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Marlborough District Council
PO Box 443
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Attention: Peter Davidson

Dear Peter

Coastal Wairau Plain, Marlborough piling, excavation and foundation review

Introduction

Background

Marlborough District Council (MDC) is evaluating issues and options relating to improving regulatory management of construction activities of deep structures which interact with the leaky-confined aquifer(s) of the Wairau Plains, Havelock and across the Marlborough District, which rely on maintaining natural artesian pressures to support groundwater dependent environments and groundwater abstraction. MDC wish to identify potential activity rules to incorporate into the Proposed Marlborough Environmental Plan (pMEP).

The construction of foundations for bridges, wharves and large buildings/structures has the potential to generate uncontrolled leakage of naturally pressurised groundwater, and/or allow transmission of contaminants into the aquifer. Contaminant transport and or leakage could develop via preferential pathways created by the construction of deep geotechnical excavations, such as piles. There is a precedent for regional councils in New Zealand to have activity rules relating to the control of excavations over or into aquifers which generally aim to assess and manage any potential adverse effects associated with water leakage and/or contamination.

Scope

MDC have engaged Beca Limited (Beca) to undertake a desktop review consisting of two stages.

Stage 1 consists of a review of existing regional and unitary plans for those areas with similar hydrogeological environments to the Wairau Aquifer System, or other confined aquifers in the Marlborough Region. The council plans which are included in this review are Canterbury Regional Council (Environment Canterbury), Greater Wellington Regional Council, Auckland Council, Bay of Plenty Regional Councill, Waikato Regional Council (Environment Waikato) and Tasman District Council.

Stage 2 involves seeking specialist geotechnical advice from engineers working in the bridging and foundation fields to identify if there are more modern approaches or systems that should be specified other than those used in existing regional council plans across New Zealand.

This letter addresses both stages 1 and 2 of the desktop review.

Geotechnical structures of potential concern

Geotechnical structures, ground improvement, or deep excavations that intercept groundwater have the potential to form preferential pathways between aquifers, and/or with the surface. Piles are generally installed to a depth where suitable bearing is encountered which depend on a complex interplay between the structural engineering design and ground conditions. Generally the gravel units which form aquifer units are suitably dense to found piles or other load bearing structures on. Ground improvement is typically completed to such depths to create a crust with sufficient bearing or resistance to liquefaction to prevent mass and/or differential movement under seismic loading, improve bearing capacity of the ground or control static settlement risk.

Potential preferential pathways may include leakage post construction via the perimeter surface of a pile (soil/pile interface), development of a void between pile and soil during construction (annulus created due to over excavation, creating a void or lateral loading or vibration of pile creating a void), or disturbance of the soil during construction (e.g. loosening or creation of defects, or drawing down soils at pile interface). Or more rarely via the pile interior, should significant degradation of the pile material occur (e.g. via air gaps within poured concrete, shrinkage cracks or degradation of pile material with time).

Pathways during construction may also provide direct connection between aquifers and surface via excavations such as deep open-holed or cased bores, albeit that this can be managed if adequately identified prior to works commencing and / or suitable controls are put in place. This is typically managed through use of drilling fluids (muds), by extending casing height above ground, by using cut off structures such as sheet piles, or by dewatering to control artesian pressures and manage any connection between surface and the deep strata.

Whilst there is a vast array of possible structures which could be constructed, the main geotechnical structures of potential concern include piles, and deep ground improvement. There are numerous methodologies for the construction of piles and for deep ground improvement, including driven piles, bored piles, screw piles, in-situ mixed piles, diaphragm walls, vibro-replacement (i.e. stone columns) and pore pressure release elements (e.g. wick drains). These structures/elements and methodologies are described, and their respective risks of developing preferential pathways in Stage 2 of the review.

Water bores, and investigation boreholes are also of potential concern, although outside the direct scope of this review, as they often form a direct pathway between the surface and deep strata and groundwater they intercept. Poorly constructed bores, or abandoned and unsealed bores pose a high risk of developing preferential pathways for groundwater leakage and/or contaminant transport between surface and aquifers.

Bore head construction, bore management and abandonment procedures are provided in NZS 4411:2001, and for drinking water supplies in the drinking water standards (current and proposed). Bores and investigation bores should be constructed and managed in accordance with these standards to mitigate the risk of preferential pathway development. Some forms of piles such as bored piles and driven piles exhibit some similar construction methodologies and performance characteristics to bores, with measures to control leakage and connections within the groundwater system correspondingly similar to bores for these pile types.

Marlborough groundwater

The Marlborough region has a number of groundwater aquifers, which are used as valuable freshwater reservoirs. The aquifers are used for drinking water supply, for irrigation, for commercial and industrial use as well as for domestic water supplies, and stockwater supplies. The largest groundwater reservoir is the aquifer system of the Wairau Plains. This is an alluvial sequence of unconfined to leaky confined aquifers hosted in alluvial gravels and interspersed by marine clays which act as aquitards and provide confinement near the coast (Davidson & Wilson, 2011)[1].

The Wairau Plains Aquifers include, the Wairau Aquifer, in addition to alluvial fan aquifers and tributary aquifers, such as the Omaka and Brancott Aquifers shown in Figure 1.

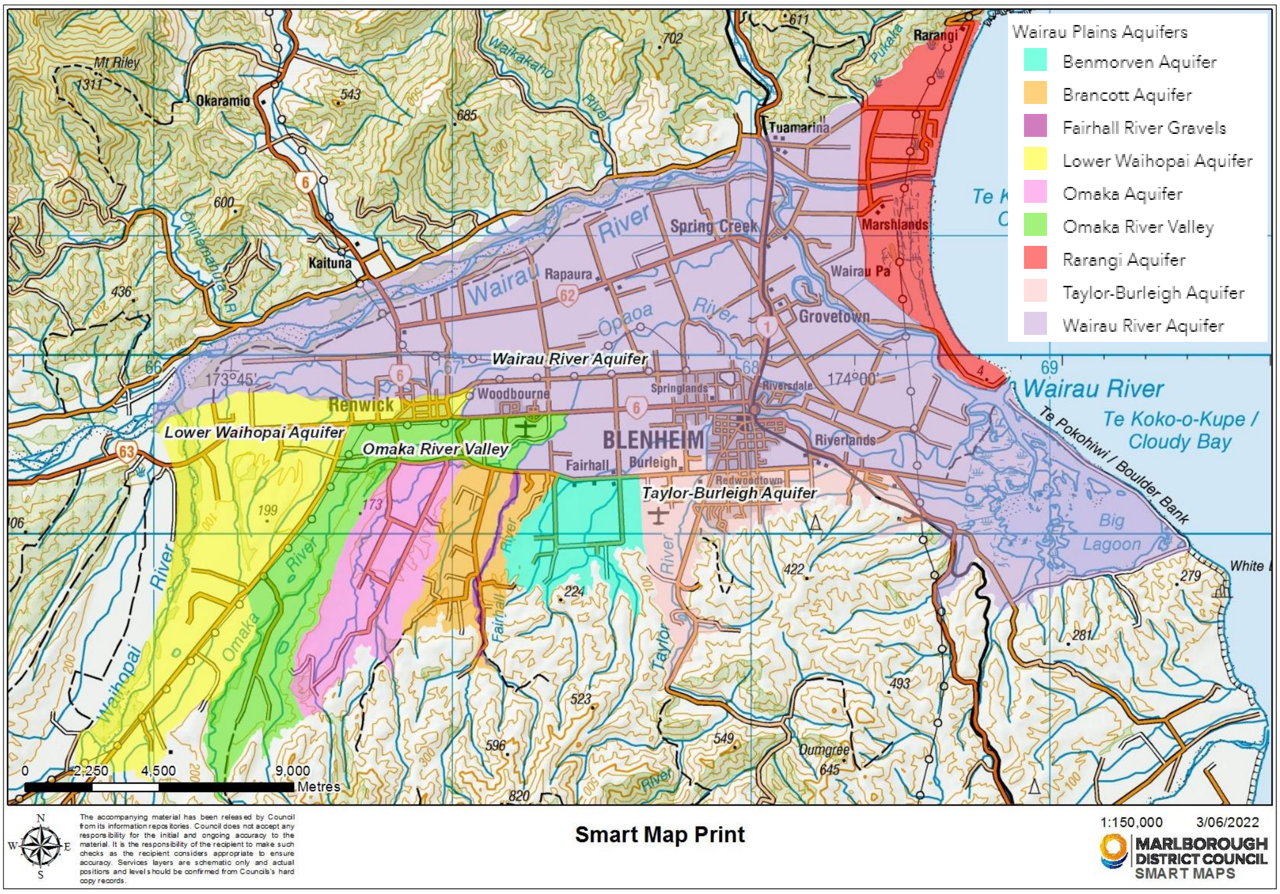

Figure 1: Schematic map defining Wairau Plains Aquifers (Source: MDC Smart Maps, 3 June 2022).

The Wairau Aquifer is the largest aquifer of the Wairau Plains, and it becomes leaky-confined about 8 km from the coastline, and confined from about 5 km (Figure 2). The aquifer is found from ground level to an unspecified depth in the upper plains, and at approximately 20 – 50 m depth at the coastal margin. It is overlain by the confining Dillons Point Formation. Artesian pressures can be up to 4 m above mean sea level at the coast (as measured at Well 1733[2]).

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[1] Davidson, P. & Wilson, S. (2011). *Groundwaters of Marlborough*. Marlborough District Council.

[2] https://www.lawa.org.nz/explore-data/marlborough-region/water-quantity/groundwater-zones/wairau/1733-bar-well

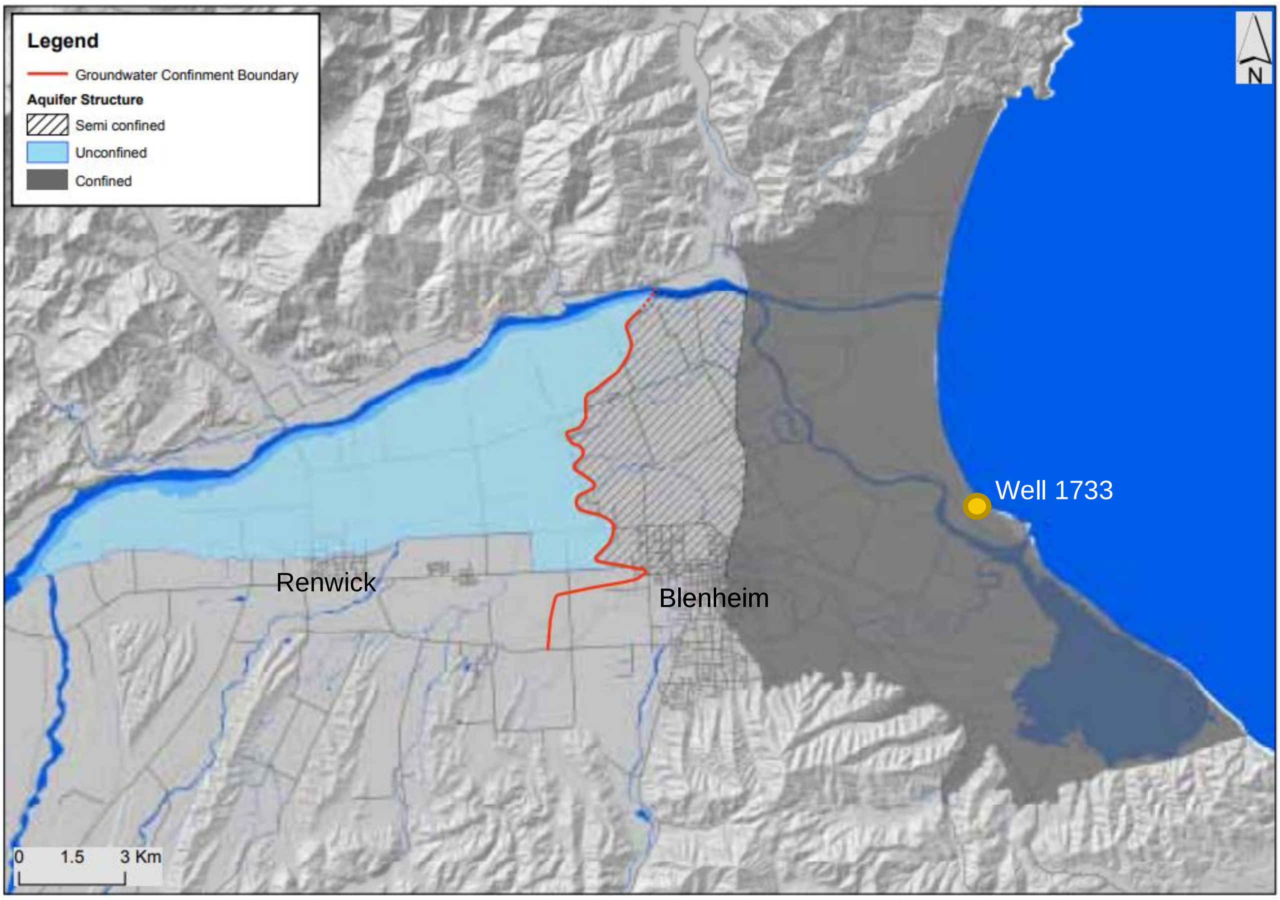

Figure 2: Confinement of Wairau Plain Aquifer (source: Groundwaters of Marlborough, 2011)

Leaky confined alluvial aquifers are also present elsewhere in Marlborough including in the Pelorus River Valley, the Kaituna Valley (near Havelock) and potentially in the Rai Valley. These aquifers are hosted within heterogenous alluvial gravel units, typically overlain by marine silts and clays which provide confinement. The Kaituna Valley Aquifer is hosted within the Pleistocene Havelock Gravels typically within 20 m of the surface, and is used for municipal supply for Havelock township, in addition to domestic supply and irrigation.

Any of these alluvial aquifers may be suitable to found deep geotechnical structures into and could be addressed by the proposed activity rule.

Stage 1 – Review of NZ regional council activity rules

Proposed Marlborough Environment Plan (pMEP) (current)

Deep geotechnical excavations or structures are not currently addressed directly in the pMEP, and the pMEP does not allow any council discretion over the management of the potential adverse effects on the environment due to leakage or transport of contaminants that may occur during construction and the lifetime of these deep geotechnical structures.

Water bores, and geotechnical bores, which pose similar environmental risks, are considered in Rules 3.3.18 and 3.3.19, although we note that this could be further standardised by reference to the NZS 4411:2001 to manage drilling, bore maintenance or abandonment in line with national standards.

The hydrogeology of the area is not explicitly defined in the Proposed Marlborough Environment Plan (pMEP), but instead any rules pertaining to the use of groundwater refer to the Freshwater Management Units (FMU). The Freshwater Management Units for the Wairau Plains is shown in Figure 3.

The FMU's are referred to within the pMEP to define groundwater related activities within these specific units, and refers to "confined layers" of specific FMU's. Confined layer is not explicitly defined within the pMEP, however, for the purposes of this review, we assume that "confined layer' refers to the gravel formation that hosts artesian groundwater, i.e. the confined aquifer.

The confined part of the Wairau Aquifer falls within the Wairau Aquifer FMU, the Riverlands FMU and potentially the Rarangi Shallow FMU but it does not extend across the full extent of any FMU. The confined aquifer near Havelock falls within the Kaituna FMU, Rai Valley within the Rai FMU and the Pelorus Valley aquifer within the Lower Pelorus FMU. The plan does not explicitly define the area(s) in which a confined layer or aquifer is present, nor does it distinguish between leaky-confined, confined and flowing artesian confined aquifers.

The pMEP also defines groundwater protection zones, which are zones of influence around potable supply takes. Additional restrictions may apply within these zones.

Deep geotechnical excavations and deep geotechnical structures/elements are not covered by any existing definition within the pMEP. The following terms are defined (bore, excavation and land disturbance activity), which are similar to, but exclude deep geotechnical activities.

Bore: means a hole in the ground constructed for the purpose of:

- investigation or monitoring conditions below the ground surface; or
- abstraction liquid substances from the ground; or
- discharging liquid substances into the ground,

but excludes test pits and soak holes.

Excavation: means to dig out soil or natural material from the ground such that the surface contour of the land is permanently altered.

Land Disturbance Activity: means any activity that includes excavation, filling, cultivation or vegetation clearance.

To adequately address the potential adverse environmental effects from deep geotechnical activities and structures, the pMEP will need to define deep geotechnical activities and structures and clarify hydrogeological definitions and potentially the existing zones before an activity rule can be finalised.

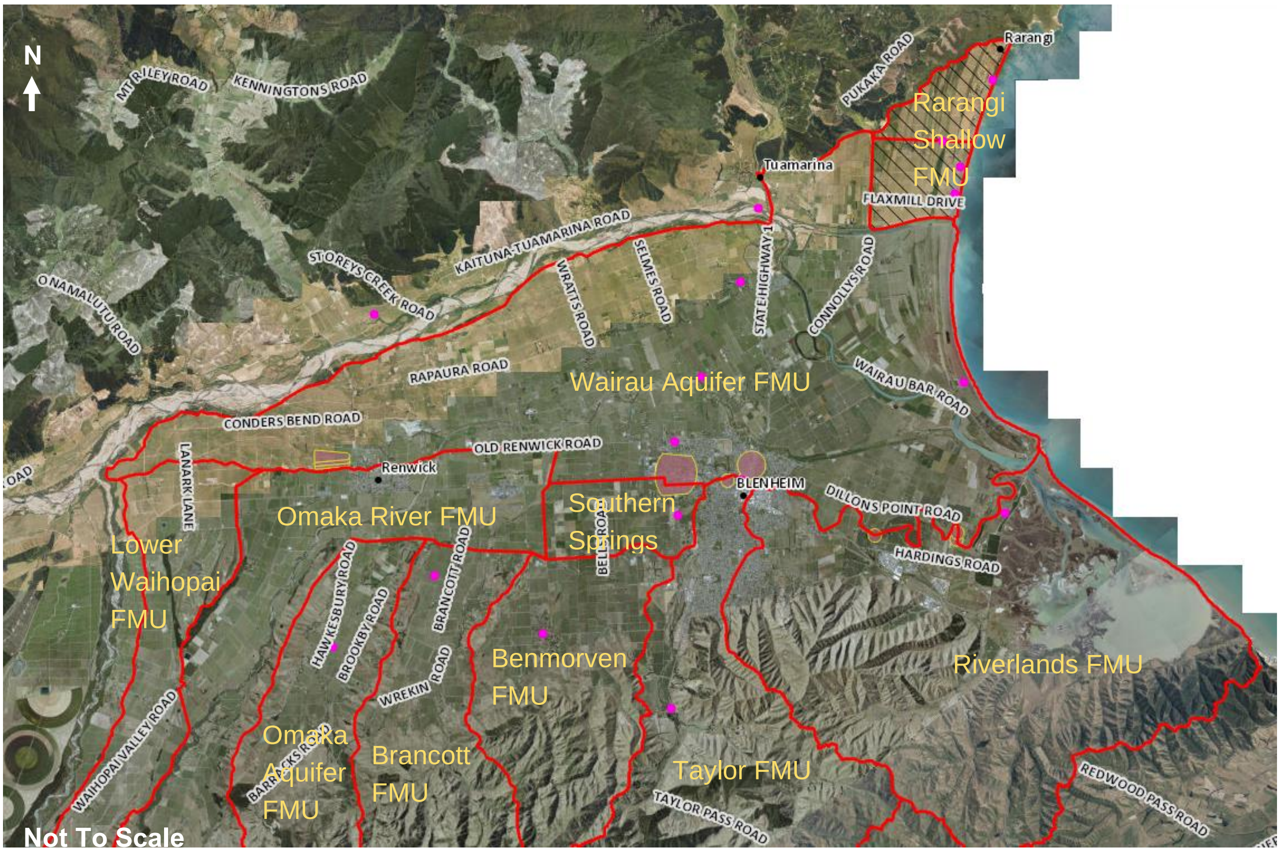

Figure 3: Freshwater Management Units (FMU) and groundwater protection zones (yellow/pink polygons) as per the pMEP.

Review of regional council activity rules outside Marlborough Region

This review focuses on those regional councils which manage aquifer systems similar to those in Marlborough. The regional plans which we have reviewed include those of Canterbury Regional Council (Environment Canterbury), Greater Wellington Regional Council, Auckland Council, Bay of Plenty Regional Councill, Waikato Regional Council (Environment Waikato) and the Tasman District Council.

Each council addresses the management of the potential risk from deep geotechnical excavations in a different manner. There are very few regional councils that have activity rules that address the risk from deep geotechnical excavation directly, with the exceptions of Environment Canterbury and Greater Wellington Regional Council which limit deep excavations over particular planning zones that delineate confined aquifers. These are the most useful activity rules for MDC to consider further, as they provide council discretion over deep geotechnical structures and excavations directly, provide a depth limit and indicate the risks intended to be managed.

Bay of Plenty Regional Council and Environment Waikato (BOPRC) have activity rules for drilling that encompass most bored piling techniques, however, planners from BOPRC have indicated that piling is not an activity that is commonly consented under this rule. Environment Waikato has issued resource consents for bored piling into artesian aquifers in accordance with their activity rules, and an example is attached (Attachment 1), along with a piling methodology and management plan prepared as per the consent conditions for council review.

Auckland Council have no specific activity rules to address deep geotechnical structures, but their dewatering activity rules require consent for large deep excavations. Tasman District Council activity rules do not appear to address piling or other deep geotechnical excavation or construction.

A summary of the most relevant activity rules from each regional/unitary council is included in Table 1.

Table 1: Summary of relevant Rules from regional plans that address, or partly address the management of deep geotechnical excavations.

Regional Council	Plan / Rule	Rule (relevant text only)	Comments
Environment Canterbury (Canterbury Regional Council)	Land and Water Regional Plan (LWRP) Also see ECan memo titled "Canterbury Land and Water Regional Plan (LWRP) – Aquifer 1"	**Rule 5.175(a)** *"The use of land to excavate material over the Coastal Confined Gravel Aquifer System is a permitted activity, provided there is more than 1m of undisturbed material between the deepest part of the excavation and Aquifer 1; and if more than 100m^3 of material is excavated, the excavation does not occur within 50m of any surface waterbody."* **Rule 5.176** *"The use of land to excavate material that does not comply with one or more condition of Rule 5.175 is a restricted discretionary activity The exercise of discretion is restricted to the following matters:* *1. The actual and potential adverse environmental effects on the quality of water in aquifers, rivers, lakes, wetlands; and* *2. Any need for remediation or long-term treatment of the excavation; and* *3. The protection of the confining layer and maintaining levels and groundwater pressures in any confined aquifer, including any alternative methods or locations for the excavation; and* 4. *The management of any exposed groundwater."*	• Piling into a confined aquifer is likely to be classified as a restricted discretionary activity. • Provides council control/discretion over 'potential contaminant pathways, accidental "spring" discharges and unpermitted dewatering takes associated with any excavation that has depth within 1m of Aquifer 1 . • Allows council discretion over potential adverse effects from piling and other deep geotechnical excavations. • Some local disagreement over the definition of "Aquifer 1", with ECan publishing a memo clarifying that they apply this definition to the water table within the Coastal Confined Gravel Aquifer System. • Piling activities in the area are often not consented, with poor awareness throughout the industry of consenting requirements.
Greater Wellington Regional Council	Proposed Natural Resources Plan (PNRP)	**Rule R146A** *"The use of land within a community drinking water supply protection area and the Hutt Valley Aquifer Protection Zone for the construction or removal of building foundations and earth retention structures or excavation (permanent or temporary) where the depth below the natural ground level exceeds 5m, including any associated* *a) diversion of water, or* *b) dewatering, or* *c) discharge of water and contaminants* *is a discretionary activity."*	• Deep geotechnical excavations into the Hutt Valley Aquifer Protection Zone are a discretionary activity. • Provides council control/discretion over deep geotechnical excavations to protect the confined Hutt Valley Aquifer, an important freshwater resource. • No region-wide rule, or rules for other confined aquifers.
Auckland Council	Unitary Plan	**Rule E7.6.1.10 Diversion of groundwater caused by any excavation (including trench) or tunnel** *"(1)(c) Piles up to 1.5m in external diameter are exempt from these standards;"* *"(2) Any excavation that extends below natural groundwater level, must not exceed:*	• Rule E7.6.1.10 is focussed on mitigation of potential effects from diversion of groundwater, however, provides discretion over deep geotechnical excavation activities. • Deep geotechnical excavations that have diameter greater than 1.5m, extend more than 6 m bgl and are also below groundwater level, or impedes the flow of

Regional Council	Plan / Rule	Rule (relevant text only)	Comments
		(a) 1ha in total area; and *(b) 6m depth below the natural ground level."* *"(4) Any structures, excluding sheet piling that remains in place for no more than 30 days, that physically impedes the flow of groundwater through the site must not:* *(a) impede the flow of groundwater over a length of more than 20m; and* *(b) extend more than 2m below the natural groundwater level.* *is a permitted activity."* *The diversion of groundwater caused by any excavation, (including trench) or tunnel that does not meet the permitted activity standards or not otherwise listed is a restricted discretionary activity.*	groundwater over a length of than 20m **and** extends more than 2m below the natural groundwater level is a restricted discretionary activity. • It is unclear whether the discretion of council is limited to assessment of the potential effects due to dewatering, or whether potential leakage and contaminant transport effects may also be considered. • Rules E7.6.1.16 to E7.6.1.20 cover risk of leakage between aquifers, leakage of groundwater to waste and risk of potential contamination pathway development for bores and drilled holes. • These rules do not appear to be applicable to deep geotechnical excavations or piles with small area, but do address the relevant potential effects.
Bay of Plenty Regional Council	Natural Resources Regional Plan	**Rule 40A Controlled – Drilling** *"The drilling of land, and associated discharge of drilling fluid, where the activity:* *(1) Does intercept a water table or aquifer; and,* *(2) Is not for the purpose of constructing a bore;* *Is a controlled activity."*	• Earthworks are covered in Rules 1, 1A, 1B & 1C, which do not consider potential effects on groundwater quantity or quality. Does consider earthworks activities in contaminated land. Does consider stormwater disposal. • Drilling of 'holes' is covered in Rules 40, 40A & 40B • The definition of bores is limited to structure/ holes in ground to access groundwater (and excludes piles) • . Bored piling is likely to be covered under rule 40A; however, it is not currently common practice to apply for consent to undertake this activity. • Driven piles are not covered under this rule.
Environment Waikato (Waikato Regional Council)	Waikato Regional Plan	**Rule 3.8.4.6 Permitted Activity Rule – Temporary Drilling Below the Water Table** *"The drilling of holes below the water table is permitted, subject to:* *(a) Holes drilled shall be sealed and abandoned within two days of completion of the drilling.* *(b) Holes drilled shall be at least 100m from any water supply well.* *(c) Holes drilled shall be sealed and managed such that leakage of water or contaminants to or from ground surface is prevented.*	• Drilling above the water table is a permitted activity by Rule 3.8.4.5. • Any piles that are 'sealed and managed such that leakage of water or contaminants to or from ground surface is prevented within two days of completion of drilling would be permitted under Rule 3.8.4.6. • Rule 3.8.4.7 addresses the risk of those deep geotechnical excavations that are undertaken by drilling methods (e.g. bored piles). • Does not address deep earthworks, driven, pushed or screwed structures where installation is not by drilling.

Regional Council	Plan / Rule	Rule (relevant text only)	Comments
		(d) Holes drilled shall be sealed and abandoned in a manner that prevents cross-contamination between different water bodies, or changes in water pressure" **Rule 3.8.4.7 Controlled Activity Rule – Drilling Below the Water Table** *"The drilling of holes/wells below the water table where not permitted by Rule 3.8.4.6 is a controlled activity subject to:* *(a) All drilled holes/wells shall be constructed, maintained and/or abandoned so that they shall not cause cross-contamination between hydraulic units (aquifers) in any water including groundwater and geothermal water.* *(c) All holes/wells shall be managed and maintained such that leakage of water or contaminants to or from the ground surface is prevented.* *(d) Materials used for well construction shall be of such quality and strength to enable the well to be completion without casing or seal leakage during construction or subsequent well operation.* **Drilling is defined as:** *"Any method (including percussion and washing) used to drill holes into land"*.	• Dewatering from excavations is considered separately under Rules 3.5.4.4, 3.5.4.5 and 3.5.4.6. • See example consent for construction of piles to support a bridge with piles into an artesian aquifer and technical letter demonstrating compliance (Attachment 1).
Tasman District Council	Tasman Resource Management Plan	**Rules 16.12.2.1 to 16.12.2.4 Bore Construction** **Rules 18.5.1 to 18.5.20 Land Disturbance**	• Requires that drilled bores are consented. • Does not appear to apply to piling or other deep engineered elements constructed below groundwater, with a focus on managed water resource and drawdown effects with defined 'water management zones'. • Specific zones are defined for confined aquifers. • Earthworks require consent where there is potential to negatively impact water bodies, although the intent appears to be restricted to surface water bodies. • No consideration of deep geotechnical excavations other than for 'quarrying' with area restrictions much larger than typically required for piling activities.

Stage 2 – Geotechnical Review

Geotechnical Structures: key factors contributing to groundwater vulnerability

Overview

There is a range of geotechnical excavation and structural elements that can extend deep into the ground, these are typically associated with piles, ground improvement and extensive and deep excavation. Table 2 provides description for a range of engineered elements extending deep into the ground, and provides high level commentary on the potential for development of preferential seepage pathways both during construction and long-term following installation. Each of the deep geotechnical excavations or structures discussed in Table 2 have several common factors which either worsen, or lessen the risk of creation of preferential pathways in the groundwater system. These include management during construction, quality assurance during construction, the local ground conditions, the method of installation (pre-excavated vs driven), cased versus uncased bores and whether the final structure is permeable or impermeable (e.g. wick drains versus steel or concrete piles).

Should MDC implement review of pile or deep engineered structure/element methodology as part of a proposed plan change, then these are the fundamental methodologies, and implications for potential preferential pathway creation that could be considered as part of drafting an activity rule and refinement of definitions.

Ground Conditions

The soil the geotechnical structure is installed into has a large impact on the risk of development of potential seepage pathways. Cohesionless soils such as sands, and gravels are likely to collapse against the pile during installation or post construction with pile movement, closing any direct pathway via the annulus. However, the permeability of adjacent soils could be higher if loosening has occurred. Saturated soft cohesive soils may anneal and close the annulus/ potential pathway although the consistency and robustness of annealing is uncertain and may not be reliable. Cohesive soils that have a material strength that is stiff or greater, are less likely to anneal, and any annuli that develops through this unit during construction is more likely to remain open or take an extended period to anneal.

There is also potential for sands in overlying layers to infill annuli through underlying lower permeability silts or clays, preventing closure of the annuli via annealing. Sand is several orders of magnitude more permeable than silts and clays, and should this occur, a permanent preferential pathway through the fine unit is developed. This is more likely to occur in thin silty or clayey units, where a loose, uniform sized sand is located directly above.

Influence of Design and Construction Methodology

The geotechnical structures discussed in Table 2 are constructed using different techniques, being;

- Excavation and construction of structural element in-situ (poured concrete, in-situ replacement or in-situ soil mixing, or local densification of soils)
- Installing pile through displacement techniques, where the structural element is driven, pushed or screwed directly into the ground,
- Structural element is constructed in-situ through densification of soils.

Risks of development of temporary or permeant preferential seepage pathways could be managed by council review of construction methodology plans and by suitable quality assurance by a qualified specialist (geotechnical engineer, or hydrogeologist).

Excavation Methods of Installation

Excavation methods include rotary drilling, percussion drilling or mechanical excavation (e.g. auguring, grab buckets), vibro-densification and in all cases require an open hole from surface to the target depth to be formed as part of the construction process.

This open-hole is a direct connection from surface to the target depth and the strata and any groundwater that is intercepted. This poses a risk similar to that of the drilling of water bores, which is generally an activity that requires resource consent.

Excavated piles, conversely, may have varying annuli depending on the construction methodology and the specific soils at the site. If a permanent casing is installed into an excavated hole, there is a high potential for creation of a void (anulus) between the casing and ground. This risk is reduced if the casing is incrementally advanced (driven/pushed) such that the excavation is solely within the casing, or the casing is advanced down a pre bored excavation (smaller diameter than the pile) with the casing cutting the ground while maintaining intimate contact at pile perimeter, or the annulus is specially grouted (complex to implement effectively).

Bored piles, where there is no casing or a temporary casing is used and removed during construction, and the concrete placed by tremie methods and/or using pressurised methods (e.g. pressure grouting) are likely to have direct interface with the soil/rock which is non-smooth. The potential for development of preferential seepage pathways is dependent on quality of the concrete/ground contact and any loosening of the adjacent ground. This risk is generally managed by suitably qualified drilling contractors through methods including;

- use of dense mud mixtures to control/limit leakage of groundwater to surface and improve excavation stability,
- use of a temporary casing to limit risk of excavation collapse,
- maintaining positive water head within the excavation during construction to limit groundwater inflow into the excavation and reduce risk of excavation base heave,
- keeping the open-hole closed at surface when unattended.
- pouring of concrete by tremie methods which reduces the risk of voids at the soil/pile interface or segregation of concrete.

Displacement Methods of Installation

Displacement techniques for installation typically exhibit a lower risk of developing preferential seepage pathways than for excavation methods, where elements installed are impermeable and the process of installation does not adversely disturb the ground.

Construction of deep geotechnical structures by way of displacement (driven, pushed or screwed), or excavation (bored, or in-situ mixed) construction techniques have varying potential for development of preferential seepage pathways.

Driven piles displace the adjacent soil, typically densifying it. Driven piles are considered to have good contact with the adjacent soils, with resulting expected small or non-existent annuli. Generally the potential for development of preferential seepage pathways at the interface between the soil and structural element is low. However, it is possible, with this risk related to the specific ground conditions, installation methodology adopted and the quality of the field implementation of this methodology (e.g., withdrawing and redriving to correct alignment, excessive vibration or lateral loading during excavation can increase risk of development of potential seepage pathways).

Methods of installation that disturb the ground can provide preferential seepage pathways. Screw piles incorporate a steel helix fixed to a steel pile that is screwed into the ground. As the pile is screwed into the ground the helix disturbs the soil creating a helical defect within the soil from the pile tip extending to the ground surface This produces a potential preferential seepage pathway, especially problematic within cohesive soils or where underlain by confined or leaky-confined aquifer.

Lifetime Effects

Degradation of piles

Over the lifetime of a deep geotechnical structure, or if the structure is abandoned, there is potential for the pile material to degrade, i.e. corrosion of steel piles, decay of timber piles or cracking and spalling of concrete. Degradation may be accelerated where local groundwater quality is poor, with increased rates of corrosion of the pile material.

Good construction practises should extend the lifetime of the feature by ensuring it is constructed in accordance with best practise. This is managed through construction via quality assurance processes, and inspections during construction by suitably qualified professionals. Where groundwater quality is known to be poor, the piles can be designed accordingly to minimise degradation. However elements in the ground will degrade with time.

Development or enlargement of annuli due to pile movement

Movement of piles by settlement, or lateral loading and/or cyclic loading on the pile due to external force (e.g. wind, waves earthquakes) can form or enlarge annuli. The motion of the pile in these conditions disturbs the adjacent soil, and in cohesive soil may form an annulus providing a preferential pathway. The potential for such circumstances to develop depends on specifics of the loading, resulting displacement of pile and the depth of influence of this down the element. Should such an annulus be prevalent along the length of the pile, from aquifer to surface, then a preferential pathway exists, and potential for leakage and contaminant transport may occur. This may be infilled by a higher permeability material, or left open (however over time consolidation and densification of soils can reduce or mitigate the preferential pathway).

Exacerbation of annuli due to water pressures

Once an annulus, or pathway exists, confined water under pressure at depth may discharge to surface along it. The flow and hydraulic pressure gradient could be sufficient to further erode adjacent soil, and enlarge the pathway. This exacerbates the potential for leakage and for flowrates to increase.

Highly permeable deep geotechnical structures

Permeable elements are sometimes installed into the ground to provide pathways for seepage (e.g. wick drains to promote consolidation), or to relieve soil pore pressure (e.g. ground improvement techniques such as stone columns and earthquake drains). These are typically installed to shallow depths but in specific instances could be +10m, and would not be effective if installed into a confined aquifer.

Should construction of either of these elements penetrate into a confined aquifer, the structure would need to be decommissioned and sealed, to allow construction of the remainder of the design (building, wall, slope, etc) to proceed. Therefore, although these features would create direct pathways, they’re very unlikely to intentionally penetrate confined aquifers, and therefore not of major concern for the purposes of this review.

Summary

Deep geotechnical structures are myriad in both design, and construction methodology which leads to highly varying risk profiles for the potential development of preferential pathways. The lowest risk deep geotechnical structures are likely to be driven piles and the highest risk structures that could intercept confined aquifers are bored piles, where a permanent casing has been installed to retain in ground after excavation is completed, or screw piles where the helix path remains open. Deep geotechnical structures/elements should therefore be assessed on a case-by-case basis to review the potential for adverse effects on the environment, such as leakage from a confined aquifer or transport of contaminants into freshwater resources, to occur. A suitably qualified professional should undertake the review on behalf of council (i.e. a hydrogeologist and/or geotechnical engineer).

Temporary and long-term risk to groundwater

Each of the deep ground improvement structures and their construction methodologies are described, and an assessment of the risk they pose for the development of preferential pathway for leakage or contaminant transport is made in Table 2.

Table 2: Deep geotechnical excavations and structures/elements, and associated potential preferential pathways.

Deep Geotechnical Excavation /Structural Element Types	Description	Risk of temporary preferential pathways during construction	Risk of permanent preferential pathways from installed structure
Driven piles	Solid steel, timber, or concrete poles are driven into the ground, displacing soil, by an impact energy or vibration to form the pile.	**Low** Construction of driven piles does not require excavation, instead the pre-cast concrete, steel or timber pile is driven into the ground displacing and densifying the adjacent soil. Some 'drag' of material may locally occur between layers of soil, adjacent to the pile. If the pile is installed using vibration, densification of the ground can be reduced, also vibration can trigger onset of liquefaction during construction for some soils.	**Low** Soil is displaced around the pile during construction, typically leading to densification. Driven piles therefore have good contact with the soils, with little to no expected annuli. Long term effective conductivity around the pile is likely to be similar to the in-situ soils. Annuli may develop during the pile's lifetime due to lateral or cyclic loading of pile from wind or waves. The pile may degrade (i.e. decay or corrode) although this is unlikely to occur within the design lifetime of the geotechnical structure.
Bored piles	A hole is excavated/ bored using a number of methods, reinforcement placed inside the bored hole and concrete introduced to form the pile. A bored pile can be cased (temporary or permanent), or uncased. Bored piles an also be installed by replacing soil with concrete during withdrawal of a continuous flight auger.	**Moderate - High** Construction of bored piles requires excavation of a hole to the target depth. If the target depth is a confined aquifer, there is a direct pathway from surface to the aquifer. This is typically managed through use of drilling fluids by drilling contractors or construction methods where pressure balance is maintained.	**High - Low** The long-term potential for preferential pathways from surface to the aquifer via the pile is variable and is dependent on the construction of the bored pile. Cased piles are more likely to have exterior annuli providing a preferential pathway. Where the casing is installed after excavation the risk is high if mitigation such as post grouting anulus is not implemented. Where the casing is pushed or driven with excavation undertaken within the casing with appropriate management of heave the risk is low. Where construction methodology is not well managed risk of development of preferential seepage pathways post construction increases. Where a temporary casing is used that is withdrawn during construction the concrete/grout of the pile is 'interfingered' into the host soil, effectively sealing the annuli, providing a lower risk of developing preferential seepage pathways. Annuli may develop during the pile's lifetime due to lateral or cyclic loading of pile from wind or waves. The pile may degrade (i.e. decay or corrode) although this is unlikely to occur within the design lifetime of the geotechnical structure.

Deep Geotechnical Excavation /Structural Element Types	Description	Risk of temporary preferential pathways during construction	Risk of permanent preferential pathways from installed structure
Screw pile	Steel piles with welded helix(s) are wound into the ground, displacing soil.	**Moderate - High** As the screw pile is progressed, a 'corkscrew' type cut is made into the soil around the pile by the helix. Cohesionless soils will collapse, and close the pathway. Cohesive soils may anneal depending on stiffness of the in-situ soil and whether additional compaction occurs from construction traffic, or construction. Leakage along the helix path could occur.	**Moderate** The helix pathway is likely to progressively anneal over the long term, unless the pathway has been infilled with another material (e.g. sand dragged down into the helix from overlying strata), or unless a leakage pathway has been established along the helix, which maintains sufficiently high pressure to prevent closure of the helix pathway. Annuli may develop during the pile's lifetime due to lateral or cyclic loading of pile from wind or waves. The pile may degrade (i.e. decay or corrode) although this is unlikely to occur within the design lifetime of the geotechnical structure.
In-situ mixed pile	A mixing mechanism or probe is inserted into the ground. The in-situ soil is mixed with an additive to improve soil strength or create a cemented column. Additive is often cementitious grout, and is introduced to the hole via jet-grouting or mechanical deep soil mixing. Usually mixed in-situ.	**Low - Moderate** Construction requires in-situ introduction and mixing of an additive and typically does not require open excavation. However, vigorous disturbance of the in-situ material potentially allows connection between surface and the strata intercepted by the pile hole. The risk is typically associated with soil type and properties, or pressure conditions encountered. Risk can be reduced though appropriate management of pressures within the soil and construction methodology.	**Low** The additive mixes with the in-situ soil and cures. The vigorous downhole mixing and jet blasting introduction of slurry during construction is likely to result in good bond with the adjacent soil, and very low likelihood of the development of an exterior annulus.
Diaphragm walls	Excavation of a trench, placement of reinforcement, followed by concrete. Analogous to bored piles, but for construction of a wall.	**Moderate - High** Construction methods are similar to bored piles via a secant or trenched methodology. Requires excavation of an open hole – typically of larger volume than for bored piles. Leakage, and support of the trench during construction is typically managed by drilling contractors using drilling fluids to maintain pressures.	**Low - Moderate** Similar to bored piles, although as it is less likely for casing to be left in ground, the pile is more likely to achieve an 'interfingered' seal with the adjacent soil. Annuli may develop during the pile's lifetime due to lateral or cyclic loading of pile from wind or waves.

Deep Geotechnical Excavation /Structural Element Types	Description	Risk of temporary preferential pathways during construction	Risk of permanent preferential pathways from installed structure
			The pile may degrade (i.e. decay or corrode) although this is unlikely to occur within the design lifetime of the geotechnical structure.
Vibro replacement, stone columns, etc.	Displacement of soil by vibration, or insertion of a mandrel, densifying the adjacent ground. Introduction of engineered fill to create a densified column of sand or gravel to improve load bearing capacity.	**Moderate - High** Construction may be open hole, or filled. Placed material is generally sand and gravel which have relatively high hydraulic conductivity compared to most in-situ soils. This results in a preferential pathway from ground level to the base of the column. Typically, stone columns are not installed to great depths (typically <12 m), and would be impractical to install into a confined aquifer.	**Moderate - High** Placement of sands and gravels from the base of the excavation to surface may create a 'shortcut' from surface to deeper strata where the placed materials have higher permeability than the in-situ soil. If the base of the excavation penetrates the aquitard this would result in leakage and potentially contaminant transport.
Pore pressure release structures	Wick drains, sand drains, earthquake drains. A pipe, column of sand, or geosynthetic tape inserted into the ground to improve drainage and release pore pressures, and reduce potential for liquefaction. Not intentionally installed into confined aquifers.	**High** Construction creates a permeable pathway from the base of the element to the ground surface providing a preferential seepage pathway.	**High** The structure is constructed to facilitate leakage between the ground and surface, and therefore provides a direct pathway – the risk of leakage is High.

Conclusion

Deep geotechnical structures/elements installed below ground are myriad in both design, and construction methodology which leads to highly varying risk profiles for the potential development of preferential pathways. Deep geotechnical structures should therefore be assessed on a case-by-case basis to review the potential for adverse effects on the environment, such as leakage from a confined aquifer or transport of contaminants into freshwater resources, to occur.

The matters to which council may wish to retain control and discretion over the potential effects of leakage and contamination transport to or from a (leaky) confined aquifer, could extend to the following:

- Be applicable where confined aquifers are present, or potentially present.
- Require resource consent where there is potential for the deep geotechnical excavation or structural element to intercept (or potentially intercept) confined groundwater.
- Clearly define the relevant technical terms quoted in the activity rule, which may include deep geotechnical excavations, deep geotechnical structures/elements, piling (driven, bored and screwed), leaky-confined aquifer, confining layer, aquitard and flowing artesian aquifer.
- Allow technical review of the proposed design and construction methodologies with consideration of the site-specific ground conditions. This should be by a suitably qualified professional (i.e. a hydrogeologist and/or geotechnical engineer), or for smaller-scale activities by following a specifically developed guide (this could be developed considering risk discussion within Table 2).
- Apply standard consent conditions (developed with industry input) in most cases, to provide consistent and standardised management of the risks. Should site specific conditions be necessary, these should be additional to the standard set of conditions.

A major barrier to the effective management of any deep geotechnical activities into aquifers is the industry-wide awareness, knowledge and willingness to apply for resource consent to undertake the activity. In most regions, even those with relevant activity rules, it is not currently common practice for resource consent to be applied for piling activities.

We recommend that during the building consent process, should deep geotechnical excavations be identified in the design, the project is referred on for resource consent, if not already obtained. This may require knowledge and understanding by people undertaking the initial review, to be aware of the different types of structures/ elements, methods of installation and varying risks to aquifers. Development of simplified targeted guidance to assist in this knowledge transfer and to help support decision making is recommended.

Building awareness of industry professionals, such as planners and geotechnical engineers, via consultation would be valuable, and likely necessary for effective use of the consenting pathway to manage potential risks.

Recommendations for pMEP

We recommend that MDC consider an activity rule in the region-wide rules section of the pMEP that addresses the potential risk of leakage and/or contamination of confined aquifer due to the construction of deep geotechnical excavations.

We have provided an indicative activity rule for MDC’s consideration of technical aspects. This has not been prepared by a planner, and should only be regarded as draft and indicative. Advisory comments are italicised.

Indicative Activity Rule: **considerations for managing technical risks of leakage or contaminant transport to/from confined aquifers due to deep geotechnical excavations and structures**:

1) Define confined aquifer zones
    a) *e.g. Wairau Aquifer FMU, Rarangi Shallow FMU Riverlands FMU, Kaituna FMU or map a new zone(s).*
2) Define necessary technical terms:
    a) Deep geotechnical earthworks/structures/elements. *The existing pMEP definitions of ‘excavation’, and ‘bore’ exclude most deep geotechnical structures/elements. ‘Land disturbance activity’ is a broader definition and could be extended to deep geotechnical earthworks. Alternatively, a new activity could be defined.*
    b) Confined (or leaky confined) aquifer*. The pMEP refers to confined layers, but these are not explicitly defined. Could include all leaky confined aquifers, or be limited to where those aquifers are flowing artesian, or have water head close to ground level.*
3) Define a permitted activity within the confined aquifer zones; where,
    (a) Earthworks do not penetrate within a specified distance above of the top of a confined (or leaky confined) aquifer. *The separation distance to achieve the same level of risk would vary between sites with variation of site-specific conditions, however 2 m suggested based on judgement.*
    (b) For specific structures/elements types where the level of risk of developing preferential leakage pathways is sufficiently low to satisfy MDC risk management criteria.
    (c) The activity is not within a source water protection zone.
4) Define a controlled, discretionary or restricted discretionary activity, where,
    a) One or more of 2(a)-(c), are not met
5) If 3, then discretion of the council shall include, but is not limited to:
    a) Potential for leakage of groundwater or contaminants between aquifers
    b) Potential for damage to the hydraulic integrity of the confining layer or aquitard
    c) Potential for “spring” discharge of groundwater to surface
    d) Potential for the creation of, or worsening of, potential contaminant pathways
    e) Diversion of water.
    f) Land subsidence and/or settlement

We recommend that MDC planners consider this letter and seek further technical advice on the wording of any proposed activity rule and standard set(s) of resource consent conditions for managing the potential adverse environmental effects from geotechnical foundations.

Yours sincerely

Leeza Becroft

Senior Hydrogeologist

on behalf of

Beca Limited

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Yours sincerely

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on behalf of

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Copy

Mike Thorley, Beca

Attachment 1 – Environment Waikato Resource Consent for Piling into an Artesian Aquifer, and associated Management Plan.

Attachment 1: Resource consent to drill below the water table

Resource Consent Certificate

Resource Consent: AUTH130361.05.01

File Number: 61 52 95A

Pursuant to the Resource Management Act 1991, the Waikato Regional Council hereby grants consent to:

New Zealand Transport Agency (Regional Office)
PO Box 973
Waikato Mail Centre
Hamilton 3240

(hereinafter referred to as the Consent Holder)

Consent Type: Land use

Consent Subtype: Land - well

Activity authorised: To drill below the water table to install bridge piles in association with the Hamilton Section of the Waikato Expressway.

Location: Waikato Expressway: Hamilton Section

Map Reference: NZMS 260 S14:169:747

Consent duration: 35 years

Lapsing: This consent shall lapse ten years from the date of commencement

Subject to the conditions overleaf:

CONDITIONS

130361-05 Land use – drilling below the water table

1. The consent holder shall ensure that the works and activities authorised by this resource consent are carried out in accordance with the conditions as set out in Schedule One.
2. In accordance with section 125 RMA, this consent shall lapse ten (10) years after the date on which it was granted unless it has been given effect to before the end of that period.
3. Prior to the commencement of construction, the consent holder must prepare a Mangaonua Gully Drilling Plan (MGDP). The purpose of the MGDP is to minimise the potential for loss of water from the aquifer during drilling in the Mangaonua Gully.
4. The MGDP is to be prepared by the consent holder and shall describe the measures to be employed to ensure compliance with condition 5.
5. The MGDP shall include, but not be limited to, the following:
    a) A plan showing sites where drilling in the aquifer would occur;
    b) Detailed description of drilling methodology;
    c) Measures to minimise loss of water from the aquifer;
    d) Measures to minimise infiltration of drilling fluids into groundwater and ensure no discharge of drilling fluids to surface water;
    e) Procedures in the event that the aquifer is breached;
    f) Notification and reporting procedures.
6. At least 40 working days prior to undertaking construction works associated with this Project, the consent holder shall submit the MGDP to the Waikato Regional Council for approval by the Waikato Regional Council - acting in a technical certification capacity - that the MGDP satisfies the requirements of condition 5. Any changes proposed to the MGDP shall be confirmed in writing by the consent holder and certified in writing by the Waikato Regional Council acting in a technical certification capacity, prior to the implementation of any changes proposed.
7. The consent holder shall undertake all activities authorised by this consent in accordance with the certified MGDP and certified changes.

    The consent holder shall ensure that a copy of the certified MGDP, including any certified amendments, is kept on-site and this copy is updated within 5 working days of any amendments being certified.

Advice notes

1. Where a resource consent has been issued in relation to any type of construction (e.g. dam, bridge, jetty) this consent does not constitute authority to build and it may be necessary to apply for a Building Consent from the relevant territorial authority.
2. This resource consent does not give any right of access over private or public property. Arrangements for access must be made between the consent holder and the property owner.
3. This resource consent is transferable to another owner or occupier of the land concerned, upon application, on the same conditions and for the same use as originally granted (s.134-137 RMA).
4. The consent holder may apply to change the conditions of the resource consent under s.127 RMA.
5. The reasonable costs incurred by Waikato Regional Council arising from supervision and monitoring of this/these consents will be charged to the consent holder. This may include

but not be limited to routine inspection of the site by Waikato Regional Council officers or agents, liaison with the consent holder, responding to complaints or enquiries relating to the site, and review and assessment of compliance with the conditions of consents.

6. Note that pursuant to s332 of the RMA 1991, enforcement officers may at all reasonable times go onto the property that is the subject of this consent, for the purpose of carrying out inspections, surveys, investigations, tests, measurements or taking samples.
7. If you intend to replace this consent upon its expiry, please note that an application for a new consent made at least 6 months prior to this consent's expiry gives you the right to continue exercising this consent after it expires in the event that your application is not processed prior to this consent's expiry.

Attachment 1: Mangaonua Guly Drilling Plan

Hamilton Section

Waikato Expressway: Hamilton Section

Report

Mangaonua Gully Drilling Plan

Prepared by: Alexis Thomas

Reference: 3311244-RPT-GA-06-03

01 May 2017

WAIKATO EXPRESSWAY – HAMILTON SECTION
CONTRACT NO: NZTA 2/09 – 015/602

Review and Approval

Status	Name	Date	Approval
Owner	Alexis Thomas	26-04-2017	Signed via Aconex
Reviewer	Sian France, Gavin Alexander, Hadley Wick	01-05-2017	Signed via Aconex
Approved	Ross Winter	01-05-2017	Signed via Aconex

Revision Record

Date	Rev	Details / Comments
01-05-2017	A	Draft for WRC comment

Contents

Appendices

1 Introduction

1.1 Purpose

The Mangaonua Gully Drilling Plan (MGDP) forms part of a comprehensive suite of environmental controls within the Construction Environmental Management Plan (CEMP) for the Hamilton Section of the Waikato Expressway 'the Project". The MGDP addresses the potential for interception of artesian groundwater, during pile installation and other construction activities in the Mangaonua Stream Gully.

While it is anticipated that some groundwater will be intercepted during the normal course of earthworks, consents and compliance procedures are in place to address this (refer to the Groundwater Monitoring and Mitigation Plan). The purpose of the MGDP is to set out the activities that could be carried out, where necessary, to mitigate and remediate interception of an artesian aquifer during pile construction for the Mangaonua Stream Bridge. This plan:

- Specifies design and construction methodology;
- Proposes methodology to manage (control, stop and / or seal) groundwater flow during construction;
- Sets out the activities that would need to be carried out to mitigate and remediate in the case of planned or accidental artesian aquifer interception; and
- Specifies the monitoring methodology, and response procedures and reporting requirements.

2 Consent Condition Framework

2.1 Consent Condition Outcome Summary

The following conditions set out the requirement to prepare a Mangaonua Gully Drilling Plan (MGDP) to manage and minimise the potential for loss of water from the aquifer during drilling. These conditions of consent were required as part of AUTH130361.05.01 which is a regional consent for land use – drilling below the water table.

Table 2.1: Summary of Conditions

Condition	Description	Key MGDP Reference
1	The consent holder shall ensure that the works and activities authorised by this resource consent are carried out in accordance with the conditions as set out in Schedule One.	-
2	In accordance with section 125 RMA, this consent shall lapse ten (10) years after the date on which it was granted unless it has been given effect to before the end of that period.	-
3	Prior to the commencement of construction, the consent holder must prepare a Mangaonua Gully Drilling Plan (MGDP). The purpose of the MGDP is to minimise the potential for loss of water from the aquifer during drilling in the Mangaonua Gully.	-
4	The MGDP is to be prepared by the consent holder and shall describe the measures to be employed to ensure compliance with Condition 5.	-

Condition	Description	Key MGDP Reference
5	The MGDP shall include, but not be limited to, the following:	-
	A plan showing sites where drilling in the aquifer would occur;	Appendix A
	Detailed description of drilling methodology;	Section 4.1
	Measures to minimise loss of water from the aquifer;	Section 4.2
	Measures to minimise infiltration of drilling fluids into groundwater and ensure no discharge of drilling fluids to surface water;	Section 4.3
	Procedures in the event that the aquifer is breached; and	Section 4.4
	Notification and reporting procedures.	Section 7
6	At least 40 working days prior to undertaking construction works associated with this Project, the consent holder shall submit the MGDP to the Waikato Regional Council for approval by the Waikato Regional Council - acting in a technical certification capacity - that the MGDP satisfies the requirements of condition 5. Any changes proposed to the MGDP shall be confirmed in writing by the consent holder and certified in writing by the Waikato Regional Council acting in a technical certification capacity, prior to the implementation of any changes proposed.	-
7	The consent holder shall undertake all activities authorised by this consent in accordance with the certified MGDP and certified changes.	-
8	The consent holder shall ensure that a copy of the certified MGDP, including any certified amendments, is kept on-site and this copy is updated within 5 working days of any amendments being certified.	-

3 Mangaonua Gully Drilling Plan

3.1 Site Location and Groundwater Conditions

The groundwater level(s) within and adjacent to the Mangaonua Stream Gully have been determined from piezometer monitoring data, test pit observations and, to a lesser extent, CPTu interpretation and dissipation testing.

Standpipe piezometers either side of the stream gully confirm an unconfined, regionally widespread water table dipping towards the Mangaonua Stream (Figure 1). A pronounced upward vertical gradient is however evident within the gully which extends north to Morrinsville Road. There is insufficient data to determine how far south the artesian conditions extend.

Deep nested vibrating wire piezometers show hydraulic head increasing with depth, with the deepest piezometer, installed at -28 mRL, indicating a pressure head of some 60 m, reaching 32 mRL (almost 7 m above the gully floor) within Unit 6 (Walton Subgroup). The confining units appear to be Unit 3a (Piako

Subgroup) and the underlying silts and silty clay within Unit 5a (Walton Subgroup). Both units are variable in thickness within the gully, but together form an effective aquitard.

Artesian pressures are expected to be encountered within and below Unit 5a (Walton Subgroup), from approximately 13-20 m bgl (6-12 mRL).

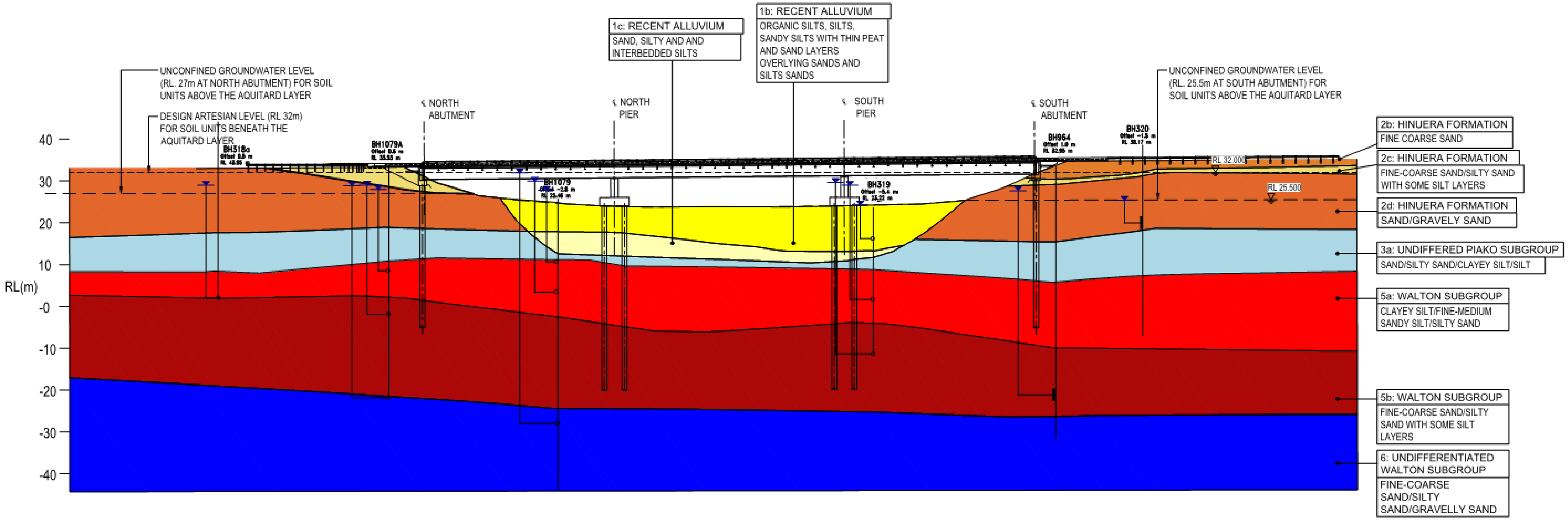


Figure 1: Mangaonua Stream Gully Hydrogeological Cross Section Showing Average Water Level Observations and Indicative Pile Depths

3.2 Final Form of Built Structure

The proposed bridge design is a 146m long, three-span twin steel ladder bridge which will carry the expressway over the Mangaonua Gully and the stream below. The bridge will cater for four 3.5m lanes, two 2.5m shoulders and a 6.0m central median. The superstructure comprises four 2750mm deep steel girders with a concrete deck of average 250mm thickness. The bridge is supported on abutments located on the slopes either side of the gully and two piers within the base of the gully.

The bridge beams at each pier will be supported directly on top of 1800mm diameter columns using fixed pot bearings. The columns will be supported on two rows of five 1200mm diameter bored concrete piles with a concrete pile cap. At each abutment the girders are supported by a concrete abutment beam, founded on six 1200mm diameter reinforced concrete piles.

The expected pile tip founding levels are summarised in Table 3.1 below.

Table 3.1: Proposed Pile Founding Levels

Pile Location	Proposed Pile Length (m)	Proposed Pile Tip Founding Level (mRL)
North Abutment	38.0	-9.5
North Pier	46.0	-22.5
South Pier	46.5	-23.0
South Abutment	42.5	-13.0

A plan and cross section showing the planned pile locations is provided in Appendix A and Figure 1 respectively.

3.3 Potential Effects on Groundwater

All piles will extend down through the aquitard and will therefore encounter elevated groundwater pressure. The effect is likely to be less marked at the sides of the valley where embedment depth of piles are not as deep, and most pronounced at the location of the two piers.

There is potential for loss of groundwater from the confined aquifer if water is able to flow upwards as the drilling penetrates the confining clays and silts of Unit 3a and 5a. Within the gully, the potentiometric surface is above ground level, therefore if inflow is not carefully controlled, flowing artesian conditions could occur.

Should prolonged and uncontrolled artesian flow occur, there is a risk that depressurisation of the aquifer may propagate some distance from the gully. While no contribution from the artesian aquifer to surface water features or the overlying unconfined aquifer has been confirmed, it remains possible that a reduction in pressure may reduce recharge to these features. The effect of this is not easily quantified, as the magnitude of drawdown will be determined by the duration and rate of discharge from the aquifer. Any effect would be temporary, as any flow from open pile holes will need to be sealed completely to ensure pile integrity.

Careful management of groundwater pressures during drilling and pile installation is therefore proposed to avoid any groundwater discharge from the aquifer.

4 Pile Installation

Installation of deep bored piles will result in interception of the artesian aquifer within the Mangaonua Gully. While it will not be possible to avoid intercepting the artesian aquifer while piling, careful control of groundwater flow is desirable in order to:

- Avoid depressurisation of the aquifer;
- Avoid uncontrolled discharge of groundwater or drilling fluids to surface water; and
- Avoid the potential for mixing of water from different aquifers.

This section outlines the drilling methodology, in accordance with condition 5b) and steps to be taken to control, stop, and seal groundwater flow during construction in accordance with conditions 5c), 5d) and 5e).

4.1 Piling Methodology

Construction of piles for the Mangaonua Stream Bridge will progress as follows:

A pre-work briefing to the site team will be undertaken prior to piling commencing, to explain the contents of the plan and so the team understand the methodology and actions required. A copy of the plan will be kept with the piling rig for site team reference.

For the pier piles, permanent casing will be installed within the dense alluvial soils (Unit 1c), to an approximate depth between 8.5mbgl and 11mbgl (12.5mRL to 15mRL). Casing will extend some 9.5 to 10m above the gully floor (approx. 33mRL) and critically, above the maximum anticipated static potentiometric artesian surface (32mRL). The casing will serve to contain artesian flow in the pile hole, and support the pile walls in the upper section of the hole.

For the abutment piles, casing will be installed to approximately 21mRL (12m below the excavated platform level, 33mRL). As for the pier piles, the casing will serve to contain artesian flow in the pile hole, and support the pile walls in the upper section of the hole. Casing will be retrieved, if practicable, once the hole has been drilled and after installation of the prefabricated reinforcing cage and concrete pour.

Soil will be excavated using a drilling bucket, under bentonite slurry support. As piling progresses below the casing, drilling fluid levels will be maintained between 32.5 and 31mRL, with a density of at least 1.05g/ml. This takes into account working volume fluctuations while maintaining a ‘positive head’ of the drilling fluid and the minimum mud level of 31mRL required to balance the artesian head (Appendix B).

On completion of drilling, mud levels will be maintained above the minimum 31mRL in order to reduce the risk of flow from the aquifer into the open hole. The density of the mud has been determined to balance the artesian pressure of the aquifer, but to avoid an excessive positive head which could result in possible loss of mud to the aquifer. The weighted mud will allow the hole to remain open until the concrete tremmie pour is complete.

The drilling bucket extraction speed will be limited to avoid turbulent flow in the hole, reducing the potential for erosion or collapse of the pile bore wall.

The drilling of any pile over the depth of beneficial skin friction (i.e. the uncased length) and the concreting of that pile will be completed within two days. Concrete will be tremmied from the base up and will seal against the formation.

4.2 Measures to Minimise Loss of Water from the Aquifer

Mud weight and minimum working mud levels have been determined by a suitably qualified geotechnical engineer (Appendix B).

These calculations consider the maximum artesian pressure anticipated, based on the proposed pile tip founding level. Provided a positive head is maintained, no loss of groundwater from the artesian aquifer is anticipated.

For the pier piles, casing will also be installed above ground to a minimum of 33mRL, 9.5 - 10 m above existing ground levels in the gully floor and a minimum 1 m above the maximum anticipated potentiometric surface of the artesian aquifer (32mRL). This will contain groundwater within the casing, should the positive head be temporarily lost and flow from the aquifer occurs, until such time as the mud levels are re-established or a more permanent solution to halt flow is completed (refer Section 4.4).

4.3 Management of Drilling Fluids

Use of a weighted drilling mud will create a head differential to offset and suppress artesian flow during pile advancement. The density of the mud has been determined to balance the artesian pressure of the aquifer, but to avoid an excessive positive head which could result in possible loss of mud to the aquifer.

Mud levels will be checked continuously as drilling progresses. A visible change in mud level within the casing will provide an immediate indication of loss of mud to the formation, or addition of groundwater into the pile bore.

Mud weight and other parameters will be checked using an onsite laboratory. The time required for sampling will cause incremental delays to drilling progress, which increases the duration the hole remains open. This can have a detrimental effect of the stability of the hole, and consequently pile integrity so sampling will be limited to the following times:

- Immediately prior to drilling proceeding below the casing;
- At completion of drilling each day;
- 1 and 2 hrs following completion of drilling;
- After de-sanding;
- Prior to and following installation of prefabricated reinforcing cage; and
- Immediately prior to the concrete pour.

The displaced bentonite mud will be pumped from the hole and stored in tanks as the concrete tremmie pour proceeds and re-used where possible. Excess or unused drilling mud will be disposed off site at an appropriate facility.

4.4 Procedures in the Event of Uncontrolled Artesian Flow

In the event that flow from the artesian aquifer into the pile borehole occurs and cannot be controlled by the addition of mud or an increase in mud weight, the following response and control measures are proposed:

- Immediately phone the Foundation Manager to inform him of the situation, so that he can coordinate the response;
- Conrete plant will be on standby for the duration of the first pile bore;
- For subsequent bores, 3 MPa concrete will be sourced by either redirecting an existing order or directly from the plant. 3 MPa concrete is proposed to seal uncontrolled flow because it will be readily available, and can be drilled through at a later time to allow completion of the pile. It is estimated that it will take approximately 30 minutes to get the concrete to site;

- During that time, the tremmie pipe will be installed to the base of the pile hole and will be ready for immediate pour when the cement trucks arrive;
- Record rate, duration and composition of fluid flow. If flow is sediment laden, this will give an indication if significant erosion is occuring due to inflows and may require a quicker reponse time;
- Implement an accelerated piezometer monitoring program;
- Flow will be contained on site using the site bund, preventing flow to the Mangaonua Stream, and pumped to the mud tanks (storage capacity 240m^3);
- The volume of concrete required to fill the pile hole, assuming drilling has progressed to target depth (45m max) is 50m^3. This includes an allowance for filling any cavities that may have formed as a result of flow into the pile bore, and assumes the hole will be filled to 2 m inside the casing (11-12mRL). Stable concrete levels will be checked and topped up if required; and
- After the concrete has set, the hole will be inspected to check that sealing has been effective prior to drilling recommencing.

Should leakage outside the casing be observed, a mini-rig would be mobilised to inject grout around the casing. If necessary grouting will be repeated.

The proposed methodology and communication procedure above would be reviewed following any incident and, if warranted, any recommendations and/or changes to the MGDP would be provided to WRC and the wider team involved in pile construction at the Mangaonua Stream Bridge site.

4.4.1 Observer Equipment

The following equipment will be provided for onsite:

- Emergency contact list, which will include but not limited to the following: Project Foundation Manager, Project Environmental Manager, WRC, CPS team (who will conduct the groundwater monitoring), concrete suppliers and any supporting or stand-by contractors that may be of assistance;
- Dip meter and readout device to measure groundwater levels in monitoring piezometers;
- Cellular phone, camera. Site staff shall be prepared to communicate the situation with WRC and the Foundation Manager and effectively document the situation; and
- 1000 ml graduated cylinder or measuring cup. Allows a qualitative estimate of the turbidity of the flow or when used with a timer determines the rate of flow.

5 Monitoring Methodology

Groundwater levels will be recorded in vibrating wire piezometers installed specifically to allow monitoring of water levels within the Mangaonua Gully and standpipe piezometers screened within the artesian aquifer either side of the gully (Figure 2, Table 5.1). While these will capture any pressure changes within the aquifer during drilling, the most immediate sign of loss from the confined aquifer will be discharge from the pile hole. Any uncontrolled discharge from the aquifer will be acted upon immediately, however mitigation/remediation action for private well owners would only be triggered if depressurisation of the aquifer is observed in the piezometers.

Table 5.1: Proposed Monitoring Piezometers

Piezometer ID	Easting (NZTM)	Northing (NZTM)	Existing Ground Elevation (mRL)	Type	Tip Depth (mbgl/mRL)	Screen Top (mbgl/mRL)	Screen Base (mbgl/mRL)
BH318a	1806328	5814644	44	VW	43 / 1		
BH1079 (green)	1806380	5814582	25.2	VW	15 / 10.2		
BH1079 (red)	1806380	5814582	25.2	VW	53.4 / -28.2		
BH1079 (yellow)	1806380	5814582	25.2	VW	21.9 / 3.3		
BH1079a (green)	1806356	5814614	33.0	VW	25 / 8		
BH1079a (red)	1806356	5814614	33.0	VW	55.4 / -22.4		
BH1079a (yellow)	1806356	5814614	33.0	VW	35.4 / -2.4		
BH319a	1806429	5814524	23.2	VW	22 / 1.2		
BH319c	1806429	5814524	23.2	VW	8 / 15.2		
BH964	1806463	5814496	33.0	SP		53 / -20	56 / -23
BH794b	1806335	5815014	43.8	SP		11 / 32.8	17 / 26.8

Should a piezometer be damaged during construction activities, a replacement will be installed. Installation details will be provided for WRC for approval.

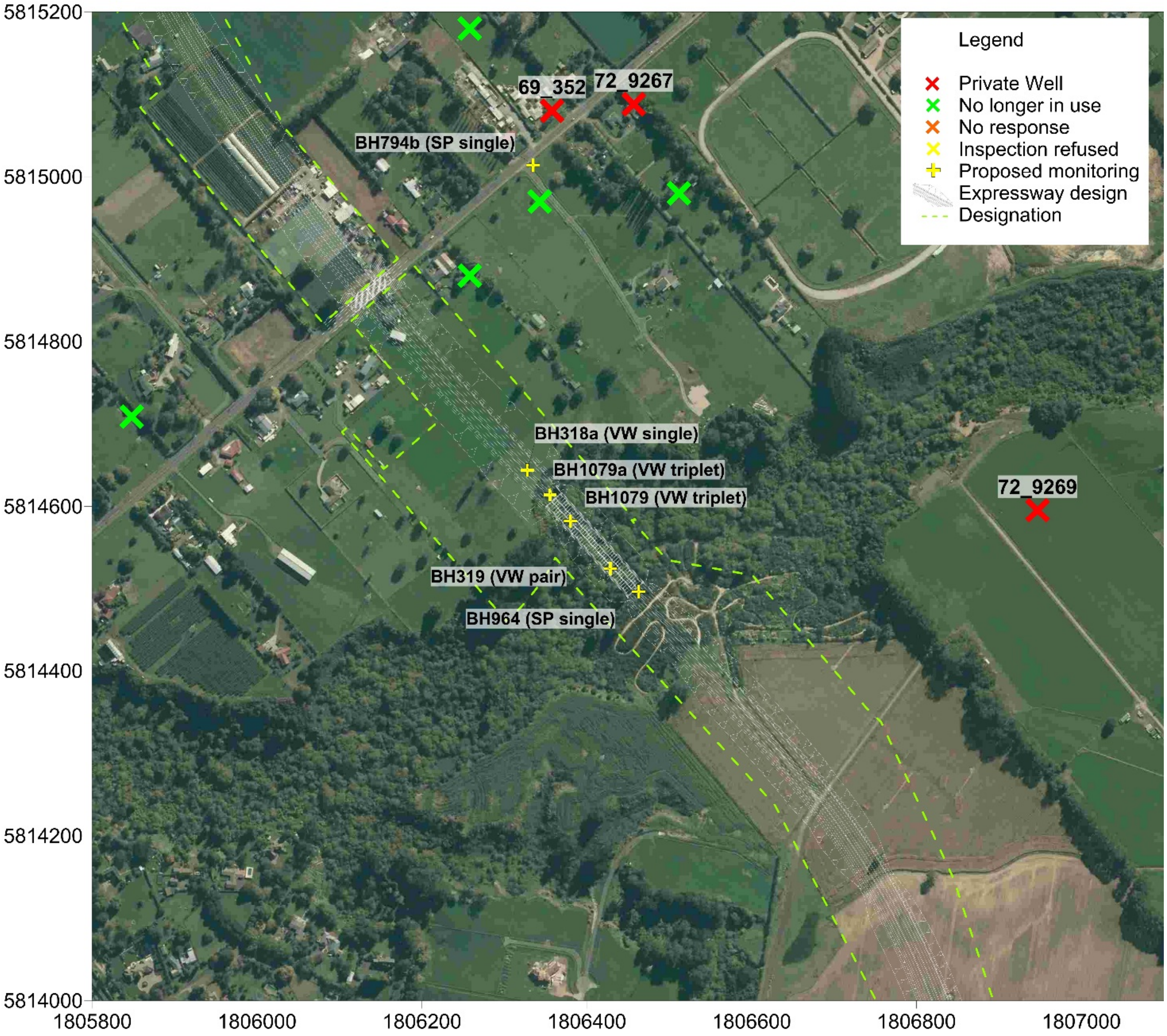


Figure 2: Potentially Affected Private Wells and Proposed Monitoring Piezometers

5.1 Monitoring Frequency

Monthly monitoring of the proposed piezometers has already commenced and will continue at monthly intervals prior to pile installation. For the final month before piling commences, the frequency of groundwater level monitoring will be increased to weekly intervals to provide confidence in the immediate pre-construction trend.

During pile installation, the frequency of groundwater level monitoring will be increased to twice weekly.

Should any uncontrolled discharge occur, monitoring would be undertaken daily until the flow has been controlled, and resume to twice weekly thereafter.

Monitoring will continue on a monthly basis for a period of six months after piling has been completed, or a lesser period where approved by Council.

5.2 Potentially Affected Parties and Proposed Mitigation Measures

Three private groundwater wells have been identified approximately 500 m from the bridge site (Figure 2). Two wells (69_352 and 72_9267) are shallow and most likely abstracting from the unconfined aquifer within the Hinuera sequence and are therefore not likely to be affected by depressurisation within the confined aquifer. The depth and construction of the third well (72_9269) is not known, therefore it is not possible to determine the likelihood that temporary depressurisation would materially affect supply.

The extent and magnitude of any drawdown effect will be proportional to the duration and rate of uncontrolled flow. As it is not possible to quantify, in advance of drilling, the magnitude of depressurisation that may occur within the aquifer, the Alliance propose that, should a drop in pressure or water level (in excess of 1m) be observed in any of the deep monitoring piezometers, Allan Copeman (owner of bore 72_9269) (Table 5.2) would be notified and, if necessary, mitigation measures will be actioned.

While it is unlikely that effects would be observed in the shallow unconfined aquifer, should depressurisation of the deep confined aquifer be observed to propagate as far as bore 72_9269, review of groundwater levels within a shallow piezometer (BH794b) near the other two private wells (69_352 and 72_9267) would be undertaken to identify any drawdown within the shallow aquifer and, if necessary, the owners would be notified and mitigation measures actioned.

If established supply is affected such that they cannot operate as expected we would supplement affected supply within two days. While it is unlikely that temporary depressurisation of the aquifer would propagate such a distance in the time it would take to seal the pile hole, at worst only a temporary supply would be required and that any drawdown would be short lived and proportional to the duration of uncontrolled discharge.

Table 5.2: Known Established Private Groundwater Wells, Well Construction Details

WRC ID	Physical Address	NZTM Easting	NZTM Northing	Well Depth (m)	Well Construction / Pump Installation	Distance from Cut (m)	Contact Details
69_352	231 SH26/ Morrinsville Rd	1806358	5815080	9.14	1000 mm dia. 9.1 m deep, WL 6.5 mbgl. Surface (suction) pump installed to replace old submersible. Pump in operation at time of inspection.	490	Sam Nunn (07 8569801)
72_9267	236 SH26/ Morrinsville Rd	1806457	5815088	7	1000 mm, 7 m well, 6.8 m casing, WL 5.36 mbgl. Surface pump	500	Andrew Steel (021 1407586)
72_9269	95F Webster Road, Matangi	1806947	5814595	Unknown	Depth and pump intake not known	500	Allan Copeman (021 874222)

6 Notification and Reporting Proceedures

Should a measurable drop in pressure or water level be observed in the monitoring piezometers the Alliance will immediately notify WRC and initiate contact with the potentially affected parties identified in Table 5.2.

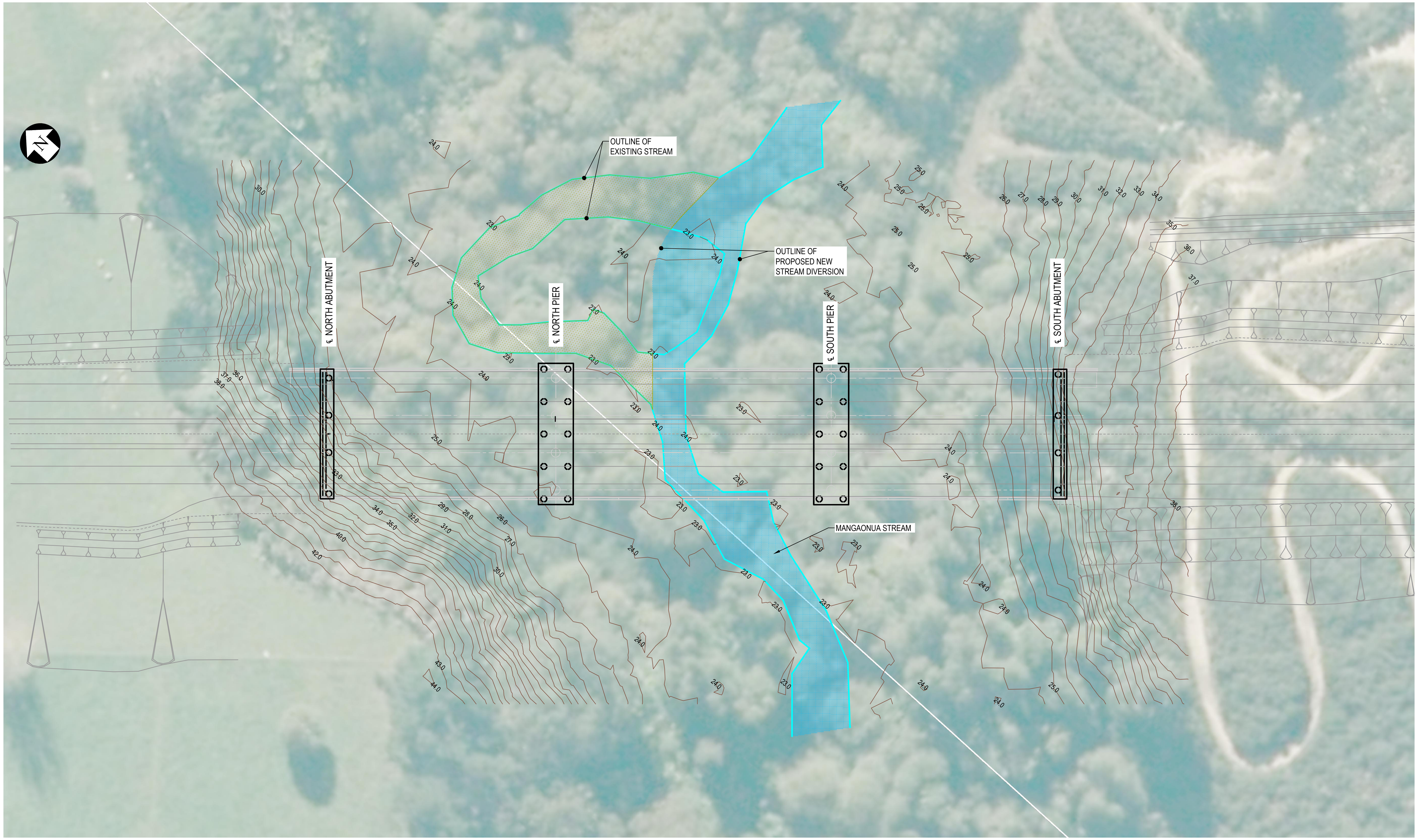
If any affected party reports an interruption to their supply, the Alliance will prepare a short summary report for WRC which will detail:

- The onset, duration and nature of the interruption;
- The nature of any construction activities, piling etc that has been undertaken;
- Any remedial or mitigation measures that have been implemented;
- Relevant pre-construction groundwater monitoring data; and
- Groundwater monitoring records since commencement of the works.

Appendix A

Pile Location Plan

Drawing Plotted: 31 March 2017 11:48 a.m.



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1:250 (A1) 1:500 (A3) 0 5 10m
1:500 (A1) 1:1000 (A3) 0 5 10 15 20m
1:1000 (A1) 1:2000 (A3) 0 10 20 30 40m

ORIGINAL DRAWING IN COLOUR

PRELIMINARY
NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
A	FOR INFORMATION	GB	AT	GWK	30.03.17

CITYEDGE

Original Scale (A1) 1:400	Design	A. THOMAS	29.03.17
Reduced Scale (A3) 1:800	Drawn	G. BROWN	29.03.17
	Dsg Verifier		
	Drg Check		

NZ TRANSPORT AGENCY
WAKA KOTAHI
Hamilton Section
Waikato Expressway
NZTA 2/09 - 015/602
SH01N RS 534 /0 to RS 557/2720

WAIKATO EXPRESSWAY
HAMILTON SECTION
MANGAONUA STREAM BRIDGE

MANGAONUA STREAM GULLY
BRIDGE PILE LOCATION
DETAIL PLAN

HYDROGEOLOGY
PROJECT NUMBER - 3311244-DR
DISCIPLINE CODE - GH-74020
A
DOCUMENT CODE
SECTOR, SEQUENTIAL NO.

Path: R:\Delivery Phase\CAD\Drawings

Beca Project No. 3311244 Document No. 3311244-DR-GH-74020.dwg

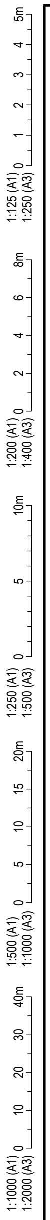
DO NOT SCALE

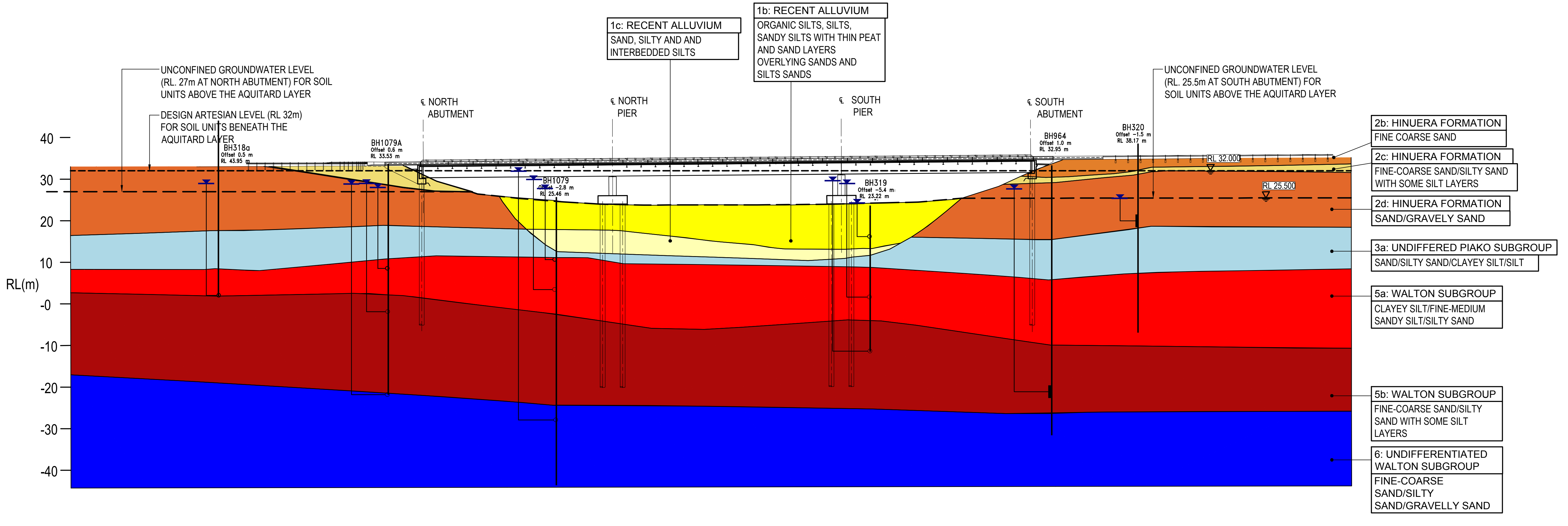
IF IN DOUBT ASK.

Drawing Plotted: 19 April 2017 3:55 p.m.

NOTES:

1. REFER TO GEOTECHNICAL DESIGN REPORT FOR FURTHER DETAILS ON GROUNDWATER CONDITIONS.





1 SB-XX020 SECTION ELEVATION
SCALE 1:500

ORIGINAL DRAWING IN COLOUR

FOR INFORMATION
NOT FOR CONSTRUCTION

No.	Revision	By	Chk	Appd	Date
A	FOR INFORMATION	GB	AT	GWK	30.03.17

Path: R:\Delivery Phase\CAD\Drawings

CITYEDGE

Original Scale (A1) 1:500	Design	A. THOMAS	19.04.17
	Drawn	R. STEENBERG	19.01.17
Reduced Scale (A3) 1:1000	Dsg Verifier		
	Drg Check		

NZ TRANSPORT AGENCY
WAKA KOTAHI
Hamilton Section
Waikato Expressway
NZTA 2/09 - 015/602
SH01N RS 534 /0 to RS 557/2720

WAIKATO EXPRESSWAY
HAMILTON SECTION
MANGAONUA STREAM BRIDGE

MANGAONUA STREAM GULLY
GEOLOGICAL SECTION

HYDROGEOLOGY
PROJECT NUMBER - DISCIPLINE CODE -
3311244-DR-GH-74021 A
DOCUMENT CODE SECTOR, SEQUENTIAL NO.

DO NOT SCALE

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Beca Project No. 3311244 Document No. 3311244-DR-GH-74021.dwg

Appendix B

Bentonite Hydraulics

The Fletcher Construction
Company Limited trading
as **Brian Perry Civil**

Level 2, 810 Great South Road, Penrose
PO Box 112 150, Penrose
Auckland 1642, New Zealand

Tel +64 9-526 3500
www.brianperrycivil.co.nz

BRIAN PERRY CIVIL

01/05/2017

Attention: Luke Clark
Email: luke.clark@cityedgealliance.co.nz

Regarding: Waikato Expressway – Hamilton Section – Mangaonua Gully – Bored Piles Hole Stability

Our Reference: GP086.9-REP001-E

Dear Luke,

Introduction

As part of the Hamilton Section of the Waikato Expressway, City Edge Alliance are constructing a bridge over the Mangaonua Gully. The bridge requires the construction of 30 No. bored piles Ø1200mm. The piles are expected to penetrate an artesian aquifer, which is reported to have an artesian pressure head to RL +32.0m.

In order to maintain a stable borehole and avoid collapse during drilling and installation, bentonite drilling fluid will be used to stabilise the hole. This memo discusses the following:

- Required minimum level of bentonite fluid to maintain a stable borehole under artesian pressures;
- Limiting drilling bucket extraction speed to avoid turbulent flow in the hole.

This memo supersedes any previous revisions of our memo GP086.9-REP001.

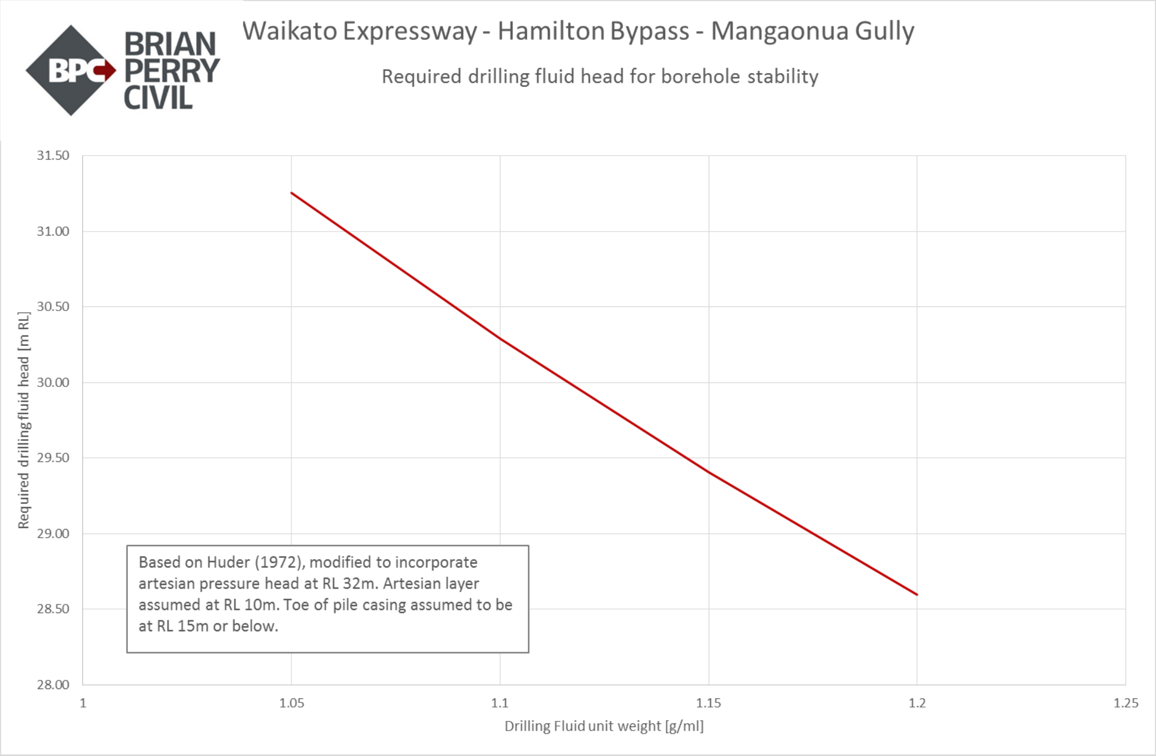
Design Parameters

- The pressure head of the artesian aquifer is reported at 8.5m (RL +32.0m) above current ground level (at RL 23.5m). This must be verified prior to construction;
- The top of the artesian aquifer is located at approximately 13.5m below current ground level (RL +10.0m);
- A steel casing will be installed in the ground to RL +15.0m or deeper;
- Bentonite mass density will need to be confirmed, but is expected to be between 1.05 and 1.2 g/ml;
- Horizontal ground pressures have been calculated as per Huder (1972);
- An overall unit weight of 20kN/m3 has been assumed for the calculations, with an internal friction angle of $\varphi' \geq 35^{o}$;
- The coefficient of horizontal earth pressure K has been taken as $K_0 = 1 - \sin(\varphi')$.

Drilling Fluid Level

In order to maintain a static equilibrium, the total pressure of the bentonite fluid column must exceed the horizontal earth pressure plus pore water pressure at all depths below the toe of casing.

We have calculated the required head of the bentonite fluid column for a range of different bentonite fluid mass densities, using the method of Huder (1972), which has been modified to incorporate artesian pressures. The result is shown in Figure 1. Calculations are included in Appendix A.



It should be noted that the calculated head is based on equilibrium and we recommend to maintain a certain redundancy (e.g. 1m) above the calculated head to allow for uncertainties in the artesian pressure. Losses due to drilling should also be taken into account when considering the minimum bentonite fluid head.

Extraction Velocity of Bucket

When extracting the bucket, the bentonite fluid can be forced into turbulent flow, which may lead to erosion or collapse of the borehole wall. In order to reduce this risk, the extraction velocity of the bucket must be limited so as to keep the Reynold's number of the annulus flow below the critical Reynold's number. The critical Reynold's number is dictated by the mass density, yield stress and plastic viscosity of the bentonite fluid. The Reynold's number is dictated by the wet perimeter and area between the bucket and the wall, as well as the mass density and plastic viscosity of the bentonite.

Testing of the bentonite fluid will be conducted as part of the QA process and this will confirm these parameters. Based on these parameters, the site team will be informed of the limit extraction velocity of the bucket.

Yours faithfully
Brian Perry Civil

Ronald Damen
Senior Geotechnical Engineer

Dr. Martin Larisch
Geotechnical Engineering Manager

Appendix A – Calculations Borehole Stability

BRIAN PERRY CIVIL

Borehole Stability under Artesian Pressure

Using Huder (1972) method for borehole stability

Project	**Waikato Expressway - Hamilton Bypass - Mangaonua Gully**	Job No.	GP086-9	Rev.	E
		Made by	RD	Date	1/05/2017
Subject	Required drilling fluid head for borehole stability	Checked by	ML	Date	1/05/2017
		Sheet No.	1	of	3

Ground water table	+23.5	[m RL]
Ground level	+23.5	[m RL]
Top of artesian layer	+10.0	[m RL]
Artesian pressure head	+32.0	[m RL]
Level of bottom casing	+15.0	[m RL]
Level of pile toe	-21.0	[m RL]
Unit weight soil	20	[kN/m3]
internal friction angle soil	35	[deg]
Depth increments	0.5	[m]
Pile Diameter	1.2	[m]

K 0.43 [-]

Bentonite Unit Weight	1.05	1.1	1.15	1.2	[g/ml]
Maximum $s_{required}$	7.75	6.79	5.91	5.10	[m]
Required Drilling Fluid Head level	31.25	30.29	29.41	28.60	[m RL]

Level [m RL]	Depth [m bgl]	u [kPa]	σ_v [kPa]	σ_v' [kPa]	n [-]	A [-]	σ_h [kPa]	$s_{required}$ [m]	$s_{required}$ [m]	$s_{required}$ [m]	$s_{required}$ [m]
23.5	0	0	0	0	0.00	1.00	0.0	0.0	0.0	0.0	0.0
23	0.5	5	10	5	0.42	0.89	0.0	0.0	0.0	0.0	0.0
22.5	1	10	20	10	0.83	0.79	0.0	0.0	0.0	0.0	0.0
22	1.5	15	30	15	1.25	0.70	0.0	0.0	0.0	0.0	0.0
21.5	2	20	40	20	1.67	0.63	0.0	0.0	0.0	0.0	0.0
21	2.5	25	50	25	2.08	0.57	0.0	0.0	0.0	0.0	0.0
20.5	3	30	60	30	2.50	0.52	0.0	0.0	0.0	0.0	0.0
20	3.5	35	70	35	2.92	0.47	0.0	0.0	0.0	0.0	0.0
19.5	4	40	80	40	3.33	0.43	0.0	0.0	0.0	0.0	0.0
19	4.5	45	90	45	3.75	0.40	0.0	0.0	0.0	0.0	0.0
18.5	5	50	100	50	4.17	0.37	0.0	0.0	0.0	0.0	0.0
18	5.5	55	110	55	4.58	0.34	0.0	0.0	0.0	0.0	0.0
17.5	6	60	120	60	5.00	0.32	0.0	0.0	0.0	0.0	0.0
17	6.5	65	130	65	5.42	0.30	0.0	0.0	0.0	0.0	0.0
16.5	7	70	140	70	5.83	0.28	0.0	0.0	0.0	0.0	0.0
16	7.5	75	150	75	6.25	0.26	0.0	0.0	0.0	0.0	0.0
15.5	8	80	160	80	6.67	0.25	0.0	0.0	0.0	0.0	0.0
15	8.5	85	170	85	7.08	0.23	93.4	0.4	0.0	0.0	0.0
14.5	9	90	180	90	7.50	0.22	98.5	0.4	0.0	0.0	0.0
14	9.5	95	190	95	7.92	0.21	103.5	0.4	0.0	0.0	0.0
13.5	10	100	200	100	8.33	0.20	108.5	0.3	0.0	0.0	0.0
13	10.5	105	210	105	8.75	0.19	113.5	0.3	0.0	0.0	0.0
12.5	11	110	220	110	9.17	0.18	118.5	0.3	0.0	0.0	0.0
12	11.5	115	230	115	9.58	0.17	123.5	0.3	0.0	0.0	0.0
11.5	12	120	240	120	10.00	0.17	128.5	0.2	0.0	0.0	0.0
11	12.5	125	250	125	10.42	0.16	133.6	0.2	0.0	0.0	0.0
10.5	13	130	260	130	10.83	0.15	138.6	0.2	0.0	0.0	0.0
10	13.5	220	270	50	11.25	0.15	223.2	7.8	6.8	5.9	5.1
9.5	14	225	280	55	11.67	0.14	228.4	7.7	6.8	5.9	5.0
9	14.5	230	290	60	12.08	0.14	233.5	7.7	6.7	5.8	5.0
8.5	15	235	300	65	12.50	0.13	238.7	7.7	6.7	5.8	4.9
8	15.5	240	310	70	12.92	0.13	243.9	7.7	6.7	5.7	4.8
7.5	16	245	320	75	13.33	0.13	249.0	7.7	6.6	5.7	4.8
7	16.5	250	330	80	13.75	0.12	254.2	7.7	6.6	5.6	4.7
6.5	17	255	340	85	14.17	0.12	259.3	7.7	6.6	5.5	4.6
6	17.5	260	350	90	14.58	0.11	264.4	7.7	6.5	5.5	4.5
5.5	18	265	360	95	15.00	0.11	269.5	7.7	6.5	5.4	4.5
5	18.5	270	370	100	15.42	0.11	274.6	7.7	6.5	5.4	4.4
4.5	19	275	380	105	15.83	0.11	279.7	7.6	6.4	5.3	4.3
4	19.5	280	390	110	16.25	0.10	284.8	7.6	6.4	5.3	4.2
3.5	20	285	400	115	16.67	0.10	289.9	7.6	6.4	5.2	4.2
3	20.5	290	410	120	17.08	0.10	295.0	7.6	6.3	5.2	4.1
2.5	21	295	420	125	17.50	0.10	300.1	7.6	6.3	5.1	4.0
2	21.5	300	430	130	17.92	0.09	305.2	7.6	6.2	5.0	3.9
1.5	22	305	440	135	18.33	0.09	310.3	7.5	6.2	5.0	3.9
1	22.5	310	450	140	18.75	0.09	315.3	7.5	6.2	4.9	3.8
0.5	23	315	460	145	19.17	0.09	320.4	7.5	6.1	4.9	3.7
0	23.5	320	470	150	19.58	0.09	325.5	7.5	6.1	4.8	3.6
-0.5	24	325	480	155	20.00	0.08	330.5	7.5	6.0	4.7	3.5
-1	24.5	330	490	160	20.42	0.08	335.6	7.5	6.0	4.7	3.5
-1.5	25	335	500	165	20.83	0.08	340.7	7.4	6.0	4.6	3.4
-2	25.5	340	510	170	21.25	0.08	345.7	7.4	5.9	4.6	3.3
-2.5	26	345	520	175	21.67	0.08	350.8	7.4	5.9	4.5	3.2
-3	26.5	350	530	180	22.08	0.08	355.8	7.4	5.8	4.4	3.2
-3.5	27	355	540	185	22.50	0.07	360.9	7.4	5.8	4.4	3.1
-4	27.5	360	550	190	22.92	0.07	365.9	7.3	5.8	4.3	3.0

-4.5	28	365	560	195	23.33	0.07	371.0	7.3	5.7	4.3	2.9
-5	28.5	370	570	200	23.75	0.07	376.0	7.3	5.7	4.2	2.8
-5.5	29	375	580	205	24.17	0.07	381.1	7.3	5.6	4.1	2.8
-6	29.5	380	590	210	24.58	0.07	386.1	7.3	5.6	4.1	2.7
-6.5	30	385	600	215	25.00	0.07	391.1	7.3	5.6	4.0	2.6
-7	30.5	390	610	220	25.42	0.07	396.2	7.2	5.5	4.0	2.5
-7.5	31	395	620	225	25.83	0.06	401.2	7.2	5.5	3.9	2.4
-8	31.5	400	630	230	26.25	0.06	406.3	7.2	5.4	3.8	2.4
-8.5	32	405	640	235	26.67	0.06	411.3	7.2	5.4	3.8	2.3
-9	32.5	410	650	240	27.08	0.06	416.3	7.2	5.3	3.7	2.2
-9.5	33	415	660	245	27.50	0.06	421.4	7.1	5.3	3.6	2.1
-10	33.5	420	670	250	27.92	0.06	426.4	7.1	5.3	3.6	2.0
-10.5	34	425	680	255	28.33	0.06	431.4	7.1	5.2	3.5	2.0
-11	34.5	430	690	260	28.75	0.06	436.5	7.1	5.2	3.5	1.9
-11.5	35	435	700	265	29.17	0.06	441.5	7.0	5.1	3.4	1.8
-12	35.5	440	710	270	29.58	0.06	446.5	7.0	5.1	3.3	1.7
-12.5	36	445	720	275	30.00	0.06	451.5	7.0	5.0	3.3	1.6
-13	36.5	450	730	280	30.42	0.06	456.6	7.0	5.0	3.2	1.5
-13.5	37	455	740	285	30.83	0.05	461.6	7.0	5.0	3.1	1.5
-14	37.5	460	750	290	31.25	0.05	466.6	6.9	4.9	3.1	1.4
-14.5	38	465	760	295	31.67	0.05	471.7	6.9	4.9	3.0	1.3
-15	38.5	470	770	300	32.08	0.05	476.7	6.9	4.8	3.0	1.2
-15.5	39	475	780	305	32.50	0.05	481.7	6.9	4.8	2.9	1.1
-16	39.5	480	790	310	32.92	0.05	486.7	6.9	4.7	2.8	1.1
-16.5	40	485	800	315	33.33	0.05	491.7	6.8	4.7	2.8	1.0
-17	40.5	490	810	320	33.75	0.05	496.8	6.8	4.7	2.7	0.9
-17.5	41	495	820	325	34.17	0.05	501.8	6.8	4.6	2.6	0.8
-18	41.5	500	830	330	34.58	0.05	506.8	6.8	4.6	2.6	0.7
-18.5	42	505	840	335	35.00	0.05	511.8	6.7	4.5	2.5	0.7
-19	42.5	510	850	340	35.42	0.05	516.9	6.7	4.5	2.4	0.6
-19.5	43	515	860	345	35.83	0.05	521.9	6.7	4.4	2.4	0.5
-20	43.5	520	870	350	36.25	0.05	526.9	6.7	4.4	2.3	0.4
-20.5	44	525	880	355	36.67	0.05	531.9	6.7	4.4	2.3	0.3
-21	44.5	530	890	360	37.08	0.05	536.9	6.6	4.3	2.2	0.2

Borehole Stability under Artesian Pressure

Using Huder (1972) method for borehole stability

Project	**Waikato Expressway - Hamilton Bypass - Mangaonua Gully**	Job No.	GP086-9	Rev.	E
Subject	Required drilling fluid head for borehole stability	Made by	RD	Date	1/05/2017
		Checked by	ML	Date	1/05/2017
		Sheet No.	2	of	3

Horizontal pressure on boreholes is calculated using the method of Huder (1972), as follows:

$$\sigma_h = u + A \cdot K \cdot \sigma'_v$$

With:

σ_h	Total horizontal pressure [kPa]
u	Pore water pressure [kPa]
σ'_v	Effective vertical stress [kPa]

$$K = 1 - \sin\varphi'$$

With:

K	Coefficient of horizontal earth pressure [-]
φ'	Effective internal friction angle [°]

$$A = \frac{1 - e^{-2nKtan\varphi'}}{2nKtan\varphi'}$$

With:

$$n = \frac{z}{D}$$

With:

z	Depth [m]
D	Pile Diameter [m]

Required drilling fluid head s is dependent on drilling fluid unit weight and should resist the earth pressure at any depth z below the casing, so that:

$$s \geq \frac{\sigma_h}{\gamma_{df}} - z$$

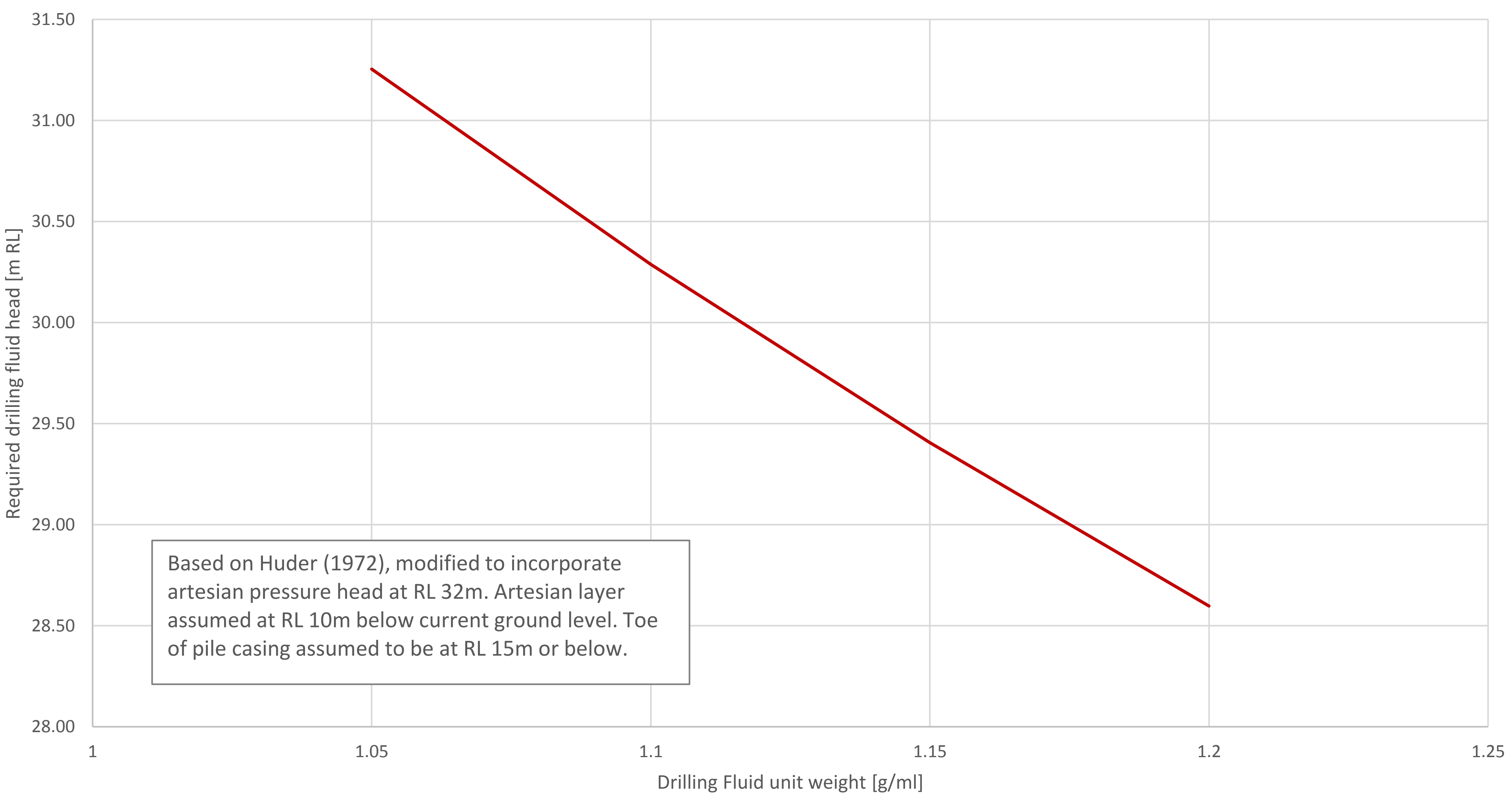
With:

s	Drilling fluid head above ground level [m]
γ_{df}	Unit weight of drilling fluid [kN/m^3]
z	Depth [m]

Ref: Huder, J., *Stability of bentonite slurry trenches with some experiences in Swiss practice* , Fifth European conference on soil mechanics and foundation engineering, Madrid, 1972, pp 517-522.

Waikato Expressway - Hamilton Bypass - Mangaonua Gully

Required drilling fluid head for borehole stability



Based on Huder (1972), modified to incorporate artesian pressure head at RL 32m. Artesian layer assumed at RL 10m below current ground level. Toe of pile casing assumed to be at RL 15m or below.