



12 November 2024

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Dear Mr Davidson,

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## **Guidance on prospecting for deep groundwater resources beneath the coastal Wairau Plain, Marlborough**

### **1.0 INTRODUCTION**

Groundwater resources of the coastal Wairau Plain have sustained socio-economic growth in Marlborough for more than 100 years. These are vital for environmental functioning, industry and agriculture, community drinking water and recreation, and iwi.

The once ample groundwater supply from shallow coastal aquifers, supplying all of the drinking water for Blenheim and other townships, as well as water for agricultural irrigation, has been taxed in recent years by increases in irrigation and population growth, with demand stressing available supplies during severe summer droughts (e.g. 2023/24).

More than 2000 boreholes have been drilled into the shallow groundwater system beneath the coastal Wairau Plain (Figure 2.1), and the allocation of water from shallow aquifers is managed by Marlborough District Council (MDC) via a network of groundwater monitoring sites. However, there are knowledge gaps concerning the freshwater–saline interface near the coast, as well as the full extent of the groundwater system that lies deep beneath the coastal Wairau Plain.

### **2.0 OBJECTIVES**

MDC requires independent guidance on the costs, benefits and methods for exploring the full extent of the hydrogeological sequence underlying the coastal Wairau Plain (Figure 2.1). The shallow hydrogeology of the Wairau plains is well understood, but knowledge about the deeper portions of the basin (>80 m), particularly in the coastal area, is lacking. Verifying the presence or otherwise of deep groundwater aquifers beneath the coastal Wairau Plain is fundamental for informed regional resource-management decision-making. GNS Science has used its geological expertise and geophysical/drilling industry contacts to provide a cost/benefit analysis of different steps needed to map the full extent of the deep groundwater system using modern geological and geophysical methods.

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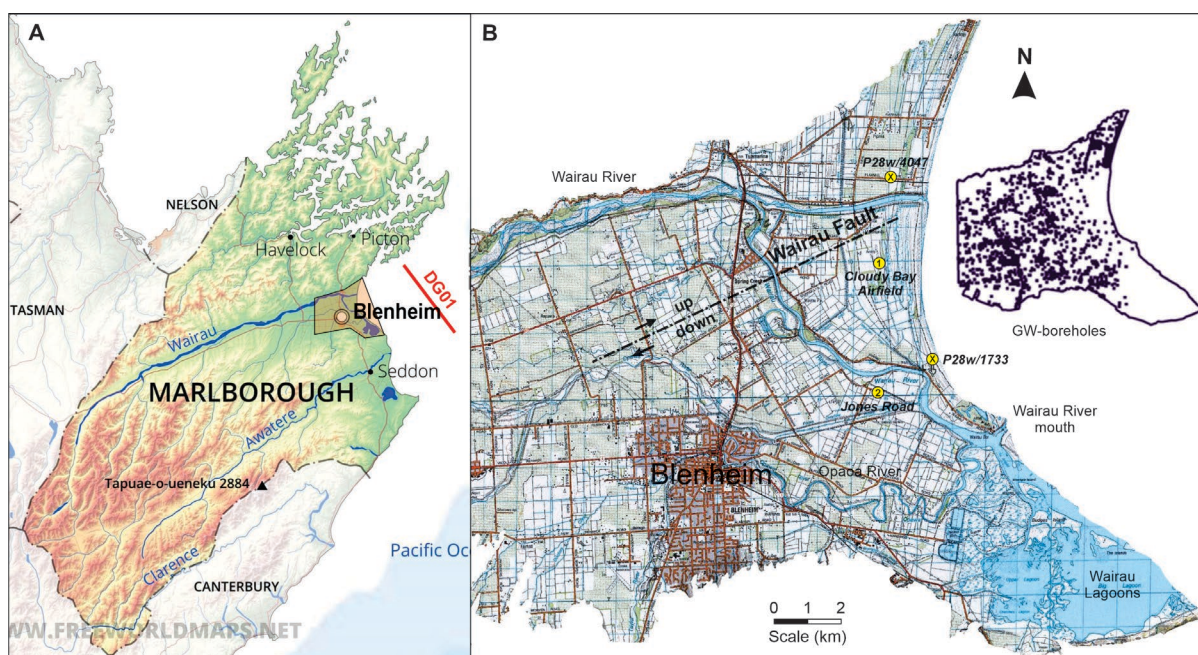


Figure 2.1 (A) Coastal Wairau Plain, Marlborough, and location of multi-channel seismic section DG01. (B) Key boreholes for the stratigraphy beneath the coastal Wairau Plain and recommended drill-site locations (1) Cloudy Bay Airfield and (2) Jones Road, as well as distribution of groundwater (GW-) boreholes (insert).

The prime focus of this guidance is on exploratory techniques, but the report also identifies techniques to measure hydrogeological properties of groundwater facies encountered to enable more sophisticated models of aquifer connections to be built and reliable aquifer management undertaken. A long-term requirement of any investigation of the coastal groundwater system is an option to monitor saline groundwater intrusion from the coast. The recommended approach also provides insight to the geological structure and tectonic history of the coastal Wairau Plain, as well as the impacts of future sea-level rise.

#### Key MDC objectives:

1. Define the full extent of the groundwater system and prospect of finding aquifers deep beneath the coastal Wairau Plain – to supplement the supply of groundwater from shallow aquifers and assist in the restoration of natural freshwater systems and river flows.
2. Develop a comprehensive hydrogeological framework for the entire (shallow to deep) groundwater system beneath the coastal Wairau Plain, including aquifer hydraulic conductivity and storativity, aquitard leakage and degree of interconnectedness of aquifers and surface waters – for informed freshwater resource management.
3. Define the freshwater–saline interface near the coast and recommend a location for a permanent monitoring well for saline groundwater intrusion from the coast – to understand the risk of consented groundwater abstraction or sea-level rise inducing a shift in the saline boundary in the future.
4. Provide insight to the geological structure and tectonic history of the Wairau plains – to build a more resilient and informed community that is equipped to address challenges associated with large earthquakes, future climate change and sea-level rise.

## 3.0 BACKGROUND

### 3.1 Geological History of the Wairau Plains Groundwater System

The present-day flat-lying geomorphology of the coastal Wairau Plain denotes a long history of finely balanced tectonic subsidence and alluvial aggradation, tempered by glacial–interglacial changes in sea level. For example, during the mid-Holocene, when sea level rose rapidly (~8000 years ago) during meltwater pulse (MWP-1C, Blanchon 2011; Blanchon and Shaw 1995), groundwater facies shifted inland at least 5 km from the present-day coast (Figure 3.1). Groundwater facies have subsequently built-out (prograded) into Cloudy Bay as the Wairau plains sedimentary system equilibrated to the higher, more stable, sea-level.

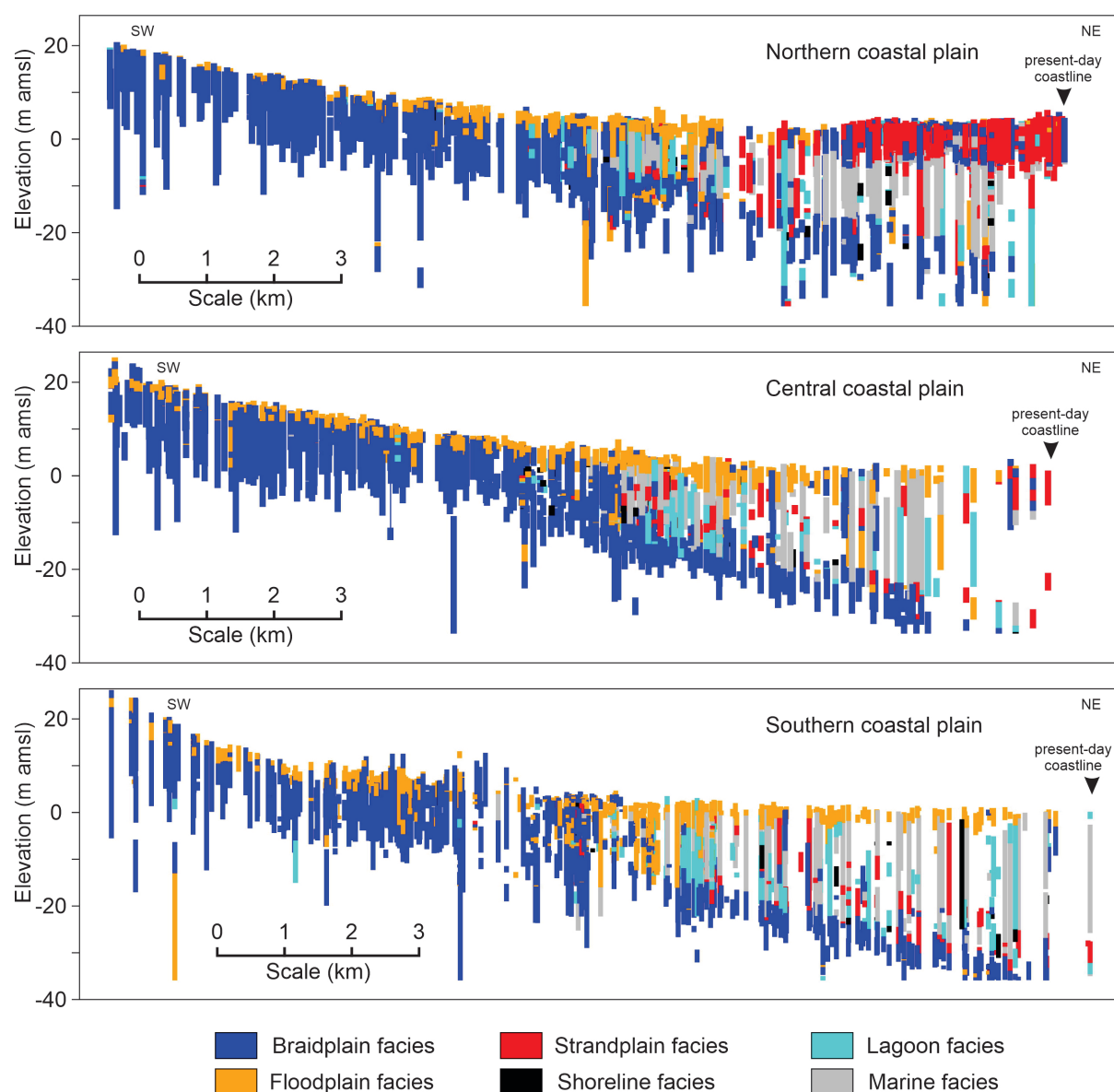


Figure 3.1 Geological cross-sections showing stratigraphic relationships and depositional architecture of groundwater facies, from Crundwell and White (2024).

Larger lateral shifts in groundwater facies are also evident. For example, ~20,000 years ago during MIS-2 (the Last Glacial Maximum), when sea level was ~120 m lower than present-day (Grant et al. 2014), gravel facies aquifers of the Rapaura and Speargrass formations extended ~30 km out beyond the present-day coastline into Cloudy Bay (Pondard and Barnes 2010).

Earlier glacial–interglacial changes in sea level, especially large changes in the last 630,000 years that occur on a frequency of ~120,000 years (Grant et al. 2014; Railsback et al. 2015), have contributed to similar shifts in groundwater facies. Sedimentary cycles of glacial gravel (potential aquifers) and interglacial mud deposits that were deposited during these changes in sea level are apparent in the thick Plio-Pleistocene sequence that extends offshore (Figure 3.2).

Most of Christchurch’s potable and irrigation water is supplied from gravel aquifers that are correlated with glacial marine isotope stages MIS-2 to MIS-10 and mapped to a depth of 130 m (Brown and Weeber 1992; Etheridge 2019). In contrast, most of the Wairau plains drinking water and water for agricultural irrigation is supplied from MIS-1 and MIS-2 gravel aquifers in the upper ~60 m (Crundwell and White 2024). Because the geological settings of Christchurch and Marlborough are similar, age equivalent MIS-6 (132–141 ka) and MIS-10 (337–346 ka) glacial gravels, as well as older MIS-12 (428–437 ka) and MIS-16 (624–627 ka) gravels, are likely to be present beneath the coastal Wairau Plain. These gravels are likely to be more deeply buried (possibly as deep as 400 m+), and the hydrogeological properties of possible gravel aquifers are expected to be poorer on account of the greater depth of burial.

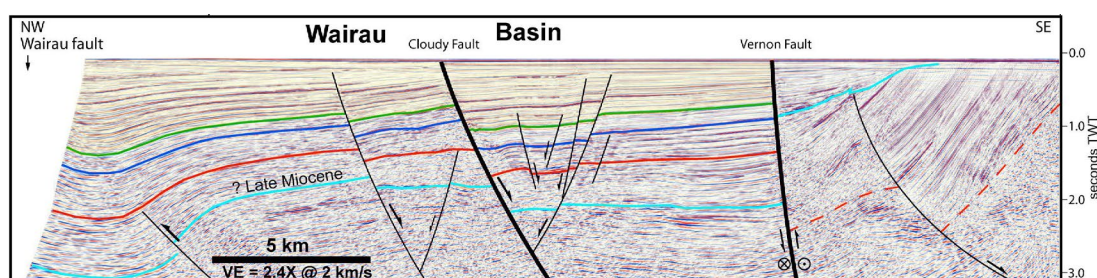


Figure 3.2 Multi-channel seismic section DG01 across the offshore central and southern parts of the Wairau Basin (see Figure 2.1), from Pondard and Barnes (2010). Thick Plio-Pleistocene sequence with potential glacial gravels aquifers (shaded yellow).

### 3.2 Geological Structure and Stratigraphy of the Wairau Basin

Multi-channel seismic section DG01 across the offshore Cloudy Bay portion of the Wairau Basin illustrates the structure and stratigraphy associated with the Wairau, Cloudy and Vernon faults (Figure 3.2). The depocenter of the basin, where the Plio-Pleistocene sedimentary section is thickest, is about 2–3 km southeast of the Wairau Fault. This is also where groundwater facies and aquifers associated with the Wairau plains groundwater system are likely to be well developed and deeply buried. The onshore extrapolation of the depocenter suggests that the thickest and most deeply buried part of the coastal groundwater system is between the Wairau Fault and Wairau River mouth – close to borehole P28/w1733 (Figure 2.1).

Boomer seismic section L1, parallel to shore and about 4 km off the coast from Wairau Lagoons, illustrates the structure and stratigraphy of groundwater facies beneath the southern part of the coastal Wairau Plain (Figure 3.3). The section shows a submarine canyon with eroded channels cut into the top of post-Last Glacial Maximum (LGM) deposits of the Speargrass, Rapaura and Dillions Point formations. The submarine canyon extends offshore and has been a conduit for coarse-grained sedimentary deposits.

The current geological and geophysical evidence suggests that the depocenter of the Wairau Basin and Vernon Canyon are important focal points for deep gravel aquifers beneath the coastal Wairau Plain and offshore beneath Cloudy Bay, where there is a likelihood of freshened groundwater (Morgan and Mountjoy 2022).

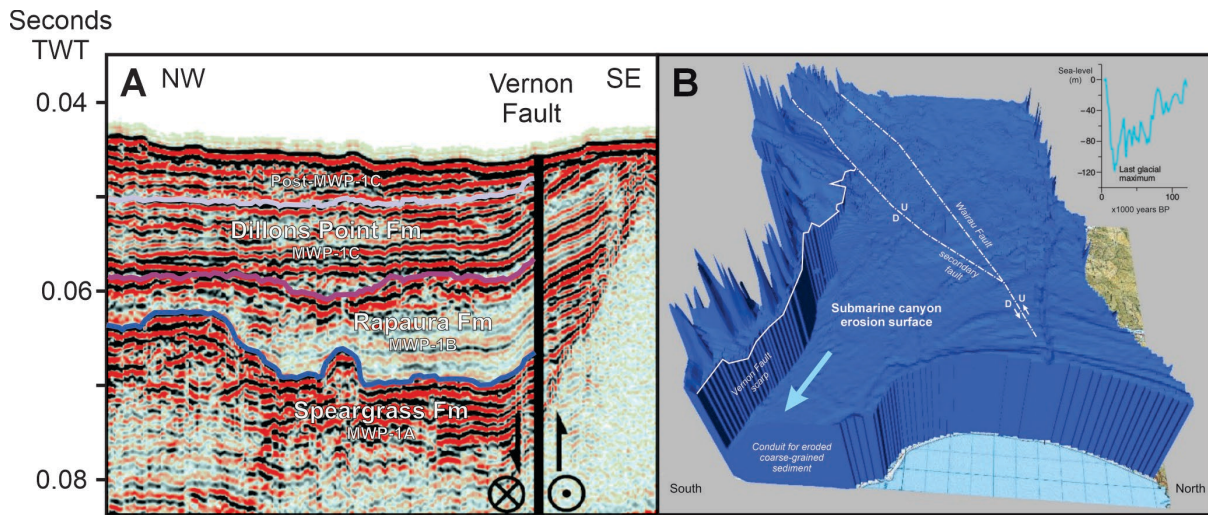


Figure 3.3 Stratigraphy beneath the southern part of the coastal Wairau Plain. (A) Boomer seismic section L1, showing Vernon Canyon deposits associated with the Speargrass, Rapaura and Dillons Point formations, after Pondard and Barnes (2010). (B) Three-dimensional geological model of Vernon Canyon illustrating the erosion surface that is associated with the top of the Speargrass Formation.

### 3.2.1 Borehole Stratigraphy

Three-dimensional (3D) geological models based on borehole data illustrate the distribution of post-LGM groundwater facies beneath the coastal Wairau Plain (Figure 3.4).

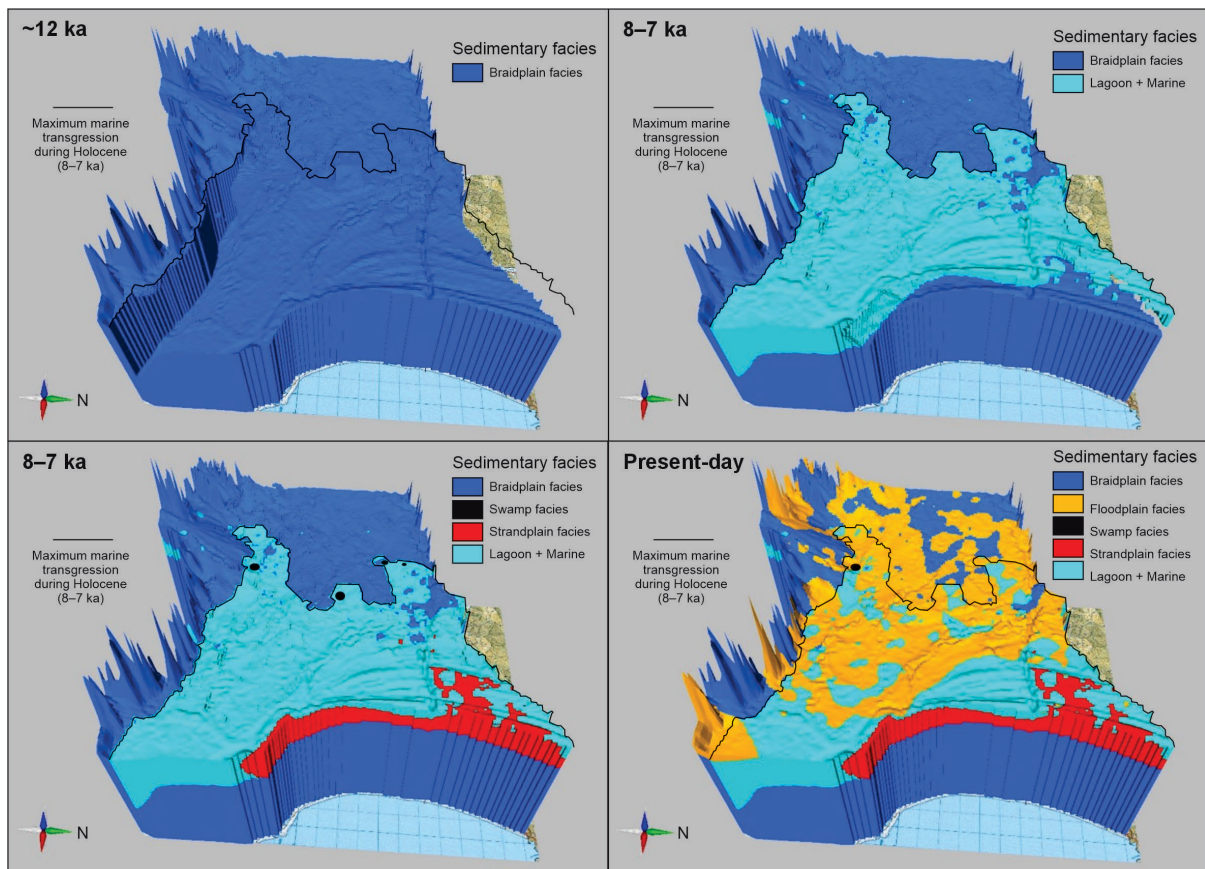


Figure 3.4 Post-LGM (Holocene and Late Pleistocene) groundwater facies beneath the coastal Wairau Plain, from Crundwell and White (2024).

Borehole P28/w4047 is a key reference section for the stratigraphy beneath the coastal plain on the northern upthrown side of the Wairau Fault (Figure 2.1). The borehole drilled into schist rock basement at 221–223 m and identified shallow aquifers associated with the Dillions Point Formation (MIS-1 strandplain beach gravels) at 0–10 m and Speargrass Formation (post-LGM MIS-1/2 braidplain gravels) at 27–35.5 m (Figure 3.6). Very tight fluvial fan and braidplain gravels at 146–200 m are tentatively correlated with MIS-6.

Borehole P28/w1733 is a key reference section for the stratigraphy beneath the coastal plain on the southern downthrown side of the Wairau Fault (Figure 2.1). The borehole is located close to the inferred Wairau Basin depocenter and thickest part of the groundwater system. The borehole identified aquifers associated with the Dillions Point Formation (MIS-1 strandplain beach gravels) at 2 m, Rapaura Formation (MIS-1 Floodplain crevasse-splay gravels) at 41 m and Speargrass Formation (post LGM MIS-1/2 braidplain gravels) at 59 m and 69 m, reaching total depth at 80 m in tight floodplain crevasse-splay gravels (Figure 3.5).

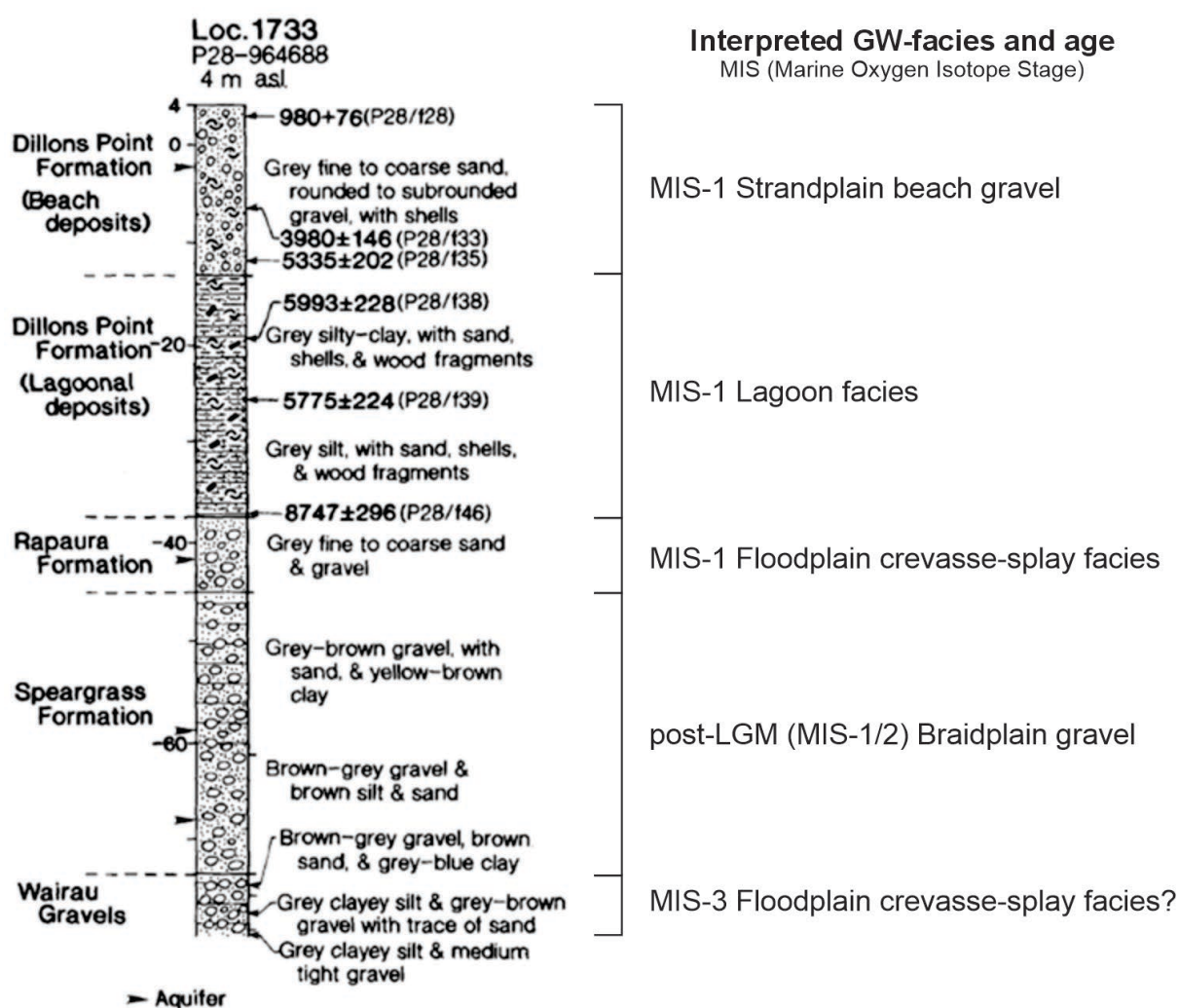


Figure 3.5 Wairau Bar borehole P28/w1733, ~2.5 km northeast of the Wairau River mouth (Figure 2.1), from Ota et al. (1995). Inferred groundwater facies and marine isotope stage (MIS)-age correlation (this study).

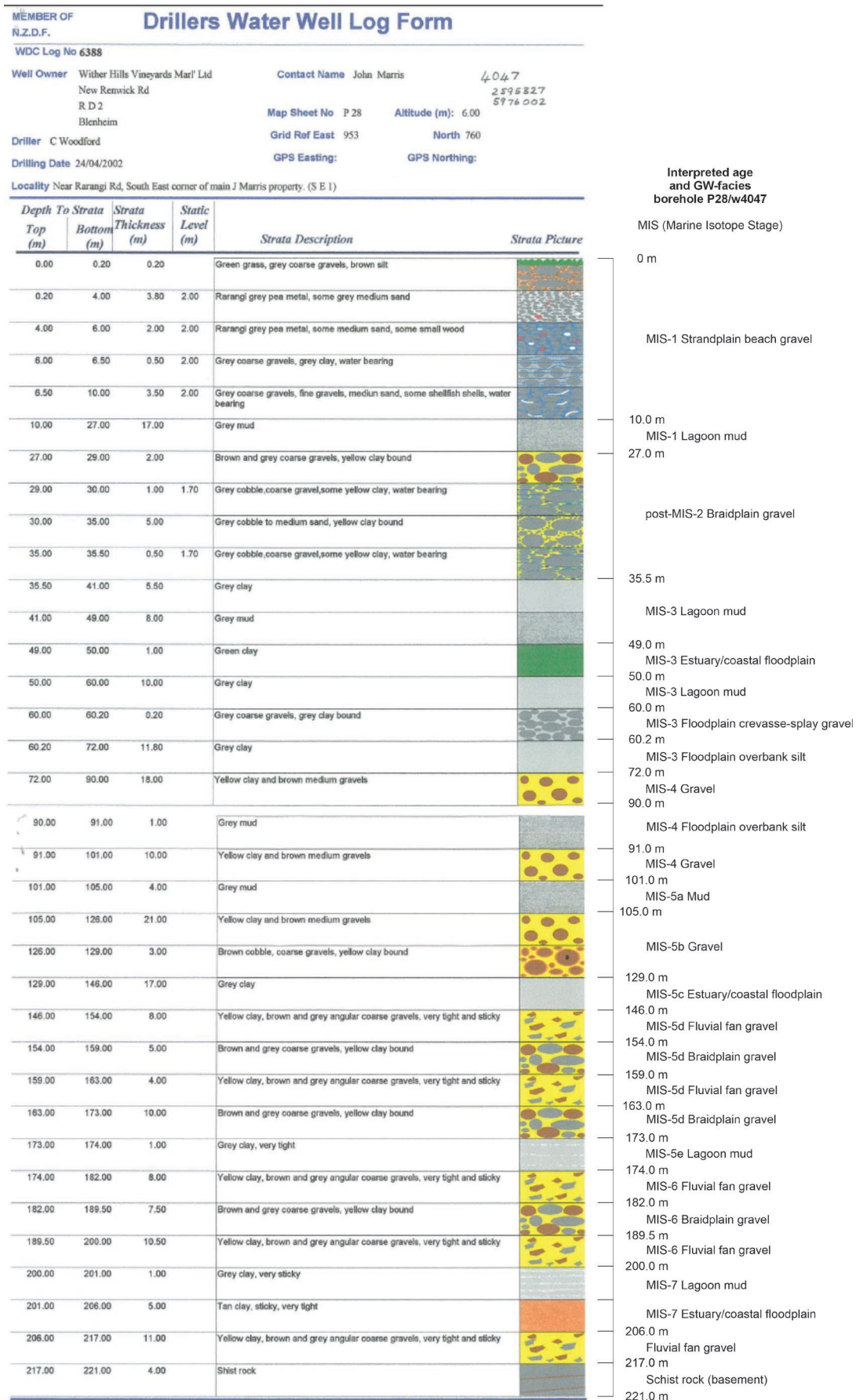


Figure 3.6 Lithological log for Rarangi Road borehole P28/w4047 on the northern upthrown side of Wairau Fault, from MDC water-well database. Interpreted groundwater facies, from Crundwell and White (2024).

## **4.0 METHODOLOGY**

### **4.1 Deep Groundwater Exploration**

Drilling is an essential part of any deep groundwater exploration programme using modern geological and geophysical methods, as it provides a fixed reference point for the lithostratigraphy and hydrogeological properties of groundwater facies and aquifers. Sedimentary and microfossil facies analysis of cored and drilled rock samples also provides insight to the geological and tectonic history of sedimentary basins, as well as the depositional history, architecture and parameters of groundwater facies that define the full extent of coastal groundwater systems. In addition, borehole lithological and wireline logging provide constraints on the geophysical properties of groundwater facies and support the interpretation of geophysical data. The borehole is ultimately key for determining the hydrogeological properties of groundwater aquifers (groundwater head, transmissivity, storativity and groundwater chemistry).

Drilling is expensive, but a commitment to drill at least one deep borehole must be made during any deep groundwater exploration programme. In order to target a well that is expected to reach a depth of 200–400 m, having some idea of the strata beneath potential drill-site locations is critical, especially in a coastal-plain setting where rapid lateral changes in groundwater facies are expected. Geophysical methods can provide this information. Typical geophysical methods include ground-based electrical resistivity and electromagnetic and seismic methods. Regional surveys can also include airborne electromagnetic methods. Details of these geophysical methods are discussed in Section 4.2.2.

#### **4.1.1 Outline of the Decision Process**

The following section provides a summary of modern geological and geophysical methods that can be used as components of a comprehensive deep-groundwater exploration programme. To limit financial risk, decision points are included between key phases of exploration so that all data (old and new) can be evaluated before Council commits to the next appropriate phase of exploration or terminates the exploration programme.

All costs are approximate. Formal quotes for services are issued when Council commits to specific phases of recommended geological and geophysical investigations. To accommodate long-term planning and budgeting, as well as the uncertainty of when Council might commit to any specific phase of the recommended investigations, Council should allow for an average annual cost increase of 5–10%, based on the approximate 2024/25 cost estimates in this report.

### **4.2 Multi-Phase Geological Investigations**

Modern geological methods for investigating shallow groundwater systems include surficial groundwater-facies mapping, based on lithological and digital terrain model (DTM) data (e.g. Crundwell et al. 2024), and 3D groundwater-facies mapping, based on borehole data (e.g. Figures 3.1 and 3.4). However, drilling and the recovery of core or cuttings samples is essential for investigations of deep groundwater systems. Drilling a single borehole provides fixed-point lithostratigraphic and hydrogeological data to build hydrogeological models and insight to the spatial distribution of groundwater facies and hydrogeological properties that ultimately define the vertical limits of a groundwater system. Drilling of two boreholes enables groundwater facies and the hydrogeological properties of aquifers to be mapped in two dimensions, as well as in three dimensions if more boreholes are drilled.

## 4.2.1 Decision Point for GEOLOGY

### 1. Commit to GEOLOGY Phase 1 Sonic Coring

*Drill a ~200-m-deep sonic-cored borehole on the southern down-thrown side of the Wairau Fault, close to the presumed basin depocenter and optimal groundwater flow path for a saline-intrusion monitoring well.*

Sonic coring is a relatively new drilling method that has been used for groundwater and geotechnical studies in New Zealand (e.g. Wellington Water, KiwiRail Interislander terminal development). It is an efficient, cost-effective method for coring sedimentary sequences where intact samples are needed for detailed geological and hydrogeological analysis. Core recovery is usually high (>95%) from fine-grained sediments and lower for gravels. Until recently, New Zealand's sonic-coring capacity has been limited to a depth of ~80 m+, but the purchase of a new 50 Hz sonic drill rig by McMillan Drilling Services has extended the capacity to ~200 m+.

In GEOLOGY Phase 1, the recommended approach is to continuously core a borehole to a depth of ~200 m, near the southern end of Cloudy Bay airfield (Figure 2.1). The advantage of coring over other drilling methods is that it provides a complete sedimentary rock record that can be sampled and analysed in the laboratory to constrain the lithological, hydrogeological and geophysical parameters of groundwater facies and aquifers, and there is no need to have a qualified/experienced geologist/hydrogeologist onsite. Data from the analysis of core samples supports the interpretation of geophysical data and enables sophisticated hydrogeological and groundwater flow models to be built.

Coring also enables the microfossil content of samples to be used to model the depositional history and architecture (spatial relationships) of groundwater facies, as well as provide insight to the age and subsidence history of groundwater facies and the hydrogeological properties of deep groundwater facies that ultimately define the vertical depth limits of a groundwater system. This is done on the basis of a fitted trendline through intersections of marine facies and the global sea-level curve of Grant et al. (2014). The slope of the trendline represents the relative vertical land movement (VLM). Figure 4.1 shows examples of age/subsidence and groundwater facies models based on the analysis of microfossils from Wellington Harbour borehole E3/E3A. When the trendline intersects multiple glacial cycles, and the net VLM (tectonic subsidence + alluvial aggradation) is less than -0.5 mm/year (-0.5 m/kyr), the likelihood of deeply buried MIS-6 and older gravel aquifers increases – see Figure 4.1.

**Objectives:** Establish a fixed reference point for the lithostratigraphy and hydrogeological properties of groundwater facies in the upper 200 m of the Wairau plains groundwater system, and define the vertical depths limits of the groundwater system.

**Risks:** (1) Sonic coring to a depth of 200 m may not be possible if the geology is unsuitable. (2) The borehole may not intercept the optimal groundwater flow-path for a saline-intrusion monitoring well.

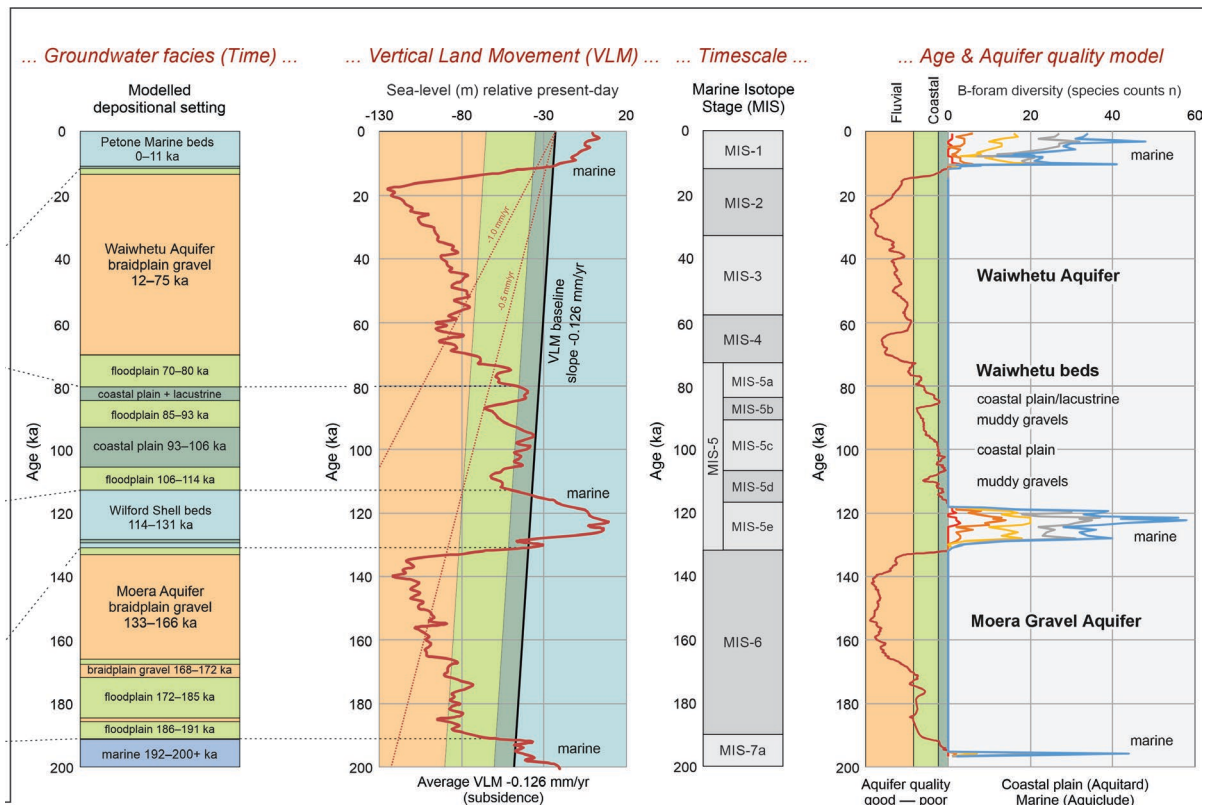
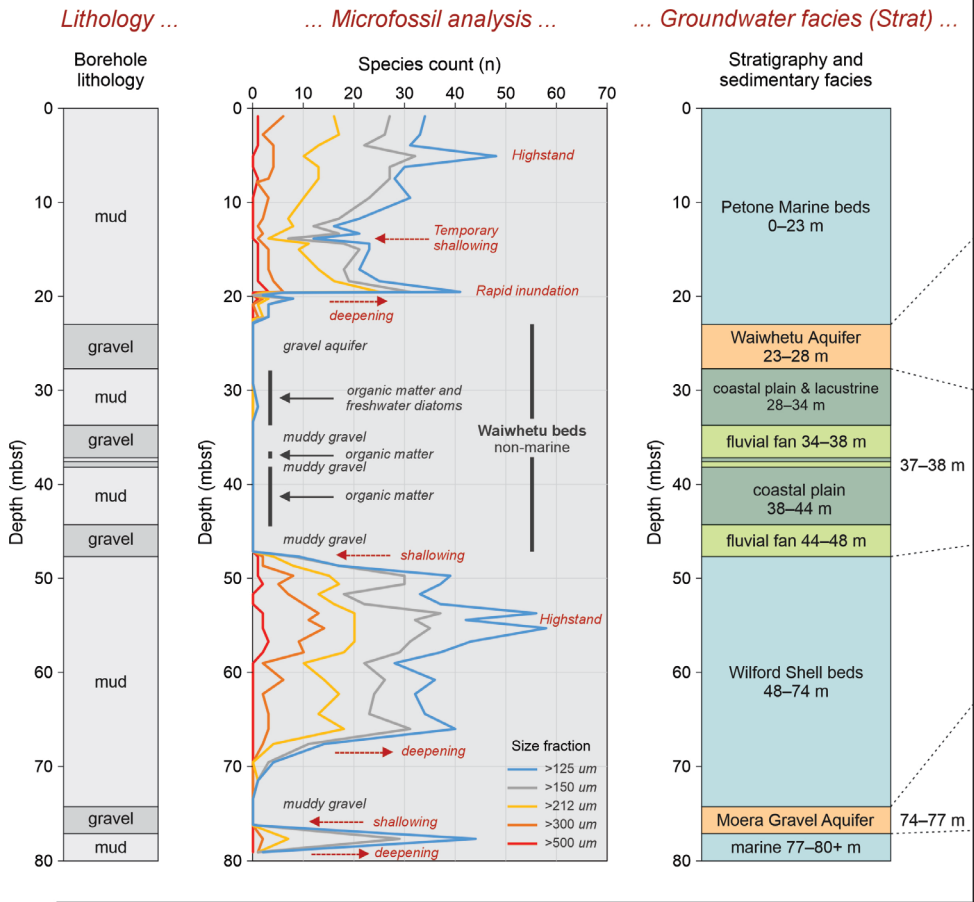


Figure 4.1 Age/subsidence and groundwater-facies models, Wellington Harbour borehole E3/E3A, based on the analysis of microfossils in cored borehole samples (after Crundwell and White [2021]).

### Estimated Cost for GEOLOGY Phase-1

- McMillan Drilling Services (based in New Zealand) has the capacity to drill a sonic-cored borehole to a depth of 200 m, dependent on favourable geology.
- GNS Science has experience and capability in supporting a wide range of geological services associated with sonic-cored boreholes. Recommended GEOLOGY Phase-1 services include:
  - The design and management of drilling operations for a 200-m-deep sonic-cored borehole, as well as core sampling to measure and model the lithological and hydrogeological properties of groundwater facies.
  - Offsite core logging supported with laboratory analyses of grain size, sample resistivity and hydraulic conductivity to understand the hydrogeological properties of aquifers.
  - Offsite paleontological services, including microfossil analysis of depositional environments and associated groundwater facies, to model age/subsidence and provide insight to the spatial distribution and hydrogeological properties of groundwater facies that ultimately define the vertical limits of a groundwater system.
  - Radiocarbon C14-AMS dating of marine and non-marine fossil material (macro- and microscopic) for age/subsidence modelling (last 40,000 years).
  - MDC would be required to arrange landowner access to the drill site.
- Drilling to a depth of 200 m is expected to take ~1 month, and the analysis of core samples, dating, modelling and reporting ~3 months.
- Drilling services: \$200,000 (cost approximately \$1000/m).
- Specialist services, including detailed lithological logging, paleontology, C14-dating, geological modelling and reporting: \$160,000.

*Approximate total cost: \$360,000.*

### Additional Options

- Wireline logging is recommended, but this is not included in the cost (see Phase 4).
- Groundwater testing at horizons of interest is possible but not recommended, as the drillers would need to install temporary casing and flush the drilling fluids from the hole, with a qualified/experienced hydrologist needed on-site. This would add to the drilling cost. There are also engagement costs to stop abstraction from surrounding impacting bores during the testing so that these do not interfere with the results.
- Completion of the borehole as a saline-intrusion monitoring well – MDC to negotiate requirements with GNS Science and McMillan Drilling Services and pay additionally.

## 2. Commit to GEOLOGY Phase 2 Rotary/Mud Drilling

*Drill a 300–400-m-deep rotary borehole on the southern down-thrown side of Wairau Fault.*

Rotary/mud drilling is a widely used method for drilling deep groundwater and geotechnical boreholes to depths of 300–400 m+. Coring is possible with rotary drilling, but it is expensive and not recommended unless a specific aquifer interval is being targeted. Lithological logging is typically conducted on-site from circulated cuttings returned to the surface, or, alternatively, bagged cuttings samples can be logged offsite by a qualified/experienced geologist. Mixing of cuttings during circulation and the ubiquitous loss of fine-grained material can affect the quality of lithological information. Cuttings samples provide important information but are not suitable for detailed laboratory analyses.

In GEOLOGY Phase 2, the recommended approach is to drill a rotary/mud borehole to a depth of 300–400 m near Jones Road (Figure 2.1). The proposed drill site is about 4 km south of the sonic-cored borehole location proposed for GEOLOGY Phase-1 drilling.

**Objectives:** Confirm the two-dimensional (2D) continuity of groundwater facies beneath the coastal Wairau Plain and the vertical limits of the groundwater system, and establish a fixed reference point for deeper groundwater facies below 200 m to support the processing and interpretation of surface geophysical data.

**Risks:** (1) Lithological data is lost if cuttings are not circulated to the surface. (2) The borehole may not intercept the optimal flow-path for a saline-intrusion monitoring well.

### Estimated Timeframe and Cost for GEOLOGY Phase-2

- New-Zealand-based contractors, including McMillan Drilling Services, have capacity in drilling rotary/mud boreholes to depths of 300–400 m and providing bagged cuttings samples to GNS Science for lithological logging.
- GNS Science has experience and capacity in supporting a wide range of geological services associated with rotary drilling. Recommended services for GEOLOGY Phase-2 include:
  - Design and management of drilling operations for a 300–400-m-deep rotary borehole.
  - Off-site lithological logging of bagged cuttings samples to document the stratigraphy and identify key aquifers.
  - Radiocarbon C14-AMS dating of marine and non-marine fossil material for age/subsidence modelling (last 40,000 years).
  - Geological modelling and reporting.
  - MDC would be required to arrange landowner access.
- Drilling to a depth of 300–400 m is expected to take ~1 month, and the analysis of cutting samples, dating and reporting ~3 months.
- Drilling services: \$300,000 to \$400,000 (drilling cost approximately \$1000/m).
- Specialist services, including project management, lithological logging, C14-dating, geological modelling and reporting: \$60,000.

*Approximate total cost: \$360,000 – \$460,000.*

## Additional Options

- Wireline logging is recommended, but this is not included in the cost (see Phase 4).
- Groundwater testing at horizons of interest is possible but not recommended, as the drillers would need to install temporary casing and flush the drilling fluids from the hole, with a qualified/experienced hydrologist needed on-site. This would add to the drilling cost. There are also engagement costs to stop abstraction from surrounding impacting bores during the testing so that these do not interfere with the results.
- Completion of the borehole as a saline-intrusion monitoring well – MDC to negotiate requirements with GNS Science and McMillan Drilling Services and pay additionally.

### 4.2.2 Decision Point for GEOPHYSICS

#### 1. Commit to GEOPHYSICS Phase 1 GroundTEM

*Collect GroundTEM data to map the resistivity structure beneath the coastal Wairau Plain and identify the optimal location of thick, high-resistivity layers likely to be aquifers.*

In order to target a well that is expected to reach a depth of 300–400 m, having some idea of the strata beneath the potential locations of coastal-plain drill sites is critical because rapid lateral changes in groundwater facies are expected. Geophysical methods deployed on the ground can provide this information. Electrical resistivity soundings have been made in parts of the Wairau plains, and the electrical properties of the different geological units are known.

In GEOPHYSICS Phase 1, the recommended approach is to collect GroundTEM soundings on a transect across the coastal plain. GroundTEM utilises a loop on the ground that generates an electromagnetic field. The decay of that field into the subsurface is a function of the resistivity of the layers. The decay of the field is detected using a small receiver loop in the centre of the transmitter loop. The data are processed using geophysical inversion software to produce a layered model of the subsurface to a depth of ~500 m. Sand- and gravel-rich layers will have high resistivity, while clay and marine silt layers will have low resistivity. Figure 4.2 shows an example of a series of GroundTEM models and the interpreted geology.

**Objectives:** Define the extent of high-resistivity gravel aquifers and low-resistivity confining layers and aquitards and identify the best location for drilling a deep borehole and establishing a saline-intrusion monitoring well.

**Risks:** (1) No clear resistivity contrast between the main geological units. (2) High electrical noise levels from high-voltage direct current powerline and local electrical fences.

#### Estimated Cost for GEOPHYSICS Phase-1

- GNS Science has the capacity to collect and process GroundTEM data.
- MDC would be required to arrange landowner access.
- A typical GroundTEM survey would require two days of field acquisition, and a report would be available within a month of collecting the data.

*Approximate cost: \$50,000.*



The seismic survey would be collected on a series of straight lines across the central part of the coastal plain. Roads and farm tracks would be utilised to reduce the time needed to collect the data. Figure 4.4 shows some examples of the likely line locations.



Figure 4.4 Proposed seismic lines across the coastal Wairau Plain. Total length 10 km.

**Objectives:** Define the extent of highly reflective packages that demark fine-grained units and large blocks of low reflectivity that are likely gravel units. Faulting will be clearly imaged. The top of the basement may also be detected with a strong enough seismic source. Identify the best location for drilling a deep well.

**Risks:** (1) Poor signal quality due to surface conditions. (2) Low reflectivity due to absence of sharp boundaries between contrasting lithological units. (3) Noise levels from traffic, powerlines and farm activity.

#### **Estimated Cost for Seismic Reflection Survey**

- GNS Science has the capacity to design and manage a seismic reflection survey.
- New-Zealand-based contractors, including Southern Geophysical, have the capacity to collect seismic data and provide the partially processed data to GNS Science.
- Options would be considered for processing the data at GNS Science or having it processed by a separate consultant.
- GNS Science would interpret the seismic lines.
- MDC would be required to arrange landowner access.

Seismic reflection surveys are logistically complex and expensive. An initial test would be undertaken to determine the acquisition properties. If poor data were collected during the test, the seismic survey would not proceed. The costs of the survey are outlined in terms of the test phase and a cost per kilometre for the complete survey. The lines shown in Figure 4.4 would require 10 days to collect and the processing, interpretation and reporting would take 3–4 months.

Field Parameter Test: \$6000.

Field Acquisition Costs: \$12,000/day (10 line-km ~\$120,000).

Processing, interpretation and reporting: \$60,000.

*Approximate total cost: \$190,000.*

### 3. Commit to GEOPHYSICS Phase 3 Regional AEM Survey (SkyTEM)

*Collect a regional airborne electromagnetic (AEM) survey over the Wairau plains to provide a detailed dataset to support a wider range of hydrogeological investigations.*

In GEOPHYSICS Phase 3, the recommended approach is to fly a high-resolution regional AEM survey over the Wairau plains. The AEM survey would be flown on lines spaced 200 m apart, covering an area of up to 600 km<sup>2</sup>. Areas around urban centres are excluded due to restrictions on flying and the impact of the electrical interference on the AEM signal. Figure 4.5 shows the planned AEM survey area.

AEM surveys are being used across New Zealand and in other parts of the world (e.g. Australia, California, Nebraska) to provide a regional view of groundwater systems, with the aim of identifying and characterising previously unmapped aquifers and the risks to known aquifers. The AEM method utilises a helicopter-deployed electromagnetic system that is capable of generating a resistivity model to a depth of 400–500 m, depending on the geology. The system is flown in lines that are 200–400 m apart and collects a resistivity sounding every 15–20 m. The data are modelled on profiles and into 3D cubes of data to provide a high-resolution model of the surveyed area. The method is analogous to the GroundTEM survey, so the data collected on any GroundTEM transect can be used to design and then interpret the AEM model.



Figure 4.5 Proposed coverage of SkyTEM survey (600 km<sup>2</sup>).

GNS Science has been collecting AEM data since 2020 using an Australian contractor (SkyTEM). Surveys have been completed in the Hawke's Bay, Southland, Northland, Wairarapa and the East Cape. Workflows have been developed that efficiently process and model the data. Converting the resistivity models into hydrogeological models requires skills in

interpretation and, for calibration, a good set of supporting geological and hydrogeological data from boreholes (see GEOLOGY Phase 1 and 2). Figure 4.6 shows an example of the SkyTEM data from the Heretaunga plains in Hawke's Bay. The survey is a significant undertaking and needs to be planned carefully to get the maximum benefit for the various users of the final products.

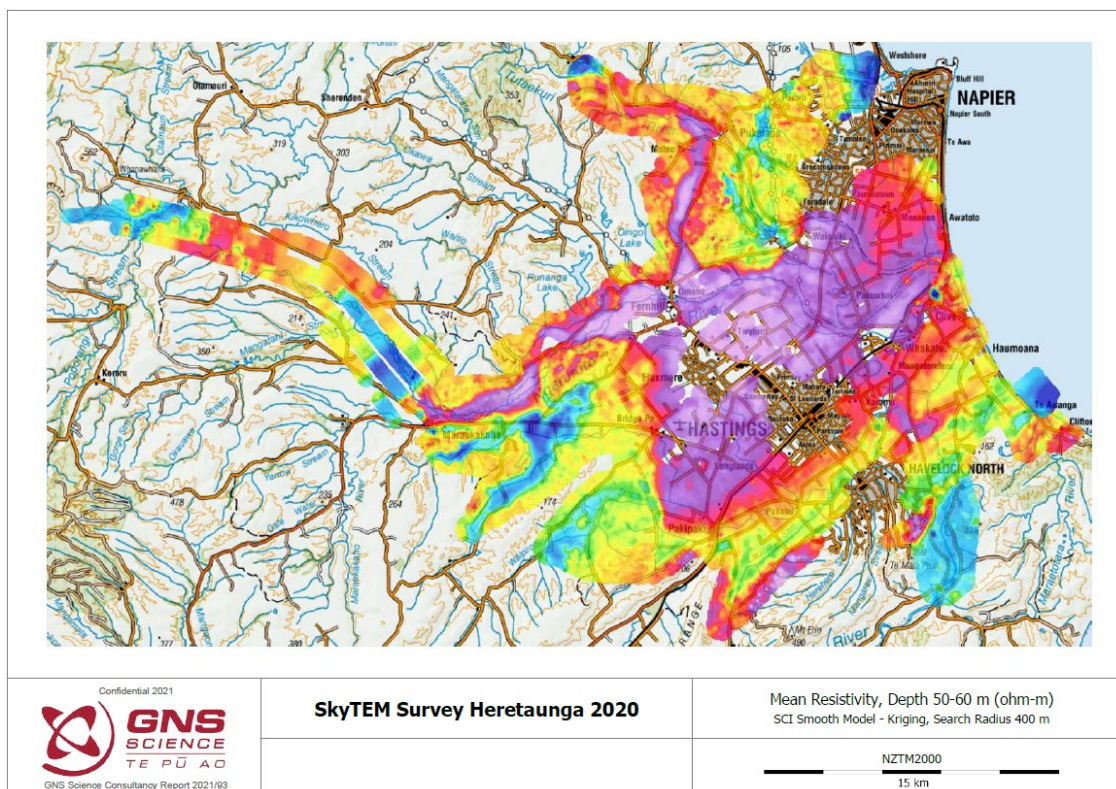


Figure 4.6 Depth slice 50–60 m from the SkyTEM survey over the Heretaunga plains of Hawke's Bay. Red regions indicate high-resistivity gravels and blue regions indicate low-resistivity silts and clays (Rawlinson et al. 2021).

**Objectives:** Define the extent of high-resistivity gravel- and sand-rich aquifers beneath the coastal Wairau Plain, to a depth of ~300 m if the geology is favourable. Identify the extent of confining layers and low-resistivity silt and clay units that provide barriers for groundwater flow. Map potential saline groundwater intrusion from the coast. Provide a hydrogeological model that is suitable for developing into groundwater flow models.

**Risks:** (1) Investment in AEM is significant, so a wider range of potential users are needed. (2) Noise levels from traffic, powerlines, urban areas, farm activity and land use (e.g. viticulture) may reduce the SkyTEM coverage.

### Estimated Cost for Regional AEM Survey (SkyTEM)

- GNS Science has the capacity to design and manage a SkyTEM survey.
- Australian-based contractor SkyTEM is utilised to collect the data and provide it partially processed to GNS Science.
- Regional initiatives are underway to investigate funding models for extensive SkyTEM surveys.
- GNS Science would interpret the SkyTEM data.
- MDC would be required to arrange landowner and community consultation.

SkyTEM surveys are logistically complex and expensive. The planning of a survey can take 1–2 years, and, once the survey has been flown and the SkyTEM data available, it can take ~2 years to process and analyse the data and deliver a regional hydrological model.

If the data from the GEOPHYSICS Phase 1 GroundTEM survey was poor, the regional SkyTEM survey would not proceed, and additional GroundTEM testing might be considered.

SkyTEM Survey costs (including acquisition, processing, and interpretation): \$1.6 million

*Approximate total cost: \$1.6 million*

#### 4. Commit to GEOPHYSICS Phase 4 Borehole Geophysical Logging

*Collect geophysical logs in any boreholes drilled as part of the groundwater investigation.*

In GEOPHYSICS Phase 4, the recommended approach is to collect borehole geophysical data to provide physical properties data to support the interpretation of the geophysical data and provide additional information on the aquifer and aquitard properties.

Borehole geophysical data can be collected using a series of probes that are lowered down the borehole. The data are best collected in boreholes with no casing, but a limited set of logs can be collected in boreholes that are lined with PVC or steel casing. Typical logs include density, natural gamma ray, electrical conductivity, seismic velocity, televiewer and acoustic images. Figure 4.7 shows the logs from a groundwater well in the Hutt Valley Aquifer. Gamma-ray logs provide information on the clay content of the units. Density and seismic velocity logs provide information on the grain size and cementation of the unit, electrical conductivity logs provide information on the clay content and the salinity of the pore water. GNS Science has experience interpreting these logs and utilising the data to support hydrogeological studies.

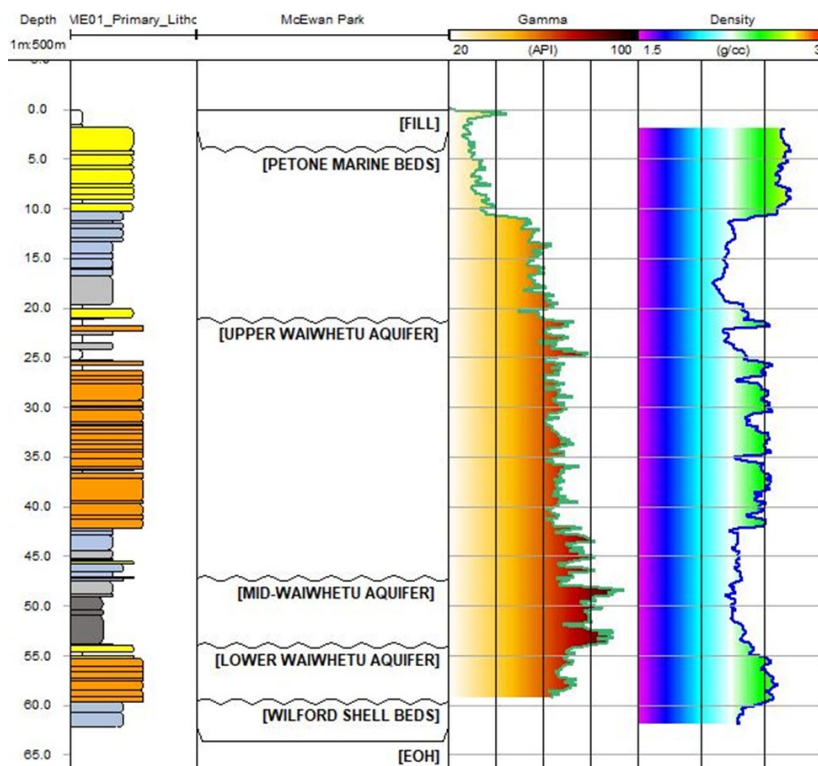


Figure 4.7 Geophysical logs in a groundwater well from the Hutt Valley Aquifer.

**Objectives:** Define the detailed properties of layers in the boreholes and support the processing and interpretation of surface geophysical data and hydrogeological investigations.

**Risks:** (1) PVC and steel casing restricts the types of tools that can be deployed. (2) Logging requires the drill rig to be on site and in standby mode, increasing the costs.

### **Estimated Cost for Borehole Geophysical Logging**

- GNS Science has the capacity to design and manage a geophysical logging programme.
- New-Zealand-based contractor RDCL is utilised to collect the data and provide it partially processed to GNS Science.
- GNS Science would interpret the logging data.
- The drilling contractor would co-ordinate the logging.

Geophysical logging is typically charged on a day rate, with some additional costs for specialised tools and standby rates to account for delays in getting access to the borehole. A 300–400 m deep well should take one day to log with a typical suite of tools, and a standard report is produced. GNS Science would incorporate the logging results into an analysis of the borehole.

Geophysical logging: \$15,000/day (includes mobilisation/demobilisation).

Standby rates: \$300/hour.

*Approximate cost: \$20,000 per borehole (including interpretation).*

## **5.0 RECOMMENDED APPROACH**

The process outlined above can be undertaken in a range of combinations and the costs of the project spread over a number of years. In order to achieve the MDC goals laid out in the objectives, GNS Science recommends the following approach.

### **Commit to Phase 1 GroundTEM and Sonic Coring**

1. **GEOPHYSICS:** GroundTEM, to identify the best location for drilling a deep borehole near the coast and establishing a saline monitoring well. *Approximate cost: \$50,000.*
2. **GEOLOGY:** Sonic coring to a depth of ~200 m (location based on GroundTEM results) in order to establish a fixed reference point for the lithostratigraphy and hydrological properties of groundwater facies and aquifers beneath the coastal Wairau Plain and define the vertical limits of the Wairau plains groundwater system. *Approximate cost: \$360,000.*
3. Complete the borehole as a saline intrusion monitoring well – MDC to negotiate requirements and cost with GNS Science and McMillan Drilling Services.

### **Commit to Phase 2 Rotary Drilling and Wireline Logging**

1. **GEOLOGY:** Drill a deeper rotary/mud borehole to a depth of 300–400 m (location based on Phase 1 results above) to establish a fixed reference point for the stratigraphy of deeper groundwater facies and aquifers beneath the coastal Wairau Plain. In addition, confirm the vertical depth limits of the groundwater system. *Approximate cost: \$360,000 – \$460,000.*

2. GEOPHYSICS: Wireline logging to identify the geophysical properties of groundwater facies in the upper 300–400 m of the Wairau plains groundwater system to support the building of sophisticated hydrogeological models. *Approximate cost: \$20,000 per borehole.*
3. Synthesis of data and reporting from Phase 1 and 2 investigations. *Approximate cost: \$10,000.*

### **Commit to Phase 3 SkyTEM and Additional Sonic Coring If Needed**

1. GEOPHYSICS: Regional AEM survey (SkyTEM) to provide a detailed electromagnetic dataset of the entire Wairau plains to support a wider range of hydrogeological investigations. SkyTEM relies on borehole data and can utilise geological, hydrological and geophysical parameters from GEOLOGY Phase 1 and 2. *Approximate cost: \$1.6 million.*
2. Additional drilling (sonic coring) and associated services may be needed to support the interpretation of SkyTEM data. This would add to Phase 3 costs.

The recommendations for geological and geophysical investigations are for planning and budgeting, and MDC must ultimately decide what geological and geophysical investigations are needed and how the investigations should be combined and staged. Formal quotes for services are issued when Council consults with GNS Science and commits to specific phases of recommended geological and geophysical investigations.

Yours sincerely,

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