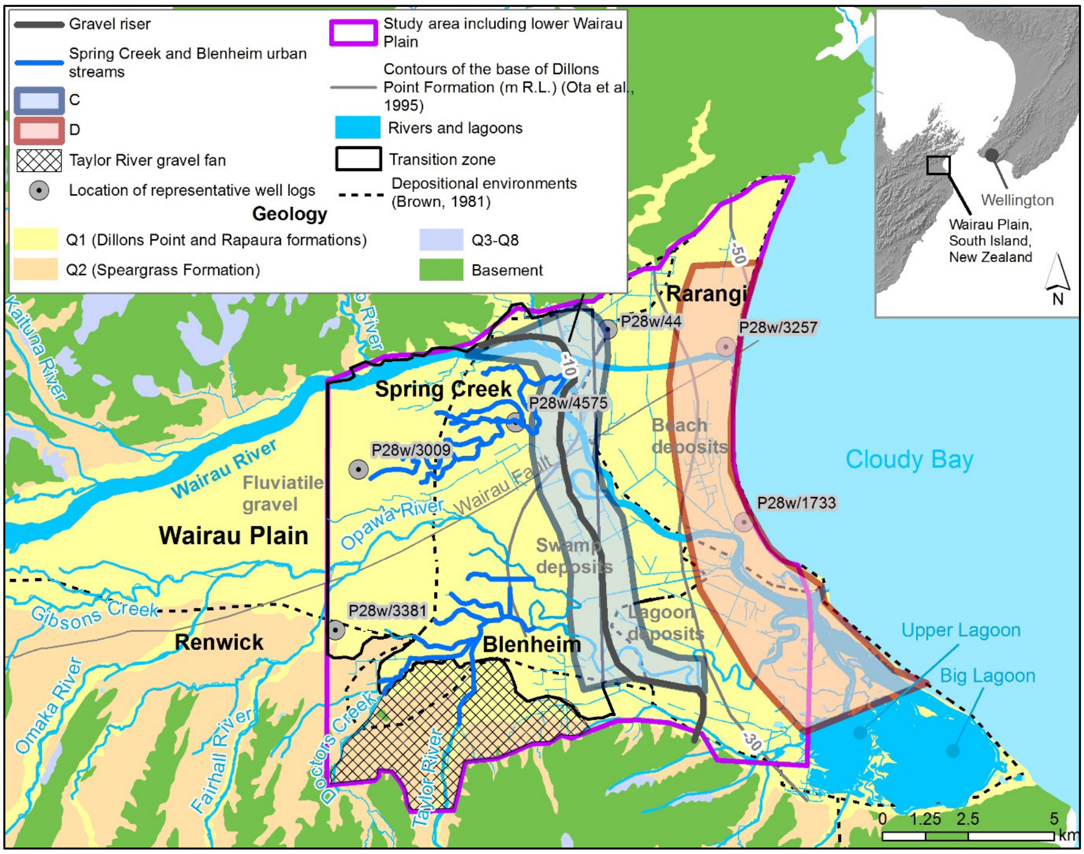

Figure 3.2 General deep-well location options ‘C’ and ‘D’.

3.2 Depth Options

The first priority is drilling the thickness of the Pleistocene sediments. A guide to the target drilling depth in the Wairau Plain comes from the thickness of the Pleistocene sediments in Christchurch, which are at least 250 m deep (Brown et al. 1995). Interpretation of off-shore seismic data has the base of Pleistocene sediments at approximately 160 m below sea level (i.e., line 48, located approximately 15 km off-shore; Holdgate and Grapes 2015). Basement could be a second drilling target. However, basement Cretaceous rocks in the off-shore Wairau Basin are an estimated 4000 m below sea level (i.e., Figure 8 of Holdgate and Grapes 2015) and is beyond the depth capability of water well-drilling technology.

3.3 Drilling Method

The cable tool method is the preferred drilling method to approximately 250 m. This is because the method gives the best opportunity for detailed sampling required in the investigation well. However, rotary methods could be used in the well should cable tool drilling strike difficult conditions. Therefore, a suitable strategy could be to use cable tool to as-deep-as-possible, and then use the rotary method to complete the well.

3.4 Well Logging

Well logging should be completed by a competent geologist, preferably one accustomed to logging deep well logs and logging of Holocene and Pleistocene unconsolidated sediments, particularly estuarine sediments and gravels. Extensive sampling should be completed during drilling to maximise the science that is produced from the well.

3.5 Data and Sample Collection During Drilling

Data and sample collection during drilling should follow standard practice for investigation/ scientific drill holes, including the following, which are guided by Dravid and Brown (1997):

- Lithology, i.e., production of a good-quality well log.
- Groundwater level, monitored at: the beginning of each day and the end of each day; and where pressures change abruptly during drilling.
- Groundwater hydraulic tests, at least regular specific drawdown tests and step draw-down tests of key permeable units.
- Lithological samples, with bag samples every drilled metre.
- Water samples, with samples of water from aquifers and aquicludes at a regular interval (a 10 m interval is suggested) as they are drilled. Water is to be sampled for the standard chemistry suite, isotopes and age tracers (e.g., C14, tritium and oxygen isotopes).
- Organic samples: macro-fauna (e.g., shells), micro-fauna (e.g., nanno-fossils), macro-flora (e.g., wood) and micro-flora (e.g., pollens), sampled every metre within relevant sediments (e.g., estuarine deposits).
- Samples for radiocarbon analysis, including organic samples, at a 1 m interval in relevant formations.
- Tephra, as identified during drilling.

4.0 POTENTIAL USES OF THE WELL FOR MONITORING

Potential uses of the well (e.g., Table 3.1) for post-completion monitoring by MDC could be considered as part of the drilling programme. These uses will contribute to decisions on:

- the aquifer, or aquifers, to monitor;
- what to monitor, e.g., groundwater level, groundwater quality, groundwater isotopes;
- the monitoring regime, e.g., interval of measurements;
- requirements for post-well drilling construction.

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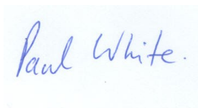
Yours sincerely



Paul White
Senior Groundwater Scientist