P & G Enterprises

Kaikatia Road Groundwater Effects Assessment

Report 1434-1-R1

Jens Rekker
Lincoln Agritech Ltd

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Lincoln/Head Office

Lincoln Agritech Limited / Engineering Drive / Lincoln University
PO Box 69133 / Lincoln / Christchurch 7640 / New Zealand

P +64 3 325 3700 / **F** +64 3 325 3725

Hamilton/Regional Office

Ruakura Science Centre / East Street
Hamilton 3240 / New Zealand

P +64 7 858 4840

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ACTION	NAME	SIGNED	DATE
Prepared By	**Jens Rekker**	[signature]	10/7/2018
Reviewed By	Scott Wilson	[signature]	10/7/18
Approved By	Blair Miller	[signature]	10/7/18.

EXECUTIVE SUMMARY

P & G Enterprises proposes establishing an orchard with 7 ha of avocado canopy within the 11.3 ha property at 12 Kaikatia Road, Northland. The proposed orchard requires seasonal irrigation to maintain tree health and fruit production in the climate prevailing in this part of Northland. The orchard also lies over the Aupōuri Sand Aquifer, and recent drilling success of a neighbouring water bore laterally about 95 m northwest from a proposed bore position provides indications that irrigation water would best be obtained from a basal sand & shell-bed layer at a depth of 70 m to 75 m below ground level. Estimation of the required irrigation supply from the aquifer based on soil-moisture modelling and measured avocado water uptake rates indicates a maximum irrigation season volume of 4,000 cubic metres per hectare (m^3/ha/year), or a total of 28,000 m^3/year. This would be the basis of the projected groundwater abstraction proposal.

P & G Enterprises propose sinking a bore to depths below ground level of 70 m to 75 m, and screening the water bore within the sand & shell-bed layer projected to be located there. Estimates of the yield and groundwater properties of the water-bearing layer tapped by the proposed bore were taken from a recent omnibus application in the neighbouring Motutangi groundwater allocation zone, and the experience of the recently drilled domestic bore adjacent to 12 Kaikatia Road. These suggested the sand & shell-bed water-bearing layer would readily provide 4 to 5 litres per second, aquifer transmissivity could be estimated as 380 square metres per day and the storage coefficient for the semi-confined aquifer could be estimated as 4.4×10^{-3}.

Several conceptual and calculated assessments of potential groundwater environment effects were then undertaken. The effect of the proposed groundwater take was calculated using the Theis Equation and relevant equation parameters. The estimated groundwater pressure decline resulting from 217 days of pumping at 350 cubic metres per day (4 litres per second) indicated that relatively small effects would extend beyond the properties' boundaries and be potentially experienced at adjoining water bores out to 2 kilometres. However, the maximum level of effect would be approximately 0.4 m on the closest bore. Note also that the neighbouring domestic bore located approximately 95 m to the northwest of the proposed new bore site is covered by a written approval for the proposed activity and therefore does not require consideration as an affected bore as part of competitive interference effects assessment. Fully penetrating bores meeting the 'efficient bore takes' definition in Policy 10.5.1 of the Regional Water and Soil Plan for Northland typically have a clearance of lowest water level of 35 m to 67 m above pump intakes. Therefore, drawdown effects in the range of 0 to 0.4 m would have less than minor impact on the ability of surrounding water bores to continue in their function.

The potential for the proposed pumping to cause depletion in the flow rate of either Kaikatia or Korakonui creeks was assessed. In view of the low permeability subsoil peats or pans, and the highly conservative calculations of depletion using the Hunt and Scott (2007) method, the possibility of depletion reaching 3.8 litres per second of the total 4 litres per second pumped from the basal sand & shell-bed layer seems unlikely. However, the calculations would constrain the depletion to less than 15 % of estimated creek base flow.

Saline intrusion has been examined as a potential effect of cumulative pumping from the Aupōuri Sand Aquifer, including examination of the groundwater pressure monitoring network and the setting of preliminary zone allocation limits. The projected drawdown in the deeper, semi-confined sand & shell-bed layer water pressure by 0.2 m at the coast line is not considered to endanger the aquifer with seawater intrusion risks as above sea level pressures measured at the coast line would be maintained. Assessments of the potential for the P & G Enterprises' groundwater pumping activities to induce or exacerbate saline intrusion found that the activity would not cause the preliminary zone allocation limit to be exceeded, nor would the measured or inferred groundwater pressures present in the aquifer surrounding the proposed bore site reveal any vulnerability to vertical saline intrusion, such as up-coning.

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1. INTRODUCTION

1.1 Background

P & G Enterprises is considering the re-development of their 11.3 ha rural residential property to higher value horticultural production The P & Enterprises property is located at 12 Kaikatia Road, Houhora. (see Figure 1 for location). The re-development would require installing efficient irrigation systems to 7 ha of avocado canopy, tailored to the avocado orchard planned for the property. Critical to the development of irrigation is the installation of headworks and consenting of water resources found beneath the property. This report is intended for the purpose of assessing some environmental effects of the proposed re-development, specifically for inclusion in an Assessment of Effects on the Environment in terms of the requirements of the Resource Management Act (1991).

Figure 1: Location of Aupōuri Sand Aquifer (outlined in red) and the 12 Kaikatia Road locality

Up to 28,000 cubic metres per annum (m^3/year) would be drawn from the Aupōuri Sand Aquifer (Wilson & Shokri, 2015) in accordance with this proposal. The taking of groundwater would be wholly within the Northland Regional Council (NRC) groundwater indicative or preliminary allocation zone named Houhora (see Table 1).

Table 1: Proposed groundwater take and corresponding NRC Groundwater Allocation

Locality	Indicative Irrigation Area (ha)	Proposed Annual Volume (m^3/year)	NRC Groundwater Allocation Zone
12 Kaikatia Road	7	28,000	Houhora

Note: Houhora Zone is considered to be allocated in consents to a Moderate level (from 25% to 75% of the preliminary allocation limit).

Any application seeking the change to irrigated land use and accompanying groundwater abstraction requires an assessment of any environmental effects in terms of groundwater impacts. The groundwater effect assessment herein includes consideration of the regional groundwater allocation context, potential localised effects and potential seawater intrusion effects.

Lincoln Agritech and its Environmental Research Group are the writers of the most recent aquifer-wide groundwater allocation assessment of the Aupōuri Sand Aquifer (Wilson & Shokri, 2015). This report has been the basis of Northland Regional Council's release of indicative or preliminary groundwater quantity and allocation limits for the Aupōuri Sand Aquifer. The Wilson & Shokri (2015) groundwater resource investigations included exhaustive numerical analysis of the aquifer, including the Waihopo – Houhora area. This investigation and the body of knowledge that it provided has assisted with the preparation of this assessment of the P & G Enterprises proposal.

1.2 Assessment Objectives

The primary objectives are intended to address the requirements of the Resource Management Act 1991 for technical supporting information. In particular, the associated objectives can be listed as follows:

1. Define and characterise the existing hydrogeological / hydrological environment to provide context for the assessments, any mitigation and monitoring proposals.
2. Assess the potential for any foreseeable groundwater effects.
3. Address the possible need for mitigation of identified groundwater effects.
4. Specify the need and nature of ongoing monitoring that may be required in connection with the proposed groundwater abstraction.

2. EXISTING ENVIRONMENT

2.1 Location & Topography

The 12 Kaikatia Road property is located to the northwest of Pukenui Township, immediately inland of Houhora Harbour, Northland. The property lies within the Far North District and Northland Region, and administered by the respective councils accordingly.

Relief across the area is dominated by the effects of wind-blown sand accumulating in the large-scale isthmus / tombolo between the basement blocks at Kaitaia and Cape Reinga – North Cape. Ninety Mile Beach along the Tasman Sea littoral defines the western margin of the sand ridge. The sand ridge achieves heights up to 100 metres Above Mean Sea Level (m AMSL) to the west. Within the property, the topography is more characterised by flats and stream gullies.

2.2 Land Use

Land use includes farming and rural residential occupation. Aquiculture in the form of Pacific Oyster farms is undertaken in Houhora Harbour to the east. Extensive grazing of sheep and cattle on sand flats adjoins an extensive area of plantation forestry named Aupōuri Forest along its western edge. Significant areas of horticulture are found at Houhora, mainly for avocados.

2.3 Soils

As one would expect, the soil classifications are dominated by those conforming to the Aeolian sand parent lithology. Sandy Recent soils and Sandy Recent soils with a silt loam as variant are found in the western margin of the sand flats. These are also classed as 'drifting or recently stabilised'. Figure 2 shows the somewhat dated DSIR New Zealand Soil Bureau (Sutherland et al, 1979) map of the P & G Enterprises' property.

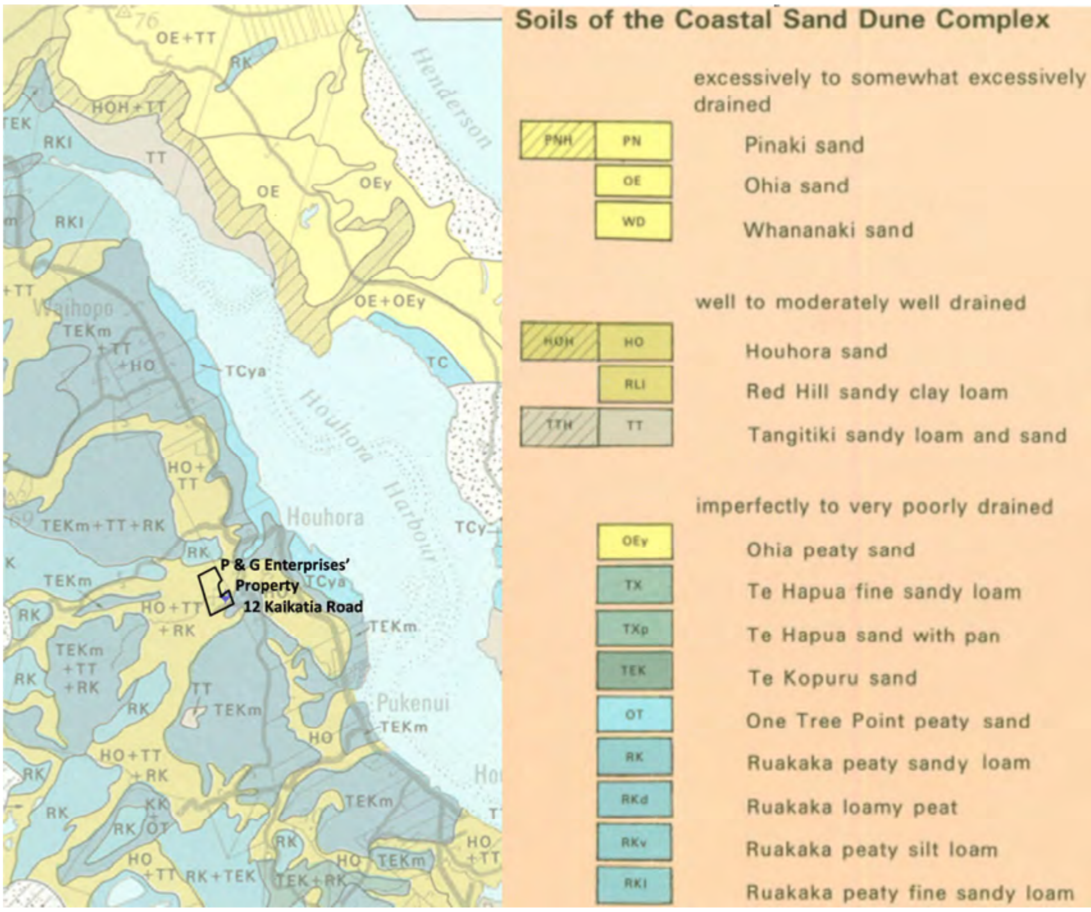

Figure 2: Soil Bureau map of the Houhora area (Sutherland et al, 1979)

The soil classes are shown primarily as those of coastal sand dune complexes. The genetic soil classifications range from the very well drained Houhora sand and Tangitiki sandy loam / sand to less well drained (imperfectly to poorly drained) Te Kopuru sand and Ruakaka peaty sandy loam. The soil classification and soil physical properties would seem to correlate strongly with the geological, hydrological or vegetation environment active at the time of soil formation. Houhora sand soils tend to be associated with southwest – northeast trending gullies along stream drainages. The Houhora sand soil is arguably a Recent sand soil. Te Kopuru sand soils, by contrast, tend to be associated with slacks or flats between dunes. The Ruakaka peaty sandy loam tends to be closely associated with the sites of former inter-dune wetlands (swamps, marshlands or bogs).

In general, the soil water retention properties of the property's soils are low to moderate. Te Kopuru sand and sandy loam variants are considered to have a readily available water capacity of approximately 37 mm. Houhora sand soils have higher median readily available water capacity that places them in the moderate range at approximately 69 mm. Peat soils such as Ruakaka are mid-way between Te Kopuru and Houhora at an readily available water capacity of 50 mm. The property's soils are permeable to the base of the rooting layer and will retain low quantities of water in moisture stores. However, hard-pans and iron-pans may form the sub-soil in places. The impact of sub-soil conditions on superficial hydrology is discussed further in section 4.3.2.

2.4 Climate

The climate is dominated by a succession of anticyclones and intervening troughs of low pressure which approach from the west across the Tasman Sea. These weather systems give rise to climatic conditions characterised by very humid and warm summers and mild winters.

The airflow over Northland is predominantly from the southwest. This is particularly so in winter and spring, but in summer the proportion of winds from the easterly quarter, especially in eastern districts, about equals that from the southwest. Airflows tend to determine the timing of temperature changes and rainfall. The area's northern maritime situation enables its lengthy coastlines to be bathed by warm oceanic currents, from which sea breezes ensure that temperatures on the land are moderated. Mean annual air temperature ranges between 15.5℃ to 16.5℃ on the Aupōuri Tombolo. Rainfall is influenced to a large extent by subtropical depressions occurring during winter, with the result that the wettest months are May, June, July and August. The driest period usually extends from December to March except in years of summer cyclonic activity.

Table 2: Monthly / annual rainfall normals in millimetres and as a percentage of annual total for each month

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Cape Reinga	mm	58	65	56	109	96	103	128	95	85	61	57	76	988
	%	6	7	6	11	10	10	13	10	9	6	6	8	
Kaitaia Observatory	mm	85	93	81	96	135	151	169	144	128	99	87	100	1367
	%	6	7	6	7	10	11	12	11	9	7	6	7	
Kaitaia Aero EWS	mm	69	121	86	119	138	125	136	104	93	93	73	99	1253
	%	5	10	7	9	11	10	11	8	7	7	6	8	

Note: Month labels abbreviated to the first three letters of the month, e.g. Jan = January; Ann = Annual

Recent soil moisture water balance modelling (Wilson & Shokri, 2015) considered a range in annual rainfall from 850 to 1,670 mm/year (average 1,280) across the Aupōuri Sand Aquifer with a trend in increasing rainfall total to the south.

2.5 Geology

The Houhora area is geologically characterised as a sand tombolo joining the basement rock outcroppings at Kaitaia and North Cape – Cape Reinga. A tombolo is a sand bar that connects the mainland with an island, and is formed by longshore drift. The Aupōuri tombolo comprises marine sands; and semi to unconsolidated dune sands that have been deposited and reworked as part of the post-Pleistocene to Holocene geomorphology of the area. The formation of sand dunes represented in residual sand deposits date from the last and penultimate interglacial periods, as old as oxygen isotope stage 5 (IO5) in the Eemian. The older sand dunes are commonly eroded to a more round profile compared to Holocene age (oxygen isotope stage 1, IO1) dunes, which have sharper crests and are more prominent in the contemporary landscape. The western side of the Aupōuri landform is extensively 'blown out', while eastern side tends to retain primary land features and a soil mantle.

Sand dunes were deposited and re-worked as arcuate, coast-parallel ridges of several metres height above their surrounds. Back-dune and dune slack deposits such as peat swamps are found and often over-ridden by young dune deposits. In the Houhora area, individual dune development processes have combined and amplified to produce an indistinct, coast-parallel crest alignment approximately equidistant between Houhora Harbour and Ninety Mile Beach. The crest is partially deflated in a few areas with blown-out breaks at elevations as low as 50 m AMSL. The more prominent crest peaks have elevations of 70 – 100 m AMSL.

Inter-dune wetland and lacustrine sediments include soft peat sand or mud; plus muddy sandstone, sandstone, carbonaceous mudstone and stiff peat gradational to low grade lignite in areas where consolidation has been more of a feature. The deeper sands were deposited in a shallow marine environment and can be identified by their blue-grey colour and the presence of shells which become more abundant towards the aquifer base (sand and shell-beds). The local convention is to call the marine sands "shell-beds" when the concentration of shells exceeds about 30%. The presence of shells in water well bore logs has been recorded as being from 0.2 to 32 m in thickness, with an average of 7 m. The thickness of the shell beds also seems to be greater in deeper bores, and shell beds tend to be found towards the basement contact. So far, these shell-rich sands have been found predominantly south of the northern end of Houhora Harbour (Waihopo Stream) where they appear to be ubiquitous in the marine sands deposited immediately above the basement.

The sand deposits are laid onto an erosional surface of the Rangiawhia Volcanics of Cretaceous age. The Rangiawhia Volcanics comprise flows of basalt, pillow lavas and basaltic andesite, interbedded with rhyolitic tuff and tuff-breccia. The base of Quaternary deposits is found at variable depths under basement structural controls. The chief control on the depths of the Cretaceous-Tertiary to Quaternary contact in the Houhora area is the action of a buried pre-Quaternary fault. Interpretation of data from the Northland airborne magnetic survey (Stagpoole et al. 2012) provides insight into the basement structure. In particular, a regional-scale fault can be inferred from the Bouger anomaly maps. The fault is shown on Figure 3 together with structure contours on the aquifer base (Wilson & Shokri, 2015). This follows a bearing of around 280˚ from Waihuahua swamp and turns towards a bearing of 300˚ near the start of Hukatere Road, and eventually goes offshore at Ninety Mile Beach at a point about 20km northwest of Hukatere. This structure was interpreted by Stagpoole *et al.* (2012) to represent the northern boundary of Permian Caples Terrane basement rocks, and is therefore a major crustal feature.

The interpolation of basement intercepts on either side of this feature shows that the basement dips in different directions (see Figure 3). In the southern domain, the basement dips quite steeply to the west-northwest, parallel to the strike of the fault. In the northern domain, the basement dip is considerably more shallow, and to the south-southwest. This means that the Aupōuri Aquifer is thickest along Ninety Mile Beach to the north of Hukatere, where the basement may be over 200 m deep as the fault is approached. In the northern domain, the aquifer is much thinner, and is expected to be less than 40m along Ninety mile beach. The northern domain is thickest along the eastern edge of the fault at Waihuahua swamp, where the basement may be over 100m deep. The fault is expected to pre-date deposition of the Quaternary sand sequence. The significance of suspected scissor faulting is that the displacement is least across the fault in the more easterly Motutangi – Waiharara groundwater allocation zone, to the point that the offset is barely discernible in the depth to basement in bore logs recorded on either side of the inferred fault (Hangjian and Williamson, 2017). The property lies wholly on the up-thrown side of the inferred fault as is clear from Figure 3.

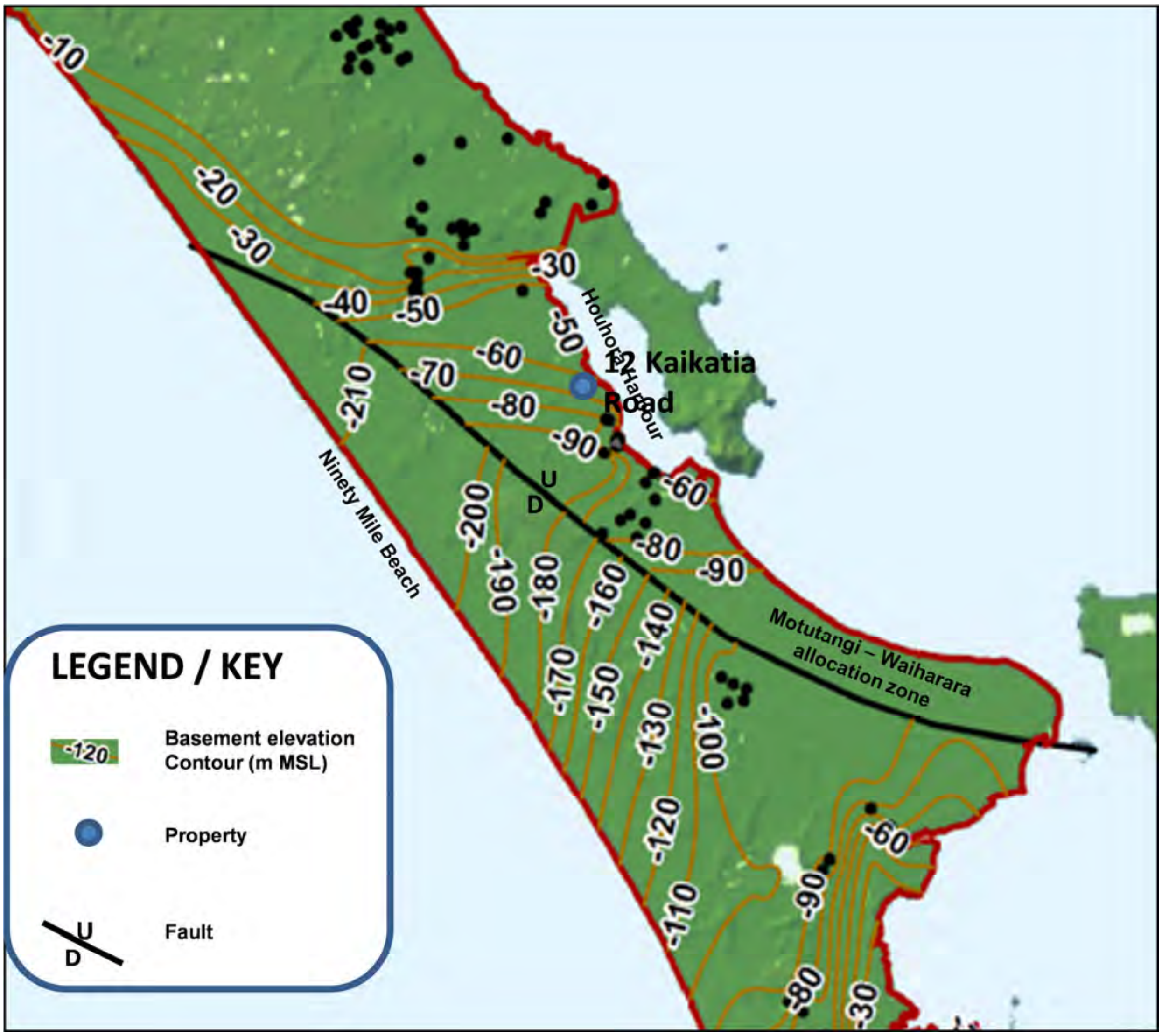

Figure 3: Basement contact elevation contours and buried, pre-Quaternary fault (Wilson & Shokri, 2015)

2.6 Hydrology

Sub-soil permeability and groundwater conditions have a significant influence on the hydrology of the Houhora – Waihopo area. Much of the Aupōuri Forest land to the west is mantled in sandy Recent soil and drains primarily to the water table. This mode of hydrology is provided by the high permeability of the thin sandy soil and is indicated by the relative absence of surface water channels or wetlands within the Forest. By contrast, the Te Kopuru and Ruakaka soils classes are imperfectly to poorly-drained and tend to require land drainage in order to avoid water logging. Consequently, open farm drains, wetlands or small lakes, and perennial streams arise in these less well drained soils and underlying peat soils. Drains and streams around the property are predominantly fringed by Houhora sand and Tangitiki sandy loam soils.

Iron pans have developed in the sub-soils under some areas of wetlands, further occluding the infiltration of surface water excess from joining the underlying water table. Soil moisture water balance modelling of three such contrasting hydrological zones (Hangjian and Williamson, 2017) indicated a transition in the balance of groundwater recharge and runoff to surface water. Loose, permeable sands associated with Recent and Houhora soils shed soil moisture predominantly to groundwater recharge. Peat soils overlying iron pans were modelled to contribute most excess to surface runoff and a small fraction to groundwater recharge (see Table 3).

Table 3: Summary of Motutangi – Waiharara hydrological zonation as expressed in relative modes of drainage

Hydrological Zone (Motutangi – Waiharara)	Groundwater recharge	Evapo-transpiration	Surface Runoff	Relevant Characteristics
Coastal sand zone	43%	52%	5%	Loose and permeable sand, high soil infiltration and percolation rate and moderate moisture storage.
Weathered sand zone	38%	54%	8%	More consolidated sand texture, lower infiltration and percolation rates that coastal sand and moderate moisture storage.
Plain / Wetland Zone	10%	56%	34%	Peat overlaying iron pan surface deposits particularly in wetlands areas, low infiltration capacity and medium soil moisture storage.

Note: Reproduced in part from Hangjian and Williamson (2017) in relation to Motutangi – Waiharara allocation zone landscape. The hydrological zones may not be directly comparable to Houhora – Waihopo zones.

Several surface streams cross Trig Flat to Houhora Harbour, including Korakonui and Kaikatia, Waimamaku streams. Kaikatia Stream passes through the P & G Enterprises' property. These streams rise from small lakes, residual wetlands and farm drains within farm land. Almost no surface water enters streams draining to the Tasman Sea, other than storm runoff, due to the thin to absent soil mantle and extremely well drained surface profile. No hydrological information is available for individual streams, although a weir is placed across Kaitatia Stream within the P & G Enterprises' property. The weir is reported to be 1.5 m wide with a water height over the weir crest of between 0.08 m and 0.30 m, which is broadly consistent with the catchment water balance in section 4.3.2 and an estimate of base flow being 30 L/s based on the equation for flow over a broad crested weir (see Equation 1, Chanson, 2004).

$$Q = 0.886\, B\, Hr^{3/2}$$

Equation 1 Where:

Q = stream base flow (m^3/s)

B = width of flow over weir (m)

H = Height of flow over weir (m)

2.7 Groundwater

The Aupōuri sand tombolo landform hosts the Aupōuri Sand Aquifer (Wilson & Shokri, 2015), covers a land area of 75,322 hectares and extends along the whole length of Ninety Mile Beach on the west coast, and from Kokota (The Sandspit) to Waimanoni on the east coast. It is a sandy aquifer, but also contains a significant proportion of clay and peat deposits that have formed between sand dunes, plus shell-beds that have been deposited in a marginal marine environment. The aquifer has been developed into a significant water resource for overlying crop and horticultural land uses, and for Kaitaia water supplies.

Geological and post-depositional processes have served to stratify the aquifer into vertically discrete water bearing layers, which have been defined in section 4.2. The aquifer has saturated depths up to 110 m in places, and has distinct higher permeability zones targeted by irrigations bores such as the coarse sand layers and shell-beds (Wilson & Shokri, 2015; and Hangjian and Williamson, 2017). Groundwater recharge is generally quite high in the coastal sand flats and weather sand flats, up to 550 mm per annum. Recharging soil water tends to percolate through unsaturated sand and clay/peat layers to the water table. Much of the active (i.e. recharge driven) groundwater flow in the aquifer's more natural state is in the unconfined and upper sand layers. Groundwater pumping of bores installed in lower sand or shell bed layers towards the aquifer's base tends to mobilise groundwater flow at these depths that would otherwise be slow to stagnant (Wilson & Shokri, 2015). By definition the basal water-bearing layers are discharge driven rather than recharge driven. There is little if any evidence that aquifer layers or compartments are isolated from each other if a gradient exists for groundwater exchange.

There have been many reviews and re-analyses of aquifer test data within the Aupōuri Aquifer (GCNZ, 1987; HydroGeo Solutions, 2000; Wilson & Shokri, 2015; and Hangjian and Williamson, 2017). In general, coastal sand aquifers have a reasonably narrow range of hydraulic properties, such as transmissivity, hydraulic conductivity or storage than more heterogeneous terrestrial sediments as glacial outwash. Across the whole aquifer, hydraulic conductivity in successful bores as measured in pumping tests varied between 0.9 m/d and 13.5 m/d (Wilson & Shokri, 2015). A subsequent analysis focused on marine sand and shell-bed layers near Houhora and Pukenui indicated a range of 0.9 m/d to 63 m/d (Hangjian and Williamson, 2017).

The groundwater flow pattern has been investigated and interpreted in the Houhora area, initially by GCNZ (1987). A composite geological – hydrological profile drawn parallel to Hukatere Road is reproduced from GCNZ (*ibid*) showing what was interpreted from test drilling, piezometer installation and a water level survey. It is worthwhile noting that only two of the cross-sections piezometers were drilled down to basement, and the existence of the pre-Quaternary fault was yet to be highlighted by geophysics. Nonetheless, the results of electrical soundings were sufficient for GCNA to infer deepening of the basement contact to the west.

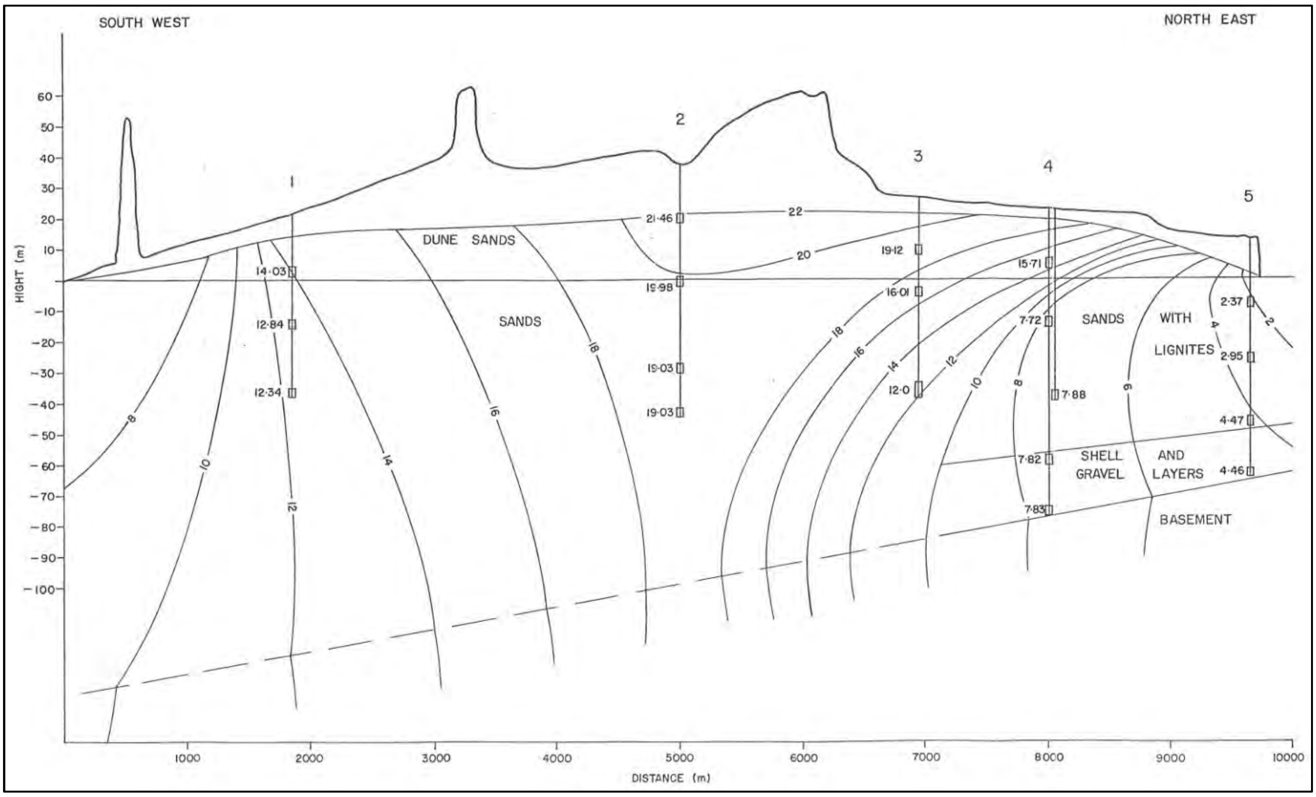

Figure 4: Interpretative hydrogeological cross section of Aupōuri Sand Aquifer Hukatere to Monkey Point, Houhora (GCNZ, 1987)

The interpretative cross-section includes contours of the groundwater level / pressure in the vertical plane as interpolated using multi-level piezometers. The cross-section level contours indicate the following:

- Recharge from the land surface, particularly beneath the tombolo crest
- Downward pressure gradient meaning that the pressure 'seen' by piezometers would be lower at greater depth, except for piezometer No. 5, which shows upwards pressure gradient on the Houhora Harbour shore line.
- The downward pressure gradient indicates infiltration of groundwater towards axis of the dunes under the pressure of groundwater recharge and upward gradients indicate discharge into the marine environment.

GCNZ (1987) used Darcy's Law equations to calculate a unit discharge for the Aupōuri Sand Aquifer to infer groundwater outflow at the Ninety Mile Beach and Houhora Harbour in the order of 4 to 40 L/s per kilometre of coast line.

3. GROUNDWATER ABSTRACTION PROPOSAL

P & G Enterprises intends to switch land use to avocado horticulture, which requires irrigation to sustain production. The irrigation supplies would be drawn from the Aupōuri Sand Aquifer directly beneath the areas to be irrigated. A provisional groundwater abstraction plan has identified that the installation of a single bore with a maximum capacity up to 5 L/s would suffice to provide the property with its irrigation requirements.

3.1 Reasonable and Efficient Use

The abstraction and irrigation plan is premised upon crop requirements of 4,000 cubic metres per hectare per year (m^3/ha/year) over 7 ha. This equates to an annual groundwater take of 28,000 m^3/year (0.028 Mm^3/year) from the Houhora groundwater allocation zone. The requirement was estimated within IrriCalc using the web-based tool provided by Irrigation New Zealand (mycatchment.info).

Table 4: IrriCalc Parameters and Results for P & G Enterprises' Avocado Crop

	Relevant Site Details	Water Requirement
Address	12 Kaikatia Road	
Latitude / Longitude	-34.801 173.101	
Area (ha)	7.0	
Estimated Profile Available Water (mm)	47.1	
System Capacity (L/s)		4.06
System Capacity (mm/d)		5
Daily Volume (m^3/d)		350
Annual/Seasonal Volume (m^3/year)		32,100, adjusted to 28,000 (or 4,000 m^3/ha)
Irrigation Season		Oct – May (up to 217 d)
Peak 90th %ile Monthly Water Requirement (m^3)		9,800 (Jan & Feb peak)

Northland Regional Council undertook an assessment of reasonable and efficient water use in relation to avocado growing on the Aupōuri Peninsula as part of Section 42A evaluation of consent number REQ-581172 by Motutangi-Waiharara Water User Group for 2124850 cubic metres of groundwater from the Aupōuri Sand Aquifer (Stride, 2018). This assessment was based on a review of local actual water use for five avocado orchards irrigated in the Aupōuri Peninsula undertaken by Northland Regional Council. Estimate crop water requirements were calculated using the Council's SPASMO tool. The average water use rates varied between 1,260 m^3/ha/year and 3,480 m^3/ha/year, while maximum usage in a drought year (2012-13) ranged between 2,570 m^3/ha/year and 4,830 m^3/ha/year. The proposed maximum rate of 4,000 m^3/ha/year thus provides security of supply for the orchard operation, while resting within the range of peak seasonal water use volumes. In these respects the proposed use of groundwater for avocado horticulture meets the definition of being reasonable and efficient.

3.2 Water Source

Drilling targets based on past drilling and well development experience, include the following:

- Marine sand aquifer beneath the terrestrial sand & peat horizon, or
- Sand & shell-bed aquifer, also known as 'shell-beds' at the base of the Quaternary sequence.

The **sand & shell-bed aquifer** has been encountered in a domestic bore with favourable yield within a short distance of the property (see Table 5), which indicates that this horizon is the most likely source for meeting irrigation demand.

A water well has recently been sunk by Jonathon Brereton on his property neighbouring P & G Enterprises' land on Kaikatia Road. The drilling and bore construction was undertaken by Kiwi Welldrillers Ltd. Table 5 to provides a summary of Brereton bore information relevant to the yet-to-be-drilled P & G Enterprises' bore.

Table 5: Dimensions and Characteristics of Brereton bore

Dimension & Capacity	Value	Additional Details
Land Parcel	Lot 1 DP 392961 Houhora East SD	Kaikatia Road
Grid Reference (NZTM)	1609273 mE 6149054 mN	
Distance to Proposed P & G Enterprises' Bore (m)	95	Brereton Bore lies in the north-north-west direction
Depth (m BGL*)	70	Base of aquifer
Bore Diameter (m)	0.104	
Screen Length (m)	3	Screened in sandy shell-bed layer
Depth to Top of Screen (m BGL*)	67	Basal screen
Pump Yield (L/s)	4.2	15 m^3/hour
End Use of water	Domestic	

Note: * BGL = Below Ground Level

Jonathon Brereton has provided an affected person's written approval to Geoffrey & Pauline Marchant (proprietors of P & G Enterprises) in relation to the proposed water take for irrigation, which is the subject of this document. The approval indicates that Jonathon Brereton is not an affected party. Accordingly, the set of assessments that follow do not consider the Brereton Bore or Mr Brereton's interests to groundwater.

4. GROUNDWATER ASSESSMENTS

4.1 Groundwater Pumping Schedule

The groundwater pumping proposed in summarised in Table 6, below:

Table 6: Schedule of proposed rates and volume that would be the basis of any water permit

Rate or Volume	Value	Comment
Peak application rate (mm/d)	5	Peak daily rate
Instantaneous maximum (L/s)	5	The proposed peak capacity of the single bore
Daily maximum rate (m^3/d)	350	Based on peak 5 mm daily application rate across 7 ha of irrigated land
Monthly maximum rate (m^3/month)	9,800	Based on 90th percentile estimate of the maximum volume of water required to irrigate 7 ha in highest demand month
Annual maximum volume (m^3/year)	28,000	Based on water demand of 4,000 m^3/ha/year and irrigated area of 7 ha
Period of irrigation season	October to May in any year	Based on analysis of climate, particularly evapo-transpirative demand across the hydrological year.

4.2 Sustainability of Proposed Bore Configuration

The primary drilling and bore screening target is the basal sand and shell beds. Figure 5 illustrates the hydro-stratigraphy of the Waihopo – Houhora compartment of the Aupōuri Sand Aquifer. Water bearing layers and water bore prospects are found within the following layering order and indicative lithologies:

Layer

1. **Dune (terrestrial) sand** between water table and the Holocene peat deposits found at sea level
2. **Dune (terrestrial) sand** between Holocene Peat and top of marine sand
3. **Marine, semi-confined sand** above sandy shell beds
4. **Sandy shell-beds**, confined to leaky in terms of pressure state.

Figure 5 illustrates the scheme of water bearing layers in accordance with the conceptual model of Wilson & Shokri (2015). Being depositional distinctions the boundaries between the layers is gradational, and not clearly defined. However, the scheme of water bearing layers is drawn from the synthesis of bore logs and hydrogeological interpretations.

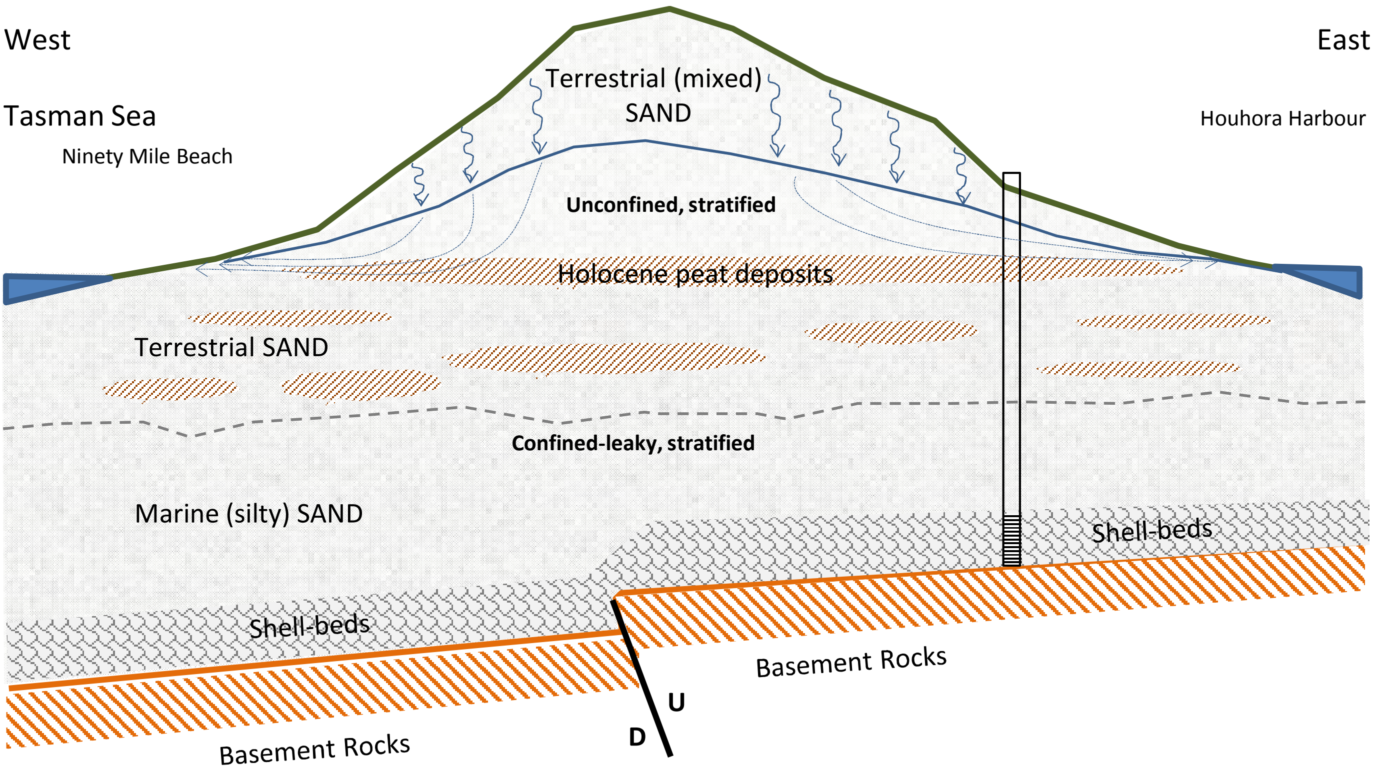

Figure 5: Schematic, exaggerated vertical scale Cross-section through the Aupōuri Sand Aquifer in vicinity of 12 Kaikatia Road

Figure 5 indicates that the depth of the water bore to be drilled down to the shell beds would be potentially predictable. Based on the 70 m depth of the neighbouring bore (see Table 5) tapping the shell bed aquifer and projection of Figure 3, a depth of 75 m below ground is anticipated. In general, deeper bores with conventional construction tend to have well hydraulics that favour higher pumping yield due to larger available self-induced drawdown freeboards.

The recent joint application by groundwater users in the Motutangi – Waiharara allocation zone included a technical analysis with a conceptual model of the Aupōuri Sand Aquifer immediately to the south of Houhora (Hangjian and Williamson, 2017). The hydro-stratigraphic model incorporated the validated results of most pumping and aquifer tests carried out for the respective layers in the Aupōuri Sand Aquifer and summarised in a table reproduced below in Table 7.

Table 7: Summary of Hangjian and Williamson (2017) hydraulic properties for Aupōuri Sand Aquifer

	Hydraulic Conductivity (m/d)			Storativity (m/m)		
	Minimum	Maximum	Arithmetic Mean	Minimum	Maximum	Arithmetic Mean
Layer 1 - Sand / silt	0.9	9.5	7.3	2.0E-04	1.5E-02	9.6E-03
Layer 2 – Upper shell-bed	18.1	63.1	31.5	2.0E-04	4.0E-04	3.0E-04
Layer 3 - Sand / silt (Assume as for Layer 1)	0.9	9.5	7.3	2.0E-04	1.5E-02	9.6E-03
Layer 4 – Lower shell-bed	11.2	63.1	38.0	3.0E-04	4.4E-03	1.6E-03

In the absence of site-specific aquifer and pumping test data for Houhora (or environs), the average value for hydraulic conductivity was adopted for each corresponding water bearing layer. The layer 1 to Layer 4 sand / shell bed sequence is saturated from the water table surface to basement. The geological basement is significantly less permeable and so can be considered the effective geo-hydrological basement.

The well construction configuration for an irrigation bore and connected aquifer is constrained by the following components as laid out in Figure 6:

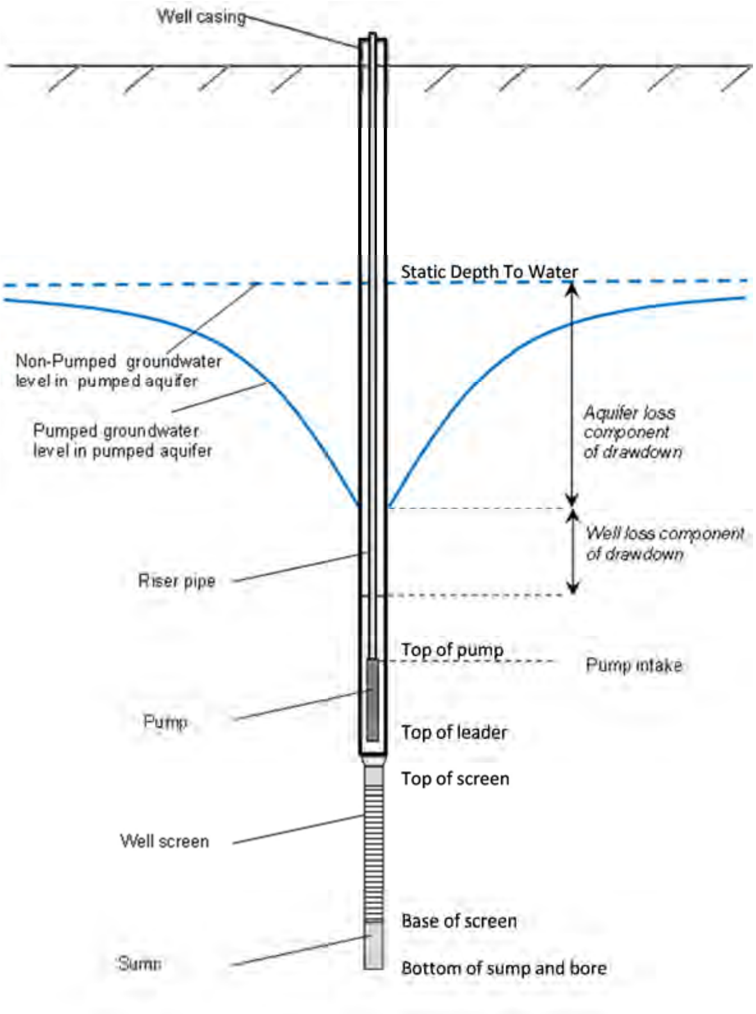

Figure 6: Schematic representation of the components of irrigation bore capacity

Table 8: Components Irrigation Bore capacity

Component	Explanation
Bore depth	This dimension dictates many of the associated dimensions relevant to the irrigation bore yield, such as base of screen, top of screen, top of leader and depth position of submersible pump intake
Top of pump & intake	The depth position of the pump intake is fundamental to the ability of the bore to tolerate pumping drawdown. Once pumping induced drawdown causes the internal water level to approach the Net Positive Suction Head (NPSH) the pump will suck air and pumping will need to shut down.
Well losses	These are the head losses related to the net hydraulic efficiency of the well as a whole. High well screen efficiency minimises well losses and the converse increases well head losses.
Aquifer loss	Head losses (aquifer drawdown) due to aquifer properties are inherent to the aquifer and water bearing layer across which the bore is screened.
Static Depth To Water (DTW)	This is the initial, pre-pumping water level from which the drawdown is added onto for the dynamic (pumping) water level.

The calculation of the interaction of these components allows the theoretical prediction of the capacity of an irrigation bore. For the nine proposed irrigation bores, estimates can be made of well dimensions relative to the maximum depth available to the bore with respect to the inferred depth to basement. Table 9 lists the depths and length dimensions used in the equation below:

$$MinWL = Depth - ScL - LdrL - PumpL - NPSH$$ (all dimensions in metres)

Table 9: Estimation of the minimum pumping water level (MinWL)

MaxQ (L/s)	Depth (m)	ToSc (m BGL)	ToLdr (m BGL)	PumpL (m)	PumpTop (m BGL)	NPSH (m)	MinWL (m BGL)	MinSWL (m MSL)
5	75.0	71.0	68.5	2.7	65.8	1.5	64.3	-39.2

Note: MaxQ = Maximum Bore Yield (L/s); Depth = Probable Depth (m BGL); ScL = Screen Length (m); ToSc = Top of Screen (m BGL); LdrL = Leader Length (m); ToLdr = Top of Leader (m BGL); PumpL= Pump Length (m); PumpTop = Pump Top (m BGL); NPSH = Net Positive Suction Head (m); MinWL= Minimum Pumping Water Level (m BGL); MinSWL = Minimum Pumping Water Level corrected to Mean Sea Level.

The minimum pumping water level estimated in Table 9 can be related to Mean Sea Level (MSL) by the ground level height taken from the LINZ 8m Digital Elevation Model (DEM) for the area (see MinSWL in Table 9). The static water level in the proposed 12 Kaikatia Road bore can be inferred from the interpolation of the coast to coast profile of basal bores monitored by NRC in five positions along the Hukatere Road – Monkey Point transect. These five bores number from 200206 to 200210 and extend south west from Houhora Harbour at a site named Waterfront, into the Aupōuri Forest to a site near the Hukatere settlement on Ninety Mile Beach. The transect includes multi-level piezometers installed in 1987, and further include deep, basal layer measurements of groundwater pressure that are representative of shell beds or the marine sand layers. Figure 7 illustrates how the profile in static water level measured as mean static water level for NRC monitoring bore in terms of distance perpendicular to the edge of Houhora Harbour was used to estimate the mean static water level in the Kaikatia Road irrigation bore according to relative position.

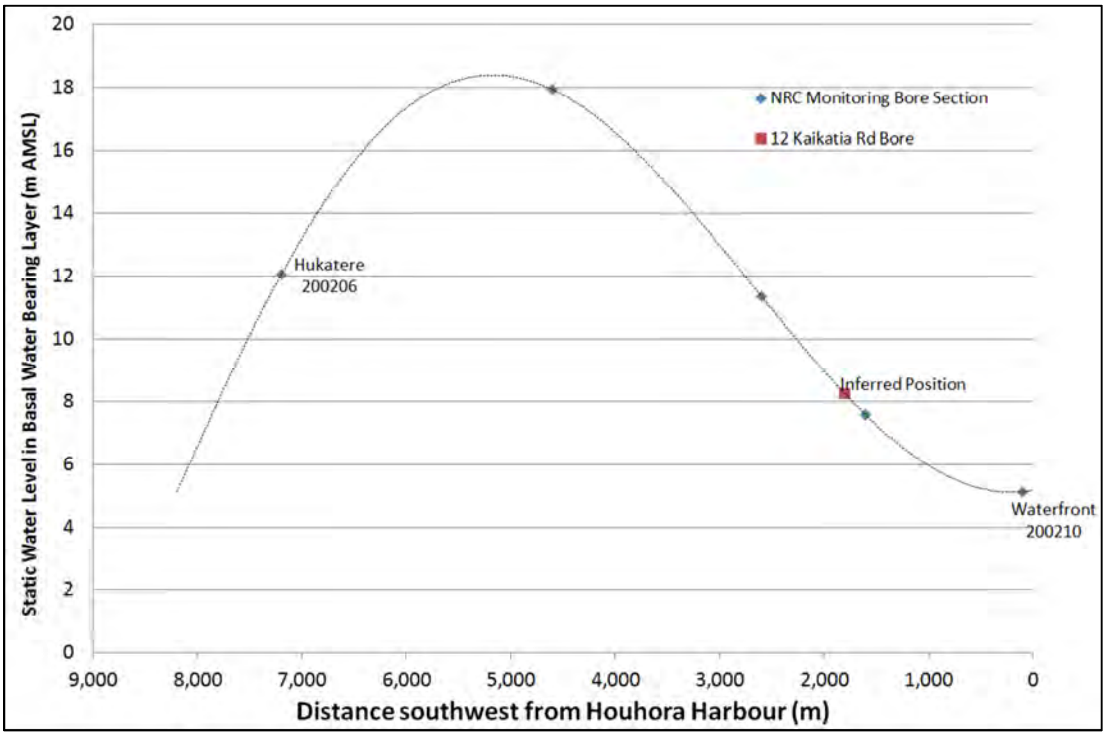

Figure 7: Indicative piezometric profile across the Aupōuri Tombolo at Houhora to estimate the deep, basal static water level in the property bore

Some further assumptions were made regarding aquifer drawdown and well screen efficiency. Cumulative aquifer drawdown was calculated with the following conservative assumptions:

- Hydraulic conductivity of 38 m/d, water bearing layer thickness of 10 m, nil recharge,
- Pumping at maximum bore capacity (see MaxQ in Table 9) for infinite time to steady state conditions,
- Drawdown calculated using the Theis Equation (Theis, 1935).

The Theis Equation is used to account for the aquifer drawdown at the bore screen of the irrigation bore assuming that it has been pumping at high rate for 365 days. The aquifer drawdown from the Theis Equation is then used the following equation to calculate the minimum pumping water level:

MinPumped WL = SWL - AqLoss – ScLoss

Once minimum pumping water level has been calculated, the freeboard between minimum viable pumping bore water level and minimum pumped water level can be determined by subtraction:

Freeboard = MinPumped WL – MinSWL (from Table 9)

Table 10 summarises these calculations and results for each of the nine proposed

Table 10: Estimation of the minimum pumping water level and freeboard for bore operation

SWL (m MSL)	AqLoss (m)	ScEff (%)	ScLoss (m)	MinPumped WL(m MSL)	MinSWL (m MSL)	Freeboard (m)
8.3	2.1	60	0.84	5.4	-39.2	44.6

Note: SWL = Static Water Level (m MSL); AqLoss = drawdown due to aquifer losses (m); ScEff = screen efficiency as a decimal, 0.6 = 60% efficient; ScLoss = screen losses due to 40% loss of efficiency; MinDTW = minimum Depth To Water (m BGL); MinPumped WL = minimum pumping water level (m MSL); MinSWL is corresponding minimum bore water level for viable operation (m MSL) taken from Table 9. Freeboard = MinPumped WL – MinSWL (from Table 9) in terms of m MSL.

The 12 Kaikatia Road bore in Table 10 was found to have positive freeboard, meaning the bore had minimum predicted water levels that lay higher than the minimum viable bore operating water level. The conservatively calculated freeboard was 44.6 m. The conclusion that should be drawn from the above is that the cumulative groundwater drawdown effects are not sufficient to overwhelm the inherent capacity to absorb the level lowering stresses. The irrigation bore is thus likely to sustain proposed water production without risk of failure and show some buffering ability to absorb stresses placed on it in terms competitive bore interference effects or natural level fluctuations.

4.3 Groundwater Effects Beyond Bore-fields

The analysis of groundwater effects beyond the P & G Enterprises' bore would include the following:

- Competitive bore interference, also known as drawdown effects
- Surface water flow depletion
- Contribution to any tendency for seawater intrusion, either lateral intrusion or up-coning of the deep saline water body.

4.3.1 Drawdown Effects

Drawdown effects are calculable using the Theis (1935) Equation. The use of the Theis Equation implies confined pressure conditions. This is a more conservative estimate of drawdown than the alternative Hantush method, which includes the addition of leakage into the deeper aquifer from above. Semi-confined conditions that would indicate the use of the Hantush method are considered to exist in the Houhora area, but the use of the Theis Equation is a more conservative over-estimate of drawdown effect. Therefore, the Theis Equation is used for making the drawdown effects estimation below.

In making the drawdown assessment, the following parameters are used.

- Transmissivity = 380 m^2/d (Hydraulic conductivity of 38 m/d, water bearing layer thickness of 10 m)
- Storage Coefficient = 4 x 10^{-3}
- Pump rate is the combined long-term rate of 4 L/s
- Critical time step was –
  - 217 days (approximately 7 months) at 4 L/s (350 m^3/d)

The computational methodology used was to calculate the Theis drawdown for every one of the registered well records within 10 km of the Kaikatia Road area. Figure 8 displays the spatial distribution of the drawdown effect as contours of drawdown.

Figure 8 reveals the drawdown effects extend into the three groundwater allocation zones; Houhora, Waihopo and Motutangi – Waiharara, plus the western Aupōuri-Other. The highest external drawdown to which an existing neighbouring bore (bore 210161 at 540 m radius) is exposed to equates to 0.39 m. Drawdown effect extends outward to zero effect in the north of the Waihopo allocation zone and to near-zero in the southeast of the Houhora allocation zone. Houhora Harbour and land underlain directly by basement rocks on the far side of the harbour are considered to be unaffected.

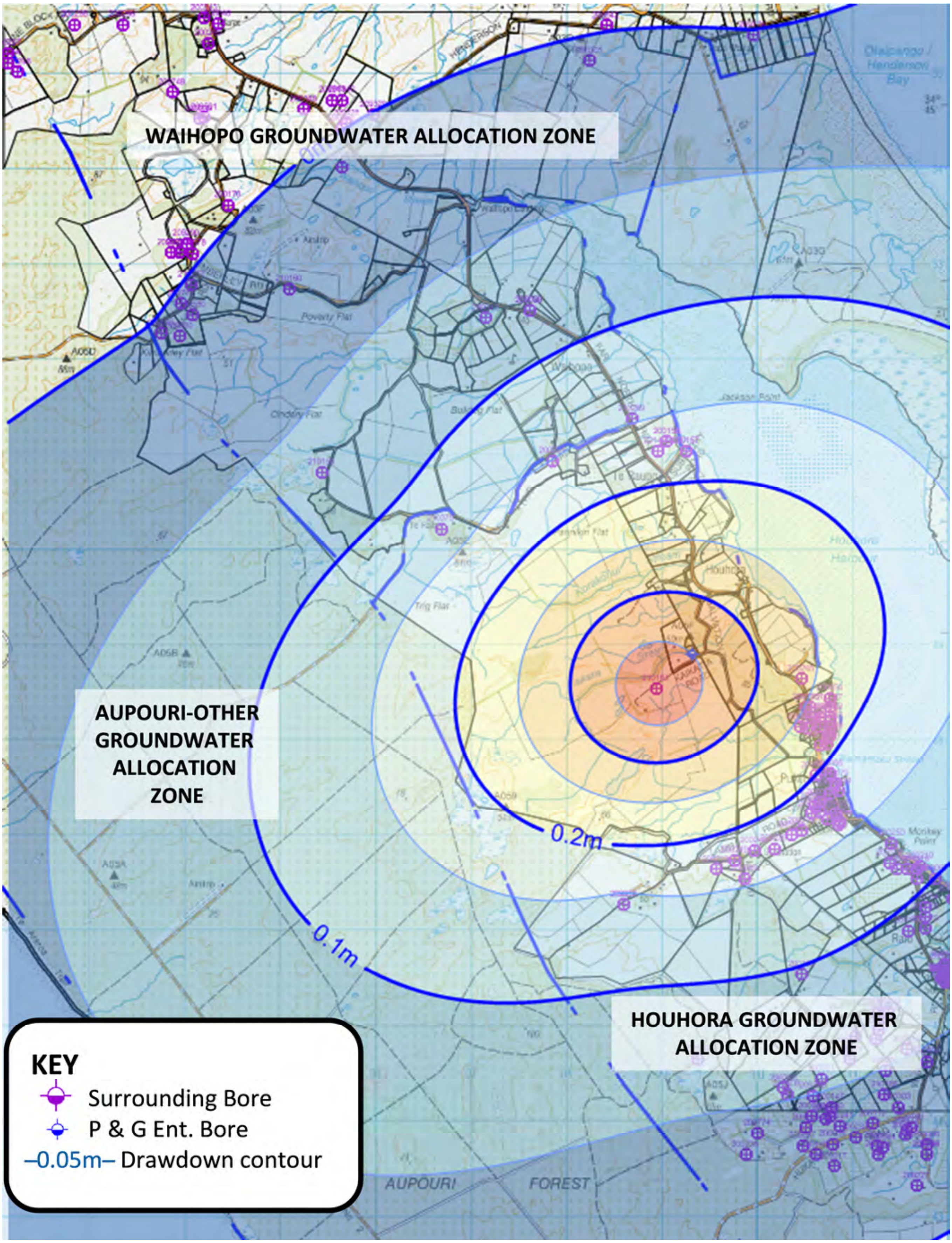

Figure 8: Contours of extrapolated contours of 217 day Theis drawdown surrounding P & G Enterprises irrigation bore (blue ⌖)

Approximately 190 bore sites were lying within 2 km of Kaikatia Road and drawing on the Aupōuri Sand Aquifer were used in the calculation of surrounding drawdown effect. Approximately 34 bores were calculated to experience zero or near zero drawdown effect, leaving 156 bores with positive drawdown effect (i.e. affected). The distribution in the numbers of bores in relation to calculated drawdown intensity is illustrated in Figure 9. Two clusters of drawdown effect were found. The first cluster of 99 bores had calculated drawdown from 0 to 0.1 m. The second cluster of 44 bores had calculated drawdown of between 0.15 m and 0.25 m. At distances greater than 1,900 m from the bore, calculated drawdown was generally less than 0.2 m (see Figure 8).

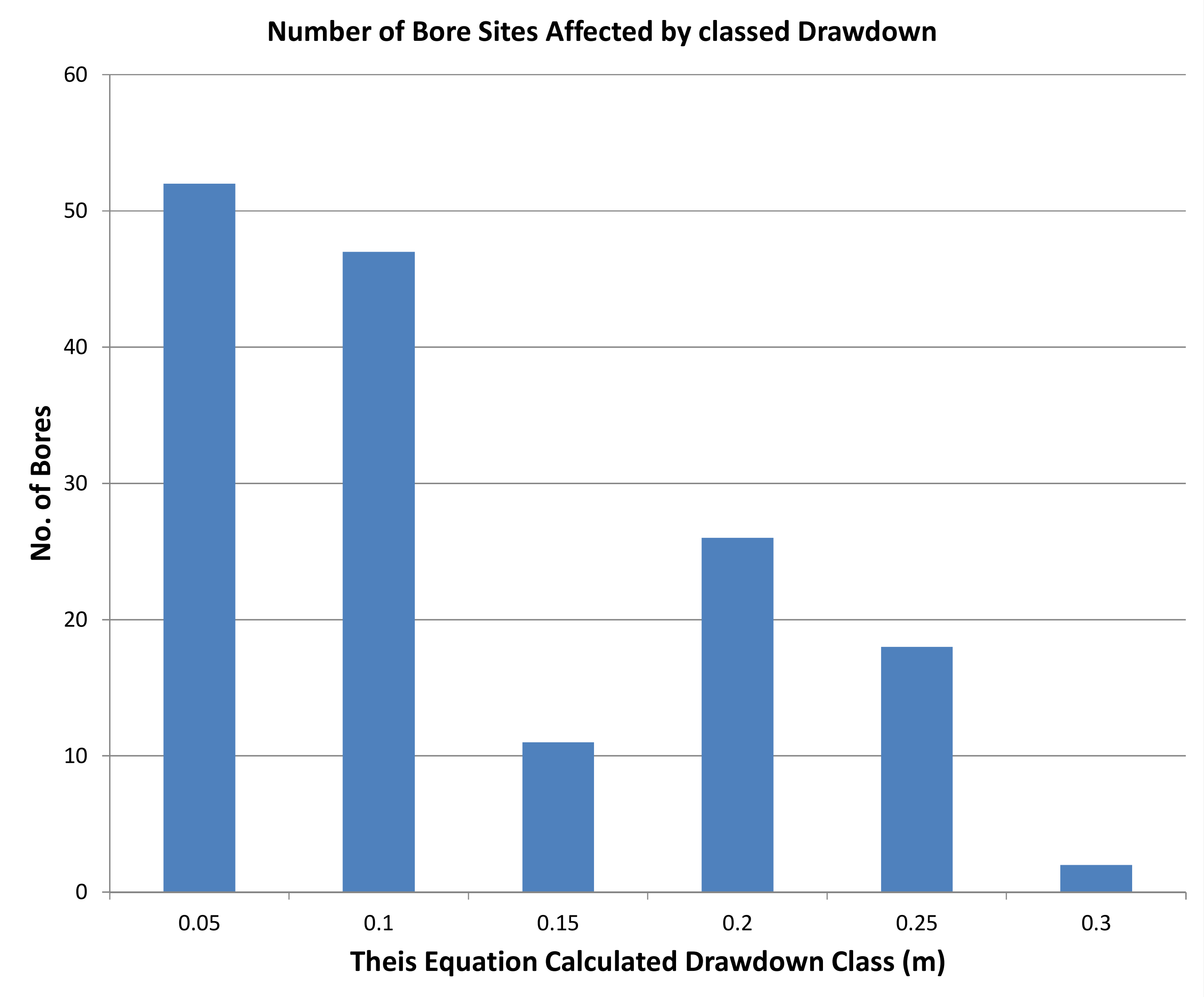

Figure 9: Frequency distribution of surrounding bores with classed drawdown

The operational effect of the calculated drawdowns is difficult to assess due to a variety of factors;

- Theis Equation derived drawdowns in the Waihopo – Houhora setting will inevitably be an over-estimate of actual drawdown due to the physical situation being less clear cut with stratified, leaky (semi-confined) pressure conditions with the expectation of drawdown being limited by leakage compensation.
- Only basal bores drawing on the shell beds or associated deep marine sand layers would be expected to receive full drawdown effect. Bores screened in shallower layers would experience a subdued or in some instances none of the calculated effect.
- The shell beds do not extend north of the Ngataki – Lake Waihopo area, so calculated cumulative drawdown is unlikely north of this area due to the screened water bearing layer pinching out.
- Bores have a variable tolerance for drawdown effect exerted by the pumping of bores in the same aquifer.

- Deep bores drawing on the shell beds or associated deep marine sand layers tend to have the highest degree of tolerance or resilience against external drawdown effects for the reasons explained in section 4.2. These bores tend to have a substantial freeboard capacity.
- All bores in the Waihopo – Houhora area are set up to sustain a moderate degree of natural and artificial water level lowering effects, such as recharge fluctuations and the timing of irrigation onset.

There are also questions of 'efficient bore takes' as defined and referred to in the Regional Water and Soil Plan for Northland (RWSP). An efficient bore is defined as one where the bore fully penetrates the water bearing layer and takes groundwater from the base of the aquifer (Policy 10.5.1 of RWSP). This policy is intended to prevent perverse outcomes where a bore partially penetrating the top of the aquifer and not to its base, serves to curtail further development of legally authorised, fully penetrating bores. P & G Enterprises' bore is proposed to extend to the base of the aquifer. An estimate has been made of the range in bore freeboards between plausible lowest pumped bore level and minimum depth for viable operation across the Houhora area, which indicated the range to be 35 m to 67 m. The indicated bore interference is thus a small percentage of such freeboard allowances.

However, a general assessment can be made that conservatively estimated drawdown effects upon registered surrounding bores, irrespective of screened depth, is small. Where those bores are also screened across the shell-bed horizon to the base of the Aupōuri Sand Aquifer they are generally more likely to be affected by drawdown approaching the full extent calculated above, but are better able to sustain the small drawdown-related lowering in piezometric pressure.

4.3.2 Stream Depletion Effect

Two streams cross the coastal flats adjoining Kaikatia Road from the sand ridge crest in a generally northeast direction towards Houhora Harbour. Flow data is unavailable for any of these named or unnamed streams / creeks, so quantification of their water resource is problematic. However, the streams and creeks tend to discharge from wetland lakes and other areas of impeded drainage. Areas of surface water stream flow generation correlates with areas of poorly drained soils, especially those such as the Te Kopuru Sand or Ruakaka Peat Sandy Loam that are pervasively underlain by either silica pan or iron pan (cemented frangipans). The significance of these areas of poorly drained soils and associated low permeability subsoils was examined in the Motutangi – Waiharara groundwater investigation (Hangjian & Williamson, 2017), and surface water flow generation was considered to be dominant. From Table 11 we can infer that up to about a third (34%) of rainfall falling over these soils in a hydrological year would be recruited to stream flow and only a tenth (10%) to groundwater recharge.

Table 11: Motutangi – Waiharara hydrological zonation for peat and fragipan (Hangjian & Williamson, 2017)

Hydrological Zone (Motutangi – Waiharara)	Groundwater recharge	Evapo-transpiration	Surface Runoff	Relevant Characteristics
Plain / Wetland Zone	10%	56%	34%	Peat overlaying iron pan surface deposits particularly in wetlands areas, low infiltration capacity and medium soil moisture storage.

The proposed P & G Enterprises irrigation bore (see map Figure 10 for location) lies in proximity to both Korakonui and Kaikatia stream, both tributaries of Houhora Harbour. Estimating the catchment areas of these streams, a mean annual rainfall of 1,280 mm per annum and the runoff coefficient of 0.34 from Table 11, the approximate base flow of Korakonui Stream would equate to 20 L/s and that of Kaikatia Stream 30 L/s. While the P & G Enterprises bore would be screened in the shell bed layer with top of screen lying at depth, semi-confined leakage could serve to cause a depletion of the overlying streams. Comparing the soil map (Figure 2) and the alignments of the main streams it can be inferred that these stream beds lay over the Te Kopuru Sand or Ruakaka Peat Sandy Loam with the associated subsoil peats and pans. Available information on soils, and subsoil peats and pans would tend to indicate that the streams are perched above an underlying water table by the impeding action of the subsoil peats and pans.

The interaction between surface water bodies (Kaimaumau wetland, Selwyn and Seymour drains) and the deep shell bed aquifer in the Motutangi – Waiharara allocation zone was investigated using radon (Rn) tracers (Hangjian & Williamson, 2017). The investigation found no correlation between radon concentration of these water bodies and the deep shell bed groundwater. The overall lithological and hydrological setting of Korakonui and Kaikatia streams in Houhora area is sufficiently similar (although not identical) for this assessment to conclude that stream flow depletion from a bore pumping in the deep shell bed is small to negligible. Lastly, the proposed irrigation bore lies within an irrigation area with 95 % efficiency of irrigation application. In view of the low permeability subsoil peats or pans, and acknowledging that no irrigation system can be 100% efficient, there is reason to anticipate that up to 5% of the groundwater pumped from the groundwater system would drain back into the streams by return flow. However, in a highly conservative light, calculations have been included in Appendix A that set out possible scale of depletion effects that ignore the presence of subsoil peats and pans.

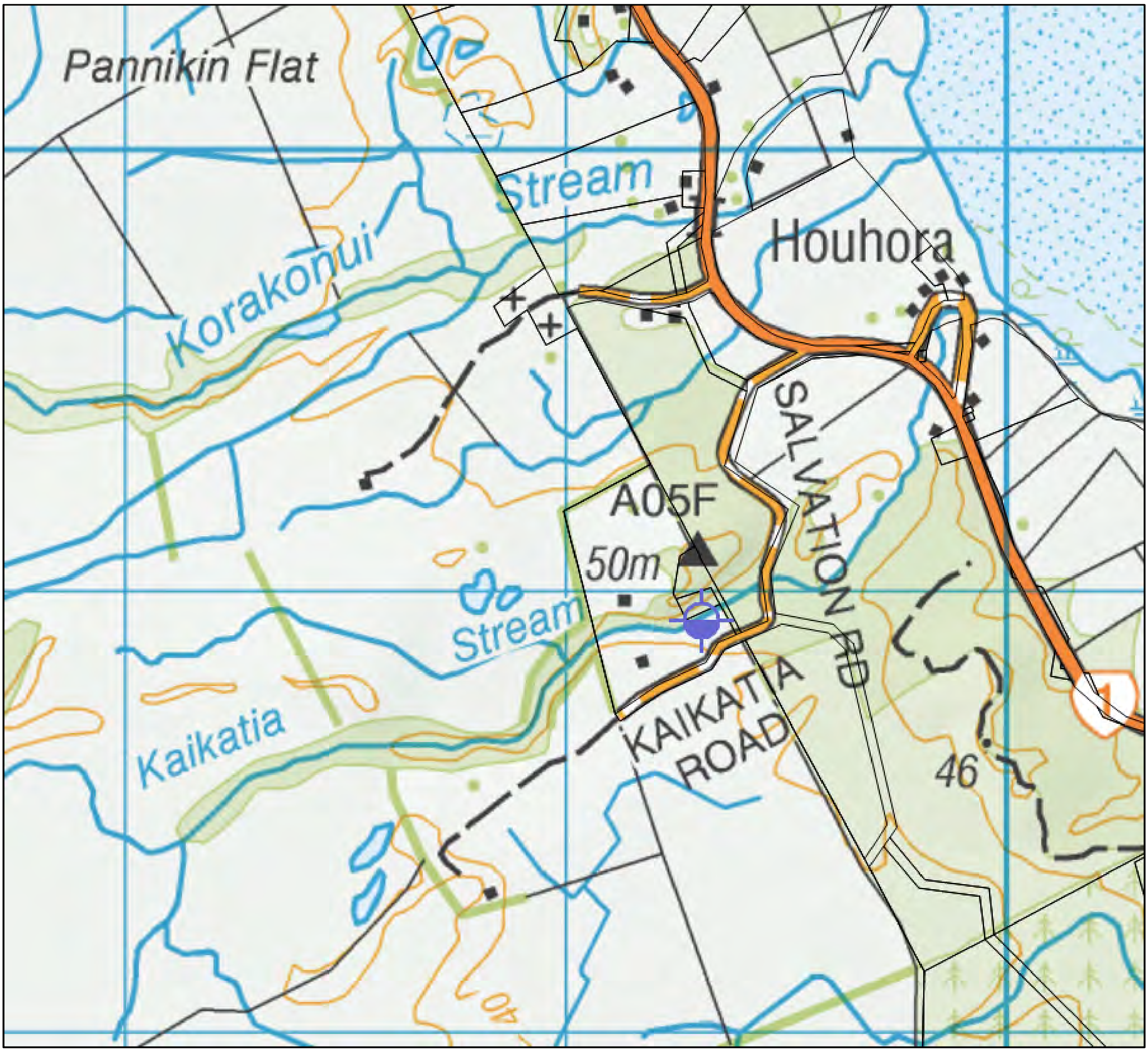

Figure 10: Location of Kaikatia and Korakonui streams in relation to Kaikatia Road and P & G Enterprises' bore (marked ⌖)

4.3.3 Saline Intrusion & Allocation

Intrusion of seawater-affected groundwater is an internationally known effect on fresh groundwater in coastal aquifers associated with over-extraction of groundwater. Investigations into the safe groundwater abstraction yield for the Aupōuri Sand Aquifer (HydroGeo Solutions, 2000; and Wilson & Shokri, 2015) have each considered the need to avoid any risk of seawater intrusion as the primary constraint on the volume of groundwater that can be allocated to consumptive uses. Wilson & Shokri (2015) state "The objective of a sustainable groundwater allocation in a coastal aquifer is to ensure that saltwater intrusion does not result in reduced groundwater quality." A sustainable allocation table was developed on the basis of MODFLOW and SEAWAT modelling of saline intrusion risk (Wilson & Shokri, *ibid*). The table segmented the Aupōuri Sand Aquifer into several distinct allocation zones and set a maximum allocation total to govern the issuing of groundwater take consents. Despite the segmentation for water management purposes, the MODFLOW and SEAWAT simulations extended across the full extent and depth of the Aupōuri Sand Aquifer.

The Aupōuri Sand Aquifer is allocated across 10 defined allocation zones. The P & G Enterprises proposal would draw from the Houhora zone. Table 12 summarises the existing groundwater allocation setting and the proposed addition to the consented & permitted groundwater take total. The Houhora allocations zone is currently sitting within 48.8% of the zone allocation limit. The consented groundwater total for Houhora allocation zone would not exceed the relevant preliminary allocation limit.

Table 12: Summary of Houhora and neighbouring Allocation status, with P & G Enterprises' proposed increased groundwater to be allocated

Zone	Current allocation* (consented & permitted) (m^3/year)	*(% of allocation limit)*	Indicated* Zone Allocation limit (m^3/year)	Allocation Sought in P & G Enterprises Proposal (m^3/year)	Percentage of Consented to Allocation limit after P & G Enterprises Proposal added (%)
Waihopo	171,170	*13.4%*	1,278,200	0	13.4%
Houhora	1,045,493	*48.8%*	2,141,300	32,100	**50.1%**
Aupōuri-Other	53,183	*0.2%*	21,991,288	0	0.2%

Note: * Current allocation consented and permitted, and indicated allocation limits based on information provided by NRC via the indicative water quantity allocation maps for groundwater https://www.nrc.govt.nz/Your-Council/Council-Projects/New-Regional-Plan/indicative-water-quantity-allocation-maps/.

The allocation limits in Table 12 were set by Wilson & Shokri (2015) and adopted as indicative or preliminary limits by NRC following a deliberate sequence of groundwater flow and transport modelling tests, which in turn referenced particular set of long-term groundwater level monitoring bores in the coastal margins of the aquifer. The most relevant groundwater level monitoring bore for the P & G Enterprises property was Bore 200210 Waterfront (Piezometer 1 installed at 60.1m) on the Houhora Harbour waterfront. This piezometer measures the pressure in the basal shell-bed layer and has a long-term mean groundwater pressure of 5.3 m AMSL. In addition, projection of the groundwater pressure at 12 Kaikatia Road indicates the likelihood of the eventual static pressure in the P & G Enterprises' bore being approximately 8.3 m above mean sea level (see Figure 7).

The Aupōuri Sand Aquifer contains exclusively fresh groundwater under the landwards portions of its extent. The adjoining marine (under-sea) extents of the Aupōuri Sand are brackish to saline, depending on the hydraulic gradients, pore pressure and relict fresh or saline water bodies lying at depth. The aquifer as a whole is not currently considered near fully allocated and groundwater modelling conceptually or numerically has shown a healthy positive freshwater outflow replenished by high rates of recharge (up to 550 mm per year). Consequently, with the P & G Enterprises proposal remaining within allocation limits, there is very little likelihood of the proposal leading to an increased tendency for seawater intrusion in the Waihopo – Houhora area.

4.3.3.1 Lateral Seawater Intrusion

This mode of movement of brackish or saline groundwater laterally into the landward parts of the Aupōuri Sand Aquifer is generally only feasible if the ground water balance is sufficiently imbalanced to reverse current lateral outflow of fresh groundwater. The current conceptual model, which is backed up by several hydrogeological models and interpretations, envisages a reasonably high rate of annual recharge surcharging the sand ridge with a recharge mound in the water table that tapers down to mean sea level at the marine margins (see Figure 4 and Figure 7). The water table recharge also surcharges the deeper, semi-confined water bearing layers at depth. Beneath the crest of the sand ridge the groundwater pressure in the deeper, semi-confined aquifers is substantially above mean sea level. The Forest monitoring bore on the Aupōuri Forest crest line has a piezometer in the deeper, semi-confined marine sand. This piezometer measures the pressure in the basal sand and shell-bed layer with a mean groundwater pressure of 17.9 m AMSL, minimum level of 15.9 m AMSL and height range in approximately 350 recorded level measurements of 3.5 m since 1987. Monitoring bores on the coastal margin measuring pressure in the deeper water bearing layers also manifest groundwater pressures above mean sea level at the coast line (see Figure 7). The Waterfront monitoring bore 200210 (Piezometer 1 at 60.1m) is located on the Houhora Harbour waterfront. This piezometer measures the pressure in the basal shell bed layer and has a mean groundwater pressure of 5.3 m AMSL, minimum level of 3.3 m AMSL and range in over 350 recorded level measurements of 2.6 m since 1987.

The recorded pattern of groundwater pressure profile across the Aupōuri sand ridge in the Waihopo – Houhora area supports the proposition of relatively stable gradients sustaining outward groundwater flow from all depths in the aquifer into the marine zone. While much of the groundwater outflow by quantity into the marine environment is likely to be in the shallower layers around sea level depths, the persistence of positive groundwater pressures in deeper layers, including the sand and shell-beds, at the margin of Houhora Harbour would oppose the reversal of gradients or the inflow of groundwater from the harbour.

The deeper, semi-confined layer drawdown due to the longer term operation of the P & G Enterprises' irrigation bore outlined in section 4.3.1 on Drawdown Effects would exert at most 0.3 m of groundwater pressure decline at the Houhora Harbour margin at the locality of Houhora, and 0.2 m at the Waterfront monitoring bore in Pukenui. Such magnitude of drawdown would be likely to cause the groundwater pressure to drop below mean sea level at even the lowest recorded pressure. Accordingly, the sustained loss of positive groundwater pressures that would be required to induce landward movement of the fresh water – saltwater interface in the aquifer would be unlikely to occur as a consequence of granting the proposed groundwater take for P & G Enterprises. Consequently, the potential for such saline intrusion effects can be considered less than minor.

4.3.3.2 Saline Up-coning

Saline intrusion can also occur by a process of pumping bore depressurisation and the presence of a saline water body at beneath the site of pumping. The depressurisation effect then has the effect of up-coning the saline groundwater towards the base of the pumping bore (Schmorak and Mercado, 1969). The process is time-dependent with the up-coning bulge in the fresh water – saltwater interface developing as pumping continues, often without any manifestation of changing water quality. Some geo-hydrologist have recognised a critical rise (see Figure 11) beyond which continued pumping is likely to result in up-coning meeting the bore intake screen and the rapid water composition shift from fresh to brackish (Oude Essink, 2001).

However, there are no known saline water bodies in or under the Aupōuri Sand Aquifer in the Houhora vicinity. Long-term monitoring of water quality at the Collville bore (number 200059) at a depth of 55 m BGL on Hukatere Road, just southwest of Pukenui and towards the crest of the sand ridge, records chloride concentrations around 55 mg/L. The chloride concentration of the Houhora Big Fish Club bore at Monkey Point on Houhora Harbour ranges around 65 mg/L. This bore has a depth of 79 m BGL. Sea water has a chloride concentration of 19,400 mg/L, so the chloride content recorded in Aupōuri groundwater is very low by comparison, and therefore more likely to be the result of sea-spray in rainfall recharge rather than the up-coning of brackish groundwater.

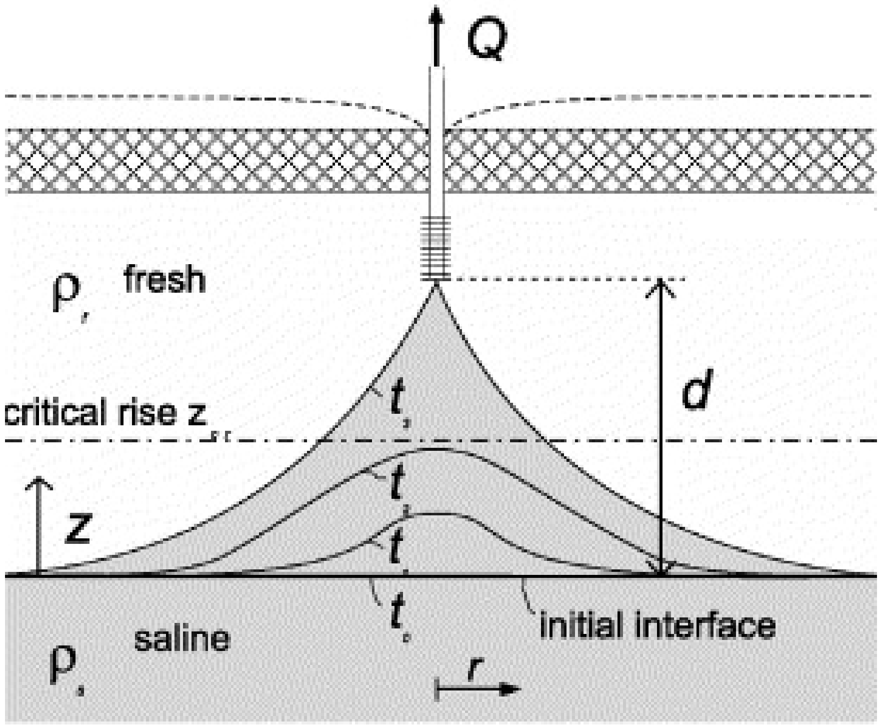

Figure 11: Theoretical example of the movement in the fresh – salt water interface in saline up-coning

The potential would exist for a saline groundwater body to exist in the fractured volcanic rock making up the basement beneath the sand aquifer. However, the height of the water table and elevation of groundwater pressures in deeper levels in the Aupōuri Sand aquifer are strongly suggestive of any such saline water body being displaced vertically some hundreds of metres under the physical processes explained in the Ghyben – Herzberg Equation (Verrjuit, 1968). Balancing all of the above considerations, it is unlikely that saline up-coning would result from the operation of the P & G Enterprises' irrigation bore, and such saline intrusion effects can be considered less than minor.

5. CONCLUSIONS

The proposed irrigation development utilising a single, yet to be drilled water bore would have a nameplate capacity of 5 L/s and require consent for 28,000 cubic metres of groundwater per irrigation year (October to May). The groundwater is required to service the drip irrigation requirement of 7 ha of avocado horticulture within an approximately 11.3 ha property at 12 Kaikatia Road. The proposed drilling target is the sand and shell-bed horizon at the base of the Aupōuri Sand Aquifer, due to the more permeable layer's capacity to under-drain groundwater in the marine sands and above. This would imply the installation and use of a bore in the depth range of 70 m to 75 m below ground. The sand and shell-beds are commonly used for irrigation, stock and domestic water supply in the area and can be inferred to extend beneath the P & G Enterprises property. In terms of the groundwater science related assessments required to determine the ability to sustainably take the groundwater as proposed, the following individual assessments have been undertaken:

- The sustainability of the proposed groundwater abstraction in terms of modern well hydraulics and the capacity of the Aupōuri Sand Aquifer to supply water to the proposed bore,
- The groundwater level lowering effects of bore pumping on surrounding groundwater users' water bores,
- The depletion of surface water flows caused by proposed groundwater pumping if any,
- The potential for saline intrusion as a result of the proposed groundwater pumping activity.

Delineation of the well hydraulics, available bore depth dimensions and calculated aquifer head losses were compared to determine the freeboard between the minimum water level that the pumping bore could tolerate on one hand, and the lowest water level indicated by head losses on the other. The proposed irrigation bore came through the assessment with freeboard of 44.6 m indicating that the bore configuration is feasible.

Conservative calculations of consequent drawdown at distance were used to predict such effects on neighbouring bores in the same aquifer. The calculations indicate that bores within 2 km of the proposed bore would experience drawdown effects between 0.4 and 0.2 m. The drawdown effect at the closest part of the Houhora Harbour shore line was calculated as 0.2 m. Such drawdown intensities lie within the 2.6 m to 3.3 m range of recorded water level fluctuations for the sand and shell-bed water-bearing layer, and within the expected operational water level tolerances of fully-penetrating bores that can be considered 'efficient bore takes' in terms of Policy 10.5.1 of the RWSP.

The proposed groundwater takes would directly affect only one groundwater allocation zone (Wilson & Shokri, 2015), although small pressure-lowering intensities could extend into surrounding zones. Indicative allocations have been published for this groundwater zone, plus surrounding zones in the Aupōuri Sand Aquifer as a whole. The added groundwater abstraction volume to allow the proposed irrigation at the P & G Enterprises' property would not cause the associated groundwater allocation zone (Houhora) to exceed the indicative limit, leaving the total consented allocation below 50.1 % of the full allocation total.

As the indicative allocation limits were conservatively set to prevent the possibilities of the aquifer exceeding its safe yield or even inducing seawater to intrude beneath the landward portion of the aquifer, the fact that the current proposal does not lead to an exceedance of these limits is reassuring. The projected depression of the deeper, semi-confined sand and shell-bed layer water pressure by 0.2 m at the coast line is not considered to endanger the aquifer with respect to seawater intrusion risks as above mean sea level pressures would be maintained.

The overall assessment of the P & G Enterprises' groundwater irrigation proposal is that it would lead to a level of effects that is less than minor.

6. REFERENCES

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APPENDIX A CONSERVATIVE STREAM FLOW DEPLATION CALCULATIONS

The proposed irrigation bore lies closest to Korakonui and Kaikatia streams, both tributaries of Houhora Harbour. It lies within 20 m of Kaikatia Stream. While both bore would be screened in the sand and shell-bed layer with top of screen between 70 m and 75 m below ground level, semi-confined leakage could serve to cause a depletion of the overlying streams. Accordingly the Hunt solution for a two-aquifer setting (Hunt and Scott, 2007) was used to calculate depletion of the two streams. These calculations take no account of the aforementioned poorly drained soils and subsoil peats and pans. Instead, conservatively high stream bed conductance of 100 m/d was utilised, which would tend to over-estimate depletion.

Temporal effects are also considered in the stream depletion calculations. The longer the bore pumping goes on the greater the proportion of the groundwater pumped induces stream water infiltration. Table 13 shows the calculated depletion effects in terms of both input parameters and results for both Korakonui and Kaikatia streams.

Table 13: Summary of stream depletion effects derived using the Hunt Solution

Input Parameters	**Korakonui Stream**		**Kaitakia Stream**	
Aquifer transmissivity (m^2/d)	380		380	
Storage coefficient	0.0044 (4.4×10^{-3})		0.0044 (4.4×10^{-3})	
Aquitard hydraulic conductivity (m/d)	0.05		0.05	
Aquitard thickness (m)	5		5	
Streambed conductance (m/d)	600		600	
Bore pump rate (L/s)	4		4	
Separation Distance (m)	460		20	
Hunt Solution Results	**Korakonui Stream**		**Kaitakia Stream**	
Time Simulated (days)	**Depletion (L/s)**	**% Effect of Total Pumping**	**Depletion (L/s)**	**% Effect of Total Pumping**
7	0.4	11%	3.5	87%
30	1.2	29%	3.6	91%
210	2.6	66%	3.7	94%
365	2.9	73%	3.8	94%
Residual Stream Flow (365 days)				
	Korakonui Stream		**Kaikatia Stream**	
Estimated Base Flow (L/s)	20		30	
Estimated Depletion (L/s)	3		3.8	
Remaining Flow (L/s)	17		26.2	