REPORT

Tonkin+Taylor

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Auckland Regional Landfill

Hydrogeological Assessment

Prepared for
Waste Management NZ Ltd

Prepared by
Tonkin & Taylor Ltd

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Exceptional thinking together

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1 Introduction

1.1 General

Tonkin & Taylor Ltd (T+T) has been engaged by Waste Management NZ Ltd (WMNZ) to undertake a hydrogeological assessment for the proposed Auckland Regional Landfill located in the Wayby Valley. The entrance to the landfill will be 13 km northwest of Warkworth and 6 km southeast of Wellsford. T+T has undertaken a geotechnical site investigation for the site, with the results presented in the Geotechnical Factual Report (Technical Report A, Volume 2). The information collected during the geotechnical investigation has been used to assist with preparing this hydrogeological assessment.

This hydrogeological assessment describes the site geological and hydrogeological conditions and associated hydrogeological conceptual model. Further, this report assesses potential groundwater related effects associated with the construction and operation of the landfill, including contaminant fate and transport of potential leachate seepage and the take and diversion of groundwater. This report is intended to address the hydrogeological considerations of the Technical Guidelines for Disposal to Land[1] and support an application for resource consent.

1.2 Scope of work

The scope of this hydrogeological assessment includes:

- Installation of electronic water pressure transducers in the monitoring wells for continuous groundwater level readings;
- Groundwater quality sampling and laboratory analysis. At the time of preparation of this report, three groundwater sampling rounds had been completed;
- Preparation of a conceptual hydrogeological model based on the information collected as part of the geotechnical investigations;
- An assessment of the potential effects of activities including the following:
  - Potential leakage of leachate (if any) through the landfill lining system and the discharge of contaminants into ground and groundwater;
  - Groundwater drawdown; and
  - The take and diversion of groundwater during and following the construction of the landfill.
- Preparation of this hydrogeological assessment to support the resource consent application process.

1.3 Site description

The proposed landfill site is located in Wayby Valley approximately 6 km southeast of Wellsford. The proposed landfill valley (Valley 1) is northwest facing and currently vegetated with pine forest (refer Figure HG-F1 attached in Appendix A). Valley 1 is located in the Eastern Block. The remainder of the Site consists of the Southern Block, which is also forested and will provide access to the landfill, and the Western Block, which is currently used for farming purposes. A full description of the project site is provided in Section 4 of the Assessment of Environmental Effects (AEE).

[1] WasteMINZ, August 2018. Technical Guidelines for Disposal to Land. Waste Management Institute New (WasteMINZ).

1.4 Project description

The project comprises the construction of a landfill with a capacity of approximately 25.8 Mm^3 to provide for the disposal of municipal solid waste for a period in excess of 35 years. It includes:

- All works associated with the development of an operating landfill on the identified footprint area including:
  - Earthworks to construct the required shape;
  - Construction of a low permeability composite lining system to prevent leachate seepage into the surrounding environment;
  - Construction of a leachate collection system above the low permeability composite liner;
  - Stormwater control around the constructed landfill and ultimate treatment of stormwater before it leaves the site; and
  - A landfill gas (LFG) collection system to collect LFG from the placed waste.
- A leachate management system, including leachate storage, tanker loading facilities, and leachate treatment facilities;
- LFG treatment by flare and an LFG to energy plant;
- Provision of water supplies for operational (non-potable) and staff (potable) requirements;
- A bin exchange area near the site entrance where road vehicles will deposit bins for site vehicles to transport them to the landfill tipping face;
- An access road from the site entrance to the main site, and all other roads required to access the various parts of the site;
- Operational infrastructure such as weighbridges and vehicle wheel wash;
- Facilities for site staff, including on-site wastewater disposal; and
- Maintenance facilities for site plant and equipment.

A full description of the proposal is provided in the AEE.

2 Site investigation methodology

2.1 Groundwater monitoring bore installation

The T+T geotechnical field investigation works undertaken for the landfill have been reported (Technical Report B, Volume 2) under separate cover. The bores drilled as part of the geotechnical investigation were installed as groundwater monitoring wells. The installation summary is provided in Table 2.1 and installation details are provided in the Geotechnical Factual Report (Technical Report A, Volume 2). The monitoring well locations are indicated in Figure HG-F2, attached in Appendix A.

Table 2.1: Monitoring well summary

Activity	Details
Dates of investigation work	26 February 2018 to 7 June 2018
Drilling contractor	McMillan Drilling
Bores installed	Fourteen monitoring wells (BH1 to BH14) were installed to depths between 25 and 50 m.
Bore construction	Bores were installed in accordance with the environmental standard for drilling of soil and rock, NZS 4411:2001. The work was performed by a licensed drilling contractor and supervised by a T+T engineer. Bores were installed with 50 Mm or 65 Mm internal diameter (ID), flush jointed class 18 PVC, threaded screen and casing. Bore logs are provided in the geotechnical factual report.
Bore pack type and arrangement	The filter pack was raised at least 1 m above the screen. A minimum 0.5 m sand blinding layer was installed above the filter pack. A bentonite seal of at least 1 m was installed above the blinding layer. The bores were grout sealed to the surface and secured with a raised cover.
Bore development	The groundwater monitoring wells were purged until the water was running clear prior to installation. The drilling contractor indicated the wells were developed following the installation using compressed air. Supplementary development of all wells using compressed air and bailing was undertaken between 22 and 27 March 2019 because some wells were experiencing slow recovery. Well development records are presented in Appendix B.

2.2 Groundwater resource investigation

A test bore has been drilled to evaluate the underlying regional aquifer. Summary details are provided in Table 2.2.

Table 2.2: Test bore summary

Activity	Details
Dates of investigation work	13 to 28 September 2018
Drilling contractor	McMillan Drilling
Bores installed	TB01
Drilling method	Rotary wash

Activity	Details
Bore construction	150 Mm diameter bore from surface to 202 m depth and 100 Mm to 251 m depth Casing to 202 m depth. Open hole from 202 m to 251 m depth
Bore development	Bore developed by airlifting for 3.5 hours.

2.3 Groundwater level monitoring

Groundwater levels have been recorded in the wells since April 2018. Manual groundwater level readings are detailed on Appendix C Table 1. Charts illustrating the continuous long term groundwater levels are also attached in Appendix C.

Groundwater level monitoring details are summarised in Table 2.3.

Table 2.3: Groundwater level monitoring details

Activity	Well ID	Details
Manual readings	BH1 to BH14 and TB01	Manual readings were taken during field investigations and on subsequent groundwater sampling visits.
Electronic readings	BH1, BH2, BH3, BH5, BH7, BH9, BH10	Continuous groundwater levels recorded using Solinst brand leveloggers. Leveloggers installed in BH1, BH2, BH7 and BH9 on 03 May 2018, BH3 and BH5 on May 25 May 2018 and BH10 on 31 May 2018.
Barometric pressure	BH1	Barometric logger installed to measure variations in atmospheric pressure. The groundwater level data have been corrected using the atmospheric pressure readings.

2.4 Groundwater sampling

The groundwater sampling activities are summarised in Table 2.4. The groundwater sampling locations are indicated on Figure HG-F2 (Appendix A).

Table 2.4: Groundwater sampling summary

Activity	Details
Dates of groundwater sampling	31 May 2018 8 August 2018 31 October 2018 21 November 2018 (TB01 only) 4 April 2019
Monitoring wells sampled	BH1, BH2, BH3, BH5, BH7, BH9, BH10 and TB01
Groundwater level measurement	Monitoring wells were manually dipped using an electronic dip meter prior to collecting the groundwater samples.
Groundwater sampling (monitoring wells)	The samples were collected by a T+T environmental scientist using Hydrasleeves, a non-purge method of water sample collection. This method was adopted because of the remote location of a number of

Activity	Details
	monitoring wells leading to difficulties in transporting sampling equipment. The samples were collected from within the screen and the sample collected is considered representative of the prevailing groundwater conditions.
Decontamination procedure	Dedicated Hydrasleeves per sampling event were used to collect the groundwater samples, thus decontamination was not required.
Sample preservation and transport	Samples were stored in a chilly bin while on-site and during transport to RJ Hill Laboratories Ltd under chain of custody documentation.

2.5 Groundwater laboratory testing

Groundwater samples were tested for the range of analytes listed in Table 2.5. RJ Hill Laboratories Ltd is an IANZ accredited laboratory for the parameters tested.

Copies of the original laboratory transcripts are attached as Appendix D and the tabulated results are presented in Table E1 (Appendix E).

Table 2.5: Summary of groundwater laboratory analysis

Well ID	Number of samples testing	Tested sample ID	Analysis
BH1, BH2, BH3, BH5, BH7, BH9, BH10	7	BH1, BH2, BH3, BH5, BH7, BH9, BH10	Heavy metals, dissolved trace (As, Cd, Cr, Cu, Ni, Pb, Zn) Polycyclic Aromatic Hydrocarbons (PAH) Total Petroleum Hydrocarbons (TPH) pH, total alkalinity, iron, manganese carbonate/bicarbonate, total hardness, EC, total boron, total calcium, hexavalent chromium, total magnesium, total potassium, total sodium, chloride, total ammoniacal-N, Nitrate-N, Nitrite-N, sulphate, BOD, COD.
TB01	1	Wayby Valley Bore	Chloride, nitrate as (N), sulphate, ammoniacal nitrogen, bicarbonate alkalinity, carbonate alkalinity, conductivity, dissolved oxygen, dissolved reactive phosphorous, free carbon dioxide, hydroxide alkalinity, pH, total alkalinity, total dissolved solids, turbidity, arsenic (total), boron (total), calcium (total), manganese (total), potassium (total), Escherichia coli and total coliforms.

2.6 In-situ rock mass permeability testing

In-situ rock mass permeability testing (Packer Testing) was undertaken during the geotechnical site investigation work by the drilling contractor. Packer testing is an in-situ method to estimate the average hydraulic conductivity of the rock mass in a portion of a borehole isolated by pneumatic packers. The details of the Packer Testing are provided in Table 2.6.

Table 2.6: Packer Testing summary

Item	Details
Bores tested	BH1 to BH14
Testing interval	Tests were undertaken at 1.5 to 6 m intervals. Some sections of the bores were not included in the Packer Testing because of practicalities associated with time constraints. The testing completed is considered representative of the overall rock mass.
Methodology	The Packer Testing methodology is fully described in Section 4.4.2 of the T+T geotechnical factual report.
Geological unit	Pakiri Formation.
Test results	The permeability results are discussed in Section 3.8 and the tabulated results are attached in Appendix F to this report.

3 Environmental setting

3.1 Geology

The Geotechnical Interpretative Report (Technical Report B, Volume 2) provides a detailed description of the regional and local geology based on published information and intrusive site investigation information. The following sub-sections summarise the geology described in the report.

3.1.1 Regional geology

The geological map of Auckland[2] shows that the surface geology of the site is Pakiri Formation, part of the Waitemata Group. Much of the Waitemata Group consists of gently inclined undulating sedimentary strata, interrupted by some geological faulting, with localized highly deformed intervals. The current landform is strongly influenced by weathering and slope movements along the arc-shaped ridgelines formed in the Waitemata Group deposits.

Northland Allochthon is shown to be present within the Western Block to the west of Valley 1, extending from the west into the low lying and gently sloping pastoral land. The position of the allochthon is marked by a thrust fault and is described as closely fractured to sheared, light or dark coloured, siliceous and sometimes calcareous mudstone with micaceous sandstone, siltstone, green and brown shale and muddy limestone.

Holocene River deposits of the Tauranga Group are located to the west of Valley 1 and follow the course of the Hōteo River. The river deposits typically consist of sand, silt, and clay with local gravel and peat beds.

3.1.2 Site geology

The geotechnical investigations confirmed the presence of the Pakiri Formation around Valley 1 and the wider site. Northland Allochthon was encountered during site investigations on the low lying land to the west of Valley 1. Tauranga Group deposits were not encountered during the investigations.

The T+T geotechnical investigations encountered a relatively consistent soil and rock profile in the vicinity of Valley 1. Table 3.1 summarises the soil and rock profile.

Table 3.1: Summary soil and rock profile encountered

Unit	Depth (m)	Description
Topsoil	0.0 to 0.3	-
Alluvium	0.0 to 12.5	Clays, silts and sands. Only encountered in BH14.
Residual soil	0.3 to 12.5	Silty sands or sandy silts or silty clays. Thicker residual soils were encountered along the ridgelines around Valley 1, becoming thinner downslope toward the valley floor.
Bedrock (Pakiri Formation)	Up to 50	Typically comprises interbedded weak to moderately strong sandstone and very weak to weak siltstone, with sandstone being the prominent lithotype. Fracture zones were encountered in the Pakiri Formation in all bores except BH7.

[2] Institute of Geological and Nuclear Sciences, 2001. 1:250,000 Geological Map, Auckland.

Unit	Depth (m)	Description
Bedrock (Northland Allochthon)	-	Completely weathered material is typically very stiff to hard silt with occasional limestone gravels, overlain by stiff, clayey residual soil. Encountered in hand augers advanced on the Western Block, west of Valley 1.

3.2 Climate

The closest meteorological site (Mahurangi Mews) is approximately 3 km south of Valley 1 and is operated by Auckland Council as part of the regional environmental monitoring programme. The annual rainfall at this location between 2014 and 2017 are presented in Figure 3.1. Also shown is the long term average for the Auckland Region (Auckland average) based on the NIWA Annual Climate Summary reports[3] for the last five years.

The annual rainfall within the Wayby Valley and Dome Valley is greater than the Auckland Region, with an annual rainfall of 1,200 to 2,000 mm/year compared to annual rainfall across the rest of the region of between 1,200 and 1,300 mm/year.

To derive an appropriate long term annual average rainfall for Valley 1 we have used daily rainfall data from NIWA's virtual climate station network (VCSN) database. The VCSN is spaced on a 5 km grid and the data is from the climate model that generates daily rainfall surfaces is based on observed rainfall at surrounding rainfall stations. Based on these data, we have adopted an annual average rainfall for Valley 1 of 1,564 mm.

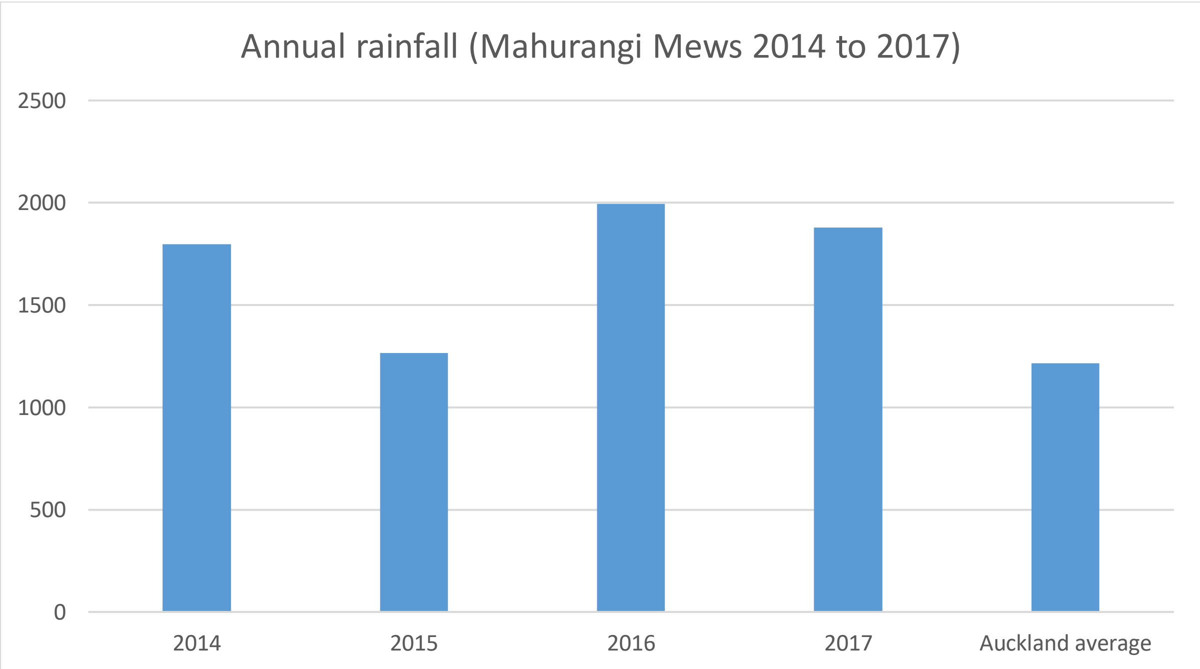


Figure 3.1: Annual rainfall recorded by Auckland Council at Mahurangi Mews.

3.3 Rainfall recharge – Valley 1 catchment

Rainfall infiltration is likely to be the main form of local groundwater recharge within the Pakiri Formation rock at higher topography and within the gully slopes encountered in Valley 1 and the site (refer discussion of groundwater systems in Section 3.6 below). For the purposes of our assessment and in the absence of other data, we have reasonably assumed that rainfall infiltration recharge of

[3] NIWA, 2018. Data accessed at https://www.niwa.co.nz/climate/summaries/annual on 14 June 2018.

the local groundwater in the higher elevations of the Pakiri Formation around Valley 1 is up to 10 % of the annual rainfall.

The rainfall recharge estimate for the shallow Pakiri Formation around Valley 1 is summarised in Table 3.2.

Table 3.2: Rainfall recharge for Valley 1

Item	Details
Valley 1 catchment area	Estimated to be 1 km^2
Annual volumetric rainfall	1.6 mm^3 calculated by multiplying 1 km^2 by 1,564 mm rainfall.
Rainfall recharge	10 % of annual volumetric rainfall = 160,000 m^3 per year.

The regional aquifer is expected to receive less recharge from rainfall. A hydrogeology assessment report[4] prepared on behalf of New Zealand Transport Agency (NZTA) for the Puhoi to Warkworth alignment indicated that 'recharge to the Waitemata group rock is typically only a small proportion of the water balance due to:

- A combination of generally steep topography and low infiltration capacity of the soils derived from weathered Waitemata Group rocks;
- High potential evaporation.

The features promote high surface runoff and soil evaporation, and suppress groundwater recharge.'

The report indicated that the deep groundwater recharge rate in the area of the alignment is about 50 mm/year or approximately 3.3 % of annual rainfall. In the same report, Auckland Council states that recharge in the Waitemata Group materials typically ranges from 2 to 4 % of mean annual rainfall.

3.4 Regional rainfall recharge: Hōteo groundwater catchment

The extent of the Hōteo groundwater catchment (of the deeper regional aquifer) and recharge estimates are set out in the Auckland Regional Council (ARC) Technical Publication 194 (TP194), 2003[5]. The groundwater catchment covers approximately 54,000 ha.

The estimate of groundwater recharge across the Hōteo groundwater catchment is detailed in Table 3.3. Also included in the table is an estimate of groundwater availability, referred to in Section 9 of this report.

Table 3.3: Hōteo groundwater catchment recharge and availability estimate

Parameter	Value	Description
Catchment size	54,000 ha	The extent of the Hōteo groundwater catchment is provided in Figure 9 in ARC technical publication TP194.
Annual volumetric rainfall	864 Mm^3	Catchment area multiplied by an annual average rainfall of 1,600 mm (rounded up from 1,564 mm from Section 3.2.
2 to 4% recharge to deep Waitemata aquifer	17 to 35 Mm^3	-

[4] Further North Alliance, 20 August 2013. Hydrogeology Assessment Report, Puhoi to Warkworth.
[5] Auckland Regional Council, May 2003. North-West Auckland Water Resource Quantity Statement 2003. Surface water and groundwater resource information availability and allocation.

Parameter	Value	Description
Annual availability estimate for allocation	6 to 12 Mm^3	35 % availability as a percentage of annual recharge set out by Auckland Council, 2016[6].

3.5 Groundwater levels

3.5.1 Groundwater monitoring wells

The manual groundwater levels recorded in the monitoring wells around Valley 1 are provided in Appendix C Table 1. The continuous groundwater level readings from 1 June 2018 to 21 March 2019 are illustrated on the charts also attached as Appendix C. Daily rainfall recorded at the Warkworth weather station (Network Number: A64464) are included on the charts. Manual groundwater level readings taken before levelogger removal are indicated as an 'x' on the charts. Although continuous monitoring commenced in May 2018, the data up to June 2018 had to be disregarded because of problems relating to the barometric correction.

A detailed description of the groundwater level observations recorded in each of the monitoring wells by the leveloggers and manual measurement is provided in Appendix C Table 1. In summary, the groundwater levels in the monitoring wells have recovered since the initial installation and development, generally at different rates. Some of the wells seem to respond to rainfall and some to seasonal variation. Some of the wells are still recovering. These observations appear to reflect the overall low hydraulic conductivity conditions of the Pakiri Formation rock mass.

3.5.2 Test bore (TB01)

Manual groundwater level readings were taken on a number of occasions from the deep test bore. The readings are summarised in Table 3.4. The relative static water level in TB01 is markedly deeper than those recorded in the majority of monitoring wells, except for BH13 and BH14, which are situated on the lower elevations of the proposed access road. These bores have consistently recorded groundwater levels between approximately 30 and 35 mRL. Figure 3.2 illustrates the differences in groundwater heights (mRL) around Valley 1 and the proposed access road. The approximate height of the Hōteo River and Waiteraire Stream are also shown.

Table 3.4: Groundwater levels in test bore (TB01)

Date	Depth to groundwater (m bgl)	Groundwater level (mRL)
29 September 2018	147.2	35
20 November 2018	147.2	35
26 November 2018	147.3	35

[6] Auckland Council. Unitary Plan, Appendix 3 Aquifer water availabilities and levels – Table 1: Aquifers not separately listed.

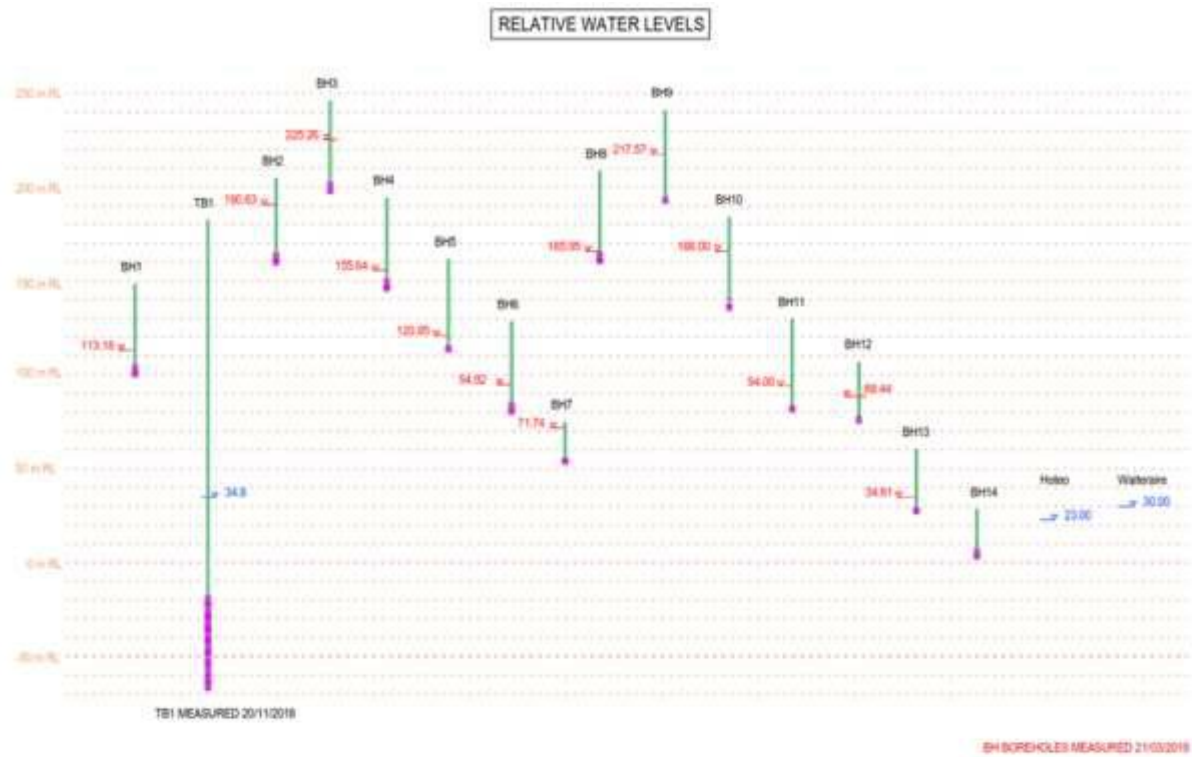


Figure 3.2: Groundwater levels as mRL in wells around Valley 1.

3.5.3 Auckland Council data

Of the eighteen bores in the regional aquifer within 5 km of Valley 1 recorded in the Auckland Council database, three recorded static water levels. The groundwater level details are summarised in Table 3.5. The locations of the three bores are indicated in Figure HG-F2, attached as Appendix A. The bores are all located to the north of Valley 1 on the lower lying land of the Hōteo plains.

The static water levels in these bores are inferred as being representative of the regional groundwater level of the Waitemata aquifer.

Table 3.5: Summary of Auckland Council bore database

Bore ID	Date	Main aquifer	Ground elevation (mRL)	Static water level (m bgl)	Static water level (mRL)
22011	12 December 2003	Waitemata	82[1]	45	37
23589	11 August 2010	Waitemata	40	1	39
1346	21 June 1994	Waitemata	56	18	38

Notes:

1. Ground elevation taken from the Auckland Council Geomaps viewer using the NZTM coordinates.

3.6 Groundwater systems

Valley 1 is characterised by the steep terrain of the Pakiri Formation, which is typical of the area. 'Groundwater in the Pakiri Formation is strongly influenced by the incised valleys, with groundwater typically being elevated along ridgelines and depressed along valley sides and floors'[4].

The site investigation information and the information from Auckland Council records suggests three groundwater systems are present in the vicinity of Valley 1, as described in the following sub-sections.

3.6.1 Shallow perched groundwater

The shallow perched groundwater can be found in the residual soils above the interface with the highly weathered Pakiri Formation. The perched groundwater was encountered in the shallow hand augers and test pits advanced around Valley 1 as part of the geotechnical investigations.

The perched groundwater will be recharged directly from rainfall and is likely to create small discrete bodies of water that will contribute to the baseflow of the stream in Valley 1.

3.6.2 Groundwater in the Pakiri Formation

There is evidence of two established groundwater systems within the Pakiri Formation beneath Valley 1 and the wider site, consistent with previous observations in the Pakiri Formation in the area. 'Perched and leaky water tables may be present at higher elevations than the local water table in discrete localities, reflecting the interbedded nature of the sandstone/siltstone formation and typically low permeability of the siltstones providing the basal layer for perching.'[4]

Figure 3.2 (above) Illustrates the two groundwater systems that exist in the Pakiri Formation in the vicinity of Valley 1. The figure illustrates the groundwater levels (blue text) in the wells (green bars, with pink screen depths) around the arc-shaped ridgelines of Valley 1 (BH1 to BH6 and BH8 to BH10), in the valley floor (BH7) and along the proposed access route (BH11 to BH14). Groundwater storage in the monitoring wells around the ridgelines will be associated with fracture zones, joints and bedding planes, which will be recharged directly by rainfall infiltration.

The deeper static water level in the test bore (TB01) and estimated water levels[7] in the Hōteo River and Waiteraire Stream are also illustrated on the figure.

TB01 is located along the same ridgeline as BH1 and BH2 and is positioned between the two wells. The ridgeline falls in elevation from BH2 toward BH1, which can be seen on the figure. There is a distinct difference in the groundwater levels in BH1 and BH2 (and the other wells around the ridgelines and on the valley floor) when compared with TB01. The difference in groundwater levels at these locations is interpreted to demonstrate a shallow groundwater system associated with the higher elevations of the Pakiri Formation that is separate to the regional water table (TB01). The water table in TB01 is also similar to the estimated water levels of the Hōteo River and Waiteraire Stream as well as BH13 and BH14, supporting the presence of the regional water table that will provide baseflow to the surface water bodies.

The differences in groundwater levels indicate the potential for downward pressure gradients to prevail between the upper groundwater system and the deeper groundwater, at least in the vicinity of Valley 1 where the wells are installed. Again, this is consistent with observations in the Pakiri Formation elsewhere in the area. 'This downward pressure gradient is typical of areas with elevated topographic relief and where the geological profile comprises layered low permeability rocks. This combination promotes horizontal seepage along rock layer interfaces, along with lesser rates of downward vertical leakage, resulting in the downward pressure gradient.'[4]

3.7 Groundwater flow direction

To estimate groundwater flow directions and rates through aquifers, individual groundwater level readings (hydraulic head) have been united to create groundwater contours. The inferred groundwater flow directions are discussed in the following sub-sections.

[7] The estimated water level is based on the contours available on the Auckland Council Geomaps viewer.

3.7.1 Perched groundwater

The perched groundwater in the residual soils at the interface of the highly weathered Pakiri Formation is reasonably expected to follow the topography of Valley 1, contribute to spring flow at the surface of Valley 1 and flow in a downward direction toward the stream at the base of the valley.

3.7.2 Groundwater flow: Pakiri Formation

Groundwater flow in the higher elevations of the Pakiri Formation is considered to be influenced by the steep terrain, which results in groundwater levels that are a muted reflection of the topography.

The groundwater level readings collected between 22 and 27 March 2019 have been used to create a groundwater contour map illustrated on Figure 3.3 and Figure HG-F3 (Appendix A). The spatial extent of the groundwater contour information is currently limited because of access constraints at the time of the site investigation work, which means the groundwater contours in the higher elevations of the Pakiri Formation are constrained to Valley 1 (and Valley 2) and the proposed access road. Groundwater flows, whilst influenced by fracture zones, will be toward the Valley floor streams.

These groundwater flow characteristics will likely form local shallow groundwater divides beneath the ridgelines around Valley 1. Figure 3.3 indicates the location of a Significant Ecological Area – Terrestrial to the west of Valley 1. We have inferred that the groundwater flow beneath Valley 1 in the higher elevations of the Pakiri Formation flows away from the ecological area.

Groundwater flow in the Upper Pakiri Formation is also expected to percolate down through the rock mass over time and eventually enter the regional groundwater, albeit at a relatively low rate, retarded by the low permeability layers. Vertical hydraulic conductivities measured for the strongly bedded sequence of thin alternating siltstone and fine sandstone of the Waitemata Group during the Waterview Tunnel project indicated vertical conductivities on the order of 40 to 250 times lower than the horizontal conductivities[4].

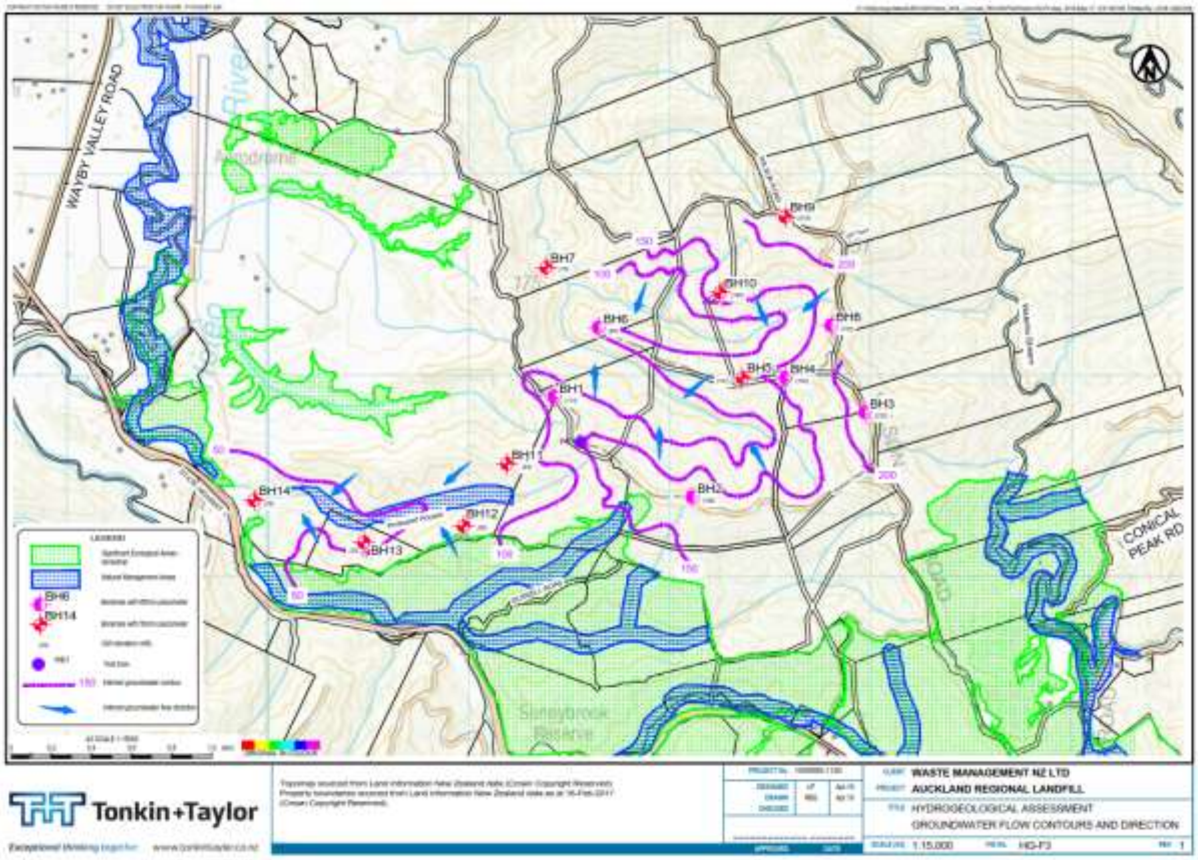


Figure 3.3: Groundwater flow contour map

On a regional scale, the deep groundwater recorded in TB01 beneath Valley 1 is inferred to flow predominantly toward the Hōteo River. However, there is also the potential for the regional groundwater to flow toward the Waiteraire Stream because of its close proximity (approximately 1 km) and the reasonable assumption that the groundwater contributes to the baseflow to the stream (refer Section 3.9). On this basis, the regional groundwater flow direction is expected to vary from the west to south west.

3.8 Aquifer hydraulic characteristics

Hydraulic conductivity characteristics have been based on the rock mass permeability testing (Packer Testing) undertaken during the bore drilling and from pumping test analysis completed for TB01. Published hydraulic conductivity values for the Pakiri Formation have also been referred to.

3.8.1 Packer Testing – Pakiri Formation

Packer Testing was completed in BH1 to BH14: the methodology is described in detail in the geotechnical factual report. A copy of the tabulated results is attached as Appendix F of this report and the calculated hydraulic conductivity values are summarised in Table 3.6.

The Packer Testing determines a Lugeon value which is a function of the amount of pressure that builds up between the Packers, the flow rate and time. Hydraulic conductivity values have been analysed using methods described in Royle[8] and Quinones-Rozo[9] and the adopted hydraulic

[8] Royle, M (unknown date). Standard Operating Procedures for Borehole Packer Testing.

[9] Quinones-Rozo, C. 2010. Lugeon Test Interpretation, Revisited. Proceedings of the United States Society on Dams, 30th Annual USSD Conference, Sacramento, California, April 12-16, 2010. pp 405-414.

conductivity has been selected following the method of Houlsby 1976[10], e.g. laminar flow, turbulent flow, etc.

The Geotechnical Interpretive Report (Technical Report B, Volume 2) indicates that the hydraulic conductivity within the Pakiri Formation is generally within the range of 1 x 10^{-9} to 3 x 10^{-6} m/s, but may be in the order of 1 x 10^{-5} m/s where fracture zones or other preferential pathways including joints and bedding planes occur. A low permeability rock mass was recorded in the Pakiri Formation from the boreholes located around Valley 1 (BH1 to BH10), supported by the general lack of water take during the Packer Testing.

The range of hydraulic conductivity values recorded in the Packer Testing is similar to published values for sandstones and siltstones of 1 x 10^{-10} to 1 x 10^{-6} m/s[11]. Published field testing of the Pakiri Formation[4] indicated hydraulic conductivity values for fresh and weathered Waitemata Group rock range between 1 x 10^{-9} m/s to 1 x 10^{-7} m/s.

The bore logs and core photographs identified the presence of fracture zones at the majority of investigation locations. These fracture zones generally coincide with higher hydraulic conductivities identified in the Packer Testing. These observations are summarised in the following points:

- The hydraulic conductivity values in the fracture zones around the ridgelines of Valley 1 are generally in the range of 1 x 10^{-3} to 8.7 x 10^{-4} m/s. This range of hydraulic conductivity values corresponds with limited to highly fractured zones within the bores. Hydraulic conductivity values in this range in hard rock indicate many open or open closely spaced rock mass discontinuities;
- There was no water take during the Packer Testing in BH7, which indicates a very tight rock mass with hydraulic conductivity values less than 1 x 10^{-7} m/s. The bore log and core photographs from BH7 reflect the observations from the testing;
- Testing of the bores (BH11 to BH14) along the proposed access route recorded relatively high hydraulic conductivity values generally between 1.7 x 10^{-3} to 7.6 x 10^{-3} m/s. Highly fractured zones are evident in the bore logs and core photographs which correspond well with the high hydraulic conductivities.

In summary, the Packer Test data indicate generally low-to-moderate permeability conditions in the Upper Pakiri Formation, with locally low hydraulic conductivities and some high hydraulic conductivity fracture zones. The data do not permit interpretation of whether higher permeability fracture zones extend for any distance, i.e. whether lengthy preferential flow pathways might exist.

Table 3.6: Hydraulic conductivity values

Borehole ID	Test range (m bgl)	Zones experiencing flow		Hydraulic conductivity values (m/s)	Description of fractures
		(m bgl)	(mRL)		
BH1	15 - 50	18 – 21 36 – 39 39 - 43.5 47 - 50	130 – 127 112 – 109 109 – 104.5 101 – 98	1.0 x 10^{-3} - 1.5 x 10^{-4}	The core indicated that the rock mass is highly fractured, predominantly from 36 m depth.
BH2	10.5 - 49.5	16.5 – 19.5 22.5 – 25.5	187.8 – 184.8 181.8 – 178.8	1.3 x 10^{-4} - 8.8 x 10^{-5}	Limited fracturing observed between 16.5 to 25.5 m depth.

[10] Houlsby, A.C. 1976. Routine Interpretation of the Lugeon water-test. Q. JI Engng Geol. Vol 9 1 pp.303-313.
[11] Freeze, R.A. and Cherry, J.A., 1979. Groundwater.

Borehole ID	Test range (m bgl)	Zones experiencing flow		Hydraulic conductivity values (m/s)	Description of fractures
		(m bgl)	(mRL)		
					The rock mass to 49.5 m depth has low hydraulic conductivity.
BH3	9 - 48	9 – 12 33 - 36	236.5 – 233.5 212.5 – 209.5	8.1 x 10^{-3} - 8.7 x 10^{-4}	The rock mass between 9 to 12 m is highly fractured. The Packer Testing and core photographs indicate less fracturing to 48 m depth, except for limited fracturing between 33 to 36 m.
BH4	13.5 - 46.5	13.5 – 16.5 43.5 – 46.5	180.2 – 177.2 150.2 – 147.2	6.2 x 10^{-4} - 5.9 x 10^{-4}	The shallow rock mass, down to 16.5 m, is highly fractured. The Packer Testing and core photographs indicate the deeper rock mass has limited fracturing and generally has low hydraulic conductivity.
BH5	28.5 - 49.5	28.5 – 31.5 34.5 – 37.5 40.5 – 43.5 46.5 – 49.5	132.7 – 129.7 126.7 – 123.7 120.7 – 117.7 114.7 – 111.7	7.6 x 10^{-3} - 3.9 x 10^{-4}	The rock mass is predominantly highly fractured.
BH6	10.5 - 49.5	10.5 – 13.5 34.5 – 37.5 46.5 – 49.5	117.5 – 114.5 93.5 – 90.5 81.5 – 78.5	1.7 x 10^{-3} - 4.4 x 10^{-4}	The rock mass is highly fractured to around 13.5 m zones of limited fracturing at depth. The core photographs indicate low hydraulic conductivity coincides with solid rock.
BH7	7.5 - 25.5	No flow.	-	-	Few to no fractures are visible in the rock mass below 7.5 m depth, which reflects the low hydraulic conductivity of the Packer Testing.
BH8	18 - 49.5	18.0 – 19.5 30.0 – 31.5 42.0 – 46.5	190.2 – 188.7 178.2 – 176.7 166.2 – 161.7	6.0 x 10^{-3} - 1.7 x 10^{-3}	The rock mass is highly fractured around 18 to 19.5 m depth and 30 to 31.5 m depth. Fracturing is less prevalent below 31.5 m depth indicating a generally low hydraulic conductivity rock mass to 49.5 m depth.
BH9	12 - 46.5	15.0 – 16.5 21.0 - 22.5	225.5 – 224 219.5 – 218	4.4 x 10^{-3} - 4 x 10^{-4}	The rock mass has highly fractured zones between 15 to 16.5 m and 21 to22.5 m depth. The Packer Testing and core photographs indicate a low hydraulic conductivity rock mass to 46.5 m depth.
BH10	12 - 49.5	12.0 – 15.0 18.0 - 21.0	171.5 – 168.5 165.5 – 162.5	4.9 x 10^{-3} - 6.4 x 10^{-5}	The rock mass appears fractured beyond 21 m depth to about 25 m depth. The Packer Testing and core photographs indicate the presence of a low hydraulic

Borehole ID	Test range (m bgl)	Zones experiencing flow		Hydraulic conductivity values (m/s)	Description of fractures
		(m bgl)	(mRL)		
					conductivity rock mass to 49.5 m depth.
BH11	15 - 49.5	21.0 – 24.0 27.0 – 30.0 33.0 – 36.0 36.0 – 39.0 42.0 – 45.0 46.5 - 49.5	108.2 – 105.2 102.2 – 99.2 96.2 – 93.2 93.2 – 90.2 87.2 – 84.2 82.7 – 79.7	5.5×10^{-3} - 6.2×10^{-6}	The Packer Testing and core photographs indicate that the rock mass is highly fractured.
BH12	12 - 33	12.0 – 15.0	94.44 – 91.44	1.7×10^{-3}	The rock mass appears highly fractured to around 15 m depth. Although some fracturing can be seen in the core photographs, the rock mass to 33 m depth is predominantly solid with low hydraulic conductivity.
BH13	12 - 35	12.0 – 15.0 16.0 – 18.0 18.0 – 21.0 21.0 – 24.0 27.0 – 30.0 32.0 - 35.0	48.1 – 45.1 44.1 – 42.1 42.1 – 39.1 39.1 – 36.1 33.1 – 30.1 28.1 – 25.1	7.6×10^{-3} - 4.0×10^{-3}	The Packer Testing and core photographs indicate a highly fractured rock mass to 35 m depth.
BH14	13.5 - 25.5	13.5 – 16.5 18.0 – 21.0 22.5 - 25.5	14.5 – 11.5 10 – 7 5.5 – 2.5	5.1×10^{-3} - 4.1×10^{-3}	The Packer Testing and core photographs generally indicate a highly fractured rock mass to the depth of the bore (26.8 m).

3.8.2 Laboratory permeability testing – weathered soil

Triaxial permeability tests were undertaken on bulk soil samples collected from test pits excavated around Valley 1. The samples were collected from the weathered soil overlying the Pakiri Formation rock and indicate that the soils have low hydraulic conductivities. A summary of the triaxial permeability testing is presented in Table 3.7.

Table 3.7: Summary of laboratory triaxial permeability tests in weathered soils

Test ID	Sampled depth (m bgl)	Material description	Coefficient of permeability (m/s)
TP03	0.2 to 1.8	Clayey SILT	5.8×10^{-10}
TP06	0.7 to 1.5	Sandy SILT	9.0×10^{-10}
TP08	2.6 to 4.1	Sandy SILT with some clay	7.6×10^{-10}
TP30	0.5 to 1.5	Silty CLAY	3.5×10^{-10}

3.8.3 Test bore observations

Observations made by the drilling contractor during the installation of the test bore (TB01) indicated that there were very little to no water losses in the upper 200 m of the bore to approximately -20 mRL. Based on the driller's observations, we have inferred that a rock mass with low hydraulic conductivity is present in the vicinity of TB01, which separates the groundwater in the higher elevations of the Pakiri Formation from the deep local or regional water table. The extent of this low permeability rock mass (i.e. whether it comprises an extensive aquiclude separating the shallow and deeper regional aquifers) cannot be inferred from the investigation data.

Section 6 provides the results of a constant rate pumping test completed from the test bore. Analysis of the information indicates that the deeper regional aquifer has a local hydraulic conductivity of 1.7 x 10^{-6} m/s.

3.8.4 Hydraulic gradient

The hydraulic gradient of the groundwater in the higher elevations of the Pakiri Formation around Valley 1 is expected to be variable and to be a muted reflection of the overall topography. As groundwater flows toward the centre of Valley 1 (refer Figure HG-F3, Appendix A, for the inferred flow directions), the groundwater gradients are estimated to be approximately 0.25. The relatively steep gradient indicates that the overall shallow rock mass has low hydraulic conductivity. The calculated hydraulic gradients are attached as Appendix G.

As groundwater in the higher elevations of the Pakiri Formation flows away from Valley 1, the hydraulic gradient will become shallower and, based on topographical contours along the floor of Valley 1, are calculated to be around 0.022 to 0.044.

The hydraulic gradient of the regional water table at depth has been estimated using the static water level recorded in the test bore and the approximate water levels in the Hōteo River and Waiteraire Stream. The hydraulic gradient of the regional water table aquifer is estimated as follows:

- 0.006 toward the Hōteo River: based on a head difference of 10 m and a horizontal separation (perpendicular to the river course) of approximately 1.7 km; and
- 0.005 toward the Waiteraire Stream: based on a head difference of 5 m and a horizontal separation (perpendicular to the watercourse) of approximately 1 km.

These much lower hydraulic gradients may indicate higher hydraulic conductivity of the regional aquifer at depth.

3.8.5 Summary of aquifer characteristics

Table 3.8 details the adopted aquifer parameters that are considered representative of the groundwater within the vicinity of Valley 1 and the wider site.

Table 3.8: Summary of adopted aquifer parameters

Aquifer parameter		Value	Details
Hydraulic conductivity	Rock mass	3 x 10^{-6} m/s	Adopted as the lower range thought to represent the low permeability rock mass.
	fractures	8.3 x 10^{-3} m/s	Adopted as the higher end of the range of the Packer Testing readings.
	Regional aquifer	1.7 x 10^{-6} m/s	Based on the analysis of the constant rate pumping test. Although, the low hydraulic gradient possibly indicates a higher hydraulic conductivity, which will be

Aquifer parameter		Value	Details
			considered in the groundwater risk assessment via sensitivity analysis.
Hydraulic gradient	Elevated Pakiri Formation	0.044	Higher end estimate of hydraulic gradients as groundwater flows away from Valley 1 in the higher elevations of the Pakiri Formation.
	Toward Hōteo River	0.006	Based on the static water level in TB01 and the estimate water levels in the surface water bodies.
	Waiteraire Stream	0.005	

3.9 Surface water

3.9.1 Valley 1 streams

Surface water is present across the site in the form of streams along the floor and slopes of Valley 1. The streams are reported to be incised into the weathered soils at the base of Valley 1 exposing the underlying bedrock (Pakiri Formation). Groundwater discharge from the exposed bedrock at the base of Valley 1, and also springs[12] on the upper north-facing slopes, provide the baseflow for the streams.

Rainfall-runoff within the Valley 1 catchment will also contribute to stream flows. Given the size of the Valley 1 catchment (approximately 1 km^2) and steepness of the topography, heavy rainfall events would be expected to result in reasonable increases in stream flow rates (see Technical Report E, Volume 2).

The stream within Valley 1 flows toward the north-west where it eventually discharges into the Hōteo River. The Hōteo River ultimately drains to the sea at the Kaipara Harbour.

3.9.2 Valley slope springs

Springs that T+T staff have observed are present at the head of gully streams as well as at higher elevations on the valley walls. We have inferred that the discharge from the springs is from either perched groundwater observed during the T+T field investigations in the residual soils or groundwater found in the higher elevations of the Pakiri Formation, which flows preferentially along the interface of fracture zones with low permeability layers that follow the dip of the underlying bedding, manifesting as seeps as the bedding intersects the ground surface. As indicated in the Geotechnical Interpretative Report (Technical Report B, Volume 2), the dip of the bedding is concordant with the north facing slopes and discordant with the steeper south facing slopes (i.e. creating scarp faces).

3.9.3 Wetlands

The T+T ecology team has mapped a number of wetlands within the Western Block (refer to Figure HG-F2, Appendix A). The locations of the wetlands are important because shallow groundwater and in some cases regional groundwater is likely to provide baseflow that supports the existence of the wetlands. Some of the wetlands, including one that forms a Significant Ecological Area – Terrestrial to the west of Valley 1 (SEA_T_629), are illustrated on our hydrogeological cross section attached as Appendix A.

[12] The T+T ecology team has undertaken detailed mapping of the streams across Valley 1 and other areas of the wider site as part of their ecological assessment, which has identified the presence of springs.

The wetlands eventually discharge to the west into small tributaries of the Hōteo River.

3.9.4 Hōteo River

The Hōteo River originates approximately 4.5 km to the north of the site at the junction of two tributaries (the Waiwhiu Stream and Whangaripo Stream) and flows toward the south west where it discharges at Mangakura into the Kaipara Harbour. The Hōteo River is fed typically by discharges from the adjacent gully slopes and drainage pathways and the adjacent Hōteo flats area. The Hōteo River is located approximately 2 km west of Valley 1 and flows adjacent to the wider site boundary.

Environmental monitoring information stored on the Auckland Council database, and accessed through the Geomaps web portal, provides water level and flow data for the Hōteo River at a location approximately 7 km down-gradient of the site (Hōteo River at Gubbs, refer to Figure 3.4). Readings from July 2017 through to July 2018 indicated flow rates in the Hōteo River generally between 5 to 10 m^3/s with numerous sharp increases in the peak flows, which during June 2018 reached up to 190 m^3/s. The Auckland Council river catchment technical report[13] indicates that mean daily flow for the Hōteo River is 6 m^3/s (1982 to 2010 average) and the Mean Annual Low Flow (MALF) is 0.54 m^3/s.

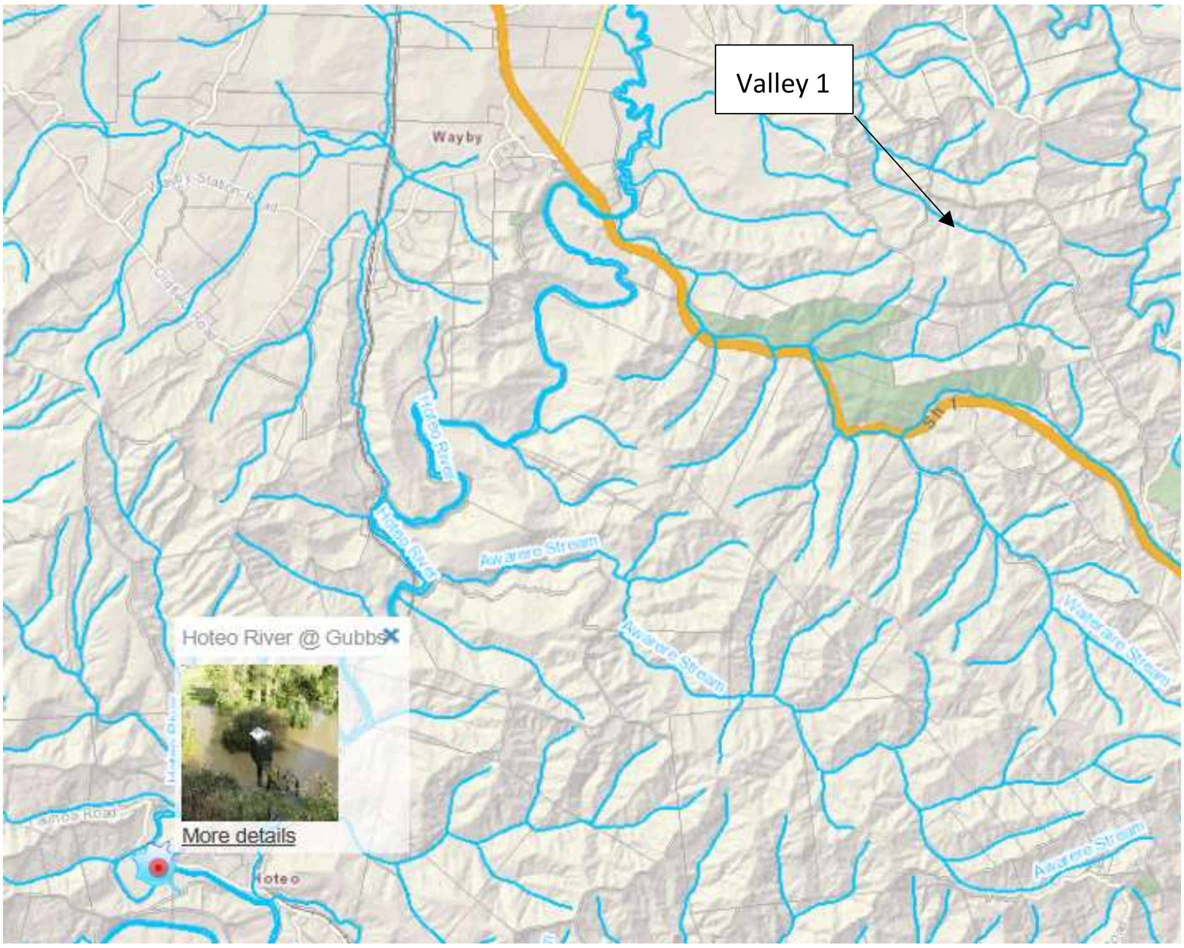


Figure 3.4: Hōteo River at Gubbs surface water flow monitoring site extracted from Auckland Council Geomaps portal.

The annual river flow readings dating back to July 2017 are illustrated in Figure 3.5. The chart indicates that the flow in the Hōteo River is variable with general low flow conditions being

[13] Auckland Council, August 2014. Hōteo River Catchment: Environment and Socio-economic Review, TR2014/021.

maintained during the summer periods and a more variable flow during the winter months as the river levels continually respond to rainfall events.

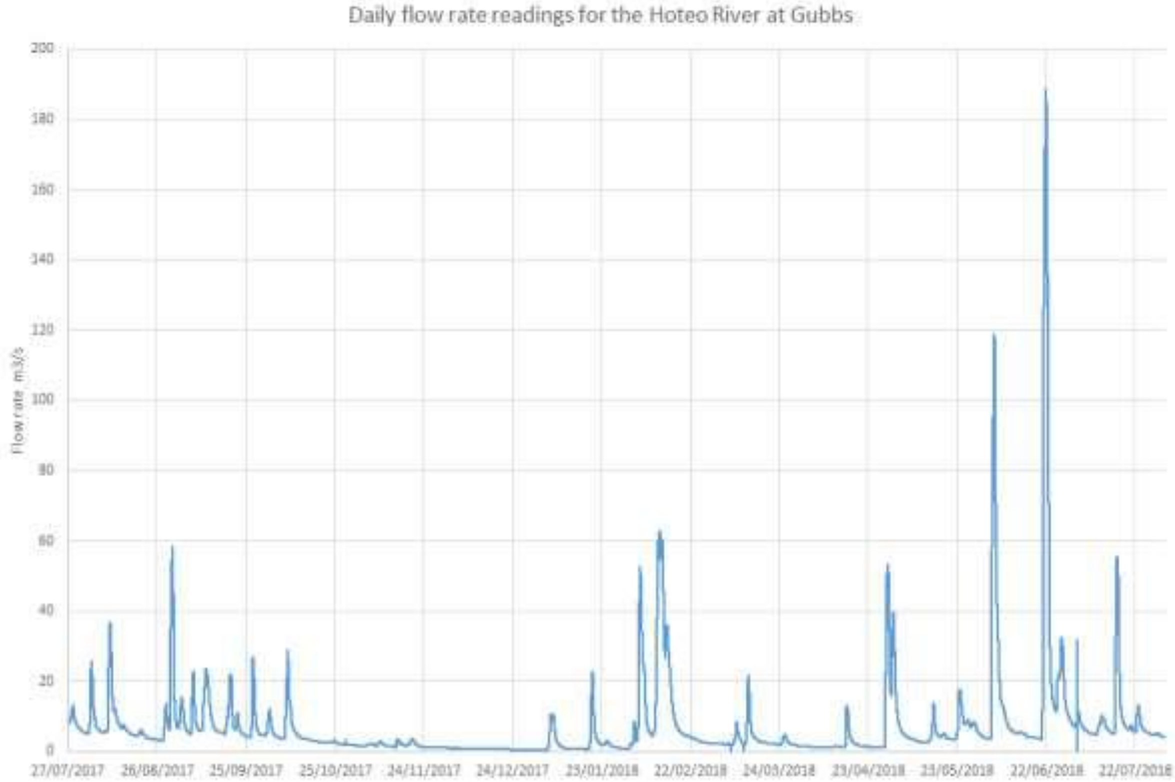


Figure 3.5: Daily flow rate readings for the Hōteo River at Gubbs.

4 Groundwater quality results

Groundwater quality samples have been collected from the monitoring wells in the higher elevations of the Pakiri Formation and also from the regional aquifer in TB01. The test results are discussed in the following sub-sections and have been evaluated against the:

- ANZECC 2000 95 % trigger values for freshwater[14] to characterise the groundwater in terms of ecological impacts; and
- Drinking water standards for New Zealand to characterise potential toxicity effects to health and also aesthetic considerations[15]. With regard to the standard metals, the characterisation of health effects has been made against the drinking water standards using the total water quality results.

4.1.1 Laboratory testing of the upper Pakiri Formation

Groundwater quality samples were taken and analysed to understand the background baseline composition of the groundwater in the higher elevations of the Pakiri Formation beneath Valley 1 (Refer Table 2.4 for a list of monitoring wells). The results of the laboratory analysis undertaken on samples collected in May, August, October 2018 and April 2019 are summarised in Table 4.1. The tabulated results and the laboratory transcripts are attached as Appendix E.

Table 4.1: Summary groundwater quality laboratory analysis

Chemical	Unit	Result range		ANZECC 2000 95% trigger values for freshwater	Drinking water standards	
		Minimum	Maximum		Maximum acceptable values (MAV)	Guideline values for aesthetics (GV)
pH	pH Units	6.8	12.2	-	-	7.0-8.5
Total Alkalinity	mg/L as $CaCO_3$	66	380	-	-	-
Carbonate	mg/L at 25°C	<1.0	56	-	-	-
Bicarbonate	mg/L at 25°C	1.3	290	-	-	-
Total Hardness	mg/L as $CaCO_3$	10.5	250	-	-	200
Electrical Conductivity (EC)	mS/m	21.9	182.1	-	-	-
Total Boron	mg/L	0.023	0.34	0.37	1.4	-
Total Calcium	mg/L	3.1	102	-	-	-
Hexavalent Chromium	mg/L	<0.001	0.0074	0.001	-	-
Dissolved Iron	mg/L	<0.02	0.36	-	-	-
Total Iron	mg/L	0.104	5.8	-	-	0.2

[14] These guidelines have been replaced by the Australian and New Zealand Guidelines for Fresh & Marine Water Quality (ANZAST). However, the Auckland Unitary Plan specifies the ANZECC water quality guidelines (October 2000), and so these have been adopted for our assessment.
[15] Ministry of Health, 2008. Drinking-water Standards for New Zealand 2005 (Revised 2008).

Chemical	Unit	Result range		ANZECC 2000 95% trigger values for freshwater	Drinking water standards	
		Minimum	Maximum		Maximum acceptable values (MAV)	Guideline values for aesthetics (GV)
Total Magnesium	mg/L	0.25	14.7	-	-	-
Dissolved Manganese	mg/L	<0.0005	0.154	1.9	-	-
Total Manganese	mg/L	0.0142	0.165	-	0.4	0.04 (staining) 0.1 (taste)
Total Potassium	mg/L	0.41	2.9	-	-	-
Total Sodium	mg/L	20	115	-	-	200
Chloride	mg/L	20	41	-	-	250
Total Ammoniacal-N	mg/L	<0.01	0.7	-	-	1.5
Nitrite-N	mg/L	<0.002	0.053	-	0.2	-
Nitrate-N	mg/L	<0.002	0.44	0.7	50	-
Nitrate-N + Nitrite-N	mg/L	<0.002	0.45	-	-	-
Sulphate	mg/L	5.8	19	-	-	250
Carbonaceous Biochemical Oxygen Demand (cBOD5)	g O_2/m^3	<2	6	-	-	-
Chemical Oxygen Demand (COD)	g O_2/m^3	<6	19	-	-	-
Dissolved heavy metals						
Dissolved Arsenic	mg/L	<0.001	0.0028	0.024	0.01	-
Dissolved Cadmium	mg/L	<0.00005	0.0001	0.0002	0.004	-
Dissolved Chromium	mg/L	<0.0005	0.0077	-	0.05	-
Dissolved Copper	mg/L	<0.0005	0.0027	0.0014	2	1
Dissolved Lead	mg/L	<0.0001	0.00076	0.0034	0.01	-
Dissolved Nickel	mg/L	<0.0005	0.0016	0.011	0.08	
Dissolved Zinc	mg/L	<0.001	0.0152	0.008	-	1.5
Polycyclic aromatic hydrocarbons (PAH)						
Acenaphthene	mg/L	<0.0001	0.00077	-	-	-
Anthracene	mg/L	<0.0001	0.00017	-	-	-
Fluoranthene	mg/L	<0.0001	0.00016	-	-	-
Fluorene	mg/L	<0.0002	0.0006	-	-	-
Phenanthrene	mg/L	<0.0004	0.0007	-		-
Total petroleum hydrocarbons (TPH)						
Total petroleum hydrocarbons (TPH)	mg/L	<0.06	<0.7	Note 2	Note 2	Note 2

Notes:

1 Drinking water standards are provided individually for TPH compounds. These compounds were all recorded below the laboratory limit of detection and have not been included in the table. Only PAH compounds with detectable concentrations are provided in the results summary.

Shading indicates guideline exceedances.

4.1.2 Laboratory testing of the regional aquifer

One sample was collected from TB01 during the constant rate pumping test. The test results are provided in Table 4.2 and laboratory transcript are attached as Appendix E. The findings of the evaluation against the guideline values are included in the following discussion.

Table 4.2: Laboratory test results of the water table aquifer

Sample name	Units	Wayby Valley Bore (TB01)	ANZECC 2000 95% trigger values for freshwater	Drinking water standards	
				Maximum acceptable values (MAV)	Guideline values for aesthetics (GV)
Lab Sample ID		181123-151-1			
Sample Date		12/11/2018			
Chloride	mg/l	28	-	-	250
Nitrate (as N)	mg/l	0.0034	0.7	50	-
Sulphate	mg/l	10	-	-	250
Ammoniacal Nitrogen (as N)	mg/l	0.059	-	-	1.5
Bicarbonate Alkalinity (as HCO3)	mg/l	170	-	-	-
Carbonate Alkalinity (as CO3)	mg/l	8.3	-	-	-
Conductivity (at 25 °C)	mS/m	38.5	-	-	-
Dissolved Oxygen	mg/l	2.5	-	-	-
Dissolved Reactive Phosphorus (as P)	mg/l	0.037	-	-	-
Free Carbon Dioxide	mg/l	<1.0	-	-	-
Hydroxide Alkalinity (as CaCO3)	mg/l	<1.0	-	-	-
pH	pH unit	8.4	-	-	7.0-8.5
Total Alkalinity (as CaCO3)	mg/l	160	-	-	-
Total Dissolved Solids	mg/l	300	-	-	-
Turbidity	NTU	13	-	-	2.5
Arsenic (Total)	mg/l	0.00037	0.024	0.01	
Boron (Total)	mg/l	0.35	0.37	1.4	
Calcium (Total)	mg/l	23	-	-	-
Iron (Total)	mg/l	0.93	-	-	0.2
Magnesium (Total)	mg/l	1.6	-	-	-
Manganese (Total)	mg/l	0.032	-	0.4	0.04 (staining) 0.1 (taste)

Sample name	Units	Wayby Valley Bore (TB01)	ANZECC 2000 95% trigger values for freshwater	Drinking water standards	
				Maximum acceptable values (MAV)	Guideline values for aesthetics (GV)
Lab Sample ID		181123-151-1			
Sample Date		12/11/2018			
Potassium (Total)	mg/l	0.16	-	-	-
Sodium (Total)	mg/l	59	-	-	200
Total hardness (as CACO3)	mg/l	63	-	-	200
Escherichia coli	MPN/100 mL	<1.0	-	<1.0 in 100 mL sample	-
Total Coliforms	MPN/100 mL	37	-	-	-

4.1.3 Groundwater quality

The summary of the test results in Table 4.1 indicates copper (BH2, BH3, BH7, BH9, and BH10), zinc (BH1, BH5, and BH10) and hexavalent chromium (BH1 and BH9) are naturally elevated in relation to the ANZECC 2000 95% guidelines for freshwater. Total iron and total manganese concentrations exceed the respective aesthetic drinking water guidelines in the majority of sample locations. The tabulated results in Table E1, Appendix E detail the individual exceedances.

The sample of the regional aquifer tested from TB01 recorded turbidity (appearance) and iron (staining) concentrations above the NZ Drinking Water Standards GVs (aesthetics). Neither of these natural exceedances poses a risk to human health or the environment.

4.1.4 Groundwater chemistry

The chemical composition of groundwater in the higher elevations of the Pakiri Formation (Waitemata Group) can be used to attempt to classify the waters. Previous work in the area has indicated that 'Shallow groundwaters (<200 m depth) commonly have a high total hardness/ total alkalinity (TH/TA) ratio, are hard calcium carbonate waters with near neutral pH, high iron (>1.0 g/m^3), and silica concentrations greater than 40 g/m^3. Deeper groundwaters commonly have a low TH/TA ratio, are soft bicarbonate water with pH>8.5, have low total iron (<0.2 g/m^3 (or mg/L)) and silica concentrations less than 40 g/m^3.'[16]

Piper plots have been used to characterise the chemical composition of the groundwater in the upper elevations of the Pakiri Formation and also the regional aquifer and are attached as Appendix H. The piper plot for the Upper Pakiri Formation is presented as Figure 4.1. The water sampled from the test bore roughly reflects what would be expected in the deep Pakiri Formation because it is a bicarbonate type, has a low TH/TA ratio and is pH8.4.

The waters sampled in the Upper Pakiri Formation generally tend toward the bicarbonate type, either magnesium, sodium or a mix of the two. The exceptions are BH9, which is shown to be predominantly sodium chloride type, and BH3 (in April 2019), which is shown to be calcium chloride type. A check of the cation/anion balance for BH3 (in April 2019) and BH9 indicates the water types may be in error because the balances are greater than 10%.

[16] Auckland Regional Council, May 2002. Auckland Water Resource Quantity Statement 2002. Surface water and groundwater resource information, availability and allocation. Technical Publication 171.

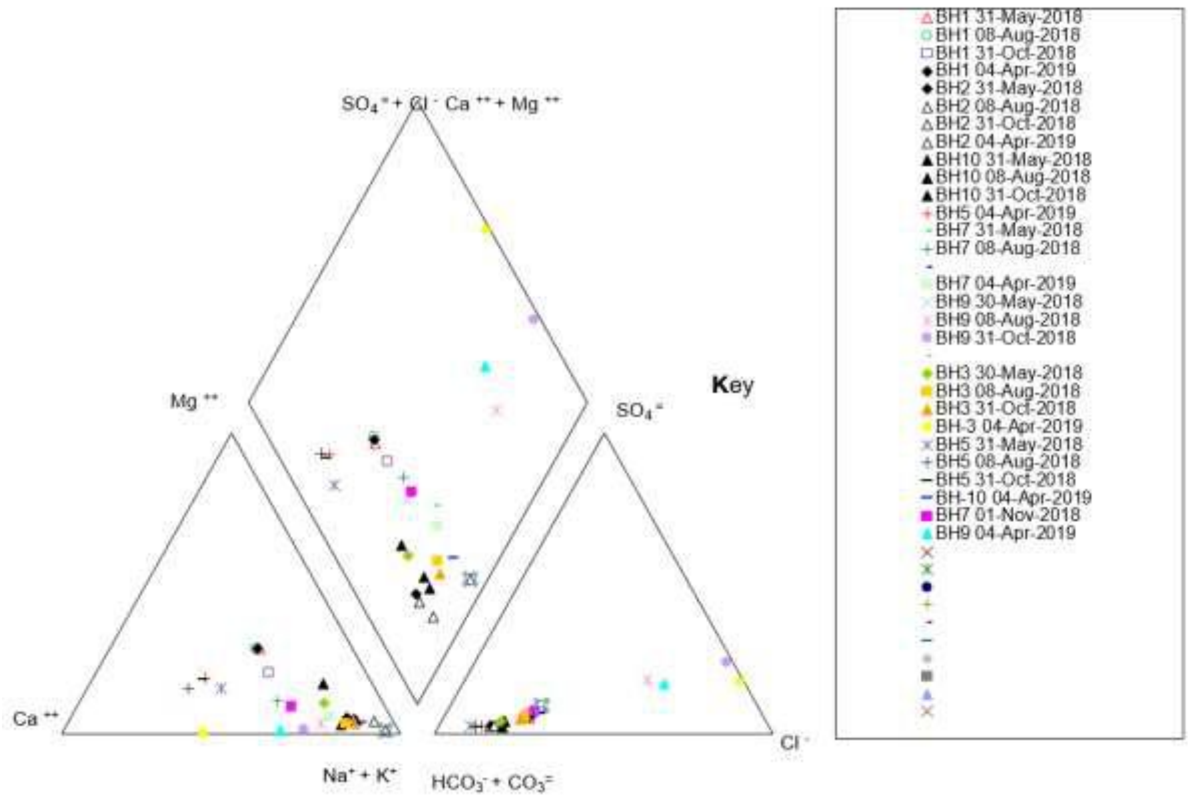


Figure 4.1: Piper plot for waters in the Upper Pakiri Formation.

5 Groundwater use and abstraction

5.1 Local to Valley 1

The site is not located on a High Use or Vulnerable Aquifer, nor is it in a Quality Sensitive Aquifer Management Area, as defined by Auckland Council's Groundwater Management Areas (attached as Appendix I).

A search of the Auckland Council database on 15 August 2018 indicates that there are no consented groundwater abstraction points within 2 km of Valley 1. The bore, consent and permitted activity search details are provided in Table 1 and 2 attached as Appendix J. The points are also shown on Figures HG-F4 and HG-F5 in Appendix A.

Of seventeen bores identified as consented to be drilled within 5 km of the centre of Valley 1, ten have been drilled. All consents for the remaining proposed bores have expired. The information provided indicates that the purpose of the bores was for domestic/municipal, stock and irrigation water supplies.

The consented groundwater take records indicate that bore 23657 belongs to Watercare Services Ltd (Watercare) and is located approximately 2.8 km north of Valley 1 along Wilson Road. The groundwater consent records confirm there is no existing consent to take groundwater from this bore and Watercare has since confirmed that bore 23657 has been backfilled due to insufficient yield.

The Watercare website[17] confirms that Watercare currently supplies Wellsford with water taken from the Hōteo River, i.e. Wellsford water supply is not supplied by groundwater. However, we understand from discussions with senior staff that Watercare is currently preparing a service strategy for Wellsford to 2024. We understand that Watercare intends to move the existing river water supply to a groundwater source for Wellsford. Watercare did not indicate the location(s) of a potential future groundwater source for Wellsford.

Further to the information provided by Auckland Council, T+T has observed an existing farm bore located on 1232A State Highway 1. This bore does not feature in the Auckland Council database and is located approximately 1.9 km to the west of Valley 1. No information is available about this bore, e.g. depth, pumping rate, etc. However, WMNZ has confirmed that they own the bore, which provides potable water to the farm cottage and woolshed as well as stock watering.

WMNZ has also indicated the location of a second bore that is not included in the Auckland Council records, which is located on 1282 State Highway 1. The bore is located on the opposite side of the Hōteo River to the bore on 1232A State Highway 1. No information is available regarding the construction of the bore.

We note that the only consented water takes in the surrounding area related to surface water takes largely from the Hōteo River. This observation reflects the information presented by Auckland Council[13], which states that 'Consents for surface water abstraction are primarily for agricultural purposes, in particular for irrigation. Surface water abstraction appears to be preferred over groundwater abstraction, for which a much smaller abstraction volume is consented, presumably because aquifers are low yielding or occur only intermittently.' Given the likelihood of low yielding aquifers, we consider it is reasonable to infer that the likelihood of future groundwater takes in the vicinity of the site is low.

[17] https://www.watercare.co.nz/Water-and-wastewater/Where-your-water-comes-from/Groundwater-and-springs

The nearest surface water take is over 4 km from the centre of Valley 1 and upstream of the confluence of the Valley 1 stream and the Hōteo River and relates to the Watercare take to supply Wellsford. The intake from the Hōteo River is located at 362 Wayby Valley Road.

5.2 Regional aquifer use

On a regional scale, the former ARC indicated in 2003 that the Hōteo groundwater catchment forms one of five groundwater management areas in the north-west[16] (refer Appendix I). Based on the groundwater consent allocation records provided by ARC as at May 2002, groundwater allocated in the Hōteo catchment was 152,000 m^3/year. This information forms the basis of the assessment of potential effects on regional groundwater resources in Section 9.3.

The relatively low allocation for the Hōteo groundwater catchment reflected the limited development of groundwater as a large scale water source, which ARC[16] indicated was primarily because of accessibility to relatively plentiful surface water resources in the Hōteo catchment.

6 Pumping test method and results

6.1 Overview

Aquifer testing and groundwater level monitoring were undertaken by McMillian Drilling Ltd at one pumping bore (TB01) and one observation well (BH2) in November 2018. The pumping bore was tested for a duration of 72 hours, comprising a constant rate test and step test followed by a 72 hour recovery period. The schedule of the pumping test and recovery period is described below and presented graphically in Figure 6.1.

The pumping test consisted of:

- Pre-test groundwater level monitoring from 16 November 2018 (14:00) to 17 November 2018 (14:00);
- Constant rate test from 20 November 2018 (08:00) to 23 November 2018 (08:00);
- Step test (during the constant rate test) from 21 November 2018 (07:00) to 21 November 2018 (10:00); and
- Recovery period from 23 November 2018 (08:00) to 25 November 2018 (17:00).

The purpose of the pumping test was to determine hydraulic parameters (i.e. transmissivity/ hydraulic conductivity) of the regional aquifer. We note only the constant rate test data has been analysed to meet this objective. The results of the step test are not reported as part of this evaluation.

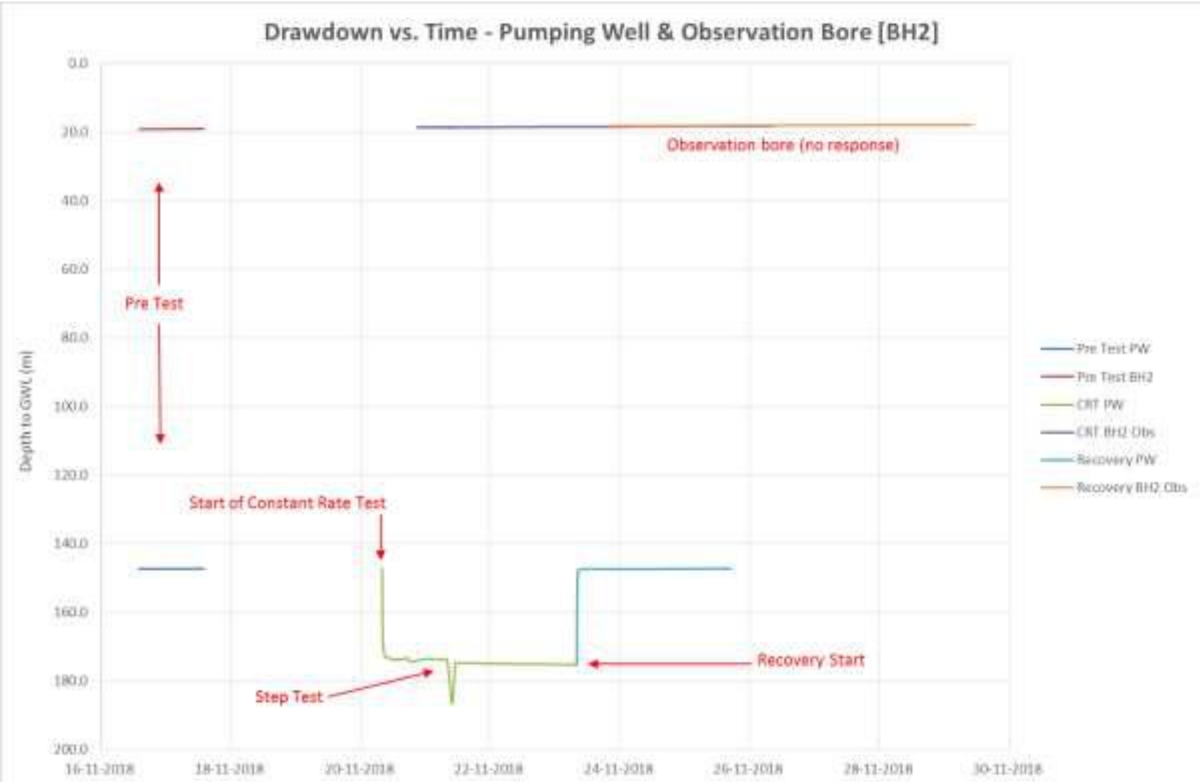


Figure 6.1: Pumping test and recovery period schedule. Drawdown vs. time plot for production bore (TB01) and observation well (BH2).

6.2 Constant rate test

Details relating to the pumping bore and observation well (BH2) used for the constant rate test is provided in Table 6.1. The distance between the pumping bore and BH2 is approximately 560 m.

Table 6.1: Summary of bore information

Bore ID	Coordinates (NZTM)		Approximate ground level (m RL)[1]	Static Water Level (m bgl)	Internal Bore Diameter (mm)	Screened interval (m bgl)	Total depth (m bgl)
	Easting (mE)	Northing (mN)					
TB01 – Pumping bore	1741578	5977656	182	147.20	150	202 -252 (open hole)	250
BH2 – Observation well	1742110.99	5977395.83	204.3	18.76	65	39.7–45.7	49.5

Note:

1. Approximated from contours layer sourced from [Auckland Council GeoMaps (https://geomapspublic.aucklandcouncil.govt.nz/viewer/).

A submersible pump was installed into TB01 for the purpose of the testing and was removed upon completion of the pumping test and post-monitoring period.

Groundwater levels within the pumped bore and monitoring well were logged using Solinst brand unvented leveloggers and were later corrected for fluctuation in barometric pressure. Water level measurements were recorded at 30-second intervals.

The constant rate pumping test was performed over a 72 hour period at a rate of 0.55 L/s with water levels within the pumping bore and observation well monitored prior to, during and following the pumping test. Table 6.2 summarises the constant rate test information.

Table 6.2: Constant rate test information

Bore ID	Pumping rate (L/s)	Pumping start		Pumping end		Drawdown (m)
		Time - date	Water level (m bgl)	Time - date	Water level (m bgl)	
Pumping bore (TB01)	0.55	20/11/18 (08:00)	147.20	23/11/18 (08:00)	175.21	28.01
BH2	None	20/11/18 (08:00)	18.76	23/11/18 (08:00)	18.351	-0.41[1]

Note:

1. Indicates the groundwater level was increasing in BH2 at the time of the constant rate test pumping.

6.3 Pumping test analysis method

The Cooper and Jacob method was used to determine the transmissivity of the regional aquifer. The assumptions of this method are:

- The aquifer has an infinite areal extent;
- The aquifer is homogeneous, isotropic and of uniform thickness;
- The pumping well is fully penetrating;

- The aquifer is non-leaky and confined; and
- Water is released instantaneously from storage with decline of hydraulic head.

Aquifer parameters were determined using AquiferTest Pro[18] software to analyse the recorded data. A copy of the AquiferTest Pro analysis plot is presented in Figure 6.2.

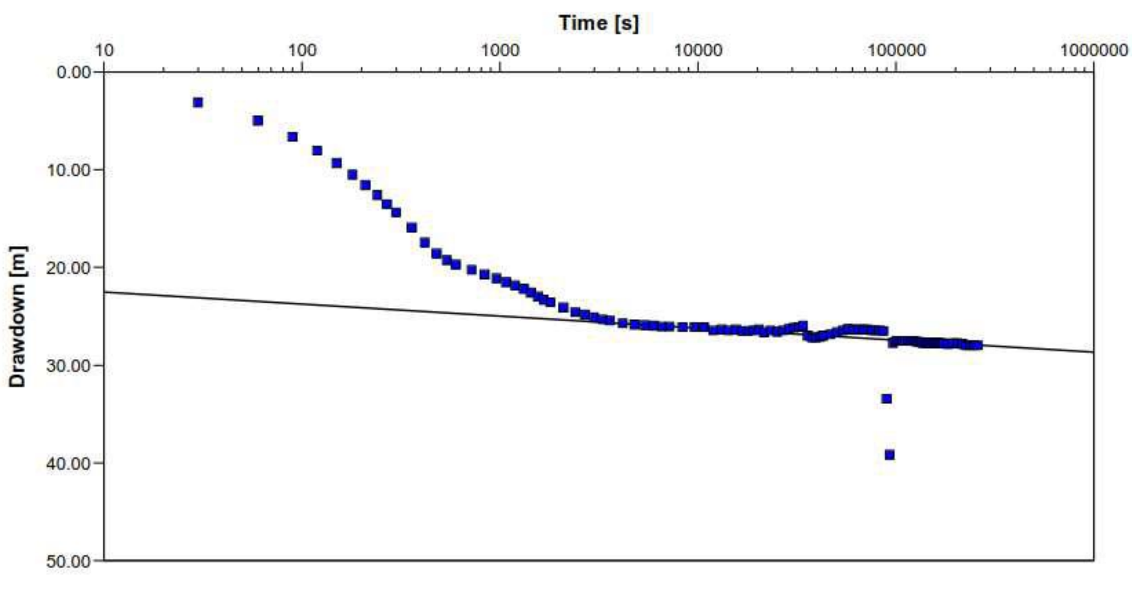
An analytical solution developed by Papadopulos and Cooper (1967) and Ramey et al. (1973) was used to account for the removal of water stored in the well casing (the casing storage effect) during the early stages of the constant rate test.

6.4 Pumping test interpretation and results

The observed rise in the groundwater level in the observation well (BH2) during the constant rate test (Figure 6.1) suggests that there is no hydraulic connectivity between the shallow groundwater and the regional groundwater that was being pumped.

The casing storage effect was observed during the first 200 minutes of the constant rate test. Accordingly, the "best fit" line used to determine the transmissivity was fitted to the portion of the curve after 200 minutes (12,000 seconds) into the test, as shown in Figure 6.2. The AquiferTest Pro output sheets are attached as Appendix K.

Location: Dome Valley	Pumping Test: Pumping Test 1	Pumping Well: Well 1
Test Conducted by: McMillan Drilling		Test Date: 20/11/2018
Analysis Performed by: KELE	Cooper Jacob	Analysis Date: 27/11/2018
Aquifer Thickness: 50.00 m	Discharge Rate: 0.55 [l/s]	



Calculation using COOPER & JACOB					
Observation Well	Transmissivity [m²/d]	Hydraulic Conductivity [m/d]			
Well 1	7.15×10^{0}	1.44 E-01			

Figure 6.2: Cooper & Jacob pumping test analysis plot, drawdown vs. log-time.

[18] Waterloo Hydrogeologic. AquiferTest Pro v.2016.1.

The transmissivity of the screened aquifer in the vicinity of TB01 was estimated to be 7.15 m^2/day. We note the transmissivity estimate was based on an aquifer thickness of 50 m, which represents the "open-hole" section of the pumping well.

The hydraulic conductivity (K) was estimated to be 0.14 m/day or 1.7 x 10^{-6} m/s.

Table 6.3: Pumping test analysis results

Aquifer parameter	Units	Adopted value
Transmissivity (T)	m^2/day	7
Hydraulic conductivity (K)	m/day	0.14
Storativity (assumed)	No units	0.0005

7 Hydrogeological setting

This section draws on the information set out earlier in the report and addresses the hydrogeological factors that the Technical Guidelines for Disposal to Land sets out for consideration.

The mountainous terrain of the Wayby Valley and the relatively low permeability of the Pakiri Formation rock mass has created a complex hydrogeological setting in and around Valley 1. A cross-section through Valley 1 and the low lying land to the west, extending to the Hōteo River, illustrates the conceptual hydrogeological setting described below (refer Figure HG-F7, Appendix A). The line of the cross-section is indicated in Figure HG-F6.

Three groundwater systems have been identified beneath Valley 1, as detailed in Table 7.1.

Table 7.1: Groundwater systems

Groundwater system	General characteristics
Shallow perched	Found at the interface of the residual soil with the highly weathered Pakiri Formation. Contributes baseflow to streams.
Upper Pakiri Formation	Found in the higher elevations of the Pakiri Formation around Valley 1. Horizontal flow along fracture zones and bedding planes proliferate as seepages in Valley 1. Seeps on the valley walls and springs near the floor.
Regional groundwater	Encountered at depth in the Pakiri Formation beneath Valley 1 (TB01). Is estimated to have a relatively shallow hydraulic gradient that flows predominantly toward the Hōteo River. The flow could also occur to the south toward the Waiteraire Stream.

A mantle of residual soil and highly weathered Pakiri Formation has formed across Valley 1 and the surrounding land. The thickness and extent of these soils in the hydrogeological model is mostly inferred because of site investigation constraints, largely related to terrain and forestry.

Around the higher elevations of the Wayby Valley and Valley 1, we have reasonably adopted a rainfall recharge of 10 %, the remainder being lost to evapotranspiration and surface runoff. The infiltration of rainwater will directly recharge the shallow perched groundwater and also the groundwater in the higher elevations of the Pakiri Formation around Valley 1. The shallow groundwater recharge in the catchment is estimated to be 140,000 m^3/year.

The Upper Pakiri Formation groundwater levels in the wells around Valley 1 are deeper beneath the ridgelines and shallower along the valley floor, and the groundwater surface is likely to form a muted reflection of the topography. Locally, groundwater divides may exist beneath the ridgelines and valley floors resulting in groundwater flows that largely follow the surface topography (refer Figure 3.3).

Hydraulic gradients in the Upper Pakiri Formation around Valley 1 are estimated to range from 0.25, as groundwater flows toward the valley floor, to between 0.022 and 0.044, as groundwater follows the fall of the valley floor. Fracture zones and sub-horizontal bedding planes will create preferential flow paths for groundwater to travel, manifesting as seeps on the valley walls or springs near the valley floor. The groundwater in the higher elevations of the Pakiri Formation and the shallow perched groundwater will contribute to the valley stream baseflow.

A downward pressure gradient or vertical gradient is evident beneath Valley 1 between the groundwater in the Upper Pakiri Formation and the regional groundwater. The downward flow of groundwater, however, is retarded by the layers of low permeability unweathered siltstone and sandstone, which are at least locally present and may exist more widely. The Packer Testing suggests the hydraulic conductivity of the overall rock mass is between 1 x 10^{-9} and 3 x 10^{-6} m/s, which is consistent with published records and the pumping test completed in the regional aquifer in TB01.

The Packer Testing also estimated hydraulic conductivity values of fracture zones that were also encountered during the geotechnical drilling. A detailed description of the hydraulic conductivity values and fracture zones is provided in Table 3.6. Hydraulic conductivities in the fracture zones generally ranged between 8.1 x 10^{-3} and 6.4 x 10^{-5} m/s. It is not clear whether these fracture zones comprise lengthy horizontal preferential flow pathways. However, there is no evidence to suggest that they provide a vertical pathway between the Upper Pakiri and regional groundwater aquifers.

The regional groundwater has been encountered in TB01 and we also infer that the groundwater in BH13 and BH14 on the lower elevations of the proposed access road also indicate regional groundwater. Recharge to the deeper regional groundwater is reported to be about 3.3 % of mean annual rainfall.

The regional groundwater flows from beneath Valley 1 toward the Hōteo River with a relatively gentle hydraulic gradient of 0.006. The regional groundwater beneath Valley could also flow toward the Waiteraire Stream, also with a gentle hydraulic gradient of 0.005.

The constant rate pumping test in the regional aquifer indicates that at the depth of the test bore, the aquifer has a relatively low sustainable yield. However, the low hydraulic gradient may indicate a relatively high overall hydraulic conductivity, potentially due to fracture zones not encountered by the test well.

The groundwater in the Upper Pakiri Formation surrounding Valley 1 recorded copper, zinc and hexavalent chromium with naturally elevated concentrations in relation to the ANZECC 2000 95% guidelines for freshwater. Total iron and manganese are also high in relation to aesthetic drinking water guidelines. Regional groundwater sampled from TB01 recorded turbidity and iron above the drinking water standards.

Overall, this hydrogeological setting is consistent with that recently documented elsewhere in the Pakiri Formation in the area. Being sited over fractured rock, the Technical Guidelines for Disposal to Land indicate that 'the (landfill) design should incorporate a higher level of engineered containment and appropriate contingency measures.'

8 Groundwater risk assessment

8.1 General

This groundwater risk assessment has been undertaken to provide an evaluation of the potential risk to groundwater and nearby environmental receptors posed by the potential seepage of contaminants through the lining system of the proposed Auckland Regional Landfill if such seepage should occur. The assessment is based on the hydrogeological information available at the time of writing.

The assessment is set out in the following sections. It consists of the following steps:

- Review of the landfill lining system and estimated potential leachate seepage;
- Review of Redvale Landfill leachate quality data and derivation of source concentrations for fate and transport modelling;
- Contaminant exposure pathway assessment including a summary of valid pathways and receptors;
- Selection of appropriate environmental criteria to be protective of the identified receptors;
- Selection of model and modelling inputs to reflect the source, exposure pathways, and points-of-exposure;
- Contaminant fate and transport modelling and comparison of results with environmental criteria; and
- Sensitivity analysis.

8.2 Proposed design of the landfill

8.2.1 Lining systems

The proposed landfill lining system is described in the Engineering Report (Technical Report N, Volume 2). It will include one of the following two containment systems:

Type 1 lining system:

- Leachate drainage material, with underlying geocushion to protect the geomembrane;
- 1.5 mm HDPE geomembrane, overlying 600 mm compacted soil (clay) with a coefficient of permeability $k < 1 \times 10^{-9}$ m/s;

Or;

Type 2 lining system

- Leachate drainage material, with underlying geocushion to protect the geomembrane; and
- 1.5 mm HDPE geomembrane, overlying geosynthetic clay liner (GCL), overlying 600 mm compacted soil with a coefficient of permeability $k < 1 \times 10^{-8}$ m/s.

8.2.2 Potential for leakage

The various components of the composite lining system will work together to minimise the potential for leakage. For example, leakage through a pinhole in the geomembrane is expected to be blocked given the direct contact with the underlying GCL or clay layer. The leachate drainage system above the geomembrane enables leachate to be removed from the landfill thereby minimising the head on top of the geomembrane. A lower driving head will result in less potential leakage through any defect.

Modelling has been undertaken to determine the possible rate of leakage through the lining system, conservatively assuming there are some defects in the geomembrane (see Technical Report N, Volume 2). This modelling shows that for the worst case, i.e. at full development of the landfill (58.5 ha of lining system), the potential leakage from the landfill for the peak year over a 50 year modelling period is approximately 3 m^3/year which is equivalent to an average of 8.2 L/day. In the unexpected event that leachate seeps through the lining system, it could enter the underlying soils, and potentially the underlying groundwater system.

The combination of the GCL ($k < 5 \times 10^{-11}$ m/s) and compacted clay layer ($k = < 1 \times 10^{-8}$ m/s) is estimated to add between 6 and 20 years of travel time to leachate migration if it seeps through the HDPE component of the lining system before entering the groundwater.

In addition to restricting the flow, the low permeability clay layer of the composite lining system will also provide chemical attenuation of any leachate seepage through the layer. Chemical constituents in the leachate will adhere to the clay particles and be removed from the seepage, reducing the contaminant concentration if leachate seepage did occur through the overall lining system.

8.2.3 Subsoil drains

Further to the above aspects of the landfill lining system and as discussed in the Engineering Report (Technical Report N, Volume 2), subsoil drains are proposed to be installed to intercept seeps and springs as they are encountered during the construction of the lining system.

The landfill is proposed to be constructed in phases, with around seven years of operation of the first three phases (1 to 3) followed by a total of around thirty-six years for the operation of Phases 4 to 7.

During the operation of Phases 1, 2 and 3, subsoil drain flow will be channelled to a central pipe installed beneath the lining system along the valley floor and eventually discharge into the stormwater pond during this period. Other subsoil drains at higher elevations will be installed for later phases of the landfill development. Discharges to the pond will be continuously monitored for electrical conductivity.

At the end of operation of Phases 1 to 3, the subsoil drains will be grouted and sealed because uplift pressures on the lining system will be offset by the weight of the waste material. When this happens, there is a possibility that groundwater levels beneath the landfill could rise. Groundwater levels could eventually rise above the leachate level within the landfill.

If groundwater levels outside of the landfill rise above the leachate levels within the landfill, then it is possible that an inward flow gradient could prevail, reducing the likelihood of leachate seepage through any damage to the lining system. However, it is difficult to determine when and to what extent this may occur, so, for the purpose of this groundwater risk assessment and to be conservative, the possibility of an inward flow gradient has not been considered.

8.3 Source concentrations

8.3.1 Redvale Landfill leachate quality data

WMNZ has provided T+T with leachate quality data from the Redvale Landfill dating back to the late 1990s. The leachate has been collected from three collection sumps: LCS1, LCS2, and LCS3. T+T has undertaken statistical analysis of the leachate quality data and calculated mean, median and maximum values for key parameters. A summary of the statistical analysis is included in Appendix L.

We have generally adopted the maximum leachate concentrations recorded at Redvale Landfill as the source concentrations for the modelling. Where analytes (including silver, endrin, and heptachlor) were not detected, the concentration assumed as the source for the modelling was half of the detection limit. The analytes selected are those discussed in the report documenting the derivation of Waste Acceptance Criteria (WAC)[19] for the proposed Auckland Regional Landfill.

Where there is an absence of Redvale-specific data for some analytes, we have adopted alternative source data, as follows:

- WMNZ provided a leachate report from 1997, which was based on sample sites across the United States. This report identified a range of cyanide concentrations from <0.01 to 0.098 mg/L[20]. Leachate data obtained from the Omarunui Landfill monitoring indicate cyanide in leachate was recorded below the laboratory limit of detection (<0.01 mg/L) during 2017[21]. To complete the risk assessment, the maximum cyanide concentration of 0.098 mg/L has been adopted; and
- The WAC TCLP limits for chlordane (gamma and alpha chlordane), methoxychlor, toxaphene, 2,4 D, 2,4,5 T, and pyridine have been adopted because these analytes are not included in the Redvale Landfill leachate data. These are extremely conservative as it effectively assumes that all waste in the landfill is discharging these contaminants at the maximum allowable concentration.

The software model adopted for assessing the environmental effects (RBCA, refer Section 8.6.3) uses equilibrium partitioning to determine leachate concentrations from total concentrations at the source. To simulate the Redvale leachate concentrations in RBCA has required back-calculating a total concentration using equilibrium partitioning. The spreadsheet detailing the equilibrium partitioning using the soil/water partition coefficient (Kd) values is attached as Appendix M.

8.4 Contaminant exposure pathway assessment

8.4.1 Contaminant linkage

In order for a contaminant to present a risk to an identified receptor, a complete exposure pathway must exist, i.e. a physical pathway for a receptor to be exposed to a contaminant. A pathway is considered to be incomplete if there is no practical way for the receptor to be exposed.

8.4.1.1 Groundwater pathway

A contaminant exposure pathway evaluation has been undertaken to determine pathways that have the potential to pose an adverse environmental or human health effect considering the landfill contaminants in leachate as the source. The evaluation has considered the estimated rate of seepage through the landfill lining system, the proposed future use of the site, potential transport mechanisms, receptors and the mitigation measures that will be implemented on the site as part of the landfill development.

The potentially complete contaminant linkages are considered as a number of points of exposure (POEs) associated with specific transport mechanisms, in either shallow unconfined/semi-confined groundwater or the deeper regional groundwater. The characteristics of the source (landfill and leachate seepage rate), potential receptors (surface water/groundwater) and the transport media (groundwater) are described in Section 7, 8.2 and 8.3. These POEs are summarised in Table 8.1 and the locations are shown on Figure HG-F8 attached as Appendix A.

[19] Tonkin & Taylor. (2019l). *Waste Acceptance Criteria* Report. Auckland, New Zealand: Tonkin and Taylor.
[20] RUST, 20 May 1997. Leachate report prepared for Waste Management Inc.
[21] Stantec, November 2017. Omarunui Landfill – Environmental Monitoring Annual Report 2017, prepared for Hasting District Council.

Table 8.1: Adopted points of exposure

Point of exposure (Distance from landfill)	Location	Receiving groundwater system	Flow direction
POE#1 Freshwater ecology (360 m)	The confluence of streams from Valley 1 and 2	Considers the seepage of leachate through the landfill lining system and into the Upper Pakiri Formation, occurring directly beneath the landfill by diffuse flow or via preferential pathways (see 8.4.1.2).	The groundwater follows the topography of the land and flows north west, potentially affecting ecological receptors.
POE#2 Freshwater ecology (2,100 m)	Hōteo River	These scenarios conservatively (because no evidence has been found to suggest such connections exist) assume that the potential seepage of leachate through the lining system migrates vertically through preferential pathways, to the regional groundwater system.	The regional groundwater flows to the west toward the Hōteo River.
POE#3 Recreational users (2,100 m)	Hōteo River		
POE#4 Stock watering/ irrigation (1,900 m)	Farm bore		The regional groundwater flows to the west toward the Farm bore.
POE#5 Potable drinking water (1,900 m)	Farm bore		
POE#6 Freshwater ecology (1,000)	Waiteraire Stream		The regional groundwater flows to the south toward the Waiteraire Stream.

An assessment of the potential effects for each of these possible points of exposure is provided in Section 8.6.

8.4.2 Absence of contaminant linkages

The Watercare intake from the Hōteo River for the Wellsford potable water supply is upstream of the site (refer Section 5). On this basis, surface water as an existing source of potable supply is not considered further in this assessment.

Although the Auckland Council records identified a number of bores for stock/domestic watering and irrigation purposes (refer Section 5), the bores are located further away than the WMNZ-owned farm bore and so have not been considered in the groundwater risk assessment. The drilled Watercare bore identified for municipal supply (23657) does not have a consented groundwater take. Watercare has confirmed that bore 23657 has been backfilled and so it has been excluded from the risk assessment.

As discussed in Section 3.9.3, a Significant Ecological Area – Terrestrial is located to the west of Valley 1. This has not been identified as a point of exposure for a number of reasons:

- The flow of groundwater in the higher elevations of the Pakiri Formation surrounding Valley 1 is influenced by the site topography and fracture flow (refer Section 3.7). These characteristics result in a groundwater flow direction that is directed away from the Significant Ecological Area – Terrestrial (refer Figure 3.3); and
- The regional groundwater is at a depth that is unlikely to contribute to the baseflow of the Significant Ecological Area - Terrestrial. For example, during the pumping test, the regional static groundwater level was recorded at 35 m RL. The 35 m RL ground contour within this ecological area is near its western extents and approximately 1,500 m distance from the test bore. Using this observation we have inferred that the regional groundwater does not provide baseflow to the ecological area. On this basis, there is no potential contaminant linkage between leachate entering groundwater and migrating toward the Significant Ecological Area – Terrestrial.

A tank or tanks will be constructed on a ridgeline as part of the landfill development to store leachate. Tanks will be located in a bunded area to prevent immediate leakage into the environment. Section 3.1 describes a layer of residual and highly weathered soils of the Pakiri Formation forming a layer of low hydraulic conductivity soils, which is deeper along the ridgelines around Valley 1 and thins out toward the valley floor. In the event of a tank rupture or overflow, the migration of leachate to groundwater is unlikely to occur in the short time that leachate would be present before removal because the bunded area around the tank is designed to mitigate leakage. The low hydraulic conductivity soils reduce the potential for migration to groundwater.

8.5 Exposure pathway assessment conclusions

The conclusions of the exposure pathway assessment are summarised in Table 8.2.

Table 8.2: Summary of exposure pathway assessment

Source	Pathway	Receptor	Potential for contaminant linkage	Assessed point of exposure
Leachate collected within the landfill	Potential seepage of leachate through the landfill lining system and migration of contaminants via diffuse flow in the groundwater in the higher elevations of the Pakiri Formation or via preferential pathways.	Freshwater ecology	Yes	Unnamed stream: POE#1
		Significant Ecological Area, SEA_T_629	No	-
	Potential seepage of leachate through the landfill lining system and migration of contaminants via the groundwater in the deep regional groundwater	Freshwater ecology	Yes	Hōteo River: POE#2 Waiteraire Stream: POE#6
		Surface water users (swimming)	Yes	Recreational users in the Hōteo River: POE#3
		Stock watering/ irrigation supply bores	Yes	Farm bore supplying water for stock watering/ irrigation: POE#4

Source	Pathway	Receptor	Potential for contaminant linkage	Assessed point of exposure
		Potable supply from groundwater	Yes	Farm bore supplying potable drinking water: POE#5
		Significant Ecological Area, SEA_T_629	No	-

8.6 Fate and transport modelling

8.6.1 Overview

The methodology and results of contaminant fate and transport modelling undertaken to assess the potential environmental effects of leachate seepage through the landfill lining system (refer Table 8.2) are described in the following sub-sections.

8.6.2 Methodology

The Groundwater Services Inc. Risk-Based Corrective Action (RBCA) software package has been used to model the fate and transport of contaminants in leachate generated by the deposited waste to the potential receptors.

RBCA simulates leaching of contaminants from the soil into groundwater models using the Soil Attenuation Model (SAM).

Contaminant fate and transport in groundwater is simulated in the RBCA software by the Domenico 3-dimensional model. This analytical solute transport model predicts advection, dispersion, adsorption of inorganic and organic contaminants and includes biodegradation of organic compounds. The model produces estimates of contaminant concentrations in groundwater at selected distances from the source. For the Hōteo River and stream POEs, mixing with surface water is accounted for through an adjustment to the POE limit based on the groundwater discharge and surface water flow rates.

8.6.3 RBCA site conceptual model and input parameters

The conceptual model is illustrated in Figure HG-F7. Input values for the RBCA model to assess the potential effects on the potential receptors are summarised in Tables 2 to 5 in Appendix N.

8.6.4 Point of exposure concentration limits

The freshwater trigger levels for the protection of 95 % of species published by ANZECC[22] in 2000 have been used for the assessment of environmental effects on the surface water receptors. We note that the ANZECC 2000 guidelines have recently been updated[23]. However, the ANZECC 2000 guidelines are considered more appropriate for the present time as they are referenced in the Auckland Unitary Plan.

We have also adopted the relevant ANZECC 2000 guidelines for recreational purposes for the Hōteo River, and the livestock drinking water guidelines for the farm bore. The drinking-water standards for

[22] Australian and New Zealand Environment and Conservation Council, October 2000, *The Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.
[23] Australian and New Zealand Environment and Conservation Council, October 2018, *The Australian and New Zealand Guidelines for Fresh and Marine Water Quality*.

New Zealand 2005 (revised 2018) have been adopted to assess the potable water supply for the farm bore. The trigger levels, recreational/livestock guideline values, and drinking water standards are presented in Appendix N Table 5 as the point-of-exposure limits.

8.7 Model conservatism

A number of conservative assumptions were made during the modelling including no degradation of inorganic contaminants and modelling to steady state, i.e. maximum predicted concentrations. The RBCA model also has some internal inherent conservative assumptions. Important assumptions are listed in Table 8.3.

In reality, some attenuation of inorganic contaminants will occur and steady-state conditions are likely to take many years to develop (on the order of 1,000 years or more). Furthermore, source concentrations will deplete over time due to dissolution and biodegradation, well before steady-state conditions can develop.

Table 8.3: Model conservatism

Item	Detail
Source concentrations	Adopted the maximum value from the historical Redvale leachate data.
	Assumed to be non-depleting over time.
Concentrations in groundwater	No degradation occurs for the inorganic contaminants.
Receptor concentrations	Maximum, i.e. steady-state concentrations are reached.
Vertical migration	Leachate migrates vertically with no attenuation/retardation directly to the regional groundwater system. In reality, the low permeability layers will retard vertical groundwater flow to the regional groundwater system.

8.8 Results

The POE concentrations predicted by the RBCA model based on the adopted seepage rate of leachate through the lining system are summarised in Table 8.4. The RBCA input and results sheets are attached as Appendix O along with the tabulated results referred to in the following sections.

Table 8.4: RBCA fate and transport modelling results

Point of exposure	Pathway and receptor type	RBCA model prediction based on the potential seepage of leachate through lining system	Results table reference (Appendix N)
Valley 1 and 2 stream confluence POE#1	High elevations of the Pakiri Formation groundwater and ecological effects.	Contaminant concentrations in groundwater prior to entering and being diluted in the river are predicted to be at least two orders of magnitude lower than the ANZECC 2000 trigger values. Highly unlikely to pose a risk to ecological life within the stream.	Table 6
Hōteo River POE#2 and POE#3	Regional groundwater, ecological and recreational effects	Contaminant concentrations in groundwater prior to entering and being diluted in the river are predicted to be at least four orders of magnitude lower than the ANZECC 2000 trigger values and the ANZECC recreational use guideline values.	Table 7

Point of exposure	Pathway and receptor type	RBCA model prediction based on the potential seepage of leachate through lining system	Results table reference (Appendix N)
		Highly unlikely to pose a risk to ecological life and recreational users of the Hōteo river.	
Farm bore POE#4 and POE#5	Regional groundwater, livestock and potable supply.	Contaminant concentrations in groundwater taken from the farm bore are predicted to be at least five orders of magnitude lower than the ANZECC livestock guideline values and drinking-water standards. Highly unlikely to pose an adverse effect to livestock or human health at the farm bore.	Table 8
Waiteraire Stream POE#6	Regional groundwater and ecological effects.	Contaminant concentrations in groundwater prior to entering and being diluted in the river are predicted to be at least three orders of magnitude lower than the ANZECC 2000 trigger values and the ANZECC recreational use guideline values. Highly unlikely to pose a risk to the ecological life of the Waiteraire Stream.	Table 9

8.9 Model sensitivity

Sensitivity analysis was undertaken to assist in quantifying the uncertainty in model predictions caused by the uncertainty in the estimation of model input parameters and for aspects of the hydrogeological setting. To assess the uncertainty, the sensitivity analyses have focussed on adjusting the following parameters:

- Hydraulic conductivity: to evaluate the effects of groundwater flow along preferential flow pathways;
- Source concentrations: to evaluate the effects of leachate being generated with higher concentrations than those adopted from the WMNZ Redvale Landfill; and
- Infiltration rate: to evaluate effects associated with a greater amount of leachate potentially seeping through the lining system.

The results of the sensitivity analysis are summarised in Table 8.5. The results indicate that no risks to the potential receptors:

- If the hydraulic conductivity is increased to account for preferential flow along fracture zones; or
- If the source concentrations are increased to allow for leachate with higher concentrations than Redvale Landfill; or
- If the infiltration rate is increased to account for more seepage of leachate.

Table 8.5: Details of the sensitivity analysis

Parameter uncertainty	Sensitivity analysis result	Conclusion
Hydraulic conductivity: Increase to 8.3 x 10^{-3} m/s	**Upper Pakiri Formation:** Reduced contaminant concentrations by a factor of approximately 2,700.	An increase in the hydraulic conductivity will result in lower levels of contaminants predicted at the receptor.
	Regional groundwater: Reduced contaminant concentrations by a factor of approximately 4,700.	
Source concentrations: Based on WAC TCLP adjusted using equilibrium partitioning (Section 8.3)	**Upper Pakiri Formation:** Increase inorganic contaminant concentrations by a maximum factor of 2,200. Generally, organic contaminants recorded little, if any change.	Increasing the source concentrations increases the predicted concentrations at the receptors. However, increasing the source to reflect the WAC TCLP does not result in unacceptable risks to receptors.
	Regional groundwater: Increase inorganic contaminant concentrations by a maximum factor of 2,200. Generally, organic contaminants recorded little, if any change.	
Infiltration rate: Increase the infiltration rate through the lining system by three orders of magnitude	**Upper Pakiri Formation:** Increase concentrations by a factor of approximately 290.	Increasing the infiltration rate increases the predicted concentrations at the receptors. However, increasing the infiltration to 0.5 cm/year does not result in unacceptable risks to receptors.
	Regional groundwater: Increase concentrations by a maximum factor of approximately 100.	

8.10 Subsoil drain pathway

Shallow or Upper Pakiri groundwater could potentially be affected by seepage through the lining system and could potentially be captured by subsoil drains. Subsoil drains will only act as preferential pathways for a short period, and seepage flows would be slow and attenuated by the GCL and compacted clay layer. A conservation of mass calculation (refer Appendix N4) has been used to assess potential effects on ecological receptors of the stream near the Valley 1 and 2 confluence. The calculation indicates that such seepage capture, in the unlikely event that it occurs, is highly unlikely to pose a risk to freshwater ecological receptors should it migrate through the subsoil drains.

8.11 Groundwater risk assessment summary

In summary, and based on a conservative rate of leachate seepage of 3 m^3/year, the potential effects outlined below are anticipated:

- Contaminant concentrations in the groundwater in the Upper Pakiri Formation at the nearby stream confluence (POE#1) are predicted to be at least four orders of magnitude below the ANZECC trigger levels for the protection of 95 % of species in freshwater. Based on this, there is no unacceptable risk to freshwater ecology;

- If leachate enters the deeper regional groundwater system and flows to the west, contaminant concentrations at the Hōteo River are predicted to be at least four orders of magnitude below the ANZECC 2000 trigger levels (POE#2) and ANZECC recreational guideline values (POE#3). Based on this, there is no unacceptable risk to freshwater ecology or human health at the point of exposure in the Hōteo River. Similarly, if regional groundwater flows to the south, contaminant concentration at the Waiteraire Stream (POE#6) are also predicted to be at least four orders of magnitude below the ANZECC 2000 trigger levels;
- Contaminant concentrations in the regional groundwater in the farm bore are predicted to be at least four orders of magnitude below ANZECC livestock drinking water guidelines (POE#4) and drinking-water standards (POE#5). Based on this, there is no unacceptable risk to livestock or human health via drinking groundwater;
- Uncertainties associated with key model parameters and the hydrogeological setting have been assessed further through sensitivity analysis. The sensitivity analysis considered increases to the hydraulic conductivity, source concentrations, and infiltration rate. The model predicts that adjusting these key parameters makes no substantive change to the modelling predictions, i.e. that the potential seepage of leachate through the lining system is highly unlikely to pose a risk to potential receptors; and
- Conservation of mass calculations to address the potential effects of leachate - affected shallow groundwater being captured by subsoil drains indicate no potential for impact to ecological receptors.

9 Assessment of hydrogeological effects

9.1 Introduction

The impact of the project on groundwater will largely arise from the excavation of the weathered and residual soil across Valley 1 to enable the construction of the landfill and the storage of waste material resulting in the generation of leachate within the landfill. We have considered potential environmental effects in the following ways:

- Groundwater drawdown associated with the groundwater take resulting from proposed subsoil drainage beneath the landfill;
- Groundwater drawdown associated with the proposed use of groundwater for potable/odour suppression supply;
- Groundwater take and diversion as a result of the excavation of weathered and residual soils for the construction of the landfill;
- Discharge of contaminants into ground and groundwater as leachate through the landfill lining system once landfilling operation commences; and

The potential groundwater effects are outlined in the following sub-sections.

9.2 Groundwater drawdown

9.2.1 Shallow groundwater take

Groundwater drawdown may occur during the flow of shallow groundwater into the subsoil drainage network beneath the landfill. As described in the Engineering Report (Technical Report N, Volume 2), stormwater will be controlled beneath the landfill by a stormwater pipe designed for the full flow from the upstream valley to minimise the potential for flooding landfill areas.

A subsoil drainage network will also be constructed beneath the landfill to control and drain groundwater flow from springs and seepages exposed within Valley 1 when excavation to base grade levels has been completed. The Engineering Report indicates that the subsoil drainage will be constructed beneath the landfill lining system approximately central through Valley 1 and extend into side valleys as required. The subsoil drainage will drain into one of the stormwater ponds beyond the foot of the landfill.

Based on the very low permeability of the weathered and residual soil and also the shallow unweathered rock expected to be encountered in the base of Valley 1 (refer Section 3.1) and because drainage is passive with no pumping of groundwater, we have inferred that groundwater drawdown is likely to be local to the subsoil drains and any effects limited to within the footprint of the landfill. On this basis, and because of the isolated nature of the proposed landfill, there is no potential for off-site adverse effects from groundwater drawdown associated with the subsoil drainage.

9.2.2 Regional groundwater take

We have assessed the potential future drawdown effects relating to groundwater take from a production bore at the location of TB01. We have been advised that WMNZ is seeking to take the sustainable yield from the bore of 0.55 L/s, 50 m^3/day or 20,000 m^3/year. A summary of the drawdown effect estimated from Hantush-Jacob analysis is presented in Table 9.1 below.

The drawdown effects have been assessed over a maximum take period of 365 days at a pump rate of 0.55 L/s. The full drawdown analysis results are attached as Appendix P. The results of the drawdown assessment using plausible aquifer parameters indicate that the effects of a groundwater take from the regional groundwater at a rate of 0.55 L/s could extend to the closest groundwater user, the WMNZ-owned farm bore, approximately 2,200 m from the proposed production bore. After 150 days of continuous pumping from the proposed production bore, the maximum drawdown is estimated to be 0.02 m at the farm bore. Drawdown at more distant wells is unlikely to be detectable.

On this basis, there are no potential adverse effects on groundwater users associated with establishing groundwater take from the regional aquifer.

Table 9.1: Summary of Hantush-Jacob drawdown analysis

Distance from the pumping well (TB01)	Pumping days at 0.55 L/s		
	10	150	365
	Estimated drawdown (m)		
50	2.453	2.9	2.9
500	0.283	0.64	0.64
2,200	-	0.024	0.024

9.3 Groundwater take and divert

Perched groundwater flow and shallow groundwater flow in the Upper Pakiri Formation will be taken and diverted as a result of the construction of the landfill. This could potentially affect baseflow in the springs and streams in Valley 1. Landfill sections presented in the Engineering Report (Fig No. ENG-16 and ENG-17 in Technical Report N, Volume 2) have been used to conservatively estimate cross-sectional areas required to be cut. Cross-sectional areas of cut have been estimated to be between 3,680 m^2 and 6,100 m^2. The largest estimated cross-sectional cut area has been adopted to assess the amount of groundwater flow that may be diverted as a result of the landfill construction.

Darcy's Law (Q = KiA) has been used to estimate groundwater flow, based on the following assumptions:

- K = hydraulic conductivity of residual and weathered soils: Based on a K of 6.5×10^{-10} m/s (refer Section 3.8) derived from laboratory testing and a rock mass permeability of 3.0×10^{-6} m/s from Packer Testing, the higher end K value has been conservatively adopted;
- i = hydraulic gradient: Adopted a value of 0.03, based groundwater levels being a muted reflection of the topography;
- A = cross section area: Adopted a conservative maximum value of 6,100 m^2; and
- Groundwater flow through the cross-sectional area is uniform and flows parallel with the valley floor.

The estimate of groundwater flow that may potentially be diverted as a result of the landfill construction is calculated as follows:

$$Q = KiA$$

$$Q = 3.0 \times 10^{-6} \text{ m/s} \times 0.03 \times 6{,}100 \text{ m}^2$$

$$Q = 5.5 \times 10^{-4} \text{ m}^3/\text{s}$$

$$Q = 47 \text{ m}^3/\text{day}$$

Based on the assumptions listed above, the construction of the landfill is conservatively estimated to result in a groundwater diversion of approximately 47 m^3/day. Subsoil drains will tap into seeps and springs as they are encountered during the excavation work so that water flow is diverted from the point of seepage, beneath the lining system and into the stormwater ponds. This water will eventually discharge close to the existing confluence of the Valley 1 and 2 streams. The flow intercepted by the subsoil drains will be diverted to the stream downgradient of the Valley 1 and 2 confluence, where it would have naturally flowed. The only areas affected by this diversion will be those covered by the landfill. Therefore, the potential effect of the diversion is assessed as negligible.

9.4 Effects on regional groundwater resources

The site is located in the Hōteo groundwater catchment, one of five Auckland Council management areas in the north-west. Auckland Council has not provided details of groundwater availability for the Hōteo groundwater catchment, however, an estimate of availability based on average annual rainfall and estimates of recharge has been provided in Section 3.4. The total availability in the Hōteo groundwater catchment is estimated to be at least 5 mm^3/annum.

The Waitemata aquifer in the Hōteo catchment has a relatively low use and a May 2002 estimate indicated an allocation of 152,000 m^3/year. If we assume a 2019 estimate that is double that of 2002, i.e. 300,000 m^3/year, the effect on the regional groundwater resource is set out in Table 9.2.

Based on the following groundwater allocation and availability data, the proposed groundwater take of 20,000 m^3/year will have no measurable effect on the allocation of the regional groundwater resource.

Table 9.2: Groundwater allocation and availability

Parameter	Value	Description
Estimate of groundwater availability	6 Mm^3/year	Based on the information presented in Section 3.4.
Estimate of the current allocation of the Hōteo groundwater catchment	300,000 m^3/year	Double the published groundwater allocation for the Hōteo groundwater catchment, May 2002.
Remaining groundwater available	4.7 Mm^3/year	Groundwater availability less current allocation
WMNZ take as a proportion of remaining groundwater available	<1%	WMNZ are seeking to take up to 20,000 m^3/year for site use.

9.5 Surface water and stream depletion effects

Groundwater level monitoring during the pumping test of the regional aquifer indicated that the deep groundwater is unlikely to be in hydraulic connection with the shallow groundwater in the vicinity of Valley 1. As described in Section 8.4, the regional groundwater is assessed as not providing baseflow to the Significant Ecological Area – Terrestrial located to the west of Valley 1. In addition, the regional groundwater that provides baseflow to the Hōteo River is estimated to experience only minimal drawdown at 2.2 km distance from the bore. This means that stream depletion of the Hōteo River as a result of a future proposed groundwater take is negligible.

9.6 Potential for saline intrusion

The base of the pumping bore (TB01) is located approximately at -69 m RL, which is below mean sea level. The nearest coastline is approximately 16.1 km to the northeast of the site.

The Ghyben-Herzberg approximation predicts that the depth below sea level to the saline interface is approximately 40 times the height of the freshwater table above sea level. This height is based on the assumption that the density of freshwater is 1,000 kg/m^3 and 1,025 kg/m^3 for seawater.

Applying the observed static water level within TB01 (34.8 m RL), using the Ghyben-Herzberg approximation, we estimate the seawater interface to be approximately -1,392 m RL (below sea level). On this basis, seawater intrusion is unlikely to occur as a result of future groundwater take from the site.

9.7 Discharge of contaminants into ground and groundwater

The potential discharge of contaminants as leachate seepage through the landfill lining system has been assessed using the RBCA software model. The process is described in detail in Section 8.6. The assessment of environmental effects has considered a number of points of exposure (referred to as POE#1 to POE#6) that leachate could migrate to if it enters groundwater through the landfill lining system.

The points of exposure included:

- The nearby confluence with the Valley 1 and 2 stream (POE#1);
- The Hōteo River via contaminant migration and regional groundwater flow (POE#2 and POE#3);
- The farm bore (POE#4 and POE#5); and
- The Waiteraire Stream via contaminant migration and regional groundwater flow (POE#6).

Based on the results of groundwater risk assessment (refer Section 8), which predicts that contaminant concentrations at all potential points of exposure will not exceed the relevant guidelines, the potential seepage of leachate through the landfill lining system is highly unlikely to have any adverse effects on the Valley 1 and 2 stream, the Hōteo River, the Waiteraire Stream or the groundwater users of the farm bore.

10 Mitigation and monitoring

10.1 Discharge of contaminants into ground and groundwater

The groundwater risk assessment indicates the potential adverse effects of contaminants in leachate entering the groundwater are nil. However, we recommend a number of groundwater observation bores are installed and monitored at locations downgradient of the toe of the landfill to screen for the presence of leachate in the shallow groundwater.

Typical indicator contaminants for leachate that are proposed to be monitored routinely (i.e. quarterly) are:

- Ammoniacal nitrogen;
- Total organic carbon;
- Biological oxygen demand;
- Chemical oxygen demand; and
- Chloride.

A full suite of contaminants included on the WAC list (refer Section Appendix N) shall be included in addition to the routine monitoring on a six monthly basis. Routine and detailed groundwater quality monitoring shall commence at least one year prior to receiving the waste to better understand the background conditions.

11 Conclusions

The hydrogeological assessment has been prepared to support an application for resource consent to establish the proposed Auckland Regional Landfill at a location in the Wayby Valley. This assessment addresses hydrogeological considerations of the Technical Guidelines for Disposal to Land and has been prepared using publicly available information and information collected during field investigations. The following conclusions have been drawn:

- Three groundwater systems have been identified beneath Valley 1, including shallow perched water in residual site soils, groundwater in the Upper Pakiri Formation, and deeper regional groundwater in the Pakiri Formation;
- Shallow groundwater flow direction is anticipated to largely follow the topographical contours, flowing away from the ridgelines and toward the valley floors. These are inferred to be a muted reflection of the terrain;
- Flow directions may also be influenced by preferential pathways in fracture zones within the Pakiri Formation. These features may result in variable flow directions and likely form a number of local shallow groundwater divides beneath the ridgelines around Valley 1;
- The assessed regional groundwater level beneath Valley 1 is based on readings from the test bore (TB01), which was recorded at approximately 147 m depth or 35 m RL. This assessment is supported by groundwater levels measured historically in bores to the north west of Valley 1;
- The height of the Hōteo River (20 mRL) to the west is lower than the regional groundwater level and so the regional groundwater is expected to flow to the west, with a gently sloping hydraulic gradient (0.006). Groundwater flow to the south in the regional aquifer has also been considered because the approximate height of the Waiteraire Stream (30 mRL) is also lower than regional groundwater level in TB01. A gently sloping hydraulic gradient of 0.005 has been estimated;
- Packer Test data indicate generally low-to-moderate permeability conditions in the Upper Pakiri Formation, with locally low hydraulic conductivities and some high hydraulic conductivity fracture zones. The reported hydraulic conductivities are similar to published values for this formation. The data do not permit interpretation of whether higher permeability fracture zones extend for any distance, i.e. whether lengthy preferential flow pathways might exist;
- The laboratory permeability testing on the weathered soils indicates that they have very low hydraulic conductivities, on the order of 6.5×10^{-10} m/s;
- The pumping test of the regional aquifer beneath Valley 1 indicates the Pakiri Formation in the vicinity of TB01 has a hydraulic conductivity of 1.7×10^{-6} m/s. We note that the low hydraulic gradients in the regional aquifer may indicate higher overall hydraulic conductivity at depth;
- Searches of the Auckland Council database indicate that there are no consented abstraction points within 2 km of Valley 1. An existing farm bore located on 1232A State Highway 1, located approximately 1.9 km west of Valley 1 and owned by WMNZ, does not feature on the database and there is no information available about this bore, e.g. depth, pumping rate, etc;
- The database provided details of a bore (23657) that belonged to Watercare and was located approximately 2.8 km north of Valley 1 along Wilson Road. Watercare confirmed that this bore has been backfilled because of insufficient yield. Watercare has indicated that they will seek to abstract groundwater from the deeper regional aquifer in the future, but no potential take locations have been provided as yet;
- Fate and transport modelling of potential contaminants in leachate was undertaken using the Groundwater Services Inc. RBCA software package. Six potential receptors were identified including the freshwater ecology at the Valley 1 and 2 stream confluence, the Hōteo River and

the Waiteraire Stream, recreational users of the Hōteo River and the water supply from the farm bore providing potable water to the farm dwellings and livestock;

- Based on the estimated rate of seepage of leachate through the landfill lining system (3 m^3/year), the fate and transport modelling indicates the following:
  - Contaminant concentrations in the shallow groundwater at the nearby stream confluence (POE#1) are predicted to be at least two orders of magnitude lower than the ANZECC trigger levels for the protection of 95% of species in freshwater. Therefore, any potential seepage of leachate is highly unlikely to pose a risk to ecological life within the stream;
  - Contaminant concentrations in the regional aquifer at the Hōteo River (POE#2 and POE#3) are predicted to be at least four orders of magnitude lower than the ANZECC 2000 trigger values and ANZECC recreational use guideline values. Therefore, any potential seepage of leachate is highly unlikely to pose a risk to ecological life and recreational users of the Hōteo River;
  - Contaminant concentrations in the regional groundwater in the farm bore are predicted to be at least five orders of magnitude below ANZECC livestock drinking water guidelines (POE#4) and the drinking-water standards 2005 (POE#5). Therefore, any potential seepage of leachate is highly unlikely to pose a risk to livestock or the existing potable water supply bore;
  - Contaminant concentrations in the regional aquifer at the Waiteraire Stream (POE#6) are predicted to be at least three orders of magnitude lower than the ANZECC 2000 trigger values and ANZECC recreational use guideline values. Therefore, any potential seepage of leachate is highly unlikely to pose a risk to ecological life and recreational users of the Waiteraire Stream; and
  - Uncertainties have been assessed further through sensitivity analysis. Adjusting key parameters makes no substantive change to the model prediction that any potential seepage of leachate through the lining system is highly unlikely to pose a risk to potential receptors. Additional dilution calculations to address the possibility of leachate - affected shallow groundwater being captured by subsoil drains also indicates no potential to impact ecological receptors;
- The following assessment of potential effects has been made:
  - The potential for adverse effects from groundwater drawdown resulting from groundwater take for future operational purposes is low beyond the site boundary;
  - There is no potential for effect from the proposed groundwater take on the regional groundwater resource;
  - The potential effect on the environment from the diversion of groundwater of 47 m^3/day is negligible because the subsoil drains will tap into seeps and springs encountered during excavation work and direct flows to the stormwater system, which will eventually flow to the stream downgradient of the Valley 1 and 2 convergence. Thus the groundwater flow will largely enter the same systems that it would naturally have contributed to;
  - Whilst many of the streams in Valley 1 are seep and spring fed, the streams will be reclaimed as a result of the project. Therefore the effects on the baseflow to the stream are not considered; and
  - Based on the results of groundwater risk assessment, which concludes that contaminant concentrations at all potential points of exposure will not exceed the relevant trigger levels, the potential seepage of leachate through the landfill lining

system is highly unlikely to have any adverse effects on the Valley 1 and 2 stream confluence, the Hōteo River, the Waiteraire Stream or the farm bore.

12 Applicability

This report has been prepared for the exclusive use of our client Waste Management NZ Ltd, 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.

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