Assessment of Environmental Effects

Application for Water Permit to take and use groundwater
Te Aupouri Commercial Development Ltd

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1. Introduction

1.1. Overview

Te Aupōuri Commercial Development Ltd. (herein referred to as 'the Applicant') is a commercial arm of Te Aupōuri, one of the five iwi of Muriwhenua in the Far North of Aotearoa. Te Aupōuri owns, operates, and leases out Te Raite Station at Houhora in the Far North District.

The farm comprises 1849 hectares (ha), the productive areas of which are used to graze sheep and beef livestock. The Applicant does not currently hold any groundwater or surface water take and use consents suitable for irrigation purposes.

Figure 1: Te Raite Station location and boundaries (source Google Earth)

The Applicant plans to convert approximately 260 ha of the farm to horticulture, cropping, and market gardening, both of which require a reliable water supply. This application seeks to obtain a resource consent to take and use groundwater to make this conversion feasible.

In the event that the Applicant is successful in obtaining the resource consent this application is being made for, further resource consent applications will be made to facilitate the conversion, for example an application will be lodged to install new bores.

1.2. Purpose of this Report

This report is the assessment of effects on the environment (AEE) to accompany the application for a water permit to take and use water, in accordance with Section 88 and Schedule 4 of the RMA.

This report describes the proposal, and provides an assessment of the requirements under the RMA, and the relevant statutory documents, including the Regional Water and Soil Plan for Northland (RSWP) and the Proposed Regional Plan (PRP). It also provides information on the nature of the existing environment and an assessment of actual or potential effects that could occur as a result of the proposed activities.

1.3. Other Activities & Resource Consents

The Applicant does not hold any permits to take and use water for irrigation purposes.

A resource consent to install new bores at Te Raite Station will be sought should this application for water be granted. The bore consent application will need to supply pump testing requirements as per Rule C.8.5.3 of the Proposed Regional Plan for Northland 2017 (PRPN)

No other resource consents are required from the Northland Regional Council for the proposed activity.

No resource consent is required from the Far North District Council.

2. Description of Proposed Activity

2.1. Overview

As detailed in the previous sections of this report, the Applicant seeks to obtain a resource consent to take and use groundwater to irrigate part of Te Raite Station.

The Applicant proposes to take groundwater from two areas within the Aupōuri Sand Aquifer for which there is water still available, the Houhora, Waihopo, and Aupōuri - Other allocation zones. The water would be used to irrigate approximately 260ha of horticultural, market garden, and cropping land through high efficiency irrigation infrastructure.

2.2. Proposed groundwater take and use

The Applicant seeks a new groundwater take and use permit to use over specific areas of the station which will be converted to horticulture, market gardening and cropping. A provisional groundwater abstraction plan has identified that the northern-most irrigation areas have aquifer depth constraints that would favour the installation of multiple bores with a maximum capacity up to 10 L/s. Further south within Te Raite Station the aquifer deepens, allowing enhanced bore yield and individual maximum bore capacities between 15 L/s and 30 L/s (see Appendix 1).

The take would be from the Houhora, Waihopo, and Aupōuri – Other allocation Zones, at the following abstraction rate and volumes:

Table 1: Summary of total abstraction rate and volumes.

RATE OR VOLUME	VALUE	COMMENT
Maximum application rate (mm/d)	4	Maximum/peak daily rate
Instantaneous maximum (L/s)	135	The proposed combined capacity of nine proposed water bores
Daily maximum rate (m^3/d)	10,400	Based on peak daily application rate across 260 ha of irrigated land
Monthly maximum rate (m^3/month)	200,000	Based on an estimate of the maximum volume of water required to irrigate 260 ha in highest demand month
Annual maximum volume (m3/year)	1,170,000	Based on nominal water demand of 4,500 m^3/ha/year and irrigated area of 260 ha
Period of irrigation season	October to April in any year	Based on analysis of climate, particularly evapo-transpirative demand across the hydrological year

Water taken would be used to irrigate the areas marked in **Error! Reference source not found.**. Bores to facilitate this take would be located in the areas marked by the blue dots in that figure, although the exact coordinates of the future bores cannot be confirmed at this stage. The exact locations of the bores would be confirmed in the land use consent application mentioned in Section 1.3 above, however at this stage it can be confirmed that they will be located within the irrigation areas marked in **Error! Reference source not found.**. Any bores would be sited at least 500m from the property boundaries.

Table 2: Irrigation area take and use details

ZONE	INTENDED IRRIGABLE AREA (HA)	INTENDED USE	PER HECTARE RATE (M^3/HA/YR)	PROPOSED RATE OF TAKE (M^3/YR)	GROUNDWATER ALLOCATION ZONE	PROBABLE BORE DEPTHS (M)
A	35	Horticulture	4,500	157,500	Aupōuri -Other	100 (x2)
B	60	Cropping / Horticulture	4,500	270,000	Waihopo	90 (x3)
C	40	Cropping / Horticulture	4,500	180,000	Waihopo	90 (single)
D	40	Cropping / Horticulture	4,500	180,000	Houhora	105 (single)
E	25	Horticulture	4,500	112,500	Houhora	120 (single)
F	60	Cropping / Horticulture	4,500	270,000	Houhora	125 (single)
Total	**260**			**1,170,000**		

A total of 562,500m^3/year will be drawn from the Houhora zone, 157,500 m^3/year from Aupōuri – Other zone, and the remaining 450,000m^3/year from the Waihopo zone. It is intended that the bores be sunk to 90m – 125m depth for the take.

Irrigation of the horticulture, market garden, and crops will be by pivot, dripline, or similarly high efficiency irrigation system.

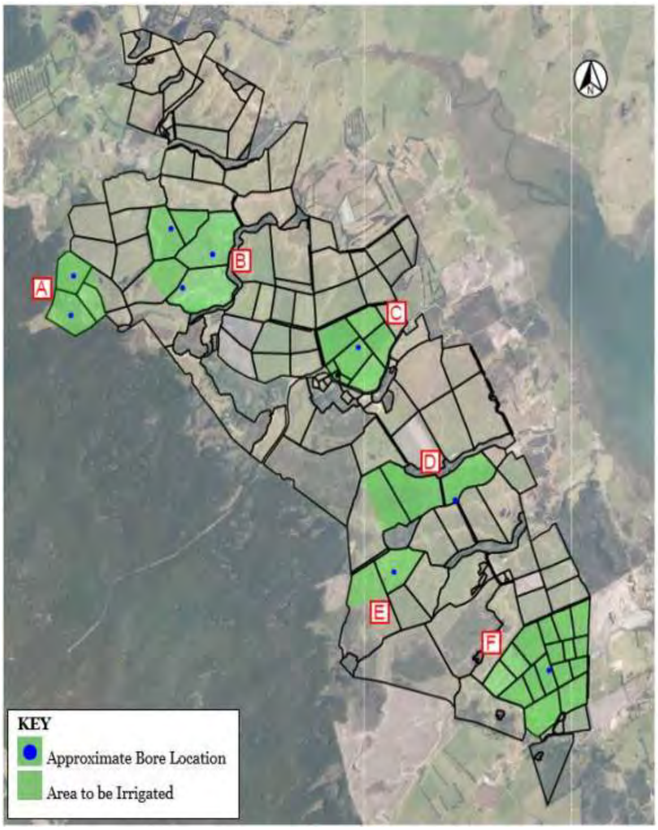

Figure 2: Proposed irrigation areas and approximate bore locations

2.3. Proposed Conditions

This section contains the proposed conditions for the water permit sought by the Applicant.

Limits

1. The combined rates of abstraction from all bores shall not exceed;
    a. 135 litres per second;
    b. 10,400 cubic metres per day;
    c. 1,170,000 cubic metres between 1 July and 30 June in the following year.
2. Water shall only be used for irrigation of agricultural and horticultural land.

Monitoring

3. The consent holder shall, before the first exercise of this consent:
    a. Install, operate and maintain devices to record the water taken to within an accuracy of plus or minus five percent over the meter's nominal flow range, and data loggers with at least 12 months data storage to record the rate and volume of take, and the date and time this water was taken.
    b. The water measurement and recording devices shall be accessible to Northland Regional Council within 24 hours of a request to the consent holder during normal working hours for inspection and/or data retrieval.
    c. The water measurement and recording devices shall be installed and maintained throughout the duration of the consent, in accordance with the manufacturer's instructions.
    d. All practicable measures shall be taken to ensure that the water measurement and recording device are fully functional at all times.
4. Easy access for a water level probe shall be provided and maintained at the wellheads to enable the measurement of water levels in the bore.

Backflow Prevention

5. a. Before the first exercise of this consent, a backflow preventer manufactured in accordance with AS 2845.1 (1998) or the American Society of Sanitary Engineers standards shall be installed within the pump outlet plumbing or within the mainline, to prevent the backflow of water and any added contaminants into the bore.

    b. The backflow preventer shall be tested to the standard set out in AS 2845.3 (1993) or an equivalent method within one month of its installation and annually thereafter by a suitably qualified person. A test report shall be provided to the Northland Regional Council, attention RMA Compliance and Enforcement Manager within two weeks of each inspection.

Efficient Water Use

6. The consent holder shall take all practicable steps to ensure that:
    a. The volume of water used for irrigation does not exceed soil field capacity of the irrigated areas ; and
    b. The irrigation does not cause surface runoff that would discharge into natural waterbodies; and
    c. There is no leakage from pipes and structures;
    d. The use of water is confined to targeted area;
    e. Irrigation induced soil erosion and soil pugging does not occur

f. Soil quality is not degraded as a consequence of irrigation; and

g. Loss of water, nutrients and agrichemicals by percolation to groundwater is minimised.

ADMINISTRATION

7. The taking of water in terms of this permit shall cease for a period of up to 48 hours, on notice from Northland Regional Council, to allow measurement of natural groundwater levels.

8. The Northland Regional Council may, in accordance with Section 128 of the Resource Management Act 1991, serve notice on the Consent Holder of its intention to review the conditions of the consent. Such notice may be served annually on any of the last five working days of May. The review may be initiated for any one or more of the following purposes:

   a. Dealing with any adverse effect on the environment which may arise from the exercise of the consent; or

   b. Requiring the adoption of the best practicable option to remove or reduce any adverse effect on the environment.

   c. Complying with the requirements of a relevant rule in an operative regional plan.

   d. Review the allocation specified in condition 1, to ensure the efficient allocation of the resource

9. The lapsing date for the purposes of Section 125 of the Resource Management Act 1991 shall be no more than 3 years from the commencement of the consent.

10. The expiry date for the purposes of Section 123(d) of the Resource Management Act 1991 shall be no more than 20 years from the commencement of the consent.

3. Description of Affected Environment

3.1. Overview

Te Raite Station is a large dryland farm in the Houhora area of the Far North District, between 90 Mile Beach to the west of the farm and running the length Houhora Harbour in the east. The land is used primarily for sheep and beef grazing. The surrounding land is agricultural land in pasture, horticulture, crops or plantation forest.

The closes township to the station is Pukenui, 1km east of the southern end of the farm boundaries. The area has a gentle downward slope towards the south-east. The area is mainly used for pastoral farming, with dairy farming being the predominant activity.

3.2. Geology and Soils

The Houhora area is geologically characterised as a sand tombolo (sand bar connecting mainland with an island) joining the basement rock outcroppings at Kaitaia and North Cape – Cape Reinga. 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.

Sand dunes rise several metres height above their surrounds, while back-dune and dune slack deposits such as peat swamps are found and often over-ridden by young dune deposits

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. Marine sands present towards the base of the aquifer bed are referred to as “shell beds” when the concentration of shells exceeds about 30%. The sand deposits are laid onto an erosional surface of the Rangiawhia Volcanics of Cretaceous age.

The soils underlying Te Raite Station are sands with varying drainage properties reflecting their origin.

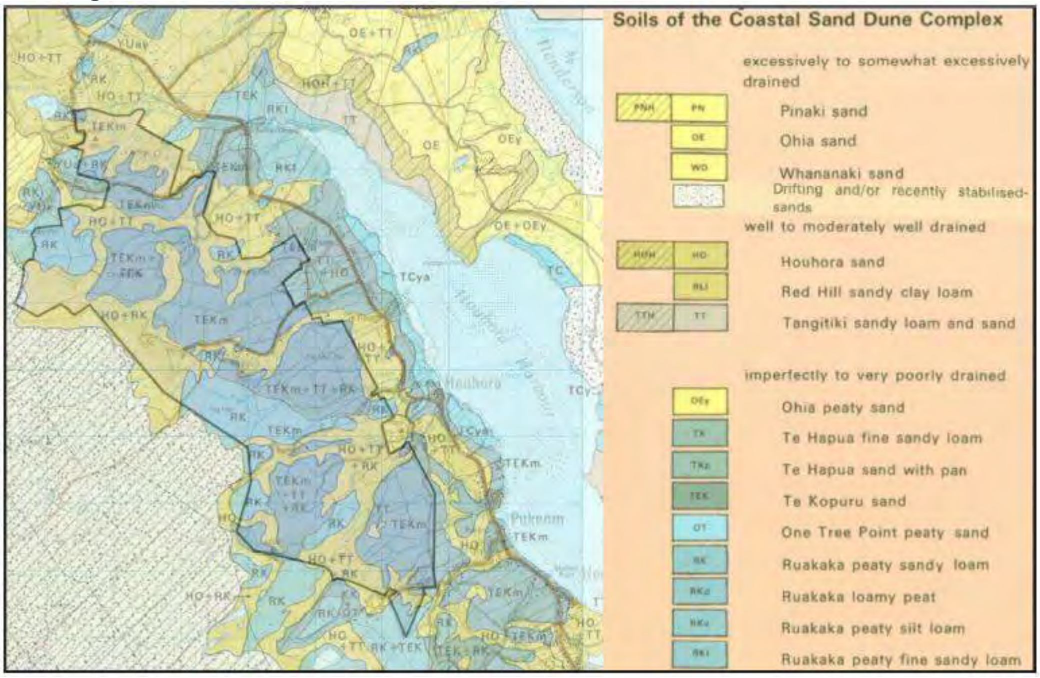

Figure 3: Soil map of Te Raite Station

The geology underlying Te Raite Station is discussed in greater detail at Section 2.5 of a groundwater effects assessment undertaken by Lincoln Agritech, annexed to this application at Appendix 1.

3.3. Groundwater

3.3.1. Aquifer Description

Te Raite Station is located over the Aupōuri Sand Aquifer in Northland, the extent of which is indicated in Figure 5. The aquifer is comprised primarily of marine sand, as well as shell beds, peat and clay deposit, and covers a land area of 75,322ha.

The thickness of the shell beds tends 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 rock.

Aupōuri Aquifer is thickest along Ninety Mile Beach to the north of Hukatere, where basement rock may be over 200 m deep. 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 underlying fault at Waihuahua swamp, where the basement may be over 100m deep.

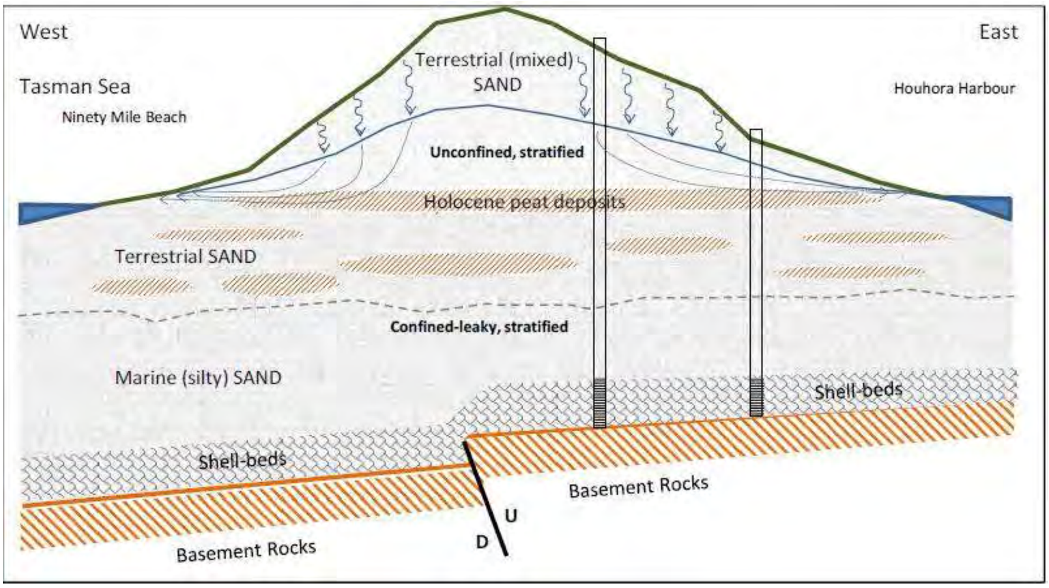

Figure 4: Cross section of the Aupouri Sand Aquifer in the vicinity of Te Raite Station

The Aupōuri Sand Aquifer is allocated across 10 defined allocation zones. The Te Raite Station proposal would draw from three of these zones to varying degrees dictated by the position of irrigation bores:

- Houhora
- Waihopo
- Aupōuri – Other

Figure 5: Aupouri Sand Aquifer (outlined in red)

3.3.2. Aquifer Parameters

The Aupōuri Sand Aquifer 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.

Groundwater recharge is generally quite high in the coastal sand flats and weather sand flats, up to 550 mm per annum. 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. 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 (see Appendix 1). 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. A subsequent analysis focused on marine sand and shell bed layers near Houhora indicated a range of 0.9 m/d to 63 m/d.

3.3.3. Groundwater Use

The aquifer has been developed into a significant water resource for overlying land uses and for Kaitaia water supplies. Uses in the vicinity include domestic supply, irrigation, stock water, and small community supply.

Approximately 190 bore sites were modelled by Lincoln Agritech (Appendix 1) in the surrounding area of Te Raite Station.

3.4. Surface Water Bodies

There are extensive surface water bodies both within Te Raite Station and in the near vicinity of the farm, as indicated in Figure 6 below.

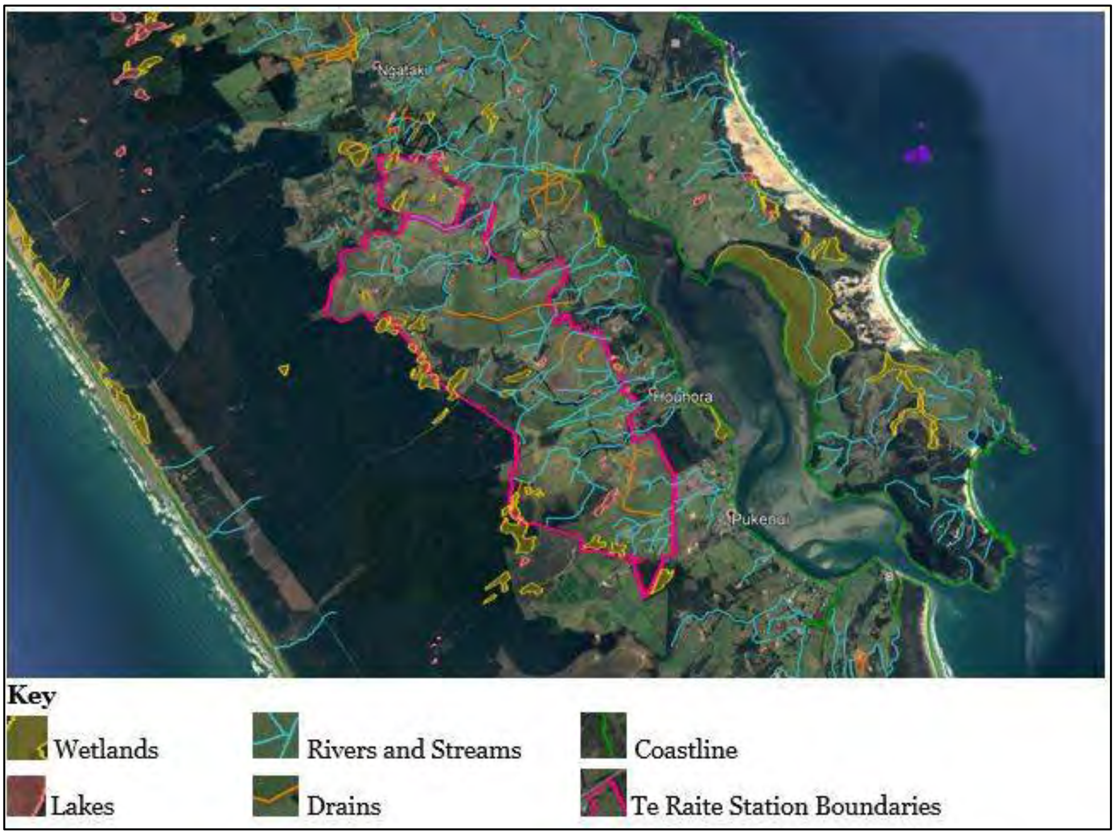

Figure 6: Surface water bodies within and in the vicinity of Te Raite Station

Waterbodies within the boundaries of the station include streams, dune lakes, ponds, wetlands, dune wetlands, and drains.

East of the farm across the harbour is a large and significant wetland, the Kaimaumau wetland.

These waterbodies are located over predominantly sandy soils, but are largely perched by peats and iron pans, which prevent them draining away through the soil.

Surface water bodies relevant to this application are discussed in further detail in the report at Appendix 1.

3.5. Cultural Values

The proposed groundwater abstraction lies within the rohe of Te Aupōuri, Ngāti Kurī, and Ngāi Takoto iwi.

The proposed take is not located within, or in close proximity to an area sensitive to the respective iwi. This has been confirmed via the ‘sites and areas of significance to tangata whenua’ GIS layer on the Northland Regional Council Proposed Regional Plan planning maps and by Te Aupōuri.

4. Activity Classification

4.1. Resource Management Act 1991

Section 14 of the RMA places restrictions on the take and use of water. Section 14 of the RMA states that:

(2) No person may take, use, dam, or divert any of the following, unless the taking, using, damming, or diverting is allowed by subsection (3):

(a) Water other than open coastal water; […]

(3) A person is not prohibited by subsection (2) from taking, using, damming, or diverting any water, heat, or energy if—

(a) The taking, using or damming is expressly allowed by a national environmental standard, a rule in a regional plan as well as a rule in a proposed regional plan for the same region (if there is one), or a resource consent.

The proposed water take and use is not expressly allowed by a National Environmental Standard, and therefore needs to be allowed by a rule in a regional plan, or by a resource consent (water permit).

4.2. Regional Plans

Northland Regional Council is in the process of developing a new regional plan to replace three existing plans that set out policies and rules for how Northland’s water, soil, air and coast are used.

The PRPN was publicly notified on 6 September 2017 and will replace the Regional Water and Soil Plan for Northland (RWSPN). At present, the rules in both these plans have legal effect, with weight given to whichever plan has the more restrictive rule for the same activity if there is a conflict between the two plans.

Both plans address groundwater abstractions that have the potential to adversely affect the environment.

4.3. Regional Rule Assessment

Rule C5.1.10 of the PRP and 25.3.1. of the RWSPN address the taking and using of groundwater for irrigation purposes which is not permitted, controlled, restricted discretionary, non-complying or prohibited. The proposed taking and using of groundwater is assessed against the rules, as detailed in Table 3 below.

Table 3: Activity classification assessment.

PLAN	PERMITTED ACTIVITY	ASSESSMENT	RELEVANT RULE
PRP	The taking and use of water from a river, lake or aquifer is a permitted subject to conditions. In this instance, the proposal is in excess of 10 m^3/day or 200 L/ha up to 20 m^3.	The taking and use of fresh water that is not [permitted, controlled, restricted discretionary, non-complying, or prohibited by another rule] is a discretionary activity.	**C5.1.10**
RWSPN	The taking, use or diversion of groundwater from an aquifer is permitted subject to conditions. In this instance, the proposal is in excess of 10 m^3/day.	The proposed take does not meet the requirements of the permitted, controlled, or non-complying activity rules. A water meter as described by the rule can be installed. As such, the proposal is a discretionary activity.	**25.3.1**

The proposed taking and using of water is therefore classified as a *discretionary activity* under both plans.

5. Non-Notification and Consultation

The recent amendments to the RMA requires the consent authority to follow a stepped process as set out in s95A of the RMA to determine whether to publicly notify an application for a resource consent. A notification assessment has been carried out in accordance with the new stepped process as follows;

Section 95A(2) RMA Step 1:

- No, the applicant has not requested public notification; and
- No, public notification is not required under s95C; and
- No exchange of recreation reserve land under s15AA of the Reserves Act 1977 is sought.

If no, go to Step 2.

Section 95A(4) RMA Step 2:

- No, there are no rules which precludes public notification:
- No activities are a controlled activity:
- No activity is a subdivision of land or a residential activity:
- No activity is a boundary activity:
- No activity is a prescribed activity (see section 360H(1)(a)(i)).

If no, go to Step 3

Section 95A(7) RMA Step 3:

- No, no activities are subject to a rule or national environmental standard that requires public notification:
- No, it is unlikely that the consent authority would decide, in accordance with section 95D, that the activity will have or is likely to have adverse effects on the environment that are more than minor.

If no, go to Step 4.

Section 95A(9) Step 4:

- No, there are no special circumstances which exist in relation to the applications to warrant the application being publicly notified.

Therefore, in accordance with s95A(9)(b) RMA, the consent authority must not notify this application but may determine whether to give limited notification under s95B.

Schedule 4 of the RMA requires that an AEE should identify:

The persons affected by the activity, any consultation undertaken, and any response to the views of any person consulted.

Potentially affected parties could include other groundwater users and occupiers of the land. However, the well interference assessment provided in Section 6.2 of this application concludes that no other groundwater users are considered to be adversely affected by the granting of this application. Therefore, no consultation has been undertaken with other water abstractors and users.

Consultation has been undertaken with the current occupiers of Te Raite Station, Waiora North Farms Limited. A copy of an affected persons approval form signed by Waiora North Farms Limited is annexed to this application as Appendix 2.

No other persons are considered to be affected by the proposed groundwater take and use.

6. Assessment of Effects on the Environment

6.1. Overview

Section 88 of the RMA requires the Applicant to make an assessment of any actual or potential effects that the proposal may have on the environment, and the ways in which any adverse effects may be avoided, remedied or mitigated. The actual and potential effects on the environment from the proposed water take and use described in this application are discussed below.

In accordance with Section 104B of the RMA, when considering an application for a resource consent for a *discretionary activity*, a consent authority may grant or refuse an application, and it if grants the application it may impose conditions under Section 108 of the Act.

The effects (or level of impacts) from the proposed taking and using of groundwater are discussed in the subsections below. The potential adverse effects include effects on other users, effects on surface water bodies, and effects on the aquifer. Potential positive effects include better utilisation of agricultural land, greater employment opportunities and corollary benefits to the community.

6.2. Consideration of Alternatives

An AEE must include a description of alternative locations or methods for undertaking an activity, if it is likely that the activity will result in any significant adverse effect on the environment.

The effects of the proposed taking and using of groundwater were assessed as being no more than minor on the environment and less than minor on persons. As such, no alternatives have been considered for this proposal.

6.3. Effects on Other Users

Pumping groundwater from the Applicant's bores may have an adverse effect on hydraulically connected neighbouring bores. The abstraction of groundwater creates a drawdown cone that extends laterally from the pumping bore and may result in a lowering of groundwater levels in neighbouring bores. Such lowering may adversely affect existing users by preventing them from taking their authorised volume or abstraction rate, and may also result in increased costs for such users through having to lower their pump, change from a surface to submersible pump or by using more electricity to abstract water.

Potential drawdown effects resulting from this groundwater take and use application being granted and used were modelled by Lincoln Agritech (Appendix 1) using the Theis (1935) Equation. Further detail on the parameters and methodology used for calculating drawdown effects is available in Appendix 1, pages 22-24.

The drawdown assessment was made for every registered well within 10km of the centre of the Te Raite Station proposed bores. Figure 7 displays the spatial distribution of the cumulative drawdown effect as contours of drawdown extrapolated from bore-position cumulative drawdown totals.

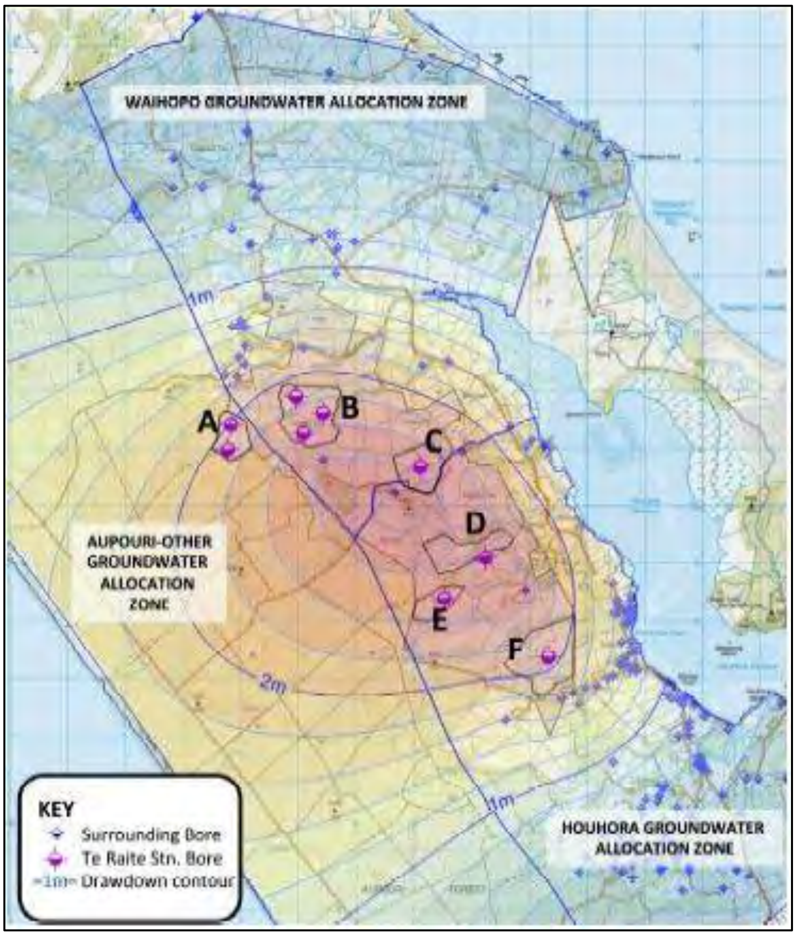

Figure 7: Contours of extrapolated contours of 217 day Theis drawdown surrounding Te Raite Station irrigation bores

Figure 8 shows the distribution of bores in relation to calculated drawdowns. There are two clusters of drawdown including a cluster of bores potentially affected by drawdowns of 0-1 m and the second of 1-2 m.

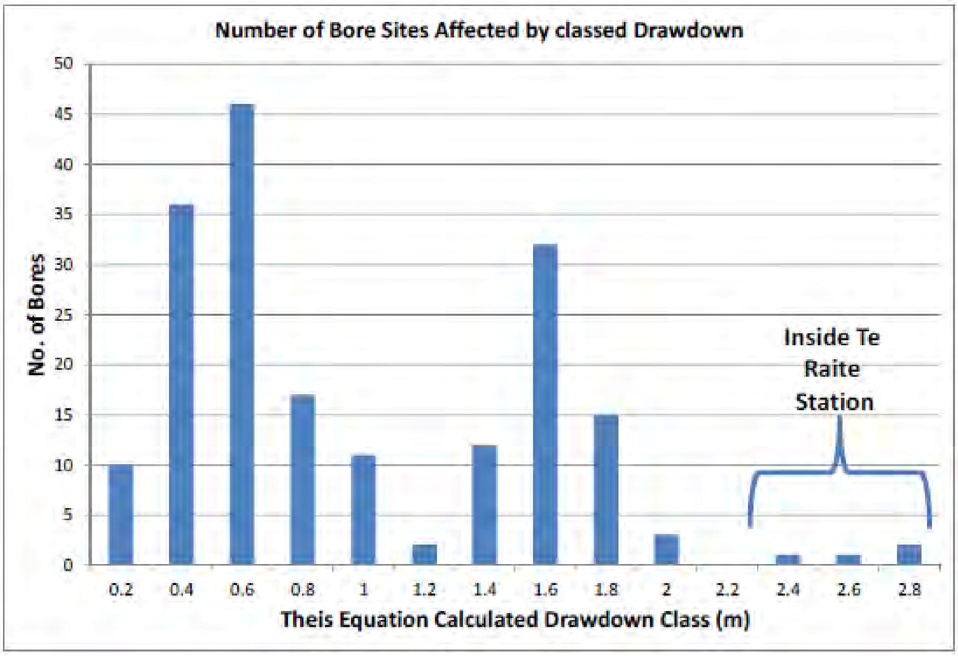

Figure 8: Frequency distribution of surrounding bores with classed drawdown

Theis inevitably over-estimates drawdown as, in this case, there is expected to be more leaky, semi-confined condition as opposed to confined. Recharge through leaky compensation has therefore not been factored into the equation.

Drawdowns of greater effect are likely to be experienced in the associated deep marine sand layers within which the new bores are proposed to be drilled to. Bores screened in shallower layers could experience a delayed and subdued drawdown effect, if anything.

In properly constructed bores, there is adequate provision for sustainable abstraction where fluctuation in water levels occur to a moderate degree.

It is therefore concluded that, while the modelled drawdown effects are between 0-2 m, these values are highly conservative and likely over-estimate actual cumulative drawdowns from proposed pumping. The modelled drawdown and any variation would not lower the groundwater table below existing efficient bore takes in accordance with Policy 10.5.1(b) of the RWSPN.

6.4. Effects on Surface Water Bodies

Prolonged decline in groundwater levels through over-abstraction can increase losses from other water bodies and reduce flows in spring-fed streams; consequently adversely affecting their life-supporting capacity, recreational value, habitat quality as well as cultural and amenity values. Irrigating within the near vicinity of surface waterbodies can have an effect on the flow of the streams, increasing the flow volume and associated velocity, which can cause increased turbidity, flooding and impact on local freshwater ecology.

The majority of the waterbodies in the vicinity of the proposed take and use areas are perched by their underlying soils, for example the dune lakes and wetlands, and so would not be adversely affected by a groundwater take. Surface water bodies in irrigation areas A, B, C, and F are not considered likely to be affected. Proposed Irrigation Areas D and E lie between the Korakonui and Kaikati streams, both tributaries of Houhora Harbour.

While bores in both area D and E would be screened in the shell layer with the top of the screen between 94 m and 110 m below ground level, semi-confined leakage could serve to cause a depletion of the overlying streams.

Calculations used to determine potential adverse effects on the streams are available at Appendix 1.

As shown in Figure 3, the stream are located over the Te Kopuru Sand or Ruakaka Peat Sandy Loam with the associated subsoil peats and pans. Prior investigations show that iron pans underlie the farm particularly in Irrigation Area D range between 0.5 – 2m in thickness.

Figure 9 shows where test pits were dug, indicating the depth at which the iron pan was encountered (first figure in brackets in meters) and then the thickness of the test pit (second figure in meters) which supports information on soils, and subsoil peats band pans would tend to indicate that the streams are perched where the water table lies deeper than the stream bed by the peats and pans. Conversely, where the water table rests above the stream bed the interaction between stream and sand aquifer would be buffered by the low permeability of the same peats and pans.

Figure 9: Iron pan investigations in Irrigation Area D

Additionally, the interaction between surface water bodies (Kaimaumau wetland, Selwyn and Seymour drains) adjacent the station and the deep shell bed aquifer in the Motutangi – Waiharara allocation zone was investigated using radon tracers in 2017 (Appendix 4). The results of that investigation suggest that there is no hydraulic connection these water bodies and the deep shell bed groundwater. The overall lithological and hydrological setting of Korakonui and Kaikatia streams in Te Raite Station is sufficiently similar that stream flow depletion from deep shell bed bore pumping is small to negligible.

Based on the proposed systems and this analysis, the effects of use of groundwater to irrigate land adjacent the Korakonui and Kaikatia streams would be less than minor.

Overall, the proposed take and use of groundwater is expected to have a less than minor effect on surface water. Due to the low risk and small effects of the take and use on surface water bodies and therefore their flow, it is considered that freshwater ecology of the waterways should not be adversely affected. Any effects that may arise are expected to be insignificant.

6.5. Effects on the Aquifer

Abstracting groundwater from the Applicant's bore may have an impact on the aquifer. This would occur if the volume of groundwater extracted over an entire season was significant, compared to the volume of groundwater inputs into the aquifer over that same period.

The Proposed Regional Plan sets allocation limits for a number of aquifers in Northland, the report prepared by Lincoln Agritech regarding the allocation limits is annexed as Appendix 3. The Waihopo and Houhora allocations zones are currently sitting within 13.4% and 48.8% of their respective zone allocation limits. The Aupōuri - Other allocation zone consented total is currently only 0.2% of its allocation limit. The effect of adding the Te Raite Station groundwater take proposal would be to take the Waihopo zone to 13.4% of its limit, and the Houhora zone to 75% of its limit. The Aupōuri - Other zone consented take would increase to 0.9% of its limit. In no case would the consented groundwater take exceed the relevant allocation limit.

In addition to causing a localised depression in groundwater levels, the taking of groundwater can, over time or in combination with other takes, cause cumulative effects such as contribution towards saline intrusion in coastal aquifers like the Aupōuri Sand Aquifer.

These allocation limits were based on an overall take that was both sustainable and which would reduce risk of causing adverse effects on the environment, including saline intrusion.

6.5.1. *Lateral Seawater Intrusion*

The lateral intrusion of saline groundwater into a freshwater aquifer can occur where the ground water balance is sufficiently imbalanced to reverse current lateral outflow of fresh groundwater. Lincoln Agritech (Appendix 1) modelled the proposed take against current outflow to assess the risk of lateral saline intrusion into the Aupōuri Sand Aquifer.

It was found that 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 at the margin of Houhora Harbour would oppose the reversal of gradients or the inflow of groundwater from the harbour.

It was considered that the modelled drawdown would be unlikely 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 not occur as a consequence of granting the proposed groundwater take for Te Raite Station. There will be no adverse lateral saltwater intrusion effect.

6.5.2. *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.

The conditions required for saline up-coning, however, are not present. There are no known saline water bodies in the Aupōuri Sand Aquifer.

Long-term monitoring of water quality at the Collville bore (number 200059) at a depth of 55 m BGL on Hukatere Road, just south of Te Raite Station 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. Seawater has a chloride concentration of 19,400 mg/L.

A scan of drillers notes as to water taste comments in bore logs for bore drilled in the south of Te Raite Station near Pukenui reveals that even this 110 m deep bore at the homestead (bore number 200213) had very good water quality indicative of chloride concentration lower than the taste threshold (i.e. less than 320 mg/L).

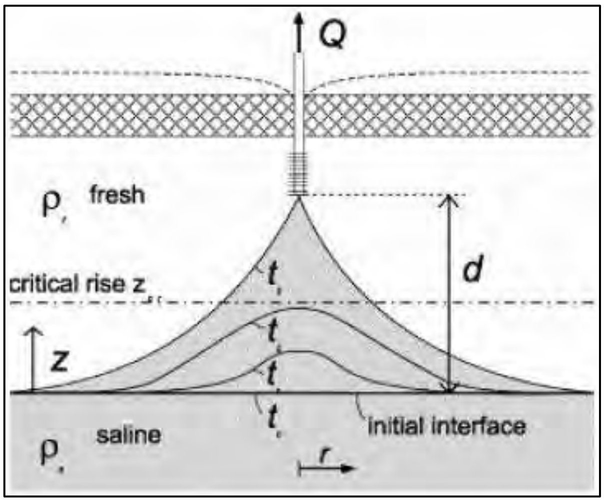

Figure 10: Theoretical example of the movement in the fresh – salt water interface in saline up-coning

It was found that there was a low risk of saline up-coning resulting from the operation of the Te Raite Station irrigation bores.

Overall and in light of the low risk, it is considered that the potential adverse effects of saline intrusion resulting from the proposed groundwater take and use at Te Raite Station are less than minor.

6.6. Efficiency of Use

The applicant will be converting this land to mixed horticultural cropping. Water requirements will vary for different crops and their growth stages.

At maximum capacity, an application depth of 4mm/day is sought to replace water lost through plant uptake and evapotranspiration. Over 260 ha this equates to the applied for 10,400 m^3/day peak. The application also seeks an application rate of 450mm/year which over 260 ha equates to 1,170,000 m^3/year of water.

Avocados are a crop which the applicant is looking to invest in. According to Irricalc, an avocado crop at this location requires up to 5 mm/day and up to 450 mm/year for plant water requirement in a 1 in 10 year (i.e., 90% reliability) high irrigation demand on this soil type.

The applicant’s proposed volumes are less than that modelled as efficient for a 1 in 10-year high irrigation demand event for a known crop. The proposed volumes are therefore considered an efficient use of water.

Measures have been proposed as conditions of consent to ensure that the system is operated in a manner which promotes efficient use of water.

6.7. Positive Effects

Converting 260ha of marginal grazing land to horticulture, cropping, and market garden land would yield a higher production and value from that land. Irrigating the land is crucial to making this conversion possible. The higher value crops would generate more income per hectare than dryland livestock. This presents a benefit to the Applicant as well as to the community that the Applicant, a local iwi-owned company which also puts money back into the region, operates in.

A conversion resulting from a groundwater take and use permit would require a significant increase in labour requirements from the current levels. This labour would need to be sourced locally and would be skilled, especially for the horticulture operation. The conversion that this application proposes to facilitate presents a positive employment opportunity in the area as well as an opportunity for the community to upskill in an area where the skills can be used and marketed beyond Te Raite Station.

Beyond the capital costs required to establish the new farm systems, there is an ongoing long term positive effect for the community. Cumulatively between the higher revenue generated by the new crops and the employment benefits to people living in the area, the community will see more money being brought into the region by the venture.

7. Statutory Considerations

Schedule 4 of the RMA requires that an assessment of activities against the matters set out in Part 2 and any relevant provisions of a statutory document referred to in s104(1)(b) of the RMA is provided when applying for a resource consent for any activity. These matters are discussed as follows.

7.1. Part 2 of the RMA

The proposed activities are consistent with the purpose and principles of the RMA, as outlined in Section 5. The proposals will have only minor effects on the natural and physical resources abilities to meet the reasonably foreseeable needs of future generations, or on the life-supporting capacity of water at this location or any ecosystems associated with it.

There are no matters of national importance under s6 of the RMA recognised in this area.

The activity is consistent with the requirements of s7 of the RMA, with particular regard given to kaitiakitanga, the ethic of stewardship, maintenance and enhancement of the quality of the environment, and any finite characteristics of natural and physical resources.

Regarding s8 of the RMA, the proposals are not inconsistent with the Treaty of Waitangi.

Overall, the activities are consistent with Part 2 of the RMA.

7.2. Section 104(1)(b) of the RMA

Documents referred to in Section 104(1)(b) of the RMA are;

(I) *a national environmental standard:*

(II) *(other regulations:*

(III) *a national policy statement:*

(IV) *a New Zealand coastal policy statement:*

(V) *a regional policy statement or proposed regional policy statement:*

(VI) *a plan or proposed plan*

The following provides assessment of the relevant provisions of the documents listed.

7.2.1. National Environmental Standards

There are no national environmental standards which are applicable to these proposed activities.

7.2.2. Resource Management (Measurement and Reporting of Water Takes) Regulations 2010

The Applicant proposes to monitor the water abstraction from all bores in accordance with the Resource Management (Measurement and Reporting of Water Takes) Regulations 2010. This requirement is reflected in the proposed conditions in Section 2.3 of this report.

7.2.3. National Policy Statement for Freshwater Management 2014

7.2.3.1. Relevant Objectives and Policies

The following objectives and policies of the NPS are relevant to this proposal:

WATER QUALITY

- *Objective A1* seeks to safeguard the life-supporting capacity, ecosystem processes and indigenous species including their associated ecosystems of fresh water, in sustainably managing the use and development of land, and of discharges of contaminants.
- *Objective A2* required that the overall quality of fresh water within a region is maintained or improved while improving the quality of fresh water in water bodies that have been degraded by human activities to the point of being over-allocated.
- *Objective A4* seeks to enable communities to provide for their economic well-being, including productive economic opportunities.
- *Policies A2, A3, and A7* are considered relevant to this application and give effect to these Objectives.

This proposal is consistent with these policies and objectives and either supports them or at the least maintains them.

WATER QUANTITY

- *Objective B2* seeks to avoid any further over-allocation of fresh water and phase out existing over-allocation.
- *Objective B3* seeks to improve and maximise the efficient allocation and efficient use of water.
- *Objective B5* seeks to provide for communities' economic wellbeing within freshwater quantity limits.
- *Policies B2 to B6* are considered relevant to this proposal and the Applicant's groundwater take and use proposal are consistent with these policies.

INTEGRATED MANAGEMENT

- *Objective C1* seeks to improve integrated management of fresh water and the use and development of land in whole catchments, including the interactions between fresh water, land, associated ecosystems and the coastal environment.
- *Policies C1 and C2* are relevant to this application and give effect to this objective. This proposal is consistent with and supports the objective and policies.

7.2.4. *Regional Policy Statement for Northland*

The following Objectives are considered relevant to this proposal:

- *Objective 3.2* seeks to maintain and improve water quality for human use and ecological health. This proposal is consistent with the objective as it will at the least maintain water quality.
- *Objective 3.3* seeks to safeguard the flows and flow variability required to maintain water's life-supporting capacity, for ecological processes, and to support indigenous species. As discussed in the assessment of effects, the proposal is consistent with this objective and can assist in achieving it by monitoring stream flows on site.
- *Objective 3.5* requires that the region's resources are sustainable managed in a way that is attractive for business and investment that will improve the economic wellbeing of the region and its communities. Granting resource consent for this proposal would achieve this objective.
- *Objective 3.10* requires efficient use and allocation of common natural resources with a particular focus on maximising the security and reliability of supple for users. Groundwater in Northland is a common natural resource and a resource consent granting groundwater take and use would allow for secure and reliable water supply that would enable the Applicant to develop its land.

The following Policies give effect to the above Objectives, and therefore are considered relevant to this application:

- *Policy 4.2.1* seeks to establish freshwater objectives, reduce contaminant loads to water and promote active management, enhancement and creation of riparian margins and wetlands. It is considered that this proposal is not inconsistent with Policy 4.2.1.
- *Policy 4.3.2* requires regulatory methods to avoid over-allocation of region-wide ecological flows and water levels. This application proposes a groundwater take that does not exceed allocation limits in the region, and so is consistent with this policy.
- *Policy 4.3.3* requires the allocation and use of water efficiently within allocation limits. A 'first in first served' approach is to be used to reduce costs to the regional council. This proposal is consistent with policy 4.3.3 and will use highly efficient irrigation methods to use the water.

Overall, is it considered that the proposal is consistent with the RPS.

7.2.5. *Regional Plans*

7.2.5.1. PRP Objectives and Policies

The following objectives and policies of the PRP are considered relevant to this proposal:

- *Objective F.0.1* seeks to manage the use, development, and protection of Northland's natural and physical resources which enables people and communities to provide for their social, economic and cultural well-being while
  1. *sustaining the natural resources to meet the reasonable foreseeable needs of future generations,*
  2. *safeguarding life-supporting capacities of water, and*
  3. *avoiding, remedying, or mitigating adverse effects on the environment.*
- *Policy D2.2* requires that regard is had to the social, cultural, and economic benefits of the proposed activity when considering resource consents. As discussed in Section 6, proposal will facilitate the economic and social benefits to Te Aupōuri Iwi and the community in the Far North District.
- *Policy D2.5* requires an authority to have regard to community and tangata whenua values. The proposal is not inconsistent with either community values, as there has been conversion to market gardening and horticulture in the area which benefits the community, or tangata whenua including Te Aupōuri.
- *Policies D4.1, D4.2, and D4.5* are considered relevant, and the groundwater take and use proposal are not inconsistent with these policies as discussed in Section 6.
- *Policy D4.17* considers allocation limits for aquifers and requires rules and applications to meet allocation limits. This proposal is consistent with Policy D4.17 as the proposed take will not exceed allocation limits over the three zones the take is proposed from.
- *Policy D4.18* concerns conjunctive surface water and groundwater management. This application is consistent with the policy, and also proposes a monitoring condition to be included in the consent conditions to monitor Korakonui and Kaikatia Streams.
- *Policy D4.20* requires the reasonable and efficient use of water for irrigation and sets requirements for a resource consent application to take water for irrigation purposes. Modelling has been undertaken supported by water usage at other similar operations in the area to what is proposed on site. The model calculated the irrigation volume required, which would be applied using high efficiency irrigation methods. It is considered that the proposal is consistent with Policy 4.20.

7.2.5.2. RWSPN Objectives and Policies

The following objectives and policies of the RWSPN are considered relevant to this proposal:

- *Objective 7.4* requires the maintenance or enhancement of water quality of natural water bodies. As discussed in Section 6 above, this application is not inconsistent with this objective.
- *Objective 10.4.1* maintains the sustainable use and development of the region's groundwater resources while avoiding, remedying, or mitigating actual and potential adverse effects on groundwater quantity and quality. This objective is relevant to this application, and the two are considered consistent. This proposal seeks to sustainably use and develop Northland's groundwater resource. As discussed in Section 6, it is considered that adverse effects can be avoided, and mitigation measures are propose as conditions through monitoring the resource and its use.
- *Policy 10.5.1* seeks to ensure the sustainable use of resources by avoiding takes that exceed recharge. Saltwater intrusion, reduced groundwater quality, significant drawdown, and adverse effects on surface water resources can arise where takes exceed recharge. The Applicant's proposal is consistent with and supports this

policy, the take will not exceed recharge and modelling has concluded saline intrusion to be of little to no risk.

- *Policy 10.5.2* recognises that aquifers are at risk in certain circumstances and that adverse effects on water quality should be avoided. This has been considered in Section 6 above and it is considered that the proposal is consistent with this policy.
- *Policy 10.5.4* seeks that groundwater allocations take into account reduction in recharge that may occur in time. The Northland Regional Council has already done so in setting its allocation limits based on modelling done in 2015.
- *Policy 10.5.7* requires the Northland Regional Council to consider effects of a groundwater take and use on surface water bodies. This proposal is consistent with the policy in that the take and use is not expected to have significant effects on surface water bodies in and around the station.

Overall, the proposal that this application supports is consistent with the objectives and policies of the incumbent and proposed regional plans.

7.3. Consent Duration, Lapse and Review

These matters were identified in Section 2.3 above.

A consent duration of 20 years is sought subject to a lapse period of 3 years from commencement of consent.

Review conditions have been proposed for the purposes laid out in Section 2.3 of this report.

8. Conclusion

Te Aupōuri Commercial Development Ltd. is a commercial arm of Te Aupōuri, one of the tangata whenua of the Far North. The company owns and operates Te Raite Station at Houhora as agricultural land in pasture. The Applicant seeks to better utilise a fraction of the large station, by being able to undertake higher value irrigated land uses.

In order to do so, a reliable water supply must be obtained to make the development feasible. The Applicant does not currently hold any groundwater take and use permits for irrigation purposes, and requires a permit to irrigate that land with water from the Aupōuri Sand Aquifer.

Nine bores are proposed in approximate areas of the farm, the exact locations of which would be confirmed following the successful application for a groundwater take and use consent.

The Applicant proposes to take from three allocation areas, in volumes that do not exceed the allocation limits. Rates of take would be managed to ensure that drawdown effects on other groundwater users are no less than minor, and would take place between spring and autumn each year. Only high efficiency irrigation infrastructure would be used to ensure reasonable and efficient use of the resource while promoting productivity.

The AEE has demonstrated that the potential adverse effects of the proposed water take and use on the environment will be minor, and the effects on persons will be less than minor. Further, the overall effects of this proposal on the wider community are considered to be beneficial by creating employment opportunities and contributing to economic benefits to both the community and to Te Aupōuri iwi.

The proposal is also considered to be consistent with the relevant objectives and policies of the NPS, the RPS, the PRP, the RWSPN, and Part 2 of the RMA.

Under Section 104B of the RMA it is considered that there is no impediment to granting the application on a non-notified basis.

Appendix 1

Te Aupōuri Te Raite Station Groundwater Effects Assessment – Report 1236 – 2 – R1

Te Aupōuri

Te Raite Station Groundwater Effects Assessment

Report 1236-2-R1

Jens Rekker
Lincoln Agritech Ltd

1 February 2018

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DOCUMENT ACCEPTANCE

ACTION	NAME	SIGNED	DATE
Prepared By	**Jens Rekker**		1 February 2018
Reviewed By	Scott Wilson		31 January 2018
Approved By	Blair Miller		**1 February 2018**

EXECUTIVE SUMMARY

The proposed irrigation development utilising nine yet to be drilled water bores would have a nameplate capacity of 130 L/s and require consent for 1,170,000 cubic metres of groundwater per annum. The groundwater pumped would be utilised over a seven month period from Spring to Autumn each year. The groundwater is required to service the spray and drip irrigation requirement of cropping and horticulture across an approximate 260 ha of land within Te Raite Station, which are yet to be developed. The proposed drilling target is the shell beds at the base of the Aupouri Sand Aquifer, due to their capacity to be used as a higher permeability under-drain of groundwater in the marine sand and above. This would prescribe the use of nine bores in the depth range of 90 m to 125 m below ground. The shell beds are commonly used for irrigation, stock and domestic water supply in the area and can be inferred to extend beneath Te Raite Station. 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 network in terms of modern well hydraulics and the capacity of the Aupouri Sand Aquifer to supply water to each bore,
- The groundwater level lowering effects of combined bore pumping operation on surrounding groundwater users utilising water bores,
- The depletion of surface water flows caused by underlying groundwater pumping, and
- The potential for saline intrusion as a result of the combined groundwater pumping activity.

Delineation of the well hydraulics, available bore depth dimensions and calculated aquifer head losses were set against each other to determine the freeboard between the minimum water level that the pumping bore could tolerate and the lowest water level indicated by head losses. The irrigation bores came through the assessment with the smallest individual freeboard as 35.5 m indicating that the bore configuration is feasible.

Highly conservative calculations of consequent drawdown were used to predict these effects on neighbouring bores in the same aquifer. The calculations indicate that bore within 10 km of the centre of the station would experience drawdown effects between 0 and 2 m. The drawdown effect at the closest part of the Houhora Harbour shore line was calculated as 1.6 m. Such drawdown intensities are within the 2.6 m to 3.3 m range of recorded water level fluctuations for the shell bed water bearing layer.

The proposed groundwater takes would be spread over three indicative groundwater allocation zones (Wilson & Shokri, 2015) due to the need to locate bore closest to their farm areas' of use. Indicative groundwater allocations have been published for each of these groundwater allocation zones, plus the Aupouri Sand Aquifer as a whole. The added groundwater abstraction volume to allow the proposed irrigation at Te Raite Station would not cause any of the associated groundwater allocation zones to exceed the indicative limits, nor would the sum of new abstraction volume cause any particular allocation zone to exceed its individual limit.

As the indicative allocation limits were conservatively set to prevent the possibilities of the aquifer exceeding its safe yield or inducing seawater to intrude beneath the landward portion of the aquifer, the fact that the current proposal does not lead to an exceedance of the limits is reassuring. The projected drawdown of the deeper, semi-confined shell bed layer water pressure by 1.6 m at the coast line is not considered to endanger the aquifer with seawater intrusion risks.

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1. INTRODUCTION

1.1 Background

Te Aupōuri is considering the re-development of the pastoral Te Raite Station to higher value arable and horticultural production (see Figure 1 for location). Te Raite Station has not required the development of its water resources beyond domestic and stock water supplies for its mainly pastoral land use. The re-development would require installing efficient irrigation systems tailored to the crops and orchards planned for the station. Critical to the development of irrigation is the installation of headworks and consenting of water resources found beneath the station land. 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 Aupouri Sand Aquifer (outlined in red) in Northland, New Zealand

Te Raite Station has a historic land use of sheep, and sheep & cattle grazing. Neither of these pastoral systems justified irrigation of pasture in the Northland climate. Te Aupōuri proposes a partial shift to market gardening, horticulture and higher intensity pastoral productive land uses over 377 ha of the station's 1,849 ha land total area. These land uses require irrigation of a nominal 260 ha of land up to a maximum application rate of 4,500 cubic metres of groundwater per hectare per annum (m^3/ha/year). The irrigated land has been identified in four distinct areas in tabular form in Table 1 and in graphic form in Figure 2.

Table 1: List of Proposed Irrigation Areas

Zone	Locality	Gross Area (ha)	Intended Irrigable area (ha)	Intended use	Per Hectare Rate (m^3/ha/yr)	Nominal Rate of Take (m^3/year)	Peak Daily Rate (mm/d)
A	Kimberley Flat	38	35	Horticulture	4,500	157,500	4
B	Cindery Flat	93	60	Cropping / Horticulture	4,500	270,000	4
C	Trig-Bulldog Flat	54	40	Cropping / Horticulture	4,500	180,000	4
D	Korakonui Str.	60	40	Cropping / Horticulture	4,500	180,000	4
E	Kaikatia Stream	29	25	Horticulture	4,500	112,500	4
F	Lamb Road	103	60	Cropping / Horticulture	4,500	270,000	4
Total		**377**	**260**			**1,170,000**	

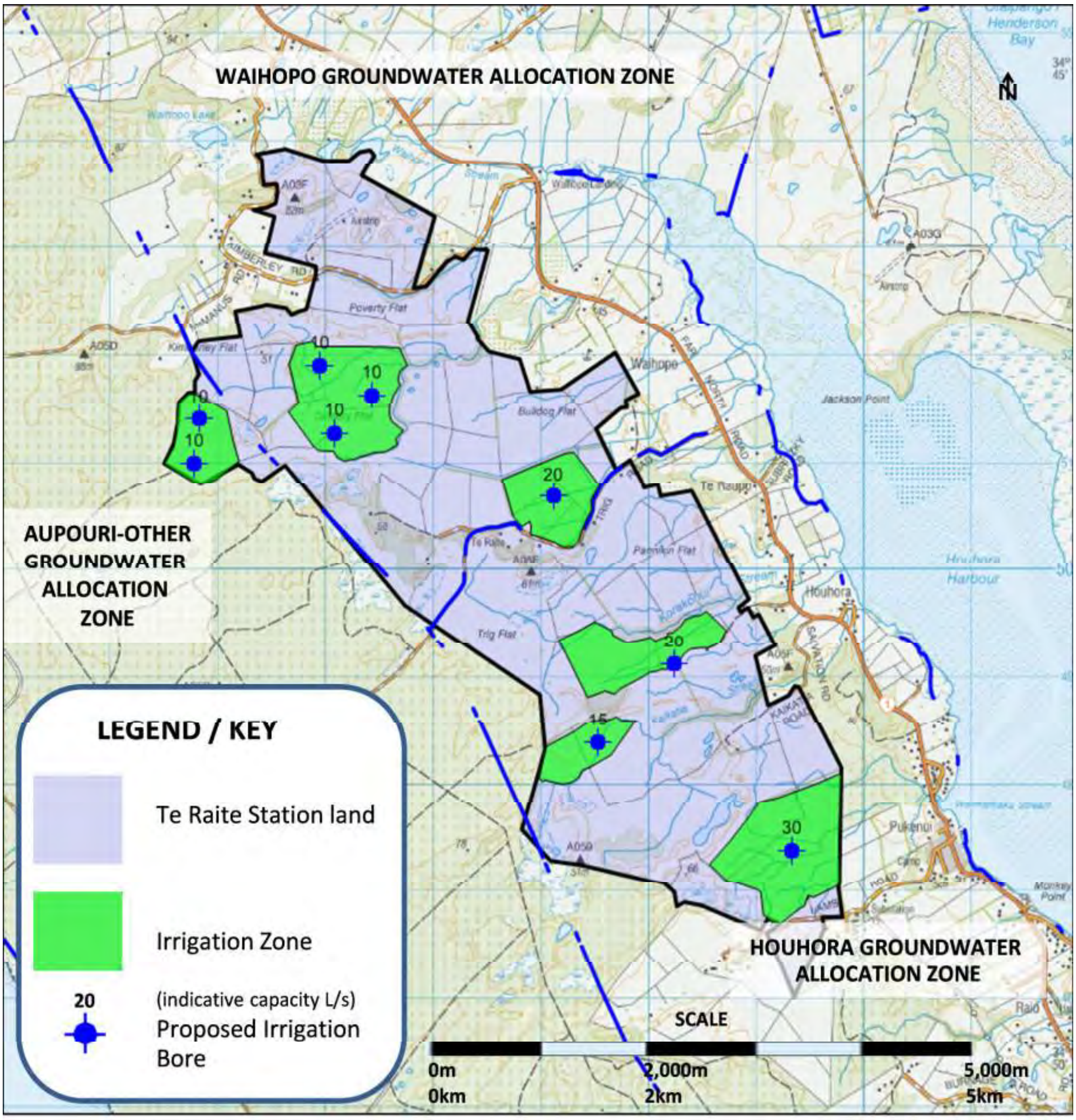

Figure 2: Te Raite Station, Irrigation Zones and proposed bore locations

Up to 1.17 million cubic metres per annum (Mm3/year) would be drawn from the Aupouri Sand Aquifer (Wilson & Shokri, 2015) within this proposal. The taking of groundwater would be spread over three Northland Regional Council (NRC) groundwater indicative allocation zones (see Figure 2 and Table 2).

Table 2: List of Irrigation Zones and corresponding NRC Groundwater Allocation Zones

Zone	Locality	Indicative Irrigation Area (ha)	Proposed Annual Volume (m^3/year)	NRC Groundwater Allocation Zone
A	Kimberley Flat	35	157,500	Aupouri-Other
B	Cindery Flat	60	270,000	Waihopo
C	Trig-Bulldog Flat	40	180,000	Waihopo
		Waihopo Zone Total Proposed Take	450,000	
D	Korakonui Stream	40	180,000	Houhora
E	Kaikatia Stream	25	112,500	Houhora
F	Lamb Road	60	270,000	Houhora
		Houhora Zone Total Proposed Take	562,500	
		Te Raite Station Proposal Total	1,170,000	

Note: Aupouri-Other Zone and Waihopo Zone are considered to be allocated in consents to a Low level (<25% of the allocation limit). Houhora Zone is considered to be allocated in consents to a Moderate level (from 25% to 75% of the 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 Aupouri Sand Aquifer (Wilson & Shokri, 2015). This report has been the basis of Northland Regional Council's release of indicative groundwater quantity and allocation limits for the Aupouri 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 Te Aupōuri 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

Te Raite Station is a former Landcorp Pastoral property located to the northwest of Pukenui Township, immediately inland of Houhora Harbour, Northland. The station lies within the Far North District and Northland Region, and administered by the respective councils accordingly. The station is bounded Far North Road to the east, Lamb Road to the south and the Crown leased forestry blocks to the west. Trig Road bisects the property and also marks the boundary between Houhora and Waihopo groundwater allocations zones.

Relief across the station 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 of Te Raite Station. Within the station, the topography is more characterised by named flats between subdued sand ridges, and stream gullies or dune lakes in low areas.

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. The station adjoins an extensive area of plantation forestry named Aupouri 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 station, including all of irrigation zone A. These are also classed as 'drifting or recently stabilised'. Figure 3 shows the somewhat dated DSIR New Zealand Soil Bureau (Sutherland et al, 1979) map of the area including Te Raite Station.

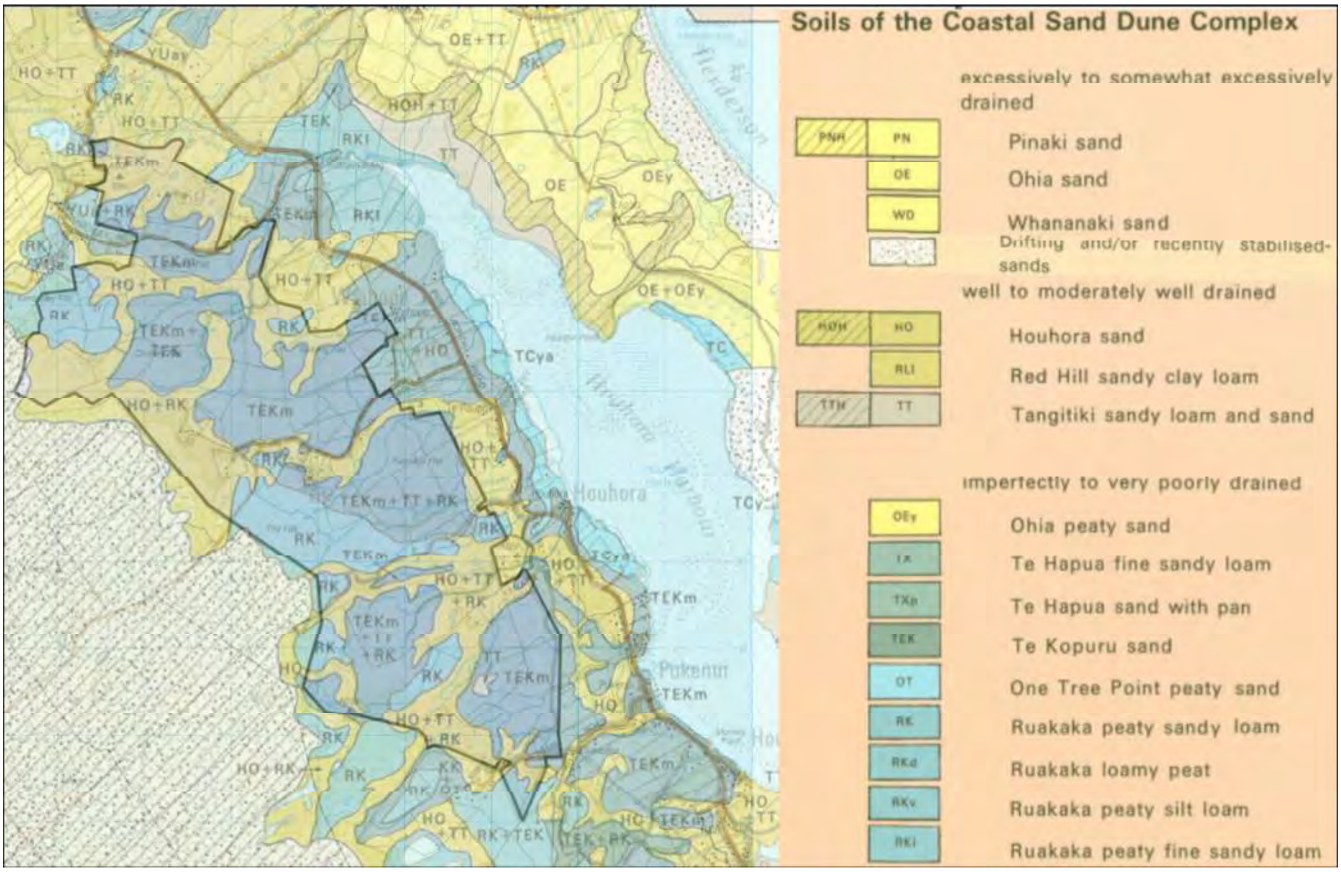

Figure 3: Soil Bureau map of the Houhora area (Sutherland et al, 1979) margin of Te Raite Station overlain.

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 Te Raite Station 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. Te Raite Station soils are permeable and will retain low quantities of water in moisture stores.

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 Aupouri 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 3: 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 Aupouri 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 Aupouri 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 Aupouri 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. 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 the 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 4 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 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 4). 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 Aupouri 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 action faulting also appears on the basis of relative displacement to be scissor fault with the hinge to the east. The significance 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). Te Raite Station lies wholly on the up-thrown side of the inferred fault as is clear from Figure 4.

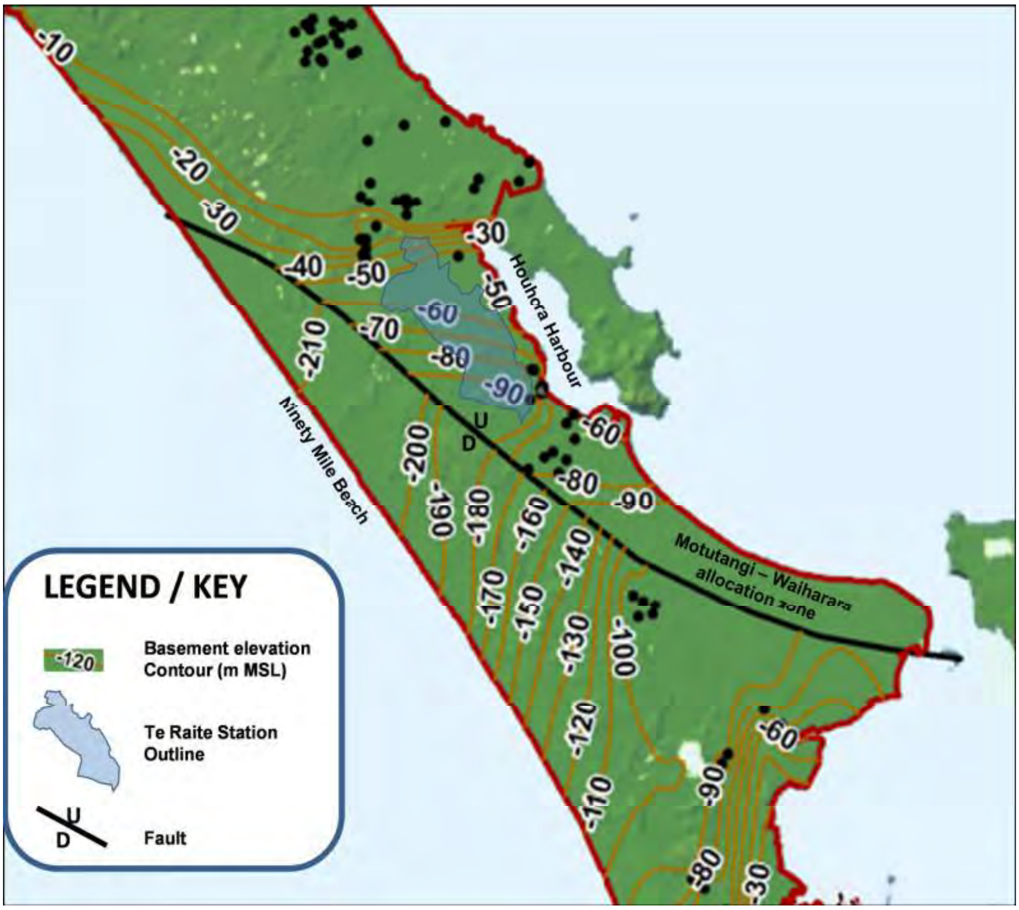

Figure 4: Basement contact elevation contours and buried, pre-Quaternary fault (Wilson & Shokri, 2015)

2.6 Hydrology

Sub-soil permeability and groundwater conditions have a significant influence on the hydrology of the Houhora – Waihopo area. Much of the Aupouri Forest land to the west of Te Raite Station 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 within Te Raite Station 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 4).

Table 4: 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 Te Raite Station to Houhora Harbour, including the unnamed southern tributary of Waihopo, Korakonui and Kaikatia, Waimamaku streams. These streams rise from small lakes, residual wetlands and farm drains within the station. No surface water enters streams draining to the Tasman Sea. No hydrological information is available for individual streams.

2.7 Groundwater

The Aupouri sand tombolo landform hosts the Aupouri 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 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). 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 Aupouri 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 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 not yet highlighted by geophysics. Nonetheless, the results of electrical soundings were sufficient for GCNA to infer deepening of the basement contact to the west.

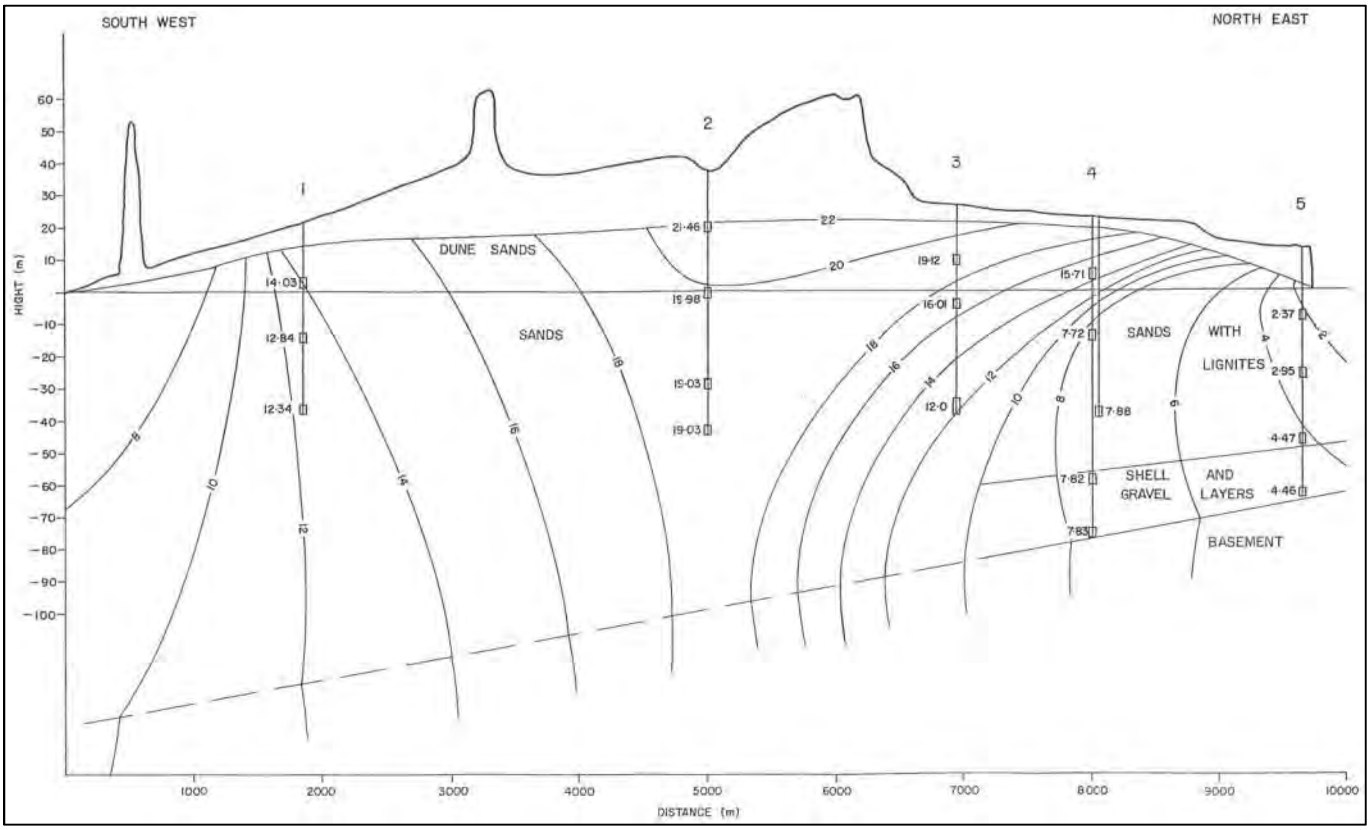

Figure 5: Interpretative hydrogeological cross section of Aupouri Sand Aquifer Hukatere to Monkey Point, Houhora (GCNZ, 1987)

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 Aupouri 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

Te Aupōuri intends that six areas of Te Raite Station are switched to new or higher value agriculture or horticulture that requires irrigation to under-pin production. The irrigation supplies would be drawn from the Aupouri Sand Aquifer directly beneath the areas to be irrigated. A provisional groundwater abstraction plan has identified that the northern-most irrigation areas have aquifer depth constraints that would favour the installation of multiple bores with a maximum capacity up to 10 L/s. These capacity-spreading measures apply to Kimberley and Cindery flats. Further south within Te Raite Station the aquifer deepens, allowing enhanced bore yield and individual maximum bore capacities between 15 L/s and 30 L/s.

The abstraction and irrigation plan is premised upon crop requirements of 4,500 m^3/ha/year over 260 ha. This equates to an annual station-wide groundwater take of 1,170,00 m^3/ha/year (1.17 Mm^3/year) spread across three separate groundwater allocation zones, but the same physical compartment of the Aupouri Sand Aquifer. Table 5 lists a summary of irrigation and allocation zones, plus the irrigation water requirements.

Table 5: Summary of Irrigation Zones, irrigation water requirements and corresponding Groundwater Allocation Zones

Zone	Locality	Intended Irrigable area (ha)	Intended use	Per Hectare Rate (m^3/ha/yr)	Proposed Rate of Take (m^3/yr)	Groundwater Allocation Zone	Probable Bores' Depth (m)
A	Kimberley Flat	35	Horticulture	4,500	157,500	Aupouri-Other	100 (x2)
B	Cindery Flat	60	Cropping / Horticulture	4,500	270,000	Waihopo	90 (x3)
C	Trig-Bulldog Flat	40	Cropping / Horticulture	4,500	180,000	Waihopo	90 (single)
D	Korakonui Stream	40	Cropping / Horticulture	4,500	180,000	Houhora	105 (single)
E	Kaikatia Stream	25	Horticulture	4,500	112,500	Houhora	120 (single)
F	Lamb Road	60	Cropping / Horticulture	4,500	270,000	Houhora	125 (single)
Total		**260**			**1,170,000**		

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 aquifer, also known as 'shell-beds' at the base of the Quaternary sequence.

Figure 6 maps the location of irrigation zones and the proposed pattern of supply bores to be installed for meeting water demand. The irrigation scheme providing for higher value primary production on Te Raite Station sources its water entirely within its legal boundaries, although the fresh water resource is held in common by all users and values attached to the aquifer (steam base-flow, wetland seepage, etc.).

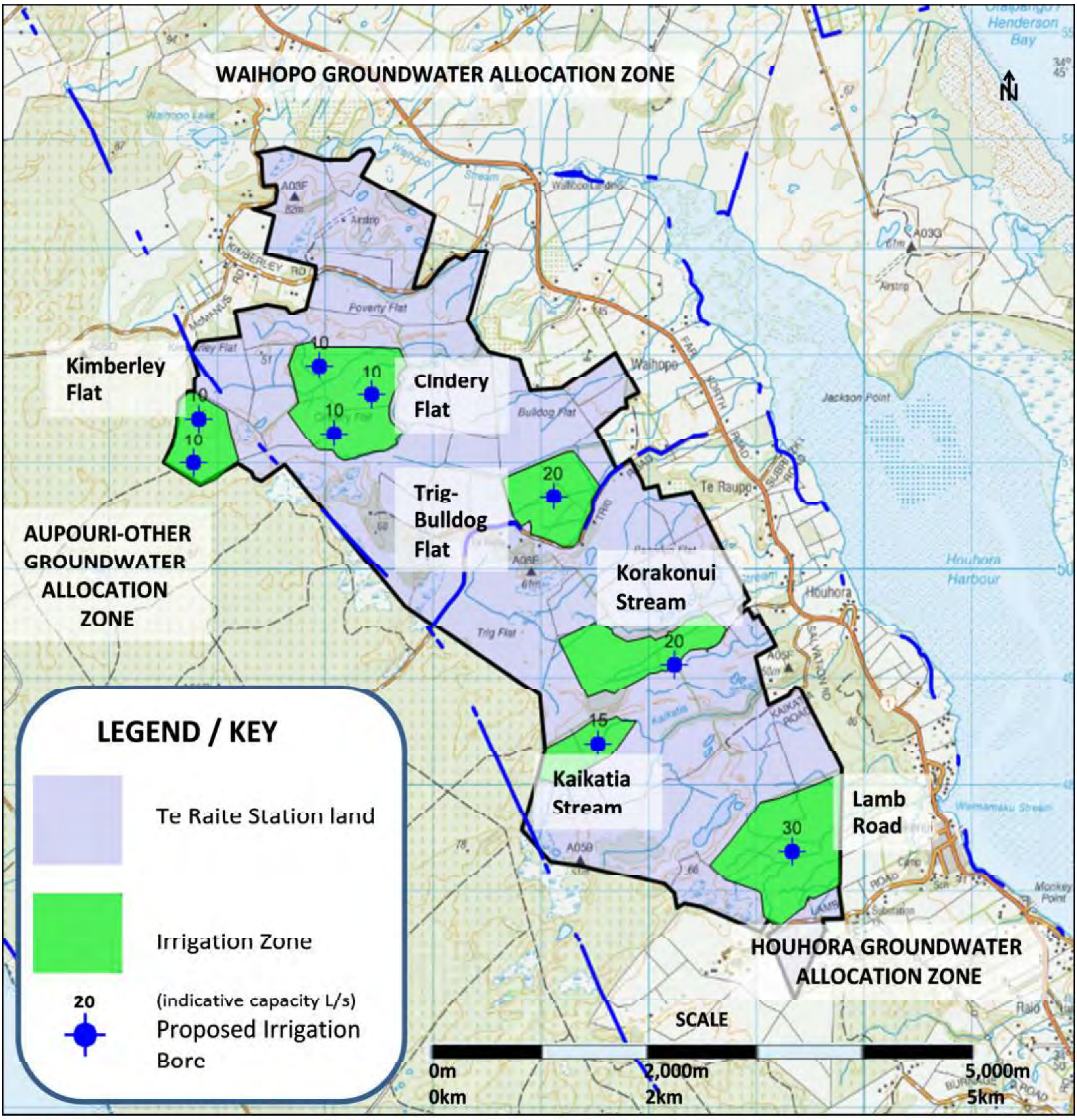

Figure 6: Te Raite Station, Irrigation Zones and proposed bore locations

The irrigation systems have yet to be finalised, although it is reasonable to assume that high efficiency drip and spray irrigations methods would be selected.

4. GROUNDWATER ASSESSMENTS

4.1 Groundwater Pumping Schedule

The groundwater pumping proposed in summarised in Table 6 and Table 7, 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)	4	Peak daily rate
Instantaneous maximum (L/s)	135	The proposed combined capacity of nine proposed water bores
Daily maximum rate (m^3/d)	10,400	Based on peak daily application rate across 260 ha of irrigated land
Monthly maximum rate (m^3/month)	200,000	Based on an estimate of the maximum volume of water required to irrigate 260 ha in highest demand month
Annual maximum volume (m3/year)	1,170,000	Based on nominal water demand of 4,500 m^3/ha/year and irrigated area of 260 ha
Period of irrigation season	October to April in any year	Based on analysis of climate, particularly evapo-transpirative demand across the hydrological year.

Table 7: Summary of required groundwater allocation and corresponding groundwater allocation zones

Zone	**Locality**	**Irrigable area (ha)**	**Proposed Rate (m^3/yr)**	**Groundwater Allocation Zone**	**Probable Depth (m)**
A	Kimberley Flat	35	157,500	Aupouri-Other	100 (x2 bores)
Aupouri-Other Allocation Zone Total			**157,500**		
B	Cindery Flat	60	270,000	Waihopo	90 (x3 bores)
C	Trig-Bulldog Flat	40	180,000	Waihopo	90 (single bore)
Waihopo Allocation Zone Total			**450,000**		
D	Korakonui Stream	40	180,000	Houhora	105 (single bore)
E	Kaikatia Stream	25	112,500	Houhora	120 (single bore)
F	Lamb Road	60	270,000	Houhora	125 (single bore)
Houhora Allocation Zone Total			**562,500**		
Total Proposed Take			**1,170,000**		

Note: Total combined groundwater pumping name-plate capacity proposed equals 135 L/s

4.2 Sustainability of Proposed Bore Configuration

A total of nine bores of depths between 90 m and 125 m are proposed. In each instance the primary drilling and bore screening target is the basal shell beds. Figure 7 illustrates the hydro-stratigraphy of the Waihopo – Houhora compartment of the Aupouri Sand Aquifer. Water bearing layers and water bore prospects are found within the following depth ranges 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 7 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 gradation and not clearly defined. However, the scheme of water bearing layers is drawn from the synthesis of bore logs and hydrogeological interpretations.

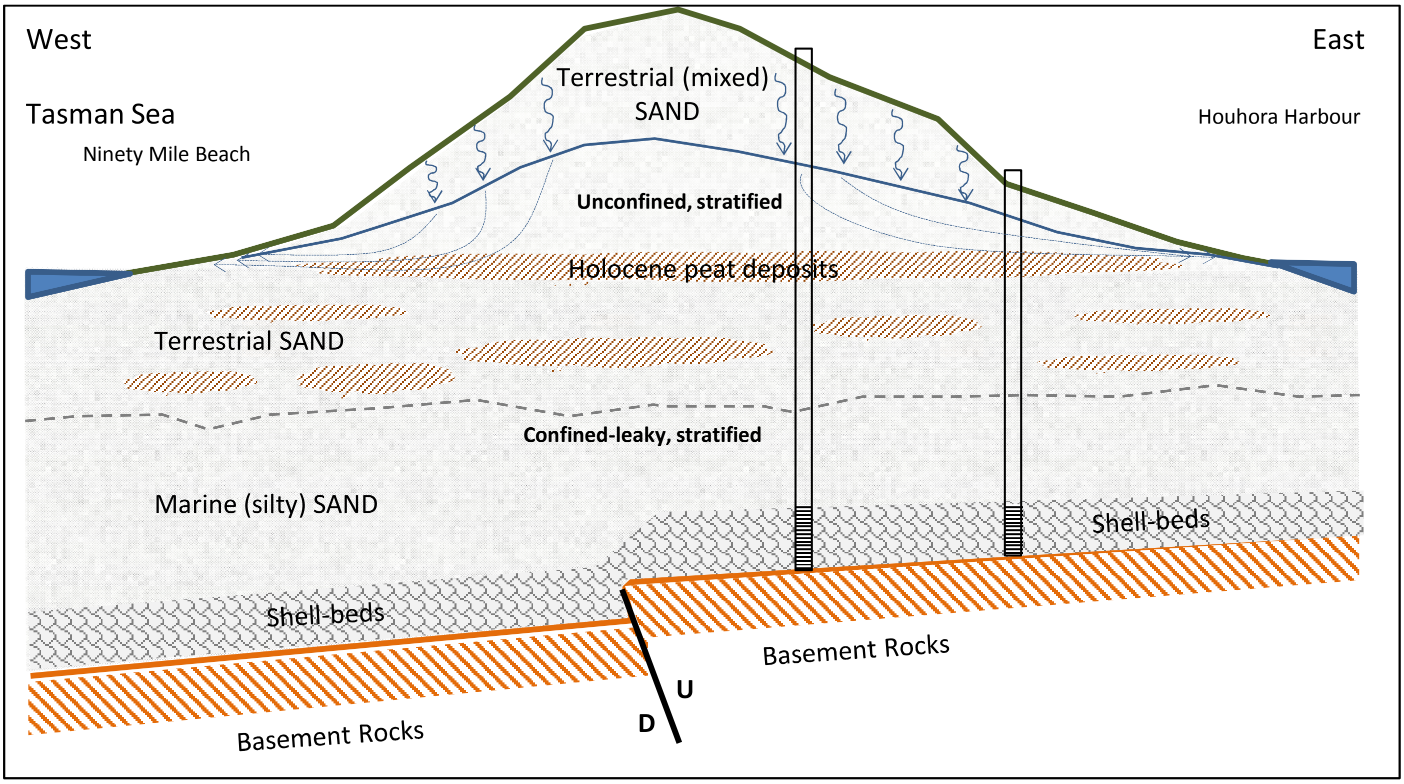

Figure 7: Schematic Cross-section through the Aupouri Sand Aquifer in vicinity of Te Raite Station

Figure 7 indicates that the depth of the water bores to be drilled down to the shell beds would vary in terms of topographic height and basement depth. From north to south across Te Raite Station, basement elevation also slopes from 50 m below sea level to more than 90 m below sea level (see Figure 4). In general, deeper bores tend to have well hydraulics that favour higher pumping yield. Viable water bearing layers within the Aupouri Sand Aquifer beneath Te Raite Station are potentially found among all four potential layers from above. However, existing knowledge of the specific capacities of the water bearing layers in the Waihopo – Houhora area would suggest that Layer 3 (marine, semi-confined sand) and Layer 4 (sandy shell beds) would be the targets most able to yield significant groundwater to irrigation bores.

The recent joint application by groundwater users in the Motutangi – Waiharara allocation zone included a technical analysis with a conceptual model of the Aupouri 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 Aupouri Sand Aquifer and summarised in a table reproduced below in Table 8.

Table 8: Summary of Hangjian and Williamson (2017) hydraulic properties for Aupouri 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 Te Raite Station (or environs), the average values for hydraulic conductivity and storativity are adopted for each corresponding water bearing layer. The layer 1 to Layer 4 sand / shell bed sequence is saturated from the free, water table surface to basement. The basement is considered to have a sufficiently strong permeability contrasts so as to be the effective geo-hydrological basement.

The well construction configuration for an irrigation bore and connected aquifer is constrained by the following components:

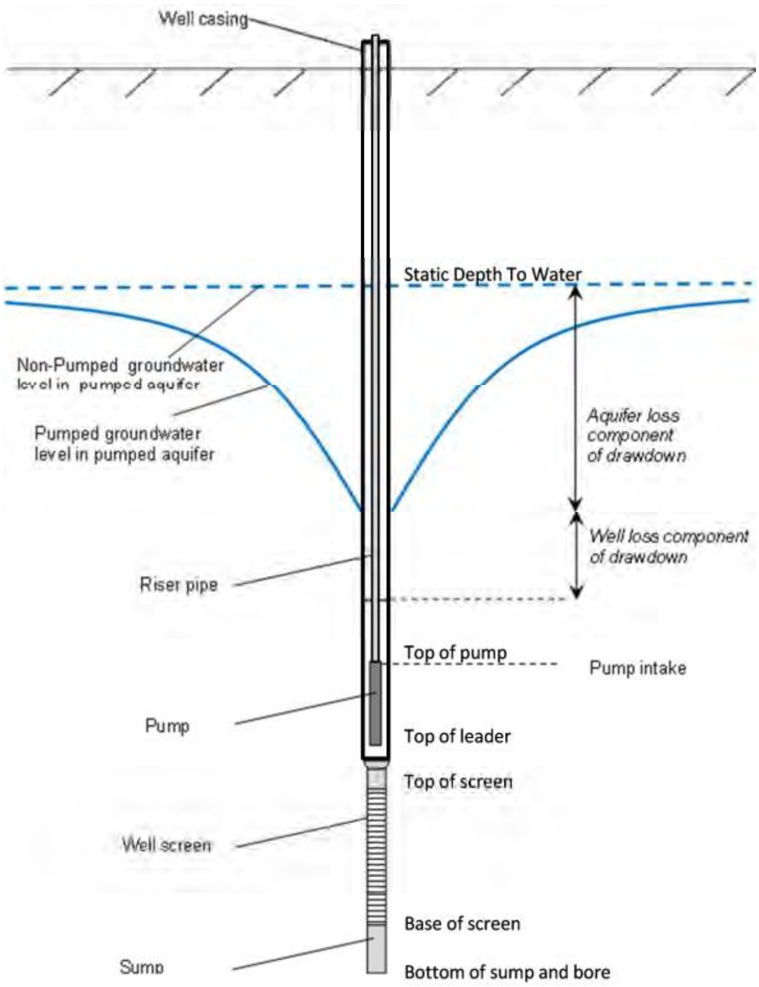

Figure 8: Schematic representation of the components of irrigation bore capacity

Table 9: 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 10 lists the depths and length dimensions used in the equation below:

$$MinWL = Depth - ScL - LdrL - PumpL - NPSH \qquad \text{(all dimensions in metres)}$$

Table 10: Estimation of the minimum pumping water level (MinWL) for

Label	MaxQ (L/s)	Depth (m)	ToSc (m BGL)	ToLdr (m BGL)	PumpL (m)	PumpTop (m BGL)	NPSH (m)	MinWL (m BGL)	MinSWL (m MSL)
Bore_A1	10	106.6	97.6	95.1	4.2	90.9	3.5	87.4	-38.7
Bore_A2	10	99.7	90.7	88.2	4.2	84.0	3.5	80.5	-34.9
Bore_B1	10	89.5	80.5	78.0	4.2	73.8	3.5	70.3	-31.8
Bore_B2	10	94.4	85.4	82.9	4.2	78.7	3.5	75.2	-36.6
Bore_B3	10	89.9	80.9	78.4	4.2	74.2	3.5	70.7	-34.9
Bore_C1	20	90.8	81.8	79.3	4.2	75.1	4.5	70.6	-37.8
Bore_D1	20	104.0	95.0	92.5	4.2	88.3	3.5	84.8	-53.6
Bore_E1	15	120.0	111.0	108.5	4.2	104.3	4	100.3	-64.5
Bore_F1	30	123.6	114.6	112.1	4.2	107.9	7	100.9	-68.1

Note: Bores are labelled with irrigation zone letter (A-F) and bore number within zone (1-3); 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 10 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 10). This reveals the northern group of irrigation bores (A1 – C1) on the Aupouri-Other and Waihopo allocation zones to have a significantly shallower (-31.8 m to -37.8 m MSL) than the southern group ((D to F), which have minimum water levels from -53.6 to -68.1 m. For this reason the abstraction of water for the northern group irrigation zones has been spread over a larger number of production bores by reducing the maximum proposed bore yield to 10 L/s. The southern group of bores have a range of larger maximum proposed bore yields from 15 L/s to 30 L/s.

The static water level in the proposed Te Raite Station bores 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 Aupouri 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 9 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 Te Riate Station irrigation bores according to irrigation zone position.

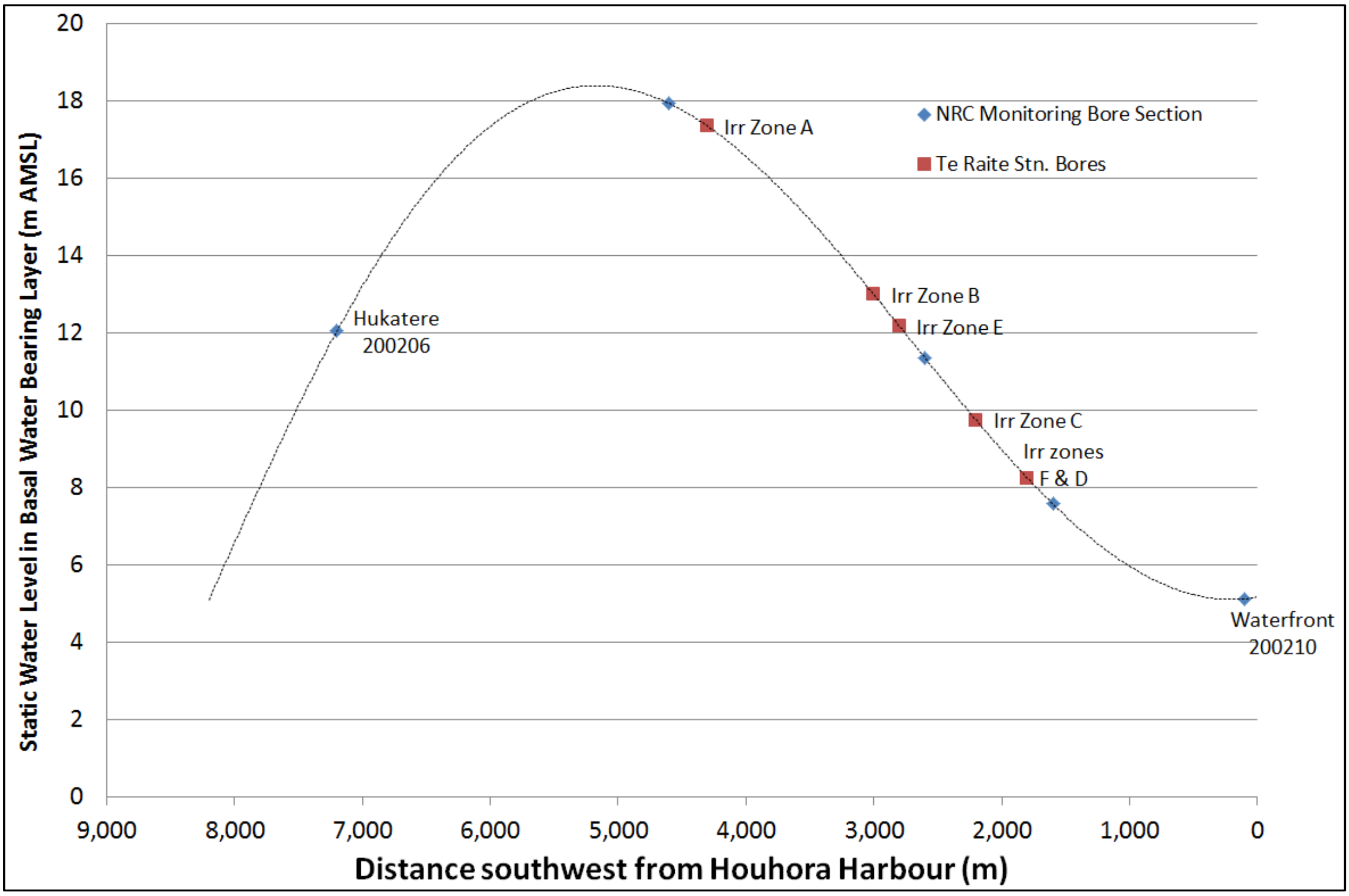

Figure 9: Indicative profile across the Aupouri Tombolo at Houhora to estimate the deep, basal static water level in station bores

Some further assumptions were made around 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 10) for infinite time to steady state conditions,
- Drawdown calculated using the AquiferWin32 analytical element software in a spatially distributed quasi-3D AEM model of the Aupouri Sand Aquifer.

The AEM model[1] is used to account for the aquifer drawdown at the bore screen of each of the irrigation bores assuming that they have been pumping at higher than consent limits at their nameplate capacity until steady state conditions established. The aquifer drawdown from the AEM model is then used the following equation to calculate the minimum pumping water level:

MinPumped WL = SWL - AqLoss – ScLoss

And 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 10)

Table 11 summarises these calculations and results for each of the nine proposed

Table 11: Estimation of the minimum pumping water level and freeboard for bore operation

Label	SWL (m MSL)	AqLoss (m)	ScEff (%)	ScLoss (m)	MinPumped WL(m MSL)	MinSWL (m MSL)	Freeboard (m)
Bore_A1	17.5	5.46	0.6	2.2	9.9	-38.7	48.5
Bore_A2	17.2	5.24	0.6	2.1	9.9	-34.9	44.8
Bore_B1	13	5.79	0.6	2.3	4.9	-31.8	36.7
Bore_B2	13.1	6.57	0.6	2.6	3.9	-36.6	40.5
Bore_B3	12.9	6.49	0.6	2.6	3.8	-34.9	38.7
Bore_C1	9.7	8.58	0.6	3.4	-2.3	-37.8	35.5
Bore_D1	8.3	8.82	0.6	3.5	-4.0	-53.6	49.6
Bore_E1	12.2	7.2	0.6	2.9	2.1	-64.5	66.7
Bore_F1	8.2	9.11	0.6	3.6	-4.6	-68.1	63.5

Note: Bores are labelled with irrigation zone letter (A-F) and bore number within zone (1-3); 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 10. Freeboard = MinPumped WL – MinSWL (from Table 10) in terms of m MSL.

Each one of the bores in Table 11 were found to have positive freeboard, meaning the bores all had minimum predicted water levels that lay higher than the minimum viable bore operating water level. The least calculated freeboard was 35.5 m in irrigation bore C1. The conclusion that should be drawn from the above is that the cumulative groundwater water level lowing effects are not sufficient to overwhelm the inherent capacity to absorb the level lowering stresses. The irrigation bores are thus likely to sustain proposed water production without risk of failure and show some buffering ability to absorb stresses placed on them in terms competitive bore interference effects or natural level fluctuations.

[1] The AquiferWin32 InFlow Analytial Element Method model was used for this assessment. The input parameters were set to a confined aquifer transmissivity of 380 square metres per day and storativity of 4.4 x 10^{-3}. The WinFlow 1.0 solution framework was used in steady state mode. The nine irrigation bores were distributed as per Figure 2. A global reference head was placed in md-stream of Houhora Harbour.

4.3 Groundwater Effects Beyond Bore-fields

The analysis of groundwater effects beyond the bore-fields of Te Raite Station 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, which is more conservative than the alternative Hantush drawdown method that 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 Waihopo – Houhora area, but the use of the Theis Equation is a more conservative over-estimate of drawdown effect. Therefore, the Theis Equation Is utilised for making the drawdown effects estimation below.

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

- Transmissivity = 380 m^2/d
- Storage Coefficient = 4 x 10^{-3}
- Pump rate is the combined long-term rate of 64.5 L/s, made up of the following individual bore rates:
  - Bore_A1 4.3 L/s
  - Bore_A2 4.3 L/s
  - Bore_B1 5.0 L/s
  - Bore_B2 5.0 L/s
  - Bore_B3 5.0 L/s
  - Bore_C1 9.9 L/s
  - Bore_D1 9.9 L/s
  - Bore_E1 6.2 L/s
  - Bore F1 14.9 L/s
  - Combined 64.5 L/s
- Critical time step was –
  - 217 days (approximately 7 months) at 64.5 L/s

The computational methodology used was to calculate the Theis drawdown for every one of the registered well records within 10 km of the centre of Te Raite Station for each of the nine proposed irrigation bores, and then add the drawdowns together as a sum total of drawdown induced drawdown, sometimes termed cumulative drawdown. Figure 10 displays the spatial distribution of the cumulative drawdown effect as contours of drawdown extrapolated from bore position cumulative drawdown totals.

Figure 10 reveals that drawdown effects extend into the three groundwater allocation zones that Te Raite Station rests within. The highest external drawdown to which an existing neighbouring bore is exposed to equates to 2 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.

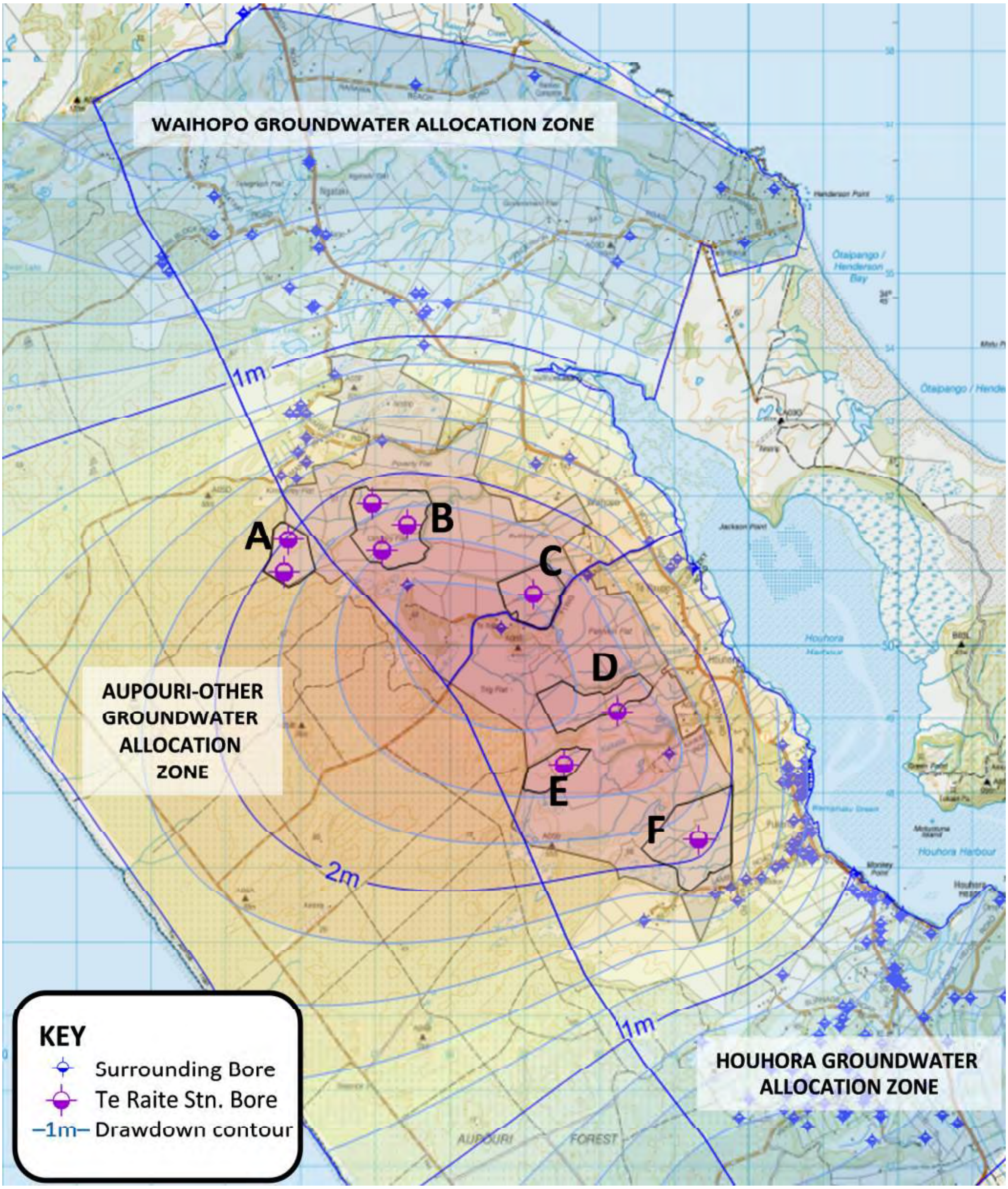

Figure 10: Contours of extrapolated contours of 217 day Theis drawdown surrounding Te Raite Station irrigation bores

Approximately 190 bore sites were modelled in the surrounding Aupouri Sand Aquifer. The distribution in the numbers of bore in relation to calculated drawdown intensity is illustrated in Figure 11. Two clusters of drawdown effect were found. The first cluster of 120 bore had calculated drawdown from 0 to 1 m. The second of 62 bores had calculated drawdown of between 1 m and 2 m. There are almost no identifiable affected bores in the Aupouri – Other allocation zone.

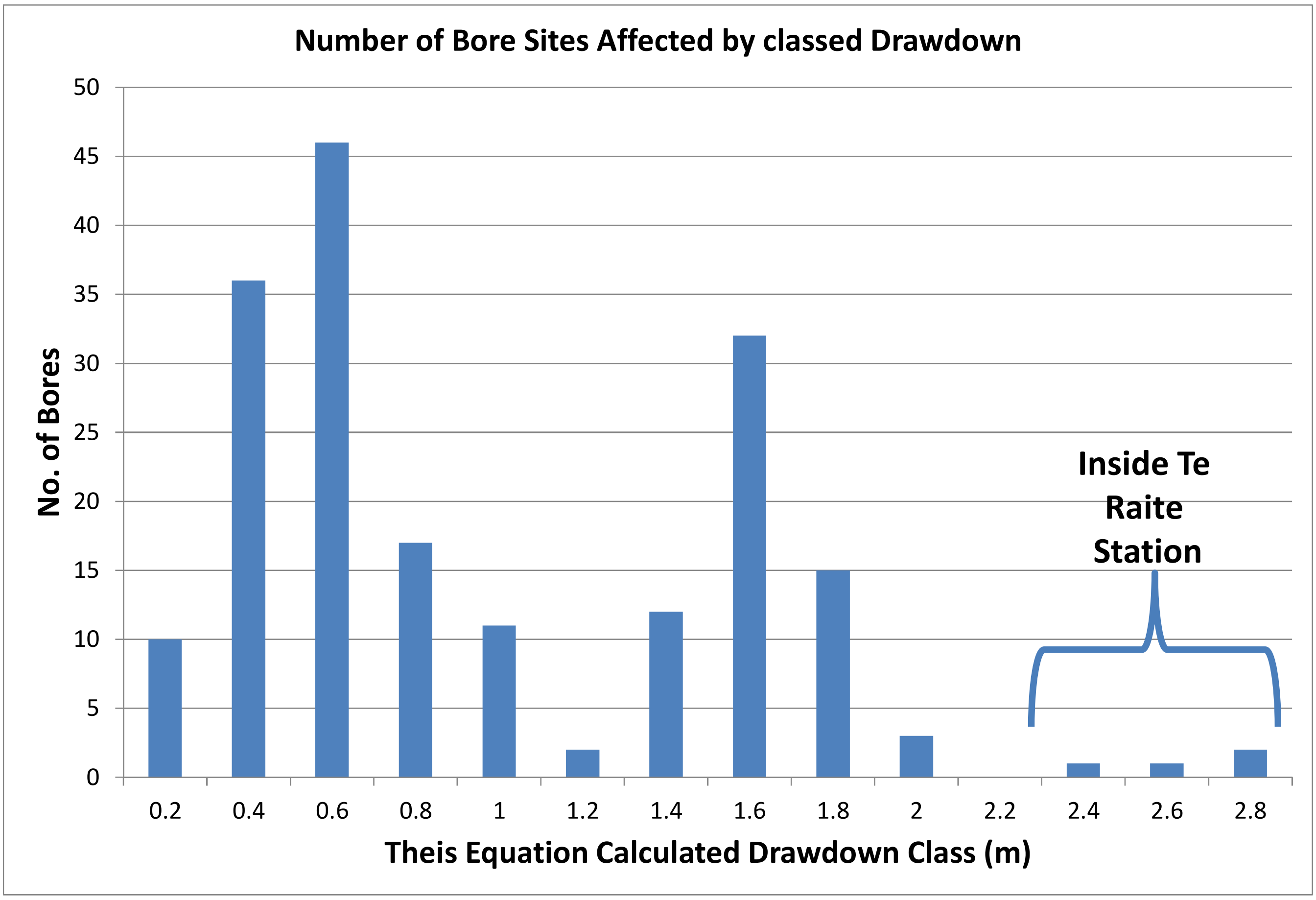

Figure 11: Frequency distribution of surrounding bores with classed drawdown

The operational effect of the calculated drawdowns is hard 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 instance 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.
- The deep bore 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 inherent in the bore dimensions.
- All bores in the Waihopo – Houhora area are designed to sustain a moderate degree of natural and artificial water level lowering effects, such as recharge fluctuations and the timing of irrigation onset.

4.3.2 Stream Depletion Effect

Several streams and creeks cross Te Raite Station from the sand ridge crest in a generally northeast direction towards Houhora Harbour. Flow data is unavailable for any of the named or unnamed streams / creeks in the vicinity of Te Raite Station, so quantification of their water resource is problematic. However, the streams and creeks tend to emanate 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 be dominant (see Table 12, below). From Table 12 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 12: 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.

Proposed irrigation bores D1 and E1 (see maps Figure 6 and Figure 10 for their location) lie 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 12, the approximate base flow of Korakonui Stream would equate to 20 L/s and that of Kaikatia Stream 30 L/s. While both bores would be screened in the shell bed layer with top of screen between 94 m and 110 m below ground level, semi-confined leakage could serve to cause a depletion of the overlying streams. Comparing the soil map (Figure 3) and the lines of the stream main stems it can be seen that the stream beds lie over the Te Kopuru Sand or Ruakaka Peat Sandy Loam with the associated subsoil peats and pans. The information on soils, and subsoil peats and pans would tend to indicate that the streams are perched where the water table lies deeper than the stream bed by the impeding action of the subsoil peats and pans. Conversely, where the water table rests above the stream bed the interaction between stream and sand aquifer would be buffered by the low permeability 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 Te Raite Station is sufficiently similar (although not identical) for this assessment to conclude that stream flow depletion from deep shell bed bore pumping is small to negligible. Lastly, bores D1 and E1 lie with the 40 ha and 50 ha associated irrigation area (see Figure 6). 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 10% 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 effect that ignore the presence of subsoil peats and pans.

4.3.3 Saline Intrusion & Allocation

Intrusion of seawater-affected groundwater is a well-known effect on groundwater quality of coastal aquifers. Investigations into the safe groundwater abstraction yield for the Aupouri Sand Aquifer (HydroGeo Solutions, 2000; and Wilson & Shokri, 2015) have each considered the need to avoid any risk of seawater intrusion 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 Aupouri Sand Aquifer into several distinct allocation zones and set a maximum allocation total to govern the issuing of groundwater take consents.

The Aupouri Sand Aquifer is allocated across 10 defined allocation zones. The Te Raite Station proposal would draw from three of these zones to varying degrees dictated by the position of irrigation bores. Table 13 summarises the existing groundwater allocation setting and the proposed addition to the consented & permitted groundwater take total. The Waihopo and Houhora allocations zones are currently sitting within 13.4% and 48.8% of their respective zone allocation limits. The Aupouri-Other allocation zone consented total is currently only 0.2% of its allocation limit. The effect of adding the Te Raite Station groundwater take proposal would be to take the Waihopo zone to 13.4% of its limit, and the Houhora zone to 75% of its limit. The Aupouri-Other zone consented take would increase to 0.9% of its limit. In no case would the consented groundwater take exceed the relevant allocation limit.

Table 13: Summary of Aupouri Groundwater Allocation with Te Raite Station 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 Te Raite Station Proposal (m^3/year)**	**Percentage of Consented to Allocation limit after Te Raite Proposal added (%)**
Waihopo	171,170	*13.4%*	1,278,200	450,000	13.4%
Houhora	1,045,493	*48.8%*	2,141,300	562,500	75.1%
Aupouri-Other	53,183	*0.2%*	21,991,288	157,500	0.9%

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 13 were set by Wilson & Shokri (2015) and adopted as indicative 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 Te Raite Station was Bore 200210 Waterfront (Piezometer 1 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.

The Aupouri Sand Aquifer contains fresh groundwater under the landwards portions of its extent. The adjoining marine extents of the Aupouri Sand are brackish to saline, depending on the hydraulic gradients, pore pressure and relict fresh or saline water bodies lying at depth. The aquifer is not currently considered near fully allocated and groundwater modelling has shown a healthy positive freshwater outflow replenished by high rates of recharge. Consequently, with the Te Raite Station proposal remaining within allocation limits and taken from landward bores lying towards the axis of the Aupouri sand ridge, 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 Aupouri 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 5). 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 Aupouri Forest crest line with a piezometer in the deeper, semi-confined marine sand. This piezometer measures the pressure in the basal shell bed layer and has a mean groundwater pressure of 17.9 m AMSL, minimum level of 15.9 m AMSL and 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 9). The Waterfront monitoring bore 200210 Waterfront (Piezometer 1 at 60.1m) 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 Aupouri 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 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 Te Raite Station irrigations bores outlined in section 4.3.1 on Drawdown Effects would exert at most 1.62 m of groundwater pressure decline at the Houhora Harbour margin at Subrizky Road, and 0.83 m at the Waterfront monitoring bore in Pukenui. Neither 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 not occur as a consequence of granting the proposed groundwater take for Te Raite Station.

4.3.3.2 Saline Up-coning

Saline intrusion can also occurred 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 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 the Aupouri Sand Aquifer. Long-term monitoring of water quality at the Collville bore (number 200059) at a depth of 55 m BGL on Hukatere Road, just south of Te Raite Station 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. Seawater has a chloride concentration of 19,400 mg/L. A scan of drillers notes as to water taste comments in bore logs for bore drilled in the south of Te Raite Station near Pukenui reveals that even this 110 m deep bore at the homestead (bore number 200213) had very good water quality indicative of chloride concentration lower than the taste threshold (i.e. less than 320 mg/L).

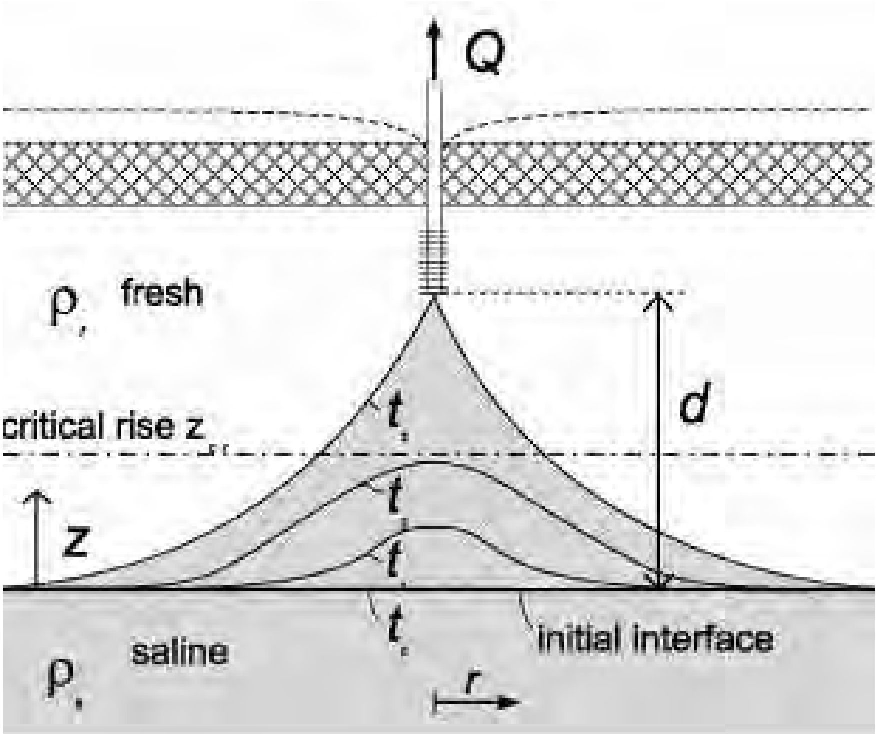

Figure 12: Theoretical example of the movement in the fresh – salt water interface in saline up-coning

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 Aupouri 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 Te Raite Station irrigation bores.

5. CONCLUSIONS

The proposed irrigation development utilising nine yet to be drilled water bores would have a nameplate capacity of 130 L/s and require consent for 1,170,000 cubic metres of groundwater per annum. The groundwater pumped would be utilised over a seven month period from Spring to Autumn each year. The groundwater is required to service the spray and drip irrigation requirement of cropping and horticulture across an approximate 260 ha of land within Te Raite Station, which are yet to be developed. The proposed drilling target is the shell beds at the base of the Aupouri Sand Aquifer, due to their capacity to be used as a higher permeability under-drain of groundwater in the marine sand and above. This would prescribe the use of nine bores in the depth range of 90 m to 125 m below ground. The shell beds are commonly used for irrigation, stock and domestic water supply in the area and can be inferred to extend beneath Te Raite Station. 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 network in terms of modern well hydraulics and the capacity of the Aupouri Sand Aquifer to supply water to each bore,
- The groundwater level lowering effects of combined bore pumping operation on surrounding groundwater users utilising water bores,
- The depletion of surface water flows caused by underlying groundwater pumping, and
- The potential for saline intrusion as a result of the combined groundwater pumping activity.

Delineation of the well hydraulics, available bore depth dimensions and calculated aquifer head losses were set against each other to determine the freeboard between the minimum water level that the pumping bore could tolerate and the lowest water level indicated by head losses. The irrigation bores came through the assessment with the smallest individual freeboard as 35.5 m indicating that the bore configuration is feasible.

Highly conservative calculations of consequent drawdown were used to predict these effects on neighbouring bores in the same aquifer. The calculations indicate that bore within 10 km of the centre of the station would experience drawdown effects between 0 and 2 m. The drawdown effect at the closest part of the Houhora Harbour shore line was calculated as 1.6 m. Such drawdown intensities are within the 2.6 m to 3.3 m range of recorded water level fluctuations for the shell bed water bearing layer.

The proposed groundwater takes would be spread over three indicative groundwater allocation zones (Wilson & Shokri, 2015) due to the need to locate bore closest to their farm areas' of use. Indicative groundwater allocations have been published for each of these groundwater allocation zones, plus the Aupouri Sand Aquifer as a whole. The added groundwater abstraction volume to allow the proposed irrigation at Te Raite Station would not cause any of the associated groundwater allocation zones to exceed the indicative limits, nor would the sum of new abstraction volume cause any particular allocation zone to exceed its individual limit.

As the indicative allocation limits were conservatively set to prevent the possibilities of the aquifer exceeding its safe yield or inducing seawater to intrude beneath the landward portion of the aquifer, the fact that the current proposal does not lead to an exceedance of the limits is reassuring. The projected drawdown of the deeper, semi-confined shell bed layer water pressure by 1.6 m at the coast line is not considered to endanger the aquifer with seawater intrusion risks.

The overall assessment of groundwater environmental effects is that the Te Raite Station groundwater irrigation proposal 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

Proposed irrigation bores D1 and E1 lie is proximity to both Korakonui and Kaikatia stream, both tributaries of Houhora Harbour. While both bore would be screened in the shell bed layer with top of screen between 94 m and 110 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 600 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 14 shows the calculated depletion effects in terms of both input parameters and results for both bore D1 and E1.

Table 14: Summary of stream depletion effects derived using the Hunt Solution

Input Parameters	**Bore D1**		**Bore E1**	
Aquifer transmissivity (m2/d)	380		380	
Storage coefficient	0.0044 (4.4 x 10^{-3})		0.0044 (4.4 x 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)	9.9		9.9	
Separation Distance (m)	200 (Korakonui & Kaitaki streams)		20 (Kaitakia Stream)	
Hunt Solution Results				
Time (days)	**Depletion (L/s)**	**% Depleted**	**Depletion (L/s)**	**% Depleted**
7	5	46%	9	92%
30	6	65%	9	96%
210	9	87%	9.9	99%
365	9	90%	9.9	99%
Residual Stream Flow (365 days)				
	Korakonui Stream		**Kaikatia Stream**	
Estimated Base Flow (L/s)	20		30	
Estimated Depletion (L/s)	15		9.9	
Remaining Flow (L/s)	5		20.1	

Appendix 2

Affected Persons Approvals

FORM 8A
AFFECTED PERSON'S WRITTEN APPROVAL
(Section 95E(3)(a)/95F(c) of the Resource Management Act 1991)

TO: Northland Regional Council

Full name of person giving written approval: Kurt Nattrass (Waiora North Farms Limited)

I am the owner / occupier *(delete one)* **of the property located at:** Occupier of Te Raite Station

(Give address of property)

I have authority to sign on behalf of all the other owners / occupiers *(select one)* of the above property. **Note**: If you are signing on behalf of a trust or company, please provide additional written evidence that you have signing authority.

This is written approval to the following activity that is subject of a resource consent application:

Applicant's Name: Te Aupouri Commercial Developments Ltd

Application Number *(if known)*:

Description of Proposal: Water permit to take and use groundwater

Location: Pukenui

I have read the full application for resource consent, the Assessment of Environmental Effects (AEE), and any site plans as follows:

Document name and date: Assessment of Environmental Effects

Plan number(s) and date(s): 22nd February 2018

In signing this written approval, I understand that the Northland Regional Council must decide that I am no longer an affected person, and the Northland Regional Council must not have regard to any adverse effects on me.

I understand that I may withdraw my written approval by giving written notice to the Northland Regional Council before the hearing, if there is one, or, if there is not, before the application is determined.

K Nattrass

Signature of person giving written approval*
(or person authorised to sign on behalf of person giving written approval)

23 - 2 - 18

Date

Address for service of person giving written approval: 5180 far north rd

Telephone: 021 186 0355

Fax/Email:

Contact person:
(name and designation, if applicable)

** A signature is not required if you give your written approval by electronic means.*

NOTES:
(1) There is no obligation for you to sign this form and no reasons need to be given. Therefore, if you do not understand what this form is, or details about the application, then **DO NOT SIGN IT**.
(2) Conditional written approvals cannot be accepted.
(3) If this form is not signed, the application may need to be notified with an opportunity for submissions.

GUIDELINES FOR AFFECTED PERSONS
REQUEST FOR WRITTEN APPROVAL

Why is your written approval being sought?

If you have been asked to sign this form, it will be because someone is proposing an activity that requires a resource consent and you have been identified as a potentially affected person.

For a resource consent application to be processed without notification the applicant needs to:

1. Show that the proposed activity has no more than minor effects on the environment; and

2. Obtain the written approval of any person that the Council considers may be adversely affected.

What should you do?

1. Study the application and plans (if any) of the proposed activity. These should help you understand any potential effects.

2. Consider how the proposal will have adversely affect you.

3. If you are happy with the proposal and wish to give your approval, you may do so by signing the written approval form, and copies of any associated plans.

If you are concerned about giving your written approval, you may wish to discuss the proposal with the applicant and/or the Northland Regional Council. Discussing the proposal may assist with resolving any issues of concern. If you continue to be concerned with the proposal, you do not have to sign the form. However, it is important that you let the Northland Regional Council and the applicant know you will not be giving your approval.

Note:
1. By signing the written approval form you still retain the right to contact the Northland Regional Council or lodge a complaint if you become concerned that the applicant is not complying with the requirements of their resource consent, or the proposal you gave written approval to.

2. This approval may be withdrawn in writing up to the time that the application is considered and determined.

If you have any queries relating to written approvals, please contact the Northland Regional Council.

Northland Regional Council Offices:			
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Appendix 3

Aupōuri Aquifer Review – Report 1056 – 1 – R1

Aupouri Aquifer Review

Report 1056-1-R1

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Lincoln Agritech Ltd

April 2015

MEASURE. MODEL. MANAGE.

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EXECUTIVE SUMMARY

This report summarises and analyses the available hydrological and geological data for the Aupouri Aquifer. A conceptual model is proposed which is based on the available information, and this understanding forms the framework for a numerical model to quantify aquifer flow balances.

The Aupouri Aquifer 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 also includes the low-lying land between Waimanoni and Ahipara. The aquifer is for the most part a deep sandy coastal system that has formed as a tombolo between islands of basement rock. Although it is a sandy aquifer, it also contains a significant proportion of clay and peat deposits that have formed between sand dunes. In particular, there is an extensive horizon of low permeability at approximately sea level, which acts as a confining layer to the deeper sediments. Most boreholes tap the more permeable shell-rich marine sands found at the base of the aquifer, although almost all of the water for these bores is provided by leakage from the overlying sands during pumping.

The shallow unconfined part of the aquifer is quite dynamic, and most of the rainfall recharge is routed towards the sea within this layer. The leaky-confined part of the aquifer that is found below sea level is relatively stagnant. Dating of groundwater samples from the top of the leaky-confined aquifer indicate a mean residence time of over 50 years, while deeper samples are over 200 years, which is older than the limits of the tritium dating method. Despite its age, the quality of the groundwater in the aquifer is very good.

A soil moisture balance model has been calculated for the whole Aupouri Aquifer. Annual rainfall over the study area ranges from 850 to 1,670 mm/year (average 1,280). Annual aquifer recharge ranges from 160 to 840 mm, averaging 500 mm, which is approximately 38% of mean annual rainfall. The average recharge volume for the entire aquifer is about 374 million m^3/year.

A numerical groundwater model was set up at a suitable grid resolution to cover the whole aquifer domain. The model calibration is adequate for making predictions at a regional scale, but would need refinement and additional data to make predictions at a sub-region scale. The model predicts that the current consented groundwater allocation of 7.44 million m^3/year is sustainable under current and projected future climatic conditions.

The model was also used to estimate a recommended safe yield of the entire aquifer for allocation purposes. To do this, sub-regions have been identified. Groundwater level thresholds have been proposed at key coastal locations in each sub-region to ensure seawater intrusion does not occur. The testing of this scenario in the model indicates that the aquifer is currently being managed sustainably. The only area of immediate concern is the Sweetwater sub-region, which is approaching its potential allocation limit. New coastal monitoring bores are recommended in the short term at Paparore, and Waihopo. It is also recommended that a groundwater level threshold be placed at Houhora to act as a precautionary measure for seawater intrusion from the east.

Sustainable management limits have been recommended for each sub-region to avoid seawater intrusion. These limits are provided in Table 8, and range from 10 to 35% of mean annual recharge. Higher allocation volumes are predicted to be sustainable in the Paparore and Sweetwater sub-regions where Holocene sand dunes hold a higher volume of water above sea level. The additional groundwater storage provided by the dunes creates a greater driving head for deeper groundwater, and maintains a steeper hydraulic gradient towards the coast. Low-lying areas such as Ahipara, Awanui, Waiparera and Motutangi have less groundwater storage above sea level and a relatively flat hydraulic gradient towards the coast. These areas are more vulnerable to seawater intrusion and have a sustainable management limit of 10-15% of mean annual recharge.

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INTRODUCTION

The Aupouri Aquifer system is located north of Kaitaia and covers approximately 788 square kilometres (78,808 ha) along the Aupouri Peninsula (Figure 1). The groundwater system is a valuable source of water for municipal, domestic, and stock supply, plus irrigation water for agriculture and horticulture.

The Northland Regional Council (NRC) has previously commissioned and undertaken various assessments to increase understanding of the Aupouri Aquifer. Since the most recent comprehensive report of the aquifer as a whole, by HydroGeo Solutions (2000), there has been on-going groundwater level and quality monitoring and an increase in consented allocation in some areas. This report presents updated conceptual and numerical models to assess sustainable yields and groundwater level thresholds on a sub-aquifer and sub-regional basis.

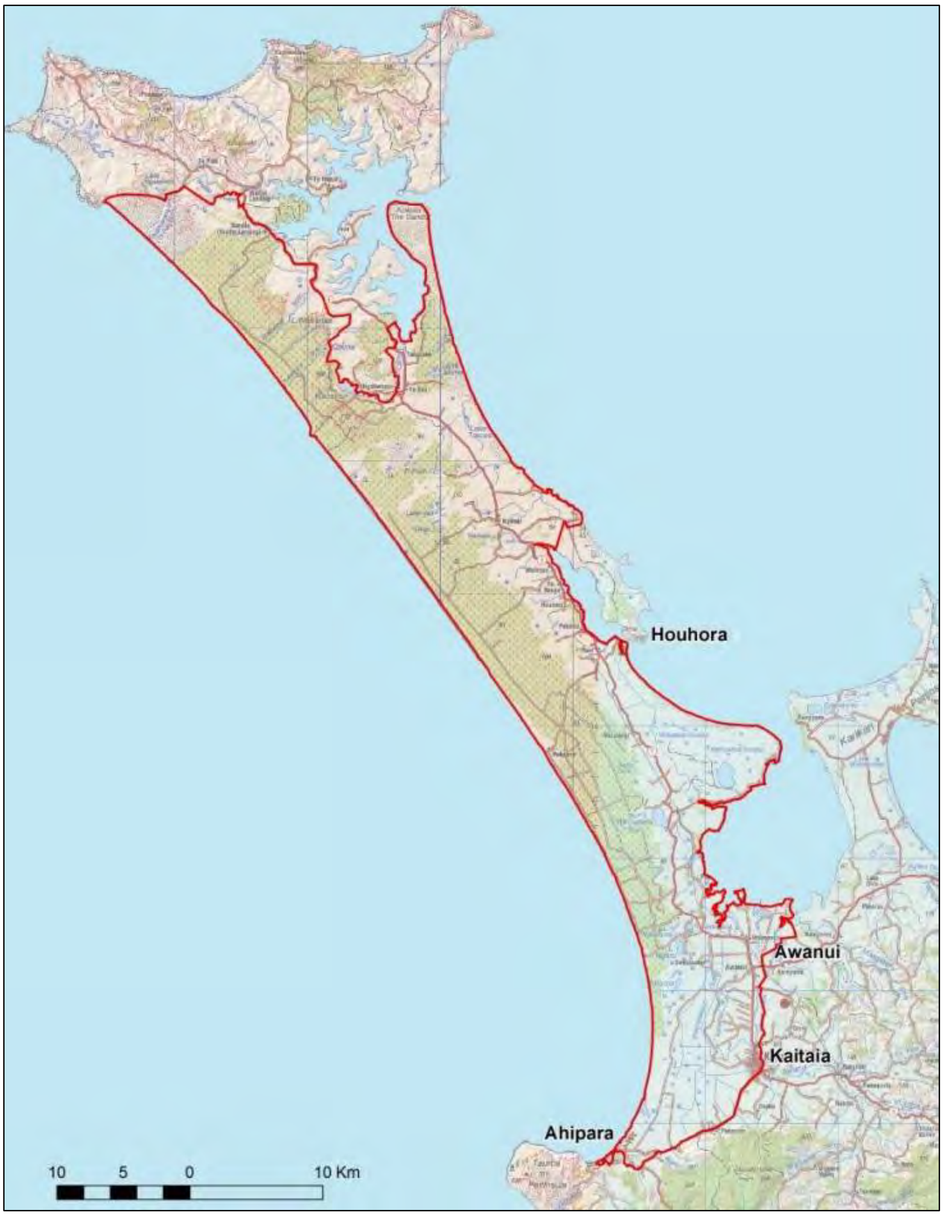

Figure 1 Map of the Far North showing the boundary of the study area in red

STUDY OBJECTIVES

The primary objective of this study is to:

Increase understanding of the aquifer to enable informed decisions on allocation limits and levels and ensure the future sustainable management of the aquifer

The secondary objectives are to:

- Increase the NRC's understanding of the aquifer with respect to groundwater recharge, discharge, storage and flow dynamics; and
- Identify information gaps and future actions required to enable the sustainable management of the aquifer

Fundamental to fulfilling the project objectives are the development of a robust conceptual model of the Aupouri Aquifer, and a numerical model that characterises the available knowledge of the system. The assessment and modelling are to be used by the NRC as decision support for establishing management units, sustainable water allocation limits and levels, and for future water resource management decisions.

SCOPE & NATURE OF THE SERVICES

The scope of this report consists of:

1. Initial review of existing reports and available data on the aquifer, including:
    a. regional geological structure;
    b. groundwater quality;
    c. groundwater levels / piezometric levels;
    d. aquifer hydraulic properties / pump test information;
    e. recharge, discharge and through flow information;
    f. bore log information (Approximately 590 bores of variable accuracy registered with the Council);
    g. current groundwater allocation (Approximately 60 consents with a total allocation of approximately 40,500 m^3/d, not including permitted takes)
2. Development of a conceptual model of the Aupouri Aquifer
3. Development of a land surface recharge model that includes the impact of forestry rotation through time
4. Development of a calibrated numerical model of the Aupouri Aquifer
5. Development of a sensitivity analysis of the optimised parameters in the numerical model
6. Document the results of predictive scenarios with associated uncertainty
7. Recommendations for aquifer management

REVIEW OF EXISTING DATA

This section of the report reviews the environmental data that is available and forms the basis for our conceptual understanding of how the Aupouri Aquifer system works. It also helps us to estimate a safe aquifer yield, which is a long-term measure of the natural replenishment rate of the aquifer, or zone within an aquifer. If groundwater abstraction is kept to within the safe yield there are unlikely to be undesirable environmental issues such as seawater intrusion.

HYDROGEOLOGY

The Geology of the far north is reviewed in the Kaitaia Q-map sheet (Isaac, 1996). This section will focus more on the basement structure and Quaternary sediments of the Aupouri Peninsula. At its simplest the peninsula can be considered as two main geological entities, Mesozoic basement and low permeability Cenozoic Era rocks, and the much younger water-rich sand and peat sequences.

BASEMENT ROCKS

Basement rocks are exposed around Mount Camel, and consist of Early Cretaceous volcanics. These rocks most likely extend across the subsurface of the Aupouri Peninsula together with greywacke, argillite and indurated conglomerate deposits of the same age.

The Cretaceous basement rocks are overlain by a complex series of Mid Cretaceous to Mid Miocene sandstone, mudstone and volcanic deposits. These deposits form the hills that lie to the east and south of Kaitaia. Limestone has also been logged at the base of some boreholes near Awanui (e.g. 209285, 209772), as has glauconitic sandstone (201375). However, most of the boreholes that reach the base of the Aupouri Aquifer tend to intercept mudstone or sandstone.

SEDIMENTS OF THE AUPOURI AQUIFER

The sandy landform that forms the peninsula between the basement rocks near Kaitaia and Awanui to the basement rocks at the end of Ninety Mile Beach is known as a tombolo. A tombolo is a sand bar that connects the mainland with an island, and is formed by longshore drift. Because of their formation by wave and current action, tombolos tend to manifest the shape of prevailing wave refraction, which is why Ninety Mile Beach forms such a fine sweeping curve.

The main sediment lithologies (sediment types) of the Aupouri Peninsula were entered into GIS in order to determine their spatial and depth distribution. Fine sand and silt are the dominant sediments, and there does not appear to be any obvious fining upwards or downwards in the sequence. 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. The local convention is to call the marine sands "shellbeds" when the concentration of shells exceeds about 30%.

The presence of shells in 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. So far these shell-rich sands have only been found 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. Thus, the success of intercepting the shell-rich sands depends on how deep one has to drill to intercept the basement.

The local practice is to call the coarser shell beds the 'aquifer', although there does not appear to be a distinct boundary between the "shell beds" and the overlying marine sands. The function of the shells is to create a macro-porosity within the sands, which increases its permeability. Thus, the shell beds effectively serve as a gallery for pumping to draw upon a wider area of storage from the overlying sands, and this access to vertical leakage effectively increases the bore transmissivity and hence yield considerably.

The boundary between the marine beds and overlying terrestrial dune sands is identified by a change in sand colour to yellow or brown due to the abundance of oxygen. These terrestrial sands are also marked by the presence of discrete peat and clay lenses formed by buried former wetlands between the sand dunes. These old wetland deposits are common throughout the upper sand sequence, and can be seen today on the surface, many of them being associated with inter-dune lakes. Perhaps the best known buried wetland is in the Sweetwater area, where a 2 to 5 m thick lignite deposit is present at about 20 m below sea level. This deposit is sufficiently extensive to form a potential economic resource (see Edbrooke, 1997).

From a hydrogeological perspective, the most significant wetland deposits are found at or around the elevation of the present day sea level. While they are not as thick as the Sweetwater lignite deposits, their significance is that they form a barrier to groundwater flow at around sea level, which is the main hydrological boundary for the aquifer. These wetlands were formed by the stabilisation of the sea level around 6,500 years ago following the last glacial period. In many places, these wetlands are still active, as evident in the Kaitaia, Motutangi, and Waihuahua swamps.

Bore logs for the Aupouri Aquifer indicate that clay and or peat deposits tend to be present beneath the sand dunes at around sea level. While these peat deposits are not laterally continuous, their widespread distribution suggests that wetlands once extended across most of the peninsula. The common occurrence of peat and clay at this elevation indicates that the stabilisation of the sea level had created a low energy depositional environment which, together with a low-lying topography, allowed a large area of wetland to form. The widespread occurrence of these low permeability deposits has implications for the flow of groundwater above and below this horizon.

The surface deposits of the Aupouri tombolo mostly consist of dune sands, interspersed with peat and clay deposits associated with wetlands. The youngest sand dunes are mobile, and are located along the west coast. The extent of these dunes is easy to identify because they were extensively planted with plantation pine trees, which has stabilised their movement. Older sand dunes (>100,000 years) form the lower lying sand country along the western margin of the tombolo (Isaac, 1996).

GEOPHYSICS

Low-level aerial geophysical surveys were carried out during 2011 (Stagpoole *et al.* 2012). The results of these surveys are useful for studying the basement structure beneath the Aupouri Aquifer, but do not provide much information about its internal structure.

Ground-based geophysical surveys have previously been applied in the Aupouri Aquifer by Groundwater Consultants NZ. Geophysical logging was carried out for piezometers drilled in some exploratory surveys (GCNZ, 1987a). The logs recorded were natural gamma, self potential, and resistivity. The resistivity response was particularly encouraging, indicating that EMI surveys may be a useful technique for distinguishing higher and lower permeability horizons. Seismic refraction surveys were carried out at Hukatere and Lake Heather (GCNZ, 1987b). The surveys were useful for detecting the depth of the basement and its slope.

Vertical electrical soundings were also carried out in the Ahipara and Awanui areas (GCNZ 1990). Interpretation of these soundings concluded that limestone forms the basement between Lake Heather and Awanui, and possibly southwards to Ahipara. The basement is found at about 75m below sea level at Lake Heather, and shallows rapidly towards Kaitaia and Awanui. This interpretation is consistent with the logging of limestone in boreholes from this area. The surveys also found that the sand content of the subsurface decreases towards Ahipara, which implies the presence of finer sediments in this area.

AQUIFER STRUCTURE

The structure of the basement is not well defined on the available geological maps, mainly because basement outcrop is sparse, being mostly hidden beneath Quaternary sediments. A number of inferred faults are shown on the Kaitaia Q-Map (Isaac, 1996), and these all strike to the southeast. What is clear from geological maps and bore logs is that the basement beneath the aquifer tends to dip generally in a westward direction, away from the hillsides that have been formed from basement rocks.

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 Bouguer anomaly maps. The fault is shown on Figure 2 together with structure contours on the aquifer base. This follows a bearing of around 280^{o} from Waihuahua swamp and turns towards a bearing of 300^{o} near the start of Hukatere Road, and eventually goes offshore at Ninety Mile Beach 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 (Figure 2). 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 Aupouri 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. From a water resources perspective, the main implications of the fault and its bearing on aquifer structure are the depth to the basal shellbeds for drilling purposes, and the spatial variability of storage in the aquifer.

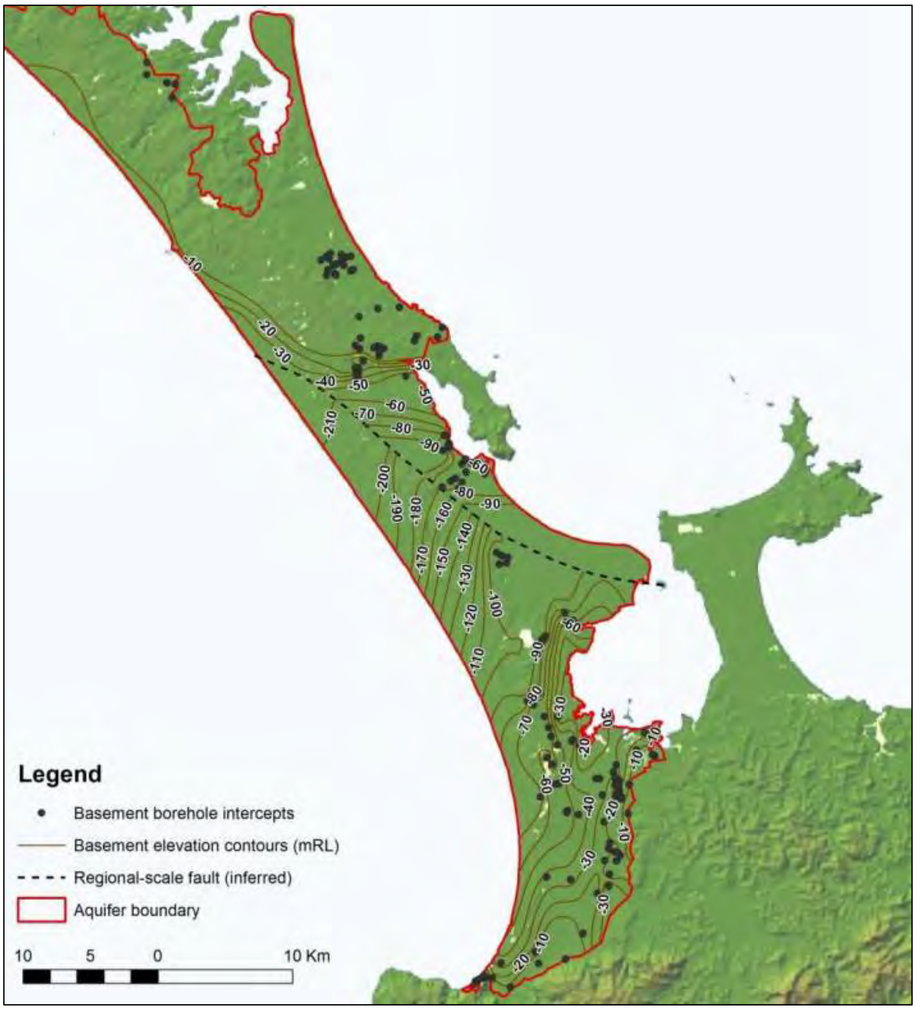

Figure 2 Map showing the structure of the Aupouri Aquifer base.

GROUNDWATER LEVELS

The Aupouri Aquifer is fortunate to have a network of multi-level piezometers for monitoring groundwater levels that have records dating back 30 years. These piezometers were drilled in two phase, firstly by the NZ Geological Survey in the early 70's (Petty, 1975) and later by the Northland Catchment Commission and Regional Water Board in the late 80's (GCNZ, 1987a). The multi-level piezometers are clustered in a number of areas, at Houhora, Paparore, Sweetwater, and Kaitaia (see Figure 3).

The Houhora piezometers have been drilled in a line between Hukatere and Houhora. This allows a dynamic cross section across the whole aquifer to be visualised. This was illustrated to good effect by Groundwater Consultants NZ (1987a), who drew a profile of potentiometric contours based on water levels in five multilevel piezometers. The profile (shown in Figure 4) shows a groundwater divide along the north eastern margin of the Aupouri Forest where the sand dunes reach their highest elevation. This flow divide follows the axis of the dune sands along the Aupouri Peninsula, so that the water table surface roughly mimics topography.

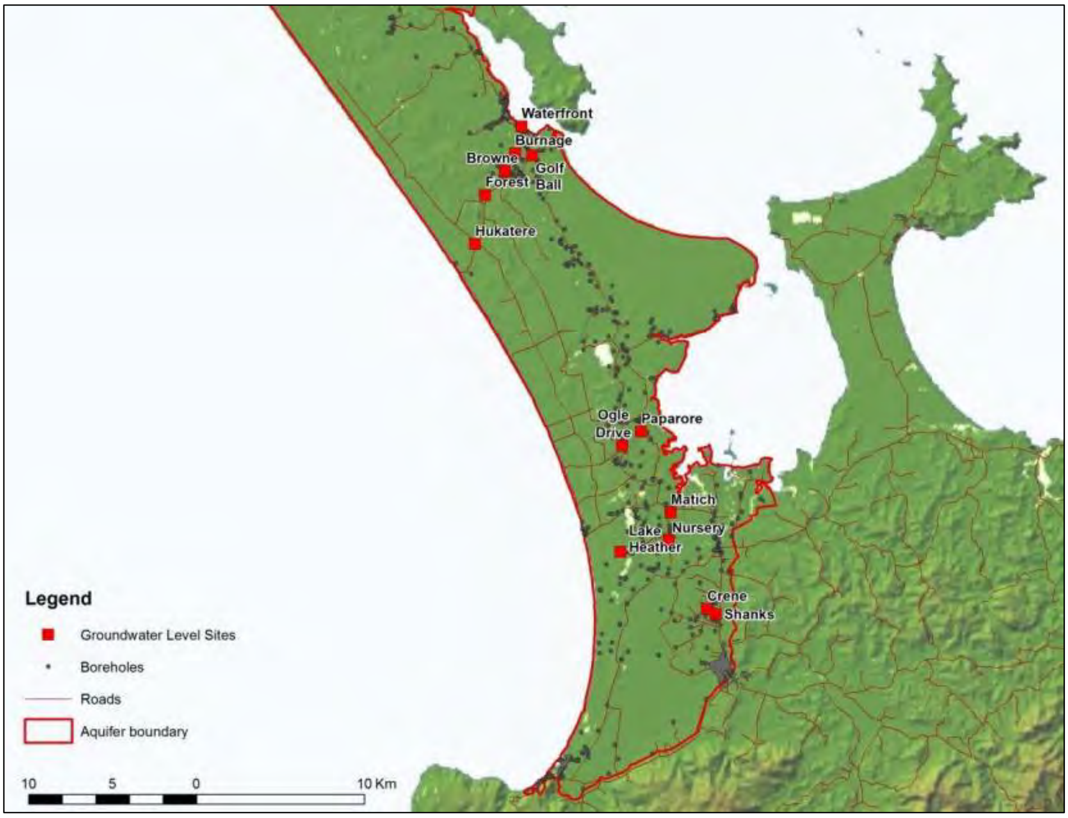

Figure 3 Map of groundwater level monitoring sites in the Aupouri Aquifer

The flow potential along the axis of the groundwater divide is vertically downwards. As we move away from this groundwater divide towards the coastline, the flow potential gradient becomes more horizontal with depth and distance from the divide. This pattern is consistent with groundwater recharge being received from rainfall, and discharge occurring along the coastline

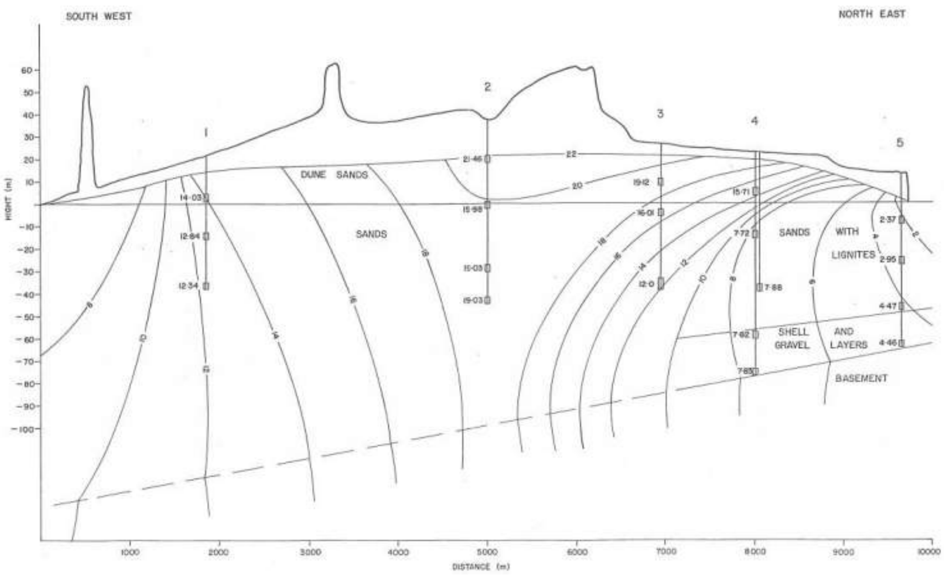

Figure 4 Profile from Hukatere to Houhora drawn by GCNZ

The flow potentials shown on the profile are also asymmetric, with a lower potential gradient occurring to the west. This asymmetry in the profile appears to be formed by the balance of two opposing factors:

1. the slope of the underlying basement, which dips to the west in this area. The dip of the basement favours discharge to the western coastline.
2. land surface recharge. Rainfall recharge is reduced over the forest (the western side of the profile) because of canopy interception and enhanced evapotranspiration. This results in relatively more recharge, and higher groundwater levels overall, on the eastern side of the groundwater divide compared to the more freely draining western side.

Despite the apparent asymmetry of the potential flow field, GCNZ (1987a) estimated very similar discharges to the two coastlines based on calculations using Darcy's law. The calculated discharges were 4.1 to 41 l/s/km length of aquifer and 4.8 to 48 l/s/km for eastward and westward flow respectively.

A summary of the active water level monitoring network is provided in Table 1, while Figure 3 shows the locations of NRC water level monitoring sites, both current and historical. The Aupouri Aquifer has a good coverage of monitoring sites overall.

It can be seen in Table 1 that the multi-level piezometers normally have three or four screen depths. The average water levels for different screen depths in the multi-level piezometers have been plotted in Figure 5 to illustrate how groundwater levels change with depth. The groundwater level seen at each site is largely governed by its proximity to the groundwater divide or the coastline. Four of the sites (Forest, Browne, Lake Heather and Hukatere) show a decrease in groundwater level with screen depth, indicating a downward flow potential. The Waterfront site shows an upwards flow potential, indicating discharge though the sea bed and perhaps increasing confinement with depth.

Table 1 Details of the active NRC monitoring network including top of screen and mean water level[1]

Bore	E	N	Name	Ground level	Piezometer	1	2	3	4
200208	1610722	6144033	Browne	26.6	Screen	-32.4	-2.5	11.1	
					Mean Water level	11.4	15.7	18.6	
200209	1611323	6145092	Burnage Road	23.5	Screen	-73.8	-57.0	-12.5	6.5
					Mean Water level	7.5	7.5	7.5	16.1
200207	1609541	6142603	Forest	37.3	Screen	-41.8	-27.2	0.8	21.3
					Mean Water level	17.9	17.9	19.2	20.2
200206	1608927	6139682	Hukatere	23.4	Screen	-34.8	-12.6	4.8	
					Mean Water level	12.0	12.4	13.5	
200226	1617605	6121325	Lake Heather 1	31.7	Screen	5.7	-27.4	-70.2	
					Mean Water level	11.7	8.6	7.9	
200227	1617258	6121482	Lake Heather 2	35.8	Screen	9.3			
					Mean Water level	10.3			
200228	1617682	6121552	Lake Heather 3	33.4	Screen	7.4			
					Mean Water level	11.4			
209581	1617702	6127677	Ogle Drive	35.7	Screen	5.7			
					Mean Water level	14.2			
200211	1618829	6128509	Paparore Road	9.1	Screen	-68.9	-54.9	-25.9	-8.9
					Mean Water level	6.8	6.8	6.5	6.4
200210	1611712	6146689	Waterfront	12.5	Screen	-60.9	-44.5	-24.2	-6.0
					Mean Water level	5.3	5.3	4.0	3.4
201025	1620470	6122039	Sweetwater Nursery	3.8	Screen	-23.2			
					Mean Water level	4.78			

For sites with a downward potential gradient, there appears to be very little change in groundwater levels below an elevation of about 10m below sea level. This indicates that the shallow groundwater is more dynamic than the deeper groundwater, which may be stabilised by sea level, and therefore relatively stagnant. The deeper Burnage piezometers show no change, and it is possible that this bore may be affected by leakage along the casing.

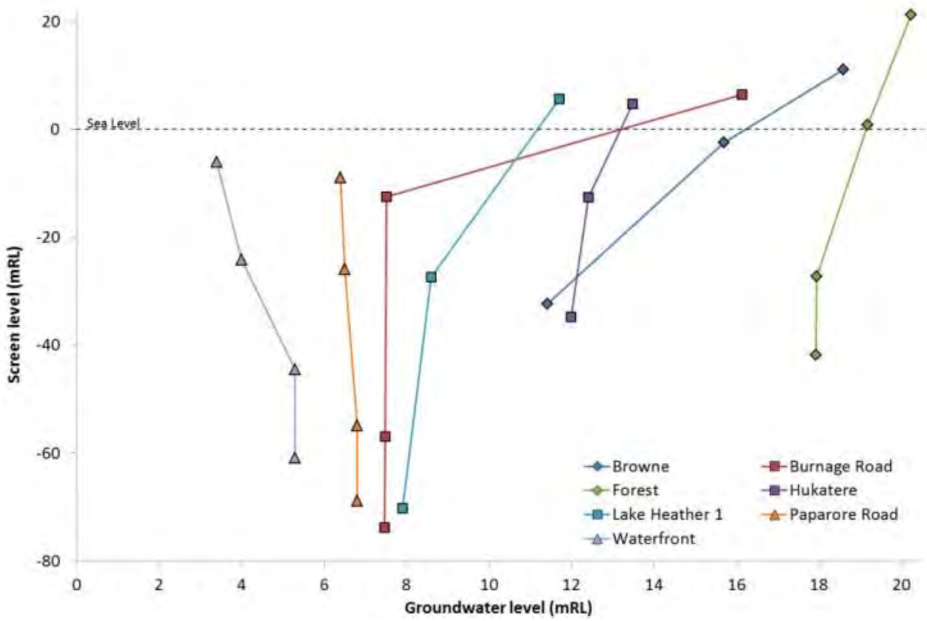

Figure 5 Graph comparing the of top of screen and water level for multi-level piezometers

[1] *All values are relative to sea level*

TRANSIENT RESPONSE

Groundwater levels in some bores have been monitored by NRC on a monthly basis since 1987. Graphs showing water levels in the piezometers are provided in Appendix 1. The groundwater elevation for each site has been coded according to screen depth, with shallow levels represented by dotted lines, mid levels represented by dashed lines, and the two deep levels represented by solid lines.

In general, bores with deeper screens are more responsive than the shallow bores. This is most likely due to lower storage coefficients at greater depths, although there is more pumping from the deeper aquifer also. Bores on the western side of the aquifer are much less responsive to individual recharge events than those in the east. A possible explanation for this is that land surface recharge is being attenuated by the unsaturated zone, which smooths the water table fluctuations. Certainly, the bores with more shallow water tables are more responsive, but not significantly so.

Multi-level piezometers with deeper screen depths respond strongly to summer pumping demand. This response is a combination of proximity to production bores and lowering of the storage coefficient with depth. The deeper bores also show more subdued long-term fluctuations than more shallow piezometers. It is interesting that this subdued response to recharge occurs despite the expected decrease in storage coefficient values with depth.

An example of delayed recharge response can be seen at Lake Heather, where the P1-3, P2, and P3 piezometers are all screened in the shallow unconfined dune sands (see Appendix 1). These piezometers show an almost identical response, the only significant difference between them being the actual groundwater level in each bore. The deeper P1-3 and P1-2 piezometers are screened in the shell-rich horizon and leaky-confined sand respectively. The Water levels in these two piezometers are very similar. The response of these piezometers is more subdued than the shallow piezometers, and also shows a relative delay of approximately 1-2 months.

HydroGeo Solutions (2000) have suggested that the observed attenuated and delayed recharge is derived from slow-release leakage from the lakes and the presence of significant peat deposits providing the attenuation. Our review of the Aupouri Aquifer hydrogeology agrees with this observation, and we have found the peat deposits to be a strong influence on the partitioning of groundwater flow vertically and laterally. However, the delayed response could also be caused by a fairly high degree of leaky confinement delaying the arrival of surface recharge at greater depths and hence subduing and delaying the pressure response

LAKES

There are a number of small lakes in the Aupouri Peninsula which have formed in the depressions between sand dunes. There are two hydraulic settings in which each of these lakes could be situated. Firstly, it is possible that a lake could be a "window lake", essentially presenting an extension of the groundwater table. If this is the case, the lakes would have a direct hydraulically connection with the aquifer, and would be affected by pumping. The alternative possibility is that a lake could be perched above the aquifer, essentially being isolated from the main groundwater system by an underlying peaty clay or pan horizon. If this is the case, the lake would not be affected by groundwater pumping, but it may contribute to the aquifer via the percolation of water downwards to the main aquifer system, thereby providing a steady source of groundwater recharge. Note that the occurrence of a perched lake does not preclude the possibility that there is also some localised perched shallow groundwater that is in hydraulic connection with the lakes.

The possibility of window lakes has implications for aquifer management, since groundwater pumping could potentially affect water levels in these lakes. There is, however, little data available on which to base a conclusion. Monitoring data is only available for lakes Waiparera, Heather, Ngatu, and Rotoroa, and fortunately these lakes also have a record of groundwater levels nearby. The monitoring records clearly show that the groundwater level at each of these lakes is situated well below the water level of the lake. For example, shallow groundwater at the nearby Lake Heather piezometer is less than 10 m above mean sea level, while the water level of nearby lakes Heather and Rotoroa is 34 and 27.5m respectively. Groundwater levels from bore logs located near lakes Ngatu and Waiparera also indicate that the main aquifer is situated well below the lake surface. We can conclude that there is no evidence of a direct hydraulic connection between these four lakes the main aquifer system.

A preliminary assessment of the connection between groundwater and other lakes in the area can be made by using data from the NRC digital elevation model (DEM). Lake levels can be estimated from the DEM and compared with nearby groundwater depths from bore logs, also adjusted by the DEM to create groundwater levels. While this is not an accurate method, it does indicate which lakes that have a high likelihood of being connected to groundwater or not if a nearby groundwater level is available. The desktop exercise indicates that Salt Lake and Lake Waihopo possibly have a hydraulic connection, while Round Lake, West Coast Road, Rotokawau, and Gleesons lakes are almost certainly disconnected.

GROUNDWATER PROPERTIES

Aquifer tests were carried out and analysed for the exploratory bores that were drilled by the NZ Geological Survey (Petty, 1975) and NRC (GCNZ 1987a). Additional aquifer tests have been carried out in more recent years as supporting evidence for resource consent applications (e.g. SKM, 2007a). GCNZ (1987a) also estimated horizontal hydraulic conductivities for more permeable sediments in the aquifer using Darcy's Law. Values ranged from 1 x 10^{-5} to 1 x 10^{-4} m/s (1-10 m/d).

Hydrogeo Solutions (2000) provided a list of the aquifer test results that had been reported up to that time. The transmissivity values that were reported range from 12 m^2/d to 850 m^2/d. Storage coefficients ranged from 0.01 to 0.0001, indicating that leaky-confined to confined conditions are common throughout the aquifer.

For this study we have considered that it is important to consider hydraulic anisotropy in the aquifer. Anisotropy can form at a macro-scale by the overlaying of finer and coarser sedimentary units such as wetland deposits and sands. Anisotropy also occurs at a micro-scale due to imbrication (alignment of particles), compaction, or stratification. All of these macro and micro-scale features are expected to be present in the Aupouri Aquifer. It is clear from the geology that the aquifer consists dominantly of fine to medium sand, and this sand is expected to become more compact with depth. This means that the horizontal hydraulic conductivity will be significantly greater than vertical values. On a broader scale, we also know that the sand deposits contain significant lenses of silt, clay and peat. This will further increase the difference between the horizontal and vertical hydraulic conductivity values.

The effect of anisotropy is evident in the drawdown curves that have been previously reported, which depart from a classical Theis type-curve. This generates bulk values of hydraulic conductivity which may be higher than horizontal values once this anisotropy has been accounted for. For the purposes of groundwater modelling, it is important to try and describe this anisotropy because it can strongly influence the direction of vertical flow potential.

All of the tests that have been reviewed for this report show the influence of an external recharge source which causes the rate of drawdown in the observation bore to decrease over time. The late-time recharge phenomenon is so pronounced that it can only be sourced from the overlying saturated sediments, which are large potential source of groundwater storage (delayed yield).

Figure 6 shows a good example of the recharge effect at the Ogle Drive bore. The initial few minutes of the drawdown curve is dominated by storage in the vicinity of the pumped bore. After 10 minutes the drawdown curve is following a typical Theis type-curve, which forms a straight line on a semi-log plot. After an hour of pumping, the drawdown curve starts to deviate from the Theis type-curve. This is interpreted to be the consequence of vertical leakage, which effects drawdown at the point where the radius of potential drawdown is of sufficient extent to make the vertical component of flow a significant contribution discharge.

The aquifer test shown in Figure 6 has been modelled with the Boulton (1963) solution, which incorporates delayed yield from storage in an overlying aquitard, and allows a value of the leakage coefficient to be determined. To do this requires a test with an observation bore, and a test of sufficient duration and drawdown to provide a marked leakage effect. Table 2 shows the results of aquifer tests that we have re-analysed to account for aquifer leakage. Suitable aquifer test data for re-analysis required the availability of drawdown results for a constant discharge test with a drawdown response in an observation bore. This requirement limited the data available for re-analysis to seven sites, since most of the tests carried out in the aquifer have not included an observation bore.

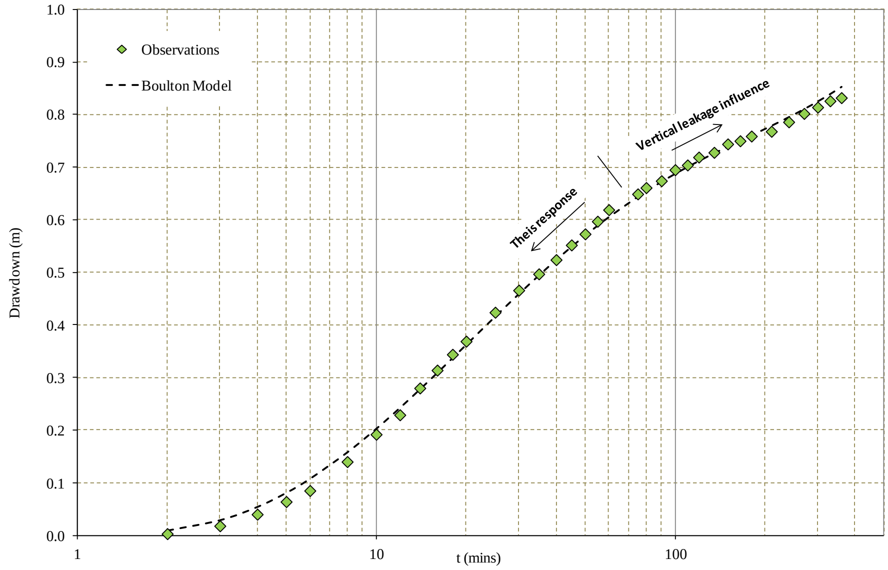

Figure 6 Time-drawdown curve plot for the Ogle Drive aquifer test

One of the difficulties in converting transmissivity (T) and leakage coefficients (K'/B') to hydraulic conductivity (Kx) and vertical leakage (Kz) components is the difficulty in characterising the aquifer (B) and overlying aquitard (B') thicknesses. These values have to be gauged from a drillers' well log, and it is not always apparent which depth to use for thickness calculations. Furthermore, the duration of the test determines how far the leakage effect will propagate through the overlying sediments. The tests carried out in the Aupouri Aquifer have typically consisted of less than a day of pumping, so it is unlikely that the well has drawn storage from the whole saturated sequence because of the large volume of storage available in the overlying sediments. Accordingly, the aquitard thickness has been interpreted here to represent the depth of more permeable sediments overlying the pumped bore until a low permeability layer such as a peat or clay is reached. Because of the uncertainty in the estimation of B', the leakage coefficients in particular (K'/B') are considered to be more reliable than the vertical hydraulic conductivity (Kz) values shown in Table 2.

Table 2 Results of re-analysis of aquifer test data

Pumped bore	Screen depth (m)	Test name	Obs piezo	Lithology	T (m^2/d)	B (m)	Kx (m/d)	S	K'/B' (d)	B' (m)	K'z (m/d)
200048	18.8	Hukatere 1	r1.5m	Sand	60	6.4	9.4	0.0017	0.1475	13.5	2.0
200048	18.8	Hukatere 1	r15m	Sand	60	6.4	9.4	0.0107	0.2927	13.5	4.0
200048	18.8	Hukatere 3	r1.5m	Sand	50	6.4	7.8	0.0022	0.1909	13.5	2.6
200048	18.8	Hukatere 3	r15m	Sand	62	6.4	9.7	0.0154	0.1909	13.5	2.6
200060	64	Browne	208 P1	Sand	400	10.4	38.5	0.0004	0.0014	21.2	0.03
200081	31.2	Ogle Drive	r1.5m	Sand	7.4	8.1	0.9	0.0467	0.8771	10.2	8.9
200229	73	Fitzwater	211 P1	Sand/shell	130	6	21.7	0.0002	0.0001	26	0.004
200229	73	Fitzwater	211 P2	Sand/shell	110	6	18.3	0.0004	0.0004	11	0.004
201025	27	Sweetwater	r17m	Sand	52	6.3	8.3	0.0004	0.0018	11	0.02
201037	27.2	Welch	r1.5m	Sand/shell	9	1.8	5	0.0005	0.0087	11.9	0.10
209606	110.5	King Avo	209607	Sand/shell	305	26	11.7	0.0007	0.0003	15.5	0.004
209606	110.5	King Avo	209608	Sand/shell	370	17	21.8	0.0011	0.0003	15.8	0.005
				Min	**7.4**	**1.8**	**0.9**	**0.0002**	**0.0001**	**10.2**	**0.004**
				Mean	**135**	**8.9**	**13.5**	**0.0067**	**0.14**	**14.7**	**1.7**
				Max	**400**	**26**	**38.5**	**0.0467**	**0.88**	**26.0**	**8.9**

Table 2 indicates that aquifer transmissivity ranges from about 5 to 400 m^2/d, and we can expect hydraulic conductivity values within the sand and shell beds to range from 1 to 40 m/d. The values we could expect for fine silt are less than 2 m/d, and for fine sand range from 0.02 to 20 m/d (Domenico and Schwartz, 1998). This suggests that the grain size within the "sandy" part of the aquifer may range from silt to medium sand, which is consistent with the driller's well logs.

The aquifer test results shown in Table 2 indicate that the leakage coefficient can vary from around 0.0001 to 1. When accounting for an estimated aquitard thickness, vertical hydraulic conductivity values in the sediments overlying the permeable pumped horizon can range from 0.004 to 9 m/d. These results indicate there is considerable aquifer anisotropy, with the estimated vertical hydraulic conductivity ranging from similar values to the horizontal, to a thousandth of the horizontal value depending on the overlying lithology. However, while the hydraulic conductivity of the overlying sediments may be small, there is a large volume of available storage for bores to draw on. Thus, a small leakage coefficient does not impose severe limits on the productivity of bores.

Values obtained for the storage coefficient range from 0.05 to 0.0002. Values of 0.3 to 0.01 are typical of unconfined conditions, while values less than 0.005 can be considered to represent confined conditions (Freeze & Cherry, 1979), although truly confined conditions aren't expected to occur until values of 0.00001 are approached. All of the tests that have been analysed can therefore be considered to represent confined (and leaky) conditions with the exception of Ogle Drive and perhaps Hukatere, which have values at the lower end of what may be considered to be unconfined conditions.

GROUNDWATER ALLOCATION

There are currently 64 consents to take groundwater from the Aupouri Aquifer. The total daily and annual allocation is around 41,100 m^3/d and 7.44 million m^3/y respectively.

Most of the consents are for irrigation of avocados, although there have recently been two large consents for public water supply (Far North District Council, 5000 m^3/d) and pasture irrigation (Landcorp, 15,525 m^3/d) which have not yet been exercised. There are also some minor takes for domestic and stock water supply, industrial use, and crop irrigation. Pumping bores are currently centred on three areas which constitute 87% of the consented total allocation volume:

Houhora: An area of concentrated avocado orchards. 5,256 m^3/d is allocated to twenty consents.

Pukenui: A more widespread area of avocado orchards. 8,046 m^3/d is allocated to fourteen consents.

Sweetwater: The Sweetwater area has more diverse water use than Houhora and Pukenui. 22,485 m^3/d is allocated to six consents. The majority of this water is allocated to the Far North District Council and Landcorp.

The Landcorp and Sweetwater consents together comprise 50% of the total volume of water that has been allocated from the Aupouri Aquifer. At the time of writing, these consents had not been exercised, so their impact on the aquifer has yet to be observed.

GROUNDWATER QUALITY

Groundwater quality sampling is currently undertaken at six sites throughout the Aupouri Aquifer by NRC. An additional site, West Coast Road, was monitored for a short period from 2007 to 2009. The only previous regional scale reporting of groundwater quality monitoring for the Aupouri Aquifer has been in national reviews of State of the Environment (SOE) and National Groundwater Monitoring Programme (NGMP) (e.g. Daughney & Randall, 2009; Daughney *et al.*, 2012).

The mean results of the NRC groundwater quality sampling are shown in Appendix 2. Overall, the quality of groundwater in the Aupouri Aquifer is very good. All of the sampled concentrations are less than half of the NZ Drinking Water Standards (Ministry of Health, 2008). Samples that exceed their respective guideline values are indicated in red in the Table on Appendix 2.

Exceptions to good water quality are found in some areas with iron, manganese and hardness exceeding half of the guideline values that have been set for aesthetic reasons. Iron and manganese can form a residue on white ware and linen in high concentrations. The guideline values for iron and manganese have been exceeded at Ahipara, Colville and Vinac sites, and the Fitzwater site exceeds the guideline value for manganese. These metals are often found in aquifers with reduced (anoxic) conditions, and their high concentrations are probably a consequence of the abundant peat deposits in the aquifer.

Hardness is a measure of the mineral content of water, with hard water having higher concentrations of calcium and magnesium. This makes it difficult for soap to form lather, and the formation of a lime crust in kettles can occur. Moderate to hard water has been sampled at the Fitzwater and Fish Club bores at Houhora. Both of these bores are screened within the shellbed layer at the base of the aquifer. The higher hardness content of these bores is most likely caused by dissolution of calcite from the shells. If this is the case, higher hardness contents can be expected from most bores screened within the shellbed layer.

Salinity is an important issue for the Aupouri Aquifer, which is bounded by the sea for most of its extent. Chloride and sodium concentrations are the best indicators of salinity. Figure 7 shows the results of chloride and sodium sampling, and it can be seen that concentrations are stable at most sites.

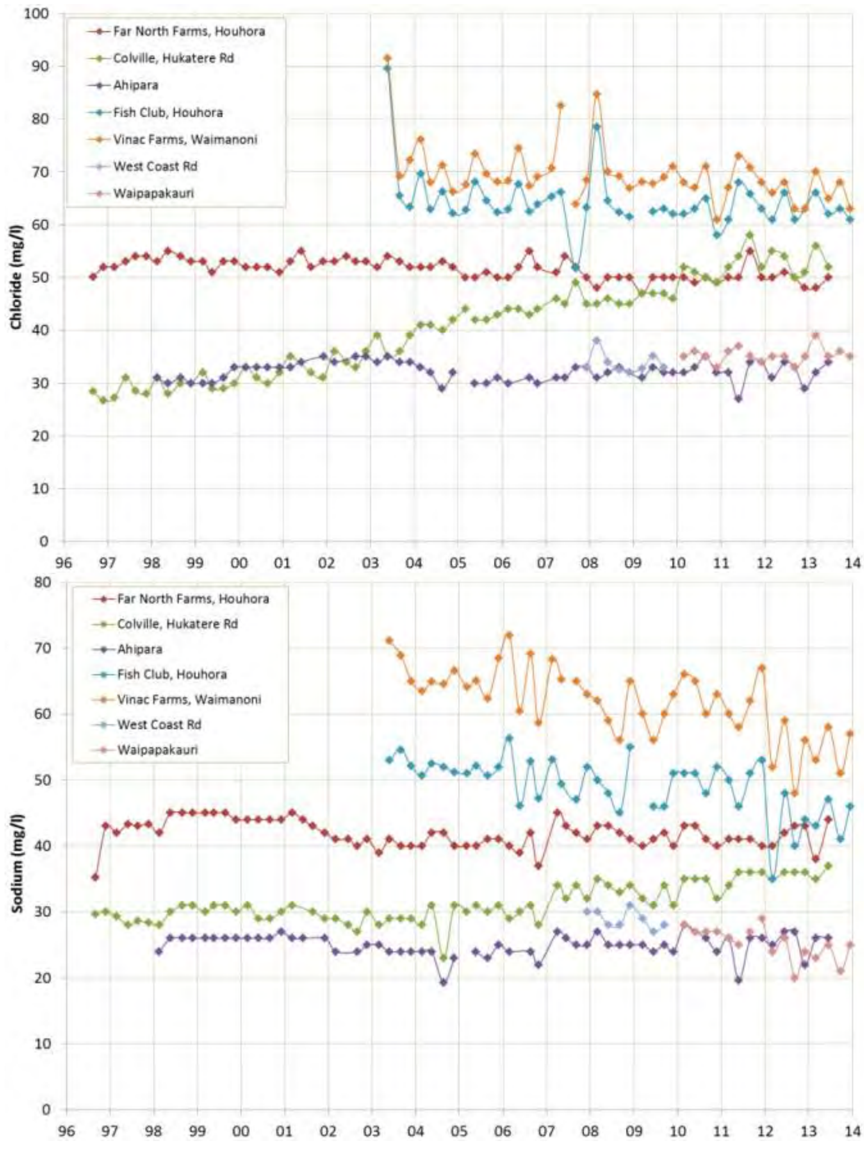

Figure 7 Time-series of chloride and sodium concentrations

Bores with higher concentrations are interpreted to represent greater mineral dissolution, and therefore represent older groundwater. The Vinac Farms and Houhora Fishing Club bores show the highest concentrations overall, and these sites show a slight decrease in both chloride and sodium over time. This suggests that younger, fresher water is being drawn into this bore in response to pumping. The nearby Waipapakauri Beach bore, which has been sampled since 2010 shows a stable response.

The Colville bore is the only site that shows an increase in chloride or sodium concentrations over time. There are a number of groundwater consents in this area, and the expected response in this bore is for decreasing concentrations over time as younger, fresher water is drawn down. The increase in concentrations in the Colville bore suggests the possibility that older water is being drawn in, perhaps from deeper sediments.

GROUNDWATER AGE

The mean residence time (MRT) of groundwater can be estimated using tritium, which is an unstable form or isotope of hydrogen. Unstable isotopes such as tritium change their atomic structure through time via radioactive decay. The decay rates for different radioactive isotopes are well known, and have been documented in numerous physics and chemistry textbooks. Tritium is a particularly useful isotope because it forms a part of the water molecule, and this enables the residence time for water to be determined.

Tritium is a radioactive form of hydrogen that has one proton and two neutrons, unlike the common form of hydrogen which has one proton and no neutrons. The decay of tritium to helium-3 has a half-life of 12.3 years and is naturally produced in the atmosphere by cosmic rays. Large amounts of tritium have released into the atmosphere by the testing of nuclear weapons since 1945. Concentrations peaked in 1965 due to the intensity of testing carried out in the early 1960's, and they are now close to background levels. A more detailed outline of the application of the tritium dating method to the NGMP is given in Morgenstern and Daughney (2012).

Table 3 shows the results of tritium analyses from the Aupouri Aquifer and the approximate elevation of the top of the bore screen relative to sea level. The analyses and interpretation have been made at the GNS isotope laboratory in Wellington. The results show consistently old MRT values of over 50 years, and four of the seven sites give values beyond the range of accurate tritium interpretation.

Table 3 Results of Aupouri Aquifer tritium analyses

Bore	Name	Screen top (m msl)	Groundwater level (m msl)	Lithology	Redox	Date	MRT (years)
210449	Long Bore, Ahipara	-28	?	Sand	Anox?	Apr-05	50
						Mar-09	52
						Dec-10	51
200059	Colville, Houhora	-28	?	Sand	Ox?	Apr-05	71
						Mar-09	53
						Dec-10	70
200211	Fitzwater, Paparore	-60	6.8	Shell bed	Ox	Apr-05	138
201563	Vinac Farms, Awanui	-31	12.7	Sand	Anox?	Jun-07	>200
209330	Waipapakauri Beach	-51	0.8	Sand/shell	Ox	Mar-12	>240
200250	Fish Club, Houhora	-68	1.4	Shell bed	Ox	Jun-13	>250
201025	Nursery, Sweetwater	-19	8.8	Alluvium	Anox	Jun-13	>250

The long mean residence times given by tritium analyses suggest that the aquifer is very sluggish, and may have very little shallow groundwater interaction under natural flow conditions at greater depths. The bores that were sampled have screen tops located below sea level, from 19m (Nursery) to 70m (Houhora Fish Club) and show upward flow gradients. The samples span a range of oxidation conditions, showing that even high quality oxidised water can be very old.

AUPOURI AQUIFER CONCEPTUAL MODEL

This section presents a conceptual model that is based on the observations made in the previous chapters.

At a regional scale the Aupouri Aquifer is best considered as a four-layer groundwater system:

1. **Unconfined dune sand and localised shallow water tables perched on peat beds**
   This upper layer is situated at or above sea level and groundwater is free to flow as gravity-driven drainage because of the high hydraulic conductivity of the sands and the ability to discharge to the coast. On a macro-scale, the sub-horizontal hydraulic conductivity is greater than vertical because of the presence of peat beds (K_x>k_z). This layer is the most dynamic part of the Aupouri Aquifer system.

2. **A widespread non-continuous aquitard of variable thickness situated approximately at sea level**
   The base of the unconfined layer is marked by a widespread Holocene peat, silt and clay horizon which is on average about 5-10 m thick. These sediments mark a low energy depositional environment that was established by the stabilisation of the sea at its present level about 6,500 years ago. The Waihuahua and 'Great Kaitaia' swamps are surface expressions of this horizon. Drillers' logs indicate that low permeability sediments at elevations similar to sea level are widely distributed beneath the dune sands.

3. **A confined-leaky sand interspersed with peat and clay and beds**
   This layer is situated below sea level and constitutes the bulk of the aquifer's storage. Sub-horizontal hydraulic conductivity is much greater than the vertical due to compaction, imbrication of particles, and the layering of silt, clay, and peat beds (K_x>>k_z). This anisotropy produces a groundwater system that can be highly stratified.

4. **Confined-leaky sand with high permeability shell beds**
   This is the deepest layer and is situated within the marine sands that overlie compacted Tertiary sediments. Sub-horizontal hydraulic conductivity is expected to be a little higher than the vertical due to compaction by the overlying sediments (K_x>k_z).

The groundwater system as a whole is referred to as the Aupouri Aquifer, but it is perhaps more accurate to think in terms of a stratified groundwater system, since sedimentary anisotropy and the localised peat bed aquitards play an important role in controlling groundwater flow paths and providing storage. A schematic profile through the groundwater system is shown in Figure 8.

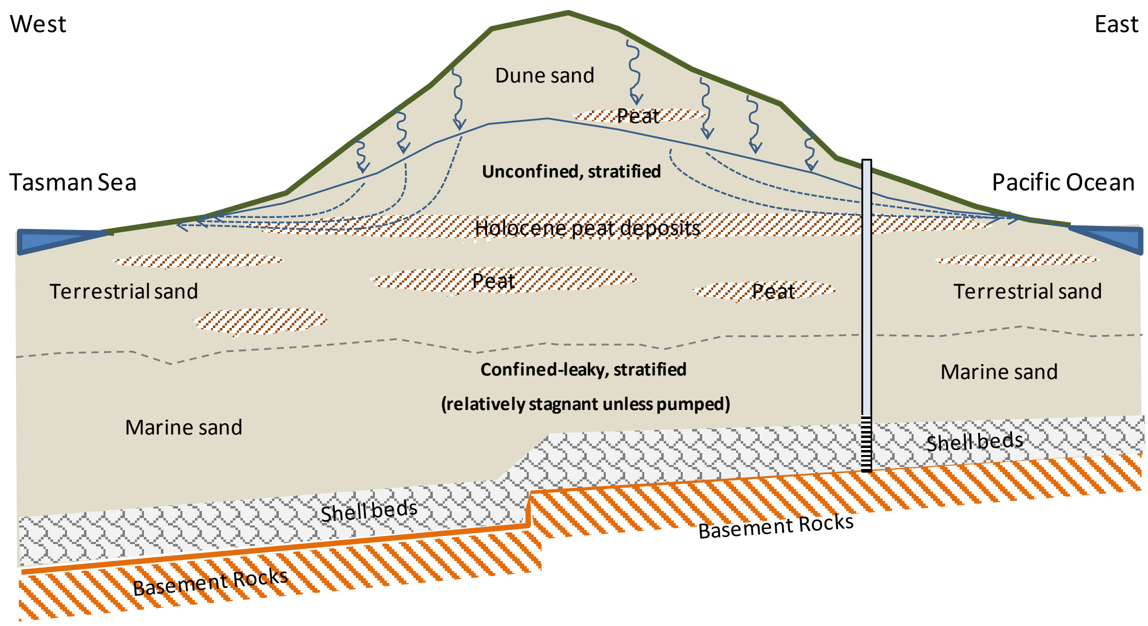

Figure 8 Schematic profile through the Aupouri Aquifer

THE UNCONFINED AQUIFER

Groundwater in the upper unconfined aquifer is recharged by rainfall and able to freely flow under gravity because it is situated above sea level. Localised perched water tables are found between sand dunes where rainfall recharge is impeded by isolated peat beds. Surface expressions of these localised water tables are the dune lakes. The underlying sands have a higher hydraulic conductivity and therefore a greater ability to drain. Most, if not all, of the dune lakes are expected to be perched above the regional water table.

The movement of groundwater in the unconfined aquifer is expected to be much greater in a lateral direction towards the coast than downwards into deeper parts of the system. The reason for this is the hydraulic anisotropy formed by the sand-wetland depositional sequence, together with imbrication and compaction of the sedimentary pile. The contrast between horizontal and vertical permeability favours a lateral groundwater movement, with drainage in the unconfined aquifer preferentially flowing towards the shoreline.

A particularly important geological horizon in the Aupouri Aquifer is the aquitard situated at sea level, which forms an important vertical hydraulic barrier over much of the Peninsula, particularly at Sweetwater. Flow above this aquitard is driven by the hydraulic gradient towards the sea, which sets the regional hydrological base level for the aquifer. The presence of low permeability sediments at sea level means that most of the recharge in the unconfined aquifer is preferentially forced out to sea rather than flowing downwards into the confined-leaky aquifer. Evidence of this discharge can be seen along Ninety Mile Beach at low tide. Ephemeral streams are also found along both coastlines, which act as a discharge mechanism when groundwater levels are high.

THE CONFINED-LEAKY SYSTEM

Flow in the confined-leaky groundwater system beneath sea level is most important to understand because this layer forms the bulk of the available storage within the aquifer, and is also the site of the most pumping.

Below sea level, flow potential is driven by the pressure of the overlying water column, including the unconfined aquifer. However, groundwater in the confined-leaky system also has a reduced ability to discharge upwards because of structural confinement by low permeability silt, clay and peat horizons. This reduced flow potential also applies to submarine discharge because of the way successive layers are draped over the gently-sloping sea floor. This is because passive coastal and marine sand deposition occurs by the successive mantling of newer sediments over older ones, and this process inherently forms a relatively low-permeability barrier between the Aupouri groundwater system and the sea.

The confined-leaky Aupouri Aquifer can be considered to be a discharge-driven system rather than a recharge-driven system. The reason for this emphasis is that groundwater recharge can only enter the deeper sediments if there is discharge to accommodate it. The rate of groundwater flow in its natural state is likely to be small because the low vertical permeability of overlying sediments limits the rate of aquifer discharge to the sea. The rate of groundwater flow in the confined-leaky system can be artificially and locally increased by discharge in the form of pumping, which induces groundwater downwards via leakage. The most influential aquifer property to understand is therefore its vertical leakage coefficient, since this regulates how the system responds to a change in pressure.

The preceding conceptual framework indicates that groundwater in the confined-leaky system will be quite old because anisotropy within the groundwater system results in a rapid decrease in natural flow velocity with depth. Tritium data supports this assumption. All of the available tritium data for the groundwater system is from bores with screens from 20 to 70m below sea level. Of these, the shallower bores have calculated mean residence times of 50 to 70 years, while residence times for deeper bores are beyond the range of tritium analysis (i.e. older than 100 years).

Special mention needs to be made of the function of the shellbed horizon at the base of the aquifer which many of the boreholes in the Aupouri system access. The shellbeds have a significantly higher overall hydraulic conductivity compared to the overlying sand sequence. However, the shellbeds are also a relatively thin layer, which limits the amount of storage available for pumping. Aquifer test responses show that the effect of pumping in this layer is to firstly draw on the highly permeable, porous shell bed sediments that surround the bore screen, since this water is most easily accessed. As pumping proceeds, the pressure in the shellbed layer drops, and additional water is progressively sourced from the overlying sandy sediments. In effect, the shell beds perform the role of a gallery, enabling the bore to access to a wider area of storage in the overlying leaky sands. Without the presence of the shellbeds, bore yields would be significantly lower and there would be more pronounced localised drawdown effects from pumping.

LAND SURFACE RECHARGE MODEL

There are three possible recharge sources to the Aupouri Aquifer: land surface recharge, peripheral aquifer boundary infiltration, and basement discharge. Volumetrically, recharge is expected to occur predominantly as land surface recharge. There may also be some additional infiltration along the edge of the hills that surround the sandy aquifer via the basement contact, and this could be a significant contribution at a local scale. For example, infiltration may occur as leakage from the Awanui River or Wainui Stream as they cross from a basement to a sandy substrate. Recharge to the Aupouri Aquifer may also occur as discharge from the basement rocks themselves, although this contribution is expected to be very small compared to the two potential surface water recharge sources because of the low permeability of the basement.

Of the three potential recharge sources there is only sufficient information available to estimate recharge over the land surface. The other two possible sources are assumed for the purpose of modelling to contribute negligible recharge to the aquifer, which is a conservative approach to an aquifer allocation assessment. However, we do recommend that surface-groundwater exchanges be characterised in the future by assessing groundwater responses in bore located close to the aquifer/bedrock boundary, and by conducting a series of concurrent flow gauging surveys on the main surface water bodies.

SOIL MOISTURE BALANCE MODEL

Land surface recharge was calculated using a daily soil moisture balance model, which has been modified from the Rushton model (Rushton *et al*., 2006; de Silva & Rushton 2007). This soil moisture balance model has been demonstrated to simulate lysimeter drainage rate data quite accurately in New Zealand if the soil hydraulic properties are known (Wilson & Lu, 2011).

A key assumption made in the recharge calculations is that water is able to freely drain from the soil profile into underlying permeable geology. An assumption is also made that recharge is not intercepted by artificial drainage before reaching the water table.

Spread-sheet calculations for soil moisture balance follow the algorithms provided in Rushton *et al.* (2006). The Rushton model consists of a two-stage process: calculation of near-surface storage and calculation of the moisture balance in the subsurface soil profile. The near-surface soil storage reservoir provides moisture to the soil profile once all the near-surface outputs have been accounted for. If there is no moisture deficit in the soil profile, recharge to groundwater occurs.

There are three steps to describe the soil moisture balance:

1. Calculation of infiltration to the soil zone (In), and near-surface soil storage for the end of the current day (SOILSTOR). Note that infiltration (In), as specified by the Rushton algorithms, is not just infiltration (rainfall-runoff), it also includes SOILSTOR from the previous day.
2. Estimation of actual evapotranspiration (AET). PET is derived by the Penman-Monteith equation (Allen *et al.*, 1998). For most of the peninsula, a crop coefficient is not applied since the crop is assumed to be pasture, which is the reference crop for the Penman-Monteith equation. Most pastures in New Zealand behave like the reference crop for most of the year (Scotter and Heng, 2003). The Aupouri peninsula also has extensive areas of forestry and native scrubland. Crop coefficients have been applied for different land uses by altering the profile readily available water value.
3. Calculation of soil moisture deficit and groundwater recharge. Recharge occurs only when the soil moisture deficit is negative, i.e. when there is surplus water in the soil moisture reservoir.

The three steps outlined above partition near-surface soil storage between near-surface soil storage for the following day, AET, and the soil moisture deficit/reservoir respectively. The Rushton model is usually started in winter when the initial soil moisture deficit can be safely assumed to be nil. This also allows a lead-in time for the model to give a satisfactory water balance for the following calendar year.

MODEL INPUTS

Rainfall and potential evapotranspiration (PET) data for the soil moisture balance model have been sourced from the NIWA Cliflo database. The virtual climate station data was used, which is available for Northland over an approximately 5km grid. In addition to rainfall and PET data, the soil moisture balance model requires input values for three soil hydraulic properties to calculate the daily water balance:

Profile Available Water (mm): PAW or TAW is calculated from field capacity, wilting point and rooting depth data. Typical values for field capacity and wilting point are given in Table 19 of Allen *et al.* (1998), and many values for New Zealand soils can be found in the literature (e.g. McLaren and Cameron, 1996). It is more difficult to determine appropriate values for rooting depth. Values quoted in the literature are usually for uninhibited root penetration. Some knowledge of the soil profile is required to estimate rooting depth, because root penetration at a particular site may be limited by the presence of a resistive layer such as a loess or clay pan. If rooting depth is not known, it may be estimated from the profile thickness for thicker soil units. However, because rooting depth is also a function of water capacity and soil aeration, some caution is needed in using profile thickness as a proxy.

Profile Readily Available Water (mm): PRAW or RAW is related to PAW by a depletion factor, *p*. The depletion factor is the average fraction of RAW that can be depleted from the root zone before moisture stress (Allen *et al.* 1998). For New Zealand conditions, *p* should be around 0.4 to 0.6, typically 0.5 for pasture.

Fracstor: This is the near-surface soil moisture retention. The contribution of Fracstor to the soil moisture balance is small, so errors resulting from estimations are considered to be negligible. Typical values are 0 for a coarse sandy soil, 0.4 for a sandy loam and 0.75 for a clay loam (Rushton, 2006, p. 388). Appropriate values can be estimated from field observations (de Silva and Rushton, 2007). If the soil dries quickly, then Fracstor will be less than 0.3. If the soil surface remains wet after heavy rainfall, so that it is not possible to work the soil for several days, then Fracstor is likely to be in the range 0.6–0.8.

Modal values for PAW and PRAW were taken from the Landcare Research FSL New Zealand Soil Classification database. Values for Fracstor were estimated based on the soil textural descriptions in this database.

MODIFICATIONS

Some modifications have been made to the Rushton model to account for runoff, avocado irrigation, and forestry harvest and growth cycle.

RUNOFF

The Rushton model has been adapted for this report to incorporate runoff, which is removed from the soil moisture balance. This was calculated using the US Department of Agriculture, Soil Conservation Service (SCS) runoff curve number model (SCS, 1972). The SCS runoff model is a commonly adopted empirical method for predicting direct runoff or infiltration from excess rainfall (Ward & Elliot, 1995), and is comprehensively described in Rawls *et al.* (1992).

The SCS runoff method involves an attribution of a hydrological soil group for each soil (A to D). Soil group data for Northland soils are available from the Landcare S-Map database. A curve number is then estimated for each soil based on its hydrological soil group, which is used to calculate maximum soil retention for the calculation of runoff. Lower curve numbers give more water soil retention, and therefore less runoff. Pasture in good condition on free-draining soil has a low curve number, whereas pasture in poor condition on a poorly drained soil has a high curve number. A list of curve numbers for different soil conditions and land covers is given in Table 5.5.1 of Rawls *et al.* (1992). Curve numbers have also been adjusted within the soil moisture balance model to account for wet or dry antecedent conditions using the method of Ward and Elliot (1995).

IRRIGATION

Irrigation increases land surface recharge because it artificially raises the soil moisture content of the soil. This means that when rain occurs, more of that rain can potentially be drained through the soil profile.

Irrigation is estimated in the soil moisture balance model according to the antecedent soil conditions. This demand-driven approach assumes that irrigators are fully efficient, and apply a pre-defined depth of water when the soil moisture falls below a certain point during the irrigation season. A pre-defined depth is used because it is assumed that the amount of water applied is usually constrained by a combination of the consent conditions and the infrastructure on the orchard. The consent details for irrigation of avocados indicate that a daily demand of 3 mm is a representative value for Northland.

Irrigation is accommodated in the soil moisture balance model with an application of 3 mm when the soil moisture at the end of the previous day reaches 85% of the TAW during December to April. Running the soil moisture balance model for these constraints gives comparable results to those provided by NRC's SPASMO calculator (Green, 2010).

FORESTRY

Forestry is expected to reduce the amount of recharge to the Aupouri Aquifer. Approximately 40% of the aquifer area is covered in exotic forestry, so there is the potential for forestry to have a significant impact of the aquifer water balance. Unfortunately there have been few studies on the affect that pine forests have on groundwater recharge. The few studies that have been undertaken have applied quite different approaches because of the difficulty measuring observations (see Rowe *et al.* 2002).

There are a number of ways that forestry reduces recharge, the main factors being interception by the forest canopy, and increased evapotranspiration. The approach we have taken is to simply remove a fixed depth of each rainfall event. Previous studies have indicated that approximately the first 2 mm of rainfall is intercepted by a full forestry canopy (Rowe *et al.* 2002).

To account for the forestry growth cycle we have included a canopy factor within the soil moisture balance. This provides a linear change in canopy interception from the time of planting (no interception), to the development of a full forestry canopy after eight years of growth (2mm of interception). Forestry was given a thirty year growth cycle from planting to harvesting if the year of planting was known. The year of planting was only available for forestry blocks located within the Aupouri Forest. Forestry located outside of this area has been assumed to have a full canopy.

For consistency, a full canopy adjustment of 1.5 was also applied to indigenous forest and scrub, and avocado orchards were given an adjustment of 0.5. No interception loss has been assumed for pasture.

LAND SURFACE RECHARGE MODEL RESULTS

Annual rainfall over the Aupouri Aquifer from 1987 to 2013 varies from 580 to 1,670 mm in a calendar year (average 1,280 mm). Figure 9 shows the results of the soil moisture balance model, which predicts recharge values of 160 to 840 mm per year (average 500 mm). In terms of volume, this is an annual average of 374.2 million m^3/year for the whole aquifer, which is equivalent to 4,968 m^3/ha/year.

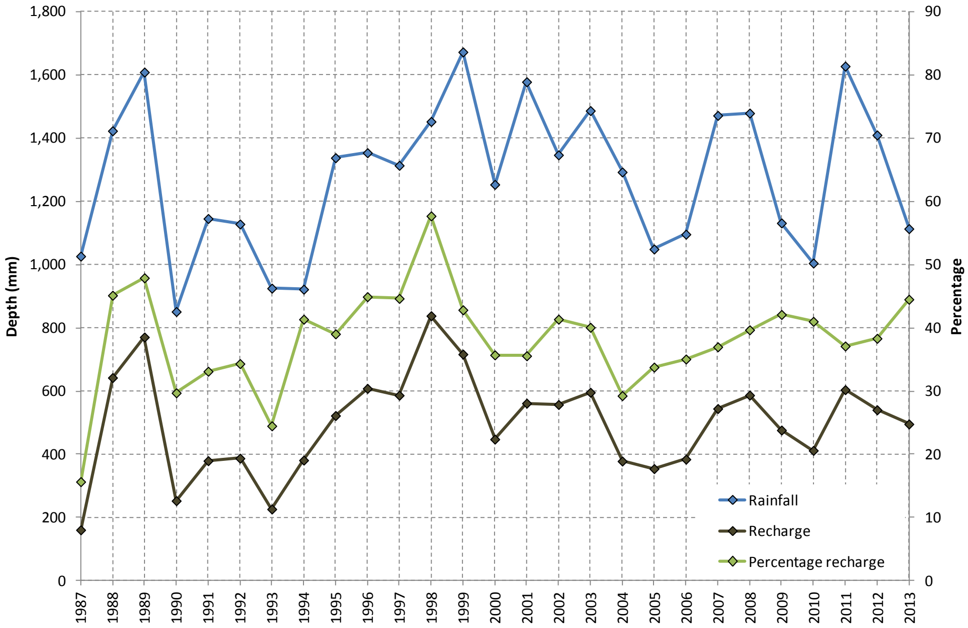

Figure 9 Annual rainfall and recharge results for the soil moisture balance model

On average 38%, of annual rainfall is infiltrated, which is high for New Zealand. Recharge is a high percentage of rainfall because of the light nature of the soils associated with sand deposits. A comparable recharge rate was reported by SKM (2007), who calculated a recharge rate in dune sand of 44% of mean annual rainfall using a soil moisture balance. The Rushton model gives an annual recharge rate around 540 mm for the dune sand beneath Aupori Forest, which is 43% of annual rainfall. The wetland areas, like Kaitaia Swamp, have a potential recharge of around 30%, although the actual recharge rate is likely to be somewhat less because of near-surface drainage.

About 21% of the area has a PAW less than 60 mm, and nearly 90% has a PAW of 75 mm or less. Heavier soils with a moderate to high PAW have a higher water holding capacity, but they also have larger moisture deficits in the summer because they are subject to more evapotranspiration (lighter soils have a limited water reserve). These factors result in much larger recharge rates over lighter soils compared to heavier soils. Consequently, the largest recharge rates are predicted to occur on the sand dunes, despite the presence of the forest plantations.

Figure 9 shows that the lowest estimate of annual recharge (16%) occurred in 1987, and the highest (58%) occurred in 1998. It is interesting that these years do not coincide with the years of lowest and highest rainfall. This illustrates that it is the timing and intensity of the events, rather than the annual amount that determine the amount of annual recharge.

Figure 10 shows the average monthly values for rainfall and recharge. Northland has a relatively high annual rainfall total for New Zealand, and it can be seen that the majority of this rainfall occurs during the winter months when PET values are low. The calculation of recharge follows a bell-shaped curve throughout the year with a peak occurring in June-July, and very little recharge occurring during summer.

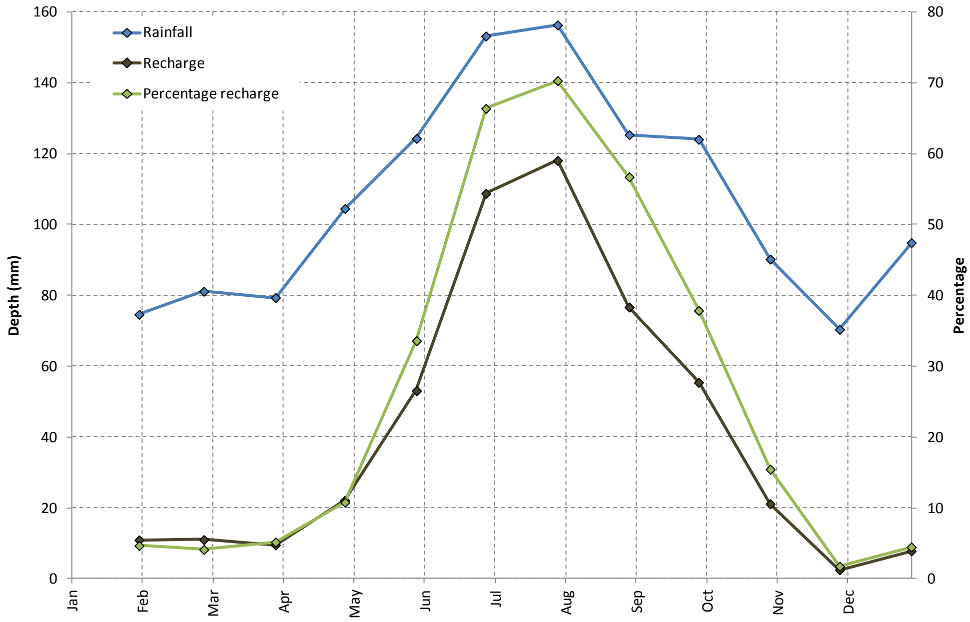

Figure 10 Average monthly variation in rainfall and recharge for the soil moisture balance model

VALIDATION OF THE SOIL MOISTURE BALANCE MODEL

The recharge values calculated by the soil moisture balance model were compared with estimates of recharge from groundwater level fluctuations. The groundwater level fluctuation method we have applied is outlined in Cuthbert (2010). Recharge is calculated from the change in water level over time, the specific yield, and an aquifer drainage term. The aquifer drainage term is a function of the distance to the aquifer boundaries and the hydraulic conductivity.

The Cuthbert method was applied to the two most responsive monitoring records in the unconfined aquifer, Browne (200208), Burnage (200209). These two sites have a relatively shallow water table (8 and 7m respectively) and are outside of the forestry plantation. These two characteristics mean that these sites are less affected by water retention in the unsaturated zone, which appears to make other sites in the aquifer less responsive to individual recharge events.

The aquifer dimensions were determined for the two sites by estimating the distance to the groundwater divide and the sea. An estimate of the specific yield needs to be made because there are no suitable aquifer test results available for the shallow sands. Johnson (1967) reported average specific yield values of 0.28 to 0.32 for fine and medium sands respectively. Domenico and Schwartz (1998) note that dune sand could have a higher value of 0.35, presumably because of its better sorting. A value of 0.3 has been used for application in the Cuthbert solution, and this value gives the best comparison overall with results from the soil moisture balance model.

Resolution of the Cuthbert solution does rely on knowledge of the aquifer transmissivity, and this is the value for which we have the least information. An aquifer test result undertaken at a deeper screen depth at Browne gave a transmissivity result of 400 m^2/d (Table 2). If this value is applied to the Cuthbert solution, we do get a close match with the soil moisture balance results (Figure 11). The results show that the soil moisture balance model estimates 70 mm more recharge than the Cuthbert method over a 27 year period, a 14% error. The error can be reduced by estimating the transmissivity value that gives the lowest sum of squares error between the two models (on the assumption that transmissivity is the parameter of least confidence). The optimised transmissivity estimate for Browne is 460 m^2/d for Browne, which reduces the discrepancy between models to 4%.

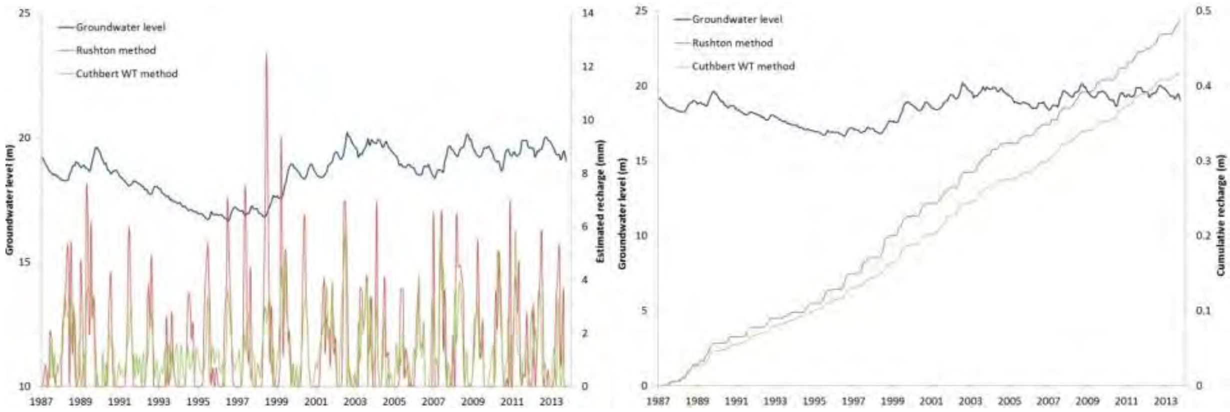

Figure 11 Land surface recharge validation at Browne

Figure 12 shows the results for recharge modelling at Burnage. In this case the soil moisture balance model underestimates recharge by 56mm over 27 years, a 12% error. The optimised transmissivity estimate for Burnage is 280 m^2/d, which reduces the discrepancy between the two models to 11%. The error at Burnage can be reduced further to just 1% by lowering the specific yield to 0.15, although there is little information to support the attribution of a different storage coefficient between the two sites.

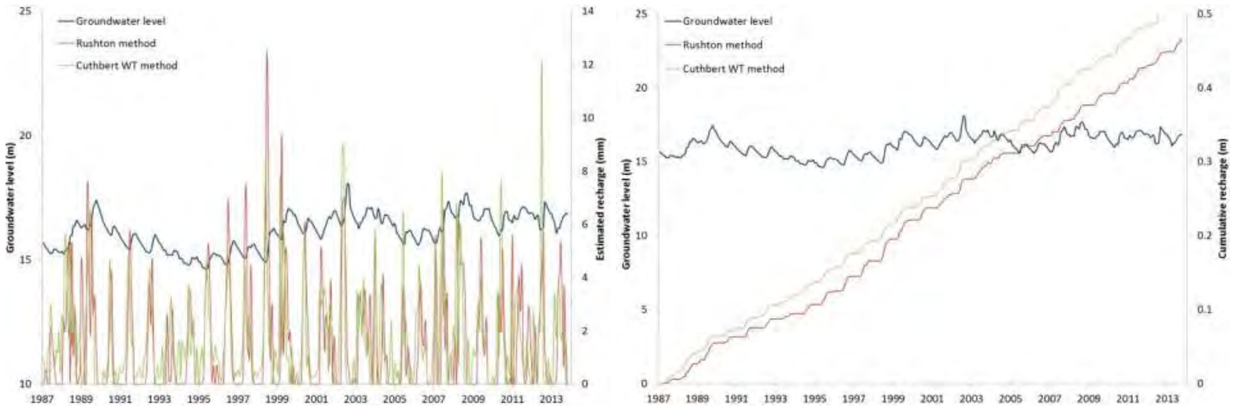

Figure 12 Land surface recharge validation at Burnage

In general, the validation has shown that the two models give comparable results over a long period of modelling. Both of the monitoring records are affected by pumping in later years, which can explain much of the error between the two models. Another source of error is the temporal resolution of groundwater level observations, since monthly measurements will miss many of the smaller recharge events that are calculated by the soil moisture balance model.

In conclusion, the validation exercise is limited by a paucity of suitable shallow groundwater level monitoring sites to use as “lysimeters”, together with a lack of transmissivity and storage coefficient observations. The soil moisture balance approach is favoured over the groundwater level fluctuation method because there is better knowledge of hydraulic properties for use in the model, particularly their spatial variability. It is recommended that NRC carry out a program of soil moisture or lysimeter monitoring in the predominant sandy soil units. This information would greatly assist the validation of land surface recharge estimations.

NUMERICAL GROUNDWATER MODEL

MODEL STRUCTURE

Our approach to the modelling process has been to start with a simple model and increase complexity as required. A Modflow2005 (Harbaugh, 2005) model was constructed in Groundwater Vistas 6.68 with three layers to represent the four-layered system identified in the conceptual model. The three layers are as follows:

1. Unconfined, mostly sandy aquifer (Layer Type 3 - Unconfined (T Varies)
2. Leaky confined sandy aquifer situated below sea level (Layer Type 0 - Confined)
3. The more permeable shell-rich horizon at the aquifer base (Layer Type 0 - Confined)

The elevation of the ground surface was taken from the NZSoSDEM v1.0, digital elevation model which has a 15 m spatial resolution. Intercepts for the bottom of each layer were identified in bore logs and subtracted from this DEM. These values were then interpolated to generate surfaces for importing into MODFLOW. The underlying basement rocks were assumed to be impermeable and therefore the base of the model represents the basement unconformity.

The structure of the model domain is shown graphically in Appendix 3. The model finite difference grid consists of 75 rows and 60 columns, with 4,755 active cells in the three layers (no-flow cells are greyed out). Grid spacing ranges from 500 m to 2,250 m, with the majority of the domain being 1km or less. The finer spacing is centred on clusters of pumping wells, and also the NRC monitoring bores (labelled), whereas the coarser spacing is situated north of Te Kao where there is little information on the aquifer. Modflow calculates groundwater levels for each cell based on the levels in neighbouring cells, so the grid resolution can affect the accuracy of the model's simulations. We consider the selected grid spacing to be a good balance between the regional scale of the model, the level of detail available for the aquifer, and computational limitations for transient modelling.

Pumping wells and observation targets were included in the model as analytic elements. Constant head boundaries (light blue squares in Appendix 3) were set around the coast in layer 1 to represent sea level. No-flow cells have been added to represent pre-Quaternary basement rocks, and have also been set offshore outside of the influence of constant head cells. Drain boundaries (dark blue) were added to remove water in wetland areas and to represent streams. Levels for the drains were set at a nominal metre depth below the DEM, and were given a high bed conductance value. Because there is little information available on these surface waterways, they were not optimised during the calibration process. Instead, vertical flows are constrained by vertical hydraulic conductivity (Kz) values. Similarly, leakage from leaky artesian bores is considered to be catered for by Kz values.

An assumption made in our modelling is that the recharge rate as calculated by the Rushton model is considered to be correct. We have not included recharge as a parameter for optimisation.

STEADY STATE CALIBRATION

The PEST routine with singular value decomposition (SVD) (Doherty and Randall, 2010) was used to automate the model calibration process. Initial calibration runs were focussed on optimising preliminary horizontal (Kx) and vertical (Kz) hydraulic conductivity values. The purpose of this optimisation was to characterise the overall vertical anisotropy of each layer caused by the clay and peat aquitards, and to generate preliminary initial heads for the transient calibration. This was done in two phases:

1. Mean water levels from 18 NRC monitoring bores were used for were used for steady state targets. Static water levels from an additional 60 bores were used to guide conductivity values in regions of the model where no monitoring data were available. These targets were given a weighting of half that given to the monitoring sites.
   Constant values of Kx and Kz were used for each layer. Under this model structure, Kx is highly correlated to its corresponding Kz value for layers 2 and 3, and the objective function is most sensitive to Kx_2, Kz_2,

and Kx_3. This preliminary model run produced significant scatter in the calculated residuals, with a sum of squares error of 1,050 m, and a residual mean of 0.4 m. The largest residuals in the monitoring bores were from layer 3. It is clear from this preliminary model run that assuming constant Kx and Kz values is inadequate for simulating the observed groundwater levels, and that a variable hydraulic conductivity field is required to fit the modelled heads to the observations.

2. Complexity was included in the model by adding prior information and regularisation with pilot points. Kx and Kz targets were added to incorporate the revised aquifer test analyses. Pilot points for Kx were added to all three layers on a grid to generate a hydraulic conductivity field. Similarly, pilot points for Kz were added to layers 1 and 2, which were expected to be the layers most sensitive to vertical conductance.

TRANSIENT CALIBRATION

The preliminary steady state head and hydraulic conductivity distributions were used to establish the initial condition for transient model calibration. The transient numerical model was set up to cover the 27 year period of available groundwater level records, from January 1987 to December 2013.

Monthly stress periods were used to provide a good balance between temporal resolution and computational demands. Monthly stress periods do result in convergence issues within the model because of large changes in flux. To improve convergence the stress periods were divided into three time steps with a multiplier of 1.3 to improve stability and provide a good mass balance. This produces model outputs for the 1st, 8th and 18th of each month. Some difficulty was found establishing a suitable initial head distribution for the transient model, so the first year of the simulation is considered to give a lead in time for the model to reach equilibrium.

All of the available time series data were used for transient calibration. The approach taken has been to use all of the available data for PEST, which is a stochastic approach to modelling. It therefore makes more sense to use the entire dataset rather than split the data into calibration and validation datasets. SVD-assist was used to streamline the parameter optimisation process.

UNSATURATED FLOW

During transient calibration it was found that water levels could not be adequately simulated with saturated flow properties alone. Water level response to recharge is both delayed, and attenuated beneath the Holocene sand dunes, which suggests that the unsaturated zone is buffering the effect that land surface recharge has on groundwater levels.

To accommodate the effect of the unsaturated zone on mediating recharge, the UZF-1 package (Niswonger *et al.*, 2006) was employed within Modflow2005. The use of the UZF-1 package does mean that some recharge is lost from the unsaturated zone to shallow drainage and does not reach the aquifer water table. A comparison between the calibrated numerical model with the input recharge rates showed that average annual recharge was reduced by approximately one third in the UZF-1 package.

The spatial distribution of zones for unsaturated properties and also the specific yield of layer 1 were based on the main Quaternary units as shown on the Kaitaia Q-map sheet (Isaac, 1996).

Vertical hydraulic conductivity in the unsaturated zone was given the same value as that of the top saturated layer (Kz1), which enabled a partial incorporation of the unsaturated zone properties into PEST. The remaining parameters for the unsaturated zone were given properties suitable for the main surficial deposits, and altered on a trial and error basis. Table 4 shows the parameter values that were considered to give the best response in the model.

The Brooks-Corey exponent characterises pore-size distribution of the sediments. Typical values for sand are 3.5 to 4, and values are higher for fine-grained and more heterogeneous sediments. Evapotranspiration was only used in the soil moisture balance model, so a soil extinction depth was not required as an input for the UZF-1 package. Additional options used were an undulation depth of 2m and total of 10 trailing-wave and trailing-wave sets.

Table 4 Unsaturated zone properties used in the model

	Zone	Residual water content (ϑr)	Brooks-Corey exponent (ε)	Specific Yield
Loose dune sands	1	0.08	4	0.33
Consolidated dune sands	2	0.1	4.5	0.23
Clay and peat wetlands	3	0.25	6	0.001

CALIBRATION RESULTS

The model calibration results for the whole domain have a residual mean and absolute residual mean of 0.02m and 0.41m respectively, with a standard deviation of 0.54m. The model error could be improved with further parameter optimisation runs. However, a PEST optimisation run on the model's hydraulic conductivity values takes approximately one week to perform, so a balance has been made between model performance and timely reporting.

No groundwater model can perfectly predict water table responses, which results in a predictive error at any point in the model. For this reason, a margin of error is required to act as a safety buffer for any model scenario testing. Table 5 shows the predictive error at each site that was used as a target for model calibration. The standard deviations tend to be greater close to the flow divide, and decrease towards the coast. We suggest that the standard deviation of the predictive error would be a good safety margin for the prediction of water levels during scenario testing. For predictions at coastal locations where no observation data are available, 0.5m would be an appropriate, albeit conservative safety margin.

Table 5 Summary of the model predictive error for each site

Monitoring Site		Model Site		Predictive Error				
Bore Number	**Bore**	**Target Name**	**Layer**	**Mean**	**Std Dev**	**Min**	**Max**	**SSE**
200206	Hukatere 3	P4_Hukatere	1	-0.06	0.41	-1.07	0.95	17.2
200206	Hukatere 2	P13_Hukatere	2	0.06	0.35	-0.82	0.80	12.6
200207	Forest 3	P3_Forest	1	0.06	0.47	-0.72	1.55	22.8
200207	Forest 1-2	P11_Forest	2	0.11	0.33	-0.50	0.96	12.6
200208	Browne 3	P1_Browne	1	0.02	0.42	-0.63	1.61	17.8
200208	Browne 2	P9_Browne	2	0.05	0.29	-0.70	0.71	8.8
200208	Browne 1	P8_Browne	3	0.12	0.66	-1.62	1.90	45.3
200209	Burnage 4	P2_Burnage	1	0.01	0.37	-0.71	1.12	13.7
200209	Burnage 1-3	P10_Burnage	3	0.05	0.39	-0.97	1.24	16.3
200210	Waterfront 1	P17_Waterfront	3	-0.01	0.32	-0.81	0.68	10.6
200211	Paparore 3	P7_Paparore	2	-0.36	0.36	-1.17	0.70	27.0
200211	Paparore 1-2	P16_Paparore	3	0.35	0.69	-0.82	2.23	59.8
200214	Golf Ball	P18_Golf Ball	1	1.08	0.38	0.37	1.98	23.6
200226	Lake Heather P1-1	P5_Heather	1	0.22	0.73	-0.91	2.33	59.6
200227	Lake Heather P1-3	P6_Heather	3	-0.70	0.63	-2.08	0.67	87.1
201025	Sweetwater Nursery	P14_Nursery	2	-0.01	0.79	-1.15	3.27	118.8
201037	Crene	P12_Crene	3	0.23	0.49	-1.38	1.39	15.7
209581	Ogle Drive	P15_Ogle	1	-0.79	0.34	-1.41	-0.07	22.0

Plots of observed and predicted water levels are shown in Appendix 4, and the calculated water levels at August 2003 are shown in Appendix 3 for each layer. This date was chosen to be drawn because the predictive error is negligible for this date and groundwater levels were quite high so we can see more spatial definition. The dynamics of most sites has been captured quite well by the model, although there are obvious exceptions at the Lake Heather and Forest sites. The deep Burnage piezometers (1-3) did also not calibrate well, although as previously mentioned it is possible that this bore is leaky and is not providing true head measurements in the deeper piezometers.

The numerical model is constructed as a regional scale model. Because of its scale and the coarseness of the grid, the model is not expected to exactly simulate local changes in groundwater levels, but is intended to simulate the flow field as a whole. However, despite its scale, the calibrated model does characterise the dynamics of the system quite well. In particular, very good model fits are found in the northern well array at Houhora.

Poorer fits are found further south at the Paparore and Lake Heather sites, and to a large extent these misfits are caused by the use of uniform storage coefficients to represent the main geological units. In the case of Paparore, uncertainty in the storage coefficient may be compounded by an overestimation of the pumping demand in this area. In the case of Lake Heather, the model has difficulty simulating the dynamics of the long-term drainage and recharge response, particularly the observed lag time in the recharge response.

Scrutiny of the observed shallow groundwater levels shows that there is a diverse range of responses to recharge, indicating that shallow vertical flow can be quite variable at a local scale. It has been difficult to simulate this variability consistently for every site with the unsaturated flow package, which requires zones of constant value to be set for residual water content and the Brooks-Corey exponent. There appears to be more variability within the shallow sands than can be accounted for by the three zones that were used for the model UFZ-1 package.

The model is suitable for its intended purpose of assessing the impact of the current allocation at a regional scale, and the setting of provisional management limits within proposed allocation zones. The model does not have sufficient detail to enable an assessment of the impact of individual abstractions, or to derive more refined allocation limits for specific zones. We recommend that individual zones be reviewed in the future if the demand approaches the provisional groundwater management limits. This can be done with more detailed modelling of the zone in question, perhaps by telescopic mesh refinement and by extracting boundary conditions from the regional scale model.

Areas where the model is less reliable are on the periphery, where there is inadequate data to constrain the aquifer structure, groundwater levels, and hydraulic properties. These areas are north of Houhora, and in the southern Awanui and Ahipara areas. Further field investigations are required to better constrain the model in these areas.

OPTIMISED AQUIFER PROPERTIES

In addition to the specific yield values for layer 1 shown in Table 4, uniform storage coefficients were applied to layers 2 and 3. The specific storage for layer 2 (leaky-confined sand) was optimised to a value of 0.0005. This value is consistent with values observed in deeper aquifer tests. The storage coefficient was not found to be very sensitive in layer 3 (shellbeds). This is consistent with our conceptual model, which predicts that most of the storage from pumping is derived from the overlying sands. Layer 3 was given a storage coefficient of 0.0007 to ensure consistency with layer 2.

Hydraulic conductivity values changed significantly from their steady state values during transient calibration due to the influence of the UZF-1 package. As previously mentioned, hydraulic conductivity values were optimised as a hydraulic conductivity field using PEST with pilot points. Pilot point bounds were given a large range so as not to overly constrain the parameter optimisation, and to incorporate the effects of heterogeneity.

A cumulative percentage of optimised hydraulic conductivity values are shown in Figure 13. The resulting curves portray what we would expect for the proposed conceptual model. Vertical hydraulic conductivity values have a much larger spread than the horizontal, and values in the deeper sandy sediments (layer 2) are the most consistent (the smallest range). Values in the shellbed horizon are considerably larger overall, as we would expect for the main productive sediments in the aquifer. The extreme values have tended to settle on hydraulic conductivities set by the pilot point bounds. However, the mean values are very similar to values determined by aquifer tests (Table 2), with an overall anisotropy ratio of about 10:1.

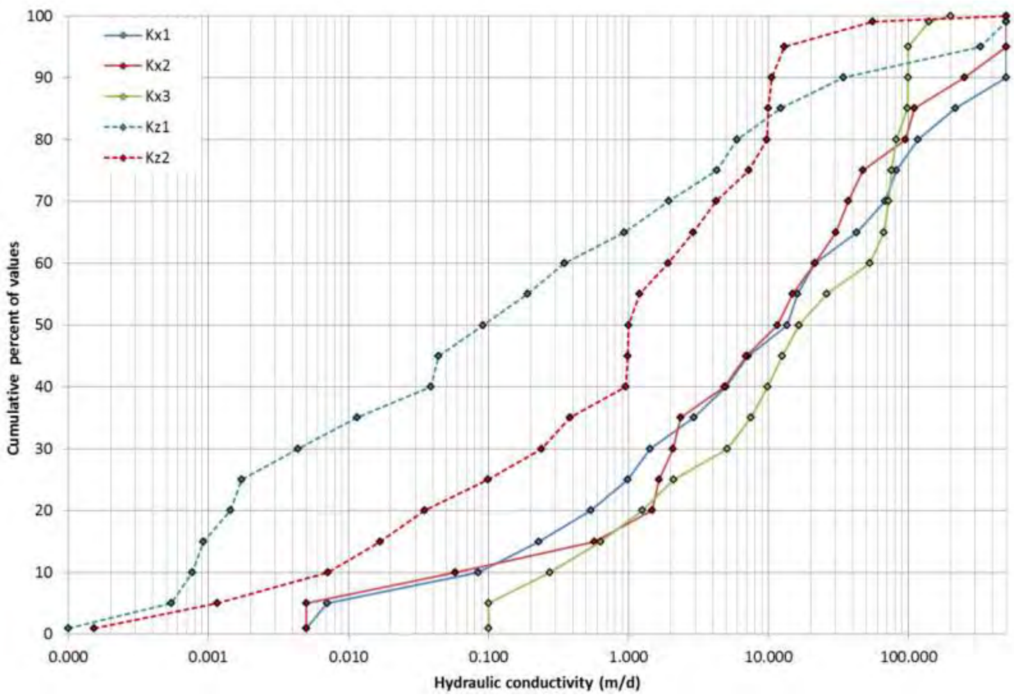

Figure 13 Cumulative percentage frequency plot of optimised hydraulic conductivity values

PARAMETER SENSITIVITY

Parameter sensitivity forms a part of the PEST optimisation routine, so the sensitivity of each parameter can easily be drawn from the PEST output file. This was done in two phases, one PEST run to determine values from the variable hydraulic conductivity fields, and a second run to determine sensitivities of the uniform values attributed to storage coefficients.

Figure 14 shows the sensitivity distribution for the optimised parameter values. The model is most sensitive to the specific yield of the dune and cemented sands of layer 1. The model is fairly insensitive to the specific yield of the unconfined clay sediments, and also the storage coefficients of the confined system. Surprisingly the model is more sensitive to horizontal hydraulic conductivity in the shellbed layer, and is less sensitive to the vertical hydraulic conductivities.

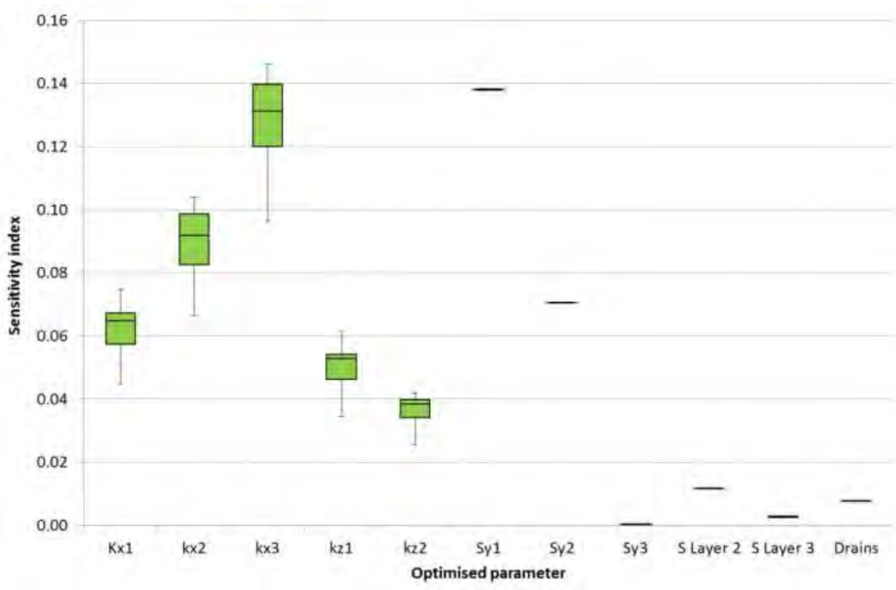

Figure 14 Optimised parameter sensitivity for the calibrated model

MODEL MASS BALANCE

The transient mass balance predicted by the numerical model is shown in Figure 15. Because the mass balance in Figure 15 is for the entire Aupouri Aquifer it deals with very large values, so the fluxes are expressed in units of million m^3/day (Mm^3/d). The annual average land surface recharge to the water table for the whole model domain is 262 Mm^3, while the annual pumping volume is 8.67 Mm^3, which is 3.3% of total recharge.

The mass balance is overwhelmingly dominated by land surface recharge, changes in aquifer storage, and offshore discharge. The pumping component is minor, although this does not preclude that it may be a significant component of the mass balance at a local scale. The model error is very small for each time-step, the largest error being 0.02% of the total inflow.

During dry periods the aquifer relies on aquifer storage and delayed recharge to supply well abstraction demand and maintain coastal discharge. The response to the prolonged dry period during the 1990s is particularly evident in the modelled land surface recharge predictions. This dry period resulted in markedly less offshore discharge than at other times.

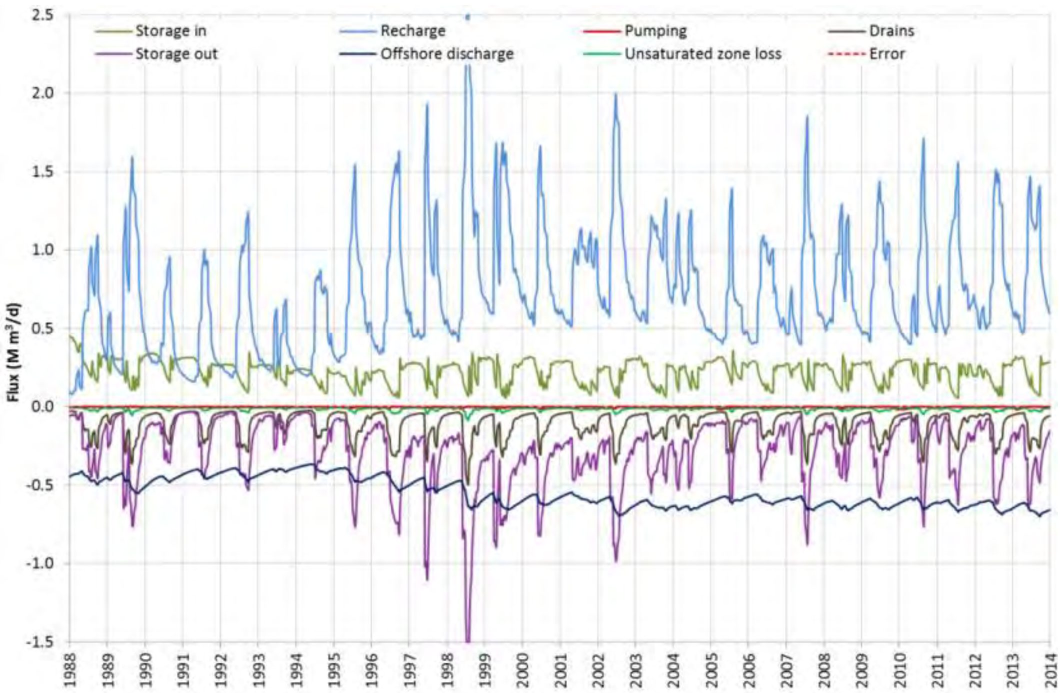

Figure 15 Daily Mass-balance of the Aupouri Aquifer as calculated by the numerical model (Mm^3/day)

PREDICTIVE SCENARIOS

A number of predictive scenarios were agreed upon in the scope and nature of services for this project. Some of these can be addressed in a quantitative manner by using the numerical model for scenario testing. Other environmental concerns can only be addressed qualitatively at this stage because data is not available for an adequate quantitative assessment to be made.

AQUIFER SUB-REGIONS

This section assesses the effect of the distribution of existing groundwater allocation on the freshwater resource. The aquifer has been divided into allocation sub-zones to assist in accounting. A number of factors were considered in developing these aquifer sub-region zone boundaries, including:

- Confined aquifer flow divide as calculated by the numerical model
- Cross-boundary flows between zones
- Location of existing coastal monitoring sites (Houhora and Waipapakauri Beach)
- Location of proposed coastal monitoring sites
- Clustering of groundwater consents
- Clustering of coastal domestic bores
- Locations of dunes and wetlands (local surface flow divides)
- Presence of forest or native scrubland (areas of little potential groundwater demand)

The existing distribution of groundwater consents shows that they tend to be clustered in a number of distinct zones. Figure 16 is a map showing the locations of existing consents, the existing monitoring network, as well as the recommended sub-regions and coastal monitoring sites used for scenario testing in the numerical model. The recommended zones have been placed into the numerical model for the purpose of calculating the approximate mass balance within each zone.

A monitoring threshold has been placed within each sub-region or zone for the purpose of observing drawdown at the coast during scenario-testing. It is recommended that these monitoring positions and thresholds be adopted for management and monitoring of the effects of pumping on the aquifer.

Proposed monitoring sites have been located where potential movement of the seawater interface may cause problems. For example, in the Houhora area there is a concentrated cluster of groundwater consents, mostly for the irrigation of avocados. This area of high groundwater demand is located up-gradient of the coastal Houhora community, which relies on groundwater for its drinking water supplies. It is important in this area that the allocation of groundwater consents does not induce saline water inwards towards these coastal water supplies.

The current NRC monitoring network as outlined in Table 6 shows that four of the nine groundwater zones have an NRC monitoring bore of some kind. This network could be greatly improved upon, since water quality samples are only taken on a quarterly basis. The installation of conductivity sensors in areas of high pumping demand would provide considerably more information about changes in salinity. Water levels could also be measured in water quality monitoring sites prior to sampling where this is possible.

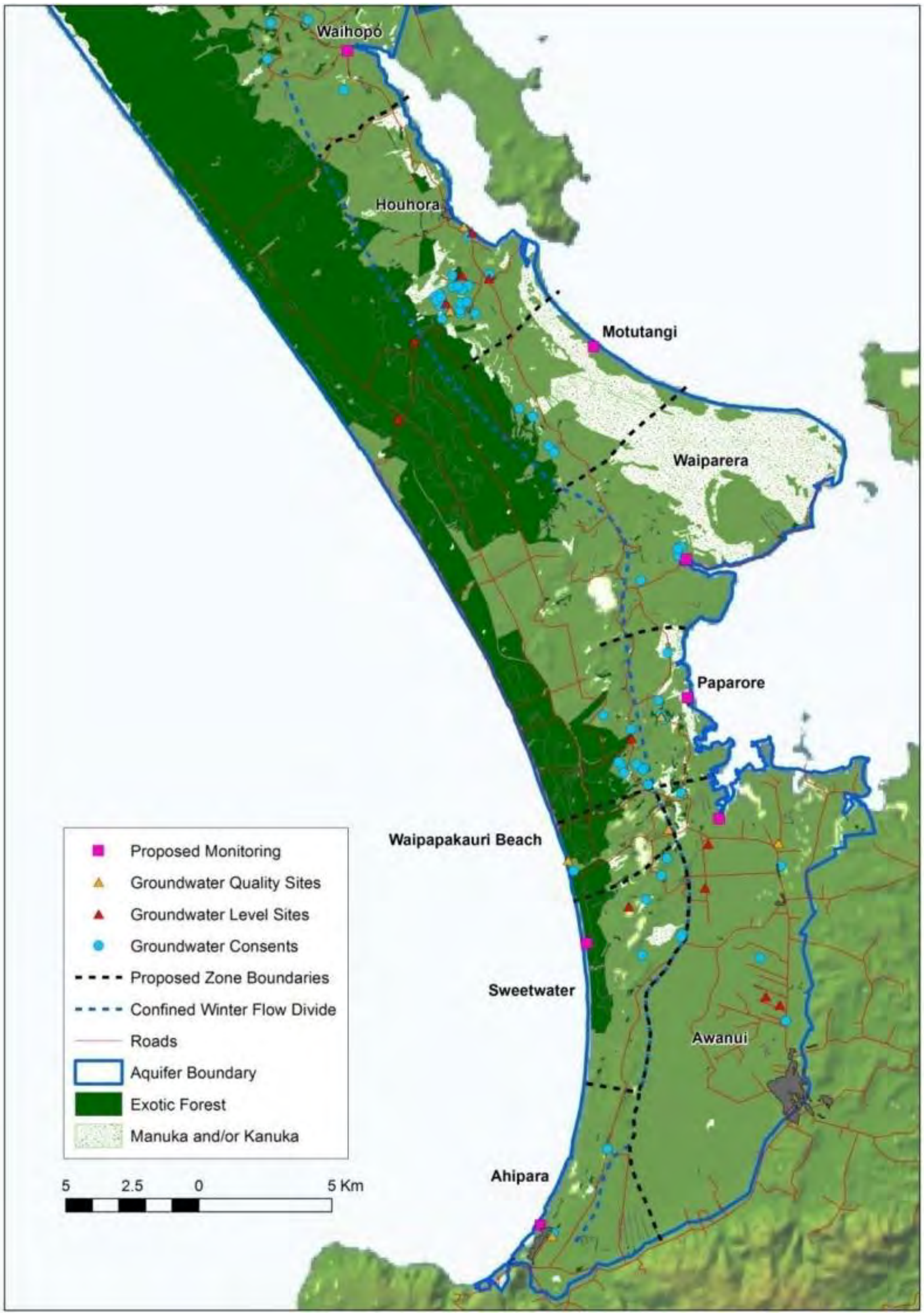

Figure 16 Location of existing groundwater consents, monitoring network, proposed monitoring, and proposed aquifer sub-regions

There is a tendency for water quality monitoring to focus on the shell-rich marine sands found at the base of the aquifer. These sediments are where the majority of production wells are screened. However, some domestic supply wells are drilled to shallow depths because they do not require the high yields that the shellbeds provide. It would be prudent to have some monitoring within these shallow dune sands at Houhora for the purpose of ensuring domestic supplies are not affected by seawater intrusion. Table 6 also summarises the existing groundwater consents, which have been sorted according to these identified aquifer sub-regions. Existing NRC monitoring bores have been identified where they exist in a zone (WL= groundwater level monitoring, WQ=groundwater quality monitoring).

Table 6 Current consented groundwater allocation by aquifer sub-region, and approximate land surface recharge volumes

Zone	Area (ha)	Consents	Allocation (m^3/d)	Allocation (m^3/year)	Monitoring Bore	Recharge (m^3/year)	% recharge allocated
Waihopo	5,307	5	710	148,320	-	8,521,629	1.7
Houhora	4,054	20	5,106	783,448	200210 (WL), 200250 (WQ)	19,946,675	3.9
Motutangi	3,017	4	1,036	161,120	-	10,696,583	1.5
Waiparera	5,403	5	1,800	226,600	-	23,122,982	1
Paparore	2,123	14	8,046	1,066,420	200211 (WL,WQ)	10,821,694	9.9
Waipapakauri	1,160	1	30	10,950	209330 (WQ)	5,964,031	0.2
Awanui	9,349	4	944	106,010	201563 (WQ)	38,670,081	0.3
Sweetwater	2,433	5	20,751	4,069,633	-	13,357,410	30.5
Ahipara	2,335	2	303	98,567	-	7,687,883	1.3
Total	**43,655**	**60**	**38,726**	**6,671,068**		**138,788,968**	**4.8**

EXISTING ALLOCATION

ENVIRONMENTAL CONSTRAINTS

From a mass balance point of view, the main constraint on water abstraction is volume of land surface recharge, which is the only source of inflow to the Aupouri Aquifer. This determines the volume of water that is available for each of the discharge components of the system, including pumping. However, it is also important to consider local environmental constraints, because pumping effects can cause nearby issues regardless of the proportion of recharge that is allocated for pumping (e.g. saline intrusion, land subsidence). Therefore, an appropriate, allocation for the Aupouri Aquifer involves setting a limit that considers both the available recharge, and the environmental effects that pumping may have.

The main environmental constraint on groundwater allocation in the Aupouri Aquifer is the presence of the sea. If bores are pumped beyond an aquifer’s safe yield, seawater can be drawn into the pumped bores, or other bores located along the coastline.

SEAWATER INTRUSION

Groundwater from coastal aquifers discharge offshore, either as seepage along the coastline or as submarine springs. Fresh water is less dense than seawater, and because of this characteristic, it naturally forms a fresh water lens or layer on top of the heavier saline groundwater derived from the sea. The zone in which the salt and freshwater layers meet is known as the seawater interface. The interface is usually not a sharp boundary, but consists of a mixing zone.

The density difference between the two layers means that the underlying saltwater lens can naturally extend inland of the coastline along the base of a coastal aquifer. The lateral position of the interface depends on a number of factors, including the density, viscosity, and temperature differences between salt and freshwater, coastal groundwater levels, aquifer depth and layering, and the rate of offshore groundwater flow. If coastal groundwater levels are lowered too far, or if offshore flow is overly-reduced, the position of the seawater interface will respond by moving inland and upwards. This phenomenon is known as seawater intrusion, and is extremely undesirable because it is so difficult to reverse the saline contamination of water supplies. The salinity of sea water is 35,000 mg/l, whereas groundwater in the Aupouri Aquifer has salinities less than 250 mg/l. A mixing of just 1.2% sea water would be enough to render groundwater unpalatable. For this reason, a conservative approach to assessing the potential for seawater intrusion is advised.

This position of the seawater interface has not been observed along the coast of the Aupouri Aquifer. Data from monitoring bores indicate show that chloride concentrations are low, and quite stable (Figure 7). This is evidence that the freshwater lens may extend for some distance offshore under existing pumping conditions.

The objective of a sustainable groundwater allocation in a coastal aquifer is to ensure that saltwater intrusion does not result in reduced groundwater quality. In Northland, consent conditions are usually placed on groundwater abstractions near the coast that might contribute to seawater intrusions. These conditions are normally stated as "To prevent saline contamination, the Regional Council reserves the right to require the Consent Holder to cease the taking of groundwater from any or all the bore/s at such times as the chloride concentration in water delivered by any of the bores is measured by standard methods to be greater than x mg/l." Where 'x' in this condition is either 200, 220 or 250 mg/l, depending on the location if the abstraction point (Callander *et al*. 2011).

The placement of salinity conditions on consents holders is a good practice. It is also important to consider that this type of approach is not 'self-regulating' because the consent holder may not be the only party affected by their pumping. We therefore recommend that individual consent conditions be supplemented with conditions that relate to strategically placed coastal monitoring bores within identified groundwater management zones. This approach has been adopted in other coastal aquifers in Northland.eg Russell.

FULL ALLOCATION ASSESSMENT

To date there have been no recorded occurrences of seawater intrusion in the Aupouri Aquifer. While this is reassuring, it is also expected that many water users are not currently using their entire allocation. Meter data of water use are not available, so estimates of abstraction demand have been made with the soil moisture balance model. The results indicate that the average annual demand is approximately 56% of the consented total for pasture, and 48% for avocados. This proportion varies between seasons and water users, however it is fair to say that there is potential for increased water demand amongst existing consent holders, particularly during prolonged dry periods.

This scenario tests whether the current total allocation can be sustained if it all consented and permitted takes were to be fully exercised. The assumption made for this assessment is that the historical aquifer recharge rates will be similar to the future. In making this assumption we can use the historical record, as characterised by the calibrated model, to simulate future increases in demand.

Our original intention was to predict movement of the seawater interface in response to pumping demand using the SEAWAT Version 4 package (Langevin *et al.* 2008) within our Modflow model. However, during our model calibration it became apparent that the flow in the unsaturated zone above the aquifer plays a large role in aquifer recharge dynamics. Unfortunately, the UZF-1 pacakge is not currently compatible with the contaminant transport package MT3DMS, which is required to run SEAWAT. We have therefore changed our approach to assessment of the groundwater resource by considering that sustainable aquifer use should meet two key environmental criteria:

1. Groundwater levels should be maintained above the critical thresholds predicted by the Ghyben-Herzberg principle to ensure there is no seawater intrusion
2. Groundwater flows should not be reversed across the coastal boundary (there should be no positive constant head boundary fluxes)

The Ghyben-Herzberg principle is a simple relationship that predicts the position of the seawater interface, assuming a static groundwater system that is in hydraulic connection with the aquifer. The assumption of a static aquifer is a reasonable assumption for the Aupouri Aquifer because recharge pulses are attenuated with depth, so the small volume of offshore flux which does travel through the confined sediments will be fairly constant. The assumption of a hydraulic connection is perhaps less tenable because the aquifer is layered and strongly anisotropic, having a vertical hydraulic conductivity which is considerably lower than its horizontal value. However, the Ghyben-Herzberg approximation will provide a conservative estimate for a suitable aquifer level at the coastline, and a conservative approach is recommended for ensuring saline intrusion does not occur.

The Ghyben-Herzberg principle states that the position of the seawater interface is determined by the density ratio between salt water and fresh water. Densities for these two waters are commonly reported as 1,250 Kg/m^3

and 1,000 Kg/m^3 respectively. Using these densities in the Ghyben-Herzberg equation calculates that if the freshwater table is 1 metre above mean sea level the fresh/saltwater interface will be 40 metres below sea level. The minimum groundwater level required to maintain the interface offshore can be calculated if the depth to the base of the aquifer is known.

Table 7 shows the calculated thresholds made at key coastal locations within each of the proposed groundwater zones. These are the minimum groundwater levels required to ensure the seawater interface does not move inland of the coastline. Model threshold values have also been shown, and these values include the standard deviation of the model predictive error from Table 5. The threshold locations shown in Table 7 were determined by increasing pumping rates in the model, and identifying where the onset of saline intrusion is most likely to occur. It is recommended that coastal monitoring be carried out at these sites if the allocation starts to approach its proposed safe yield.

It is important to recognise that we can only have confidence in the model's predictions in areas where data is available to constrain the calibration. For five of the groundwater zones we consider the model to be poorly constrained due to a lack of available data, and we do not recommend that the model be used for predictive purposes within these zones. The level of confidence in the predictive ability of the model has been indicated in Table 7.

Table 7 also shows predictions of groundwater levels at the key threshold locations for the sub-regions where there is sufficient information to have some confidence in the model predictions. These predictions were made using the numerical model under a full allocation scenario, which consisted of all irrigation consents pumping at their maximum rate from Nov-April (six months), and industrial, stock and water supply consents pumping at their maximum all year. Stock and domestic supply bores were pumped at 5 and 1 m^3/d respectively throughout the year. This gives an additional permitted activity use of 289,460 m^3/y for the whole aquifer.

The predicted groundwater levels are shown as a map in Appendix 5. All groundwater levels remain above sea level for this scenario, and there is no reversal of groundwater flow across the coastline boundary (no constant head inflow).

Table 7 Coastal thresholds at key points within each groundwater zone, and the predicted level at full allocation

Location	E	N	Aquifer base	Threshold (m)	Model threshold (m)	Confidence	Full allocation level (mamsl)	Freeboard (m)
Waihopo	1606830	6153780	-30	0.75	1.25?	Low	2.2	-
Houhora (200210)	1611712	6146689	-76.4	1.91	2.2	High	3.8	1.6
Motutangi	1616290	6142240	-99	2.47	3.0?	Low	0.2	-
Waiparera	1619720	6134490	-66.7	1.66	2.2?	Low	4.7	-
Paparore	1619720	6129430	-28.6	0.71	1.1	Mod	2.0	0.9
Waipapakauri (209330)	1615319	6123074	-75.4	1.88	2.4?	Low	4.4	-
Sweetwater (210527)	1616374	6119055	-72.5	1.81	2.3	Low-Mod	3.9	1.6
Awanui	1621400	6124500	-25.3	0.63	1.1	Mod	2.4	1.3
Ahipara	1613260	6108310	-35	0.87	1.4?	Low	1.5	-

Groundwater levels also remain above the thresholds calculated by the Ghyben-Herzberg approximation with the exception of Motutangi. This area has a low hydraulic gradient, and the projected deep aquifer base in this area gives a high sea water intrusion threshold level using the Ghyben-Herzberg approximation. As a result, groundwater levels at the recommended Motutangi monitoring site do not meet the threshold groundwater water levels during model calibration. We interpret this to be an artefact of the model since there is insufficient information to constrain the aquifer structure and hydraulic properties, or to characterise groundwater levels in this area. While the low predicted water levels are not a cause for immediate concern, the relatively flat hydraulic gradient and deep aquifer base do indicate that the Motutangi area is an area of potential risk for seawater intrusion. It is recommended that further investigations be carried out prior to further allocation in the Motutangi sub-region.

RECOMMENDED AQUIFER MANAGMENT LIMITS

MANAGEMENT LIMITS FOR AVOIDING SEAWATER INTRUSION

We have used the numerical groundwater model to estimate the aquifer management limits for sub-regions where we have confidence in the model's predictive capability based on the existing arrangement of abstraction bores. It is considered that this approach is more sensible than trying to guess the locations of future abstractions. The maximum safe pumping rate is calculated by increasing the allocation in the model by a factor until either the sea water intrusion threshold shown in Table 7 has been reached (potential limit), or sea water is drawn into the model (reversal of constant head flux).

The model can also be used to give an indication for suitable management limits in areas where there is little information, or where the model is less well constrained. In areas where there is little information, some guidance for setting allocation limits is currently given by Section 5.1.1 of the National Environmental Standard (NES) on ecological flows and water levels (MFE, 2008b). The proposed allocation limits in these guidelines are:

- For shallow, coastal aquifers (predominantly sand): 15% of the average annual recharge as calculated by the regional council
- For all other aquifers: 35% of the average annual recharge as calculated by the regional council

These two land surface recharge thresholds of 15% and 35% are useful measures for comparing the modelled limits, particularly in areas where there is little information to constrain the model.

Table 8 shows the results of the aquifer sub-region safe yield assessment as annual volumes (m^3/y) and as a percentage of average annual land surface recharge (%LSR). The modelled limits shown in Table 8 are the most that each sub-region could be pumped without drawing groundwater levels below the suggested threshold values, or inducing seawater into the aquifer. A map of the resulting groundwater levels is shown in Appendix 6.

Table 8 Modelled and recommended management limits for proposed sub-regions of the Aupouri Aquifer

Zone	Current allocation (consented & permitted)		Modelled limit		Recommended limit		Comments
	m^3/y	% LSR	m^3/y	% LSR	m^3/y	% LSR	
Waihopo	166,435	2.0	2,799,766	33	1,278,200	**15?**	Water level threshold reached at 33%, little information for area
Houhora	827,310	4.1	2,141,278	11	2,141,300	**11**	Water level threshold reached at 11%, model well constrained
Motutangi	176,758	1.7	1,606,613	15	1,069,600	**10**	Low lying area, little information for area
Waiparera	266,124	1.2	712,961	3.1	2,312,200	**10?**	Low lying area, little information for area
Paparore	1,025,727	9.5	3,845,640	36	3,787,500	**35**	Water level threshold reached at 36%, model well constrained
Waipapakauri	17,119	0.3	1,261,281	21	1,192,800	**20?**	Seawater drawn in above 21%, model not well constrained
Awanui	209,922	0.5	4,640,978	12	4,640,400	**12**	Threshold unresponsive, seawater drawn into Ahipara at higher allocation
Sweetwater	4,054,527	30.4	4,658,983	35	4,675,000	**35**	Limit to 35%, model not well constrained at Lake Heather
Ahipara	112,721	1.5	922,218	12	922,500	**12**	Vulnerable to seawater intrusion, little information for area

The results of the modelling indicate that overall, the aquifer is currently not being utilised to its full potential. The sub-region or zone with the highest allocation as a percentage of recharge is Sweetwater, which is close to the 35% guideline of the NES. Aquifer properties are constrained with less confidence in this area due to the difficulty in simulating groundwater levels at the Lake Heather monitoring bores. This has resulted in rising groundwater levels in the Sweetwater and Waipapakauri Beach sub-regions of the numerical model. The most likely reason for this is that the unsaturated zone hydraulic properties and also the aquifer storage coefficients in these areas differ from those in the rest of the Aupouri Aquifer. The values shown in Table 8 for these two areas should be treated with caution.

The pattern of drawdown caused by pumping in the model is influenced by the arrangement of existing wells, and local aquifer structure and properties. Perhaps the most influential factor is the distribution of sand dunes, since groundwater storage in these dunes provides the driving head to maintain higher groundwater levels and a steeper hydraulic gradient towards the coast. Scrutiny of the modelled limits shown in Table 8 indicates that areas with fewer sand dunes (e.g. Motutangi, Waiparera, Awanui and Ahipara) have a lower ability to sustain higher pumping demand. These areas have sustainable allocations that are less than the 15% of annual recharge recommended by the NES. Areas with more sand dunes (e.g. Paparore and Sweetwater) have a greater volume of groundwater storage above sea level, and these areas have the potential to sustain more pumping demand, perhaps up to the 35% guideline value recommended by the NES.

The model does show that the southern sub-regions of the Aupouri Aquifer show strong evidence of cross-boundary pumping effects. The main reason for this is that the Waipapakauri Beach, Awanui, Sweetwater and Ahipara zones collectively straddled the groundwater flow divide that runs through the middle of the aquifer. This means that an increase in pumping within one of these zones tends to affect groundwater levels in the adjacent zones. For example, it was found that an allocation of 15% of land surface recharge was not feasible for both the Awanui and Ahipara sub-regions without drawing seawater into the Ahipara coastline.

The management limits proposed here are intended to be interim limits for the purpose of avoiding saline intrusion. If allocation beyond these interim limits is made in any the proposed sub-regions, we recommended that additional work in the form of more detailed modelling be carried out. More refined modelling is particularly important in areas where there is less information, or where our model is poorly constrained. Given the severity of seawater intrusion as a threat to water quality, it is also prudent to be conservative, and the recommended management limits shown in Table 8 should be considered as maximum values until better information becomes available, and should be paired with coastal monitoring sites.

LAND SUBSIDENCE

Land subsidence resulting from groundwater abstraction could potentially occur in two ways:

1. If organic soils or peat deposits are drained, they can become oxidised, lose buoyancy, and shrink. Of these three processes, oxidation is of most concern for subsidence because the loss of organic material is irreversible.
2. When water is withdrawn from a confined aquifer, some of the water is provided by the elastic expansion of water, which is very slightly compressible. This is known as elastic storage. Any loss in pressure is compensated for by a reduction of the aquifer porosity by compaction. The compressibility of fine-grained sediments such as clay or silt is greater than that of coarser sediments such as sand. The sediments that host the Aupouri Aquifer are an alternating mix of silt and clay with low storage coefficients and coarser grained sand and shellbeds, with higher storage coefficients. This combination may result in some compaction of the aquifer matrix, particularly in areas where there are thicker deposits of clay and peats coincide with areas of significant depressurisation.

Compression resulting from the drainage of organic material only applies to sediments located above or near to sea level. Most of these areas are already low-lying, because they constitute the wetland areas that formed when the sea level stabilised to its present position around 6,500 years ago. Consequently, many of these areas such as the Kaitaia swamp are already drained because of their high water table. If subsidence is significant in these organic horizons, it would most likely have already occurred due to the existing drainage networks.

Perhaps of more concern because of its uncertainty is subsidence resulting from depressurisation and compaction. At this stage, we have little knowledge about the compressibility and abundance of different materials within the aquifer. To get an indication of the potential for compaction would require a geotechnical engineer to take undisturbed samples of some of the finer materials from a borehole in order to assess compressibility under different pressures in a laboratory test.

LEAKY ARTESIAN BORES

Many of the drains within the Awanui area are thought to intercept old artesian bores that have corroded and become leaky. In 2007 NRC commissioned a study to determine the impact that these bores have on the Aupouri Aquifer (SKM, 2007).

The Awanui study consisted of a detailed Modflow model at a 100 to 200m grid resolution. Leaky bores were simulated in the model by placing drain cells in the shellbed layer at locations where leaky bores were thought to occur. Leakage would then occur at these model cells when water levels rose above ground level. The model predicted that, on average, 4,865 m^3/d would be discharged through these leaky bores, which is about 6% of the recharge over the model domain. Variability of groundwater levels throughout the year is quite low, so discharge through the leaky bores would only fluctuate by 30% of the average value.

One of the main limitations of the study was an understanding of the number and locations of leaky artesian bores in the area. The results of the study were reported to be indicative only until further data on bore locations become available.

Leaky bores have not been included in this report because of the uncertainty in their location and total discharge volume. Also, this study differs from the Awanui model in that it is of a regional nature in both its scale and resolution. However leaky bores could be included within the current model if there was more certainty about their number and location.

CLIMATE CHANGE PREDICTIONS

Predictions of climate change at a national and regional level have been carried out by NIWA (Mullan *et al*. 2005, MFE, 2008). Climate projections for New Zealand were derived by the statistical downscaling of a number of global climate models, and these were downscaled further to generate predictions at a regional level. The results of this downscaling indicate that Northland's annual temperature is expected to increase 0.9°C by 2040, and 2.1°C by 2090 (MFE, 2008).

RAINFALL PREDICTIONS

Figure 17 shows the predicted future variability in annual rainfall across New Zealand. These predictions are based on downscaled precipitation changes for the twelve best global climate models, re-scaled to match the IPCC global warming range for six indicative emission scenarios (MFE, 2008). It can be seen that Northland is expected to behave similarly to much of the east coast of New Zealand, and will become drier as the global temperature rises, particularly the far north.

Table 9 shows the expected future change in rainfall at Kaitaia with the lower and upper limits of the predictions shown in brackets (MFE, 2008). Annual rainfall is expected to decrease by approximately 3% by 2040 and 6% by 2090 with most of this reduction occurring in the winter and spring. Summer rainfall may increase slightly, however a previous, more detailed report does predict an increase in future drought risk for Northland (Mullan *et al.* 2005).

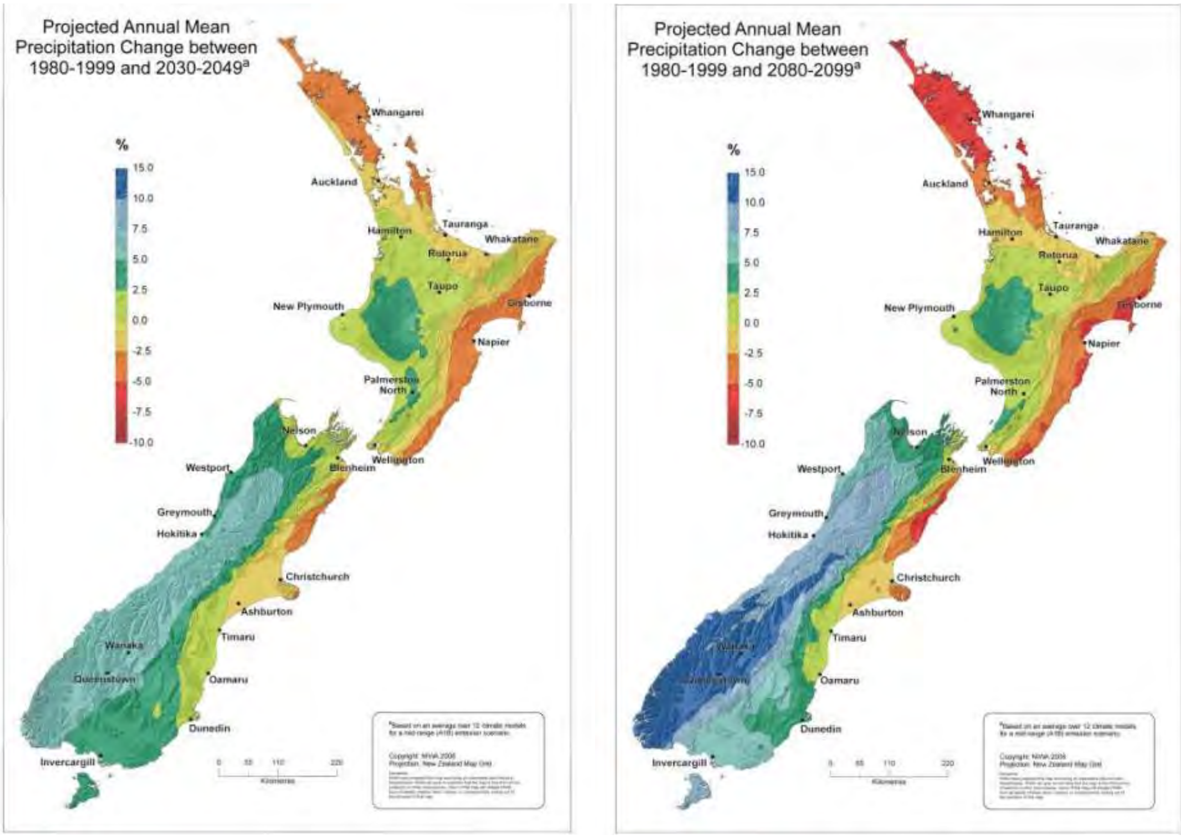

Figure 17 Predicted future change in precipitation for New Zealand[2]

While the climate models predict a drier future climate for Northland in the future, we can also expect more extreme events. For every degree of warming, the atmosphere can hold 8% more moisture. Rainfall is expected to become considerably more variable, with individual events becoming less frequent but more intense, particularly those associate with ex-tropical cyclones. Drought events are likely to become more common and more intense.

Table 9 Projected percentage change in seasonal and annual rainfall at Kaitaia (MFE, 2008)

Period	Summer	Autumn	Winter	Spring	Annual
1990-2040	1 (-15, 20)	0 (-14, 16)	-5 (-23, 1)	-6 (-18, 4)	-3 (-13, 5)
1990-2090	-1 (-26, 21)	-3 (-22, 11)	-8 (-32, 2)	-11 (-33, 8)	-6 (-22, 5)

The expected impact that the predicted climate changes will have on the Aupouri Aquifer is a slight increase in recharge during the winter and spring period because of the increase in rainfall intensity. However, the predicted increase in dry weather will mean that there is less recharge occurring during the spring and autumn. This will result in a net loss in aquifer recharge.

There will also be an increase in demand in the future because of higher temperatures and evapotranspiration rates, and less frequent rainfall events during summer and autumn. This increase applies to existing consent holders, but there is also likely to be additional water demand as landholders that don't currently irrigate apply for consents. A drying of the climate is also likely to increase the length of the irrigation season, and we can expect an increase in the length of the shoulder seasons, as well as the demand within those shoulder seasons.

In theory it is possible to make quantitative predictions about the influence that climate change will have on groundwater resources. To do this would require either the generation of generic synthetic rainfall and

[2] Source: NIWA: https://www.niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios

evapotranspiration records, or the application of corrections to historical datasets. These records could then be used as input datasets for our soil moisture balance model to estimate groundwater recharge and irrigation demand. However, guidance on generating region-specific records for predicting future rainfall intensity and frequency are not yet available for New Zealand let alone for specific regions. More generalised regional-scale predictions are currently the best information we have available, so any assessment of future climate impacts on groundwater resources can only be made at a qualitative level.

SEA LEVEL RISE

One factor that can be incorporated in our groundwater flow model in a quantitative manner is the impact of rising sea level. The Fifth IPCC Assessment Report estimates a global mean sea level rise of 0.60 (0.42 to 0.80) m by 2100 relative to 1986–2005, and 0.57 (0.40 to 0.76) m by 2090–2099 relative to 1990 (IPCC, 2013).

A change in sea level is expected to have two main impacts on the Aupouri Aquifer. Firstly, it will move the position of the saline interface further inland. The second impact that sea level rise will have is to raise the hydrological base level of the entire freshwater system by increasing water levels at the coastal discharge points. This has the effect of raising the water table, thereby increasing the extent of wetland areas and raising water levels in streams and drains. During wetter periods this has implications for flooding, and the discharge efficiency of existing watercourses and drainage networks. During drier periods, there will an increased risk of saline water encroaching further inland via the same water courses.

A third impact of sea level rise is for seawater or brackish estuarine water to extend further up the tidal range of rivers and estuaries. In some instances, the introduction of saline water has the effect of inducing the infiltration of salty water into fresh groundwater supplies. The study of this kind of impact requires detailed surveys of coastal estuary and stream bed levels, and is not feasible at the resolution of modelling carried out for this study.

A sea level rise scenario was tested in the numerical model by raising the constant head boundary to 0.57m. This rise was also added to the depth of the aquifer base for each of the coastal monitoring sites to adjust the Ghyben-Herzberg thresholds, although this makes very little difference to the threshold values. Additional demand was included by pumping the full allocation, and the irrigation season was extended from October to April to account for drier conditions.

The resulting groundwater levels for the sea level rise scenario are shown in Appendix 7. The results of the modelling predict that sea level rise will have no impact on the integrity of existing groundwater supplies. The model predictions show that raising the constant heads simply raises groundwater heads in the aquifer. There is no reversal of flow across the sea boundary, and groundwater levels are maintained above the coastal threshold levels (with the exception of the previously discussed Motutangi sub-region).

RECOMMENDATIONS

MANAGEMENT RECOMMENDATIONS

The aquifer is currently being used in a sustainable manner. The results of this study indicate that the aquifer is receiving recharge well in excess of its pumping demand. The aquifer is also fairly robust, as it has a large volume of storage to draw upon.

However, this does not mean that the aquifer is not vulnerable to being over-pumped. Because it has formed as a tombolo, the Aupouri Aquifer is long and narrow, and there is nowhere in the aquifer that is far from the coastline. This means that pumping impacts can affect the seawater interface at a local scale, which makes it a challenge to monitor and sustainably manage the aquifer.

Fortunately, the locations of domestic wells and existing consents are clustered into quite distinct areas. It is recommended that the aquifer zones and monitoring site thresholds that have been proposed in this report be adapted for monitoring and management purposes. In the short term, new coastal monitoring sites are recommended firstly at Paparore and Waihopo. A threshold and water level recorder should also be placed at Houhora.

Groundwater allocation management limits for each aquifer sub-region have also been proposed in Table 8 of this report, and it is recommended that these limits be adopted until better information becomes available within individual zones. In particular, it would be prudent to conduct more detailed zone-specific future resources investigations followed by more detailed modelling in the areas of highest demand, such as Houhora and Sweetwater.

The numerical model shows that low-lying parts of the aquifer have less potential to sustain higher allocation volumes since their hydraulic gradients are relatively flat, and less groundwater storage is held above sea level in these areas. The current allocation in these low-lying areas is currently quite small so there is no immediate cause for concern, although demand in the Awanui and Ahipara areas in particular should be closely monitored.

TECHNICAL RECOMENDATIONS

- Additional groundwater monitoring would be of great benefit for the purposes of constraining numerical modelling to refine allocation volumes. There is a shortage of data at Sweetwater, Ahipara, Waipapakauri Beach, Motutangi, Waiparera, and Waihopo.
- Fluxes in the groundwater model are largely dependent on land surface recharge calculations. There is currently no soil monitoring data available to verify the recharge results. Recharge estimates would benefit from the installation of lysimeters at locations representative of the main soil types. Recharge estimates can also be greatly improved if there is a better understanding of the effect that forest interception has on land surface recharge.
- New consents should carry out an aquifer test to improve knowledge of aquifer properties. These tests should be carried out with an observation piezometer to enable the assessment of vertical hydraulic conductivity and storage coefficient values.
- The groundwater quality monitoring programme could be optimised to focus more on land use impacts (samples from the unconfined rather than confined aquifer), and coastal impacts.
- Flows in surface water ways should be gauged or monitored to estimate aquifer discharge, particularly the Awanui River. Surface-groundwater exchanges should be characterised by conducting a series of concurrent flow gauging surveys on the main surface water bodies.
- The relationship between dune lakes and groundwater can be assessed by dipping neighbouring shallow wells and comparing them to lake levels on the DEM.
- Groundwater quality sites should be dipped for water level prior to sampling. This takes very little time to do in the field, and would make a great difference to the available data for numerical modelling.
- Bore 200210 (Houhora Waterfront) should be considered as a coastal monitoring site for detecting the onset of seawater intrusion. Water level and conductivity recorders are recommended for this site, and also for any future coastal monitoring bores.
- A new early warning coastal monitoring site is recommended at Paparore.
- Additional coastal monitoring sites are recommended at the locations specified for the Waihopo, Waiparera, Awanui, and Ahipara zones if the volume of allocated groundwater increases significantly in these areas.
- Consider bore development and maintenance regime particularly for the Burnage Road Bore

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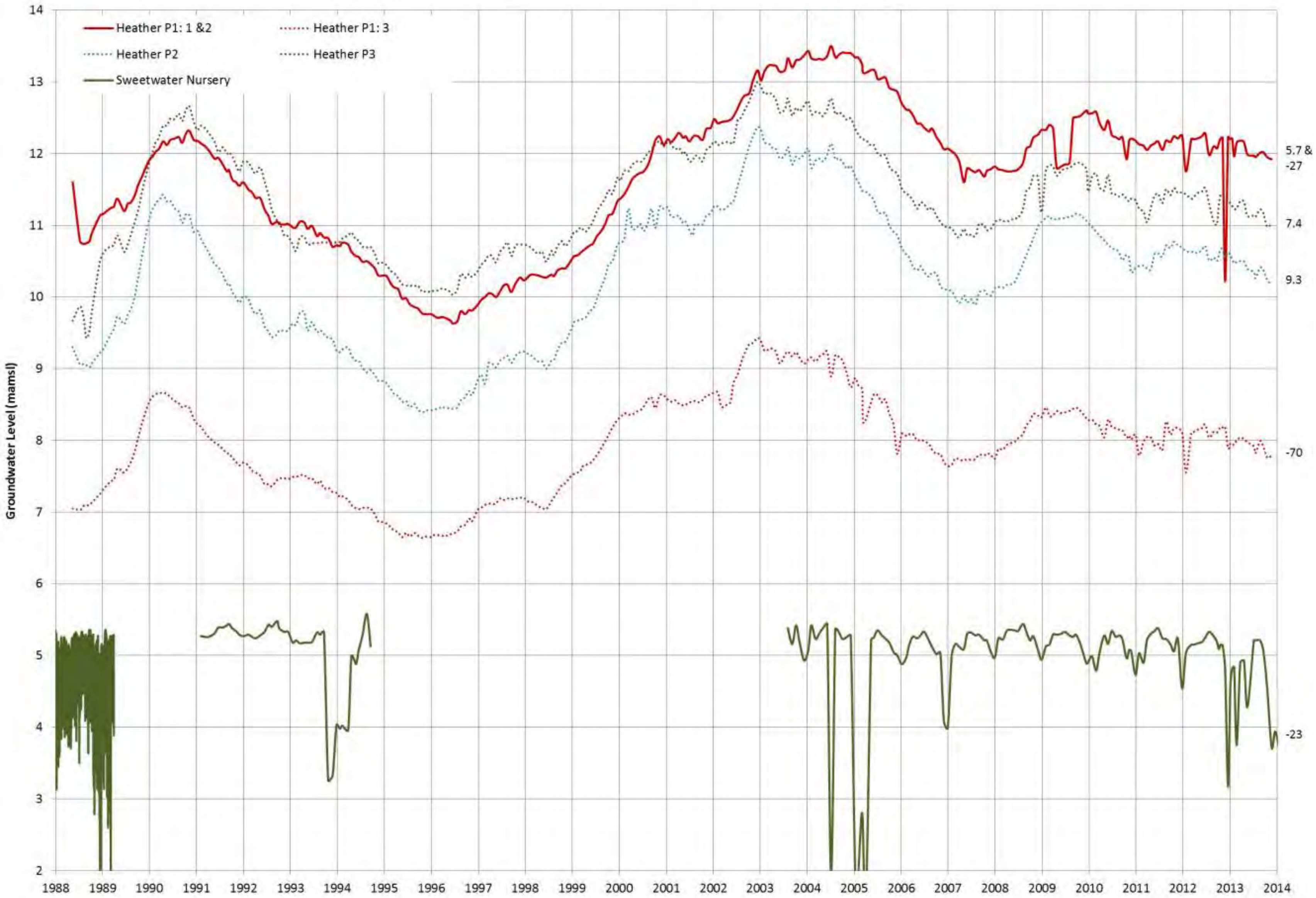
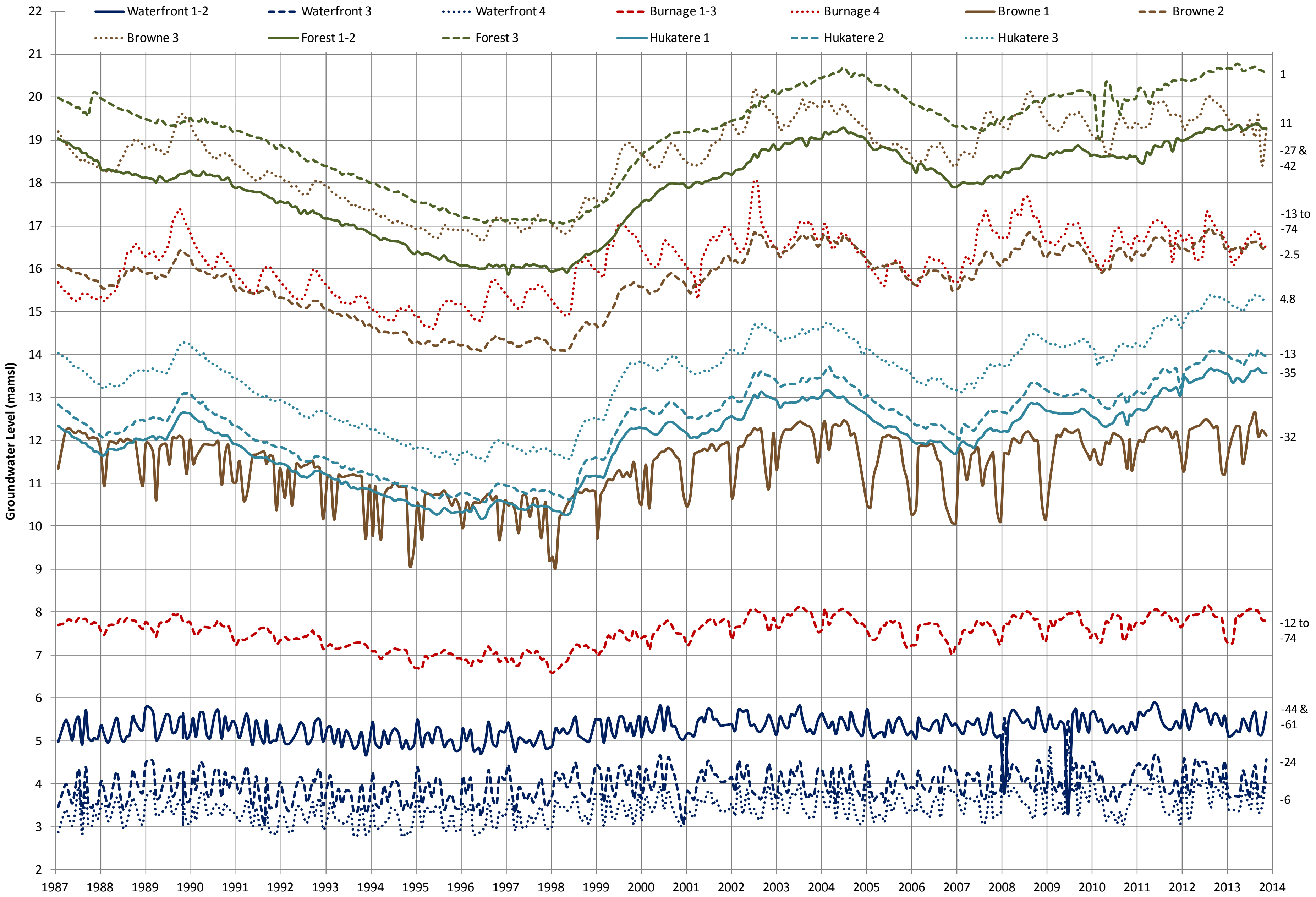
Appendix 1: Water level records (top of screen is annotated on right hand side of graph)

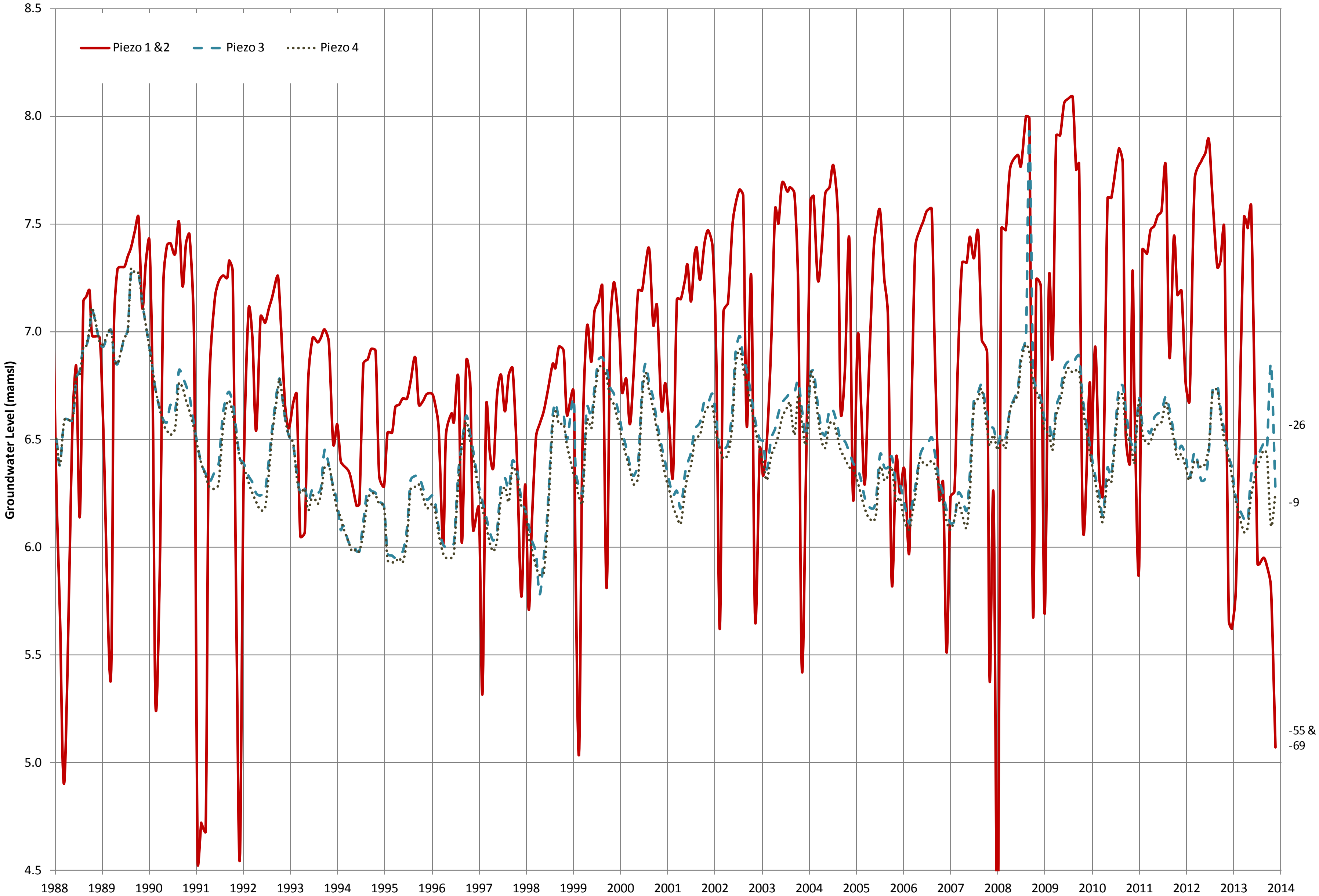
Lake Heather



Houhora to Hukatere



Paparore



Piezo 1 &2
Piezo 3
Piezo 4
Groundwater Level (mamsl)
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
-26
-9
-55 &
-69

Appendix 2: Summary of water quality monitoring data

Median values

Bore	Name	Screen elevation	Samples	Br	Ca	Cl	DRP	F	Fe	HCO_3	K	Mg	Mn	Na	NH_4	NO_3	Si	SO_4	E.Coli	Conductivity (mS/m)	pH	Redox status
200250	Fish Club, Houhora	-67.1	43	0.03	30.0	63	0.074	0.03	0.06	88	3.3	2.8	0.017	51	0.070	0.001	21	13.5	0	44	7.8	Ox?
200059	Colville, Houhora	-22.1	68	0.29	6.3	42		0.08	1.40	48	1.4	4.4	0.060	31	0.005	0.015	41	7.45	0	24	6.6	Ox?
200211	Fitzwater, Paparore	-63.8	70	0.17	34.0	52		0.07	0.06	145	2.7	5.7	0.110	42	0.060	0.015	41	8.55	0	41	7.8	Ox
209536	West Coast Rd, Waipapakauri	-55	8	0.04	9.0	33	0.035	0.04	0.01	30	0.8	1.5	0.008	29	0.003	0.001	16	3.10	0	27	8.4	Ox
201563	Vinac, Awanui	-27.9	44	0.01	11.0	68	0.001	0.01	0.22	55	2.5	2.7	0.019	63	0.001	0.001	15	0.03	0	48	7.7	Anox
209330	Waipapakauri	-43.7	18	0.06	7.0	35	0.060	0.01	0.001	26	0.7	1.6	0.0001	25	0.001	0.001	22	2.45	8	25	8.2	Ox
210449	Long Bore, Ahipara		59	0.07	4.3	32		0.02	1.50	34	1.7	3.5	0.040	25	0.090	0.290	36	6.60	0	19	6.3	Anox?

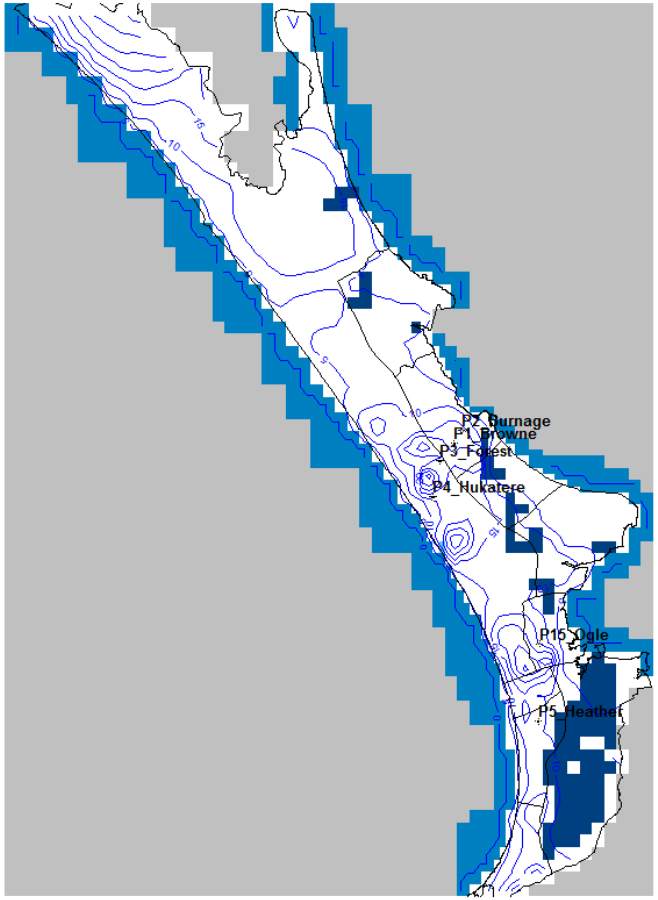
Maximum values

Bore	Name	As	B	Br	Ca	Cl	DRP	F	Fe	HCO_3	K	Mg	Mn	Na	NH_4	NO_3	Si	SO_4	E.Coli	Conductivity (mS/m)
200250	Fish Club, Houhora	0.001	0.04	0.36	35.0	90	0.11	0.24	0.11	110	3.9	3.4	0.021	56	0.24	0.50	47	16.5	14	47
200059	Colville, Houhora	0.001	0.00	0.44	9.1	58	0.08	0.14	6.90	65	2.4	6.9	0.090	37	0.13	0.48	50	9.95	0	28
200211	Fitzwater, Paparore	0.001	0.06	0.22	38.0	55	0.15	0.15	0.12	154	13.9	6.9	0.170	45	0.50	0.43	47	9.40	2419	46
209536	West Coast Rd, Waipapakauri	0.000	0.03	0.13	19.0	38	0.19	0.11	0.03	78	2.1	3.4	0.018	31	0.03	0.04	35	7.23	0	27
201563	Vinac, Awanui	0.001	0.07	0.39	27.2	92	0.36	0.27	0.60	141	6.6	6.4	0.120	72	0.60	0.03	65	24.1	1190	56
209330	Waipapakauri	0.004	0.02	0.26	17.2	39	0.15	0.07	0.03	64	1.9	3.8	0.007	29	0.06	0.02	46	7.10	326	44
210449	Long Bore, Ahipara	0.001	0.00	0.14	6.0	35	0.05	0.08	7.10	43	2.2	4.2	0.071	28	0.36	0.77	42	9.90	0	41

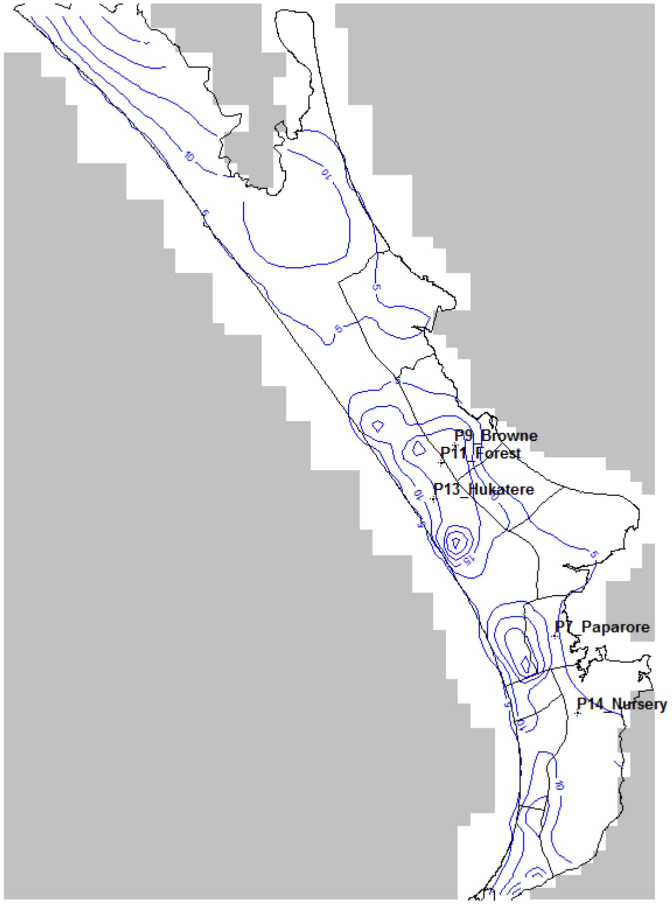
Values shown in red exceed guideline values in the NZ Drinking Water Standards (Ministry of Health, 2008)

Appendix 3: Numerical model structure

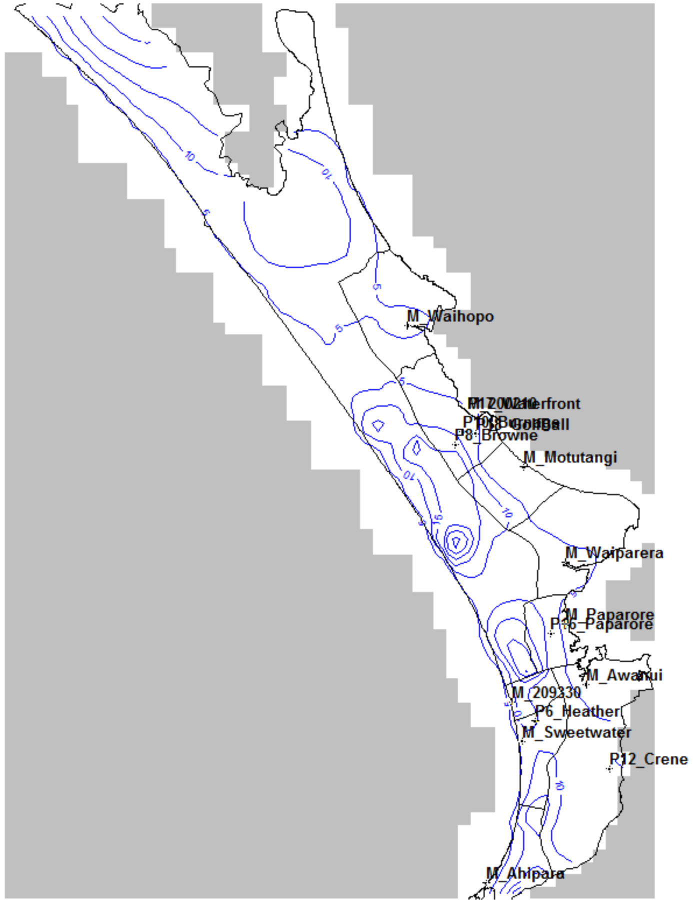
Layer 1



Layer 2

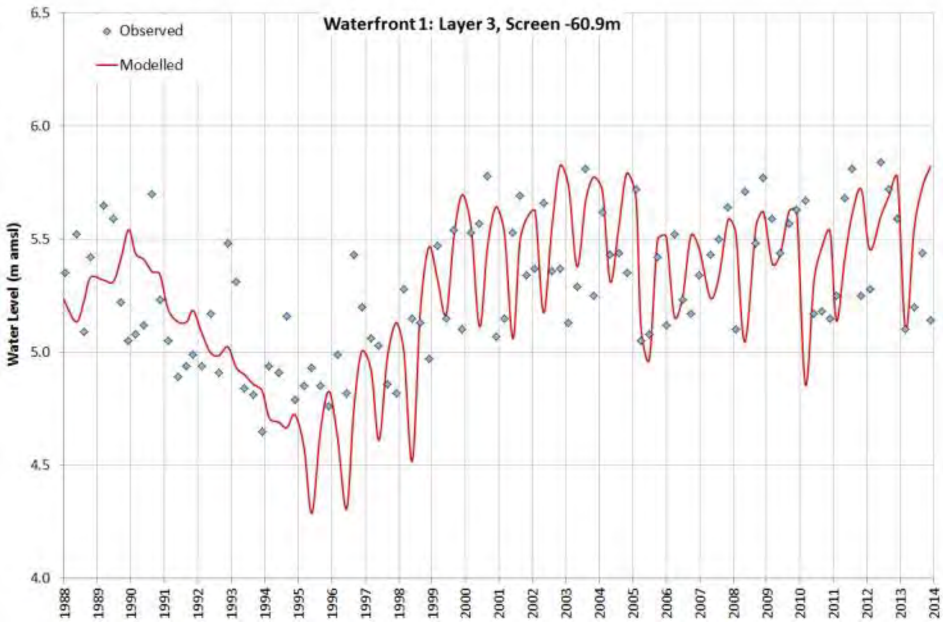


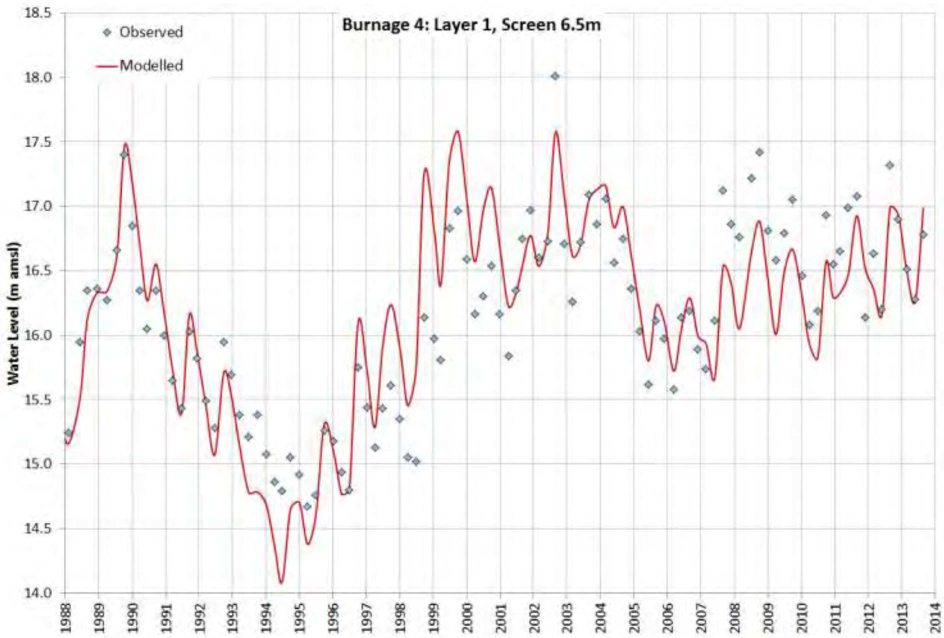
Layer 3

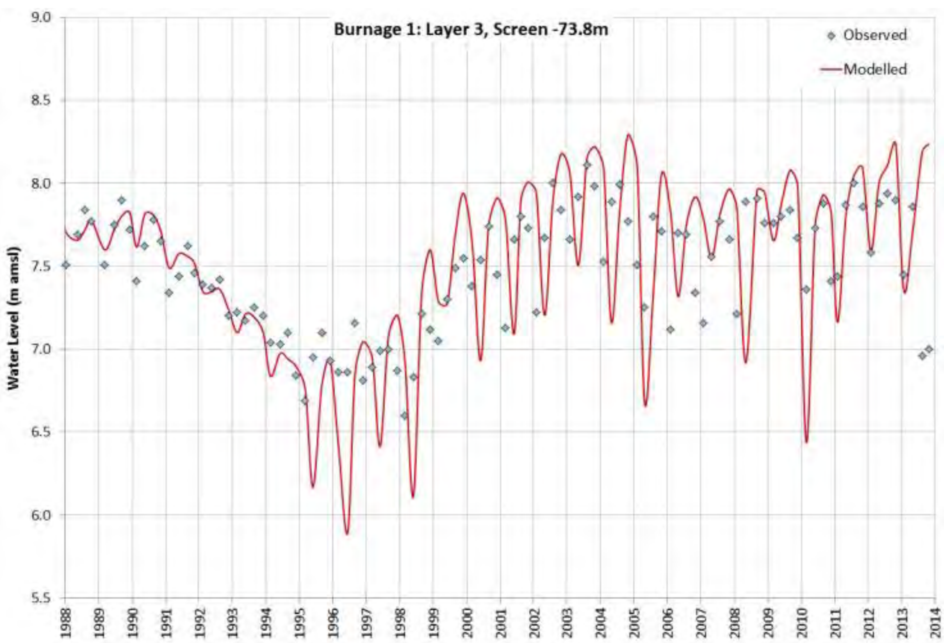


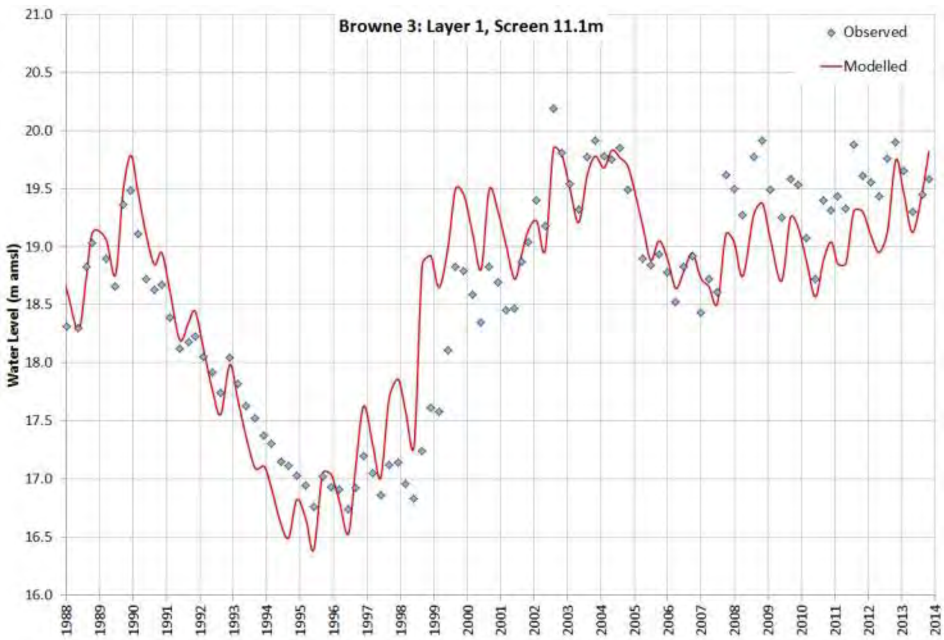
Water levels for each layer have been calculated for November 2003

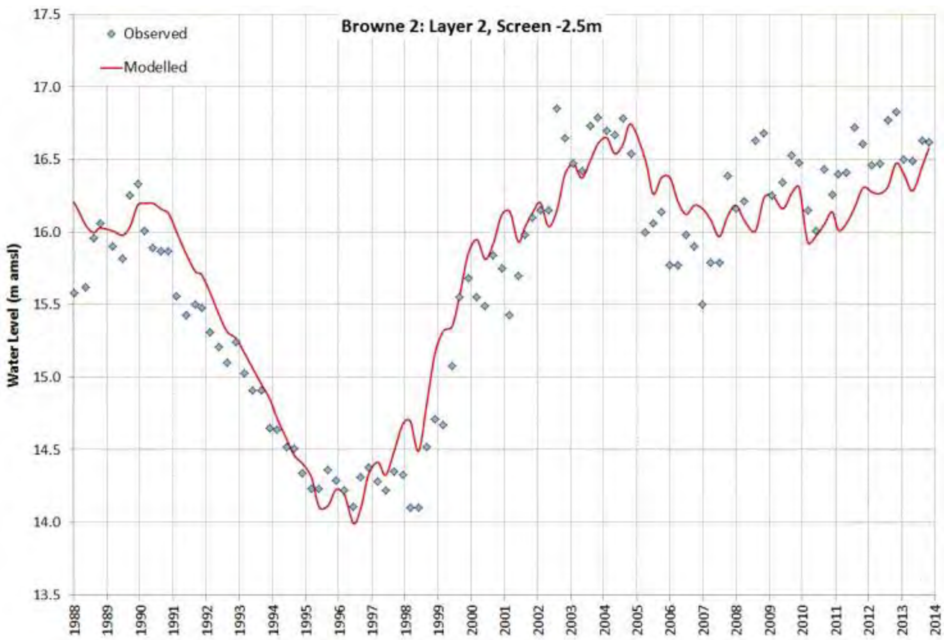
Appendix 4: Numerical model transient heads

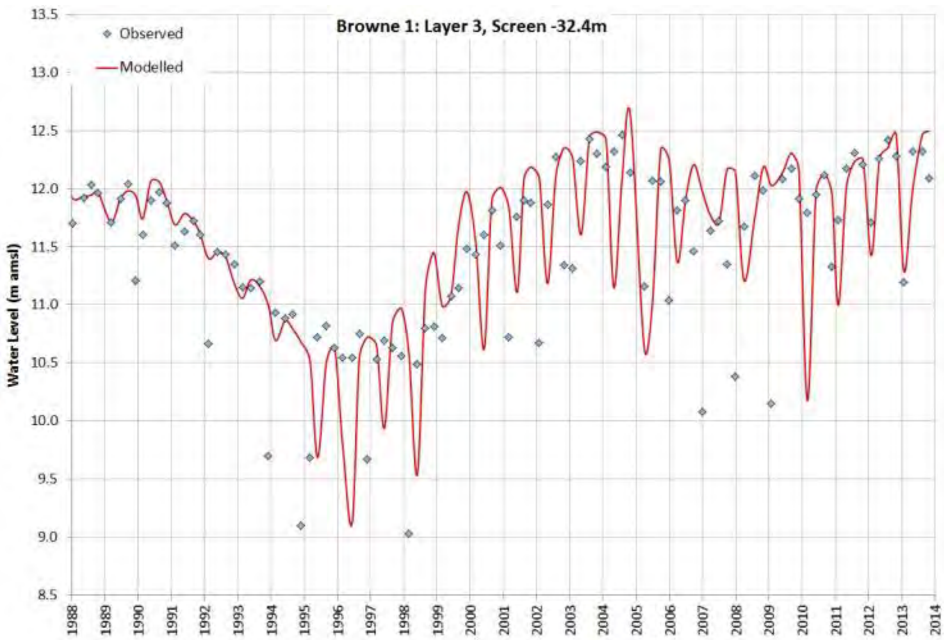


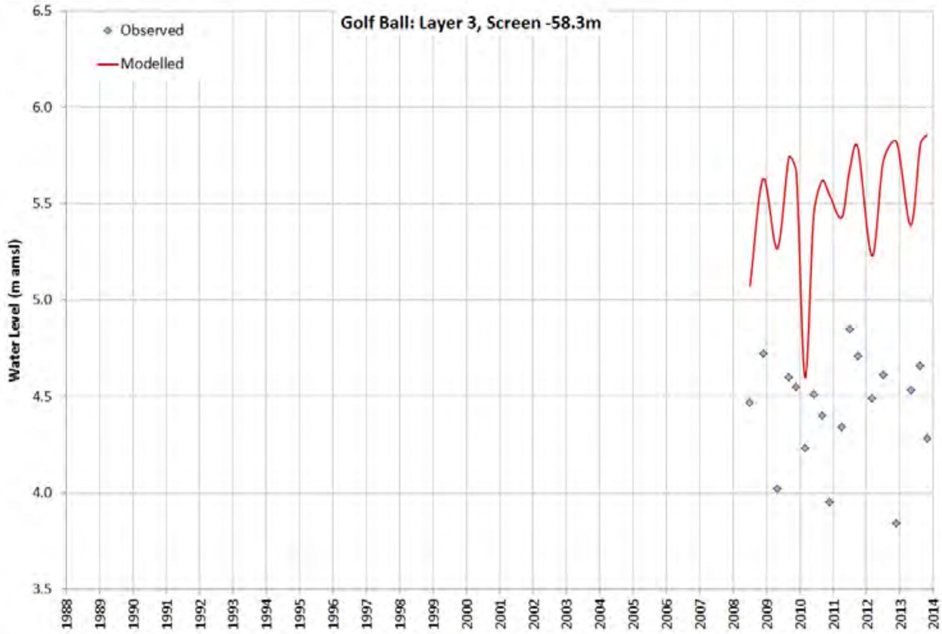


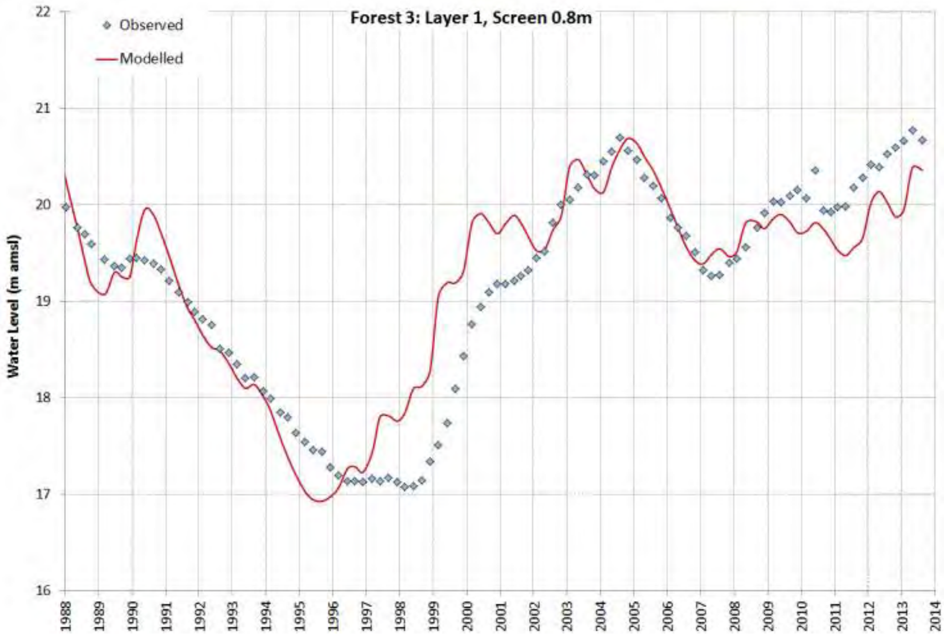


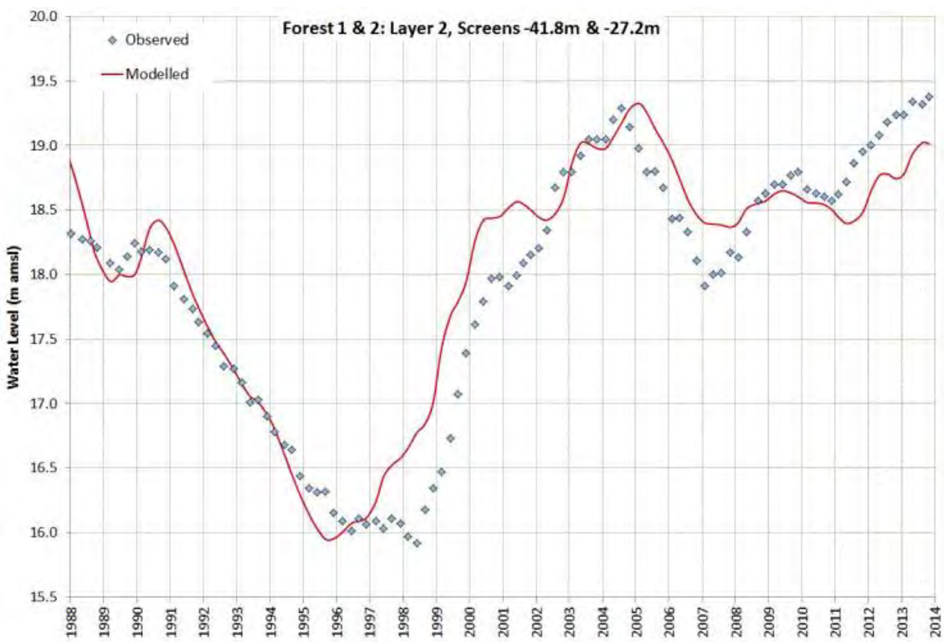

Browne 3: Layer 1, Screen 11.1m
Observed
Modelled
Water Level (m amsl)

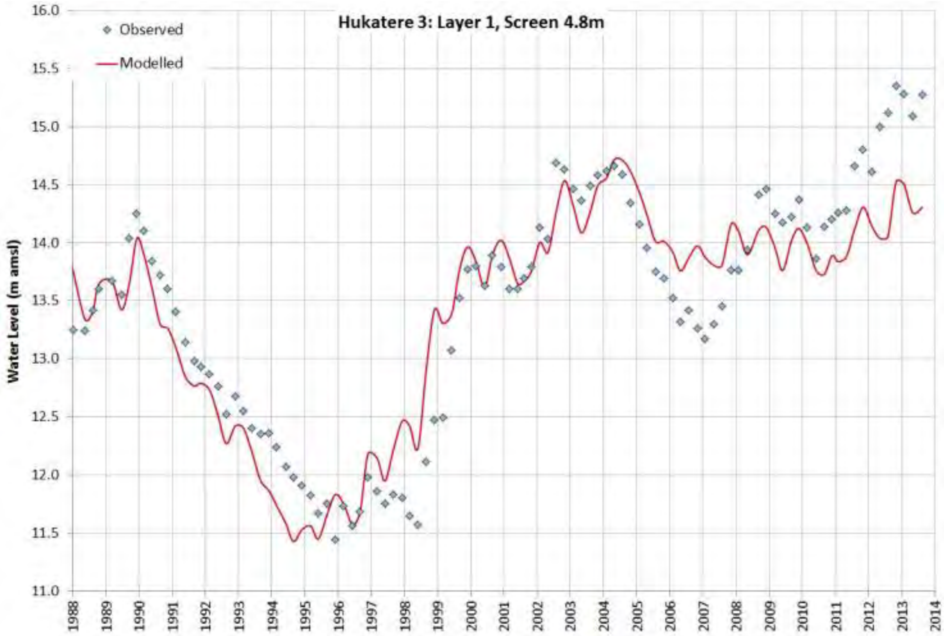

Browne 2: Layer 2, Screen -2.5m
Observed
Modelled
Water Level (m amsl)

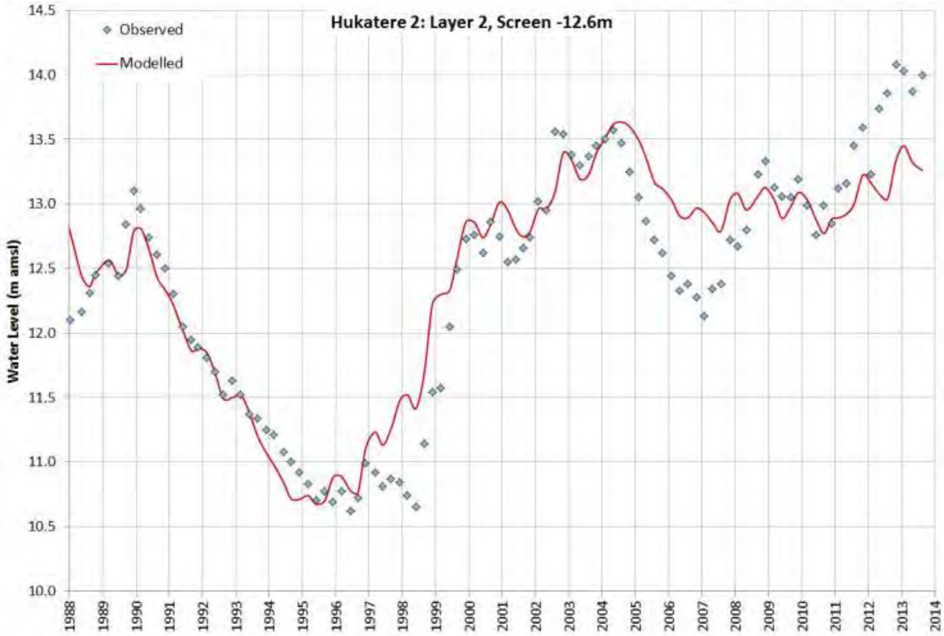

Browne 1: Layer 3, Screen -32.4m
Observed
Modelled
Water Level (m amsl)

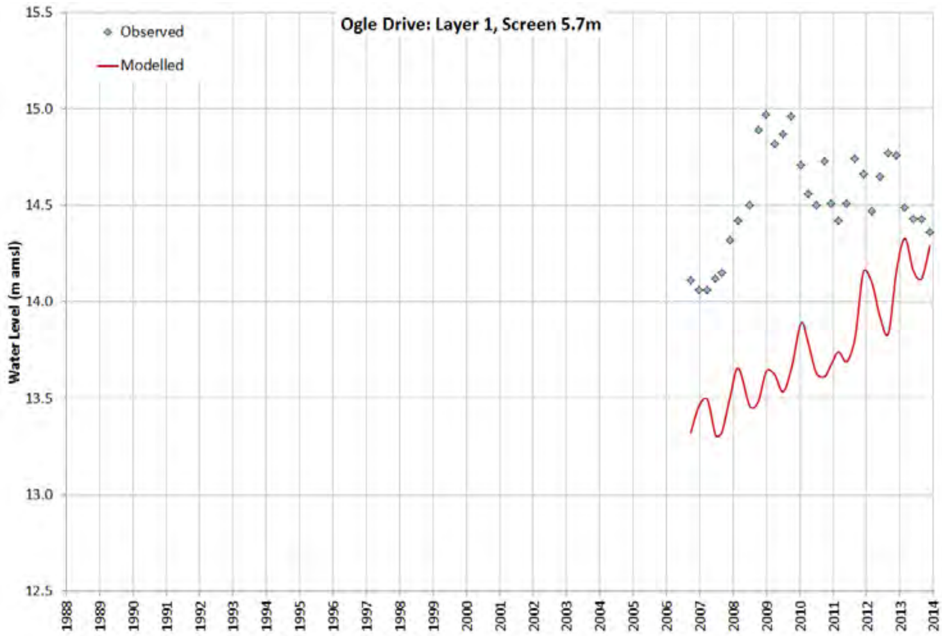

Golf Ball: Layer 3, Screen -58.3m
Observed
Modelled
Water Level (m amsl)

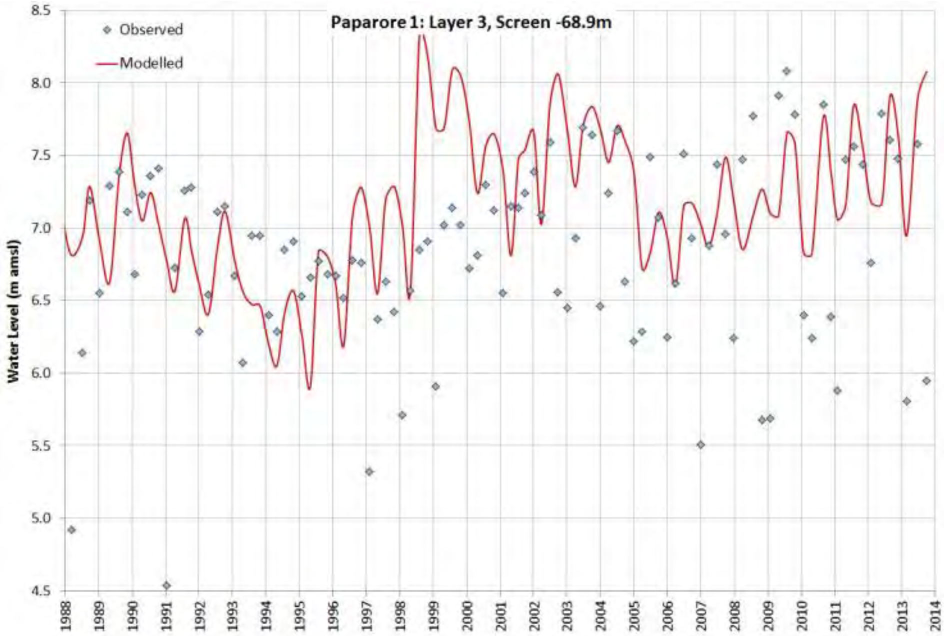

Forest 3: Layer 1, Screen 0.8m
Observed
Modelled
Water Level (m amsl)

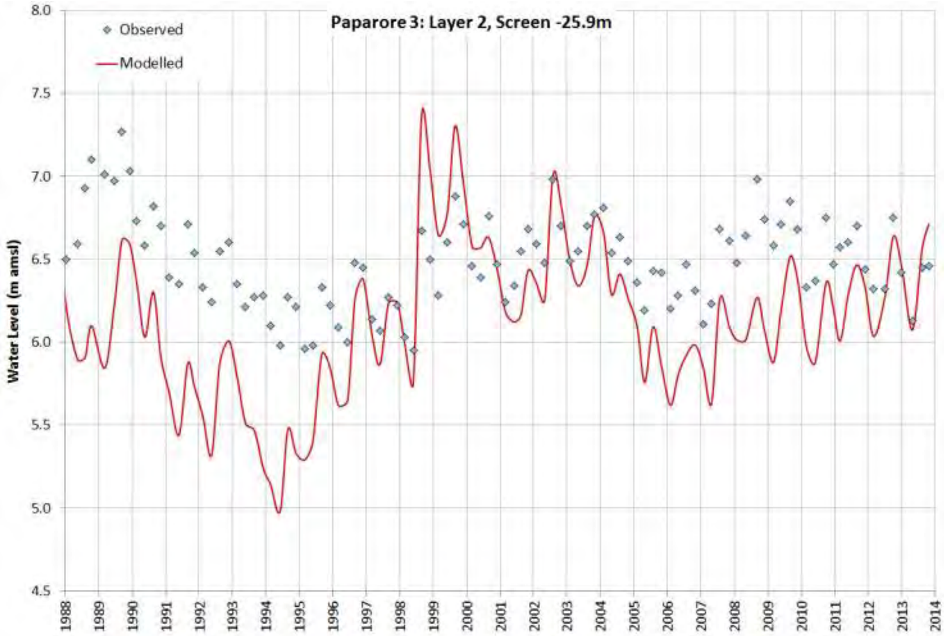

Forest 1 & 2: Layer 2, Screens -41.8m & -27.2m
Observed
Modelled
Water Level (m amsl)

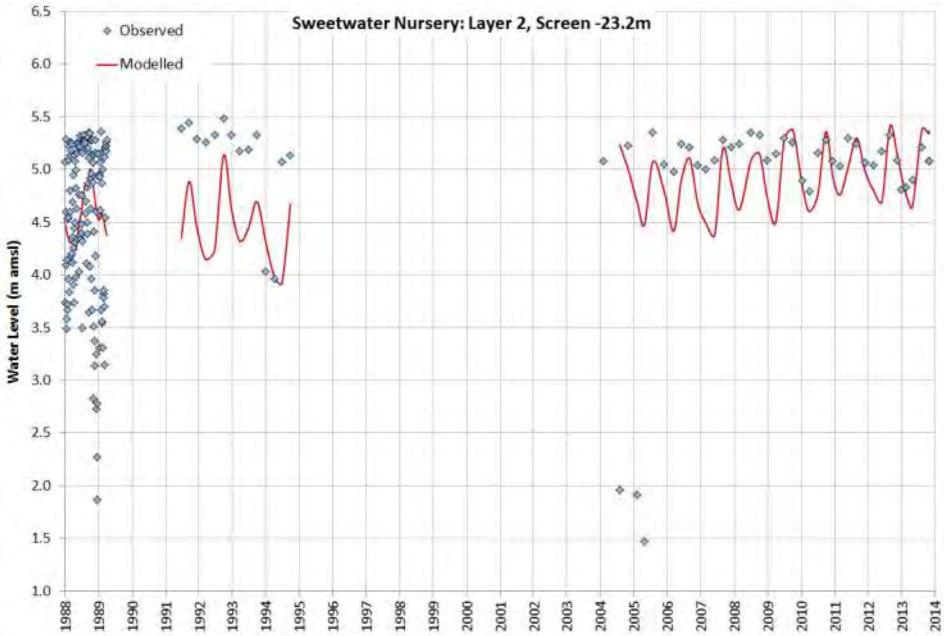

Hukatere 3: Layer 1, Screen 4.8m
Observed
Modelled
Water Level (m amsl)

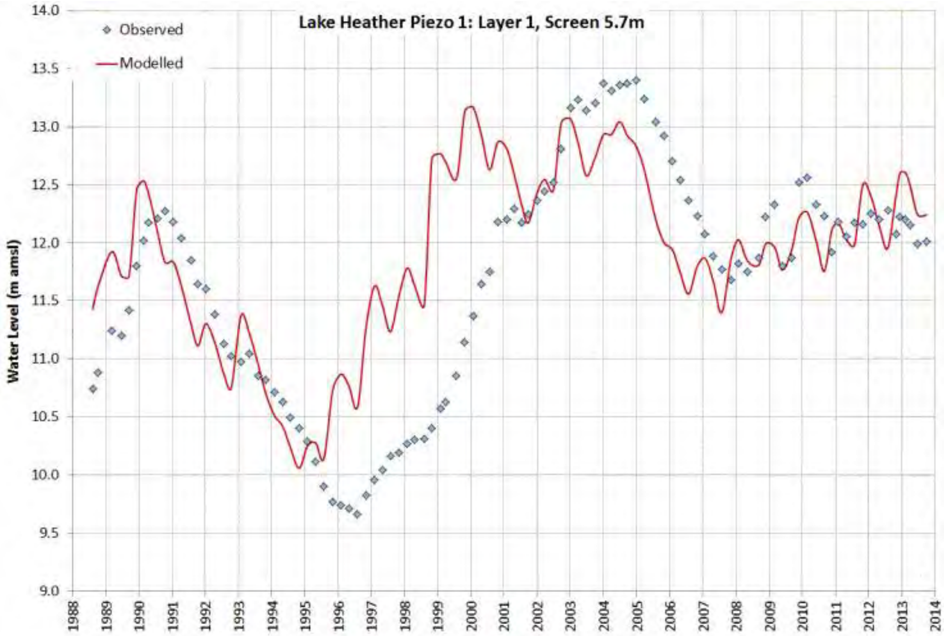

Hukatere 2: Layer 2, Screen -12.6m
Observed
Modelled
Water Level (m amsl)

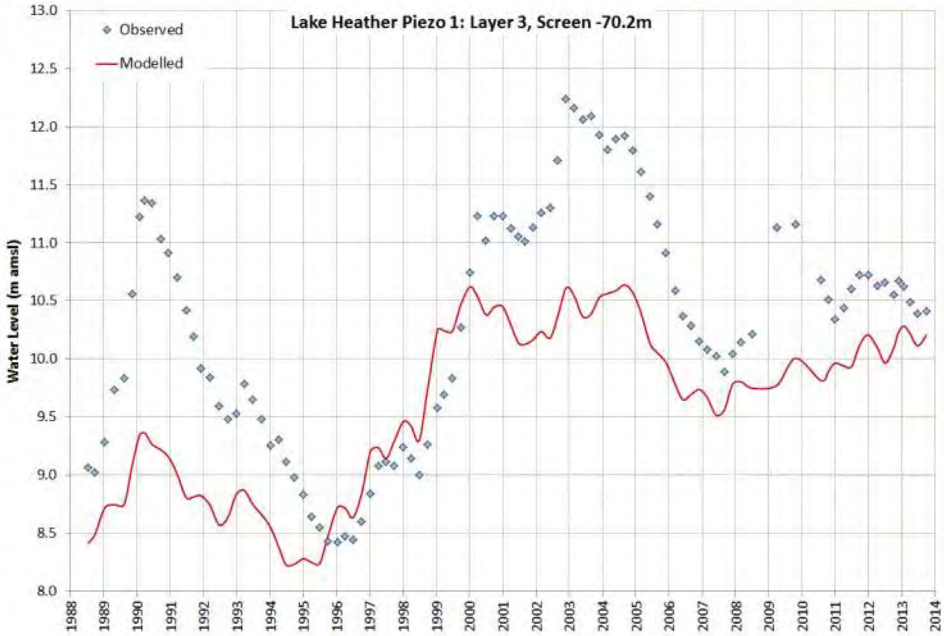

Ogle Drive: Layer 1, Screen 5.7m
Observed
Modelled
Water Level (m amsl)

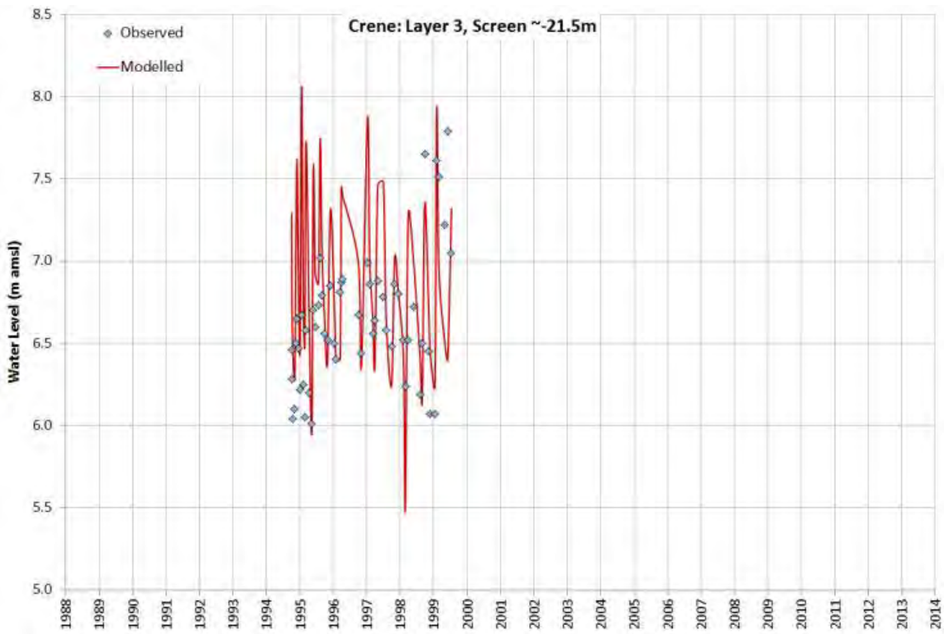

Paparore 1: Layer 3, Screen -68.9m
Observed
Modelled
Water Level (m amsl)


Paparore 3: Layer 2, Screen -25.9m
Observed
Modelled
Water Level (m amsl)


Sweetwater Nursery: Layer 2, Screen -23.2m
Observed
Modelled
Water Level (m amsl)

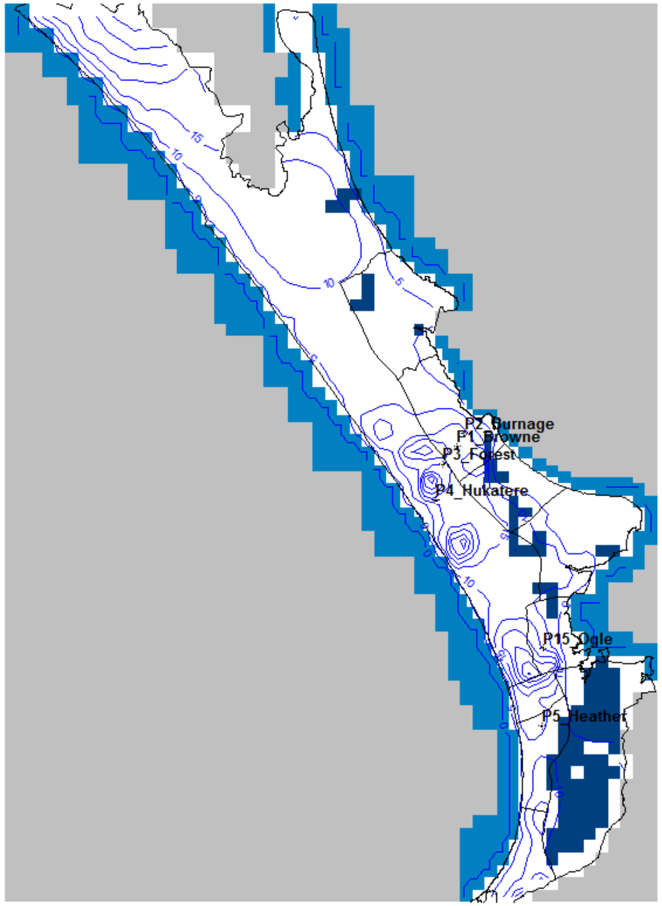

Lake Heather Piezo 1: Layer 1, Screen 5.7m
Observed
Modelled
Water Level (m amsl)


Lake Heather Piezo 1: Layer 3, Screen -70.2m
Observed
Modelled
Water Level (m amsl)

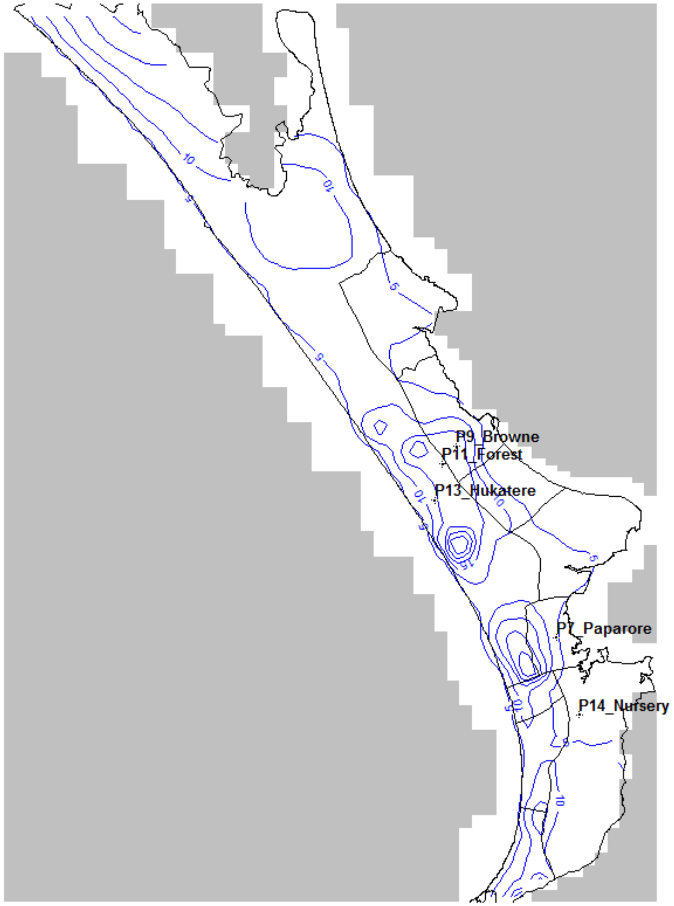

Crene: Layer 3, Screen ~-21.5m
Observed
Modelled
Water Level (m amsl)

Appendix 5: Groundwater levels for the current full allocation

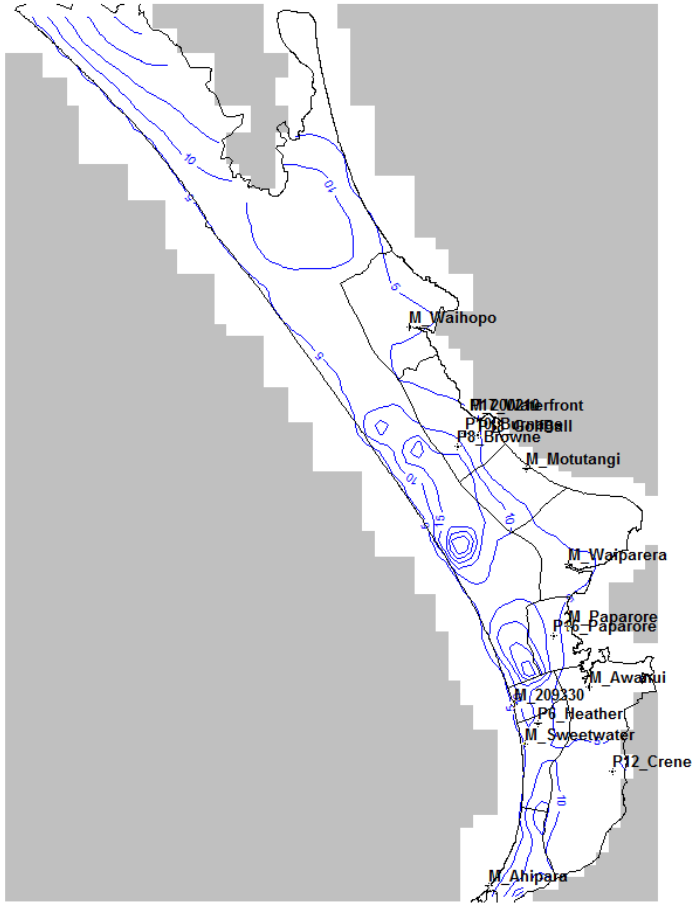
Layer 1



Layer 2



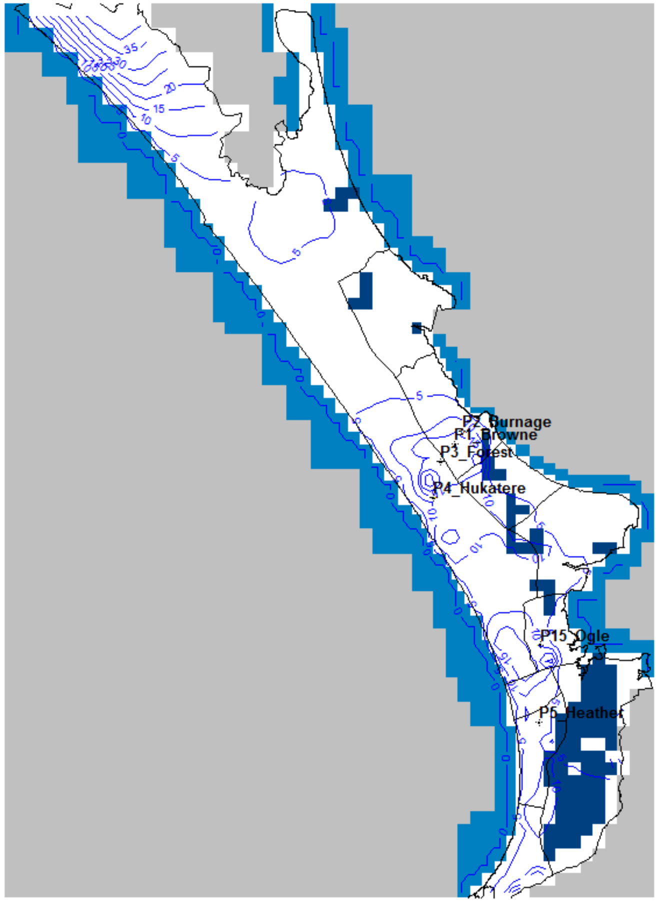
Layer 3



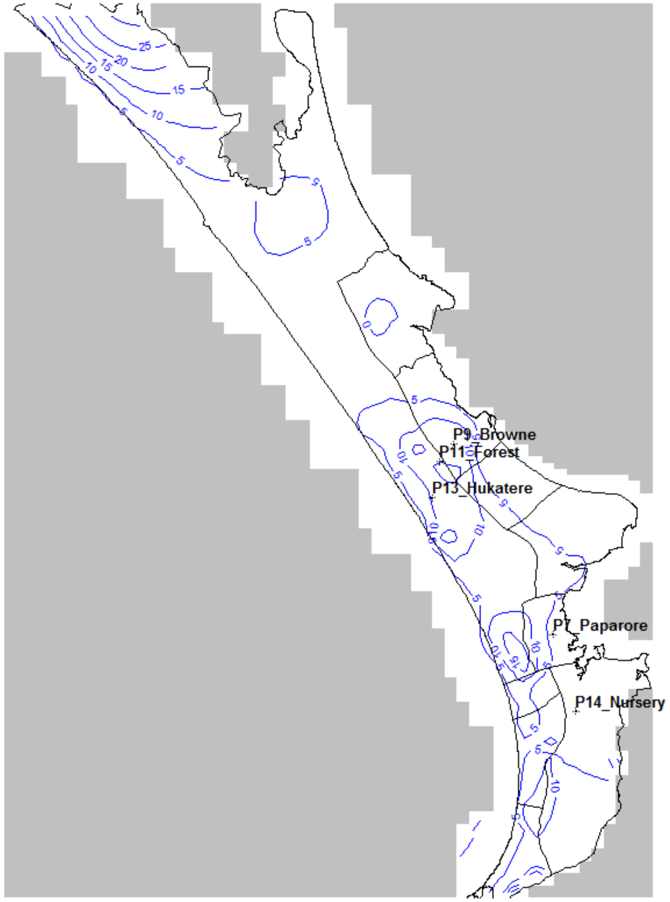
Water levels for each layer have been calculated for March 1995

Appendix 6: Groundwater levels for a maximum allocation scenario

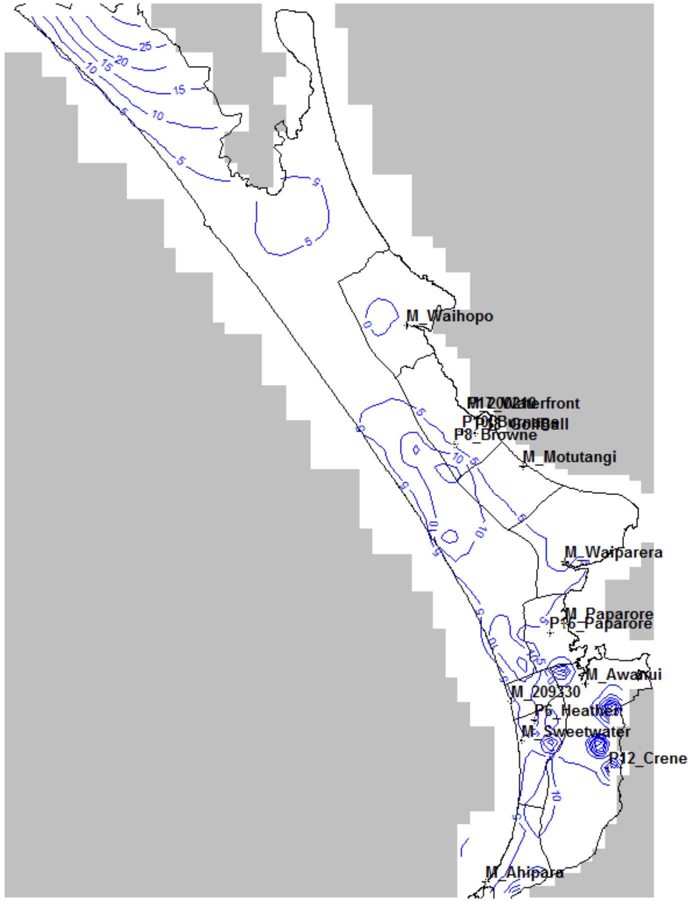
Layer 1



Layer 2



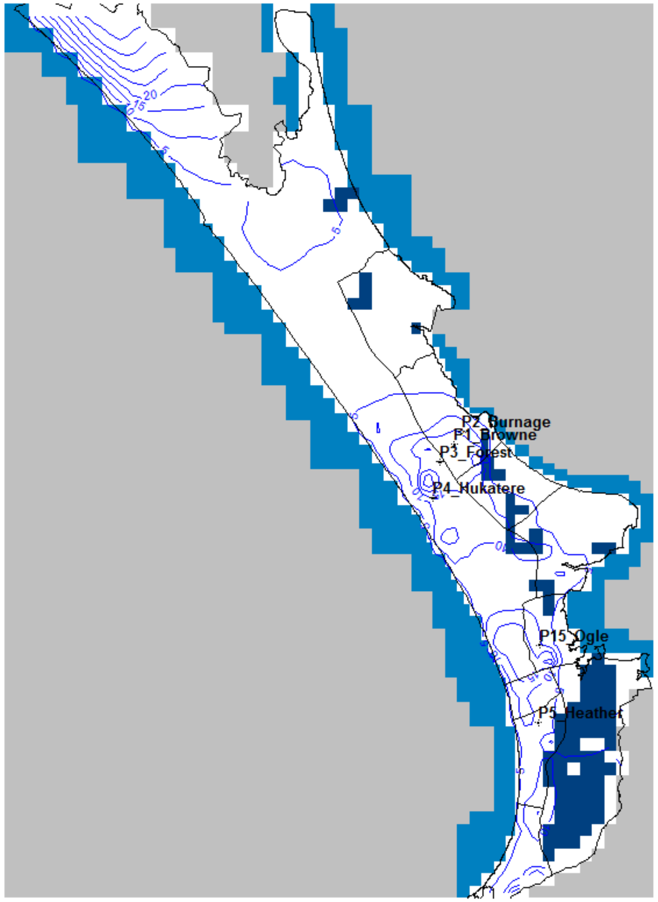
Layer 3



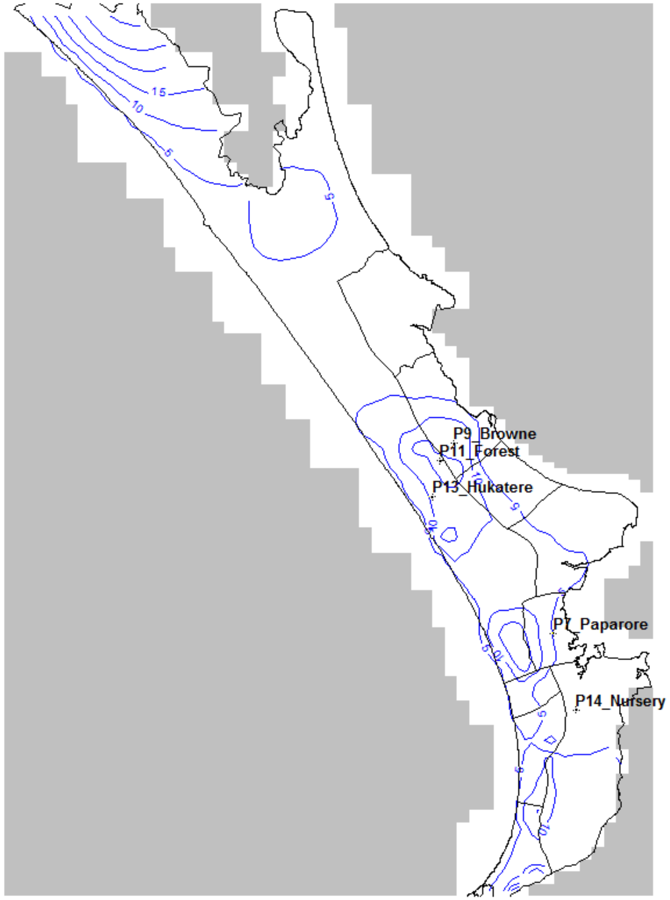
Water levels for each layer have been calculated for March 1995

Appendix 7: Groundwater levels for climate change scenario with 0.57m sea level rise and current full allocation

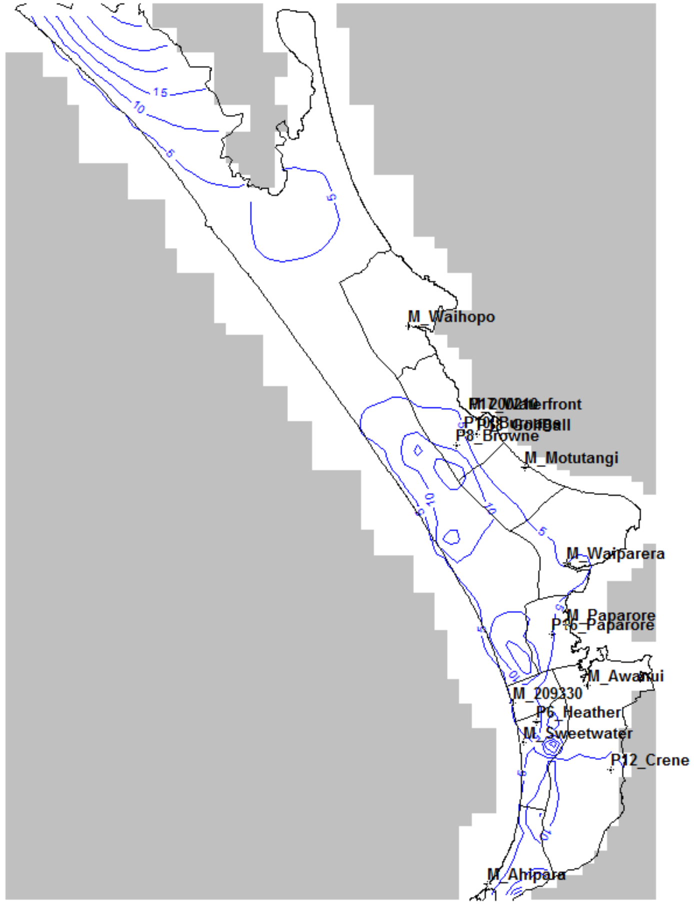
Layer 1



Layer 2



Layer 3



Water levels for each layer have been calculated for March 1995

Appendix 4

Motutangi – Waiharara Groundwater Model – Factual Technical Report – Modelling

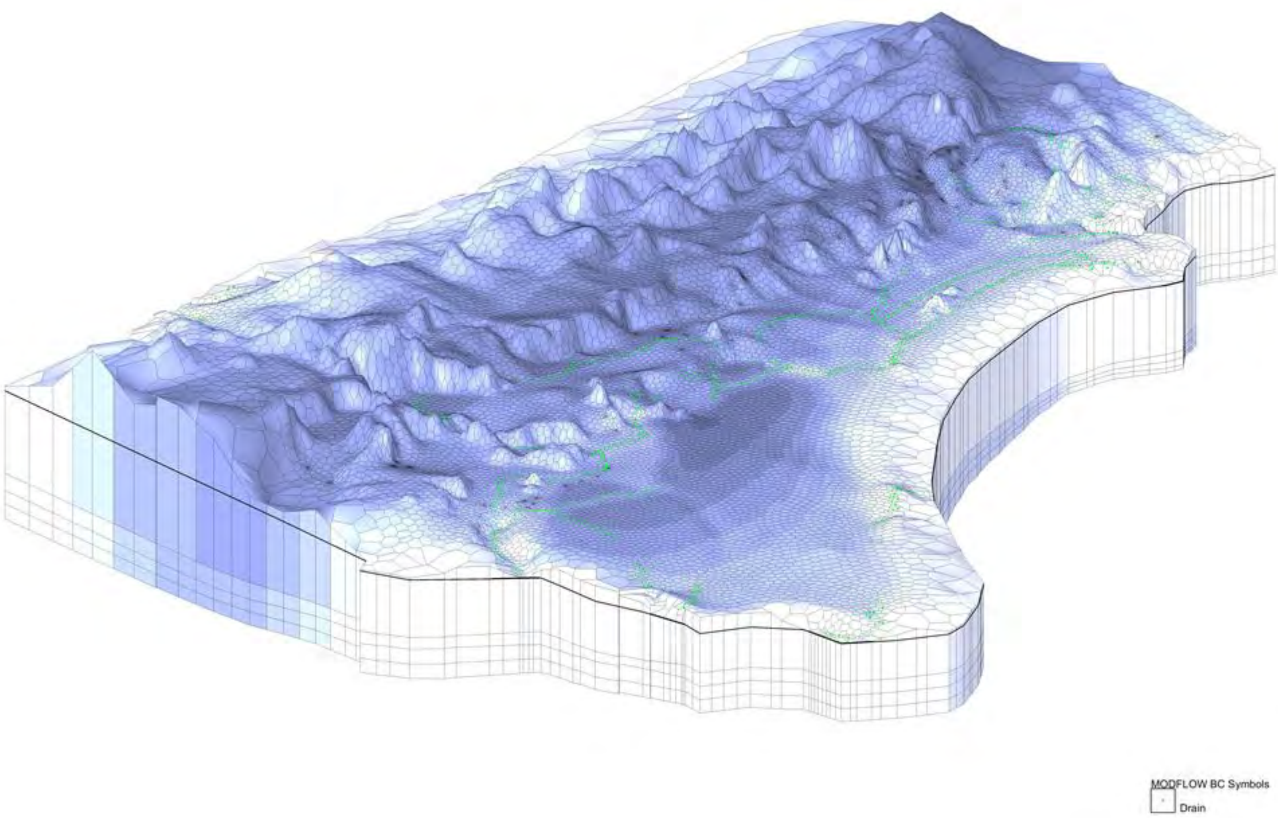
Motutangi-Waiharara Groundwater Model

Factual Technical Report - Modelling

MOTUTANGI-WAIHARARA WATER USER GROUP

WWA0026 | Final - Rev. 9

31 August 2017



Motutangi-Waiharara Groundwater Model

Project no:	WWA0026
Document title:	Groundwater Modelling Analysis
Revision:	Final - Rev. 9
Date:	31 August 2017
Client name:	MOTUTANGI-WAIHARARA WATER USER GROUP
Project manager:	Jon Williamson
Author(s):	Hangjian Zhao and Jon Williamson
File name:	C:\Users\Jon Williamson\Google Drive\WWA\Projects\Motutangi-Waiharara WUG\WWA0026_Houhora South_Motutangi_Waiparera Groundwater Model\Deliverables\2. Peer Review\Modelling Report\Motutangi_Waiharara Groundwater Modelling Report_rev9_300817.docx

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Document history and status

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6	19 May 2017	Final for NRC submission.		Edda Kalbus	Jon Williamson
7	17 July 2017	Revised following peer review comment	Hangjian Zhao	Edda Kalbus	Jon Williamson
8	26 July 2017	Final			Jon Williamson
9	31 August 2017	Final			Jon Williamson

Distribution of copies

Rev	Date issued	Issued to	Comments
5	9 May 2017	Motutangi-Waiharara Water User Group	
6	19 May 2017	Northland Regional Council	
7	17 July 2017	Brydon Hughes (Land and Water People - on behalf of Northland Regional Council)	Draft provided for further Peer review.
8	26 July 2017	Brydon Hughes (Land and Water People - on behalf of Northland Regional Council)	Final
9	31 August 2017	Brydon Hughes (Land and Water People - on behalf of Northland Regional Council)	Final

Contents

Figures

Executive Summary

Williamson Water Advisory (WWA) were commissioned by the Motutangi-Waiharara Water User Group (MWWUG) that comprises eighteen parties to develop a numerical model and prepare an assessment of effects report addressing the questions raised in the s92 RMA Request from Northland Regional Council (NRC) dated 14 June 2016. The MWWUG participants are seeking both increases and new groundwater takes for avocado orchard irrigation that total 16,775 m^3/day.

A numerical groundwater flow model was developed to determine the potential impact from the proposed groundwater abstraction on the regional aquifer system and the hydrological condition of relevant surface water. In particular, the model was used to define the potential impact from seasonal pumping on the aquifer system water budget, aquifer groundwater levels, surface water drain flows and discharges from Kaimaumau wetland, and the position of the saltwater/fresh water interface.

A scenario comprising three simulations representing potential future additional allocations (over and above the proposed scenario) was also simulated for comparison to the basecase and proposed abstraction scenarios.

This report presents the factual results of the modelling study, while an accompanying Assessment of Environmental Effects report analyses and interprets the results from a Resource Management Act perspective.

1. Introduction

Williamson Water Advisory (WWA) were commissioned by the Motutangi-Waiharara Water User Group (MWWUG) to develop a numerical model and prepare an assessment of effects report addressing the questions raised in the s92 RMA Request from Northland Regional Council (NRC) dated 14 June 2016 with respect to the MWWUG participants' proposed groundwater abstraction for avocado irrigation.

WWA's scope of work included:

- ***Test pumping and data analysis of three bores.*** – i) Heath Road, Waiharara; ii) Norton Road, Waiharara; and iii) Turk Valley Road, Motutangi.
- ***Wetland groundwater connection investigation*** – flow and chemical isotope analysis of water in drains adjacent to and within the wetlands.
- ***Groundwater modelling*** - Development of a calibrated three-dimensional groundwater model using MODFLOW, to enable assessment of:
  a) Interference effects on individual bores;
  b) Cumulative effects on surface water features (streams, lakes and swamps); and
  c) Saline intrusion.
- ***Reporting*** - Preparation of a comprehensive s92 Report and associate maps.

The MWWUG comprises 18 parties as shown with their proposed allocation or in some cases increase in allocation in **Table 1**.

The extent of the model domain and location of the MWWUG members along with other key features of the area are shown in **Figure 1**.

Figure 1. Project locality map. (See A3 attachment at rear).

This report presents the factual results of the modelling study, while an accompanying Assessment of Environmental Effects report analyses and interprets the results from a Resource Management Act perspective.

1.1 Report Structure

The structure of this technical report is as follows:

- **Section 2** provides an overview of the conceptualisation of the groundwater flow model, including a discussion of the results from field testing on the surface water and groundwater connectivity within the Kaimaumau wetland and deep shellbed aquifer.
- **Section 3** details the model construction and configuration.
- **Section 4** details the calibration of the steady-state and transient models.
- **Section 5** details the setup and results from predictive simulations.
- **Section 6**. provides a summary of the key findings and conclusions of this project.

Table 1. Membership and application volumes of the Motutangi-Waiharara Water User Group.

Full Name	Consent Status	Maximum Inst. Rate (L/s)*	Maximum Daily Volume (m^3/d)	Maximum Annual Volume (m^3/yr)
Mapua Avocados Ltd, C/o Murray Forlong	New	116	5,000	745,000
Honeytree Farms Limited, C/o Tony Hayward	New	81	3,500	521,500
Georgina Tui and Mate Nickolas Covich	New	35	1,500	223,500
Largus Orchard Ltd Partnership, C/o Jason McLarnon	New	30	1,300	193,700
Te Runanga o Ngai Takoto, C/o Rangitane Marsden	New	30	1,300	193,700
Candy Corn Ltd, C/o Bryan Candy	New	19	800	119,200
Elbury Holdings Limited, C/o Kevin and Fiona King	Increase	12	500	74,500
Bernard Kim & Sheryl Dianne Shine	Increase	12	500	74,500
Ivan Anthony Stanisich	Increase	10	430	64,070
Kevin and Dani Thomas	New	9	400	59,600
Neil & Alma Violet Thompson and Steven & Josephine Suzanne Thompson	Increase	7	320	47,680
Tony and Diane Hewitt	Increase	6	270	40,230
Cypress Hills Ltd, C/o Alan Anderson & Carolyn Dawn Smith	Increase	6	280	41,720
Ian McLarnon & Jason McLarnon	Increase	5	200	29,800
Kathy Valadares	Increase	3	150	22,350
Johno and Carol Brien (Hukatere Road)	Increase	3	125	18,625
Daimen & Katherine Holloway	Increase	2	100	14,900
Johno and Carol Brien (Lamb Road)	Increase	2	100	14,900
TOTAL		**388**	**16,775**	**2,499,475**

Notes: * assumes 12 hours pumping.

1.2 Response To Peer Review Comments

A peer review was undertaken by Brydon Hughes from Land and Water People (Christchurch). Peer review comments on this modelling report and the accompanying Assessment of Environmental Effects report were received on 22 June 2017. The current version of the report (revision 7) incorporates text and figures that provide further clarity in areas raised by the peer reviewer.

2. Model Conceptualisation

This section describes the conceptualisation applied in the construction of the numerical groundwater flow model.

2.1 Geology

The geology of the Motutangi-Waiharara aquifer consists of Pleistocene and Holocene unconsolidated sedimentary materials deposited in beach and dune (abandoned shorelines and marine terraces) and associated alluvial, intertidal estuarine, shallow marine, lakebed and wetland environments.

The geologic units in the model domain were identified through the available bore logs sourced from NRC. The sediments near the surface typically comprise fine-grained sands, interspersed with sporadic iron pan, peat, lignite, silt, gravel and shellbeds.

With distance inland from the coast, the sand deposits become progressively older and have a higher degree of compaction and weathering compared to the younger foredune sands located at the coast.

With increasing depth, the occurrence of shellbed layers increases. The shellbeds comprise layers that typically range in composition from 30-90% medium to coarse shell and 10-70% fine sand. The shellbed aquifer typically resides from approximately 70 to 120 mBGL, and is the most prolific water yielding aquifer in the region and hence the target for irrigation bores.

Underlying the shellbed aquifer are basement rocks of the Mount Camel Terrain, which typically comprise hard grey to dark green / black igneous rocks described in Isaac (1996) as intercalated basalt and basaltic andesite lava, pillow lava, rhyolitic tuff, tuff-breccia, conglomerate, sandstone and mudstone.

Drilling data in the Motutangi-Waiharara area indicates that the sedimentary sequence can be broadly classified into two lithological units. The upper bulk layer comprises the fine-grained sands, interspersed with iron pan, peat, lignite, and silt. The lower layer comprises mostly shell beds, although recent drilling has identified the existence of two discrete shell units separated by a thin fine sand or silt layer. The lithological unit classification developed for this study is exemplified in **Figure 2** using three reliable bore logs, and is described as follows:

- ***Layer 1 – Sand / Silt.*** A sequence of predominately unconsolidated fine sand intersperses with discontinuous layers of alternating iron pan, silt and peat. The layer varies in thickness from approximately 40 m to 75 m.
- ***Layer 2 – Upper Shellbed.*** A sequence of shellbeds comprising medium to coarse shell with some fine sand in the matrix. The proportion of shell typically varies from 30% to 90%. The layer is typically encountered at a depth of 80 - 95 mBGL and varies in thickness from typically 5 m to 10 m.
- ***Layer 3 – Sand.*** A thin layer of finer sediment separating the upper and lower shellbed.
- ***Layer 4 – Lower Shellbed.*** A sequence of shellbeds typically comprising a higher proportion of shell and coarser grain size than the upper shellbed. In some locales, the shell is more consolidated and described by drillers as shellrock. Drillers also report circulation losses when drilling this formation. The layer is typically encountered at depths of 100 - 115 mBGL and varies in thickness from typically 5 m to 15 m.

Honey Tree Farm Bore
(Drilled on 20 June 2016)

From (mBGL)	To (mBGL)	Lithology
0	1	Brown pan
1	4	Brown sands
4	5	White/green sands
5	8	Brown sands
8	22	Grey/brown Sands
22	37.6	Very fine green/grey sands
37.6	38.4	Brown silt
38.4	40.1	Grey silt
40.1	42.2	Fine brown/grey sands
42.2	47	Green/grey sandy silts
47	58	Green sandy silt- some shell
58	58.9	Cemented black sand
58.9	60	Shellbed 40% shell
60	65	Shellbed 70% shell
65	68	Coarse shells, gravels
68	72.6	80% shell/coarse gravel 30mm
72.6	72.8	Silty sand
72.8	82	Fine sands, some shell
82	83	10% shell/ sand
83	110	Consolidated shell - soft shell - rock
110.3	110.7	Grey soft rock
110.7	111.6	Harder black rock

Model layers: Layer 1 - Sand/Silt; Layer 2 - Upper Shellbed; Layer 3 - Sand; Layer 4 - Lower Shellbed

Mapua Orchard Bore
(Drilled on 19 April 2017)

From (mBGL)	To (mBGL)	Lithology
0	6	Brown dune sands
6	12	Green/grey sands
12	15	Black sandy peat/silts
15	24	Fine grey sands
24	25	Brown organic silts
25	28	Brown fine sand, silica
28	29	Peat/timber
29	40	Silica sands/brown sands
40	44	Fine grey sands/silica
44	47	Brown sands/organic silts
47	48.5	Grey sandy silt
48.5	60	Clean fine grey sands, Mica
60	62	Grey sands, flecks of organics
62	82	Dark grey sands, some black sand
82	83.2	Fine black/grey sand
83.2	86	30% Medium shell
86	87	50% Medium shell
87	91	60% Medium shell
91	94	Fine sand, traces of shell
94	97	60% Medium/ coarse shell, a few lenses of silt. Balance sand
97	98	50% M/c blk shell
88	99	60% M/c blk shell
99	101	90% Medium/coarse black shell
101	102	Fine grey sand
102	103	90% Coarse blk shell
103	104	70% Coarse blk shell
104	105	50% Coarse blk shell
105	106	25% Coarse blk shell
106	107	40% Coarse blk shell
107	108	30% Coarse blk shell
108	110	Fine grey sand, shell fragments
110	111.4	30% Coarse shell
111.4	112	Dark grey rock

Model layers: Layer 1 - Sand/Silt; Layer 2 - Upper Shellbed; Layer 3 - Sand; Layer 4 - Lower Shellbed

Largus Orchard Bore
(Drilled on 12 April 2017)

From (mBGL)	To (mBGL)	Lithology
0	1	Golden dune sand
1	4.5	Peat and timber
4.5	18	Brown/green fine sands
18	42.7	Grey/white sands
42.87	45.5	Firm grey sandy silts
45.5	47	Brown peaty silts
47	53	Brown/grey fine sands
53	63	Green/grey fine sands, some thin bands fine gravel
63	67.5	Sandy silt, flecks of shell
67.5	68.5	Cleaner silt, shell
68.5	73	Grey silt
73	74.1	Cleaner sand, shell
74.1	76	60% Coarse shell
76	77	20% Coarse shell
77	78	50% Coarse shell
78	80	20% Coarse shell
80	83	70% Coarse shell
83	84	50% Coarse/med shell
84	86	50% Medium shell
86	88	30% Medium shell
88	89	50% Medium shell
89	91	30% Medium shell
91	93.6	50% Coarse/med shell
93.6	93.8	Light green silt
93.8	105	Firm, clean, grey/white shell rock
105	106	Softer mushy shell rock
106	107	Clean firm shell rock
107	110.9	Softer mushy shell rock

Model layers: Layer 1 - Sand/Silt; Layer 2 - Upper Shellbed; Layer 3 - Sand; Layer 4 - Lower Shellbed

Figure 2. Lithological unit classification from example borelogs.

2.2 Aquifer Hydraulic Parameters

Groundwater is found throughout the unconsolidated sedimentary materials, although the materials show strong variation in their ability to store and transmit water, primarily due to grain size, cementation, weathering and compaction.

Numerous test pumping exercises for irrigation take resource consent applications have been undertaken over the years. These have been summarised in the reports of HydroGeo Solutions (2000), SKM (2007a), SKM (2010) and more recently by Lincoln Agritech (2015). Data from these reports has been reproduced in tables in **Appendix A**, and in conjunction with the results for Layer 2 and Layer 4 testing undertaken by WWA (**Appendix D**) is summarised in accordance with our conceptual model presented in the previous section in **Table 2**.

The testing results indicate that hydraulic conductivities in the shellbed aquifers are an order of magnitude higher than the sand aquifer in general. The storativity values tend to decrease with depth and compaction, with the exception of the lower shellbed, which appears to have slightly higher storativity than the upper shellbed, which is likely due to the coarser grain size.

Table 2. Summary of previously measured and modelled hydraulic properties for WWA layer conceptualisation.

Unit	K_x (m/s)			S (-)		
	Min	Max	Arithmetic Mean	Min	Max	Arithmetic Mean
Layer 1 - Sand / silt	1.0E-05	1.1E-04	8.4E-05	0.0002	0.015	0.0096
Layer 2 – Upper shellbed	2.1E-04	7.3E-04	3.65E-04	0.0002	0.0004	0.0003
Layer 3 - Sand	Assume same as Layer 1			Assume same as Layer 1		
Layer 4 – Lower shellbed	1.3E-04	7.3E-04	4.4E-04	0.0003	0.0044	0.0016

2.2.1 Perched Aquifers and Aquifer Confinement

There is anecdotal evidence of localised perched water within the wetlands and lakes in the area. For example, Lake Waiparera, located in the southwest of the study area has an average lake stage of 33.8 mAMSL, yet the groundwater level estimated from an adjacent bore is around 7 mAMSL.

Before the intervention of man, lake and wetland complexes that formed in dune swales were self-accentuating over time. As sediment fines were washed into the swale with stormwater runoff, bed sediment permeability progressively decreased, which led to widening and deepening of the wetland or lake. As this progressed, acid conditions in the wetland environment led to dissolution of metals and as the sediment substrate conditions shifted from aerobic to anaerobic (or reducing conditions) and pH became more neutral, subsequent precipitation of the dissolved metals occurred as metal hydroxides, particularly iron hydroxide. Iron hydroxide is the primary constituent of iron humus pan or iron pan, which is the main factor (along with peat and silt deposits) in restricting vertical drainage in the Aupouri aquifer.

The aquifer system is unconfined at the surface but behaves in a manner that suggests a progressive degree of confinement with depth (leaky confinement). There is no well-defined regionally extensive confining layer but there are numerous low-permeability layers (e.g. iron pan, brown (organic) sand, silt, peat) that vary in depth and thickness, which over multiple occurrences collectively provide a degree of confinement that lends to the development of vertical pressure gradients, as discussed in **Section 2.6**.

Towards the east coast, there is strong evidence for groundwater levels in nested piezometers showing the aquifer is confined by buried hardpans, similar to the surficial hardpan on the older foredunes but much older, and deeply buried by successive accumulations of sand (Hicks, et. al., 2001).

Long-time local farmers and orchard developers provided the following anecdotal information:

- "The iron pans vary in both thickness and number of layers" (*pers. com.* Stanisich, Broadhurst, Hayward).
- "There are multiple layers of pan at varying depths and our pan breaking for planting rows only seems to create vertical drainage at the top" (*pers com.* McClarnon).
- "Monitoring of bores screened in different zones during test pumping often show no effect at shallower levels to the pumping bore, indicating some separation of zones" (*pers. com.* Stanisich, Hayward).
- "From bore logs, iron pans are often recorded as consolidated brown sands. However, these may not be the only confining layers. Consolidated mica sands and silts are also good barriers" (*pers. com.* Stanisich).

2.3 Kaimaumau Wetland

During this project, Department of Conservation expressed concern regarding the water table in the wetland, and its hydrological connection to the drains and regional groundwater system in this area, especially the effect of proposed additional groundwater extraction from the deep aquifer on the hydrologic condition of the surface wetland.

The Kaimaumau wetland is classified as a bog system (Wildland Consultants, 2011), and by definition, the water of bog system is mostly contributed from precipitation rather than surface runoff, groundwater or streams (EPA U.S.,2016).

It has been historically observed that the water levels in the wetland were very responsive to the seasonal climate variation, given the water supply from the rainfall and the significant presence of an impermeable hardpan beneath the wetland (Hicks, et. al., 2001). The hardpan serves as a flow barrier and prevents the upward movement of deep and shallow groundwater. Groundwater springs in the Motutangi Swamp were also observed at its western edge that intercepts with an unconfined aquifer, and the water leakage from the wetland to the shallow groundwater system is likely along its eastern margin (Hicks, et. al., 2001).

It was demonstrated during a Northland Catchment Commission groundwater resources investigation that there is an artesian aquifer deep beneath the Aupouri Peninsula (Northland Regional Council, 1991). The distribution of head in the boreholes suggested that the groundwater outflows to the west and east coastline, and the aquifer is deeply buried by successive sand layers, and confined by the buried hardpans toward the east. The recharge of the wetland from the deep aquifer becomes possible when the successively buried hardpans are breached, but there was no evidence showing the upwelling of deep groundwater to the surface (Hicks, et. al., 2001).

If there is a direct and dynamic connection between the deep shellbed and surface drains and wetlands, specifically a groundwater up-flow from the pressurised artesian shellbed to the wetland, groundwater extraction from the shellbed aquifer may reduce up-flows to the wetland and thus impact on the water levels and flows in the surficial drains and wetland. To address the concern, a field investigation and groundwater isotope study using radon was undertaken.

2.3.1 Radon Analysis

The naturally occurring Radon-222 (Rn-222) isotope has been used as an environmental tracer to study the interaction between surface water and groundwater. Rn-222 is generated from the decay of uranium which is present in almost all rocks and soils, and this leads to the abundance of Rn in groundwater system. As a contrast, the rapid loss of Rn to the atmosphere through degassing results in almost negligible concentrations in surface water (Martindale, 2014). The distinct Rn concentration differences between groundwater and surface water facilitate its application in hydrological tracer studies. Surface water with a significantly higher Rn concentration (>0.5 BqL^{-1}) indicates the location where groundwater discharges to surface water (Geological and Nuclear Science Ltd (GNS)).

Water samples were taken at selected drains adjoining and within the wetland, and a groundwater sample was taken as a comparison (**Figure 3**). The collected water samples were delivered to and analysed by the Tritium and Water Dating Laboratory at GNS.

Table 3 shows the Rn concentration in the water samples obtained. The Rn concentration in the groundwater sample collected from the shellbed aquifer in the Stanisich cow shed bore (6.3 BqL^{-1}) is significantly higher than the concentration in the surface water samples, which range between 0.1 BqL^{-1} and 2.6 BqL^{-1}, with a median value of 0.85 BqL^{-1}.

The sample collected at the Pirini Stream, which drains the southeast of Kaimaumau wetland, has a Rn concentration that is very low (close to the detection limit – 0.1 BqL^{-1}) indicating no interaction with groundwater at this location. Similarly, the Salles upstream and middle sampling sites, which drain from the southwestern side of the Kaimaumau swamp both have low values at 0.2 and 0.1 BqL^{-1} respectively, indicating it is unlikely the water coming from the swamp has a significant groundwater component. However, it is interesting to note that the drain appears to be picking up some shallow groundwater flow as it moves downstream into lower-lying areas towards the coast.

It would appear that the drains that cross farmland in the west of the Motutangi area and flow towards the northern end of the Kaimaumau wetland, particularly Selwyn and Seymour drains, potentially show some influence of groundwater given as their values are around 1 BqL^{-1}, which is consistent with anecdotal information from the locals, who indicated that the area is perennially wet and receives groundwater seepage from the base of the sand dunes.

Similarly, Okohine drain in the southwest, which drains low-lying farmland also appears to show a small amount of groundwater input given its Rn concentration of 1.7 BqL^{-1}.

In summary, the analysis shows that the deeper groundwater has a significantly different Rn signature than the surface water. Given the Rn information and the anecdotal and hydrogeological knowledge of the iron pans and other small confining layers, it is unlikely that the deep shellbed aquifer has a strong hydrological connection with the surface drains and wetlands.

Figure 3. Location of surface water samples for Rn analysis. (See A3 attachment at rear).

Table 3. Radon concentration in surface water and groundwater samples*.

Site ID	Rn Concentration (BqL^{-1})	$\pm 1\sigma$	Type	Sampling date
Bryan Drain	0.6	0.1	Surface water	21/02/2017
Selwyn Drain	1.1	0.1	Surface water	22/02/2017
Seymour Drain	1.1	0.1	Surface water	22/02/2017
Pirini Stream	0.1	0.0	Surface water	21/02/2017
Salles Upstream	0.2	0.1	Surface water	21/02/2017
Salles Drain (before intersection with Waikaramu Drain)	0.1	0.3	Surface water	21/02/2017
Salles Downstream	2.6	0.0	Surface water	21/02/2017
Okohine Stream	1.7	0.2	Surface water	21/02/2017
Stanisich Bore (Cow Shed)	6.3	0.5	Groundwater	22/02/2017

Note: * Radon is measured by liquid scintillation counting using Quantulus low-level counters. Quoted errors is one sigma standard measurement error. The detection limit for radon is approximately 0.1 BqL^{-1}.

2.4 Recharge

2.4.1 Background Data

The proportion of rainfall that infiltrates the soils and ultimately recharges the groundwater system is relatively large, due to the high infiltration capacity of the sandy soils. The model used in the Aupouri Aquifer Review by Lincoln Agritech (2015) suggested an annual recharge rate of 540 mm for the dune sand beneath Aupouri forest, accounting for 43% of annual rainfall, and 30% of annual rainfall recharges to the Kaitaia Swamp. In other groundwater studies for the region, the percentage of rainfall recharging the dune sands ranged from 10.4% to 43.7%, while for the floodplains the recharge range was 4.2% to 12.0% of annual rainfall (HydroGeo Solutions, 2000; SKM, 2007a; SKM, 2007b).

2.4.2 Estimating Recharge

The Soil Moisture Water Balance Model (SMWBM) was used to estimate groundwater recharge in this study. This model had been successfully applied in predicting groundwater recharge under coastal conditions (Mackie and Williamson, 1998; HydroGeo Solutions, 2000; SKM, 2007a; SKM, 2007b). In this study, a recent modification to the code incorporating vadose zone functionality has been utilised.

This was required because groundwater levels in observation bores in the model area often show a delayed response to rainfall, particularly for the inland piezometers with greater depth to groundwater (i.e. more extensive vadose zone). This is due to the delay between the water infiltrating the soil and time taken to drain vertically through the unsaturated zone to the water table. To account for this delay, groundwater recharge was simulated using the vadose zone module in the SMWBM.

Daily rainfall data and mean monthly pan evaporation data were used in the SMWBM to simulate the transient rainfall recharge. Further details of the model are included in **Appendix A**.

Based on the distribution of different soil types and landuse within the area, three primary recharge zones were identified, as follows:

- ***Coastal sand zone*** – loose and permeable sand situated on the east and west coast of the model domain. This dune sand has high soil infiltration and percolation rate, medium soil moisture storage, and limited surface runoff.

- ***Weathered sand zone*** – Inland sands are progressively more consolidated with distance from the coast. The weathered sand zone, located in the central part of the model domain, has a relatively high soil infiltration (albeit less than the coastal sands) and moderate soil moisture storage.

- ***Plain zone*** – the plain zone represents the peat overlaying iron pan surface deposits in Kaimaumau wetland area located at the southeast of the model domain. This zone has low infiltration capacity and medium soil moisture storage, with the iron pan restricting the vertical drainage of water, which leads to saturated soils and a higher surface runoff component.

Table 4. The average annual water mass balance for each recharge zone from the SMWBM.

Recharge zone	Groundwater recharge	Evapo-transpiration	Runoff	Description
Coastal sand zone	43%	52%	5%	Loose sand, high infiltration capacity, low surface runoff
Weathered sand zone	38%	54%	8%	Relatively more compacted sand, high infiltration capacity, reduced surface runoff
Plain zone	10%	56%	34%	Low infiltration capacity, medium soil moisture storage, high surface runoff

2.5 Drainage

In the lower-lying farmland area, there is a man-made drainage network that typically connects to short fetch streams that discharge to the coast. The drains where installed to lower the shallow groundwater table to promote more manageable farming conditions, but also are likely to have had an impact on margins of the adjacent Kaimaumau wetland. The Kaimaumau wetland appears to have five sub-compartments, each individually draining to one of the coastal streams (**Figure 4**).

Figure 4. Drainage map. (See A3 attachment at rear).

2.6 Groundwater Level Data

There are five multi-level piezometers constructed by the Northland Catchment Commission in the 1980s and two single piezometers that are currently maintained for groundwater monitoring purposes in the Houhora area by the Northland Regional Council (**Figure 5**), collectively defined as the Hukatere piezometer transect.

Figure 6 shows a not-to-scale cross-section along the transect with the bore depths and static water levels shown. The groundwater gradient shown from each piezometer nest is governed by hydrogeological position on the landscape, i.e. recharge or discharge zone. For piezometers that are close to the groundwater divide (Browne piezometer) the observed vertical downward gradient indicates the occurrence of recharge from the surface to the deep aquifers. The piezometers near the coast at the waterfront showed an upward flow potential, indicating groundwater discharge to the sea.

Figure 5. Location of NRC piezometers. (See A3 attachment at rear).

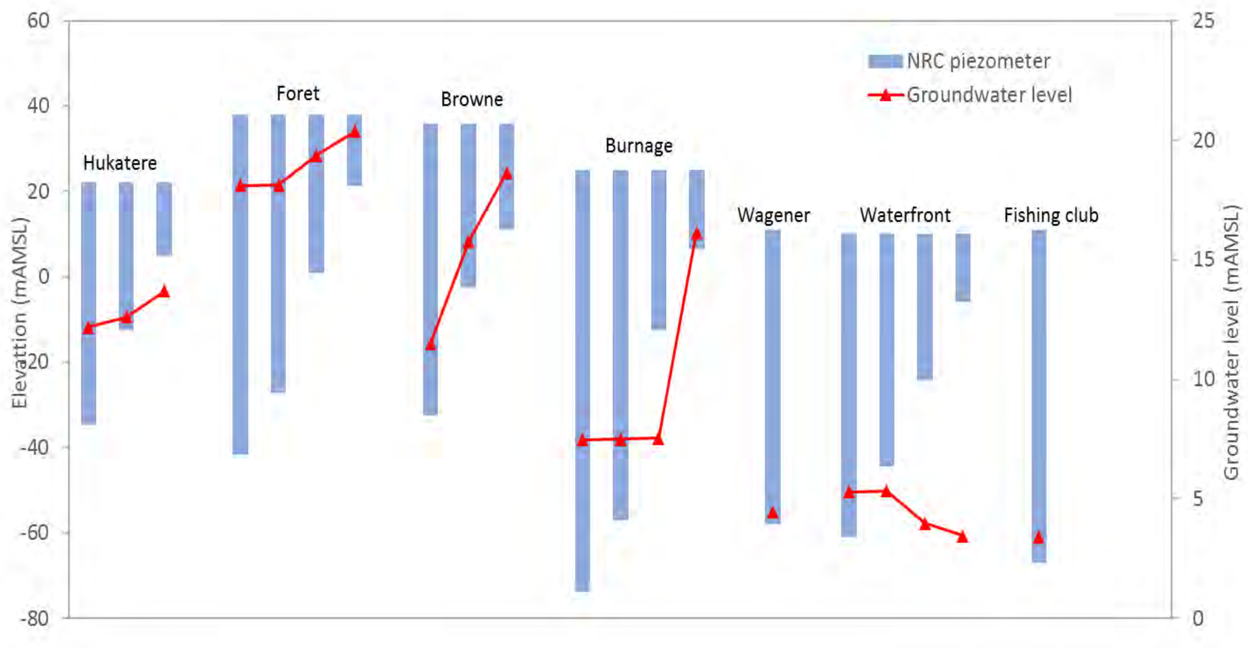


Figure 6. Mean groundwater levels of piezometer nests at Houhora.

The Burnage piezometer 1, 2 and 3 had similar mean groundwater level and temporal variation, and it is likely there is leakage within the piezometer completion at this location. Thus, these three piezometers were excluded in the model calibration.

2.7 Groundwater Abstraction

Figure 7 shows the location of existing and newly proposed groundwater abstraction consents.

The current level of water allocation from the Motutangi-Waiharara regional aquifer is a peak daily take of 11,810 m^3/day and 1.8 million m^3 (Mm^3) per annum from 35 groundwater take consents. In the 25-year period between November 1987 and December 2012, 27 groundwater consents with a total peak daily allocation of 5,786 m^3 were granted. Most of the consents are required to irrigate avocado farms in the region.

The total allocation from the Motutangi-Waiharara regional aquifer should the MWWUG consents be granted (16,775 m^3/day) equates to 28,585 m^3/day.

Figure 7. Location of existing and proposed groundwater take bores. (See A3 attachment at rear).

2.7.1 Actual Use Dataset

A historical actual use dataset is required to calibrate a groundwater model and to use the model to simulate the effects of groundwater extraction on the aquifer and surface water resources.

The SMWBM Irrigation Module was used to develop an estimate of historical actual use. The exercise combined typical irrigation scheduling (Oct - Apr) and commencement dates the consents where granted, along with an allowance for orchard development and tree growth rates to maximum water requirement. Details and results of the development of the actual use dataset are provided in **Appendix C,** while **Figure 8** shows the development sequence of water take consents and **Figure 9** shows the total annual volume of simulated actual use.

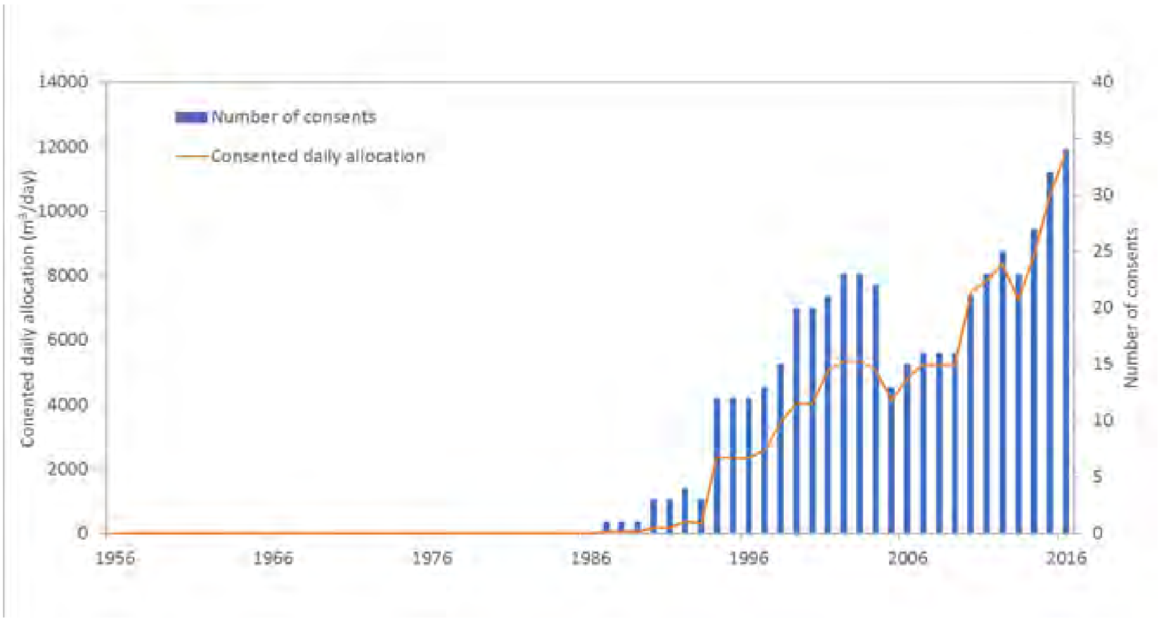


Figure 8. Water take consents issued (number and daily volume) by calendar year.

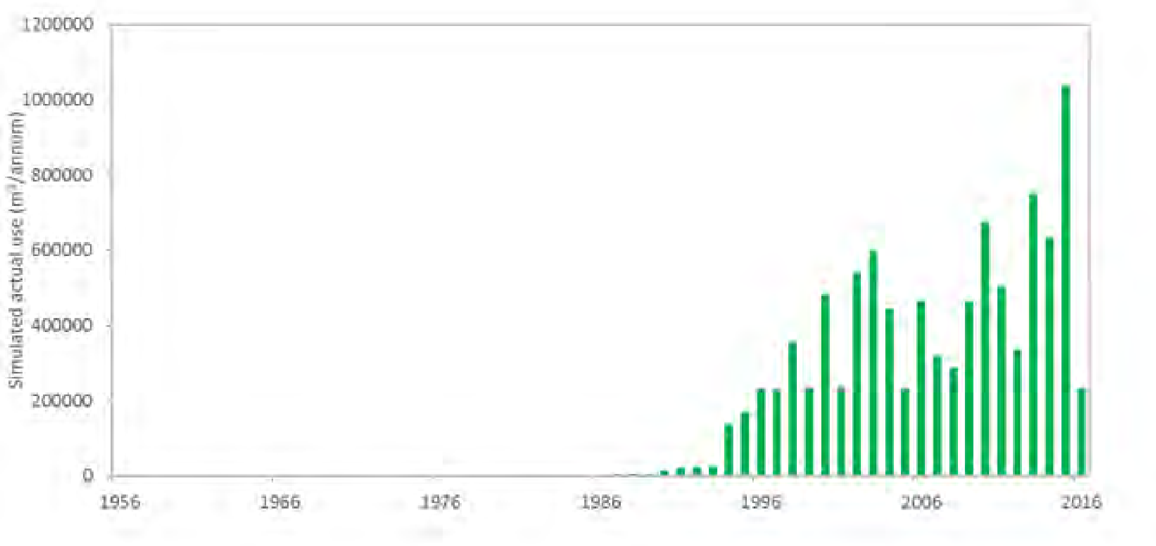


Figure 9. Simulated actual use (m³/annum partial groundwater use in 2016 due to the end of the model simulation).

3. Model Configuration

The MODFLOW Unstructured Grid (MODFLOW-USG) developed by the United States Geological Survey (USGS) was utilised within the GMS10.2 modelling platform to construct the groundwater flow model in this project. The unstructured discretisation of the model domain provides the capacity of fitting irregular boundaries into the model, and increasing the resolution to the areas of maximum interest and decreasing resolution in other areas, hence increasing the efficiency in model computation compared to the equivalent regular MODFLOW grid.

3.1 Model Domain

The model was constructed based on 6 layers, consisting of 90,048 active Voronoi cells (or polygons) and covers an area of 203 km^2. The model was discretised using different refinement schemes for major drains and bores. Finer resolution at each bore is achieved by setting the maximum radius at the refinement point of 20 m. This spatially varying discretisation approach could reduce model computational time, without losing the model resolution at the point of interest (**Figure 10**).

Figure 10. Plan view of unstructured model grid discretisation (See A3 attachment at rear).

The boundary conditions included in the model are constant head, general head, drain, and no-flow boundaries.

3.1.1 Constant Head Boundaries

The constant head boundary was assigned an elevation of 0 mAMSL along the eastern and western coastlines in Layer 1 of the model to represent the mean hydraulic head of the ocean at these locations.

3.1.2 General Head Boundaries

A general head boundary (GHB) is typically used to simulate the flow interaction between groundwater and external water sources to the model domain.

Lake Waiparera, located in the southwest of the model domain, was observed to have an average lake stage of 33.8 mAMSL. The groundwater level estimated from the adjacent bore was around 7 mAMSL, and this suggest that Lake Waiparera is perched above the regional groundwater system. This is also consistent with the conclusion made in the Aupouri Aquifer Review Report that the main aquifer is situated well below the surface of Lake Waiparera (Lincoln Agritech, 2015). The general head boundary was assigned to the lake to simulate lake water seeping to the underlying groundwater system, with consideration of the impedance provided by the lower-permeability lake bed sediments and/or iron pan.

The cells along the coastline from Layer 2 to 4 were also assigned with GHBs. The head values for all the cells were assigned as 0 mAMSL and the conductance value of each layer decreases with the depth to reflect the progressively increasing disconnection with the free water surface of the ocean (i.e. the impedance of flow to the ocean floor increases with depth) and also the resistance of higher-density seawater offshore.

3.1.3 No-Flow Boundaries

No-flow boundaries were assigned to cells located on the northern and southern boundaries of the model domain. Groundwater is expected to predominantly flow parallel to these boundaries from areas of high topography to low-lying coastal areas. The base of the model was also assigned a no-flow boundary on the basis that the significantly lower permeability of the basement rocks has negligible bearing on the overall flow budget of the aquifer system above.

3.1.4 Drain Boundaries

Drain boundaries were assigned in the model to simulate the groundwater discharged to the major surface drains, and to simulate a seepage face within the wetland area. The drain bed elevations were derived from the Digital Elevation Model (DEM), with a nominal depth assignment depending on locality as follows:

- ***Drains in farmland*** – DEM minus 2 m;
- ***Drains in wetland*** – DEM minus 1 m; and
- ***Seepage face drains in wetland*** – DEM;

The conductance value of the drains was set relatively high to reflect limited impedance to water removal (or drain functionality), to account for the significant water drainage in the farmland area and flow of water over the surface in the wetland.

3.1.5 Well Boundaries

Well points were used to represent the groundwater extraction from within the model. The model cells were assigned with negative pumping rate to represent the groundwater extraction from the model.

3.2 Simulation Package

3.2.1 Sparse Matrix Solver

The Sparse Matrix Solver (SMS) package was utilised to solve linear and non-linear equations. A maximum head change of 0.01 m between iterations was set as the model convergence criteria. Default values were used for the maximum number of iterations for linear and non-linear equations.

3.2.2 Ghost Node Correction Package

MODFLOW-USG is built on the control volume finite difference formulation, which enables the model cell to be connected to an arbitrary number of adjacent cells (Panday et al., 2013). However, this formulation will be reduced to a lower order of approximation, when the line between two connected nodes does not bisect the shared face at right angles, which will lead to errors in the simulation (Edwards, 1996). To account for this, the ghost node correction package was utilised to improve the simulation results by adding higher order correction term in the matrix solver. Ghost nodes are implicitly built into the simulation through the interpolation factors. The simulated head is systematically corrected through the ghost nodes to achieve a correct solution.

3.3 Model Layer Configuration

3.3.1 Layer Geology

The model comprises six layers that are used to represent the varying geology located in the area. The geological units assigned to each layer of the numerical model are shown in **Table 5**.

Table 5. Geological units in the model conceptualisation.

Model Layer	Stratigraphic Layer	Name	Description	Locality
1-3	1	Coastal sand	Loose coast sand, highly permeable	Western and eastern coastal strips.
	1	Weathered sand	Weathered dune sand, moderately compacted	Inland hilly or rolling country areas.
	1	Plain zone	Peaty and clayey sediments, low permeability	Inland low-lying plain areas.
4	2	Shellbed	Sand presented with shells, highly permeable	Throughout model, albeit thickness varies.
5	3	Fine sand	Old sand deposits, fine sand, moderately permeable	
6	4	Shellbed	Sand presented with more shells, highly permeable	

Model layers 1-3 are used to represent a complex stratigraphic unit comprising alternating sands, silt, peat, clay and iron pans in a bulk sense (not discretely). It is very difficult to define with any degree of accuracy the sub-division in the stratigraphic layers of these deposits. For modelling purposes, the base of model layer 1 was defined as an elevation of -1 mAMSL, while the base of model layer 2 was defined as the base of model layer 3 plus 25 m.

All model layer bases other than model layer 1 and 2 confirm to stratigraphic interpolations as discussed in the following section.

3.3.2 Layer Elevations

The top and bottom elevation for the geological unit contacts were identified from the reliable bore logs in the area. The elevations for each unit were then interpolated using the Kriging geospatial method to generate a digital elevation surface. During interpolation, rules were applied so that geological layers did not overlap, and the surface is stratigraphically continuous.

The geometry of the basement rocks has been recognised through interpolation of the basal contact from the available bore logs in the area. **Figure 11** shows the elevation contours of the interpolated basement surface, which was assigned to base of model Layer 6 (i.e. the model bottom).

Figure 11. Basement rock elevation contours (model Layer 6 base). (See A3 attachment at rear).

NRC (1991) and Lincoln Agritech (2015) identify a significant displacement in the basement structure, inferred to be associated with a NW-SE trending fault crossing the southern extent of the model domain. The implication of potential displacement is either increased or reduced aquifer storage volume for the down- and up-thrusted side of the fault, respectively. While the location and nature of such a structural feature remains uncertain, we consider it does not have significant bearing on the model configuration and utility for the following reasons:

- In the south-eastern portion of the model the inferred trace of the fault underlies the Kaimaumau swamp, where there are no groundwater users, hence the depth to basement in this area is relatively insensitive from a groundwater development and effects on other users perspective; and
- In the northern portion of the model the inferred fault crosses an area of high intensity of drill hole data (Houhora-Hukatere). Consequently, there is excellent ground truthing in this area, which means i) we have high confidence in the interpolated basement elevation in this area, and ii) the fault displacement would not appear to be a significant feature.

Four geological cross-sections were developed from the kriged surfaces in west to east (W-E) and north to south (N-S) directions to demonstrate the relative thickness of each geological unit. The locations of the cross-sections are shown in **Figure 12** and the cross-sections themselves are shown in **Figure 13** to **Figure 16**. The constructed model grid based on the interpolated layer elevations is shown in **Figure 17**.

Figure 12. Hydrogeological cross section locations. (See A3 attachment at rear).

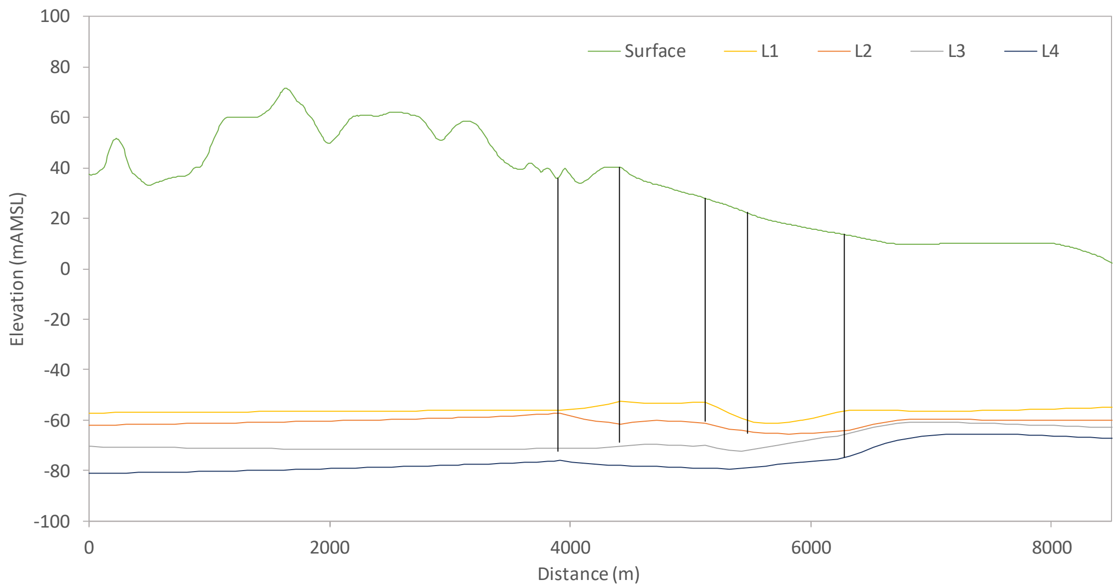


Figure 13. Interpolated cross-section at W-E (1).

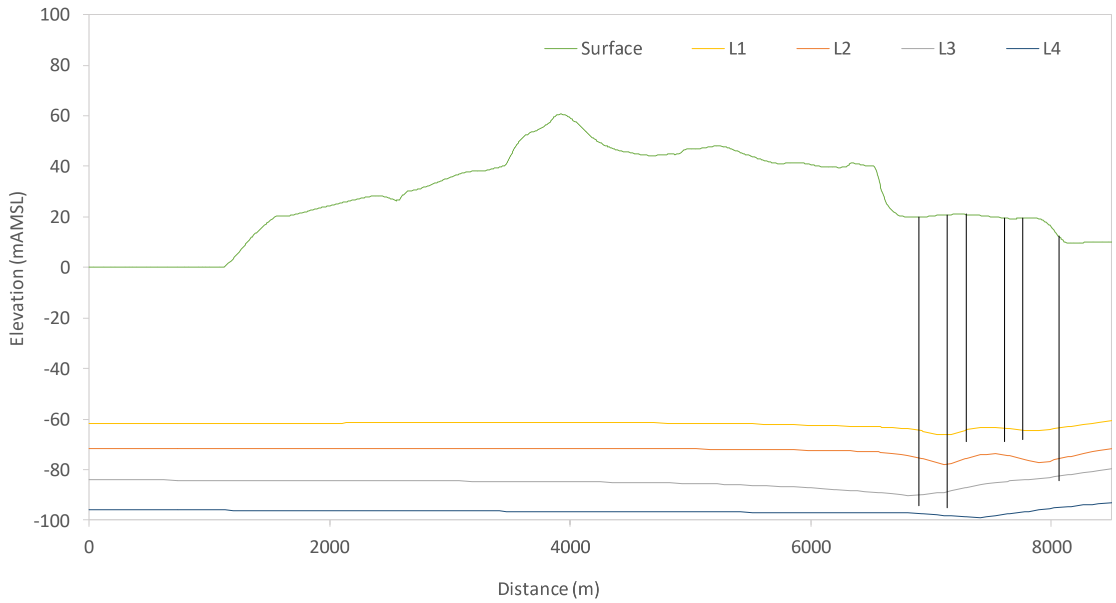


Figure 14. Interpolated cross-section at W-E (2).

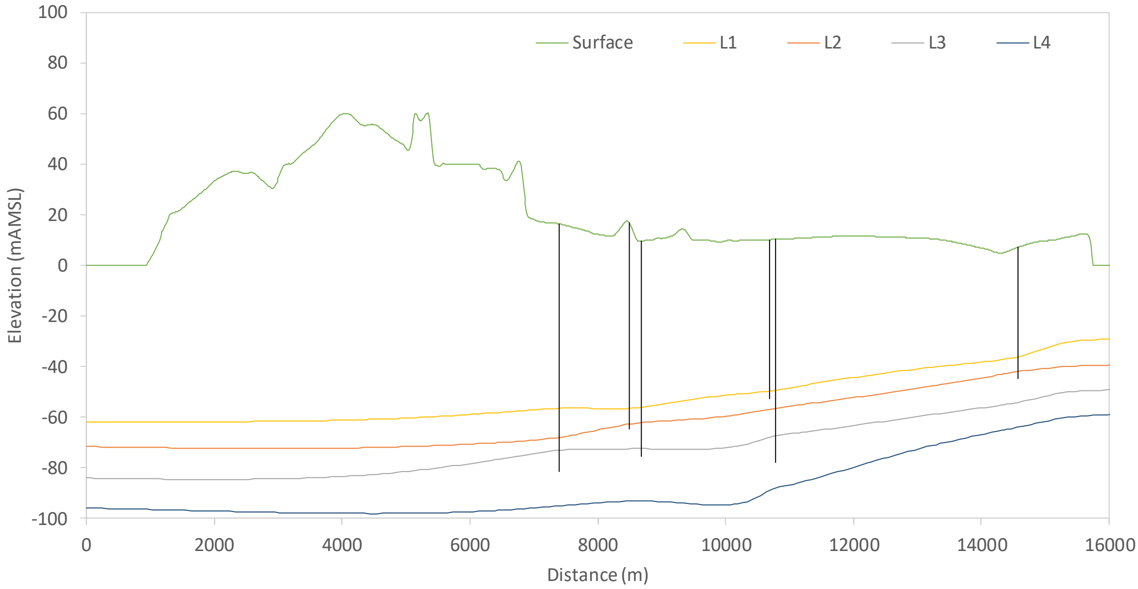


Figure 15. Interpolated cross-section at W-E (3).

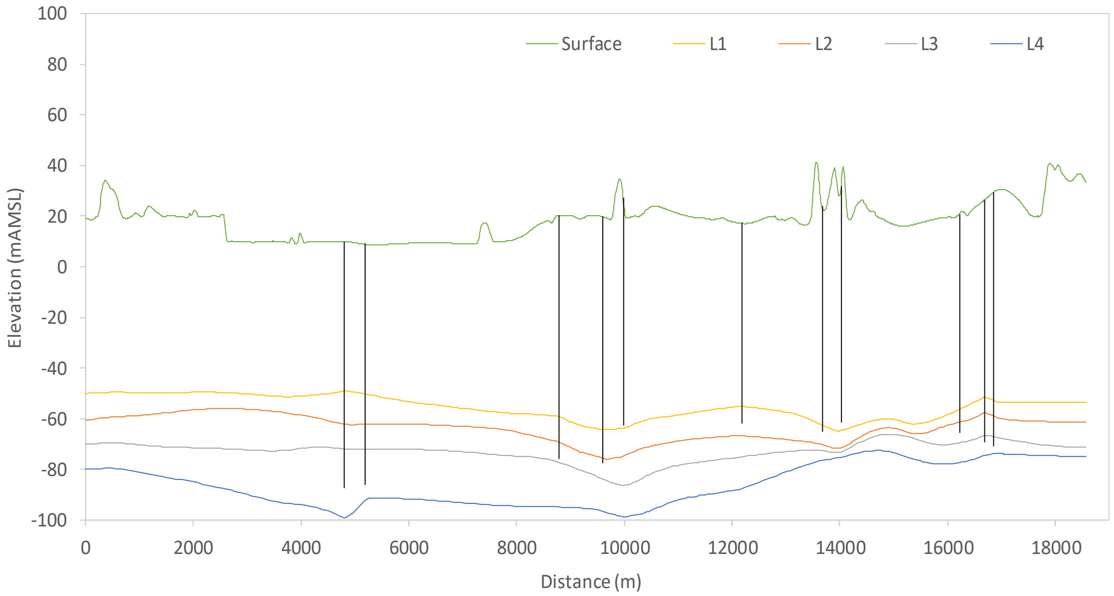


Figure 16. Interpolated cross-section at N-S (4).

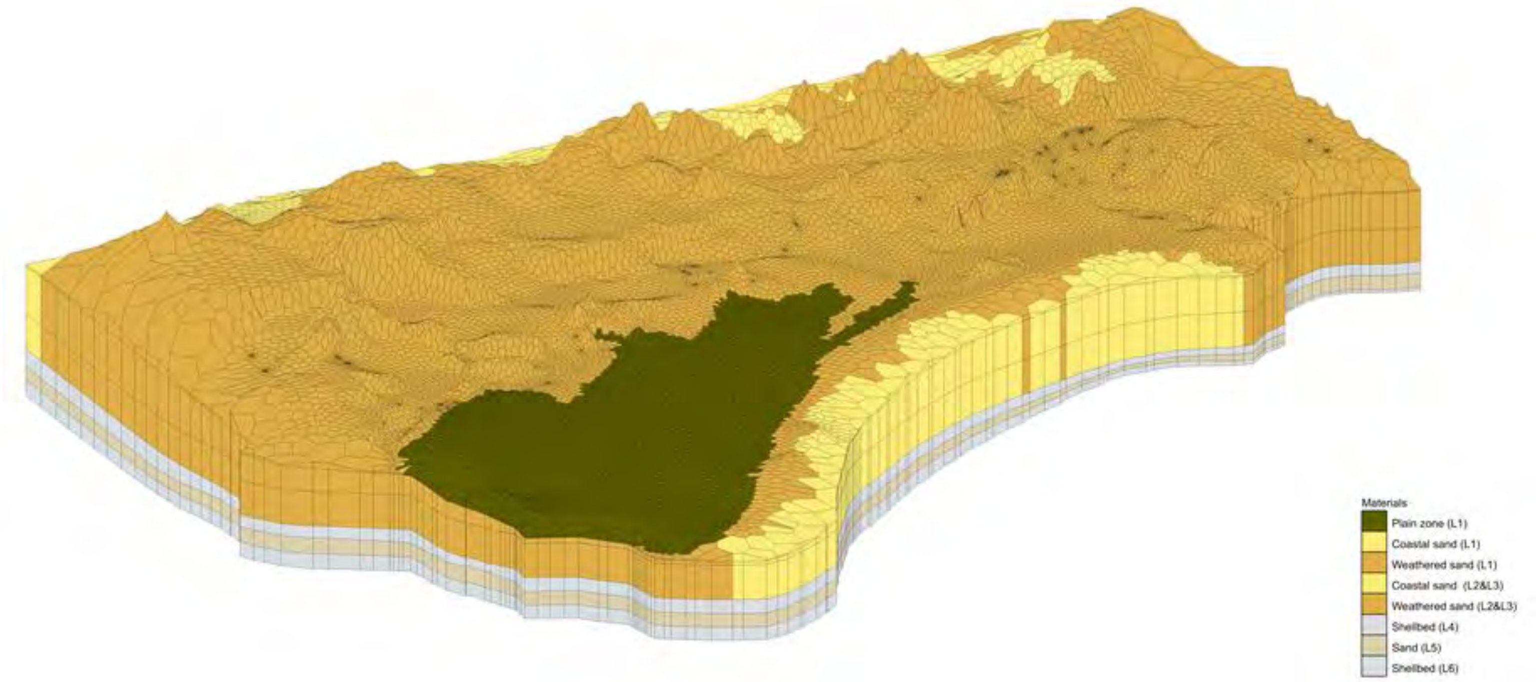


Figure 17. MODFLOW grid with vertical magnification of 20.

4. Model Calibration

The model calibration was conducted by manually changing the model hydraulic parameters to achieve an acceptable fit to measured groundwater levels. Groundwater recharge was not considered a calibration parameter.

4.1 Observation Points

The piezometers used for calibration of the model are shown in **Figure 5** and the key properties of the piezometers relevant to model calibration are summarised in **Table 6**. The piezometers are mostly nested piezometer configurations comprising adjacent standpipes installed to different depths or aquifer levels. The observation points from these piezometers were predominately located in the stratigraphic layer 1, which meant that the vertical gradients observed in these shallow(ish) piezometers would require multiple layers with vertical anisotropy to be incorporated in the model to simulate the vertical hydraulic gradients (as were discussed in **Section 2.6**). To achieve this, a finer vertical discretisation of the model was required, and this was a key driver for splitting stratigraphic layer 1 into three model layers.

Table 6. Summary of piezometers used in calibration.

Site	Piezometer	Mean groundwater level (mAMSL)	Standard deviation (m)	Top of screen elevation (mAMSL)	Model Layer
Waterfront	4	3.45	0.36	-6	2
	3	3.98	0.36	-24.2	2
	2	5.32	0.28	-44.5	3
	1	5.29	0.29	-60.9	5
Hukatere	3	13.70	1.17	4.8	1
	2	12.60	1.08	-12.6	2
	1	12.18	1.05	-34.8	3
Forest	4	20.37	1.01	21.3	1
	3	19.37	1.21	0.8	1
	2	18.12	1.10	-27.2	2
	1	18.10	1.10	-41.8	3
Burnage	4	16.14	0.71	6.5	1
	3	7.53	0.36	-12.5	-
	2	7.49	0.37	-57	-
	1	7.47	0.37	-73.8	-
Browne	3	18.64	0.92	11.1	1
	2	15.77	0.81	-2.5	2
	1	11.50	0.77	-32.4	3
Wagener at Golf ball	1	4.46	0.28	-58.3	4
Fishing Club at Houhora	1	3.42	0.63	-67.1	6

4.2 Steady-State Calibration

A steady-state model was developed and calibrated to validate the conceptualisation of the groundwater flow model. The objective of the calibration was to obtain approximate values of the model parameters, and to obtain initial heads for transient model simulation.

The average water levels from 17 piezometers registered on the NRC bore database were used as the calibration targets. The simulated head is plotted against the observations **(Figure 18**). The steady-state simulation has a mean head residual of 0.20 m, and root mean square error (RMSE) of 3.1 m, which is approximately 15% of the model range. However, this value includes the Fishing Club bore, which is not consistent with the Waterfront bores. More emphasis is placed on the transient calibration goodness of calibration fit, which is discussed in **Section 4.3**.

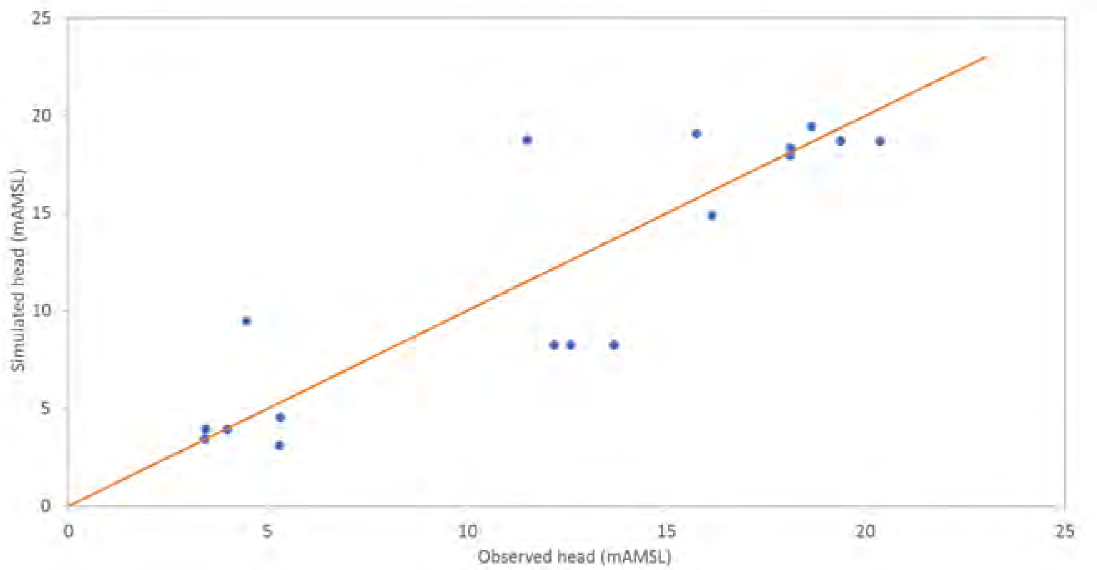


Figure 18. Simulated head versus observed head.

4.3 Transient Calibration

The model was simulated approximately 150 times to obtain a satisfactory calibration. Each transient simulation takes 30 minutes to run, and post processing of results takes 3 minutes, hence a cycle time of approximately 33 minutes for each model simulation. This cycle time enabled a significant number of calibration and sensitivity assessment runs to be undertaken.

After each run, simulated heads from the relevant model layer and cell were extracted and processed with Python code that automatically developed hydrographs, which permitted rapid comparison of simulated versus measured data.

The transient calibration setup is described in the following sections.

4.3.1 Stress Periods and Time Steps

The model was simulated in transient mode from 1/08/1956 to 31/08/2016. The simulation was subdivided into 442 stress periods, where imposed stresses (e.g. recharge and pumping) remain constant. The number of stress periods was selected on the basis of i) temporal variation of the transient dataset values; and ii) computational time. The resulting stress period lengths ranged from 7 to 212 days. Stress periods were locked on 1 October and 30 April in each year for the start and end of the irrigation season, respectively, to ensure the irrigation demands were distributed to the correct timeframe.

Each stress period consisted of 5 time steps, with head and flow volume in each model cell evaluated at the end of each time step.

4.3.2 Groundwater Pumping

The historical use dataset described in **Section 2.7.1** and shown in **Figure 9** was implemented in the calibration simulations.

4.3.3 Initial Conditions

The transient model used the steady-state model heads as the starting condition. During the transient calibration process, the starting heads were re-set from time to time using average water levels selected from a particular time in the model to reflect average conditions. This enabled the starting condition to better reflect the dynamic head distribution within the model under the imposed set of stresses, and resulted in minimisation of rapid fluctuations in simulated levels and flows at the start of the simulation (i.e. increased stability).

4.3.4 Model Parameters

The calibrated model parameters are shown in Table **6**. The calibrated model parameters are consistent with the results from the field hydraulic testing undertaken on three of the applicant bores in the area (**Appendix D**) and calibrated model parameters used in previous modelling.

The calibrated model hydraulic conductivity for the upper and lower shellbed aquifers are 4.1×10^{-4} m/s and 2.5×10^{-4} m/s, respectively. As shown in **Table 2,** these values are within the range in horizontal hydraulic conductivity measured and modelled in the past (layer 2 and 4). Similarly, for the various sand units, the calibrated model values range from 3.2×10^{-5} m/s to 6.9×10^{-5} m/s, which is consistent with the range in previously documented values shown in **Table 2.**

Table 7. Calibrated model parameters.

Model Geological Units	Model Layer	K_x		Vertical Anisotropy	S_y	S_s
		(m/d)	(m/s)	(-)	(-)	(m^{-1})
Coastal sand	1	4.5	5.2E-05	70	0.3	-
Weathered sand	1	2.8	3.2E-05	90	0.25	-
Plain zone	1	0.1	1.2E-06	15	0.01	-
Coastal sand	2&3	4	4.6E-05	30	-	0.0005
Weathered sand	2&3	3	3.5E-05	80	-	0.0005
Shellbed	4	35	4.1E-04	1	-	0.0016
Sand	5	6	6.9E-05	30	-	0.0005
Shellbed	6	22	2.5E-04	1	-	0.0016

4.4 Calibrated Model Output

4.4.1 Groundwater Levels

As previously stated in **Section 2.6**, groundwater levels recorded within 17 NRC monitoring piezometers were used to calibrate the transient groundwater model. **Appendix E** provides hydrographs and water level maps of simulated groundwater levels plotted against observed data for comparison purposes, and an assessment and commentary on the goodness of fit for each hydrograph is provided in **Table 8**.

The mean residual head is -0.47 m and the geometric mean of the RMSE is 0.99 m, which is 5% of the observed range in groundwater head (19.6 m). A simulated RMSE of less than 10% of the measured range is considered a good calibration.

Table 8. Comparative assessment summary of the goodness of fit between simulated and observed groundwater heads.

Piezometer nest	Location	Piezometer	Layer	Fit		Comments
				Qualitative	RMSE	
Waterfront	Western coastal area	4	2	Good	0.5	Simulated head is slightly higher than the observation. The groundwater level fluctuation is well simulated.
		3	2	Good	0.4	Simulated head is within the range of observation. The groundwater level fluctuation is well simulated.
		2	3	Good	0.3	Simulated head is within the range of observation. The groundwater level fluctuation is well simulated.
		1	5	Good	0.4	Simulated head is slightly higher than the observation. The groundwater level fluctuation is well simulated.
Hukatere	Eastern side, near the coast	3	1	Moderate	1.0	Simulation and observation vary simultaneously, except the observed head shows higher variation.
		2	2	Good	1.0	
		1	3	Good	1.0	
Forest	Northwest, central high topography	4	1	Moderate	1.0	Simulation is slightly lower than the observation.
		3	1	Good	1.1	Simulation and observation vary simultaneously, except the observed head shows higher variation.
		2	2	Good	1.0	
		1	3	Good	0.9	
Burnage	North	4	1	Moderate	1.2	Simulated head is lower than the observation. The groundwater level fluctuation is well simulated.
Browne	North east, low lying area	3	1	Good	0.7	Simulated head well matches the observation near the end of the simulation. The groundwater level fluctuation is well matched.
		2	2	Moderate	1.4	Simulation and observation vary simultaneously, except the observed head shows higher variation.
		1	3	Poor	5.4	Simulated head is significantly higher than the observation. Similar fluctuation is shown from the simulation.

Piezometer nest	Location	Piezometer	Layer	Fit		Comments
				Qualitative	RMSE	
Wagener at Golf ball	North east, low lying area	1	4	Poor	5.9	Simulated head is significantly higher than the observation. This discrepancy was similarly shown in the Aupouri Aquifer Review (Lincoln Agritech, 2015). This discrepancy is further discussed below.
Fishing Club at Houhora	Western coastal area	1	6	-	-	The observed head in Fishing Club piezometer is not consistent with the gradient shown from the adjacent Waterfront piezometers. Excluded from the calibration.

For the inland piezometers (e.g. Hukatere and Forest), the simulated groundwater level fluctuates simultaneously with the observed groundwater level. However, there is a greater variation in the observed groundwater levels.

A potential reason for this are variations in recharge rates in response to land use changes. The groundwater model has been set up with recharge rates that were simulated based on a constant land use over the model period. However, land use changes and the associated spatial distributions of land cover will affect the quantity and quality of water being recharged to the groundwater system. In fact, the plantation forestry felling cycles on the western side of the peninsula may significantly affect the variation of groundwater recharge. In general, compared to bare land, forestry land tends to decrease the groundwater recharge due to increased interception and evapotranspiration.

Changes in land use take time to propagate to the groundwater system. Depending on the climate, geology, intensity and extent of the land use change, recovery of the groundwater system may vary from 3 to more than 20 years (Moore and Wondzell, 2005). In the meantime, this effect on groundwater system is masked by the climate variation.

It is therefore likely that the mismatch in calibration is in fact due to a temporal variation in groundwater recharge in response to land use change. However, detailed historical land cover data was not available. Reconstructing historical land use change would be a separate study in its own right, and it was therefore not possible to incorporate the transient variability of recharge into the groundwater model to reflect the land use change in the area.

4.4.1.1 Comparison against spot data

The simulated groundwater levels were compared with available manual groundwater dip levels for the bores used in the WWA pumping tests (**Appendix D**). Simulated mean groundwater levels were calculated from the transient simulation. As no surveyed ground elevation data were available from the bore locations, ground elevations were estimated from an 8-m digital elevation model (DEM) (LINZ, 2012) for calculating observed groundwater levels with reference to mean sea level. The observed groundwater level data are attached in **Appendix G**, and the comparison is shown in **Table 9**.

Table 9. Comparison between simulated and observed groundwater levels at test pumping bores.

Farm	Bore	Ground elevation (mAMSL)	Depth to static water level (mBGL)	Mean static water level (mAMSL)	Simulated mean groundwater elevation (mAMSL)	Layer
Stanisich	Production bore	20	5.4	14.6	14.2	6
	Monitoring bore 1	20	4.5	15.5	16.2	1
	Monitoring bore 2	27	16.3	10.7	14.8	6
	Monitoring bore 3	20	3.1	16.9	13.7	6
Honeytree	Production bore 1	10	0.6	9.4	9.8	6
	Production bore 2	10	0.6	9.4	10.1	6
	Monitoring bore 1	10	3.1	6.9	8.0	1
De Bede Ltd	Production bore	19	7.1	11.9	13.3	6

To investigate the uncertainty in the estimated ground elevations from the DEM, ground elevations were also estimated for the NRC piezometers for which surveyed elevations of the top of casing were available (see **Table 10**).

Table 10. Comparison of top of casing and estimated ground elevations for NRC bores.

Piezometer Site	Top of casing (mAMSL)*	DEM elevation (mAMSL)
Waterfront	13	10
Hukatere	23.97	23
Forest	37.76	36
Burnage	24.1	23
Brown	27.05	35
Wagener	5.67	11
Fishing club	11.717	10
Ogle drive	36.39	40
Paparore	9.67	20

*Top of casing data were sourced from field data provided by NRC, and were used in adjusting the observed groundwater elevation in the calibration.

The surveyed top of casing elevations are close to the DEM elevation estimates at most sites. However, at some sites (e.g. Brown, Wagener, Paparore) deviations are in the order six to ten meters. This indicates that some of the deviations between simulated and observed groundwater levels displayed in **Table 8** might be due to deviations in ground levels. Considering the lack of transient monitoring data, uncertainty in ground elevations, and the bores being screened across multiple layers, the deviations shown in **Table 8** are considered acceptable as a calibration verification.

A comparison with static water levels was also undertaken at two piezometer sites that are located just outside the southern model boundary (Ogle Drive and Paparore). Simulated groundwater elevation contours were extrapolated to the location of the piezometers based on the groundwater level gradient. Given that the groundwater flow is from the central topographic high toward the low-lying east and west coasts, the recharge rates are similar to the model domain (given similar geology and climate), and the width of the peninsular at this location is similar to the width within the model domain, it was assumed that the groundwater level gradient just outside the southern model boundary is similar to the gradient simulated within the model boundary.

The comparison between observed and simulated groundwater elevation is shown in Table xx. Considering that exact values of simulated groundwater levels could not be obtained as the extrapolation was based on simulated contour lines, it can be concluded that observed and simulated groundwater levels are reasonably close.

Table 11. Groundwater level comparison for Ogle drive and Paparore piezometers.

Site	Bore	Top of screen elevation (mAMSL)	Mean groundwater elevation (mAMSL)	Extrapolated groundwater elevation* (mAMSL)	Qualitative description
Ogle Drive	1	5.7	14.4	15	Central part of peninsula, close to extrapolated 15 m contour.
Paparore	4	-68.9	6.9	5	Located near the east coast line, a sharper groundwater gradient eastward, in the range of 5-10 m contour, closer to 5 m contour.
	3	-54.9	6.9		
	2	-25.9	6.5		
	1	-8.9	6.4		

* The exact value could not be determined, and the estimates are based on simulated groundwater contour inside the model boundary.

4.4.2 Test Pumping Exercise

The model was set up and run for a discrete period of time to match the three-day test pumping exercise conducted on production bore No. 2 at Honeytree Farms on Norton Road.

Figure 19 shows the simulated and observed drawdown hydrograph from the test pumping exercise at the productions bore. A semi-regional scale numerical model should underestimate the drawdown in a bore due to hydraulic efficiency losses within a pumping bore that are not considered by regional scale models, and as can be seen in **Figure 19** the model matches this expectation appropriately.

Drawdown was not observed (manual dips during daylight hours) in the shallow piezometer adjacent to the pumping test bore, while the model tends to conservatively overestimate this with a slight drawdown simulated as shown in **Figure 20.**

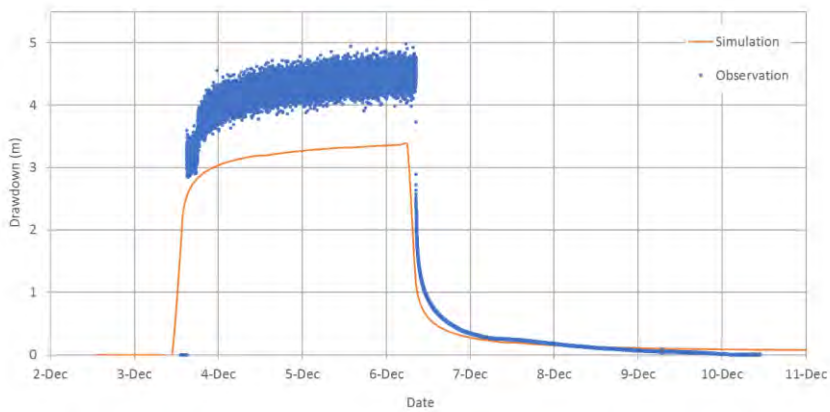


Figure 19. Simulated versus observed test pumping drawdown in production bore.

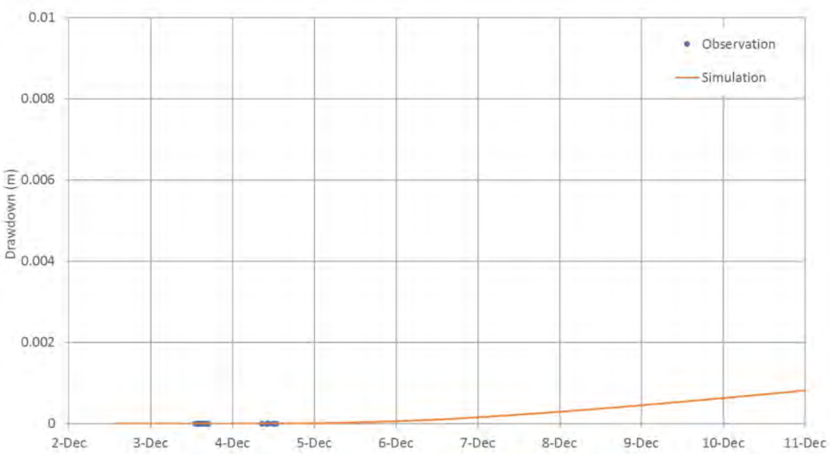


Figure 20. Simulated versus observed test pumping drawdown in shallow observation bore (radius 5 m).

4.4.3 Model Flow Budget

Table 12 provides the long-term average water budget for the transient calibration model. The main input to the model is groundwater recharge at 78% of the total inflow. The predominant discharge component from the model are the subsurface coastal discharges, which are comprised of the constant head in Layer 1 (53%) and the GHB in Layer 2 to 6 (7%). Surface water discharges via the drains account for 16% of the model water budget.

Table 12. Average daily mass balance for 60-year simulation from 1/08/1956 to 31/08/2016.

Mass balance	Components	Flow (m^3/d)	Percentage of Flow (%)
Inflow	Storage	64,407	22.3
	CH	0	0
	Recharge	223,908	77.7
	Lake Waiparera	3	0
	Total inflow	**288,318**	**100**
Outflow	Storage	67,738	23.5
	Shallow Coastal Discharge (CH)	153,424	53.2
	Wells	426	0.1
	Drains (DC)	35,381	12.3
	Wetlands (DC)	10,641	3.7
	Deep Coastal Discharge (GHB)	20,759	7.2
	Total outflow	**288,369**	**100**
Percentage discrepancy		-0.02%	

Note: CH = constant head; GHB = general head boundary; DC = drain cells. Changes in storage are due to the difference in climatic and hence water table conditions between the start and the end of the model run.

5. Predictive Simulations

5.1 Scenario Setup

The numerical groundwater model was developed to assess the effect of various groundwater abstraction rates on the regional aquifer. A transient pumping dataset for each bore was developed using the simulated irrigation demand time series described in **Appendix C**.

Stress periods in the predictive scenario were the same as in the transient calibration simulations, as described in **Section 4.3.1**. In effect, the climatic conditions of the last 60-years have been utilised to simulate the next 60 years.

Three predictive model scenarios were developed, described as follows:

- ***Scenario 1: Base case*** – the calibration model which includes the current 35 consented groundwater takes at a peak abstraction rate of 11,810 m^3/day.
- ***Scenario 2: Proposed Extraction*** – includes current and proposed groundwater extraction totalling a combined peak rate of 16,775 m^3/day. This was applied through 24 new groundwater take bores in addition to the 35 existing bores.
- ***Scenario 3: Future Allocation*** - a set of simulations to assess the effect of future potential groundwater allocation from maximum development. This was represented through 263 fictitious bores placed over a 500 m by 500 m grid within the area of the model domain that is currently in farmland and has potential for future conversion to orchard (**Figure 21**). The rate of abstraction from the 263 fictitious bores (over and above Scenario 2) was progressively increased in each simulation as summarised in **Table 13**. The total combined rate of abstraction from the fictitious bore array is of key significance, rather than the rate per individual bore *per se*.

Table 13. Daily future allocation used in the scenario 3 simulations.

Scenarios	Future allocation (m^3/day)	Daily irrigation demand per bore (m^3/day)
3a	Currently proposed + 20,000	76
3b	Currently proposed + 40,000	152
3c	Currently proposed + 80,000	304

In the same manner as the base model, a transient pumping dataset for each bore was developed based on the irrigation demand time series simulated with the SMWBM, with the total daily future allocation amount equally shared among these bores to summate to the total daily rate.

Figure 21. Placement of fictitious bores used to evaluate future groundwater allocation scenarios. (See A3 attachment at rear).

5.2 Model Results

Based on the rainfall record and simulated groundwater response in the base model, the end time of a dry period was selected for impact analysis. The time period selected was 30/04/2010, which is the end of the irrigation season that required the largest volume of irrigation from the simulated actual use record.

5.2.1 Mass Balance

A comparison of the average flow budget over the simulated 60-year model time period from Scenarios 1 to 3c is provided in **Table 14**.

Table 14. Average flow budget for the 60-year model time period.

Scenarios		Scenario 1 (Base Case)		Scenario 2		Scenario 3a		Scenario 3b		Scenario 3c	
Components		Flow (m^3/d)	Prop (%)	Flow (m^3/d)	Prop (%)	Flow (m^3/d)	Prop (%)	Flow (m^3/d)	Prop (%)	Flow (m^3/d)	Prop (%)
Inflow	Storage	64,407	22.3	66,637	22.9	69,264	23.6	72,362	24.4	78,924	26.1
	CH	0	0	0	0	0	0	0	0	0	0
	Recharge	223,908	77.7	223,908	77.1	223,908	76.4	223,908	75.6	223,908	73.9
	Lake Waiparera	3	0	3	0	3	0	4	0	4	0
	Total inflow	**288,318**	**100**	**290,548**	**100**	**293,175**	**100**	**296,274**	**100**	**302,836**	**100**
Outflow	Storage	67,738	23.5	69,621	24.0	71,757	24.5	74,352	25.1	79,871	26.4
	Shallow Coastal Discharge (CH)	153,424	53.2	151,978	52.3	149,960	51.1	147,910	49.9	143,702	47.4
	Deep Coastal Discharge (GHB)	20,759	7.2	20,542	7.1	20,075	6.8	19,602	6.6	18,638	6.2
	Wells	426	0.1	5,196	1.8	10,883	3.7	16,570	5.6	27,943	9.2
	Drains (DC)	35,381	12.3	33,484	11.5	31,473	10.7	29,492	10.0	25,628	8.5
	Wetlands (DC)	10,641	3.7	9,776	3.4	9,075	3.1	8,395	2.8	7,099	2.3
	Total outflow	**288,370**	**100**	**290,597**	**100**	**293,223**	**100**	**296,321**	**100**	**30,2876**	**100**
Discrepancy (%).		-0.02		-0.02		-0.02		-0.02		-0.01	

Based on the proposed extraction over the 60-year simulation time period (Scenario 2), the water taken for irrigation accounts for 1.8% of the total water budget. The abstraction derives water from the coastal discharges (CH/GHB), surface drains (drain cell) and some accession from storage. For the three higher allocation simulations, the percentage of water being extracted from the system is 3.7%, 5.6% and 9.2%, respectively.

Lake Waiparera is hydraulically disconnected to the regional groundwater system, as evidenced by water observed to overflow the surface of the lake by local residents. The water discharged from the lake to the groundwater system is a small component of the overall water budget (0.001%). Scenario 2-3 results indicate the proposed extraction of water has negligible effect on the lake discharges.

The model water budgets suggests the impact from pumping on the Kaimaumau wetland would be a reduction in outflow from 3.7 to 3.4% of the total water budget. However, as indicated in **Section 2.3**, the existence of hard pan acts as a flow barrier between the groundwater system and wetlands and the model setup has not captured this feature due to the difficulty in being explicit about the spatial extent and thickness of the iron pans. We consider the model conservative with respect to wetland impacts, and given the hydraulic separation in practice, the proposed pumping is likely to have a significantly lesser effect than that modelled.

The water budget of each predictive scenario was also compared against the base model and the flow difference and percentage difference is summarised in **Table 15**. Under the proposed abstraction, the coastal discharge (CH/GHB) and drains (DC) decrease by 1.9% and 13.5% compared to the base case, respectively. The groundwater abstraction from the bores has a greater impact on the inland drain flows, as the proposed groundwater takes are distributed mostly in the central part of the peninsula. The groundwater abstraction will reduce water being discharged to the ocean via reduction in the direct coastal groundwater discharge and drain flow.

Table 15. Average flow budget in terms of flow difference and percentage difference compared to the base case.

Scenarios		Scenario 1 (Base Case)	Scenario 2		Scenario 3a		Scenario 3b		Scenario 3c	
Components		**Flow (m3/d)**	**Flow diff (m3/d)**	**Prop diff (%)**	**Flow diff (m3/d)**	**Prop diff (%)**	**Flow diff (m3/d)**	**Prop diff (%)**	**Flow diff (m3/d)**	**Prop diff (%)**
Inflow	Storage	64,407	2,230	3.5	4,857	7.5	7,955	12.4	14,517	22.5
	CH	0	0	0	0	0	0	0	0	0
	Recharge	223,908	0	0	0	0	0	0	0	0
	Lake Waiparera	3	0	0	0	0	1	33.3	1	33.3
	Total inflow	**288,318**	**2,230**	**0.8**	**4,857**	**1.7**	**7,956**	**2.8**	**14,518**	**5.0**
Outflow	Storage	67,738	1,883	2.8	4,019	5.9	6,614	9.8	12,133	17.9
	Shallow Coastal Discharge (CH)	153,424	-1,446	-0.9	-3,464	-2.3	-5,514	-3.6	-9,722	-6.3
	Deep Coastal Discharge (GHB)	20,759	-217	-1.0	-684	-3.3	-1,157	-5.6	-2,121	-10.2
	Wells	426	4,770	1119.7	10,457	2454.7	16,144	3789.7	27,517	6459.4
	Drains (DC)	35,381	-1,897	-5.4	-3,908	-11.0	-5,889	-16.6	-9,753	-27.6
	Wetlands (DC)	10,641	-865	-8.1	-1,566	-14.7	-2,246	-21.1	-3,542	-33.3
	Total outflow	**288,370**	**2,227**	**0.8**	**4,853**	**1.7**	**7,951**	**2.8**	**14,506**	**5.0**

5.2.2 Drain Flows

An analysis of the impact on flow in the farm drain was undertaken for low-flow situations. The annual minima in daily flow was obtained from the global flow budget for all drains combined for each time step exported from the model. Annual recurrence intervals were calculated from this table of data for each scenario, and the resulting data is presented in **Table 16** and **Figure 22**.

Comparison of the current proposal (scenario 2) against the base case indicates that the mean annual (1-year) low flow has potential to be reduced by a maximum of 5% and the 5-year low flow by 7%. However, as stated earlier, we consider the model to exaggerate groundwater level reduction in the shallow aquifer and at the surface because of the lack of hard pans in the model. In this regard, these values should be treated as conservative upper estimates.

Table 16. Low-flow analysis of drain discharge and percentage reduction in flow from base case.

Recurrence Interval	Scenario								
	1	2		3a		3b		3c	
(years)	(L/s)	(L/s)	(%)	(L/s)	(%)	(L/s)	(%)	(L/s)	(%)
1	406	386	5%	380	7%	378	7%	376	7%
2	324	302	7%	281	13%	259	20%	218	33%
5	303	281	7%	258	15%	236	22%	192	37%
10	290	267	8%	244	16%	222	23%	181	37%
25	269	245	9%	220	18%	197	27%	154	43%
50	265	241	9%	218	18%	196	26%	152	43%
100	262	238	9%	215	18%	192	27%	148	43%

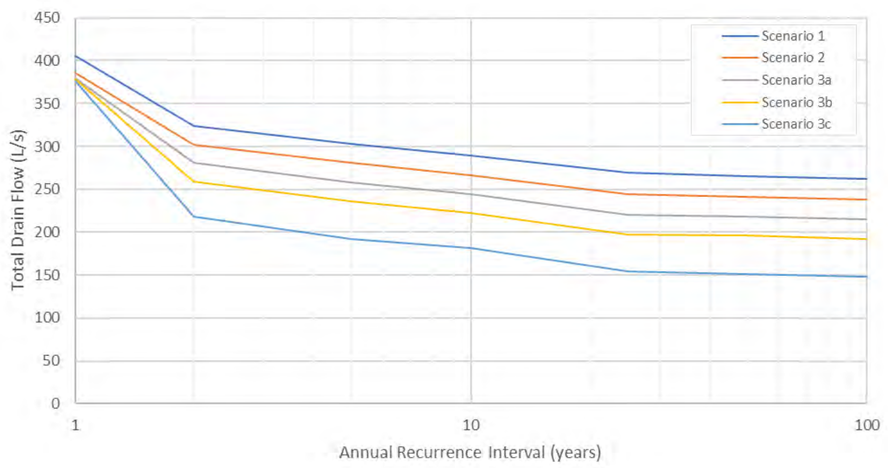


Figure 22. Farm drain low flow analysis for model predictive scenarios.

5.2.3 Wetland Discharge

In a similar manner to the drain low flow analysis, analysis of the impact on dry time discharges from the 35 km^2 area of the Kaimaumau wetland was undertaken.

Surface discharge from the wetland was converted to a specific discharge by dividing by the wetland area and the percentage reduction in flow was computed for each development scenario, as presented in **Table 17**.

Comparison of the current proposal (scenario 2) against the base case indicates that the mean annual dry time discharge has potential to be reduced by a maximum of 7% and during the 5-year low flow by11%. However, as stated earlier, we consider the model to exaggerate groundwater level reduction in the shallow aquifer and at the surface because of the lack of hard pans in the model. In this regard, these values should be treated as conservative upper estimates.

Table 17. Low-flow analysis of surface discharge from the wetland.

Recurrence Interval	Scenario								
	1	2		3a		3b		3c	
(years)	(L/s/km^2)	(L/s/km^2)	(%)	(L/s/km^2)	(%)	(L/s/km^2)	(%)	(L/s/km^2)	(%)
1	3.1	2.9	7%	2.9	9%	2.8	10%	2.8	10%
2	2.3	2.1	9%	1.9	17%	1.8	24%	1.4	39%
5	2.2	1.9	11%	1.8	19%	1.6	27%	1.2	43%
10	2.1	1.8	11%	1.6	20%	1.4	29%	1.1	46%
25	1.9	1.6	13%	1.4	24%	1.2	34%	0.9	53%
50	1.8	1.5	13%	1.4	24%	1.2	34%	0.8	52%
100	1.7	1.5	14%	1.3	25%	1.1	35%	0.8	53%

5.2.4 Water Level Impacts

The difference in water levels at three key locations (Houhora-Motutangi, Waiharara, Kaimaumau wetland) were assessed for each scenario for the shallow and deep aquifer, respectively. The relative responses for Houhora-Motutangi, Waiharara, Kaimaumau are shown in **Figure 23** to **Figure 25**, respectively. These graphs are provided to give a sense of the comparative differences in water levels expected at different depths in the aquifer from the scale of pumping utilised in the model scenarios.

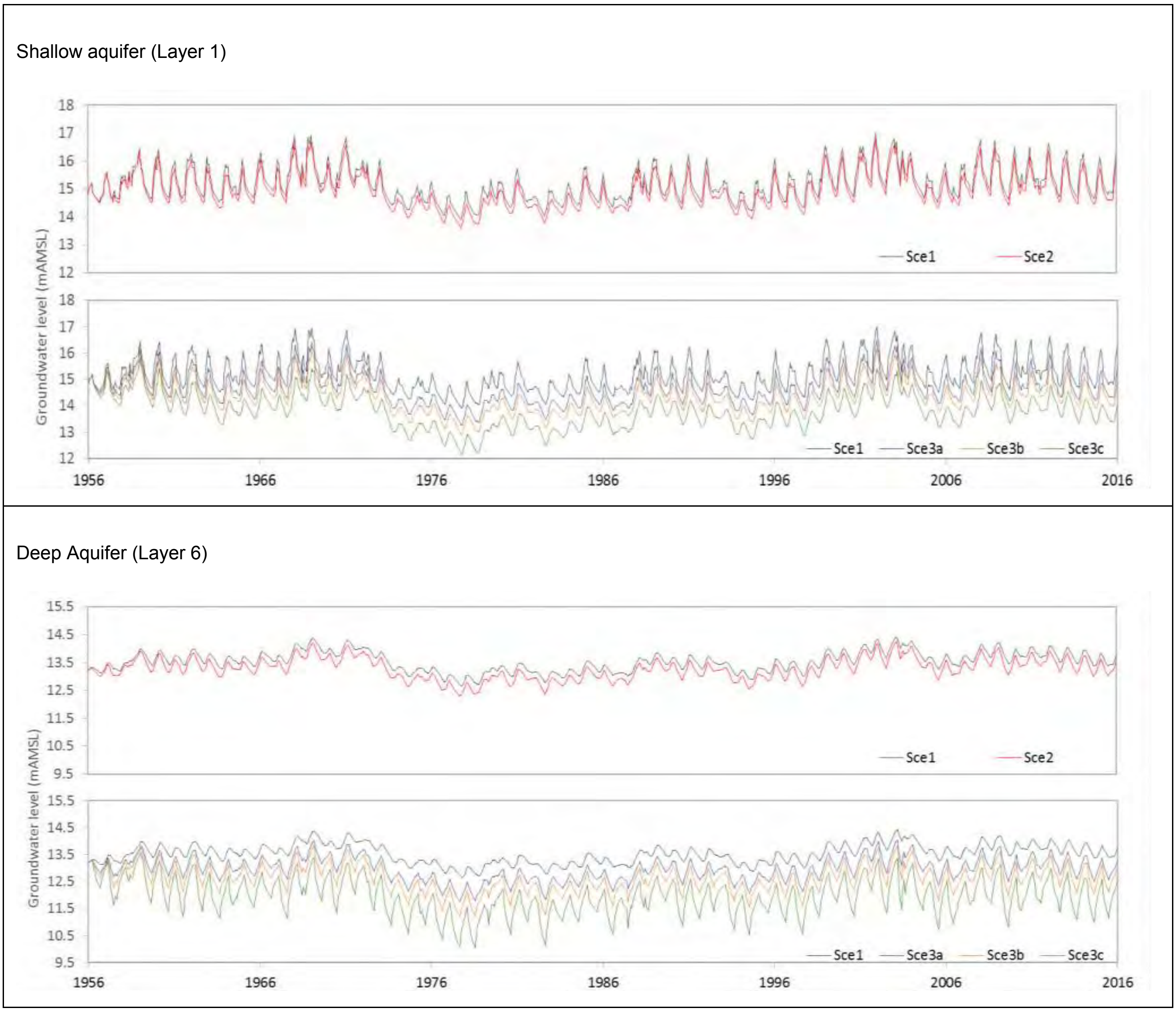
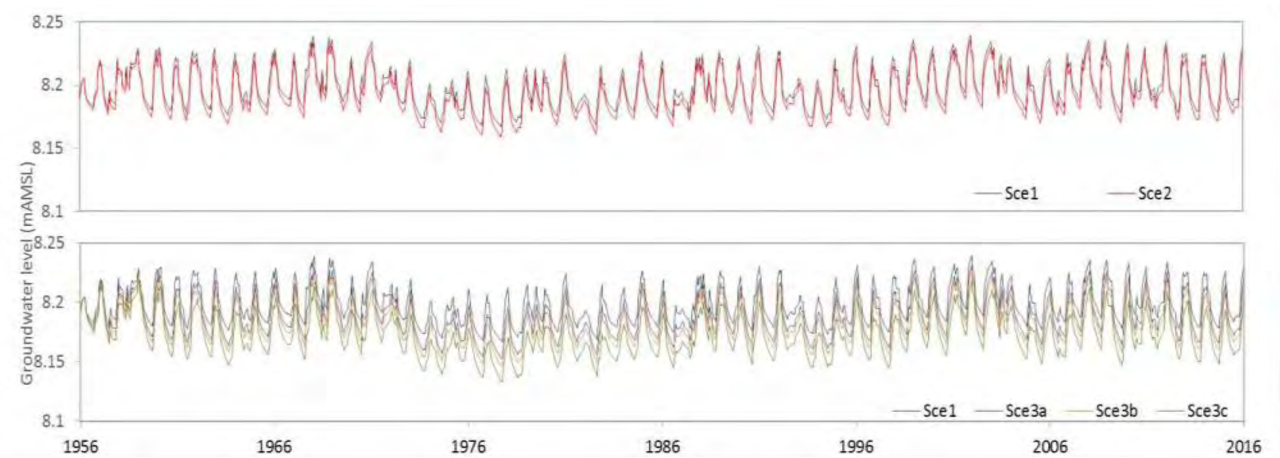


Figure 23. Groundwater level hydrographs for Houhora.

Shallow aquifer (Layer 1)



Deep Aquifer (Layer 6)

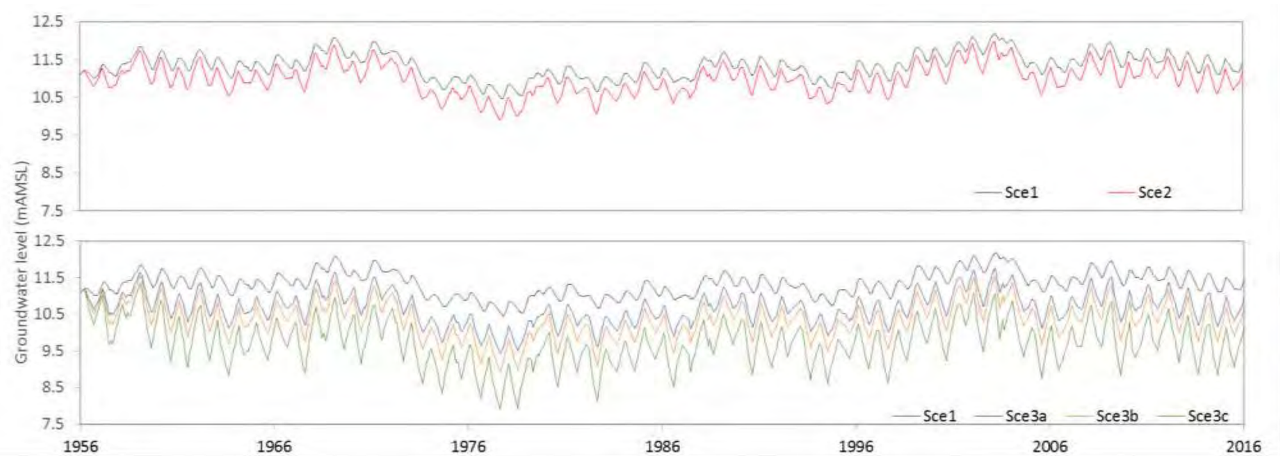


Figure 24. Groundwater level hydrographs for Waiharara.

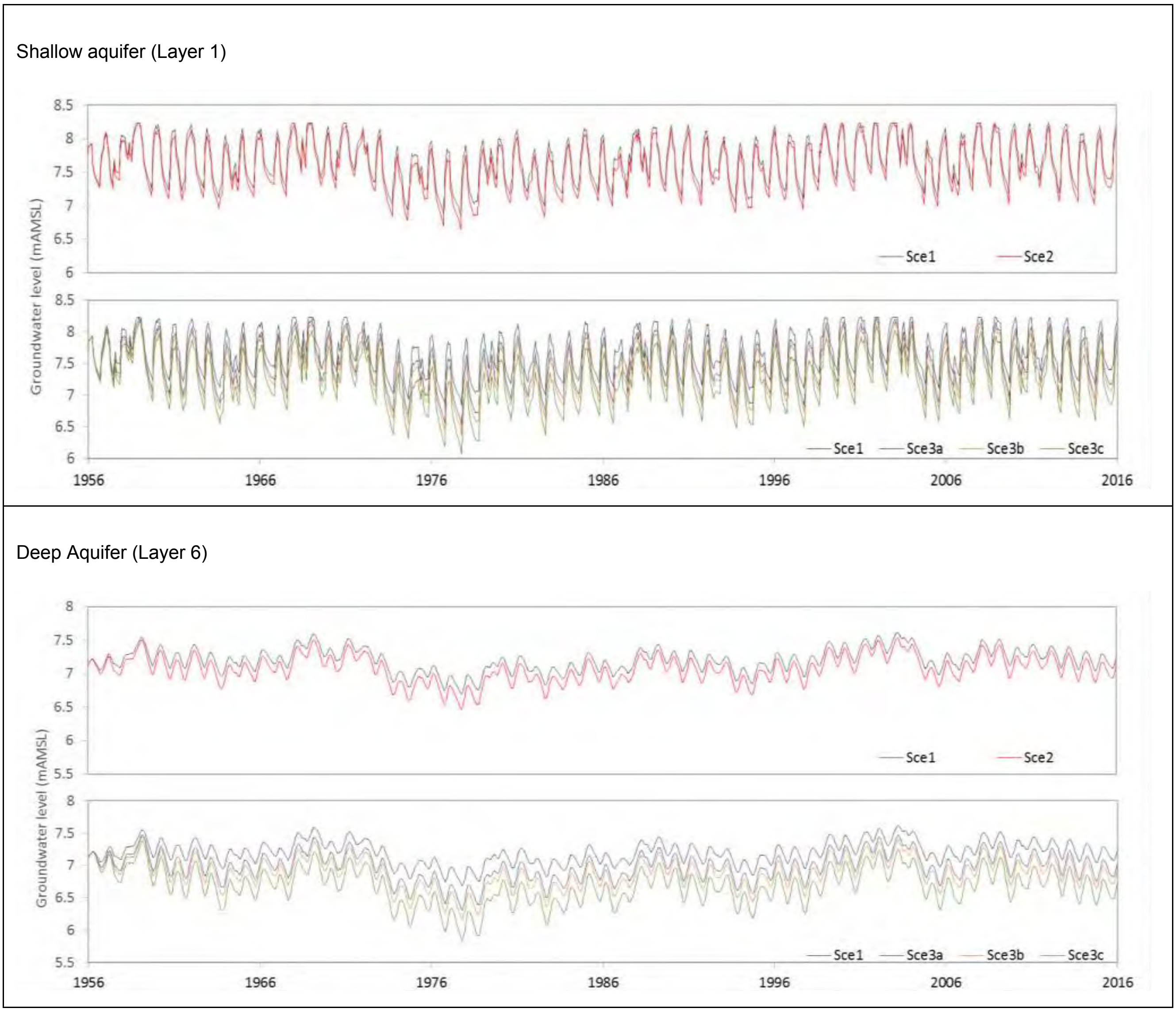


Figure 25. Groundwater level hydrographs for Kaimaumau.

It becomes evident from **Figure 23** to **Figure 25** that pumping has a greater effect on the deep aquifer than on the shallow aquifer, even considering that the buried hardpan layers were not represented in the model due to the limited information. Thus, as indicated above, the signal that propagates to the shallow aquifer due to the pumping from the deep aquifer is likely to be exaggerated.

It is also clear that groundwater levels respond very quickly to seasonal climate variations. The irrigation takes from proposed bores were simulated through the entire 60-year time period, and all of the irrigation takes were synchronized – being driven by the same climate condition simultaneously. In practice, the irrigation is unlikely to be synchronized, which would mean the seasonal response would never be as exacerbated as shown by the model.

5.2.5 Drawdown Effects

The simulated groundwater level from each scenario at the time of interest was subtracted from the head simulated from the base model at the corresponding time to produce regional drawdown maps, which are used to assess the impact from the respective pumping scenarios.

The following paragraphs discuss the results for the various features.

The pumping from the deep aquifer induced a greater drawdown in the deep aquifer compared to the drawdown in the shallow aquifer. The magnitude of the simulated drawdown and the extent of impact spreads laterally as allocation increases from the current to proposed and fictitious future allocation scenarios simulations. The largest drawdown is centred near the Motutangi and Waiharara areas due to the concentration of the bores with relatively large proposed groundwater extraction.

Deep aquifer

Compared to the base model, the proposed extraction shows a maximum of 0.8 m drawdown in the deep aquifer. The location of the proposed bores and their adjacency to each other lead to the cumulative effect on the aquifer to different extents. For the future allocation scenarios, the simulated maximum drawdown at deep aquifer is 1.3 m, 2.0 m and 3.4 m, respectively at the observation time period (30/04/2010).

Figure 26. Simulated drawdown of deep aquifer (Scenario 2). (See A3 attachment at rear).

Figure 27. Simulated drawdown of deep aquifer (Scenario 3a). (See A3 attachment at rear).

Figure 28. Simulated drawdown of deep aquifer (Scenario 3b). (See A3 attachment at rear).

Figure 29. Simulated drawdown of deep aquifer (Scenario 3c). (See A3 attachment at rear).

Shallow aquifer

The shallow aquifer is less affected by the pumping at the deep aquifer, however, there is drawdown simulated based on the current model set-up. For proposed extraction scenario, the maximum drawdown is 0.4 m at shallow aquifer. A maximum drawdown of 0.8 m, 1.3 m, and 2.3 m was shown for shallow aquifer corresponding to the three future allocation scenarios, respectively.

Figure 30. Simulated drawdown of shallow aquifer (Scenario 2). (See A3 attachment at rear).

Figure 31. Simulated drawdown of shallow aquifer (Scenario 3a). (See A3 attachment at rear).

Figure 32. Simulated drawdown of shallow aquifer (Scenario 3b). (See A3 attachment at rear).

Figure 33. Simulated drawdown of shallow aquifer (Scenario 3c). (See A3 attachment at rear).

Existing bores

The drawdown at 34 existing bores induced by the groundwater take utilised in each scenario was calculated and plotted similarly as a boxplot, with the maximum and minimum drawdown shown in **Figure 34**.

The drawdown at the existing bores is largely affected by their distance to the proposed new groundwater take locations. At the driest condition (30/04/2010), the observed drawdown ranges between 0.1 to 0.73 m, 0.57 to 1.39 m, 1.03 to 2.07 m and 1.86 to 3.46 m for the proposed extraction scenario, and future allocation scenario 3a, 3b, 3c, respectively. The maximum drawdown was observed at IA Stanisich bore and the minimum drawdown was observed at LL & DF Rasmussen bore.

Given the depth of standing water available in the bores above the shellbed aquifer (~70 m) this level of drawdown is considered negligible as it represents less than 5% of standing water potentially available under all scenarios considered.

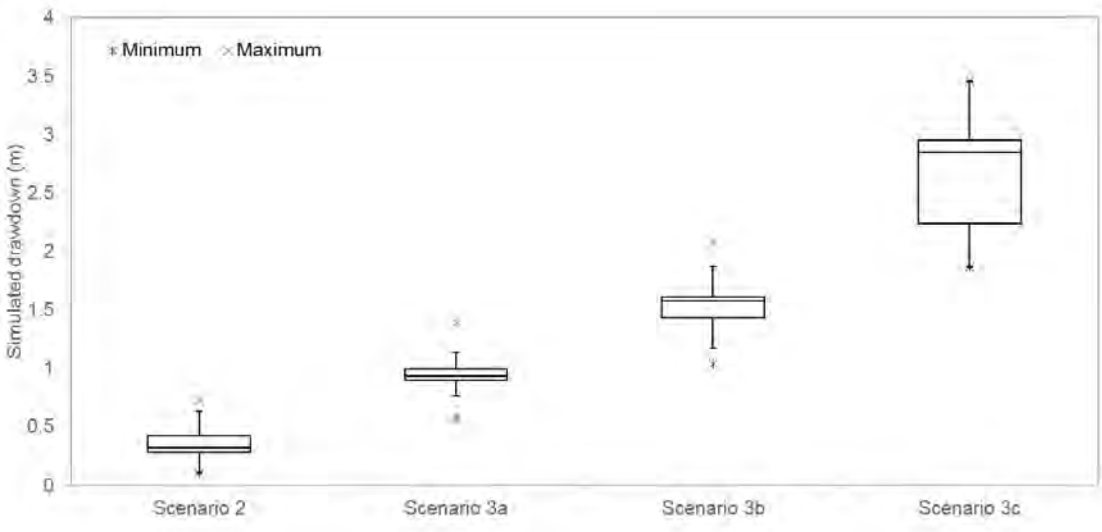


Figure 34. Drawdown observed at existing bores at the observation time step for each scenario.

5.2.6 Saltwater Intrusion

The Ghyben-Herzberg analytical solution was used to estimate the depth of freshwater and saltwater interface. Based on the density of freshwater and saltwater, the relation states that there is 40 m of freshwater in the aquifer below sea level, when there is 1 m of freshwater in the aquifer above sea level (Badon-Ghijben and Herzberg, 1901).

To address uncertainty in what constitutes the most plausible mechanism of saline instruction in this hydrogeological setting, two potential mechanisms for saline intrusion potential were assessed:

1. ***Upconing*** – assumes the water pressures in the aquifer would translate to a saline interface at some point underneath the aquifer under steady state conditions in accordance with the Ghyben-Herzberg equation and regardless of the material types;
2. ***Lateral migration along the aquifer/bedrock interface*** – considers the material under the aquifer impermeable and the inland migration of salinity would occur via the permeable shellbed sediments along the basement contact. This mechanism assumes that the pressure at the coastal margin is relevant to maintaining an offshore position of the saline interface.

5.2.6.1 Upconing Analysis

To investigate the potential saltwater intrusion due to upconing under the proposed groundwater extraction, six cross section profiles were extracted from each model simulation. The location of the six cross sections are shown in **Figure 35** and the cross sections themselves are provided in **Figure 36** to **Figure 40**.

The depth to the saltwater/freshwater interface was calculated based on the simulated groundwater level at the driest condition (30/04/2010) of each scenario following the Ghyben-Herzberg solution

Figure 35. Location of cross sections for saline intrusion analysis. (See A3 attachment at rear).

The estimated position of the saltwater interface varies depending on the geographical distribution of the new groundwater take bores and the proposed abstraction volume. There was no significant saltwater upconing observed for cross section A'-A and B'-B, between the proposed extraction and the base model. Based on the proposed consented volume (Scenario 2), the largest saltwater interface rising was estimated to be 101 m at cross section C'-C, which is induced by the accumulative groundwater take from the three Forlong bores, and the second largest saltwater interface rising was about 61 m at the cross section E'-E. However, while there has been a significant potential rise in the level of the saline interface, it still remains a minimum of approximately 390 m below the base of the sedimentary (shellbed) aquifer.

With the increased groundwater allocations in Scenario 3, the saltwater upconing becomes more significant across the model domain. However, based on simulated groundwater level at the driest condition and the calculated saltwater depth, the vertical distance between the depth of the groundwater extraction (screen zone) and saltwater interface is still large enough at >50 to 600 m to prevent the saltwater intrusion into the pumping bores.

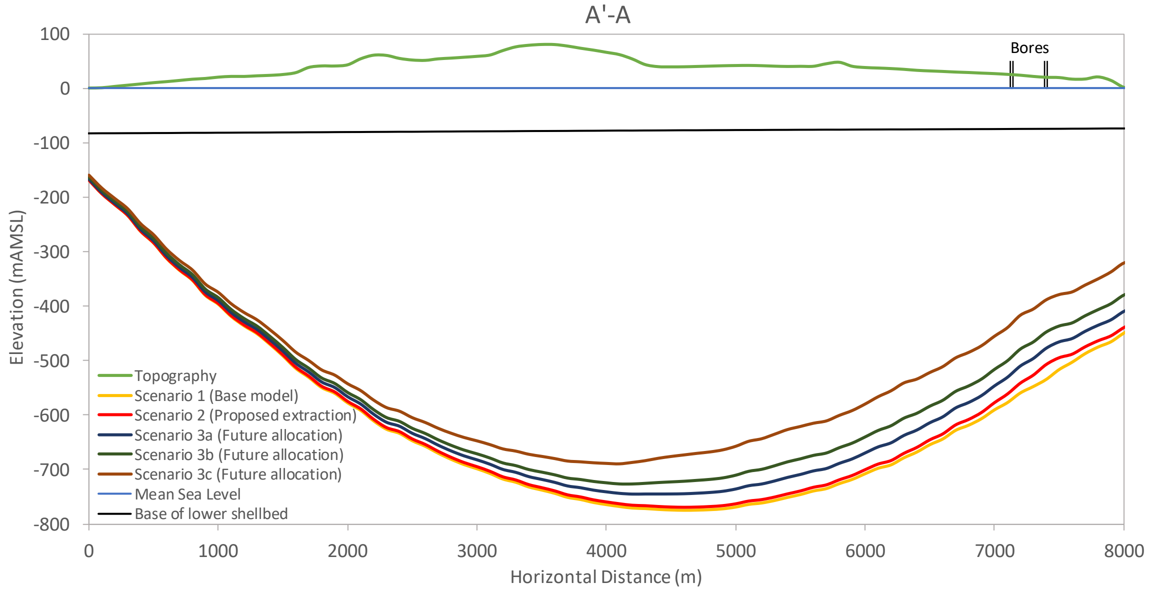


Figure 36. Calculated saltwater/freshwater interface at c**ross section A'**-A (bores are only shown for location indication).

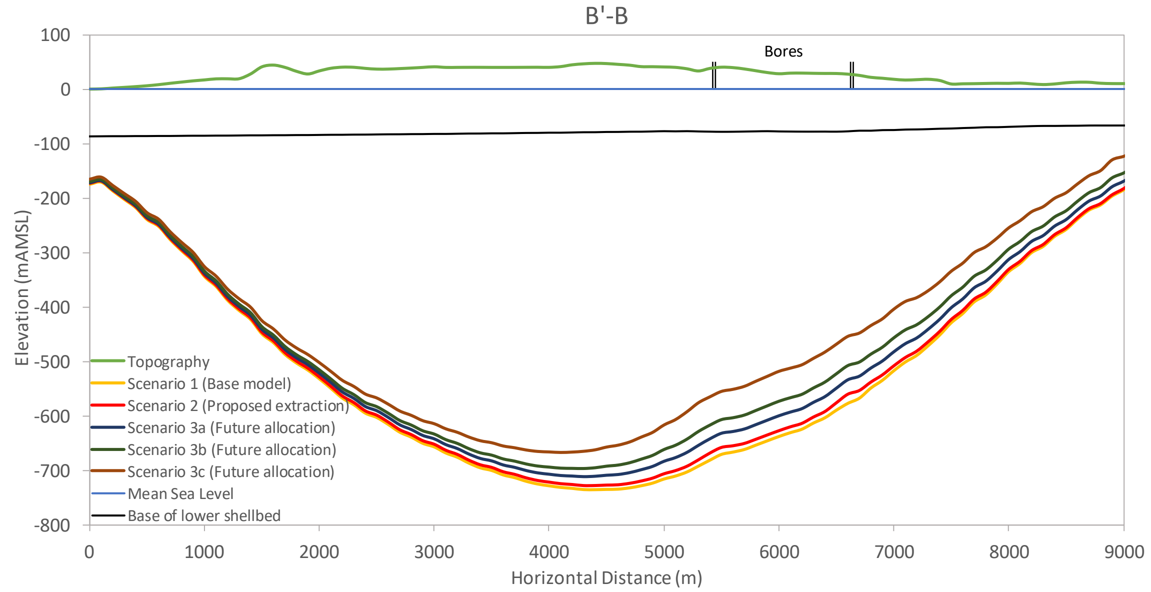


Figure 37**. Calculated saltwater/freshwater interface at cross section B'**-B (bores are only shown for location indication).

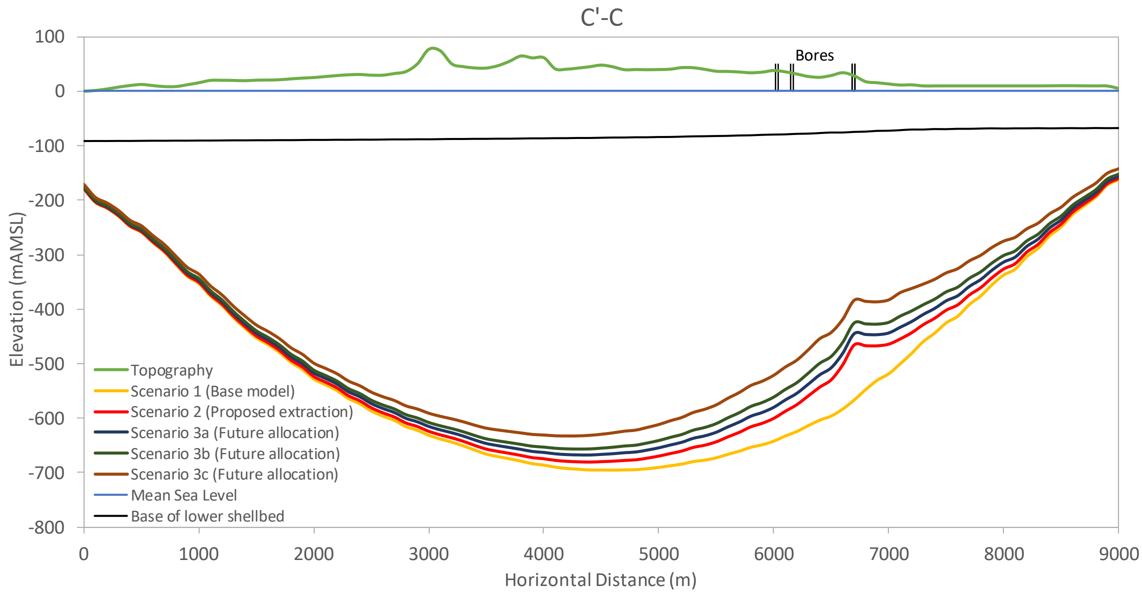


Figure 38. **Calculated saltwater/freshwater interface at cross section C'**-C (bores are only shown for location indication).

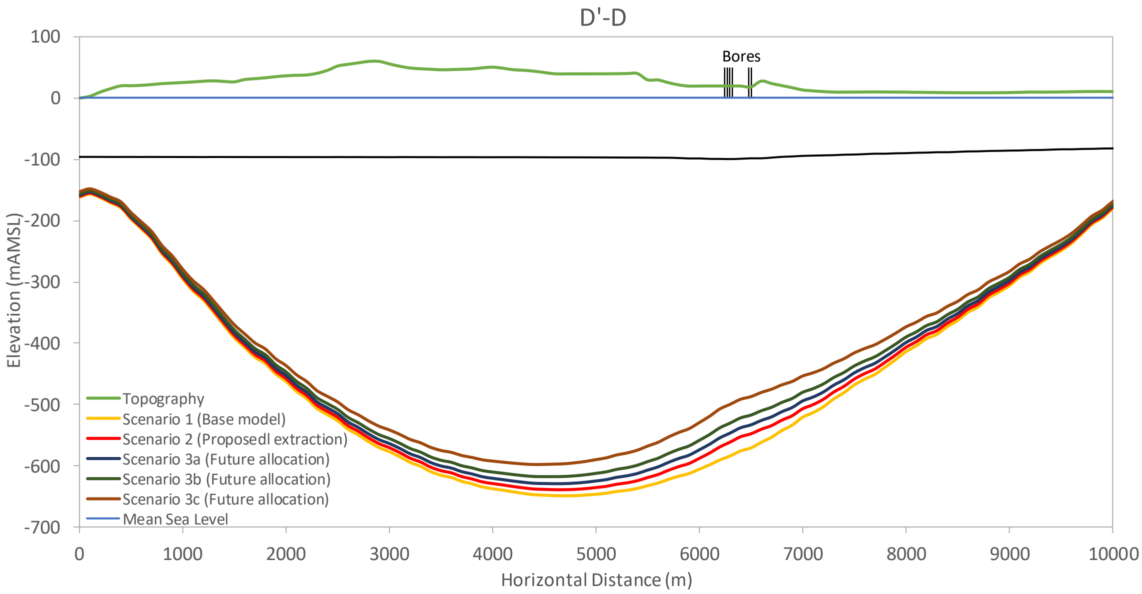


Figure 39**. Calculated saltwater/freshwater interface at cross section D'**-D (bores are only shown for location indication).

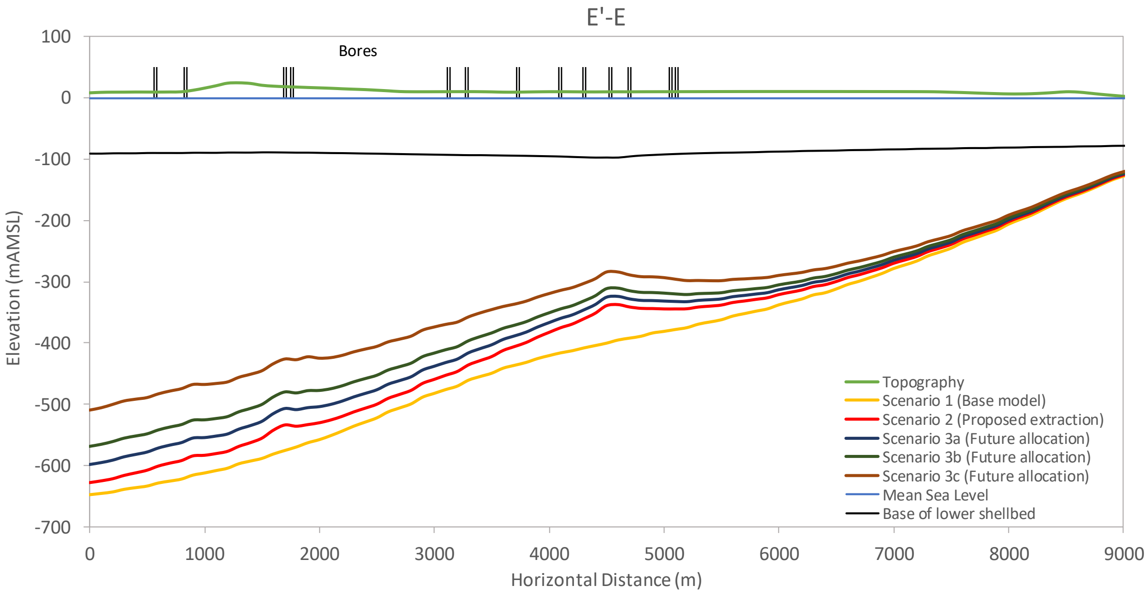


Figure 40. **Calculated saltwater/freshwater interface at cross section E'**-E (bores are only shown for location indication).

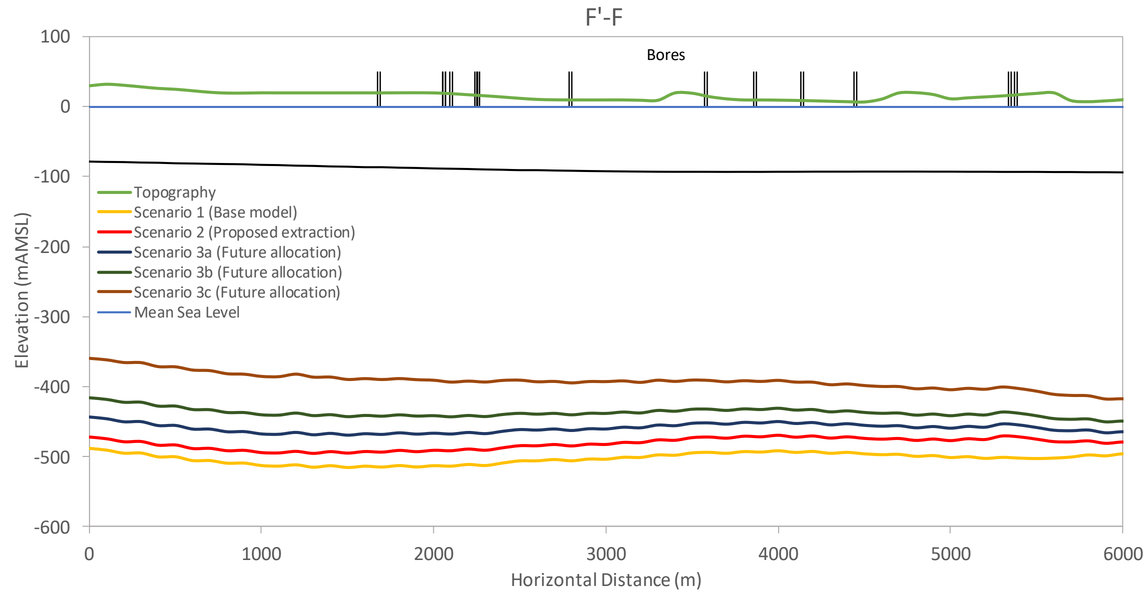


Figure 41. Calculated saltwater/freshwater interface at cross s**ection F'**-F (bores are only shown for location indication).

5.2.6.2 Lateral Migration Analysis

Based on the estimated depth to the basement rock at the coastal margins, the Ghyben-Herzberg relation was used to back-calculate the minimum hydraulic head required to maintain the saline interface below the shellbed aquifer (i.e. the "Trigger Level"). This calculation was performed at selected points at approximately 500 m intervals around the coastal margins of both the west and east coast. The simulated groundwater levels for Layer 6 from each scenario were extracted for these points.

Saltwater intrusion is not an instantaneous response to the lowered water table - it is a gradual process requiring prolonged reduction in groundwater level below a critical level to initiate the landward migration of the saline interface. A 90-day rolling average (RA) was calculated from the simulated groundwater level to reflect this slow process. The simulated groundwater levels were then compared against the Trigger Level at the model times 03/08/1999 and 25/06/1979, which represent an average and lowest groundwater level drought condition, respectively.

The location of the points is shown in **Figure 42.** The points were selected on the basis of i) coastal location and ii) proximity to possible development areas (i.e. there is little point selecting a sentinel monitoring point in a location that has saline groundwater under natural conditions, is a significant distance from any current or potential future development, or separated from current or potential development areas by a nature reservesd E).

and the comparison between the simulated level for each scenario and the Trigger Level are provided in **Appendix F**. The hydraulic heads in the deep shellbed at the two selected time steps (03/08/1999 and 25/06/1979) in Scenario 2 are on average approximately 2.5 m and 2.1 m greater than the pressure required to maintain the saline interface below the shellbed aquifer at the selected points.

The minimum groundwater level over the entire simulation time (1956-2017) for the coastal locations are shown in **Figure 43.** This shows that the simulated minimum groundwater levels are greater than the head required to maintain the saline interface below the deep shellbed aquifer. Therefore, it can be concluded that saltwater inland migration along the basement contact is unlikely to occur in response to the proposed groundwater extraction from any of the scenarios that were considered, although it can be seen that at Point 11 and between Point 33 and 37 the simulated head is becoming closer to the Trigger Level with the higher abstraction scenarios.

Figure 42. Location of the selected coastal points. (see A3 attachment at rear).

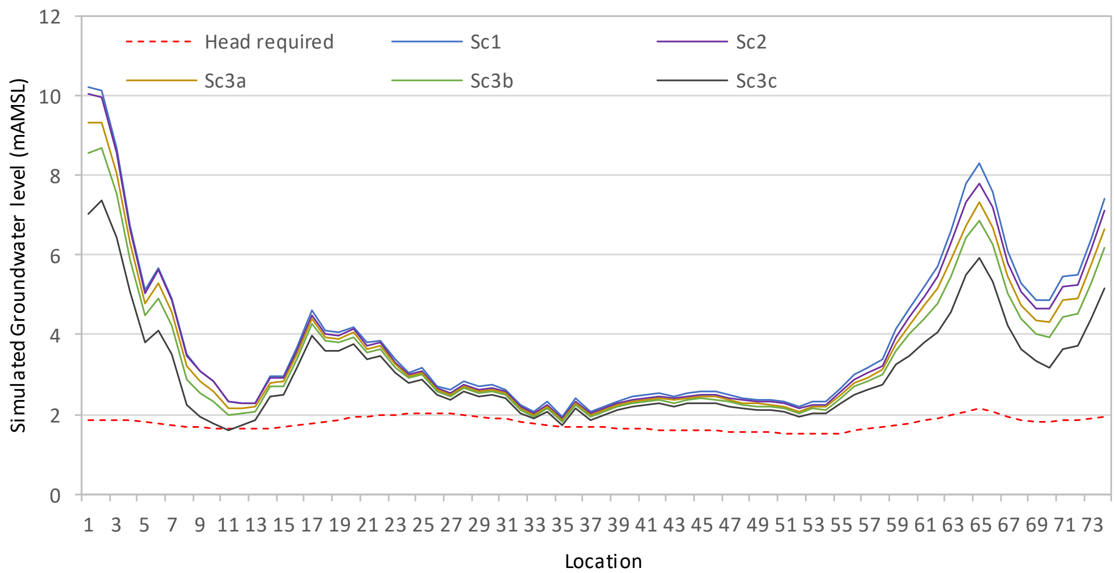


Figure 43. Simulated minimum groundwater level between 1956 and 2016 in Layer 6 (East Coast, NE to SE).

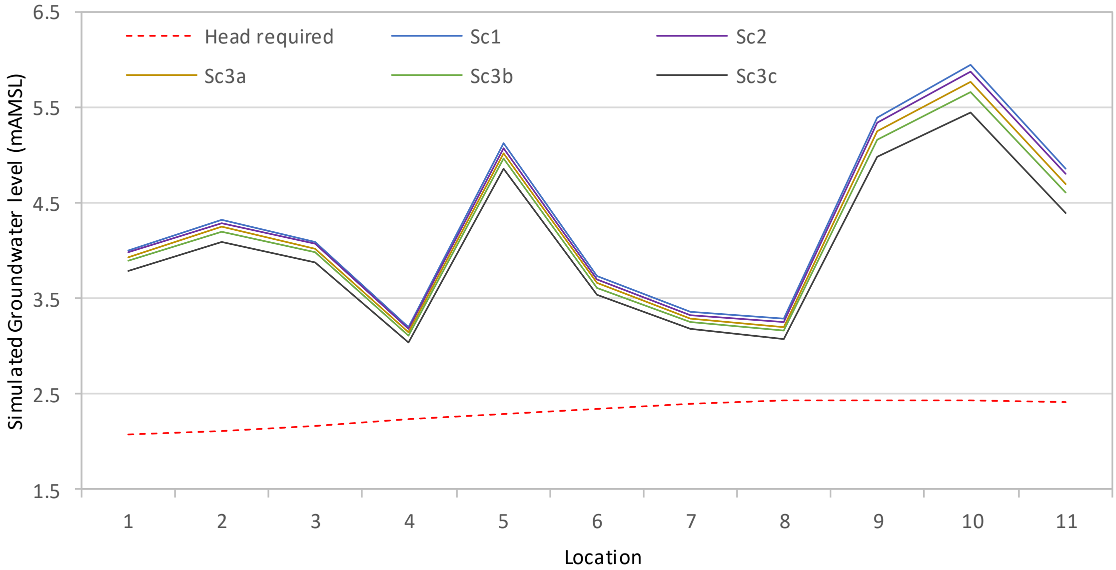


Figure 44. Simulated minimum groundwater level between 1956 and 2016 in Layer 6 (West Coast, NW to SW).

As noted above, in Scenario 3c (the highest abstraction scenario) the minimum groundwater level at coastal point 11, which is near the Houhora Heads, is approaching to the Trigger Level. At this location, the simulated groundwater level in Layer 6 was higher than the head required during most of the simulation period, except for four summers (1977, 1978, 1979 and 1983) where it came close to or receded below temporarily, as shown in **Figure 45.** The 90-day RA was compared with the simulated groundwater level shown in **Figure 45** and **Figure 46.** The 90-day RA groundwater level was still above the head required, even though the simulated groundwater level dropped below the trigger level at that point of time. Given the slow process of saltwater intrusion, the 90-day average groundwater level is considered a more realistic calculation for resource management purposes with respect to the potential saltwater intrusion.

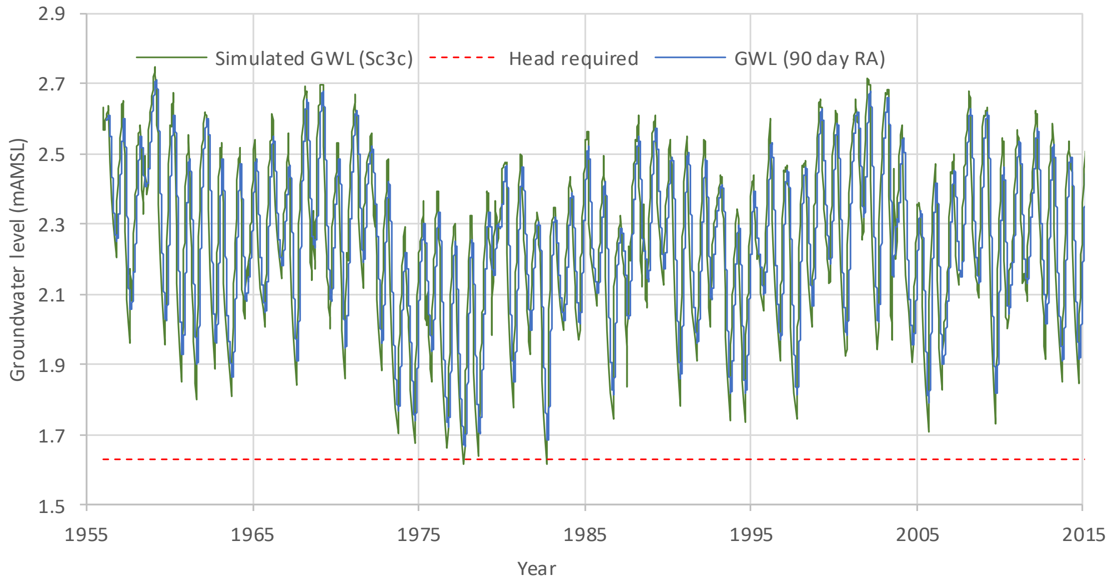


Figure 45. Simulated groundwater level in Layer 6 at coastal point 11.

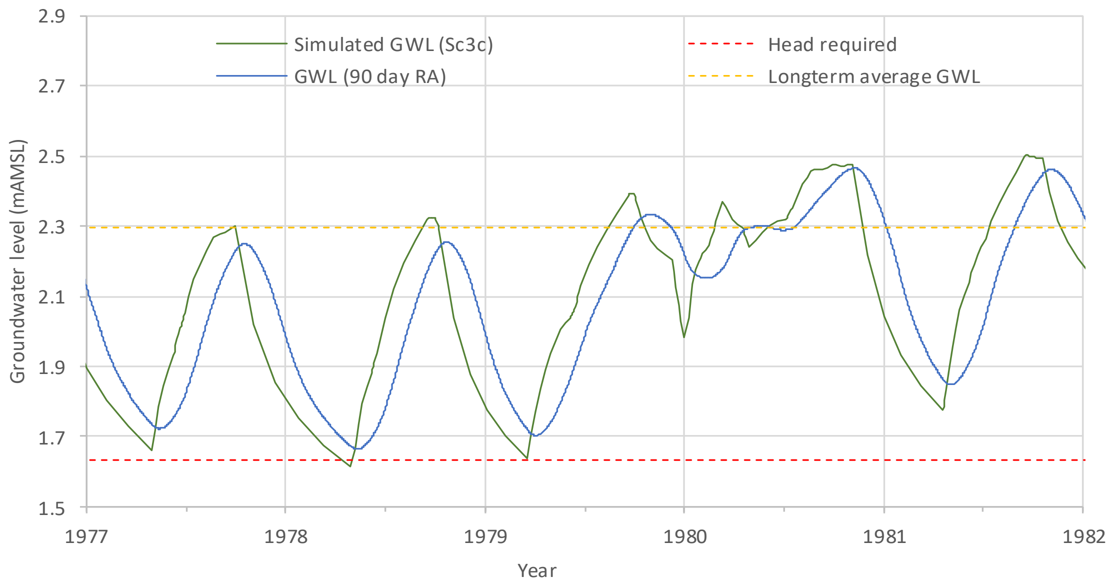


Figure 46. Simulated groundwater level in Layer 6 at coastal point 11 with 90-day RA.

Considering the future development and its adjacency to the coastline, it is recommended to establish another two sentinel piezometers at points 16 and 64 shown in **Figure 42,** together with existing Waterfront Piezometer to effectively monitor the trigger level of saltwater intrusion.

In the previous study modelling study undertaken by Lincoln Agritech (2015), simulated groundwater level in the Motutangi sub-zone was lower than the pressure required to maintain the saline interface offshore or below the base of the deep shellbed layer. The report specifically notes that modelled groundwater levels in this zone were not sufficient to maintain the interface offshore under the base pumping scenario (existing allocation) and recommends further investigations in the area before any further allocation occurs. However, it was also noted in the report that the simulated groundwater levels in this zone were likely to have a large degree of uncertainty due to the lack of information (presumably drill hole and test pumping information at the time) to constrain the model.

Since the time of the Lincoln Agritech project, further boreholes have been drilled to the base of the shellbed, one test pumping exercise has been undertaken, and additional groundwater level data has been acquired. The basement horizon in the WWA model has been interpolated from the borehole geological data, rather than inferred from a geophysical survey, hence we are of the view that the current model has significantly less uncertainty than the earlier model.

In the Motutangi sub-zone the simulated hydraulic heads in the deep shellbed at the two selected time steps (25/06/1979 and 03/08/1999) are on average approximately 1.1 to 1.5 m (respectively) greater than the pressure required to maintain the saline interface offshore.

5.3 Uncertainty

As discussed in **Section 2.3**, the calibrated groundwater model has an acknowledged limitation with regard to its ability to predict vertical leakage (and associated water level drawdown in shallow and deep aquifers) due to the irregular and discontinuous nature of iron pans and other low permeability horizons within the sedimentary sequence. In particular, the model setup has not fully captured the existence of these hard pan layers that likely act as a flow barrier between the deeper groundwater system and the surface drains and wetlands. There was insufficient information on the spatial extent and thickness of the hard pans to be represented in the groundwater model. As a result, the model likely exaggerates the effects of the proposed abstraction on the groundwater levels in the shallow aquifer and at the surface. Conversely, the model may under-predict the local-scale drawdown in the deeper aquifer.

To investigate the potential predictive error in drawdown in the deeper shellbed layer, a sensitivity analysis was undertaken involving modifying the permeability within the depth range where iron pans and peats layers prevail (model Layer 2).

Hydraulic conductivity (both horizontal and vertical) of Layer 2 was decreased by one, two and three orders of magnitude (e.g. K_z changed from $1x10^{-6}$ to $1x10^{-9}$ m/s), as shown in **Table 18**. Boundary and source/sink conditions remained the same as in Scenario 2 and drawdown was calculated at the same time step (30/04/2010) for comparison.

The three alternative leakage scenarios were not calibrated, and are therefore considered only appropriate to illustrate relative (rather than absolute) changes in groundwater level.

Table 18. Hydrogeological parameters of model Layer 2 used in the sensitivity analysis.

Scenario	**Geological units of Layer 2**	**K_x**		**K_z**		**Vertical anisotropy**	**S_s (m^{-1})**
		(m/d)	**(m/s)**	**(m/d)**	**(m/s)**		
2 (proposed extraction)	Coastal sand	4	4.6E-05	0.13	1.5E-06	30	0.0005
	Weathered sand	3	3.5E-05	0.04	4.3E-07	80	0.0005
4a (alternative leakage 1)	Less permeable layer (confining units)	8.6E-01	1.0E-05	1.7E-02	2.0E-07	50	0.0005
4b (alternative leakage 2)		8.6E-02	1.0E-06	1.7E-03	2.0E-08	50	0.0005
4c (alternative leakage 3)		8.6E-03	1.0E-07	1.7E-04	2.0E-09	50	0.0005

The simulated drawdown in the deep aquifer is shown in **Figure 47** to **Figure 49** for the three sensitivity simulations. With the permeability decreasing in Layer 2, hydraulic separation becomes more significant, leading to a greater drawdown in the deeper shellbed layer. A decrease in vertical hydraulic conductivity (K_z) by one, two or three orders of magnitude (Scenario 4a, 4b and 4c) causes an increase in the simulated maximum drawdown of 0.90 m, 1.4 m and 2.2 m, respectively, while maximum drawdown in Scenario 2 was 0.8 m.

The sensitivity simulation test results show that under the scenarios with the greatest degree of plausible confinement (Scenario 4c) localised maximum drawdown in the deep aquifer almost triples in magnitude from 0.8 m to 2.2 m in the Motutangi high development area.

Figure 47. Simulated drawdown in deep aquifer (Scenario 4a). (See A3 attachment at rear).

Figure 48. Simulated drawdown in deep aquifer (Scenario 4b). (See A3 attachment at rear).

Figure 49. Simulated drawdown in deep aquifer (Scenario 4c). (See A3 attachment at rear).

The simulated drawdown was extracted for 34 existing groundwater bores for each of the sensitivity simulations and compared against Scenario 2, as shown in **Figure 50** . The simulated drawdown ranges from 0.12 to 0.82 m, 0.28 to 1.30 m and 0.55 to 2.11 m for scenario 4a, 4b and 4c, respectively. The maximum drawdown was simulated at IA Stanisich bore and Ongare Trust (Whalers Road), and the minimum drawdown was simulated at LL & DF Rasmussen bore.

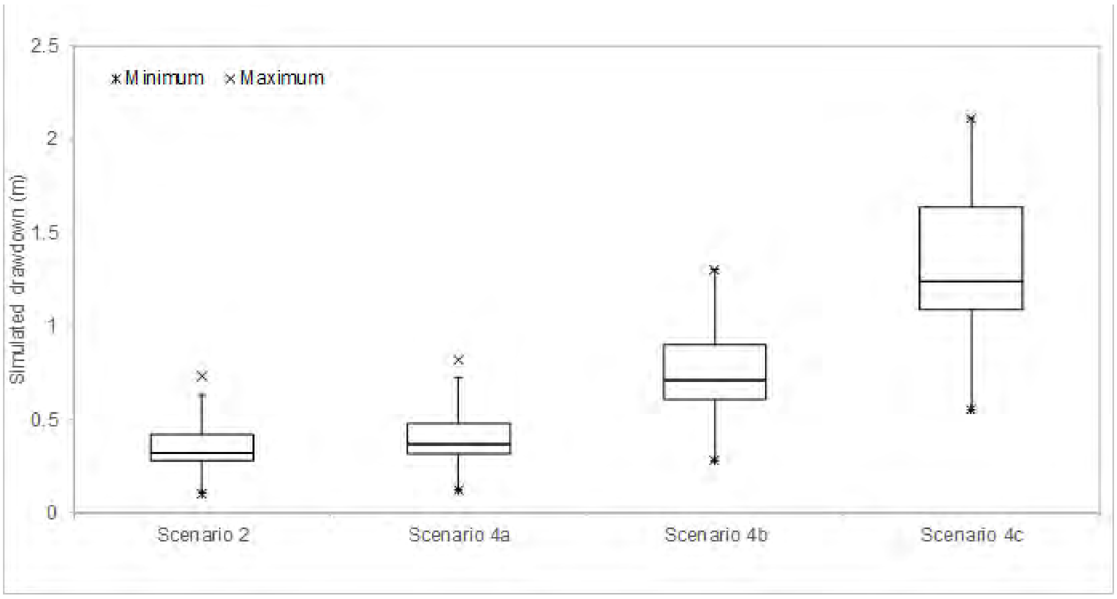


Figure 50. Drawdown observed at existing bores at the observation time step for scenario 2 & 4.

A continuous confining layer as implemented for the sensitivity scenarios is unlikely to accurately represent the confining conditions as the low-permeability units are discretely distributed in the project area. However, this sensitivity analysis does provide a perspective on how the model behaves and how the deep shellbed aquifer responds with additional confinement.

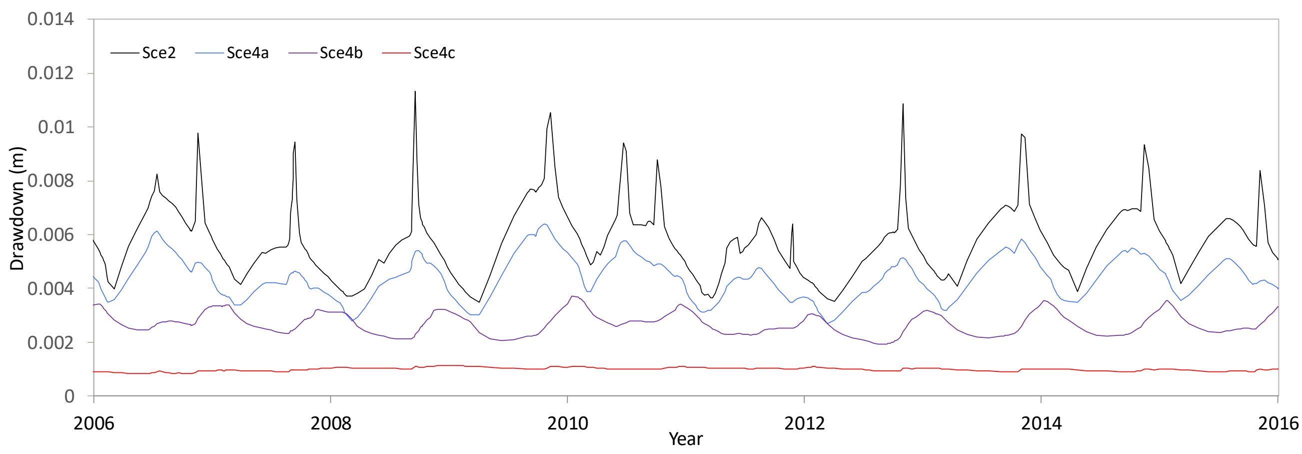
The uncertainty in the predicted drawdown primarily lies in the degree of leakage/confinement defined in the model. The inherent variation in the location and degree of confining conditions was not possible to be explicitly represented in the model as only limited information was available on the spatial extent and permeability of confining units. Assigning one layer with uniform low permeability to represent increased confinement provides an upper bound for the potential drawdown in the deeper shellbed aquifer for the total extraction proposed.

The simulated drawdown at the same three key locations as used previously (Houhora-Motutangi, Waiharara, Kaimaumau wetland) were compared for each sensitivity scenario and Scenario 2 model (higher leakage) for the shallow and deep aquifer, as shown in **Figure 51** to **Figure 53**, respectively. These graphs are provided to give a sense of the relative drawdown response with reduced leakage (increasing confinement) and shows that:

- drawdown in deep shellbed layer increases as the permeability of Layer 2 decreases; and
- drawdown in shallow aquifer decreases and shows a delayed response to pumping in the deep shellbed aquifer.

Figure 51. Simulated drawdown for Scenario 2 and uncertainty scenarios for Houhora.

Shallow aquifer (Layer 1)



Deep Aquifer (Layer 6)

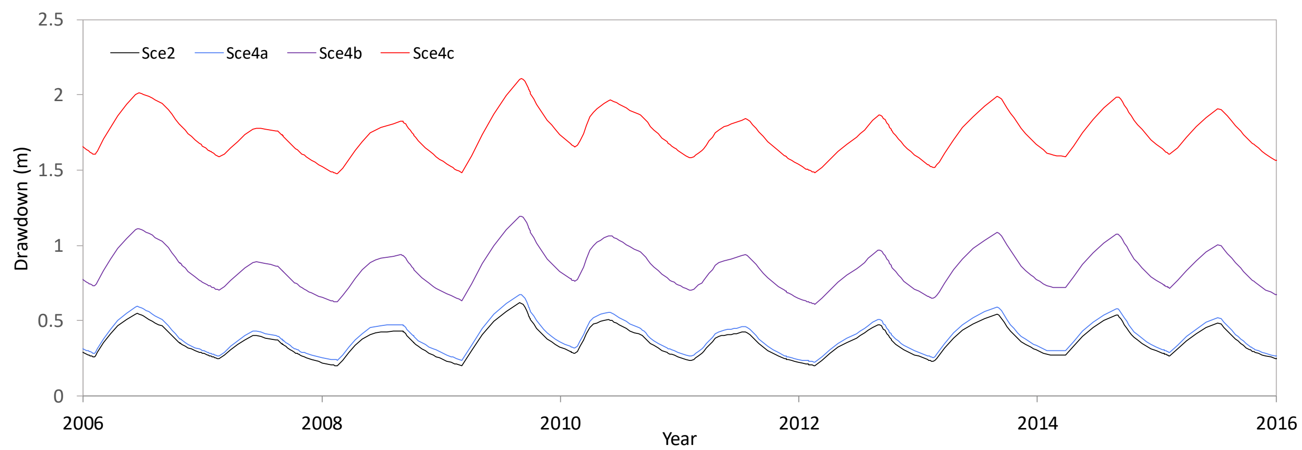


Figure 52. Simulated drawdown for Scenario 2 and uncertainty scenarios for Waiharara.

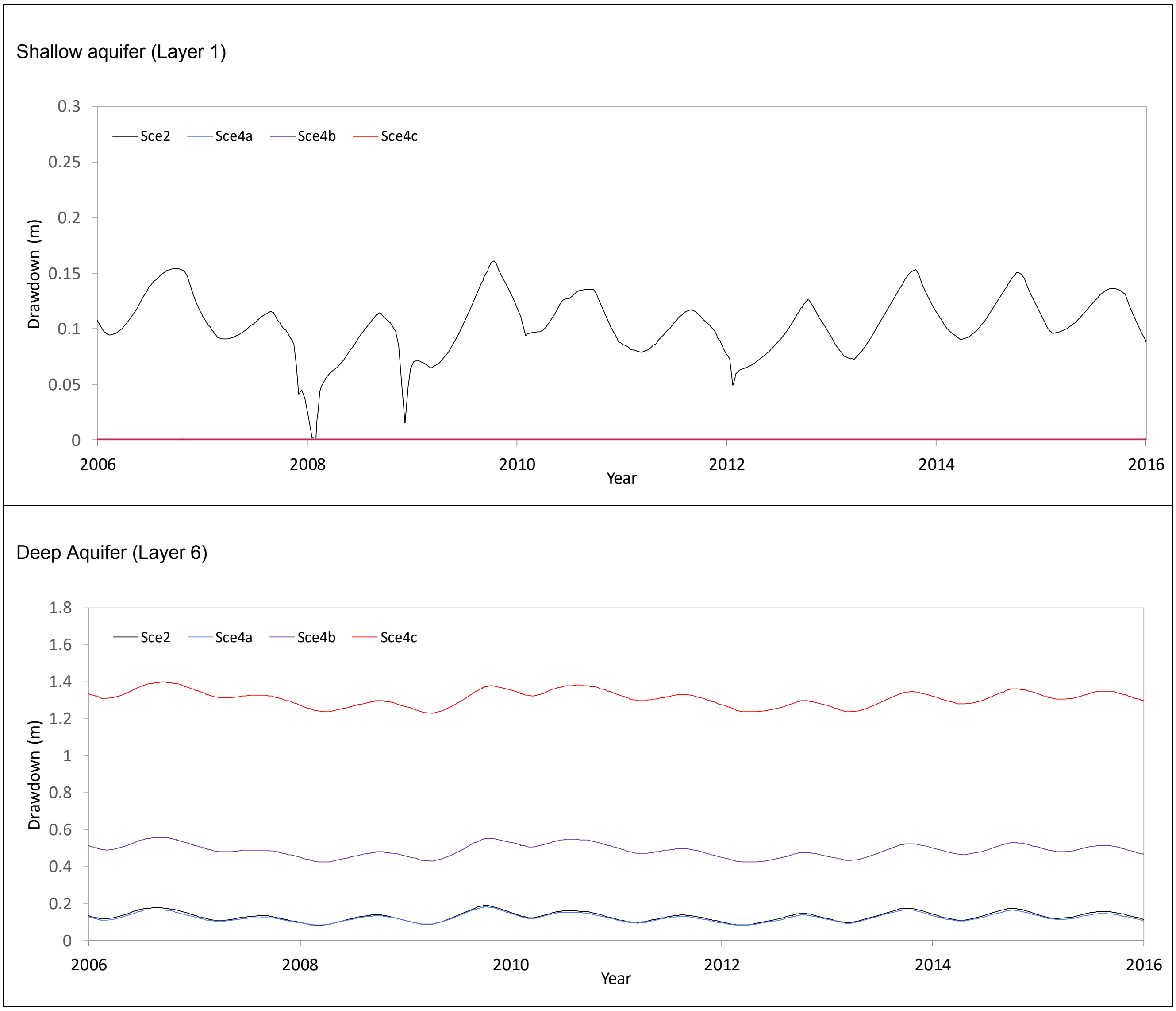


Figure 53. Simulated drawdown for Scenario 2 and uncertainty scenarios for Kaimaumau

6. Conclusions

A numerical groundwater flow model was developed to determine the potential impact from the proposed groundwater abstraction on the regional aquifer system and the hydrological condition of relevant surface water. In particular, the model was used to define the potential impact from seasonal pumping on the aquifer system water budget, aquifer groundwater levels, surface water drain flows and discharges from the Kaimaumau wetland, and the position of the saltwater/fresh water interface.

Water Budget

Total groundwater abstraction accounts for 1.8% of the water budget under the currently proposes consenting scenario, which is 1.7% more than currently is taken on average. Three additional scenarios were simulated with higher abstraction volumes to test future potential allocation and sustainability of the aquifer. These scenarios represent 3.7%, 5.6% and 9.2% of the flow budget, respectively.

Change in Drain Flow and Discharges from Kaimaumau Wetland

Under the proposed extraction, flow from the drains and wetland account for 11.5% and 3.4% of the water budget, respectively. Compared to the base model, the total flow in the drains and wetland has potential to decrease by a maximum of 0.8 % and 0.3%, respectively.

Analysis of the recurrent interval of low flows in the drains and wetlands indicated a reduction in annual low flow by a maximum of approximately 7% and the 1 in 5-year low flow by a maximum of approximately 11%, respectively.

However, because the model does not adequately simulate the presence of iron pans, it is considered that this estimate is exaggerated and therefore conservative.

Change in Water Levels

The proposed abstraction has potential to change groundwater levels in both the deep and the shallow aquifer, particularly during dry times, but the aquifers respond quickly to wetter climate following the irrigation season.

Aquifer drawdown was calculated for 30/04/2010, which was considered the heaviest irrigation use season. At this time, the proposed abstraction induces a maximum of 0.8 m and 0.4 m drawdown in the deep and the shallow aquifer, respectively. The drawdown at the existing bores is governed by their distance to the proposed new groundwater take locations. At the driest time (30/04/2010), the observed drawdown ranges between 0.1 to 0.73 m for the current abstraction proposal.

As the model setup has not captured the existence of hard pan layers in the shallow aquifers and thus the degree of confinement of the deeper shellbed aquifer, drawdown in the deeper aquifer may be under-estimated. A sensitivity analysis that involved implementing various degrees of confinement in the model indicated a maximum drawdown of 2.2 m under the proposed abstraction. This is likely to be the upper bound for drawdown in the deeper shellbed aquifer.

Saline Interface

While the model shows a significant potential rise in the level of the saline interface at the proposed abstraction compared to the base model, the saline interface remains at a significant distance below the sedimentary (shellbed) aquifer and also the simulated pressure at the coast will withstand inland migration of saline water along the shellbed aquifer/bedrock interface.

Lake Waiparera Water Levels

Lake Waiparera is perched above the regional aquifer, thus it is hydrologically disconnected to the groundwater system. No change is expected in the hydrological functionality of the lake due to deep groundwater pumping.

Kaimaumau Wetland Water Levels

The hard pan formed from buried sand existing beneath the Kaimaumau wetland and across the model domain is likely to reduce the flow interaction between surface drains and wetlands and the groundwater system. Field testing in the Kaimaumau wetland using radon isotope analysis shows that drainage water from the Kaimaumau wetland had significantly lower concentrations of radon compared to the deep groundwater sample. This provides supporting information of the likely disconnection between the deep shellbed aquifer and surface wetlands and drains.

While the model shows water level effects in the range of less than a metre in the wetland in the proposed pumping scenario, it is considered to be an over-estimation due to the model not being configured for the discrete impeding layers such as iron pans.

Therefore, these surface hydrological features being disconnected to groundwater system are unlikely to be significantly affected by the proposed extraction.

Assessment of Effects

The factual data presented in this report will be considered in the context of an assessment of effects under the Resource Management Act in a companion document.

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Appendix A. Summary of Aquifer Hydraulic Properties

The following tables summarise hydraulic property values that have been measured and estimated in models across the Aupouri Peninsula from various reports since 2000.

Table A1. Analysis of aquifer test data (Lincoln Agritech, 2015).

Pump	Screen depth	Test name	Lithology	T	B	Kx	S	K'/B'	B'	K'z
	(mBGL)			(m^2/d)	(m)	(m/d)	(-)	(d)	(m)	(m/d)
200048	18.8	Hukatere 1	Sand	60	6.4	9.4	0.0017	0.1475	13.5	2.0
200048	18.8	Hukatere 1	Sand	60	6.4	9.4	0.0107	0.2927	13.5	4.0
200048	18.8	Hukatere 3	Sand	50	6.4	7.8	0.0022	0.1909	13.5	2.6
200048	18.8	Hukatere 3	Sand	62	6.4	9.7	0.0154	0.1909	13.5	2.6
200060	64	Browne	Sand	400	10.4	38.5	0.0004	0.0014	21.2	0.03
200081	31.2	Ogle Drive	Sand	7.4	8.1	0.9	0.0467	0.8771	10.2	8.9
200229	73	Fitzwater	Shell/sand	130	6	21.7	0.0002	0.0001	26.0	0.004
200229	73	Fitzwater	Shell/sand	110	6	18.3	0.0004	0.0004	11.0	0.004
201025	27	Sweetwater	Sand	52	6.3	8.3	0.0004	0.0018	11.0	0.02
201037	27.2	Welch	Sand/shell	9	1.8	5	0.0005	0.0087	11.9	0.1
209606	110.5	King Avo	Shell	305	26	11.7	0.0007	0.0003	15.5	0.004
209606	110.5	King Avo	Shell	370	17	21.8	0.0011	0.0003	15.8	0.005
			Min	7.4	1.8	0.9	0.0002	0.0001	10	0.004
			Mean	135	8.9	13.5	0.0067	0.14	15	1.7
			Max	400	26	38.5	0.0467	0.88	26	8.9

Table A2. Analysis of aquifer test data (HydroGeo Solutions, 2000).

NRC Bore	Depth	Top of screen	Aquifer type	SWL	T	K	S
	(m)	(mBGL)		(mBGL)	(m^2/d)	(m/s)	(-)
43	55	52	Fine sand	9.3	240 - 280	6E-05 to 7.1E-05	-
48	67	19	Med sand	5.3	80 - 300	6.1E-05 to 7.1E-05	0.01-0.001
59 (s)	6	-	Fine sand	2.8	140	5.10E-04	-
59 (d)	55	49	Fine sand	13.4	190	5.30E-05	-
60	60	-	Fine sand	14.9	220 - 850	5.6E-06 to 1.3E-04	-
81	32	31	Fine sand	20.9	12 - 28	1.25E-05 to 2.9E-05	0.07-0.03
152	66	60	Fine sand	30.1	260	8.40E-05	-
184	110	101	Shelly sand	17.2	140 -340	1.7E-05 to 4.2E-05	-
229 (211)	79	70	Shelly sand	2.6	140	2.10E-05	1.4E-04 to 1.8E-03
230	88	63	Shelly sand	4.6	240 - 310	4.3E-05 to 3.3E-05	-

NRC Bore	Depth	Top of screen	Aquifer type	SWL	T	K	S
	(m)	(mBGL)		(mBGL)	(m^2/d)	(m/s)	(-)
1007	50	45	Fine sand	33.7	275 -305	2.1E-04 to 1.9E-04	-
1025	30	27	Fine sand	1.55	60 -103	2.2E-05 to 3.7E-05	2.5E-04 to 5.0E-04
1374	32	26.6	Fine sand	0.8	48	1.80E-05	1.0E-05 to 2.0E-05
1424*	82	70	-	-	260	-	-

Table A3. Summary of aquifer test data (SKM, 2010).

Bore Owner	Well ARC No	Easting (NZMG)	Northing (NZMG)	Test Type	Test Dur. (hrs)	Rate (m^3/day)	Obs. Bores	Screen Geology	K (m/s)	Information Source
King	201374	2533400	6681500	Constant Rate	24	576	Yes (1)	Shell	1.8E-05	HydroGeo Solutions (2000)
Sweetwater Orchards	201424	2529558	6684434	Constant Rate	72	1,176	Yes (1)	Shell	1.9E-04	Woodward Clyde (1998)
Kaurex Corporation	200230	2530331	6697328	Constant Rate	9.5	273	No (PB only)	Shell	4.3 – 3.3E-05	HydroGeo Solutions (2000)
Matai Orchards	201507	2529399	6691299	Constant Rate	88.5	497	Yes (1)	Shell	4.0 – 2.0E-04	SKM (2007)
Hopkins	200184	2520300	6706800	Constant Rate	24	260	No (PB only)	Shell	4.2 – 1.7E-05	HydroGeo Solutions (2000)
Fitzwater	200229	2529743	6690648	Constant Rate	24	864	Yes (4)	Shell	2.1 – 1.4E-04	HydroGeo Solutions (2000) and SKM (2007)
Brown	200060	2521699	6706300	Constant Rate	22	708	Yes (3)	Sand	5.6E-06 – 1.3E-04	HydroGeo Solutions (2000)
Hogg	201007	2528300	6685799	Constant Rate	20.9	160	No (PB only)	Sand	2.1 – 1.9E-04	HydroGeo Solutions (2000)
Waiharara	209499	2528580	6690100	Constant Rate	91	1,113	Yes (2)	Shell	2.0E-04	SKM (2007)
King Avocado Ltd	209606	2527482	6690562	Constant Rate	168	2,393	Yes (3)	Shell	4.3 – 1.5E-04	SKM (2007)
Hamilton Nurseries	201025	2531401	6684155	Constant Rate	6	300	Yes (2)	Sand	1.2E-04	SKM (2001)
Stanisich Orchard	200192	2528600	6695799	Constant Rate	1	1,442	No (PB only)	Shell	5.0E-05	SKM (2002a)
Terra Nova Orchard	200335	2521199	6706499	Constant Rat	39	674	Yes (6)	Shell	4.0 – 3.0E-04	SKM (2002b)
Northland Catchment Commission	200048	2519855	6701857	N/A	N/A	N/A	N/A	Sand	7.1 – 6.1E-05	HydroGeo Solutions (2000)
Northland Catchment Commission	200081	2528583	6689795	N/A	N/A	N/A	N/A	Sand	2.9 – 1.25E-05	HydroGeo Solutions (2000)

Colville	200059	2521792	6705887	Step (4)	22.3	63 - 233	No (PB only)	Sand	5.3E-05	HydroGeo Solutions (2000)
Fraser	201002	2525552	6671053	Step (3)	22	89 - 163	No (PB only)	Sand	3.0E-04	NRC database
Richards Enterprises	200043	2522513	6708792	Step (4)	19	149 -333	No (PB only)	Sand	7.1 – 6.0E-05	HydroGeo Solutions (2000)
Herbert	200152	2528178	6688977	Step (4)	20	127 - 319	No (PB only)	Sand	8.4E-05	HydroGeo Solutions (2000)

Table A4. Calibrated model parameters (SKM, 2007a).

Material ID	Hydraulic Conductivity		Vertical anisotropy	Sy
	(m/d)	(m/s)	(-)	(-)
Loose dune sand	10	1.20E-04	10	0.2
Weathered dune sand	6	6.90E-05	10	0.2
Fine sand	3	3.50E-05	25	0.25
Peat and sand	0.1	1.20E-06	30	0.2
Upper alluvium	0.55	6.40E-06	10	0.3
Alluvium	0.06	6.90E-07	20	0.05
Shell bed	50	5.80E-04	2	0.3

Table A5. Aquifer hydraulic parameters derived from SKM102PB test pumping (SKM, 2007b).

Bore	T	K	
	(m^2/s)	(m/d)	(m/s)
SKM101b	3.70E-03	32	3.70E-04
SKM102b	1.50E-03	13	1.50E-04
SKM103b	3.50E-03	30	3.50E-04
SKM104b	4.30E-03	37	4.30E-04

Table A6. Material parameters used within PLAXIS geotechnical subsidence model (SKM, 2007b).

King Avocado Orchard Groundwater Take Consent Application (AEE Final)							
Material	Density (KN/m$^{3)}$		Permeability (m/d)		Stiffness (kN/m^2)	Cohesion (kN/m^2)	Friction Angle (°)
	δunsat	δsat	Kx	Ky	E50ref	cref	ø
Loose Dune Sand	15	17	5	0.25	10000	0.2	28

Compact Dune Sand	17	19	0.7	0.07	15000	0.2	28
Shell Bed	18	20	22	2.2	30000	1	30

Appendix B. Recharge Modelling

B.1 Model Parameters

The soil moisture water balance model (SMWBM) is a deterministic lumped parameter model originally developed by Pitman (1976) to simulate river flows in South Africa. The code was reworked into a Windows environment and the functionality extended to include a surface ponding function, additional evaporation functions and an irrigation module.

The model utilises daily rainfall and potential evaporation data to calculate soil moisture conditions and the various components of the catchment water balance under natural rainfall or irrigated conditions. The model operates on a time-step with a maximum length of daily during dry days, with smaller hourly time-steps implemented on wet days.

The model incorporates parameters that characterise the catchment in terms of:

- interception storage,
- evaporation losses,
- soil moisture storage capacity,
- plant available water capacity,
- soil infiltration,
- sub-soil drainage;
- vadose zone vertical drainage'
- surface runoff (quickflow);
- stream baseflows (groundwater contribution); and
- the recession and/or attenuation of groundwater and surface water flow components, respectively.

B.2 Fundamental Operation

The fundamental operation of the model is as follows and in **Table B1**:

When a rainday occurs, daily rainfall is disaggregated into the hourly time-steps based on a pre-defined synthetic rainfall distribution, which includes peak intensities during the middle of the storm. This time stepping approach ensures that rainfall intensity effects and antecedent catchment conditions are considered in a realistic manner by refined accounting of soil infiltration, ponding and evaporation losses.

Rainfall received must first fill a nominal interception storage (PI – see below) before reaching the soil zone, where the net rainfall is assessed as part of the runoff/infiltration calculation.

Water that penetrates the soil fills a nominal soil moisture storage zone (ST). This zone is subject to evapotranspiration via root uptake and direct evaporation (R) according to the daily evaporation rate and current soil moisture deficits. The soil moisture zone provides a source of water for deeper percolation to the underlying aquifer, which is governed by the parameters FT and POW.

If disaggregated hourly rainfall is of greater intensity than the calculated hourly infiltration rate (ZMAX, ZMIN) surface runoff occurs. Surface runoff is also governed by two other factors, which are the prevailing soil moisture deficit and the proportion of impervious portions of the catchment directly linked to drainage pathways (AI).

Rainfall of sufficient intensity and duration to fill the soil moisture storage results in excess rainfall that is allocated to either surface runoff or groundwater percolation depending on the drainage and slope characteristics of the catchment (DIV).

Finally, the model produces daily summaries of the various components of the catchment water balance and calculates the combined surface runoff/percolation to groundwater to form a total catchment discharge.

Table B1. Summary of SMWBM parameters and value assignments for this study.

Parameter	Name	Parameter Values			Description
		Coastal sand	Weather-ed sand	Plain zone	
ST (mm)	Maximum soil water content.	178.5	178.5	100	ST defines the size of the soil moisture store in terms of a depth of water. ST is approximately equivalent to root zone depth divided by soil porosity.
SL (mm)	Soil moisture content where drainage ceases.	0	0	0	Soil moisture storage capacity below which sub-soil drainage ceases due to soil moisture retention.
ZMAX (mm/hr)	Maximum infiltration rate.	30	20	5	ZMAX and ZMIN are nominal maximum and minimum infiltration rates in mm/hr used by the model to calculate the actual infiltration rate ZACT. ZMAX and ZMIN regulate the volume of water entering soil moisture storage and the resulting surface runoff. ZMIN is usually assigned zero. ZMAX is usually assigned the saturated infiltration rate from field testing. ZACT may be greater than ZMAX at the start of a rainfall event. ZACT is usually nearest to ZMAX when soil moisture is nearing maximum capacity.
ZMIN (mm/hr)	Minimum infiltration rate.	0	0	0	
FT (mm/day)	Sub-soil drainage rate from soil moisture storage at full capacity.	5	3.8	0.8	Together with POW, FT (mm/day) controls the rate of percolation to the underlying aquifer system from the soil moisture storage zone. FT is the maximum rate of percolation through the soil zone.
POW (>0)	Power of the soil moisture-percolation equation.	2	2	2	POW determines the rate at which sub-soil drainage diminishes as the soil moisture content is decreased. POW therefore has significant effect on the seasonal distribution and reliability of drainage and hence baseflow, as well as the total yield from a catchment.
AI (-)	Impervious portion of catchment.	0	0	0.01	AI represents the proportion of impervious zones of the catchment directly linked to drainage pathways.
R (0,1,10)	Evaporation-soil moisture relationship	0	0	0	Together with the soil moisture storage parameters ST and SL, R governs the evaporative process within the model. Three different relationships are available. The rate of evapotranspiration is estimated using either a linear (0,1) or power-curve (10) relationship relating evaporation to the soil moisture status of the soil. As the soil moisture capacity approaches full, evaporation occurs at a near maximum rate based on the mean monthly pan evaporation rate, and as the soil moisture capacity decreases, evaporation decreases according to the predefined function.
DIV (-)	Fraction of excess rainfall allocated directly to pond storage.	0	0	0	DIV has values between 0 and 1 and defines the proportion of excess rainfall ponded at the surface due to saturation of the soil zone or rainfall exceeding the soils infiltration capacity to eventually infiltrate the soil, with the remainder (and typically majority) as direct runoff.
Kv (m/s)	Vertical hydraulic conductivity	8E-6	5E-6	2E-8	Kv along with the VGn parameter and the soil moisture status governs the unsaturated hydraulic conductivity and travel times within the vadose zone.

VGn (-)	van Genuchten parameter	2.68	2.68	1.09	Defines the soil moisture to unsaturated conductivity relationship according to van Genuchten's equation.
VPor (-)	Average porosity of the vadose zone	0.15	0.15	0.40	This is typically fixed and not changed during calibration as changes can easily be compensated for in Kv.
D (m)	Average depth of the vadose zone	10	10	1	The deeper the vadose zone, the longer the travel times.
TL (days)	Routing coefficient for surface runoff.	1	1	1	TL defines the lag of surface water runoff. This is not necessary to define for this study as we are only interested in the groundwater percolation component of the water balance.
GL	Groundwater recession parameter.	1	1	1	GL governs the lag in groundwater discharge or baseflow from a catchment.

B.3 Vadose zone discharge functionality

Based on the simulated groundwater percolation from the soil moisture model, the vadose zone discharge functionality was utilised to simulate the vertical movement of water in the unsaturated zone. The depth and hydraulic properties of the vadose zone govern the delay in groundwater response to climate variation.

The vadose zone functionality built into the SMWBM is premised on three principals:

1. ***Unsaturated hydraulic conductivity -*** The van Genuchten (1980) equation was used to determine unsaturated hydraulic conductivity in the vadose zone, which is governed by the saturated hydraulic conductivity that sets the upper value, and the degree of saturation in the soil zone as a proxy for general sub-surface degree of wetness.

2. ***Vertical flux rate*** - The simplified Richard's equation is used to estimate the vertical flux rate of water, which is assumed to be driven by gravitational force (only) and therefore governed by unsaturated hydraulic conductivity and porosity.

3. ***Transport time*** - The Muskingum equation was used to translate the vertical flux into a routing scheme, using the depth of the vadose zone and vertical flux rate (velocity) as the time component of the equation.

The delay in groundwater recharge was observed for coast sand, weathered sand and peat and clay to different extents. The simulated results for weathered sand suggest that the groundwater recharge has approximately 2-3 months delay in responding to the rainfall variation, depending on locality. **Figure B1.** provides an example of the functionality of the vadose zone model.

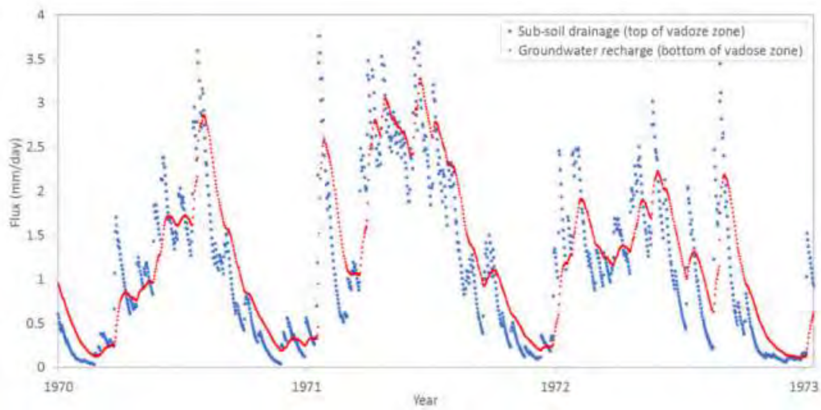


Figure B1. Graph comparing inputs and outputs from vadose zone model.

Appendix C. Irrigation Scheduling and Actual Irrigation Use

C.1 Development of an irrigation scheduling dataset

The irrigation module of Soil Moisture Water Balance Model was utilised to optimise irrigation applications for avocado orchards in the area and to provide input into the transient irrigation scenario for groundwater modelling purposes. The parameters and associated values used in the model are shown in **Table C1**.

Table C1. Summary of parameters used in the irrigation model

Parameter	Description	Values	Basis of Values
Maximum Soil Moisture Content (ST)	The capacity of water in mm in the soil at field capacity.	178.5	Estimated from potential rooting depth (PRD) and macroporosity (n). ST = PRD x n/100. 1190 mm x 15%= 178.5 mm
Plant Available Water (PAW)	The amount of water physically accessible by the plants in the root zone in mm.	125	Table 22 of Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements from the Food and Agricultural Organisation of the United Nations (FAO)[1] states that 70% of Total Available Soil Water (interpreted as equivalent to ST in the SMWBM) can be depleted before the point where avocado trees suffer stress. Therefore, PAW = 0.7 x ST
Allowable Deficit (AD)	Soil moisture level where irrigation ceases.	90% of PAW	The avocado is very flood-sensitive with even short periods of waterlogging resulting in reduced shoot growth, altered mineral uptake and root death. To avoid flooding and surface runoff, soil moisture levels during irrigation should not exceed 90% of field capacity.
Minimum/ Critical Deficit (CD)	Percentage of PAW at which further drying of soil would start to have an impact on plant growth rates, and hence CD represents the soil moisture level at which irrigation commences.	40% of PAW	The rule of thumb for critical deficit is 50% of PAW. However, a grower aiming to maximise crop yield may want a small critical deficit of only 20% (80% PAW)[2]. A balance is also required between a small critical deficit (high soil moisture levels) and water wastage, which results under high moisture conditions when rainfall occurs during summer. Through trial and error, we have used CD values of 40% PAW.
Peak Application Depth	Maximum daily irrigation depth applied to soil (mm/day).	4.0 mm	Selected through optimisation target of minimisation in losses, while maintaining moisture levels at or above the CD. Note. This is the amount of irrigation water reaching the soil surface, which is less that the amount applied by the irrigator *per se*. due to application inefficiencies (losses).
Application Duration	Duration in hours over which the peak application depth is applied	2 hours	Data estimated
Rain Threshold	Daily rainfall total in mm when a farmer would choose not to irrigate.	10 mm	Judgement
Season	Irrigation season start and finish	October – April	General irrigation season length.

The same historical rainfall record from 01/08/1956 to 31/08/2016 described in **Appendix B** was used in the model. The simulated soil moisture content with/without irrigation are shown in **Figure C1**.

1 http://www.fao.org/docrep/x0490e/x0490e0e.htm
2 Anon. Scheduling overview. NZ Avocado Industry 11 Mar 2010. (accessed 16 Jul 2015) <http://www.hortinfo.co.nz/factsheets/fs110-68.asp>.

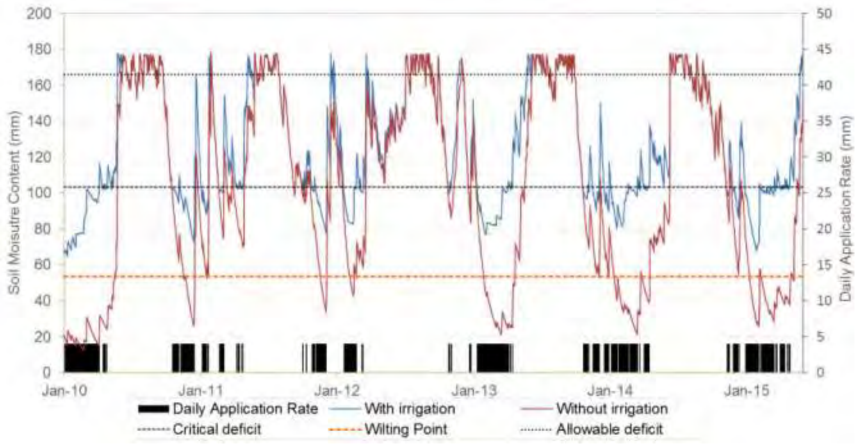


Figure C1. Irrigation simulation output for time period 2010-2015

The daily peak application rate was optimised through a set of simulations, aiming to minimize the water losses through surface runoff and percolation to groundwater system, while maintaining a soil moisture content that is above the plant critical deficit.

The simulations indicate an optimized peak application rate of 4 mm/day. The relationship between annual irrigation amount and peak application rate is shown in **Figure C2**.

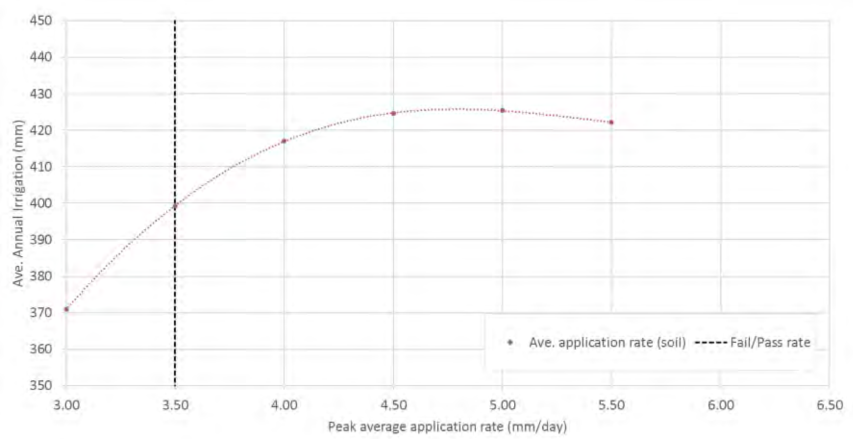


Figure C2. Assessment of peak application rate that is water conservative for sandy soils.

The irrigation demand was simulated for the period of 01/08/1956 to 31/08/2016 and a summary graph showing the number of days irrigation was required per season is shown in **Figure C3**.

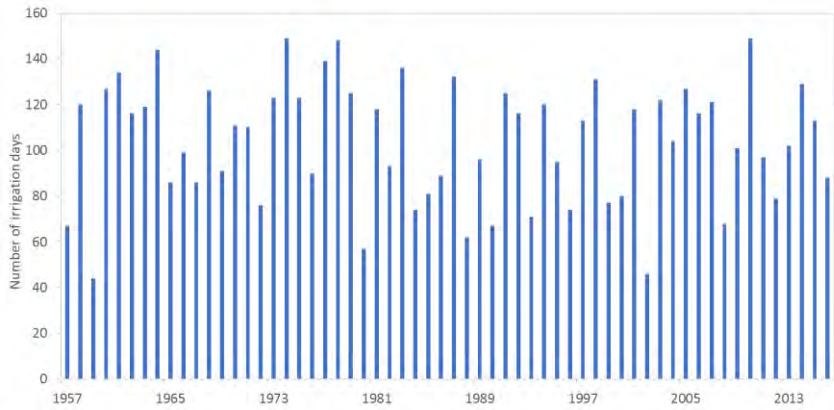


Figure C3. Simulated number of irrigation days per season.

The statistical distribution of monthly irrigation application totals, with 10% additional water added to account for irrigation inefficiency, is shown in **Figure C4**.

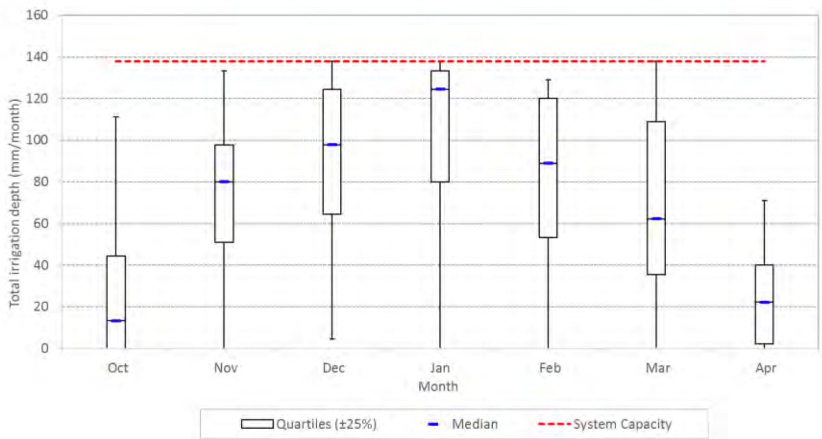


Figure C4. Seasonal irrigation demand for sandy soil.

The annual irrigation demand volume and commensurate number of days of irrigation was calculated and it was found that the 90%ile of simulated annual demand is equivalent to approximately 150 days pumping at the peak rate. This closely aligns with the annual volumes specified in consents granted.

C.2 Development of an irrigation actual use dataset

The simulated irrigation demand time series was applied to one of the currently consented groundwater bores with a peak allocation rate of 720 m^3/day owned by Ivan Stanisich (NRC consent No. CON20102739101). The total amount of demand simulated during the irrigation period was calculated and compared with available historical use records, as shown in **Figure C5**.

The simulated demand varies with climate conditions from a minimum of 44 days irrigation to a maximum of 149 days irrigation during the irrigation season. For the years where records were available for comparison, measured demand is approximately 30% of simulated demand. There are a number of minor reasons for this including human operational decision and actual rainfall not being totally consistent with site rainfall, but the primarily reason is that the orchard is not fully developed.

Considering the scope and purpose of this modelling, this irrigation demand time series is a conservative estimate and therefore appropriate to use in effects assessment from the abstraction of groundwater.

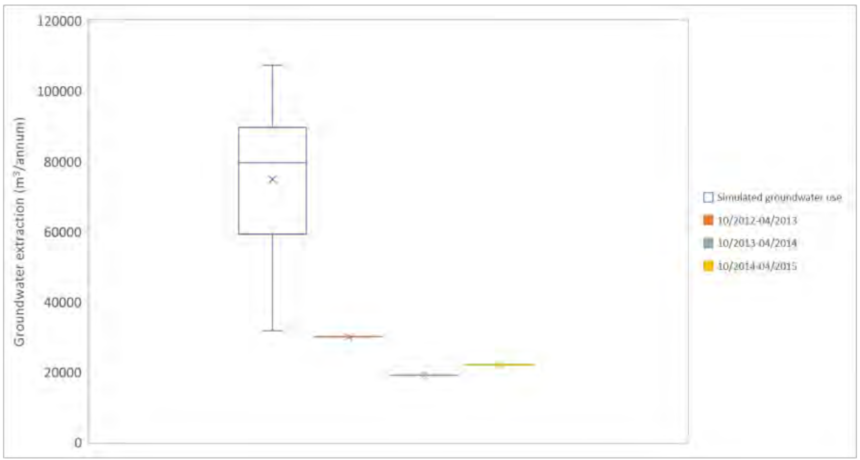


Figure C5. Comparison between the simulated groundwater demand and the historical records.

Consent Database

Table C2 provide a summary table of the date and volume of consents granted and expired. **Figure C6** indicates the total daily consented allocation with time.

Table C2. NRC consent database for Motutangi-Waiharara model area.

Consent No.	Commence date	Expiration date	Status	Peak Rate (m^3/d)	Annual Volume (m^3/yr)
AUT.002839.01.01	6/10/1994	30/11/2004	Expired	400	
AUT.002890.01.01	6/10/1994	30/11/2004	Expired	160	
AUT.003372.01.01	6/10/1994	30/11/2004	Expired	170	
AUT.003513.01.01	9/02/1990	30/11/1994	Expired	25	
AUT.003527.01.01	6/10/1994	30/11/2004	Expired	200	
AUT.003726.01.01	6/10/1994	30/11/2004	Expired	600	
AUT.003841.01.01	6/10/1994	30/11/2004	Expired	90	
AUT.003870.01.01	30/03/1990	30/11/1994	Expired	100	
AUT.003883.01.01	28/07/1999	30/11/2004	Expired	125	
AUT.003883.01.02	28/06/1999	30/11/2004	Expired	125	
AUT.003888.01.01	6/10/1994	30/11/2004	Expired	170	
AUT.003964.01.01	6/10/1994	30/11/2004	Expired	125	
AUT.004320.01.01	27/11/1987	30/11/1992	Expired	40	
AUT.004543.01.01	6/03/1995	30/11/2000	Expired	60	
AUT.004543.01.02	7/02/2000	30/11/2004	Expired	200	

Consent No.	Commence date	Expiration date	Status	Peak Rate (m^3/d)	Annual Volume (m^3/yr)
AUT.004903.01.01	25/11/1992	30/11/1999	Expired	200	
AUT.007108.01.01	6/10/1994	30/11/2004	Expired	125	
AUT.007115.01.01	6/03/1995	30/11/2004	Expired	25	
AUT.007524.01.01	28/09/1999	30/11/2004	Expired	70	
AUT.007735.01.01	11/12/2001	30/11/2012	Expired	800	132,000
AUT.008203.01.01	14/07/1997	30/11/2004	Expired	250	
AUT.008306.01.01	15/06/1998	30/11/2003	Expired	270	
AUT.008340.01.01	25/05/1998	30/11/2004	Expired	600	
AUT.008586.01.01	7/11/2001	30/11/2004	Expired	300	49,000
AUT.008605.01.01	8/06/1999	30/11/2004	Expired	160	
AUT.008647.01.01	31/05/1999	30/11/2004	Expired	96	
AUT.009561.01.01	6/09/2002	31/05/2004	Expired	1 L/s	
AUT.009808.01.01	10/09/2002	30/11/2012	Expired	300	49,500
AUT.002890.01.02	20/07/2005	30/11/2025	Current	240	43,200
AUT.003372.01.02	20/07/2005	30/11/2025	Current	170	25,920
AUT.003527.01.02	20/07/2005	30/11/2025	Current	200	26,040
AUT.003726.01.02	20/07/2005	30/11/2005	Current	600	74,400
AUT.003841.01.02	20/07/2005	30/11/2025	Current	90	14,800
AUT.003883.01.03	17/03/2005	30/11/2020	Current	125	26,400
AUT.003888.01.02	20/07/2005	30/11/2025	Current	170	34,560
AUT.003964.01.03	17/07/2015	30/11/2025	Current	370	67,106
AUT.004543.01.03	26/09/2007	30/11/2020	Current	400	45,000
AUT.007108.01.02	20/07/2005	30/11/2025	Current	125	16,740
AUT.007735.01.04	18/09/2014	30/11/2025	Current	400	66,000
AUT.008203.01.02	22/07/2005	30/11/2025	Current	250	37,200
AUT.008340.01.03	20/05/2015	30/11/2025	Current	860	158,520
AUT.008586.01.02	1/02/2006	30/11/2025	Current	300	48,000
AUT.008586.02.01	1/02/2006	30/11/2025	Current	156	30,000
AUT.008605.01.02	21/07/2005	30/11/2025	Current	360	52,080
AUT.008647.01.03	11/11/2014	30/11/2025	Current	320	52,800
AUT.009808.01.02	6/11/2012	30/11/2025	Current	300	51,200
AUT.012472.01.01	21/07/2005	30/11/2025	Current	700	17,856
AUT.016914.02.01	1/12/2006	30/11/2025	Current	240	40,000
AUT.017559.02.01	24/03/2010	30/11/2018	Current	600(840)	105,000
AUT.017559.02.01	24/03/2010	30/11/2018	Current	240(840)	
AUT.020726.02.02	6/12/2012	30/11/2025	Current	200	33,000
AUT.020727.02.02	18/09/2014	30/11/2025	Current	200	33,000
AUT.023557.01.02	24/06/2015	30/11/2025	Current	276	46,000
AUT.026611.01.01	15/09/2010	30/11/2025	Current	448	49,752

Consent No.	Commence date	Expiration date	Status	Peak Rate (m^3/d)	Annual Volume (m^3/yr)
AUT.027391.01.01	13/12/2010	30/11/2025	Current	720	120,000
AUT.028511.01.02	17/09/2015	30/11/2025	Current	300	32,000
AUT.028834.01.01	15/06/2011	30/11/2025	Current	140	20,000
AUT.029109.01.01	24/03/2010	30/11/2018	Current	240	20,000
AUT.029171.01.01	16/08/2011	30/11/2018	Current	240	24,000
AUT.036910.01.02	8/07/2016	30/11/2025	Current	900	135,000
AUT.037274.01.01	8/12/2014	30/01/2025	Current	500	74,500
AUT.038075.01.01	3/12/2015	30/01/2025	Current	80	12,000
AUT.038379.01.01	31/05/2016	30/11/2036	Current	350	70,000

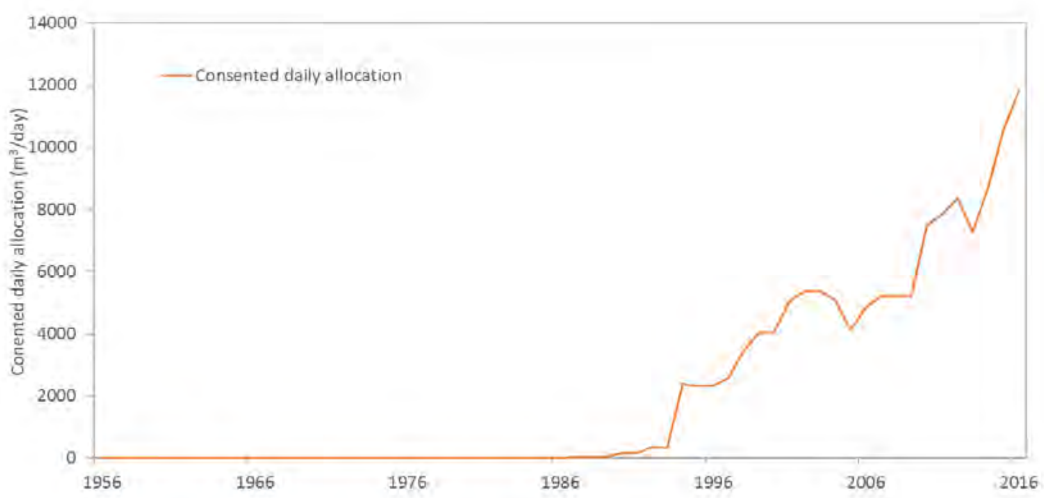


Figure C6. Consented allocation total (m^3/day) over time in the Motutangi-Waiharara project area.

Demand Timeseries

The simulated irrigation demand pattern from **Section C1** was applied to all the groundwater take bores in this study on the basis of the year they were granted or expired to produce a simulated daily demand time series, which is shown in **Figure C7**.

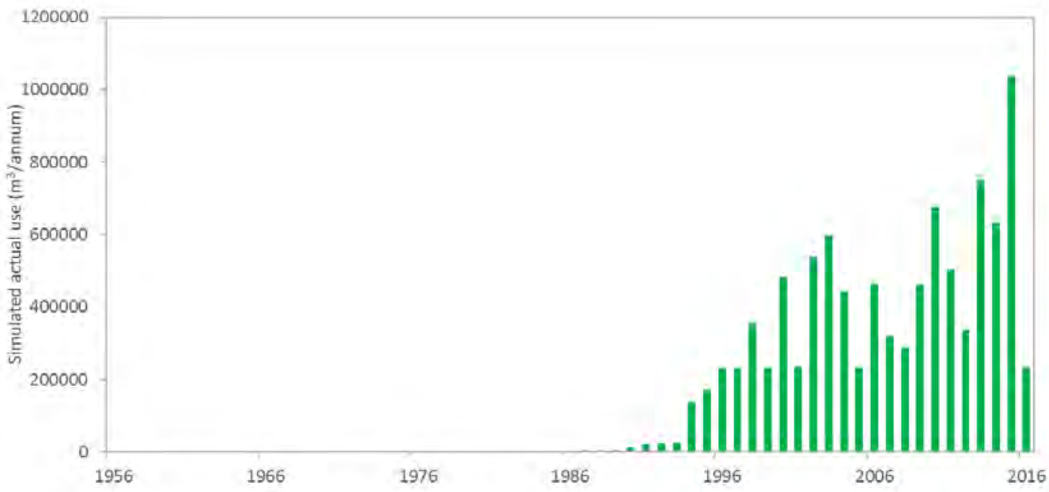


Figure C7. Simulated water demand (actual use) time series (m^3/annum).

Appendix D. Test Pumping Analysis

Pumping tests were conducted for three groundwater production bores located in the model domain, including:

1. Stanisich – AUT.037465.01.01
2. Honeytree Farms PB2 – AUT.038294.01.01
3. De Bede Ltd - AUT.017244.01.01

Table D1 summarises the details of each test. The bores were pumped for at least 24 hours, with monitoring of the groundwater levels in the production bores and monitoring bores recorded during pumping and recovery periods.

Table D1. Test pumping key information.

Consent No.	Stanisich	Honeytree Farms PB2	De Bede Ltd
Pumping rate (L/s)	25	29	2.3
Date pumping started	30/11/2016 12:19 PM	03/12/2016 1:00 PM	02/12/2016 8:27 AM
Date pumping ended	01/12/2016 12:30 PM	06/12/2016 8:30 AM	03/12/2016 8:45 AM
Date monitoring started	30/11/2016 11:52 AM	03/12/2016 11:10 AM	02/12/2016 8:10 AM
Date monitoring ended	02/12/2016 7:09 AM	10/12/2016 10:51 AM	03/12/2016 10:04 AM
Total depth of bore (mBGL)	101	95	97
Screen depth (mBGL)	87-101	62-68,68-71,84-93	91-97
Screen stratigraphy	Shellbed	Shellbed	Shellbed
No. of monitoring bores	2	2	0
Details of monitoring bores	Monitoring bore 1– 5m radius, shallow aquifer (~9m).	Production bore 1– 390 m radius, same aquifer (~95 m).	-
	Monitoring bore 2 (Hilltop) – 550 m radius, same aquifer (~86 m).	Monitoring bore 1 – 5 m radius, shallow aquifer (~10 m).	

D.1 Test data

Stanisich bore test data

Figure D1 shows the drawdown and recovery in the in the Stanisich pumping bore and indicates the maximum drawdown observed was 26.8 m. The tested shellbed aquifer has a relatively rapid response to the pumping. Within three minutes, the groundwater level recovered about 90% of the drawdown.

The monitoring bore 2 (Hilltop) that was located approximately 550 m away and screened in the same aquifer, was observed to have a maximum drawdown of 0.12 m. There was no significant groundwater level change observed in the piezometer screened at shallow aquifer (Monitoring bore 1), which is adjacent to the testing bore.

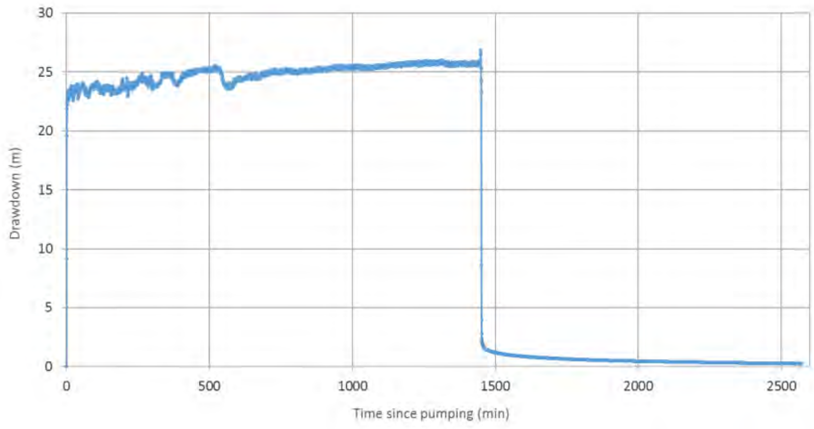


Figure D1. Drawdown in Stanisich bore.

The aquifer transmissivity and specific storage were calculated and shown in **Table 1**.

Honeytree Farms PB2 bore test data

Figure D2 shows the drawdown and recovery in the Honeytree Farms PB2, and a maximum drawdown of 4.9 m was observed during the pumping test. The groundwater level recovered the 90% of drawdown about 12 hours after the pumping ceased. The slower recovery rate compared to Stanisich bore is due to the longer duration of the pumping period.

The production bore 1 that was located approximately 390 m away and screened in the same aquifer, was observed to have a maximum drawdown of 1.2 m. There was no significant groundwater level change observed in the piezometer screened at shallow aquifer (Monitoring bore 1), which is located within 5 m radius of the pumping bore.

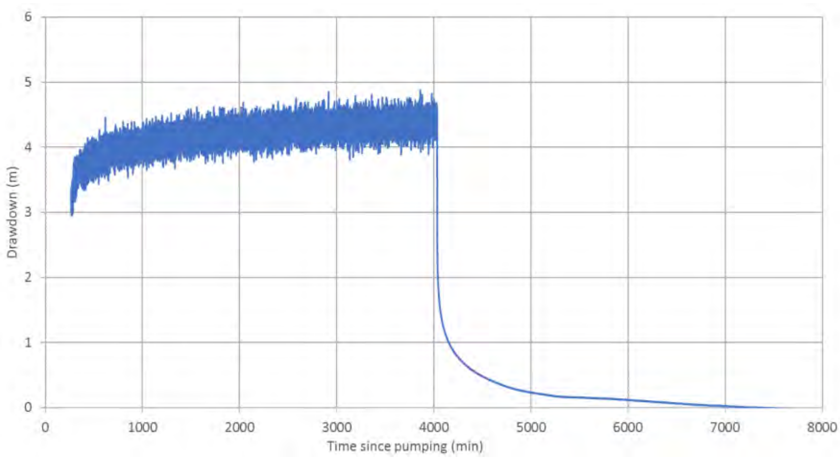


Figure D2. Drawdown in Honeytree Farms PB2 bore.

De Bede bore test data

Figure D3 shows the drawdown and recovery in the De Bede farm bore, and a maximum drawdown of 10.8 m was observed during the pumping test. The aquifer recovered 90% of the drawdown within 14 minutes.

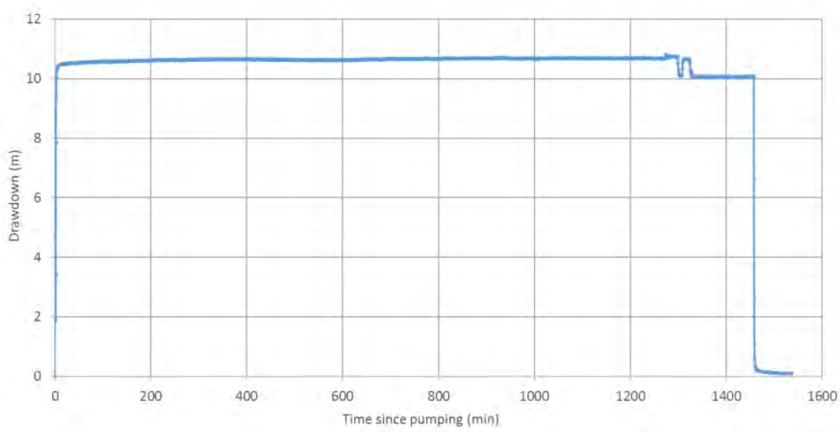


Figure D3. Drawdown of De Bede bore.

D.2 Test Pumping Analysis Results

Table D2 summarises the analyses results from various different methods of analysis, while **Figure D4** to **Figure D6** show the straight-line analysis of Jacob for reference to the appropriateness of the curve fitting procedure implemented.

Table D2. Hydrogeological data calculated from pumping tests

Farm	Rate (L/s)	Bore	Screen Depth (mBGL)	Method	T (m^2/d)	S (-)	B (m)	K (m/d)	K (m/s)
Stanisich Farm	25	Pumping bore	87-101	Single well Jacob	485	-	14	35	4.1E-04
				Theis Recovery	512	-		37	4.3E-04
	-	Monitoring bore	77-85	Theis (point match)	356	0.0044	8	45	5.2E-04
Honeytree Farm	29	Pumping bore	62-68, 68-71,84-93	Single well Jacob	618	-	18	34	3.9E-04
				Theis Recovery	511	-		28	3.2E-04
	-	Monitoring bore	63-69, 69-72,86-95	Theis (point match)	751	0.0003	18	42	4.9E-04
				Cooper Jacob	784	0.0003		44	5.1E-04
De Bede Farm	2.3	Pumping bore	91-97	Single well Jacob	377	-	6	63	7.3E-04
				Theis Recovery	363	-		61	7.1E-04
				Max	784	0.0044		63	7.3E-04
				Min	356	0.0003		28	3.2E-04
				Mean	528	0.0016		43	5.0E-04

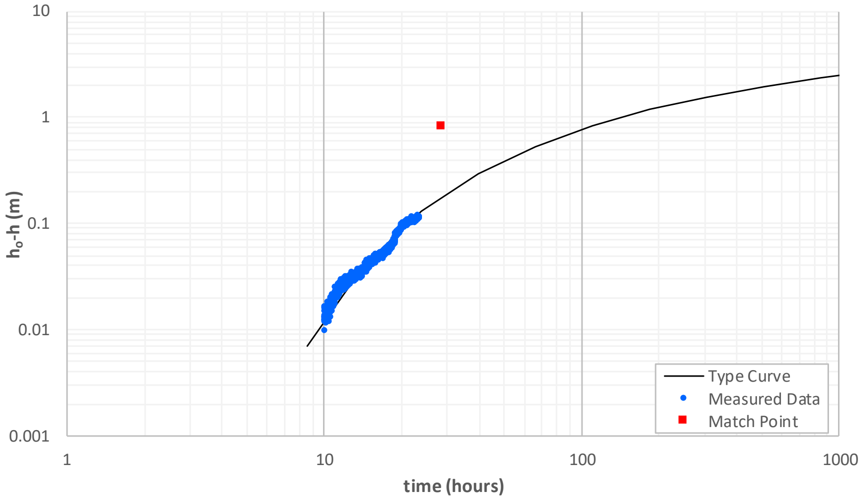


Figure D4. Curve fitting procedure for Theis curve analysis on Stanisich monitoring bore.

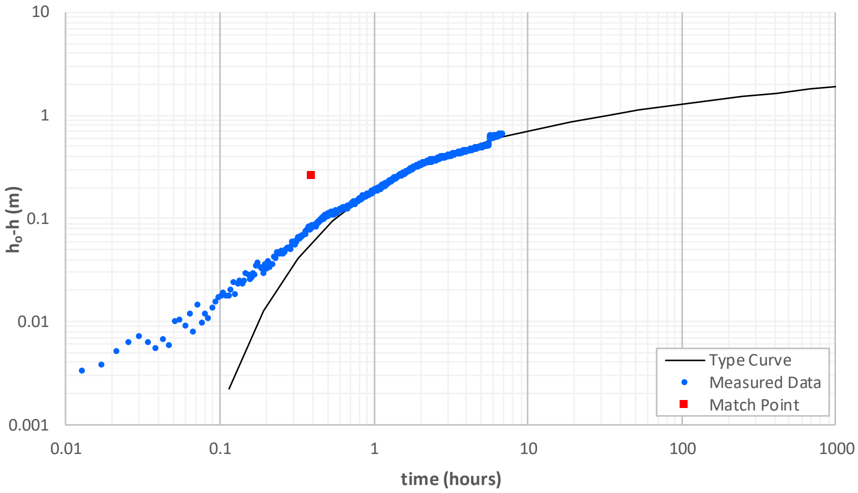


Figure D5. Curve fitting procedure for Theis curve analysis on Honeytree Farms monitoring bore.

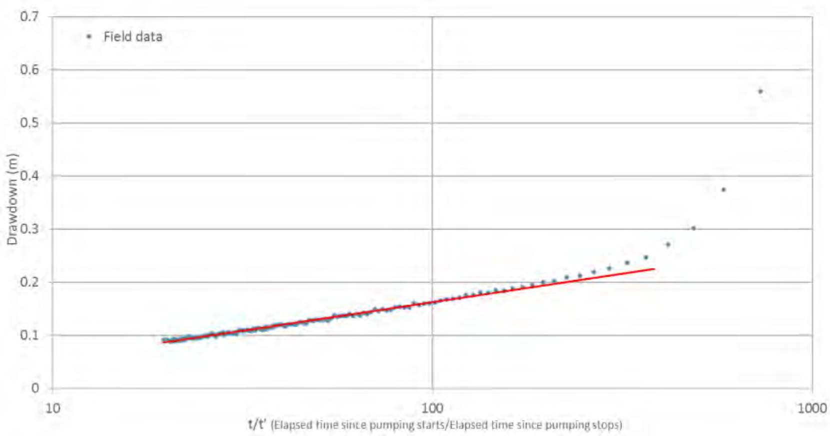


Figure D6. Curve fitting procedure for single well Theis recovery analysis on De Bede pumping bore.

Further analysis of the pumping test data was undertaken to investigate the effect of leakage.

The observed drawdown at each pumping bore was plotted against elapsed time on a semi-log and log-log graph (**Figure D7**). At early pumping times, the leaky confined aquifer behaves like a confined aquifer, with the pumped water being released from storage. However, as the pumping continues, more and more water will be drawn to the bore from the overlying aquifer through leakage and the drawdown stabilises (Krusemann and de Ridder, 1994).

Compared with the theoretical time-drawdown relationship (**Figure D8**), the test pumping data suggest the response for Stanisich and Honeytree are less leaky than De Bede, but overall they show leaky confined conditions within the tested shellbed aquifer.

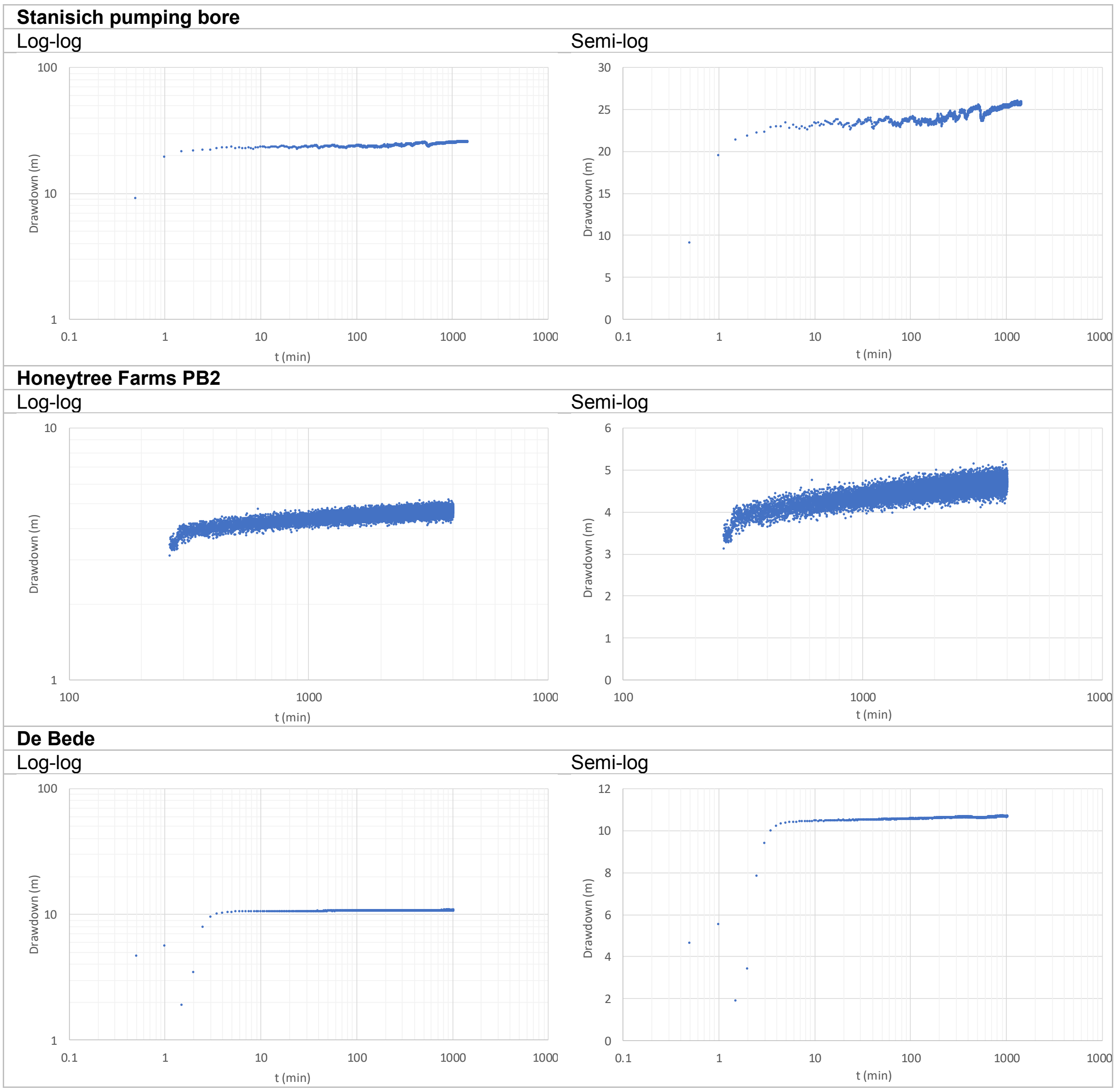


Figure D7. Log-log and semi-log plot of pumping tests data.

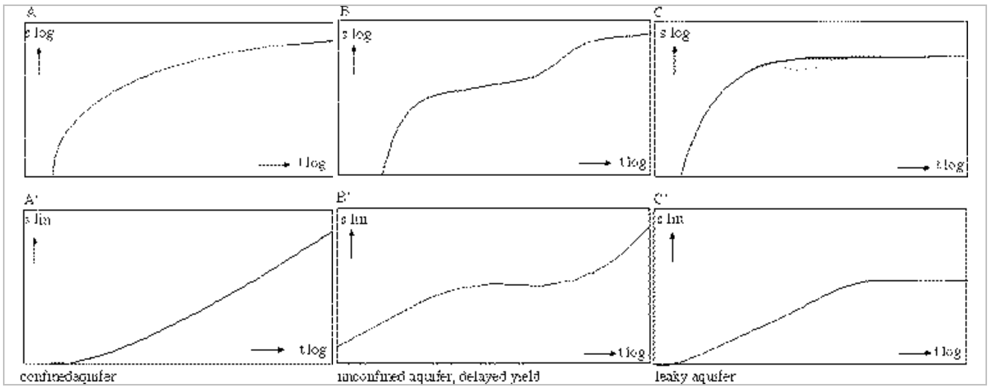


Figure D8. Log-log and semi-log plots of theoretical time-drawdown relationships (sourced from Kruseman and de Ridder, 1994, Figure 2.12).

Additional analyses were conducted to estimate the hydraulic conductivity of the shellbed aquifer based on methods for leaky confined aquifers. The methods adopted are the Single Well Jacob's Straight-Line Method (Cooper and Jacob, 1946) and the Hantush-Jacob Method (Hantush and Jacob, 1955; Hantush, 1964).

Single Well Jacob's Straight-Line Method

Jacob's straight-line method can be applied to single well pumping test, with time constraints. For a single well test in leaky aquifer, the pumping test data evaluation time (t, day) should meet the following equation, to neglect the influence of the leakage.

$$\frac{25r^2}{T} < t < \frac{cS}{20}$$

Where:
r: Radius of the bore (m)
T: Calculated transmissivity (m^2/d)
c: Hydraulic resistance of the aquitard (d)
S: Storativity

The value of c and S can be estimated at c=1000 days and $S=4\times10^{-4}$ (Mulder, 1983).

The drawdown plot with straight line fitting is shown in **Figure D9**. The calculated hydrogeological parameters are shown in **Table 19**.

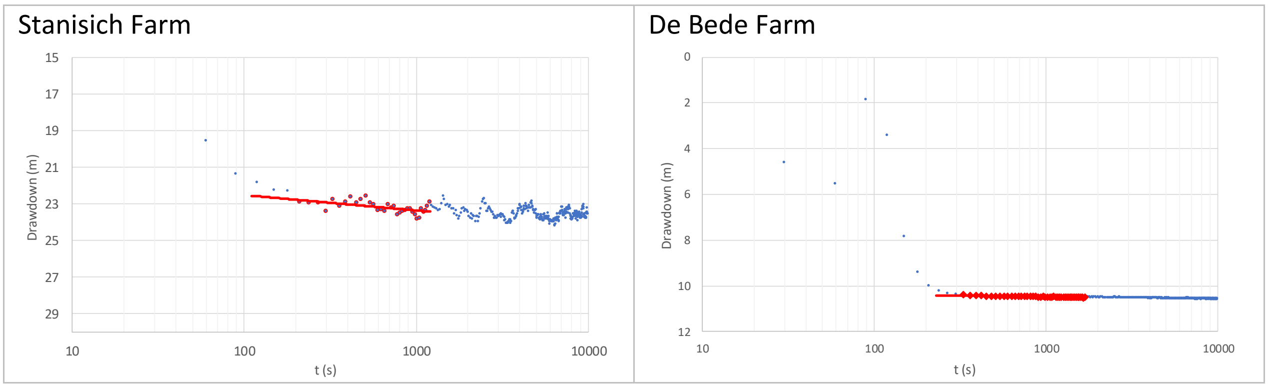


Figure D9. Drawdown plot for single well Jacob analysis.

Table 19. Calculated hydrogeological property from Single well Jacob method.

Farm	Q (L/s)	Bore	Screen Depth (mBGL)	Evaluation time (s)	T (m^2/d)	B (m)	K (m/d)	K (m/s)	Time (s) evaluation criteria	
									Minimum	Maximum
Stanisich	25	Pumping bore	87-101	210 - 1200	471	14	34	3.9E-04	183	1728
De Bede	2.3	Pumping bore	91-97	330 - 1470	273	6	46	5.3E-04	86	1728

Hantush – Jacob Method

The Hantush – Jacob method with Walton (1962) curve-fitting procedure was used to derive leakage coefficients for the pumping tests conducted at Honeytree Farm and Stanisich bores.

Type curves were manually fit to the pumping test data. A range of curve fits were tested to derive a likely range of leakage coefficients.

The estimated hydrogeological parameters are summarised in **Table D3**. Depending on the matching between observed drawdown and type curve, the leakage coefficients range from 7.36×10^{-4} to 1.83×10^{-3} d-1 at the Stanisich bore, and from 5.09×10^{-5} to 2.84×10^{-4} d-1 at the Honeytree bore. Compared with the leakage coefficients obtained from Lincoln Agritech (2015) shown in their Table A1, the estimated leakage coefficients at the Stanisich and Honeytree sites are at the lower end of the range, comparable with the Fitzwater and King Avocado sites, which implies less leakage than inferred for the majority of bores by Lincoln Agritech (2015). It is also interesting to note, that the only longish duration test pumping exercises are Stanisich, Honeytree and King Avocado, which places more emphasis on the reliability of these results.

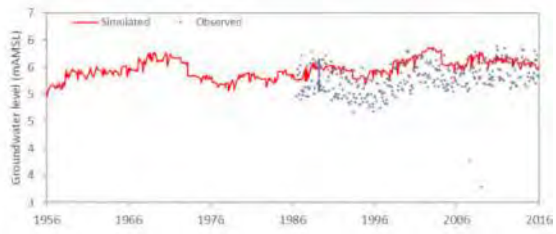
Table D3. Estimated hydrogeological parameters from Hantush – Jacob method.

Bore	T	K_h	K_h	K'/B'	S_s
	m^2/d	m/d	m/s	d^{-1}	m^{-1}
Stanisich observation bore 2 (monitoring bore)	138	10	1.14E-04	1.83E-03	1.55E-04
	408	29	3.38E-04	1.35E-03	3.07E-04
	348	25	2.88E-04	7.36E-04	3.13E-04
Honeytree farm production bore 1(monitoring bore)	579	32	3.72E-04	1.50E-04	1.63E-05
	484	27	3.11E-04	2.84E-04	2.17E-05
	707	39	4.54E-04	5.09E-05	1.70E-05

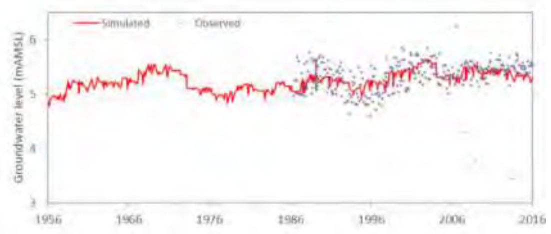
The estimated hydraulic parameters obtained from methods for leaky confined aquifers (particularly K_h) are in the same range as the parameters obtained in the previous analysis using methods for confined aquifers. It can therefore be concluded that the effect of leakage at the pumping test sites is negligible.

Appendix E. Calibrated Model Hydrographs

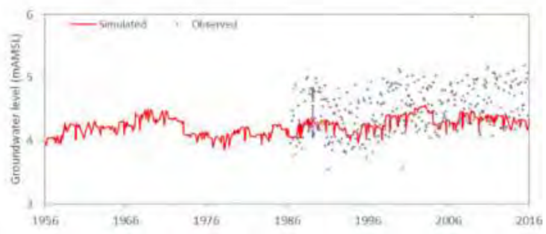
Waterfront Piezometer 1



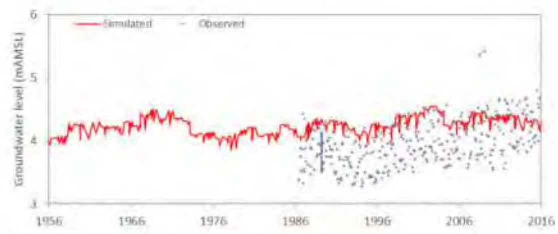
Waterfront Piezometer 2



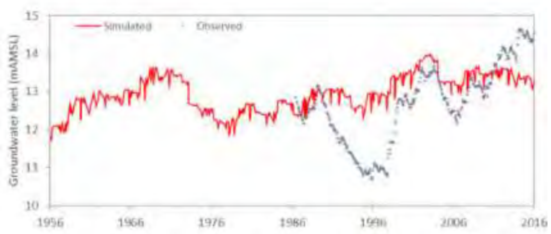
Waterfront Piezometer 3



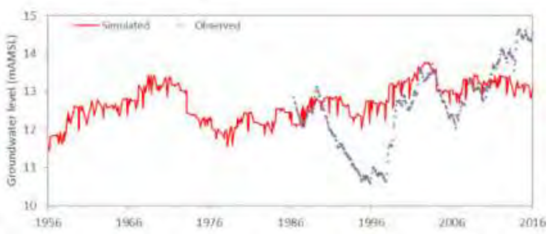
Waterfront Piezometer 4



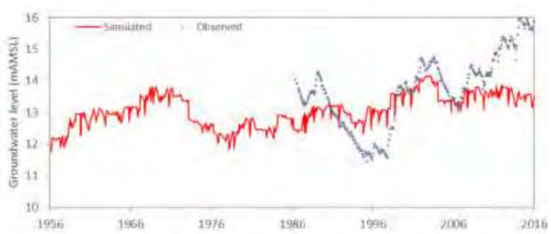
Hukatere Piezometer 1



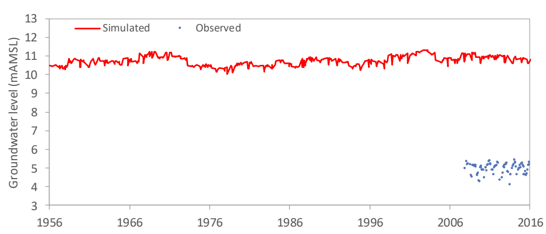
Hukatere Piezometer 2



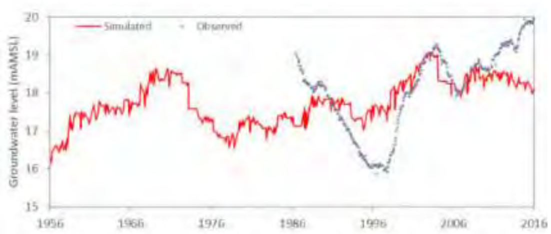
Hukatere Piezometer 3



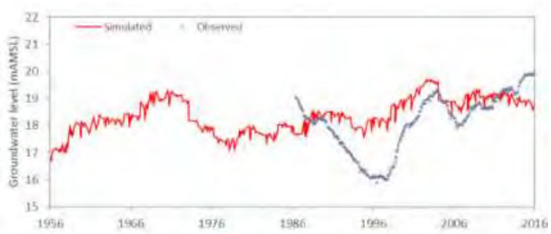
Wagener



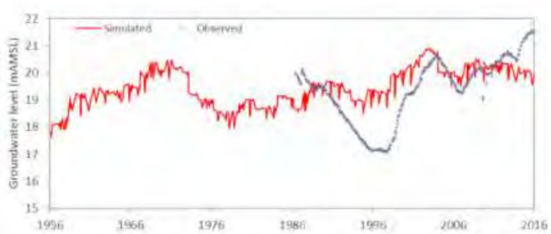
Forest Piezometer 1



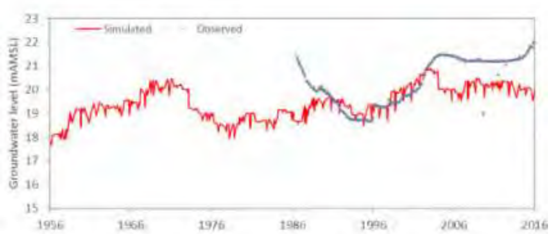
Forest Piezometer 2



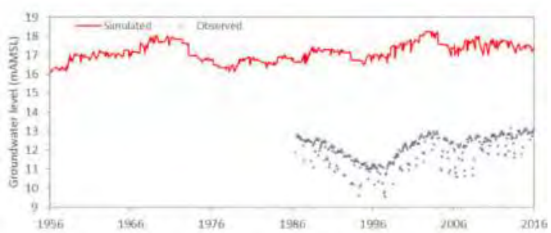
Forest Piezometer 3



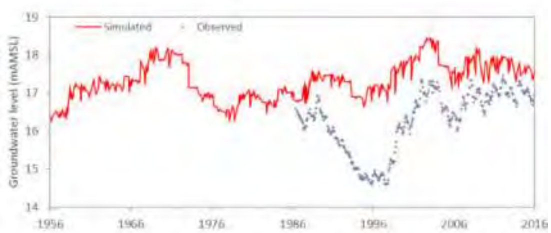
Forest Piezometer 4



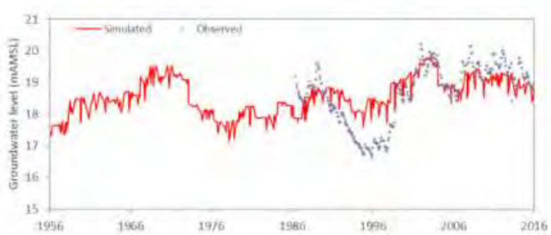
Browne Piezometer 1



Browne Piezometer 2



Browne Piezometer 3



Burnage Piezometer 4

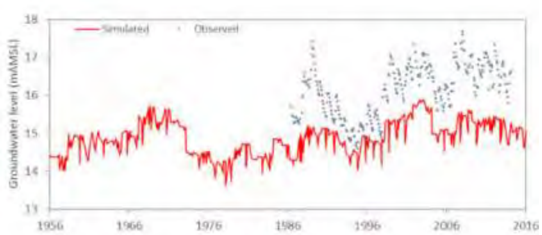


Figure E1. Hydrographs of simulated versus observed groundwater levels.

Figure E2. Simulated groundwater levels for Layers 1-6. (see A3 attachment at rear).

Appendix F. Saltwater coastal intrusion

To understand the impact of pumping at the coast assuming a saline intrusion mechanism of lateral migration along the aquifer/bedrock interface, the minimum pressure head requirement to maintain salinity offshore is provided in **Table F1.** In addition, **Table F1** provides the 90-day rolling average (RA) of the simulated head for the two time steps (03/08/1999 and 25/06/1979) from the 60-year simulation and the additional drawdown from the sensitivity model (Scenario 4a-c – lower leakage scenario).

The analysis shows the following:

- With the calibrated model, pressure during the driest times on record is maintained above the required pressure to withstand saline intrusion; and
- Assuming a lower leakage scenario, in most cases there is still significant headroom for withstanding saline intrusion at key coastal locations.
- For the additional drawdown scenario assuming a low leakage, at a few locations the inferred water level would seem to just recede below the pressure head requirement as highlighted in yellow. However, this is likely a short term transitory response at the very end of the driest periods on record (and assuming virtually no leakage). We do not consider this would manifest in a permanent saline intrusion issue, but nevertheless saline intrusion monitoring is warranted as condition of consent.

Table F1. Pressure head requirement, head (90-day RA) and additional drawdown (with sensitivity model) during time step (03/08/1999) at base of shellbed aquifer at selected coastal locations.

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower Leakage		
				GWL 90-day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
1	1610727	6147852	1.8	10.9	10.8	10.4	10	9.2	0.2	0.3	0.6
2	1610868	6147576	1.8	10.8	10.7	10.3	9.9	9.2	0.1	0.3	0.6
3	1611137	6147194	1.8	9.2	9.1	8.8	8.5	7.9	0.1	0.3	0.5
4	1611511	6146880	1.9	7.2	7.1	6.9	6.7	6.2	0.1	0.2	0.4
5	1611852	6146597	1.8	5.5	5.4	5.2	5.1	4.7	0.1	0.2	0.4
6	1612226	6146340	1.8	6.1	6	5.9	5.7	5.4	0.1	0.2	0.5
7	1612665	6146253	1.7	5.3	5.3	5.1	5	4.7	0.1	0.3	0.6
8	1613081	6146557	1.7	3.9	3.8	3.7	3.6	3.4	0.1	0.2	0.6
9	1613391	6146660	1.7	3.4	3.4	3.3	3.2	3	0	0.2	0.5
10	1613741	6146418	1.6	3.2	3.2	3.1	3	2.9	0	0.2	0.6
11	1614182	6146206	1.6	2.7	2.6	2.6	2.5	2.4	0	0.2	0.6
12	1614194	6145717	1.6	2.6	2.6	2.5	2.5	2.3	0.1	0.3	0.6
13	1614226	6145224	1.6	2.5	2.5	2.5	2.4	2.3	0.1	0.3	0.7
14	1614354	6144744	1.6	3.2	3.2	3.1	3.1	3	0.1	0.4	0.8
15	1614603	6144314	1.7	3.2	3.2	3.1	3.1	3	0.1	0.4	0.9
16	1614913	6143926	1.7	4	3.9	3.8	3.8	3.7	0.1	0.4	1
17	1615246	6143565	1.8	4.9	4.9	4.8	4.7	4.6	0.1	0.5	1
18	1615629	6143226	1.8	4.4	4.3	4.3	4.2	4.1	0.1	0.5	1.1
19	1615987	6142878	1.9	4.4	4.3	4.3	4.2	4.1	0.1	0.5	1.1
20	1616350	6142538	1.9	4.5	4.5	4.4	4.4	4.2	0.1	0.5	1.1

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower Leakage		
				GWL 90-day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
21	1616725	6142203	2	4.1	4	4	3.9	3.8	0.1	0.5	1.1
22	1617147	6141955	2	4.2	4.1	4.1	4	3.9	0.1	0.4	1.1
23	1617513	6141685	2	3.6	3.6	3.6	3.5	3.4	0.1	0.4	1.1
24	1617994	6141440	2	3.3	3.3	3.2	3.2	3.1	0.1	0.4	1.1
25	1618431	6141170	2	3.4	3.4	3.3	3.3	3.2	0.1	0.4	1.1
26	1618905	6141034	2	3	2.9	2.9	2.9	2.8	0.1	0.4	1.1
27	1619360	6140842	2	2.9	2.8	2.8	2.8	2.7	0.1	0.4	1.1
28	1619798	6140606	2	3.2	3.1	3.1	3.1	3	0.1	0.4	1.1
29	1620282	6140482	1.9	3.1	3	8.1	2.9	2.9	0.1	0.3	1
30	1620658	6140265	1.9	3.2	3.1	3.1	3	3	0.1	0.3	1
31	1620802	6140310	1.9	3	3	2.9	2.9	2.8	0.1	0.3	1
32	1621373	6140212	1.8	2.6	2.6	2.5	2.5	2.4	0.1	0.3	0.9
33	1621752	6140143	1.8	2.4	2.4	2.4	2.3	2.3	0.1	0.2	0.9
34	1622165	6139995	1.7	2.7	2.7	2.6	2.6	2.5	0	0.2	0.8
35	1622454	6139805	1.7	2.3	2.3	2.2	2.2	2.2	0	0.2	0.8
36	1622608	6139620	1.7	2.9	2.8	2.8	2.8	2.7	0	0.2	0.8
37	1622749	6139449	1.7	2.5	2.5	2.4	2.4	2.3	0	0.2	0.8
38	1622888	6139272	1.7	2.7	2.6	2.6	2.6	2.5	0.1	0.2	0.8
39	1623021	6139085	1.7	2.9	2.8	2.8	2.7	2.7	0.1	0.2	0.8
40	1623153	6138897	1.6	3	2.9	2.9	2.9	2.8	0.1	0.2	0.8
41	1623268	6138708	1.6	3.1	3	3	2.9	2.9	0.1	0.2	0.8
42	1623391	6138502	1.6	3.1	3.1	3	3	2.9	0.1	0.2	0.8
43	1623504	6138315	1.6	3	3	3	2.9	2.8	0.1	0.2	0.8
44	1623585	6138099	1.6	3.1	3.1	3	3	2.9	0.1	0.2	0.8
45	1623648	6137879	1.6	3.2	3.1	3.1	3	2.9	0.1	0.2	0.8
46	1623744	6137679	1.6	3.2	3.1	3.1	3	2.9	0.1	0.2	0.8
47	1623857	6137471	1.6	3.1	3	3	2.9	2.9	0.1	0.2	0.8
48	1623964	6137267	1.6	3	2.9	2.9	2.8	2.8	0.1	0.2	0.8
49	1624061	6137063	1.5	2.9	2.9	2.8	2.8	2.7	0.1	0.2	0.8
50	1624144	6136850	1.5	2.9	2.9	2.8	2.8	2.7	0.1	0.2	0.8
51	1624219	6136632	1.5	2.8	2.8	2.7	2.7	2.6	0.1	0.2	0.8
52	1624322	6136380	1.5	2.7	2.6	2.6	2.5	2.5	0.1	0.2	0.8
53	1624369	6136022	1.5	2.8	2.7	2.7	2.7	2.6	0.1	0.2	0.8
54	1624342	6135663	1.5	2.8	2.7	2.7	2.6	2.5	0.1	0.2	0.8
55	1623878	6135429	1.5	3.2	3.1	3	3	2.9	0.1	0.2	0.9
56	1623452	6135167	1.6	3.5	3.4	3.3	3.3	3.1	0.1	0.3	1
57	1623059	6134875	1.6	3.7	3.6	3.5	3.4	3.3	0.1	0.3	1

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower Leakage		
				GWL 90-day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
58	1622646	6134590	1.7	3.9	3.8	3.7	3.6	3.4	0.1	0.3	1.1
59	1622179	6134410	1.7	4.7	4.6	4.4	4.3	4	0.1	0.4	1.2
60	1621753	6134235	1.8	5.3	5.1	4.9	4.8	4.5	0.2	0.5	1.3
61	1621293	6134188	1.8	5.9	5.7	5.5	5.3	4.9	0.2	0.5	1.4
62	1621007	6134173	1.9	6.4	6.2	6	5.8	5.4	0.2	0.6	1.4
63	1620561	6134028	2	7.4	7.1	6.9	6.7	6.2	0.3	0.6	1.5
64	1620104	6134195	2.1	8.6	8.3	7.9	7.8	7.2	0.3	0.7	1.5
65	1619843	6134221	2.1	9.1	8.8	8.6	8.3	7.7	0.3	0.7	1.5
66	1620170	6134015	2	8.4	8.2	7.8	7.6	7.1	0.3	0.7	1.5
67	1620807	6133827	1.9	6.8	6.6	6.4	6.2	5.7	0.2	0.6	1.4
68	1621222	6133886	1.9	6	5.8	5.6	5.4	5	0.2	0.6	1.4
69	1621586	6133732	1.8	5.5	5.3	5.1	5	4.6	0.2	0.5	1.3
70	1621490	6133283	1.8	5.5	5.3	5.1	4.9	4.5	0.2	0.6	1.4
71	1621321	6132892	1.8	6.2	6	5.7	5.5	5	0.2	0.6	1.4
72	1621149	6132398	1.8	6.2	6	5.8	5.6	5.1	0.2	0.6	1.4
73	1620829	6132055	1.9	7.2	7	6.8	6.5	5.9	0.3	0.7	1.4
74	1620416	6132125	1.9	8.4	8.1	3.1	7.5	6.9	0.3	0.7	1.5
75	1604608	6142803	2.1	4.4	4.4	4.3	4.3	4.2	0.1	0.3	0.6
76	1605408	6141653	2.1	4.8	4.8	4.7	4.7	4.5	0.1	0.3	0.7
77	1606201	6140487	2.2	4.5	4.5	4.4	4.4	4.3	0.1	0.4	0.7
78	1606983	6139317	2.2	3.5	3.5	3.5	3.4	3.4	0.1	0.4	0.8
79	1607741	6138232	2.3	5.7	5.7	5.6	5.6	5.4	0.1	0.4	0.8
80	1608525	6137014	2.3	4.1	4.1	4.1	4	3.9	0.1	0.4	0.9
81	1609309	6135741	2.4	3.7	3.7	3.7	3.6	3.5	0.1	0.4	0.9
82	1610056	6134496	2.4	3.6	3.6	3.5	3.5	3.4	0.1	0.4	1
83	1610813	6133251	2.4	5.9	5.9	5.8	5.7	5.6	0.1	0.4	1
84	1611491	6132014	2.4	6.5	6.5	6.4	6.3	6.1	0.1	0.4	1
85	1612136	6130690	2.4	5.3	5.2	5.2	5.1	4.9	0.2	0.5	1.1

Table F2. Pressure head requirement, head (90-day RA) and additional drawdown (with sensitivity model) during time step (25/06/1979) at base of shellbed aquifer at selected coastal locations.

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower leakage		
				GWL 90 day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
1	1610727	6147852	1.8	10.3	10.1	9.6	9.1	8.1	0.2	0.4	0.8
2	1610868	6147576	1.8	10.2	10	9.5	9	8.1	0.2	0.4	0.7
3	1611137	6147194	1.8	8.7	8.6	8.2	7.8	7	0.1	0.3	0.7
4	1611511	6146880	1.9	6.8	6.7	6.4	6.1	5.5	0.1	0.2	0.5
5	1611852	6146597	1.8	5.2	5.1	4.9	4.6	4.2	0.1	0.2	0.5
6	1612226	6146340	1.8	5.8	5.7	5.5	5.2	4.7	0.1	0.3	0.6
7	1612665	6146253	1.7	5	4.9	4.7	4.5	4.1	0.1	0.3	0.7
8	1613081	6146557	1.7	3.6	3.5	3.4	3.2	2.9	0.1	0.3	0.7
9	1613391	6146660	1.7	3.2	3.1	3	2.8	2.5	0.1	0.3	0.7
10	1613741	6146418	1.6	2.9	2.9	2.8	2.6	2.3	0.1	0.3	0.7
11	1614182	6146206	1.6	2.4	2.4	2.3	2.2	2	0.1	0.3	0.7
12	1614194	6145717	1.6	2.4	2.3	2.2	2.1	2	0.1	0.3	0.8
13	1614226	6145224	1.6	2.3	2.3	2.2	2.2	2	0.1	0.4	0.9
14	1614354	6144744	1.6	3	3	2.9	2.8	2.6	0.1	0.5	1
15	1614603	6144314	1.7	3	3	2.9	2.8	2.6	0.1	0.5	1.1
16	1614913	6143926	1.7	3.7	3.6	3.6	3.5	3.3	0.1	0.6	1.2
17	1615246	6143565	1.8	4.7	4.6	4.5	4.4	4.1	0.1	0.6	1.3
18	1615629	6143226	1.8	4.2	4.1	4	3.9	3.7	0.1	0.6	1.3
19	1615987	6142878	1.9	4.1	4.1	4	3.9	3.7	0.1	0.6	1.3
20	1616350	6142538	1.9	4.3	4.2	4.1	4	3.8	0.1	0.6	1.3
21	1616725	6142203	2	3.8	3.8	3.7	3.6	3.5	0.1	0.5	1.3
22	1617147	6141955	2	3.9	3.9	3.8	3.7	3.5	0.1	0.5	1.3
23	1617513	6141685	2	3.4	3.4	3.3	3.2	3.1	0.1	0.5	1.3
24	1617994	6141440	2	3.1	3.1	3	3	2.8	0.1	0.5	1.3
25	1618431	6141170	2	3.2	3.2	3.1	3	2.9	0.1	0.5	1.3
26	1618905	6141034	2	2.8	2.7	2.7	2.6	2.5	0.1	0.5	1.3
27	1619360	6140842	2	2.7	2.6	2.6	2.5	2.4	0.1	0.4	1.2
28	1619798	6140606	2	2.9	2.8	2.8	2.7	2.6	0.1	0.4	1.2
29	1620282	6140482	1.9	2.8	2.7	7.1	2.6	2.5	0.1	0.4	1.2
30	1620658	6140265	1.9	2.8	2.8	2.7	2.7	2.6	0.1	0.4	1.1
31	1620802	6140310	1.9	2.7	2.6	2.6	2.6	2.5	0.1	0.4	1.1
32	1621373	6140212	1.8	2.3	2.3	2.2	2.2	2.1	0.1	0.3	1.1
33	1621752	6140143	1.8	2.2	2.1	2.1	2	1.9	0.1	0.3	1
34	1622165	6139995	1.7	2.4	2.3	2.3	2.2	2.2	0.1	0.3	1
35	1622454	6139805	1.7	2	2	1.9	1.9	1.8	0.1	0.3	0.9

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower leakage		
				GWL 90 day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
36	1622608	6139620	1.7	2.5	2.4	2.4	2.4	2.3	0.1	0.2	0.9
37	1622749	6139449	1.7	2.2	2.1	2.1	2	2	0.1	0.2	0.9
38	1622888	6139272	1.7	2.3	2.3	2.2	2.2	2.1	0.1	0.2	0.9
39	1623021	6139085	1.7	2.5	2.4	2.4	2.3	2.2	0.1	0.2	0.9
40	1623153	6138897	1.6	2.6	2.5	2.4	2.4	2.3	0.1	0.2	0.9
41	1623268	6138708	1.6	2.6	2.5	2.5	2.5	2.4	0.1	0.2	0.9
42	1623391	6138502	1.6	2.7	2.6	2.5	2.5	2.4	0.1	0.2	0.9
43	1623504	6138315	1.6	2.6	2.5	2.5	2.4	2.3	0.1	0.2	0.9
44	1623585	6138099	1.6	2.7	2.6	2.5	2.5	2.4	0.1	0.2	0.9
45	1623648	6137879	1.6	2.7	2.6	2.6	2.5	2.4	0.1	0.2	0.9
46	1623744	6137679	1.6	2.7	2.6	2.6	2.5	2.4	0.1	0.2	0.9
47	1623857	6137471	1.6	2.6	2.5	2.5	2.4	2.3	0.1	0.2	0.9
48	1623964	6137267	1.6	2.5	2.5	2.4	2.4	2.2	0.1	0.2	0.9
49	1624061	6137063	1.5	2.5	2.4	2.4	2.3	2.2	0.1	0.2	0.9
50	1624144	6136850	1.5	2.5	2.4	2.4	2.3	2.2	0.1	0.2	0.9
51	1624219	6136632	1.5	2.4	2.4	2.3	2.3	2.1	0.1	0.2	0.9
52	1624322	6136380	1.5	2.3	2.2	2.2	2.1	2	0.1	0.2	0.9
53	1624369	6136022	1.5	2.4	2.3	2.3	2.2	2.1	0.1	0.2	0.9
54	1624342	6135663	1.5	2.4	2.3	2.3	2.2	2.1	0.1	0.2	0.9
55	1623878	6135429	1.5	2.8	2.7	2.6	2.5	2.4	0.1	0.3	1
56	1623452	6135167	1.6	3.1	3	2.9	2.8	2.6	0.1	0.3	1.1
57	1623059	6134875	1.6	3.3	3.1	3	2.9	2.7	0.2	0.4	1.2
58	1622646	6134590	1.7	3.5	3.3	3.2	3.1	2.8	0.2	0.4	1.3
59	1622179	6134410	1.7	4.2	4.1	3.9	3.7	3.3	0.2	0.5	1.4
60	1621753	6134235	1.8	4.8	4.5	4.3	4.1	3.7	0.3	0.6	1.5
61	1621293	6134188	1.8	5.3	5.1	4.8	4.6	4.1	0.3	0.7	1.6
62	1621007	6134173	1.9	5.8	5.6	5.3	5	4.4	0.3	0.7	1.7
63	1620561	6134028	2	6.7	6.4	6.1	5.7	5.1	0.3	0.8	1.8
64	1620104	6134195	2.1	7.9	7.5	7	6.8	6	0.4	0.8	1.8
65	1619843	6134221	2.1	8.4	8	7.6	7.2	6.5	0.4	0.9	1.9
66	1620170	6134015	2	7.7	7.4	6.8	6.6	5.8	0.4	0.8	1.8
67	1620807	6133827	1.9	6.2	5.9	5.6	5.3	4.6	0.3	0.8	1.7
68	1621222	6133886	1.9	5.4	5.2	4.9	4.6	4	0.3	0.7	1.6
69	1621586	6133732	1.8	5	4.7	4.5	4.2	3.7	0.3	0.7	1.6
70	1621490	6133283	1.8	5	4.8	4.5	4.2	3.7	0.3	0.7	1.6
71	1621321	6132892	1.8	5.6	5.3	5	4.7	4.1	0.3	0.7	1.7
72	1621149	6132398	1.8	5.6	5.4	5	4.7	4.1	0.3	0.8	1.7

Point	X	Y	Head required (mAMSL)	Base Case	Proposed Extraction	Future Allocation			Lower leakage		
				GWL 90 day RA (mAMSL)					Additional drawdown (m)		
				Sc1	Sc2	Sc3a	Sc3b	Sc3c	Sc4a	Sc4b	Sc4c
73	1620829	6132055	1.9	6.5	6.3	5.9	5.5	4.8	0.3	0.8	1.7
74	1620416	6132125	1.9	7.5	7.3	2.7	6.4	5.6	0.4	0.8	1.8
75	1604608	6142803	2.1	4	4	4	3.9	3.8	0.1	0.3	0.7
76	1605408	6141653	2.1	4.3	4.3	4.3	4.2	4.1	0.1	0.3	0.8
77	1606201	6140487	2.2	4.1	4.1	4	4	3.9	0.1	0.3	0.8
78	1606983	6139317	2.2	3.2	3.2	3.2	3.1	3.1	0.1	0.4	0.9
79	1607741	6138232	2.3	5.2	5.1	5.1	5	4.9	0.1	0.4	1
80	1608525	6137014	2.3	3.8	3.7	3.7	3.6	3.6	0.1	0.4	1
81	1609309	6135741	2.4	3.4	3.4	3.3	3.3	3.2	0.1	0.4	1.1
82	1610056	6134496	2.4	3.3	3.3	3.2	3.2	3.1	0.1	0.4	1.1
83	1610813	6133251	2.4	5.4	5.4	5.3	5.2	5	0.1	0.4	1.1
84	1611491	6132014	2.4	6	5.9	5.8	5.7	5.5	0.1	0.5	1.2
85	1612136	6130690	2.4	4.9	4.8	4.7	4.6	4.4	0.1	0.5	1.2

Appendix G. Static groundwater level records

Table D3 includes the static groundwater levels recorded before pumping tests.

Table D3. Recorded static groundwater levels before pumping test.

Farm	Bore	Date	Depth to water (mBGL)
Stanisich bore	Production bore	29/11/2016 9:27 AM	5.39
		30/11/2016 8:28 AM	5.35
	Monitoring bore 1	29/11/2016 9:24 AM	4.52
		30/11/2016 8:30 AM	4.53
		30/11/2016 12:24 PM	4.52
		30/11/2016 12:47 PM	4.52
		30/11/2016 1:01 PM	4.52
		30/11/2016 1:31 PM	4.52
		30/11/2016 1:53 PM	4.52
		30/11/2016 2:20 PM	4.52
		30/11/2016 2:49 PM	4.52
		30/11/2016 3:28 PM	4.52
		30/11/2016 4:01 PM	4.52
		30/11/2016 5:11 PM	4.52
		30/11/2016 5:42 PM	4.52
	Monitoring bore 2	28/11/2016 1:30 PM	16.25
		29/11/2016 10:47 AM	16.28
		30/11/2016 8:09 AM	16.25
	Monitoring bore 3	28/11/2016 2:00 PM	3.26
		29/11/2016 1:27 PM	3.06
		30/11/2016 8:21 AM	3.16
		30/11/2016 12:38 PM	3.26
		30/11/2016 1:09 PM	3.21
		30/11/2016 1:14 PM	3.16
		30/11/2016 1:18 PM	3.16
		30/11/2016 2:00 PM	3.06
		30/11/2016 3:13 PM	3.06
		30/11/2016 5:26 PM	3.04
Honeytree	Production bore 1	29/11/2016 7:35 AM	0.49
		1/12/2016 8:57 AM	0.54
		1/12/2016 1:37 PM	0.55
		2/12/2016 8:54 AM	0.68
		3/12/2016 11:07 AM	0.65
	Monitoring bore 1	28/11/2016 3:00 PM	3.08
		29/11/2016 7:52 AM	3.07
		1/12/2016 8:52 AM	3.08

		1/12/2016 1:26 PM	3.08
		2/12/2016 9:07 AM	3.09
		2/12/2016 4:32 PM	3.10
		3/12/2016 11:33 AM	3.10
	Production bore 2	28/11/2016 2:56 PM	0.57
		29/11/2016 7:48 AM	0.53
		1/12/2016 8:48 AM	0.56
		1/12/2016 1:24 PM	0.57
		2/12/2016 9:05 AM	0.66
		2/12/2016 3:55 PM	0.67
		3/12/2016 11:31 AM	0.65
De Bede	Production bore	29/11/2016 12:40 PM	7.1
		29/11/2016 12:45 PM	7.1

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