NZ TRANSPORT AGENCY
WAKA KOTAHI

Roads of national significance

Ara Tūhono – Pūhoi to Wellsford

FURTHER NORTH

Pūhoi to Warkworth

Hydrogeology Assessment Report

August 2013

Pūhoi to Warkworth

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Glossary of abbreviations

Abbreviation	Definition
AEE	Assessment of Environmental Effects
ARC	Auckland Regional Council (preceded the Auckland Council)
K	Hydraulic conductivity
L/s	Litres per second
m^3/day	Metres cubed per day
mAMSL	Metres Above Mean Sea Level
mBGL	Metres Below Ground Level
m/s	Metres per second
m^2/s	Metres squared per second
MSE	Mechanically stabilised earth
mRL	Metres Reduced Level
NGTR	Northern Gateway Toll Road
NZTA	NZ Transport Agency
RMA	Resource Management Act 1991
RoNS	Roads of National Significance
SHx	State Highway (number)

Glossary of defined terms

Term	Definition
Allochthon	A large block of rock which has been moved from its original site of formation, usually by low angle thrust faulting.
Anion	See cation.
Anisotropy	Anisotropy in an aquifer occurs when there is a difference in conductivity in two different directions. Whenever there is a difference in conductivity, water prefers to travel along the path with least resistance. In other words, water travels preferentially along the direction of higher conductivity.
Auckland Council	The unitary authority that replaced eight councils in the Auckland Region as of 1 November 2010.
Bore	Any hole (typically cylindrical) that has been constructed to provide access to groundwater (for example, for monitoring of ground or groundwater conditions, taking of groundwater or the discharge of stormwater).
Cation	Cations (positively-charged ions) and anions (negatively-charged ions) are formed when a metal loses electrons, and a non-metal gains those electrons. The electrostatic attraction between the positives and negatives brings the particles together and creates an ionic compound, such as sodium chloride.
Culvert	A pipe with an inlet from a watercourse and outlet to a watercourse, designed to convey water under a specific structure (such as a road).
Earthworks	The disturbance of land surfaces by blading, contouring, ripping, moving, removing, placing or replacing soil or earth, or by excavation, or by cutting or filling operations.
Groundwater	Natural water contained within soil and rock formations below the surface of the ground.
Ground settlement	The gradual sinking of the ground surface as a result of the compression of underlying material.
Hydraulic conductivity	The ability of an aquifer material to transmit water, measured as the flow rate of water through a cross section of $1m^2$ under a unit hydraulic gradient. Hydraulic conductivity is typically reported in units of m/d or m/s.
Hydraulic gradient	The change in level or pressure of water over a unit distance, expressed as a percentage or fraction (e.g. a 1m pressure change over 100m horizontal distance is a 1% or 0.01 hydraulic gradient).
Permeability	The ability of a porous material to allow fluids to pass through it.
Piezometer	A device used to measure groundwater pressure head at a point in the subsurface.
Piezometric surface	An imaginary surface representing the static groundwater level as defined by the level that water resides within a tightly cased bore.

Term	Definition
Project	Pūhoi to Warkworth section of the Pūhoi to Wellsford Road of National Significance Project.
Project area	From the Johnstone's Hill tunnel portals in the south to Kaipara Flats Road in the north.
Specific yield	The quantity of water yielded or taken into storage under gravity by a unit change in water level. Specific yield is expressed either as a ratio or as a percentage of the volume of the aquifer, with values typically residing between 0.01 and 0.3 or 1% to 30%.
Storativity	The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.
Transmissivity	Transmissivity is the aquifer hydraulic conductivity (ability of the aquifer to transmit water) multiplied by the saturated thickness (vertical section) of the aquifer under consideration.
Wetland	Vegetated stormwater treatment device designed to remove a range of contaminants, providing superior water quality treatment to ponds with increased filtering and biological treatment performance.

Contents

1. Introduction

1.1 Purpose of Report

This Report forms part of a suite of technical reports prepared for the NZ Transport Agency's (NZTA's) Ara Tūhono Pūhoi to Wellsford Road of National Significance (RoNS) Pūhoi to Warkworth Section (the Project). Its purpose is to inform the Assessment of Environmental Effects (AEE) and to support the resource consent applications and Notices of Requirement for the Project.

The indicative alignment shown on the Project drawings has been developed through a series of multi-disciplinary specialist studies and refinement. A NZTA scheme assessment phase was completed in 2011, and further design changes have been adopted throughout the AEE assessment process for the Project in response to a range of construction and environmental considerations.

It is anticipated that the final alignment will be refined and confirmed at the detailed design stage through conditions and outline plans of works (OPW). For that reason, this assessment has addressed the actual and potential effects arising from the indicative alignment, and covers the proposed designation boundary area.

Except as noted in this Report:

- We consider that the sites we have selected for hydrogeological investigation and testing are generally representative of all areas within the proposed designation boundary; and
- The recommendations we propose to mitigate adverse effects are likely to be applicable to other similar areas within the proposed designation boundary, subject to confirmation of their suitability at the detailed design stage.

1.2 Project description

This Project description provides the context for this assessment. Sections 5 and 6 of the Assessment of Environment Effects (Volume 2) further describe the construction and operational aspects of the Project and should be relied upon as a full description of the Project.

The Project realigns the existing SH1 between the Northern Gateway Toll Road (NGTR) at the Johnstone's Hill tunnels and just north of Warkworth. The alignment will bypass Warkworth on the western side and tie into the existing SH1 north of Warkworth. It will be a total of 18.5 km in length. The upgrade will be a new four-lane dual carriageway road, designed and constructed to motorway standards and the NZTA RoNS standards.

1.3 Project features

Subject to further refinements at the detailed design stage, key features of the Project are:

- A four lane dual carriageway (two lanes in each direction with a median and barrier dividing oncoming lanes);
- A connection with the existing NGTR at the Project's southern extent;

- A half diamond interchange providing a northbound off-ramp at Pūhoi Road and a southbound on-ramp from existing SH1 just south of Pūhoi;
- A western bypass of Warkworth;
- A roundabout at the Project's northern extent, just south of Kaipara Flats Road to tie-in to the existing SH1 north of Warkworth and provide connections north to Wellsford and Whangarei;
- Construction of seven large viaducts, five bridges (largely underpasses or overpasses and one flood bridge), and 40 culverts in two drainage catchments: the Pūhoi River catchment and the Mahurangi River catchment;
- A predicted volume of earthworks being approximately 8M m^3 cut and 6.2M m^3 fill within a proposed designation area of approximately 189 ha earthworks.

The existing single northbound lane from Waiwera Viaduct and through the tunnel at Johnstone's Hill will be remarked to be two lanes. This design fully realises the design potential of the Johnstone's Hill tunnels.

The current southbound tie in from the existing SH1 to the Hibiscus Coast Highway will be remarked to provide two way traffic (northbound and southbound), maintaining an alternative route to the NGTR. The existing northbound tie in will be closed to public traffic as it will no longer be necessary.

1.4 Interchanges and tie-in points

The Project includes one main interchange and two tie-in points to the existing SH1, namely:

- The Pūhoi Interchange;
- Southern tie-in where the alignment will connect with the existing NGTR; and
- Northern tie-in where the alignment will terminate at a roundabout providing a connection with the existing SH1, just south of Kaipara Flats Road north of Warkworth.

The Project area is shown in Figure 1.

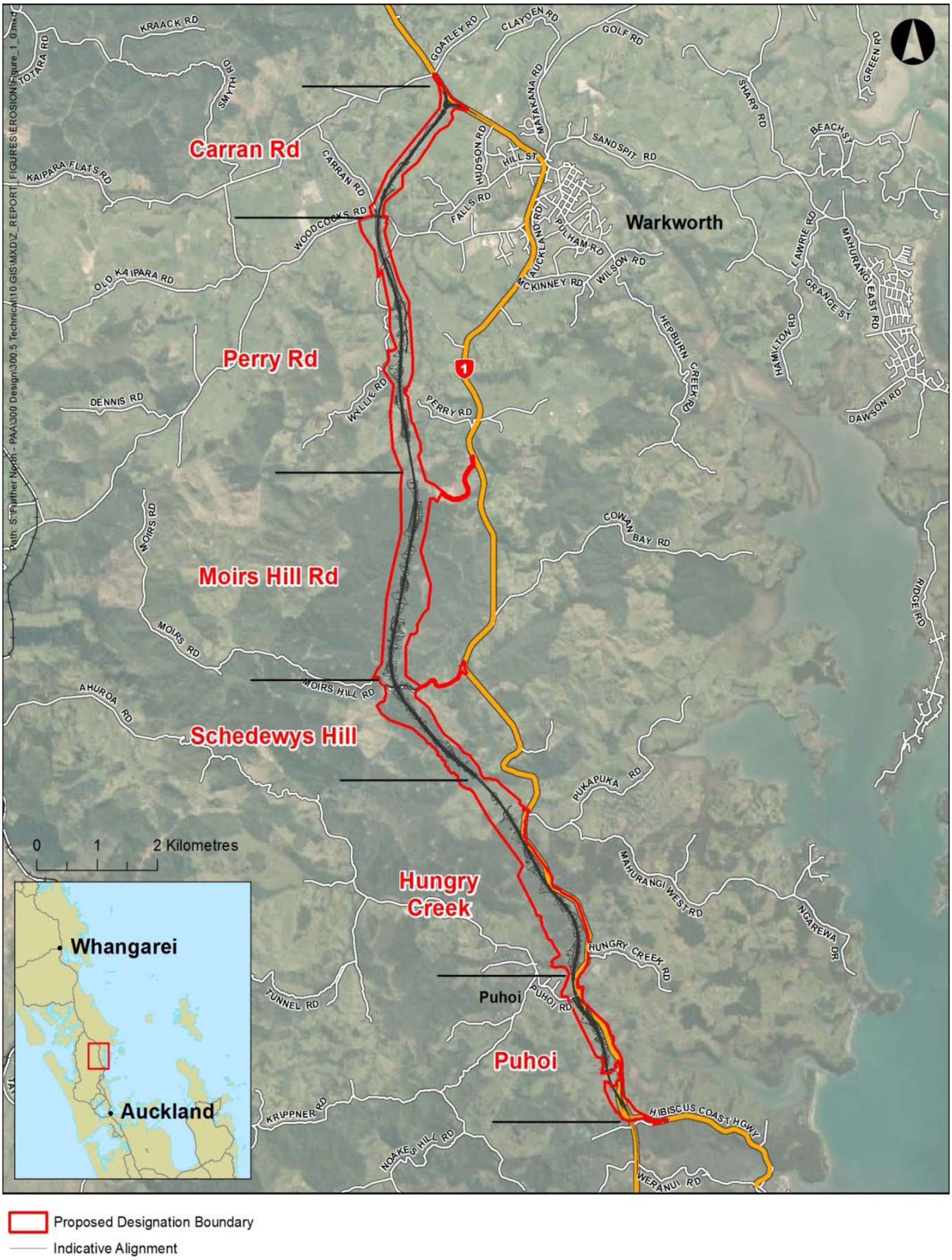

Figure 1: Project area

2. Methodology

The methodology that was undertaken in this study is summarised as follows:

- Desktop study to determine existing groundwater levels, current groundwater use and abstraction and groundwater/surface water interfaces;
- Core drilling and geological logging;
- Piezometer installation;
- Groundwater level recording;
- Hydraulic testing in piezometers to determine aquifer hydraulic conductivity;
- Groundwater model development and calibration; and
- Predictive simulations using the groundwater model to assess potential groundwater impacts.

2.1 Summary of methodology

In order to obtain site specific geological and hydrogeological data an initial desktop study was undertaken, followed by a field investigation programme undertaken between February and May 2013. The scope of this investigation included:

- Drilling of 28 boreholes;
- Geotechnical testing (standard penetration test) in the boreholes;
- Installation of piezometers in all possible boreholes for recording groundwater levels;
- Monitoring of groundwater levels; and
- Aquifer hydraulic testing, including rising and falling head tests, and packer (lugeon) testing.

Each of these aspects is discussed in further detail in the following sections and in conjunction with the existing environment information presented in Section 3, is used as the basis for the assessment of effects presented in Section 4.

2.2 Desk-top study

2.2.1 Groundwater levels

Two sources of information were identified as being most applicable to determine existing groundwater levels within the Project area as follows:

- Borehole information within the Project area from Auckland Council; and
- Borehole information from the Northern Gateway Toll Road (NGTR) project.

Auckland Council borehole information

An indication of groundwater levels in the vicinity of the Project area was obtained from borehole records provided by Auckland Council. We have focused on the bores within a 2 km radius of the centreline of the indicative alignment, given the anticipated low permeability of the sub-surface materials, we considered it very unlikely that bores at greater distances will experience any groundwater impacts.

The borehole information collated is presented and discussed in the existing environment section (Section 3.6).

Northern Gateway Toll Road project borehole information

We undertook a review of groundwater levels recorded during the NGTR project to provide an indication of groundwater level variations across seasons.

Groundwater levels were recorded between 2004 and 2008 for 159 piezometers across the NGTR project area. The data collated is presented in the existing environment section (Section 3.7).

2.2.2 Groundwater use and abstraction

We assessed potential groundwater use in the Project area from the borehole records obtained from Auckland Council, as described above. We acknowledge that there are many boreholes located greater than 2 km from the centreline of the indicative alignment; however this Report focuses on the bores within 2 km as it is very unlikely that bores at greater distances will experience any groundwater impacts as a result of the Project. We gathered further information regarding groundwater use in the Project area by reviewing information on existing consented groundwater takes.

The data collated is presented in the existing environment section (Section 3.8), while Section 4 discusses groundwater impacts in detail.

2.2.3 Groundwater / surface interaction

We undertook an initial desktop survey involving a review of aerial photographs and topographical maps followed by a field survey to identify features (ponds, seepages and springs) that have potential to be affected by the Project. Drawings ES101-117 show the locations of the features identified.

2.3 Exploratory drilling

A total of 28 boreholes were drilled as part of the current phase of the Project by McMillan Drilling Group between February and April 2013 for both geotechnical and hydrogeological investigation purposes. We reviewed each borehole location to provide the most relevant geological and hydrogeological information. Reasoning for each borehole / piezometer location included:

- Characterisation of hydrogeology and rock structure, particularly along deep cut sections;
- Assessment of the impacts of cuts on surface water features;
- Assessment of the impacts of increased drainage; and
- Characterisation of groundwater in recharge areas.

Drilling was undertaken using three specialist rotary diamond core drilling rigs. Coring diameter comprises HQ (96mm external, 63mm internal) and PQ (122mm external, 85mm internal) using a

Triple Tube barrel system. All drilling was undertaken under the guidance and supervision of a Further North Field Engineer. All recovered core was kept and stored in purpose built core boxes.

The boreholes were drilled to depths of between 10m and 60mBGL. A summary of the borehole locations and construction details is presented in **Appendix A** (Table A1). Borehole logs for the 200 series bores are provided in the Geotechnical Engineering Appraisal Report.

The results of the exploratory drilling are discussed in the existing environment section (Section 3.1.1).

2.4 Piezometer construction

A piezometer is a small-diameter observation well used to measure the hydraulic head of groundwater in aquifers. Further North piezometers were installed in 25 boreholes according to specifications and specific details as described in **Appendix B**.

In summary, the piezometers comprise open standpipes (PVC pipes installed vertically), which allow access for manual groundwater measurements with an electronic tape measuring device (dipper). Each piezometer has a short screen and filter zone that targets a point in the aquifer where hydraulic head is of interest. Twelve of these piezometers were nested, which means that multiple piezometers were installed at variable depths in the one borehole, to allow measurement of groundwater pressures at different levels within the aquifer and hence assesse vertical pressure gradients.

Details of groundwater level measurements in the piezometers are discussed in the existing environment section (Section 3.7).

2.5 Groundwater levels and flow direction

Groundwater levels have been manually recorded using a dip meter on a semi-regular basis (i.e. weekly) at the majority of the Further North piezometers between 27 February and 2 May 2013. In addition, groundwater levels in five piezometers (219, 224a, 225, 227a, and 227b) were recorded using Solinst pressure transducers (with six hourly readings) between the period 21 March and 2 May 2013.

The data collected during this period is presented in Appendix B (Table B1) and **Appendix C**, and discussed in the existing environment section (Section 3.7).

2.6 Aquifer hydraulic testing

We conducted two forms of aquifer hydraulic tests on the 200 series boreholes – falling head/rising head permeability tests and packer (Lugeon) tests.

2.6.1 Falling and rising head permeability tests

Falling and rising head permeability tests are performed in-situ within piezometers to measure the hydraulic conductivity of the geology in the immediate vicinity of the borehole. The tests were conducted by adding a known solid volume (slug) to the piezometer and measuring the change in water level over time (falling head test). The slug was left in the piezometer for up to 24 hours, and then the recovery in water levels were recorded for a further 24 hours following the removal of the slug (rising head test). Water levels were recorded using Solinst pressure transducers.

We have conducted falling and rising head permeability (slug) tests on twelve piezometers. The data and results are presented and discussed in the existing environment section (Section 3.4.1).

2.6.2 Packer testing

Packer or Lugeon tests are conducted in order to isolate specific sections of bedrock within a borehole to allow the vertical distribution of hydraulic conductivity to be measured, specifically focussing on targeted fracture zones. During packer tests water is injected at specific pressure 'steps' and the resulting pressure is recorded when the flow has reached a quasi-steady state condition. The steps are used to 'ramp' up and down through the expected pressure range.

During drilling of borehole 215, fractured rock was encountered between 30 and 31.5mBGL, as shown in Figure 2. Further investigation of the downhole camera photos of this borehole indicated a fracture, although it appeared that this fracture was infilled with clay.

This fracture was the first encountered during the 200 series drilling investigation that was located below the groundwater table, and as such a packer test was undertaken on this borehole. A double packer test was completed on two sections of the borehole, the first between 28 and 32.5mBGL to investigate the permeability of the fracture zone, and the second between 33 and 36mBGL to investigate the permeability of the non-fractured Pakiri Formation in the borehole.

Figure 2: Borehole 215 Core from 29.4 to 32.4m.

The data and results are presented and discussed in the existing environment section (**Section 3.4.1**).

3. Existing environment

Several contrasting hydrogeological regimes are found within the Project area and are strongly influenced by the underlying geological units.

The majority of the study area is characterised by the steeply and incised elevated terrain of Pakiri Formation (part of the Waitemata Group), which comprises interbedded sandstone and mudstones. 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. 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 proving the basal layer for perching.

Northern Allochthon is found within the Project area, which comprises highly sheared mudstones, siltstones, sandstones and limestones. Permeability of the Northern Allocthon is typically very low, and groundwater is typically observed as a line of seepage or minor springs at geological boundaries between units within the formation.

The majority of valleys in the study area have been infilled with deep, soft estuarine and alluvial sediments comprising clay, silt, peat and fine sand.

3.1 Regional geological units

A detailed description of the geology in the Project area is presented in the Geotechnical Engineering Appraisal Report, and has been summarised below for the purposes of conceptualisation of the groundwater system.

The majority of the Project area is underlain by sedimentary rocks of the Pakiri Formation (part of the Waitemata Group), which were deposited by submarine mass flow events (turbidite flows, debris flows and currents) in a deep marine basin approximately 15 to 21 million years ago. Also present within the Project area are rocks of the Northland Allochthon[1], which were accreted from the Pacific plate as it was subducted beneath New Zealand at the same time as the Pakiri Formation was deposited.

The above mentioned geological processes have resulted in a complex arrangement and juxtaposition of weak to moderately strong sandstones and mudstones (the Waitemata Group), with large lenses or disrupted slices of significantly weaker, highly sheared mudstones, siltstones, sandstones and limestones of the Northland Allochthon (Isaac, Herzer, Brook, & Haywood, 1994). Some rocks of the Northland Allochthon in the region are colloquially known as the Onerahi Chaos Breccia.

In the Project area the Tertiary age Pakiri Formation rocks comprise interbedded volcaniclastic sandstones and mudstones that form the majority of the steep rugged topography found in the Project area. Occasional harder beds of strong coarse-grained andesitic conglomerates and submarine mass flow deposits of volcaniclastic materials (Parnell Grit/Albany Conglomerate) are

[1] Allochthon: a large block of rock which has been moved from its original site of formation, usually by low angle thrust faulting.

also present. These coarser grained deposits are typically moderately hard to hard and usually more resistant to erosion than the surrounding Waitemata Group rocks. They tend to be graded, fining upwards with coarser material at the base, which often makes it difficult to segregate from sandstone of the Waitemata group rocks.

The Northland Allochthon rocks are older than the Waitemata Group, and were initially formed about 15 to 25 million years ago. They were then transported and emplaced towards the south or south west into the deepening Waitemata Basin from approximately 21 million years ago by a complex process of thrust faulting and submarine land sliding. Consequently, they are severely deformed, crushed and sheared (Winkler, 2003), and often inter-finger with the Waitemata Group sediments.

In the Project area, the Northland Allochthon rocks generally comprise undifferentiated rocks of the Mangakahia Complex (primarily mudstone) and Mahurangi Limestone of the Motatau Complex. Small serpentinite bodies may also be present but known bodies have been quarried out (Rait, 2000).

Major rivers have eroded deep valleys into the landscape, many which were ‘drowned’ and infilled with sediments as a result of sea level rises since the last glaciation. These drowned valleys dominate the east coast of Northland, including the Pūhoi, Mahurangi and Warkworth valleys. These valleys are infilled with deep, soft estuarine and alluvial sediments, often with terrace levels representing previous, higher sea levels or lower land levels (Ballance & Williams, 1992).

Colluvium is present on many slopes, typically resulting from landsliding or downhill creep of residual soils. This slope movement has been exacerbated as a result of human impacts on the landscape since the 1820s, including the changing land-use from kauri forest to scrub, pasture, or urban land (Ballance & Williams, 1992).

3.1.1 Exploratory drilling results

The ground conditions encountered during drilling, as well as those identified through geomorphological mapping, Cone Penetration Testing and Test Pit investigation methods, typically comprise Pakiri Formation, with alluvium and colluvium deposits observed in low lying regions and valleys. Northland Allochthon was identified in the Schedewys Hill area and near the Moirs Hill Road area (boreholes 207 and 210).

A geological long section and cross sections through specific areas along the alignment have been constructed using the collected borehole and groundwater level information. These sections can be found in Geotechnical Engineering Appraisal Report with the long sections referenced as GT-151 to GT-161 and the cross sections referenced as GT-231 to GT-233.

3.2 Geological structure

The inter-bedded Pakiri Formation rock that forms the surface geology across the majority of the site has few distinct marker horizons, making it difficult to correlate the rock across the Project area. The Northland Allochthon rock is typically highly sheared and closely fractured with little discernible structure. In addition, long-continued weathering in a warm, moist climate on rock that is rich in easily altered minerals has caused most of the rock to weather deeply, with the result that the stratigraphy and structure of the region are difficult to decipher from surface exposures.

The main regional geological structures are inactive thrust faults, defining many of the main boundaries between the Pakiri Formation and Northland Allochthon thrust sheets. Deposition of the Pakiri Formation sediments continued above the newly emplaced allochthon sheets. A schematic of this relationship is shown in Figure 3. Syn- and post-depositional faults and folds have resulted in additional and often complex local deformation of the rocks in the area.

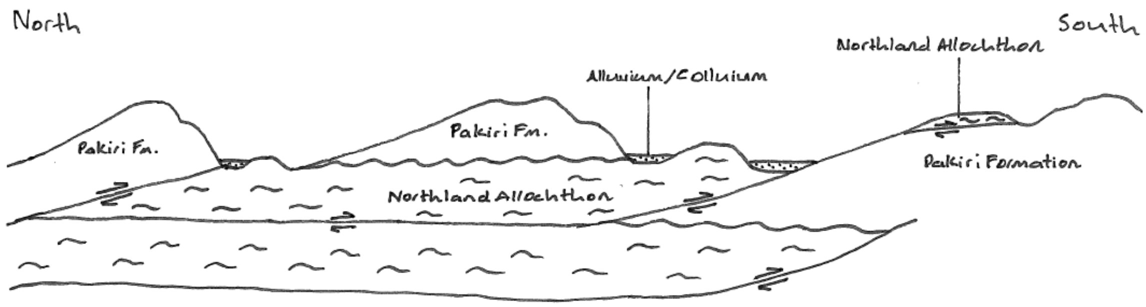

Figure 3: Simplified, inferred geological relationships within the Pūhoi to Warkworth section, adapted from Issac et al. (1994) and Edbrooke (2001).

Only one main fault is identified on the published geological map in the Project area (Edbrooke, 2001). This fault is an east-west orientated thrust fault along the southern margin of the Mahurangi West Valley.

Several topographic lineaments are also observed from the alignment of streams, linear gullies and other topographic features. These lineaments may reflect preferential erosion along the weaker crushed or sheared rock, marking significant fault zones. These are shown in the Geotechnical Engineering Appraisal Report.

The geological structure is the dominant mechanism controlling slope stability, and the existing topography is largely controlled by the underlying geological structure. The main ridgelines are often formed by anticline folds and main valleys often reflect the axes of syncline folds. The geological mapping shows that the Pakiri Formation rocks are locally folded, forming a number of tight folds.

3.3 Regional aquifer hydrogeological characteristics

The hardrock geology and complex geological structure has resulted in typically low yielding aquifers in the Project area (as discussed in detail below), with the exception being localised zones of higher yields associated with faulting (e.g. Watercare's Sanderson Road bore for Warkworth township) and the localised more gravelly components of the generally silty shallow alluvial deposits infilling valleys.

The hydrogeological regimes of the main geological units encountered within the proposed designation boundary (the Waitemata Group, Northern Allochthon and Tauranga Group) are fundamentally different and are discussed separately for each geological unit below. Following the descriptions, Table 1 provides a summary of indicative hydraulic conductivity and storage characteristics for these units, taken from work compiled as part of the Waterview Connection project for the NZTA (Tūhono Consortium, 2011).

3.3.1 Northland Allochthon

Northland Allochthon mudstone and limestone rock can display highly variable and complex hydrogeological conditions relative to various response zone depths. Northland Allochthon rocks typically comprise poor to very poor permeability rocks with hydraulic conductivity (the ability of the rock to transmit water) generally less than 10^{-7}m/s. To place this in context, clean gravels typically have a permeability of 10^{-3} m/s and concrete is 10^{-10} m/s or lower. The ability of the Northland Allochthon aquifer to release groundwater (the specific storage characteristics) are typically low 9×10^{-6} m^{-1}.

Both matrix permeability (flow through the bulk unit materials) and secondary permeability (flow along bedding planes and/or fractures) in Northland Allochthon rocks is typically poor due to secondary infill through either weathering products (clay) or precipitation products (limonite or calcite). However, localised zones of high tertiary (conduit) porosity have been experienced in water supply boreholes in the Warkworth area as a result of faulting in the area that has induced shattering of the rock.

The weathering profile and transition zone within many Northland Allochthon lithologies often act as confined aquifers with low hydraulic conductivity, but with significant elevated pore water pressures.

Drainage from the Northland Allochthon rocks is typically observed as a line of seepage or minor springs at geological boundaries between units within the Northland Allochthon rocks, hence flow rates are typically very low.

3.3.2 Waitemata group

The vast majority of the area between Pūhoi and Warkworth comprises Pakiri Formation rocks of the Waitemata Group. Perched water tables[2] (see Figure 4) and leaky water tables may be present and reflect the interbedded nature of the sandstones and siltstones of contrasting permeability.

[2] A perched groundwater table (or perched aquifer) is a groundwater level within an aquifer that occurs above the regional groundwater table (i.e. in the unsaturated zone). This occurs when there is an impermeable layer of rock or sediment (aquiclude), or relatively impermeable layer (aquitard) above the main water table/aquifer but below the surface of the land. If a perched aquifer's flow intersects the ground surface, on a valley side for example, the water is discharged as a spring.

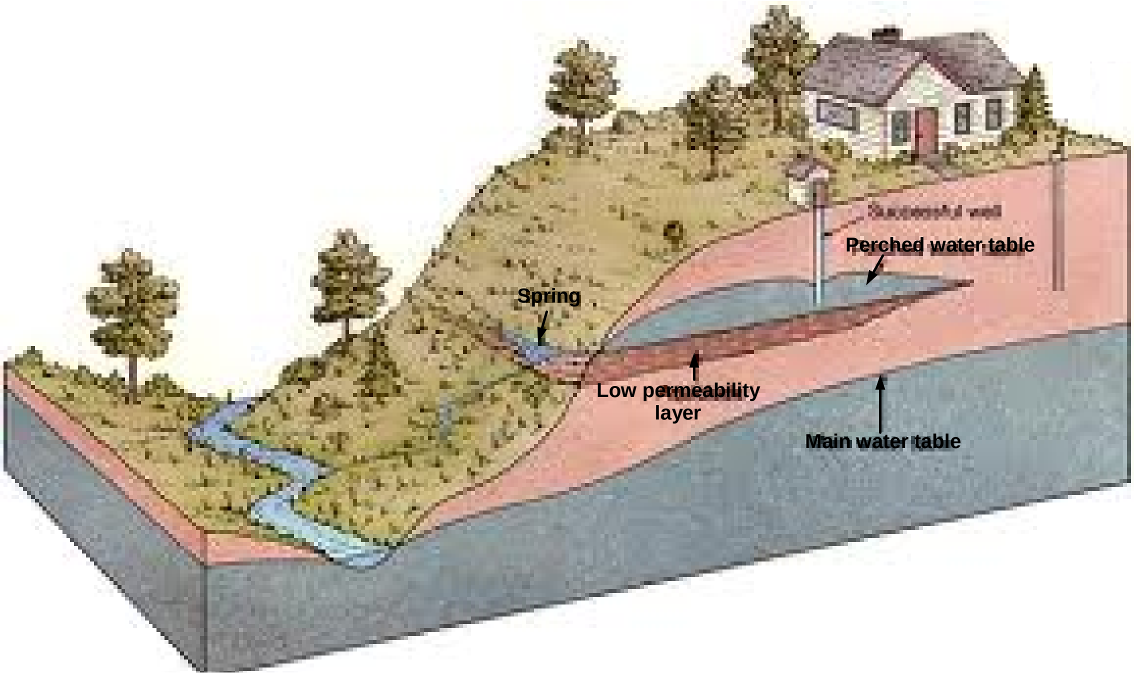

Figure 4: Schematic of a perched water table.

Literature based values of hydraulic conductivity for sandstones and mudstones range from $1x10^{-10}$ to $1x10^{-6}$ m/s (Freeze and Cherry, 1979) and field testing in the Auckland area indicates practical results generally fall within this publicised range.

Recent studies in the region, such as the Waterview Tunnel project (Earthtech, 2010; Tūhono Consortium, 2011), presented measured hydraulic conductivities for weathered Waitemata Group materials in the range of 10^{-9} to 10^{-7} m/s, with marginally higher, but still low overall hydraulic conductivity of 10^{-8} to 10^{-7} m/s for unweathered Waitemata Group rocks. Overall, the vast majority of these rocks typically comprise hydraulic conductivity values at the lower end of the 10^{-7} m/s range, averaging $2.3x10^{-7}$ m/s (Earthtech, 2010).

The strongly bedded sequence of thin (typically 0.1 to 0.5m) alternating siltstone and fine sandstone give rise to vertical anisotropy in hydraulic conductivity, with horizontal hydraulic conductivity typically 40 to 250 times greater than vertical hydraulic conductivity (Tūhono Consortium, 2011). This anisotropy range was determined on the basis of lab test analysis of vertical permeability, field testing results of horizontal permeability and model calibration to field test pumping with adherence to the range of values employed on previous hydrogeological engineering projects in the Auckland region (Tūhono Consortium, 2011).

Strong vertical anisotropy as evidenced in these layered rock materials tends to retard vertical groundwater movement and impacts with increasing or decreasing depth from any depressurisation or mounding application (depending on the application).

3.3.3 Tauranga Group Alluvium

Recent alluvium, found within river valleys and estuarine embayments within the Pūhoi to Warkworth area comprises shallow aquifers that have limited potential to supply good quality or high yields of groundwater. While hydraulic conductivity of this material is low ranging from 10^{-8} to 10^{-7} m/s, higher hydraulic conductivities may be found locally where cleaner sands and gravels are encountered. While these higher permeability materials may be conducive to excellent groundwater yields, the lensoidal[3] nature and limited lateral extent of the materials, shallow depth and susceptibility to surface contamination limit use of these aquifers.

3.4 Aquifer hydraulic parameters

Table 1 provides a summary of indicative hydraulic conductivity and storage characteristics for these units, taken from work compiled as part of the Waterview Connection project for the NZTA (Tūhono Consortium, 2011).

Table 1: Summary of aquifer hydraulic parameters

Unit	K_h (m/s) range	K_h:K_v ratio	S_s (m^{-1}) range	S_y
Northland Allochthon	10^{-8}	10	$9x10^{-6}$	0.01
Fresh Waitemata Group	10^{-8} to 10^{-7}	40 to 250	$9x10^{-6}$	0.01
Weathered Waitemata Group	10^{-9} to 10^{-7}	>10	$1x10^{-3}$	0.01
Coarser sandstone / conglomerate units within WGR	10^{-7} to 10^{-5}	1	$9x10^{-6}$	0.05
Tauranga Group Alluvium	10^{-8} to 10^{-7}	>10	$1x10^{-3}$	0.01

Note: K_h – horizontal hydraulic conductivity; K_v – vertical hydraulic conductivity; S_s – storativity; S_y – specific yield.

3.4.1 Further North permeability test results

We analysed the data from the falling and rising head permeability tests using the Hvorslev (1951) method, which assumes that the aquifer is homogenous, isotropic and is an infinite medium. Results from the test are presented in **Appendix D** (Table D1).

The results from both the falling and rising head test were relatively consistent and show that hydraulic conductivity in the immediate vicinity of the boreholes range in the order of 10^{-9} to 10^{-7} m/s. These are low values of hydraulic conductivity and are consistent with the range of expected values as discussed in Section 3.3 and summarised in Table 1.

Borehole 201b and 207 had very low rates of recovery and could not be analysed – in these boreholes a value of less than $1x10^{-7}$ m/s has been applied in the model, given the expected low hydraulic conductivity. In several boreholes, recharge during the rising head test meant that the data were unable to be analysed.

[3] Thin oval lens or eclipse shaped deposit.

We analysed the data from the packer testing using the Lugeon testing and analysis methods described in Royle (date unknown) and Quiñones-Rozo (2010). Results from the test are presented in Appendix D (Table D2).

The results indicate only slightly elevated permeability in the fractured rock part of the bore compared to the unfractured part, however the difference is only approximately half an order of magnitude. Compared to typical hydraulic conductivity values for Waitemata Group rocks as described in Section 3.3.2, which indicates a range of 10^{-9} to 10^{-7} m/s, the fractured zone is again only slightly higher, suggesting the fracture is not significantly different to the bulk rock mass.

The fracture encountered in bore 215 was the only obvious fracture observed in any of the drill core along the indicative alignment, hence we consider it to be a relatively rare feature. The hydraulic characteristics as determined from the Lugeon testing do not indicate a marked significant difference to background Waitemata Group rocks, which implies that the implications of this fracture with respect to potential groundwater impacts from the Project are not of significance.

3.5 Aquifer recharge

Aquifer recharge is the flow or infiltration of water into the saturated zone of the subsurface profile and can be either directly from rainfall, or from other surface water movement such as baseflow recharge from rivers and surface water bodies. Recharge is controlled by a number of variables, the main ones being rainfall, evaporation, topography, soil type, geology and landuse.

In order to quantify aquifer recharge, rainfall data was obtained from Auckland Council for a number of rainfall stations within the Project area. For the purposes of this assessment, the Warkworth Composite Record was used as it has the longest (91 years) record. Over the length of record (1921 – 2012) received from Auckland Council, the average annual rainfall was 1,505mm/year.

We have focussed on deep recharge to the Waitemata group rock, which is the primary rock type in the area and only aquifer type potentially impacted by excavation. 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; and
- high potential evaporation (mean annual pan evaporation is approximately 1,300mm/year).

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

A deep groundwater recharge rate for hardrock in the area is considered to be 50mm/yr (or approximately 3.3% of annual rainfall). Auckland Council indicates recharge in the Waitemata group materials typically ranges from 2 to 4% of mean annual rainfall (pers. com., Kelsey, 2013 working on behalf of Auckland Council).

3.6 Groundwater boreholes

Auckland Council boreholes

The borehole database records from Auckland Council showed a total of 112 boreholes drilled within a 2km radius of the centreline of the indicative alignment. The location of the Auckland Council registered boreholes are shown in Figure 5.

Further North piezometers

Drawings ES101-ES117 present the location of standpipe piezometers installed in the vicinity of the indicative alignment. Of the twelve nested piezometers, the shallow piezometer was initially dry in six. In this situation the installation was completed to prove the lack of shallow and/or perched groundwater tables, and to assess the likelihood of an ephemeral groundwater table re-emerging during wetter periods, as we recognised that the installation period was during the exceptionally dry summer of 2012/2013. All of the dry nested piezometers were installed within the Waitemata Group aquifer.

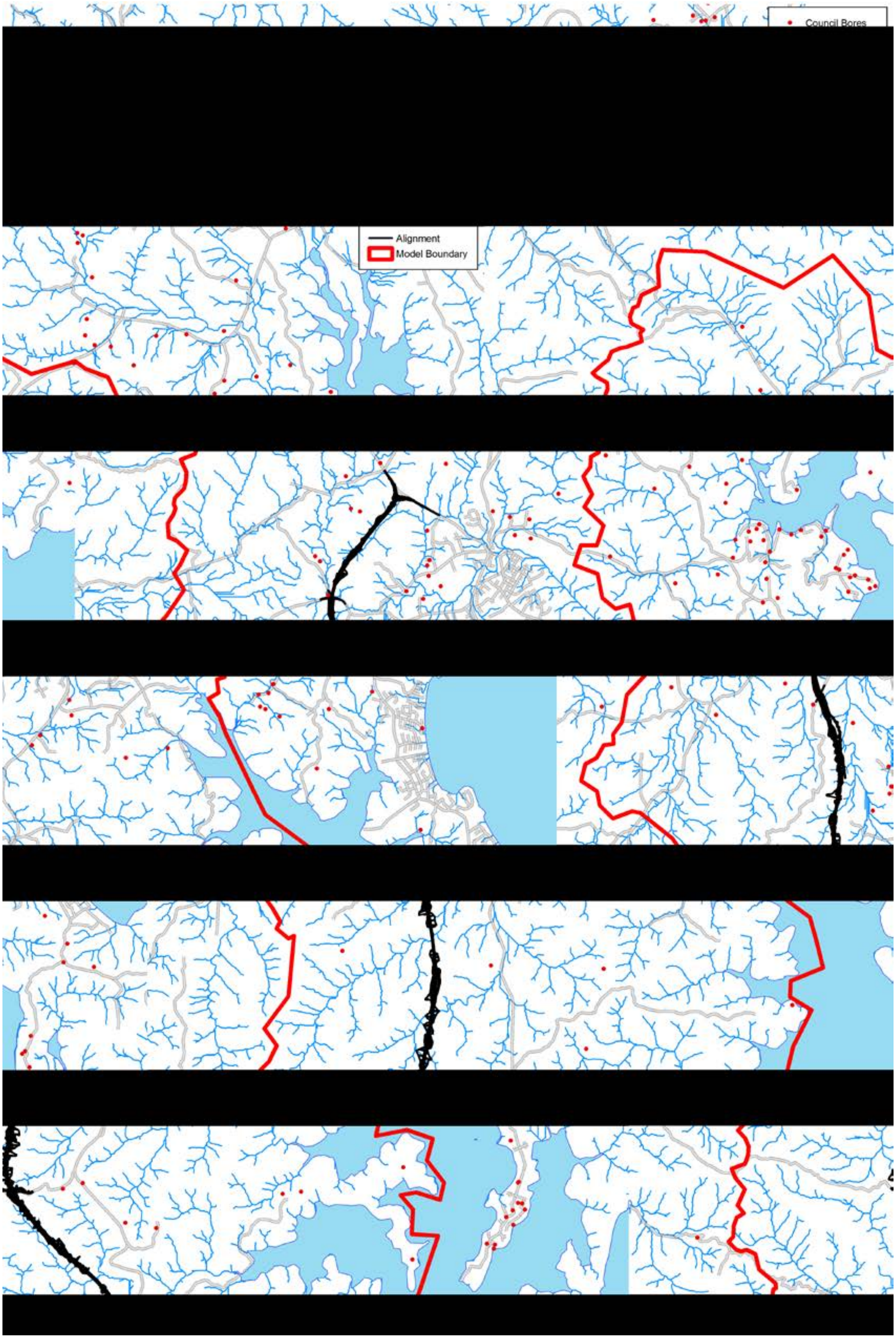

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Figure 5: Registered Bores in Auckland Council Database.

3.7 Groundwater levels

3.7.1 Depth to groundwater

Auckland Council data

Of the 112 bores in the Auckland Council bore database, we obtained groundwater levels from 44 boreholes. We believe the remainder of the boreholes were either dry, or in some cases water level was not recorded at the time of drilling.

Depth to groundwater in the 44 boreholes ranges from 1 to 132 meters below ground level (mBGL), with a median depth of 8mBGL.

Northern Gateway Toll Road data

Groundwater level recorded from the 159 piezometers during the NGTR project ranged in depths between 2.2 and 70mBGL. Overall, 68 of the piezometers were recorded as having less than 1m of groundwater level fluctuation, and a total of 131 piezometers recorded less than 5m groundwater level fluctuation. Only seven piezometers had groundwater level variations of over 10m, although external factors may have effected these variations, e.g. abstraction from neighbouring bores or long-term water level recovery following drilling.

This information indicates that in general, there is not a large degree of seasonal groundwater variation in similar geology to that of the Project area.

Further North data

Static groundwater levels (recorded on 27 June 2013) are shown in Table B1 in Appendix B, with plots of groundwater levels included in Appendix C. Static groundwater levels interpolated from data recorded in the piezometers are also shown on the eleven Geological Longitudinal Sections in the Geotechnical Engineering Appraisal Report Drawings GT-151 to GT-161.

The following paragraphs summarise the depth to groundwater from each piezometer, by aquifer type.

Alluvium

Groundwater levels in the alluvial deposits are shallow, typically residing between 0.17 and 0.9mBGL.

Alluvium groundwater levels are relatively sensitive to rainfall events and higher stream flows as evidenced in bores 224a, 227a and 227b, which showed increased levels (albeit less than 1m) corresponding to rainfall events (as recorded at the Hoteo rainfall station no.130507), as follows:

- 15 April 2013 – 32mm;
- 16 April 2013 – 17.4mm; and
- 20 April 2013 – 35mm.

This information confirms that the alluvium deposits are directly connected to surface processes.

Waitemata Group

Groundwater levels in the Waitemata Group are deeper and typically range between 3.8 and 39.93mBGL. In contrast to the alluvium, groundwater levels in the Waitemata aquifer have shown very little variation over time, and in many cases (e.g. 207, 218, 219 and 223) have continued to recover (decline) following drilling. The groundwater levels in piezometer 219 have not shown any response to the rainfall events that occurred during the period recorded by the Solinst pressure transducers indicating the aquifer may be either very low permeability or partially confined at this location. However, groundwater levels in 225 showed a slight increase in groundwater levels following the rainfall events outlined above. This response is consistent with the depth and location of 225, which is relatively shallow and alongside the alluvial plains (albeit on slightly higher ground than the alluvium piezometer 224).

Of the 28 boreholes drilled, six piezometers (201a, 206a, 209a, 213a & b and 226) were dry at the time of drilling (i.e. did not encounter groundwater). Water levels will continue to be monitored at these locations until March 2014 to see if levels recover during the winter, i.e. recover following the drought of the 2012/1013 summer.

In the more strongly alternating sandstones and siltstones (flysch) deposits of the Waitemata Group rocks, perched groundwater tables are sometimes encountered above a low permeability siltstone bed. Perched groundwater can have implications for highwall stability in excavations and ongoing drainage. If the perched groundwater supports significant spring flow on the side of a valley, there may be implications for any groundwater dependent wetland.

There are three potential examples of perched groundwater in the Project area (see further discussion in the following Section 3.7.2).

3.7.2 Vertical groundwater gradients

Alluvium

Two sets (of the twelve) dual nested piezometers were installed within alluvium bores at bore locations 224 and 227. The piezometer configuration details, static groundwater levels and calculated vertical pressure gradients are summarised in Appendix B (Table B2).

Both piezometers have a small positive pressure gradient, which suggests that in these valley floor locations at the time of data recording, the underlying rock has a greater pressure head than the alluvium. This difference in groundwater level suggests an upward flow potential, however, the pressure gradient is not strong, and likely influenced by the very dry conditions experienced during the period of drilling and groundwater level monitoring. It is likely that during winter, when stream flows are typically higher, the pressure gradient would be negated and during periods of high to flood flow, potentially reversed such that downwards flows may occur.

Waitemata Rocks

Ten of the twelve nested piezometers are located in the Waitemata Group rocks. Four of these lacked groundwater in the shallow piezometer, which suggests that the deeper piezometer represents the local water table and no vertical pressure gradient prevailed within the profile sampled.

The remaining six nested piezometers in the Waitemata group rocks showed moderate to strong downward pressure gradients, which mean shallow groundwater has a higher level than deep groundwater, as shown in Figure 6. 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.

The horizontal seepage does manifest at the surface on valley sides as seeps (generally higher up the profile) and springs (generally towards the valley floor). Because of the progressive skimming off of percolating groundwater (through valley side seepage), the residual percolating groundwater is lesser in volume and hence pressure potential.

Excavations through the shallow groundwater profiles on valley sides may give rise to temporary groundwater discharge during the initial excavation, but given the nature of all the materials encountered, the flow is unlikely to be sustained for longer than a few days.

All of the nested piezometer boreholes with the exception of 217 and possibly 220 (although there is some doubt about the shallow piezometers as discussed below) show groundwater levels in the bottom piezometer that overlap or extend upwards past the base of the upper piezometer. This tends to indicate (although is not totally conclusive due to the spacing of screens) that the groundwater system is continuously saturated beneath the upper groundwater table.

The groundwater levels in bore 217 would tend to indicate multiple perched water tables. However, inspection of the logs indicates that the water levels recorded in each piezometer represent the top of the gravel pack in each instance. These results suggest that horizontal seepage along the interfaces between rock layers is pooling in each respective piezometer, and is not actually a true reflection of groundwater pressures at each point in the profile. For example, if another piezometer was to be installed with its base at 15m and top of the screen zone at 8m, the groundwater level would most likely be at 8m and therefore overlapping as per the other piezometers.

The shallow piezometer in bore 220 was dry in summer and has only indicated water in July 2013. We are not certain this represents true groundwater at this stage, as the level recorded was just above the piezometer base. From experience, condensation on the walls of the piezometers which becomes more prevalent during the cooler winter months can be mistaken by the electronic dippers for a water level.

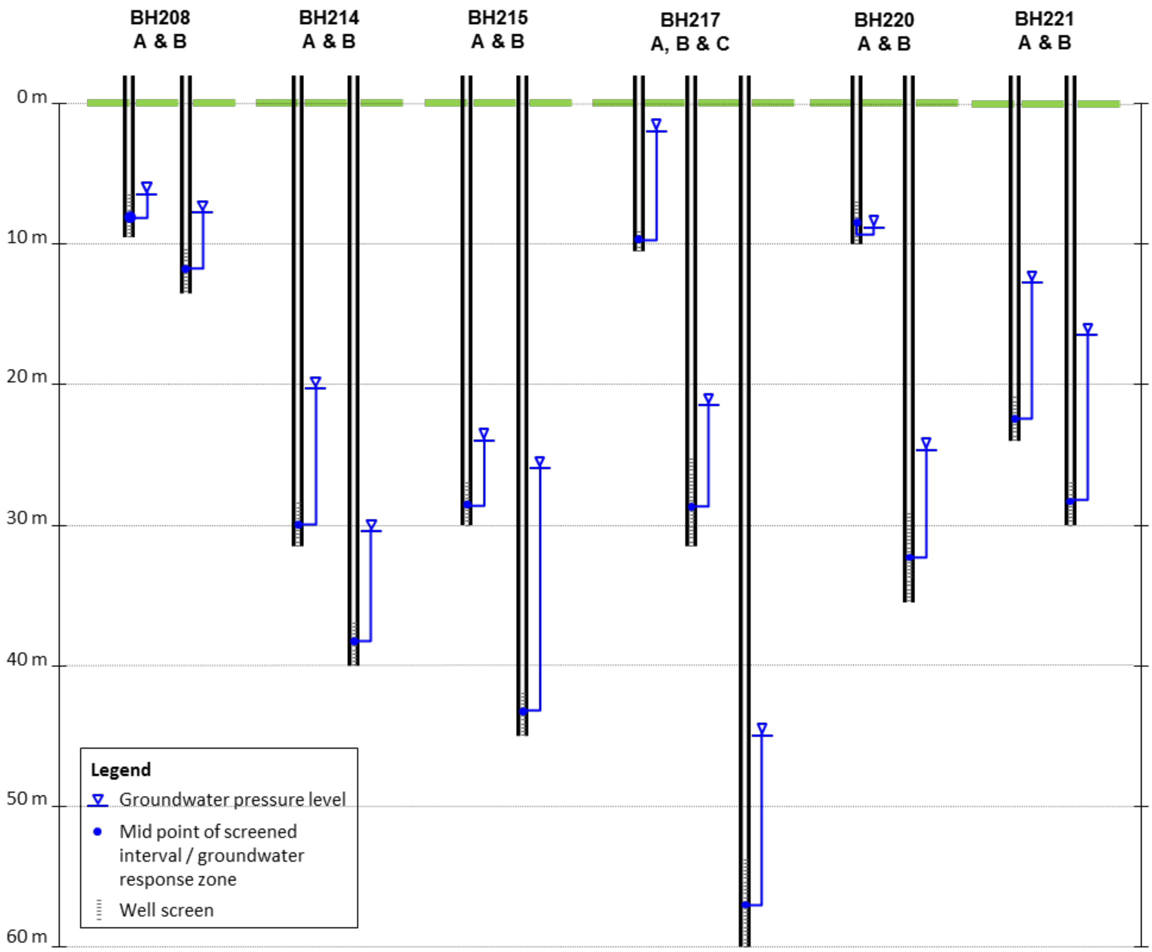

Figure 6: Groundwater Level Differences In Waitemata Group Nested Piezometers

3.7.3 Groundwater flow direction

Groundwater flow direction is typically defined through analysis of maps showing the piezometric surface, which is an imaginary surface of contour lines, with each contour line representing equal groundwater pressure or level. Typically, a piezometric surface is generated from interpolation of groundwater levels measured in boreholes over a wide area. However, in this project, the vast majority of reliable boreholes available were constructed by Further North along the relatively narrow corridor of the indicative alignment.

This narrow corridor would have made interpolation of groundwater levels a subjective and laborious task, and the accuracy in areas distant from the alignment poor. For these reasons, Further North developed a piezometric surface through simulation of a conceptual level, semi-regional groundwater model that was calibrated to the available groundwater monitoring data. The Groundwater Modelling Report provides a summary of the groundwater model development and predictive simulations.

The simulated piezometric surface and associated flow directions are shown in Figure 7. The piezometric surface pattern is highly dendritic[4] and strongly mimics the surface topographic and stream drainage pattern.

[4] Dendritic pattern is seemingly completely random, resembling the branching pattern of blood vessels or tree branches.

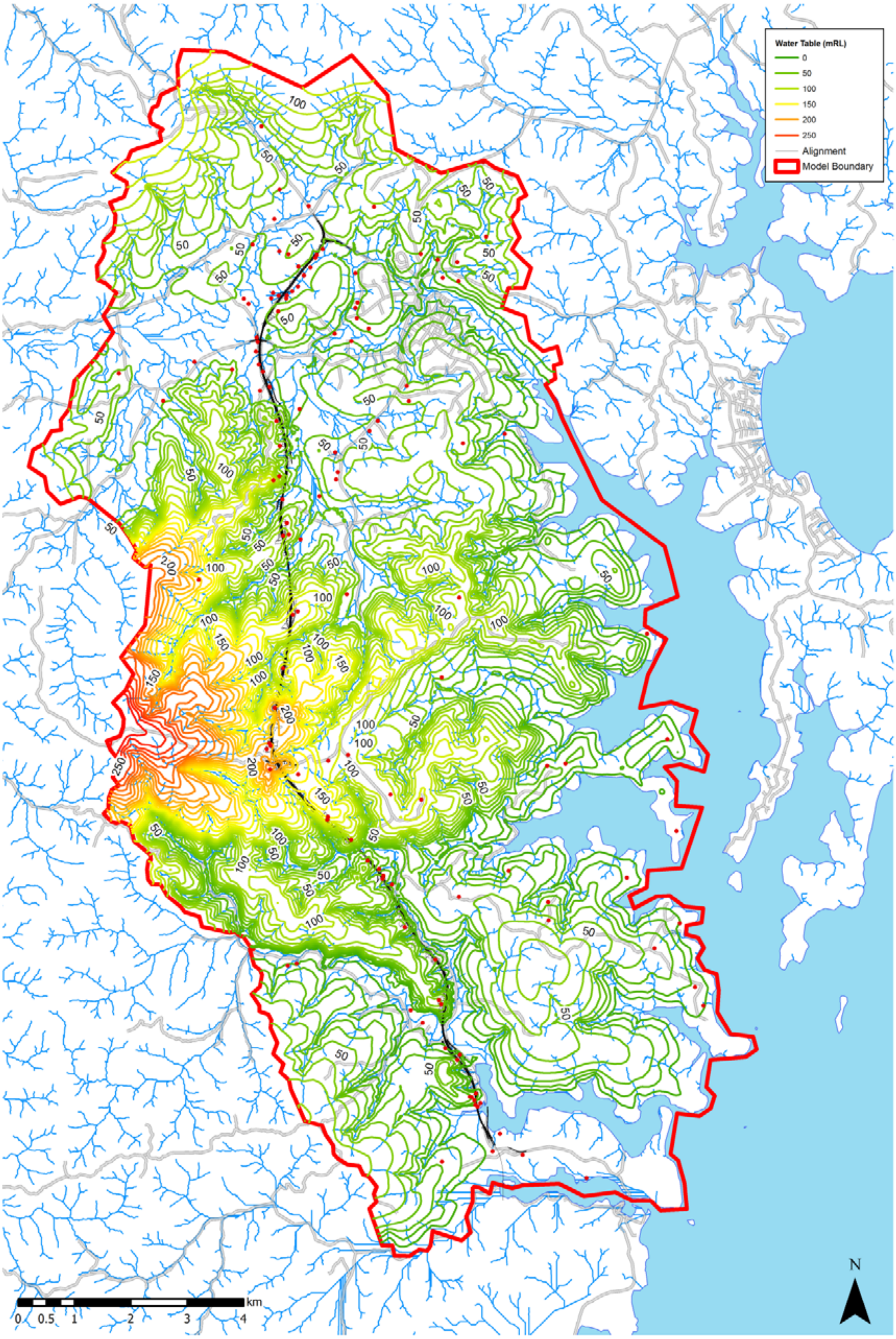

Figure 7: Groundwater Piezometric surface and flow directions

On a broad scale, groundwater levels are typically greatest in the west, with a maximum elevation of approximately 280mRL at Moirs Hill range, and lowest in the east along the coastline, where groundwater levels are approximately 0mRL. On a localised scale, as inferred above, groundwater flow is following surface drainage pathways and changes direction rapidly as the topographical control changes.

Groundwater predominantly flows through the alignment from the west to the east. However, south of Moirs Hill Road between Chainage 57000 to 58000, groundwater is flowing southward, and crossing the alignment from the eastern side.

In summary, within the Project area groundwater levels represent a subdued expression of the topography. Groundwater levels are typically lower and close to surface in the valleys infill alluvium areas, while in the upland areas typically comprising Waitemata Group materials, groundwater levels are higher albeit deeper (i.e. greater distance from the ground surface).

3.8 Groundwater use and abstraction

There are two main clusters of boreholes in the Project area, namely at Pūhoi and Warkworth, with the boreholes primarily tapping the Waitemata Group. There are no Auckland Council records of boreholes tapping the Northland Allochthon rocks. Borehole depths range between 6 to 305mBGL, with an average depth of 135mBGL. The Auckland Council database states that the boreholes have been drilled primarily for either domestic/stock water supply purposes or as observation piezometers. As such, the bore diameters are variable and range between 38 to 300mm, with a typical diameter of 100mm.

Table 2 summarises the information on existing consented groundwater takes within the Pūhoi and Mahurangi catchment. There are currently eleven consented groundwater takes within the catchments, with the majority of these consented abstractions located to the south of Warkworth.

The allocations for the eleven consented groundwater abstractions range between 40 and 4,320m^3/day, with the total consented groundwater allocation being 5,510m^3/day as shown in Table 2. The consented groundwater allocations are stated as being for industrial, irrigation or potable uses. The majority of the yields are low to very low, with the aquifers generally not being conducive within reasonable economic consideration for higher flows required for broad water supply or irrigation purposes. However, the exception is the recently obtained Watercare Services Ltd municipal supply abstraction in Warkworth, which is consented to abstract groundwater at a rate of up to 50L/s (4,320m^3/day). This bore is extremely high yielding, having intersected a highly fractured zone associated with a local fault, and is considered atypical for the rock type and region.

The Auckland Regional Plan: Air, Land and Water states that water takes for an individual's reasonable domestic needs and existing lawful water takes for animal drinking water purposes are permitted provided specific criteria are met. Auckland Regional Plan: Air, land and water Rules 6.5.30 and 6.5.31 provide for groundwater takes up to 20m^3/day as Permitted Activities provided not from an identified heavily allocation aquifer (High Use Aquifer Management Zone). Permitted groundwater takes are not recorded within the Auckland Council database, however consent is required to drill a bore. Due to the lack of information regarding the exact number and location of permitted takes within the area, this level of allocation was not assessed in this study.

Table 2: Existing groundwater consents

Consent No.	Name	Allocation (m^3/day) [L/s]	Bore depth (mBGL)	Expiry date	Purpose
21606	Buckley	100 [1.2]	168	31/05/2015	Irrigation Market Garden
22840	Morton-Jones	40 [0.46]	305	31/05/2014	Community Supply
23056	Lawson Investments Ltd	40 [0.46]	15	01/05/2015	Irrigation Market Garden
31071	Warwick Rhodes Contractors Ltd	80 [0.93]	Unknown	31/05/2015	Potable Supply
34117	Summerset Villages Ltd	60 [0.69]	180	31/12/2029	Potable Supply
34119	Stockyard Holdings Ltd	60 [0.69]	180	31/12/2029	Potable Supply
35264	Watercare Services Ltd	4,320 [50.0]	200	03/04/2045	Municipal
35620	Atlas Concrete Ltd	80 [0.93]	160.5	31/05/2029	Industrial
36585	Bio Marine Properties Ltd	100 [1.2]	Unknown	31/05/2029	Industrial
38170	Pūhoi Valley Cheese	130 [1.5]	Up to 4 bores	31/05/2025	Industrial
40713	Southern Paprika Ltd	500 [5.8]	60	31/05/2029	Irrigation

3.9 Groundwater / surface water interaction

Knowledge of the localised interaction between groundwater and surface water is important as potential changes in groundwater level or flow may affect surface water features such as:

- Streams / rivers;
- Springs / seeps;
- Ponds;
- Wetlands; and
- Drains.

In areas underlain by the Waitemata Group and the Northern Allochthon the topography is moderately steep to steep with deeply incised valleys. In these areas, groundwater typically emerges at the base of slopes in the form of seeps, and along geological boundaries (sometimes partway up slopes) in the form of springs. These seepage areas are typically identified from the wetland type and/or green vegetation present year round (as shown in Figure 8), particularly evident during drought. Some of these springs and seeps feed small streams however many of these streams are ephemeral and were not flowing during the 2013 summer (refer to the Freshwater Ecology Assessment Report for further details).

Figure 8: Vegetation located at top of spring (dry) near Borehole 228 (5 April 2013)

In areas where alluvium has infilled the valleys, groundwater is responsible for the baseflow in the larger streams and rivers. Baseflow also feeds wetlands such as those found north of Carran Road in the vicinity of Warkworth.

3.10 Groundwater quality

The groundwater quality of the Waitemata Aquifers can be broadly divided into two different “types” of water. Shallow groundwater (<200m depth) commonly have a high total hardness/total alkalinity ratio[5], and are hard calcium carbonate waters with near-neutral pH, high total iron (>1.0g/m^3), and silica concentrations greater than 40g/m^3 (ARC, 2002). In comparison, deeper groundwater commonly have a low total hardness/total alkalinity ratio, and are soft sodium bicarbonate waters with pH >8.5, low total iron (<0.2g/m^3) and silica concentrations of less than 40g/m^3.

Auckland Regional Council (1995) outlines the development of the chemical character of the two composition types of groundwater:

[5] Total hardness is a measure of total concentration of calcium and magnesium while total alkalinity is a measure of the total concentration of carbonate and bicarbonate anions.

- "Shallow groundwater, that is high in dissolved carbon dioxide, dissolves calcareous and silicate minerals as it flows through the shallow weathered rocks producing high total hardness/total alkalinity water. Iron is a common constituent of shallow groundwater being derived from weathering of the shallow sandstone strata; and

- Deep groundwater that generally is of good quality, low hardness (soft water). This evolves over time, as the groundwater percolates through the geology, calcium and magnesium cations[6] are exchanged for sodium and potassium that are present as cations absorbed on clay minerals. This process increases the sodium concentration and decreases the calcium and magnesium concentrations in deeper groundwater. The change in these cations also changes the pH and silica concentrations."

[6] Cations are positively charged ions.

4. Assessment of hydrogeological effects

The assessment of hydrological effects concluded the following:

- Drawdown is confined to a narrow 700m corridor parallel to the indicative alignment, with the majority of drawdown occurring within 160m;
- There are only two private bores for the taking and use of groundwater within 2km of the indicative alignment and the maximum drawdown impact simulated in these bores is only 0.5m. Both these bores are over 150m deep and hence this level of impact is considered less than minor;
- The reduction in stream baseflows due to predicted groundwater diversions at the highways cuts range from approximately 0.0002 L/s (0.02 m^3/day) to 0.1135 L/s (9.8 m^3/day). This represents up to 2.6% of the baseflow in the larger streams and up to 46% of baseflow in the smaller streams. However, the smaller streams assessed are so small, they are more likely ephemeral wet areas from wet season groundwater seeps rather than streams per se. The ecological consequence of this is assessed in the Freshwater Ecology Assessment Report;
- The potential effects on groundwater quality are considered to be less than minor, primarily because of the very slow groundwater infiltration and flow rates due to the low permeability of the Waitemata Group materials, and the very small volumes of water that will be diverted at the cuts;
- Construction and operational impacts on groundwater are considered minor because of the surface water containment system developed for the Project (as outlined in the Construction Water Assessment Report: Section 9.7), the underlying groundwater system being so impermeable, and the fact that any diverted groundwater will be re-directed in natural water courses through the surface water drainage system; and
- No mitigation or monitoring is considered necessary for groundwater impacts because of the very low likelihood of any significant impacts, the fact that there are no affected parties, and that any diversion are routed through the project's stormwater system or when discharged back into natural watercourses.

4.1 Introduction

The impact of the Project on groundwater will largely arise from deep excavations below the groundwater table, which can impact on the natural groundwater regime in the following ways:

- ***Drawdown*** - Groundwater drawdown and associated ground settlement that may have the potential to impact on existing structures and services;
- ***Surface water resources*** - Reduction in groundwater levels that may affect stream baseflow regimes, and alter present inflows and outflows from springs, streams, rivers, ponds and wetlands;
- ***Groundwater quantity and quality*** - Reduction in groundwater quantity (yield) and quality at existing abstraction bores through the alteration of groundwater flow patterns; and

- ***Migration of existing contaminants*** - Potential to spread contaminants residing in areas of past landfilling and/or contaminated sites through groundwater drawdown in these areas.

The potential groundwater effects with regards to the Project construction and operation activities are outlined below.

4.2 Potential groundwater drawdown

Drawdown is the reduction in groundwater level resulting from any form of development or activity, for example, pumping from a borehole or drainage through an excavation. The magnitude and maximum extent of drawdown are important considerations as these define the potential severity and zone of impact from the activity, respectively.

We assessed the drawdown for each of the indicative cuts along the indicative alignment with a calibrated numerical groundwater model, as described in the Groundwater Modelling Report. Figure 9 provides an overview of the extent of drawdown from the indicative alignment cuts, and fifteen detailed maps sheets showing the same data in localised areas are provided in Drawings ES-101 to ES117.

From Figure 9 it can be seen that drawdown is very localised to the areas of cuts along the indicative alignment. The maximum extent of drawdown (which we have based on the 0.1m drawdown contour) is 700m is from the centre of the indicative alignment. However, groundwater drawdown of any significance (i.e. say 5m or greater) is constrained to within 160m of the indicative alignment.

The relatively small lateral extent of drawdown is typical of construction dewatering effects within low permeability materials. The implication of this is that there will be negligible impact on either existing groundwater users or groundwater dependent ecosystems outside of this area.

Groundwater drawdown has the potential to induce ground settlement in soft compressible sediments, such as alluvium and highly weathered rock or clay. In this project, the cuts that will induce groundwater drawdown are mainly located in Waitemata Group materials that display very low compressibility potential, as discussed in the Geotechnical Engineering Appraisal Report: Section 13. Groundwater drawdown is typically localised to within the Waitemata Group materials, and hence measureable settlement is not expected.

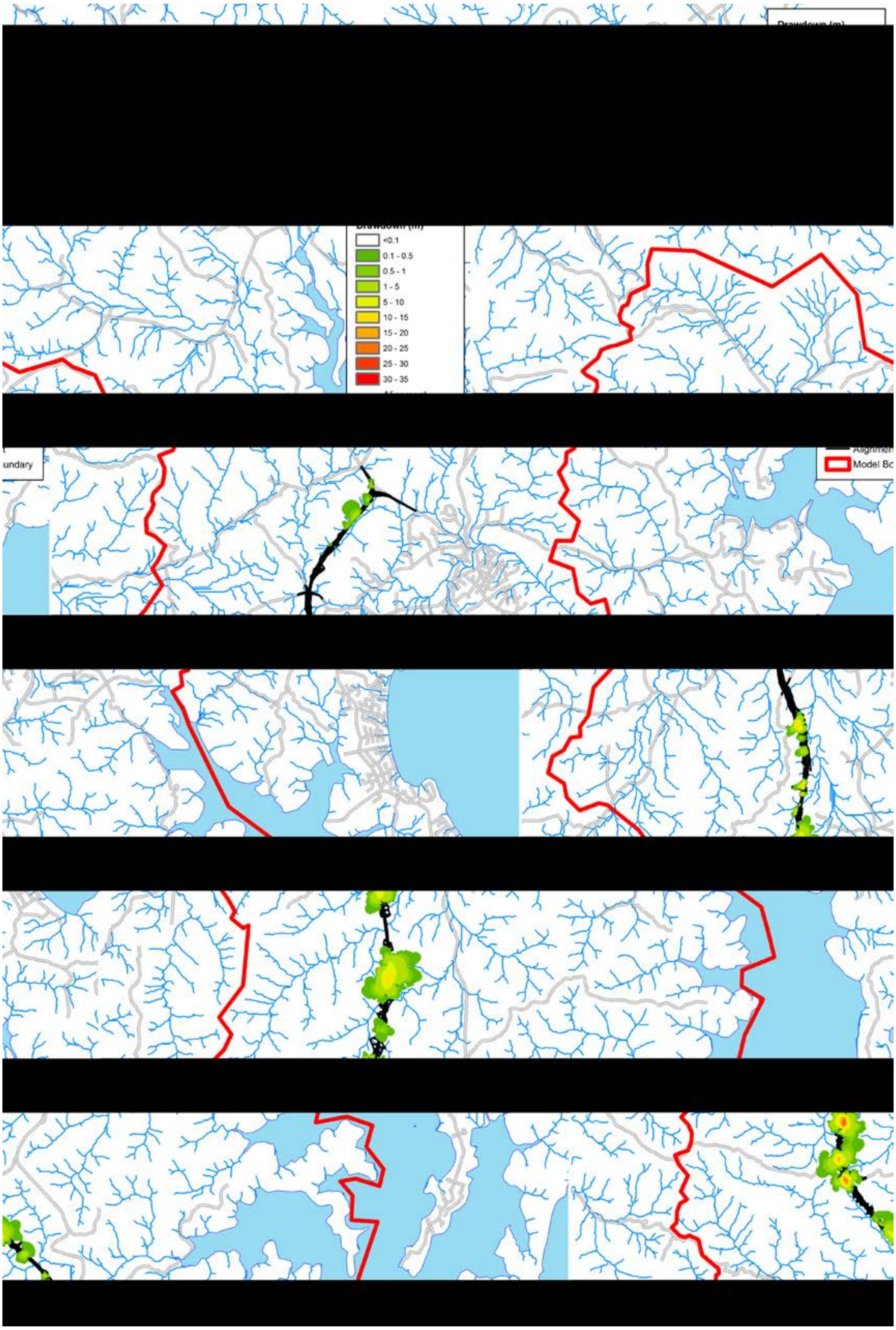

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Figure 9: Extent of groundwater drawdown from indicative alignment cuts

4.3 Potential impact on neighbouring groundwater users

As discussed above, we undertook a search of the Auckland Council bore database within a 2 km radius of the indicative alignment to determine if the anticipated groundwater drawdown profile would impact any lawfully existing groundwater users.

As identified in Section 3.6, there are many boreholes located greater than 2 km from the centreline of the indicative alignment; however this Report focuses on the bores within 2 km as it is very unlikely that bores at greater distances will experience any groundwater impacts.

The bore database contains bores that were registered for drilling or bore construction purposes, along with resource consents for the taking and use of groundwater. Analysis of this data ensures that all legally entitled and/or existing groundwater users have been considered in our analysis including users for/under:

- reasonable stock and domestic purposes under section 14(3)(B) and (C) of the RMA;
- permitted activity provisions in the Auckland Region Air Land and Water Plan (<5m^3/day);
- controlled activity provisions in the Auckland Region Air Land and Water Plan (<20m^3/day); and
- discretionary and higher ranked activity provisions in the Auckland Region Air Land and Water Plan (>20m^3/day).

The bore database contains 112 bores within a 2km radius of the indicative alignment, of these 112 private bores, only two are located within the calculated drawdown profile, as indicated in drawings ES-101 to ES-117.

Table 3 summarises the key details of these bores, and indicates the following key observations that:

- All of the private bores are small diameter (100mm) and deep (between 160-200m), suggesting the shallow aquifer has very low permeability and that depth was required to gain permeability and hence groundwater yield;
- The surficial drawdown indicated in bore 828 is 0.5m or less, and since this bore is so deep and has a large bore water column to obtain water from beneath the extent of the cut, the impact on its ability to supply groundwater for stock and domestic purposes will be less than minor; and
- The predicted drawdown at bore 22861 is < 0.5m as this bore is located in the vicinity of the large cut at Billings Road. However, this property and bore have been purchased by the NZTA, hence the bore will no longer be used for a domestic water supply.

Table 3: Details of bores located within predicted drawdown profile

AC bore ID	Owner	Purpose	Bore details	Estimated drawdown (m)
828	C Brown	Stock and domestic supply	Diameter: 100mm Bore Depth: 160m Casing Depth: 50m	0.5
22861	Boys to Men Trust	Domestic Supply	Diameter: 100mm Bore Depth: 200m Casing Depth: 80m	< 0.5m (located in cut)

4.4 Potential stream baseflow reduction

We assessed the reduction in groundwater contributions to local streams (stream baseflow reduction) as a result of the Project through the use of a calibrated numerical groundwater model, as described in the Groundwater Modelling Report.

As indicated in Table 4, we calculated stream baseflows under natural conditions in the proposed designation to range from 0.03 to 7.29 L/s. These flow rates range from a trickle or a 15% of a typical garden hose (0.2 L/s) to roughly a third of a fire hydrant (20 L/s), respectively. The absolute magnitude of reduction in baseflows is from 0.0007 L/s to 0.11 L/s.

Stream order, as defined in the national stream classification system developed by NIWA, reflects the scale of flow with low orders being smaller streams with less baseflow and higher orders being larger streams. Stream orders in the Project area range from 1-4.

Table 4 shows that lower order streams (i.e. smaller streams with less baseflow) are impacted more significantly by stream baseflow reduction (0.3 – 46.0% of flow) than higher order streams (0.1 to 2.4% of flow). However, flow in these lower order streams is small and hence the stream is likely to be a perennial wet area rather than a perennial stream. Furthermore, the absolute reduction in flow in L/s in these areas is also very small and unlikely to be detectable over and above the influence surface runoff generated flows may have.

We consider the reduction in baseflow as a result of the Project, from a flow volume perspective, to be less than minor, and the ecological significance of these reductions is discussed in the Freshwater Ecology Assessment Report.

Table 4: Modelled stream baseflow reduction

Stream chainage	Stream order	Baseflow (natural) (L/s)	Baseflow (with cut) (L/s)	Baseflow reduction (L/s)	Percentage decrease (%)
47400	1	0.10	0.10	0.01	6.3
47700	1	0.03	0.02	0.01	46.0
48000	2	0.66	0.62	0.04	5.9

Stream chainage	Stream order	Baseflow (natural) (L/s)	Baseflow (with cut) (L/s)	Baseflow reduction (L/s)	Percentage decrease (%)
49500	4	2.69	2.69	0.00	0.1
50800	1	0.06	0.05	0.01	16.3
52100	4	3.41	3.33	0.08	2.4
54700	4	7.29	7.18	0.11	1.6
55000	1	0.14	0.14	0.00	1.4
55300	2	0.53	0.50	0.03	5.2
56400	2	0.16	0.14	0.01	9.5
56700	2	0.30	0.26	0.04	12.9
58400	2	0.16	0.15	0.01	3.5
60200	3	1.18	1.17	0.00	0.4
61100	2	0.20	0.20	0.00	0.3
61300	1	0.04	0.04	0.00	2.4

4.5 Potential effects to groundwater quality

This section addresses the potential for groundwater quality impacts from groundwater disturbance. Other Further North reports address water quality outcomes from the disturbance of soils (Construction Water Assessment Report) and through stormwater movements (Construction and Operational Water Assessment Reports).

Groundwater quality may be impacted by the indicative alignment via the following mechanisms:

- ***Mobilisation of Metals*** - Change in the state of oxidation (redox characteristics) within the aquifer at the position of the new “drawn down” groundwater table resulting in the mobilisation of connate[7] metals from within the aquifer sediments- commonly seen as iron seeps or staining on cut exposures or drainage swales;
- ***Turbidity Production*** – any excavation of aquifer materials to beneath the groundwater table has the potential to increase the turbidity of groundwater;
- ***Reduced Assimilative Capacity*** - Reduction in stream baseflow may reduce the assimilative capacity of the streams exacerbating any water quality issues already occurring in streams; and

[7] Connate = trapped in sediment or rock at the time of deposition.

- *Shallow Aquifer Contamination* - Road runoff infiltration of the local groundwater system may contaminate shallow groundwater.

We consider all of the potential groundwater quality impacts identified above to be less than minor for the Project, primarily because of:

- the very slow groundwater flow rates in the Project area due to the low permeability of the Waitemata Group materials; and
- the very small volumes of water that will be diverted at the indicative cuts.

The following paragraphs provide specific commentary on each of the potential impacts identified above.

4.5.1 Mobilisation of Metals

As indicated in Section 3.10, iron is a common metal found in shallow groundwater within the Waitemata Group rocks. Where a water table fluctuates strongly or is dewatered, exposure of the aquifer material to oxygen has the potential to increase the solubility of iron in the rock, which when mobilised into solution, typically precipitates causing iron flocculation. This can leave an orange staining and sometimes scum on the ground surface where the water discharges. However, this is not toxic to humans or animals, but is more of a nuisance and aesthetic issue.

4.5.2 Turbidity Production

Groundwater discharging at the cuts will have low suspended solids because it is sourced from within sub-surface materials that naturally filter the water. However, after the groundwater has discharged it may come into contact with sediment that increases the turbidity. At this point, the groundwater is no longer groundwater and is considered part of the stormwater system. The impacts of turbid stormwater or high suspended solids in stormwater are discussed in the Construction Water Assessment Report.

4.5.3 Reduced Assimilative Capacity

As indicated in Section 4.4 reduction in stream baseflow volumes are expected to be less than minor, therefore the assimilative capacity of these streams will not be impacted by groundwater diversions.

4.5.4 Shallow Aquifer Contamination

There is no potential to contaminate the shallow aquifer from changes to the groundwater regime itself, because the lowering of the groundwater table through Project excavations will result in outward pressure or discharge, rather than the potential for water to re-infiltrate the shallow groundwater system.

4.6 Potential of construction effects on groundwater

Generally, temporary effects to groundwater from construction activities relate to diversion of groundwater during excavation of the cuts, and potential groundwater quality impacts due to discharges of water with high sediments loads.

Impacts from diversion of groundwater with respect to groundwater level (drawdown), neighbouring bore users, and stream baseflows are discussed in Sections 4.2 to 4.4. Our data analysis focused on the long-term impact and indicated that was less than minor in all cases. Therefore, we consider any temporary impacts, which are expected to be even less than the long-term impacts will be less than minor.

It is unlikely that surface discharges of suspended solids from the construction phase of the indicative alignment could affect groundwater quality in this aquifer at any substantial distance from any works, because the rock is of such low permeability that surface discharges are more likely to runoff than enter the groundwater system. In this regard, we consider the risk of impacts on groundwater quality to be less than minor, provided that run-off from construction materials and storage areas is not directed to any form of soakaway or ground disposal.

To ensure prevention of this, we recommend that any stormwater ponds that are placed in areas where there is downward pressure gradients (i.e. elevated topographic areas) should have a clay liner or synthetic liner with a transmissivity (liner thickness times the material hydraulic conductivity) of $1x10^{-9}m^2/s$ or less. In wetland areas, there is no need for a liner as groundwater flow potential is upwards towards the surface and hence providing hydrogeological security from surface contamination.

4.7 Potential operational effects on groundwater

As indicated in Section 4.4, long-term groundwater diversion volumes are very small and hence we consider the resulting potential stream baseflow reductions to be less than minor. However, during operation of the road, any groundwater diversions will be contained within the Project's surface water drainage system and subsequently discharged to downstream surface water bodies. As groundwater flows to these downstream discharge areas naturally, no significant impact is likely.

Water Quality – the only effective risk to groundwater is likely to arise from major spills of potential contamination from vehicles. We consider this risk to be very low based on the likelihood of this event occurring, the surface water containment system of the Project, as well as the low permeability of the aquifer.

4.8 Mitigation measures and monitoring

We do not consider any mitigation or monitoring is necessary for groundwater impacts from the Project because of the very low likelihood of any significant impacts, the fact that there are no affected parties, and that any diversions are to be routed through the Project's stormwater system and will be discharged back into natural watercourses.

5. Conclusions and recommendations

The hydrogeological regime of the Project area comprises very low permeability rocks with no appreciable shallow aquifers within the depth range of Project excavations (60m). Most bores in the area are greater than 150m in depth and provide only very small yields (< 1 L/s).

The most significant hydrogeological potential impact from the Project is the reduction in stream baseflows or groundwater flows to wetland areas. However, because of the very low permeability rocks encountered in the Project area, groundwater flow rates are very low and we have assessed impacts to these water courses, which would only be experienced during drought anyway, as less than minor.

No impacts on existing groundwater users, groundwater quality impacts or construction and operational impacts are expected due to the following reasons:

- Very low permeability and hence flow rates of the rocks; and
- The surface water containment system will deal with any groundwater diversions and discharge them back into natural water courses.

We do not consider any mitigation or monitoring is necessary for groundwater impacts from the Project, which as stated above are considered less than minor.

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Appendix A. Exploratory borehole details

Table A1: Borehole details

Borehole ID	Size	Depth (m)	Easting (m)	Northing (m)	Elevation (mRL)
BH201	PQ	30.0	5956445.1	1749928.1	44.49
BH202	PQ	18.0	5956450.0	1749894.5	46.59
BH204	HQ	30.0	5958096.3	1749385.6	62.27
BH205	HQ	30.0	5958887.5	1749277.9	57.69
BH206	HQ	25.0	5959463.5	1748736.9	70.13
BH207	HQ	14.8	5960372.1	1748354.9	44.23
BH208	HQ	15.0	5961018.1	1747785.7	104.42
BH209	HQ	30.0	5961367.8	1747359.4	158.66
BH210	HQ	30.0	5962171.5	1746845.4	176.51
BH212	HQ	25.0	5962265.6	1746346.6	223.74
BH213	HQ	19.0	5962620.1	1746284.7	234.33
BH214	HQ	40.0	5962683.3	1746353.8	223.68
BH215	HQ	49.5	5963356.2	1746429.9	212.72
BH216	HQ	35.0	5964058.1	1746576.3	161.75
BH217	HQ	60.0	5965067.4	1746835.4	169.91
BH218	HQ	40.0	5966434.3	1746680.4	98.37
BH219	HQ	35.0	5966410.1	1746577.0	111.60
BH220a	HQ	10.3	5966634.3	1746641.2	97.02
BH220b	HQ	35.0	5966634.3	1746641.2	97.02
BH221	PQ	30.0	5967394.3	1746406.5	120.39
BH222	HQ	20.0	5968003.0	1746518.1	74.00
BH223	PQ	30.0	5968445.8	1746457.4	82.22
BH224	HQ	20.0	5969058.3	1746337.8	34.68
BH225	PQ	15.0	5969452.0	1746146.5	38.64
BH226	PQ	15.0	5970397.2	1746487.6	59.37
BH227	HQ	18.09	5971035.7	1746948.3	33.43
BH228	HQ	19.51	5967056.5	1746563.8	47.79

Appendix B. Piezometer Construction & Groundwater Level Details

The Further North piezometers were constructed according to the following specifications:

- Casing was either 25, 32 or 50mm internal diameter PVC with self-sealing flush joints;
- The screened sections comprised 1mm machine slotted with an end cap at the base of each piezometer;
- A geotextile filter sock was wrapped around each screen;
- Filter pack (2mm diameter sorted quartz gravel) was placed to at least 1m above the top of the screen;
- At least 300mm of quartz blinding sand was placed above the gravel pack;
- A minimum of a 1m granular bentonite (10mm) seal was installed above the blinding;
- The remainder of the annulus was backfilled with drill cuttings or similar material; and
- A 1m surface bentonite seal was installed.

Table B1: Piezometer installation details and groundwater levels

Borehole ID	Piezometer ID	Ground elevation (mRL)	Depth to bottom of screen (m)	Screen length (m)	Aquifer type	Groundwater level (27 June 2013)	
						Static level (mBGL)	Static level (mRL)
BH201	201a	44.49	7.0	3	Waitemata	Dry	Dry
	201b		21.0	6	Waitemata	11.32	33.17
BH204	204	62.27	13.0	3	Waitemata	8.18	54.09
BH205	205	57.69	30.0	3	Waitemata	29.31	28.38
BH206	206a	70.13	10.0	3	Waitemata	Dry	Dry
	206b		25.5	3	Waitemata	24.03	46.1
BH207	207	44.23	14.6	6	Allocthon	2.43	41.83
BH208	208a	104.42	8.8	3	Waitemata	6.49	98.23
	208b		13.2	3	Waitemata	8.15	96.28
BH209	209a	158.66	9.7	3	Waitemata	Dry	Dry
	209b		30.0	3	Waitemata	29.45	129.21
BH210	210	176.51	30.0	6	Waitemata	28.10	148.41
BH212	212	223.74	25.0	6	Waitemata	13.57	210.17
BH213	213a	234.33	14.6	3	Waitemata	Dry	Dry
	213b		19.0	3	Waitemata	Dry	Dry
BH214	214a	223.68	32.0	3	Waitemata	20.82	202.86
	214b		40.0	3	Waitemata	31.12	192.57

Borehole ID	Piezometer ID	Ground elevation (mRL)	Depth to bottom of screen (m)	Screen length (m)	Aquifer type	Groundwater level (27 June 2013)	
						Static level (mBGL)	Static level (mRL)
BH215	215a	212.72	31.5	3	Waitemata	24.31	188.41
	215b		45.0	3	Waitemata	26.17	186.56
BH216	216	161.75	34.0	6	Waitemata	21.35	130.40
BH217	217a	169.91	11.0	1.8	Waitemata	3.29	166.62
	217b		30.4	6	Waitemata	23.82	146.10
	217c		60.0	6	Waitemata	45.34	124.37
BH218	218	98.37	40.0	6	Waitemata	11.72	86.65
BH219	219	111.60	35.0	3	Waitemata	32.06	79.54
BH220	220a	97.02	10.0	3	Waitemata	8.56	88.46
	220b		35.0	6	Waitemata	21.38	72.74
BH221	221a	120.39	23.8	6	Waitemata	13.66	106.73
	221b		30.0	3	Waitemata	15.44	104.95
BH222	222	74.00	20.0	6	Waitemata	12.63	61.37
BH223	223	82.22	30.0	6	Waitemata	18.07	64.15
BH224	224a	34.68	3.8	3	Alluvium	0.24	34.44
	224b		15.0	6	Alluvium	0.43	34.25
BH225	225	38.64	10.8	6	Waitemata	3.10	35.54
BH226	226	59.37	8.3	3	Waitemata	Dry	Dry
BH227	227a	33.43	2.4	1	Alluvium	1.36	32.07
	227b		14.0	3	Alluvium	1.08	32.35
BH228	228	47.79	11.0	6	Waitemata	4.45	43.34

Table B2: Summary of Vertical Pressure Gradients

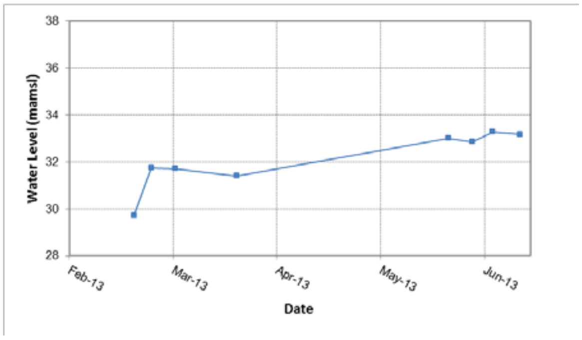
Bore	Aquifer type	Shallow piezometer		Deep piezometer		Vertical pressure gradient
		Screen bottom (mBGL)	Static GWL (mRL)	Screen bottom (mBGL)	Static GWL (mRL)	(m/m)[1] [h/L]
201	Waitemata	7.0	Dry	21	33.17	N/a
206	Waitemata	10.0	Dry	25.5	46.1	N/a
208	Waitemata	8.8	98.28	13.2	96.23	-0.46 [-2.05/4.4]
209	Waitemata	9.7	Dry	30.0	129.21	N/a
213	Waitemata	14.6	Dry	19.0	Dry	N/a

Bore	Aquifer type	Shallow piezometer		Deep piezometer		Vertical pressure gradient
		Screen bottom (mBGL)	Static GWL (mRL)	Screen bottom (mBGL)	Static GWL (mRL)	(m/m)[1] [h/L]
214	Waitemata	32.0	202.86	40.0	192.57	-1.28 [-10.29/8.0]
215	Waitemata	31.5	188.41	45	186.56	-0.14 [-1.85/13.5]
217	Waitemata	11.0	166.62	60.0	129.98	-0.75 [-36.64/49]
220	Waitemata	10.0	88.46	35.0	72.74	-0.63 [-15.72/25]
221	Waitemata	23.8	106.73	30.0	104.95	-0.29 [-1.78/6.2]
224	Alluvium	3.8	34.44	15	34.25	-0.02 [+0.19/11.2]
227	Alluvium	2.4	32.07	14	32.55	0.04 [0.48/11.6]

Note: 1. A positive pressure gradient indicates upward flow potential. The larger the value the stronger gradient and hence flow potential.

Appendix C. Groundwater level plots

201b



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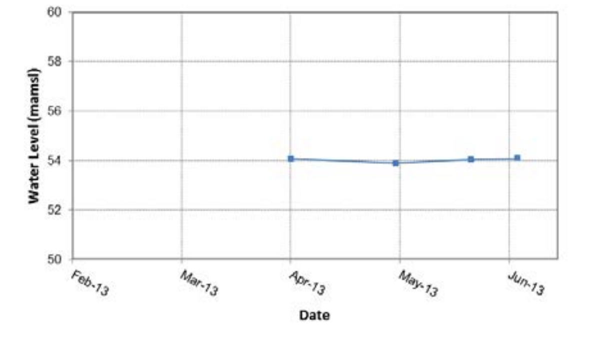

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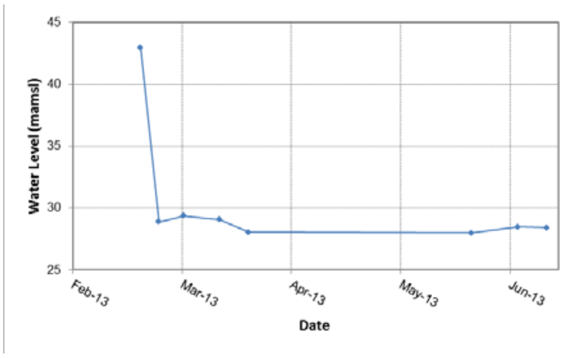

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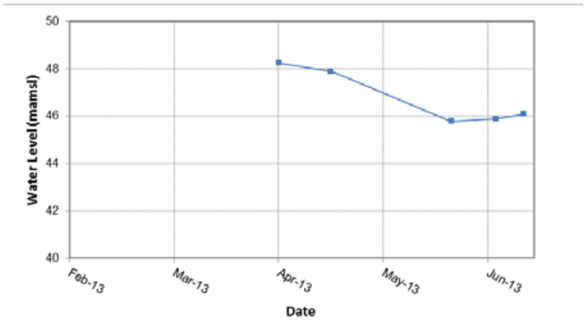

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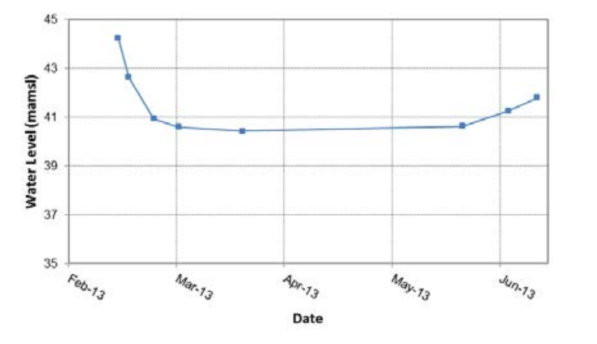

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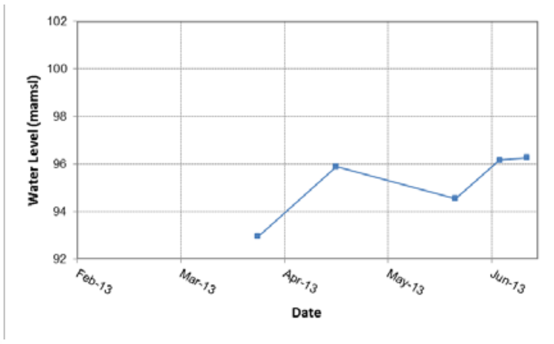

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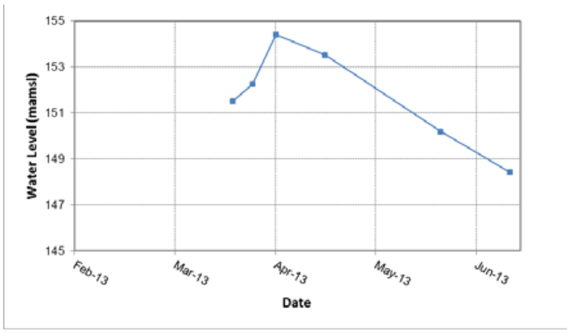

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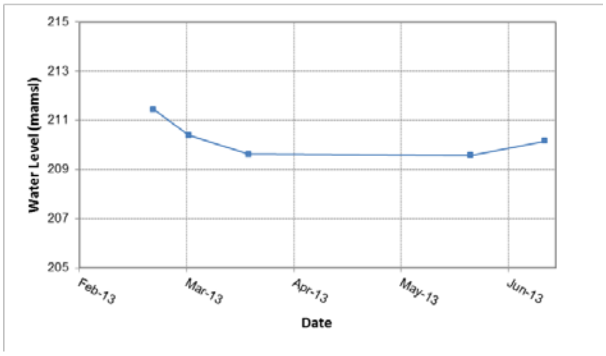

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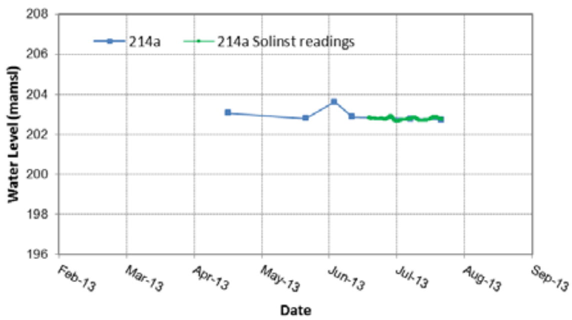

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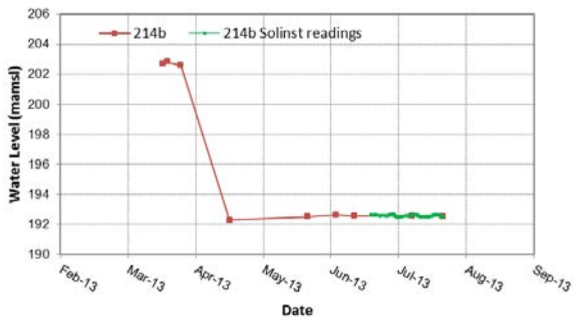

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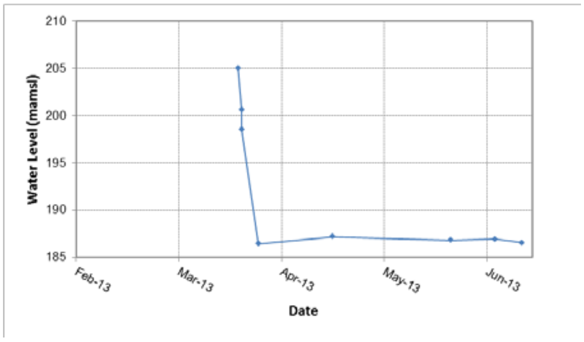

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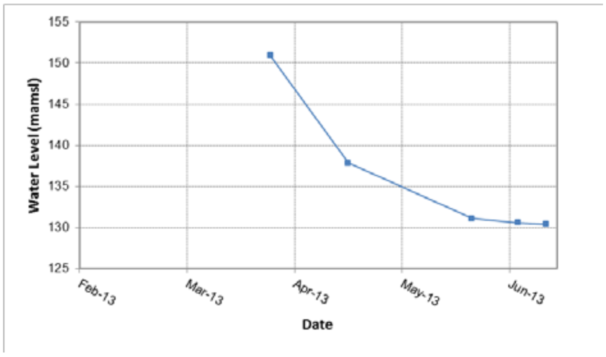

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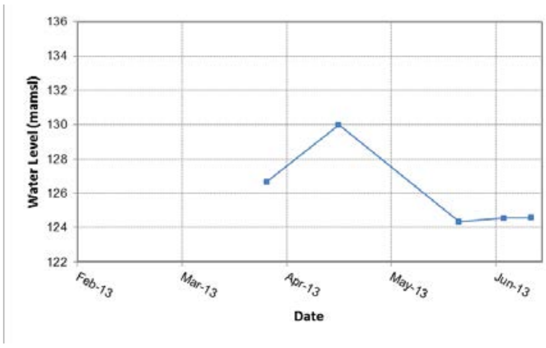

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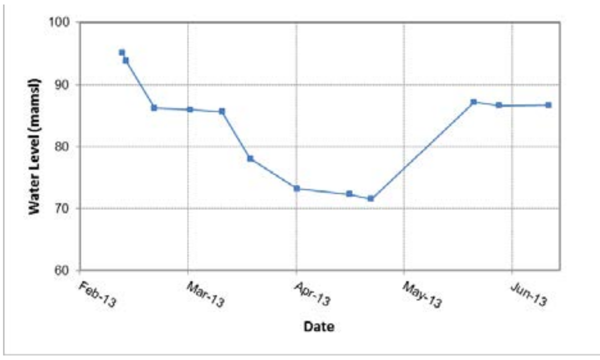

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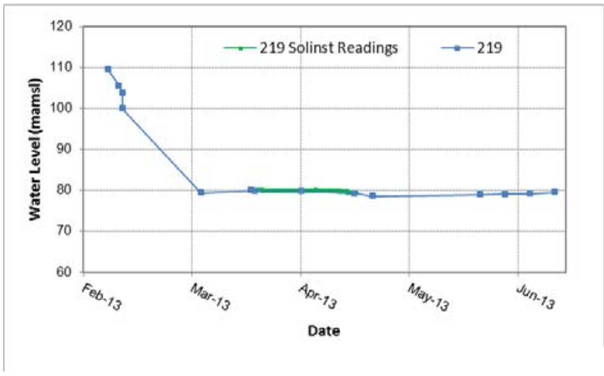

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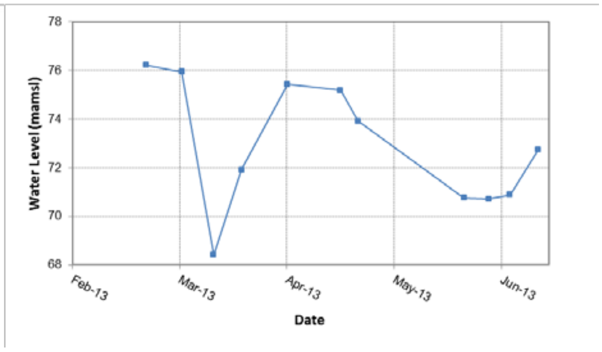

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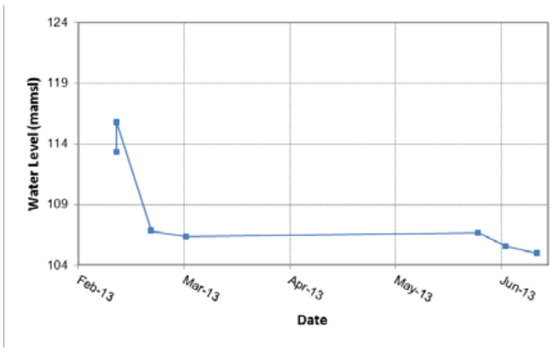

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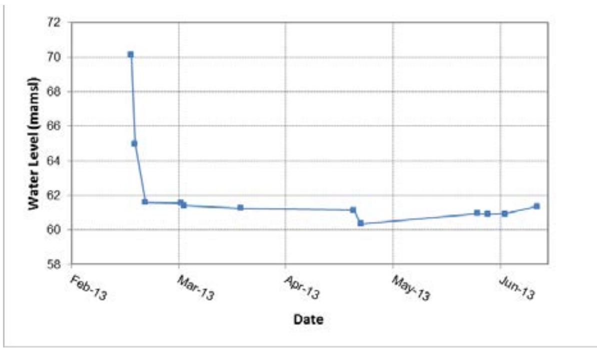

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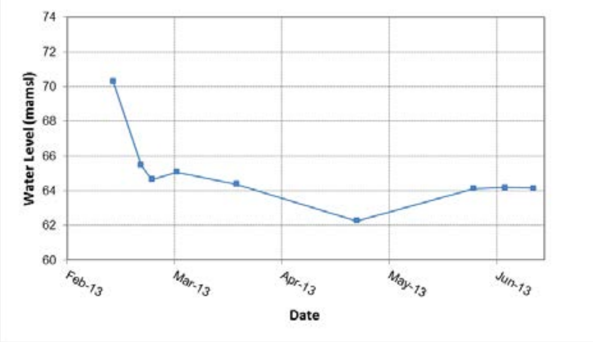

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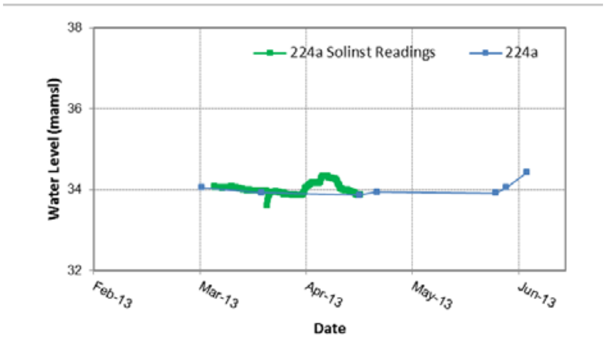
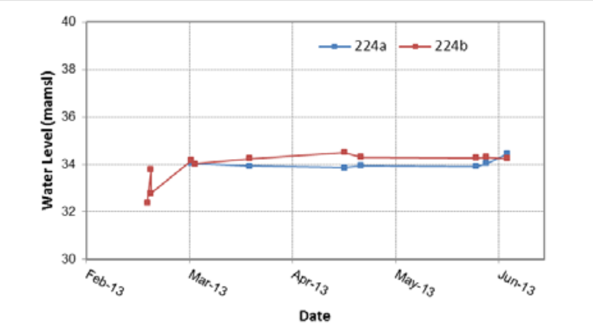


224a and b



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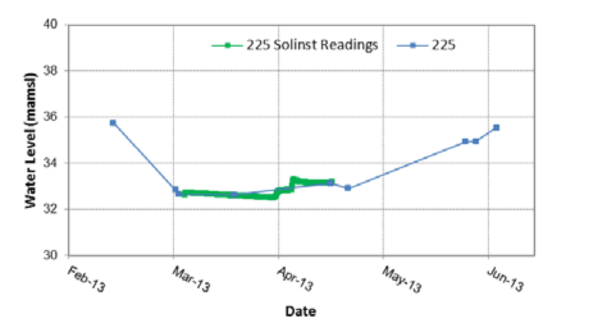

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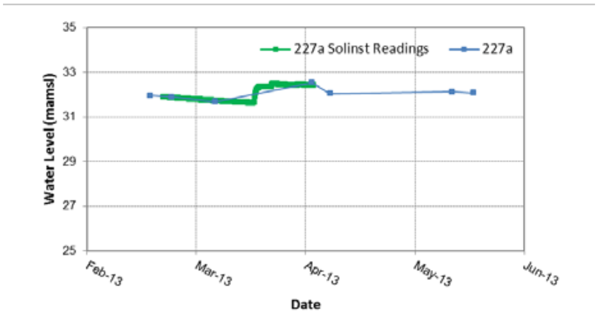

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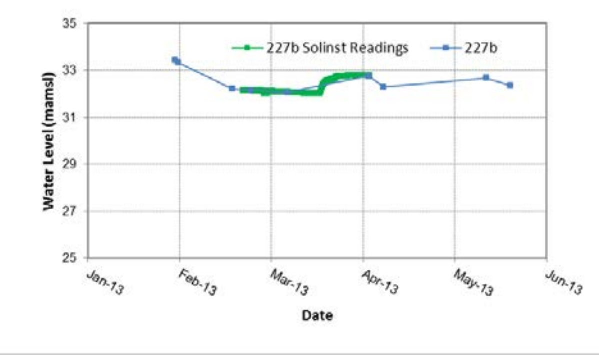

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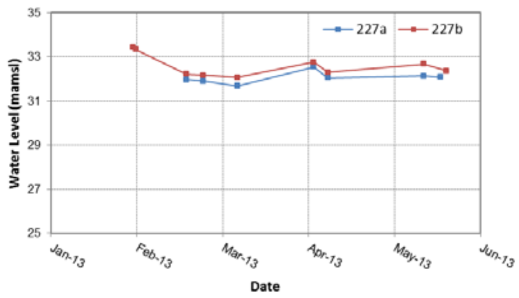

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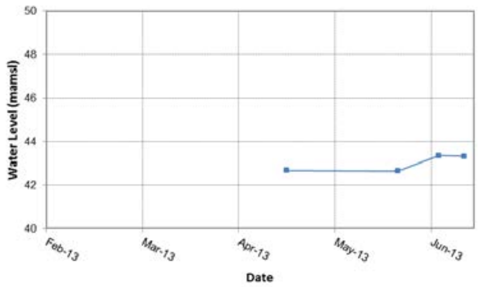

Appendix D. Falling and rising head permeability tests

Table D1: Falling head testing results.

Piezometer ID	Aquifer type	Falling head test K (m/s)	Rising head test K (m/s)
201b	Waitemata	$1.73x10^{-8}$	$<1x10^{-7}$ *
207	Waitemata	$<1x10^{-7}$ *	$<1x10^{-7}$ *
214a	Waitemata	$2.77x10^{-7}$	-
214b	Waitemata	$3.38x10^{-7}$	-
218	Waitemata	$1.53x10^{-9}$	-
219	Waitemata	$1.17x10^{-8}$	-
220	Waitemata	$2.64x10^{-9}$	$2.10x10^{-9}$
222	Waitemata	$1.22x10^{-9}$	-
223	Waitemata	$1.98x10^{-9}$	$2.87x10^{-9}$
224a	Alluvium	$9.91x10^{-9}$	-
224b	Alluvium	-	$2.10x10^{-9}$
225	Waitemata	$3.85x10^{-7}$	-
227b	Alluvium	$3.05x10^{-8}$	$2.95x10^{-8}$

Notes: * = Recovery was unmeasurable or did not reach 37% recovery (required for Hvorslev calculation) over the monitoring period.
- = Not performed

Table D2: Packer Testing Results.

Borehole ID	Geology	K (m/s)
215	Fracture Zone	3.09×10^{-6}
215	Waitemata Group	8.4×10^{-7}